MAY 1962 EDITION
GSA GEN. REG. NO. 27
UNITED STATES GOVERNMENT

Memorandum

EA/M.A. Faget

TO : See list below

DATE: MAR 7 1968
68-PA-T-54A

FROM : PA/Chief, Apollo Data Priority Coordination

SUBJECT: Sixth "C" Mission Rendezvous Mission Techniques meeting

1. This March 1 meeting conflicted with the President's speech but a few of us dedicated jokers pressed on as follows.

2. It had been stated that all "C" mission SPS burns would be performed in a heads down attitude (that is, 180° roll). This presents a problem on one or two of the SPS burns in the rendezvous sequence--NCC_1 and maybe NCC_2--since to constrain ourselves in that way would make it impossible to do the final sextant/star burn attitude check. These burns are expected to be within 15° radial which makes heads up/heads down rather meaningless anyway, except for the FDAI 8-ball presentation. Phil Shaffer checked with Tom Stafford and got agreement that the attitude check was of more value than the standard 180° roll indication. Accordingly, it is our plan to make NCC_1 and NCC_2 (if it is downward) in a heads up attitude and include the sextant/star check in the sequence.

3. As reported in the last meeting's minutes it is our proposal that if a platform failure is detected just prior to NCC_1, it will be necessary to delay the rendezvous exercise a day. This ruling does not necessarily apply to the PNGCS attitude tests prior to NCC_2 and NSR since after NCC_1 has been performed we are committed to the rendezvous exercise. Accordingly, if we can assume the GDC is aligned we probably should press on with the rendezvous using the SCS, at least through NCC_2 and NSR.

4. Apparently, consideration is being given by someone to extending the launch window. In particular, it is apparently being proposed to launch earlier in the day. It appears to us that to launch prior to local noon would preclude making a platform alignment between NCC_2 and NSR. This alignment is thought to be essential for terminal phase. Accordingly, we would like to request that very serious attention be given to this matter prior to choosing a launch time earlier than currently planned.

5. An item came up concerning real time selection of the elevation angle to be utilized in determining TPI time. As you recall, it is intended to utilize the elevation angle option in the TPI targeting processors such that if everything works properly TPI will occur when the line-of-sight to the target vehicle coincides with the maneuver thrust vector (spacecraft x-axis). According to Ed Lineberry, if dispersions in the

trajectory are not taken into account in designating this elevation angle, the thrust direction at TPI will be substantially off the line-of-sight. The elevation angle adjustment should be less than $\frac{1}{2}^{\circ}$. Apparently, the RTCC/MCC is capable of determining the optimum value by means of manual iteration. Since the effect of this on crew TPI backup charts may be unacceptable, FCSD was given the action item of checking into that.

6. Another action item assigned the FCSD was to establish which was more important---lighting conditions during the braking maneuver or thrust vector coincident with the line-of-sight at TPI. If the lighting conditions are the more critical, it may be necessary to include a decision point in our operations to assure proper lighting at braking by not allowing the TPI time to slip more than some specified amount---probably about 10 minutes. If the TPI time based on the elevation angle option slips too much the crew would have to utilize the TPI "time option" for targeting. Obviously, the decision would have to be made onboard the spacecraft after sextant data had been incorporated into the PNGCS.

7. There have been a number of comments regarding the TPI backup charts and their usefulness on the "C" and "D" missions. At the next meeting, currently scheduled at 1:00 p.m. on March 8, we will review this subject and try to establish the role of the PNGCS, MSFN and backup charts for the TPI maneuver. The primary questions to be answered are: shall there even be TPI backup charts, and if there are, should they or the MSFN computation for TPI be used in the event of a PNGCS failure. It is evident that in either case the subsequent midcourse correction will have to be based on charts, since the MSFN has no capability for computing that maneuver.

Howard W. Tindall, Jr.

Howard W. Tindall, Jr.

Addressees:
(See attached list)

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA GEN. REG. NO. 27

5010-107

UNITED STATES GOVERNMENT

Memorandum

EA 5/P.M. Deans
info

TO : See list below

DATE: MAY 10 1968

68-PA-T-99A

FROM : PA/Chief, Apollo Data Priority Coordination

SUBJECT: "C" rendezvous open item clean up

1. Paul Kramer, Phil Shaffer, Duane Mosel, Ed Lineberry, and myself spent the morning of May 7 trying to close out major open items remaining on the "C" mission rendezvous. These items were:

a. How to handle an excessive slip in TPI time.

b. What kind of cross checking and backup modes should be used for the TPI maneuver.

This memorandum briefly summarizes the results of our discussion.

2. First of all, let me point out that without radar, it is important that the CSM does not approach the S-IVB while in darkness since range information is only obtained visually. Also, the sun must not be too near the line-of-sight - i.e., in back of the CSM - during braking for the same reason. These two constraints can be used to establish a "window" of acceptable TPI times to provide optimum lighting during the braking phase.

a. At this meeting we concluded that it is still best to locate TPI at the midpoint of darkness nominally.

b. In addition, we have specified that tolerable slip in TPI time is from 12 minutes early to 18 minutes late about that nominal time. That is, if the onboard solution for TPI time, based on the first sextant rendezvous tracking period following NSR falls within that period, no steps will be taken to change it. (It is currently estimated that the 3σ uncertainty of the onboard computation of TPI time at that point in the mission is 4 minutes. Exceeding the bounds listed above by 4 minutes is not unacceptable.)

c. On the other hand, if the predicted TPI time slips earlier than 12 minutes or later than 18 minutes, the TPI elevation angle will be adjusted as necessary to bring the TPI time back to the closest bound. This is done as follows. Let us assume that at the end of the first tracking period the TPI time is found to be more than 12 minutes early by having run through the TPI program (P34) using the "elevation angle option." P34 would be recalled using the "TPI time option" and the crew will input a TPI time exactly 12

EA5/P. M. Deans info

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA FPMR (41 CFR) 101-11.6

UNITED STATES GOVERNMENT

Memorandum

TO : See list below

DATE: JUN 25 1968

68-PA-T-138A

FROM : PA/Chief, Apollo Data Priority Coordination

SUBJECT: "C" Rendezvous W-Matrix

This memorandum is to inform everyone in writing that MIT has now agreed with MPAD that it is acceptable to use the same values of the W-Matrix when reinitializing (after three marks of the last batch of marks between NSR and PTI) as are used initially. That is, it is not necessary for the crew to punch new values into the DSKY - a clumsy procedure everyone wanted to delete if possible. I think Paul Pixley is to be commended for finally getting MIT's agreement to this crew procedure simplification.

The actual values to be used initially - that is, the pre-launch erasable load values - have not been finally agreed to yet, but that will not affect the crew procedures. Today's best guess is 1000 feet and 1 fps.

It is recommended that the flight crew and those responsible for documenting crew procedures, etc. adopt this mission techniques immediately. I have already told most of those concerned by the Don Ameche.

Howard W. Tindall, Jr.

Addressees:
(See list attached)

PA:HWTindall, Jr.:js

info

EA 5/P.M. Deans

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA FPMR (41 CFR) 101-11.6

UNITED STATES GOVERNMENT

Memorandum

TO : See list attached

DATE: JUL 9 1968

68-PA-T-153A

FROM : PA/Chief, Apollo Data Priority Coordination

SUBJECT: Good news on "C" mission SPS burns

The following is a verbatum copy of a note to me from Rick Nobles (MPAD). I thought it worth distributing.

"The cross axis velocity errors resulting from SPS mistrim (CSM alone) will be about one half of what was previously anticipated. The reduction in error is due to the new DAP filter constants that the G&CD is recommending for the "C" mission erasable load. The only adverse effect is the mission planning that has been done to date."

Howard W. Tindall, Jr.

PA:HWTindall, Jr.:js

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA FPMR (41 CFR) 101-11.6

UNITED STATES GOVERNMENT

Memorandum

TO : See list attached

DATE: JUL 23 1968

68-PA-T-162A

FROM : PA/Chief, Apollo Data Priority Coordination

SUBJECT: "C" Mission Retrofire and Reentry Mission Techniques meeting

On Friday morning, July 19, we had a "C" Mission Retrofire and Reentry Mission Techniques meeting to clean up some open items. It is evident that a distribution of correction pages to our previously distributed Mission Techniques document will be inadequate and it is our current plan to republish the whole book. Some of the most significant items resolved at this meeting are described in this memo.

1. It has been established that the G&N guidance system will be used in the event of a hybrid RCS deorbit. (A hybrid deorbit is one in which both the command module and service module RCS jets are used.) The retrofire will be targeted for a half-lift reentry.

2. It has been established that the G&N is mandatory for performing a hybrid deorbit; thus, if the G&N has failed and the service module RCS remaining has fallen below the return-line limits, the only remaining system for retrofire is SPS using SCS control. Accordingly, there is a mission rule that retrofire will be performed to land in the next best planned recovery area (PLA).

3. It has been established that if insufficient time is available for a fine alignment prior to retrofire, the G&N will be used with a coarse alignment if that can be done. Current estimate is that a coarse alignment will be to within 2° on all axis, which can result in as much as a 30 mile landing point miss.

4. In the absence of response to our request for better numbers, we have established the following limits beyond which the G&N will be declared No Go for reentry and the backup system will be used. The DSKY VG displays must be within 1 fps and the gimbal angles must be within 1°. Guidance and Control Division and MIT people please pay particular note.

5. Apparently the procedure has been established that command module separation from the service module will be performed following retrofire while still in the SPS thrust program (P40). This is to

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA FPMR (41 CFR) 101-11.6

UNITED STATES GOVERNMENT

Memorandum

TO : See list attached

DATE: JUL 23 1968
68-PA-T-162A

FROM : PA/Chief, Apollo Data Priority Coordination

SUBJECT: "C" Mission Retrofire and Reentry Mission Techniques meeting

On Friday morning, July 19, we had a "C" Mission Retrofire and Reentry Mission Techniques meeting to clean up some open items. It is evident that a distribution of correction pages to our previously distributed Mission Techniques document will be inadequate and it is our current plan to republish the whole book. Some of the most significant items resolved at this meeting are described in this memo.

1. It has been established that the G&N guidance system will be used in the event of a hybrid RCS deorbit. (A hybrid deorbit is one in which both the command module and service module RCS jets are used.) The retrofire will be targeted for a half-lift reentry.

2. It has been established that the G&N is mandatory for performing a hybrid deorbit; thus, if the G&N has failed and the service module RCS remaining has fallen below the return-line limits, the only remaining system for retrofire is SPS using SCS control. Accordingly, there is a mission rule that retrofire will be performed to land in the next best planned recovery area (PLA).

3. It has been established that if insufficient time is available for a fine alignment prior to retrofire, the G&N will be used with a coarse alignment if that can be done. Current estimate is that a coarse alignment will be to within 2° on all axis, which can result in as much as a 30 mile landing point miss.

4. In the absence of response to our request for better numbers, we have established the following limits beyond which the G&N will be declared No Go for reentry and the backup system will be used. The DSKY VG displays must be within 1 fps and the gimbal angles must be within 1°. Guidance and Control Division and MIT people please pay particular note.

5. Apparently the procedure has been established that command module separation from the service module will be performed following retrofire while still in the SPS thrust program (P40). This is to

keep Average G on during the separation maneuver without having to wait one minute as the entry programs are currently coded. The entry programs (P61, P62, etc.) will be sequenced after separation. Thus, these programs are being used in a completely different way than they were designed.

6. IMU PIPA and gyro drift compensation values are monitored continuously by MCC-H. It has been established that if the values currently loaded in the G&N are in error by more than .003 ft/sec^2 and .075 $^\circ$/hr, they will be updated in the CMC.

Howard W. Tindall, Jr.

PA:HWTindall, Jr.:js

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA FPMR (41 CFR) 101-11.6

UNITED STATES GOVERNMENT

Memorandum

TO : See list attached

DATE: JUL 24 1968

68-PA-T-167A

FROM : PA/Chief, Apollo Data Priority Coordination

SUBJECT: July 19 "C" Rendezvous Mission Techniques meeting

Although most of the things discussed in our Friday, July 19 "C" Rendezvous Mission Techniques meeting are not of general interest, there were a couple of things I would like to let you know about.

First of all, in an effort to reduce the probability of having to make the NCC2 maneuver, which would be an extra SPS burn, it has been decided to trim the NCC1 ΔV residuals if they are less than 10 fps. In addition, the time of the NSR maneuver will be adjusted in real time by as much as 30 seconds thereby changing the differential altitude. These two new things together should be adequate to maintain the nominal TPI time, which is the primary objective in targeting these maneuvers. The nominal differential altitude, you recall, is about 7.8 n.m. and it was finally agreed that acceptable targeting bounds are from 7 n.m. on the low side to 9 n.m. on the high side. These adjustment limits give us a capability of adjusting TPI time by about 20 minutes to account for dispersions. Using these procedures, it will only be necessary to make the NCC2 burn if we encounter dispersions far in excess of those expected.

Something else which has been changed is that the elevation angle at TPI is considered more sacred than any lighting limits at all and should be retained at the nominal value at all cost even though the so-called lighting limits are violated. Previously the elevation angle was to be changed if the lighting limits could not be met.

Another important mission rule adopted now is that the rendezvous exercise will be terminated if the G&N fails prior to NSR, and probably will be terminated any time the G&N fails. This is to conserve SM RCS and permit flying a full duration mission.

The changes to the mission techniques are relatively minor and it is probable that it will not be necessary to reissue the entire document. Rather than that, we will probably distribute change pages of some sort.

Howard W. Tindall, Jr.

PA:HWTindall, Jr.:js

info

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA FPMR (41 CFR) 101-11.6

UNITED STATES GOVERNMENT

Memorandum

EA5/R.H. Deans

TO : See list attached

DATE: October 16, 1968

68-PA-T-222A

FROM : PA/Chief, Apollo Data Priority Coordination

SUBJECT: C' maneuvers - SPS versus RCS crossover

Neil Townsend (EP2) informed me by phone - and will supply written confirmation - that the minimum duration SPS burn for C' should be no less than 0.5 seconds. We had been assuming something smaller. According to MPAD (Otis Graf, FM7) this makes the crossover point between use of the RCS versus the SPS engine:

Translunar midcourse correction - 5 fps

Transearth midcourse correction - 12 fps

These values will be explained completely in an FM7 memo soon to be distributed. I just want everybody to be aware of the new values and to start using them in his planning.

Bill T

Howard W. Tindall, Jr.

PA:HWTindall, Jr.:js

5010-108

info

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA FPMR (41 CFR) 101-11.6

UNITED STATES GOVERNMENT

Memorandum

TO : See list attached

DATE: December 6, 1968

68-PA-T-266A

FROM : PA/Chief, Apollo Data Priority Coordination

SUBJECT: C' Abort Maneuver Overburn Monitoring

In response to a C' Mission Techniques action item, Rick Nobles informs me that they have established the burn monitoring procedure to guard against overburn during any non-nominal C' maneuver. As a standard procedure the crew should manually shut down the SPS as soon as the duration of the burn exceeds the nominal value by one percent and the EMS ΔV Counter indicates an overburn of one percent over its nominal reading. The nominal value of burn time and ΔV Counter reading are included in the PAD messages and block data relayed from the MCC-H for all abort maneuvers. (Current Mission Techniques Documentation reflects this procedure.) It is to be emphasized that this overburn monitoring procedure is only for the non-nominal maneuvers and does not apply to TLI, LOI, and TEI for which specific techniques have been developed.

Bill T

Howard W. Tindall, Jr.

PA:HWTindall, Jr.:js

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA GEN. REG. NO. 27

UNITED STATES GOVERNMENT

Memorandum

TO : See list below

DATE: MAR 1 [illegible]
68-PA-T-49A

FROM : PA/Chief, Apollo Data Priority Coordination

SUBJECT: Fifth "D" Mission Rendezvous Mission Techniques meeting---don't miss Paragraph 5; it's great.

1. We spent just about the entire February 26 meeting discussing the way the AGS and PNGCS should be used during the "D" Mission rendezvous. I feel as though we have accomplished quite a lot in this area having reached agreement on how the AGS should be used throughout that mission phase, with one minor exception. It is all based on the ground rule that on this mission the AGS should be maintained in that state which makes it most useful to perform the rendezvous in the event of PNGCS failure. It was noted that if, after having established the preferred techniques in accordance with that ground rule, it is possible to include some AGS systems tests without jeopardizing crew safety or other mission objectives, they would be considered.

2. Nominal situation: PNGCS seems to be working properly and is prime; AGS must be maintained in optimum state to take over in the event the PNGCS fails. This applies to all maneuvers---CSI, CDH, TPI.

(a) Checking of the PNGCS will be by comparison with the ground computed solution <u>only</u>. That is, comparisons of maneuver targeting from other sources, such as the AGS, backup charts or the CSM, will not be made to commit to the PNGCS. The PNGCS solution will be used providing it is within acceptable limits of the MSFN solution. One possible exception here is that, since the CSM optics provide very strong solutions to the TPI delta V components perpendicular to the line of sight, comparison with them may be advantageous.

(b) The state vectors in the AGS will be updated each time PNGCS is confirmed to be acceptable. This will likely be at each time it is committed to make the next maneuver using the PNGCS.

(c) AGS alignments will be made each time the PNGCS is realigned and each time the state vector in the AGS is updated from the PNGCS.

(d) No radar data will be input into the AGS as long as the PNGCS is working. In effect, it is obtaining benefit of the radar via the PNGCS state vector updates since the PNGCS is processing the radar data.

and AGS (with radar) solutions differ we would be inclined to believe the charts and use that solution instead of the AGS anyway.

5. The following is the most startling conclusion reached today! If the LM PNGCS is working but rendezvous radar has failed, we have a serious problem with the LM since no external data will be input to the spacecraft systems---PNGCS, AGS or charts. In this case, it is our recommendation that the command module execute the TPI and subsequent midcourse correction maneuvers and the LM do the braking maneuvers.

(a) The command module would compare its TPI solution with the MSFN. If the comparison is favorable that maneuver would be executed; if not, the command module would execute the MSFN delta V's using its own time of ignition.

(b) The command module would voice relay to the LM the maneuvers it has executed in order that the LM crew could update the command module state vectors in the LGC using the Target Delta V program.

6. I would like to present here the rationale for making the command module active for TPI and midcourse when only the rendezvous radar has failed. The justification is based on assuring ourselves the capability of making a good midcourse correction subsequent to TPI which is extremely important since with no ranging device the braking maneuver is going to be very difficult for the LM to do. The whole point is that only the command module is able to maintain a closed loop knowledge of the situation (with its sextant) and maintain an up-to-date set of state vectors in the computer to target the midcourse correction maneuver. Furthermore, it is only able to do this well if it makes the TPI maneuver, so that its PNGCS senses that too. It should be noted that this does not use a great deal of CSM RCS propellant. Nowhere near that budgeted for LM rescue. All of the other maneuvers are carried out by the LM and the really large RCS drinker---braking---will also be carried out by the LM. The reason for that, of course, is that since the LM will be coming in from below, viewing the command module against a star background, it will be in a much better position to do the braking maneuver. In addition, we would prefer to save CSM fuel where possible.

7. An obvious additional advantage to this is that it keeps the procedures as simple as possible in this critical situation. In fact, it is a standard CSM TPI for which a great deal of planning and training will have been carried out. On the other hand, for the LM to make these two maneuvers would require a great deal of coordination and communication between the spacecraft crews in real time which is undesirable. And, it avoids having to prepare procedures and training for this special situation.

and AGS (with radar) solutions differ we would be inclined to believe the charts and use that solution instead of the AGS anyway.

5. The following is the most startling conclusion reached today: If the LM PNGCS is working but rendezvous radar has failed, we have a serious problem with the LM since no external data will be input to the spacecraft systems---PNGCS, AGS or charts. In this case, it is our recommendation that the command module execute the TPI and subsequent midcourse correction maneuvers and the LM do the braking maneuvers.

(a) The command module would compare its TPI solution with the MSFN. If the comparison is favorable that maneuver would be executed; if not, the command module would execute the MSFN delta V's using its own time of ignition.

(b) The command module would voice relay to the LM the maneuvers it has executed in order that the LM crew could update the command module state vectors in the LGC using the Target Delta V program.

6. I would like to present here the rationale for making the command module active for TPI and midcourse when only the rendezvous radar has failed. The justification is based on assuring ourselves the capability of making a good midcourse correction subsequent to TPI which is extremely important since with no ranging device the braking maneuver is going to be very difficult for the LM to do. The whole point is that only the command module is able to maintain a closed loop knowledge of the situation (with its sextant) and maintain an up-to-date set of state vectors in the computer to target the midcourse correction maneuver. Furthermore, it is only able to do this well if it makes the TPI maneuver, so that its PNGCS senses that too. It should be noted that this does not use a great deal of CSM RCS propellant. Nowhere near that budgeted for LM rescue. All of the other maneuvers are carried out by the LM and the really large RCS drinker---braking---will also be carried out by the LM. The reason for that, of course, is that since the LM will be coming in from below, viewing the command module against a star background, it will be in a much better position to do the braking maneuver. In addition, we would prefer to save CSM fuel where possible.

7. An obvious additional advantage to this is that it keeps the procedures as simple as possible in this critical situation. In fact, it is a standard CSM TPI for which a great deal of planning and training will have been carried out. On the other hand, for the LM to make these two maneuvers would require a great deal of coordination and communication between the spacecraft crews in real time which is undesirable. And, it avoids having to prepare procedures and training for this special situation.

8. It was stated by FCOD that the command module pilot will be unable to computer onboard chart solutions for TPI due to the press of other activity and so they will not be available as a data source.

9. The manner in which the AGS can be used to execute LM chart solutions is by loading a zero magnitude maneuver into its External Delta V processor which zeros the registers and permits it to be used like the PNGCS Average G program (P-47). The crew would thrust sequentially along each of the three body axes, probably burning the largest component first. The sequential operation is necessary since there is only one digital readout on the DEDA register.

10. I expect that at the next meeting we will review all this and tune it up a little. We should then probably apply these techniques to the earlier "pseudo-TPI" maneuver which occurs half way through the exercise including special considerations associated with a TPI maneuver that we do not really intend to execute.

Howard W. Tindall, Jr.

Enclosure
List of Attendees

Addressees:
(See attached list)

ATTENDEES

E. E. Aldrin	CB
J. A. McDivitt	CB
R. L. Schweickart	CB
D. R. Scott	CB
M. C. Contella	CF
S. H. Gardner	CF
S. G. Paddock	CF
J. V. Rivers	CF
C. T. Hackler	EG
J. M. Balfe	EG
J. Craven	FC
W. E. Fenner	FC
M. V. Jenkins	FM
E. C. Lineberry	FM
A. Nathan	GAEC
J. Shreffler	FM
K. L. Baker	TRW
R. Boudreau	TRW
C. R. Shook	TRW
J. E. Scheppan	TRW
H. W. Tindall, Jr.	PA

Enclosure 1

EA/11 ½ Forgot

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA GEN. REG. NO. 27

5010-107

UNITED STATES GOVERNMENT

Memorandum

TO : See list below

DATE: MAR 13 1968

68-PA-T-61A

FROM : PA/Chief, Apollo Data Priority Coordination

SUBJECT: Seventh "D" Mission Rendezvous Mission Techniques meeting

1. The "D" Rendezvous Mission Techniques meeting of March 10 was probably one of the least productive so far, and I sincerely apologize for it. I must have been tired or something. Even so, with all that talent present, there must be something worthwhile reporting.

2. At one of our earlier meetings we tentatively established that platform alignments would be performed by both vehicles during each period of darkness throughout the rendezvous exercise. Paul Pixley (MPAD) presented some data at this meeting which showed that, from a rendezvous navigation standpoint, loss of observational data---rendezvous radar in the LM and sextant in the CSM---during platform alignment hurts us more than a little platform drift. Accordingly, it is their proposal that platform alignments only be performed prior to the separation burn which initiates the football rendezvous in the beginning and in the darkness period shared by the psuedo-TPI when the LM is above the command module. This applies to both the LM and the CSM. Unless someone has reason for disagreeing with this, their recommendation is accepted and all further work should be based upon it.

3. In response to an action item from the very first meeting, the Orbital Mission Analysis Branch (formerly the Rendezvous Analysis Branch) reported their progress on developing techniques for insuring proper station coverage and lighting conditions during the rendezvous exercise in spite of trajectory perturbations earlier in the mission. The most significant of these perturbations, of course, is failure to launch on time. As a result of their work, it is anticipated they will recommend selection of an earlier nominal launch time and change in direction of the SPS engine tests early in the mission so that the spacecraft will nominally fly in a higher orbit, during the period between them. In addition, it will probably be recommended that these big SPS burns be separated in time by approximately a day instead of occurring within the same period of activity. If these things are done it will be possible to compensate for lift off time delays by decreasing the horizontal, in-plane component of these SPS burns in real time such that the spacecraft does not go to such a high altitude, thereby shortening the orbital period during that period. The implementation to carry out targeting of these maneuvers in real time may utilize the rendezvous mission planning tools in the RTCC that are already available. Their proposed approach would be to modify the SPS burns using the Gemini Agena maneuver logic to cause

the spacecraft to rendezvous with a phantom target. The phantom target being where the spacecraft would have been if it had been launched on time and had followed the nominal maneuver sequence. If this technique proves to be as reasonable as it seems to be now, changes to the nominal mission plan noted above will be processed through the FOP by Morris Jenkins.

4. I just reread that last paragraph and it sounds like I'm still asleep. Does it make sense to you?

Bill T

Howard W. Tindall, Jr.

Enclosure
List of attendees

Addressees:
(See attached list)

ATTENDEES

E. E. Aldrin	CB
C. Conrad	CB
M. C. Contella	CF
S. H. Gardner	CF
J. E. Hutchins	CF
C. T. Hackler	EG
G. E. Paules	FC
H. D. Reed	FC
G. P. Walsh	FC
A. L. Accola	FM
H. L. Conway	FM
M. V. Jenkins	FM
E. C. Lineberry	FM
A. Nathan	FM
C. Pace	FM
P. T. Pixley	FM
D. Reed, Jr.	FM
R. R. Regelbrugge	FM
H. O. Spurlin	FM
J. L. Hall	FS
K. D. Leach	FS
H. W. Tindall, Jr.	PA
N. L. Bedford	TRW
R. Boudreau	TRW
D. L. Rue	TRW
J. E. Sheppan	TRW
C. E. Wilkins	TRW

UNITED STATES GOVERNMENT

Memorandum

TO : See list below

DATE: JUN 25 1968

68-PA-T-137A

FROM : PA/Chief, Apollo Data Priority Coordination

SUBJECT: "D" Rendezvous Mission Techniques Ground Rules, Working Agreements, and other things

On June 14 we cranked up the "D" Rendezvous Mission Techniques activities again. It was a grueling profitable day. In fact, we had such a good time we've scheduled another one for July 12.

Prior to the meeting I distributed a list of working agreements I thought we had reached previously. The crew presented another list dealing primarily with the docked LM activation/mini-football period based on a lot of planning and simulations they have been doing lately. The major part of the meeting was spent going through these lists. I have since compiled a new set derived from those - including the changes, agreements, and comments the discussion brought about. This list is attached and we can review it July 12. The last section lists some major discussion items still open. A list of action items is also attached since they help to paint the picture of our current status, which I would describe as being typically frantic.

Howard W. Tindall, Jr.

Howard W. Tindall, Jr.

Enclosures 3

Addressees:
(See list attached)

PA:HWTindall, Jr.:js

ATTENDEES

H. W. Tindall, Jr.	PA	H. K. Fanning	FC
J. A. McDivitt	CB	C. T. Essmeier	FC
D. R. Scott	CB	N. B. Hutchinson	FC
A. L. Bean	CB	M. G. Kennedy	FC
R. F. Gordon	CB	M. C. Contella	CF
R. L. Schweickart	CB	S. H. Gardner	CF
E. E. Aldrin	CB	J. V. Rivers	CF
C. Conrad	CB	T. W. Holloway	CF
E. C. Lineberry	FM	A. A. Jackson	CF
C. W. Pace	FM	D. D. Traviss	CFK
B. F. McCreary	FM	D. K. Mosel	CF
P. T. Pixley	FM	S. Paddock	MDC
A. L. Accola	FM	R. J. Boudreau	TRW
L. D. Hartley	FM	J. W. Wright	TRW
A. Nathan	FM	J. E. Scheppan	TRW
J. B. Craven	FC	H. R. Klein	TRW
J. G. Renick	FC	R. L. Baker	TRW
W. E. Fenner	FC	H. C. Woodring	NR
H. D. Reed	FC	R. D. Lowenstein	Link/Sincom
R. Holkan	FC	J. L. Nevins	MIT/IL
J. Neubaur	FC	P. M. Kachmar	MIT/IL
E. E. Marzano	FC	E. S. Muller	MIT/IL
J. Wegener	FC	R. A. Larson	MIT/IL

Enclosure 1

June 18, 1968

"D" MISSION RENDEZVOUS GROUND RULES WORKING AGREEMENTS

AND THINGS LIKE THAT

1. General

a. The reference trajectory is that provided by MPAD dated June 7 1968.

b. Nomenclature for the burn sequence following undocking is:

(1) RCS Separation
(2) Phasing
(3) Insertion
(4) TPI_0 - If abort from football
(5) CSI_1
(6) CDH_1
(7) TPI_1 - If abort from 1st bubble
(8) CSI_2
(9) CDH_2
(10) TPI_2
(11) TPF

c. The rendezvous will be run throughout with the vehicle roll angles $\cong$ 0°. The only exception to this is the RCS Separation burn where the CSM roll is 180°. A 180° roll will be performed by the CSM immediately prior to or during the IMU alignment following the RCS Separation burn. (i.e., TPI from above will be initiated "heads down" and TPI from below will be initiated "heads up" for either vehicle.)

d. LM and CSM state vectors time tagged 12 minuted before RCS Separation are uplinked to the CMC and LGC prior to undocking. State vectors are not sent to either vehicle again until immediately after TPI_1, when the rendezvous navigation problem is reinitialized. At that time, state vectors are sent for both spacecraft and to both computers. IMU alignments will also be made at these points in the exercise and take precedence over the state vector updates if timeline conflicts develop.

e. On both spacecraft all rendezvous navigation will be carried out to update the LM state vector. That is, the LM radar data would be used to update the LM state vector in the LGC and the CSM sextant data would be used to update the LM state vector in the CMC.

f. The CMC's LM state vector will be updated after each LM maneuver with the R-32 Target ΔV routine using the preburn values as determined in the LM's pre-thrust program.

g. The AGS should be maintained in that state which makes it most useful to perform the rendezvous in the event of PGNCS failure. If, after having established the preferred techniques in accordance with that ground rule, it is possible to include some AGS systems tests without jeopardizing crew safety or other mission objectives, they would be considered.

h. The state vectors in the AGS will be updated each time PGNCS is confirmed to be acceptable. This will likely be at each time it is committed to make the next maneuver using the PGNCS except perhaps TPI.

i. AGC alignments will be made each time the PGNCS is realigned and each time the state vector in the AGS is updated from the PGNCS.

j. If PGNCS, RR, or G&N fails, the rendezvous is terminated at the next TPI opportunity.

k. The AGS is not mandatory for the rendezvous exercise. That is, if it fails prior to or during this mission phase, the exercise shall continue.

2. <u>Prior to Undocking</u>

a. The crew will synchronize the CMC clock as precisely as possible utilizing information voiced from the ground. The crew will provide initial synchronization of the LGC to the CMC clock. The ground will provide the necessary information by voice for fine synchronization of the LGC clock.

This supercedes the mission rule which specifies resynchronization of a spacecraft clock only whenever it disagrees with the ground reference by more than 0.5 seconds.

b. The LM Rendezvous REFSMMAT is that of a "nominal" alignment for T (align) = TIG (TPI_2). It will be uplinked from the ground.

c. The CSM Rendezvous REFSMMAT is defined by a stable member orientation where:

$\overline{X}$ CSM = $\overline{Z}$ LM

$\overline{Y}$ CSM = $\overline{Y}$ LM

Z CSM = -$\overline{X}$ LM

d. Prior to undocking, the CSM will maneuver the docked vehicles to an inertial attitude such that with no further attitude maneuvering the CSM will be oriented approximately 180, 0, 0 (roll, pitch, yaw) with respect to the local vertical frame at the time of the RCS Separation. The difference between the exact local vertical attitude and 180, 0, 0 is due to the regression of the line of modes from TIG (RCS Separation) to TIG (TPI_2), and the fact that the CSM REFSMMAT is nominal at TPI_2.

e. Prior to undocking, but following the CSM attitude maneuver to RCS Separation attitude, the LM IMU will be aligned to the CM IMU using the docked alignment procedure which takes advantage of a known CSM inertial attitude and known CSM/LM geometry (with account of the docking ring angle $\Delta\phi$ being taken) to coarse align the LM IMU to the inertial frame. The CSM and LM gimbal angles are then compared directly (via V16N20) and coarse align and attitude dead banding errors are removed by direct torquing of the LM IMU gyros via the fine align routine (V41).

f. The formula used for docked alignment with identical REFSMMATS is:

$$OGA_{LM} = (300 - \Delta\phi) - OGA_{CM}$$
$$IGA_{LM} = IGA_{CM} + 180$$
$$MGA_{LM} = -MGA_{CM}$$

Where $\Delta\phi$ is the docking ring angle.

g. The formula used for docked alignment where the stable members are oriented:

$$\overline{X}_{LM} = -\overline{Z}_{CM}$$

$$\overline{Y}_{LM} = \overline{Y}_{CM}$$

$$\overline{Z}_{LM} = \overline{X}_{CM}$$

is:

$$OGA_{LM} = (300 - \Delta\phi) - OGA_{CM}$$

$$IGA_{LM} = IGA_{CM} + 90$$

$$MGA_{LM} = MGA_{CM} = 0$$

This is a special formula only valid where the CM MGA = 0. This set of equations will be used for the LM alignment prior to undocking.

3. Undocking, station keeping and LM inspection

a. Undocking will take place 15 minutes prior to the RCS Separation burn with the CSM oriented to the inertial attitude for that burn. Average G will not be on in either vehicle during the undocking or station keeping phase. This will preserve the relative state vectors until average G comes on in the CSM 30 seconds prior to RCS Separation.

b. Following undocking, the CSM will maintain attitude and will be responsible for station keeping. The LM will yaw right 120° and pitch up 90° placing the two spacecraft "nose-to-nose." (crewmen "nose-to-nose")

c. The LM will yaw through 360° ($\sim 1^{\circ}$/sec) permitting the CSM to conduct a visual inspection of the landing gear and LM structure.

d. After completion of 3c, the LM assumes the station keeping task while the CSM prepares for RCS separation.

4. RCS Separation and Mini-football

a. The configuration of the spacecraft at the RCS Separation burn will be LM leading the CSM, both heads down facing each other with zero relative velocity. (Orbit rate FDAI's - LM: 0, 180, 0 - CSM: 180, 0, 0). (FDAI total attitude is read in the order roll, pitch, yaw; IMU gimbal angles are read in the order outer, inner, middle).

b. The CSM will execute a 1 FPS radial inward burn for the RCS Separation burn; i.e., the CSM will burn 1 FPS -Z (body). This burn will employ the P-30, P-41 sequence. LM uses R-32 to update CSM state vector in the LGC.

c. On entering darkness after the RCS Separation both spacecraft will perform REFSMMAT IMU alignments.

d. The LM COAS will be calibrated during the mini-football and will not be moved again after that.

5. Phasing Maneuver

a. Phasing targeting is established pre-flight.

b. The phasing burn will be executed under AGS control with PGNCS monitoring. The throttle will be set at 10% for 15 seconds at which time it will be advanced crisply to approximately 40% and left there til auto-cutoff. The PGNCS residual velocities will be burned to zero by use of programs 30 and 40.

c. The horizon is used as a burn attitude check prior to the phasing burn when AGS is under control. The ground supplies the LPD pitch angle for this check.

6. TPI_0

a. If PGNCS, rendezvous radar, or CSM G&N fails prior to insertion but after phasing, TPI_0 is performed. As a standard operating procedure during the football rendezvous, the LM and CSM should both be targeted and prepared to execute the TPI if an abort is necessary. If the failure is LM PGNCS, AGS is used for executing TPI. A 130° transfer angle shall be used for aborts from the football rendezvous. (See action item 5)

7. Insertion Maneuver

Preflight targeting will not be used for this maneuver. The ground procedures for determining the insertion maneuver are as follows: The MCC/RTCC will utilize the two-impulse logic (NCC/NSR combination) to achieve the proper differential altitude. The computed value of the NCC maneuver will be used as the insertion maneuver. The NSR will be forced to occur at apogee even if station coverage will not be available there for this (CDH_1) maneuver.

8. $CSI_{1,2}$ and $CDH_{1,2}$

a. As a nominal procedure, the command module will be targeted with "mirror image" maneuvers to be executed with a one minute time delay in the event the LM is unable to maneuver. Some biases will be added (See action item No. 4)

b. In the event the LM has performed an ullage maneuver prior to a main engine failure, the LM will remove that ΔV to maintain correct targeting of the CSM mirror image burn.

c. LM PGNCS ΔV solutions will be compared with the ground. If the solutions agree, the PGNCS solution will be burned. There will not be comparisons with AGS, charts, or CSM.

d. In the event the ground solution is to be used, it will be executed using the AGS which has been targeted with the MSFN solution as a standard procedure. The external ΔV mode is used.

e. No radar data shall be input into the AGS prior to CSI and CDH.

f. There will not be any backup charts used for $CSI_{1,2}$. The LM shall have backup charts for CDH and TPI. The command module pilot will be unable to compute onboard chart solutions for TPI due to the press of other activity and so they will not be available as a data source.

9. $\underline{TPI_{0,1,2}}$

a. If the LM PGNCS is working but rendezvous radar has failed, no external data will be input to the spacecraft systems----PGNCS, AGS or charts. In this case, the command module executes the TPI and subsequent midcourse correction maneuvers and the LM does the braking maneuver if visibility permits. However, the command module, of course, must compare its TPI solution with the MSFN and that comparison must be favorable. (If not, see 10b) The command module would voice relay to the LM the maneuvers it has executed in order that the LM crew could update the command module state vector in the LGC using the target ΔV program.

b. If the LM PGNCS has failed but the RR is working, compare the onboard chart solution for TPI with the MSFN. If the comparison is favorable, execute the chart solution and, if not, use the MSFN ΔV's executed at a time determined onboard the spacecraft. The maneuver would be made using the AGS external ΔV mode.

10. For Discussion

a. $CDH_{1,2}$

If LM PGNCS/MSFN comparison shows disagreement, shall a LM chart/MSFN comparison be made and used if favorable or shall the ground solution be burned regardless of the chart solutions?

b. If both RR and CSM G&N have failed, shall the LM perform TPI using chart solution or what?

c. G&CD has recommended in their memo, EG21-M-59-68-376, that the AGS be used in the following manner on the "D" Rendezvous:

(1) Align and initialize the AGS to the PGNCS after each PGNCS alignment.

(2) Perform AGS targeting for all real and pseudo-burns using the onboard solution. Execute the burns with PGNCS, unless PGNCS has failed.

(3) Perform an accelerometer calibration before each real and pseudo-burn.

(4) Perform gyro calibrations in sufficient number (at least four times over a two-hour period) to verify the technique.

(5) Perform at least one AOT or COAS alignment of the AGS, preferably AOT.

(6) Update the AGS with the RR near the second TPI burn.

(7) In the event of a PGNCS failure during the second rendezvous sequence, compare the AGS solutions with either charts or MSFN and execute the burns with the AGS if there is reasonable agreement. The AGS should be updated with the RR.

d. Review procedure and expected accuracy of the initial LM platform drift test made while docked to the CSM.

e. Review Mission Control Center/crew pad message formats.

June 18, 1968

"D" RENDEZVOUS MISSION TECHNIQUES

ACTION ITEM LIST

(To be discussed at next meeting)

1. FCSD and MPAD will provide for review an up-to-date rendezvous navigation tracking schedule for both the LM and CSM.

2. MPAD to present the pre-rendezvous maneuver ground rules and techniques to provide adequate lighting conditions and station coverage.

3. MPAD to report on analysis regarding modification of the RCS Separation burns to reduce probability of recontact due to small maneuver execution dispersions.

4. MPAD to report on which mirror image maneuvers need be biased as well as consequence of not doing so.

5. Crew will report results of simulator exercise regarding use of unstaged LM in terminal phase rendezvous.

6. FCD to report on techniques for checking the rendezvous radar during the mini-football and the football phase for purpose of go/no go.

7. MPAD to report consequences of using the MSFN uplinked PGNCS CSI/CDH targeting in the AGS for maneuver execution in the event of PGNCS failure. That is, are the errors thus incurred acceptable?

8. FCSD will define limits of acceptable TPI time slippage beyond which corrective action must be taken. Apparently, they will be based on CSM active rendezvous lighting constraints.

9. MPAD to establish acceptable difference limits for use in comparison of onboard vs MSFN rendezvous targeting (CSI, CDH, and TPI).

10. MIT to present recommended procedure for controlling the W-matrix by crew input to the LGC and CMC.

Enclosure 3

11. MPAD to report results of their survey into the onboard computation of CDH execution time which has been showing a tendency to be late. If this persists, it will result in TPI time slip, excess RCS ΔV costs, and difficulty in solution comparison.

12. FCD will report on acceptability of onboard PGNCS accelerometer bias determination while out of MSFN station coverage.

13. Rendezvous maneuver monitoring procedures will be reviewed for both critical and non-critical rendezvous phase burns. Attitude, attitude rate, and over and under speed limits will be established as well as the actions to be taken if they are exceeded. This, in effect, encompasses the procedures to be followed in the event of a partial burn.

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA FPMR (41 CFR) 101-11.6

UNITED STATES GOVERNMENT

Memorandum

TO : See list attached

DATE: JUL 25 1968

68-PA-T-168A

FROM : PA/Chief, Apollo Data Priority Coordination

SUBJECT: "D" Rendezvous

1. A great many things were discussed and resolved at the July 22 "D" Rendezvous Mission Techniques meeting. They will all be fully recorded in the minutes. There were three items, however, I would like to call particular attention to at this time by this memo.

2. In order to avoid any chance of recontact as a result of maneuver dispersions in the CSM RCS separation maneuver which starts off the "D" mission rendezvous, it was decided to increase its magnitude from 1.0 to 2.5 fps. It will still be performed in a radial direction. This was brought about when it was recognized that an error of about 0.4 fps in the horizontal retrograde direction would result in recontact after the big phasing burn. Dispersions of that magnitude could easily occur due to imperfect velocity nulling during station keeping, G&N maneuver dispersions, spacecraft venting, etc.

3. It has been established that the elevation angle to be used by both spacecraft in determining all TPI times - nominal and contingency - will be 27.5°.

4. The out-of-plane component of the TPI maneuvers shall be targeting to force a node at TPF rather than at the second midcourse correction maneuver. This will also apply to the lunar rendezvous mission, which the "D" was attempting to simulate in this respect. The change is being made to simplify the crew timeline and procedures; it is felt to be entirely adequate based on the recently adopted plans for handling out-of-plane on the lunar rendezvous.

5. The above decisions are considered firm and should be immediately incorporated in all aspects of the Apollo Program to which they apply. They will only be changed if there is a <u>darned good reason</u> - not just to make things a little better!

Howard W. Tindall, Jr.

PA:HWTindall, Jr.:js

UNITED STATES GOVERNMENT

Memorandum

TO : See list attached

DATE: JUL 26 1968

68-PA-T-172A

FROM : PA/Chief, Apollo Data Priority Coordination

SUBJECT: "D" Rendezvous Mission Techniques meeting of July 22

1. We cleaned up a lot of stuff at the subject meeting. Attached are updated "Ground Rules, Working Agreements, and other things," and another list of open items to be discussed at our next meeting currently scheduled for September 6, 1968, or whenever the crew is available after that.

2. One facet of this business that has become extremely critical involves how to do rendezvous navigation! The tracking schedule overwhelms and influences everything else the crew is doing. It is essential that it be established immediately along with W-matrix initialization procedures - whatever that is - taking into account the rendezvous radar thermal control required, etc. If all this changes much from that which has been assumed to be proper, crew training - among other things - will be severely impacted. Accordingly, a Rendezvous Navigation Mission Techniques Panel is being established to concentrate on this and get it all squared away. I have attached to this memo a "charter" which explains exactly what they are to do and lists the specific people assigned to do it. Anyone who can help these guys are requested to do so - particularly with regard to those rendezvous radar thermal constraints. Those are really going to screw us, I'm afraid.

Howard W. Tindall, Jr.

Howard W. Tindall, Jr.

Enclosures 3
Rendezvous Navigation Mission Techniques Panel
  Charter and Composition
Working Agreements, etc.
Open Items

PA:HWTindall, Jr.:js

July 25, 1968

"D" MISSION RENDEZVOUS NAVIGATION
MISSION TECHNIQUES PANEL

I. Objectives of the panel are to establish the following rendezvous navigation mission techniques

A. Initially to establish a tracking schedule for the "D" Mission Rendezvous Navigation

B. Investigate the schedule determined in "A" by considering the following:

a. W-matrix reinitialization procedures

b. Thermal constraints of the rendezvous radar

c. Standardization of tracking schedules around a maneuver

d. Desire to minimize the effect of missing marks as a result of procedural or spacecraft systems problem

e. Larger than nominally expected MSFN errors

C. Standardize the mission techniques which establish the following:

a. The expected navigation accuracy at maneuver times for:

(1) The LM PGNCS using RR tracking data

(2) The CSM PGNCS using sextant tracking data

b. E-memory constants specifications

II. Membership of the panel

A.	P. T. Pixley, Chairman	Code FM
B.	J. Shreffler	FM
C.	R. W. Becker	FM
D.	P. Shannahan	FM
E.	H. D. Reed	FC
F.	W. E. Fenner	FC
G.	D. Blue	CF
H.	D. K. Mosel	CF
I.	E. Muller	MIT
J.	P. Kachmar	MIT
K.	N. Nevins	MIT
L.	R. Larson	MIT
M.	A. Satin	TRW
N.	S. Paddock	MDC
O.	A G&CD man to be named soon	

Enclosure 1

July 22, 1968

"D" MISSION RENDEZVOUS GROUND RULES WORKING AGREEMENTS AND THINGS LIKE THAT

1. General

a. The reference trajectory is that provided by MPAD dated June 24, 1968.

b. Nomenclature for the burn sequence following undocking is:

(1) RCS Separation
(2) Phasing
(3) Insertion
(4) TPI_o - If abort from football
(5) CSI_1
(6) CDH_1
(7) TPI_1 - If abort from 1st bubble
(8) CSI_2
(9) CDH_2
(10) TPI_2
(11) TPF

c. The rendezvous will be run throughout with the vehicle roll angles ≌ 0°. The only exception to this is the RCS Separation burn where the CSM roll is 180°. A 180° roll will be performed by the CSM immediately prior to or during the IMU alignment following the RCS Separation burn. (i.e., TPI from above will be initiated "heads down" and TPI from below will be initiated "heads up" for either vehicle.)

d. LM and CSM state vectors time tagged 12 minutes before RCS Separation are uplinked to the CMC and LGC prior to undocking. State vectors are not sent to either vehicle again until immediately after TPI_1, when the rendezvous navigation problem is reinitialized. At that time, state vectors are sent for both spacecraft and to both computers. IMU alignments will also be made at these points in the exercise and take precedence over the state vector updates if timeline conflicts develop.

e. On both spacecraft all rendezvous navigation will be carried out to update the LM state vector. That is, the LM radar data would be used to update the LM state vector in the LGC and the CSM sextant data would be used to update the LM state vector in the CMC.

f. On both spacecraft the rendezvous navigation W-Matrix will be set to 1000 feet and 1 fps initially and whenever it is reinitialized periodically during the rendezvous.

g. The CMC's LM state vector will be updated after each LM maneuver with the R-32 Target ΔV routine using the pre-burn values as determined in the LM's pre-thrust program.

h. The AGS should be maintained in that state which makes it most useful to perform the rendezvous in the event of PGNCS failure. If, after having established the preferred techniques in accordance with that ground rule, it is possible to include some AGS systems tests without jeopardizing crew safety or other mission objectives, they would be considered.

i. The state vectors in the AGS will be updated each time PGNCS is confirmed to be acceptable. This will likely be at each time it is committed to make the next maneuver using the PGNCS except perhaps TPI.

j. AGC alignments will be made each time the PGNCS is realigned and each time the state vector in the AGS is updated from the PGNCS.

k. If PGNCS, RR, or G&N fails, the rendezvous exercise is aborted at the next TPI opportunity.

l. The AGS is not mandatory for the rendezvous exercise. That is, if it fails prior to or during this mission phase, the exercise shall continue.

2. Prior to Undocking

a. The crew will synchronize the CMC clock as precisely as possible utilizing information voiced from the ground. The crew will provide initial synchro-

nization of the LGC to the CMC clock. The ground will provide the necessary information by voice for fine synchronization of the LGC clock. This supercedes the mission rule which specifies resynchronization of a spacecraft clock only whenever it disagrees with the ground reference by more than 0.5 seconds.

b. The LM Rendezvous REFSMMAT is that of a "nominal" alignment for T(align) = TIG (TPI_2). It will be uplinked from the ground.

c. The CSM Rendezvous REFSMMAT is defined by a stable member orientation where:

$\overline{X}$ CSM = $\overline{Z}$ LM

$\overline{Y}$ CSM = $\overline{Y}$ LM

Z CSM = $-\overline{X}$ LM

d. Prior to undocking, the CSM will maneuver the docked vehicles to an inertial attitude such that with no further attitude maneuvering the CSM will be oriented approximately 180, 0, 0, (roll, pitch, yaw) with respect to the local vertical frame at the time of the RCS Separation. The difference between the exact local vertical attitude and 180, 0, 0 is due to the regression of the line of modes from TIG (RCS Separation) to TIG (TPI_2), and the fact that the CSM REFSMMAT is nominal at TPI_2.

e. The only in-flight adjustment of the LGC PIPA bias compensation parameters included in the nominal flight plan shall be done by the crew while docked to the CSM. The values will be updated regardless of how small the change. (i.e., There is no lower threshold.) The crew will inform the MCC-H of the new values at the next MSFN station contact possible. The MCC-H will continually monitor the IMU performance and will advise and assist in additional updates if the compensation becomes in error by more than a specified threshold.

f. An AGS accelerometer calibration shall be performed while docked at about the same time as the PIPA compensation. This will be the only AGS accelerometer calibration in the nominal flight plan unless time is available for a second one between TPI_1 and CSI_2. AGS gyro calibration shall not be performed during the rendezvous exercise period of activity.

g. Prior to undocking, but following the CSm attitude maneuver to RCS Separation attitude, the LM IMU will be aligned to the CM IMU using the docked alignment procedure which takes advantage of a known CSM inertial attitude and known CSM/LM geometry (with account of the docking ring angle $\Delta\phi$ being taken) to coarse align the IM IMU to the inertial frame. The CSM and LM gimbal angles are then compared directly (via V16N20) and coarse align and attitude dead banding errors are removed by direct torquing of the LM IMU gyros via the fine align routine (V41).

h. The formula used for docked alignments with identical REFSMMATS is:

$$OGA_{LM} = (300 - \Delta\phi) - OGA_{CM}$$

$$IGA_{LM} = IGA_{CM} + 180$$

$$MGA_{LM} = -MGA_{CM}$$

Where $\Delta\phi$ is the docking ring angle.

i. The formula used for docked alignment where the stable members are oriented:

$$\overline{X}_{LM} = -\overline{Z}_{CM}$$

$$\overline{Y}_{LM} = \overline{Y}_{CM}$$

$$\overline{Z}_{LM} = \overline{X}_{CM}$$

is:

$$OGA_{LM} = (300 - \phi) - OGA_{CM}$$

$$IGA_{LM} = IGA_{CM} + 90$$

$$MGA_{LM} = MGA_{CM} = 0$$

This is a special formula only valid where the CM MGA = 0. This set of equations will be used for the LM alignment prior to undocking. (Equation verification is given in MIT/IL Apollo G&N System Test Group Memo No. 1187, dated July 8, 1968.)

3. Undocking, station keeping and LM inspection

a. Undocking will take place 15 minutes prior to the RCS Separation burn with the CSM oriented to the inertial attitude for that burn. Average G will not be on in either vehicle during the undocking or station keeping phase. This will preserve the relative state vectors until Average G comes on in the CSM 30 seconds prior to RCS Separation.

b. Following undocking, the CSM will maintain attitude and will be responsible for station keeping. The LM will yaw right 120° and pitch up 90° placing the two spacecraft "nose-to-nose." (crewmen "nose-to-nose")

c. The LM will yaw through 360° (1°/sec) permitting the CSM to conduct a visual inspection of the landing gear and LM structure.

d. After completion of 3c, the LM assumes the station keeping task while the CSM prepares for RCS Separation.

4. RCS Separation and Mini-football

a. The configuration of the spacecraft at the RCS Separation burn will be LM leading the CSM, both heads down facing each other with zero relative velocity. (Orbit rate FDAI's - LM: 0, 180, 0 - CSM: 180, 0, 0). (FDAI total attitude is read in the order roll, pitch, yaw; IMU gimbal angles are read in the other outer, inner, middle).

b. The CSM will execute a 2.5 fps radial inward burn for the RCS Separation burn; i.e., the CSM will 2.5 fps -Z (body). This burn will employ the P-30, P-41 sequence. LM uses R-32 to update CSM state vector in the LGC. (Reference 68-FM62-229)

c. On entering darkness after the RCS Separation both spacecraft will perform REFSMMAT IMU alignments.

d. The LM COAS will be calibrated during the mini-football and will not be moved again after that.

5. Phasing Maneuver

a. Phasing targeting is established pre-flight.

b. The phasing burn will be executed under AGS control with PGNCS monitoring by use of programs 30 and 40. The throttle will be set at 10% for 15 seconds at which time it will be advanced crisply to approximately 40% and left there until auto-cutoff.

c. The horizon is used as a burn attitude check prior to the phasing burn when AGS is under control. The ground supplies the LPD pitch angle for this check.

d. Phasing burn monitoring

(1) Attitude and/or attitude rate limits are exceeded - terminate the burn.

(2) Overburn - Back up AGS engine off three (3) seconds after the PGNCS "engine off time" is indicated.

e. Upon completion of the burn, the LM shall be oriented with X-axis vertical and the y and z body axis ΔV residuals will be trimmed to zero.

6. TPI_0

a. If PGNCS, rendezvous radar, or CSM G&N fails prior to insertion but after phasing, TPI_0 is performed. As a standard operating procedure during the football rendezvous, the LM and CSM should both be targeted and prepared to execute the TPI if an abort is necessary. If the failure is LM PGNCS, AGS is used for executing TPI. A 130° transfer angle shall be used for aborts from the football rendezvous. (See action item 7)

7. Insertion Maneuver

a. Pre-flight targeting will not be used for this maneuver. The ground procedures for determining the insertion maneuver are as follows: The MCC/RTCC will utilize the two-impulse logic (NCC/NSR combination) to achieve the proper differential altitude. The computed value of the NCC maneuver will be used as the insertion maneuver. The NSR will be forced to occur at apogee even if station coverage will not be available there for this (CDH_1) maneuver.

b. In the event the LM has performed a ullage maneuver prior to a DPS engine failure to start, the LM will remove that ΔV to maintain correct targeting of the CSM TPI_o maneuver. The CSM shall continue to countdown for TPI_o during the LM insertion burn.

8. $CSI_{1,2}$ and $CDH_{1,2}$

a. CSI and CDH maneuvers shall be targeted to cause TPI time to occur when the CSI is 11 minutes into darkness. TPI time is defined as the time at which the elevation angle of the CSM with respect to local horizontal as observed by the LM is 27.5° (see 9b).

b. The MCC-H will select and relay to the crew a single solution for each of the CSI and CDH rendezvous maneuvers which will be used by both spacecraft - for PGNCS comparison, AGS targeting, and CSM G&N mirror image targeting, etc. It shall be that solution which is most compatible with the PGNCS. Some biases will be necessary for use in the AGS and CSM G&N.

c. As a nominal procedure, the command module will be targeted with "mirror image" maneuvers to be executed with a one minute time delay in the event the LM is unable to maneuver. In order to maintain TPI time and differential altitude within acceptable bounds it is necessary to bias the radial ΔV component of the CDH maneuvers relayed to the CSM from the MCC-H by an amount established pre-flight (approximately 7 fps). No other ΔV components of either the CSI or CDH maneuvers need to be biased in the CMC.

d. The crew shall bias CDH time 100 seconds earlier than determined by the PGNCS CSI targeting program (P32) when sequencing through the CDH targeting program (P33) to compensate for an inadequate approximation in P32. The crew shall bias CDH_2 time 70 seconds later than determined in P32.

e. An out-of-plane ΔV component will be computed by the LM PGNCS for CSI_2 and $CDH_{1,2}$ using R36. This maneuver ΔV shall be executed unless it is less than 2 fps. This ΔV component will be included in the LGC/MSFN solution comparision.

f. LM PGNCS ΔV solutions will be compared with the ground. If the solutions agree, the PGNCS solution will be burned. There will not be comparisons with AGS, charts, or CSM.

g. In the event the ground solution is to be used, it will be executed using the AGS which has been targeted with the MSFN solution as a standard procedure. The external ΔV mode is used. It is necessary to bias the radial ΔV component of the CSI_2 maneuver relayed to the LM (AGS) from the MCC-H by an amount established pre-flight in order to maintain TPI_2 time within acceptable bounds. No other ΔV components of either the CSI or CDH maneuvers need to be biased in the AGS.

h. No radar data shall be input into the AGS prior to CSI and CDH.

i. There will not be any backup charts used for $CSI_{1,2}$. The LM shall have backup charts for CDH and TPI. The CDH charts require a minimum of 29 minutes between CSI and CDH. The command module pilot will be unable to compute onboard chart solutions for TPI due to the press of other activity and so they will not be available as a data source.

j. In the event the LM has performed an ullage maneuver prior to a main engine failure, the LM will remove that ΔV to maintain correct targeting of the CSM mirror image burn.

9. $\underline{TPI_{0,1,2}}$

a. Although studies have shown that if TPI time falls outside a window of approximately four minutes duration undesirable lighting conditions will result for one or both spacecraft, it has been established that it is more important to execute TPI at the proper elevation angle than to honor lighting constraints in terminal phase. That is lighting constraints are desirable but not mandatory. Nominal TPI elevation angle is mandatory.

b. The elevation angle to be used in the TPI targeting programs (P34) in both spacecraft shall be 27.5° for all rendezvous.

c. The LM shall always use the elevation angle option in P34 for TPI targeting.

d. The CSM shall always use the elevation angle option in P34 for TPI targeting whenever it becomes the active vehicle. Therefore, the first time the CSM cycles through P34 it will use the elevation angle option; however, if the LM TPI solution is determined to be acceptable by comparison checks, the CSM will recycle through P34 using the LM TPI time as input to the "time" option. (TPI maneuvers will not be biased.)

e. TPI shall be targeted onboard and at MCC-H to force a node at TPF (i.e., intercept). The MCC-H shall supply this maneuver via voice (pad message) in both External ΔV and line-of-sight components.

f. If the LM PGNCS is working but rendezvous radar has failed, no external data will be input to the spacecraft systems---PGNCS, AGS or charts. In this case, the command module executes the TPI and subsequent midcourse correction maneuvers and the LM does the braking maneuver if visibility permits. However, the command module, of course, must compare its TPI solution with the MSFN and that comparison must be favorable. (If not, see 9h) The command module would voice relay to the LM the maneuvers it has executed in order that the LM crew could update the command module state vector in the LGC using the target ΔV program.

g. If the LM PGNCS has failed, but the RR is working, compare the onboard chart solution for TPI with the MSFN. If the comparison is favorable, execute the chart solution and, if not, use the MSFN ΔV's executed at a time determined onboard the spacecraft. The maneuver would be made using the AGS external ΔV mode.

h. If both the RR and the CSM G&N have failed, use the LM PGNCS to execute the MSFN TPI solution given in LOS coordinates at the time at which the elevation angle is 27.5° as determined onboard the spacecraft.

July 25, 1968

"D" RENDEZVOUS MISSION TECHNIQUES
OPEN ITEM LIST

(to be discussed at next meeting)

1. Rendezvous Navigation Mission Techniques Panel Report.
2. MPAD to determine expected trajectory dispersions at initiation of the rendezvous exercise.
3. MPAD to determine CSI/CDH out-of-plane ΔV lower threshold.
4. MPAD to determine CDH_2 time bias.
5. ASPO to determine expected LM IMU alignment accuracy when docked to the CSM.
6. Review of MCC-H/Crew Pad Message Format.
7. Crew to determine from simulator exercises the maneuverability of the LM in the docked configuration during terminal phase.
8. MPAD to establish acceptable difference limits for use in comparison of onboard vs MSFN rendezvous targeting (CSI, CDH, & TPI).
9. Review of rendezvous maneuver monitoring procedures.
10. TRW to present AGS align and initialization procedures.

Enclosure 3

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA FPMR (41 CFR) 101-11.6

UNITED STATES GOVERNMENT

Memorandum

TO : See list attached

DATE: AUG 5 1968

68-PA-T-185A

FROM : PA/Chief, Apollo Data Priority Coordination

SUBJECT: Propulsion system to be used on the "D" Mission Rendezvous CSI Maneuver

One of the planned rendezvous maneuvers (CSI_1) on the "D" mission is nominally zero. Since it is intended to make this maneuver based on the real time situation, some logic must be established to govern when and how the maneuver would be made. This memo is to describe the proposed logic.

If the computed value of the CSI_1 maneuver is less than 1* fps, the maneuver will not be executed at all. If the maneuver is greater than 1 fps but less than 6* fps, the spacecraft will be oriented with the minus X-axis in the direction of the velocity vector and the maneuver will be carried out using four jet RCS. The reason for this orientation is to avoid losing rendezvous radar lock. This means, of course, that the maneuver may be executed in either $\pm$ X direction with equal probability.

The 6 fps upper limit is necessary in order to conserve RCS propellant as well as to remain within jet impingement constraints. If the CSI_1 is in excess of 6 fps, the DPS will be used at 10% thrust (even though rendezvous radar lock may be lost).

There was concern about using the DPS to carry out small maneuvers from the standpoint of how the PGNCS would work as well as whether a short burn for CSI would preclude use of the DPS for the 60 fps CDH maneuver approximately 30 minutes later. Harry Byington checked into this and has determined that the propulsion people intend to adopt the following DPS constraint for the "D" mission: the DPS may be used provided at least 30 minutes has elapsed since the previous burn, no matter how short it was. In other words, we have no problem there. It has also been determined that the PGNCS does not limit us either. Although the DPS thrust program (P40) does not have short burn logic like the SPS and APS programs have, including start up and tail off characteristics, it is capable of

---

* I selected these values to illustrate the point. They're probably not far off. MPAD is in the process of determining the proper values, OMAB - the first based on rendezvous considerations; G&PB - the second based on engine characteristics and consumables. (Task assignments are needed.)

5010-108

info

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA FPMR (41 CFR) 101-11.6

NASA-Manned Spacecraft Center
Mission Planning & Analysis Division

UNITED STATES GOVERNMENT

Memorandum

EA5/ P. M. Deans

TO : Informal Distribution

DATE: AUG

68-FM46-331

FROM : FM4/Mathematical Physics Branch

SUBJECT: D Mission Rendezvous Navigation Mission Techniques Panel Meeting

1. The first meeting of the D Mission Rendezvous Navigation Mission Techniques Panel was held July 28, 1968. The purpose of this panel is to coordinate the onboard navigation analyses conducted at MIT and MSC with the crew timeline worked up by the FCOD and minimize the effect of procedural or spacecraft systems problems to the navigation procedures.

2. The first item of business was to define the time periods when the rendezvous radar would be powered up for tracking or other purposes. Two schedules of rendezvous radar operation were established for the purpose of determining their adequacy for thermal control. The first schedule is simply to power up the rendezvous radar at 94 hours 27 minutes g.e.t. and power down when the rendezvous radar is no longer needed - sometime in the terminal phase at approximately 102 hours and 10 minutes g.e.t. The second schedule is as follows:

RR on	94:27, 95:45, 96:48, 97:59, 99:14, 99:56, 100:41
RR off	95:31, 96:29, 97:48, 98:31, 99:41, 100:30, 102:10.

(Time is hr:min g.e.t.)

The first schedule is the most desirable because of simplicity in the crew activity. The second schedule represents the minimum schedule such that if it is shortened crew confidence in the system will be degraded or a serious perturbation in the crew timeline will be induced. The IESD has received this schedule and has been requested to have thermal analyses conducted of these two methods as soon as possible. It should be recognized that the crew and ground procedures are proceeding according to the second schedule and any significant change to these procedures are considered to be not only highly undersirable but must be accompanied by proper justification.

3. In order to use the LM navigation system effectively, MIT has proposed the W-matrix reinitialization when performed be placed frou marks deep into the tracking interval following a maneuver. The rendezvous radar thermal cool down process affects the boresight axis orientation. Mr. Mele of RCA commented that for a cool down of 15° from 140°F. to 125°F. typical numbers

for the affect of the cool down process on the orientation is considerably less than 1" of arc for a 15-minute cool down. The reinitialization procedure should be unaffected by this type of variation in orientation.

4. The remainder of the day was devoted to establishing the tracking schedules which were developed with the following assumptions different from or in addition to those from the D Rendezvous Mission Techniques meeting of July 22. (See attachment)

a. The June 24 reference trajectory was used as a standard with the time between CSI_1 and CDH_1 increased to 32 minutes.

b. The requirement that the command pilot computer backup charts solutions for TPI_2 requires the LM navigation to terminate earlier than the nominal 12 minutes prior to TPI_2. The time assumed in designing the schedule was 15 minutes.

c. For the CSI_2 and $CDH_{1,2}$ maneuvers, one minute from the LM maneuver initiation time was allowed for the command module pilot to either

(1) initiate his mirror image maneuver or

(2) initiate the maneuver to take him to the track attitude.

d. To standardize the LM tracking schedule following the CSI_2 and $CDH_{1,2}$ maneuvers, the time required to maneuver to the track attitude is assumed to be completed six minutes following these maneuvers.

3. In order to standardize navigation procedures and use the CSM and LM navigation systems effectively, MIT has proposed the W-matrix reinitializations when performed (see schedule) be placed three marks and four marks deep into the tracking interval following a maneuver for the CSM and LM, respectively.

Paul T. Pixley

Paul T. Pixley

Attachment

Distribution (See attached list)

AP/R. R. Gilruth
AB/G. C. Trimble
CA/D. K. Slayton
CB/A. B. Shepard
CB/J. A. McDivitt
CB/N. Armstrong
CB/F. Borman
CB/M. Collins
CB/C. Conrad
CB/L. G. Cooper
CB/C. M. Duke
CB/R. F. Gordon
CB/J. Lovell
CB/R. L. Schweickart
CB/D. R. Scott
CB/T. P. Stafford
CB/W. R. Pogue
CB/W. M. Schirra
CB/D. F. Eisele
CB/E. E. Aldrin
CB/A. L. Bean
CF/W. J. North
CF13/D. F. Grimm
CF2/J. Bilodeau
CF212/C. Jacobsen
CF212/W. Haufler
CF22/C. C. Thomas
CF24/P. Kramer
CF24/M. C. Contella
CF24/D. W. Lewis
CF24/D. K. Mosel
CF3/C. H. Woodling
CF32/J. J. Van Bockel
CF33/C. Nelson
CF33/M. Brown
CF34/L. J. Riche
CF34/T. W. Holloway
EA/M. A. Faget
EA1/J. Chamberlin
EA2/J. B. Lee
EA5/P. M. Deans
EB/P. Vavra
EB/L. Packham
[illegible]/M. J. Kingsley
[illegible]/R. G. Irvin
[illegible]/R. L. Chicoine
[illegible]/G. B. Gibson
[illegible]/R. C. [illegible]
[illegible]/R. A. Gardiner
[illegible]. C. Cheatham
[illegible]/M. Kayton
[illegible]/C. T. Hackler
[illegible]/K. J. Cox
[illegible]/E. H. Smith
[illegible]/T. V. Chambers
[illegible]/P. [illegible]
[illegible]/R. Sawyer
EG26/W. J. Klinar
EG27/H. E. Smith
EG41/J. Hanaway
EG42/B. Reina
EG43/J. M. Balfe
EG44/C. W. Frasier
KA/R. F. Thompson
PA/G. M. Low
PA/C. H. Bolender
PA/K. S. Kleinknecht
PD/O. E. Maynard
PD/C. D. Perrine
PD12/J. G. Zarcaro
PD12/R. J. Ward
PD12/R. W. Kubicki
PD12/M. H. von Ehrenfried
PD4/A. Cohen
PD6/H. Byington
PD7/W. R. Morrison
PD8/J. Loftus
PA2/M. S. Henderson
PE/D. T. Lockard
FA/C. C. Kraft, Jr.
FA/S. A. Sjoberg
FA/C. C. Critzos
FA/R. G. Rose
FC/E. F. Kranz
FC/M. P. Frank
FC/G. S. Lunney
FC/C. E. Charlesworth
FC2/J. W. Roach
FC27/W. E. Platt (3)
FC3/A. D. Aldrich
FC35/B. N. Willoughby (5)
FC4/J. E. Hannigan
FC44/R. L. Carlton (5)
FC5/J. C. Bostick
FC5/P. C. Shaffer
FC54/J. S. Llewellyn
FC54/D. V. Massaro
FC54/C. F. Deitrich
FC55/E. L. Pavelka (6)
FC56/C. B. Parker (8)
FL/J. B. Hammack
FS/L. C. Dunseith
FS5/J. C. Stokes
FS5/T. F. Gibson, Jr.
FS5/J. E. Williams
FS5/G. R. Sabionski
FS5/T. M. Conway
FS5/R. Allen
FM3/J. H. Sasser
FM3/J. E. Dornbach
FM/J. P. Mayer
FM/C. R. Huss
FM/D. H. Owen
FM/R. P. Parten (8)
FM3/C. T. Hyle
FM4/P. T. Pixley
FM4/R. T. Savely
FM4/W. R. Wollenhaupt
FM5/R. E. Ernull
FM5/H. D. Beck
FM5/R. D. Duncan
FM6/R. R. Regelbrugge
FM6/K. A. Young
FM6/R. W. Becker (3)
FM7/S. P. Mann
FM7/R. O. Nobles
FM7/R. H. Brown
FM/Branch Chiefs
HM-31/H. E. Dornak
HM-31/D. W. Hackbart
Bellcomm/Hqs./R. V. Sperry
Bellcomm/Hqs./G. Heffron
Bellcomm/Hqs./MAS/A. Merritt
GAEC/Bethpage/J. Marino
GAEC/Bethpage/M. Pollack
GAEC/Bethpage/R. Mangulis
MAC/Houston/R. P. Rudd
MIT/IL/R. R. Ragan (15)
MIT/IL/E. Copps
MIT/IL/M. W. Johnston
NR/Downey/M. Vucelic
NR/Downey/D. Zermuchlen
NR/Downey/B. C. Johnson, AB75
NR/Downey/W. H. Markarian, FB95
NR/Downey/E. Dimitruk, FB30
TRW/Houston/R. J. Boudreau
TRW/Houston/M. Fox
TRW/Houston/R. L. Baker
TRW/Houston/H. Rikelman
TRW/Redondo Beach/R. Braslou
GSFC/550/F. O. Vonbun
GSFC/550/B. Kruger
KSC/CFK/R. D. McCafferty
KSC/CFK/P. Baker

ATTENDEES

Name	Organization
R. Larson	MIT/IL
J. Nevins	MIT/IL
P. Kachman	MIT/IL
E. Muller	MIT/IL
E. Melle	RCA (GAEC)
J. Shreffler	MSC/FM4
P. Shannahan	MSC/FM6
P. Pixley	MSC/FM4
D. Mosel	MSC/CF24
M. Contella	MSC/CF242
S. Paddock	MDC
J. McCown	MSC/EE6
F. Lipps	TRW
A. Satin	TRW
J. Hutchins	MSC/CF24
D. Blue	MSC/CF24
C. Neily	MSC/CF24

TABLE

LM Activity Timeline

Ground Elapsed Time, hr:min	Event
94:10	Docked IMU Alignment Completed
95:52	Phasing Maneuver
96:00	Initiate Tracking
96:05	Cease Tracking
96:07	Initiate Tracking
96:16	Cease Tracking
96:18	Initiate Tracking
96:28	Cease Tracking
96:47	Insertion Maneuver
96:50	Initiate Tracking
96:53	Cease Tracking, Reinitialize W-matrix
96:55	Initiate Tracking
97:05	Cease Tracking
97:06	Initiate Tracking
97:13	Cease Tracking
97:23	CSI_1 Maneuver
97:25	Initiate Tracking
97:29	Cease Tracking, Reinitialize
97:30	Initiate Tracking
97:42	Cease Tracking
97:55	CDH_1 Maneuver
98:01	Initiate Tracking
98:05	Cease Tracking
98:07	Initiate Tracking
98:18	Cease Tracking
99:02	Navigation State Vector Update
99:17	Initiate Tracking
99:21	Cease Tracking
99:22	Initiate Tracking

CSM Activity Timeline

Ground Elapsed Time, hr:min	Event
92:35	IMU Alignment Completed
96:03	Initiate Tracking
96:14	Cease Tracking
96:28	Initiate Tracking
96:37	Cease Tracking
96:59	Initiate Tracking
97:01	Reinitialize W-matrix
97:12	Cease Tracking
97:28	Initiate Tracking
97:38	Cease Tracking
98:07	Initiate Tracking
98:09	Reinitialize W-matrix
98:16	Cease Tracking
99:02	Navigation State Vector Update
99:11	Initiate Tracking
99:30	Cease Tracking

LA/M.A Faget

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA FPMR (41 CFR) 101-11.6

UNITED STATES GOVERNMENT

Memorandum

TO : PA/Chief, Apollo Data Priority Coordination

DATE:

FROM : EG/Acting Chief, Guidance and Control Division

In reply refer to: EG23-229-68-1136

SUBJECT: Method of RCS separation for football trajectory in Mission D

Reference is made to memorandum 68-PA-T-203A, "D Rendezvous Ground Rules and Working Agreements Update," September 23, 1968.

The Guidance and Control Division (GCD) was given the action item to determine the best thrusting procedure for the RCS separation burn yielding a football trajectory in the D rendezvous mission. The burn is required to impart a delta V to the CSM of 5 ft/sec in the -Z direction.

This delta V maneuver can be accomplished by either (1) a direct -Z translation burn, or (2) a combination of +90° pitch maneuver, a +X translation burn, and ultimately, a -90° pitch maneuver to regain the original attitude.

In determining the procedural tradeoffs, two factors must be considered: (1) The RCS propellant consumption, and (2) procedure simplicity. With respect to the former, propellant consumption data was obtained from the GCD's AGC functional simulator (AGCFS). These data are tabulated in Table I.

TABLE I.

CSM weights (pounds)	Z-translation	X-translation (AC Quads)
27542 (nominal)	18	19.3
28042 (high)	18.6	20.1
27042 (low)	19.2	18.5

Data was obtained not only for the nominal CSM weight of 27542# (supplied by the Mission Planning and Analysis Division) but also for variations about the nominal of ±500#. The X-translation poundage includes the actual +X-translation propellant and the propellant for the two required 90°

maneuvers at 0.5°/sec rate. The data indicates that a 500# lower CSM weight causes a slightly higher (1.2#) propellant usage for a -Z translation. This is due to an increase in the Xcg to thruster plane distance, which is very sensitive to SPS propellant loading.

In general, it can be seen that either method consumes approximately the same RCS propellant. Hence, the deciding factor is the relative simplicity of the procedures. On this basis, the -Z translation method is superior, as it requires only one action as opposed to three actions for the X-translation method, two of which are attitude maneuvers lasting three minutes each.

Based on this analysis, the Guidance and Control Division recommends, for the given CSM weight and delta V requirement, that a -Z translation be used for this maneuver.

Robert G. Gilruth
for
Robert A. Gardiner

cc:
EG2/D. C. Cheatham
EG21/C. F. Wasson
EG41/J. F. Hanaway
EG/Branches & Project Offices
EA/M. A. Faget
FM/J. P. Mayer
FM7/M. D. Cassetti
PD12/R. W. Kubicki
EA2/R. A. Gardiner
EG23:ETKubiak:dbb 10-21-68

Original signed by
ROBERT A. GARDINER

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA FPMR (41 CFR) 101-11.6
UNITED STATES GOVERNMENT

Memorandum

TO : See list attached

DATE: September 23, 1968

68-PA-T-203A

FROM : PA/Chief, Apollo Data Priority Coordination

SUBJECT: D Rendezvous Ground Rules and Working Agreements update

Attached are the ground rules and working agreements updated based on our September 9 Mission Techniques meeting. They reflect the new, simplified D Rendezvous exercise - primarily changes in the football trajectory and the "insertion maneuver" plus a bunch of things we were able to delete. As noted in my last report of this subject, the most significant open item is the selection of the nominal TPI time and definition of the acceptable lighting conditions for it - i.e., its "window". Based on the studies underway, the procedures will have to be adjusted to assure meeting the constraints after they are defined and put in order of priority.

And - of course, we've gotta get that rendezvous radar thermal mickey mouse fixed! Other action items I failed to list previously are as follows:

a. The AGS people of TRW were asked to recommend the proper technique for managing the AGS in the event the PGNCS has failed and the CSM makes maneuvers since it has no program comparable to the PGNCS "Target ΔV" R32.

b. FCD was asked to determine the latest time the E memory could be dumped providing the MCC-H sufficient time to respond in its check-out and correction, if necessary.

c. GCD was asked to determine which CSM RCS thruster should be used for the RCS Sepration burn (i.e., -z or x) - or at least which would cost less RCS propellant, taking into account the altitude maneuvers and altitude hold required in each case. CSM=27542

d. MIT was asked to look into reducing the time required for observing the PIPA's in their bias test to less than the current 256 seconds.

I guess we'll get together again sometime. We haven't scheduled that meeting yet. We are planning to get a smaller group together to review the revised D Rendezvous Mission on October 4, 1968.

Howard W. Tindall, Jr.

Enclosure

PA:HWTindall, Jr.:js

September 12, 1968

"D" MISSION RENDEZVOUS GROUND RULES, WORKING AGREEMENTS AND THINGS LIKE THAT

1. General

a. The reference trajectory is that provided by MPAD, dated August 22, 1968, and as amplified in Appendix I.

b. Nomenclature for the burn sequence following undocking is:

(1) RCS Sepration
(2) Phasing
(3) TPI_0 - If abort from football
(4) Insertion
(5) CSI
(6) CDH
(7) TPI
(8) TPF

c. The rendezvous will be run throughout with the vehicle roll angles $\cong$ 0°. The only exception to this is the RCS Separation burn where the CSM roll is 180°. A 180° roll will be performed by the CSM immediately prior to or during the IMU alignment following the RCS Separation burn. (i.e., TPI from above will be initiated "heads down" and TPI from below will be initiated "heads up" for either vehicle.)

d. LM and CSM state vectors time tagged 12 minutes before RCS Sepration are uplinked to the CMC and LGC prior to undocking. State vectors are not sent to either vehicle again during the rendezvous.

e. On both spacecraft all rendezvous navigation will be carried out to update the LM state vector. That is, the LM radar data would be used to update the LM state vector in the LGC and the CSM sextant data would be used to update the LM state vector in the CMC.

f. On both spacecraft the rendezvous navigation W-matrix will be set to 1000 feet and 1 fps initially and whenever it is reinitialized periodically during the rendezvous.

g. The CMC's LM state vector will be updated after each LM maneuver with the P-76 Target ΔV routine using the pre-burn values as determined in the LM's pre-thrust program

h. The AGS should be maintained in that state which makes it most useful to perform the rendezvous in the event of PGNCS failure. If, after having established the preferred techniques in accordance with that ground rule, it is possible to include some AGS systems tests without jeopardizing crew safety or other mission objectives, they would be considered.

i. The state vectors in the AGS will be updated each time PGNCS is confirmed to be acceptable. This will likely be at each time it is committed to make the next maneuver using the PGNCS except perhaps TPI.

j. AGC alignments will be made each time the PGNCS is realigned and each time the state vector in the AGS is updated from the PGNCS.

k. If PGNCS, RR, or G&N fails while in the football trajectory, the rendezvous exercise is terminated at the TPI_O opportunity.

l. The AGS is not mandatory for the rendezvous exercise. That is, if it fails prior to or during this mission phase, the exercise shall continue.

m. As soon as possible after powering up the LGC, the E memory will be dumped via T/M so that the MCC-H may check its contents for completeness and accuracy. If necessary, the MCC-H will reload via uplink any important parameters found to be in error.

2. Prior to Undocking

a. The crew will synchronize the CMC clock as precisely as possible utilizing information voiced from the ground. The crew will provide initial synchro-

nization of the LGC to the CMC clock. The ground will provide the necessary information by voice for fine synchronization of the LGC clock. This supercedes the mission rule which specifies resynchronization of a spacecraft clock only whenever it disagrees with the ground reference by more than 0.5 seconds.

b. The LM Rendezvous REFSMMAT is that of a "nominal" alignment for T (align) = TIG (TPI). It will be uplinked from the ground.

c. The CSM Rendezvous REFSMMAT is defined by a stable member orientation where:

$\overline{X}$ CSM = $\overline{Z}$ LM

$\overline{Y}$ CSM = $\overline{Y}$ LM

$\overline{Z}$ CSM = $-\overline{X}$ LM

d. Prior to undocking, the CSM will maneuver the docked vehicles to an inertial attitude such that with no further attitude maneuvering the CSM will be oriented approximately 180, 0, 0, (roll, pitch, yaw) with respect to the local vertical frame at the time of the RCS Separation. The difference between the exact local vertical attitude and 180, 0, 0 is due to the regression of the line of modes from TIG (RCS Separation) to TIG (TPI), and the fact that the CSM REFSMMAT is nominal at TPI.

e. The only in-flight adjustment of the LGC PIPA bias compensation parameters included in the nominal flight plan shall be done by the crew while docked to the CSM. The values will be updated regardless of how small the change. (i.e., there is no lower threshold) The crew will inform the MCC-H of the new values at the next MSFN station contact possible. The MCC-H will continually monitor the IMU performance and will advise and assist in additional updates if the compensation becomes in error by more than a specified threshold. Currently this threshold is set at .003 ft./sec.^{2}.

f. The AGS accelerometer calibration shall be performed while docked at about the same time as the PIPA compensation. This will be the only AGS accelerometer calibration in the nominal flight plan. AGS gyro calibration shall not be performed during the rendezvous exercise period of activity.

g. Prior to undocking, but following the CSM attitude maneuver to RCS Sepration attitude, the LM IMU will be aligned to the CSM IMU using the docked alignment procedure which takes advantage of a known CSM inertial attitude and known CSM/LM geometery (with account of the docking ring angle $\Delta\phi$ being taken) to coarse align the LM IMU to the inertial frame. The CSM and LM gimbal angles are then compared directly (via V16N20) and coarse align and attitude dead banding errors are removed by direct torquing of the LM IMU gyros via the fine align routine (V42). It is necessary for the MCC-H to compute and relay the gyro torquing angles to the crew in order to carry out this procedure.

h. The formula used for docked alignments with identical REFSMMATS is:

$$OGA_{LM} = (300 + \Delta\phi) - OGA_{CM}$$

$$IGA_{LM} = IGA_{CM} + 180$$

$$MGA_{LM} = -MGA_{CM}$$

Where $\Delta\phi$ is the docking ring angle.

i. The formula used for docked alignment where the stable members are oriented:

$$\bar{X}_{LM} = -\bar{Z}_{CM}$$

$$\bar{Y}_{LM} = \bar{Y}_{CM}$$

$$\bar{Z}_{LM} = \bar{X}_{CM}$$

is:

$$OGA_{LM} = (300 + \Delta\phi) - OGA_{CM}$$

$$IGA_{LM} = IGA_{CM} + 90$$

$$MGA_{LM} = MGA_{CM} = 0$$

This is a special formula only valid where the CM MGA = 0. This set of equations will be used for the LM alignment prior to undocking. (Equation verification is given in MIT/IL Apollo G&N System Test Group Memo No. 1224, dated August 28,1968. This reference notes there is a possible error in the sign of the $\Delta\phi$ term.)

3. Undocking, station keeping and LM inspection

a. Undocking will take place 25 minutes prior to the RCS Sepration burn with the CSM oriented to the inertial attitude for that burn. Average G will not be on in either vehicle during the undocking or station keeping phase. This will preserve the relative state vectors until Average G comes on in the CSM 30 seconds prior to RCS Sepration.

b. Following undocking, the CSM will maintain attitude and will be responsible for station keeping. The LM will yaw right 120° and pitch up 90° placing the two spacecraft "nose-to-nose." (crewmen "nose-to-nose")

c. The LM will yaw through 360° (1°/sec) permitting the CSM to conduct a visual inspection of the landing gear and LM structure.

d. After completion of 3c, the LM assumes the station keeping task while the CSM prepares for RCS Separation.

4. RCS Sepration and Mini-football

a. The configuration of the spacecraft at the RCS Separation burn will be LM leading the CSM, both heads down facing each other with zero relative velocity. (Orbit rate FDAI's - LM: 0, 180, 0 ; CSM: 180, 0, 0). (FDAI total attitude is read in the order roll, pitch, yaw; IMU gimbal angles are read in the order outer, inner, middle).

b. The CSM will execute a 5 fps radial inward burn for the RCS Separation burn; i.e., the CSM will 5 fps -Z (body). This burn will employ the P-30, P-41 sequence. LM uses R-32 to update CSM state vector in the LGC. The ΔV residuals will be trimmed to within 0.2 fps, all components.

c. On entering darkness after the RCS Sepration both spacecraft will perform REFSMMAT IMU alignments.

d. The CSM and LM COAS will be calibrated during the mini-football and will not be moved again after that. The LM utilizes the foward window.

5. <u>Phasing Maneuver and Football</u>

a. The magnitude of the phasing burn is always re-established inflight.

b. The phasing burn will be executed under AGS control with PGNCS monitoring by use of programs 30 and 40. The throttle will be set at 10% for 15 seconds at which time it will be advanced crisply to approximately 40% and left there until auto-cutoff.

c. The horizon is used as a burn attitude check prior to the phasing burn when AGS is under control. The crew determines the LPD pitch angle for this check.

d. Phasing burn monitoring

(1) Attitude and/or attitude rate limits are exceeded - terminate the burn.

(2) Overburn - Back up AGS engine off three (3) seconds after the PGNCS "engine off time" is indicated.

e. Upon completion of the burn, the LM shall be oriented with X-axis vertical and the y and z body axis ΔV residuals will be trimmed to zero.

The x body ΔV residual will be trimmed to within 2 fps to maintain Δh with 1/4 mile.

f. While in the football, both vehicles will exercise their complete rendezvous navigation systems and will update the LM state vectors in the LGC and CMC. The TPI targeting resulting will be used not only for maneuver execution if necessary, but also to evaluate the performance of the LM PGNCS and CSM G&N, providing confidence in proceeding with the Insertion maneuver. As noted previously, these onboard determined state vectors will not be updated from the MCC-H.

g. On entering the darkness period about a quarter of a revolution before the phasing burn, both spacecraft will perform REFSMMAT IMU alignments.

h. If it is found necessary to remain an extra revolution in the football prior to executing TPI_o or the Insertion burn, the same procedures will be followed as during the initial football revolution.

6. TPI_o

a. IF PGNCS, rendezvous radar, or CSM G&N fails prior to insertion but after phasing, TPI_o is performed. As a standard operating procedure during the football rendezvous, the LM and CSM should both be targeted and prepared to execute the TPI if an abort is necessary. If the failure is LM PGNCS, AGS is used for executing TPI. A 130° transfer angle shall be used for aborts from the football rendezvous. But staged or unstaged.

7. Insertion Maneuver

a. MCC-H will compute and target the LM PGNCS for the Insertion maneuver in real time. External ΔV targeting will be used, transmitted via the RTC uplink route if the timeline permits. Voice backup (pad data) will always be relayed.

b. The CSM will also be targeted to make a maneuver to guard against a partial LM DPS burn falling outside the capability of the LM RCS to correct.

This maneuver will probably be fixed preflight (for example - 20 fps, horizontal, posigrade) which would permit the LM to return to a football by RCS.

c. In the event the LM has performed a ullage maneuver prior to a DPS engine failure to start, the LM will remove that ΔV to stay in the football.

8. <u>CSI and CDH</u>

a. CSI and CDH maneuvers shall be targeted to cause TPI time to occur when the CSM is $25\frac{1}{2}$ minutes before sunrise. TPI time is defined as the time at which the elevation angle of the CSM with respect to local horizontal as observed by the LM is 27.5° (see 9b).

b. The MCC-H will select and relay to the crew a single solution for each of the CSI and CDH rendezvous maneuvers which will be used by <u>both</u> spacecraft - for PGNCS comparison, AGS targeting, and CSM G&N mirror image targeting, etc. It shall be that solution which is most compatible with the PGNCS. Some biases will be necessary for use in the CSM G&N.

c. As a nominal procedure, the command module will be targeted with "mirror image" maneuvers to be executed with a one minute time delay in the event the LM is unable to maneuver. In order to maintain TPI time and differential altitude within acceptable bounds it is necessary to bias the radial ΔV component of the CDH maneuver relayed to the CSM from the MCC-H by an amount established pre-flight (probably 4.3 fps). No other ΔV component of either the CSI or CDH maneuvers need to be biased in the CMC.

d. In order to compensate for approximations in the onboard CSI targeting program (P32) resulting in a "nominal" TPI time shift, it is necessary to bias the TPI time the LM crew inputs to that program 120 seconds late. The crew shall bias CDH time 110 seconds later than determined by the PGNCS CSI targeting program (P32) when sequencing through the CDH targeting program (P33) to compensate for an approximation in P32 which would cause a large radial component if uncorrected.

e. An out-of-plane ΔV component will be computed by the LM PGNCS for CSI and CDH using R36. This maneuver ΔV shall be executed unless it is less than 2 fps. This ΔV component will be included in the LGC/MSFC solution comparison.

f. LM PGNCS ΔV solutions will be compared with the ground. If the solutions agree, the PGNCS solution will be burned. There will not be comparisons with AGS, charts, or CSM.

g. In the event the ground solution is to be used, it will be executed using the AGS which has been targeted with the MSFN solution as a standard procedure. The external ΔV mode is used. No ΔV components of either the CSI or CDH maneuvers need to be biased in the AGS.

h. No radar data shall be input into the AGS prior to CSI and CDH.

i. There will not be any backup charts used for CSI. The LM shall have backup charts for CDH and TPI. The CDH charts require a minimum of 29 minutes between CSI and CDH. The command module pilot will be unable to compute onboard chart solutions for TPI due to the press of other activity and so they will not be available as a data source.

j. In the event the LM has performed an ullage maneuver prior to a main engine failure, the LM will remove that ΔV to maintain correct targeting of the CSM mirror image burn.

9. TPI

[NOTE: Some of the following items (e.g., 9a and 9c) which involve lighting constraints have not been established as being right, since they are based on an assumption that lighting is not mandatory. In fact, the lighting is currently considered mandatory under certain circumstances. These items are included here to draw attention to this extremely important matter. It is all to be resolved as soon as results of analysis to determine firm lighting requirements and expected TPI time dispersions are available. Consideration is being given to shifting to the P34 TPI "time option" from the "elevation option" if necessary to force TPI to occur within the window. This business also has implications on 9d regarding the CSM procedures and the MCC-H solutions transmitted for comparison. These results of these studies may also cause a change in the nominal TPI time noted in 8a.]

a. Although studies have shown that if TPI time falls outside a window of approximately four minutes duration undesirable lighting conditions will result for one or both spacecraft, it has been established that it is more important to execute TPI at the proper elevation angle than to honor lighting constraints in terminal phase. That is, lighting constraints are desirable but not mandatory. Nominal TPI elevation angle is mandatory. (See note above)

b. The elevation angle to be used in the TPI targeting programs (P34) in both spacecraft shall be 27.5° for all rendezvous. A 130° transfer angle will be used for all rendezvous.

c. The LM shall always use the elevation angle option in P34 for TPI targeting. (See note above)

d. The CSM shall always use the elevation angle option in P34 for TPI targeting whenever it becomes the active vehicle. Therefore, the first time the CSM cycles through P34 it will use the elevation angle option; however, if the LM TPI solution is determined to be acceptable by comparison checks, the CSM will recycle through P34 using the LM TPI time as input to the "time option." (TPI maneuvers will not be biased.)

e. TPI shall be targeted onboard and at MCC-H to force a node at TPF (i. e., intercept). The MCC-H shall supply this maneuver via voice (pad message) in both External ΔV and line-of-sight components.

f. If the LM PGNCS is working but rendezvous radar has failed, no external data will be input to the spacecraft systems----PGNCS, AGS, or charts. In this case, the command module executes the TPI and subsequent midcourse correction maneuvers and the LM does the braking maneuver if visibility permits. However, the command module, of course, must compare its TPI solution with the MSFN and that comparison must be favorable. (If not, see 9h) The command module would voice relay to the LM the maneuvers it has executed in order that the LM crew could update the command module state vector in the LGC using the target ΔV program.

g. If the LM PGNCS has failed, but the RR is working, compare the onboard chart solution for TPI with the MSFN. If the comparison is favorable execute the chart solution and, if not, use the MSFN ΔV's executed at a time determined onboard the spacecraft. The maneuver would be made using the AGS external ΔV mode.

h. If both the RR and the CSM G&N have failed, use the LM PGNCS to execute the MSFN TPI solution given in LOS coordinates at the time at which the elevation angle is 27.5° as determined onboard the spacecraft.

i. If the CSM performs the TPI maneuver, RCS will be used rather than SPS as the propulsion system. This simplification significantly reduces the CSM crew loading and gives greater assurance he will be able to do all things required of him.

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA FPMR (41 CFR) 101-11.6

UNITED STATES GOVERNMENT

Memorandum

Center
Division

TO : PA/Chief, Apollo Data Priority Coordination

DATE: September 17, 1968

68-FM61-293

FROM : FM6/Chief, Orbital Mission Analysis Branch

SUBJECT: Reference trajectory usage for mission D rendezvous simulations and analyses

1. As a result of the recent change in the rendezvous profile for mission D, formal documentation does not currently exist which provides the trajectory information required for rendezvous-associated analyses. The OMAB was requested in the "D" Rendezvous Mission Techniques meeting of September 9 to define which, of the existing reference trajectories, should be utilized for interim analyses, software testing, and flight crew support prior to the publication of the operational trajectory (currently scheduled for publication November 15, 1968). The OMAB recommends that the document, "Revision 2 to the Apollo Mission D Spacecraft Reference Trajectory, Volume I - Nominal Trajectory," (MSC Internal Note No. 68-FM-210, dated August 22, 1968) be utilized for this purpose. The portion of the rendezvous profile from a ground elapsed time (g.e.t.) of 98:42:44.7 (Hr:Min:Sec) through TPF in this document is identical to the current profile following the insertion burn from a lighting and relative motion standpoint. That is, the relative position and velocity at 98:42:44.7 are identical to those in the current profile at the completion of the insertion burn. MSFN coverage can be obtained from the reference document by using the current g.e.t.'s for significant events. These are as follows:

Event	Current g.e.t.
Undocking	92:45:00
Mini-football separation	93:01:45
Phasing	93:46:07
Insertion	95:37:49
CSI	96:18:45
CDH	97:01:33
TPI	97:54:51
TPF	98:26:49

APPENDIX I

2. The flight crew is currently performing rendezvous simulations based upon the mission D reference trajectory (April 30, 1968). By starting simulations at the 97:55:10 reset point, performing CSI at the time reflected in this document (98:52:14), and using as a nominal TPI time 100:29:00 (as opposed to the old value of 100:15:25) would afford almost the identical relative conditions as those in the current profile. That is, a ΔH of 10 n. mi. and a time between CDH and TPI of approximately 53 minutes would result. This procedure is recommended for future simulations until the rest points are updated to reflect the operational trajectory.

Edgar C. Lineberry

Edgar C. Lineberry, Chief
Orbital Mission Analysis Branch

UNITED STATES GOVERNMENT

Memorandum

TO : See list attached

DATE: September 12, 1968

68-PA-T-197A

FROM : PA/Chief, Apollo Data Priority Coordination

SUBJECT: D Rendezvous Mission Techniques Meeting - September 9, 1968

On September 9, we had another D Rendezvous Mission Techniques meeting. Basically what we did there was to discuss the new, simplified rendezvous mission plan and its effect on the work we have done so far. Based on this discussion, I am revising the ground rules and working agreements and will send them out within a week or so. I think we were all quite pleased to find that the changes were relatively minor and for the most part made things simplier - as they should. The two biggest unresolved areas deal with selection of the nominal TPI time and the rendezvous navigation tracking schedule as influenced by the rendezvous radar thermal constraints. I'll discuss these two things in little more detail in this memo.

Flight Crew Support Division has done some excellent work defining the terminal phase lighting constraints. For a LM rendezvous from below, command module from above situation the TPI time window providing acceptable lighting is only about four minutes long. That is, the TPI maneuver should occur within that small time period. It is almost inconceivable, we can expect to hit such a short window even with reasonable system dispersions. Therefore, we have asked Milt Contella's people to re-examine this situation, particularly taking into account the influence of the sun being located out of the orbital plane in an attempt to widen the window as much as possible. We also requested that its boundaries be "hard," that is mandatory as opposed to merely desirable lighting constraints. In parallel with this, we have asked MPAD to determine the sort of dispersion we can expect to have in TPI time based on the new mission plan and the latest spacecraft systems performance estimates. When this information is available, we will select the nominal TPI time. This choice must be made quite soon because it influences the Operational Trajectory and many other associated things. (If the VHF ranging device is added to the D mission command module, the situation could be relaxed considerably. That would certainly increase the command module rescue capability by a substantial amount.)

The Rendezvous Navigation Mission Techniques panel we set up last time reported the results of their work. They were quite successful, I think, in establishing a set of procedures for W-matrix reinitialization independent of where they are in the timeline. Unfortunately, the tracking schedule they developed has proven to be unacceptable from a rendezvous radar thermal standpoint, at least for the old double-bubble rendezvous.

An RCA man was at our meeting and gave us an excellent description of the problem. Essentially what it amounts to is that the rendezvous radar thermal protection has been defined (as per specification) to an obsolete lunar landing mission profile. As a result, there is too much insulation on the stability gyro package and shaft motor for a long, earth orbital rendezvous like D. What actually happens is that the fluid in the gyro expands until the expansion bellows burst. After that there is no control of antenna position making it impossible to obtain radar observations of the command module. The new mission profile will probably be marginally acceptable but it involves a lot of turning on and off the rendezvous radar by the crew. This seems like a rather serious problem that could be fixed quite easily. That is, reduce the amount of insulation. Since the meeting, I have contacted Aaron Cohen, who is now geting his people looking into this. It seems to me that the insulation should be designed specifically for the D mission radar. Without the radar the situation becomes extremely serious - no data into the LM at all. And the CSM has a pretty lousy rendezvous guidance system unless the VHF is added.

Howard W. Tindall, Jr.

Howard W. Tindall, Jr.

PA:HWTindall, Jr.:js

EPS Mans

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA FPMR (41 CFR) 101-11.6

UNITED STATES GOVERNMENT

Memorandum

TO : Informal Distribution

DATE: SEP 13 1968

68-FM46-339

FROM : FM4/Mathematical Physics Branch

SUBJECT: D Mission Rendezvous Navigation Mission Techniques Panel Meeting of September 11, 1968.

1. A meeting was held to define the time periods when the rendezvous radar would be powered up for tracking or other purposes and establish tracking schedules for the CSM and LM for the D Mission LM active single bubble rendezvous.

2. The rendezvous radar heaters are turned on at 90:56 (hr:min g.e.t.) and the subsequent rendezvous radar on-off schedule is as follows:

RR on	92:21	93:02	93:41	94:23	95:52	96:23	97:06
RR off	92:42	93:25	94:12	95:17	96:08	96:57	98:42

It is imperative that a thermal analysis be performed as soon as possible using this schedule. R. Kubicki has been given the action to initiate the thermal analysis. The trajectory data contained in MSC memorandum 68-FM64-280 of 1968 should be used.

3. The CSM and LM tracking and W-matrix reinitialization schedules are included in the attached table. The assumptions used to arrive at these schedules are also included in the table.

Paul T. Pixley
Paul T. Pixley

Attachment

Distribution: (See attached list)

Check with Wasson & Turner on RR tracking times?

ATTENDEES

P. T. Pixley	FM4
D. K. Mosel	CF24
S. C. Paddock	MDC
L. S. Diamant	TRW
J. Shreffler	FM4
E. Melle	RCA (LM-TRNG. GAEC-Bethpage)
E. S. Muller	MIT
R. A. Larson	MIT

ATTACHMENT

LM Activity Timeline

Ground Elapsed Time, hr:min; Event

	93:20	IMU Alignment
	93:46	Phasing
7	93:53	IT*
	94:00	CT**
9	94:02	IT
	94:11	CT
20	94:25	IT
	94:28	***
	94:45	CT
	94:06	Undocked Alignment (start at 94:51)
3	95:08	IT
	95:11	CT
	95:38	Insertion
4	95:44	IT
	95:48	CT,***
4	95:49	IT
	95:53	CT
13	95:54	IT
	96:07	CT
	96:19	CSI
4	96:25	IT
	96:29	CT,***
20	96:30	IT
	96:50	CT
	97:02	CDH
4	97:08	IT
	97:12	CT,***
4	97:14	IT
	97:18	CT
5	97:20	IT
	97:25	CT

CSM Activity Timeline

Ground Elapsed Time, hr:min; Event

	93:20	IMU Alignment
	93:46	Phasing
11	93:57	IT*
	94:08	CT**
14	94:30	IT (3/1, ***)
	94:44	CT
	95:06	Undocked Alignment
2	95:08	IT (3/1, ***, 3/1)
	95:10	CT
	95:38	Insertion
15	95:45	IT (3/1, ***)
	96:00	CT
	96:19	CSI
2	96:31	IT (3/1, ***, 3/1)
	96:33	CT, ***
10	96:37	IT
	96:47	CT
	97:02	CDH
6	97:09	IT (3/1, ***, 6/5)
	97:15	CT, ***
2	97:36	IT (3/2)
	97:38	CT
5	97:40	IT [(X>5)/5]
	97:45	CT

97 mins

LM Activity Timeline

	Ground Elapsed Time, hr:min	Event
16	97:27	IT
	97:43	CT
	97:55	TPI
4	97:58	IT
	98:02	CT
	98:05	MCC1
2	98:06	IT
	98:08	CT,***
6	98:08	IT
	98:14	CT
	98:17	MCC2

CSM Activity Timeline

	Ground Elapsed Time, hr:min	Event
	97:55	TPI
3	98:00	IT (5/3)
	98:03	CT
	98:05	MCC1
2	98:07	IT (3/1, ***, 3/1)
	98:09	CT
3	98:12	IT (5/3)
	98:15	CT
	98:17	MCC2

* Initiate Track, IT

** Cease Track, CT

*** Reinitialize

a/b a = number of marks and b = time interval

ASSUMPTIONS USED IN TRACKING

SCHEDULE PREPARATION

1. To standardize the LM tracking schedule preceding the CSI, CDH and TPI maneuvers, the time required for the preparation to execute CSI, CDH, or TPI is assumed to be 12 minutes.

2. For the CSI and CDH maneuvers, one minute from the LM maneuver initiation time was allowed for the command module pilot to either

   a. initiate his mirror image maneuver or

   b. initiate the maneuver to take him to the track attitude.

3. To standardize the LM tracking schedule following the CSI and CDH maneuvers, the time required to maneuver to the track attitude is assumed to be completed six minutes following these maneuvers.

4. In order to standardize navigation procedures and use the CSM and LM navigation systems effectively, MIT has proposed the W-matrix reinitializations when performed (see schedule) be placed three marks and four marks deep into the tracking interval following a maneuver for the CSM and LM, respectively.

5. The trajectory used for determining these schedules is documented in MSC memorandum 68-FM64-280.

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA FPMR (41 CFR) 101-11.6

UNITED STATES GOVERNMENT

Memorandum

TO : See list attached

DATE: September 23, 1968

68-PA-T-203A

FROM : PA/Chief, Apollo Data Priority Coordination

SUBJECT: D Rendezvous Ground Rules and Working Agreements update

Attached are the ground rules and working agreements updated based on our September 9 Mission Techniques meeting. They reflect the new, simplified D Rendezvous exercise - primarily changes in the football trajectory and the "insertion maneuver" plus a bunch of things we were able to delete. As noted in my last report of this subject, the most significant open item is the selection of the nominal TPI time and definition of the acceptable lighting conditions for it - i.e., its "window". Based on the studies underway, the procedures will have to be adjusted to assure meeting the constraints after they are defined and put in order of priority.

And - of course, we've gotta get that rendezvous radar thermal mickey mouse fixed! Other action items I failed to list previously are as follows:

a. The AGS people of TRW were asked to recommend the proper technique for managing the AGS in the event the PGNCS has failed and the CSM makes maneuvers since it has no program comparable to the PGNCS "Target ΔV" R32.

b. FCD was asked to determine the latest time the E memory could be dumped providing the MCC-H sufficient time to respond in its check-out and correction, if necessary.

c. GCD was asked to determine which CSM RCS thruster should be used for the RCS Sepration burn (i.e., -z or x) - or at least which would cost less RCS propellant, taking into account the altitude maneuvers and altitude hold required in each case.

d. MIT was asked to look into reducing the time required for observing the PIPA's in their bias test to less than the current 256 seconds.

I guess we'll get together again sometime. We haven't scheduled that meeting yet. We are planning to get a smaller group together to review the revised D Rendezvous Mission on October 4, 1968.

Howard W. Tindall, Jr.

Enclosure

PA:HWTindall, Jr.:js

September 12, 1968

"D" MISSION RENDEZVOUS GROUND RULES, WORKING AGREEMENTS AND THINGS LIKE THAT

1. General

a. The reference trajectory is that provided by MPAD, dated August 22, 1968, and as amplified in Appendix I.

b. Nomenclature for the burn sequence following undocking is:

(1) RCS Sepration
(2) Phasing
(3) TPI_o - If abort from football
(4) Insertion
(5) CSI
(6) CDH
(7) TPI
(8) TPF

c. The rendezvous will be run throughout with the vehicle roll angles $\cong$ 0°. The only exception to this is the RCS Separation burn where the CSM roll is 180°. A 180° roll will be performed by the CSM immediately prior to or during the IMU alignment following the RCS Separation burn. (i.e., TPI from above will be initiated "heads down" and TPI from below will be initiated "heads up" for either vehicle.)

d. LM and CSM state vectors time tagged 12 minutes before RCS Sepration are uplinked to the CMC and LGC prior to undocking. State vectors are not sent to either vehicle again during the rendezvous.

e. On both spacecraft all rendezvous navigation will be carried out to update the LM state vector. That is, the LM radar data would be used to update the LM state vector in the LGC and the CSM sextant data would be used to update the LM state vector in the CMC.

f. On both spacecraft the rendezvous navigation W-matrix will be set to 1000 feet and 1 fps initially and whenever it is reinitialized periodically during the rendezvous.

g. The CMC's LM state vector will be updated after each LM maneuver with the P-76 Target ΔV routine using the pre-burn values as determined in the LM's pre-thrust program

h. The AGS should be maintained in that state which makes it most useful to perform the rendezvous in the event of PGNCS failure. If, after having established the preferred techniques in accordance with that ground rule, it is possible to include some AGS systems tests without jeopardizing crew safety or other mission objectives, they would be considered.

i. The state vectors in the AGS will be updated each time PGNCS is confirmed to be acceptable. This will likely be at each time it is committed to make the next maneuver using the PGNCS except perhaps TPI.

j. AGC alignments will be made each time the PGNCS is realigned and each time the state vector in the AGS is updated from the PGNCS.

k. If PGNCS, RR, or G&N fails while in the football trajectory, the rendezvous exercise is terminated at the TPI_O opportunity.

l. The AGS is not mandatory for the rendezvous exercise. That is, if it fails prior to or during this mission phase, the exercise shall continue.

m. As soon as possible after powering up the LGC, the E memory will be dumped via T/M so that the MCC-H may check its contents for completeness and accuracy. If necessary, the MCC-H will reload via uplink any important parameters found to be in error.

2. Prior to Undocking

a. The crew will synchronize the CMC clock as precisely as possible utilizing information voiced from the ground. The crew will provide initial synchro-

nization of the LGC to the CMC clock. The ground will provide the necessary information by voice for fine synchronization of the LGC clock. This supercedes the mission rule which specifies resynchronization of a spacecraft clock only whenever it disagrees with the ground reference by more than 0.5 seconds.

b. The LM Rendezvous REFSMMAT is that of a "nominal" alignment for T (align) = TIG (TPI). It will be uplinked from the ground.

c. The CSM Rendezvous REFSMMAT is defined by a stable member orientation where:

$\bar{X}$ CSM = $\bar{Z}$ LM

$\bar{Y}$ CSM = $\bar{Y}$ LM

$\bar{Z}$ CSM = $-\bar{X}$ LM

d. Prior to undocking, the CSM will maneuver the docked vehicles to an inertial attitude such that with no further attitude maneuvering the CSM will be oriented approximately 180, 0, 0, (roll, pitch, yaw) with respect to the local vertical frame at the time of the RCS Separation. The difference between the exact local vertical attitude and 180, 0, 0 is due to the regression of the line of modes from TIG (RCS Separation) to TIG (TPI), and the fact that the CSM REFSMMAT is nominal at TPI.

e. The only in-flight adjustment of the LGC PIPA bias compensation parameters included in the nominal flight plan shall be done by the crew while docked to the CSM. The values will be updated regardless of how small the change. (i.e., there is no lower threshold) The crew will inform the MCC-H of the new values at the next MSFN station contact possible. The MCC-H will continually monitor the IMU performance and will advise and assist in additional updates if the compensation becomes in error by more than a specified threshold. Currently this threshold is set at .003 ft./sec.^{2}.

f. An AGS accelerometer calibration shall be performed while docked at about the same time as the PIPA compensation. This will be the only AGS accelerometer calibration in the nominal flight plan. AGS gyro calibration shall not be performed during the rendezvous exercise period of activity.

g. Prior to undocking, but following the CSM attitude maneuver to RCS Sepration attitude, the LM IMU will be aligned to the CSM IMU using the docked alignment procedure which takes advantage of a known CSM inertial attitude and known CSM/LM geometery (with account of the docking ring angle $\Delta\phi$ being taken) to coarse align the LM IMU to the inertial frame. The CSM and LM gimbal angles are then compared directly (via V16N20) and coarse align and attitude dead banding errors are removed by direct torquing of the LM IMU gyros via the fine align routine (V42). It is necessary for the MCC-H to compute and relay the gyro torquing angles to the crew in order to carry out this procedure.

h. The formula used for docked alignments with identical REFSMMATS is:

$$OGA_{LM} = (300 + \Delta\phi) - OGA_{CM}$$

$$IGA_{LM} = IGA_{CM} + 180$$

$$MGA_{LM} = -MGA_{CM}$$

Where $\Delta\phi$ is the docking ring angle.

i. The formula used for docked alignment where the stable members are oriented:

$$\bar{\bar{X}}_{LM} = -\bar{\bar{Z}}_{CM}$$

$$\bar{\bar{Y}}_{LM} = \bar{\bar{Y}}_{CM}$$

$$\bar{\bar{Z}}_{LM} = \bar{\bar{X}}_{CM}$$

is:

$$OGA_{LM} = (300 + \Delta\phi) - OGA_{CM}$$

$$IGA_{LM} = IGA_{CM} + 90$$

$$MGA_{LM} = MGA_{CM} = 0$$

This is a special formula only valid where the CM MGA = 0. This set of equations will be used for the LM alignment prior to undocking. (Equation verification is given in MIT/IL Apollo G&N System Test Group Memo No. 1224, dated August 28,1968. This reference notes there is a possible error in the sign of the $\Delta\phi$ term.)

3. Undocking, station keeping and LM inspection

a. Undocking will take place 25 minutes prior to the RCS Sepration burn with the CSM oriented to the inertial attitude for that burn. Average G will not be on in either vehicle during the undocking or station keeping phase. This will preserve the relative state vectors until Average G comes on in the CSM 30 seconds prior to RCS Sepration.

b. Following undocking, the CSM will maintain attitude and will be responsible for station keeping. The LM will yaw right 120° and pitch up 90° placing the two spacecraft "nose-to-nose." (crewmen "nose-to-nose")

c. The LM will yaw through 360° (1°/sec) permitting the CSM to conduct a visual inspection of the landing gear and LM structure.

d. After completion of 3c, the LM assumes the station keeping task while the CSM prepares for RCS Separation.

4. RCS Sepration and Mini-football

a. The configuration of the spacecraft at the RCS Separation burn will be LM leading the CSM, both heads down facing each other with zero relative velocity. (Orbit rate FDAI's - LM: 0, 180, 0 ; CSM: 180, 0, 0). (FDAI total attitude is read in the order roll, pitch, yaw; IMU gimbal angles are read in the order outer, inner, middle).

b. The CSM will execute a 5 fps radial inward burn for the RCS Separation burn; i.e., the CSM will 5 fps -Z (body). This burn will employ the P-30, P-41 sequence. LM uses R-32 to update CSM state vector in the LGC. The ΔV residuals will be trimmed to within 0.2 fps, all components.

c. On entering darkness after the RCS Sepration both spacecraft will perform REFSMMAT IMU alignments.

d. The CSM and LM COAS will be calibrated during the mini-football and will not be moved again after that. The LM utilizes the foward window.

5. Phasing Maneuver and Football

a. The magnitude of the phasing burn is always re-established inflight.

b. The phasing burn will be executed under AGS control with PGNCS monitoring by use of programs 30 and 40. The throttle will be set at 10% for 15 seconds at which time it will be advanced crisply to approximately 40% and left there until auto-cutoff.

c. The horizon is used as a burn attitude check prior to the phasing burn when AGS is under control. The crew determines the LPD pitch angle for this check.

d. Phasing burn monitoring

(1) Attitude and/or attitude rate limits are exceeded - terminate the burn.

(2) Overburn - Back up AGS engine off three (3) seconds after the PGNCS "engine off time" is indicated.

e. Upon completion of the burn, the LM shall be oriented with X-axis vertical and the y and z body axis ΔV residuals will be trimmed to zero.

The x body ΔV residual will be trimmed to within 2 fps to maintain Δh with 1/4 mile.

f. While in the football, both vehicles will exercise their complete rendezvous navigation systems and will update the LM state vectors in the LGC and CMC. The TPI targeting resulting will be used not only for maneuver execution if necessary, but also to evaluate the performance of the LM PGNCS and CSM G&N, providing confidence in proceeding with the Insertion maneuver. As noted previously, these onboard determined state vectors will not be updated from the MCC-H.

g. On entering the darkness period about a quarter of a revolution before the phasing burn, both spacecraft will perform REFSMMAT IMU alignments.

h. If it is found necessary to remain an extra revolution in the football prior to executing TPI_o or the Insertion burn, the same procedures will be followed as during the initial football revolution.

6. $\underline{TPI_o}$

a. IF PGNCS, rendezvous radar, or CSM G&N fails prior to insertion but after phasing, TPI_o is performed. As a standard operating procedure during the football rendezvous, the LM and CSM should both be targeted and prepared to execute the TPI if an abort is necessary. If the failure is LM PGNCS, AGS is used for executing TPI. A 130^o transfer angle shall be used for aborts from the football rendezvous. But staged or unstaged.

7. <u>Insertion Maneuver</u>

a. MCC-H will compute and target the LM PGNCS for the Insertion maneuver in real time. External ΔV targeting will be used, transmitted via the P27 uplink route if the timeline permits. Voice backup (pad data) will always be relayed.

b. The CSM will also be targeted to make a maneuver to guard against a partial LM DPS burn falling outside the capability of the LM RCS to correct.

This maneuver will probably be fixed preflight (for example - 20 fps, horizontal, posigrade) which would permit the LM to return to a football by RCS.

c. In the event the LM has performed a ullage maneuver prior to a DPS engine failure to start, the LM will remove that ΔV to stay in the football.

8. CSI and CDH

a. CSI and CDH maneuvers shall be targeted to cause TPI time to occur when the CSM is $25\frac{1}{2}$ minutes before sunrise. TPI time is defined as the time at which the elevation angle of the CSM with respect to local horizontal as observed by the LM is 27.5° (see 9b).

b. The MCC-H will select and relay to the crew a single solution for each of the CSI and CDH rendezvous maneuvers which will be used by both spacecraft - for PGNCS comparison, AGS targeting, and CSM G&N mirror image targeting, etc. It shall be that solution which is most compatible with the PGNCS. Some biases will be necessary for use in the CSM G&N.

c. As a nominal procedure, the command module will be targeted with "mirror image" maneuvers to be executed with a one minute time delay in the event the LM is unable to maneuver. In order to maintain TPI time and differential altitude within acceptable bounds it is necessary to bias the radial ΔV component of the CDH maneuver relayed to the CSM from the MCC-H by an amount established pre-flight (probably 4.3 fps). No other ΔV component of either the CSI or CDH maneuvers need to be biased in the CMC.

d. In order to compensate for approximations in the onboard CSI targeting program (P32) resulting in a "nominal" TPI time shift, it is necessary to bias the TPI time the LM crew inputs to that program 120 seconds late. The crew shall bias CDH time 110 seconds later than determined by the PGNCS CSI targeting program (P32) when sequencing through the CDH targeting program (P33) to compensate for an approximation in P32 which would cause a large radial component if uncorrected.

e. An out-of-plane ΔV component will be computed by the LM PGNCS for CSI and CDH using R36. This maneuver ΔV shall be executed unless it is less than 2 fps. This ΔV component will be included in the LGC/MSFC solution comparison.

f. LM PGNCS ΔV solutions will be compared with the ground. If the solutions agree, the PGNCS solution will be burned. There will not be comparisons with AGS, charts, or CSM.

g. In the event the ground solution is to be used, it will be executed using the AGS which has been targeted with the MSFN solution as a standard procedure. The external ΔV mode is used. No ΔV components of either the CSI or CDH maneuvers need to be biased in the AGS.

h. No radar data shall be input into the AGS prior to CSI and CDH.

i. There will not be any backup charts used for CSI. The LM shall have backup charts for CDH and TPI. The CDH charts require a minimum of 29 minutes between CSI and CDH. The command module pilot will be unable to compute onboard chart solutions for TPI due to the press of other activity and so they will not be available as a data source.

j. In the event the LM has performed an ullage maneuver prior to a main engine failure, the LM will remove that ΔV to maintain correct targeting of the CSM mirror image burn.

9. TPI

[NOTE: Some of the following items (e.g., 9a and 9c) which involve lighting constraints have not been established as being right, since they are based on an assumption that lighting is not mandatory. In fact, the lighting is currently considered mandatory under certain circumstances. These items are included here to draw attention to this extremely important matter. It is all to be resolved as soon as results of analysis to determine firm lighting requirements and expected TPI time dispersions are available. Consideration is being given to shifting to the P34 TPI "time option" from the "elevation option" if necessary to force TPI to occur within the window. This business also has implications on 9d regarding the CSM procedures and the MCC-H solutions transmitted for comparison. These results of these studies may also cause a change in the nominal TPI time noted in 8a.]

a. Although studies have shown that if TPI time falls outside a window of approximately four minutes duration undesirable lighting conditions will result for one or both spacecraft, it has been established that it is more important to execute TPI at the proper elevation angle than to honor lighting constraints in terminal phase. That is, lighting constraints are desirable but not mandatory. Nominal TPI elevation angle is mandatory. (See note above)

b. The elevation angle to be used in the TPI targeting programs (P34) in both spacecraft shall be 27.5° for all rendezvous. A 130° transfer angle will be used for all rendezvous.

c. The LM shall always use the elevation angle option in P34 for TPI targeting. (See note above)

d. The CSM shall always use the elevation angle option in P34 for TPI targeting whenever it becomes the active vehicle. Therefore, the first time the CSM cycles through P34 it will use the elevation angle option; however, if the LM TPI solution is determined to be acceptable by comparison checks, the CSM will recycle through P34 using the LM TPI time as input to the "time option." (TPI maneuvers will not be biased.)

e. TPI shall be targeted onboard and at MCC-H to force a node at TPF (i. e., intercept). The MCC-H shall supply this maneuver via voice (pad message) in both External ΔV and line-of-sight components.

f. If the LM PGNCS is working but rendezvous radar has failed, no external data will be input to the spacecraft systems----PGNCS, AGS, or charts. In this case, the command module executes the TPI and subsequent midcourse correction maneuvers and the LM does the braking maneuver if visibility permits. However, the command module, of course, must compare its TPI solution with the MSFN and that comparison must be favorable. (If not, see 9h) The command module would voice relay to the LM the maneuvers it has executed in order that the LM crew could update the command module state vector in the LGC using the target ΔV program.

g. If the LM PGNCS has failed, but the RR is working, compare the onboard chart solution for TPI with the MSFN. If the comparison is favorable execute the chart solution and, if not, use the MSFN ΔV's executed at a time determined onboard the spacecraft. The maneuver would be made using the AGS external ΔV mode.

h. If both the RR and the CSM G&N have failed, use the LM PGNCS to execute the MSFN TPI solution given in LOS coordinates at the time at which the elevation angle is 27.5° as determined onboard the spacecraft.

i. If the CSM performs the TPI maneuver, RCS will be used rather than SPS as the propulsion system. This simplification significantly reduces the CSM crew loading and gives greater assurance he will be able to do all things required of him.

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA FPMR (41 CFR) 101-11.6

UNITED STATES GOVERNMENT

Memorandum

[illegible] Center
[illegible] Analysis Division

TO : PA/Chief, Apollo Data Priority Coordination

DATE: September 17, 1968

68-FM61-293

FROM : FM6/Chief, Orbital Mission Analysis Branch

SUBJECT: Reference trajectory usage for mission D rendezvous simulations and analyses

1. As a result of the recent change in the rendezvous profile for mission D, formal documentation does not currently exist which provides the trajectory information required for rendezvous-associated analyses. The OMAB was requested in the "D" Rendezvous Mission Techniques meeting of September 9 to define which, of the existing reference trajectories, should be utilized for interim analyses, software testing, and flight crew support prior to the publication of the operational trajectory (currently scheduled for publication November 15, 1968). The OMAB recommends that the document, "Revision 2 to the Apollo Mission D Spacecraft Reference Trajectory, Volume I - Nominal Trajectory," (MSC Internal Note No. 68-FM-210, dated August 22, 1968) be utilized for this purpose. The portion of the rendezvous profile from a ground elapsed time (g.e.t.) of 98:42:44.7 (Hr:Min:Sec) through TPF in this document is identical to the current profile following the insertion burn from a lighting and relative motion standpoint. That is, the relative position and velocity at 98:42:44.7 are identical to those in the current profile at the completion of the insertion burn. MSFN coverage can be obtained from the reference document by using the current g.e.t.'s for significant events. These are as follows:

Event	Current g.e.t.
Undocking	92:45:00
Mini-football separation	93:01:45
Phasing	93:46:07
Insertion	95:37:49
CSI	96:18:45
CDH	97:01:33
TPI	97:54:51
TPF	98:26:49

APPENDIX I

2. The flight crew is currently performing rendezvous simulations based upon the mission D reference trajectory (April 30, 1968). By starting simulations at the 97:55:10 reset point, performing CSI at the time reflected in this document (98:52:14), and using as a nominal TPI time 100:29:00 (as opposed to the old value of 100:15:25) would afford almost the identical relative conditions as those in the current profile. That is, a ΔH of 10 n. mi. and a time between CDH and TPI of approximately 53 minutes would result. This procedure is recommended for future simulations until the rest points are updated to reflect the operational trajectory.

Edgar C. Lineberry

Edgar C. Lineberry, ~~Chief~~
Orbital Mission Analysis Branch

UNITED STATES GOVERNMENT

Memorandum

TO : See list attached

DATE: October 10, 1968

68-PA-T-218A

FROM : PA/Chief, Apollo Data Priority Coordination

SUBJECT: D Rendezvous Mission Techniques

On October 4 we met to review a draft of the D Rendezvous Mission Techniques. Although we spent the entire day we didn't get past page 3 and so it is obvious we are going to have to beef up our effort in order to get all this cleaned up. In fact, I am going to schedule all day meetings every other Monday specifically for this purpose.

I feel we did accomplish some rather important things in this meeting. The most significant was identifying exactly what pieces of equipment must be working in both spacecraft at each of four go/no go points, namely:

a. Undocking

b. Separation into mini-football

c. Phasing into football

d. Insertion into CSI/CDH rendezvous

This is the first time we have made a coordinated attack on this subject and I feel we were probably 90% successful or better. I have attached a table summarizing the results which you may find interesting. The decision as to whether each piece of equipment was required or not in order to go on with the mission phase is based on a pretty detailed understanding of how we want to do the rendezvous exercise and how we want to get out of trouble if other pieces of equipment subsequently fail. We adopted, as a general philosophy, that the command module <u>must</u> be prepared to rescue the LM and so we insisted on having redundant CSM capability for all crucial operations. In the LM we were somewhat more liberal assuming that the CMC rescue capability provides an adequate backup for the next LM systems failure for all operations except braking. This philosophy seemed to us to provide the best tradeoff between crew safety and assurance of meeting mission objectives. One item I would particularly like to point out regards the AGS which we feel is not required for anything except Insertion into the CSI/CDH rendezvous. It may seem inconsistant that we are willing to make the phasing burn into the football rendezvous but then not go for the second bigger loop. The reason was that most objectives will have been achieved in the football and the additional experience gained in the CSI/CDH rendezvous does not appear to justify the risk of demanding CSM rescue for subsequent PGNCS failure. Incidentally, the thing we want the AGS for in this case is not rendezvous navigation or maneuver capability but as an attitude reference in the event we lose the PGNCS. This is considered important since without it, it may not be possible to keep the tracking light oriented toward the command module.

Some other items I would like to list briefly are:

a. Whereas previously we had stated the MSFN solution for CSI and CDH would be used to target the AGS, the crew has a strong preference for using the PGNCS solution once it has been tested and found satisfactory. They feel this gives a better burn monitoring. Our main reason for having suggested using the MSFN solution was to avoid unnecessary activity close to burn time. However, since the PGNCS solution is checked before the AGS targeting is loaded - that concern is not longer valid.

b. We had stated that no radar data would be input into the AGS prior to CSI and CDH. To this we are adding the football prior to TPI_o unless the PGNCS fails or it is known that TPI_o will be executed.

c. It has been established that the LGC rendezvous navigation W-matrix will be initially set to 1,000 feet and 1 fps. In addition, it is necessary to set initialization value for the radar angle biases. The value selected for this is .001 radians.

d. We have established a mission rule the flight controllers should utilize in targeting the maneuvers prior to the rendezvous exercise in order to meet satisfactory rendezvous lighting conditions and MSFN coverage. They may permit the Δh for TPI_o (that is, the football rendezvous) to vary $\pm$ 1 nautical mile. The Δh for TPI should be targeted to be 10 $\pm$ 0 nautical miles. Actually this tolerance variation in the football provides quite a bit of control for the real time mission planner and he should be able to do the CDH targeting to meet the TPI Δh constraint.

An open item still hanging around deals with whether or not an AGS gyro calibration should be performed during the rendezvous exercise. I believe both GAEC and GCD have stated it should not for fear of screwing up the AGS gyro calibration. TRW's AGS people, I believe, would like to have the calibration done since they feel it would greatly improve the accuracy of the system. Of course, everyone agrees with that providing the calibration works. We must vote everyone concerned with this again, I guess; right now the crew has included it in the timeline while docked to the CSM.

Howard W. Tindall, Jr.

Enclosures 2
List of Attendees
Table of LM systems and CSM systems

PA:HWTindall, Jr.:js

ATTENDEE LIST

H. W. Tindall, Jr.	FM
E. C. Lineberry	FM
R. R. Regelbrugge	FM
C. Pace	FM
J. H. Shreffler	FM
W. R. Lacy	FM
L. D. Hartley	FM
J. D. Alexander	FM
G. Michess	FM
K. Henley	FM
M. C. Contella	CF
D. W. Lewis	CF
J. V. Rivers	CF
R. L. Schweickart	CB
A. L. Bean	CB
D. R. Scott	CB
R. F. Gordon	CB
M. P. Frank	FC
H. D. Reed	FC
J. Saltz	FC
B. J. McCoy	EC
R. J. Boudreau	TRW
J. E. Scheppan	TRW
L. Diamiant	TRW
C. Summers	TRW
R. W. Puschinsky	MDC
W. Haufler	MDC
M. J. McRae	MDC
E. Lewandoski	GAEC

Enclosure 1

LM systems required to continue the exercise assuming that CSM rescue provides an adequate backup for failure (except Braking).

LM SYSTEMS	UNDOCKING	SEPARATION INTO MINI-FOOTBALL	PHASING INTO FOOTBALL	INSERTION, CSI/CDH
PGNCS LGC	R[1]	R	R	R
IMU	R[1]	R	R	R
AGS[3] AEA	NR	NR	NR	R[2]
ASA	NR	NR	NR	R[2]
CES	R[1]	R	R	R
DPS/DECA	NR	NR	R[4]	NR[5]
RR[6]	NR	R[7]	R	R
Tape Meter[8]	NR	NR	NR	NR
Event Timer	NR	NR	NR	NR
FDAI's[9]	NR	R	R	R
AOT or COAS[10]	NR	NR	R	R
Hand Controllers[11]	R	R	R	R
Cross Pointers	NR	NR	NR	NR
CSM Tracking Light	NR	NR	NR	NR

Redundant CSM Systems required to provide LM rescue capability without LM assistance.

GNCS CMC	NR	NR[9]	R	R
IMU	NR	NR[9]	R	R
Optics SXT	NR	NR	R	R
SCT	NR	NR	R	R
COAS	NR	NR	NR	NR
SCS BMAGS	NR	NR[9]	R[12]	R[12]
GDC	NR	NR	NR	R
FDAI's	NR	NR[9]	R	R
SPS	NR	NR	NR	R
DKSY[13]	NR	NR	R	R
Handcontrollers	R	R	R	R
EMS ΔV Counter	NR	NR	NR	R
Event Timer	NR	NR	NR	NR
LM Tracking Light	NR	NR[14]	R	R

1. Either PGNCS or CES required since "Direct" is assumed acceptable for docking.
2. Assuming additional experience gained in the CSI/CDH rendezvous does not justify the risk of demanding CSM rescue for subsequent PGNCS failure.
3. Includes DEDA.
4. Alternate mission may be possible.
5. Nominal trajectory possible with APS/RCS.
6. Includes transponder.
7. Separation acceptable if some important test objective can be accomplished.
8. Assuming RR self-test (V62) provides raw RR readout.
9. One or the other required - not both.
10. Assuming rendezvous navigation studies show uncalibrated COAS IMU alignment is adequate to make flight meaningful.
11. Translation and at least one RHC.
12. One/channel.
13. Crew to verify one CSM DSKY adequate to perform rescue for SPS burns and navigation.
14. Assuming running or cabin lights are visible at 2.5 NM.

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA FPMR (41 CFR) 101-11.6

UNITED STATES GOVERNMENT

Memorandum

TO : See list attached

DATE: October 17, 1968

68-PA-T-227A

FROM : PA/Chief, Apollo Data Priority Coordination

SUBJECT: D Rendezvous Open Items, Action Items or whatever you call them

I've reviewed my notes of the D Rendezvous meetings over the last couple of months and have found the following open/action items. I guess most, if not all, are being worked on. But time grows short and so I'm sending this list around to make sure of it. If you know of others, please give me a call.

1. (TRW) What are the expected ΔV residuals at the conclusion of the AGS controlled, DPS phasing burn? We want to null the x-axis to within 2 fps but must avoid excessive RCS jet impingement.

2. (MPAD) Shall the DPS be staged for rendezvous at TPI? It has been decided that the greatly improved vehicle maneuverability and resultant saving in RCS fuel makes this desirable, provided no recontact with the staged DPS is positively assured. Ed Lineberry is developing a technique to do this.

3. (MIT) Braking procedures are placing heavy weight on the rendezvous radar range and range rate, of course. If the tape meter fails, it is hoped that the crew can get raw radar data displayed on the PGNCS DSKY by use of the V62 RR self test routine. MIT is requested to verify this technique works and inform us of any constraints or idiosyncrasies involved in this procedure.

4. (MPAD/ASPO) What is the accuracy of the PGNCS rendezvous navigation when using an IMU aligned with the COAS rather than the AOT? ASPO should define the accuracy of a COAS which has not been calibrated inflight.

5. (MPAD/MIT) When computing the TPI$_o$ solution using the PGNCS Elevation angle option, what solution will^{o}be obtained? Note that the spacecraft will pass through 27.5^o two times in the football trajectory.

6. What other problems or special procedures are needed for the TPI$_o$ maneuver, if any? For example, can dispersions make it more desirable to use the time option. It is interesting to note that the TPI$_o$ maneuver is applied more-or-less away from rather than toward the target^{o}spacecraft! This certainly affects the backup techniques involving boresighting along the LOS developed for a "standard" rendezvous TPI.

7. (TRW/AGS) How is the CSM state vector in the AGS updated if the PGNCS has failed and the CSM makes a maneuver? Note the AGS has no program equivalent to the PGNCS "Target ΔV" (R32).

8. (FCD) Assuming the LGC is powered down after the docked DPS burn (is this true or is it set to standby?), an E memory check is probably needed to commit to rendezvous. If required it must be added to the timeline and positive procedures developed to do it.

9. (MIT) Can the time required to make a GNCS PIPA bias test be reduced to less than 256 seconds?

10. (MPAD) Determine expected (3 sigma) shift in TPI time from nominal during the rendezvous to assist in selecting the TPI situation to aim for.

11. (FCSD) Define TPI window of acceptable lighting conditions and degree of constraint "hardness."

12. (Data Priority) Based on 9 and 10 (above) establish the mission techniques regarding under what conditions, if any, the "Elevation Angle" option for TPI should be abandoned in favor of the "Time" option.

13. (GAEC/TRW/GCD) Shall an AGS gyro calibration be performed during the rendezvous period of activity? This depends on expected improvement in performance versus probability of screwing up the system.

14. How do we verify that the AGS is properly aligned from the PGNCS given the possibility of CDU transients?

15. Of course techniques for monitoring all of the main engine maneuvers are still undefined and must be developed.

Howard W. Tindall, Jr.

Howard W. Tindall, Jr.

PA:HWTindall, Jr.:js

info

UNITED STATES GOVERNMENT

Memorandum

TO : See list attached

DATE: November 12, 1968
68-PA-T-248A

FROM : PA/Chief, Apollo Data Priority Coordination

SUBJECT: D Maneuver Monitoring Mission Techniques

On November 4 we had our first-and-last D Maneuver Monitoring Mission Techniques meeting. In addition to all interested MSC organizations, it was attended by MIT, NR, TRW, and GAEC. We spent the day going through all of the SPS maneuvers both docked and undocked, except for those associated with the rendezvous and the docked DPS burn, and discussing the pre-burn systems checks and the actual burn monitoring techniques. I believe we established procedures which should do the job and I feel they can be considered firm. The crew and the flight controllers intend to use these techniques in the forthcoming simulations and changes will only be considered to those which simulations show to be unacceptable.

Following is a list of final agreements which apply to all SPS maneuvers:

1. It is intended to use the onboard computed weight and SPS trim gimbal angles stored from the previous burn in the DAP, unless they differ from the MCC-H ground values by more than 10 percent and .5 degree respectively. If any of the three parameters exceed the limit, all three will be updated.

2. Except for retrofire, it is intended to use the onboard computed REFSMMAT for all maneuvers as determined by using the "preferred" alignment option. The MCC-H will compute and compare REFSMMAT with the onboard values primarily as a check for some procedures or communications error. This will be done by determining the angular difference between them, which should be zero. If it is in excess of .5 degree, the G&N should be considered no go.

3. It was concluded that the check of onboard computed apogee and perigee heights (ha and hp) is unnecessary and will be dropped from the procedures. In addition, these values will be dropped from the maneuver PAD message.

4. Prior to each maneuver, the crew shall make a maneuver attitude check using a sextant star. The shaft and trunnion angles of the star must agree with the PAD values to within five degrees or the burn is no go. If the crew is unable to see any stars, that check will be dropped for that burn.

5. In place of the previously proposed P40 VG test, we are substituting a check on the ΔV_R. This parameter must agree with the PAD value to within 10 fps.

6. Another CMC pre-burn check is through use of the Ground Track Determination program (P21). The crew will check latitude, longitude, and altitude against the PAD values to determine that they are within limits in order to give a G&N go. The limits are .02 degree and .2 n.m. respectively.

7. An attitude excursion limit of 10 degrees has been established for all SPS burns. Five degrees a second is the attitude rate limit. If the crew ascertains that either of these limits have been exceeded as indicated by two independent data sources (primarily the BMAGS and visible cues), they will takeover using SCS MTVC to damp rates and will shutdown the engine. An exception to this is that during the initial start transient, an attitude excursion beyond 10 degrees will be considered acceptable if, in the crew's judgment, it is truly due to the start transient and GNCS control of the spacecraft is still acceptable. (G&CD has the action item of approving this MTVC takeover procedures for safety when applied to docked burns. I have been told by Ken Cox that studies are underway, the results of which so far indicate this procedure is acceptable.)

8. The EMS ΔV counter will not be used as part of the crew monitoring procedure to avoid overburn. That is, for purposes of simplicity it was decided to backup the GNCS engine cutoff based on burn duration only. The procedure is for the crew to manually shutdown the engine if the GNCS has not done so within five seconds of the nominal burn time for docked SPS burns and within one second of the nominal burn time for undocked SPS burns. The nominal burn time is included on the maneuver PAD for each burn.

9. Although the EMS will not be used to monitor against an overburn, it will always be set up to provide an automatic cutoff if the crew switches to SCS. Accordingly, it is intended to slew into the ΔV counter that value (ΔVC) which would cause it to provide as accurate a cutoff as possible. In other words, tailoff and known accelerometer bias will be taken into account when computing the ΔVC included on the maneuver PAD.

10. Except for retrofire, the crew will not trim any ΔV residuals following any SPS maneuver.

11. Since the first SPS burn is made before adequate checks of the G&N can be carried out to insure proper GNCS operation, we propose to utilize some special techniques for that one burn. Essentially we intend to evaluate the GNCS performance during the launch phase on the D mission exactly as we do as part of our TLI go/no go procedure on the C' mission. The procedure involves comparing the performance of the spacecraft GNCS with the SIVB IU

during the launch phase. If the differences do not exceed certain pre-established limits (which incidentally are the same as · C') no further special checks are required to declare the GNCS go for SPS_1. If the limits are exceeded, the crew will perform an additional platform alignment (REFSMMAT Option) to the pre-launch orientation just prior to the aligning to the burn REFSMMAT. If the gyro torquing angles indicate that the drift rate has been less than .6 degree/hour since the fine alignment while docked to the SIVB, the GNCS is declared go for the burn. Incidentally, the GDC is also checked during the same period. Its no go limit is 10 degrees/hour on all three axes.

Obviously, special procedures are required for the docked DPS burn. This maneuver is extremely unusual and provides the greatest chances of screwing up procedurally. Prior to the maneuver, the following steps are taken:

1. The LGC E-memory will be dumped to the ground and checked by MCC-H. If any of the critical E-memory values are in error, they must be updated prior to the burn.

2. MCC-H will compute and relay to both spacecraft that REFSMMAT which is consistant with the LM x-axis aligned along the velocity to be gained by the maneuver and the y-axis shall be horizontal. Both spacecraft will utilize the same REFSMMAT.

3. The MCC-H will update the state vectors for both vehicles. The same external ΔV targets will be uplinked to both vehicles. (There is some question as to how the CSM will monitor the maneuver. One proposal is to call up the SPS thrust program (P40), which would be operated just as though it was controlling the maneuver. However, we're not sure how it will perform when the ΔV targeted and achieved is in the negative x direction. MIT was asked to advise us on this matter.)

4. The CSM will maneuver the two spacecraft to near burn attitude using onboard computed gimbal angles. The LM completes this attitude maneuver using R60.

5. Both spacecraft will perform burn attitude checks, the command module using a sextant star and the LM using an AOT star while the LM controls attitude during the last darkness period prior to the burn. Five degrees has been established as the go/no go limit.

6. The DPS trim gimbals will be moved prior to the maneuver to verify they are operating properly and will be reset to align the thrust vector through the c.g. taking into account engine mount compliance at 40 percent thrust. Assistance by MCC-H is required since there is no onboard indication of engine gimbal angle. The technique will involve iterative attempts to align the engine which will be continued until they are within a 0.1 degree of the desired values.

7. The AGS will be initialized and used in the follow-up mode exactly as it is for the undocked DPS burns. Of course, there is no consideration given to taking over with the AGS.

8. We established an attitude limit of 10 degrees and an attitude rate limit of five degrees per second. However, this maneuver is likely to include some pretty wild attitude excursions, particularly as the thrust level is varied, which could easily exceed those limits. During these transient periods, it must be left to the crew's judgment whether a divergent situation is occurring or not. We did establish that a 45 degrees attitude excursion is an absolute limit. This should be coincident with the "VG increasing" alarm. If these occur, the DPS should be manually shutdown. The trim gimbal light is essentially ignored throughout the burn since it cannot really be trusted for anything.

9. Following manual shutdown, attitude control is turned over to the CSM. If a malfunction occurs requiring premature burn termination with excessive attitude rates, they will be damped using the LM y and z-axis RCS translation jets.

As noted previously, the above techniques do not necessarily apply to the maneuvers during the rendezvous or rendezvous abort situations. These techniques will be discussed at our next rendezvous meeting on November 18, at which time any special procedures for those maneuvers will be identified, agreed to, and documented.

Howard W. Tindall, Jr.

Howard W. Tindall, Jr.

Enclosure
List of Attendees

PA:HWTindall, Jr.:js

ATTENDEE LIST

H. W. Tindall, Jr.	FM
T. H. Skopinski	FM
C. Pace	FM
S. P. Mann	FM
R. Nobles	FM
O. F. Graf	FM
C. Conrad, Jr.	CB
R. F. Gordon, Jr.	CB
J. A. McDivitt	CB
R. L. Schweickart	CB
D. R. Scott	CB
G. Renick	FC
J. E. I'Anson	FC
L. S. Cannin	FC
J. E. Roberts	FC/NR
J. B. Craven	FC
H. D. Reed	FC
J. E. Scheppan	TRW
H. R. Klein	TRW
P. Weissman	MIT/IL

Enclosure 1

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA FPMR (41 CFR) 101-11.6

info

UNITED STATES GOVERNMENT

Memorandum

TO : See list attached

DATE: November 29, 1968

68-PA-T-262A

FROM : PA/Chief, Apollo Data Priority Coordination

SUBJECT: D Rendezvous Mission Techniques

This memo is to tell you about the results of the November 25 D Rendezvous Mission Techniques meeting. Except for a number of small clean up items, we spent most of our time talking about how to handle slippage of TPI time and incomplete Insertion and Phasing maneuvers. After an exhausting discussion, I think we have those items under pretty good control now.

1. There was a discussion of various techniques for aborting from the mini-football. The only procedure we will pursue is for the CSM to make a "tweak" maneuver at the horizontal crossing if necessary to return the two spacecraft to a nominal relative motion mini-football. This maneuver will be made only if it is known that an abort is required. It shall be based on a chart the command module pilot carrys.

2. It had previously been decided to stage the DPS if the LM must make the TPI_o maneuver - abort from the football. Of the several techniques proposed, the one most favored now to preclude DPS recontact is to impart an out-of-plane ΔV to it as part of the TPI_o maneuver. The crew is going to try out the following procedures in the simulator and if acceptable we will stick with them for flight.

a. Just prior to TPI TIG but after Average g comes on, the LM will thrust laterally using the y-axis RCS jets to build up approximately 5 fps out-of-plane.

b. At TIG they will start thrusting with the plus x-axis RCS jets and stage the DPS as soon as acceleration exists. The out-of-plane ΔV will be removed with the TPI thrusting with the x-axis jets by yawing the spacecraft (i.e., spacecraft roll). (We are told there is no problem in reinitializing the attitude control DAP for the staged configuration in SUNDANCE.) If the CSM is active for TPI_o, the LM shall not stage the DPS.

3. It had been recognized that when computing TPI in the football trajectory it is possible to get two different solutions since there are two times the relative angle between the spacecraft passes through 27.5 degrees. Both MPAD and MIT have run analysis to determine what happens and how to handle the situation. The following table summaries

the results:

Time From Phasing	PGNCS Operation
0 to 45 minutes	Alarm code (no solution)
45 to 85 minutes	Desired solution obtained (TPI = 70 minutes)
85 to 87 minutes	Wrong solution obtained (TPI = 87 minutes)
Greater than 87 minutes	Fails to converge

The nominal TPI time we want to use is about 70 minutes after the Phasing burn and if the crew uses that value as an input to P34, there should be no trouble since it's well inside the boundaries which yield the desired solution.

4. Experience has shown that the crew simulators - LMS and CMS - do not accurately duplicate the true spacecraft guidance system with respect to the time the computers take to perform their operations. Specifically, the crew trainers run considerably faster than the actual flight computer and if not taken into account, this characteristic can badly mislead those responsible for setting up crew procedures. As a result, we levied an action on MIT to determine the actual, real-life computer time required to perform a list of specific operations. This list is included as an attachment to this memo. Based on this, I'm told the simulators can be fixed to be more realistic.

5. At this meeting we finally defined the acceptable TPI window and the procedures to be followed in the event TPI falls outside the window. MPAD reports that the current three sigma estimate of TPI time dispersion is $\pm$ 4 minutes. What I mean by this is that by using the LM radar navigation to perform the CSI and CDH targeting, errors can result causing the time at which the nominal TPI elevation angle actually occurs to be as much as four minutes from the time the targeting was aiming for. FCSD reports that the acceptable TPI window is 3.5 minutes which you recall, is centered about the nominal TPI time - 25.5 minutes before the CSM breaks into the sunlight. You can see from this that we have a very good chance of being within the acceptable window. However, obviously techniques must be developed to handle the case when we miss.

a. Our discussion revealed that it is unacceptable for TPI to slip earlier than the 3.5 minutes before nominal, since that would cause braking to occur in darkness. Accordingly, if that occurs the crew will recycle into the TPI targeting program (P34) using the Time Option with an input of the nominal TPI time.

b. Discussion also showed that, although undesirable, late TPI is not unacceptable and, in fact, it is preferable to continue to use the elevation angle option with a nominal 27.5 degree value regardless of how late TIG occurs. And, so this is what we shall do.

As you see then, we have a fairly simple logic to guide the crew in choosing their procedure. That is, the crew procedure is based on whether the TPI time as determined onboard the spacecraft occurs earlier than 3.5 minutes before nominal TPI. Since they only have to recycle the TPI computation switching to the Time Option if the TPI is too early by more than 3.5 minutes, they always have at least an additional 3.5 minutes to take action. This makes it possible for the crew to wait for the final computation of TPI after the last rendezvous navigation to make the decision of which way to go.

6. There is a problem brought about by this procedure with regard to what the MCC-H must do for the TPI PAD message. This data - relayed by voice to the crew - is normally used for two things. First to verify that the onboard guidance system is working acceptably and the second is to provide a backup maneuver to be executed in the event it is not. The procedure noted above presents an obvious problem if the crew has to go into the Time Option since there is no way for the ground to compute a compatible solution for comparison. Accordingly, the following procedures were developed, which are only used if the onboard solution of TPI time is more than 3.5 minutes early:

a. The MCC-H computes and relays only one maneuver PAD message - namely, a maneuver based on executing TPI with an elevation angle of 27.5 degrees, regardless of when TIG occurs.

b. Even though the LM crew determines that TPI time is too early, they will call for the 27.5 degree ΔV solution and compare it with the ground data to determine if their PGNCS is working. If it is acceptable, they will use the procedure noted in 5a above, calling for the Time Option with nominal TPI and continuing on without a ground backup maneuver.

c. If the LM comparison with the ground solution is not favorable, the CSM also compares its 27.5 degree TPI solution with the ground and if acceptable, will recycle into the Time Option of P34 using the nominal TPI time and will execute the resultant maneuver. In other words, if the LM PGNCS is broken and the CSM GNCS is working, the CSM should become active for TPI.

d. If the CSM solution is also found to be unacceptable, the LM crew should compare their chart solution with the ground and execute it if acceptable.

e. If all of these fail, we have a situation in which TPI has slipped too early, both spacecraft guidance systems have failed, as has the LM backup chart solution and there seems nothing to do but to perform the MCC-H solution. Boy!

7. A lengthy detailed discussion of what to do in the event of incomplete Phasing and Insertion maneuvers led to the following Mission Techniques:

a. Phasing

If the DPS does not light or if the DPS lights but shuts down prematurely, do not stage, null horizontal ΔV's and if possible, trim radial (x-body) $\overline{\Delta V}$ to within 2 fps of nominal. This places the LM in a football, its size dependent on the extent of the ΔV gained. Then it is necessary to choose one of the following courses of action in Real Time, dependent on what caused the premature shutdown.

(1) Execute TPI_O from the present trajectory this rev or next.

(2) Complete the phasing one rev later (CSM shall be mirror image targeted for this maneuver) using DPS under PGNCS control, RCS (Staged), APS, or CSM (RCS or SPS) followed by TPI_O at the next opportunity or insertion a quarter rev after that.

This is an appalling number of choices which must be substantially reduced before the flight based on systems considerations, mission objectives and extent of flexibility affected by the crew procedures. The latter is extremely important since the procedures are complex and completely time dependent; they are not easy to recycle into.

b. Insertion

(1) If DPS does not start, stay in football by nulling out ullage.

(2) If DPS does start, the primary goal is to complete the burn using RCS with APS interconnect. If the ΔV required is greater than about 8 fps, staging is required.

(3) In order to be prepared for some mysterious time critical problem discovered within one minute after TIG, the CSM will be targeted with the same burn as the LM to be executed with a one minute delay. This is not a mirror image burn. It nulls the LM burn.

8. MIT reported on an old action item that the CSM PIPA bias check cannot be conveniently reduced below 256 seconds duration.

9. In case everyone has not heard, the SUNDANCE program has been fixed so that the crew can use the rendezvous radar self-test program (R04) during terminal breaking with the Average g program (P47) running simultaneously. That is great!

10. Although not part of the D mission rendezvous, our final discussion of the day involved what the CSM should do during the docked DPS maneuver. Options for the CSM are to use the SPS thrust program (P40), the RCS thrust program (P41), or the Average g program (P47). Due to a limitation in the displays available in P47, which we know would work, the crew would prefer to use P40 or P41. We're not too sure how they will do so we asked MIT to look into how each of these programs would operate during the docked DPS burns such that we may make a final choice.

I don't expect to have any more full blown D rendezvous meetings until the final review of the Mission Techniques Document now scheduled for distribution about December 16. This review will probably be about January 10, 1969.

Howard W. Tindall, Jr.

Howard W. Tindall, Jr.

PA:HWTindall, Jr.:js

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA FPMR (41 CFR) 101-11.6

UNITED STATES GOVERNMENT

Memorandum

TO : See list attached

DATE: December 13, 1968
68-PA-T-271A

FROM : PA/Chief, Apollo Data Priority Coordination

SUBJECT: D Rendezvous Mission Techniques

This memo is to let you know about some things on the D Rendezvous that have been giving us a lot of trouble. The problem we have been having is associated with the football trajectory and how to exit from it gracefully. It seems like most of the significant mission techniques open items deal with this subject. In fact, we submitted a Trajectory Change Request in an attempt to relieve this problem area a little bit. It was disapproved - rightfully, I think.

The thing that is beginning to bother me is the realization that the probability of aborting the D Rendezvous from the football trajectory is rather great. This is due to a center wide feeling that a rendezvous from the football accomplishes almost everything we want and going through the CDI/CDH does not offer enough benefit to justify the additional risk of two or three extra hours of LM operation unless all systems are operating. That is, even failure of equipment like the rendezvous radar and the AGS currently appear to be justification not to exit the football. The other thing that I am slowly beginning to realize is that the football rendezvous is by no means simple. In many ways it is a lot more difficult than the standard coelliptic rendezvous. Not only are many special procedures required for it but the TPI maneuver is very sensitive to small dispersions in the relative trajectory of the two spacecraft. By the same token, small errors in the MSFN state vectors will cause the ground computed solution to differ significantly from the onboard. These things have led us to propose a basic ground rule - namely that TPI_0 should never be executed on the first opportunity except in a time critical situation. Furthermore, we could define no single guidance, navigation, or control system problem which we consider time critical. That is, time critical situations must arise from some serious environmental or electrical problem or something like that. By going an extra revolution in the football we give both the crew and the flight controllers an opportunity to get squared away before going into the critical terminal phase. We should have considerably more confidence in the MSFN state vectors too since we would have a sustained period of unperturbed radar tracking. Unfortunately, spending an extra revolution in the football for this purpose aggravates another problem. Small dispersions prior to and during the phasing burn can cause a situation wherein the spacecraft never arrives at a 27.5 degree elevation angle for execution of

TPI. Going the extra revolution makes us even more susceptable to this. It was due to this that we proposed a trajectory change. Specifically, by reversing the direction of the CSM 5 fps Separation burn from radially down to radially up, we become tolerant of much larger dispersions. However, the impact on other things at this late a date was considered unacceptable.

It is recognized by everyone that we still do not have TPI_0 procedures worked out yet and that by disapproving the trajectory change we were buying additional complexity in them. We are also making the probability greater for having to do TPI_0 at some angle smaller than the nominal (27.5^o).

We have initiated an analysis to determine if it is possible for the ground to give useful assistance for TPI_0 at the first opportunity. There is a feeling on the part of some of us that the ground solution for the first TPI_0 could be substantially in error making it useless both for comparison with the onboard system and for backup in the event of an onboard failure. The point is we may have to establish a technique whereby the rendezvous must be carried out independent of the ground in the time critical case.

In summary:

1. It is obvious that we must have well thought-out procedures and thorough training to handle the football rendezvous since the probability of doing it is very great (e.g., 5 or 10 percent, I would guess).

2. The football rendezvous is significantly more difficult to perform than intuition leads you to believe. Accordingly, we are proposing to always spend one extra revolution in the football prior to attempting the rendezvous if it is at all possible to do so.

3. The crew procedures will be developed to make sure they serve well for initiation of rendezvous on all revolutions in the football not just the first.

In attempt to finally clean up those darned TPI_0 mission techniques prior to start of MCC-H/crew simulations, we will probably get together over the Christmas Holidays - whatever that is.

Howard W. Tindall, Jr.

Howard W. Tindall, Jr.

PA:HWTindall, Jr.:js

UNITED STATES GOVERNMENT

Memorandum

Ea/Mr. A Fagot

TO : See list below

DATE: MAR 7 1968
68-PA-T-55A

FROM : PA/Chief, Apollo Data Priority Coordination

SUBJECT: First "E" Mission Rendezvous Mission Techniques meeting - March 4

1. On March 4 we had the first "E" Mission Rendezvous Mission Techniques meeting. It was devoted almost exclusively to understanding what the mission requirements and mission plans are for this phase of the flight. The discussion raised a few questions and some action items were assigned to get them answered.

2. It is evident that activities prior to the rendezvous such as the big S-IVB maneuver simulating translunar injection (TLI) will substantially perturb conditions at the start of the rendezvous unless compensation is provided. This, of course, means that the logic and capability to plan this "compensation" in real time must be designed and implemented. Ed Lineberry and his people were asked to look into this. (They're doing a similar job for Mission "D" already.)

3. The "E" mission is typical of any involving LM operations. It starts with an undocking and visual inspection. This is followed by a small RCS maneuver by one vehicle or the other to provide a controlled mini-distance separation trajectory to avoid costly station keeping. This is followed in turn by a larger separation maneuver which kicks off whatever is to be done. In this case, the larger separation maneuver, called a "Phasing maneuver", places the LM ahead and above the command module properly located to execute the CDH coelliptic maneuver about 2 hours and 40 minutes later. It is intended that these Phasing and CDH maneuvers will be computed in real time in the RTCC utilizing the so-called NCC/NSR rendezvous maneuver logic developed for Gemini. This targeting will force the CDH maneuver to occur at spacecraft apogee over Hawaii, with the proper differential altitude and phase angle.

4. The entire rendezvous will be carried out with a single inertial platform orientation (REFSMMAT) for each spacecraft. They will be computed and relayed to the spacecraft from the ground. Of course, more then one platform alignment will be performed. The point is they will all be carried out to achieve the same inertial platform orientation. Furthermore, it is anticipated that the REFSMMAT on Mission "E" will be selected essentially the same as for the "D" and "G" missions. That is, they will be tied to TPI and will provide an FDAI 8-ball display of 0, 0, 0 when the spacecraft is aligned in-plane, horizontal, wings level, heads up.

Betty Please request that Mr Tindall add Paul Vavra and Ralph Sawyer to his distribution list. Chamberlain, Dean, and [illegible]

5. It was agreed that an undocked platform alignment would be made between the separation and Phasing maneuvers. In order to permit this we established that separation will occur 5 minutes before the start of the darkness period prior to the Phasing maneuver. Since this will result in almost a complete revolution between the separation and Phasing maneuvers a small radial separation burn such as planned for missions "D" and "G" may not work out too well here, and the Rendezvous Analysis Branch was given the action item of selecting an optimum separation burn to be illustrated at the next meeting with the standard relative motion plot. Flight Planning was requested to work out the crew timeline in detail for the period between undocking and the Phasing maneuver. We want to make sure that the various crew activities associated with LM checkout and trajectory control do not conflict nor are unduly crowded. I'm sure someone will also be interested in determining the consumables required during this period since apparently both electric power and RCS propellant are at a premium.

6. Finally, the crew procedures people were requested to evaluate and report at the next meeting the preferred lighting conditions for the TPI maneuver when it is executed by a spacecraft approaching from ahead and above. This will be the situation for the first TPI opportunity on the "E" mission. Although that maneuver would not actually be executed as long as everything is still going along okay, we should be prepared to do it if we have to. And the preferred lighting conditions influence scheduling of the Phasing maneuver itself.

7. The current rendezvous plan provides two opportunities to perform a CSI maneuver, both of which are nominally zero. However, it was questioned as to whether the first opportunity really exists since it occurs only 36 minutes after the Phasing maneuver with insufficient ground tracking and communications to support it. It may be desirable for the crew to perform rendezvous navigation and target this maneuver; the question is whether they would ever really execute it. The point is, if it turns out to be small there seems to be no disadvantage in delaying until the next CSI opportunity one revolution later, and if the onboard systems indicate that a large CSI maneuver is needed there is reason to suspect some system malfunction. This is based on the assumption there had been no indication of non-nominal performance during the Phasing burn, which implies that CSI should be near zero. It seems we ought to obtain some MSFN confirmation before making a big burn that might screw up the situation. In conjunction with all this, the Rendezvous Analysis Branch was given the action item of determining parametrically theeffects of residuals in the Phasing maneuver in terms of CSI maneuver magnitude and other trajectory dispersions such as TPI time slippage.

8. It has been stated that a primary mission objective on this flight is to perform a comprehensive AGS systems test. This, of course, must involve rendezvous navigation and targeting as well as maneuver guidance and control.

This can be done in a number of ways. For example, the AGS could be allowed to operate continuously without PNGCS update throughout the entire rendezvous exercise. Or the test could be broken down into a number of individual tests with re-initialization provided periodically. It is also necessary to specify when and under what conditions radar data should be input into the AGS. G&C Division was requested to amplify their mission requirement by providing a more detailed description of exactly what they would like accomplished and if possible how they would like to do it.

9. That is about all we covered during this short meeting. One nice thing apparent was the substantial carryover from the "C" and "D" mission techniques meetings which should permit us to complete work on "E" in a considerably shorter period than would otherwise be the case. It was agreed that Monday afternoon is a good meeting time and so, if possible, we intend to get together every other week at that time. The next meeting is scheduled at 1:00 p.m., March 18, in Building 4, Room 396. That's 1300 for you, Frank.

Howard W. Tindall, Jr.

Howard W. Tindall, Jr.

Enclosure
List of Attendees

Addressees:
(See attached list)

ATTENDEES

E. Aldrin, Jr.	CB
W. A. Anders	CB
N. Armstrong	CB
F. Borman	CB
M. C. Contella	CF
G. L. Doerre	CF
T. Guillory	CF
T. H. Kaiser	CF
C. M. Neily	CF
E. B. Pippert	CF
C. T. Hackler	EG
J. L. Petersen	PD
J. G. Zarcaro	PD
W. E. Fenner	FC
G. C. Guthrie	FC
M. G. Kennedy	FC
J. G. Renick	FC
K. W. Russell	FC
W. J. Strahle	FC
D. Toups	FC
G. R. Sabionski	FS
D. D. DeAtkine	FM
E. C. Lineberry	FM
R. L. McHenry	FM
P. T. Pixley	FM
R. R. Regelbrugge	FM
J. Shreffler	FM
A. Woronow	FM
K. A. Young	FM
R. Boudreau	TRW
K. L. Baker	TRW
J. E. Sheppan	TRW
H. W. Tindall, Jr.	PA

Enclosure 1

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA FPMR (41 CFR) 101-11.6

Dult

File

UNITED STATES GOVERNMENT

Memorandum

NASA Manned Spacecraft Center

TO : See list attached

DATE: April 11, 1969

69-PA-T-59A

FROM : PA/Chief, Apollo Data Priority Coordination

SUBJECT: F Rendezvous Mission Techniques Clean-up

On April 5 we had what I expect is the last of the F Mission Rendezvous Techniques meetings. We resolved a number of open items which had not been covered before, or which popped up during simulations. This memo is to list them for the record. Some are trivial, some are really quite significant.

1. Since the first planned DPS maneuver is DOI, it was agreed that the gimbal angles included in the LGC erasable memory load should be right for that maneuver. These values should also be included in the crew check list (Stan Mann please respond).

2. The LM attitude and attitude rate limits for the DPS burns are 5° and 5°/sec unstaged and for the APS are 10° and 10°/sec.

3. We agreed upon the following course of action regarding imperfect DOI maneuvers.

a. First of all, only the x-axis residual shall be trimmed. The y and z-axes residuals shall be left untrimmed since they do not bother anything and trimming wastes RCS propellant and can result in excessive plume impingement.

b. Underburns - Underburns less than 5 fps will be trimmed up to 7 seconds plus x RCS burn duration, which is a plume impingement constraint. (Note: that's only 3 fps of trimming and thus can leave a small residual which will force retargeting the later burns) Underburns in excess of 5 fps will not be trimmed and will result in a "PDI abort." (A PDI abort, you recall, involves making a maneuver at about PDI time yielding CSI one-half rev later. In other words, it eliminates the rev in the nominal mission between phasing and insertion. The PDI abort will be made with DPS if it is considered an operating system, otherwise with the APS.)

c. Overburns - Overburns less than 12 fps will be trimmed with minus x RCS. Again, this limit is based on a RCS plume impingement constraint. It should never occur since this is about a 4 second overburn which could have been manually stopped before reaching this value.

Overburns greater than 12 fps result in lunar impact and therefore call for a direct return of the LM to the command module by the immediate, brute force technique discussed in previous memos.

d. I guess it goes without saying that any PGNCS failure during DOI also dictates a direct return abort.

4. The following agreements were reached regarding the phasing maneuver:

a. It was emphasized that at least 40 fps should be achieved by the LM somehow if at all possible.

b. Underburns - Trim underburns less than 5 fps with plus x RCS up until the 7 second plume impingement limit. If the underburn is greater than 5 fps, but less than 25 fps, stage and complete the maneuver with RCS. If the underburn is in excess of 25 fps, stage and complete the burn with APS using the AGS.

c. Overburns - Trim overburns less than 12 fps with minus x RCS. For overburns in excess of that, trim out 12 fps and standby for an update of the Insertion targeting.

5. Insertion

a. Underburns - If the total velocity gained is less than 45 fps, take it out using minus x RCS. This limit is based on the 30 second minus x RCS plume impingement constraint. In this event, the CSM does the insertion burn three minutes later. If the underburn is less than 80 fps, use the plus x RCS to complete the maneuver. (This limit is based on the 55 second RCS plume impingement constraint.) For the approximate 100 fps band of cutoff velocities in between these two limits, the LM should do nothing immediately and the command module will have to rescue.

b. Overburns must be removed somehow to avoid lunar impact.

6. It has been said repeatedly before, and I say again here today, that there is no such thing as a 200 n.mi. range limit on the VHF ranging by the CSM. That is merely a fictitious design value which has no bearing on how the operation should be conducted. VHF ranging should be used to its full 327 n.mi. recycle limit provided the data is good. The ΔR ΔV limits, which the CMP should use to decide if it's good or not are currently set at 0.5 n.mi. and 3 fps. (These values may be changed this week following a rendezvous navigation meeting of the experts.)

It was agreed that the CMP could do P20 rendezvous navigation, updating the LM state vector in the CMC, between DOI and phasing, if this does not conflict with other more urgent activity.

7. The TPI window has been established as being from minus 8 minutes to plus infinity. The nominal TPI location is at the time the target vehicle is 23 minutes before sunrise. The significance of the window is that if after CSI it is discovered that the TPI associated with the elevation angle option has slipped earlier than 8 minutes, the crew will recycle the TPI program (P34) using the time option with nominal TPI minus 8 minutes on the input time.

8. The CSM always uses the LM computed CDH time for input to P33 as long as the LM PGNCS is assumed to be working okay.

9. It was agreed that all CSM mirror image targeting (that is, for CSI, CDH, and TPI) shall use the same TIG as the LM. That is, mirror image targeting will not be delayed one minute or three minutes as had previously been considered. This technique considerably simplifies procedures and results in (minor) difficulty only if the LM failure, which forces the CSM to become active, becomes apparent when the LM attempts to make the maneuver. Such a last instant failure on an RCS burn is considered very unlikely and does not result in too bad a situation if the command module then executes the maneuver late.

One of the simplifications obtained by eliminating TIG delays is the elimination of all biases that need to be applied to the CSM solutions for use in the LM with one exception. It is necessary to subtract 1 fps from the CSM CSI (P32) solution when the LM uses it for comparison with their own solutions or for execution.

10. Comparison limits were established for evaluating the acceptability of the various rendezvous maneuver solutions. In each case, it is most desirable to use the LGC if possible. Accordingly, it will be used if it compares favorably with either the CSM or the LM chart solution. If it fails, the LM chart is compared with the CSM solution and is used if acceptable. If both the LGC and chart solutions fail their test, it is recommended that the LM execute the maneuver computed by the CSM since a rendezvous radar failure is the most likely cause of trouble. The comparison limits are 2 fps, 5 fps, and 6 fps for x, y, and z-axes, respectively, in both local vertical and in line-of-sight coordinates.

This comparison technique shall be used for the CDH and TPI burns for sure. It may also be possible to use it for CSI, provided analyses between now and the flight show that the CSM will have an acceptable performance. Since it is not certain that the CSM will shape up, we have adopted the following weird technique which should be used for CSI unless the CSM is eventually certified to be okay. It is based on use of three possible solutions - the PGNCS, the LM chart, and the pre-separation canned burns. It is also based on a desire to insure too large a CSI burn, if anything, in order to avoid having TPI slip early, which is considered a serious dispersion, as noted in paragraph 7 above. The rule is that the LM crew should execute the latest of these solutions, provided it is no more than 2 fps bigger than the next-to-largest solution! If the rendezvous radar has failed, it wipes out both the PGNCS and chart solution, the LM crew uses the same comparison scheme, only in this event it is a comparison of only two sources - the pre-separation canned burn against the CSM CSI solution after it has been biased 1 fps as noted in paragraph 9.

11. There were at least two situations in which it seems desirable for the CSM and LM to share the braking task and it was agreed that they would do so if either occurs. If the LM fails to stage the DPS or if the LM is not able to visually acquire the CSM during braking, lateral line-of-sight control by the LM is not practical and the CSM shall do it. The LM will continue to be responsible for performing the actual braking maneuver provided the rendezvous radar is working.

And that's how we spent Saturday.

Howard W. Tindall, Jr.

Howard W. Tindall, Jr.

PA:HWTindall, Jr.:js

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA FPMR (41 CFR) 101-11.6

UNITED STATES GOVERNMENT

Memorandum

TO : See list below   DATE: April 30, 1969

FROM : FM/ Apollo 10 , Mission Design Manager

SUBJECT: Trajectory Change Evaluation Report

Title		
Lunar orbit orientation change		
TCR Number: F-12		
MCRG Meeting Date	CCB Meeting Date	Requested Completion/ Date
N/A	N/A	May 5, 1969

The attached proposal change is forwarded for your evaluation and recommendations concerning its impact on the mission plan. Please submit your comments on MSC Form 1119C, "Trajectory Change Evaluation." A report of ACCEPTABLE is expected if you are in no way affected. Send reply to FM13/Mission Planning Support Office, Attention: William J. Bennett, no later than the above-listed completion date. An ACCEPTABLE reply will be implied if your report is not received by this date.

Enclosure

Addressees:
CB/J. Lovell
M. Collins
CF/W. Anderson
CF/J. Cotter
EA5/P. Deans
EG/D. Cheatham
PD/J. Sevier
R. Ward
FC/G. Lunney
C. Charlesworth
FS2/J. Watkins
FM/J. P. Mayer
H. W. Tindall, Jr.
D. H. Owen

FC/E. F. Kranz
FA/R. T. Rose
EG2/C. F. Wasson
CF/Lt. Col. T. P. Stafford
Cmdr. E. A. Cernan
Cmdr. J. W. Young
Col. L. G. Cooper
Maj. D. F. Eisele
Cmdr. E. D. Mitchell
Maj. C. M. Duke

cc:
FM/Branch Chiefs
FM2/J. C. Harpold
C. Grover
J. K. Burton
FM5/R. L. Berry
H. D. Beck
FM6/K. A. Young

MSC FL 1119B-9-68

TRAJECTORY CHANGE REQUEST

TCR NUMBER: F-12

ORIGINATOR: Donald L. Berry/William J. Bennett
Mission Planning & Analysis Div.

DATE: April 25, 1969

APPROVAL (DIVISION MCRS REP): [signature]

REASON FOR CHANGE: Based on Apollo 8 postflight lunar orbit navigation analysis, it may be necessary to derive empirical corrections to the MSFN/RTCC orbit determination solutions to enable accurate vector propogation and targeting of the "G" mission DOI and landing maneuvers. Since the effect of orbit orientation on the empirical corrections is unknown, the corrections would potentially have to be derived in real time unless an identical orbit ground track had been flown on a previous mission. Therefore, if "F" flies the exact "G" lunar orbit, the empirical corrections for "G" can be derived with a high degree of confidence prior to the "G" mission.

Also, the identical ground track will yield an increased applicability of "F" strip photography and crew observations to "G" training.

DESCRIPTION OF CHANGE: The lunar orbit orientation change will be accomplished via a combination of a translunar midcourse and LOI_1 maneuver. The midcourse would be targeted by the RTCC free return best adaptive path (BAP) mode through the use of a MED to control the lunar landing site approach azimuth so as to obtain a resultant translunar trajectory compatible with the desired new orbit orientation. LOI_1 would be targeted in the usual manner using a MED to obtain the desired new lunar landing site approach azimuth.

[X] APPROVED [ ] DISAPPROVED DATE:

[ ] TYPE I (CCB REFERRAL) [X] TYPE II

SCHEDULE IMPACT: NONE

AFFECTED BASELINE DOCUMENTS: Operational Trajectory

REMARKS:

The enclosed tables show a comparison of significant mission parameters between the "old" F mission profile and the "new" F profile with the "G" mission lunar orbit orientation. The end-of-mission ΔV and propellant reserves shown are over and above that required for a quick return TEI and 3σ dispersions. These reserves are sufficient to cover a typical CSM rescue of the LM (300 - 500 fps) but are not always sufficient for a "worst case" LM rescue (800 fps). However, this latter contingency can always be covered by targeting TEI for a day later return in real time. The reductions in the ΔV and propellant reserves for the "new" profile are due primarily to the translunar midcourse and the increased magnitude of LOI_1. Note, however, that the new SPS performance requirements still allow a quick return TEI and, thus, approximately an eight-day mission.

PM SIGNATURE: D H Owen

MSE SIGNATURE: William J Bennett for Robert J. Ward

per tel con 4/30/69

MSC Form 1119A (Sep 68)

F MISSION LUNAR ORBIT ORIENTATION CHANGE FOR MAY LAUNCH WINDOW

	Site 2		Site 3	
	Old	New	Old	New
Launch date	May 18	May 18	May 20	May 20
Lunar landing site approach azimuth (deg)	-95.25	-91.0	-95.75	-89.0
Lunar orbit inclination (deg)	5.3	1.2	5.8	1.1
Translunar midcourse ΔV (fps) ($72^{\circ}/90^{\circ}/108^{\circ}$ launch azimuth - 1 st injection opportunity)	-	56/65/54	-	21/22/20
LOI (1 + 2) ΔV (fps)	2982/2996/2982	3104/3156/3100	2990/3002/2990	3198/3240/3191
SPS ΔV reserve (fps)	1306/1108/984	966/677/655	1786/1686/1632	1349/1188/1210
SPS propellant reserve (lbs)	3011/2518/2214	2171/1479/1427	4279/4015/3874	3141/2736/2791

F MISSION LUNAR ORBIT ORIENTATION CHANGE FOR JUNE LAUNCH WINDOW

	Site 2		Site 3	
	Old	New	Old	New
Launch date	June 17	June 17	June 19	June 19
Lunar landing site approach azimuth (deg)	-95.25°	-91.0	-95.75	-89.0
Lunar orbit inclination (deg)	5.3	1.2	5.8	1.1
Translunar midcourse ΔV (fps) (72°/90°/108° launch azimuth -1st injection opportunity)	-	6/TBD/5	-	16/12/TBD
LOI (1 + 2) ΔV (fps	2986/2989/2988	3079/TBD/3073	3011/3006/TBD	3113/3138/TBD
SPS ΔV reserve (fps)	1812/1721/1650	1610/TBD/1467	1922/1874/TBD	1575/1484/TBD
SPS propellant reserve (lbs)	4344/4108/3922	3816/TBD/3444	4645/4514/TBD	3725/3490/TBD

TRAJECTORY CHANGE EVALUATION

TRAJECTORY CHANGE EVALUATION		TCR NUMBER
☐ ACCEPTABLE	☐ UNACCEPTABLE	TYPE APPROVAL ☐ YES ☐ NO

REMARKS:

SCHEDULE IMPACT:

EVALUATOR (MDRG REPRESENTATIVE)	DATE

DISPOSITION:

[SIGN]ATURE OF MDM	DATE

MSC Form 1119C (Sep 68)

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA FPMR (41 CFR) 101-11.6

UNITED STATES GOVERNMENT

NASA-Manned Spacecraft Center
Mission Planning & Analysis Division

Memorandum

TO : Informal Distribution

DATE: APR 17 1969
69-FM46-107

FROM : Chairman, F Rendezvous Navigation Mission Techniques Panel

SUBJECT: F Rendezvous Navigation Mission Techniques Panel Meeting, April 10, 1969

1. Reference: "Onboard Tracking Schedules for Missions F and G," 69-FM46-29, FM4/Jack H. Shreffler, February 7, 1969.

2. The purpose of this meeting was to review navigation error analyses performed by MIT and MSC and to determine the nominal onboard navigation techniques or identify a specific course of action to establish the navigation techniques for the F Mission rendezvous. Navigation and dispersion analyses have determined the LGC navigation techniques which are described in the reference to be acceptable. Some minor navigation techniques changes to simplify crew procedures were made at the meeting, but these changes have no impact on the expected maneuver accuracy. Navigation and dispersion analyses have determined the CMC navigation techniques (reference) to be unacceptable for CSI maneuver targeting. Proposed methods for solving the CSI navigation problem are discussed later in this memorandum. The CSM navigation techniques for the other rendezvous maneuvers are acceptable. Updated onboard rendezvous tracking schedules, W-matrix reinitialization schedules, and P-20 erasable memory parameter lists are included in this memorandum.

3. Bruce Williamson (MPAD) provided a discussion on the emperical technique developed by E. R. Schiesser and himself for computing navigation covariance matrices for MSFN tracking of a spacecraft in lunar orbit. These matrices provide the estimated accuracy with which the spacecraft's lunar orbit can be determined by the RTCC orbit determination program using the tracking data of the MSFN.

4. MIT and MPAD presented the results of CSM navigation and dispersion analyses. The MPAD estimate of the CSM capability to provide CSI maneuver targeting data (per the reference) is not sufficiently accurate to satisfy the CSI maneuver voting logic. At the last F Mission rendezvous data priority meeting, the CMC solution was omitted from consideration. In order that the CSI maneuver targeting situation can be improved, the Insertion to CSI tracking schedule has been revised to increase the tracking interval to the maximum possible. However, MPAD results indicate that by inhibiting the SXT data between Insertion and CSI, acceptable CSI ΔV calculations can be expected. To determine the CSM navigation procedures piror to CSI, the following four cases of CSM navigation between Insertion and CSI are to be analyzed. These cases are arranged in descending order of preference.

The information in this paper is unedited and is not official FOD or MPAD information. It is released to provide rapid circulation and may later be incorporated in a formal paper.

1. SXT + VHF

2. SXT + VHF with tracking terminating at CSI-9 minutes (VHF only from CSI-12 minutes to CSI-9 minutes)

3. SXT + VHF for 8 minutes, reinitialize the W-matrix, initialize VHF only tracking to CSI-9 minutes

4. VHF only to CSI-9 minutes

MIT and the Mathematical Physics Branch (MPAD) are to generate the covarinace matrices of expected errors in the LM and CSM state vectors for these navigation cases. The Orbital Mission Analysis Branch (MPAD) is to determine the CSI maneuver ΔV statistics with Monte Carlo dispersion analysis programs. If the increased tracking between Insertion and CSI in cases 1 or 2 provide acceptable CSI ΔV statistics, then the onboard procedures will conform to these results. That is, onboard tracking for the purpose of targeting the CSI maneuver will terminate at CSI-12 if case 1 is acceptable. If case 1 is not acceptable, VHF only between CSI-12 and CSI-9 will be included. Assuming as previous analyses have indicated, the case 4 results are acceptable and cases 1 and 2 are not, then the results of case 3 will be compared to case 4. If case 3 results are also acceptable, the recommendation will be made that the command module pilot adopt the case 3 navigation. The tracking schedule and crew procedures would be changed accordingly. If case 3 results are not acceptable, then case 4 navigation techniques are to be recommended. The case 3 navigation technique has the advantage of providing the necessary out-of-plane information prior to CSI required for the LM to make an out-of-plane velocity correction at CSI. The eight minutes of SXT tracking are expected to determine the out-of-plane velocity to better than 1 fps. If the SXT tracking is not performed prior to the CSI maneuver, then the nominal procedure of performing the out-of-plane corrections at CSI and PC would be changed to PC and CDH. These maneuvers are optimally separated by 90° in central angle just as CSI and PC are; therefore, no maneuver penalty would be incurred. The analysis of these four cases are to be completed and a recommended course of action will be made Wednesday, April 16, 1969, in order that the navigation technique can be exercised in the full network simulation scheduled on Thursday, April 17, 1969. It should be pointed out that the recommendation of cases 3 or 4 navigation prior to CSI is tantamount to the requirement that VHF range data be available.

5. The differential corrections limits (RMAX and VMAX) in the LM and CSM were set to 2000 ft. and 2 fps. In determining the RMAX and VMAX limits and the techniques associated with accepting and rejecting navigation data, we found that the heart of the problem is bound up in how to determine and declare the navigation system failed. As you can tell from reading, not too much thought has been devoted here. The following procedure was outlined for determining if the correction to the state which violates the RMAX or VMAX limit should be accepted are rejected. Between DOI and CSI, the first mark after a maneuver or after a long time period of no navigation, the RMAX and VMAX are expected to be exceeded

and the mark is to be accepted if RMAX is less than 12000 ft. and VMAX is less than 12 fps. The next mark should be a large correction but not so large as the first. This downward trend in the magnitudes of the correction should continue as the relative state is continually improved. If the corrections do not decrease, then the crew should investigate the tracking data source to verify that the system is operating correctly. For instance, the astronaut knows if he made a good SXT mark; the VHF range readout data can be checked verbally with the RR range meter; the RR antenna can be checked for side lobe lock on; and the range rate compared to the dsky display (V83E) in CSM or LM. If it has been determined that the tracking data source is operating correctly and yet corrections to the state vector are not decreasing, there is a point where the navigation system should be considered failed, whatever that means. The logic of how the astronaut should come to this conclusion was not discussed at this meeting. There are no plans to consider exploring this question in quest of solving it. If it is considered to be worthwhile, then a meeting can be called for the purpose of attempting to solve this riddle. If the correction to the state which triggers the RMAX, VMAX alarm is more than 12000 ft. or 12 fps, then the mark is rejected and the astronaut takes action to determine that his data source is valid. If he determines the data source is valid, then he accepts the next mark and the same process previously discussed is followed. If he determines that the data source is invalid, he takes action to correct the situation, if possible. If he cannot correct the problem, the corrections that are being made to the state vector are too great to allow them to continue and the tracking source should be considered failed. The RMAX and VMAX are set to 2000 and 2 because corrections greater than this are only expected after a long period of no navigation or at the first mark or two after a maneuver except Insertion when four to six large corrections can be expected. If we get a correction greater than this amount in the middle of the tracking interval, then the mark is bad and should be rejected. After CSI, this differential correction acceptability limit is dropped from 12000 ft. and 12 fps to 5000 ft. and 5 fps, because the expected relative errors between the onboard state vectors are larger before CSI than following CSI.

Paul T. Pixley

Paul T. Pixley

Attachments

Distribution: (See attached list)

P-20 Erasable Memory Parameter List

LGC	Recommended Value
RANGEVAR	0.1111111111E-4
RATEVAR	1.877777E-5
RMAX	2000 ft.
VMAX	2 ft/sec
RVARMIN	66.(meters)^2
VVARMIN	.17445E-5(meters/centi-sec)^2
SHAFTVAR	.000001 (rad)^2
TRUNVAR	.000001 (rad)^2
WRENDPOS	10000. ft.
WRENDVEL	10 ft/sec
WSHAFT	.015 rad.
WTRUN	.015 rad.

CMC	
WRENDPOS	10000. ft.
WRENDVEL	10 fps
RMAX	2000 ft.
VMAX	2 ft/sec
RVAR	0.
RVARMIN	900 ft.^{2}
INTVAR	196.(meters)^2

F Mission Rendezvous Navigation Meeting

Attendees

Paul T. Pixley	FM4
David Dvorkin	FM4
Jack Shreffler	FM4
J. L. Nevins	MIT/IL
J. Blucker	FM4
B. Cockrell	FM4
J. H. Suddath	EG23
G. R. Sabionski	FS5
J. E. Hutchins	CF24
F. W. Lipps	TRW
J. L. Knoedler	TRW
W. T. Miller	TRW
Art Satin	TRW
Dave Detchmendy	TRW
T. H. Skopinski	FM6
E. C. Lineberry	FM6
R. W. Becker	FM6
P. Shannahan	FM6
R. J. Otto	CF212
R. W. Puschinsky	CF212
Bruce Smith	CF212
Peggy Dugge	CF212
S. G. Paddock	CF212
G. Muller	MIT/IL
P. Kachmar	MIT/IL
B. Williamson	FM4
R. Larson	MIT/IL

Tracking Schedule for F Mission Rendezvous

LM Rendezvous Radar

TIME (Min.)	EVENT
-189	DOI
-117	Phasing
-111	Initiate tracking, update CSM in this interval
-106	Cease tracking
- 87	Initiate tracking, update CSM in this interval,V93 after fourth mark, W= 10000 ft.- 10 fps- 15 MRAD
- 72	Cease tracking
- 35	Initiate tracking, update CSM in this interval
- 22	Cease tracking*
0	Insertion
	V93 before first mark, W= 10000 ft.- 10 fps- 15 MRAD
18	Initiate tracking
39	Cease tracking
51	CSI
56	Initiate tracking V93 after fourth mark, W= 2000 ft.- 2 fps- 5 MRAD
74	Cease tracking
80	Plane change
82	Initiate tracking V93 after fourth mark, W= 2000 ft.- 2 fps- 5 MRAD
97	Cease tracking
109	CDH
111	Initiate tracking V93 after fourth mark, W= 2000 ft.- 2 fps- 5 MRAD
134	Cease tracking

* Before Insertion there is a P27 update of the MSFN CSM State to the LGC

Tracking Schedule for F Mission Rendezvous, cont'd.

LM Rendezvous Radar

TIME (Min.)	EVENT
146	TPI
	V93 before first mark, W= 2000 ft.- 2 fps- 5 MRAD
149	Initiate tracking
158	Cease tracking
161	MO1
	V93 before first mark, W= 2000 ft.- 2 fps- 5 MRAD
163	Initiate tracking
173	Cease tracking
176	MC2

Tracking Schedule for F Mission Rendezvous

CM Sextant and VHF Ranging

TIME (Min.)	EVENT
-189	DOI
-136	Initiate tracking*
-126	Cease tracking
-117	Phasing
-112	Initiate tracking, V93 after third mark, W= 10000 ft., 10 fps, SXT TRK terminated between -102 and -89 during LM IMU alignment
- 79	Cease tracking
- 54	Initiate tracking, V93 after third SXT mark, W= 10000 ft., 10 fps
- 34	Cease tracking
0	Insertion**
	V93 before first mark, W= 10000 ft., 10 fps
19	Initiate tracking***
39	Cease tracking
51	CSI
58	Initiate tracking
	V93 after third mark, W= 2000 ft., 2 fps
79	Cease tracking

---

* If valid VHF Range data are available at ranges less than about 327 n.mi., the P-20 navigation program should accept and allow the range data to correct the state vector. Since a range ambiguity exists at ranges greater than 327 n.mi, the data should be inhibited beyond 327 n.mi. For the purpose of navigation capability analysis, VHF range data will only be assumed at ranges less than 200 n.mi., the hardware specifications limit.

** Before insertion there is a P27 update of the MSFN CSM state to the CMC and following Insertion there is a P27 update of the LGC LM state to the CMC.

*** Analyses are in progress to determine the CSM navigation technique and a recommendation will be made Wednesday, April 16, 1969.

Tracking Schedule for F Mission Rendezvous, cont'd.

CM Sextant and VHF Ranging

TIME (Min.)	EVENT
80	Plane change
85	Initiate tracking
	V93 after third mark, W= 2000 ft., 2 fps
97	Cease tracking
109	CDH
115	Initiate tracking
	V93 after third mark, W= 2000 ft., 2 fps
133	Cease tracking
146	TPI
	V93 before first mark, W= 2000 ft., 2 fps
151	Initiate tracking
158	Cease tracking
161	MC1
	V93 before first mark, W= 2000 ft., 2 fps
164	Initiate tracking
173	Cease tracking
176	MC2

Addressees:
AA/R. R. Gilruth
AB/G. S. Trimble
CA/D. K. Slayton
CB/A. B. Shepard (25)
CF/W. J. North
CF13/D. F. Grimm
CF212/C. Jacobsen
CF212/W. Haufler
CF212/W. Hinton
CF2Y/J. Bilodeau
CF22/C. C. Thomas
CF22/D. L. Bentley
CF22/R. L. Hahne
CF22/M. C. Gremillion
CF24/P. Kramer
CF24/J. Rippey
CF24/M. C. Contella
CF24/D. W. Lewis
CF24/D. K. Mosel
CF32/J. J. Van Bockel
CF32/M. F. Griffin
CF33/M. Brown
CF33/C. Nelson
CF34/T. W. Holloway (6)
EA/M. A. Faget
EA2/J. B. Lee
EA2/R. A. Gardiner
EA4/J. Chamberlin
EA5/P. M. Deans
EB/P. Vavra
EE/L. Packham
EE/R. Sawyer
EE13/M. J. Kingsley
EE13/R. G. Irvin
EE3/R. L. Chicoine
EE6/G. B. Gibson
EE6/R. G. Fenner
EE6/J. R. McCown
EG/R. G. Chilton
EG/D. C. Cheatham
EG13/W. J. Klinar
EG2/C. T. Hackler
EG23/K. J. Cox
EG23/E. E. Smith
EG25/T. V. Chambers
EG26/P. E. Ebersole
EG27/W. R. Warienburg
EG27/H. E. Smith
EG41/J. Hanaway
EG42/B. Reina
EG43/A. R. Turley
EG44/C. W. Frasier
EG/MIT/T. Lawton
KA/R. F. Thompson
PA/G. M. Low
PA/C. H. Bolender
PA/K. S. Kleinknecht
PA2/M. S. Henderson
CF3/C. H. Woodling

PB/A. Hobokan
PC/W. H. Gray
PD/O. E. Maynard
PD/C. D. Perrine
PD/R. V. Battey
PD12/J. G. Zarcaro
PD12/R. J. Ward
PD12/R. W. Kubicki
PD12/J. Sevier
PD13/A. Cohen
PD6/H. Byington
PD7/W. R. Morrison
PE/D. T. Lockard
HA/J. P. Loftus
TJ/J. H. Sasser
TH3/J. E. Dornbach
CO7/J. Nowakowski
FA/C. C. Kraft, Jr.
FA/S. A. Sjoberg
FA/C. C. Critzos
FA/R. J. Rose
FA4/C. R. Hicks
FC/E. F. Kranz
FC/G. S. Lunney
FC/M. P. Frank
FC/C. E. Charlesworth
FC/M. Windler
FC/J. W. Roach
FC2/C. S. Harlan
FC2/H. M. Draughon
FC2/J. H. Temple
FC25/C. R. Lewis
FC27/W. E. Platt (3)
FC3/A. D. Aldrich
FC3/N. B. Hutchinson
FC35/B. N. Willoughby (3)
FC4/J. E. Hannigan
FC44/R. L. Carlton (3)
FC5/J. C. Bostick
FC5/P. C. Shaffer
FC54/J. S. Llewellyn
FC54/C. F. Deiterich
FC54/J. E. I'Anson
FC55/E. L. Pavelka (6)
FC56/C. B. Parker (3)
FC6/C. B. Shelley (4)
FL/J. B. Hammack
FL2/R. L. Brown (2)
FL6/R. W. Blakley
FS/L. C. Dunseith
FS5/J. C. Stokes (8)
FM/J. P. Mayer
FM/C. R. Huss
FM/D. H. Owen
FM13/R. P. Parten (10)
FM2/C. A. Graves (3)
FM3/C. T. Hyle
FM4/P. T. Pixley (2)

FM4/R. T. Savely
FM4/W. R. Wollenhaupt
FM5/R. E. Ernull (5)
FM5/J. D. Yencharis (4)
FM5/H. D. Beck
FM5/R. D. Duncan
FM6/K. A. Young (4)
FM6/R. W. Becker (3)
FM7/D. A. Nelson
FM7/S. P. Mann
FM7/R. O. Nobles
FM/Branch Chiefs

HA-74/R. B. McMuldo (Boeing)
HA-58/R. L. Allen
HM-25/H. E. Dornak
HM-25/D. W. Hackbart
Bellcomm/Hqs./R. V. Sperry
Bellcomm/Hqs./G. Heffron
Bellcomm/Hqs./D. Corey
Bellcomm/Hqs./MAS/A. Merritt
GAEC/Bethpage/W. Obert-Thorn
GAEC/Bethpage/J. Marino (3)
GAEC/Bethpage/R. Mangulis
GAEC/Bethpage/R. Pratt
GAEC/Bethpage/Consulting Pilot's Office
GAEC/Bethpage/B. O'Neal
MIT/IL/R. R. Ragan (20)
MIT/IL/E. Copps
MIT/IL/M. W. Johnston, IL 7-279
NR/Downey/M. Vucelic, FB84
NR/Downey/R. Zermuehlen, FB59
NR/Downey/J. E. Roberts, FB59
NR/Downey/B. C. Johnson (4), AB46
NR/Downey/W. H. Markarin, FB55
NR/Downey/E. Dimitruk, BB49
NR/Downey/J. E. McIntyre, BB48
GSFC/550/F. O. Vonbun
NASA/Hqs./MAO/R. B. Sheridan
NASA/Hqs./MAOP/R. O. Aller (2)
KSC/CFK/R. D. McCafferty
KSC/CFK/P. Baker
TRW/Redondo Beach/R. Braslau
TRW/Houston/W. J. Klenk
TRW/Houston/B. J. Gordon
TRW/Houston/R. J. Boudreau
TRW/Houston/M. Fox
TRW/Houston/K. L. Baker
IBM/Houston/G. Cailow, D70

FM4/PTPixley:rmr

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA FPMR (41 CFR) 101-11.6

UNITED STATES GOVERNMENT

Memorandum

NASA Manned Spacecraft Center

TO : See list attached

DATE: March 20, 1969

69-PA-T-47A

FROM : PA/Chief, Apollo Data Priority Coordination

SUBJECT: F mission lunar orbit attitude sequence

This belated memo is to describe the results of our March 10 Mission Techniques meeting on the F mission lunar orbit attitude sequences - as well as I can remember them.

I realize the following statement must sound inconsistent, but although there were a large number of changes to the attitude sequence as documented in Rocky Duncan's Internal Note, 69-FM-51, dated February 21, 1969, my impression is that it is basically nearly right. Of course, it will have to be updated to reflect the many picky changes we arrived at, but in the meantime it's still a good reference. It certainly served one useful purpose. That is, at this meeting it brought out a number of misunderstandings and minor disagreements which we were able to resolve.

The F mission attitude sequence must obviously be constrained to avoid excessive RCS propellant usage. As a result, whenever possible an inertial attitude was selected which would provide all of the various desired characteristics. For example, on the first couple of revs in lunar orbit, it was planned to keep the spacecraft essentially in the LOI burn attitude, just rolling it to provide hi-gain S-band coverage with the earth. This unfortunately doesn't provide much opportunity for the crew to view the lunar surface. That can't be called mandatory for the mission, of course, but in practice is just plain unreasonable. Who could suggest that the crew not look at the sunlit moon once they have gotten there, even if it costs some RCS. Accordingly, we asked Duncan to work out a new attitude/attitude rate which would not only give the hi-gain antenna coverage but also a visual view of the lunar surface on the daylight side. It must also support a P52 alignment in the darkness. This inertial attitude sequence will be defined pre-flight and will only be updated in real time (during cis-lunar coast) if the launch date slips.

As you know, the landmark tracking with the LM attached will be done in the pitch mode. An attitude/attitude rate sequence proposed by Duncan was accepted. It provides three minutes of useful observations above 55 degrees elevation angle. It involves holding a pre-determined inertial attitude until the spacecraft is at a 35 degree elevation angle as viewed from the landmark. At this time, a pitch rate of at least 0.3 degree is initiated. I would like to emphasize that "at least." The local vertical pitch at the time of starting the rate is -2.1 degrees; the roll and yaw angles are 0. MCC-H will supply the following data in real time:

a. Time at which the Initial Point (I.P.) is at elevation angle of 35 degrees.

b. The time to start pitching.

c. The inertial attitude to be held until the pitch rate is started.

d. The shaft and trunnion angle at that time as well as an indication as to whether the landmark will be north or south of the ground track.

Although it may be necessary to slightly roll the spacecraft if the landmark is too close to the ground track in order to avoid excessively high sextant shaft rates, it was decided to let the crew take care of this themselves. John Young says it's no problem. The constraint is that the sextant trunnion angle should never get less than 10 degrees.

Landmark tracking with the LM attached is done two times on the F and G missions. The first time with a pseudo-landing site, it occurs on the fifth rev just before the rest period and is used primarily for on the job training (OJT). The second time, of course, is just before DOI for descent targeting. We discussed the possibility of adding a second OJT into the flight plan to guard against problems or failures encountered on the first, but finally decided that, if necessary, this would be added in real time, perhaps at the cost of some sleep if the situation warrants it.

Rocky and his friends have been able to select an inertial attitude for use during sleep in lunar orbit. It is an in-plane alignment with the SPS engine forward in the direction of orbital motion and a pitch angle which results in the sunlight within 40 degrees of perpendicular to the x-axis. The spacecraft should be set up with a ± 10 degrees deadband. The inertial angles will be computed pre-flight and will provide continuous hi-gain S-band coverage but not a continuous view of the lunar surface. Duncan was requested to determine the LM yaw attitude for the APS burn to depletion which provides best S-band coverage.

The attitude/attitude rate sequence for the undocked landmark tracking exercise prior to TEI is different from the docked one. It was decided that the spacecraft will maintain orbit rate torquing continuously with a pitch angle of about -20 degrees. This will give an optics tracking period of about 160 seconds. Duncan was asked to tune-up the pitch angle a little to give about the same period of coverage before zenith as after. In this exercise, of course, it will only be necessary for the MCC-H to supply the crew with the two acquisition times (items a and b noted above).

Howard W. Tindall, Jr.

Howard W. Tindall, Jr.

PA:HWTindall, Jr.:js

info

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA FPMR (41 CFR) 101-11.6

UNITED STATES GOVERNMENT

Memorandum

NASA Manned Spacecraft Center

TO : See list attached

DATE: March 14, 1969

69-PA-T-44A

FROM : PA/Chief, Apollo Data Priority Coordination

SUBJECT: Happiness is having plenty of hydrogen

As I understand it, there has been a desire or requirement to have the capability of surviving a cryo-tank failure at any time in the lunar mission. After C', it was decided to keep the IMU powered up throughout all lunar missions even though it might be at the cost of having the backup cryos. However, according to a recent analysis by MPAD's Guidance and Performance Branch (R. C. Wadle, W. Scott, and D. A. Nelson), these two characteristics are not incompatible. Since this is quite different from what I have heard in the past, I thought you might find it interesting, too.

According to Wadle, Scott, and Nelson, it is possible to operate with the platform powered up and even if one tank fails as late as TEI, there is still enough hydrogen left in the other tank to provide a four day return-to-earth in a powered-down state. (Hydrogen is the most critical consumable.) The powered-down state still provides for communications; essentially it consists of just taking the guidance system and one fuel cell off the line and turning off non-essential equipment.

Howard W. Tindall, Jr.

PA:HWTindall, Jr.:js

info

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA FPMR (41 CFR) 101-11.6
UNITED STATES GOVERNMENT

Memorandum

NASA Manned Spacecraft Center

TO : See list attached

DATE: February 27, 1969
69-PA-T-37A

FROM : PA/Chief, Apollo Data Priority Coordination

SUBJECT: Some more trivia for the F mission

This memo is to point out a couple of oversights in our F Mission Techniques.

1. With regard to docked DPS burns we should remember that the LUMINARY program used on F is the same as the SUNDANCE program to be used on D, which due to scaling problems or something barely recognizes that the DPS is running when it is at only 10 percent thrust in the docked configuration. Accordingly, it is necessary for the crew to manually advance the throttle to 40 percent thrust for awhile prior to going to full thrust in order for the PGNCS to trim the DPS thrust vector through the CG. (Note: LUMINARY 1A for G has been fixed so that gimbal trimming will be done at 10 percent and the stopover at 40 percent is not required.)

2. During the planning of the special F mission landmark tracking exercise just prior to TEI we forgot to include the CMC state vector updating from the MCC-H once per rev. This is so obviously necessary that it would certainly have been caught during the earliest simulations. However, we might as well start including it in F mission documentation now to be done at about the same time as the periodic P52 platform realignments.

Bill T

Howard W. Tindall, Jr.

PA:HWTindall, Jr.:js

info

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA FPMR (41 CFR) 101-11.6

UNITED STATES GOVERNMENT

Memorandum

NASA Manned Spacecraft Center

TO : See list attached

DATE: February 26, 1969

69-PA-T-35A

FROM : PA/Chief, Apollo Data Priority Coordination

SUBJECT: F/G Mirror Image Targeting shall use a three-minute delay

As you know, we have established as a standard procedure during Apollo rendezvous having CSM backup LM maneuvers in order to retain the nominal relative motion during this critical mission phase. On the D mission these "mirror image" CSM maneuvers are targeted with a TIG delayed one minute after the LM TIG. One minute was chosen based on our estimate that it would be adequate for the crew to determine whether or not the command module should go active and to take the proper steps subsequent to that decision. John Young - the F mission CMP - was concerned that by using a one-minute delay he is forced to turn on his SPS trim gimbal motors for each of the mirror image maneuvers whether he has to execute the burn or not. Since there is no significant disadvantage in making the delay larger, we are changing it to three minutes for the F and G missions in order to avoid having to turn on those motors unnecessarily. Henceforth, all F/G analyses, simulations, procedures, and techniques will be based on that value.

Howard W. Tindall, Jr.

PA:HWTindall, Jr.:js

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA FPMR (41 CFR) 101-11.6

UNITED STATES GOVERNMENT

Memorandum

NASA Manned Spacecraft Center

TO : See list attached

DATE: February 24, 1969
69-PA-T-31A

FROM : PA/Chief, Apollo Data Priority Coordination

SUBJECT: Let's have no unscheduled water dumps on the F mission

During a recent Data Selection Mission Techniques meeting we were informed that the CSM has some sort of automatic water dump system. It was even rumored that it might be enabled on the F mission while the crew is sleeping during cis-lunar flight. This memo is to inform everyone that an unscheduled water dump can really screw up MSFN orbit determination. Accordingly, if we have a vote, this automatic capability, if it exits, should be inhibited and water dumps should only be performed as scheduled by MCC-H.

Howard W. Tindall, Jr.

PA:HWTindall, Jr.:js

UNITED STATES GOVERNMENT

Memorandum

NASA Manned Spacecraft Center

TO : See list attached

DATE: February 19, 1969
69-PA-T-27A

FROM : PA/Chief, Apollo Data Priority Coordination

SUBJECT: All about F APS burn to depletion and landmark tracking

On February 14 we had a Mission Techniques meeting to pin down F lunar orbital operations between the end of rendezvous and TEI. Aside from a rest period, this consists of two exercises - the APS burn to propellant depletion and landmark tracking with the optics. I think we have a good understanding of how to do both of these things. We are recommending the addition of an extra rev in lunar orbit in order to complete them and to obtain one pass of strip photography on the sunlit part of the moon prior to TEI. This will make the time between wakeup and TEI approximately 12 hours which does not seem unacceptable, and does not increase total mission time.

1. <u>APS Burn to Depletion</u>

Although we went into considerable detail in planning this exercise I will only list here several of the most significant items. The detailed procedures, of course, will be documented elsewhere.

a. As you know, the APS burn to depletion is initiated at approximately zero degrees longitude in a horizontal, posi-grade direction. It occurs about $1\frac{1}{4}$ rev after docking.

b. After docking, the command module will be used for controlling attitude of the docked configuration. As soon as convenient after docking, the command module will reorient to near the burn attitude based on gimbal angles computed pre-flight and included in the flight plan.

c. The only data required from MCC-H is as follows:

(1) A P27 command load to the LM PGNCS of LM state vectors.

(2) Voice PAD message to the LM for PGNCS and AGS targeting. This will be the standard P30 PAD with a number of parameters omitted, which are only applicable to a manned burn.

(3) Voice to the CSM of the gimbal angles for the burn attitude. Having obtained these, the CMP is able to orient the CSM/LM accurately in burn attitude based on real time data and the LM crew is able to orient the steerable S-band antenna to achieve maximum signal

strength with MSFN.

d. Just prior to LOS, about 3/4 rev before TIG, the LM crew will update the state vectors in the AGS and will align it to the PGNCS. They will already have run through the SPS pre-thrust program (P30) and will leave the PGNCS in Program P00.

e. The CSM will jettison the LM $\frac{1}{4}$ rev before TIG and will null the relative velocity. They will then execute a 2 fps separation burn in a radially upward direction which will place the command module above and behind the LM at the time of the burn.

2. Landmark Tracking

Before C' we thought we knew how the optics tracking and MSFN orbit determination capability should be used for a lunar landing flight. Unfortunately we are worse off now since C' has proved we really don't know. At this time - with incomplete post-flight analysis, we have a dilemma. The optics data seems to indicate that spacecraft altitude was not changing while in lunar orbit; on the other hand, the MSFN data clearly shows a continuous change in altitude which was more or less what was expected based on Lunar Orbiter data. These two systems disagree with each other and yet both appear to be operating right. It may be possible eventually to figure out what is happening by further analysis of the C' data but unfortunately we are at a point when we must pin down the F mission flight plan. So what we were trying to do at this time, based on what we know now was to develop an exercise which we feel will give us the greatest opportunity to resolve our difficulties in time to support the G mission descent targeting accurately and dependently. Simply stated, we need as much data as we can obtain. Essentially, we are asking for a repeat of the C' lunar landmark exercise with some minor modification. Since the thing we are most concerned about is trends (i.e., the change in altitude) - it seemed that tracking on four successive revs is the minimum that would provide any kind of confidence in the results. I think everyone in attendance agreed with that. Secondly, although MPAD was asking for observation on four landmarks on each of these revs, we all agreed that three are probably adequate and so our proposal is to do landmark tracking on three sites on each of four successive revs.

To be a little more specific, we are currently recommending:

a. One of these be the same pseudo-landing site landmark we used on C'. It is called B1.

b. The first backside landmark as the spacecraft enters daylight (CP_1) should probably be chosen by the CMP in real time at about 20 degrees passed the terminator, the same as Lovell did.

c. The third landmark (CP2) can probably be moved closer to the sub-solar point than on C'. We are recommending a landmark about 25 degrees prior to local high noon.

Of course, we are specifying that all observations be made with the sextant and that they be spaced as far apart as possible - in the order to 25 seconds. It appears that it should be possible to use lunar orbit rate torquing during the landmark tracking period if that is easiest for the crew.

It is possible to include the exercise as described here in the current F mission timeline without affecting the rest period or the TEI burn currently scheduled at about 127:50. However, this would preclude obtaining strip photography desired on one pass over the entire sunlit lunar surface. In order to include that it will be necessary to delay TEI one rev to about 129:50. This will increase its magnitude by about 100 fps but does not change Pacific landing time. Of course, it is possible to retain the earlier orginal TEI as an optional maneuver time in the event of crew exhaustion to be utilized based on a real time judgment, if necessary. It appeared advantageous to us to put the strip photography after the more strenuous landmark exercise since it is less demanding on the crew, interferes less with TEI preparation and is of lower priority. The ASPO mission engineer, Bob Ward, will submit a Trajectory Change Request for this extra rev and everyone else I think will begin now to include it in their planning and documentation on the assumption that it will be approved.

Except for odds and ends, this pretty well finishes off the main line F Mission Techniques work.

Howard W. Tindall, Jr.

Howard W. Tindall, Jr.

PA:HWTindall, Jr.:js

info

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA FPMR (41 CFR) 101-11.6

UNITED STATES GOVERNMENT

Memorandum

NASA Manned Spacecraft Center

TO : See list attached

DATE: February 11, 1969
69-PA-T-24A

FROM : PA/Chief, Apollo Data Priority Coordination

SUBJECT: F/G Rendezvous Mission Techniques - mostly F

As part of F/G Torture Week, we spent Thursday, January 30 on the rendezvous. Overall, I would say this mission phase is in pretty good shape with only a few unresolved items that we know about right now. I would like to tabulate here a bunch of odds and ends we agreed to at this meeting - as well as my memory serves me. It's mostly trivia and if I were you I wouldn't waste my time reading anymore except maybe paragraph 3.

1. On the D mission the CMP is prepared to make a so-called "Horizontal Adjust" maneuver if it is decided to stay in the mini-football in order to insure a closing trajectory. The F and G crews both felt this is an unnecessary complexity and so they will not make such a maneuver or be prepared to make one on these missions.

2. Everyone worries about overburning the LOI maneuver. Wait until they discover it just takes an extra 12 fps on DOI to cause a lunar impact. The LM picks up that much ΔV in about three seconds when operating at about 40 percent and so it is unlikely we will be able to establish a manual backup protecting against overburn which would provide a safe orbit. On the other hand, some sort of monitoring is required and Rick Nobles (MPAD) was given the action of establishing the limits for the crew to shut down the DPS manually when both the AGS AND the Burn Time have been exceeded by these amounts.

3. LM aborts due to a fouled up DOI maneuver are attracting a lot of attention. For the past year, everyone agreed that the best technique is to make a brute force burn right back to the CSM immediately. This probably works pretty well if it's done within five to eight minutes of DOI. After that it doesn't and the crew feels more time than that will be required for them to ascertain an abort is necessary and then to execute it. Ed Lineberry was given the action item of performing a parametric study to establish the best technique for aborts up to about 15 minutes after DOI with the maximum possible overburn based on our backup cut-off procedures. Whatever it turns out to be we are tentatively proposing to use the DPS at 40 percent thrust, controlled manually with the AGS maintaining attitude hold. The crew would shut down about

10 to 15 fps short and finish off the burn with 4 jet RCS while simultaneously jettisoning the DPS. Milt Contella ventured the opinion that DOI aborts are going to turn into the F equivalent of D's TPI_0 - Endless discussion and a mess in the end! I believe it already.

4. We decided to create a new PAD message which the CMP can use for loading his Target ΔV program (P76) for the ground computed maneuvers - DOI, Phasing and Insertion. It consists of Purpose, TIG, and ΔV's. In addition we decided to add burn time (BT) to the LM P30 PAD.

5. It was determined that it will not be possible for the F crew to use their descent program (P63) for the landing radar test as they had planned because MCC-H will not be prepared to support it with the necessary input data. Don't get excited. This is no great loss.

6. We pinned down the complete rendezvous tracking schedules for both spacecraft and established the following W-matrix values. The initial values shall be 10,000 feet, 10 fps, and 15 milliradians. The values for reinitialization shall be 2,000 feet, 2 fps, and 5 milliradians. (For the unique F rendezvous tracking period between the Phasing and Insertion burns, the W-matrix shall be initialized using 2,000 feet, 2 fps, and 5 milliradians.) MIT was asked why the PGNCS computer program (LUMINARY) does not provide a simple way for initializing the W-matrix value for radar bias as it does the position and velocity values. Perhaps a PCR should be submitted for that.

7. We had a lengthy discussion on rendezvous navigation during the phasing revolution. It was soon recognized that, since the LM has no tape recorder, it is only possible to evaluate its performance if we allow the rendezvous navigation to update the state vector. However, the flight controllers were concerned that if the rendezvous navigation in back of the moon fouled up the LM state vector they could have problems targeting the Insertion Burn which occurs shortly after AOS. On the other hand, it is possible that the rendezvous navigation could be useful in detecting dispersions in the Phasing maneuver. Accordingly, we reached the following agreements:

a. Rendezvous navigation by the command module will be used only to update the LM state vector.

b. Rendezvous navigation in the LM will be used to update the LM state vector until shortly before LOS. After that, the LM crew will switch the LGC to update the CSM state vector.

c. While the LM is in back of the moon the flight dynamics people will determine if the LM onboard state vector is acceptable for executing the insertion burn. If it is, it will be left alone; in fact, MCC-H will transmit it to the CSM after insertion. If it is not acceptable, the LM crew will be advised at AOS to terminate their navigation program (P20) immediately and the update program (P27) will be called so that the ground may send a good LM state vector for the Insertion maneuver. It is unlikely that they will have to do this but if they do it must be recognized that we will not get the rendezvous radar tracking data at the maximum ranges which we are so interested in.

d. As a standard procedure the ground will always update the CSM state vector in both spacecraft computers after insertion.

8. Rendezvous radar thermal study must be performed, I suppose, and we established the following profiles for that purpose listed here in order of our preference:

a. Rendezvous radar continuously operating from during the mini-football to completion of the rendezvous.

b. Same as "a" except turned off from DOI until just after Phasing.

c. Same as "b" except turned off during the platform alignment while in the phasing orbit.

If GAEC and RCA feel the rendezvous radar cannot support any of these profiles - we would rather fight than switch!

9. After a little merry-go-round we agreed on what the CSM should do for TPI targeting. He starts out running the P34 using the elevation angle option in order to obtain a TPI solution for comparison with the LM PGNCS. He then recycles using the time option with a TIG one minute later than the LM's in order to backup the LM TPI maneuver.

10. Both the F and G crews and just about everyone else who stuck it out to the end seemed to want to keep the LM active for TPI even if the rendezvous radar had failed. You recall the D mission rule says the CSM should go active for that failure. I guess that must be the right thing to do since so many people thought so and I was just too groggy to understand.

11. MIT was asked the following brief questions:

a. Does the CMC automatically inhibit VHF ranging data beyond the recycle range of 327 miles?

b. How does the crew request the half-period-between - CSI-and- CDH option in the rendezvous navigation program (P32).

c. Are these options in shared erasible memory or is it possible to load them pre-launch on the E-memory K-Start tape.

d. How should the crew handle the sign of the out-of-plane velocity display from R36 if: (1) the CMP requests the LM option for relay to the LM or (2) if he uses R36 to target his own plane change maneuvers.

Well, I warned you!

Howard W. Tindall, Jr.

PA:HWTindall, Jr.:js

info

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA FPMR (41 CFR) 101-11.6

UNITED STATES GOVERNMENT

Memorandum

NASA Manned Spacecraft Center

TO : See list attached

DATE: February 11, 1969

69-PA-T-23A

FROM : PA/Chief, Apollo Data Priority Coordination

SUBJECT: F/G Mission Techniques - except for the lunar orbit phase - are ready to eat

Some of the decisions and open items that came out of our F/G Mission Techniques meetings in late January are listed in this memo. Basically, I would say that all mission phases aside from the lunar orbit activity are very well understood at this time - primarily as a result of the C' mission - and should be formally documented within the next couple of weeks.

1. Flight Control Division is going to establish the detailed procedures for manning and activating those LM systems required to establish communications in the unlikely event CSM communication is lost. They must include the techniques for orientating the LM steerable antenna toward the earth if the omnis are inadequate. It is also necessary to give some thought to when the crew should initiate these procedures. That is, what should be done with the CSM communication systems first after the total failure seems to have occurred.

2. As a standard procedure, MCC-H will update CSM state vectors on a more-or-less periodic basis - say every 10 hours or so when it is mutually convenient to the crew and ground, unless they have changed so little as to make it useless. Whenever the state vectors are updated, it will be to both the LM and CSM computer memory slots, CSM first.

3. <u>REFSMMATS</u>

a. The launch REFSMMATS will be retained until the IMU alignment after MCC$_1$ time whether the maneuver is made or not.

b. The same PTC REFSMMAT will be used translunar and transearth during the periods from the post-MCC$_1$ to pre-MCC$_4$ and from TEI plus two or three hours to EI - 5 hours.

c. The lunar orbit REFSMMAT to be used for the period between the PTC times defined in "b" shall be such that the LM in landing attitude, over the landing site after DOI would have 0, 0, 0 on the FDAI. This REFSMMAT will be computed by the MCC-H prior to MCC$_4$ for use in the CSM. According to my notes, the REFSMMAT will be updated on DOI day to compensate for prediction uncertainties. I can't remember why. (On the

G mission, of course, the REFSMMAT in the LM will be updated several times automatically while on the lunar surface by the LGC to correspond to the ascent alignment. Currently we plan to update the CSM more or less to the ascent REFSMMAT but we will not attempt to maintain it precisely the same as the LM.)

4. The only burn monitoring limit it is necessary to change from those used on C' is the one used for overburn protection on LOI_1. The extra mass of the LM makes this maneuver substantially longer in duration, so that limit has been made correspondly larger. Specifically, it will be 10 seconds rather than 6 seconds.

5. Math Physics Branch was requested to determine if in order to maintain a good MSFN orbit determination capability, it is really necessary for the crew to reverse the orientation of the spacecraft x-axis every three hours during periods of venting. It seems as though the net effect of the venting is almost exactly in the least sensitive direction when using the PTC attitude currently proposed and it would certainly be nice to avoid unnecessary spacecraft maneuvers; perhaps even unnecessary awakening of the crew.

6. In order to insure that the crew never experiences CMC Program 65 during entry, MCC-H will make a real time selection of entry range to avoid P65 prior to targeting TEI. This should not be a difficult thing to do while in lunar orbit but cannot be done pre-mission to suit all launch opportunities.

7. The crew is looking for a recommendation as to whether the entry should be performed using one or two RCS rings. Claude Graves is said to be working on this.

8. Docked DPS burns in lunar orbit

a. It was established that, if a docked DPS burn is to be used for TEI, it should be carried out with one burn only as opposed to two as has been suggested.

b. In this event the LM platform will be aligned using docked AOT sightings of stars in order to determine platform orientation (P51). Given the accuracy of pulse torquing, it will be possible to reorient the IMU for the maneuver without additional AOT sightings.

c. The CSM will use the Average G Program (P47) for maintaining state vectors if we make a docked DPS burn.

d. It was estimated that the LM could be made ready for such a burn easily within $1\frac{1}{2}$ hours.

e. MIT was asked to determine if the DPS gimbal trimming would work in the docked configuration at 10 percent thrust in the LUMINARY program.

f. It is evident that complete docked DPS check list must be prepared for the F and G crews by FCSD.

9. The crew was somewhat concerned with the technique MPAD has developed for the LOI-15 minute abort. This abort maneuver, you recall, is one the crew must target for themselves in the event of a premature SPS shutdown during LOI. The crew charts that MPAD has developed present the ΔV required assuming the maneuver will be executed exactly 15 minutes from the time of SPS shutdown. Since the spacecraft clocks are all keyed to LOI TIG, the crew feels it would be easier for them if the maneuver were scheduled to occur 15 minutes from LOI TIG. The point is, they were concerned that in the event of an emergency they may not note the time of shutdown or are more likely to make a mistake in determining when to execute the abort maneuver. Flight Analysis Branch, MPAD, is looking into reworking these charts based on TIG rather than SECO.

10. Since there is concern over premature shutdown on either the LOI or TEI maneuver, the crew asked if it were not logical to protect against it, particularly in the unstable butterfly region, by use of the Thrust Direct On switch. For example, during LOI they suggest turning that switch On from TIG + 1 minute to TIG + 5 minutes and on the TEI maneuver they would switch it On from TIG + 15 seconds to TIG + 2 minutes. Flight Control and other guys are going to think about that! I think the greatest fear is what would happen if the crew neglected to switch it off in time.

That's all I can rememeber. Mostly trivia, you see which probably shows better than anything the status of F/G Mission Techniques for these mission phases.

Bill T

Howard W. Tindall, Jr.

PA:HWTindall, Jr.:js

nnjo

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA FPMR (41 CFR) 101-11.6

UNITED STATES GOVERNMENT

Memorandum

NASA Manned Spacecraft Center

TO : See list attached

DATE: February 6, 1969

69-PA-T-18A

FROM : PA/Chief, Apollo Data Priority Coordination

SUBJECT: F/G cis-lunar midcourse correction mission techniques

This memo is to document the cis-lunar midcourse correction mission techniques we agreed to January 27 and 28 at the F and G Mission Techniques meetings. The translunar maneuvers are based on the following assumptions and guidelines:

a. We are not concerned about getting substantially further off the free return trajectory than on C' - primarily because we have the DPS backup.

b. We are especially anxious to conserve RCS propellant, which led to the procedures of allowing the midcourse corrections to grow to SPS size if possible.

c. In order to maintain best control over the situation we decided to use MCC_3 (at LOI - 22 hours) as the prime MCC, leaving MCC_4 essentially for fine trimming if necessary.

d. The minimum SPS burn is 0.5 seconds which is equivalent to approximately 3 fps.

Based on all that, we established the following:

a. <u>MCC_1 (at TLI + 7 hours) and MCC_2 (at TLI + 24 hours)</u>

The need for these maneuvers will be based on how big MCC_3 would be if we did not make them. Specifically, MCC_1 and/or MCC_2 will not be executed as long as MCC_3 is less than about 25 fps without them. Furthermore, we will not make them unless we can use the SPS (that is, they must be bigger than 3 fps) and we will not trim residuals.

b. <u>MCC_3 (at LOI - 22 hours)</u>

This is the prime maneuver to achieve the desired trajectory around the moon. It will be made if the predicted MCC_4 is greater than about 3 fps in order to avoid using SPS for MCC_4. Residuals will be trimmed to within 0.5 fps on this maneuver, which will most likely be made with the SPS.

c. MCC_4 (at LOI - 5 hours)

By taking advantage of the significant flexibility provided with two-stage LOI maneuver in targeting the LOI maneuvers, we are often able to avoid making an MCC_4. That is, the LOI targeting can be done to achieve a 60 mile circular orbit in spite of substantial approach trajectory dispersions. This is done by rotation of the major axis of the initial 60 x 170 n.m. lunar orbit. However, we established that the apsidal rotation should be limited to less than 45 degrees. If it is necessary to use the SPS for MCC_4, the residual will be trimmed to within 1 fps.

Midcourse correction techniques on transearth leg phase of the flight were somewhat simpler. We are retaining the C' technique of utilizing transearth midcourse corrections only for corridor control. We have concluded that it is desirable to avoid making the last midcourse correction (i.e., MCC_7 at EI - 3 hours) if at all possible. Accordingly, we opened up the entry interface (EI) flight path angle limits a little more than on C'. Specifically, we will not execute MCC_7 if the flight path angle falls between 6.3 and 6.6 degrees (6.5 degrees is nominal). In order to minimize the probability of that midcourse correction, we set the threshold for MCC_6 (scheduled at EI - 15 hours) at .5 fps which is close to the MSFN targeting accuracy at that time. The first transearth midcourse correction (MCC_5 at TEI + 15 hours) will not be executed unless it is greater than 1 fps.

The most significant change from C', of course, is brought about by the DPS backup which safely permits deviation from the free return trajectory. This makes the logic much simpler since we don't have to consider moving the maneuvers earlier to stay within RCS return-to-earth capability.

Howard W. Tindall, Jr.

PA:HWTindall, Jr.:js

wyo

UNITED STATES GOVERNMENT

Memorandum

TO : See list attached

DATE: January 15, 1969

69-PA-T-8A

FROM : PA/Chief, Apollo Data Priority Coordination

SUBJECT: F and G Lunar Orbital operations - mostly pre-DOI LM activation stuff

On January 10 we had an F and G Mission Techniques meeting dealing mostly with Lunar Orbital operations, which I would like to record with this thing.

In our continuing effort to figure out the best way to minimize the DOI day timeline, I think we have finally converged on the best basic procedure for getting the LM checked out. As usual we went over the three most popular ways proposed - namely:

a. All at one time on DOI day

b. Two work periods - one prior to LOI and one on DOI day

c. Two work periods - one on DOI day and one after LOI_2

We finally selected the last of these, basically by the process of elimination. Trying to do everything on DOI day not only lengthens that day by at least one hour but it also sets up a situation which is completely intolerant of even the most minor trouble as the crew goes through the process of manning, powering up, and checking out the LM. And, it should be emphasized that although it may be possible in real time to slip DOI a revolution, it will be by no means a simple procedure to get all squared away again in preparation for the most complex operation we have ever attempted in flight. What I am trying to say is that we want to avoid perturbing the timeline around DOI at almost any cost and, splitting up the LM preparation into two periods helps to do this.

Having accepted the two period technique, the question remains - where to put the first period? Although the pre-LOI period of checkout was attractive for a number of reasons, it seemed to us questionable in terms on what it might do to the spacecraft thermal situation and more seriously to what might happen to the LM steerable S-band antenna if it were unstowed prior to the big SPS LOI maneuvers. Except for the fact that this time period provides continuous MSFN coverage, all other advantages are also obtainable if we schedule this activity after LOI_2. The thing we like about putting a two or three hour checkout period after LOI_2 and before the crew rest period is that it provides an opportunity for the crew to get the LM squared away - that is, things stowed and other housekeeping chores done before DOI day. It also provides an opportunity to add an additional activity which might be discovered during the D mission or as a result of continued detailed planning of the F and G missions without perturbing the complicated pre-DOI timeline. (It also provides a place to stick in some F unique DTO's.) Of course, this checkout period is much more tolerant of problems than DOI day. For example, it can be extended although at the cost of some crew rest. And, perhaps more important, will provide more time for the MCC-H to evaluate and digest the checkout data. Charlie Duke is going to head a tiger team mostly composed of FCD and FCSD people to develop a detailed timeline for LM preparation including all those systems tests considered essential and no more than that. They will integrate these into the total timeline which includes the crew suiting and eating and all of the other LM activation activity as well as the CSM landmark tracking which now consists of only one tracking time period.

We will review the results of their work at a later Mission Techniques meeting so that everyone in the world can criticize it and finally bless it.

In addition to that one big item there were a pot full of little things we discussed and resolved as follows:

a. There is a minor difference of opinion between the F and G crew as to whether the landmark tracking should be done in the pitch or roll mode. John Young, who favored the pitch mode, is going to try out the other technique in an attempt to resolve this.

b. Most of us have pretty well agreed that docked AOT IMU alignments are expensive to do and are not necessary. Accordingly, we now propose to use the same procedure as D for docked LM alignments referenced to the CSM platform using the known relative orientation of the CSM and LM navigation bases. This does mean that an accurate LM IMU gyro drift check can not be made although we expect it will be good enough for a go/no go of the system. Just how good it is will depend on how stable the relative orientation of the navigation bases is over a two hour period. We must get this information from ASPO as soon as possible.

c. Prior to and during DOI we want the LM radar turned on to check it out and if necessary to verify PGNCS performance of the DOI burn. After that the rendezvous radar may be turned off since there appears to be no strong requirement for its use until after the phasing burn on the F mission or until about five minutes before powered descent on the G mission.

d. In lieu of some other positive proposal we stated that the DPS would be separated from the ascent stage 10 minutes prior to the insertion maneuver by executing a 2 fps horizontal retrograde RCS burn. AGS control will probably be used for that.

e. It has been stated that there is very little difference in the accuracy of the results obtained using the sextant rather than the scanning telescope for landmark tracking therefore until C' it was proposed to use the telescope because acquisition and tracking was expected to be easier. However, the C' crew informs us that it is actually easier to track a given lunar feature using the sextant once it is acquired and so that is what will be done on the F and G flights.

f. Since there seems to be time available following LOI for the CMP to get some practice landmark tracking, it will be included in the timeline. Of course, the actual landing site will be in darkness then so some other feature located to the east must be used instead. It is our intention to select a landmark which will be at a 3 degree sun elevation angle on a nominal mission since this experience would give us a little more confidence of tracking at a low sun elevation angle. This benefit is not important enough, however, to make any real time change in the landmark to be used like we were prepared to do on C'.

Howard W. Tindall, Jr.

Howard W. Tindall, Jr.

Enclosure
List of Attendees

PA:HWTindall, Jr.:js

info

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA FPMR (41 CFR) 101-11.6

UNITED STATES GOVERNMENT

Memorandum

TO : See list attached

DATE: January 21, 1969

69-PA-T-10A

FROM : PA/Chief, Apollo Data Priority Coordination

SUBJECT: F and G mission cis-lunar and abort plan

On January 8 a gang of us FOD types got together to develop a proposal on how we should use the LM for cis-lunar and lunar orbit aborts. In other words, how should the C' techniques be modified due to having the LM DPS available to backup or use in place of the SPS. A great deal of work has been done and documented by Carl Huss, the Flight Analysis Branch of MPAD, and the Apollo Abort Working Group and the results belatedly reported here are heavily dependent on that work.

First of all I'd just like to state a few facts and assumptions upon which the Abort Plan given in the attachment are based.

a. Except in the case of aborts from lunar orbit, the SPS will always be the primary abort propulsion system. That is, the maneuver will be made with the SPS, bringing along the LM, when possible, so that the DPS can be used as a backup if the SPS fails.

b. Since the SPS does not have enough propellant for TEI with the LM attached, we must reverse the order for leaving the moon if we want a TEI propulsion system backup. And, I guess we do.

c. There is a period during translunar coast - from TLI until about LOI - 20 hours that the fastest return to earth can be made directly using a maximum SPS burn after jettisoning the LM. After that period there is no advantage to direct returns and we don't ever suggest making one.

d. There appears to be no period wherein it is faster to make a direct return using the DPS than it is to perform a post-pericynthion maneuver following a 60 mile flyby.

e. It is always preferable to perform a lunar flyby than a direct return using the SPS unless we truly have a time critical situation, in which case we would only consider use of the maximum available ΔV solution which, of course, includes jettisoning the LM.

f. The fastest return trajectory including a lunar flyby is with a pericynthion altitude of 60 n.m. If we maneuver to provide a higher altitude, the trip time is most likely going to increase. This accounts for the use of 60 n.m. in the time critical flyby modes. Of course, the procedure must include making the standard regularly scheduled translunar midcourse corrections to achieve 60 n.m.

g. Although the real time situation (particularly spacecraft configuration has an overwhelming bearing on what should be done), it seems like a good idea to place the spacecraft on a trajectory targeted to the prime CLA as soon as practical, even though that causes an increase in trip time, and perhaps a second maneuver after pericynthion to speed it up.

h. Although we always list the SPS maneuvers as the prime mode and only utilize the DPS as a backup to the SPS, it is recognized that the crew and ground must be trained and prepared to carry out a docked DPS burn. Accordingly, numerous additional options are available to be agreed to either pre-flight or in real time wherein the DPS is used instead of or in addition to the SPS. For example, the desire to make a DPS system test may justify its use in a non-critical time situation or the use of both the DPS and SPS may provide a significant advantage given certain spacecraft system failures to provide greatest crew safety.

Finally - we briefly discussed how to handle partial LOI_1 Burns. First of all we are recommending the same procedures as C' in the event of guidance or control problems during LOI_1 - namely SCS MTVC rate command takeover and burn completion. This is proposed for all the same reasons as for C' - basically it results in a better situation. For SPS failures prohibiting completion of LOI_1, Flight Analysis Branch recommends ground targeted aborts using the DPS as preferable to the C' type "15 minute abort" SPS burn using on-board chart targeting. This is probably the best thing to do and I'm sure we'll talk about it a lot more before it finally is resolved. One thing to be emphasized though is that, since we have the DPS backup we don't have to be in such a hurry to take action after SPS troubles show up as we were on C'.

All of this will be thoroughly reviewed at a slam-bang Mission Techniques meeting scheduled for January 29.

Howard W. Tindall, Jr.

Howard W. Tindall, Jr.

Enclosure

PA:HWTindall, Jr.:js

CIS-LUNAR ABORT PLAN

Categories depend on when the need for the abort is recognized as follows:

CATEGORY I

From TLI until abort LOI - 20 hours (The actual time will be approximately at the equi-return time - direct return using the SPS vs flyby. This tradeoff will be biased as described in Note I.)

A. Time Critical

1. SPS direct return without the LM, to any CLA (ΔV less than about 8,000 fps). (See Note II)

2. DPS maneuver at pericynthion + 2 hours to any CLA following a 60 mile flyby. (1500 fps ΔV max.)

B. Non-time Critical

1. SPS (or RCS) burn at convenient time before LOI - 5 hours, to flyby pericynthion between 60 and 1500 n.m., to the prime CLA.

2. DPS (or RCS) burn at convenient time before LOI - 5 hours, to flyby pericynthion between 60 and 1500 n.m., to the prime CLA.

CATEGORY II

LOI - 20 hours until the last translunar coast midcourse correction at LOI - 5 hours.

A. Time Critical

1. SPS burn at pericynthion + 2 hours to any CLA following a 60 n.m. flyby.

2. DPS burn at pericynthion + 2 hours to any CLA following a 60 n.m. flyby.

B. Non-Time Critical

1. SPS or RCS burn at convenient time before LOI - 5 hours, to flyby pericynthion between 60 and 1500 n.m. to the prime CLA.

2. DPS or RCS burn at convenient time before LOI - 5 hours, to flyby pericynthion between 60 and 1500 n.m. to the prime CLA.

Enclosure

CATEGORY III

After LOI - 5 hours - or when propulsion system failures are recognized too late to do Category II.

A. Time Critical

1. SPS burn at pericynthion + 2 hours to any CLA following a 60 n.m. flyby.

2. DPS burn at pericynthion + 2 hours to any CLA following a 60 n.m. flyby.

B. Non-Time Critical

1. SPS or RCS at earliest practical time before MCC 5 (about TEI + 15 hours avoiding sphere of influence) to the prime CLA as fast as practical. (See Notes I and III)

2. DPS or RCS at earliest practical time before MCC 5 (about TEI + 15 hours avoiding sphere of influence) to the prime CLA as fast as practical. (See Notes I and III)

NOTE I : There is an important real time judgment factor influencing the non-critical abort techniques trading off reduced return time vs. large maneuvers which may modify the priorities.

NOTE II : The LM is jettisoned only in the case of Category I, time critical, SPS direct return aborts.

NOTE III : Normal return velocities shall be limited to less than 36,323 fps. Time critical aborts must provide entry velocities of less than 37,500 fps.

info

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA FPMR (41 CFR) 101-11.6

UNITED STATES GOVERNMENT

Memorandum

TO : See list attached

DATE: January 14, 1969

69-PA-T-4A

FROM : PA/Chief, Apollo Data Priority Coordination

SUBJECT: F and G cis-lunar midcourse correction scheduling

This memo is to make sure everyone is aware that we are scheduling the final midcourse corrections before LOI and Entry differently than on C'.

The final translunar midcourse correction shall be scheduled at LOI - 5 hours since that provides optimum midcourse correction effectiveness and confidence in subsequent MSFN tracking for LOI targeting. You recall on C' this maneuver was at LOI - 8 in order to provide a short crew rest period after that. This is not required on the F and G missions at this time.

The basic criteria for selecting EI - 2 hours as a last transearth midcourse correction was to make it as late as possible while still providing adequate MSFN tracking for entry initialization. On the C' mission it was found that although two hours is adequate, an additional hour would be advantageous. Since there appears to be no disadvantage to moving this maneuver one hour earlier to EI - 3 hours we propose to do so. One associated item North American is going to check out is with regard to the effect of this on the RCS quads. There is a slim possibility that this schedule may present a thermal problem.

I would like to emphasize that the intermediate cis-lunar midcourse correction schedule is not based on trajectory consideration but rather will be selected to fit most conveniently in the crew work/rest cycle just as it was done on C'. Accordingly, the scheduling of these maneuvers must await development of the flight plan after which they will be shuffled in at the most convenient times.

Howard W. Tindall, Jr.

Howard W. Tindall, Jr.

PA:HWTindall, Jr.:js

unfo

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA FPMR (41 CFR) 101-11.6

UNITED STATES GOVERNMENT

Memorandum

TO : See list attached

DATE: January 10, 1969

69-PA-T-2A

FROM : PA/Chief, Apollo Data Priority Coordination

SUBJECT: Some decisions regarding lunar landmark tracking on the F and G missions

We had an Ad Hoc Mission Techniques meeting on January 9 to talk over lunar landmark tracking. In particular, we wanted to discuss what we thought had been learned from the C' mission and what we want to do on the F and G missions. This memo is to outline all that briefly. The specific things we were trying to decide were:

a. Whether special tests of any sort should be included on the F mission which might permit us to broaden the acceptable sun elevation angle constraints associated with the lunar landing and

b. To decide if optical observations (SCT or SXT) of the landing site are required on DOI day for descent targeting and if so how many, when should they be taken, and how should they be used?

Jack Schmitt has probed extensively into the landing sun elevation angle constraints problem both before and after C' and probably has a better understanding of this overall situation than anyone else I know. He has intensely debriefed all of the C' crewman on this specific subject and is confident that the visibility will be acceptable for landing if the sun elevation angle is no less than about 3 or 4 degrees. The upper constraint he feels is in excess of 20 degrees and the actual limit will probably be based on heating considerations on the spacecraft or the crew during EVA rather than visibility during descent (we'll find out what that limit is). In other words, it looks like we have a sufficiently wide band of acceptable sun elevation angles that this imposes no real constraint on G launch opportunities! Furthermore, there appears to be no reason to provide special tests on F designed to broadened these limits or give us greater confidence in them. One interesting point he emphasizes, though, is that we should avoid landing with a glide path within about 2 degrees of the sun elevation angle since there is a definite degradation in visibility along that line which would impair the crew's capability of evaluating the landing site. This means that we should avoid sun elevation angles between about 14 and 18 degrees - a little band of unacceptable lighting conditions within the much larger acceptable limits. He feels that this band may be avoided in the few instances we encounter it by delaying launch somewhat or by adding an extra revolution or two in lunar orbit. It is also evident that by the use of the hybrid flight plan we can extend the translunar coast time with the same effect.

In summary, it appears that the sun elevation angle constraint on G mission launch opportunities is not significant at this time and there is no need to provide special tests on F to confirm this opinion.

The question of optical tracking of the landing site is not so clearly understood. However, the consensus is that it would be a serious mistake at this time for the flight plan not to include optical observations of the landing site as part of the descent targeting operation. But, based on the ease with which the C' crew located and tracked the landmark on their first opportunity there seems to be no reason not to eliminate the first series of landmark tracking, which we had previously included primarily for on-the-job training. Accordingly, we intend to utilize the tracking plan and ground targeting operations previously developed in our Descent Mission Techniques meetings except that the first of the two tracking periods will be deleted or moved to LOI day if it can be conveniently included in the timeline. Since the landing site will be in darkness at that time, this particular session would have to be on some other landmark located 5 or 10 degrees to the east of the landing site.

I would like to discuss briefly the reasons for retaining the optical observations. Basically, they reduce to two things neither of which could be described as mandatory - but they are certainly not just "nice to have" things either. The first, of course, is to significantly improve the accuracy of the descent targeting which will make the descent trajectory more nearly nominal. In line with this, it also makes it more likely the landing radar can return the trajectory to within acceptable limits. The second benefit is that they provide a complete, independent check on the overall targeting system in the same sense that the star check confirms burn attitude or the horizon check confirms retro attitude on other mission phases.

Our discussions included numerically defined MSFN and spacecraft systems performance (expected and/or experienced) compared to descent targeting requirements which, you see, I have not included at all on this memo. However, they support the above conclusions substantially and could be made available to you if you want to see them. I left them out here simply because it is too complex a matter to discuss clearly in a memo such as this. What I am trying to say is that I feel these are well-founded conclusions which may be applied to both the F and G missions and we are going to press on based on them.

Howard W. Tindall, Jr.

Howard W. Tindall, Jr.

PA:HWTindall, Jr.:js

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA FPMR (41 CFR) 101-11.6

UNITED STATES GOVERNMENT

Memorandum

TO : See list attached

DATE: January 14, 1969

69-PA-T-3A

FROM : PA/Chief, Apollo Data Priority Coordination

SUBJECT: Operations required for communication loss on F and G are sure better than on C'

I think we have pretty well established how to handle a communication loss situation on the F and G missions. In effect, we have defined which Block data must be sent and what onboard cis-lunar navigation needs to be carried out. In both cases, of course, it is possible to cut back substantially from the C' techniques. This is because we feel it is reasonable to assume that the LM provides a "perfect" backup for the CSM communications.

BLOCK DATA

We established a ground rule that it is only necessary to send Block data for abort situations when either the LM is not available or if sufficient time to use the LM is not available. Following is a table of all the Block data transmissions planned for F and G giving the time of transmission for the abort opportunity which it would be used for:

Time of Transmission	Time of Abort Maneuver
During earth orbit	TLI + 90 minutes. CSM only, direct return
LOI - 15	PC + 2 for fast return following flyby
Pre LOI_1	$TEI_{1\ \&\ 2}$ assuming perfect LOI_1
Pre LOI_2	TEI_2 Update and TEI_3 assuming no LOI_2
Post LOI_2	For TEI after sleep
Pre LM Jettison	TEI 2 revs from jettison
After LM Jettison	C' rev by rev technique except during sleep

In addition, remember the crew has the capability of using the GNCS (P37) to compute their own return-to-earth maneuvers in the event of a communication loss. In order to simplify the crew's procedures, we intend to transmit a small amount of additional information for use a first guess in the operation of P37. Specifically MCC-H will periodically send the crew values of the landing area (CLA), the maneuver magnitude (ΔV), and the burn ignition time (TIG) for possible future abort times.

CIS-LUNAR NAVIGATION

As you recall on C', the onboard capability for cis-lunar navigation using P23 was thoroughly exercised and proven to be an excellent system. Furthermore, it appears that Jim Lovell was able to do his job just about as well in the beginning as he was later in the mission, indicating that inflight training is not particularly necessary. Based on this experience, only two batches of P23 star/earth horizon navigation sightings shall be scheduled on the entire F and G flights. In order to get the most from these two periods, one should be scheduled before TLI + 5 hours and the other after TLI + 14 hours, if it is convenient to do so. The advantage of making the first batch that early is that it will permit the MCC-H to make an accurate determination of the actual horizon altitude the CMP is using in order to update the CMC in real time just as we did on C'. To do this it is necessary that the observations be made in altitude less than 50,000 n.m. and preferably lower than 35,000, which is the altitude at TLI + 5 hours. I would like to point out that the horizon Jim Lovell used so successfully was sort of a nebulous one of his choice and was not well defined making it unreliable to use the "C'" horizon altitude for the F and G missions. Although not disasterous, a good knowledge of the horizon substantially improves navigation prior to entry which is when it is most important in the event of communication loss. Whatever that is.

Recognize that implicit in this plan of scheduling only two batches of observations early in the translunar coast is that there can be no independent onboard confirmation of the MSFN navigation which was considered so important to insure that we miss the moon on C'.

Math Physics Branch of MPAD has been requested to develop a P23 tracking schedule to be used for transearth navigation in the event of no communication. This schedule will be included in the Flight Plan labeled "loss of communication contingency."

As you recall, the primary purpose of onboard navigation during transearth coast was for conditioning the W-matrix. We have selected a procedure for F and G which makes it possible to eliminate that operation. Specifically, we have concluded that a crossover point exists at 30 hours before entry, which has the following characteristics. If communication has been lost prior to that time, the onboard system is capable of providing acceptable navigation, maneuver targeting, and entry initialization starting from scratch with no special W-matrix conditioning. (The flight path angle error at entry should be no greater than 0.5° under the worse conditions.) In addition, it has been shown that the MSFN will be sufficiently accurate at EI - 30 hours that in the event of subsequent communication loss there is no need to perform onboard navigation but rather the crew may safely return to earth using the data supplied for that purpose at EI - 30 by the MCC-H. In other words, the same procedure used on C' at EI - 15 will be carried out on F and G at EI - 30. Namely, spacecraft state vectors will be updated and the crew will be provided with midcourse maneuver targeting and entry pad data needed to complete the mission without further communication.

In summary, F and G operations associated with communication loss are being considerably simplified from those used on C'. Utilization of LM communications makes it possible to markly reduce the number of abort Block data pad messages; the onboard and MSFN navigation performance experienced on C' permits us to reduce onboard navigation to a total of only two batches of star/horizon observations. No special procedures are required for W-matrix initialization. I'd call that a giant step in the right direction!

Howard W. Tindall, Jr.

Howard W. Tindall, Jr.

PA:HWTindall, Jr.:js

UNITED STATES GOVERNMENT

Memorandum

EA/M. B. Faget

TO : See list below

DATE: MAR 7 1968
68-PA-T-56A

FROM : PA/Chief, Apollo Data Priority Coordination

SUBJECT: Guidance system oriented ground rules for TLI Go/No Go

1. This memo is to document the guidance system oriented ground rules we intend to apply in the development of mission techniques for making the Translunar Injection (TLI) Go/No Go decision, unless directed otherwise. Effective immediately, it is intended that all RTCC computer programs, MCC displays and decision limit lines, crew and ground procedures and timelines, mission rules, and related matters will be based on these ground rules. They represent a change from the tentative ground rules previously governing this work. Accordingly, it is important that you understand them and make your views known right now if you do not concur. This specifically applies to the "F" and "G" missions. In summary:

(a) A TLI maneuver will not be attempted if there is <u>any</u> indication that the S-IVB IU guidance system is not working properly.

(b) A properly operating CSM PNGCS is <u>not</u> mandatory for TLI. That is, it is acceptable to make a TLI maneuver with a failed CSM PNGCS if the subsequent alternate mission is considered more valuable than remaining in earth orbit.

The remainder of this memo presents the rationale for these ground rules and outlines the manner in which the guidance systems' performance may be evaluated in flight.

2. <u>Degraded S-IVB IU in earth orbit.</u>
Analysis has shown that even with a grossly degraded guidance system, the S-IVB is able to perform a TLI maneuver which would permit some sort of lunar operations. Depending on the extent of degradation the lunar operation could take the form of a hybrid (non-free return) lunar landing mission, an "F" type lunar rendezvous mission, or a lunar flyby. In all cases, the mission would certainly at least start out on a non-free return trajectory. The alternate to this is to not perform the TLI maneuver but rather to remain in earth orbit and conduct a rendezvous mission (probably "E" type) with the LM and CSM. The priority of these alternate operations is currently in the order listed above; that is, if possible, it is preferable to obtain lunar operations experience. We have discussed at

great length the extent of the IU degradation which would still permit lunar operations and it is certainly gross. For example, we are told 10° misalignment of the IU platform throughout the entire TLI may be tolerable. I note these things since previous ground rules were based on considerations of that type, but we have now concluded that they do not account for the real problem. Namely, if the S-IVB has failed to any detectable extent we would have very little confidence that it would be able to perform any sort of TLI. That is, probability of its failing completely during TLI is very great. If this were to happen we would not only lose the lunar operation, but would lose the capability of doing an earth orbital mission as well. And, on top of that, the grossly perturbated TLI would leave us in a serious non-nominal situation. These considerations finally led us to the conclusion that we should not attempt to do the TLI maneuver if there is any indication that the S-IVB IU is not performing properly.

3. There are two sources of failure indication. The first is by the S-IVB's own failure detection system which indicates failures via telemetry. The second is by comparison with the CSM PNGCS and MSFN tracking. These comparisons, it must be emphasized, are extremely gross. That is, the S-IVB IU is designed to be at least an order of magnitude more precise than the CSM PNGCS and the MSFN. Thus, these monitoring systems---telemetry, CSM, and MSFN---do not provide data to prove that the IU is performing normally but rather are only able to show us when it has degraded very badly---for example, 30 to 100 sigma! Whereas, MSFC's definition of a definitely and absolutely broken IU is anything beyond 3 sigma. Therefore, the actual limits we would select for TLI Go/No Go based on the S-IVB IU performance evaluation can only be the smallest, dependably, detectable failure. That is, we would use the smallest failure which we can confidently attribute to the S-IVB rather than the comparison system itself. Deviations in excess of that amount are certainly true S-IVB IU failures and would result in a No Go for TLI, and the alternate mission must be earth orbital.

4. CSM PNGCS failure, detected in earth orbit on the first lunar mission attempt (F or G).

If CSM PNGCS failure is detected, the options are:

(a) Perform a lunar flyby performing all midcourse corrections on the SCS and high speed reentry with the backup systems.

(b) Remain in earth orbit and perform long duration spacecraft systems tests on the command module and LM.

No LM rendezvous should be considered since command module rescue capability is not available with PNGCS failure. We would certainly not brake into lunar orbit either.

It is not clear at this time which of these options is preferable. In fact, this will probably not be known until after completion of the mission prior to the one under discussion here. However, this is not important since, as far as we could determine, there is no reason why either of these alternate missions could not be performed. For example, it was noted that we can expect the lunar flyby to be on a free return trajectory since the S-IVB is assumed to be working normally. There apparently is adequate redundancy in the SCS to be tolerant of further systems failures. Also, consideration may be given to using the PNGCS even if it has failed to the extent that the platform is drifting at the rate of 5° per hour. For example, that is just equivalent to the SCS. Indications from all knowledgeable lunar return entry people are that no crew safety problems are involved in that mission phase using the backup systems, although, of course, the spacecraft may not land as close to the recovery ships as we've become accustomed to. There was some question as to whether or not the acceleration time history during a backup, constant g entry is tolerable to the crew. All indications to date are that it is acceptable. To my knowledge, there is only one loose end to track down. And that is, is the SXT/SCT mandatory for TLI, or are alternate sighting devices adequate for guidance and control system alignment? We think they are. ? If not, the SXT will have to be checked before the burn.

5. By accepting these ground rules, it should be possible to establish a monitoring technique which would permit performing TLI on the first opportunity even for an Atlantic injection (i.e., about 100 minutes after lift off). The technique would be to compare the CSM PNGCS and the S-IVB IU during the launch phase and earth parking orbit. If this comparison is favorable, that is, to within the tolerance to be specified as described in paragraph 3, it can be assumed that both the S-IVB IU and the CSM PNGCS are performing well and we would execute TLI. If the comparison were not within those limits, one of the systems must have failed by our definition, but we have insufficient knowledge to determine which one without performing a CSM PNGCS platform alignment in earth orbit. This would be carried out as soon after the failure was detected as possible, but would certainly necessitate going another revolution and TLI could not occur until the second opportunity. If the failure turns out to be in the IU, we would not perform TLI but would carry out a CSM/LM long duration mission with rendezvous in earth orbit. If the failure is in the CSM PNGCS, we have the option (to be determined preflight) of doing TLI at the second opportunity and performing a lunar flyby, or of scrubbing TLI for that flight and remaining in earth orbit.

6. I would like to conclude by expressing my appreciation to Carl Huss and his Alternate Mission Review Panel for helping us at his February 29 "F" and "G" Lunar Mission meeting. Our last TLI Mission Techniques

meeting got stalled on top dead center in the absence of a clear understanding of alternate mission priority, among other things, and they gave us the needed push to get going again.

Howard W. Tindall, Jr.

Addressees:
(See attached list)

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA FPMR (41 CFR) 101-11.6
UNITED STATES GOVERNMENT

Memorandum

TO : See list attached

DATE: November 15, 1968
68-PA-T-252A

FROM : PA/Chief, Apollo Data Priority Coordination

SUBJECT: F Rendezvous Mission Techniques

We had our first F Rendezvous Mission Techniques meeting on November 12. We went through the whole thing rather smoothly with very few open items, probably due to all the past work on D and G. Obviously it is a much simplier exercise than the D rendezvous. This memo is to record a few of the significant agreements. Many more were reached but have been understood for some time and are not considered particularly controversial. Attached is a list of action items assigned to MIT.

1. The CSM Separation maneuver from the LM an hour before DOI shall be radially downward 2.5 fps.

2. We intend to use identical REFSMMAT in the CSM and LM. It will be computed by MCC-H at the beginning of the DOI period of activity and will not be changed throughout the entire rendezvous. In fact, it will probably be used for TEI as well. It is keyed to the pseudo-landing site and will not incorporate information obtained by later orbit determination or by optics observations of the pseudo-landing site - just like G.

3. Both the DOI and Phasing maneuvers shall be targeted from the MCC-H, of course. This will be done prior to DOI and relayed to the crew as a maneuver pair. We do not intend to update the spacecraft state vectors between DOI and Phasing from the MCC-H. However, a period of rendezvous tracking and navigation has been tentatively scheduled for about 30 minutes during that period.

4. The CSM will be targeted and counting down to make the first maneuver of a Hohmann transfer to a 20 n.m. circular orbit if the LM becomes inactive at phasing. The command module will also be prepared to execute a mirror image type maneuver when the LM executes the Insertion burn which starts its duplication of the lunar landing mission rendezvous.

5. Targeting for the Insertion maneuver will be updated in real time from the MCC-H, designed to achieve a 15 n.m. differential attitude during rendezvous. There is some question, however, if this targeting is to be based on MSFN tracking or on state vectors as determined onboard by rendezvous navigation during the phasing orbit.

6. We were not able to conclude much with regard to AGS operation since it is not clear what computer program will be available for the F mission. We hope to know what its capability will be about November 15. Of course, we are assuming that the primary guidance systems will be using COLOSSUS II and LUMINARY.

7. Just as is planned for the G mission, we intend for the MCC-H to relay the LM state vector obtained by telemetry following the Insertion maneuver back to the CSM. This will be followed by REFSMMAT alignments by both spacecraft.

8. The CSM will use its P30 series rendezvous targeting programs both for its own mirror image targeting and for relay to the LM. In order for the LM to compare solutions, it will be necessary to include certain bias on the maneuvers as determined pre-flight due to the errors induced by using P30's rather than the P70's and also because of the one minute time delay in TIG (for example, at 1.5 fps, bias is required on CSI). It is intended that the CSM backup CSI, CDH, and TPI using the SPS. Incidentally, it is intended to use LM +X RCS for CSI and +Z RCS for CDH and TPI.

9. As planned for G, we are labeling the CSM maneuver targeting as the "yard stick" for LM maneuver verification in real time. This is based on our belief that it is possible to independently verify GNCS performance in real time - something we can't do with the LM PGNCS.

10. We had our usual discussion regarding tolerable TPI time slip. It appears that with VHF ranging, the TPI window is quite large - perhaps ± 15 minutes or so. If this is the case, we should have very little problem. FCSD has accepted the task of determining just what the window is and of defining precisely the optimum location of TPI. MPAD will determine the anticipated three sigma TPI slip. The point that really counts though is that we should never have to abandon the TPI elevation angle option in favor of the time option and we are to carry out our planning based on that assumption. Incidentally, there is complete agreement that we must use two elevation angles for TPI. One for approach from above, the other from below just as was planned for G.

11. There may be some problem associated with recording LM low bit telemetry in the command module on the back side of the moon if someone really wanted to do that. It apparently conflicts with simultaneous VHF ranging which we consider mandatory. Whoever wants this data will have to look for some other substitute for a LM tape recorder, it seemed to us.

12. Our next meeting will be in a month or so. We'll firm up the tracking schedule and will list the equipment we feel required to continue

at each milestone in this exercise at that time. Something else we'll try to get squared away by then is all the "mickey mouse" required to get landing radar data at the same time we are doing the Phasing burn! And, we need to pin down the burn monitoring procedures to the Phasing and Insertion maneuvers.

Howard W. Tindall, Jr.

Howard W. Tindall, Jr.

Enclosure

PA:HWTindall, Jr.:js

MIT ACTION ITEMS FOR F RENDEZVOUS

(November 12, 1968)

1. Is the Target ΔV going to be or has it been changed from a routine (R32) to a program (e.g., P76) in LUMINARY? If not, why not?

2. What program sequence choices have we for getting landing radar data on the downlink just before the Phasing burn?

3. What program sequence should be used for the APS Insertion burn preceeded by DPS staging to insure proper RCS attitude control by the DAP?

4. What is the cost of slipping TPI execution in COLOSSUS without updating TIG?

Enclosure 1

info

UNITED STATES GOVERNMENT

Memorandum

TO : See list attached

DATE: December 9, 1968

68-PA-T-270A

FROM : PA/Chief, Apollo Data Priority Coordination

SUBJECT: F Mission Techniques - LM Checkout

On December 6 we had our first F Mission Techniques meeting dealing with pre-DOI activity. It resulted in a lot of things I never expected, since I thought the timeline and procedures for LM checkout and CSM landing site tracking were pretty well organized and acceptable with just minor tune-up. At this meeting we really shook up the world and are now looking into substantial changes in overall concept as well as changes to the detailed techniques. The two most significant proposals under consideration now involve the following:

a. There are good reasons - and a strong desire on the part of the crew - for manning and checking out the LM prior to putting on their bunny suits (PGA's). The significance of this as I understand it is that the crew feels they can perform their tasks much easier without the suits on - including moving from one spacecraft to the other quickly and easily and then suiting up at some convenient time integrated in with the other activity just prior to DOI.

b. Everyone is now seriously looking into the benefits and disadvantages of scheduling a period of LM checkout prior to DOI Day. The idea is to see if it is possible to shorten DOI Day by manning, powering up and checking out many of the LM systems, and then powering it down again prior to LOI (actually before the last translunar midcourse correction) or immediately after LOI_2 before the rest period. Of course, it must be determined that checkout carried out at this time need not be repeated after powering down the LM and that the time and energy spent during this earlier period is not too expensive. It must be emphatically stated that our decisions must be based on G mission constraints since they may be tougher to meet than the F mission. The point is that we certainly do not want to set up a special technique just for F since one of our primary objectives is to use F as a dress rehearsal for G.

If we schedule a pre-LOI period for LM activation and checkout, the configuration on DOI Day will be:

a. LM will be pressurized

b. Drogue and probe will be stowed in the CSM (any structure or c.g. problem for LOI?)

And the following system checks will have been made:

a. S-Band steerable has been checked

b. VHF - B simplex checked

c. COAS and AOT lighting checked

d. LR checked

e. LM S-Band (PRN) ranging DTO accomplished

f. Cabin regulator checked

g. DPS throttle checked

h. Oxygen purge system checked

i. RCS cold firing (requires LGC and IMU powered up)

j. Gimbal drive test (requires LGC and IMU powered up)

k. PGNCS gyro drift checked

l. PIPA gyro drift checked

m. CES rate gyro checked

n. LGC E-memory dumped and checked - and reloaded if necessary

Again, the major reason for doing this is to reduce the pre-DOI timeline since on both F and G the DOI Day has grown excessively long. Specifically, the current timeline provides about 10 hours between wake-up and the DOI maneuver. More than one-half the day is gone before they even start doing anything.

So you see quite different than my naive pre-meeting impression, we have a lot of things to do to get this thing squared away, but before we can even do that we have to get some fairly significant decisions on the two items noted above. Of course, we must do enough work to supply the data required to get these decisions, unless someone wants to arbitrarily choose our course of action. We intend to get together again on Friday, December 13 to continue our deliberation. In the meantime, we are hoping to get some opinions from around the country whether this is an insane approach or not.

Howard W. Tindall, Jr.

Howard W. Tindall, Jr.

PA:HWTindall, Jr.:js

info

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA FPMR (41 CFR) 101-11.6

UNITED STATES GOVERNMENT

Memorandum

NASA Manned Spacecraft Center

TO : See list attached

DATE: May 12, 1969
69-PA-T-76A

FROM : PA/Chief, Apollo Data Priority Coordination

SUBJECT: G mission lunar descent is uphill - all the way

Just in case you didn't know, I thought I would send you this note about some nominal G mission landing site characteristics which I thought were kind of interesting. First of all, apparently this landing site (2-P-6) is about 9,000 feet lower than the mean lunar radius. The significance of this, of course, is that all ascent and descent targeting - in fact, all lunar altitudes - are referenced with respect to the landing site radius. That is, the 60 mile circular, LOI orbit is targeted with respect to the landing site and thus is lower by 9,000 feet than you might have assumed. But more important, the insertion altitude after ascent which is nominally 60,000 feet above the landing site is really only 51,000 feet above the mean lunar surface and, of course, less than that over the bumps.

Another interesting characteristic is that the approach to this landing site is even lower. Specifically, the estimated slope of the lunar surface as the spacecraft approaches the landing site is about 1° uphill. This in itself appears to be tolerable, although it does perturb the descent trajectory a little causing the approach angle to be low - that is, toward the visibility washout direction. Something we do want to look into about this was brought out by Bernie Kriegsman (MIT) the other day. One of his computer runs showed that during the final portion of the descent trajectory under automatic control, the spacecraft would actually stop descending and would achieve a positive altitude rate prior to landing. The dispersion that caused this was a 1° slope uncertainty in the lunar datum, which when added to the aforementioned estimated slope resulted in a 2° uphill grade. We are going to have to cross-check this to see if this is really what happens. If it is, we are going to have to look in to the effect of this on how the crew would respond and how the landing radar works under this condition.

Howard W. Tindall, Jr.

PA:HWT:js

UNITED STATES GOVERNMENT

Memorandum

NASA Manned Spacecraft Center
Mission Planning & Analysis Division

TO : See attached list

DATE: JUL 1 1 1969

FROM : FM5/Lunar Mission Analysis Branch

69-FM51-194

SUBJECT: CSM lunar orbit plane change maneuver on Apollo 11

As everyone is well aware, we are trying to get as accurate an estimate as possible of the perturbations to the lunar orbit for the landing mission. The current revision to the Spacecraft Operational Trajectory is predicting a 16 ft/sec CSM/SPS lunar orbit plane change maneuver based on the current R-2 lunar potential model. This maneuver is scheduled about 4 hrs 18 mins after LM landing. However, when comparing the effects predicted by the R-2 model and the new thirteenth order potential model currently being evaluated by the Mathematical Physics Branch with the perturbations observed during Apollo 10, it appears that the plane change required may be very much less (or none at all).

The reason for all this is that on Apollo 10, it was observed that the descending node remained relatively fixed at around 0,0 selenographic latitude and longitude and that the orbital inclination tended to become more equatorial, thus moving the orbital latitude at Site 2 toward the south. The R-2 potential model predicts a northerly change of orbital latitude at the longitude of Site 2, much the same as the triaxial model. The thirteenth order model predicts an inclination change which moves the latitude in a southerly direction but overpredicts this shift by 30 to 50%.

The predicted change in inclination was $.0002^{\circ}$/rev for R-2 and 0.0251°/rev for "13,13" versus 0.020°/rev observed. This change in inclination results in an observed change in latitude at Site 2 of approximately 0.007°/rev. This would mean a plane change maneuver of around 7 ft/sec if the same $\Delta\phi$ were observed on Apollo 11.

Due to the difference in the predicted change in inclination for a May versus a July mission (0.35° versus 0.25°), the latitude change could require as little as 5 ft/sec for a lunar orbit plane change maneuver.

The best current estimate of a minimum SPS ΔV for the nominal CSM weight after LM undocking is 10.25 ft/sec based on a 0.5-second burn time and a 18-second ullage beginning 16 seconds before burn initiation. If a lunar orbit plane change maneuver required less ΔV than this minimum limit for the SPS, it would be done by the LM during ascent. Thus, it seems probable that there will not be a CSM/SPS lunar orbit plane change maneuver.

Martin D. Jenness

Martin D. Jenness

APPROVED BY:

John P. Mayer, Chief
Mission Planning and
Analysis Division

FM51:MDJenness:jrh

info

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA FPMR (41 CFR) 101-11.6

UNITED STATES GOVERNMENT

Memorandum

NASA Manned Spacecraft Center

TO : See list attached

DATE: March 7, 1969
69-PA-T-42A

FROM : PA/Chief, Apollo Data Priority Coordination

SUBJECT: G Lunar Surface stuff is still incomplete

On February 27 we held a Mission Techniques meeting which I thought was going to simply edit the "final" version of the Lunar Surface Document prior to its release. To my chagrin we discovered that there are at least two areas requiring much more thought and analysis. We will probably meet again to resolve these during the last week of March. The release of the Mission Techniques Document will have to be delayed accordingly.

Before delving into these major items, there are a couple of other things I would like to mention. The first may seem trivial. It deals with terminology - specifically, use of the expression "go/no go" regarding the decision whether to stay or abort immediately after landing on the lunar surface. Every time we talk about this acitivity we have to redefine which we mean by "go" and "no go." That is - confusion inevitably arises since "go" means to "stay" and "no go" means to "abort" or "go." Accordingly, we are suggesting that the terminology for this particular decision be changed from "go/no go" to "stay/no stay" or something like that. Just call me "Aunt Emma."

Last summer GAEC honored us with their presence at one of our meetings and to celebrate the occasion we give them an action item. We asked them how to make the tilt-over decision and to establish the attitude and rate limits for aborting. We haven't heard from them since, on that or anything else except RCS plume impingement. Don't worry, we still have four months to figure out how to do it.

I would like to emphasize that we do not want to trim residuals following the CSM plane change maneuver. It is recognized that they may be rather large since it is the first SPS undocked burn, but we would rather take them into account by adjusting the ascent targeting than by spending CSM RCS propellant.

Another thing we realized about the CSM was that we had not definitively established the attitude the CSM should maintain during LM ascent nor whether it was necessary for the MCC-H to compute the associated IMU gimbal angles.

Our biggest problem in this mission phase deals with platform alignments. Specifically, we are still not sure what sequence of alignment options should be used, although, I think everyone agrees we should use a gravity alignment for the actual ascent. The basic problem seems to stem from a lack of understanding of just how the LM Lunar Surface Program (P57) actually works and, in each case, what the torquing angles really indicate. Of course, the thing we are primarily interested in accomplishing is to evaluate the performance - that is, the drift of the IMU - in order to decide if it is working, if we should align the AGS to the PGNCS, if we should update the IMU compensation parameters, if we should lift-off on the PGNCS or the AGS, etc. Prior to our meeting at the end of March, TRW will write out in detail how they think the system actually works along with a description of how we should use it. Guidance and Control Division may do the same. Then, we will all get together with MIT to see if we can get this thing straighten out and cleared up.

Finally, our other big problem has to do with how we should handle the LM location on the moon (RLS) and the CSM state vector, particularly during the first two hours on the lunar surface in preparation for the countdown demonstration and, if necessary, ascent at the end of the first CSM revolution. The point is we will have all the data needed to determine the LM's location but we do not want to change it in the various computers (LGC, CMC, RTCC) unless we can maintain a consistant CSM state vector, too. And, it is not at all clear how we can do all that. This subject becomes another major item on the agenda of the "ides of March" meeting.

Howard W. Tindall, Jr.

Howard W. Tindall, Jr.

PA:HWTindall, Jr.:js

info

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA FPMR (41 CFR) 101-11.6

UNITED STATES GOVERNMENT

Memorandum

NASA Manned Spacecraft Center

TO : See list attached

DATE: February 11, 1969

69-PA-T-22A

FROM : PA/Chief, Apollo Data Priority Coordination

SUBJECT: G Lunar Surface Phase Mission Techniques

During the first half of 1968 we held a sequence of meetings which culminated in a proposed set of mission techniques concerning use of the guidance and propulsion systems while the LM is in the lunar surface. This was documented in a Lunar Surface Phase Mission Techniques book, dated October 6, 1968. On February 5 we reviewed these techniques with the newly selected G crews, MIT, and other organizations concerned with this business. Some changes were made, which I would like to tell you about.

Probably the most significant change deals with CSM activity during this period of time, something which most people almost completely ignore. The most important thing the command module does is to execute a plane change such that the LM ascent can be carried out essentially in-plane. The second thing the CMP does is to attempt sextant tracking of the LM on the lunar surface in order to refine targeting for the LM ascent maneuver. Our proposed plan had both of these things scheduled in the period immediately prior to LM ascent, taking almost eight hours of fairly continuous activity. The plane change was $1\frac{1}{4}$ revs before lift-off. As a result of somebody's suggestion - I think it was Buzz Aldrin - we looked into performing the plane change about $2\frac{1}{4}$ revs after the LM lands. We found that this resulted in considerable improvement in the overall operation, provided it is unnecessary for the LM to lift-off prematurely. This single disadvantage is brought about by the fact that the plane change targeting is based on an assumed LM lift-off time. The advantages are:

a. It provides a long period of stable trajectory conditions prior to the LM lift-off.

b. It makes the mission plan tolerant of slippage in plane change execution or any other CSM activity, for that matter.

c. It shortens, simplifies, and balances the periods of CSM activity better and makes them more consistant with LM periods of activity.

By moving the plane change into the landing period of activity, it is only necessary for the CMP to start LM ascent preparation about 3/4 rev before

LM lift-off. It is at that time while in darkness that he aligns his platform such that during the last pass over of the LM he may hopefully make sextant observations for MCC-H's use in targeting the ascent.

Incidentally, you will probably be interested to know that the nominal plane change for a mission carried out in July will be about 60 fps and in August about 170 fps. Although the state vectors for MSFN tracking should provide ample stability for carrying out the CSM plane change maneuver this long before ascent, it is probable that some LM yaw steering will be necessary to compensate for whatever errors propagate to lift-off time. These errors, we feel, should be well within the LM yaw steering capability. (Note: The yaw steering propellant requirement is proportional to the square of the yaw steering required; one-fourth degree costs about 5 fps, one-half degree yaw steering costs about 20 fps of APS propellant.)

Considerable time was spent discussing the insertion orbit for which we should target aborts immediately after LM landing. As you know, during powered descent, aborts are targeted for a variable insertion velocity to achieve the desired rendezvous light and ΔH characteristics. At the start of powered descent abort targeting aims for a high apogee. This is continuously decreased for aborts later in power descent until it reaches 30 n.m. apogee below which we do not care to aim. Therefore, for aborts from powered descent later than that and when first on the lunar surface we continue to aim for a 10 x 30 orbit. After passing the first go/no go approximately three minutes after touchdown the crew exits the descent programs which deactivates the "instantaneous" abort capability. Thereafter, if it is necessary to abort they must use the standard ascent program (P12). The question was - what should we aim for then? After lengthy discussion we arrived at the non-unanimous decision to target an abort at that time to the 10 x 30 orbit also. The most favorable alternate was to aim for the standard 10 x 45 which is used in the nominal mission, although in this case, you recall, it is necessary for the LM to remain in the insertion orbit for two revolutions in order to catch up to the command module before going into the standard rendezvous sequence. The primary advantage of the lower orbit is that its higher catch up rate permits spending about three more minutes on the lunar surface evaluating the LM systems and preparing for the LM lift-off if it's necessary. It also reduces probability of APS propellant depletion which is somewhat more likely in an abort since the crew has not yet gotten rid of some of the equipment which they plan to jettison on the lunar surface. We may hear some more about this decision.

The third topic consuming most of our time dealt with lunar surface PGNCS alignment. I think everyone is now pretty well satisfied that the operational alignment procedure should use the gravity vector as opposed to the

AOT since it is not only easier for the crew to perform but is more likely to provide the smaller dispersion in flight path angle - that is, it is the safer. On the other hand, it was finally agreed that AOT/star alignments should also be attempted - not only as a test of the system but also for the data they will provide for determining the location of the LM on the lunar surface. For those familiar with the various alignment options, we all finally agreed on the following sequence for both the simulated count-down to lift-off at the end of the first CSM revolution (abort) and for the lift-off at the end of the nominal lunar surface operation; the option order is 1, 2, 1, 3. (One thing someone ought to look into is whether the LM legs deflect as a result of crew movement within the spacecraft because if it does significantly change the spacecraft attitude they must be careful not to move around during these alignments. This sounds like a good action item for the FOP.)

George Cherry suggested an alternate way of stopping RCS jet firing immediately after touchdown. He pointed out that just jogging the hand controller will not necessarily immediately stop the firing and suggests instead cycling the PGNCS mode control switch to Off and then back to either Attitude Hold or preferably Auto to reset the DAP.

In summary, I would say this whole business was substantially simplified at our clam bake and is in pretty good shape right now. We have a solid plan for the crew and ground activity which everyone is satisified with. I think the only soft spot is in regard to the targeting for aborts from the second go/no go point and that should be easy to settle soon.

Howard W. Tindall, Jr.

Howard W. Tindall, Jr.

PA:HWTindall, Jr.:js

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA FPMR (41 CFR) 101-11.6

UNITED STATES GOVERNMENT

Memorandum

TO : See list attached

DATE: JUL 26 1968

68-PA-T-169A

FROM : PA/Chief, Apollo Data Priority Coordination

SUBJECT: July 9 and July 24 "G" Rendezvous Mission Techniques meetings

1. During the July 9 and July 24 "G" Rendezvous Mission Techniques meetings we have developed preliminary intra-vehicular rendezvous navigation sighting schedules. Crew work load estimates currently in use for the "D" mission rendezvous are included. These tracking schedules are very important since they have a predominating influence on almost everything else. For example, from these it has been possible to develop a preliminary spacecraft attitude time history which shows some fairly large gaps are going to be present in the CSM MSFN telemetry coverage. This, of course, is due to the fact that the S-band antenna is on the same side of the spacecraft as the sextant, which must be pointed down in order to observe the LM. Of course, during maneuvers occuring within sight of the earth, the CSM can be yawed to a heads down attitude enabling S-band telemetry coverage. The rendezvous activities do not ordinarily interfere with LM telemetry coverage.

2. The Orbital Mission Analysis Branch (OMAB) of MPAD has distributed a memo (68-FM62-217, dated July 15, 1968) which presents the revised rendezvous profile including the relative motion plots and visibility and slant range time histories. Some of the most interesting features are:

a. Insertion occurs at approximately 340 n.m. slant range. By CSI this range will have decreased to approximately 170 n.m.

b. The LM will appear to the CSM to be less than 8^{o} above the lunar horizon for the entire first two hours after insertion into orbit. After that, it will move below the lunar horizon.

c. There will be two points of sun interference for the sextant tracking of the LM, one immediately after insertion and another approximately two hours later, about 20 minutes before TPI.

3. OMAB presented the results of a study which shows that it is not possible to use the same maneuver solutions for LM maneuver targeting and CSM mirror image targeting on a lunar mission as is done on the "D" mission. Accordingly, if the CSM does not have CSI targeting capability in its computer, the LM crew will have to sequence through P72 to provide mirror image

maneuver targeting to the CSM and then P32 to target its own guidance systems. If the CSM does have the CSI targeting programs, the LM crew will be relieved of this job and will use P32 only. The CSM pilot will pick it up since the nominal procedure would call for his determination of the LM maneuver targets using P72, which he would relay to the LM for PGNCS solution comparison and AGS targeting. He would then use P32 to compute his own mirror image maneuver. It appears that the TPI time used in the P32 and P72 computations may have to be different regardless of which spacecraft does it. Since the mirror image maneuver is to be executed with a one minute time delay after planned LM ignition time, it may also be necessary to change CSI time. OMAB is looking already into this.

4. There was considerable discussion regarding initialization of the LM PGNCS and CSM G&N for rendezvous navigation. As reported previously, platform alignments by both vehicles right after insertion are now included in the timeline. Upon completion of the CSM platform alignments, the MCC-H will relay a new LM state vector into the CMC based on LGC telemetry after insertion. Even with this update, it is anticipated that the uncertainties in these state vectors will be quite large, making it necessary to use initial values in the W-matrix which will not be suitable for W-matrix reinitialization during the rendezvous sequence. The Math Physics Branch is looking into that. We ended the meeting by starting the development of some "G" mission rendezvous ground rules and working agreements similar to those developed for "D". Those we agreed to so far are attached.

5. The next meeting will be in September since many key people will be on leave during August.

Howard W. Tindall, Jr.

Enclosure

PA:HWTindall, Jr.:js

July 25, 1968

"G" MISSION RENDEZVOUS GROUND RULES WORKING AGREEMENTS
AND THINGS LIKE THAT

1. <u>General</u>

a. The reference trajectory is that provided by MPAD, dated August 15, 1968.

b. Nomenclature for the burn sequence following insertion is:

(1) CSI
(2) CDH
(3) PCI
(4) TPI
(5) TPF

c. The rendezvous will be run throughout with the vehicle roll angles $\cong$ 0°. The only exception to this is when during maneuvers within sight of the earth the CSM roll is 180°. TPI from above will be initiated "heads down" and TPI from below will be initiated "heads up" for either vehicle.

d. A LM state vector time tagged 12 minutes after insertion will be uplinked to the CMC within five minutes after insertion. State vectors are not sent to either vehicle again during the rendezvous phase.

e. IMU alignments will be made starting five minutes after insertion by both spacecraft and take precedence over the state vector update if timeline and/or attitude conflicts develop.

f. On both spacecraft all rendezvous navigation will be carried out to update the LM state vector. That is, the LM radar data will be used to update the LM state vector in the LGC and the CSM sextant and VHF data will be used to update the LM state vector in the CMC.

g. The CMC's LM state vector will be updated after each LM maneuver with the P76 Target ΔV Program using the pre-burn values as determined in the LM's pre-thrust program.

h. The state vectors in the AGS will be updated each time PGNCS is confirmed to be acceptable. This will likely be at each time it is committed to make the next maneuver using the PGNCS except perhaps TPI.

i. AGC alignments will be made each time the PGNCS is realigned and each time the state vector in the AGS is updated from the PGNCS.

Enclosure 1

UNITED STATES GOVERNMENT

Memorandum

TO : See list attached

DATE: SEP 12 1968

68-PA-T-195A

FROM : PA/Chief, Apollo Data Priority Coordination

SUBJECT: G Rendezvous

In spite of the feverish activity we have on three swinging missions C, C', and D, a few of us found a couple of minutes to spend on the G Rendezvous. Some things came out of it that are probably worth reporting:

1. As you know, on the D mission during a LM active rendezvous the command module will be targeted with mirror image maneuvers to backup the LM for CSI and CDH. These mirror image maneuvers are identical in magnitude but opposite in direction, since it has been found that the small errors resulting are a reasonable price for the simplicity we obtain in the operation. Unfortunately, when operating around the moon it's apparently not possible to use identical ΔV components for CSM mirror image targeting. This means that it will probably be necessary for the crew to first cycle through the CSI/CDH targeting program for the other spacecraft (P70 series programs) and then run through the targeting for their own spacecraft (P30 series programs).

2. For the D mission it was decided that a single TPI elevation angle could be adopted (27.5°) for all rendezvous situations. That is, either spacecraft coming in from either above or below. Unfortunately, the lunar rendezvous geometry prevents us from adopting this operational simplification and we must use different values of elevation angle depending on whether the approach is from above or below. The values we have selected (based on Jerry Bell's work) are 26.6° for the approach from below and 28.3° for the approach from above. The basic difference between these values is the phase angle between the two vehicles at TPI, which in lunar orbit is much greater than around the earth for the same separation distance. The primary reason for having to use different values is to keep the TPI maneuver along the line-of-sight. Another reason is to keep component maneuver execution time for the two vehicles the same except for differences in their navigation.

If you have any comments or questions about any of this, our next get together on the lunar rendezvous is currently scheduled for 9 a.m. on September 18, 1968.

Bill

Howard W. Tindall, Jr.

PA:HWTindall, Jr.:js

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA FPMR (41 CFR) 101-11.6

UNITED STATES GOVERNMENT

Memorandum

TO : See list attached

DATE: September 23, 1968

68-PA-T-202A

FROM : PA/Chief, Apollo Data Priority Coordination

SUBJECT: G Rendezvous Mission Techniques

If you can stand it, I would like to announce another change in the G mission lunar rendezvous timeline. In order to provide more tracking which will hopefully improve CSI targeting and to avoid bothersome real time variations of time between CSI and CDH which foul up the plane change scheduling, we propose:

a. Move CSI five minutes later - to 55 minutes after insertion which is nominal apogee. This is primarily to avoid a rather large radial ΔV at CDH.

b. Always schedule CDH one half a revolution (180°) after CSI.

c. Schedule plane changes 30 minutes prior to CDH and at CDH, as before. The LM should use the Z-axis RCS LM thrusts for the CDH maneuver (by yawing if necessary) to avoid losing RR acquisition.

d. The LM may include a plane change at CSI if the CSM has adequate sextant tracking for targeting it. Rendezvous radar only is not considered adequate.

The new timeline looks like this:

55 27 30 33
0 55 82 112 145
INS. CSI P.C. CDH & P.C. TPI

The only disadvantage we currently see is that it reduces the time between CDH and TPI to about 33 minutes. However, 33 minutes should be adequate even with dispersions and the advantages of a relatively fixed maneuver schedule and better navigation before CSI seem well worth it. It should be noted that a (hopefully small) change in the CSI targeting programs (P32 and P72) would be required to force the computer to use the 180° spacing between CSI and CDH. This can be done in either of two ways. Our preference would be to provide the crew control probably by modifying the second P32 DSKY display format to utilize the third register which is currently blank as option code. [The other two displays in this format are apsidal crossing (N) and TPI elevation angle (E).] The simplier but less flexible way of doing this job is to increase the magnitude of the parameter currently stored in fixed memory which is used in the CSI $\dot{R}$ test, which forces the logic to use a 180° transfer when the pre-CSI orbit is found to be essentially circular and apsidal crossings become ill-defined. Ed Lineberry will submit a PCR for this.

Several action items came out of our meeting as follows:

a. MPAD - It is necessary to develop a rule governing the use of the VHF data in the event no sextant data is being obtained. It is our understanding that VHF data by itself is not only inadequate, but could actually degrade the processing. If this is so, we need to establish procedures whereby the crew inhibits VHF into the CMC when sextant data is not available.

b. MPAD - It is our proposal that the CSM be the prime source of targeting the plane change maneuver regardless of which spacecraft executes it. This is because the sextant is potentially more accurate than the rendezvous radar for this particular purpose. Here again a rule is needed to define how much sextant data is needed to target the plane change maneuver as opposed to using the rendezvous radar solution.

c. MPAD - We came to the conclusion at the last meeting that it was not possible to use the same maneuver solution for CSM mirror image targeting as the LM uses for burn execution. This meant the crew would have to cycle through two programs rather than just one. On further thought, it seems as though we can avoid this extra complexity, which is really rather serious. I am sure we can for the CDH burn and it seems probable that something can be done for the CSI burn too, particularly since it's constrained to be horizontal. Accordingly, we have requested OMAB to re-examine this procedure to see if we can't clean it up. We must also determine whether one minute delay in the mirror image targeting is really a requirement since these are RCS burns and problems at TIG don't appear to be too likely.

d. ASPO - Milt Contella repeated a rumor that the rendezvous radar may have random error in the shaft angle measurement when the line-of-sight from LM to CSM is close to the lunar surface. We must find out what the true situation is as quickly as possible and start figuring out some workaround procedure to be added to all the other ones.

Odds and Ends

We are assuming that the CSM will backup the LM CSI and CDH maneuvers using the SPS; it is probable, however, as on the D mission, that it will backup TPI with RCS. We have also concluded that the CSM should not backup the plane change since that requires yawing out-of-plane and disrupts tracking between CSI and CDH. Of course, if it is known that the LM will not be able to perform the plane change maneuver, the CSM will do it at that time. If the LM and CSM both fail to perform the plane change 30 minutes before CDH, the CDH plane change will force the node near TPI and so in that event the plane change will be taken out during the TPI burn targeted with R-36 to force a new node 90° after TPI time. This, of course, is a departure from the nominal TPI plan which calls for forcing the node at intercept (TPF).

That's it!

Howard W. Tindall, Jr.

Howard W. Tindall, Jr.

PA:HWTindall, Jr.:js

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA FPMR (41 CFR) 101-11.6

info

EAS/P.H. Deans

UNITED STATES GOVERNMENT

Memorandum

TO : See list attached

DATE: October 25, 1968
68-PA-T-236A

FROM : PA/Chief, Apollo Data Priority Coordination

SUBJECT: CSI and CDH back into the AGS - maybe

Apparently the TRW AGS people have done a good job of putting the new rendezvous radar navigation filter into that dinky computer. In fact, they now estimate a surplus of some 80 words.

One of our brilliant ~~young~~ engineers here in MPAD - Ed Lineberry - has developed a simple technique for computing the CDI and CDH rendezvous maneuvers provided the CSM orbit is near circular as it should be on the G mission (reference MPAD memo, 68-FM61-318, dated October 15, 1968, subject: Linearized solution for CSI and CDH for a multiple-half-orbital-period transfer between maneuvers!). In fact, he expects that it could be fit into the aforementioned 80 words. He and Milt Contella have already discussed this with the TRW people who are looking it all over. If things go well, he expects they will come to the Software Configuration Control Board with the proposal to include it in some future AGS program and we can decided at that time if that is the best way to use our little 80 word Christmas present.

I wrote this because that idiot Ed Lineberry is too darn modest to tell anybody and I thought you might find it interesting.

Bill

Howard W. Tindall, Jr.

PA:HWTindall, Jr.:js

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA FPMR (41 CFR) 101-11.6

UNITED STATES GOVERNMENT

Memorandum

NASA Manned Spacecraft Center

TO : See list attached

DATE: May 12, 1969
69-PA-T-77A

FROM : PA/Chief, Apollo Data Priority Coordination

SUBJECT: Manual Steering for LM Ascent

Over the years various groups have attacked the problem of if and how the crew can manually steer the LM back into orbit from the lunar surface. These studies were started before GAEC was even selected to build the LM and some analysis is still going on to define the optimum pitch attitude profile, which should be used in this mode. On May 8, I invited representatives of the MSC groups I knew had been involved in this business to a discussion - the purpose of which was to pin down just what the status is today. We were also interested in determining if something useful could be done between now and the G mission. In summary, I think we all agreed that:

a. We should certainly not count on a manual operational backup mode for lunar ascent in the same sense that manual modes backup some other critical mission phases such as rendezvous targeting, burn control, etc. However, it's better than nothing and we ought to be prepared to do something.

b. Without a rate command attitude control system, it is extremely doubtful they could achieve orbit even if they had trained thoroughly in the technique. (Currently there is <u>no</u> training planned for the G crew.)

c. There are some things we should and will do before the G mission to prepare for this contingency, since it is an unfortunate fact that there are apparently quite a variety of two-failure combinations that can put us into this serious situation.

One of the first impressions you get when you start looking into manual ascent is that the procedures which should be used are strongly dependent upon the character of the system failures. That is, there are many different combinations of failures, each of which should be handled in a different way. As a matter of fact, the multiple-procedure-sets idea, combined with the low-probability-of-occurring idea has probably been the major reason we haven't got this whole thing all worked out in detail now. However, Jack Craven has finally convinced me the situation is not that remote and a worse situation can hardly be imagined. Furthermore, our discussion leads me to believe that these multitude of procedures don't really present an insurmountable problem that can only be resolved in real time. I get the feeling that the "variation in procedures" which come about from many of the component failures is primarily a reconfiguration of spacecraft switch settings and the crew procedures probably aren't too different than for the nominal ascent itself. Of course, in that case the MCC must be prepared to advise the crew exactly how the spacecraft should be configured to best support ascent in one of these degraded modes. It was interesting to find that the method which must be used for the next level or class of failures essentially boils down to the following few options:

a. Prior to lift-off, some sort of initial azimuth reference must be chosen such as a prominent landmark or probably the LM's shadow on the lunar surface. Immediately after lift-off, the crew would yaw the spacecraft to place the LPD line on the shadow prior to initiating pitchover, after which a landmark to aim for could be selected by the crew in real time.

b. After manual "Engine Start", the crew would hold the vertical rise pitch/roll attitude for 15 seconds. They would then pitch the spacecraft in accordance with pre-selected four step pitch profile. These angles are essentially known today both:

(1) In inertial coordinates for use if a spacecraft inertial reference system is available and

(2) In a relative coordinate system - that is, the overhead window marks which should be held on the lunar horizon.

c. Propellant depletion should probably be used as the "Engine Off" technique and it is recommended that the interconnect not be used for attitude control since APS propellant is marginal to start with and should be utilized exclusively for getting into orbit. The "Engine Off" command could possibly be issued manually using the DEDA output of ΔVX provided the AEA and x-axis accelerometer are functional but probably shouldn't be.

This procedure, which essentially targets the spacecraft to the nominal insertion altitude and flight path angle most likely will result in a large dispersion in velocity, which of course would foul up the subsequent rendezvous. At least it provides the greatest chance of achieving orbit at all and probably minimizes the dispersions to give us a reasonable whack at rendezvous.

It is evident the two things that the crew needs to do on this job are an attitude reference and an attitude control mode. I was very interested to find that if we constrain ourselves to talking about pure manual as opposed to the various levels of degraded automatic ascent modes, we really came out with a very short list of candidates for these two things. Specifically for attitude reference, we have the following:

a. If the CES is broken, but the AEA, ASA, FDAI, and needles are available, they provide an excellent attitude reference. In fact, in this case, the crew should fly the needles as opposed to the four step pitch profile noted previously since they are driven by the actual ascent guidance error signal. (Unfortunately, it probably means having to fly in Direct Attitude Control - heaven forbid!)

b. If only the LGC is broken, we can use the IMU and GASTA driving the FDAI to provide a good inertial attitude reference if we can align it somehow (caging, probably) and can figure out how it is aligned.

c. The overhead window has been especially configured for use with the horizon during ascent, which fortunately is sunlit throughout the nominal ascent. (A sunlit horizon is not always available for descent aborts or lift-off immediately after touchdown.) Spacecraft pitch is controlled using the horizon and window marks; spacecraft yaw utilizes the horizon tilt and roll (that is, azimuth) must use some landmark as noted previously.

Those are all the choices we could think of for an attitude reference if automatic control has been lost. Furthermore, we found there are only three manual attitude control modes, which I will list in order of preference:

a. If a PGNCS accelerometer is broken, it is possible to use the LGC, IMU gyros, and hand controller to obtain a DAP rate command mode.

b. If the ASA and/or AEA is broken, it is possible to use the ATCA, rate gyros, and hand controller to obtain a rate command mode.

c. The rotational hand controller (ACA) can be used in either of two Direct Attitude Control modes, both of which are probably unacceptable. They are four jet - 12° (hardover) and two jets - $2\frac{1}{2}^{\circ}$.

Following is a list of things we are going to do:

a. MPAD/TRW will recommend the final angles - inertial and horizon - to be used for carrying out the four step pitch profile.

b. FCSD will check with the crew to determine if they want to add these numbers into their checklist along with the nominal attitude profile check points they have already, or if they want to leave this for a real time voice relay from the MCC.

c. Clark Hackler and Jack Craven are going to develop a complete matrix defining the preferred spacecraft configuration and capability remaining for degradation or failure of each component. This should be done by the first week in June. Incidentally, something along this line has apparently been worked out by GAEC already.

d. I am going to see if it possible for some experienced pilot, preferably Pete Conrad, to run a few simulations of some of these manual abort modes, particularly to evaluate using the overhead window attitude reference with the three rate command and direct attitude control modes noted above.

In mid June, we will set up a Mission Techniques meeting on this subject with world-wide participation - particularly MIT, TRW, and GAEC - to see where we stand at that time. Considering the catastrophic nature of the situation under discussion here, it seems some effort is certainly justifiable to get prepared. I would recommend that it be an effort equivalent to manual TLI steering. In other words, a blank check. Everyone at MSC and particularly the prime crew can spend full time on it, if they want to. And, I currently plan to have a Mission Techniques document prepared specifically for it, too - prior to G.

Howard W. Tindall, Jr.

PA:HWT:js

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA FPMR (41 CFR) 101-11.6
UNITED STATES GOVERNMENT

Memorandum

NASA Manned Spacecraft Center

TO : See list attached

DATE: May 6, 1969

69-PA-T-71A

FROM : PA/Chief, Apollo Data Priority Coordination

SUBJECT: Ascent newsletter

This memo is to report several interesting things regarding lunar ascent, both nominal and after a descent abort.

1. It turns out we demand better performance of the PGNCS to support ascent to orbit than we do descent. Accordingly, if it is necessary to abort during descent due to degradation of the PGNCS, it is automatically necessary to switchover from the PGNCS to the AGS. Of course, this assumes that the AGS is performing better than the PGNCS.

2. We have recently had a running philosophical argument regarding ascent switchover. Of course, switchover in itself is not catastrophic as is an abort; if the system you switch to is working okay, the mission continues just as planned. This led me to push for establishing fairly tight switchover limits since I felt that it was highly desirable to assure as near nominal rendezvous characteristics as possible. That is, why stick with a degraded PGNCS if the AGS is working better? The only disadvantage seems to be the hazard involved in the act of switchover itself; all the switches, relays, and so forth have to work. In other words, it comes down to a tradeoff between the hazards involved in switching over versus the dispersions in the rendezvous situation which could be avoided by switching over.

More recently we have adopted a procedure for eliminating dispersions at insertion following descent aborts by making an adjustment maneuver immediately after insertion. This so-called tweak burn is used specifically to assure satisfactory rendezvous conditions. This procedure may also be used to compensate for degradation of the PGNCS during ascent and makes it possible to leave the PGNCS in control as long as it is still capable of providing a safe orbit. However, if the PGNCS degradation is sufficient to justify it (say, worse than 3 sigma) the crew should be advised of the situation during powered flight such that they will stand by for a tweak burn to be executed immediately after insertion using the same procedures as for the descent abort.

Having adopted this technique, it seemed reasonable to set the PGNCS switchover limits fairly wide. The value chosen was 6 sigma. The compromise here, of course, is the operational messiness of a tweak burn traded off against the switchover to AGS "hazard."

3. One thing which could give us bad trouble is a misaligned PGNCS prior to ascent, particularly if we align the AGS to it as was planned. The problem, of course, is that small misalignments can result in unacceptable insertion conditions and, even though ground monitoring would probably detect the situation during ascent, switchover would do no good since the AGS would be equally misaligned. To avoid this situation entirely, we have concluded that the best course of action is to independently align the AGS while on the lunar surface rather than to align it to the PGNCS. This makes the two systems truly independent, which not only gives us a cross-check on the accuracy of the alignment of each but also permits a useful switchover if somehow a PGNCS misalign escapes our detection techniques. Incidentally, this also eliminates the problem of CDU transients in the AGS lunar surface alignments. Accordingly, we are proposing that the procedures be changed to always utilize the AGS gravity lunar surface alignment technique rather than alignments to the PGNCS. I expect this will be done once some details have been worked out.

4. It is interesting to note that the problem just discussed is not quite as severe in the event of a descent abort. In that case, of course, the AGS must have been aligned to the PGNCS and so they both will suffer the same misalignment at PDI. What happens then if we have a descent abort and try to achieve orbit with both systems misaligned? It turns out that this particular error is partially compensating - that is, the trajectory dispersion during descent is partially eliminated by the trajectory dispersion during ascent back into orbit. In addition, the descent abort limits will be tight enough that unacceptable dispersions should not occur prior to descent. In other words, we feel we have a safe situation here.

Howard W. Tindall, Jr.

Howard W. Tindall, Jr.

PA:HWTindall, Jr.:js

info
Mission "G"

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA FPMR (41 CFR) 101-11.6

UNITED STATES GOVERNMENT

Memorandum

NASA Manned Spacecraft Center

TO : See list attached

DATE: July 7, 1969

69-PA-T-104A

FROM : PA/Chief, Apollo Data Priority Coordination

SUBJECT: Manual Ascent revisited

On July 2 we had another meeting regarding Manual Ascent. As I have pointed out previously, the consensus is that the crew should have an excellent chance of achieving a safe orbit by manually steering the LM from the lunar surface if they have a rate command attitude control system by using the horizon view in the overhead window as an attitude reference. The two primary facets we discussed this time were:

a. What sort of ground support could be provided to the crew during powered flight and

b. What sort of rendezvous sequence would be pursued following the LM insertion.

This memo is to summarize the results of this session. Briefly though - the ground assistance can be substantial and the rendezvous can be a fairly standard CSM rescue requiring one or two extra revs.

As you recall, the flight controllers on the ground have a substantial capability for monitoring the LM's trajectory during powered ascent, even with the guidance systems broken, providing the RTCC powered flight processor (the "Lear") is working. This program provides a complete up-to-date state vector to drive the analog and digital displays in the control center. As a result it is possible for the Flight Dynamics Officer (FDO) to monitor the ascent trajectory continuously and to discern deviation from the nominal. For example, by monitoring the altitude vs. downrange distance plot and the velocity vs. flight-path-angle plot, he will be able to advise the crew if the radial velocity (altitude rate) becomes unacceptably dispersed. Specifically, starting about three and a half or four minutes into ascent, after the trends are well established, he should be able to advise the crew to bias the remainder of their pitch profile up or down probably using 2° increments. Given this assistance, it is anticipated that the crew should insert with a nearly nominal flight-path-angle.

It is also possible for the FDO to assist the crew in maintaining a near nominal out-of-plane velocity. That is, once the crew has keyed their initial launch azimuth on their shadow and then aimed for a prominent landmark (such as the south rim of Crater Schmit for landing site 2), the

FDO will call out 2° north/south (or left/right) attitude changes whenever his digital display of out-of-plane velocity exceeds 50 fps. This vectoring of the crew can start very soon after lift-off if necessary.

A major problem we feel we have now resolved has to do with when the crew should shutdown the APS. Analysis has shown that a continuous pitch angle bias of 2° can result in an unsafe perigee unless the APS is run to propellant depletion. Therefore without ground vectoring, as noted above, we feel it is advisable to permit the APS to operate until propellant depletion; a 2° bias does not appear to be out of reason for manual steering using that weird lunar horizon as a reference. However, given ground assistance in attitude control a propellant depletion cutoff will certainly result in an excessively high apogee, which makes the rendezvous situation more difficult and costly. Accordingly, we propose that as long as the ground monitoring of the trajectory indicates that it is reasonably close to nominal, the FDO will voice command engine "Off" when his display of safe velocity (V_s) equals zero. (Briefly, V_s is the ΔV required to assure a 35,000 feet perigee at the current altitude and flight-path-angle.) A call at this time, assuming a 15 second delay, will produce an overspeed of about 300 fps yielding about 200 miles of excess apogee which should be adequately safe. The important thing is that it protects against apogees in excess of 250 n. mi. (which have been regularly occurring in simulations). Although these high orbits can be handled, there seems to be no reason to accept them. In this same vein, analysis has shown that we have been unduly conservative in proposing use of the RCS propellant for attitude control during ascent. We now feel confident that it is safe to stick with the nominal procedure of using APS propellant for attitude control during manual ascent and saving the RCS for whatever comes next.

Just about any failure combination which makes it necessary to perform a manual ascent will also demand a CSM rescue sequence. The sequence which seems to suit the situation best is as follows:

a. CSM performs a phasing burn (NC1) on the LM's major axis "maneuver line" approximately one rev after LM insertion.

b. CSM will perform CSI $\frac{1}{2}$ to $1\frac{1}{2}$ revs after NC1 depending on how high the LM apogee turns out to be.

c. CSM performs CDH $\frac{1}{2}$ rev after CSI.

d. CSM performs TPI at nominal elevation angle which should occur about midpoint of darkness.

e. Braking can be done by the LM and/or CSM at the crew's discretion, based on the real-time situation.

f. Plane changes should be handled in the standard way - that is, combined with the other CSM maneuvers and with the extra plane change burn between CSI and CDH performed by the CSM if it is necessary. (It is to be noted that any large out-of-plane situation must almost certainly be due to a velocity error at insertion and not an out-of-plane position error.) This would cause the node of the orbital planes to fall near the major CSM burns such that most of the plane change required would be efficiently combined with them. Given control center assistance in ascent steering though, a large out-of-plane situation seems unlikely.

To insure that even a very low insertion orbit can be handled, it was decided to bias the LM lift-off late, approximately three and one-half minutes. Specifically, the FDO will compute a LM lift-off time consistent with a 10 mile circular insertion orbit and a nominal rendezvous sequence. However, since it is most desirable to utilize the sequence noted above rather than having to make rendezvous maneuvers soon after insertion if a low orbit is achieved, we feel the best course of action is for the LM crew to be advised to make whatever ground computed maneuver is required at insertion to achieve an orbit equivalent to at least 10 x 30 n mi. orbit. That is, if they truly burn out very low, they should boost their orbit with RCS to permit use of the CSM rendezvous sequences noted above. Incidentally, they will also be advised to make an apogee maneuver to pull up perigee to about 16 n. mi. as a safety measure in any case.

If for some reason the LM does not achieve a safe orbit with or without the control center assistance noted above, we still have a straw to fall back upon. The flight controllers have the capability immediately after insertion of computing a maneuver to insure at least a 35,000 feet perigee based on the Lear Processor. This maneuver will be scheduled at three minutes after APS shutdown or at apogee, whichever is required. It is to be noted that ample RCS should be available to execute this maneuver.

Although we have nowhere nearly the same confidence of success, procedures have been established for the crew to execute manual Descent Aborts. The problem here, of course, is that a single pitch attitude time history cannot be established for aborts occurring at any time in powered descent. However, the necessary work has been done by MPAD and TRW to provide the flight controllers with an acceptable pitch profile as a function of abort time in powered descent using the horizon attitude reference which would provide a safe orbit if the crew were to follow it. Accordingly, if communications are retained or regained after a descent abort, the crew can be informed of a pitch profile to follow to achieve orbit.

One other item we discussed was the relative merits of flying a completely manual ascent vs. a completely automatic ascent using the AGS with a broken z-axis accelerometer. You recall in this event it would be necessary to fly the LM into orbit on its side in order to place the broken accelerometer in the out-of-plane direction and bring the good y-axis accelerometer into plane to provide the automatic AGS capability. If the AGS works, everything should be just fine, but the crew will be unable to monitor its performance which leads to consideration of a completely manual ascent with its horrible overspeed problem. However, given ground monitoring we feel confident that a malfunctioning AGS can be detected and it is our strong recommendation that it be used. If the control center detects an unacceptable failure, the crew would be advised to yaw in-plane and proceed into orbit using the standard manual ascent technique.

Howard W. Tindall, Jr.

PA:HWT:js

MAY 1962 EDITION
GSA FPMR (41 CFR) 101-11.6

UNITED STATES GOVERNMENT

Memorandum

NASA Manned Spacecraft Center

TO : See list attached

DATE: June 19, 1969
69-PA-T-94A

FROM : PA/Chief, Apollo Data Priority Coordination

SUBJECT: Ascent with busted guidance and control systems

On June 11 we had a Mission Techniques meeting to discuss manual ascent from the lunar surface. The term manual ascent, though, is somewhat misleading since most of our discussion had to do with how the guidance systems should be operated if certain of its components failed prior to ascent. In summary, I think everyone generally agrees that:

a. Given a rate command attitude control system, the crew should be able to guide the spacecraft into orbit quite satisfactorily using the horizon viewed through the overhead window as his attitude reference. The resultant orbit will be far from nominal which could present rendezvous problems, but at least we feel fairly confident he can get into orbit. Manual steering in the "Direct" attitude control mode is considered pretty hopeless in the sense that it is probably impossible to control the spacecraft at all - not in the sense that the insertion conditions are not acceptable.

b. Both the AGS/CES and the PGNCS have a substantial capability, even if the accelerometers are broken. However, special procedures are required to utilize this capability.

c. Gyro failures virtually wipe out the system with the possible exception of the rate gyros in the AGS/CES package.

The rest of this memo just adds a little detail to the above summary if you are interested.

<u>Pure Manual Ascent using rate command and the horizon</u>

Since our last meeting, Paul Kramer and Chuck Lewis have set up and run a series of simulations using CES rate command and the overhead window, which I understand were generally quite successful. They are in the process of documenting their results, so I suggest you contact them if you are interested. Briefly, they found that using the four step pitch profile MPAD/TRW has recommended works very well. They also found that it is possible to use the pitch angles in the current checklist that the crew uses to monitor a nominal guided ascent. These angles are tabulated for each 30 second time-hack. They found that letting the APS run to propellant depletion always resulted in an excessive overspeed - that is, yielding apogees up around 400 miles or so which suggests that it may be desirable to use the interconnect during manual ascent just as during nominal, thereby using APS propellant rather than RCS for attitude control. I expect we will all agree this is the right thing to do. Due to simulator limitations, they used the initial FDAI as an azimuth reference. It was the consensus of those at the meeting that if the inertial reference is not available, as could easily be the case, an acceptable alternate is for the crew to yaw the spacecraft during vertical rise to place the LPD line on the LM shadow. Given this initial launch azimuth as a reference, they should be able to choose prominent features downrange to head for in real time. In addition to the horizon angles, as viewed through the overhead window, corresponding angles as displayed on the FDAI are also available for the crew's use if an inertial reference is available. The reason we place greatest emphasis on the horizon is that it will always be there and a good FDAI may not be.

<u>PGNCS with accelerometer failed still provides attitude hold rate command and FDAI</u>

As well as anyone can determine, there is no reason why the PGNCS IMU cannot be aligned even with accelerometers broken. Of course, the gravity align is out, but it still should be possible to use the LM body attitude option and the AOT two star sightings option (alignment techniques 0 and 2). The accelerometers will cause program alarms but the alignment programs should still work. In either case, we would recommend aligning the IMU to the standard nominal REFSMMAT. No special procedures are required for this and the crew would be provided a perfectly nominal FDAI display.

Of course, no navigation or automatic guidance can be carried out without the accelerometer, but it still should be possible to get a rate command attitude, hold control capability provided we are able to manage the digital autopilot (DAP) in the LGC properly. Of specific concern is what special inputs, if any, are required to take care of vehicle mass as the ascent progresses. You recall, the LGC decrements mass as part of its DAP function but without PIPA's it won't. This also had some impact on which program the LGC should be operated in during ascent. It was our impression that the standard Ascent program (P12) is preferable. Alternates suggested were the Average G program (P47) or the Idling program (P00). MIT was assigned the action item of advising us precisely how we should handle the mass in the DAP and which program was best from their viewpoint. One thing, reasons for preferring P12 is that the PGNCS might offer a redundant Engine-On capability as well as a more favorable attitude deadband. If the PGNCS is used with a broken accelerometer, the crew should follow the standard four step pitch profile and fly to propellant depletion as noted above.

PGNCS-LGC failed leaves only an attitude reference - maybe

If the LGC has failed, it is impossible to realign the IMU. This presents two choices, if the alignment is known and favorable at the time of LGC failure, it may be desirable to leave it alone. If that is not the situation, it is possible to cage the IMU thereby aligning it to the LM body axis, which may provide a useful reference if the LM has landed in a fairly level attitude with the z-axis close to in-plane. Obviously if the LGC has failed, the only capability the PGNCS can possibly offer is an inertial attitude reference since attitude control and navigation demand a functional LGC.

AGS y or z accelerometer failed - AGS can still go "Auto"

If either the y or z-axis accelerometer is broken, it is impossible to do a lunar surface gravity alignment. However, it is possible to align the AGS given two AOT star sightings and ground assistance to compute the LM body attitude. Given the star data, the MCC will compute and relay to the crew both the LM and CSM state vectors in the AGS coordinate system assuming a body axis alignment (DEDA entry 400 + 50,000). It will be based on the assumption the crew will select initial guidance (DEDA entry 400 + 10,000) at precisely two minutes before lift-off. By zeroing the bias and scale factor coefficients in the AGS computer for the failed accelerometer, it is possible to use automatic AGS steering into orbit with a guided cutoff. Of course, no out-of-plane steering will result since the spacecraft will always be oriented such that the broken accelerometer is oriented out-of-plane.

If it is the z-axis accelerometer which is broken, it would be necessary for the LM to fly into orbit on its side. It is instructed to do this by loading the so-called W_B (Addresses 514, 515, 516) as relayed from ground to arm the W_B (DEDA entry 623 + 10,000). It may be possible to load a pseudo bias to compensate for the $1\frac{1}{2}^o$ APS engine cant angle. There is a real trade-off to be made here between using the manual guidance noted above with a resultant overspeed or to fly the automatic AGS guidance with the LM on its side. The crew would be unable to monitor its performance but, if it works as advertized it would produce good insertion conditions for the subsequent rendezvous.

If AGS x accelerometer is broken a good inertial reference is all that's left

If the AGS x accelerometer is broken, it is possible to perform a lunar gravity alignment using the standard procedures associated with broken PGNCS/good AGS. In this case, we are assured of a good initial attitude reference for use in flying the pitch profile, but the automatic guidance and navigation is completely lost by the AGS.

AGS/CES with a rate gryo broken

No one is able, at this time, to say whether or not the AGS can fly completely automatically with a rate gyro disabled. It is suspected that rate feedback is required to provide a stable system but we are not sure. Accordingly, some runs are planned on the GAEC facilities with the RGA disabled to see what happens. If it can't handle it, the crew will have to fly Direct in the channel with the broken rate gyro using the error as a reference. This will also be simulated.

One major open item coming from all this is how we should play the rendezvous game given any of the situations here. Specifically, should we bias the lift-off time either late or early to give more time to do the rendezvous or to put the command module behind the LM at insertion? Should some CSM maneuver be made prior to or immediately after launch? A number of people will think about this and we'll probably get together in the next couple of weeks to lay out some plans since this is just as important as knowing how to get in orbit in the first place.

In all of the above cases a number of action items were identified, primarily dealing with establishment of precise procedures for initialization of the systems. It is expected that the necessary information should be available within a few weeks so that we can document all this before the G flight.

Howard W. Tindall, Jr.

Howard W. Tindall, Jr.

PA:HWT:js

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA FPMR (41 CFR) 101-11.6

UNITED STATES GOVERNMENT

Memorandum

NASA Manned Spacecraft Center

TO : See list attached

DATE: April 8, 1969

69-PA-T-56A

FROM : PA/Chief, Apollo Data Priority Coordination

SUBJECT: Some things about Ascent from the moon

On April 3 we had an Ascent Mission Techniques meeting - the first in a long time. This memo is mostly to express some rather general observations.

I guess we all recognize that Ascent is really different from most other maneuvers in an Apollo lunar landing mission. It is one in which fairly small dispersions in the guidance can create an unsafe situation either by setting up an imminent lunar impact or poor conditions for carrying out the subsequent rendezvous, or by running the APS out of propellent. Accordingly, special efforts have been spent in trying to set up techniques for monitoring and detecting dispersions of this type onboard the spacecraft so that the crew can switch over from the PGNCS to the AGS in hopes of correcting the degrading situation. Of course, in a case of an obvious failure like the platform turned upside down, or something, the crew should have no problem in knowing they should switchover. However, I am confident that they will not be able to detect insidious, slow drift malfunctions of a magnitude, which could be catastrophic, in time to save the mission. The techniques which have been proposed for this are not sure-fire, even if executed to perfection. And, they are so complex that I seriously doubt the crew, with their limited training, would ever learn to use them with enough confidence that they would switchover from the PGNCS to the AGS even when it was necessary. If my assumptions are correct, then it seems we must recognize that the ground is not only <u>prime</u> for detecting and advising the crew of slow drift malfunctions but, in fact, MCC is virtually the only source for this. This in turns means that if the MCC loses hi-gain S-band telemetry there will be no drift malfunction monitoring carried out and we will simply have to trust that the PGNCS is working. Off-hand, that does not strike me as an unacceptable situation since we only get in trouble if communications are lost <u>AND</u> the PGNCS fails insidiously.

Another thing we must face up to is that we do not have a manual backup for Ascent Guidance and Control. Unlike the rendezvous, where crew charts provide an excellent capability to press on in spite of guidance system failures, no such capability exists for backing up Ascent. It is true that techniques have been studied and proposed, some of which might possibly work. However, the fact is that we do not have a workable technique in hand today, and even if we did, it certainly could not be considered operational unless the crew were thoroughly trained in its use. And, that they certainly will not be. Here again, this situation strikes me as no worse than "unfortunate."

So much for general observations. Following are a few specific items coming from our discussion:

a. I would like to re-emphasize that like most other maneuvers in the Apollo mission, lift-off must occur on time. We are not planning for some sort of launch window. Accordingly, if in counting down to Ascent TIG the crew falls behind for some reason, the lift-off should be delayed one CSM rev and the trouble that caused the tardiness should be cleaned up. For example - one test for determining whether it is possible to lift-off or not is the PGNCS alarm coming on at about TIG -40 seconds, indicating average g will not be turned on at the right time and the PGNCS will not be ready for lift-off.

b. In the event the PGNCS displays a ΔV Thrust Monitor Alarm after the APS engine actually comes on, the crew should stick with the PGNCS which should be holding attitude until they have determined that the PGNCS is not going to control the spacecraft properly such as yawing it to the proper launch azimuth and pitching over as programmed. When these various cues have all confirmed lack of PGNCS guidance, the crew should switchover to the AGS without attempting to recycle the PGNCS first. Of course, before switching over to the AGS they should ascertain that it is working better than the PGNCS. To do this we recommend that the nominal display for initial ascent on the AGS DEDA should be altitude rate ($\dot{H}$). Following switchover, recycle attempts should be made to clear up the ΔV monitor alarm in an attempt to get the PGNCS back on the air.

c. In order to provide redundancy for the "Engine On" signal, procedures call for manually pushing the "Engine Start" switch. It is to be emphasized, however, that this should be done only after the crew determines that the LGC "Engine On" command has caused the engine to start. We do not want to lift-off if the PGNCS is not issuing commands. Of course, in order to get an automatic guidance engine cutoff at insertion, this manual Engine Start signal must be removed. The procedure calls for doing this when the velocity remaining to be gained is about 200 fps (i.e., about 10 seconds to go). Immediately preceding setting the "Engine Arm" to "off" the interconnect should be closed. If removing the "Engine Arm" does turn off the engine, the crew should use the same switch to turn it back on. Of course, they will then have to stop the engine again when the velocity displayed by the PGNCS reaches nominal.

d. We have no procedure for monitoring and backing up the PGNCS "Engine Off" command like those used for TLI, LOI, DOI, and TEI. Due to RCS attitude control activity during Ascent, the burn time can vary as much as 20 seconds from nominal, which makes that a useless parameter for this purpose. The AGS and the rendezvous radar range rate are potential candidates, but it was finally decided that rather than adopt some complex voting logic involving those systems, the best technique was to simply utilize the ground monitoring to determine which system should be used to control the Ascent Guidance and to use whichever system is guiding as the sole cue for APS cutoff. That is, as long as we are riding the PGNCS, let it do the job and back it up manually only if it indicates the spacecraft has exceeded the desired velocity. If a switchover to AGS has occurred, then use the AGS as the sole source. It seems to us that, since this maneuver is always in sight of the ground, a procedure like this is acceptable. Of course, it depends on not losing telemetry.

Howard W. Tindall, Jr.

Howard W. Tindall, Jr.

PA:HWTindall, Jr.:js

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA GEN. REG. NO. 27

5010-107

UNITED STATES GOVERNMENT

Memorandum

TO : See list below

DATE: MAR 4 1968
68-PA-T-48A

FROM : PA/Chief, Apollo Data Priority Coordination

SUBJECT: Ascent Phase Mission Techniques meeting - February 27, 1968

1. In the absence of Charley Parker, our beloved leader, I inherited the job of chairing this meeting which probably accounts for why we didn't really get an awful lot done. However, there are a couple of things that are probably worth reporting.

2. We discussed the importance of the "stage verify" discrete to the spacecraft computer. Apparently, its sole purpose is to initialize the DAP such that it may perform properly. For example, it stops sending steering commands to the DPS trim gimbals. It also changes the spacecraft mass used in DAP operations from the ascent stage, plus whatever remains of the descent stage, to ascent mass only. Based on this information it computes jet firing duration for attitude control differently, of course. I had been concerned that failure to get this signal during Ascent would cause poor attitude control and we are initiating a program change request to back up "stage verify" with the "lunar surface flag" since whenever that event occurs use of the ascent stage only is a certainty. Jack Craven (FCD) pointed out that due to the design of the system the much more probable failure is to get a "stage verify" signal prematurely. If that happened, when we are still operating on the DPS, it would stop DPS steering and would make the RCS attitude control extremely sluggish. That would be bad news! All that is required to do this is for either of two relays to inadvertently open.

3. As you know, we are planning to devote a short period of time immediately after landing on the lunar surface to checkout of critical systems. This would be done both onboard and in the MCC leading to a GO/NO GO for one CSM revolution (about 2 hours). This is exactly the same sort of thing as the GO/NO GO for one revolution following earth launch. Jack Craven accepted the action item, which I had previously discussed with Gene Kranz, to establish how long it should take to do this systems check in order that we may make all other mission planning and crew procedures consistent. It is expected to be in the order of 3 minutes, unless it takes a long time to really detect an APS pressure leak. Until the GO/NO GO we intend to remain in a state from which we can instantly "abort stage" and go. After that it will take much longer.

4. Almost all the rest of our discussion dealt with what the command module should be doing during and immediately following LM ascent from the lunar surface. One unresolved question was whether or not the command module should attempt to observe the LM ascent with the sextant. It was not clear what purpose would be served other than more rapid acquisition for rendezvous navigation tracking after insertion. It seemed to us the most important thing, of course, was for the command module to take whatever steps are necessary to assure getting a good LM state vector in its computer for rendezvous maneuver targeting as soon as possible. It seems almost certain that we should load the nominal LM insertion state vector in the CMC from the ground prior to LM ascent to guard against subsequent communication breakdown. It was also agreed that we should probably prepare the MCC to automatically take the LM post-insertion state vector from the LM telemetry and transmit it back to the command module. Whether we would actually do this or not depends on whether we lose more by forcing the command module to stay in the Uplink Command program (P-27) thereby preventing rendezvous tracking and onboard navigation for a substantial period of time. That is, analysis may show that with good VHF ranging and/or sextant tracking the command module may be able to converge on an acceptable LM state vector better without this ground participation, if it gets going more quickly.

5. I guess I am attacking the old "MIT me" in stating that we are seriously handicapped by having no reliable definition of the Luminary lunar surface and ascent programs (e.g., GSOP Chapters 4 and 5). I understand review copies of these should be available within 3 to 6 weeks and I am sure nothing can be done to speed them up. We'll eat'em raw when they get here!

Howard W. Tindall, Jr.

Howard W. Tindall, Jr.

Enclosure
List of Attendees

Addressees:
(See attached list)

ATTENDEES

E. E. Aldrin	CB
E. B. Pippert	CF
C. T. Hackler	EG
J. B. Craven	FC
E. L. Pavelka	FC
D. Beggs	FM
H. W. Tindall	PA
R. Boudreau	TRW
P. Hanna	TRW
J. R. Henson	TRW

Enclosure 1

Addressees:
CA/D. K. Slayton
CB/A. B. Shepard
J. A. McDivitt
E. Aldrin, Jr.
N. Armstrong
F. Borman
M. Collins
C. Conrad
R. Gordon
J. Lovell
R. L. Schweickart
D. R. Scott
T. P. Stafford
CF/W. J. North
C. Jacobsen
CF13/D. F. Grimm
CF2/J. Bilodeau
CF22/C. C. Thomas
CF24/P. Kramer
M. C. Contella
D. W. Lewis
CF3/C. H. Woodling
CF34/T. Guillory
T. W. Holloway
E. B. Pippert
EA/M. A. Faget
EG/R. A. Gardiner
D. C. Cheatham
EG2/M. Kayton
C. T. Hackler
EG23/K. J. Cox
E. E. Smith
EG25/T. V. Chambers
EG26/P. E. Ebersole
EG41/J. Hanaway
EG42/B. Reina
KA/R. F. Thompson
PA/G. M. Low
C. H. Bolender
K. S. Kleinknecht
PA2/M. S. Henderson
PD/C. E. Maynard
PD12/J. G. Zarcaro
R. J. Ward
R. W. Kubicki
M. H. von Ehrenfried
PD4/A. Cohen
PD6/H. Byington
PD7/W. R. Morrison
PD8/J. Loftus
PE7/D. T. Lockard

FA/C. C. Kraft, Jr.
S. A. Sjoberg
C. C. Critzos
R. G. Rose
C. Kovitz
FC/J. D. Hodge
E. G. Kranz
D. H. Owen
D. B. Pendley
FC2/J. W. Roach
FC3/A. D. Aldrich
G. E. Coen
G. D. Griffin
FC4/J. E. Hannigan
R. L. Carlton
J. B. Craven
J. Elliott
FC5/G. S. Lunney
J. S. Llewellyn
J. C. Bostick
C. B. Parker
C. E. Charlesworth
S. L. Davis
C. F. Deiterich
W. E. Fenner
G. E. Paules
E. L. Pavelka
W. S. Presley
H. D. Reed
P. C. Shaffer
FL/J. B. Hammack
FS/L. C. Dunseith
FS5/J. C. Stokes
T. F. Gibson, Jr.
J. E. Williams
G. R. Sabionski
TH3/J. E. Dornbach
FM/J. P. Mayer
C. R. Huss
M. V. Jenkins
FM13/R. P. Parten
E. D. Murrah
J. R. Gurley
A. Nathan
FM4/P. T. Pixley
R. T. Savely
FM5/R. E. Ernull
R. Berry
FM6/B. Becker
FM7/S. P. Mann
D. Beggs
R. O. Nobles
FM/Branch Chiefs

Bellcomm (Hqs.)/R. V. Sperry
G. Heffron
GAEC (Bethpage)/J. Marino
MIT/IL/R. R. Ragan
NR (Downey)/M. Vucelic
D. Zermuchlen
TRW (Houston)/R. Boudreau
W. Fox
J. R. Henson
P. Hanna

PA:HWTindall, Jr.:pj

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA FPMR (41 CFR) 101-11.6

UNITED STATES GOVERNMENT

Memorandum

TO : See list attached

DATE: JUL 18 1968

68-PA-T-161A

FROM : PA/Chief, Apollo Data Priority Coordination

SUBJECT: LM Ascent lift-off time can be determined by the crew

Some months ago we submitted a PCR to remove the pre-Ascent targeting program (P10) from Luminary and this was done. This action was based on an assumption that a simple crew procedure could be developed for doing the same job, in the event of loss of communications, making the rather complicated computer program unnecessary. The Lunar Mission Analysis Branch of MPAD has concluded their development and analysis of this technique and is in the process of documenting it. It is only necessary for the ground to supply two parameters by voice to the crew prior to DOI which will allow them to independently determine lift-off time to within about six seconds. This dispersion takes into account current estimates of MSFN accuracies, etc. The effect on the rendezvous differential altitude due to this error is less than one mile, which is certainly far smaller than other dispersions which would occur in a non-communication situation. In other words, it is more than adequate.

Quite simply the procedure requires that the crew determine the time of closest approach of the CSM one pass before lift off by noting the time rendezvous radar range rate passes through zero on the tape meter. To that time, he must add the CSM orbital period and another ΔT to obtain lift-off time. These are the two parameters included in the pre-DOI pad message noted above which will be determined by MCC-H based on the actual CSM orbit.

Howard W. Tindall, Jr.

PA:HWTindall, Jr.:js

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA FPMR (41 CFR) 101-11.6

UNITED STATES GOVERNMENT

Memorandum

TO : See list attached

DATE: JUL 1 8 1968

68-PA-T-159A

FROM : PA/Chief, Apollo Data Priority Coordination

SUBJECT: No 15 minute constraint for Lunar Ascent Guidance

The Luminary GSOP indicates that it is necessary for the astronaut to call up the Ascent Guidance Program (P12) at least 15 minutes prior to lift off. This, of course, is not consistant with our desire to be able to use P12 if we get a No Go for lunar stay approximately 10 minutes after landing. In that case, we intend to call up P12 with less than seven minutes to go before lift off. By checking with MIT, we have verified that the 15 minute limit is not a real constraint and that the only limit is the time required for the crew to go through the operations associated with P12, which is currently estimated to be less than five minutes. (Simulations will eventually refine this, probably to a smaller value.)

I have asked MIT to modify their GSOP (by PCN) to reflect this.

Howard W. Tindall, Jr.

PA:HWTindall, Jr.:js

UNITED STATES GOVERNMENT

Memorandum

TO : See list attached

DATE: JUL 16 1968

68-PA-T-151A

FROM : PA/Chief, Apollo Data Priority Coordination

SUBJECT: Lunar Ascent preparation

1. At the July 3 Lunar Ascent Mission Techniques meeting we cleaned up the last of the main open items for the phase of the lunar landing mission from LM touchdown to liftoff. We are now ready to go to press for that part of the mission and will hold a world-wide review of it before the end of the month.

2. Most of the discussion was devoted to establishing the CSM timeline prior to LM Ascent. Much to my surprise, the CSM requires about eight hours (four orbits) to prepare for LM Ascent. Involved is all of the work associated with determining the position of LM with respect to the CSM orbit and with making a plane change if it is necessary. Time required for the LM to get ready is less than two and one-half hours unless rendezvous radar tracking is required. In that case, the LM crew would have to start powering up the PGNCS about three hours before liftoff, in order to track the command module during its last pass overhead. It is necessary for either the command module to track the LM on the lunar surface using the sextant or, if that is not possible, for the LM to track the command module using the rendezvous radar. The data thus obtained is required to target the CSM plane change or the LM Ascent. In the timeline that we settled on, the sextant tracking of the LM would be done three revolutions (approximately six hours) before Ascent and the CSM plane change, if it is required, would be performed one and one-fourth revolutions (approximately two and one-half hours) before liftoff. If the command module pilot is unable to track the LM with the sextant it will be necessary for us to target the command module plane change based on MSFN tracking and navigation, realizing that that the resultant CSM orbit may be as much as 0.3° away from the LM position as a result of MSFN inaccuracies. It is only in this event that we would require the LM to track the CSM with the rendezvous radar to obtain the data the ground would use to determine the out-of-plane steering the LM should execute during Ascent. It is only in the event that the command module is unable to track the LM that both the command module plane change and LM Ascent out-of-plane steering would be performed.

3. The other thing we firmed up was the logic defining when to use the command module SPS to make a pre-Ascent plane change vs. yaw steering

the LM into the command module orbit during Ascent. The rule we established was that if the LM is less than half a degree out of the CSM orbital plane, the LM would take care of it during Ascent at an APS propellant cost of approximately 19 fps. If the plane change required is greater than half a degree, the command module would be used. Thus, the minimum SPS burn would be 50 fps. The maximum should be no more than 200 fps, depending on the location of the landing site and the inclination of the plane. These limits represent burn times between three and thirteen seconds.

Howard W. Tindall, Jr.

PA:HWTindall, Jr.:js

UNITED STATES GOVERNMENT

Memorandum

TO : See list attached

DATE: September 26, 1968

68-PA-T-208A

FROM : PA/Chief, Apollo Data Priority Coordination

SUBJECT: Unusual procedure required for LM Ascent from the moon

Jack Craven surprised us with a little jewel the other day during the Lunar Surface Mission Techniques meeting. He says that in order to enable the APS engine-on and staging commands from the LGC, it is necessary for the crew to depress (now get this) the Abort-Stage button! That is, depressing this button must be part of the standard countdown procedure to LM liftoff.

Alternately the crew can manually arm the engine which permits them to send the engine-on command manually, but it does not enable the LGC signal. Furthermore, if they do this, it is necessary for the crew to also send the engine-cutoff signal manually since the signal from the LGC is inhibited.

Howard W. Tindall, Jr.

PA:HWTindall, Jr.:js

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA FPMR (41 CFR) 101-11.6

UNITED STATES GOVERNMENT

Memorandum

NASA Manned Spacecraft Center

TO : See list attached

DATE: May 28, 1969

69-PA-T-82A

FROM : PA/Chief, Apollo Data Priority Coordination

SUBJECT: Descent, Lunar Surface, and Ascent Mission Techniques with the H crew

On May 20 and 21 we reviewed Descent, Lunar Surface, and Ascent Mission Techniques with the H crew (Pete Conrad and co.). This get together had two major objectives - to tell the H crew how we think these things should be done and conversely, for the first time to get a flight crew reaction to the techniques since in the main, they have been firmed up too late to review thoroughly with the G crew. In general, I think we are in pretty good shape on this stuff although there are, of course, the inevitable open items and questions we never seem able to rid ourselves of completely.

It was interesting to note that the H crew seems desirous of cutting back some of the activities the G crew considered worthwhile. There are also obvious philosophical differences in their attitude regarding the use of the automatic systems vs. a more manual mode. Conrad seems much more inclined to stay with the automatic system longer than Armstrong as well as insisting that they work. For example, he does not propose to continue in the face of no landing radar data, whereas Neil apparently feels he can substitute visual data for it. Some other interesting examples are:

a. Pete would like to drop out all the visual observations of the lunar surface, both before and after PDI including the LPD altitude checks.

b. Pete would like to substitute a landing radar altitude check prior to PDI.

c. Pete wants to do PDI face up. (Hallelujah baby!)

d. Pete also wants to drop the crew voice report of their estimate of where they actually landed.

It might be worth reporting some other interesting things resulting from our discussion:

a. We probably ought to add in some sort of AGS drift check pre-PDI after the PGNCS alignment check using the sun.

b. There is still a controversy over when we should switch to the AGS. Some feel it should be done only if the PGNCS is degraded to a point where it can't make a safe orbit; others feel we should switch-over as soon as it is certain the AGS will do a significantly better job than the PGNCS.

c. The decision has been firmly made that the crew will not manually backup the automatic landing radar antenna position switch.

d. There is still some work to be done in establishing procedures in the event the GDA failure light comes on late in descent. Early in descent, I think everyone agrees the crew must await secondary cues before deactivating the GDA. There may be some advantage to immediately turning it off if the light comes on late in descent in that it may be possible to complete the landing using RCS attitude control only.

e. It was suggested that some sort of VHF ranging check could be done while the LM is on the lunar surface, perhaps during the last over-pass prior to LM ascent or even during the ascent itself. We will have to look into this to see if it is practical and useful.

Given the longer lunar stay of the H mission, it is clear the guidance system must be turned off to conserve electrical power. This has obvious implications on how the system should be used just after landing and just before lift-off. We have also decided to throw out the simulated countdown for lift-off at the end of the first CSM rev. As a result of these and other things, I have asked TRW to revise the Lunar Surface Mission Techniques and we will review them with everyone when they get done.

Howard W. Tindall, Jr.

Howard W. Tindall, Jr.

PA:HWT:js

AMR

info

UNITED STATES GOVERNMENT

Memorandum

NASA Manned Spacecraft Center

TO : See list attached

DATE: July 16, 1969

69-PA-T-111A

FROM : PA/Chief, Apollo Data Priority Coordination

SUBJECT: Change in delayed PDI Descent targeting procedures

This probably doesn't amount to a gnat's elbow to you, but I would like to change something in a memo that I just sent out the other day dealing with spacecraft state vector updating if we delay PDI one rev. Previously we planned to leave the state vector in the LM computer alone but to change the landing site position (RLS) to account for propagation error for the extra rev. Since then there has been a big flap brought about by our discovery that the command module is making uncoupled attitude maneuvers which cause surprisingly large perturbation to the orbit. In order to minimize these effects in the descent targeting for the delayed PDI situation, we have concluded that it is best to redetermine the LM state vector based on the newer MSFN tracking (revs 12 and 13) and uplink it to the LM if PDI is delayed. Since the RLS already has been compensated properly for the associated propagation errors, it does not need to be changed.

Howard W. Tindall, Jr.

PA:HWT:js

info

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA FPMR (41 CFR) 101-11.6
UNITED STATES GOVERNMENT

Memorandum

NASA Manned Spacecraft Center

TO : See list attached

DATE: July 11, 1969
69-PA-T-106A

FROM : PA/Chief, Apollo Data Priority Coordination

SUBJECT: Descent Data Select procedures are finalized

On July 7 and 8 we held a final review of the Data Select procedures and Flight Controller interface during the Descent phase of the lunar landing mission. This lengthy memo is to describe briefly some of the items discussed, all of which are being thoroughly documented before the flight.

On F, as you know, John Young did not track the center of the Landing Site 2 landmark - a crater designated "130" - but rather used a much smaller crater on the rim of 130. He did this primarily because it was much easier to do and, he thought, would improve the accuracy. It is planned to use this smaller crater, which has been called "130 Prime," on the G mission also, and the RTCC is set up to do so. However, it was emphasized that we must also be prepared to use the old "130" if for some reason lighting makes it impossible for Mike Collins to acquire "130 Prime."

It was strongly emphasized by the Data Select people that they should be in the high-speed mode for Lear filter initialization and conditioning at least four minutes before PDI. If for some reason they are delayed past this point, their confidence in the system will be degraded. In fact if initialization is delayed until 20 seconds before PDI - the drop-dead point - they feel they will have no confidence in the system throughout descent at all.

Analysis of the F flight data has revealed that the Lear processor for some reason gives best results when using three tracking stations rather than four, which it was originally set up to use. Accordingly, it will be operated in the mode where the fourth station's data are available but are excluded from the solution. If one of the three active sites fails during descent, the Data Select people will immediately replace it with the previously excluded site. If it is concluded that the failed site will not be restored quickly, another site will be called up immediately to provide backup for a second failure. It is to be emphasized that bringing up this new station is to provide a backup and an opportunity to observe its data. It will not be actively used unless another site breaks down or the performance of the Lear processor unexpectedly becomes degraded in a manner consistent with poor station location geometry which the new station could help correct.

The Data Select people reviewed their real-time procedures for declaring the "Lear filter is go" as follows:

a. During the free-flight processing after going into the high-speed mode at PDI minus four minutes, they plot and compare Lear results with their best estimate of radius and altitude rate based on previous MSFN tracking and a confirmed DOI maneuver. If these parameters differ by more than 3,000 feet and 13 fps, respectively, the Lear is considered uncertain.

b. During powered descent they have doppler comparison plots for each of the individual MSFN sites vs. the PGNCS. These are used to sort out a bad station.

c. They monitor Lear output plots of altitude, altitude rate, pitch, and LM mass rate of change looking for discontinuities, internal incompatibilities, smoothness, etc.

d. The Lear filter displays an estimate of its own performance - residuals, rate biases, and so forth. A particularly strong indicator of performance is the residuals of the fourth (excluded) site, which is not included in the solution.

During the Descent briefing to the management people, a week or so ago, Chris Kraft proposed that some sort of inflight lunar orbit checkout be made of the Lear Processor prior to Descent. After lengthy and sometimes emotional discussion, we have concluded that it is most advantageous to use the same tracking stations and communication lines as during descent. To do this we must perform the test on either the first or second lunar orbits before the Madrid station is lost due to earth's rotation. It was also concluded that to perform this test in the on-line RTCC computers with the active third floor MOCR was too risky. Accordingly, the proposal is as follows. Configure the network stations to transmit high-speed data for a period of 15 minutes during the first lunar rev when the spacecraft is more-or-less over the landing site. Log the data in the control center and then play it through a third, off-line computer utilizing the second floor MOCR display system. Since no compatible G&N telemetry will be available at this time, it will be impossible to operate some of the displays such as the guidance officer strip charts. It will be possible however to make a realistic, useful comparison of the Lear output with the other MSFN processing to see that this system is working properly end-to-end - from spacecraft to display system in the MCC. Mike Conway (FSD) is responsible for assigning personnel to do this and for getting the control center configured for the test. He also intends, if possible, to get some simulated data and practice this test before the flight. I think the consensus is that this test is like airline flight insurance - a small waste of resources with very little chance of gain; however, it can pay off real big, if we're lucky!

Another question answered was, What spacecraft position should be used for initialization of the Lear Processor in preparation of the T_2 lift-off? ("T_2," you recall, is the delayed abort time shortly after landing associated with the second stay/no-stay decision.) The problem here is that very little time is available to assess the descent tracking and telemetry data in order to select the best estimate of the actual landing site location. We finally concluded that the best solution was to use the preflight nominal value - the one computed from the F mission tracking.

One very significant item resulting from our meeting dealt with reconfiguring the MSFN tracking network after a T_2 stay decision. It had been planned to keep all stations in the same configuration as during descent in order to support a lift-off one rev later (T_3) if that turned out to be necessary. Unfortunately this leaves only two tracking stations with very little geometry on the command module which produces two substantial disadvantages. First, the command module state vector hasn't been updated since before DOI and it's getting kinda worn out and yet it is the one which would have to be used in support of a T_3 launch and rendezvous. Probably more significant is the effect on the nominal mission, namely it is intended for the CSM to track the LM with the sextant at the end of that first rev. It is anticipated that this data will provide the best estimate of LM position on the lunar surface in support of nominal ascent targeting as well as post-flight analysis. In fact, we intend to use this RLS determination in preference to any of the other RLS sources unless there is some reason to suspect it is screwed up. However, for the sextant data to be useful we must have an accurate CSM state vector to reference the sextant data too. This requires better MSFN tracking than had been planned. Accordingly, it was decided that immediately after a T_2 stay decision, the Ascension station would be reconfigured for CSM tracking on the remainder of the descent rev and for the next rev too. It will only be switched back to the LM in the event of a T_3 no-stay decision.

The problem of determining LM position (RLS) to support a T_3 launch is a tough nut to crack. Our choices are based on powered flight navigation by the PGNCS, AGS, and Lear adjusted after touchdown with an improved estimate of LM position at PDI. It is anticipated that the LM's AOT/gravity alignment data will not be available in time to support the Ascent targeting although if everything goes just right it might be. The point is that none of these data sources have ever been used before and each has its own potential problems that could foul it up badly. This makes its unreasonable to assign hard and fast priorities to these sources today, although everyone agrees that the Lear should probably be the best. The point is, determination of RLS for T_3 is being left open to real-time judgment of the experts who will include whatever bits of intelligence are available during the flight to select the best value. As noted before, the CSM state vector and sextant tracking will normally be used for the nominal ascent, but it obviously won't be available for a T_3 launch.

We discussed the PGNCS reinitialization required if PDI is delayed one rev. It was finally decided that virtually under no circumstance would the state vectors in the PGNCS be updated even though later tracking data is available. The values of RLS will be updated by applying additional propagation biases to account for the extra rev. The exact procedure for doing this is too complicated to put in this memo but I believe it is understood by everybody involved.

And that's that!

Howard W. Tindall, Jr.

PA:HWT:js

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA FPMR (41 CFR) 101-11.6
UNITED STATES GOVERNMENT

Memorandum

NASA Manned Spacecraft Center

TO : See list attached

DATE: July 3, 1969

69-PA-T-103A

FROM : PA/Chief, Apollo Data Priority Coordination

SUBJECT: Some new ideas on how to use the AGS during Descent

This memo is to fill you in on a couple of late crew procedure changes proposed for the G mission regarding AGS operation during descent. The first is a technique to prepare the AGS for immediate ascent which can be used to quickly reinitialize the AGS LM state vector immediately after touchdown if there is any concern that the navigation during descent has fouled them up somehow. This is possible since the LM state vector on the lunar surface can be easily predicted before descent. Specifically, it involves loading some storage location through the DEDA just after the final state vector update from the PGNCS at about seven minutes before PDI. The numbers loaded would be the lunar radius (240 + 56923) and the lunar rotation (262 - 00150), which essentially constitute the entire state vector on a lunar surface. The rest of the state vector elements (241, 242, 260, 261) are all loaded zeros. None of these addresses are used during descent or descent aborts so this procedure does not conflict with anything planned. The idea is that immediately after touchdown, when the lunar surface flag is set, the crew would key in 414 + 20,000 instead of updating altitude as currently planned. This would initialize the AGS state vector with these quantities quite accurately to support an immediate ascent. This procedure is supposed to be brought to the Crew Procedures Change Control Board very soon, but I noticed that Buzz Aldrin was already doing it during the Descent simulations last week.

Everyone I have talked to feels it is a good thing to do provided it does not overload the crew.

The second possible addition to the crew timeline involves making use of the AGS DEDA display just after touchdown to provide the crew a little more information regarding his touchdown attitude condition. Bob Battey called me with a Braslau suggestion (AGS/TRW) that, since the DEDA is not used during the terminal descent, immediately after touchdown it is possible to call up address 130, a component of the transformation matrix, which is essentially the cosine of the tilt angle displayed in octal. It was noted that this parameter has an interesting characteristic. If the spacecraft is perfectly vertical, the DEDA will read 40,000. If the spacecraft is tilted 42°, which is the critical tilt angle, the DEDA will read just under 30,000 regardless of the direction of tilt. Display above

30,000 is okay - the bigger, the better - and below 30,000 is bad news. This convenient crossover value seems to make this a possible extra cue for the crew to quickly assess whether the spacecraft has tilted more or less than the critical tilt-over angle. So far, none of the experts I have spoken to have seen anything wrong with this idea and generally consider it a desirable thing to do. That is, the procedure should work and should provide some useful intelligence for the crew, if they get into a suspected tilt-over situation. It could certainly not be considered mandatory and so the decision as to whether to do it or not to do it rests entirely on the crew's task loading during the last several hundred feet of descent. Simply, should the crew be fooling with the DEDA at this time? Ordinarily I would say no, but Buzz seems to be able to get music from that little mommy with his head turned off and both hands tied behind him.

Howard W. Tindall, Jr.

Howard W. Tindall, Jr.

PA:HWT:js

UNITED STATES GOVERNMENT

Memorandum

NASA Manned Spacecraft Center

info

TO : See list attached

DATE: April 16, 1969
69-PA-T-64A

FROM : PA/Chief, Apollo Data Priority Coordination

SUBJECT: How the MSFN and sextant data are used to target DOI and Descent

We had a meeting on April 9 which was extremely interesting to me. We discussed and settled on how the MSFN tracking and sextant landmark observations would be used in the MCC/RTCC to produce optimum DOI and Descent targeting for the LM. The big new factor that had to be taken into account somehow was the propagated state vector errors resulting from our inaccurate modeling of the lunar potential. This has forced us to change our planned techniques somewhat from those proposed before the C' mission. Most of what we now plan to do is just as the Math Physics Branch (MPB) of MPAD proposed to us at this meeting. I feel they should be commended for a pretty fair piece of work.

I would first like to describe the manner in which MPB proposed that the RTCC orbit determination consistency checks be made during the flight. As you recall, in a previous memo I noted that they feel it is best to use the orientation of the orbital plane determined pre-LOI to which they add the in-plane orbital elements based on new MSFN tracking. Of course, it is necessary to continuously monitor and confirm that the plane established in this way is right. They intend to do this by performing single-pass MSFN solutions after each lunar orbit and comparing the resulting inclination with that established pre-LOI. It is expected that the single-pass solutions will show a random variation about the pre-LOI value indicating it is safe to continue using it. If they detect a bias or trend in these single-pass inclinations away from the pre-LOI value, they will have to update it.

In addition to the inclination check performed continuously, they also plan some discrete consistency checks made in revs 6, 7, and 8. These checks will be made by processing MSFN tracking just as will be done later for the DOI and Descent targeting. That is, they will determine the orbit based on rev 3 and 4 data and propagate it to rev 6. They will make a "plane-free" single-pass solution in rev 6 based on rev 6 tracking. They will compare the three position components in local vertical coordinates (that is, downtrack, altitude, and crosstrack) at 20 minute intervals throughout rev 6 and will plot the differences vs. time. These plots should show the propagated error from the older solution as a function of time throughout rev 6. They will do the same thing using revs 4 and 5 data propagated to rev 7 and compared with a single-pass rev 7 solution. They will do the same thing with revs 5 and 6 propagated to rev 8. These position difference plots determined for revs 6, 7, and 8 will be superimposed upon each other to make sure there is consistency on determination of propagated state vector errors. This consistency, incidentally, has been demonstrated on C' and we expect to reconfirm it on the F mission prior to G. If it works as expected, it should be possible to determine the propagated error in all three components as a function of time on a state vector propagated ahead two revs. The significance of this, of course, is that the DOI and descent targeting is performed with a state vector which is two revs old and if we are able to determine the propagation error, bias may be applied to compensate for them. That is a description of a rather complicated process. The important thing for you to understand is that a technique appears to be available for determining and compensating for propagation error in real time.

The manner in which we intend to use sextant tracking of the landing site has not changed since before C'. That is, we intend to determine the landing site position by applying the measured relative displacement in all three components - latitude, longitude, and radius - to the current MSFN solution at the time of the sextant observations. Thus, the targeting solves the relative problem compensating for errors in both MSFN state vectors and the preflight estimate of the landing site location. We have established that the change from the preflight value in each of these components based on the real time data must not exceed the following values:

a. Latitude must not be changed more than 12,000 feet.

b. Longitude must not change more than 6,000 feet.

c. Radius must not change more than 6,000 feet.

These values are based on our current 3 sigma estimates of preflight map accuracy RSSed with the MSFN orbit determination accuracy. It is felt that corrections larger than these must indicate some sort of gross failure demanding either that the sextant tracking be redone by delaying DOI one rev or that the sextant tracking be ignored and the Descent targeting be based on the preflight values. Incidentally, the mission rule defining which of these choices to pursue is a significant open item which must be resolved.

Now I would like to describe how the propagated errors are compensated for.

a. Crossrange, which is essentially latitude, will not be compensated for propagation errors at all. Since we are using the frozen plane technique, by definition, no propagated error can occur.

b. Error in spacecraft altitude is compensated for by changing the radius of the landing site by an amount equivalent to the propagated state vector error in the altitude direction. The empirical correction is determined from the propagation state vector plots described above by reading out the error in altitude associated with a time in orbit equivalent to touchdown time. The point is that the state vector is <u>not</u> corrected, but rather compensation is applied to the landing site radius since this is a much cleaner procedure.

c. Downrange error is more-or-less equivalent to landing site longitude and presents special problems. Consideration was given to compensating downrange propagation errors by changing landing site location in a manner similar to the radius bit just discussed. That would work fine for Descent, but can result in a serious problem in Descent aborts. Specifically, downrange error in the state vectors during powered flight act in a way equivalent to a platform alignment error in inertial space. Specifically, 10,000 feet downrange error is equivalent to 0.1° IMU misalignment. Therefore, if we were to leave the propagated downrange error in the state vector, all powered flight by the inertial guidance system would be carried out with 0.1° error and, in the event of a Descent abort, would cause the system to aim for the wrong insertion conditions by that amount. Of course, the AGS, which is initialized from the PGNCS would also have this error. Although we don't expect the downrange error to exceed about 5,000 feet, we have no assurance of this and conservatively feel that an alternate approach for compensating downrange error is preferable. The alternate approach we adopted is to change the time tag on the state vectors such that the downrange error at touchdown time is zero. Changing a state vector time tag is not a simple thing to do in the RTCC. It has not yet been "automated." As a result, it is necessary for the Data Select Officer to manually enter the entire state vector into the RTCC using his typewriter like input device. This is a time consuming process because it must be very carefully checked. (It is recognized that the RTCC program for the lunar landing mission has been frozen, but it was suggested to the Data Select people that they consider automating this input since it is becoming part of the nominal operation.) It is to be emphasized that this time tag compensation is applied to both the LM and CSM state vectors in all three computers - RTCC, LGC, and CMC. We may eventually establish a lower bound in this downrange compensation below which it is considered acceptable to live with the error. For example, if the downrange error is less than 5,000 feet, we may choose to apply that small correction to the landing site longitude and leave the state vectors time tag alone since that is a much simpler thing to do. But that's not the current technique.

One significant open item I failed to mention in passing is that there is still a controversy raging on whether a single-pass or two-pass MSFN orbit determination should be used for Descent targeting. That is, the sextant tracking is done on rev 11 and the MSFN tracking on that rev is certainly used. The question is, should rev 10 MSFN tracking be incorporated in as well? The solution to this depends on ironing out inconsistencies between two computer programs which are given conflicting results. The answer could come at any time. Once the one-rev vs. the two-rev decision is reached, of course, it will not only apply to orbit determination techniques for Descent targeting but will also be incorporated in the MSFN propagation error determination techniques described above.

It is currently planned that these G mission operations will be carried out on the F mission exactly as if that flight were a lunar landing. This obviously means that to the maximum extent possible these techniques will also be used in the F mission simulations. There is some question, however, if changing the state vector time tag to compensate for propagated downrange error is a reasonable thing to do on the F mission. Accordingly, this must be discussed with the F mission operations people before we naively assume they will do it.

Much of the preceding discussion deals with the landing site location to be used in the LGC during Descent. The landing site position (RLS) to be loaded in the command module computer should be the preflight map values of the prime landing site landmark and there is no reason to go through this "mickey mouse" of updating the CMC values from the MCC before the LM lands.

The time tags on the state vectors transmitted to the spacecraft computers on G are essentially the same as on the F mission. The LM state vector sent to both the LGC and CMC will be time tagged at DOI -10 minutes. The CSM state vector sent to both spacecraft will be time tagged at PDI + 25 minutes, which should be close to the initiation of rendezvous navigation in the case of a late Descent abort.

Except for the open items noted above, I think this pretty well establishes how we plan to do the targeting for DOI and Descent on the lunar landing mission, at least until F mission results come in.

Howard W. Tindall

Howard W. Tindall, Jr.

PA:HWTindall, Jr.:js

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA FPMR (41 CFR) 101-11.6

UNITED STATES GOVERNMENT

Memorandum

NASA Manned Spacecraft Center

TO : See list attached

DATE: May 15, 1969

69-PA-T-78A

FROM : PA/Chief, Apollo Data Priority Coordination

SUBJECT: Some "improvements" in the Descent preparation procedures

As we wade deeper and deeper into Descent Mission Techniques, one thing coming into focus is that, of all IMU error sources, the two that hurt the most are accelerometer bias and y-axis (pitch) misalignment at PDI. Having recognized this, we are now proposing some specific procedures to minimize them. This memo is to tell you all about it in some length, I'm afraid.

There is no better test bed for determining accelerometer bias than a spacecraft in orbit. Any output from an accelerometer is bias and procedures have been well established for monitoring, selecting, and updating the accelerometer bias compensation terms in the LGC. On flights prior to G, the practice has been to establish a threshold below which the compensation would be left alone and above which it would be updated from the MCC. Many of us now feel, and I am proposing that on the G mission, it should be standard procedure prior to DOI for the MCC to update accelerometer bias compensation terms in the LGC routinely, regardless of how good or bad the currently stored values are. The threshold is zero.

Pitch misalignment is a little bit tougher. May I first just state some facts to build on?

a. The current Mission Techniques provide only a coarse IMU drift check by comparison of the docked IMU alignment at DOI - $2\frac{1}{2}$ hours to the undocked AOT alignment performed at DOI - $\frac{1}{2}$ hour. The docked alignment uses the CSM IMU as its reference and has an estimated accuracy of 0.5° in all axes, so drift rates as large as 0.5°/hr could go undectected. (Specifically, the accuracy of this drift estimate is $\pm .25^\circ$/hr.) PDI occurs about $1\frac{1}{2}$ hours after the AOT alignment, which means it is possible for pitch misalignments like $3/4^\circ$ to build up. That's sort of a worst case kind of number, and to quote such a value will drive statistically-minded people out of their gourds, but it helps me make a point.

b. Tolerable pitch misalignment at PDI to support a successful landing is in the order of 1° assuming the landing radar comes in early enough to compensate for the dispersions that have built up.

c. Descent aborts become hazardous if the pitch misalignment at PDI exceeds about 0.35°. (This number is being more accurately determined, but I'll bet it comes out within 0.05° of that guess.) This is assuming the worst abort situation, namely aborting at an altitude of about 13,000 feet because no landing radar data has been accepted. If we are willing to go beyond that point with no landing radar, the tolerable misalignment is smaller than that. The point is that the IMU performance requirement to support descent aborts appears to be the more constraining than to support descent itself and I think we all feel that it is intolerable to continue descent beyond the point a safe abort could be executed with the degraded PGNCS.

d. Since the AGS has to be aligned to the PGNCS prior to PDI, and pitch misalignment in the PGNCS has an equal effect on the AGS. They are not independent in this respect.

e. Given high bit rate telemetry, ground monitoring techniques are adequate to detect an unacceptable IMU misalignment within the first two minutes of powered descent. Thus, the crew could be informed and instructed to abort safely.

f. To abort a lunar landing mission, if it could have been saved by improving procedures, is rather unacceptable.

Based on all that, we have two recommendations, either or both of which should help the situation considerably.

The first is a proposal for a better docked PGNCS alignment suggested by Bob White of MIT, which should allow us not only to detect a drifting IMU, but to update its compensation such that we may proceed with a nominal mission. Detailed procedures development and performance analysis is under way at this time. It will demand some modification in the crew timeline during the LM activation and checkout period as well as the implementation of a new RTCC and/or ACR computer program and MCC procedures. The technique requires two spacecraft attitude maneuvers while in the docked configuration with the LM and CSM crew simultaneously keying out CDU angles before and after each of these attitude changes. All of this must be done after the LM IMU has been coarsely aligned as in the current flight plan. With this data, the flight controllers can compute the LM IMU orientation and torquing angles required. This technique is expected to be as good as an AOT alignment. It does not require knowing the relative orientation of the two navigation bases nor reading the docking ring index!

The other proposal involves making a drift check prior to PDI; it requires no MCC participation. Considerable effort was given to including an IMU alignment in the timeline but many of us have concluded the lighting conditions make it chancey at best. The only place it fits in the timeline is from PDI - 30 to PDI - 15. This period is almost perfectly centered around local high noon. Either the sun or the moon is in the AOT field of view for almost this entire time, making use of stars almost impossible. Except the sun! The nice thing about the sun is that it is certainly visible. Also since the whole mission profile is keyed to lighting regardless to landing site and month of the year, the sun will always be located in the same place with respect to the LM. MIT has been asked to write up a precise step by step procedure for doing this. Essentially it consists of the following:

After entering the descent program (P63), the crew would accept the option offered them to go into the alignment program (P52). They would specify the sun as their first "star". The LGC has the solar ephermis and will control the spacecraft attitude to place the sun in the center of the AOT. (The rear detent position should probably be used to minimize attitude change unless we do PDI with windows up.) The crew would readout the CDU gimbal angles to which the LGC is positioning the spacecraft; of particular interest is DSKY register No. 2 - the y-axis. The crew would then take over attitude control and cause the sun to cross the AOT retical line in the pitch direction at which time the actual spacecraft CDU angles would be keyed out on the DSKY. The difference between this actual pitch CDU angle and the previously noted predicted value is a direct indication of drift since the AOT alignment one hour earlier. The mission rule would be: if indicated misalignment is less than 0.25^{o}, the nominal mission should be continued; if the indicated misalignment exceeds that value, PDI must be delayed one rev, an AOT alignment would be performed two hours after the previous one and the MCC would determine and update the PGNCS drift compensation prior to LOS.

The value of the first recommendation is that it provides a chance to detect and fix a problem without perturbing the nominal mission. The value of the second is that it allows detecting and fixing a problem before PDI is attempted, although in the worse case it forces delay of PDI one rev, which I am sure we are going to find is a highly undesirable thing to do.

That in a million words-or-less is where we stand on this matter today. We will continue our analysis and procedures development based on this. One unfortunate fact is that if we adopt these proposals, they will not have been tested on the F mission, but I think we would all be naive if we thought we are not going to learn things on F that force us to change the procedures anyway.

Howard W. Tindall, Jr.

PA:HWT:js

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA FPMR (41 CFR) 101-11.6
UNITED STATES GOVERNMENT

Dmf

info
file

Memorandum

NASA Manned Spacecraft Center

TO : See list attached

DATE: June 13, 1969

69-PA-T-93A

FROM : PA/Chief, Apollo Data Priority Coordination

SUBJECT: Some significant LUMINARY program changes you should know about

I really blew it at the June 5 Apollo Spacecraft Software Configuration Control Board meeting. Although dozens of rather minor changes were approved, the one I was most concerned about wasn't even discussed and I completely forgot it. This memo is to inform you that we are now desperately trying to include a capability in the LM computer program for a lunar landing flight in November which substantially improves descent abort targeting and procedures. Currently the LM descent abort programs target the spacecraft to insertion conditions which is not entirely accurate. This is because the more sophisticated equations required to do the job right were too complicated to get in the program for the G mission and we settled for some approximations that only do a pretty good job. Unfortunately, if we have a descent abort this makes it necessary to trim the insertion conditions based on ground targeting. This is the so-called "tweak" maneuver you've heard so much about which either the LM or command module must execute shortly after LM insertion into orbit. It is a messy procedure and the program change proposed will eliminate its need. Furthermore, for aborts late in powered descent (that is, after PDI + 10 minutes) it is necessary for the LM to execute a phasing maneuver approximately one-half rev after insertion to set up the proper rendezvous conditions. This, too, is a messy ground targeted procedure which will be eliminated if this program change is implemented.

Although I wanted to tell you about that, my main purpose in writing this memo was to inform you that in order to get this program change in we have to sacrifice some other things and I thought you should have an opportunity to complain if you wanted to. First of all, storage has again become a problem and so we propose that, if necessary, MIT should delete the two Stable Orbit Rendezvous targeting program (P38 and P39) from the LM program. We have never discovered an operational use for these programs but maybe this deletion may bug somebody. (Incidentally, in order to provide more room for the dozen or so other changes already approved, the externally targeted Lambert pre-thrust program [P31] has already been deleted.) The other capability which may have to be dropped is the rendezvous radar automatic acquisition provided by the PGNCS during the Descent Abort programs (P70 and P71). Disabling this capability (R29), may be required to avoid a computer cycle problem. That is, obviously the computer can only do so much in a given period of time and it is MIT's option that adding the proposed sophistication in the guidance may cause us to exceed that limitation. This in turn forces us to give up another task and we have chosen the so-called Rendezvous Radar Designate Routine.

This final paragraph is on another subject, but I thought I would point out that one of the more significant capabilities added last Thursday was the capability for the crew to readout raw rendezvous radar range and range rate data on the DSKY during the operation of the Rendezvous Navigation program (P20). This capability had been requested several times previously but never made it in to the program due to scheduling problems. It is a real nice thing to have.

Howard W. Tindall, Jr.

Howard W. Tindall, Jr.

PA:HWT:js

Addressees:

AA/R. R. Gilruth
AB/G. S. Trimble
CA/D. K. Slayton
CB/A. B. Shepard (48)
CF/W. J. North
CF13/D. F. Grimm
CF212/C. Jacobsen
CF212/W. Haufler
CF212/W. Hinton
CF2/J. Bilodeau
CF22/C. C. Thomas
CF22/D. L. Bentley
CF22/R. L. Hahne
CF22/M. C. Gremillion
CF22/W. B. Leverich
CF22/T. H. Kiser
CF24/P. Kramer
CF24/J. Rippey
CF24/M. C. Contella
CF24/D. W. Lewis
CF24/D. K. Mosel
CF3/C. H. Woodling
CF32/J. J. Van Bockel
CF32/M. F. Griffin
CF33/M. Brown
CF33/C. Nelson
CF34/T. W. Holloway (6)
EA/M. A. Faget
EA2/J. B. Lee
EA2/R. A. Gardiner
EA4/J. Chamberlin
EA5/P. M. Deans
EB/P. Vavra
EE/L. Packham
EE/R. Sawyer
EE13/M. J. Kingsley
EE13/R. G. Irvin
EE3/R. L. Chicoine
EE6/G. B. Gibson
EE6/R. G. Fenner
EE6/J. R. McCown
EP2/W. R. Hammock
EG/R. G. Chilton
EG/D. C. Cheatham
EG13/W. J. Klinar
EG2/C. T. Hackler
EG23/K. J. Cox
EG23/E. E. Smith
EG25/T. V. Chambers
EG27/W. R. Warrenburg (2)
EG27/H. E. Smith
EG41/J. Hanaway
EG42/B. Reina
EG43/A. R. Turley
EG44/C. W. Frasier
EG/MIT/T. Lawton
KA/R. F. Thompson
PA/G. M. Low
PA/C. H. Bolender
PA/K. S. Kleinknecht
PA2/M. S. Henderson
PB/A. Hobokan

PC/W. H. Gray
PD/O. E. Maynard
PD/C. D. Perrine
PD/R. V. Battey
PD12/J. G. Zarcaro
PD12/R. J. Ward
PD12/R. W. Kubicki
PD12/J. Sevier
PD13/A. Cohen
PD6/H. Byington
PD7/W. R. Morrison
PE/D. T. Lockard
HA/J. P. Loftus
TJ/J. H. Sasser
TH3/J. E. Dornbach
CO7/J. Nowakowski
FA/C. C. Kraft, Jr.
FA/S. A. Sjoberg
FA/C. C. Critzos
FA/R. J. Rose
FA4/C. R. Hicks
FC/E. F. Kranz
FC/G. S. Lunney
FC/M. P. Frank
FC/C. E. Charlesworth
FC/M. Windler
FC/J. W. Roach
FC/G. D. Griffin
FC2/C. S. Harlan
FC2/H. M. Draughon
FC2/J. H. Temple
FC25/C. R. Lewis
FC27/W. E. Platt (3)
FC3/A. D. Aldrich
FC3/N. B. Hutchinson
FC35/B. N. Willoughby (3)
FC4/J. E. Hannigan
FC44/R. L. Carlton (3)
FC5/J. C. Bostick
FC5/P. C. Shaffer
FC54/J. S. Llewellyn
FC54/C. F. Deiterich
FC54/J. E. I'Anson
FC55/E. L. Pavelka (6)
FC56/C. B. Parker (3)
FC6/C. B. Shelley (4)
FL/J. B. Hammack
FL2/R. L. Brown (2)
FL6/R. W. Blakley
FS/L. C. Dunseith
FS5/J. C. Stokes (10)
FM/J. P. Mayer
FM/C. R. Huss
FM/D. H. Owen
FM13/R. P. Parten (10)
FM2/C. A. Graves (3)
FM3/C. T. Hyle
FM4/E. R. Schiesser
FM4/P. T. Pixley (2)
FM4/R. T. Savely
FC35/R. Fruend
FM4/W. R. Wollenhaupt

FM5/R. E. Ernull (5)
FM5/J. D. Yencharis (4)
FM5/H. D. Beck
FM5/R. D. Duncan
FM6/K. A. Young (6)
FM6/R. W. Becker (3)
FM7/D. A. Nelson
FM7/S. P. Mann
FM7/R. O. Nobles
FM/Branch Chiefs (7)

BOEING/Houston/R. B. McMurdo (2), HA-74
BOEING/Houston/D. Heuer, HM-08
BOEING/Houston/R. L. Allen, HA-58
BOEING/Houston/H. E. Dornak, HM-25
BOEING/Houston/D. W. Hackbart, HM-25
BELLCOMM/HQS./R. V. Sperry
BELLCOMM/HQS./MAS/A. Merritt
BELLCOMM/HQS./D. Corey
BELLCOMM/HQS./G. Heffron
GAEC/Bethpage/W. Obert-Thorn
GAEC/Bethpage/R. Schendwolf (3)
GAEC/Bethpage/R. Mangulis
GAEC/Bethpage/R. Pratt
GAEC/Bethpage/Consulting Pilot's Office
GAEC/Bethpage/B. O'Neal
GAEC/Houston/G. Kingsley
MIT/IL/R. R. Ragan (25)
MIT/IL/M. W. Johnston, IL 7-279
NR/Downey/M. Vucelic, FB84
NR/Downey/R. Zermuehlen, FB59
NR/Downey/J. E. Roberts, FB59
NR/Downey/B. C. Johnson (4), AB46
NR/Downey/W. H. Markarin, FB55
NR/Downey/E. Dimitruk, BB49
NR/Downey/J. E. McIntyre, BB48
NR/Downey/M. B. Chase, AB33
NR/Downey/D. W. Patterson, AC50
MITRE/Houston/W. P. Kincy
GSFC/500/F. O. Vonbun
NASA/HQS./MAO/R. B. Sheridan
NASA/HQS./MAOP/R. O. Aller (2)
NASA/HQS./XS/R. Sherrod
KSC/CFK/R. D. McCafferty
KSC/CFK/P. Baker
KSC/CFK/C. Floyd
KSC/CFK/M. Walters
TRW/Redondo Beach/R. Braslau
TRW/Houston/W. J. Klenk
TRW/Houston/B. J. Gordon
TRW/Houston/R. J. Boudreau
TRW/Houston/C. R. Skillern
TRW/Houston/M. Fox
TRW/Houston/K. L. Baker
IBM/Houston/G. Carlow, D70
TRW/Houston/W. Hill

info

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA FPMR (41 CFR) 101-11.6

UNITED STATES GOVERNMENT

Memorandum

NASA Manned Spacecraft Center

TO : See list attached

DATE: February 20, 1969

69-PA-T-28A

FROM : PA/Chief, Apollo Data Priority Coordination

SUBJECT: Descent Abort Mission Techniques

On February 13 we went over our Descent Abort Mission Techniques with the world. In general they were accepted as is. That isn't to say we didn't have some lengthy discussions resulting in some improvements and/or changes but we didn't make any substantial changes to the basic ground rules, philosophy, or overall procedures. I would like to list here some of the things we decided as well as some open items requiring work.

1. Although we didn't spend any appreciable time discussing this, it probably would be worthwhile to look into fixing the spacecraft computer program (LUMINARY) such that we could use the DPS and APS Descent Abort Programs (P70 and P71) before PDI (TIG). In other words, prior to PDI the crew and/or MCC-H may decide PDI is "no go." Since the descent abort programs have the capability of targeting and guiding an ideal maneuver to set up the standard rendezvous sequence it may be quite an advantage if we are able to call upon those programs without actually having attempted PDI as the program is currently constrained.

2. It was agreed that if the steerable S-band antenna lock-on is lost during a descent abort, the crew will not attempt to reacquire with that antenna but rather will switch to the omnis as soon as it is convenient for them to do so. Of course, this will only supply the ground with low-bit rate data but reacquisition with the steerable is considered to be almost impossible, particularly in an emergency situation like this. (Landing Analysis Branch was given the action item of determining if the initial descent abort attitude maneuver for any period in a nominal descent would cause the S-band steerable to loose lock.)

3. It was concluded that there is a significant advantage to having the AGS Mode Control switch nominally set to Attitude Hold during descent in order to permit the crew to complete a landing using the AGS if they have a PGNCS problem late in descent and consider it safer to land than to abort. Of course, this means that an extra switch setting must be made if it is necessary to abort on the AGS. Specifically the AGS abort sequence would be:

a. Set Guidance Control to AGS

b. Make a manual maneuver to approximately the abort attitude

c. Set Mode Control:AGS to Auto (This is the "extra")

d. Push Abort or Abort Stage

4. We had a lengthy discussion about whether or not the DPS should be run to propellant depletion. The Propulsion people (who are never in attendance in any meeting dealing with how their systems are going to be used) have stated that running the DPS to propellant depletion should not be done unless crew safety is involved. There are obviously times in the descent aborts at which crew safety is decreased if we turn off the DPS any sooner than we have to. Accordingly, in order to avoid some sort of complicated logic to guide the crew in determining when they can or cannot run to propellant depletion, we all agreed that the DPS will ordinarily be run to propellant depletion if the guidance system does not shut it off first. The crew took proper note that there is some hazard incurred in doing that and plan to manually shutdown the DPS when the propellant gauge reads 1 or 2 percent remaining provided they are clearly in the region that shutting down the DPS is not going to increase the probability of hitting the moon AND it is clear an APS burn will be required to achieve orbit. Implicit, of course, is that they are not so busy in treating the cause of the abort that they fail to monitor and take this action.

5. In the event it is necessary to use the APS to achieve orbit, it was concluded that the crew will not attempt to provide ullage prior to pushing the Abort Stage Button. Although this is not accepted practice for an in-orbit maneuver, we could see no reason why it should not be perfectly safe to do this following a DPS burn of any magnitude with completely full APS propellant tanks.

6. By far our longest discussion dealt with how to handle the situation at insertion following an abort during the first 300 seconds of powered descent. Specifically, we are faced with the problem of how to jettison the DPS conveniently and safely and at the same time trim the ΔV residuals in order to get on the desired rendezvous trajectory. The results of this discussion were so meager that I will not report them here. Particularly since subsequent to the meeting several new proposals have been made that appear better than anything we considered. What I'm saying is that our discussion was fruitful to the extent that it got a lot of people thinking about this problem but we probably need to get together again to discuss all the resultant ideas and choose our course. I will set up a get together just for that purpose.

Howard W. Tindall, Jr.

Howard W. Tindall, Jr.

PA:HWTindall, Jr.:js

EA / Dr. M. Faget

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA FPMR (41 CFR) 101-11.6

UNITED STATES GOVERNMENT

Memorandum

TO : See list below

DATE: MAY 1 4 1968

68-PA-T-101A

FROM : PA/Chief, Apollo Data Priority Coordination

SUBJECT: Aborts to the lunar surface from powered descent

1. We spent the entire May 8 Ascent Data Priority meeting discussing mission techniques associated with aborts from powered descent on a lunar landing mission. This discussion led to some pretty simple procedures which are outlined in this memo. They are based on some assumptions which I've also listed below. If you feel that they are in error, please let us know.

of which these are valid!

2. The basic assumptions we made are:

EP/Lambert
EG/Kayton

a. From a DPS engine performance and dependability standpoint, it is preferable to operate the DPS at full thrust throughout the abort ascent trajectory rather than at some lower level. (Is this okay after operating for awhile at reduced thrust? Also, we must make sure there are no bad guidance system transient problems at staging.)

EP/Lambert

b. The low level sensor light comes on when there is 1200 pounds of propellent remaining, which is equivalent to about 120 seconds burn time at 25% thrust, and 30 seconds burn time at maximum thrust.

EP/Lambert

c. It is operationally acceptable to run the DPS to fuel depletion. That is, there is no reason for the crew to prematurely shut down the DPS engine if there is an advantage to be gained by running it to fuel depletion. (I'll bet I hear something about this!)

d. Use of the "Abort Stage" automatic sequence is as safe or safer than manually proceeding through it one step at a time. (Someone's not going to like this either.)

e. The crew can make a go/no go decision one minute after the DPS low level sensor light comes on, at which time they should be prepared to either commit to landing or to abort immediately. (At least we are recommending this if it is at all possible. Of course, they may abort after that, but it's getting hairy.)

f. There is a very great advantage to be gained by keeping the variety of abort modes to a minimum - that is, always do the same thing as often as possible. The point is, there may be some special cases in which some benefit could be gained by doing things a little differently. But, we always felt the advantage of standarized procedures outweighted them in those cases we recognized and discussed.

3. The abort procedure is really very simple, at least if the above assumptions holdup. So simple, in fact, that I'm sure you'll wonder how we spent the day! Basically, whenever an abort situation arises at any time during descent, the crew will hit the "Abort" button which will automatically put the PGNCS (or AGS) into the DPS abort program (P70) and the DPS should be run to fuel depletion or to a guided cutoff at orbital conditions, whichever occurs first. If fuel depletion occurs, the crew should then "Abort Stage," which will automatically cause separation of the DPS and will put the PGNCS (or AGS) in the APS abort program (P71), leading to a guided insertion into orbit. We propose never initiating an abort with "Abort Stage" as long as the DPS is still operating okay.

4. There is one special case requiring attention which occurs with an abort approximately five minutes into power descent. It is at about that time when the DPS is able to return the spacecraft all the way to nominal orbit. If the DPS does make it all the way to orbit, all is well and good. If, however, fuel depletion results in DPS shut down just shy of that, something must be done of course. The procedure we propose if the velocity required to get into orbit is less than 10 fps, is for the crew to remain in P70, <u>not</u> to stage the DPS, and to use four jet RCS to achieve orbit. This requires approximately a 15 second burn. (This value was selected in deference to the problems brought about by a spacecraft whose thrusters shoot at itself.) If the velocity required to achieve orbit is in excess of 10 fps, which would require an APS burn of one second duration or greater, the procedure is as before - "Abort Stage" and use the APS.

5. One item requiring some research is to make sure that the spacecraft computer program (P71) will provide proper guidance to the APS for a "small" maneuver following DPS shut down. Another is to confirm that 10 fps is within the APS minimum impulse mode capability.

6. Consideration was given to establishing a special procedure in this region where the RCS would be used to insert the <u>staged</u> spacecraft. However, there was no advantage apparent to avoiding use of the APS unless there is some sort of freezing problem for short burns. In addition to keeping the procedure simple and standard, this technique should reduce the demand on RCS propellent and thruster lifetime. As a matter of interest, the magnitude of the remaining APS and/or RCS maneuvers in the coelliptic rendezvous sequence for an abort at that time are approximately as follows: CSI 35 fps, CDH 100 fps, and TPI 30 fps.

7. The only other situation I'd like to discuss deals with aborts late in the descent phase after the DPS low level sensor light has come on. There is a real advantage to be gained if the crew spends no more than about 60 seconds in that state before aborting since after that time the DPS will have less than 15 seconds of burn time remaining at full thrust. This duration would assure getting through "vertical rise" and pitchover before DPS fuel depletion. After that, it's cutting things pretty close. However, even then, it stills seems best to always attempt "Abort" on the DPS in order to get as much out of that engine as possible - if it's only a cough. The full thrust DPS acceleration is over twice that of the APS and if it's ever needed it's there! The only disadvantage occurs with a more-or-less simultaneous "Abort" and DPS fuel depletion causing a delay in "Abort Stage" with no engine on. If the crew has been watching the fuel gauge, etc., he should never let this situation arise and special procedures should not be required to handle it.

8. Finally, I'd like to outline the alternate techniques we established if fuel depletion DPS is not acceptable. As before, we always recommend "Abort" rather than "Abort Stage." The modified procedures are based on providing the equivalent of at least five seconds of DPS burn time at maximum thrust as a pad against fuel depletion. This is equivalent to shutting down the engine with about 120 fps DPS remaining. There are two classes of abort which must be considered:

a. The first is if the abort situation is detected before the low level sensor light has come on. In this case after "Aborting" into P70, it is necessary to monitor the inertial velocity in the DSKY (or the DEDA) at the time the light comes on. If the inertial velocity is less than 5,000 fps, the astronaut should "Abort Stage" 25 seconds after the light comes on and proceed into orbit on the APS. If the inertial velocity is greater than 5,000 fps, it is possible to proceed into orbit on the DPS without fuel depletion occurring. (Note: it is only necessary to monitor the "thousands" digit to make this decision.)

b. If the abort situation arises after the low level sensor light has came on, the crew should "Abort Stage" immediately after the pitch-over maneuver following vertical rise. This would occur about 10 seconds after the "Abort," if the abort is from hover.

9. In summary, if the DPS is still working, always use the DPS to initiate the abort and after getting as much as possible from the DPS, "Abort Stage" if necessary to achieve orbit. This provides the following advantages:

a. Avoids shutting down and changing engines at a time critical point and insures a positive altitude rate before staging.

b. Obtains the maximum delta V available from the DPS.

c. Produces the greatest possible acceleration at the abort time to get the heck out of there.

d. Makes the procedure standard for all cases - and simple!

Howard W. Tindall, Jr.

Enclosure
List of Attendees

Addressees:
(See list attached)

PA:HWTindall, Jr.:js

ATTENDEES

H. W. Tindall, Jr.	PA
T. G. Price	FS5
C. T. Hackler	EG2
L. Pavlow	FC2
R. H. Sutton	FC2
G. C. Guthrie	FC5
A. Nathan	FM13
F. V. Bennett	FM2
J. D. Payne	FM2
D. Boudreau	TRW
J. R. Henson	TRW
K. Nickerson	TRW
D. Dral	TRW

Enclosure 1

Addressees:

AA/R. R. Gilruth
AB/G. S. Trimble
CA/D. K. Slayton
CB/A. B. Shepard
J. A. McDivitt
N. Armstrong
F. Borman
M. Collins
C. Conrad
L. G. Cooper
C. Duke
R. Gordon
J. Lovell
R. L. Schweickart
D. R. Scot
T. P. Stafford
W. R. Pogue
W. M. Schirra
D. F. Eiselle
CF/W. J. North
CF13/D. F. Grimm
CF2/J. Bilodeau
CF212/C. Jacobsen
CF22/C. C. Thomas
CF24/P. Kramer
M. C. Contella
D. K. Mosel
D. W. Lewis
CF3/C. H. Woodling
CF32/J. J. Van Bockel
CF33/C. Nelson
M. Brown
CF34/T. Guillory
T. W. Holloway
EA/M. A. Faget
EA1/J. Chamberlin
EA2/J. B. Lee
~~EA5/P. M. Deans~~
EB/P. Vavra
EE/R. Sawyer
L. Packham
EE13/M. J. Kingsley
R. G. Irvin
EE3/E. L. Chicoine
EE6/G. B. Gibson
R. G. Fenner
EG/R. A. Gardiner
EG2/D. C. Cheatham
EG27/W. J. Klinar
H. E. Smith
EG41/J. Hanaway
EG42/B. Reina
EG2/C. T. Hackler
EG43/J. M. Balfe
EG44/C. W. Frasier
KA/R. F. Thompson
PA/G. M. Low
C. H. Bolender
K. S. Kleinknecht
PA2/M. S. Henderson
PD/O. E. Maynard
PD12/J. G. Zarcaro
R. J. Ward
R. W. Kubicki
M. H. von Ehrenfried
PD4/A. Cohen
PD6/H. Byington
PD7/W. R. Morrison
PD8/J. Loftus
PE7/D. T. Lockard
FA/C. C. Kraft, Jr.
S. A. Sjoberg
C. C. Critzos
R. G. Rose
FC/J. D. Hodge
E. G. Kranz
D. H. Owen
D. B. Pendley
M. P. Frank
FC2/J. W. Roach
FC3/A. D. Aldrich
G. E. Coen
B. N. Willoughby
G. P. Walsh
FC4/J. B. Craven
R. L. Carlton
J. C. Elliott
FC5/G. S. Lunney
J. S. Llewellyn
J. C. Bostick
D. Massaro
C. B. Parker
C. E. Charlesworth
C. F. Deiterich
S. L. Davis
W. E. Fenner
G. E. Paules
W. S. Presley
H. D. Reed
P. C. Shaffer
J. H. Greene
K. W. Russell
S. G. Bales
FL/J. B. Hammack
FS/L. C. Dunseith
FS5/J. C. Stokes
T. F. Gibson, Jr.
G. R. Sabionski
J. E. Williams
T. M. Conway
TH3/J. E. Dornbach
J. H. Sasser
FM/J. P. Mayer
C. R. Huss
M. V. Jenkins
FM12/R. R. Ritz
FM13/R. P. Parten
J. R. Gurley
E. D. Murrah
A. Nathan
FM3/M. Collins
FM4/P. T. Pixley
R. T. Savely
FM5/R. E. Ernull
FM6/R. R. Regelbrugge
K. A. Young
FM7/S. P. Mann
R. O. Nobles
FM/Branch Chiefs

HE-03/H. E. Dornak
D. W. Hackbart
Bellcomm (Hqs.)/R. V. Sperry
G. Heffron
GAEC (Bethpage)/J. Marino
MAC (Houston)/W. Haufler
MIT/IL/R. R. Ragan
NR (Downey)/M. Vucelic
D. Zermuchlen
E. Dimitruk, FB30
TRW (Houston)/R. Boudreau
M. Fox
C. Pittman
W. R. Lee, Jr.
T. V. Harvey
TRW (Redondo Beach)/R. Braslou
GSFC/F. O. Vonbun, 550
B. Kruger, 550
KSC/R. D. McCafferty (CFK)
P. Baker (CFK)
NASA (Hqs.)/A. Merritt, MAS

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA FPMR (41 CFR) 101-11.6

UNITED STATES GOVERNMENT

Memorandum

TO : See list attached

DATE: JUL 2 1968

68-PA-T-148A

FROM : PA/Chief, Apollo Data Priority Coordination

SUBJECT: Throttle up time is fixed during the powered descent maneuver

1. We learned something interesting during our Descent Mission Techniques meeting June 28 from the MIT people there. It dealt with the way the DPS gimbal trim phase of the powered descent maneuver is programmed.

2. It is extremely important that the engine be at full throttle at the right place in the trajectory. (The figure given is that for each second of time delay in throttling up to the FTP, we lose 12 seconds of hover time.) Therefore, MIT has programmed the computer so that throttling up does not occur after a fixed duration DPS gimbal trim time, but rather at the "right time" regardless of how much trim gimbal there has been. For example, if the engine failed to start when it was suppose to and the crew chooses to recycle to TIG minus five seconds there can be as much as 13 seconds delay in engine ignition and the trim time would be reduced by that amount. This procedure is an argument for maintaining a 10% trim gimbal time of 26 seconds, making us somewhat tolerant of this sort of an event. We hadn't thought about this situation very much yet, but I think the consensus is that if the DPS fails to ignite under PGNCS control initially and again fails on a recycle, we should abort without attempting manual ignition since something serious is probably wrong.

3. This really looks like a good way to program it, but is different than documented in the GSOP. Accordingly, MIT will submit a PCN to correct the documentation.

Howard W. Tindall, Jr.

Howard W. Tindall, Jr.

PA:HWTindall, Jr.:js

EA5/ P. Deans

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA FPMR (41 CFR) 101-11.6
UNITED STATES GOVERNMENT

Memorandum

TO : See list attached

DATE: JUL 16 1968

68-PA-T-155A

FROM : PA/Chief, Apollo Data Priority Coordination

SUBJECT: LM Descent abortability computation is proposed

Ed Copps of MIT attended one of our mission techniques meeting recently during which we discussed the use of the LM Descent Propulsion System low level sensor light. This is the light, you recall, which comes on when approximately 30 seconds worth of propellant is still available at full thrust or two minutes at 25% thrust. Recognizing that the astronaut has a complicated job to perform during the terminal part of descent, Ed Copps is proposing a rather simple new program to be added to the LM computer to relieve the situation. Rather than the astronaut trying to keep track of his status based on altitude, altitude rate, time since the low level sensor light came on, and the throttle profile he has executed since that time, this new program would predict for him the time at which he would no longer be able to abort. This would be in the form of a five second warning, during which he must either commit to landing or must get out of there. The PGNCS would be telling him that if he fails to abort before that time, it is probable that an abort would not be successful.

This sounds like a good thing to me - perhaps allowing us to get more out of the systems more than we would otherwise be able to do. If enough interest can be generated in it, it will probably be added to the Luminary Hopper.

Howard W. Tindall, Jr.

PA:HWTindall, Jr.:js

UNITED STATES GOVERNMENT

Memorandum

TO : See list attached

DATE: JUL 17 1968

68-PA-T-156A

FROM : PA/Chief, Apollo Data Priority Coordination

SUBJECT: Powered descent throttle logic correction

On July 2 I sent you a note regarding the way the DPS is throttled up after the gimbal trim phase during the powered descent maneuver. There were a couple of errors in that memo which are too significant to be left uncorrected.

I pointed out that MIT has programmed the LM computer so that the throttle up time was a fixed number of seconds after the targeted time of ignition (TIG). To illustrate how important it is that the engine be throttled up to the FTP at that time, I pointed out that for each second delay in throttling we lose 12 seconds of "hover time." This was my first error since it is not hover time that is lost but rather "throttle recovery time." Throttle recovery time is that period which has been allotted in the powered descent maneuver for the guidance system to regulate the thrust such that it can achieve the hi-gate targeting conditions. Failure to provide a sufficient period of throttling will jeopardize meeting those conditions and can result in a fouled up descent.

I went on to say that if the engine failed to start when it was supposed to, the crew could recycle to TIG minus five seconds and the PGNCS would countdown to ignition again with a delay of about 13 seconds from TIG (all true) and that the trim time would be reduced by that amount since the throttle up time was maintained as originally set. George Cherry informs me that this is not true since in the event of a recycle to TIG minus five seconds the throttle up time is redesignated. Accordingly, the recycle capability is really not an acceptable thing to use on the powered descent maneuver. I do not believe that the program has been designed improperly. It is just that the capability, as I described it, does not really exist.

MIT is submitting a PCN describing how the program has actually been coded since it is different than documented in the GSOP.

Howard W. Tindall, Jr.

PA:HWTindall, Jr.:js

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA FPMR (41 CFR) 101-11.6

UNITED STATES GOVERNMENT

Memorandum

TO : See list attached

DATE: JUL 1 8 1968

68-PA-T-160A

FROM : PA/Chief, Apollo Data Priority Coordination

SUBJECT: The LM can handle big Descent plane changes but requires protection against APS abort fuel depletion

We have recently verified that the LM has a substantial capability to translate out of its initial orbital plane during powered Descent at very little cost. That is, whereas previously a limit of 0.3° had been quoted, it now appears that 1° or more is probably possible without effecting the performance of the guidance equations, the landing radar, the visibility of the crew during landing, nor are the ΔV costs excessive. This capability gives us more than adequate assurance that it will not be necessary to perform a plane change trim burn on DOI day. And that's darn important!

In order to take advantage of this capability, however, it appears that something may have to be done to limit the yaw steering the LM would do in the event of an APS abort during powered Descent. As currently programmed, the PGNCS would attempt to guide the LM all the way back into the CSM plane. If the abort were to occur at "hover" or after touchdown, the APS ΔV cost could be excessive (i.e., 1° costs approximately 80 fps and could result in fuel depletion prior to obtaining a safe orbit). Obviously the thing we must do is to achieve the targeted in-plane conditions in the case of an abort. We can take care of the plane change after the LM is in orbit, perhaps using the CSM. Therefore, it seems necessary to make a (hopefully) rather small change to the APS abort program (P71) which would limit the extent of the out-of-plane steering. MPAD and MIT people are both in the process of studying this and we plan to recommend specific action very soon. Something similar will be needed in the AGS too, I suppose.

Howard W. Tindall, Jr.

PA:HWTindall, Jr.:js

EA/M. Faget

EAS

Deans

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA FPMR (41 CFR) 101-11.6

UNITED STATES GOVERNMENT

Memorandum

TO : See list attached **DATE:** SEP 1968

FROM : FS/Chief, Flight Support Division

SUBJECT: Minutes of technical interchange meeting - LM powered descent analysis

1. A technical interchange meeting was held on August 20, 1968, at MSC to discuss results of studies of the LM powered descent guidance by MIT/IL and MSC organizations. The agenda for this meeting is given in enclosure 1. The purpose of this meeting was to assess the adequacy of the present implementation of the LM powered descent guidance together with the navigation routines utilized during the descent and to point out any areas requiring possible changes if the present system were not deemed adequate. These minutes will describe the highlights of the meeting and no attempt will be made to discuss in detail the slides which were presented. The slides, however, will be enclosures to this memorandum.

2. Mr. B. A. Kriegsman presented the results of the MIT/IL studies. The results using the present descent guidance implementation resulted in no velocity update during the braking phase for a nominal run with landing radar drop out which was assumed. The cases run with the vehicle high and the slope declining had no landing radar updates during the braking phase. These test cases rejected landing radar updates even though no reasonability test was included; that is, the vehicle did not attain the desired velocity and/or altitude which would allow updates of the state vector with landing radar data. Mr. Kriegsman referenced Mission Simulation Memos 20, 32, 34, and 35 to be used as background information (enclosures 2 through 5). The slides used during the presentation given by Mr. Kriegsman are presented as enclosure 6 to this memorandum. MIT/IL suggests the descent be redesigned so that the weighting factor used by the landing radar routine be implemented as a function of time-to-go or range-to-go. Also, to further reduce the sensitivities immediately preceding the targets at hi-gate, when the landing radar sees a ΔH between the LGC computed altitude and the landing radar altitude, both the present altitude and the target altitude should be updated. The results of runs using this method and a summary of the recommendations are also included in the slides that MIT/IL presented.

3. The next presentation was made by Messrs. W. M. Bolt and R. J. Labrecque of the Lunar Landing Branch of the Mission Planning and Analysis Division (MPAD), who discussed the results of the studies made by the MPAD. The results of these cases agreed with the results of the MIT/IL studies and are presented in this memorandum as enclosure 7. Mr. J. H. Alphin of the Lunar Landing Branch of MPAD presented a one-phase descent guidance technique which relieved to a substantial extent the sensitivities incurred with the present system prior to hi-gate. This method involves targeting only to a

lo-gate target in such a manner as to throttle down prior to the so-called hi-gate and still, during the later portions of the descent (approach phase), satisfy the constraints that have been specified previously. For further information on this one-phase descent technique, refer to MSC Internal Note 68-FM-177, "A One Phase Targeting Concept for the LM Powered Descent," dated July 22, 1968.

4. Dr. K. J. Cox of the Guidance and Control Division (G&CD) stated that results of studies made by that division agreed with MPAD and MIT/IL. The slides presented by G&CD are presented as enclosure 8.

5. Mr. N. E. Sears, when asked about the accelerometer bias, said that the number of 0.2 cm/sec^2 or 0.006 ft/sec^2 is being used. It was agreed by those in attendance (see enclosure 10) that these are the best available numbers, but that in-flight calibration would reduce this by about one-half.

6. Mr. E. R. Schiesser of the Mathematical Physics Branch of MPAD presented the covariance matrix for the best estimate of MSFN accuracies derived from inputs of various error sources. These slides are presented as enclosure 9.

7. The following action items were assigned at the meeting.

a. The Flight Crew Support Division, G&CD, and MPAD are to review the constraints used for the powered descent.

b. G&CD is to verify the landing radar error models that were used.

c. MPAD and G&CD are to further investigate the one-phase guidance technique.

d. MIT/IL is to assess their suggested method for other landing sites, covariance matrices, etc.

8. The meeting was closed after the following general discussions. Mr. Sears stated that MIT/IL would be performing some man-in-the-loop studies on the hybrid computer, but probably would not be able to do so for another month or so. The attendees then agreed that if PCR's were submitted during the following few weeks, then all organizations should concentrate on the verification of the system which results from the submittal of these PCR's.

Haywood C. Dunseith

Haywood C. Dunseith

Enclosures 10

FS55:TGPrice:flb

Addressees:
NASA Hqs/R. Sperry (Bellcomm, MAS)
G. Heffron (Bellcomm, MAS)
GAEC(Bethpage)/D. Portnoy
J. Marino
MIT/IL/N. Sears
G. Cherry
IBM(Houston)/H. Norman
D. Weldon
R. Kirchoff
TRW(Houston)/J. Hass
R. Boudreau
R. Kidd
D. Johnson
CA/D. Slayton
CB/A. Shepard, Jr.
E. Aldrin
N. Armstrong
C. Conrad
CF/W. North
CF22/C. Thomas
CF24/P. Kramer
ED3/M. Keathley
J. Raney
EG/R. A. Gardiner
D. C. Cheatham
EG23/K. J. Cox
EG27/D. Gilbert
EA/M. Faget
PM/O. Maynard
J. Tomberlin
PM2/P. J. Ward
PM3/R. Battey
PM5/W. Goeckler
FA/C. C. Kraft, Jr.
R. G. Rose
FC/E. F. Kranz
G. S. Lunney
J. Llewellyn
J. Bostick
C. Parker
J. Hannigan
FM/J. P. Mayer
H. W. Tindall, Jr.
C. R. Huss
FM2/F. V. Bennett
FM7/M. Cassetti
R. Nobles
FM13/R. Parten
A. Nathan
FS6/J. Miller
FS5/T. Gibson, Jr.

Review of LM Descent Analyses

Room 378, Building 4 — August 20, 1968 - 9:00 a.m.

Tentative Agenda

		Time
I.	Comments/Status of Check Runs - MIT, GCD/TRW, MPAD	9:00 - 9:15 a.m.
II.	Operational constraints/criteria - MIT, MSC	9:15 - 9:45 a.m.
III.	MIT Study Results/Recommendations	9:45 - 10:45 a.m.
IV.	MSC Study Results	
	A. MPAD	10:45 - 11:30 a.m.
	B. GCD/TRW	11:30 - 12:15 p.m.
	LUNCH	
V.	Input Requirements for Future Studies	
	A. Orbit Navigation Accuracy - MPAD	1:00 - 1:45 p.m.
	B. Accelerometer Bias - MIT	1:45 - 2:00 p.m.
	C. Landing Radar Performance - GCD/IESD (bias/noise, dropout boundaries)	2:00 - 2:45 p.m.
VI.	Future Studies - MIT, MSC	2:45 - 3:00 p.m.
VII.	Potential Program Changes - MIT, MSC	3:00 - 3:30 p.m.

Enclosure 1

Enclosure 2

Massachusetts Institute of Technology
Instrumentation Laboratory
Cambridge, Massachusetts

Mission Simulation Memo # 20

TO: Distribution

FROM: B. A. Kriegsman and D. E. Gustafson

DATE: June 14, 1968

SUBJECT: Simulation of Powered Landing Maneuver with Current Trajectory-Targeting Parameters, DPS Model, Terrain Model, and LR Dropout Boundaries.

SUMMARY:

At a recent technical meeting at MSC, information was provided on the latest landing-trajectory targeting parameters and performance characteristics. Data were also provided on the performance of the DPS, the altitude variation profile for the worst site under consideration, and the relation of LR dropout boundaries to the vehicle's altitude and velocity. This new information has been incorporated into the landing-maneuver simulation and a series of test runs have been made to study the guidance-and-navigation system's performance for a variety of conditions.

The important results from the test runs were the following:

(1.) With the present LR antenna configuration and dropout-boundary models, no velocity updatings can be obtained until after the start of the visibility phase on the nominal trajectory.

(2.) Under the assumption that the rear LR velocity beams must be tracking in order to obtain LR altitude information, altitude information is lost about 30 seconds before the end of the visibility phase on the nominal trajectory.

(3.) From the viewpoint of minimizing the possibility of LR dropout, it appears that the LR antenna is switched too early from Position 1 to Position 2.

(4.) A nominal-trajectory throttle-down time of 120 seconds before High Gate appears desirable with the new DPS data.

(5.) Test runs showed that worst-case initial-condition errors along, and 3-sigma thrust-acceleration variations alone did not adversely effect overall guidance-and-navigation system performance. Aim conditions were accurately met and terminal constraints on the trajectory were satisfied.

(6.) With the present LR altitude weighting function, the state estimate appears to follow the local terrain too rapidly during the braking phase. New weighting functions should be found.

(7.) The selected terrain has significant altitude variations in the region below the vehicle during the latter part of the braking phase. These variations acting on the guidance system (through navigation-system updatings) caused severe vehicle attitude maneuvers during this period. It therefore appears that the present guidance law should be made less sensitive to updatings as time-to-go is decreased.

(8.) Test runs with the selected terrain model alone, i.e. no other navigation system errors or DPS thrust variations, led to significant High-Gate altitude and vertical velocity errors. In the absence of an additional terrain slope there were moderate deviations from the visibility-phase terminal constraints, but the 4-second dead man's curve was not violated until the range-to-go was below 200 feet.

(9.) Over the last 10-15 miles of the approach trajectory the selected site terrain profile had an average slope of about 100 ft/n.mi (terrain high). When a terrain slope of + 1 degree (terrain high) was superposed on the site profile, the guidance-and-navigation system could not perform properly. High-Gate altitude errors were over 2500 feet, visibility phase trajectory constraints were grossly violated, and the dead man's curve was exceeded at a 570 foot range-to-go from the site.

(10.) A selected combination of worst-case initial errors, 3-sigma IMU errors, and a 1-degree slope superposed on the site terrain profile caused LR altitude updatings to be inhibited throughout the major part of the braking phase. The resultant trajectory caused the vehicle to hit the moon. LR altitude data were lost in this case about 60 seconds before the end of the visibility phase.

GENERAL INFORMATION

A technical interchange meeting was held at MSC on April 10, 1968 to discuss the simulation of the LM landing-maneuver guidance-and-navigation system. The purpose of the simulation was to study the system's performance for various landing sites presently under consideration. The details of this meeting are described in Ref. 1.

At the above-mentioned meeting it was decided that the M.I.T. landing-maneuver simulations be updated to reflect the best currently available information on the landing trajectory, the descent propulsion system (DPS), the radar dropout boundaries, and the lunar terrain variations in the vicinity of selected sites. A series of preliminary test runs were chosen (Ref. 1) to check out the simulation and for comparison with other similar simulations at MSC. This memo is primarily concerned with the presentation of data for these selected runs and the discussion of the results from the series of runs.

NEW ITEMS IN LANDING SIMULATION

The simulation used in the study of this memo is basically as described in the LUMINARY GSOP (Ref. 2). The basic changes from preceding simulations (Refs. 3 and 4) are the following:

(1.) The landing maneuver aim conditions are as given in Ref. 5. These are based on a 60-mile CM orbit altitude and a Low-Gate altitude of about 75 feet.

(2.) DPS thrust variations at the high throttle setting are as described in Ref. 1. This implies 3-sigma initial deviations of +0.9 and -2.5 percent of 10,500 pounds, in contrast to the $\pm$ 3.0 percent values previously used.

(3.) The average buildup rate of thrust as a function of burning time at the high throttle settle is nominally about .6 lbs/sec (Ref. 1). In earlier simulations a nominal buildup rate of about 1.1 lbs/sec was used.

(4.) The specific impulse (I_{SP}) at the maximum throttle position (92.5-percent of 10,500 pounds nominally) is assumed to be 302 seconds. In earlier simulations a value of 306 seconds was used for the nominal engine I_{SP} at this setting. The I_{SP} model assumed for the continuously-throttleable region of the DPS is as given in Ref. 1. The I_{SP} values for a given thrust level here are about 3-4 seconds lower than in previous simulations.

(5.) To be consistent with the new engine model, the constant value of I_{SP} used in the updating of the current estimated vehicle mass (i.e. I_{SPC}) has been decreased from 305.0 to 300.5 seconds.

(6.) The throttle-down and throttle-up limits for the DPS have been raised from 6090 and 5250 pounds (58 and 50 percent of 10,500 pounds) to 6825 and 5985 pounds (65 and 57 percent).

(7.) As a result of the changes in CM orbit altitude, landing-maneuver aim conditions, and the DPS model, new coefficients are required for the DPS ignition algorithm. A detailed description of the procedure for computing these coefficients is given in Ref. 6 including the values in current use. For convenience, these values are given here, using the LUMINARY GSOP notation:

$$r_{IGXG} = -130,700 \text{ ft}$$

$$r_{IGZG} = -1,430,400 \text{ ft}$$

$$v_{IGG} = 5574 \text{ ft/sec}$$

(8.) The lunar-terrain altitude variation model has been chosen as Profile A of Site III P-11, at the direction of MSC. This supposedly represents the most difficult terrain for the landing sites currently under consideration. An altitude profile for this terrain is given in Fig. 1. It should be noted that this particular terrain model was chosen because it produces large altitude variations in the last 20-40 seconds prior to the High-Gate point.

(9.) More realistic models have been incorporated in the simulation to represent LR acquisition and dropout boundaries, using the data of Ref. 8, as described in Ref. 7. The dropout boundaries consist basically of the maximum angular displacements that a given beam can make with respect to the local vertical without losing track. In the case of the velocity beams (Nos. 1, 2, and 3) the data is given as a function of beam velocity and altitude; for the range beam it is given simply as a function of altitude. The acquisition boundaries are assumed to be 2-degrees smaller than the dropout boundaries, i.e. if at a given time and state a beam just dropped out at an angle of 40 degrees w.r.t. local vertical, it could not reacquire at the same state until the beam angle were less than 38 degrees w.r.t. local vertical.

(10.) In order to obtain altitude information, it is necessary that the range beam (No. 4) and the rear velocity beams (Nos. 1 and 2) all be tracking. In order to obtain velocity information, it is necessary that all three velocity beams (Nos. 1, 2, and 3) be tracking. To simulate the reacquisition sweep delay of the radar trackers, it is required that there be a 12-second delay after a given beam falls below the acquisition boundary, before reacquisition is assumed to take place.

(11.) The LR is assumed to have the altitude data-read flag set at an estimated altitude of 35,000 feet, and the velocity data-read flag set at an estimated altitude of 23,000 feet. This does not mean that altitude updating is started at 35,000 feet. Before altitude updating can be begun, the three rear beams (Nos. 1, 2, and 4) must all be tracking. After this occurs, the earliest time that altitude updating can be accomplished with the LR is 30 seconds from the time that the beams started to track.

(12.) The flag for switching the LR antenna from Position No. 1 to Position No. 2 is set when the estimated braking-phase time-to-go is less than or equal to 12 seconds. The antenna is assumed to move from Position 1 to Position 2 at the constant rate of 24/7 degrees/sec. No LR measurements are taken while the antenna is being repositioned.

(13.) Thrust-vector rotation rates are limited to a maximum value of 10 deg/sec. At the time that the guidance equations are processed (essentially the PIPA-processing times) the present actual and desired thrust-vector orientations are compared. A thrust-vector rotation rate is then computed to drive the thrust vector to the desired orientation in one computation cycle (2 seconds) subject to the 10 deg/sec rotation rate limit.

(14.) The raw altitude measurement is assumed to be taken at the PIPA processing time for which it is used in the updating process. The velocity measurement, on the other hand, is assumed to be taken 1.5 seconds prior to the time of incorporation into the state-vector update.

(15.) Site visibility computations are based on the computed LPS angle ($\theta_{e\ell}$ of Fig. 3.4.4-7 in LUMINARY GSOP Ref. 2) rather than the line-of-sight to a particular point such as the initial site. In the presence of navigation errors, the vehicle may land as much as 9000 feet down range from the initial site.

(16.) The vehicle's assumed weight before the start of the ullage maneuver has been increased 612 pounds from 32,184 to 32,796 pounds.

DESCRIPTION OF TEST RUNS

A series of test runs were selected at MSC (Ref. 1) to check out the landing-maneuver simulations. The salient characteristics of these runs are summarized in Table 1.

The initial errors #1191 are worst-case errors as determined in Ref. 9. The 3-sigma IMU errors are taken as 3 mr alignment, .02 ft/sec^2 accelerometer bias, and 450 p.p.m. accelerometer scale-factor along each axis. No LR random or bias errors are included in these initial test runs. The 3-sigma thrust-acceleration deviations are + .9 and -2.5 percent of 10,500 pounds at the start of the DPS burn, with the buildup characteristics as given in Ref. 1.

NOMINAL TRAJECTORY CHARACTERISTICS

The important characteristics of the current nominal landing trajectory (targeted according to Ref. 5) are presented in the plots of Figs. 2-7.

The thrust-vector elevation angle and thrust magnitude are shown in Fig. 2 as a function of time during the landing maneuver. The profiles are relatively smooth because there are no navigation-system errors or terrain altitude variations. The DPS throttles down at a time of 346 seconds which corresponds to a braking-phase time-to-go of 119.6 seconds. The required ΔV is 6476 ft/sec, which is about 45 ft/sec less than the previously used nominal of Ref. 3.

The displacement of the four landing radar beams from their dropout boundaries are shown in Fig. 3 as a function of time for the nominal trajectory. The quantity plotted is the difference between the angle of the beam (AB) relative to the local vertical, and the dropout angle for the beam of interest (ABL). The dropout angle (ABL), as mentioned earlier, is computed as a function of vehicle altitude and beam velocity. When the difference AB-ABL is positive for a given beam, the beam is assumed to dropout, i.e. it loses track. In order for reacquisition to take place, the beam-angle difference must be less than -2 degrees. The simulation also included a 12-second delay after the -2 degree criterion is satisfied, before new LR data can be obtained.

There are several points of interest to be seen from the nominal trajectory of Fig. 3:

(1.) No LR velocity data can be obtained until about 15 seconds after the start of the visibility phase, when the vehicle's altitude is about 7200 feet. The reason for this is that with the present LR antenna configuration, the forward velocity beam (No. 3) is typically between 60 and 70 degrees forward from the local vertical during the major part of the braking phase. With the assumed dropout boundary it can be seen that Beam No. 3 will not acquire during the braking phase.

(2.) LR altitude information is first obtained at about 290 seconds after the start of the braking phase, when the vehicle's altitude is about 25,000 feet. This is about 30 seconds after the three rear beams (Nos. 1, 2, and 4) have all started to track (AB-ABL less than -2 degrees). It should be noted that the Range Data-Read Flag is set at an estimated altitude of 35,000 feet in the simulation.

(3.) With the assumed conservative dropout-boundary model, all the radar beams are seen to maintain track once they have started to track, until about 25 seconds before the end of the visibility phase. At this time the rear velocity beams (Nos. 1 and 2) lose track, preventing any further altitude and velocity updating by the LR.

(4.) The sharp spikes on the AB-ABL curves occur when the antenna is switched from Position No. 1 to Position No. 2, and when the vehicle pitches up to start the visibility phase. Presently, the antenna-switching flag is set when the estimated braking-phase time-to-go is less than or equal to 12 seconds. On the basis of the data of Fig. 3 it appears that from the viewpoint of maintaining track, i.e. minimizing the difference AB-ABL, this switching is done at too early a time. This stems from the fact that the axis of symmetry of the beam cluster is about 40 degree forcard from the local vertical (in the trajectory plane) during the latter part of the braking phase. Switching antenna positions moves the beams forward (w.r.t. local vertical), whereas the pitch-up to start the visibility phase moves them backward (w.r.t. local vertical).

(5.) The range beam (No. 4) does not drop out at the end of the visibility phase. The reason for this is that its dropout boundary (as modeled in the simulation) is dependent upon vehicle altitude only and not beam velocity.

(6.) The angle difference curves (AB-ABL) for the two rear velocity beams (Nos. 1 and 2) are slightly different from each other because of the 6-degree skew angle of the antenna configuration about the vehicle's X-axis.

The computed visibility angle for the nominal trajectory is presented in Fig. 4 as a function of time. The quantity actually presented is the complement of the LPD angle ($90 - \theta_{e\ell}$ of Ref. 2). When this quantity is less than 25 degrees, site visibility is lost. From the curve it can be seen that the site is 10 degrees above the window edge (angle greater than 35 degrees) for about 125 seconds during the visibility phase.

Various constraints have been set up by MSC on the altitude, horizontal velocity, and vertical velocity as a function of range-to-go to the landing site during the last 2000 feet of the approach trajectory. These constraints are documented in Ref. 10. The targeting parameters for the nominal trajectory have been selected by MSC (Refs. 5, 11, 12) to satisfy these constraints. Curves showing the relevant trajectory quantities and their constraints during the last 2000 feet of the landing are given in Figs. 5-7. As can be seen, the trajectory parameters follow the constraint curves quite closely for the nominal case.

The dead-man's curve for a 4-second reaction and staging delay (Ref. 11) was violated on the nominal trajectory at a range-to-go of about 185 feet. The constraint limit here is 200 feet.

TEST RUNS #102 AND #103: INITIAL-CONDITION ERRORS ALONE

Two cases are considered using worst-case initial error vector #1191 of Ref. 9. In Run 102, which uses error-vector #1191, the vehicle starts out low with a larger negative vertical velocity than indicated by the navigation system. In Run 103, on the other hand, with error vector #1191 the vehicle starts out high with a larger positive vertical velocity than indicated by the navigation system. No IMU or LR measurement errors are assumed to be present in these runs.

In the first case where the vehicle starts high (Run 102), the trajectory characteristics were not significantly different from those of the nominal case (Figs. 2-7). The throttle-down occurred about 5 seconds later than for the nominal case, i.e. at a time-to-go to High-Gate of about 115 seconds. Altitude and vertical velocity deviations of -34 feet and +8.6 ft/sec, respectively, occurred at the High-Gate point.

In the second case where the vehicle starts low (Run 103), the thrust-vector elevation profile deviates a bit from that of the nominal case. This can be seen from a comparison of the profiles of Figs. 2 and 8. The reason for this is that the LR range beam (No. 4) and right rear velocity beam drop out at about 328 seconds after the start of the braking phase, as indicated in Fig. 9. Altitude updating with the LR is not begun again until 14 seconds later. It should be noted, however, that dropout just barely occurred (see Fig. 9) and with a slightly less conservative model probably would not have occurred at all. When the guidance system is informed by the navigation system (after LR updatings have begun) that the vehicle is higher than previously indicated (Run 103), the corrective action taken by the guidance system is to place the thrust vector in a more nearly horizontal attitude than in the nominal case. This in turn displaces the LR-beam cluster further forward from the local vertical, increasing the possibility of LR dropouts.

The High-Gate altitude and vertical velocity deviations for Run 103 are + 35 feet and -9.3 ft/sec respectively. As a result, the visibility-phase trajectory characteristics are not significantly differently from those of the nominal trajectory (Figs. 4-7).

The magnitudes of the altitude updatings for Runs 102 and 103 are presented in Fig. 10 as a function of the braking-phase time-to-go. The curve for Run 103 has a break in it because of LR dropout at a time-to-go of about 134 seconds. As can be seen, the initial altitude errors are primarily removed after 30-40 seconds of LR updating, i.e. after 15-20 updatings. The residual or steady-state δh's are caused by the vertical velocity errors acting over the 2-second interval between updatings. The manner in which the altitude estimation errors decrease during these runs is shown in Fig. 11. As can be seen, in the absence of terrain altitude variations the major altitude estimation error is removed after 30-40 seconds of LR updatings.

TEST RUN # 104: TERRAIN III-P-11A, NO SLOPE

The effects of lunar terrain altitude variations on the landing trajectory are investigated by Runs 104-106 of Table 1. The selected terrain is Profile A for site III-P-11, which is shown in Fig. 1. This site was selected by MSC as being the most difficult to land at of those currently under consideration. In Run 104 no slope is superposed on the terrain altitude variations; in Runs 105 and 106 slopes of +1 degree and -1 degree are superposed on the terrain variations. No navigation system initial errors, no IMU errors, and no LR measurement errors are present in any of these runs.

Thrust-vector elevation and magnitude profiles are shown in Fig. 12 for the no-slope case (Run 104). As can be seen, fairly large elevation angle deviations occur during the last 50 seconds of the braking phase. The reasons for these deviations are:

(1.) Large abrupt variations in the terrain profile occur at this time when the vehicle is 8-12 n. miles from the landing site. This can be seen in Fig. 1. Variations of this magnitude were not considered in the terrain model used to derive the weighting function.

(2.) With the present weighting function, terrain variations will be followed fairly rapidly in the navigation system estimates of position. This can be seen from Fig. 13 where the current altitude weighting function is given. In the region of interest the LR altitude weighting function is about 0.4.

(3.) The guidance law is too sensitive at this time. By requiring that the final position and velocity errors be zero, fairly severe maneuvers can be required at the end of the landing-maneuver phase. With the present law the maneuver required to correct a given change in altitude (δ h), as introduced by a LR updating, increases rapidly as the time-to-go for the phase becomes small. Methods for reducing this sensitivity are currently being investigated.

At about 29 seconds time-to-go from the end of the braking phase, the throttle-up limit for the DPS (6825 pounds) was exceeded. This again was caused by the severe maneuvers required because of abrupt changes in estimated altitude due to terrain altitude changes. The DPS was not permitted to throttle-up, however, as can be seen in Fig. 12, because the braking-phase time-to-go was less than 30 seconds (Ref. 2).

Because of the severe maneuvers required at the end of the braking phase with Terrain III-P-11A present (Run 104), the LR loses track at about 30 seconds before the end of the braking phase. It does not reacquire until after the start of the visibility phase. This can be seen in Fig. 14. No altitude or velocity updatings are obtained during this interval.

The High-Gate errors in the case of interest here were about 1550 feet in altitude and 21 ft/sec in vertical velocity. This is due in part to the fact that the terrain near the High-Gate point is several hundred feet above that of the landing site. Also, the severe maneuver required to meet the High-Gate conditions is inhibited at the last 20 seconds of the braking phase by the switch to open-loop linear guidance there. As a result, the vertical velocity during the last 2000 feet of the approach trajectory is about 80 percent larger than on the constraint curve. This can be seen from Fig. 15. Likewise, the vehicle's altitude at this time is about 30-percent higher than the constraint value, as indicated in Fig. 16. In spite of these constraint violations, the dead-man's curve was not exceeded until the vehicle's altitude was down below 200 feet. Satisfactory site visibility was also obtained.

TEST RUNS #105 and #106: TERRAIN III-P-11A, ± 1-DEGREE SLOPES

The thrust-vector elevation angle profiles are shown in Fig. 17 for a +1 degree slope (terrain high), and in Fig. 18 for a -1 degree slope (terrain low). As can be seen, fairly severe attitude maneuvers are required in either case at the end of the braking phase in an attempt to meet the High-Gate conditions.

Of particular interest in Runs #105 and #106 are the following:

(1.) In the positive-slope case (terrain high) the LR altitude updating was started about 80 seconds earlier than in the negative-slope case (terrain low). The vehicles started at the same state in both cases, with no navigation, IMU, or LR errors present. The reason for this is that the LR dropout (and acquisition) boundaries (Ref. 7 and 8) are modeled as functions of local altitude. In the positive-slope case where the vehicle was closer to the terrain initially, acquisition could take place earlier. This is shown in Figs. 19 and 20.

(2.) In the positive-slope case (terrain high), the navigation information after LR updating indicates that the vehicle is lower in altitude than previously estimated. To correct for this condition, the vehicle is required to first pitch up (higher than nominal) and then to pitch down (lower than nominal). This tends to swing the LR beam cluster closer to the local vertical during the early part of the updating period (which is very desirable to avoid dropouts). In the negative-slope case (terrain low) the vehicle is pitched down shortly after the start of altitude updating. This tends to increase the probability of an early dropout, as can be seen in Figs. 19 and 20.

(3.) No LR velocity updatings are obtained during the braking phase in either of the runs. No altitude updatings are obtained during the last 25 seconds of the braking phase. In the negative-slope case (terrain low) neither altitude or velocity updatings are obtained during the last 25 seconds of the visibility phase. It should be noted here that the assumed LR dropout boundary model is very conservative.

(4.) The assumed terrain profile, as indicated in Fig. 1, has a mean slope of about + 100 ft/n. mi during the last 15 miles of the approach trajectory. Accordingly, when the -1 degree slope is superposed on the terrain model (Run 106), the resultant terrain is relatively smooth from about 8 miles into the site. This can be seen from the curve of Fig. 21. As a result, the High-Gate errors are not unreasonably large (500 feet in altitude and 14 ft/sec in vertical velocity). This in turn leads to satisfactory site visibility, and a trajectory that is reasonably close to the specified constraints during the last 2000 feet of the approach trajectory.

(5.) The positive 1-degree slope coupled with the terrain model, on the other hand, results in a terrain slope of about 200 ft/n. mi up from the site over the last 8-10-miles of the approach. This is shown on the upper curve of Fig. 21. The High-Gate errors, as might be expected, are somewhat larger than for the negative -1 degree slope case. The numerical values are 2500 feet for altitude and 22 ft/sec for vertical velocity. The end result is an approach trajectory with a site-visibility interval significantly smaller than the nominal case, and one whose altitude and vertical velocity are significantly larger than the constraint values over the last 2000 feet of the approach phase. These undesirable trajectory characteristics are shown in Figs. 22-24.

(6.) The dead man's curve (4-sec reaction and staging delay time curve of Ref. 11) was violated at a range-to-go of 570 feet in the positive 1-degree slope test case (Run 105). The maximum permissible range-to-go for exceeding this curve has been set at 200 feet (Ref. 10).

Errors in the estimate of vehicle altitude are presented in Fig. 25 for test Run #105. Two different types of estimation errors are presented:

(1.) Local-altitude estimation error

(2.) Error in estimate of vehicle altitude relative to the site.

No initial-condition navigation errors, no IMU errors, and no LR measurement errors are present. The only error source is the deviation of local terrain altitude from that of the site.

The important point to be seen from Fig. 25 is that with the present LR altitude weighting functions, the navigation-system altitude estimates tend to follow the terrain in a very short time after the start of altitude updating (236 seconds starting time). This is evident from the local-altitude estimation-error curve. Because of the combination of the terrain III-P-11A and the +1 degree slope, however, the errors in the estimate of vehicle altitude with respect to the site become very large after the LR updating is begun, as shown in Fig. 25. As the vehicle approaches the site, this error converges toward zero.

On the basis of the data of Fig. 25 it appears that the present LR weighting functions are too large during the initial part of the updating interval (e.g. between 250-450 seconds). It should be noted, however, that down-range terminal position errors of as large as 9000 feet may occur in worst-case situations (assuming that no astronaut-initiated site redesignations are made). Under these conditions, terrain-following with large LR altitude weighting functions is desirable during the final approach phase (last few miles) to insure a safe landing.

TEST RUNS #107 AND #108: 3-SIGMA THRUST-ACCELERATION DEVIATIONS

The primary effect of 3-sigma thrust-acceleration deviations acting alone on the guidance-and-navigation system during the powered landing maneuver was a change in DPS throttle-down time. For the 3-sigma high case, the throttle-down time was about 138 seconds before High-Gate. The required ΔV in this case was 6490 ft/sec, which is 14 ft/sec above the nominal case. For the 3-sigma low case, the throttle-down time was about 44 seconds before High-Gate, which is felt to be reasonable in the absence of navigation errors and terrain altitude variations.

In both of these test runs, the High-Gate aim conditions were accurately met. Accordingly, the visibility-phase trajectory characteristics were similar to those for the nominal trajectory.

TEST RUNS #109 AND #110: WORST-CASE RUNS

The final two runs of the series given in Table 1 are intended to represent extremely difficult situations for the guidance-and-navigation system. These runs include initial-condition error-vector #1191, 3-sigma IMU errors, 3-sigma thrust-acceleration deviations, and terrain profile III-P-11 combined with a 1-degree slope. No LR measurement errors are assumed in these runs.

In the first run of this set, i.e. Run #109, where the vehicle was initially high (error-vector -#1191) and the terrain was low relative to the site (-1 degree slope), no LR updatings were obtained throughout the entire landing maneuver. As a result of this, the landing was not successful, with the vehicle still 13000 feet above the site at the end of the visibility phase. It should be noted here that the range beam maintained track during the last 80 seconds of the braking phase and throughout most of the visibility phase. The reason that no altitude measurements were taken is that the rear velocity beams were dropped out for essentially the entire landing maneuver.

In the second run of this set, i.e. Run #110, where the vehicle was initially low (error-vector #1191) and the terrain was high relative to the site (11 degree slope), the landing was accomplished in a much more successful manner than in the other run (#109). One reason for this is that with the vehicle low and the terrain high, LR updating is obtained early in the braking phase as shown in Fig. 27. The corrective action taken by the guidance system after the initial updatings is to pitch the vehicle up initially, as shown in Fig. 26. This orients the radar beams more favorably with respect to the dropout boundaries and, in fact, even permits some velocity updating during the braking phase, as indicated in Fig. 27. The present velocity weighting functions, however, have zero values during the period that the beams are locked on here (speed greater than 1800 ft/sec). Vertical-velocity estimation errors of the order of 35 ft/sec occur at the end of the braking phase.

In this particular case the High-Gate vertical-velocity and altitude errors were -76 ft/sec and 471 ft. One reason for this is that with a low value of thrust, it was not possible to reduce the command thrust below the throttle-down level before time-to-go was less than 30 seconds in the braking phase. As soon as the time-to-go dropped below 30 seconds, the DPS was automatically throttled-down for the remainder of the braking phase. In spite of the High-Gate errors, the visibility phase of the trajectory appears to be satisfactory. The visibility interval is as on the nominal trajectory. The terminal trajectory is somewhat shallower than the nominal case, as can be seen in Fig. 28, but the 4-second dead man's curve is not violated until the vehicle is about 100 feet down-range from the site.

LR dropout in Run 110 occurs about 23 seconds before the end of the visibility phase. The resultant Low-Gate altitude error is 21 feet.

REFERENCES

(1.) Kriegsman, B., "Notes from Powered Descent Technical Interchange Meeting at MSC on April 10, 1968", MIT Instrumentation Lab Memo, April 22, 1968.

(2.) LUMINARY GSOP Section 5, Guidance Equations, MIT Instrumentation Lab Report R-567, January 1968.

(3.) Kriegsman, B., and Gustafson, D., "Powered-Landing Maneuver Simulation Runs with New LR Dropout Boundary and Terrain Models", MIT Instrumentation Lab Mission Simulation Memo #17-68, April 26, 1968.

(4.) Kriegsman, B., and Gustafson, D., "Recent Studies on LM Powered-Landing Guidance and Navigation System", MIT Instrumentation Lab 504 Mission Simulation Memo #15, April 5, 1968.

(5.) Alphin, J., Taylor, B., and Kirkland, B., "LM Powered Descent Trajectory for the Apollo Lunar Landing Mission", MSC Internal Note No. 68-FM-78, March 29, 1968.

(6.) Gustafson, D., "Ignition Computations for the LM Powered Landing Maneuver", MIT Instrumentation Lab Memi No.

(7.) Kriegsman, B., and Gustafson, D., "Lunar Terrain and LR Dropout Boundary Models for Lunar Landing Simulations", MIT Instrumentation Lab Apollo Mission Simulation Memo No. 21, June 18, 1968.

(8.) Dyer, D., "A Simplified LM Landing Radar Operating Boundary Model", MSC Internal Note No. 67-EG-35, December 5, 1967.

(9.) Kriegsman, B. and Sears, N., "LEM PGNCS and LR Operation During the Powered Landing Maneuver", MIT Instrumentation Lab Report E-1982, August 1966.

(10.) Kelly, W.R., "Trajectory Constraints to Be Used in Design of Guidance Equations for the Region between the High-Gate and Hover Aim Point", NASA MSC G& C Memo EG27-72-67, June 27, 1967.

(11.) Bolt, W., and Bennett, F., "Mission Planning Charts for Targeting Final Approach Phase of LM Powered Descent", NASA Memo 67-FM61-40, April 7, 1967.

(12.) Bolt, W., "Trajectories to Meet LM Descent Low-Gate Conditions, NASA Memo 67-FM62-93, June 30, 1967.

TABLE 1: LANDING SIMULATION TEST RUNS

PURPOSE	Run No.	Initial Errors	IMU Errors	Terrain Vars.	Terrain Slope	Thrust Acc. Dev
(1.) Nominal	100	No	No	Smooth	0	0
(2.) Initial-Condition Errors Alone	102	+#1191	No	Smooth	0	0
	103	-#1191	No	Smooth	0	0
(3.) Terrain Variations Alone	104	No	No	III-P-11A	0	0
	105	No	No	III-P-11A	+1 deg.	0
	106	No	No	III-P-11A	-1 deg.	0
(4.) Thrust Accelerations Alone	107	No	No	Smooth	0	3-σ High
	108	No	No	Smooth	0	3-σ Low
(5.) Worst-Case Runs	109	-#1191	3-σ Neg	III-P-11A	-1 deg.	3-σ High
	110	+#1191	3-σ Pos	III-P-11A	+1 deg.	3-σ Low

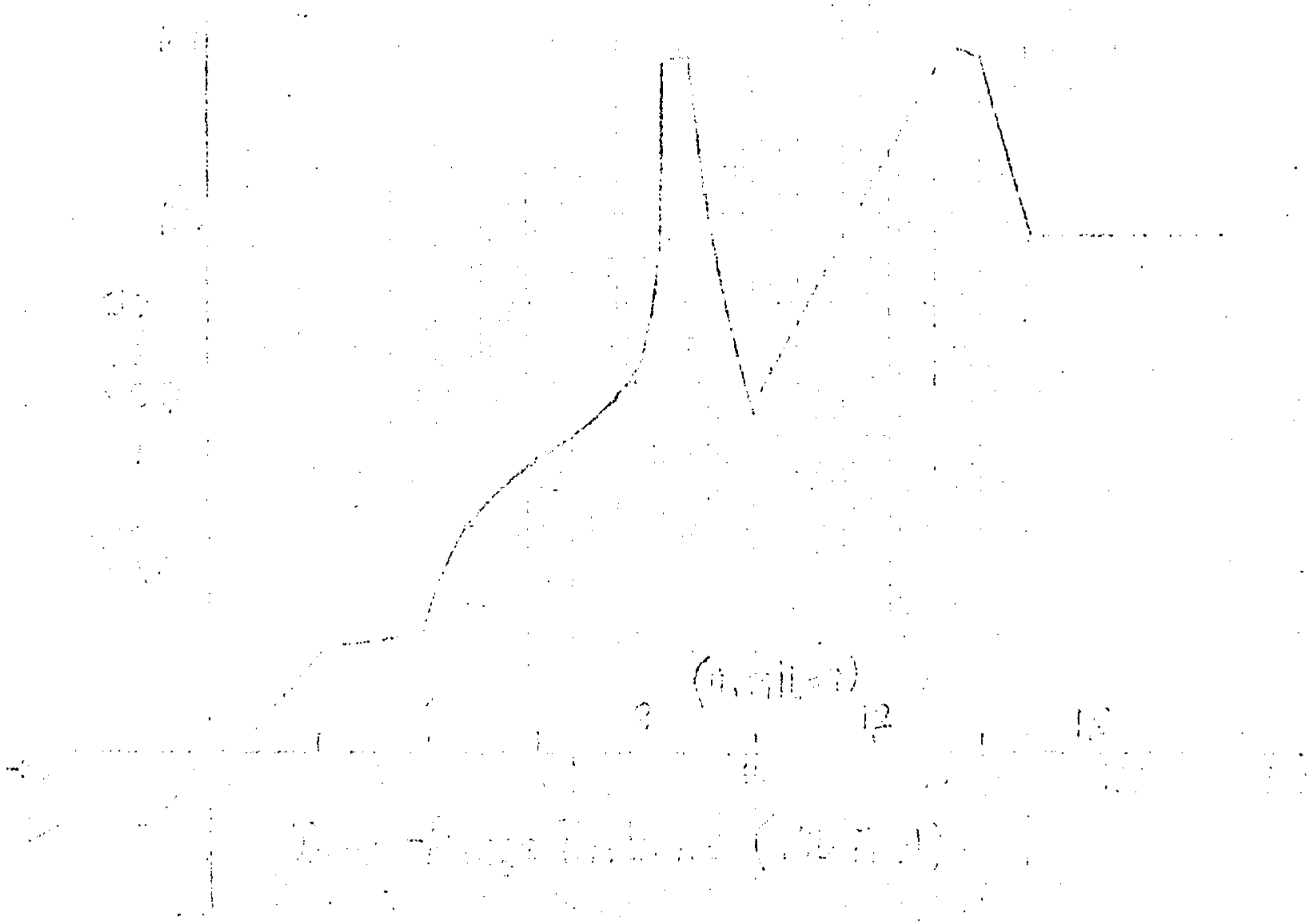


Fig. 2: Thrust Vector Elevation and Magnitude

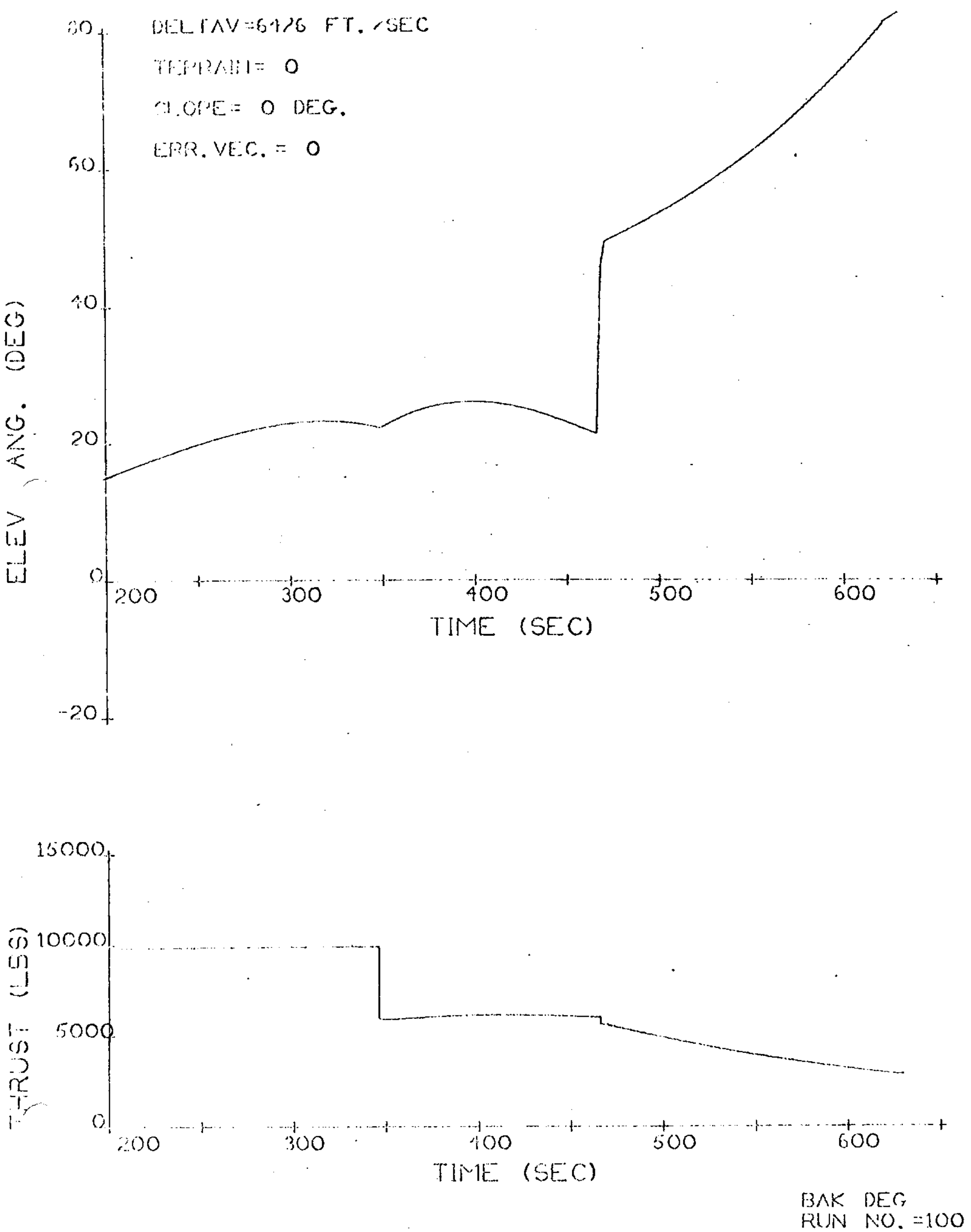


Fig. 3: Displacement of LR Beams from Dropout Boundaries

Beam #1 = o--o--o
Beam #2 = ·--·--·
Beam #3 = +--+--+
Beam #4 = ———

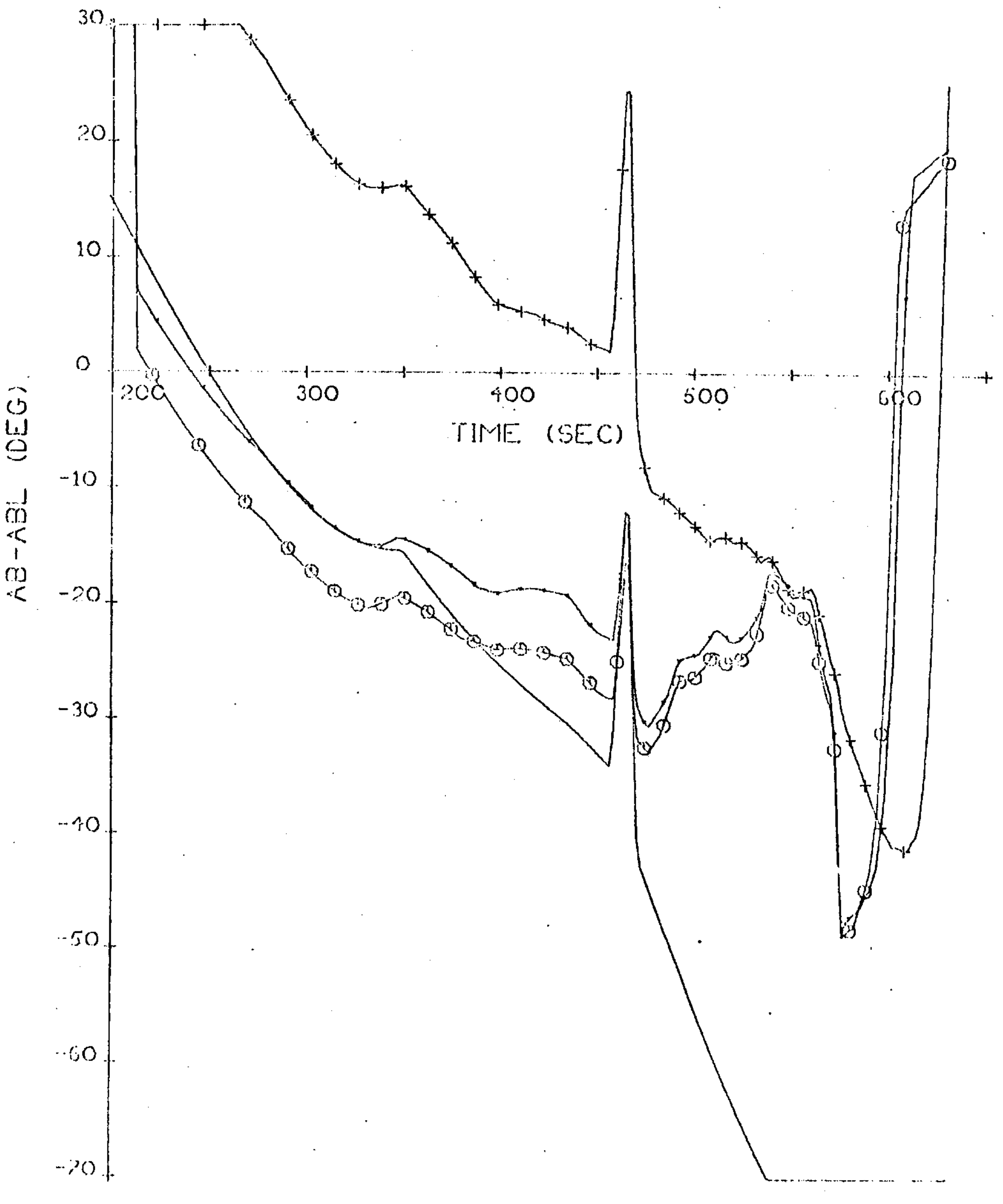


Fig. 4: Computed Visibility Angle ($90-\theta_{el}$ in deg.)

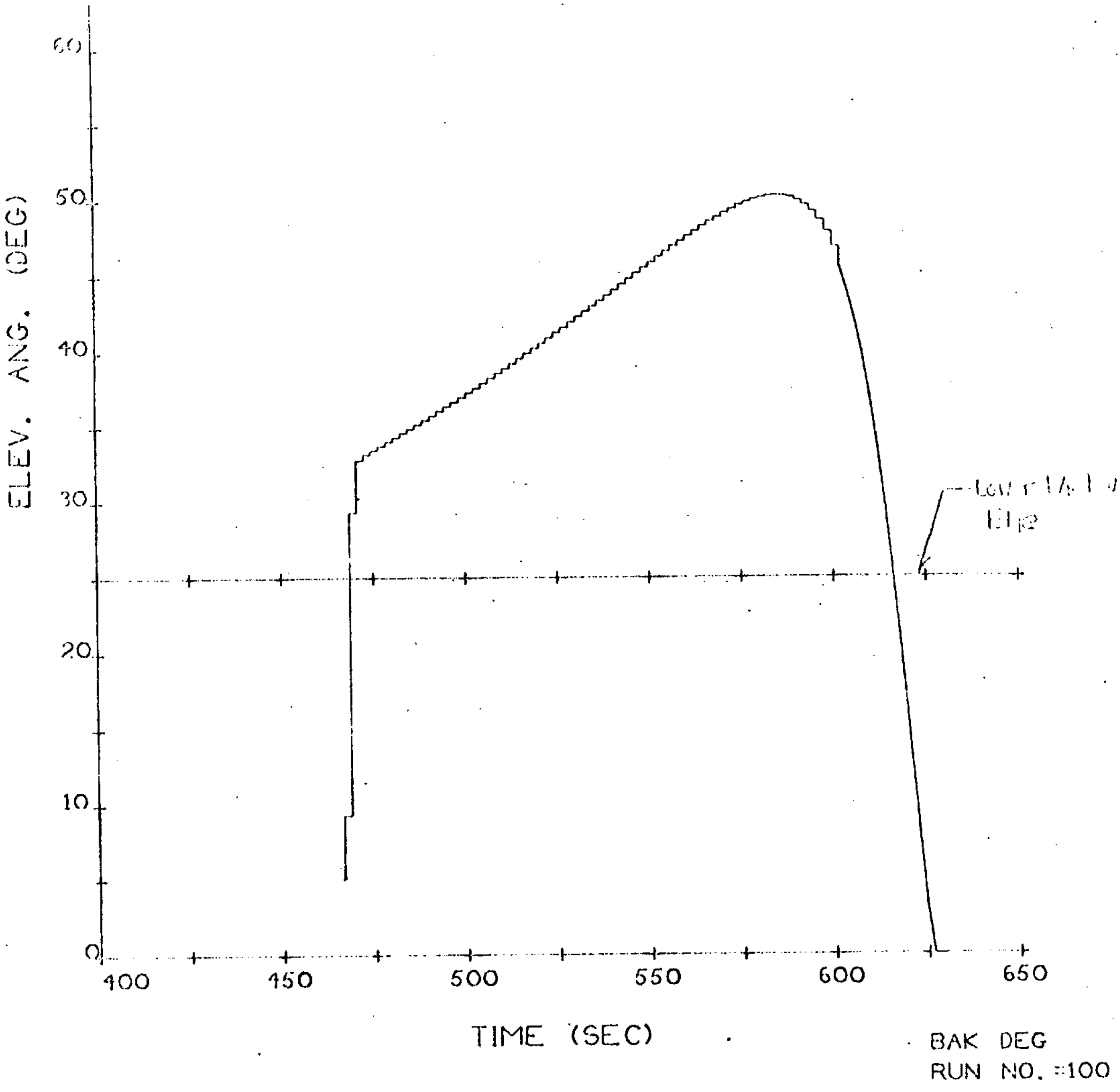


Fig. 5: Altitude vs. Range to Site

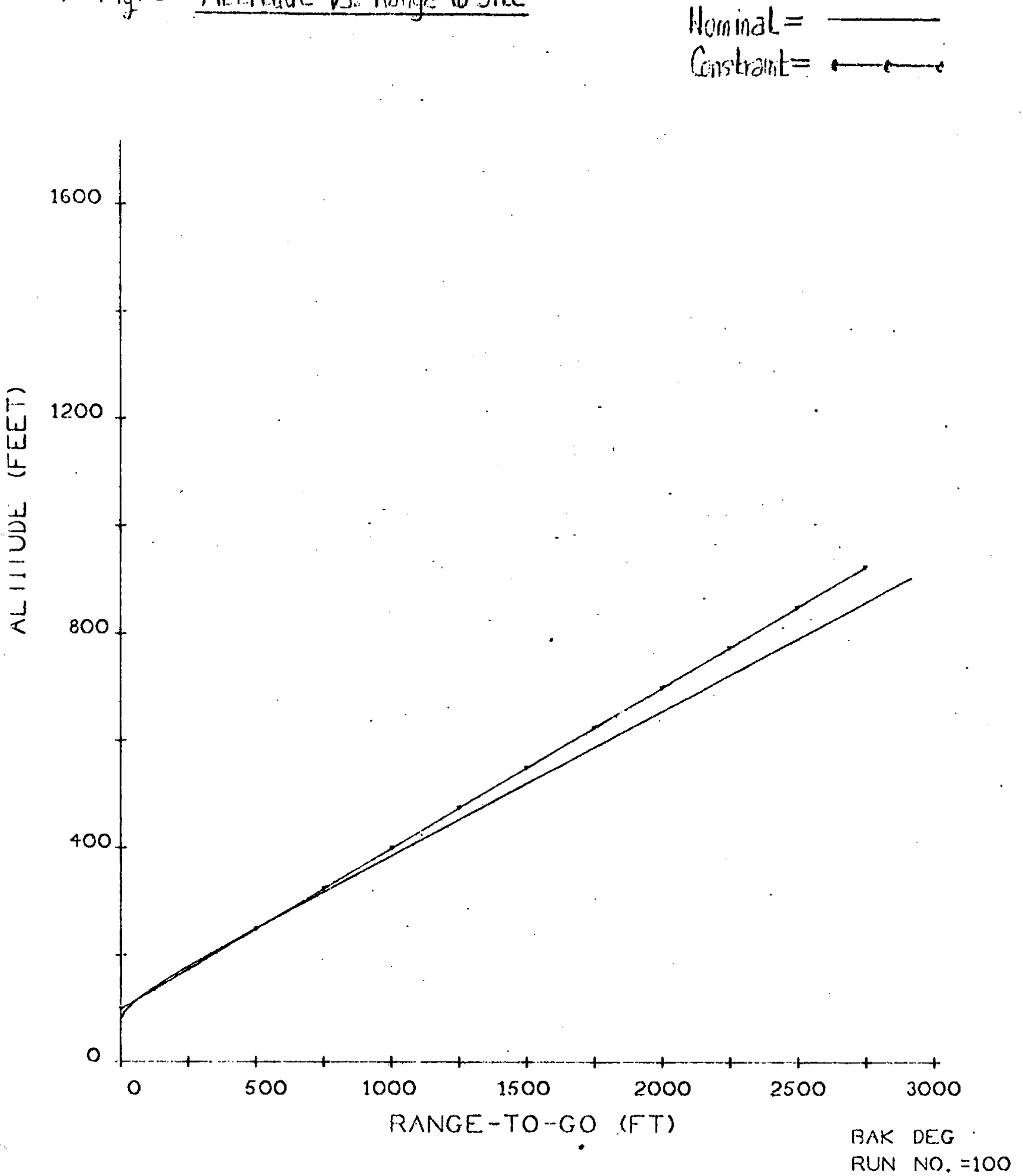


Fig. 6: Vertical Velocity vs. Range to Site

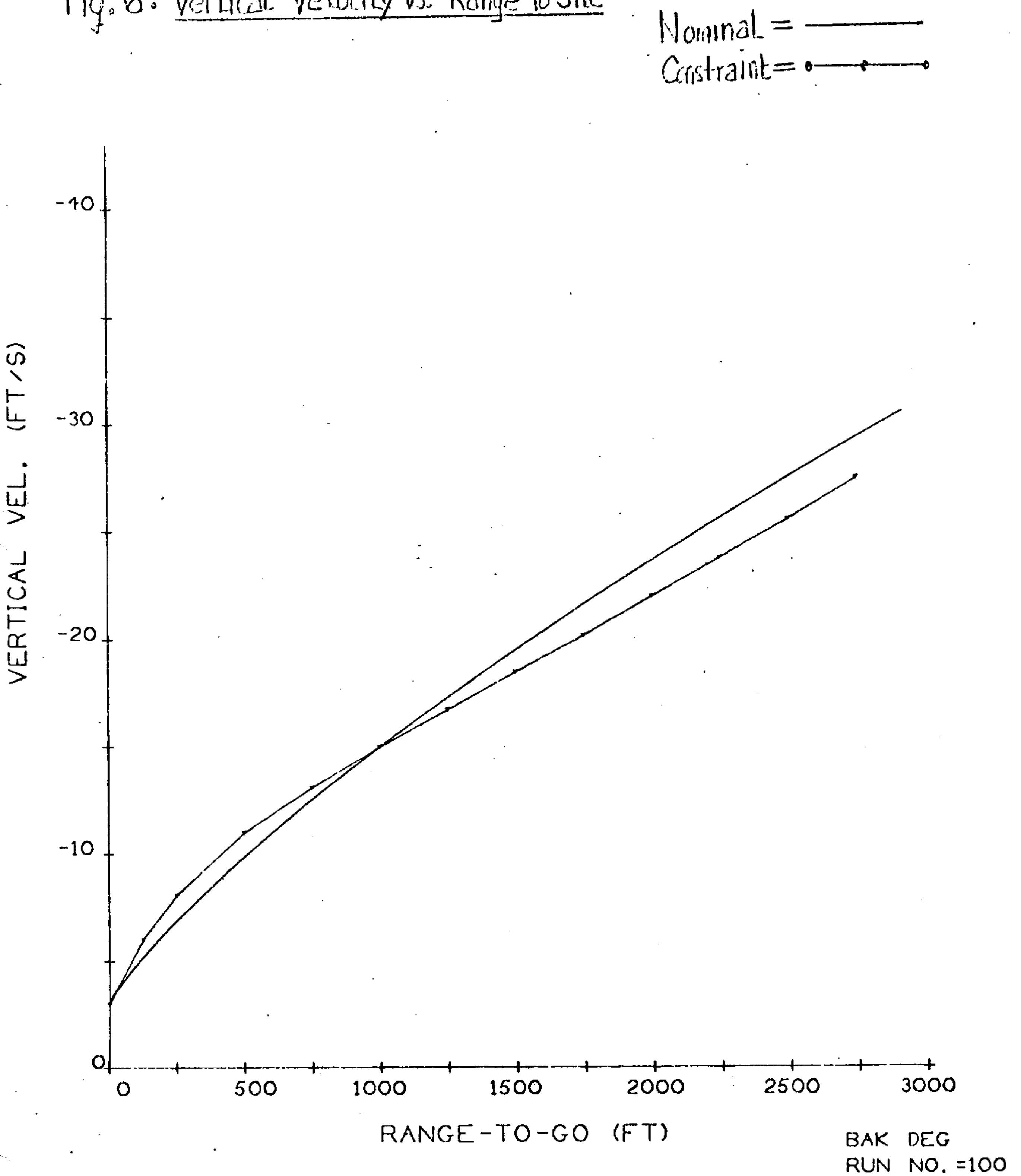


Fig. 7: Horizontal Velocity vs. Range to Site

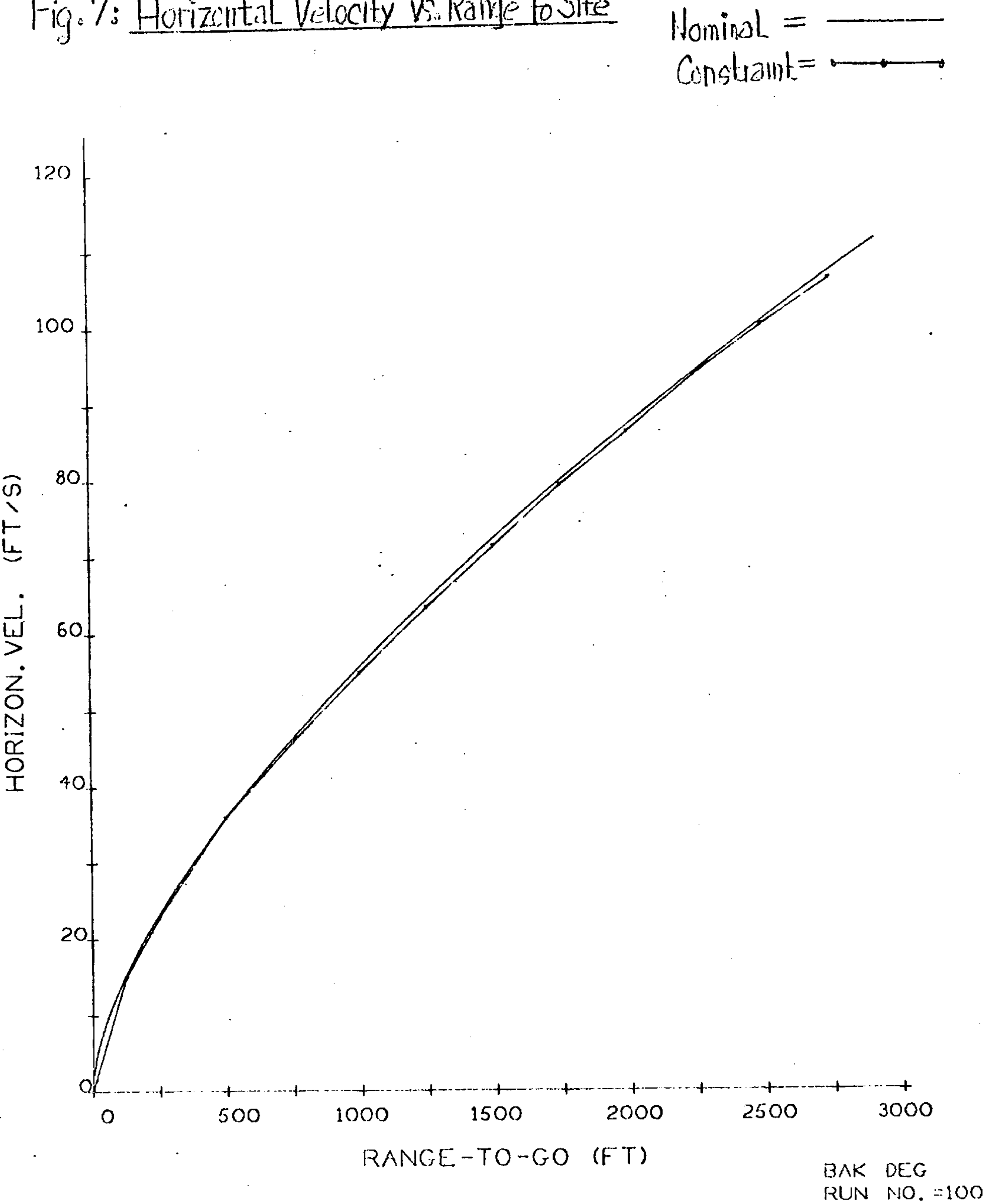
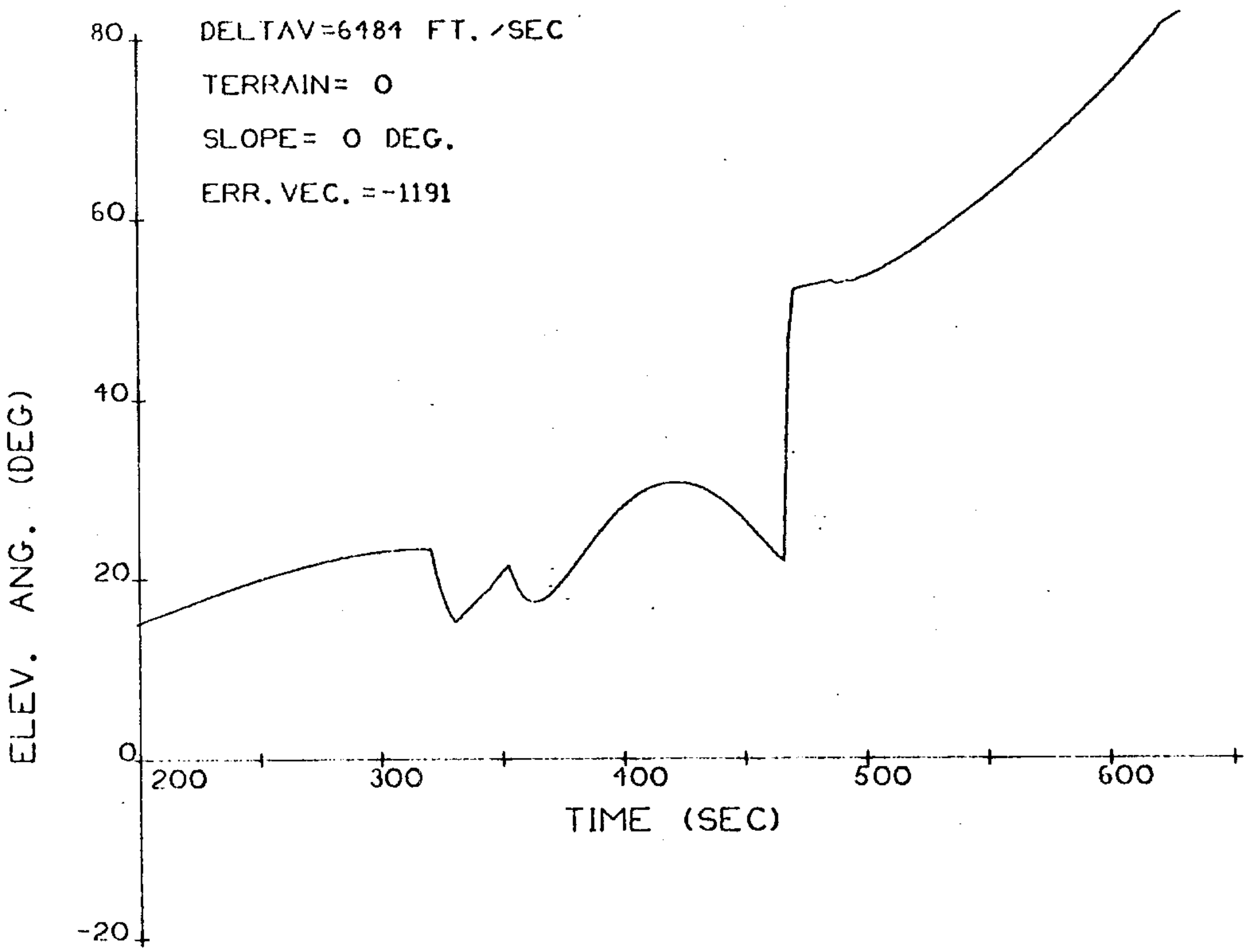


Fig 8: Thrust Vector Elevation and Magnitude

Large initial error--- —#1191   Run 103



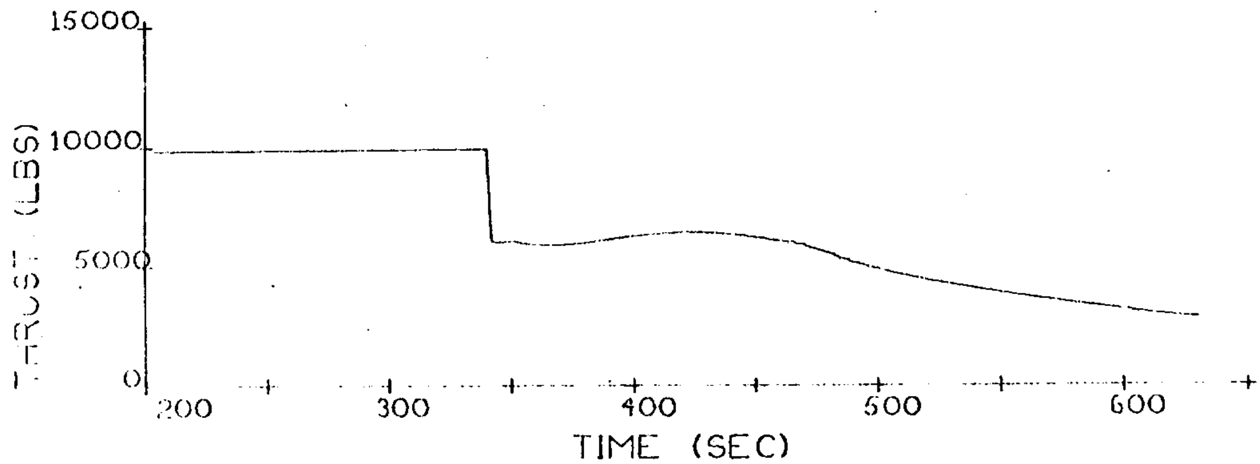


Fig. 9: Displacement of LR Beams from Dropout Boundaries

Large Initial Error --- #1191 Run 103

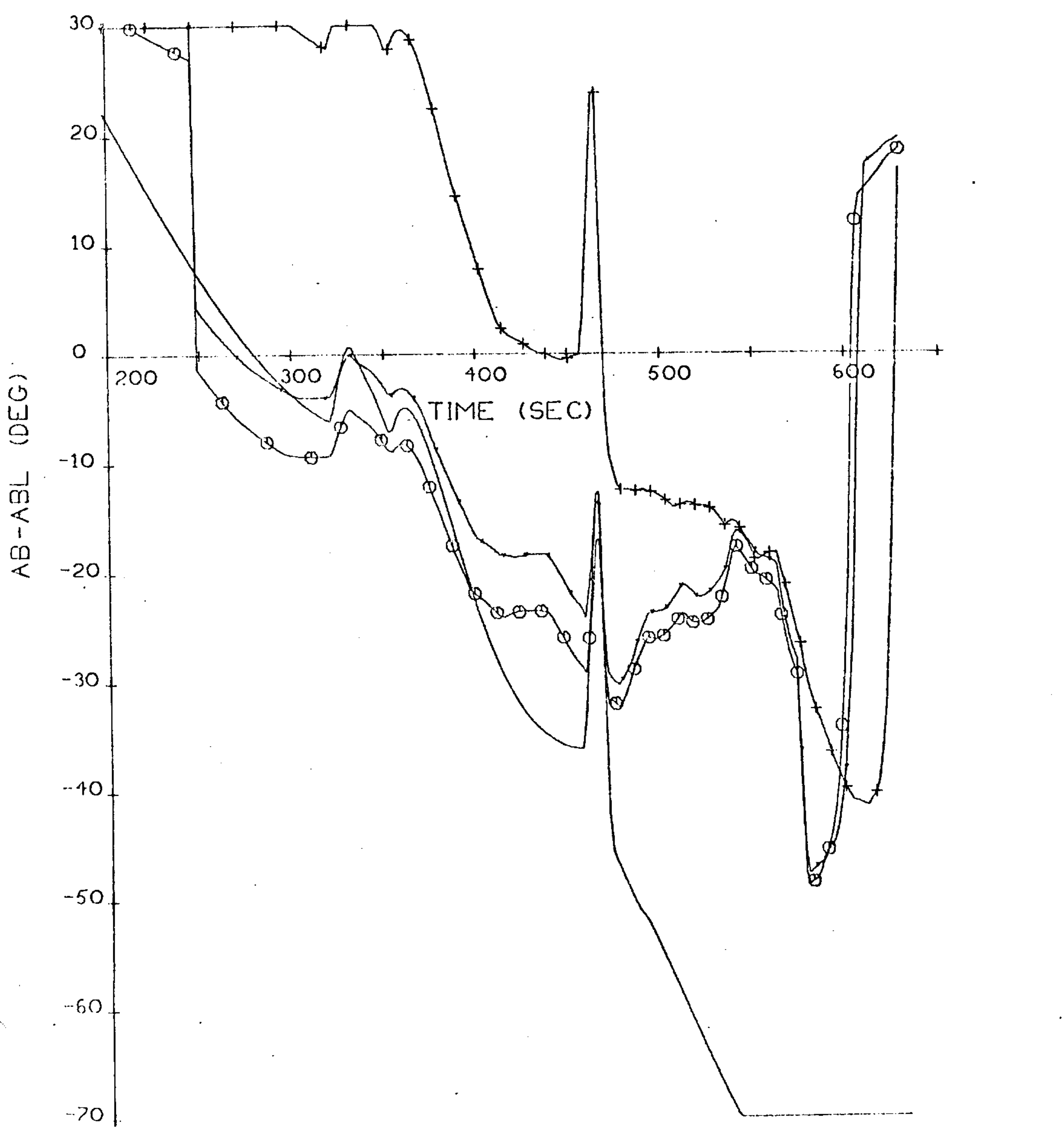


Fig. 10: Altitude Undershoots vs. Braking-Phase Time-to-Go ---- Initial Condition Errors Only

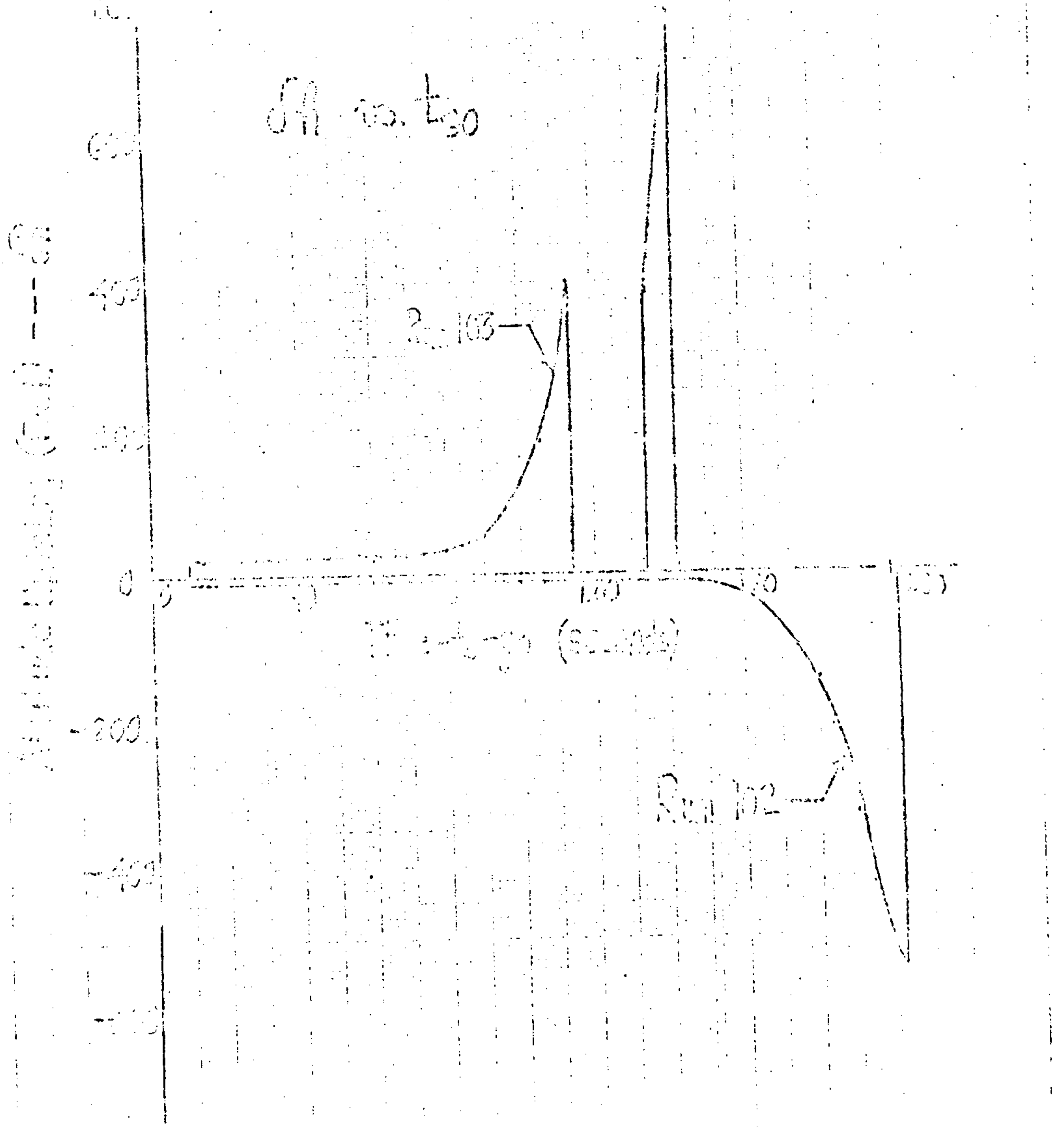


Fig. 11: Attitude Estimation Errors vs. Braking Phase Time-to-Go ----- Initial Condition Errors Only

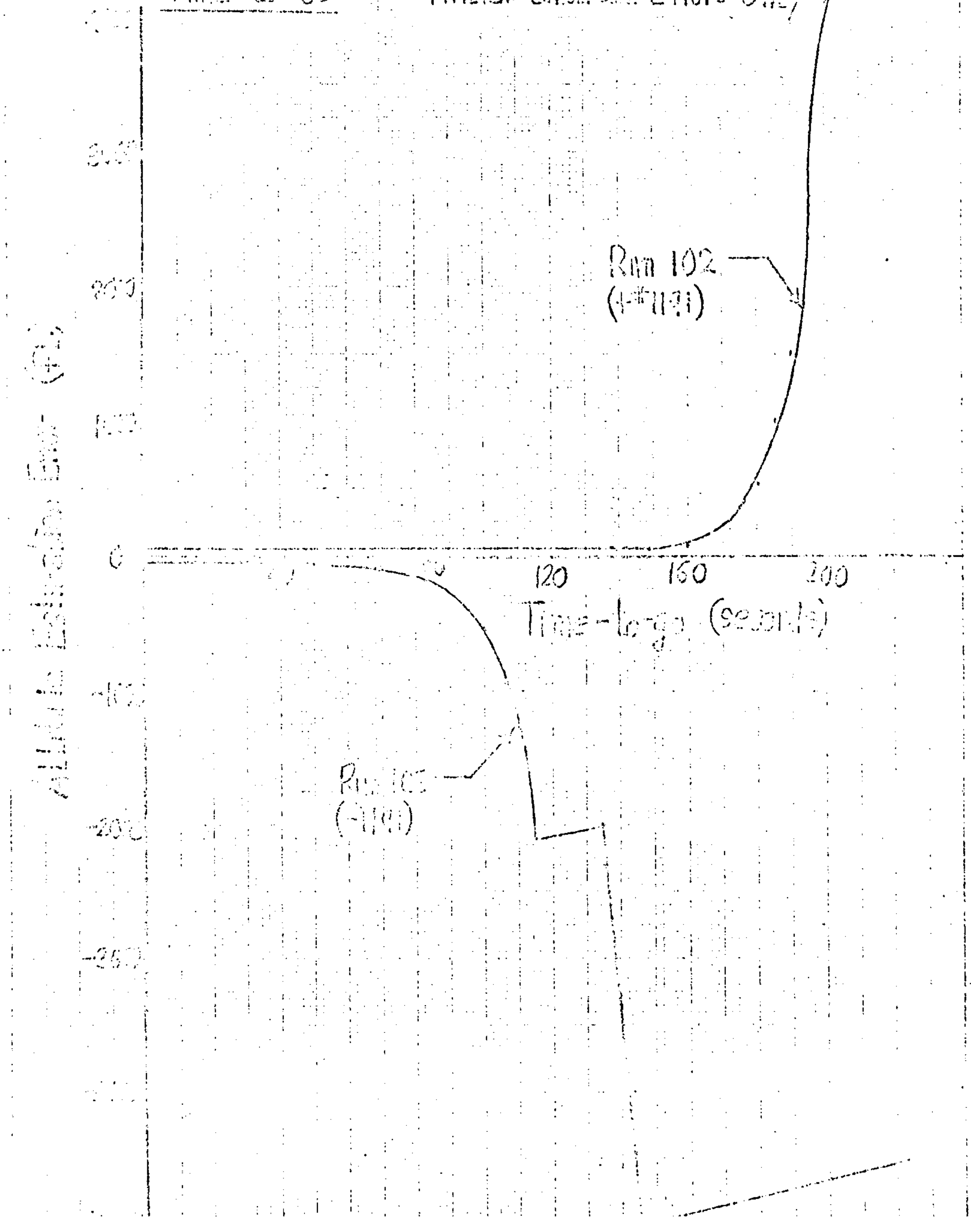


Fig. 12: Thrust-Vector Elevation and Magnitude

Terrain Variations Only --- Run 104

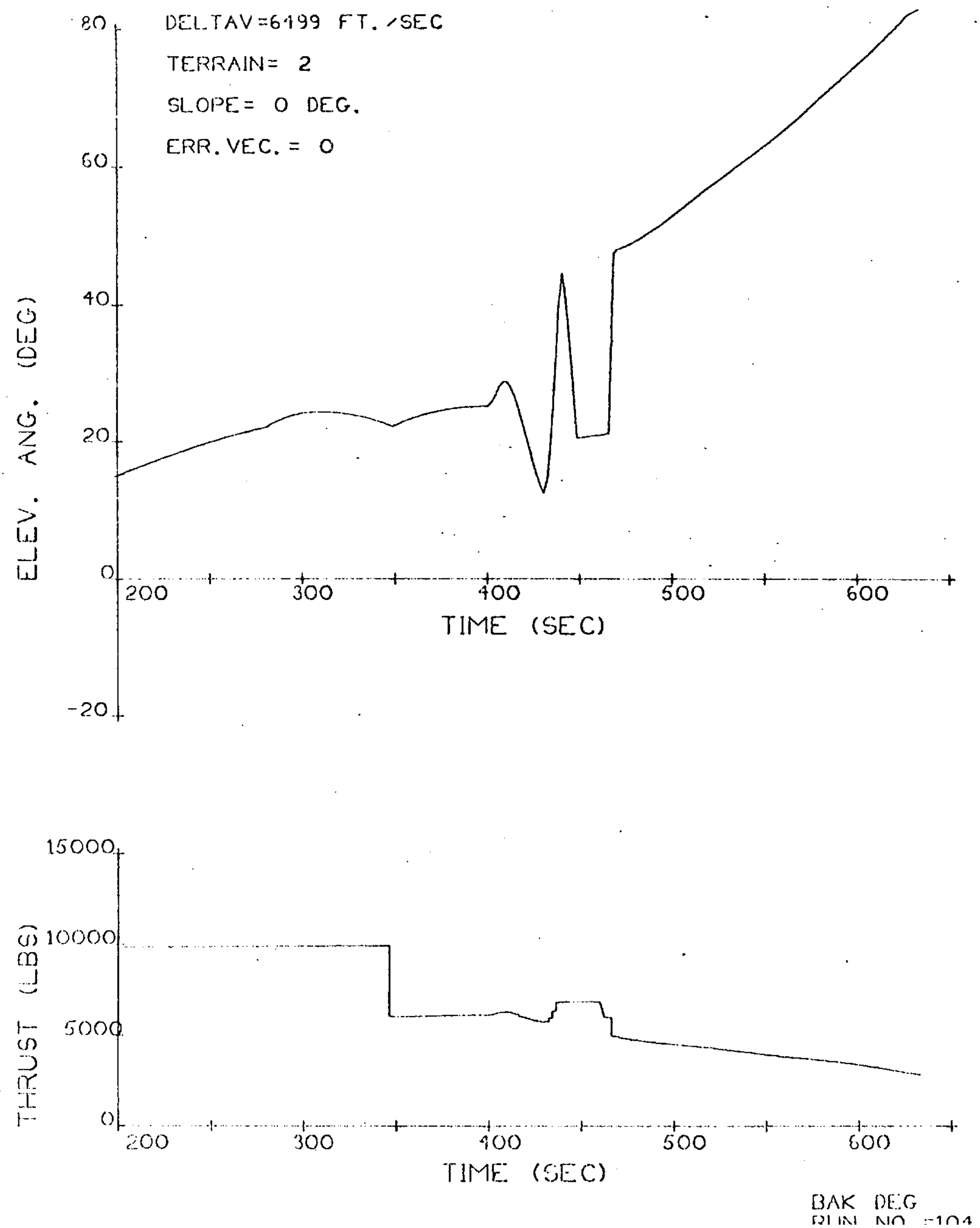
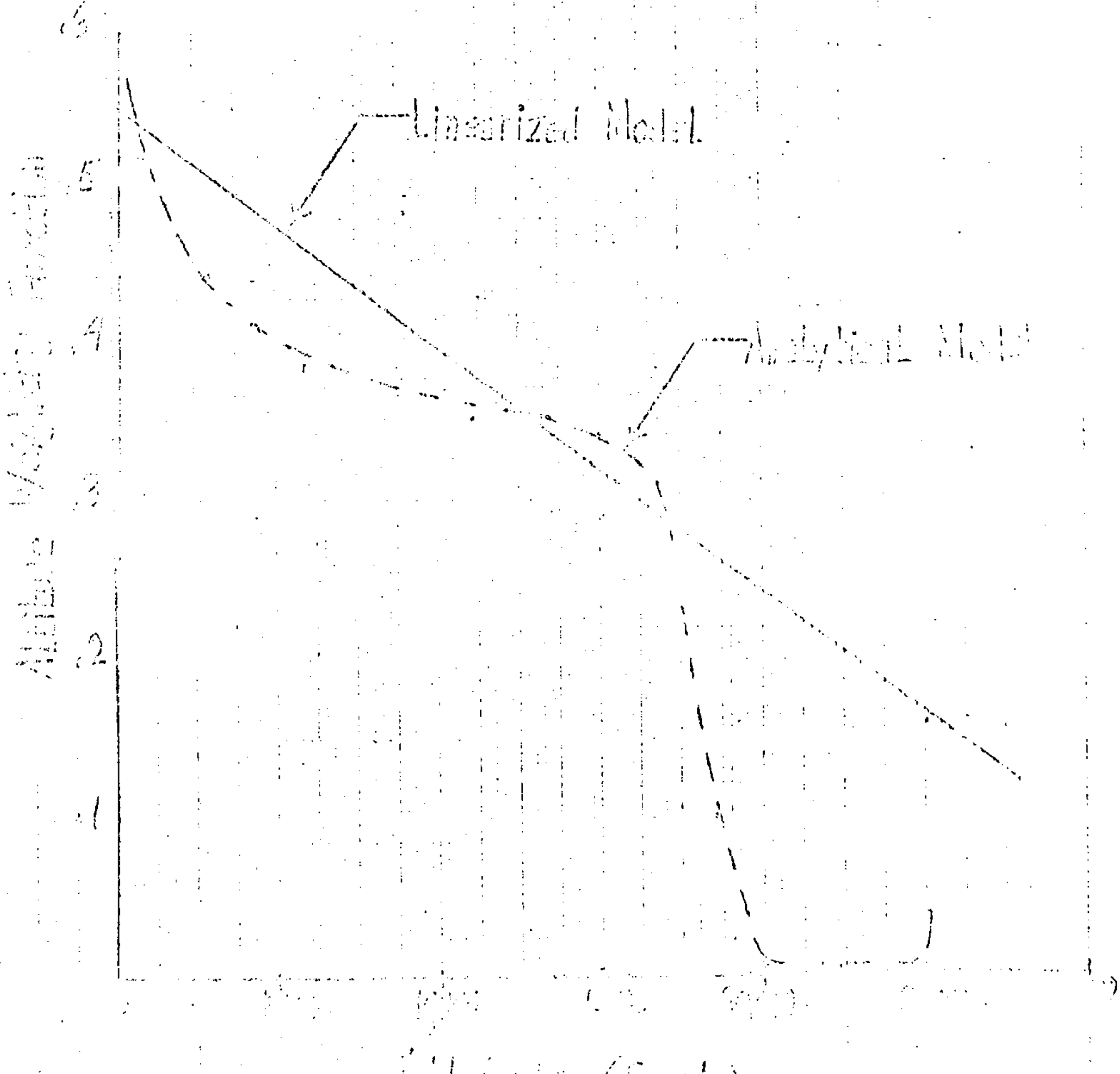


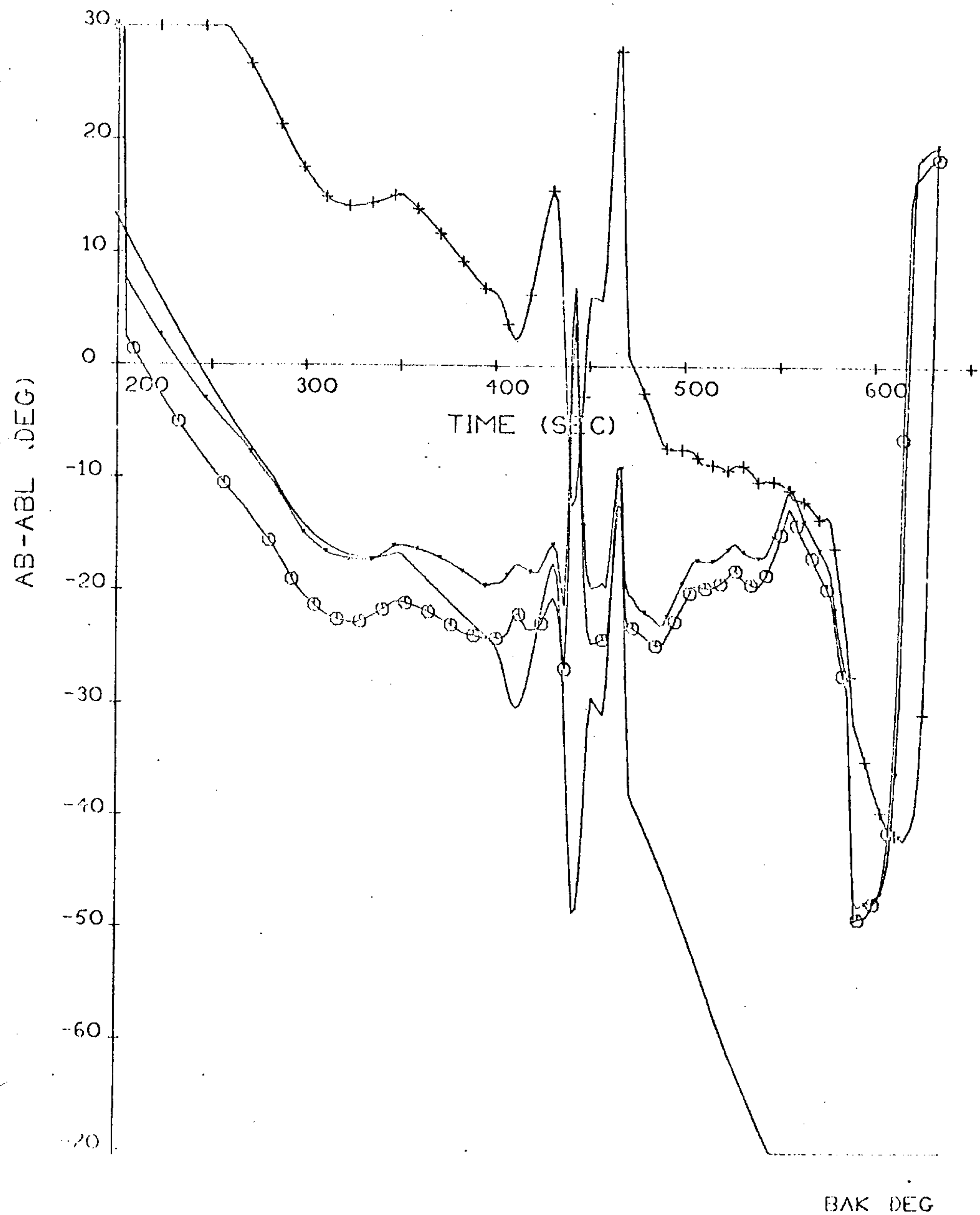
Fig. 13: Current Attitude Weighting Functions.



...ment of ER Beams from Dropout Boundaries

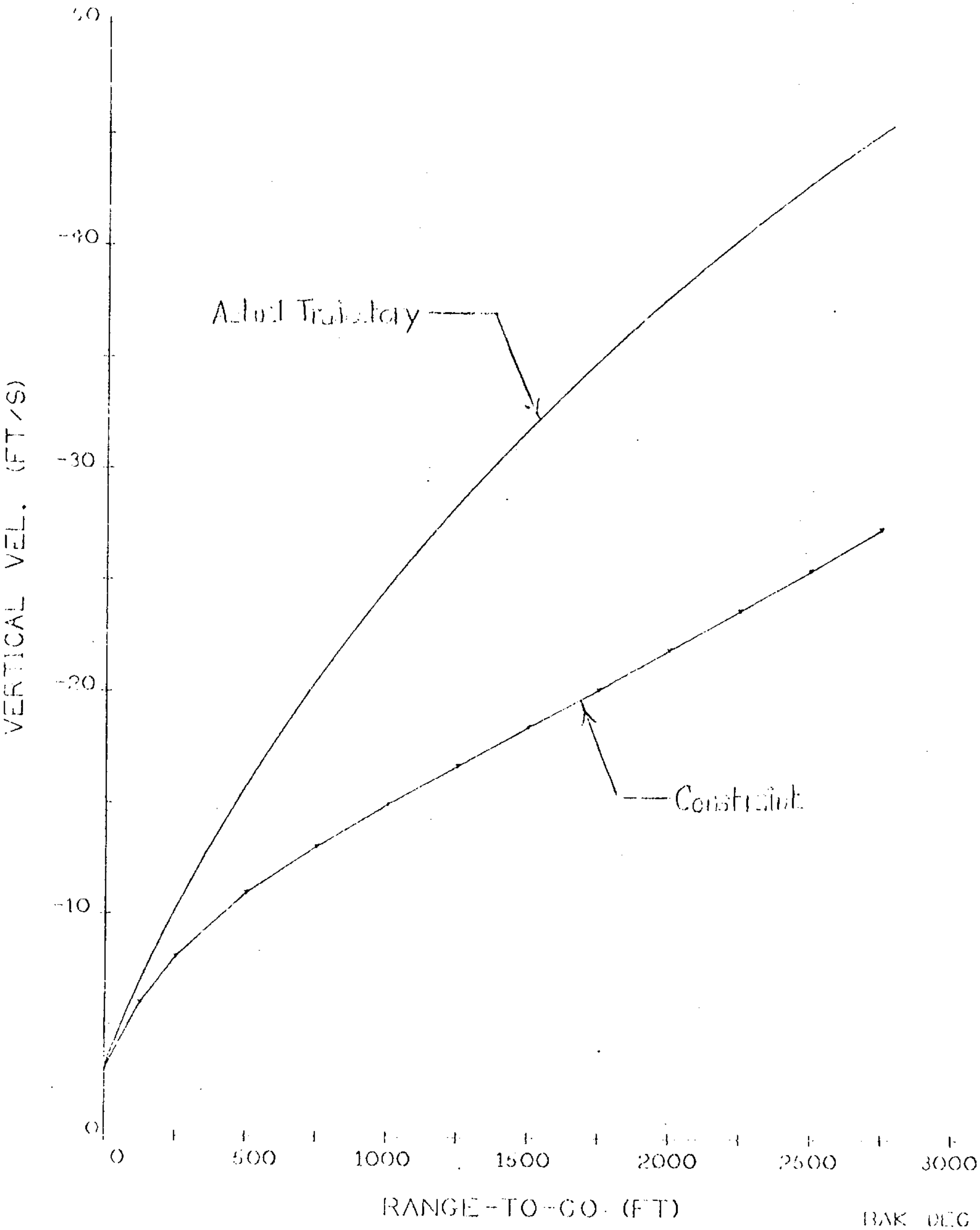
Terrain III-P-II Profile A, No Slope   Run 104

Beam #1 = o—o
Beam #2 = •—•
Beam #3 = +—+
Beam #4 = ------



Vertical Velocity vs. Range-to-Go

Terrain III P-11 Profile A Run 104



BAK OEC
RUN NO. 104

Fig. 16: Altitude vs. Range-to-Go

Terrain III-P-11   Run 104

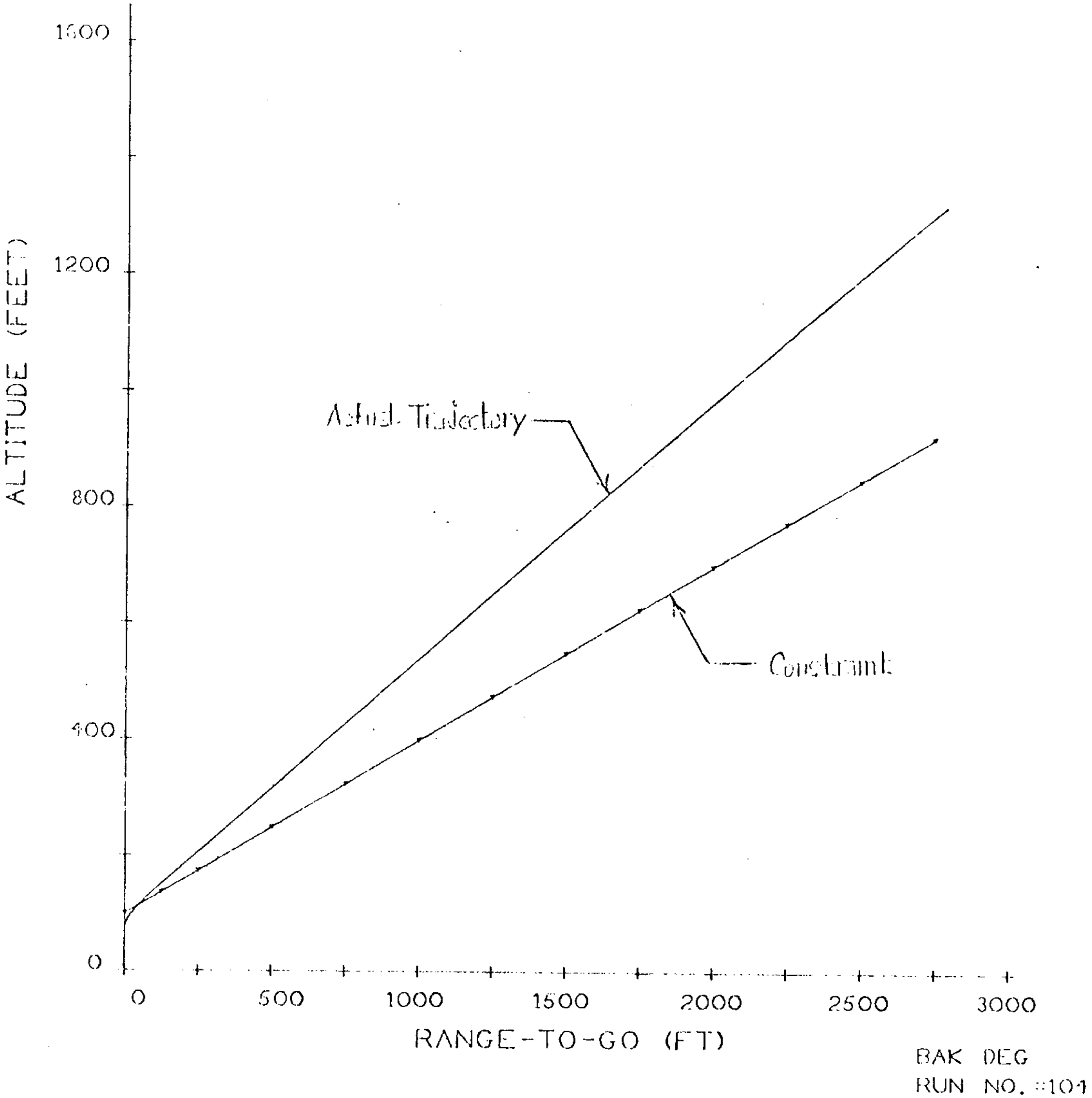
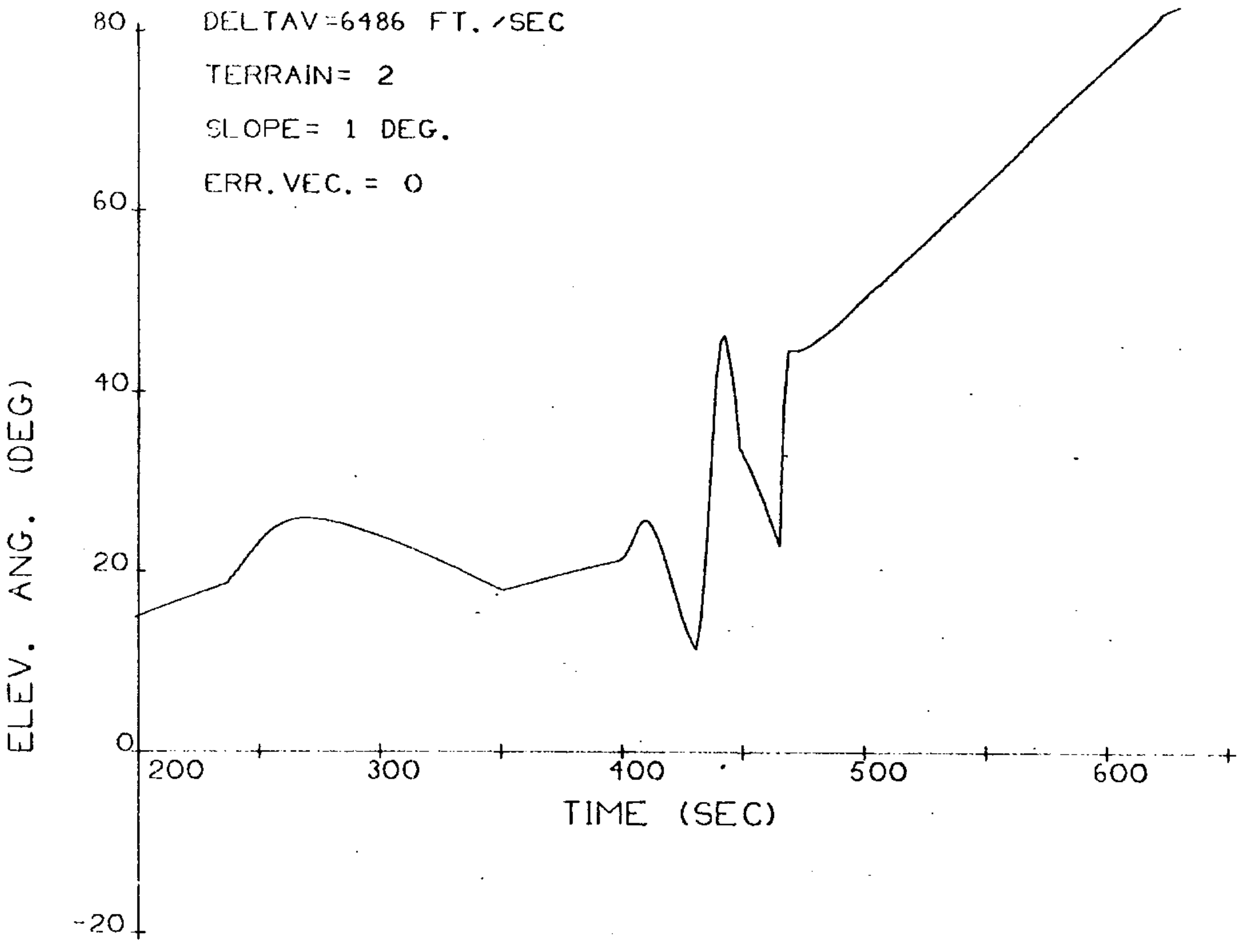
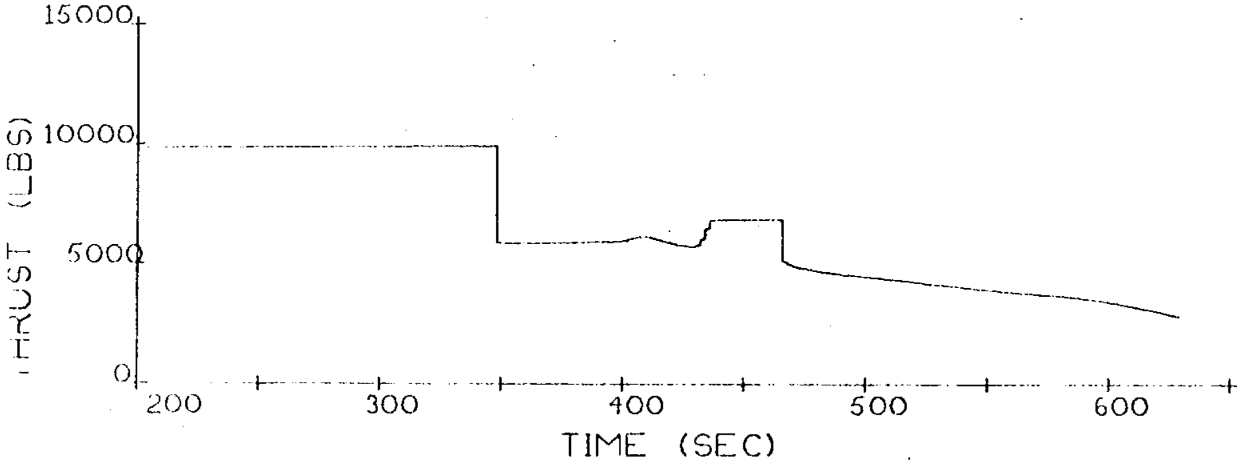


Fig. 17: Thrust-Vector Elevation and Magnitude

Terrain III-P-IIA : +1 Deg. Slope

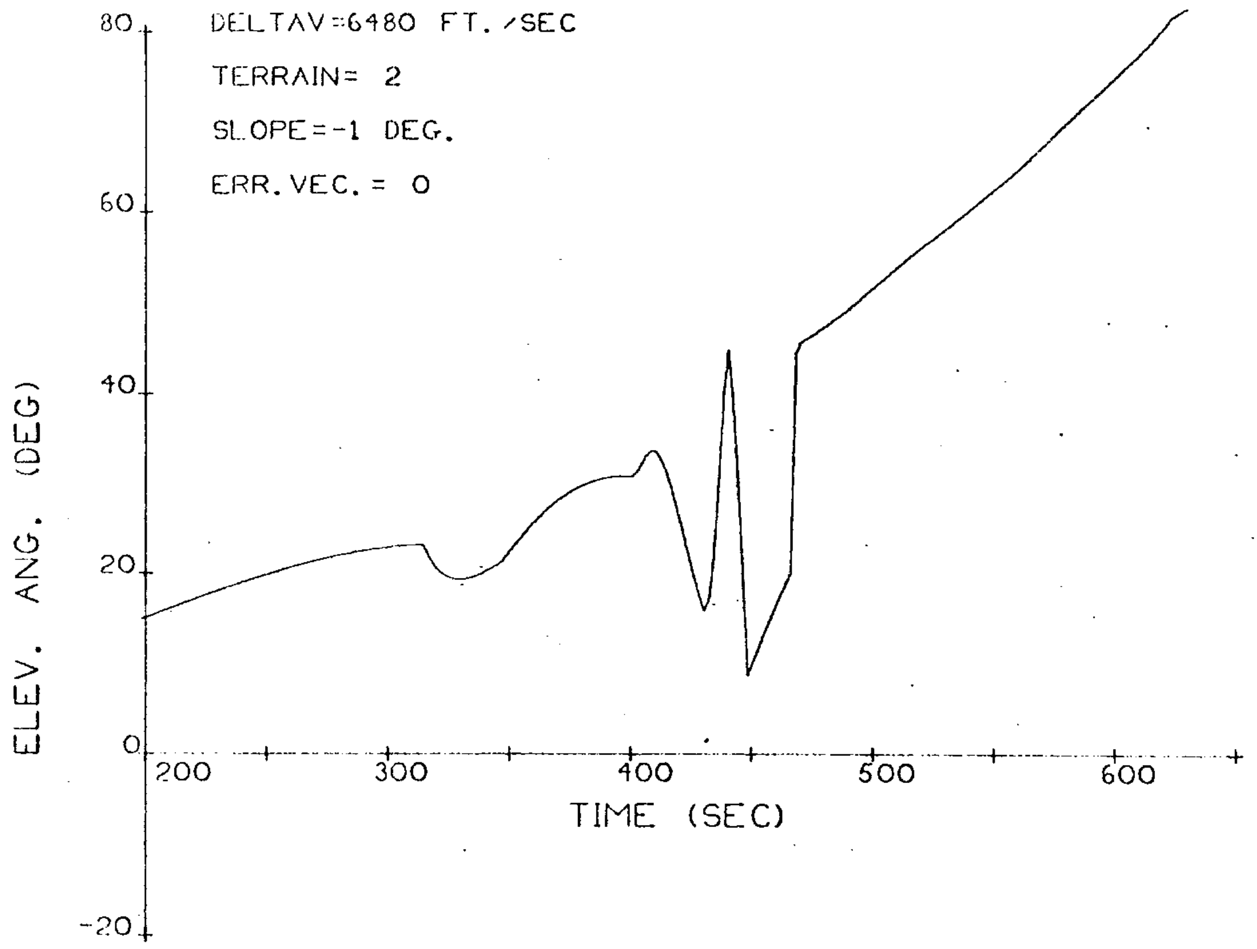




BAK DEG
RUN NO. =105

Fig. 10: Thrust Vector Elevation and Magnitude

Terrain III-P-11A : −1 Deg. Slope



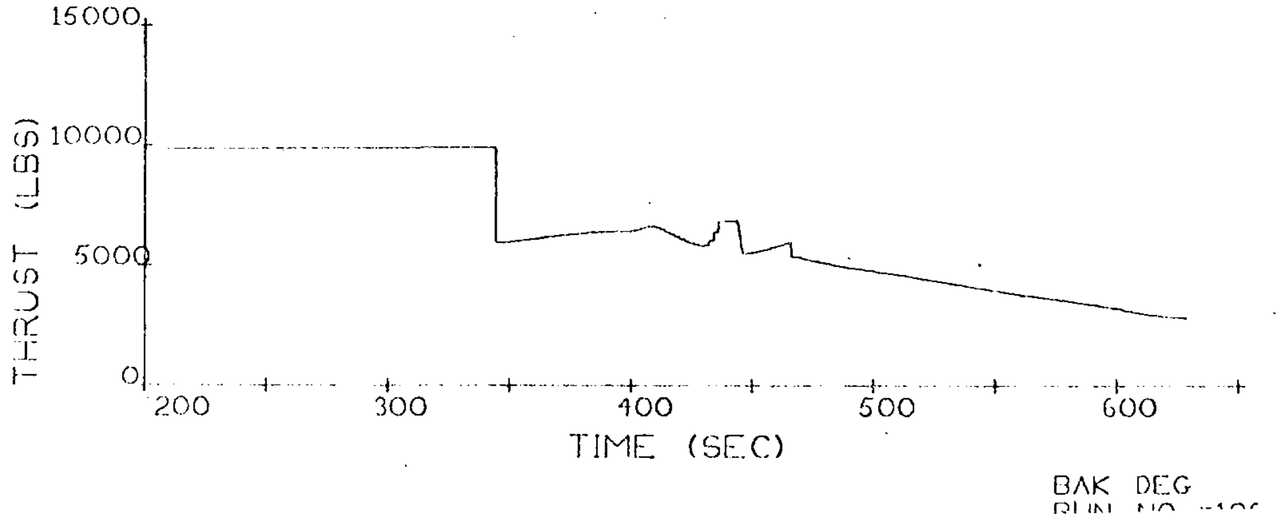
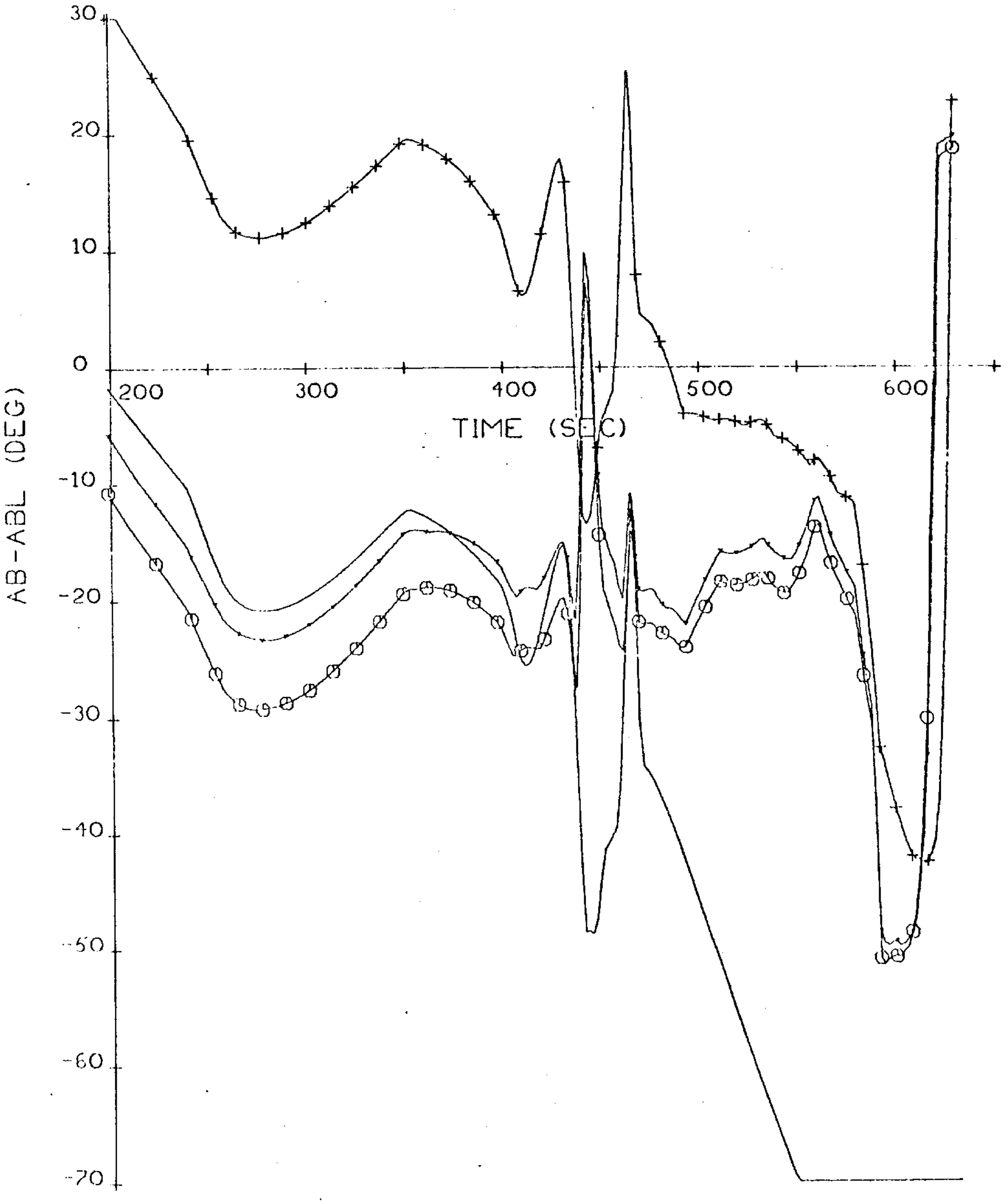


Fig 14: Displacement of LR Beams from Dropout Boundaries

Terrain III-P-II Profile A: +1 Degree Slope (terrain high)

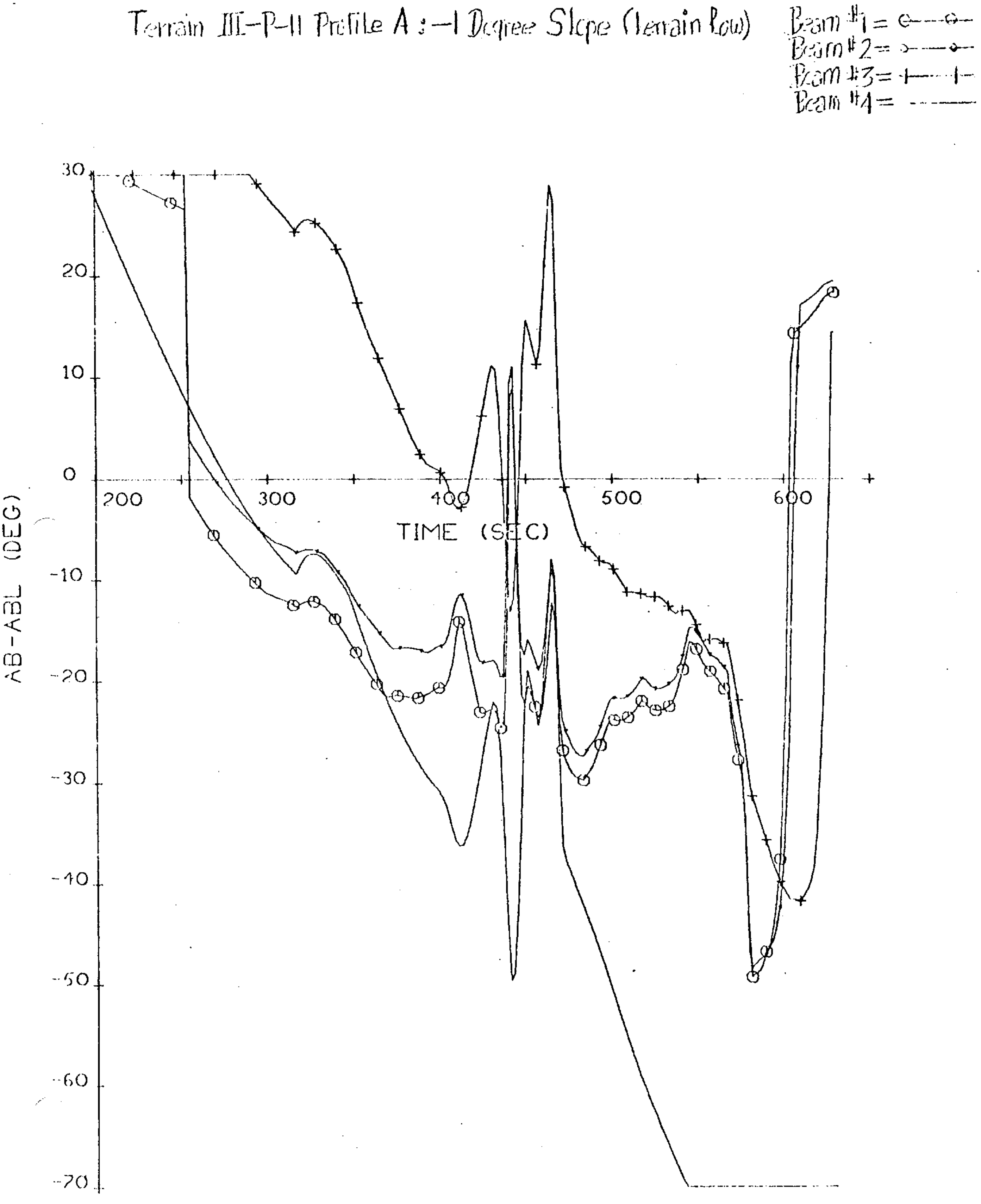
Beam #1 = o
Beam #2 = o-
Beam #3 = +
Beam #4 = --



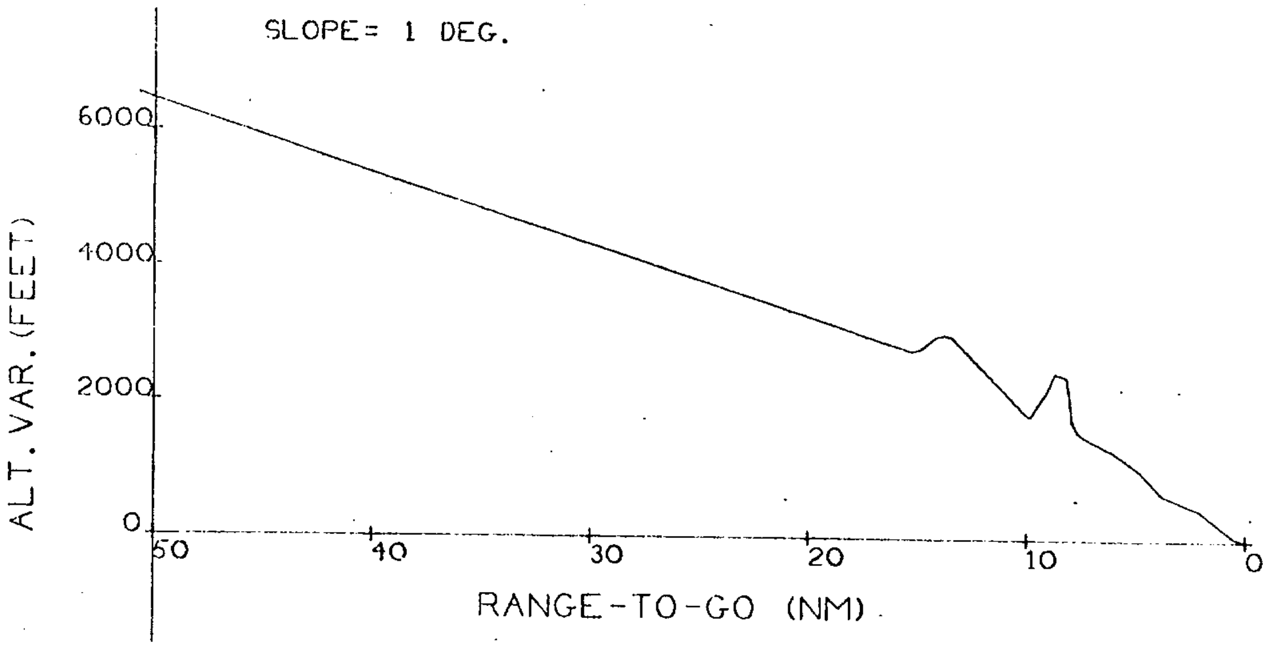
RAK DEC

Displacement of LR Beams from Dropout Boundaries

Terrain III-P-II Profile A: -1 Degree Slope (Terrain Low)



[illegible] Combined With 1-Degree Slopes



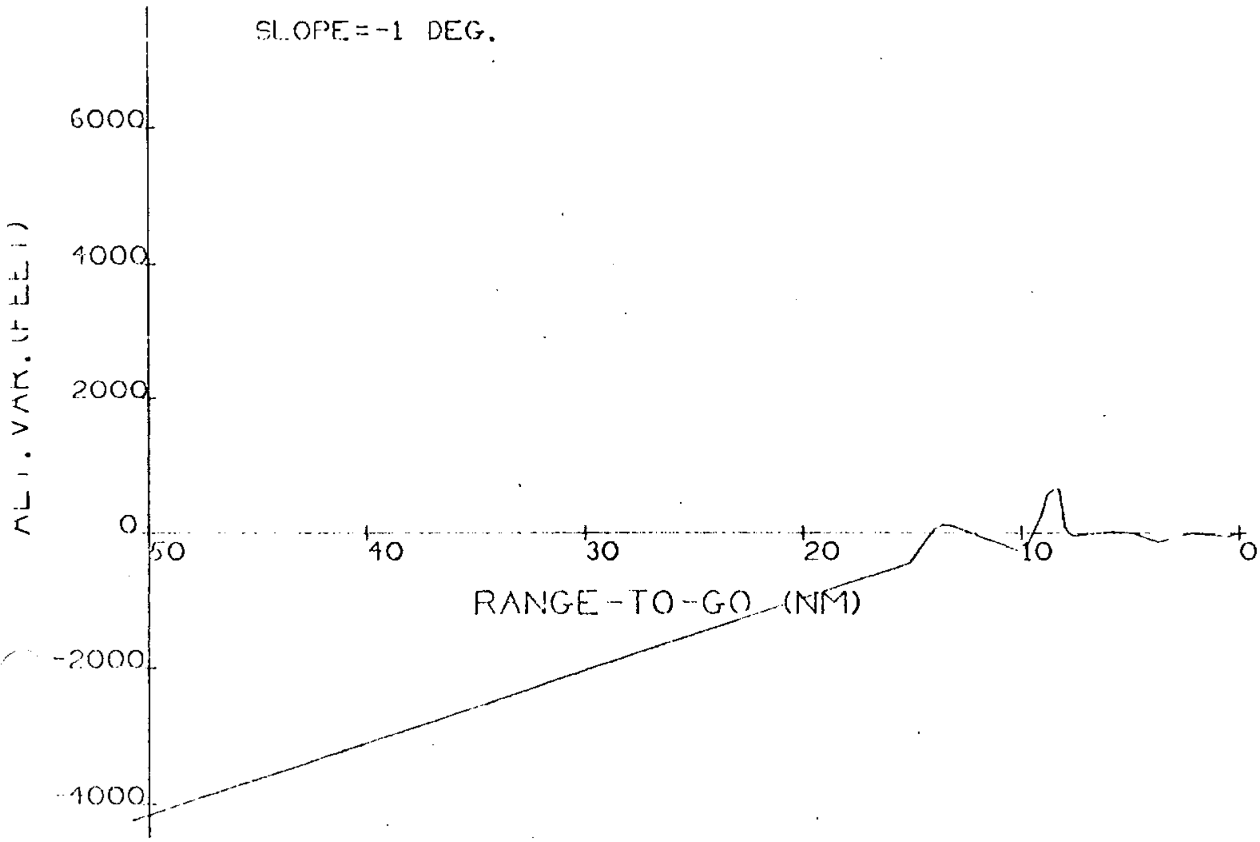


Fig. 22: Computed Visibility Angle ($90-\theta_{ep}$)

Terrain III-P-11 Profile-A, +1 Degree Slope

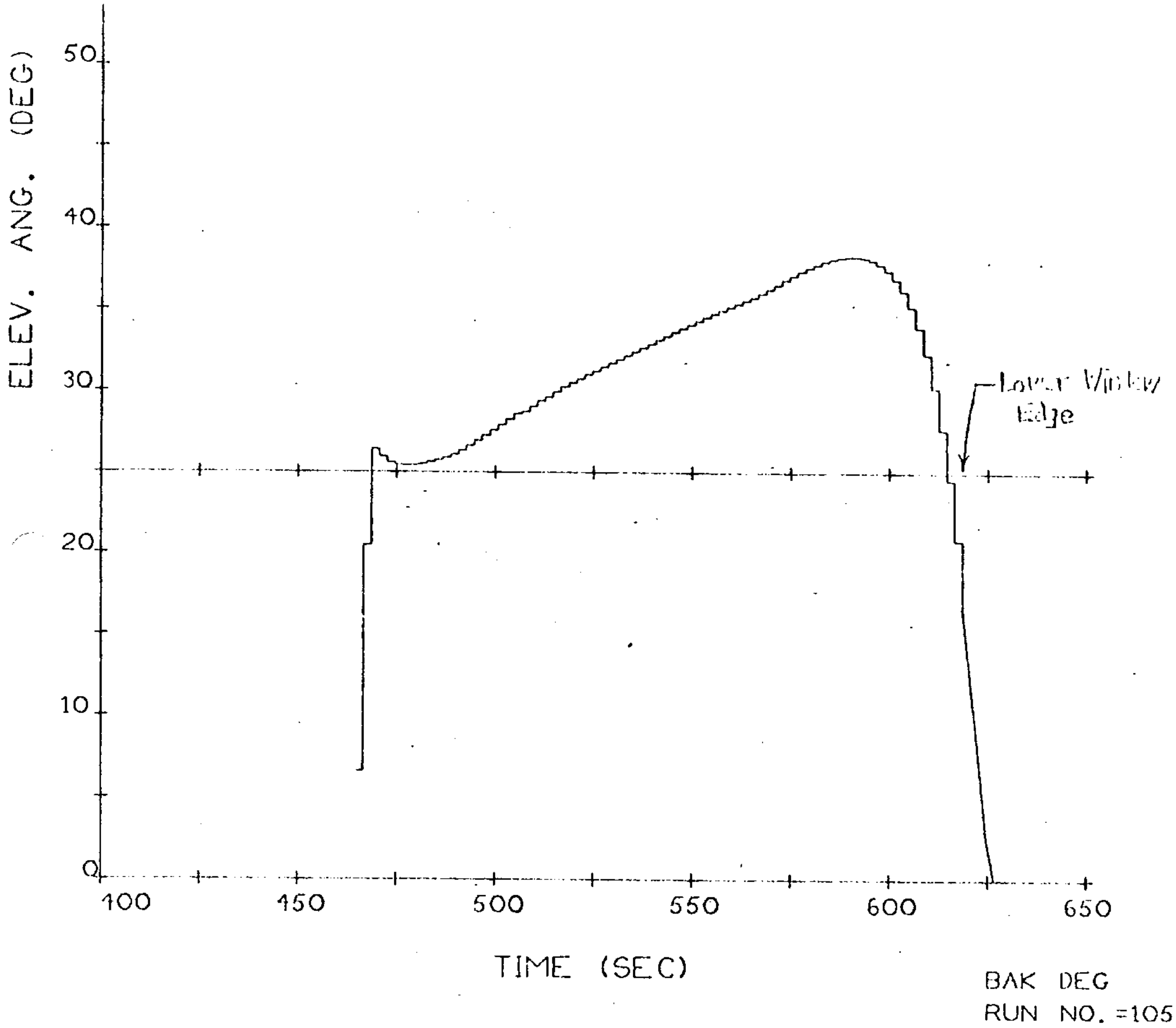


Fig. 23: Vertical Velocity vs. Range-to-Go

Terrain III-P-II, Profile A, +1 Degree Slope

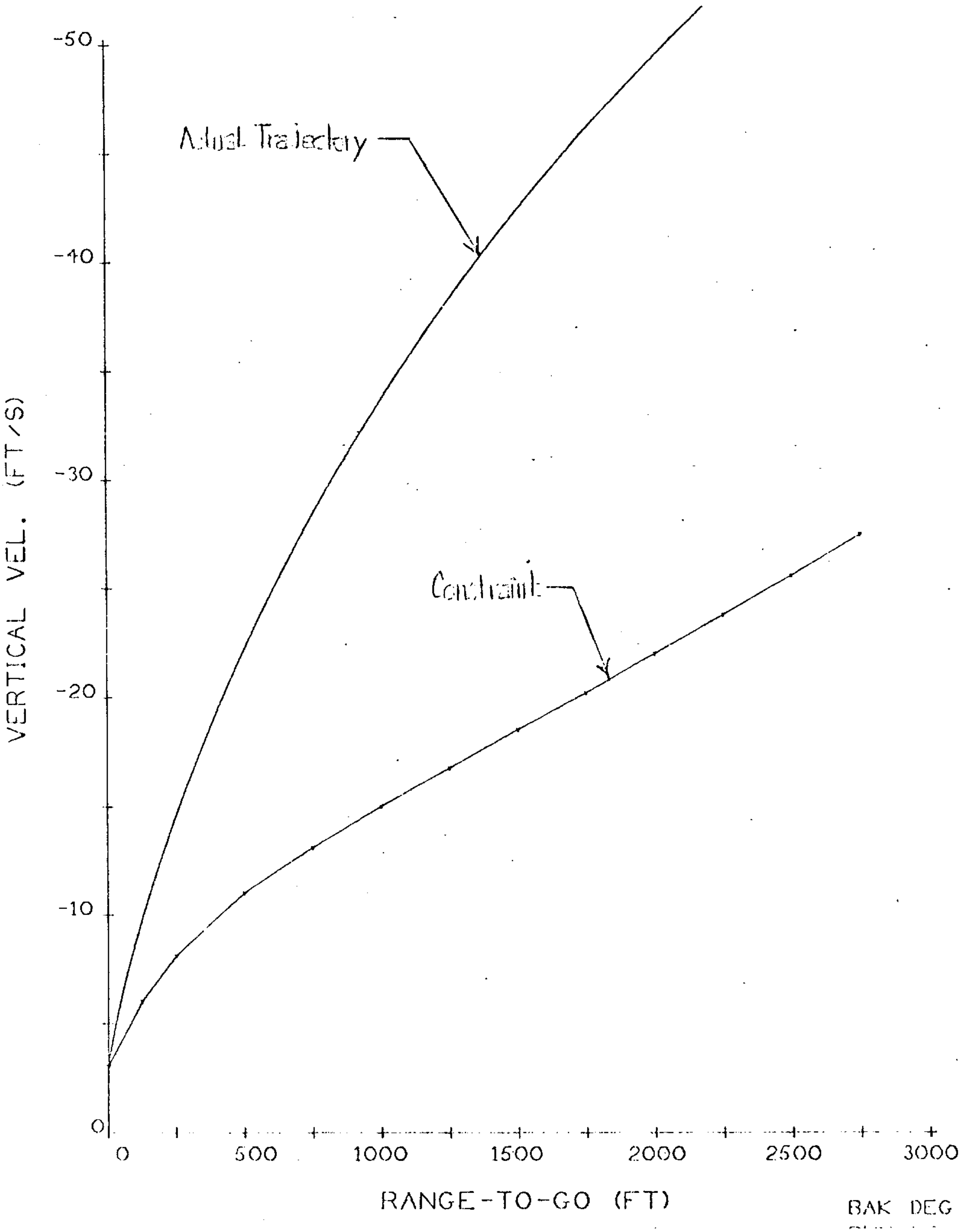


Fig 24: Altitude vs. Range-to-Go

Terrain III-P-11, Profile A, +1 Degree Slope

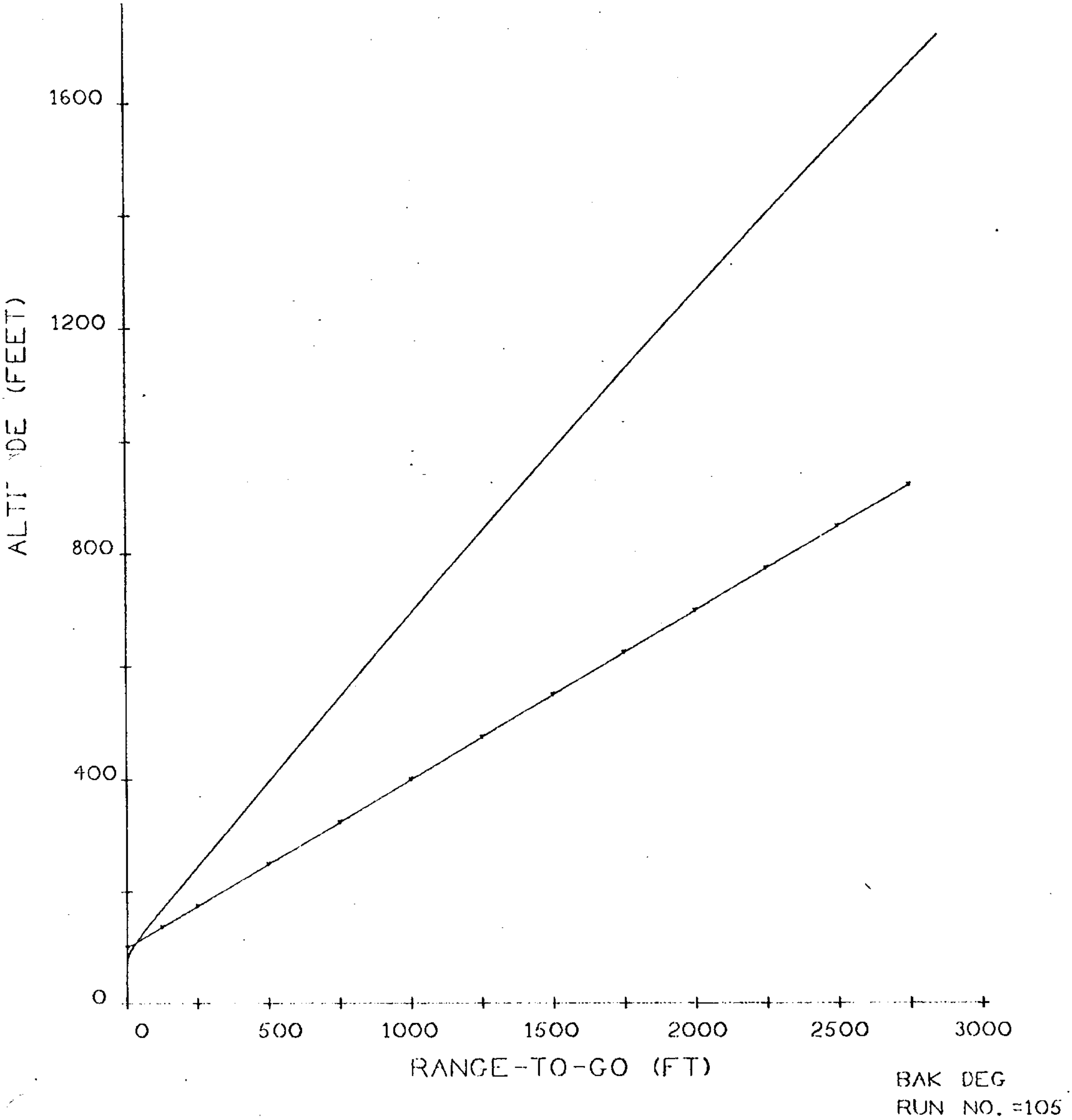
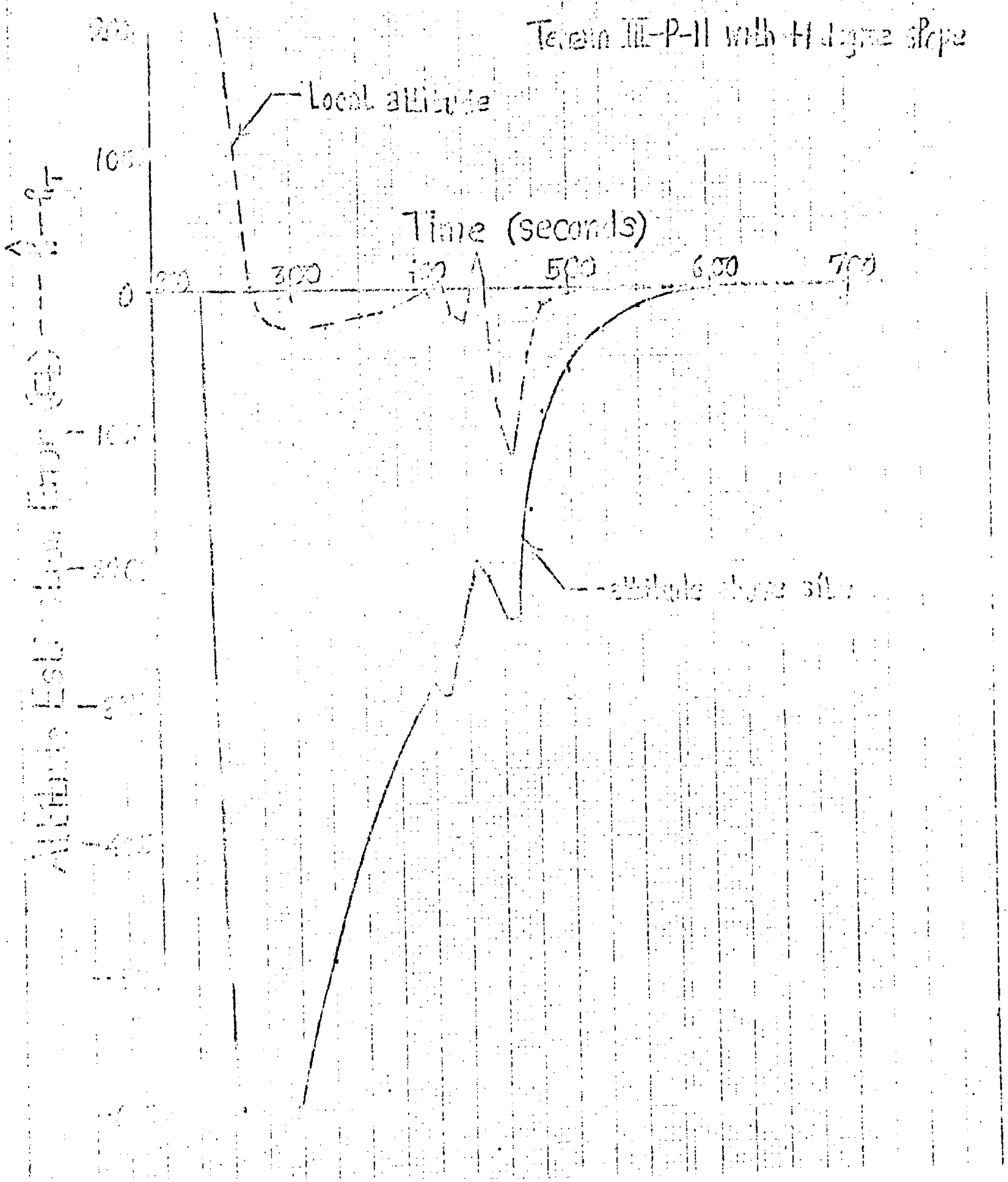


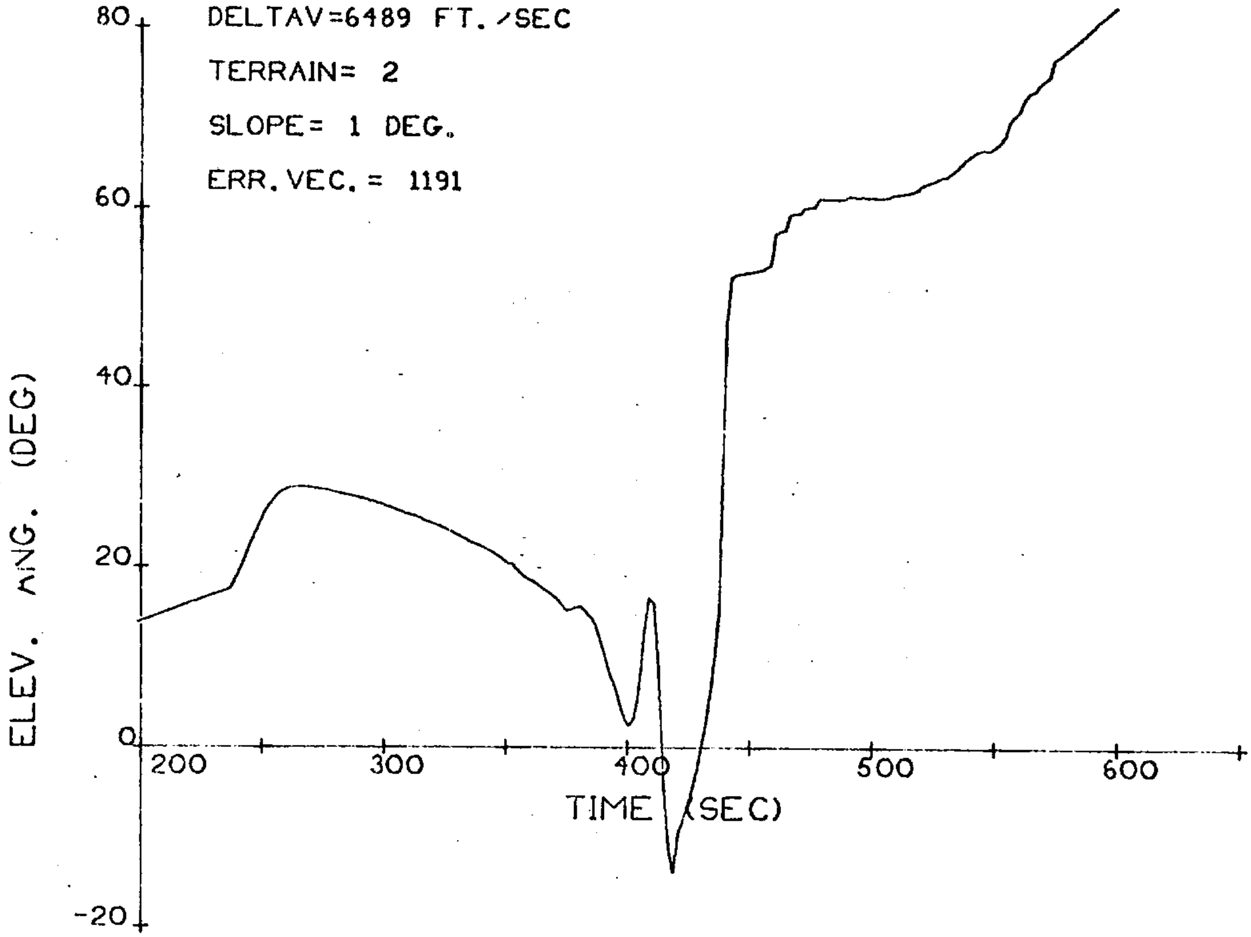
Fig 95: Altitude Estimation Errors for Test Run #105 with No Navigation Errors except for Terrain Altitude Variations

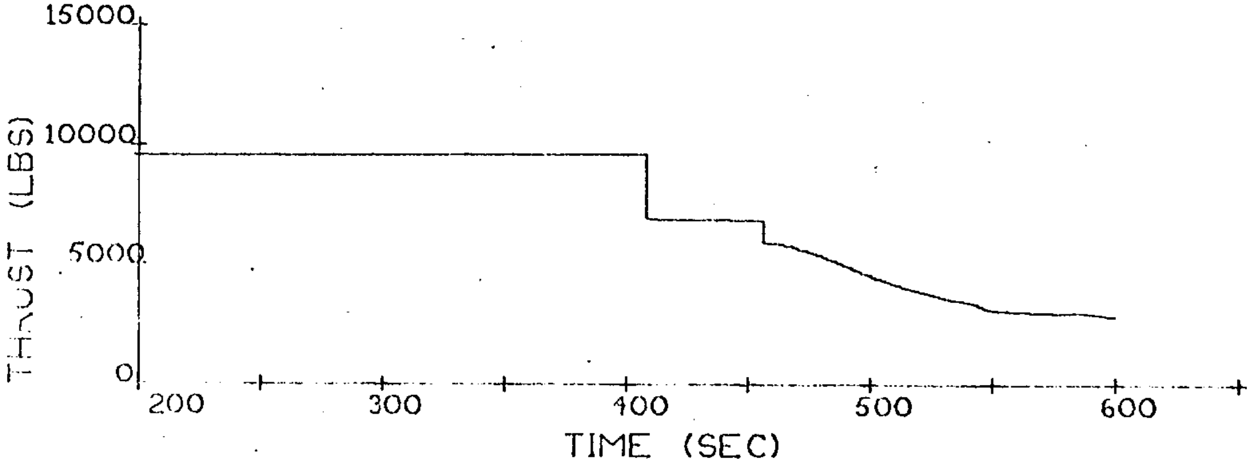


Thrust-Vector Elevation and Magnitude

Worst-Case Run #110

3-sigma pos. IMU errors
3-sigma low thrust
Terrain III-P-11A with +1 deg. slope (terrain high)





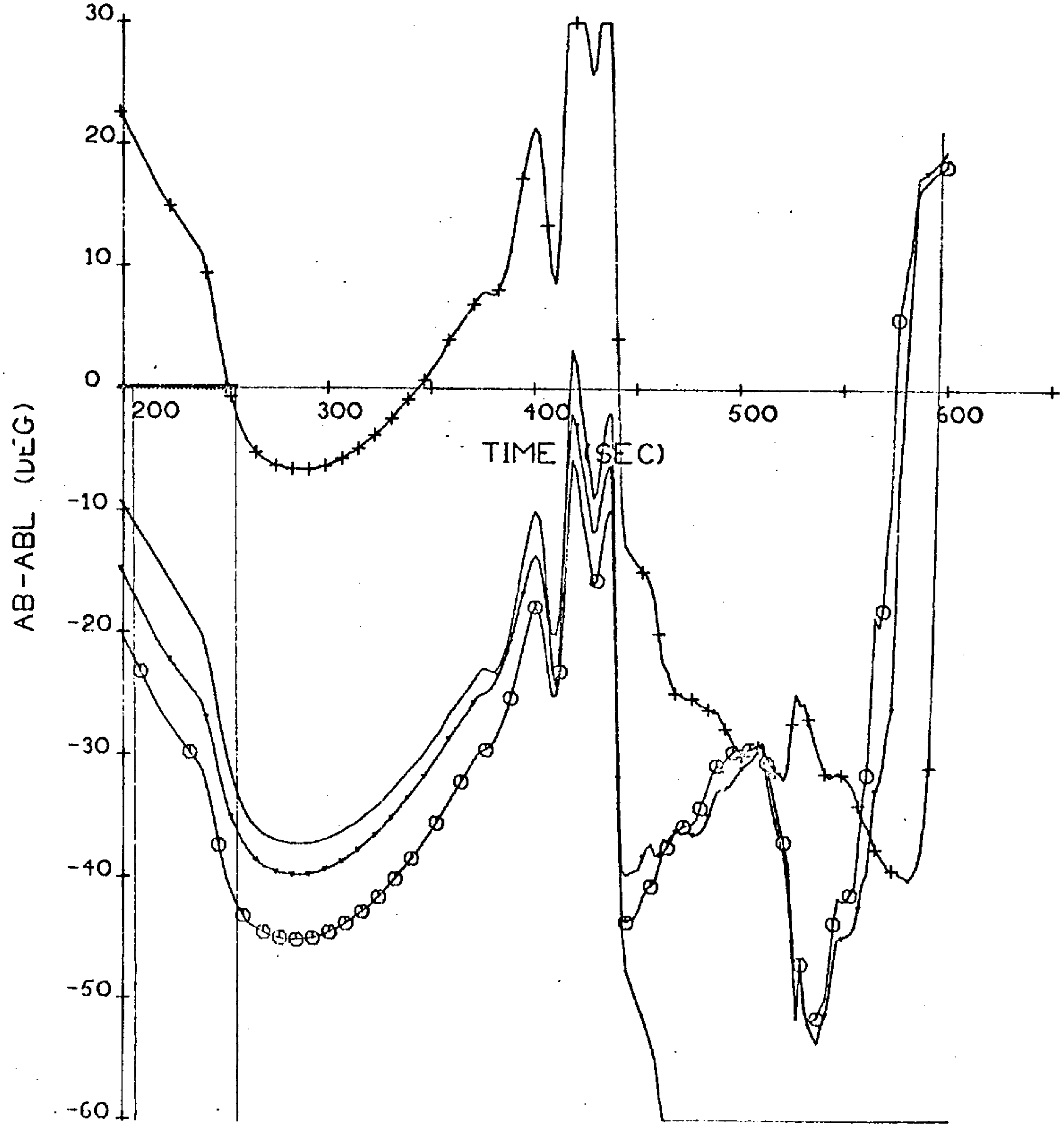
... of Radar Beams from

Dropout Boundaries

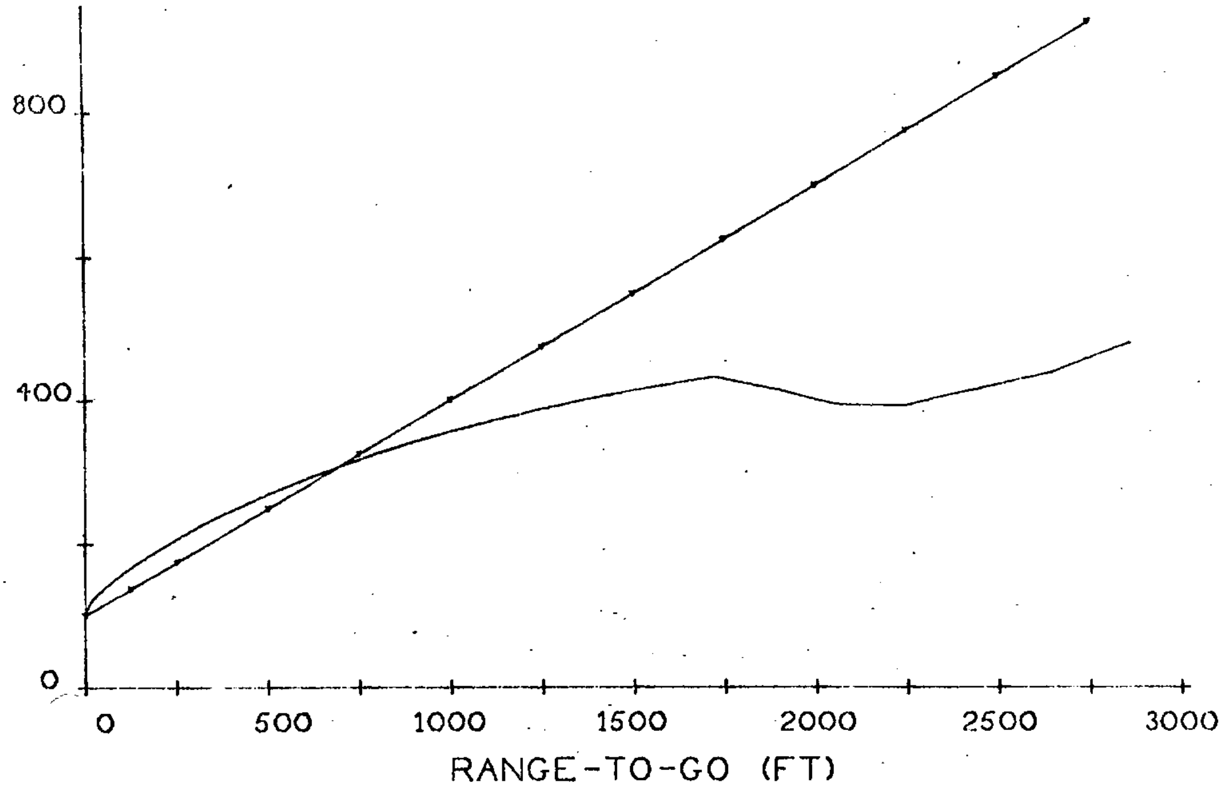
Worst-Case Run #110

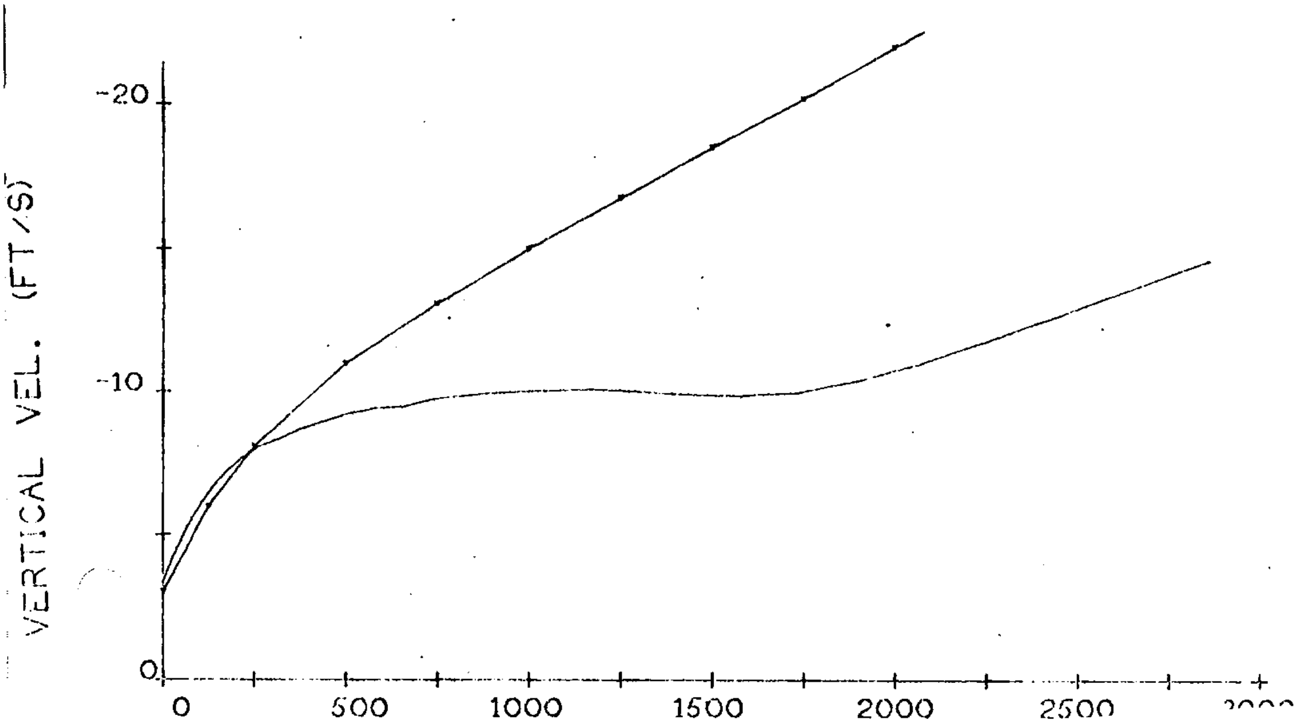
3-sigma pos. IMU errors
3-sigma low thrust
Terrain III-P-11A with -1 deg. slope (terrain low)

Beam # 1 = o——o——
Beam # 2 = •——•——
Beam # 3 = +——+——
Beam # 4 = ————



Altitude and Vertical Velocity for Final Approach Phase of Worst-Case Run #110





Massachusetts Institute of Technology
Instrumentation Laboratory
Cambridge, Massachusetts

Mission Simulation Memo # 32

TO: Distribution
FROM: B. A. Kriegsman
DATE: August 14, 1968
SUBJECT: Effect of High-Gate Altitude and Velocity Deviations on Ability of LM PGNCS to Satisfy Visibility-Phase Constraints for Landing Maneuver.

SUMMARY

The effects of High-Gate altitude and velocity deviations on visibility-phase trajectory constraints are studied under ideal error-free conditions. The constraints requiring the smallest High-Gate deviations are the 75-second visibility interval and the flight-path angle during the latter part of the visibility phase. Based on this study, 3-sigma High-Gate deviations should be limited to about 1500 feet in altitude and 20 ft/ sec in vertical velocity.

GENERAL INFORMATION

A primary consideration in the selection of LR weighting functions for the powered landing maneuver is the accuracy with which the High-Gate altitude and velocity aim conditions must be met. This is also very important in determining the type of guidance scheme required during the latter part of the braking phase, where high accuracy may demand considerable thrust-vector maneuvering.

The present memo attempts to answer the question of what accuracy is required in meeting the High-Gate altitude and velocity aim conditions under ideal conditions. The basic criteria chosen to evaluate the High-Gate errors are:

(1.) The length of time during the visibility phase of the landing maneuver that the line-of-sight to the predicted landing site is at least 7 degrees above the lower edge of the LM window.

(2.) The down-range distance from the LM to the landing site when the vehicle's downward velocity at a given altitude is greater than that for the 4-second deadman's curve of Fig. 1.

(3.) The deviations in vehicle altitude and flight-path angle at a range-to-go of 2000 feet, with respect to the constraint curves of Ref. 1.

(4.) The deviations in vehicle attitude at a range-to-go of 2000 feet.

The various trajectory constraints and their justification are discussed in Refs. 1 and 2. The visibility-interval is necessary to permit the astronaut to observe and assess the computed landing site. It is also important that the deadman's curve not be violated until after the final landing site has been selected, i.e. at a range-to-go greater than about 200 feet where the astronaut has the capability of site redesignation. The flight-path angle, velocity, and altitude constraints are imposed to permit the astronaut to manually take-over control of the vehicle without difficulty during the last 2000 feet of the approach phase, if required.

SIMULATION ASSUMPTIONS

The landing maneuver simulation was essentially according to the LUMINARY GSOP (Ref. 3), including the new items described in Ref. 4. High-Gate altitude and velocity perturbations were introduced simply by modifying the High-Gate aim conditions as required.

To simplify the analysis, no guidance or navigation system errors were included, i.e. perfect IMU and LR were assumed. Also, a perfectly smooth terrain was assumed. No initial-condition errors were assumed present at the start of the braking phase. Finally, the LR drop-out boundaries were removed.

Under these conditions it is expected that the simulation results will tend to be optimistic, i.e. the permissible High-Gate deviations will appear to be larger than in a realistic non-ideal situation. Care must be exercised in extrapolating these results to the non-ideal world where factors such as measurement errors, DPS-performance variations, and LR drop-out boundaries are present.

VISIBILITY-INTERVAL RESULTS

The effect of deviations in High-Gate altitude and vertical velocity on the landing-site visibility interval is shown in Fig. 2. The visibility interval referred to here is the interval during which the line-of-sight to the predicted site is at least 7 degrees above the lower edge of the LM window. It is desirable that this interval be at least 75 seconds.

From Fig. 2 it can be seen that positive High-Gate deviations in vehicle altitude and vertical velocity tend to reduce the visibility interval. These deviations (vehicle is higher and traveling with a larger upward velocity component than in the nominal case) cause the thrust vector to pitch further away from the local vertical than in the nominal case, in order to meet the Low-Gate aim conditions. This reduces the visibility interval.

The sensitivity of the visibility interval to High-Gate altitude deviations is on the average about -15 seconds / 1000 feet. The average sensitivity to High-Gate vertical-velocity deviations is about -0.5 sec./fps. The maximum visibility interval in all cases was about 144 seconds.

The sensitivity of the visibility interval to High-Gate horizontal velocity deviations is shown in Fig. 3. In the region of interest it is seen that the sensitivity varies between -0.4 and -0.8 seconds/fps.

In order to obtain limits on the High-Gate deviations, it was first assumed that the maximum horizontal-velocity deviations to be expected were about 20 ft / sec. This assumption is based on the various landing trajectories simulated up to this time. Using the data of Fig. 3, it can be seen that this will lead to a reduction in visibility interval of about 12 seconds.

Next, it was assumed that with guidance-and-navigation system errors present, the visibility interval would be reduced an additional 10-15 seconds below the values given in Fig. 2. Accordingly, if a 75-second visibility interval is desired, it seems reasonable to enter the error-free data of Fig. 2 at a visibility interval of 100 seconds.

Typical maximum terrain slopes are about 1 degree or 100 ft/n.mi. Under these conditions it is unlikely that High-Gate altitude deviations will be less than several hundred feet.

If the reasonable assumption is now made that the maximum High-Gate vertical-velocity deviations will be at least as great as the horizontal-velocity deviations, then one set of permissible 3-sigma deviations is 1500 feet and 25 ft/sec. Alternately, if the horizontal and vertical deviations could each be held to about 10-15 ft/sec then the permissible altitude deviations could be increased to about 2000 feet.

DOWN-RANGE DISTANCE WHERE DEADMAN'S CURVE IS VIOLATED

The down-range distance from the landing site where the 4-second deadman's curve is violated is shown in Fig. 4 for High-Gate altitude and vertical velocity deviations. The basic constraint requirement is that this does not occur at a distance greater than about 200 down-range from the site.

For the ideal conditions of Fig. 4 it is evident that the violation distance is relatively insensitive to High-Gate altitude and vertical velocity deviations. Typical sensitivities from Fig. 4 are 7 ft/1000 feet (altitude deviations) and .2 ft/fps (vertical-velocity deviations).

It can be seen that positive altitude and vertical velocity deviations increase the violation distance. Even with deviations of 4000 ft and 60 ft/sec, however, the violation distance has only increased to 250 ft.

Under these conditions it is felt that the High-Gate requirements imposed by violations of the deadman's curve are less demanding than those relating to visibility interval.

DEVIATIONS FROM ALTITUDE CONSTRAINT CURVE

The basic constraint curve of interest is given in Refs. 1 and 4. To simplify the evaluation of High-Gate perturbations, only the deviations at a down-range distance of 2000 feet are compared. It is felt that the percent altitude deviations at shorter down-range distances will be essentially the same.

The effects of the High-Gate perturbations on the vehicle's altitude at a range of 2000 feet from the landing site are summarized in Fig. 5. The maximum deviations are seen to occur when the High-Gate altitude and vertical-velocity deviations have the same algebraic sign.

If it is assumed that the maximum altitude deviations at 2000 feet be limited to 30-40 percent of the constraint-curve altitude, then a reasonable set of maximum High-Gate altitude and vertical velocity deviations is 1500-2000 ft and 30 ft/sec.

CHANGE IN FLIGHT-PATH ANGLE FROM CONSTRAINT VALUE

Constraint curves for vehicle vertical velocity are given in Refs. 1 and 4. For evaluating High-Gate deviations, however, it is felt that flight-path angle is more meaningful and easier to interpret. To simplify the analysis, flight-path-angle deviations are compared at a single down-range distance, i.e. 2000 feet. It is felt that the percentage deviations will be similar at the shorter ranges of interest.

The constraint-curve flight-path angle at a range-to-go of 2000 feet from the landing site is about -15 degrees. The effect of deviations in High-Gate altitude and vertical velocity on the flight-path angle at this range are shown in Fig. 6.

It is difficult to say how large a flight-path angle deviation at this range is acceptable. If a 50-percent change can be tolerated, then a High-Gate altitude deviation of about 1500 feet requires that the vertical-velocity deviation be limited to about 15 ft/sec. If, on the other hand, ltitude deviations are limited to 1000 feet, then the permissible vertical velocity deviations are increased to about 30 ft/sec.

THRUST VECTOR ORIENTATION AT 2000 FT. RANGE-TO-GO

The landing constraints (Refs. 1 and 4) state that the vehicle's pitch attitude (relative to local vertical) be smaller than 30 degrees at 2000 feet range-to-go. The constraint curve linearly decreases to 20 degrees at the landing site.

The effects of High-Gate altitude and velocity deviations on pitch angle at 2000 feet range-to-go are shown in Fig. 7. It is evident from Fig. 7 that the pitch angle is well below the constraint value and is insensitive to High-Gate variations.

REFERENCES

(1.) Kelly, W.R., "Trajectory Constraints to Be Used in Design of Guidance Equations for the Region between the High-Gate and Hover Aim Point", NASA MSC G & C Memo EG27-72-67, June 27, 1967.

(2.) Hackler, C., "Trajectory and Constraints for Final Approach and Landing Approach Phases of LEM Lunar Landing", NASA MSC Memo EG27-4-66, January 14, 1966.

(3.) LUMINARY GSOP Section 5, Guidance Equations, MIT Instrumentation Lab Report R-567, January 1968.

(4.) Kriegsman, B.A., and Gustafson, D.E., "Simulation of Powered Landing Maneuver with Current Trajectory-Targeting Parameters, DPS Model, Terrain Model, and LR Dropout Boundaries", MIT Instrumentation Lab Mission Simulation Memo No. 20, June 14, 1968.

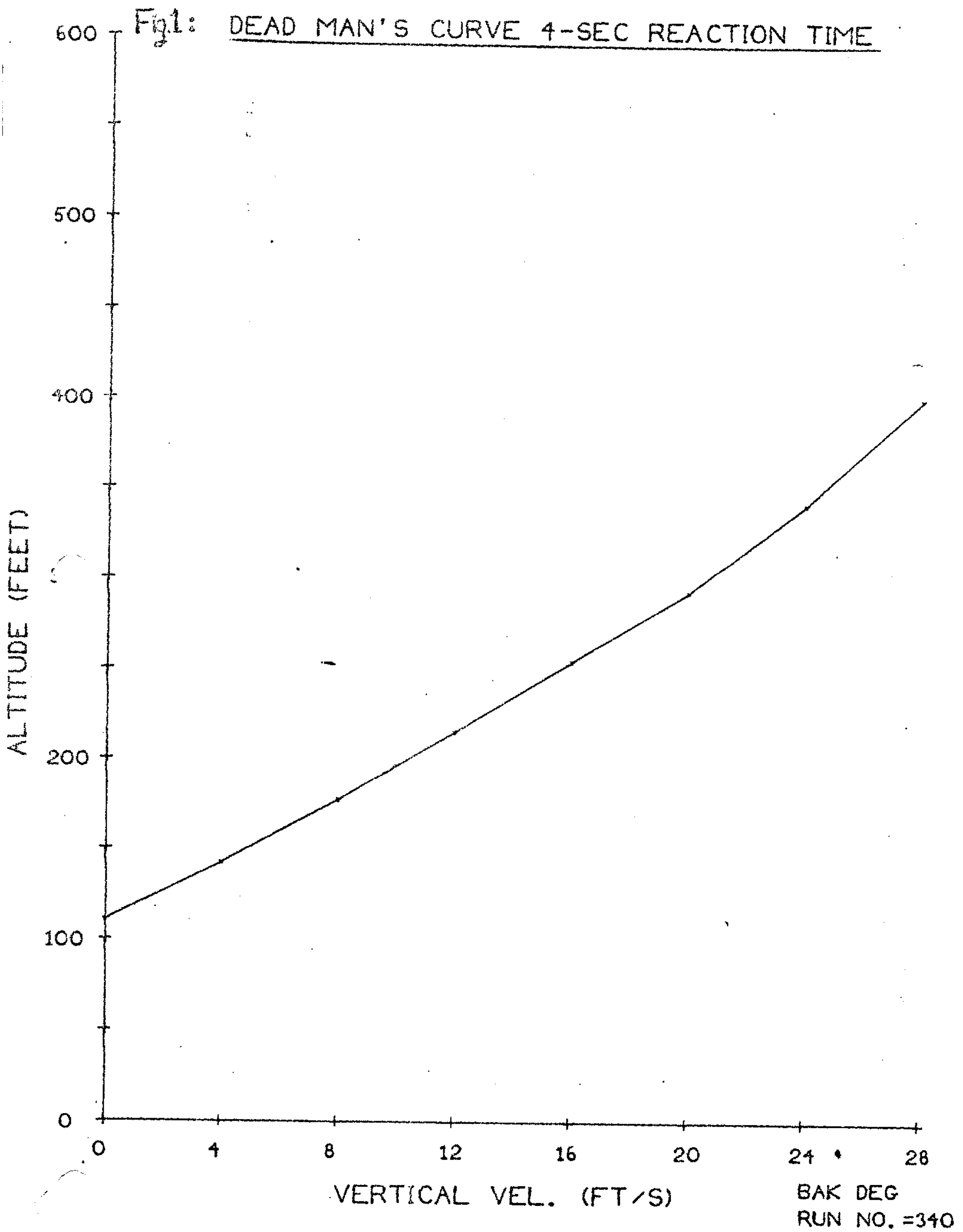


Fig1: DEAD MAN'S CURVE 4-SEC REACTION TIME
600
500
400
200
100
0
ALTITUDE (FEET)
0
4
8
12
16
20
24
28
VERTICAL VEL. (FT/S)
BAK DEG
RUN NO. =340

Fig. 2: Effect of High-Gate Altitude and Vertical-Velocity Deviations on Visibility Interval

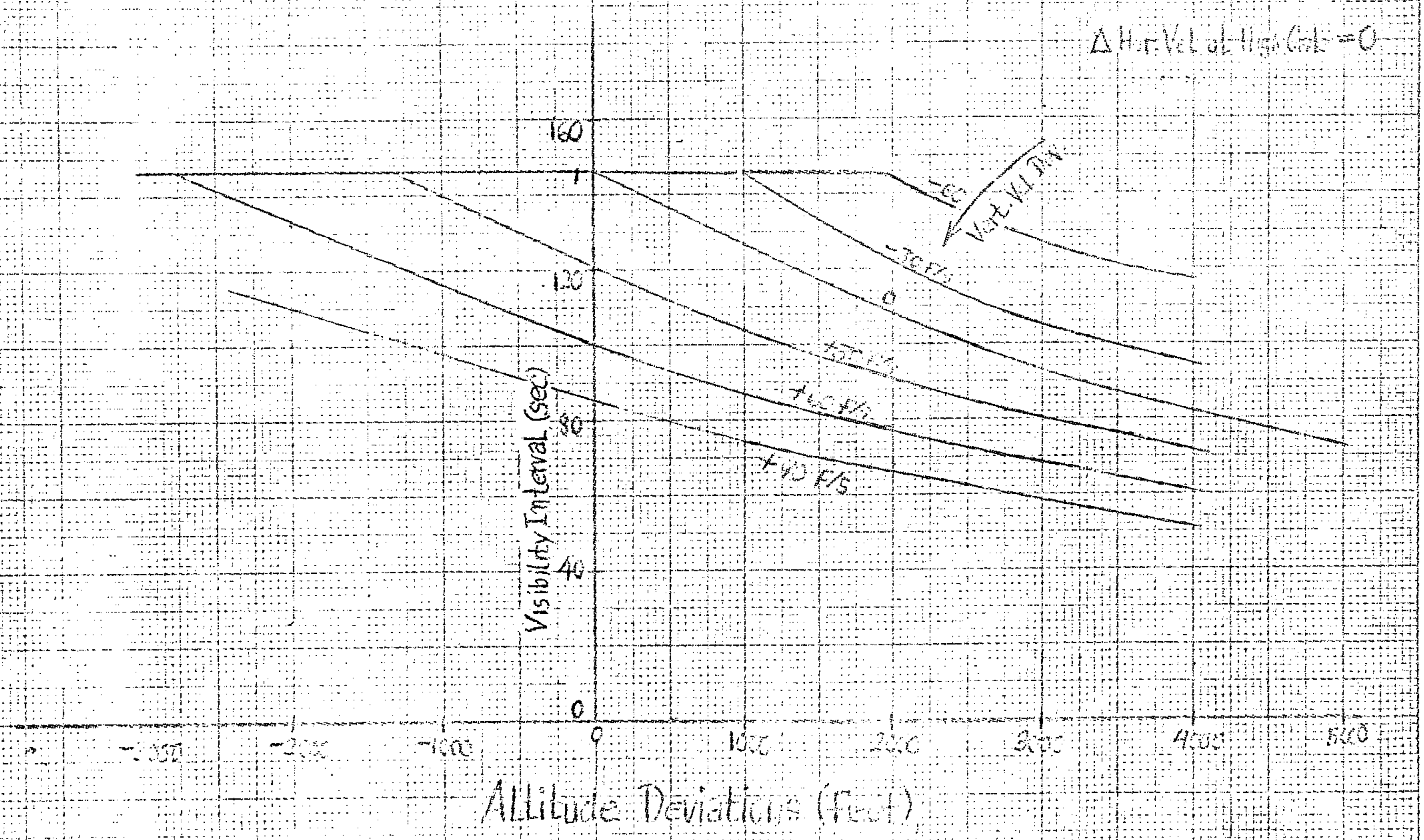


Fig. 5.1 Sensitivity of Visibility Interval to High-Gate Horizontal Velocity Deviations

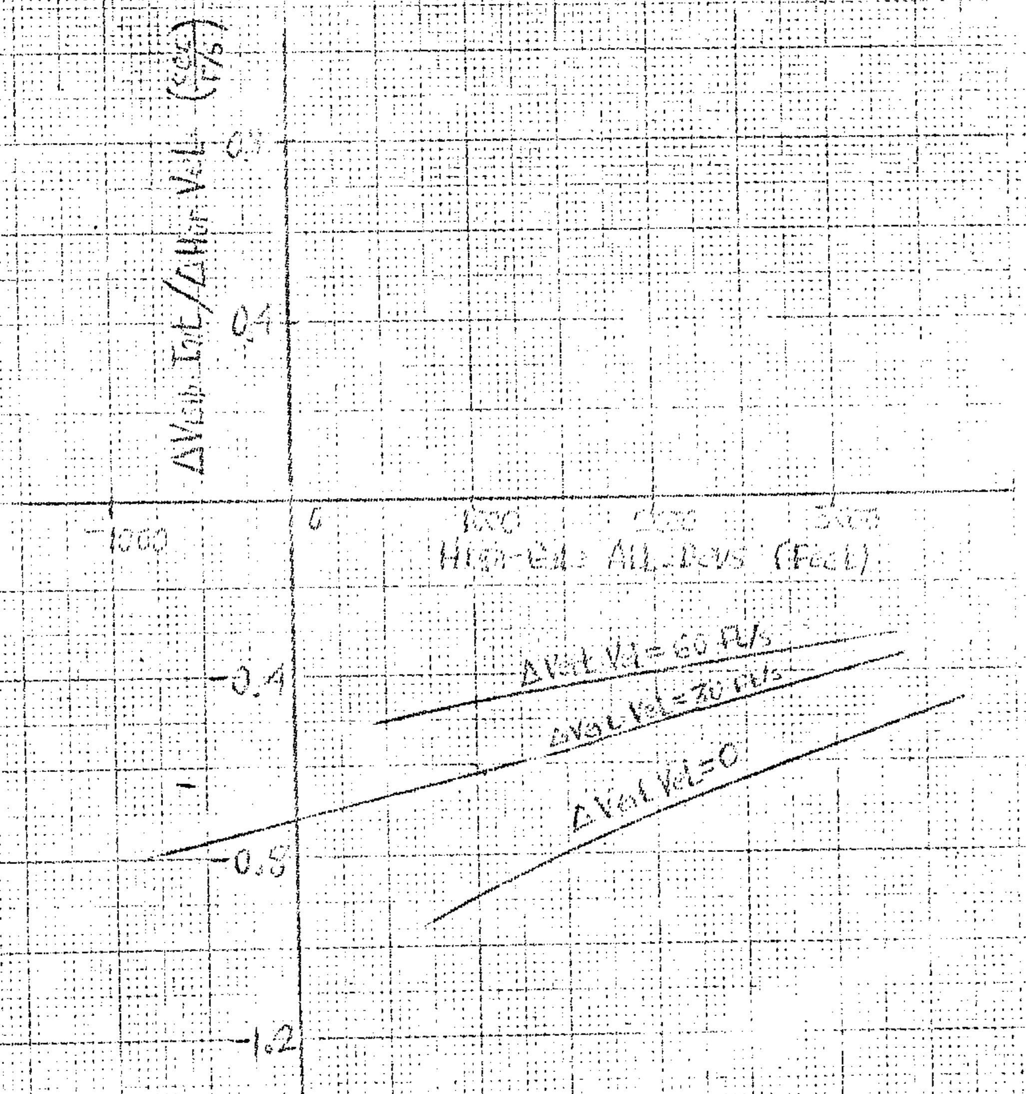
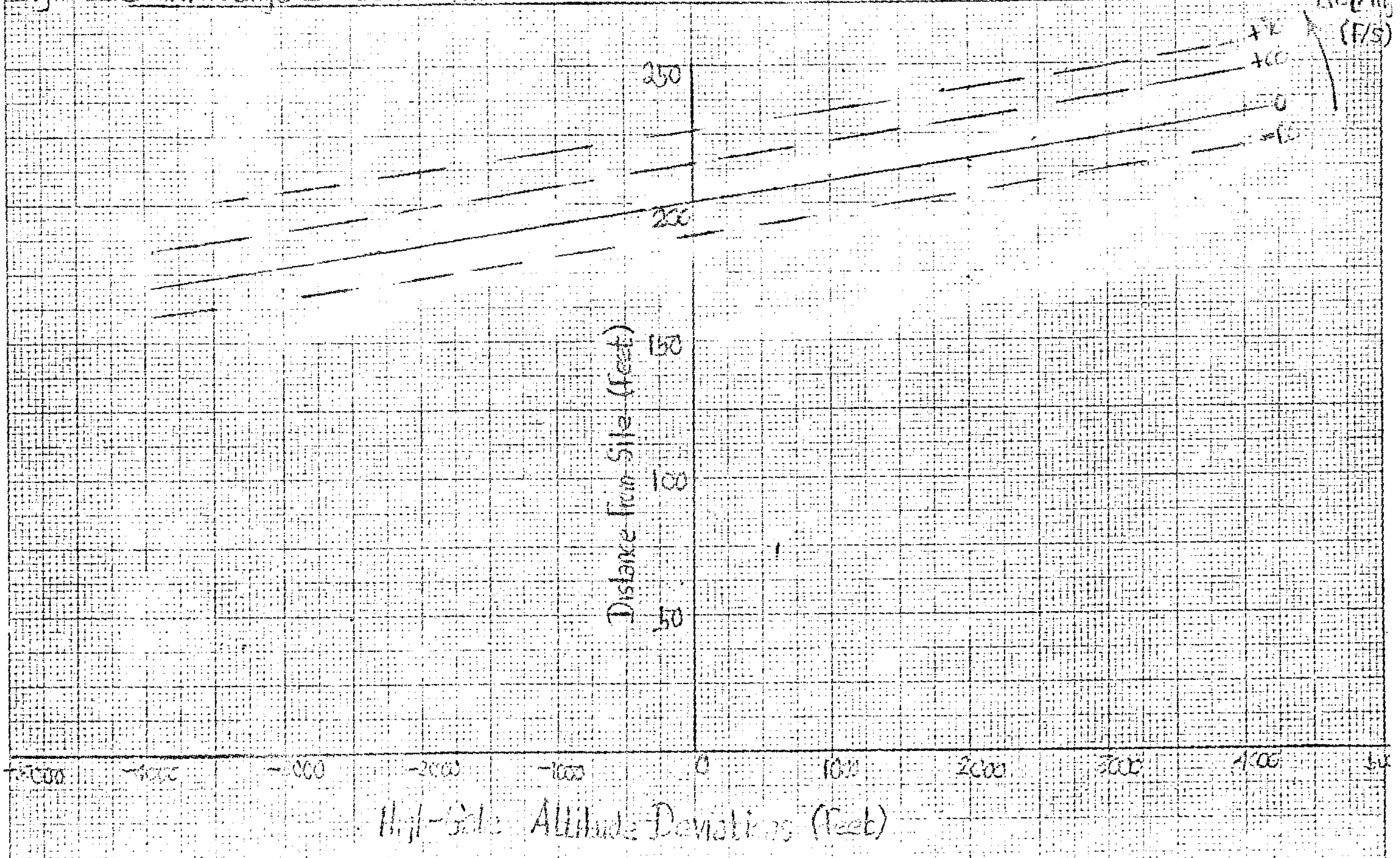


Fig 4: Down-Range Distance where 4-Second Dead-Man's Curve is Violated



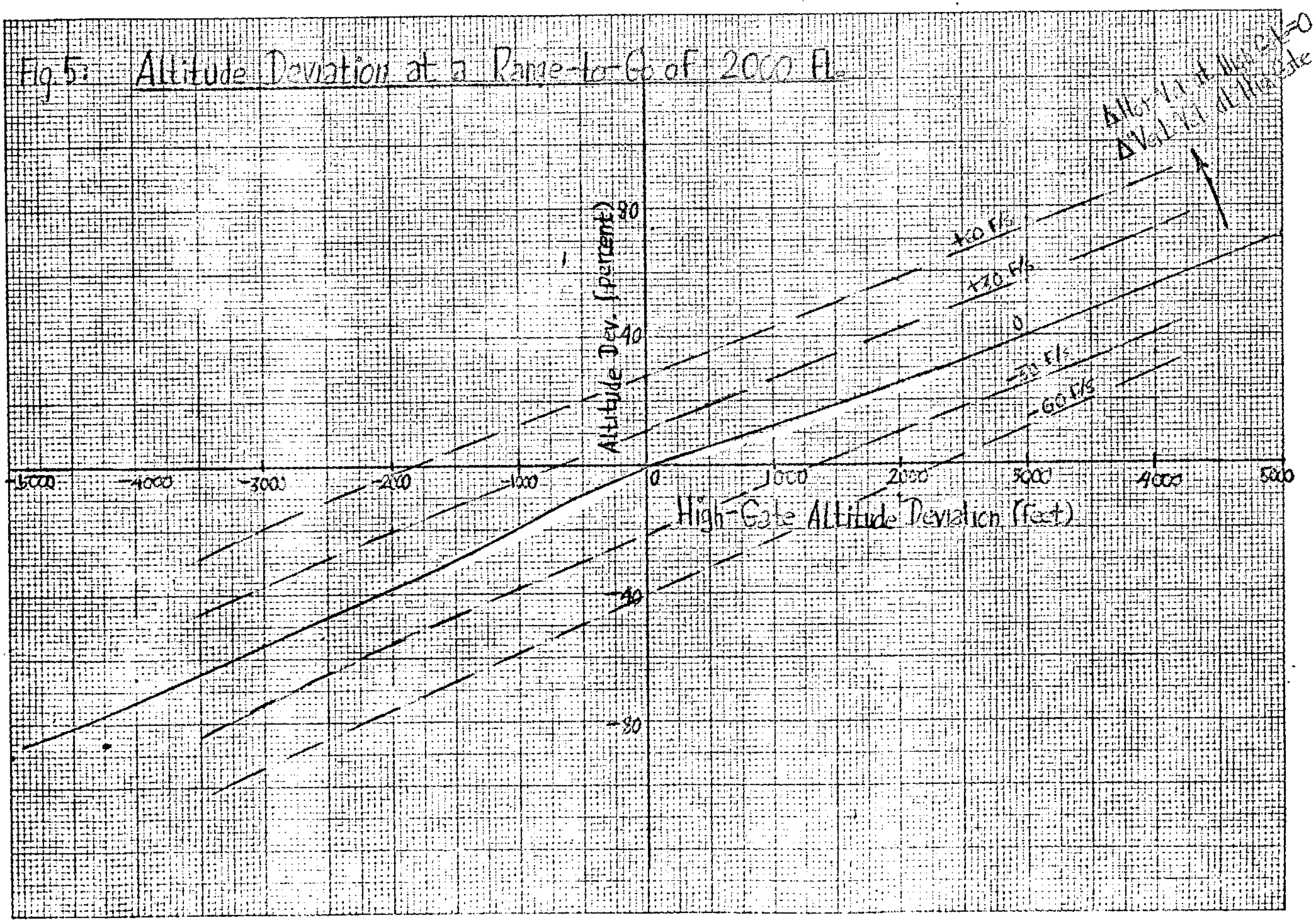


Fig. 5: Altitude Deviation at a Range-to-Go of 2000 Ft.

Fig. 6: Change in Flight-Path Angle at a Range-to-Go of 2000 Feet

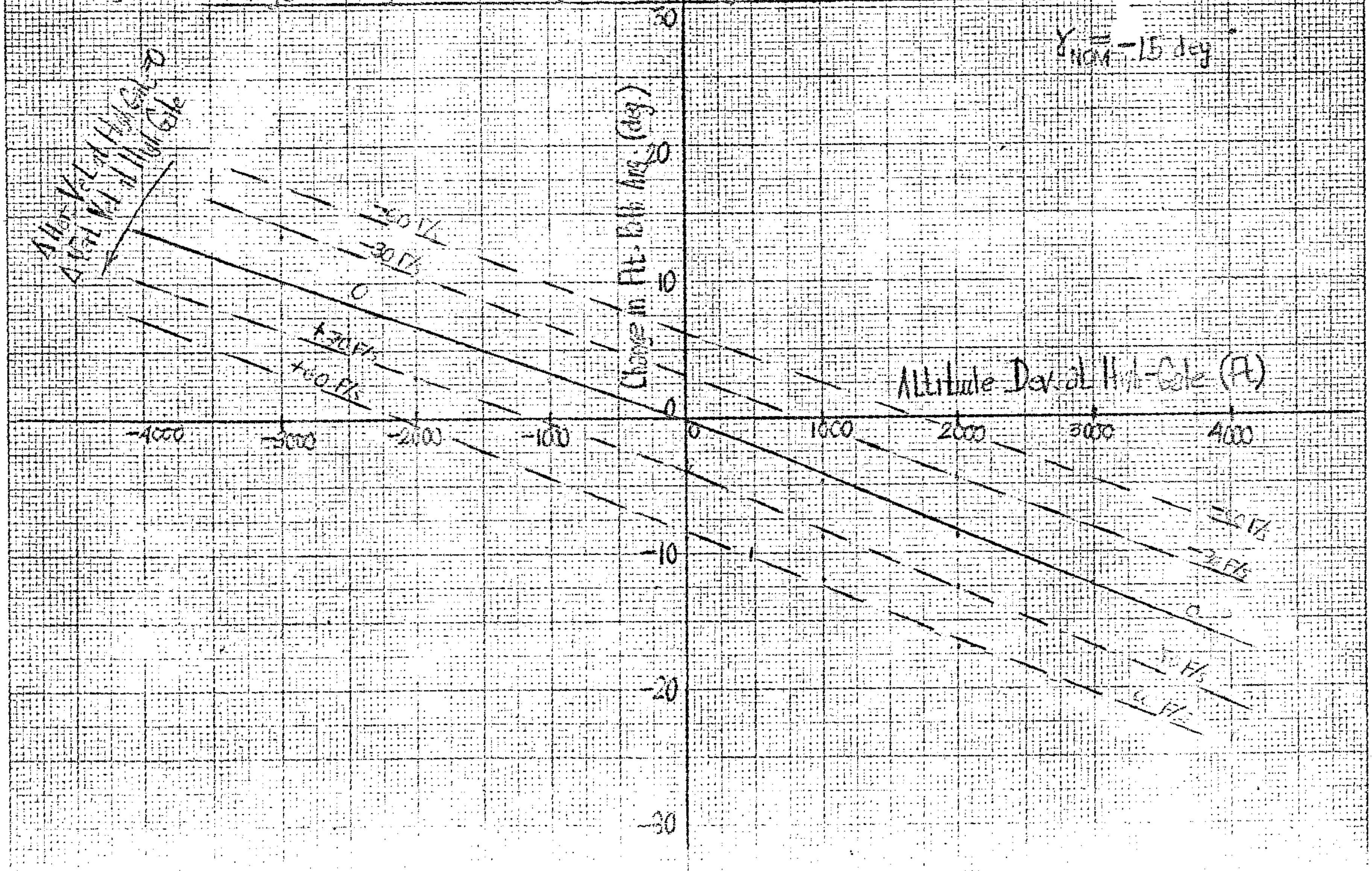
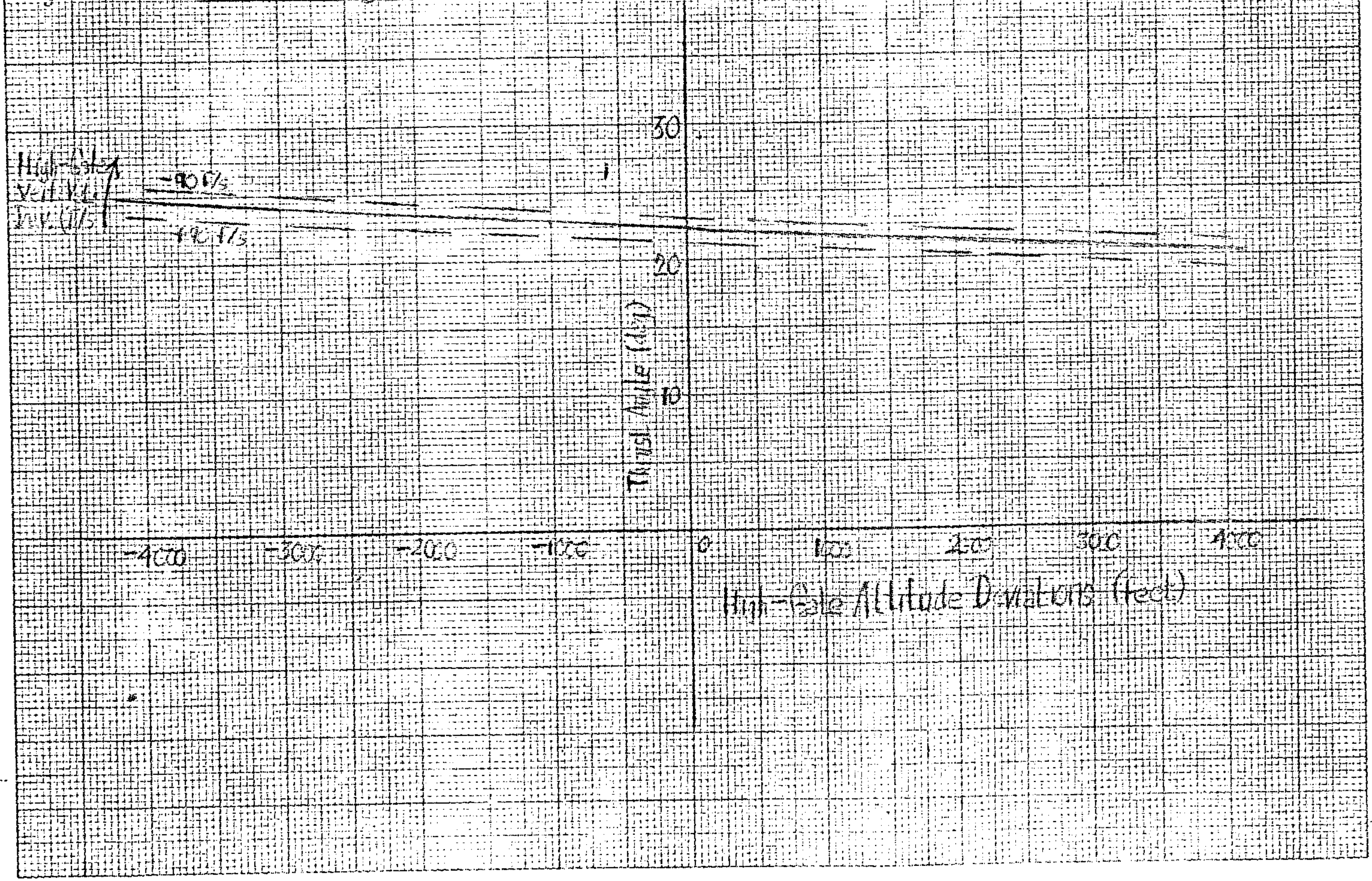


Fig. 7: Thrust Angle Relative to Local Vertical at 2000 ft. Range-to-Go



Massachusetts Institute of Technology
Instrumentation Laboratory
Cambridge, Massachusetts

Mission Simulation Memo # 34

TO: Distribution

FROM: B. A. Kriegsman and D. E. Gustafson

DATE: August 16, 1968

SUBJECT: New Landing Radar Error Models and Weighting Functions.

SUMMARY

A simplified measurement-error model for the landing radar is described, including curves of the rms random and bias error components on a nominal trajectory. The terrain-slope bias (33.3 ft/n. mi 1-sigma) is the dominant altitude measurement error component; the random error components dominate in the velocity measurement errors. In the new model the 1-sigma Y and Z axis random errors have been increased roughly by a factor of 2 over the values used in earlier studies.

Using this error model, a set of weighting functions have been computed to minimize the mean-squared errors in the present estimates of vehicle position and velocity. These weighting functions are similar in form to those in the current GSOP (Ref. 4) in the sense that they are uncoupled, and in the treatment of bias errors in their derivation.

The new altitude weighting function is essentially the same as the one in current use (Refs. 1 and 5) for value of range-to-go out to 30 n. miles. It is much lower in value at the longer ranges. The new Y and Z velocity-component weighting functions are much smaller than those in present use. The X velocity-component weighting function is essentially the same as the present one.

Curves of computed weighting functions are given for changes in various model parameters such as the terrain slope, initial-condition covariance matrix, LR alinement, and bias errors. RMS errors are presented for certain cases where the assumed measurement errors and terrain slope differ from those used to compute the weighting functions.

GENERAL INFORMATION

There have been several changes relating to the landing radar (LR) since the weighting functions were originally developed (Ref. 1). The most important of these are the following:

(1) A new reference trajectory has been adopted for the powered landing maneuver (Ref. 2), based on a 60-mile CM orbit altitude and a 9700-foot High-Gate altitude.

(2) The orientation of the LR-beam axis of symmetry with respect to the vehicle's X-axis has been changed from 54 degrees to 24 degrees (Position-1) and zero degrees (Position-2). The antenna configuration has also been skewed -6 degrees about the vehicle's X-axis.

(3) The range-measurement accuracy specification has been changed (Ref. 3) from 0.5 percent of range (1-sigma) to the values shown below in Table 1.

Table 1: Range-Measurement Accuracy Specification

Altitude Range (feet)	Range Accuracy (percent) 1-sigma
25,000 – 3,000	0.667
3,000 – 2,000	1.0
2,000 – 10	0.5 + 5 ft.

(4) The velocity-measurement accuracy specifications have been changed to the values shown below in Table 2.

Table 2: Velocity-Measurement Accuracy Specifications

Altitude Range (feet)	v_{XA} Accuracy (percent) 1-sigma	v_{YA} Accuracy (percent) 1-sigma	v_{ZA} Accuracy (percent) 1-sigma
15,000 – 6,000	0.500	0.667	0.667
6,000 – 2,500	0.500	1.170	0.833
2,500 – 200	0.500	1.333	1.000
200 – 5	0.500	0.833	0.833
Lower Limit	0.5 f/s (1-σ)	0.833 f/s (1-σ)	0.833 f/s (1-σ)

The velocity components v_{XA}, v_{YA}, and v_{ZA} are along the X, Y, and Z antenna axes as given in Ref. (6). Previously, the velocity measurement accuracies had been modeled by the combination of a 6-mr. bias error (1-sigma each axis) and a 0.33-percent speed random error (1-sigma each axis).

(5) The altitude data-read flag is presently set at an estimated altitude of 35,000 feet, and the velocity data-read flag at an estimated vehicle speed of 2,000 ft/sec. This extends the range over which updatings can be obtained. The radar-beam lock-on problem is discussed in Refs. (4) and (5). It should be noted that there will be a time delay after the data-read flags are set, before LR updatings can be made (Ref. 5).

(6) New terrain-model data have been obtained. Previously the terrain had been modeled statistically as a 100 ft/n. m. (1-sigma) slope away from the site. Now it appears that a 33.3 ft/n. mi. (1-sigma) slope is more realistic. Also, data have been made available on local terrain altitude variations in the vicinity of the candidate landing sites.

(7) Certain IMU errors have increased from their values assumed in Ref. (1). The accelerometer bias errors have been increased to .0067 ft/sec.^{2} (1-sigma), and the accelerometer scale-factor errors have been increased to .015 percent (1-sigma).

This memo describes the current LR error models used in powered-landing maneuver simulation runs. Using these error models, LR weighting functions are presented which minimize the mean-squared errors in the estimate of vehicle position and velocity with respect to an inertial frame at the initial landing site. Weighting functions that do not minimize the mean-squared estimation error are not considered here. The effects of changes in the IMU and LR model parameters are also presented.

MODELING OF LR VELOCITY ERRORS

The LR radar random and bias measurement errors are not explicitly defined in the LR specifications (Table 2). Only the total errors are given there.

To circumvent this difficulty, the following procedure has been adopted. From Ref. (7) the r.m.s. static alinement errors of the antenna configuration have been obtained as:

$$\sigma_{AXB} = 2.07 \text{ mr} \quad \text{(1-sigma)}$$

$$\sigma_{AYB} = 3.69 \text{ mr} \quad \text{(1-sigma)}$$

$$\sigma_{AZB} = 3.26 \text{ mr} \quad \text{(1-sigma)}$$

where the subscript B is used to indicate that the alinements are about the navigation-base axes (not the antenna axes). The subscript A is used to indicate an alinement error. In the absence of information to the contrary, it is assumed that these alinement errors are not correlated with each other.

The error in measurement of a given velocity component (γ_{VA_j}) as the result of alinement errors γ_{AXB}, γ_{AYB}, and γ_{AZB} about vehicle axes is given by:

$$\gamma_{VA_j} = \underline{m}_{VA_j} \cdot (C_{BA} \underline{\gamma}_{AB}) \tag{1}$$

where the vector $\underline{\gamma}_{AB}$ represents the antenna alinement errors (γ_{AXB}, γ_{AYB}, γ_{AZB}) in vehicle coordinates. The matrix C_{BA} transforms the alinement-error vector ($\underline{\gamma}_{AB}$) from vehicle coordinates (subscript B) to antenna coordinates (subscript A). The vector $\underline{m}_{VA}$ is used to compute the velocity error along a given antenna axis (XA, YA, or ZA) resulting from a radar alinement error (expressed in antenna coordinates). The subscript j in Eq. (1) is used to indicate the XA, YA, or ZA component.

The vectors $\underline{m}_{VA_j}$ relating alinement errors to velocity-component errors are given by the relations:

$$\underline{m}^T_{VXA} = (0, \ -v_{ZA}, \ v_{YA}) \tag{2}$$

$$\underline{m}^T_{VYA} = (v_{ZA}, \ 0, \ -v_{XA}) \tag{3}$$

$$\underline{m}^T_{VZA} = (-v_{XA}, \ v_{XA}, \ 0) \tag{4}$$

where v_{XA}, v_{YA}, and v_{ZA} represent the components of vehicle velocity along the antenna X, Y, and Z axes. The superscript $\underline{T}$ is used to indicate the transpose of the related vector.

Using Eqs. (1) and (2) the mean-squared velocity-component measurement error due to alinement is given by:

$$\overline{\gamma^2_{VA_j}} = \underline{m}_{VA_j} \cdot (C_{BA} \overline{\underline{\gamma}_{AB} \underline{\gamma}^T_{AB}} C_{AB}) \underline{m}_{VA_j} \tag{5}$$

where the bars over th<u>e various q</u>uantity are used to indicate ensemble averages. The matrix $\underline{\gamma}_{AB} \underline{\gamma}^T_{AB}$ is a diagonal matrix whose principal elements are the mean-squared errors σ^2_{AXB}, σ^2_{AYB}, and σ^2_{AZB} referred to earlier in this section.

To obtain the r.m.s. random velocity error at a given point in the landing trajectory, the velocity-accuracy specification σ_{SPEC_j} is first computed from Table 2 at the altitude of interest. The mean-squared velocity error due to alinement $\overline{\gamma^2_{VA_j}}$ is then subtracted from the specification error σ_{SPEC_j}, as shown below to obtain the r.m.s. value of the random error σ_{V_j}:

$$\sigma_{V_j} = \sqrt{\sigma^2_{SPEC_j} - \overline{\gamma^2_{VA_j}}} \tag{6}$$

where the subscript j refers to the velocity component of interest, i.e. v_{XA}, v_{YA}, or v_{ZA}.

The relations of Eqs. (2) - (6) are used in both Monte-Carlo and statistical-analysis simulations of the landing maneuver to generate the random velocity measurement errors. Bias errors included in the LR-velocity error model are assumed to have r.m.s. values corresponding to the Ref. (7) alinement errors mentioned earlier.

MODELING OF LR ALTITUDE ERRORS

In the statistical-analysis simulations of the landing maneuver from which weighting functions are derived, the lunar terrain is modeled as a constant slope emanating from the landing site. The model assumes that the constant slope is normally distributed about a zero mean value. Previous studies have assumed an r.m.s. value of 100 ft/n.mi. for the slope (1-sigma); presently an r.m.s. value of 33.3 ft/n.mi. (1-sigma) is being used.

In Monte-Carlo simulations, lunar-terrain altitude variations are superposed on a constant slope to model the terrain. Current terrain models in use are given in Ref. 8.

In both the statistical and Monte-Carlo simulations the random range-measurement errors are modeled in accordance with the data of Table 1. For convenience the 5-foot threshold is presently being modeled as a random error in the statistical simulations.

COMPUTED LR WEIGHTING FUNCTIONS

Using the basic statistical-analysis approach described in Ref. (1), LR weighting functions have been computed corresponding to the present IMU and LR error models, and the new reference landing trajectory. The simulation program used here determines optimum weighting functions subject to certain modeling constraints. One constraint is that velocity bias errors and terrain variations are not estimated. Another constraint is that a given measurement is used to update only that component of the state corresponding to the measurement, i.e. an altitude measurement is used to update altitude only and not velocity. In all cases the covariance matrix of navigation-system estimation errors at the start of the powered landing maneuver is the same as given in Ref. (1). The performance criterion used in the generation of weighting functions is the minimization of the mean-squared errors in the estimation of vehicle position and velocity relative to the landing site.

The computed LR weighting functions for normal IMU and LR errors are shown in Figs. 1 and 4. A terrain slope of 33.3 ft/n.mi. is assumed here. Superposed on these curves (shown dotted) are the weighting functions used in earlier simulation studies (Ref. 5). It should be noted that the altitude weighting function is plotted vs. range-to-go to the landing site rather than estimated altitude.

From Fig. 1 it can be seen that the present linear altitude weighting function is too large at large distances from the site, i.e. between 30 and 50 n.miles range-to-go. This will cause the vertical component of the vehicle position with respect to the site to follow local terrain variations too rapidly. During the last 20-30 n.miles range-to-go, on the other hand, the present linear weighting function appears to reasonably approximate the curve derived in the statistical simulation.

A few general comments on the shape of the computed altitude weighting-function curves are appropriate at this point. The predominant measurement-error in the current model is the slope of the terrain. This can be seen from Fig. 2 where the random measurement error is plotted as a function of range-to-go to the landing site on a nominal trajectory. At large values of range-to-go where the r.m.s. altitude estimation error caused by IMU and initial-condition errors is smaller than the r.m.s. slope error, the weighting function is low. This can be seen from Figs. 1 and 3. With the slope model of 33.3 ft/sec. (1-sigma), the r.m.s. estimation error from the radar-updated IMU becomes roughly of the same magnitude as the slope error at about 30 n.miles range-to-go. Thereafter, the r.m.s. altitude estimation error follows the terrain-slope error fairly closely, as shown in Fig. 3. The change in weighting function between 30-40 miles is fairly rapid because the variances (not r.m.s. values) of the terrain-slope and LR-updated IMU errors are compared in the statistical weighting-function computations. Discontinuities appear in the computed curve of Fig. 1 at the point where the visibility phase begins, and also at the points where the altitude error specification is abruptly changed (Table 1).

In regard to the velocity weighting functions, the dominant error source with the assumed model is the random measurement error. This can be seen from Figs. 5-7 where the random and bias velocity-measurement errors are shown for a nominal trajectory. In the weighting-function computations where error variances are compared, the random errors will clearly have the major effect. The abrupt changes in the computed weighting functions result from the method used to compute the random errors (described in the preceding section) and the discontinuity in the accuracy specification (Table 2). It is interesting to note in Fig. 4 that the v_{XA} weighting function is the largest of the three components for speeds below 500 ft/sec. In earlier studies it was the lowest of the three components. The v_{XA} radar measurement errors are the smallest of the three components in this region (see Figs. 5-7).

The data of Fig. 4 indicate that the current GSOP v_{YA} and v_{ZA} weighting functions are somewhat larger than those computed in the current statistical simulation. One reason for this is that the random measurement errors as shown in Figs. 5-7 are larger than the 0.33 percent values used in Ref. 1. A second reason is that the orientation of the LR antenna with respect to the vehicle has been changed from that used in the derivation of weighting functions in Ref. 1.

In the data of Fig. 4 it has been assumed that LR velocity updatings are begun when the vehicle's estimated altitude is below 15,000 ft., which nominally corresponds to a vehicle speed of about 900 ft/sec. With the new LR dropout boundaries in the simulation (Refs. 4 and 5), velocity updating is not begun until after the start of the visibility phase when the vehicle's speed is only about 500 ft/sec.

In order to obtain a rough estimate of the random velocity-component measurement errors, straight line approximations were made to the data of Figs. 5-7. The resultant 1-sigma random error models obtained in this way were:

$$\sigma_{VXA} = .45 \text{ percent of speed } (1\text{-}\sigma)$$

$$\sigma_{VZA} = .70 \text{ percent of speed } (1\text{-}\sigma)$$

$$\sigma_{VYA} = \begin{array}{l} 1.1 \text{ percent of speed } (1\text{-}\sigma) \text{ for } v < 400 \text{ ft/sec.} \\ 0.7 \text{ percent of speed } (1\text{-}\sigma) \text{ for } v > 400 \text{ ft/sec.} \end{array}$$

It should be noted here that the specification threshold values must be included in the radar analytical model at small values of speed. Also, it is evident that the random and not the bias component of the velocity measurement error is the predominant component.

EFFECT OF TERRAIN-SLOPE PARAMETER VARIATIONS

The altitude weighting functions computed from the statistical simulation are, as might be expected, strongly affected by the assumed terrain slope model. This can be seen from Fig. 8 where the r.m.s. value of the assumed terrain slope has been increased from 33.3 to 100 ft/n.mi. (1-sigma). Comparing the curves of Figs. 1 and 8, it can be seen that the major effect of the increased slope-model value is a lowering of the altitude weighting function at values of range-to-to beyond 15 n. miles.

The effect of using the weighting function of Fig. 8 when the actual terrain slope is 33.3 ft/n.mi. is shown in Fig. 9. The important point here is that the r.m.s. errors for ranges-to-go less than about 15 n. miles (or braking phase times-to-go less than about 75 seconds) are the same as for the weighting functions of Fig. 1, which were based on a 33.3 ft/n.mi. slope. The fact that the errors are somewhat larger beyond 15 n. miles is less important. The key requirement here is that High-Gate altitude estimation errors be less than about 500 ft (1-sigma) to satisfy the visibility phase constraints (Ref. 9). From this viewpoint it appears desirable that the rms altitude estimation errors be made as small as possible no later than 60 seconds (about 15 n. miles) from the end of the braking phase. As can be seen in Fig. 9, this requirement is met by either weighting function.

VARIATIONS IN INITIAL-ERROR COVARIANCE MATRIX

The effect on the LR altitude weighting function of increasing and decreasing the elements of the initial-condition error covariance matrix by 4 are shown in Fig. 10. As can be seen, if the quality of the initial condition information is improved, then the radar information is weighted more lightly at the larger values of range-to-go where initial-condition errors are corrected by the LR. In the region of prime interest, i.e. the last 15-20 miles range-to-go, the weighting functions are not affected by the model variations of Fig. 10.

The velocity-component weighting functions were also computed for the cases shown in Fig. 10. No significant differences from the nominal case could be seen.

EFFECT OF INCREASE IN RANDOM ALTITUDE MEASUREMENT ERROR

At large values of range-to-go,the terrain slope dominates the altitude measurement error by a large factor, as shown in Fig. 10. If the rms altitude measurement error is increased, then the altitude weighting function will be lighter than nominal at the lower ranges-to-go (where random errors are more important) because of the poorer quality measurement. It is interesting to note that for the large increase in error shown in Fig. 11, the decrease in weighting function is only moderate. It should also be noted that these weighting functions are based on the criterion of minimizing the mean-squared estimation errors.

EFFECT OF LR ALINEMENT ERROR VARIATIONS

With the present LR error models, the random components of velocity measurement error dominate the bias components. Accordingly, a reduction in the value of alinement error will not significantly change the LR velocity weighting functions. This can be seen from the curve of Fig. 12 where the rms error has been reduced by a factor of 4. With an increased alinement error, on the other hand, the weighting functions are increased at the lower speeds as shown in Fig. 13. The rms velocity estimation errors at these speeds are larger than those of Fig. 12, which leads to the larger LR weighting functions.

REFERENCES

(1.) Kriegsman, B. and Sears, N., "LEM PGNCS and LR Operation During the Powered Landing Maneuver", MIT Instrumentation Lab Report E-1982, August 1966.

(2.) Alphin, J., Taylor, B., and Kirkland, B., "LM Powered Descent Trajectory for the Apollo Lunar Landing Mission", MSC Internal Note No. 68-FM-78, March 29, 1968.

(3.) Grumman Aircraft Engineering Corporation, Specification Change Notice No. 22-41, Spec. No. LSP-370-3.

(4.) Dyer, D., "A Simplified LM Landing Radar Operating Boundary Model", MSC Internal Note No. 67-EG-35, December 5, 1967.

(5.) Kriegsman, B., and Gustafson, D. E., "Simulation of Powered Landing Maneuver with Current Trajectory-Targeting Parameters, DPS Model, Terrain Model, and LR Dropout Boundaries", Mission Simulation Memo No. 20, MIT Instrumentation Lab, June 14, 1968.

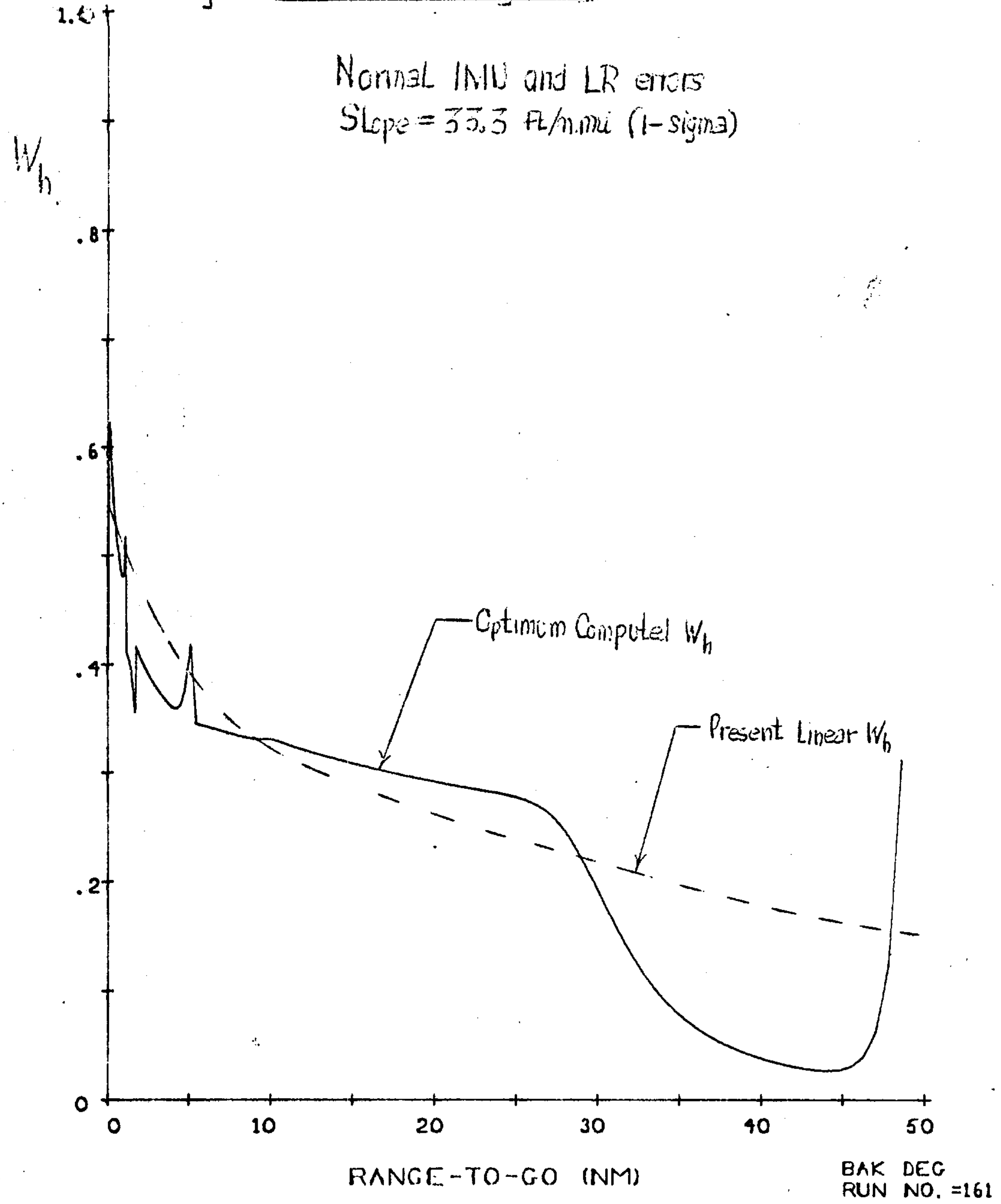
(6.) LUMINARY GSOP Section 5, Guidance Equations, MIT Instrumentation Lab Report R-567, January 1968.

(7.) Per Angelo, J., "Estimated LR Antenna Beam Group Center Shift due to Vehicle Mechanical Alinement", GAEC Radar Coordination Meeting, February 21, 1967.

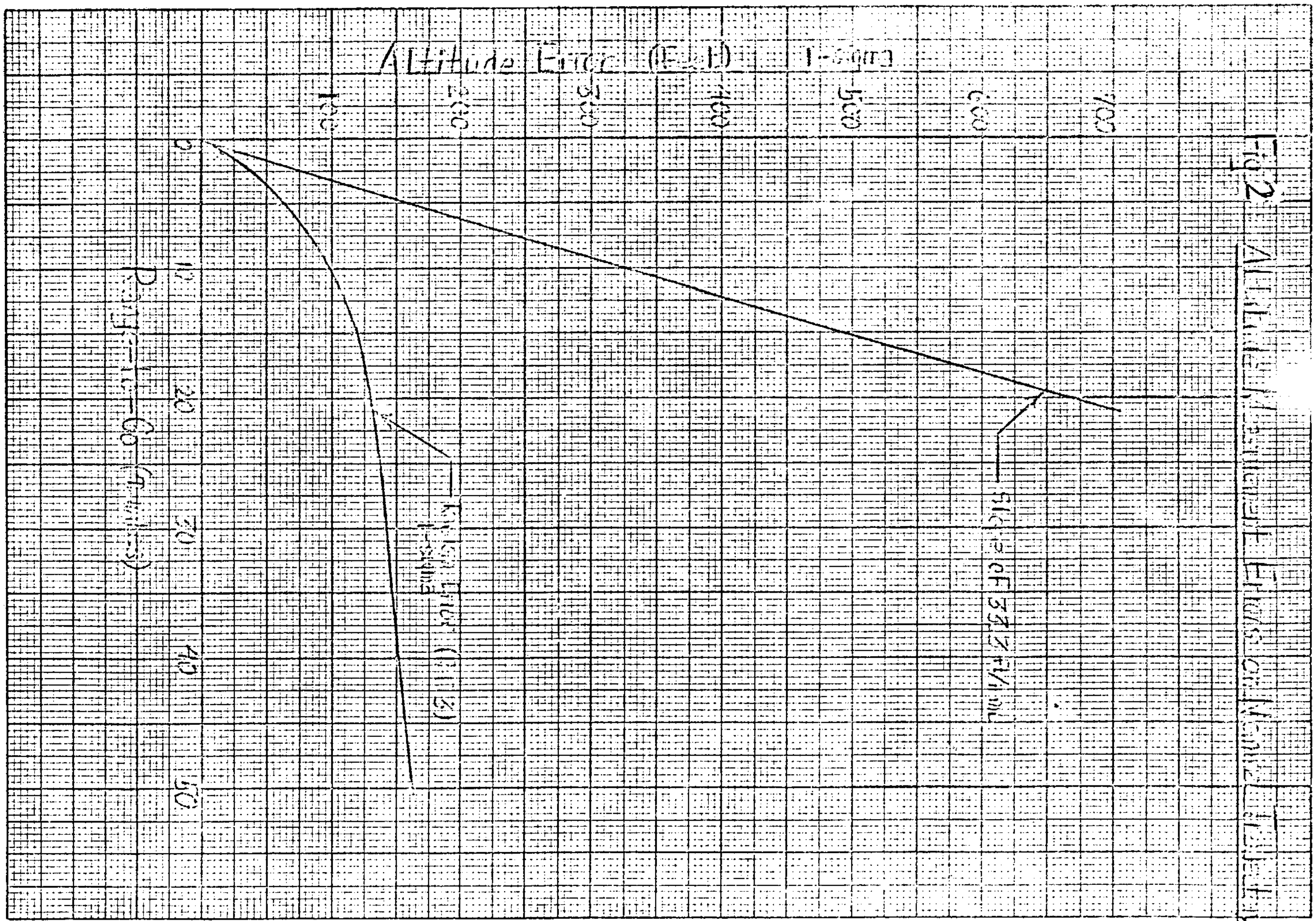
(8.) Kriegsman, B., and Gustafson, D., "Lunar Terrain and LR Dropout Boundary Models for Lunar Landing Simulations", MIT Instrumentation Lab Apollo Mission Simulation Memo No. 21, June 18, 1968.

(9.) Kriegsman, B., "Effect of High-Gate Altitude and Velocity Deviations on the Ability of LM PGNCS to Satisfy Visibility-Phase Constraints for Landing Maneuver", MIT Instrumentation Lab, Mission Simulation Memo No.32, August 14, 1968.

Fig 1: Altitude Weighting Functions



FORM 1 T TECHNOLOGY STORE, H. C. S. MASS. AVE., CAMBRIDGE, MASS.



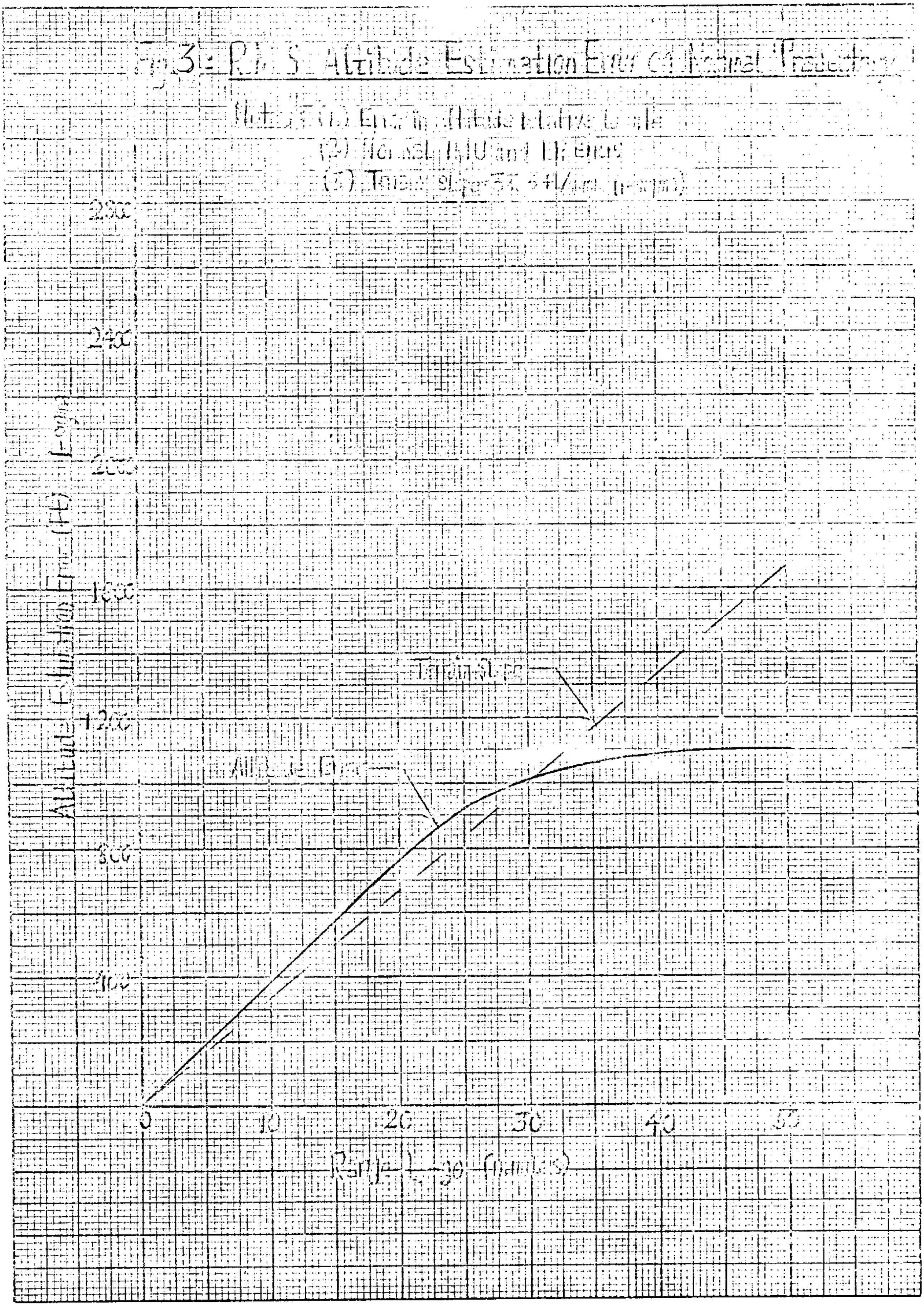
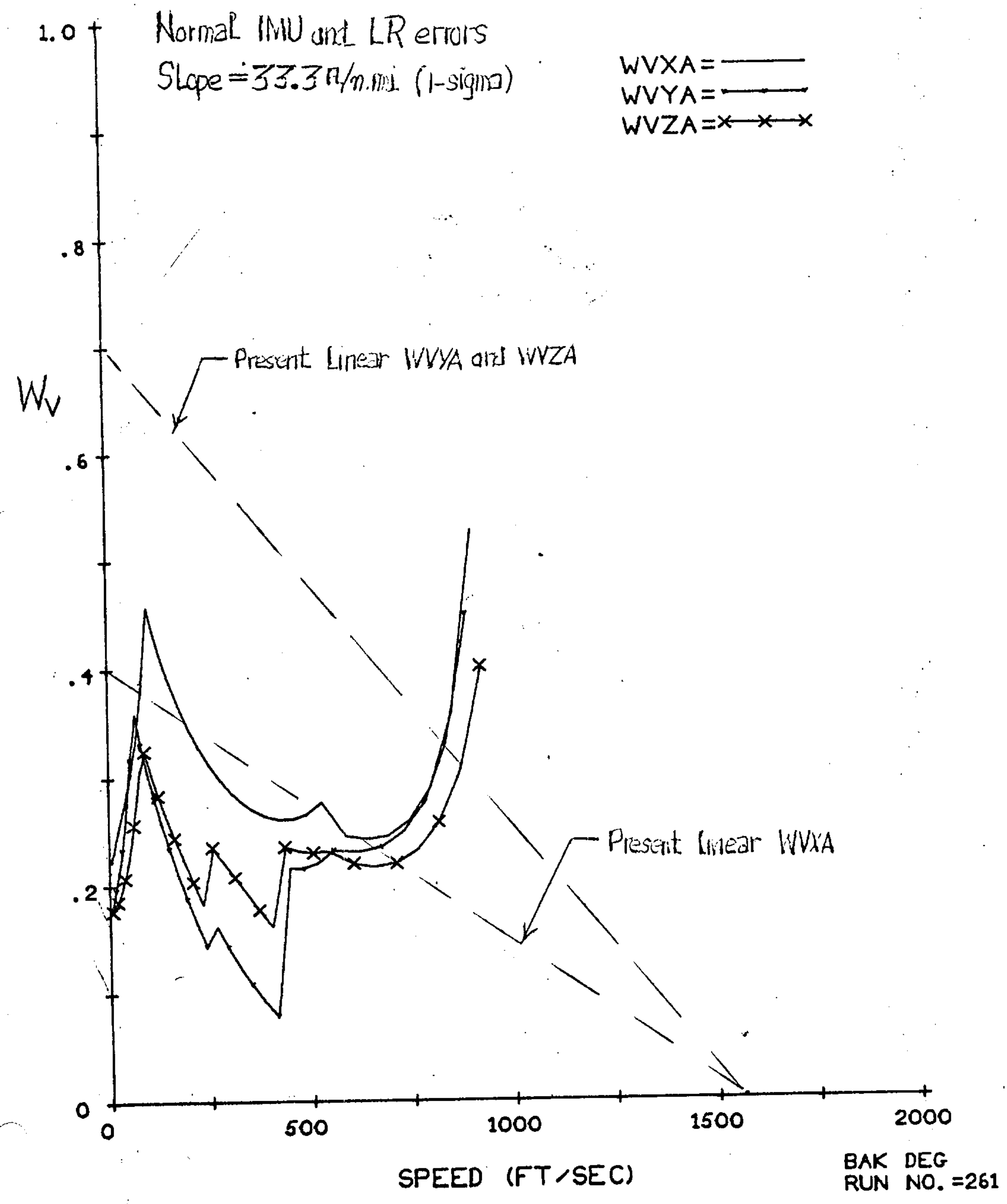
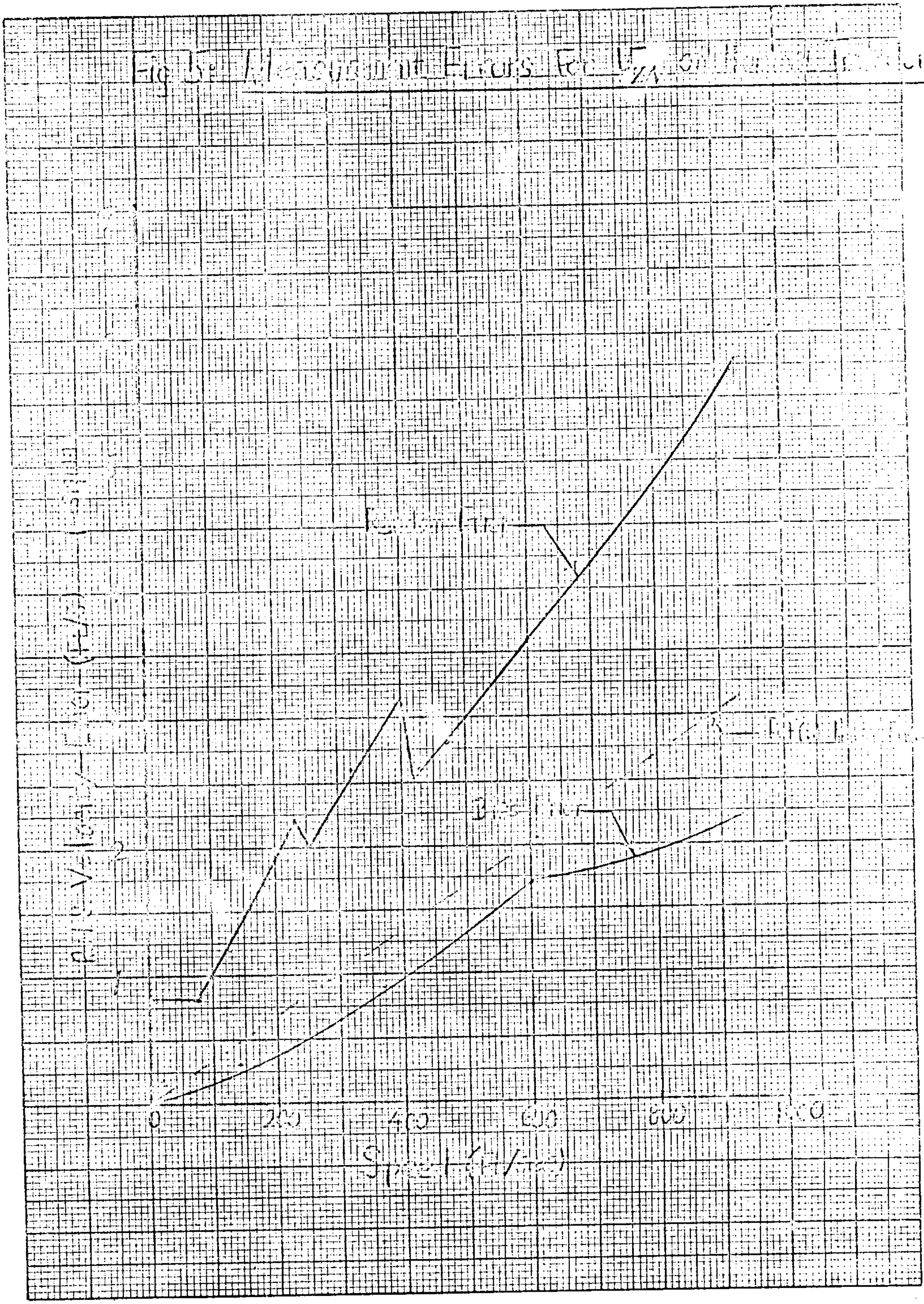
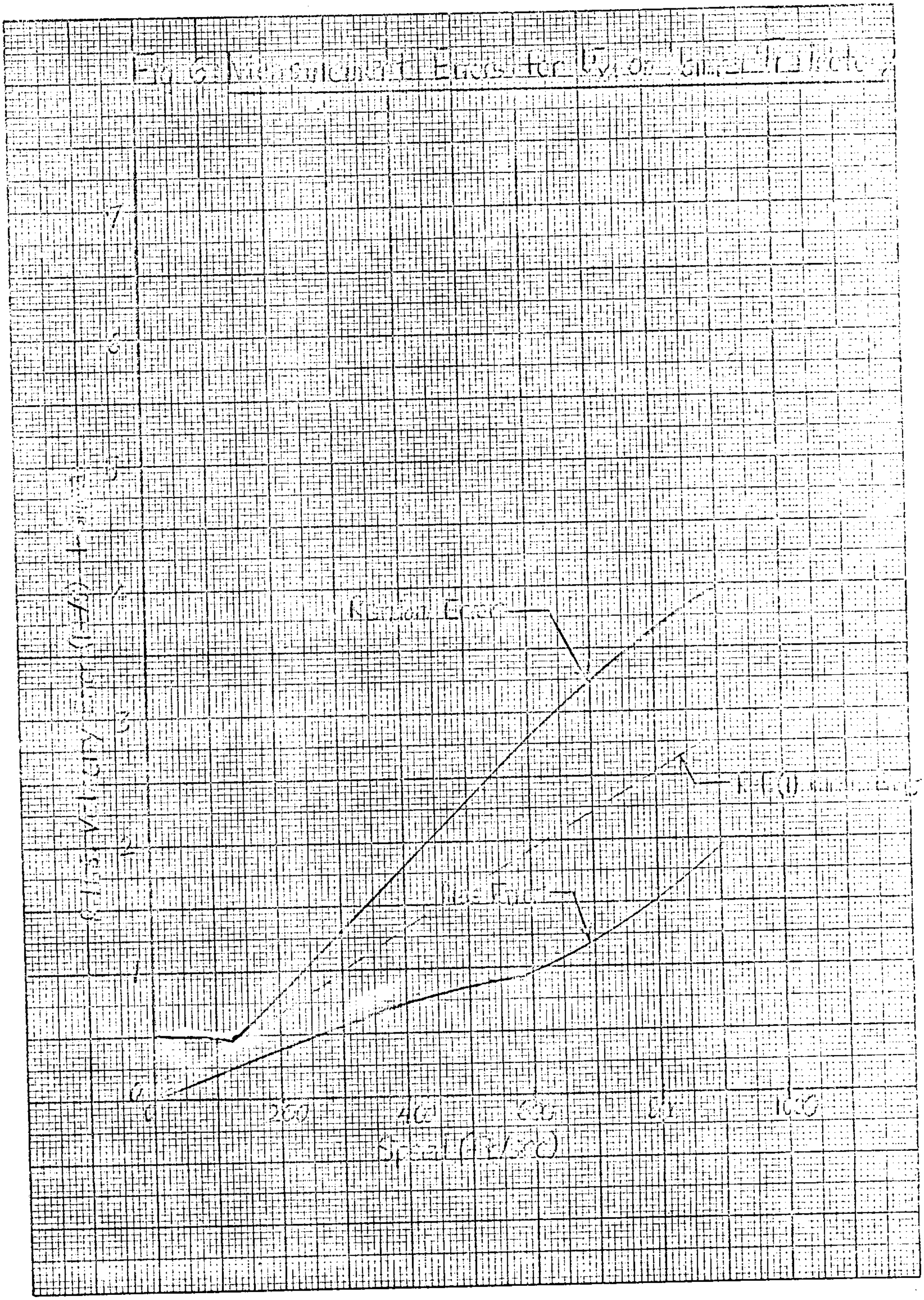


Fig 3: R.M.S. Altitude Estimation Error on Nominal Trajectory

Fig. 4: Velocity-Component Weighting Functions




0
200
400
600
800


7
6
5
4
3
2
1
0
0
200
400
600
800
1000

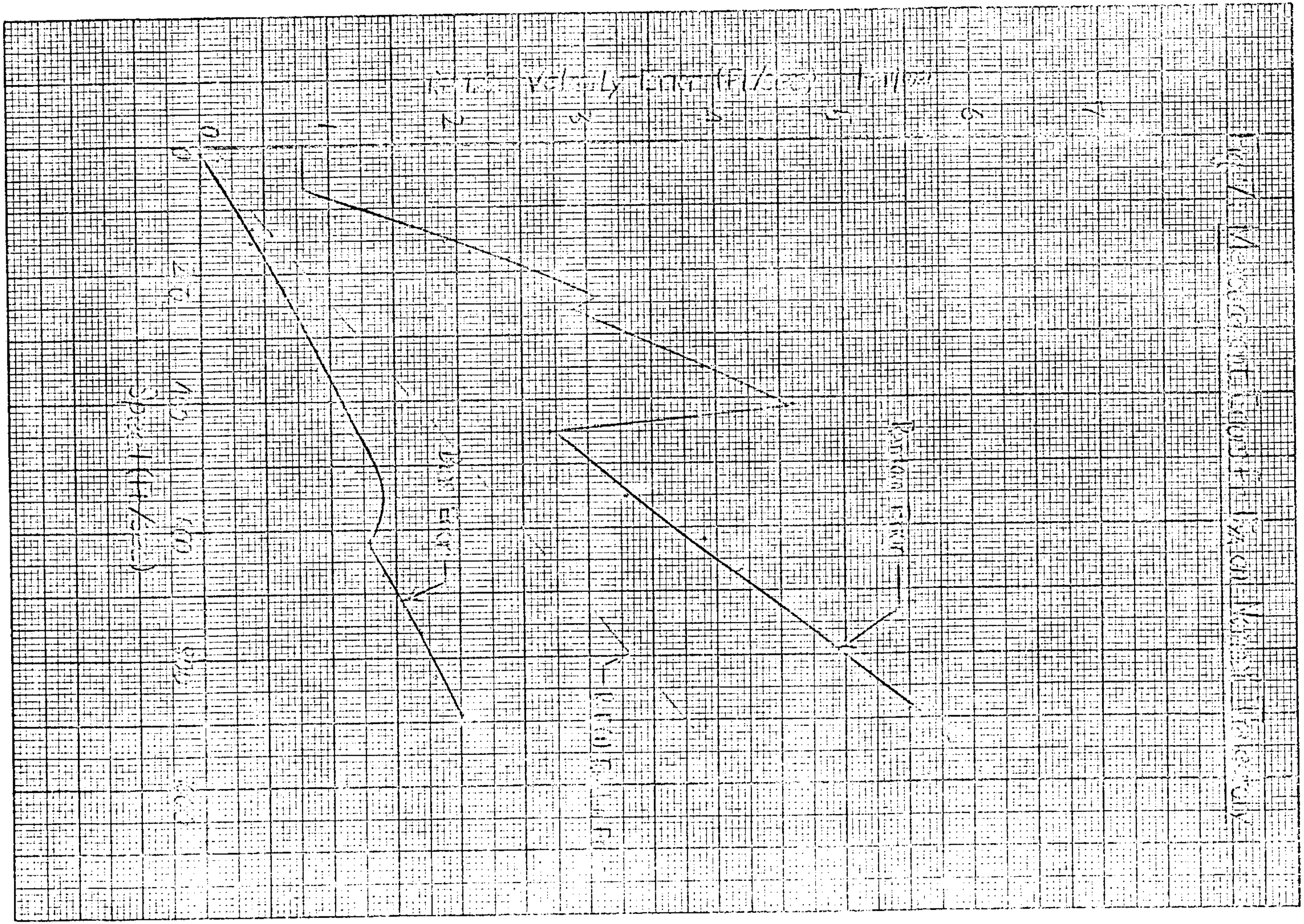


Fig. 8 : Altitude Weighting Functions

Normal IMU and LR errors
Slope = 100 ft/n.mi (1-sigma)

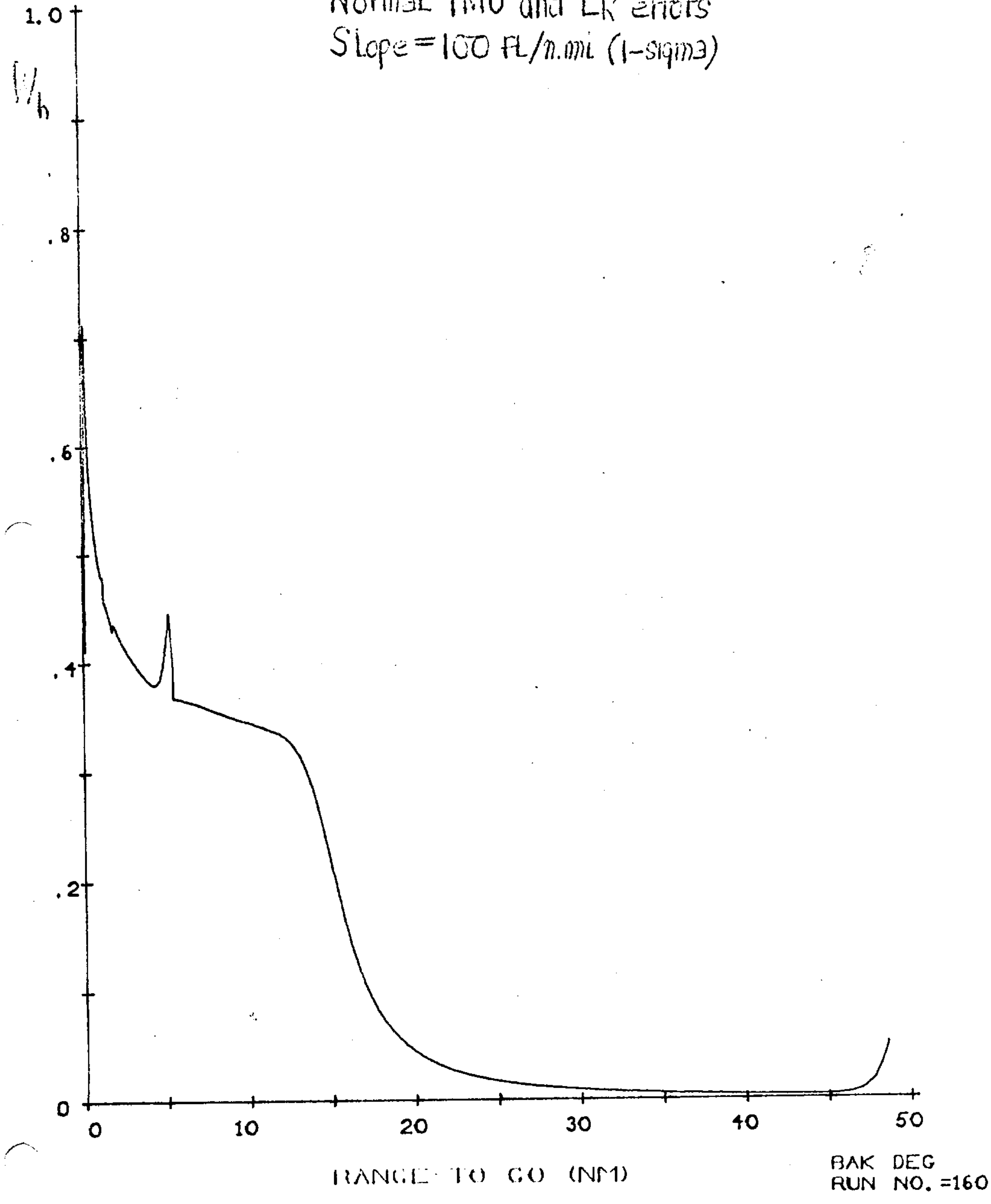
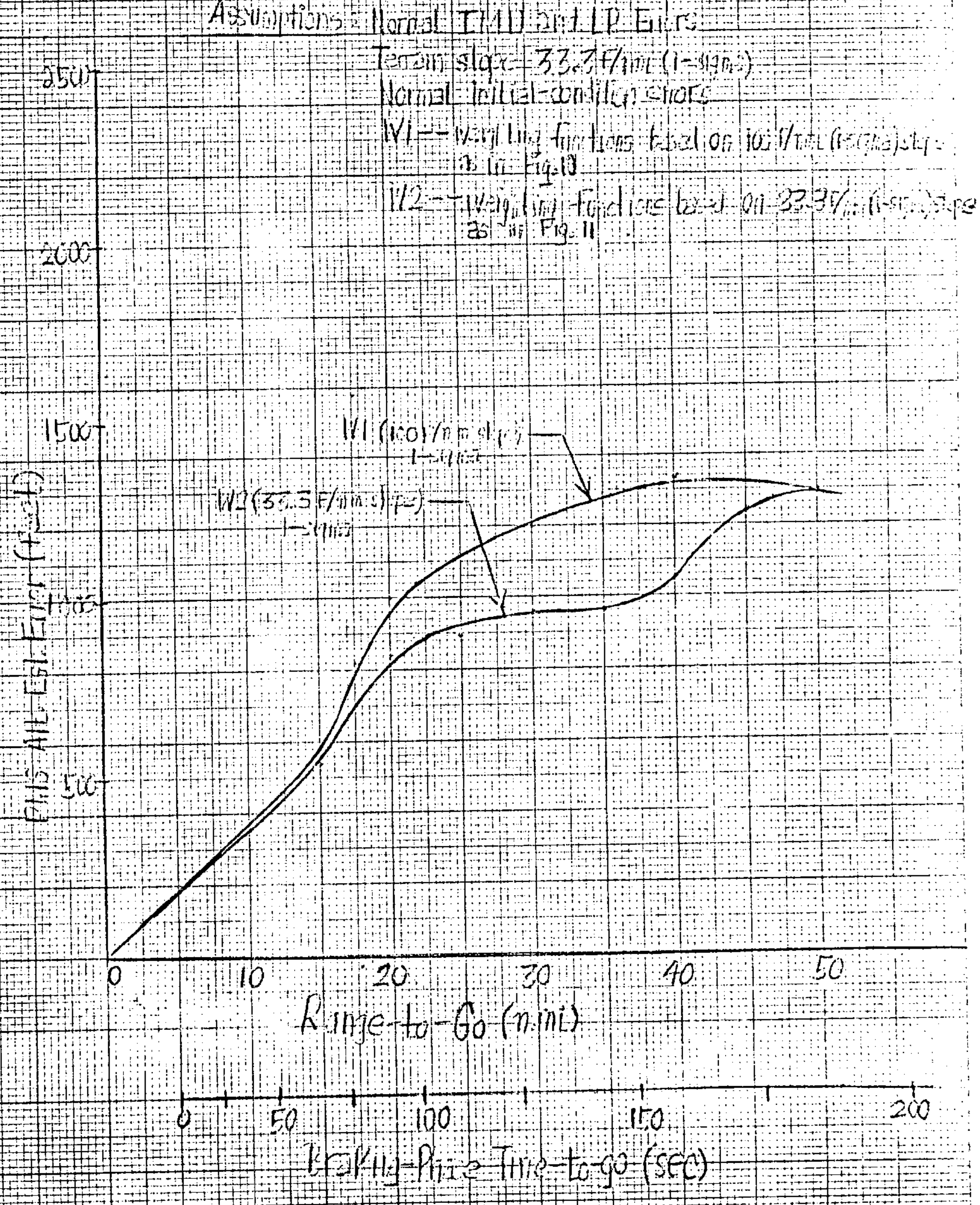


Fig 9: R.M.S. Altitude Estimation Errors with Different LR Altitude Weighting Functions



IT Graph

Fig. 10: Altitude Weighting Function with 100 Ft/n.m Slope Model

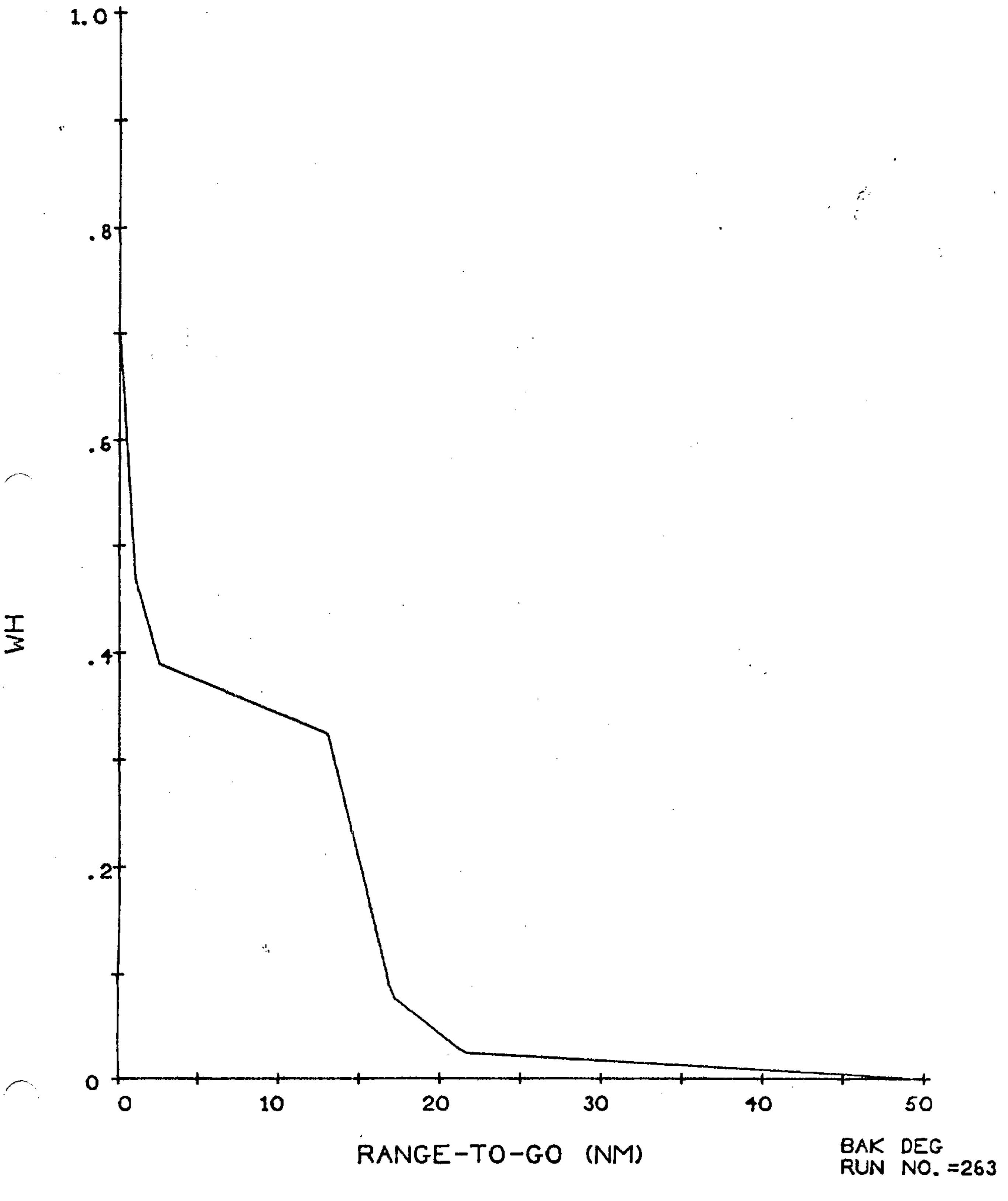


Fig. 11: Altitude Weighting Function with 33.3 ft/n.m. Slope Model

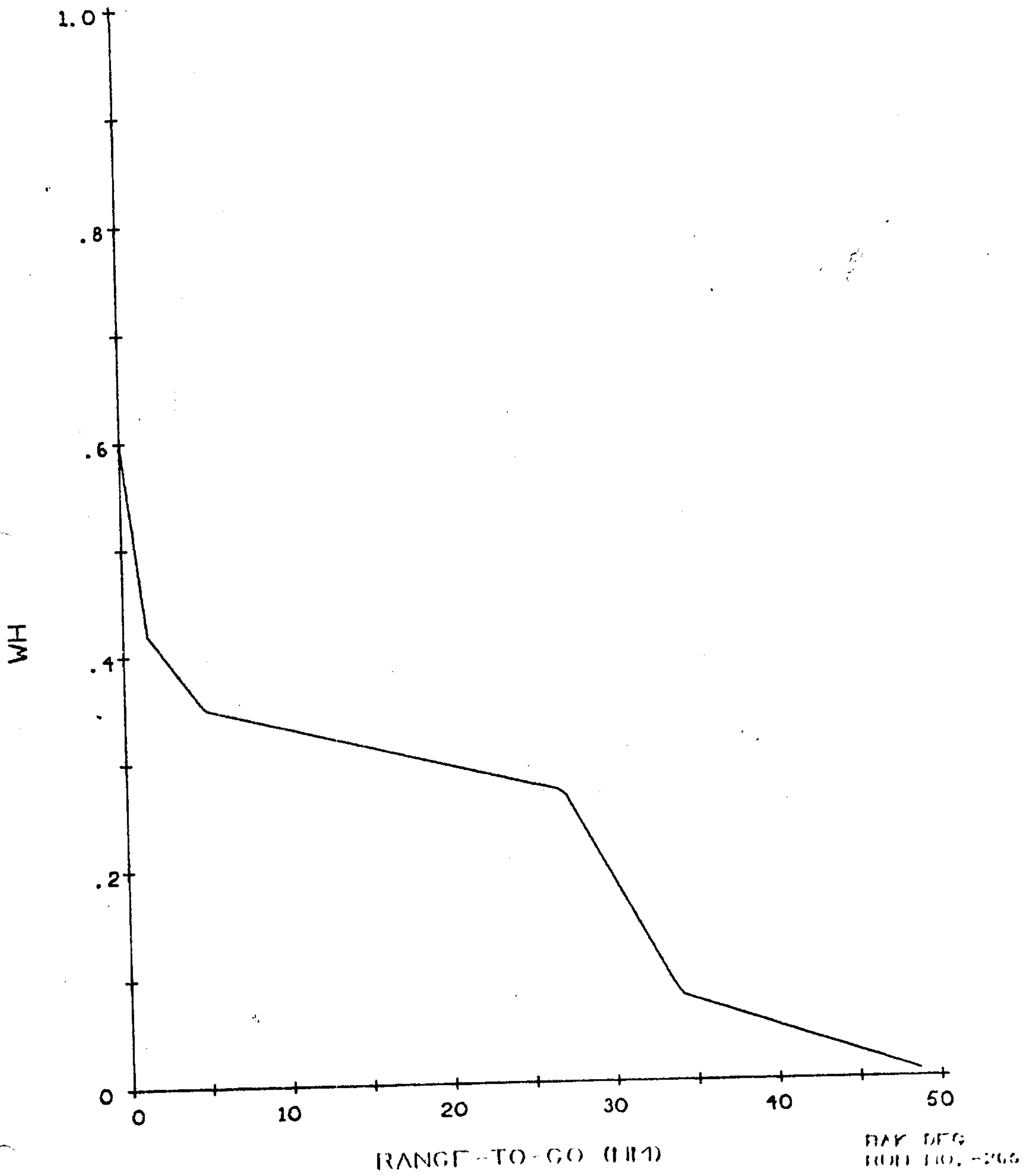


Fig 10: Effect of Variations in Initial-Condition Covariance Matrix on Altitude Weighting Function

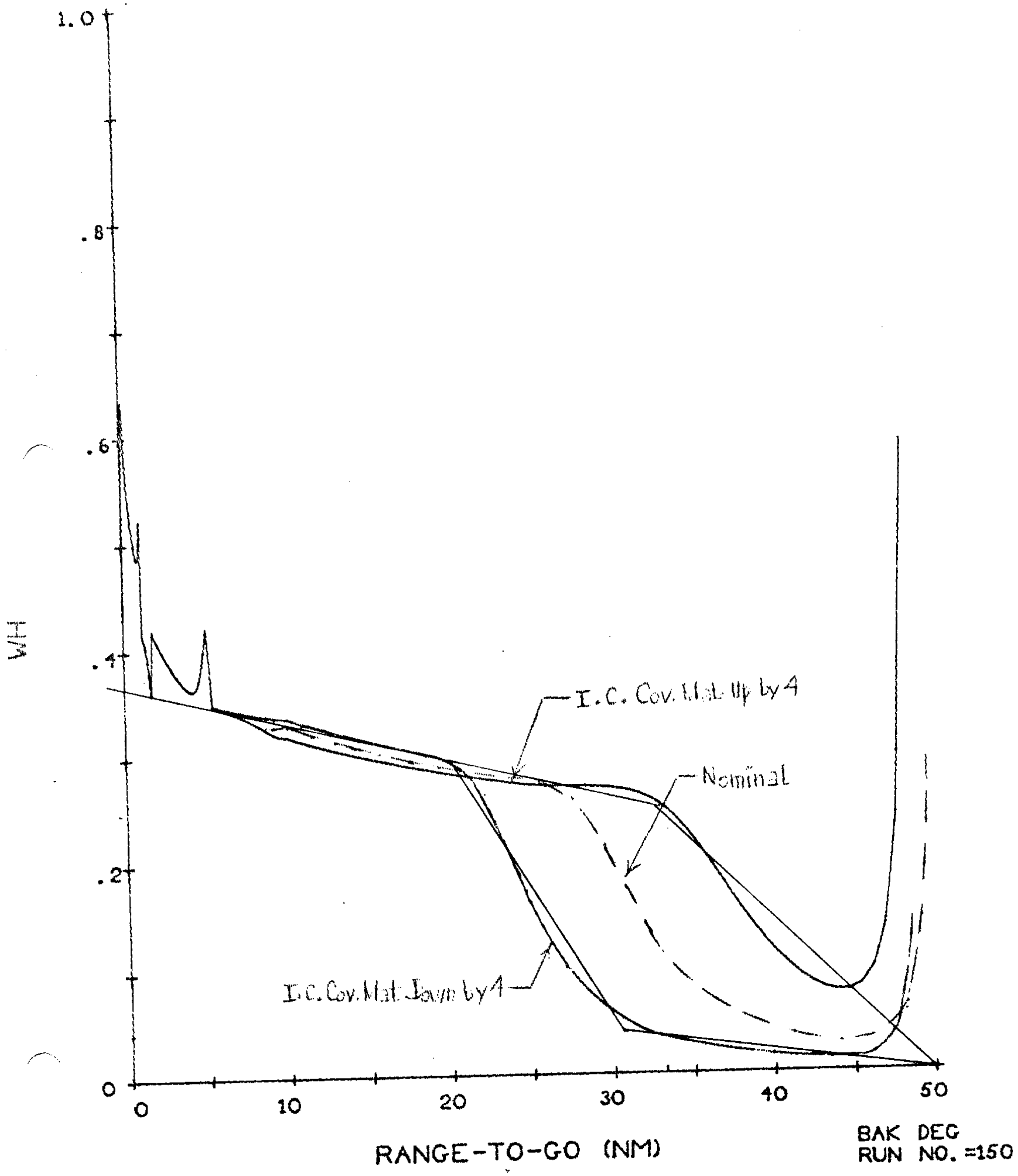


Fig. 11: Effect of Increased Random Altitude Measurement Error on Altitude Weighting Function

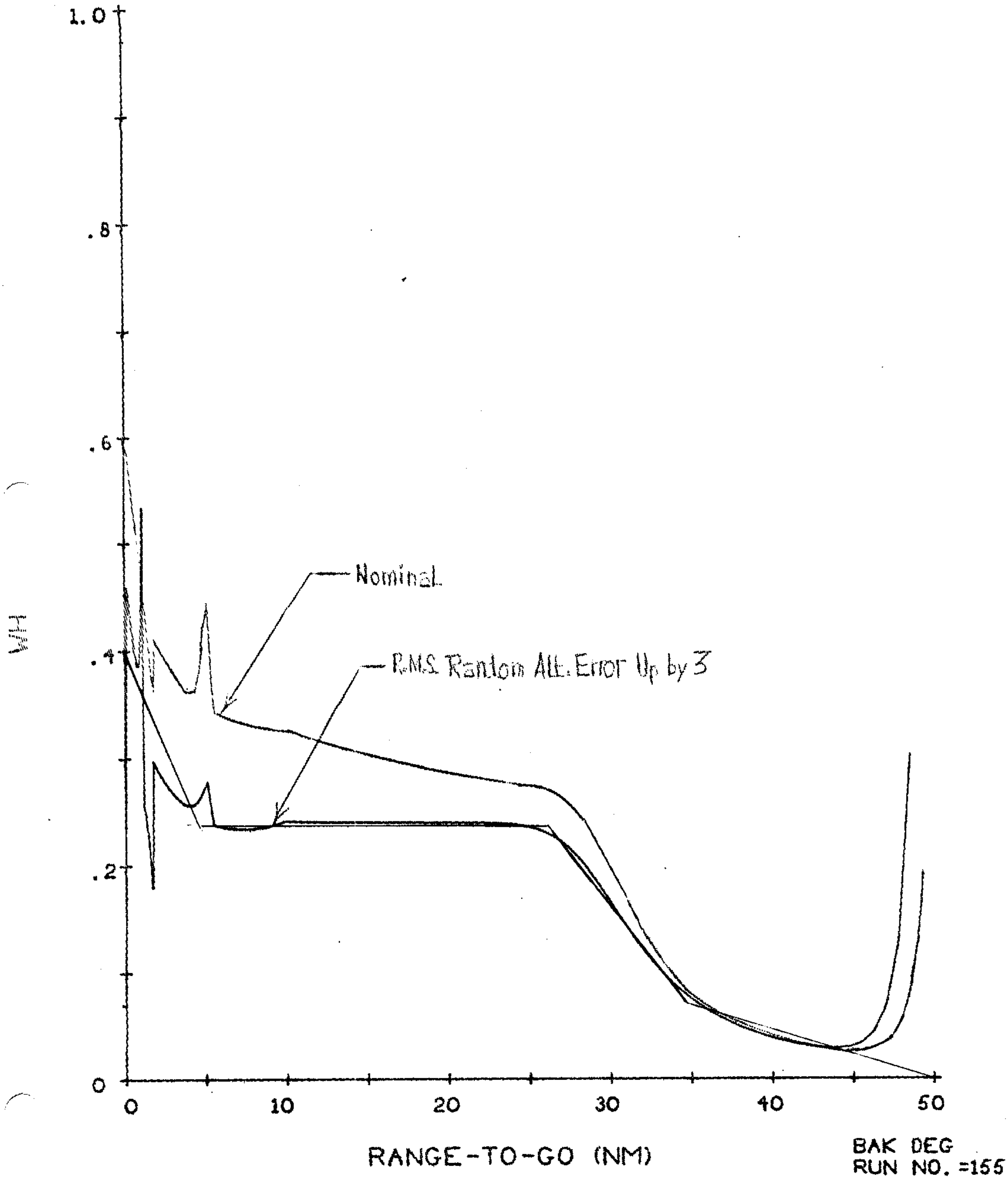
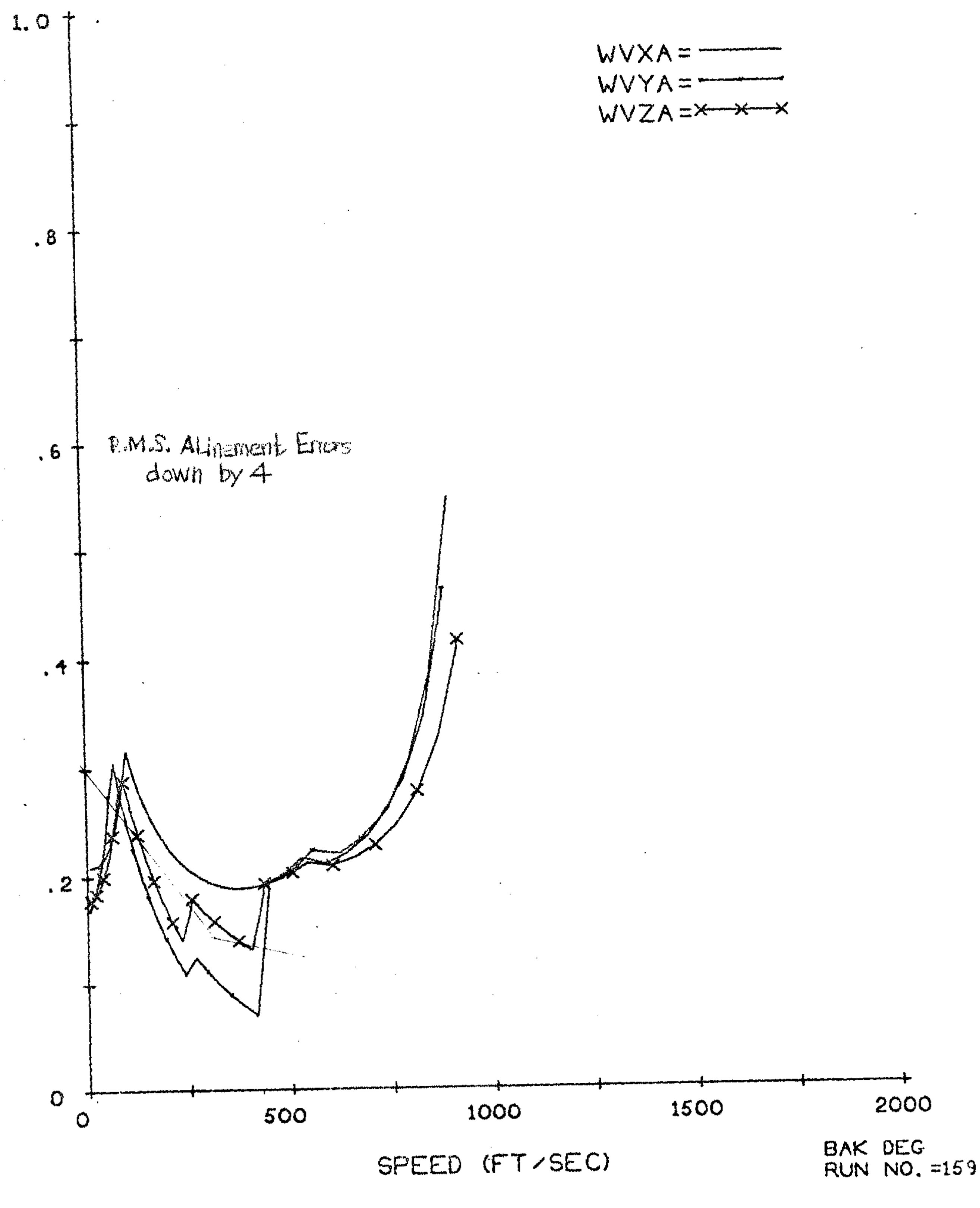


Fig. 12: Effect of Reduced LR Alignment Errors on Velocity Weighting Functions



Massachusetts Institute of Technology
Instrumentation Laboratory
Cambridge, Massachusetts

Mission Simulation Memo # 35

TO: Distribution

FROM: B. A. Kriegsman and D. E. Gustafson

DATE: August 16, 1968

SUBJECT: Storing the Landing-Radar Altitude Weighting Function as a Function of Range-to-Go to the Landing Site.

SUMMARY

The predominant LR altitude measurement error is terrain slope bias, which is proportional to range-to-go to the landing site. The altitude weighting function should be related directly to the magnitude of this error, i. e. to the range-to-go. Profiles of altitude vs. range-to-go differ significantly from the nominal trajectory at ranges-to-go-larger than 20 miles on representative off-nominal trajectories. To obtain best performance under these conditions the weighting functions should be stored as a function of range-to-go, braking-phase time-to-go, or the down-range vehicle position in the guidance-coordinate frame.

GENERAL INFORMATION

The present LR altitude weighting function (Ref. 1) is stored in the LGC as a linear function of estimated local altitude. The new landing radar error model described in Ref. 2 indicates that the predominant altitude measurement error is the terrain slope (33.3 ft/n.m. 1-sigma). This results in a bias error whose magnitude is proportional to the range-to-go to the site, since the measurement actually desired is altitude relative to the site.

Since the major altitude measurement error is a function of range-to-go (rather than altitude) it is reasonable to consider the possibility of storing the weighting function in terms of range-to-go.

ANALYSIS OF PROBLEM

Optimum LR altitude weighting functions to minimize mean-squared estimation errors are shown for a nominal trajectory in Fig. 1 as a function of altitude, and in Fig. 2 as a function of range-to-go. The magnitude of these weighting functions at a given point is determined by the relative mean-squared errors of the radar-updated IMU and the radar. Since terrain slope is the major altitude measurement error, the weighting function is basically related to range-to-go.

If there were a unique relationship between range-to-go and altitude on all landing trajectories of interest, then it would make little difference whether range-to-go or altitude were used as the storage variable. The approximations in linear-fitting the curves of Figs. 1 and 2 are not significantly different.

It turns out, however, that the altitude vs. range-to-go profiles for representative off-nominal landing trajectories are significantly different from the nominal case. This can be seen from the curves of Fig. 3. With the weighting function stored in terms of altitude, as in the present GSOP, significantly different altitude weighting functions can be obtained at a given range-to-go greater than 20 miles, depending upon the particular landing trajectory. This is undesirable since the weighting function here should be determined by the size of slope bias error, i.e. the range-to-go.

Curves of braking-phase time-to-go are presented in Fig. 4 vs range-to-go for the three trajectories of Fig. 3. As can be seen, the curves lie on top of each other. This implies that time-to-go to the end of the braking phase would also be a satisfactory quantity for use in storing the altitude weighting functions.

It should also be noted here that in the region of interest, the range-to-go is essentially equal to the down-range component of vehicle position in the guidance-coordinate frame. This quantity is computed during quadratic guidance modes for use in computing time-to-go.

REFERENCES

(1.) LUMINARY GSOP Section 5, Guidance Equations MIT Instrumentation Lab Report R-567, January 1968.

(2.) Kriegsman, B.A., and Gustafson, D.E., "New Landing Radar Error Models and Weighting Functions", MIT Instrumentation Lab Mission Simulation Memo No.34, August 16, 1968

Fig. 1 : Altitude Weighting Function vs. Range-to-Go

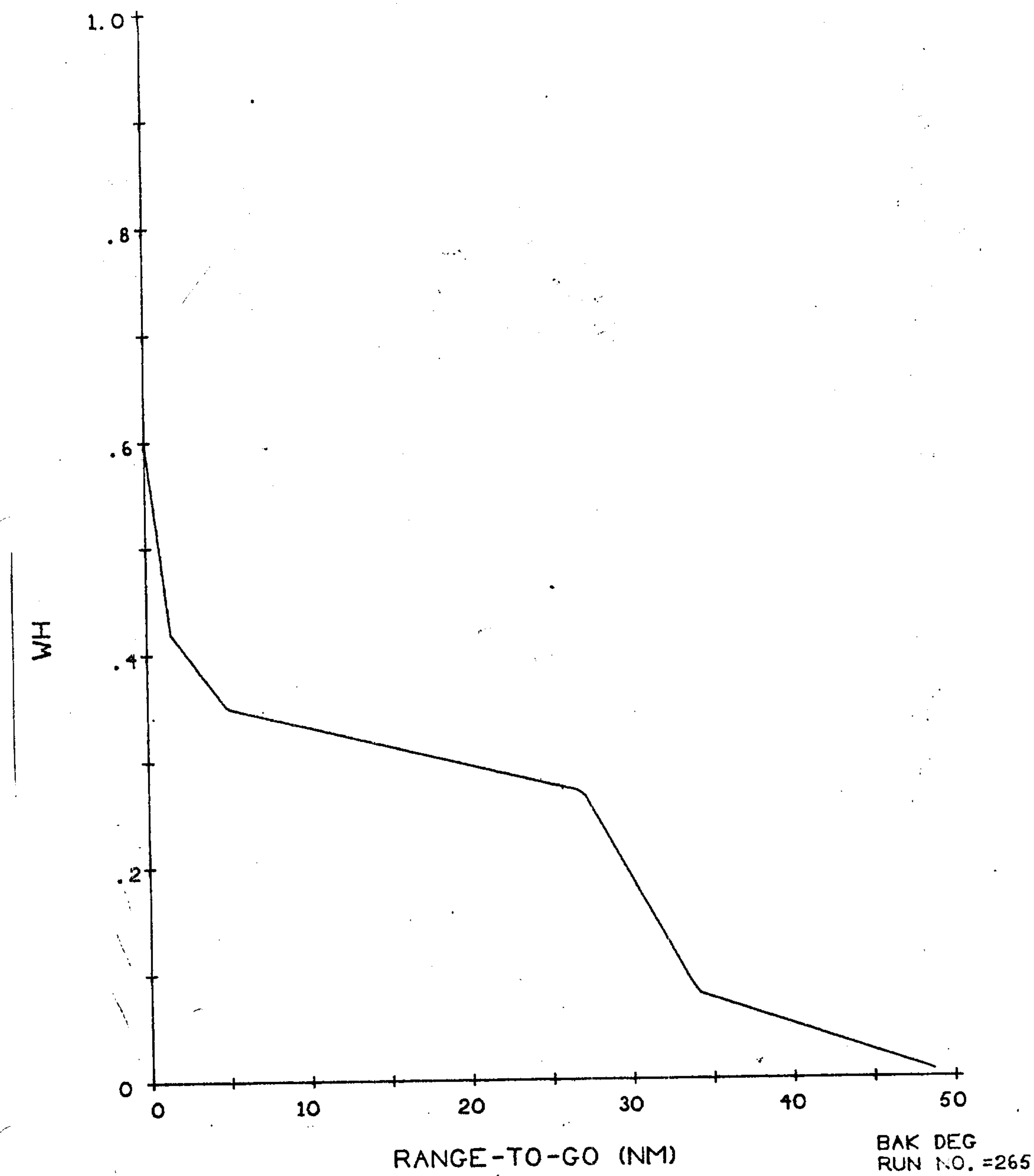


Fig. 2: Altitude Weighting Function vs. Altitude

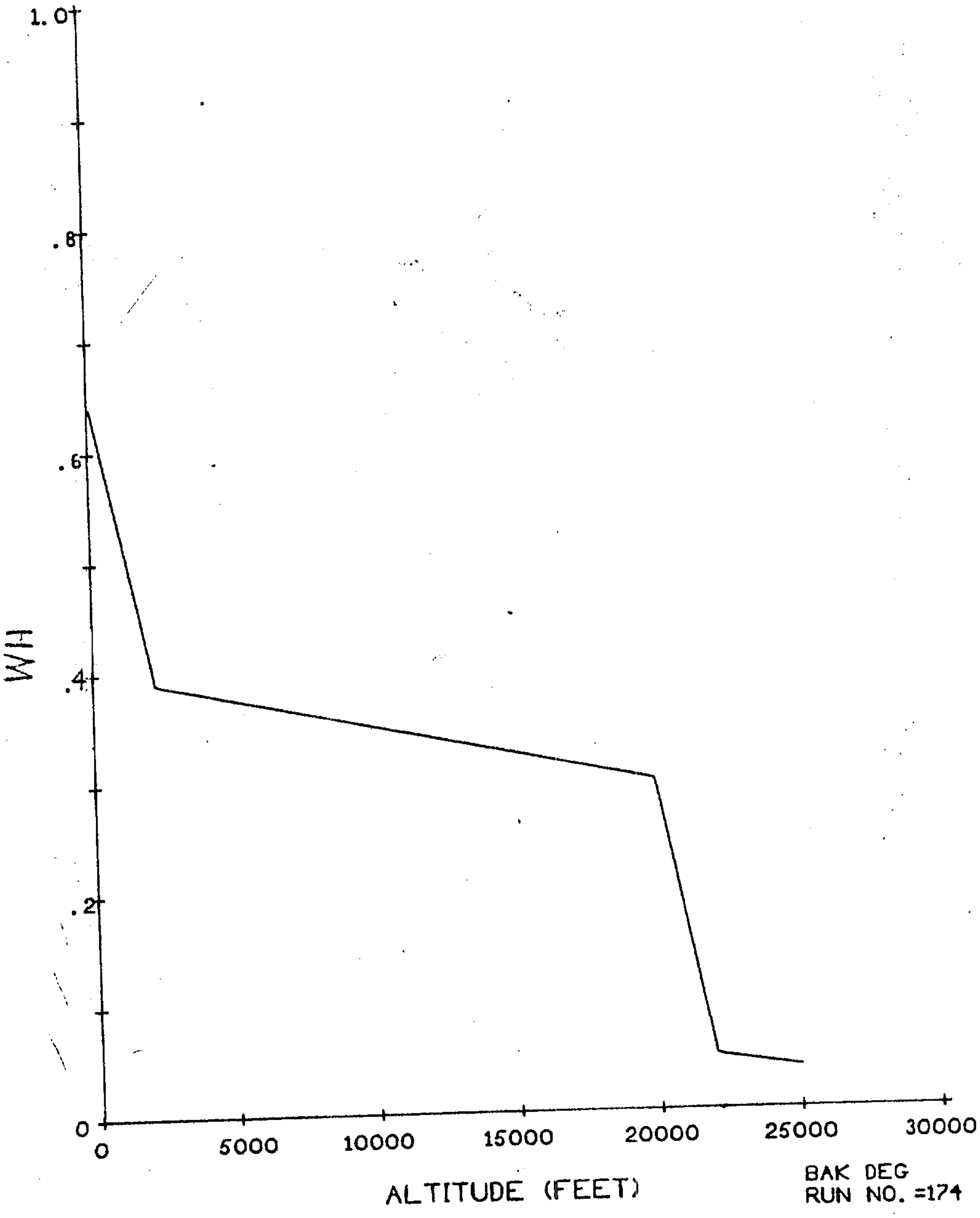


Fig. 3: Altitude vs. Range-to-Go for Off-Nominal Landing Trajectories

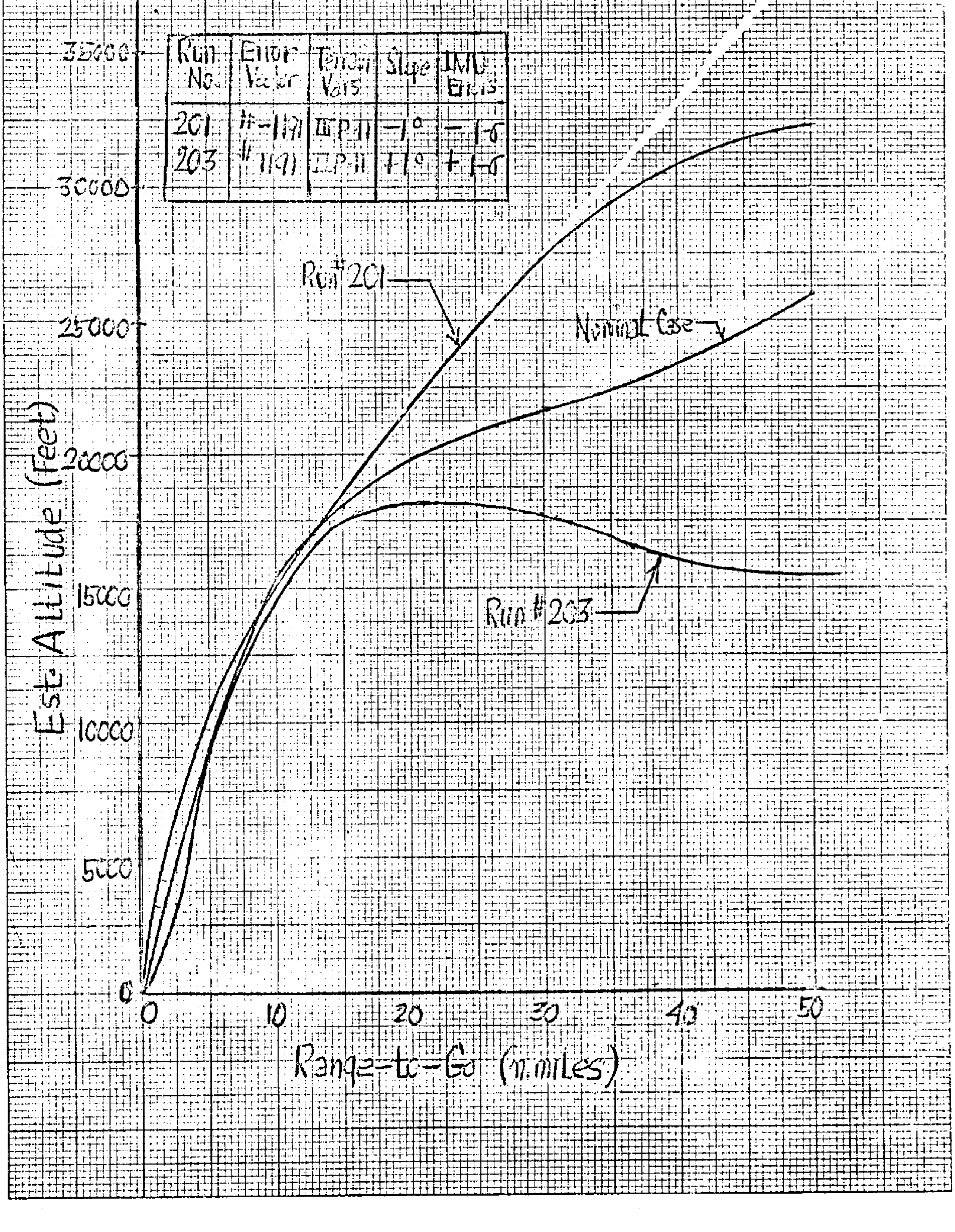
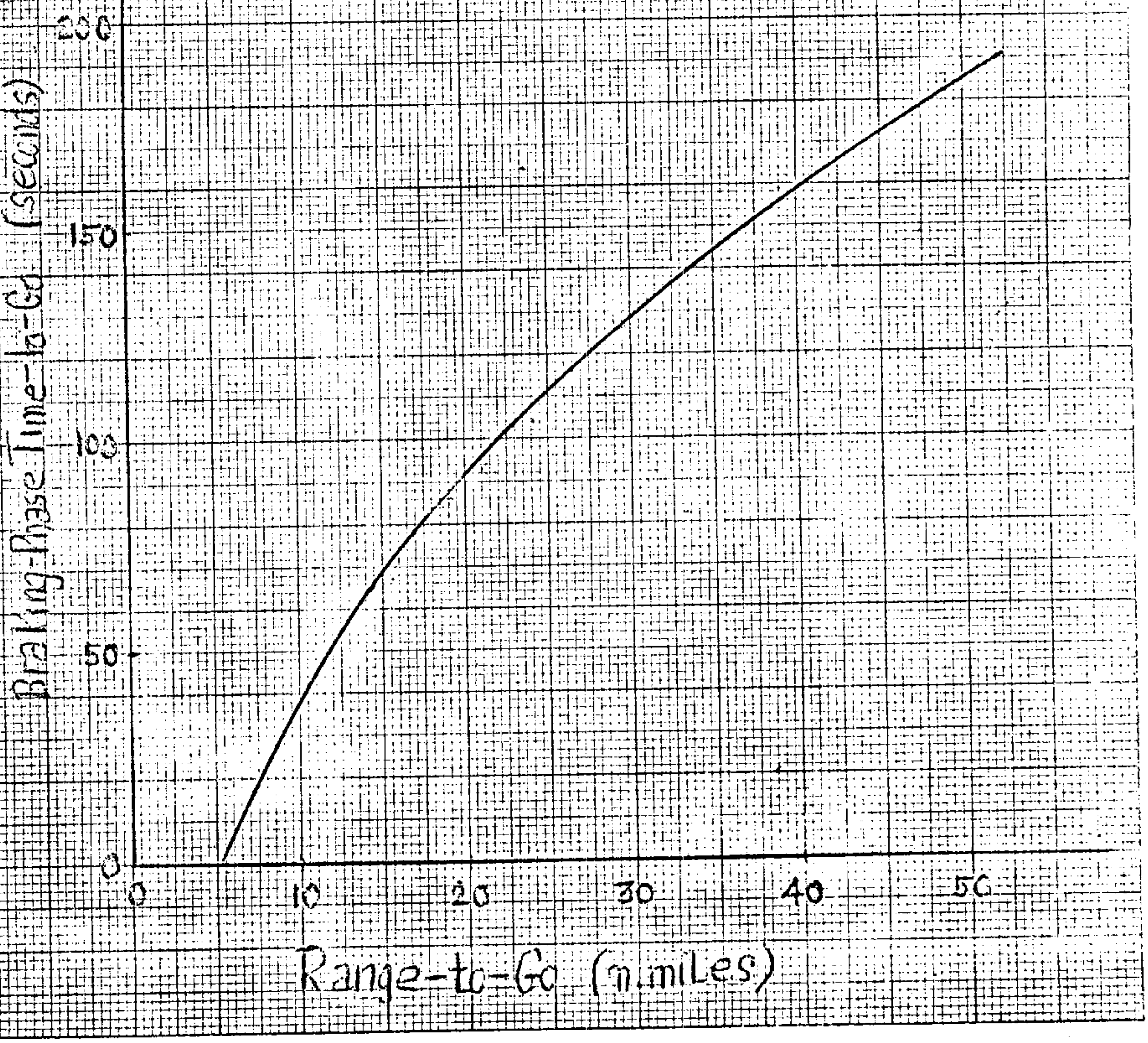


Fig 4. Braking-Phase Time-to-Go vs Range-to-Go for Off-Nominal Trajectories



IT Graph

Landing Simulation Test Runs

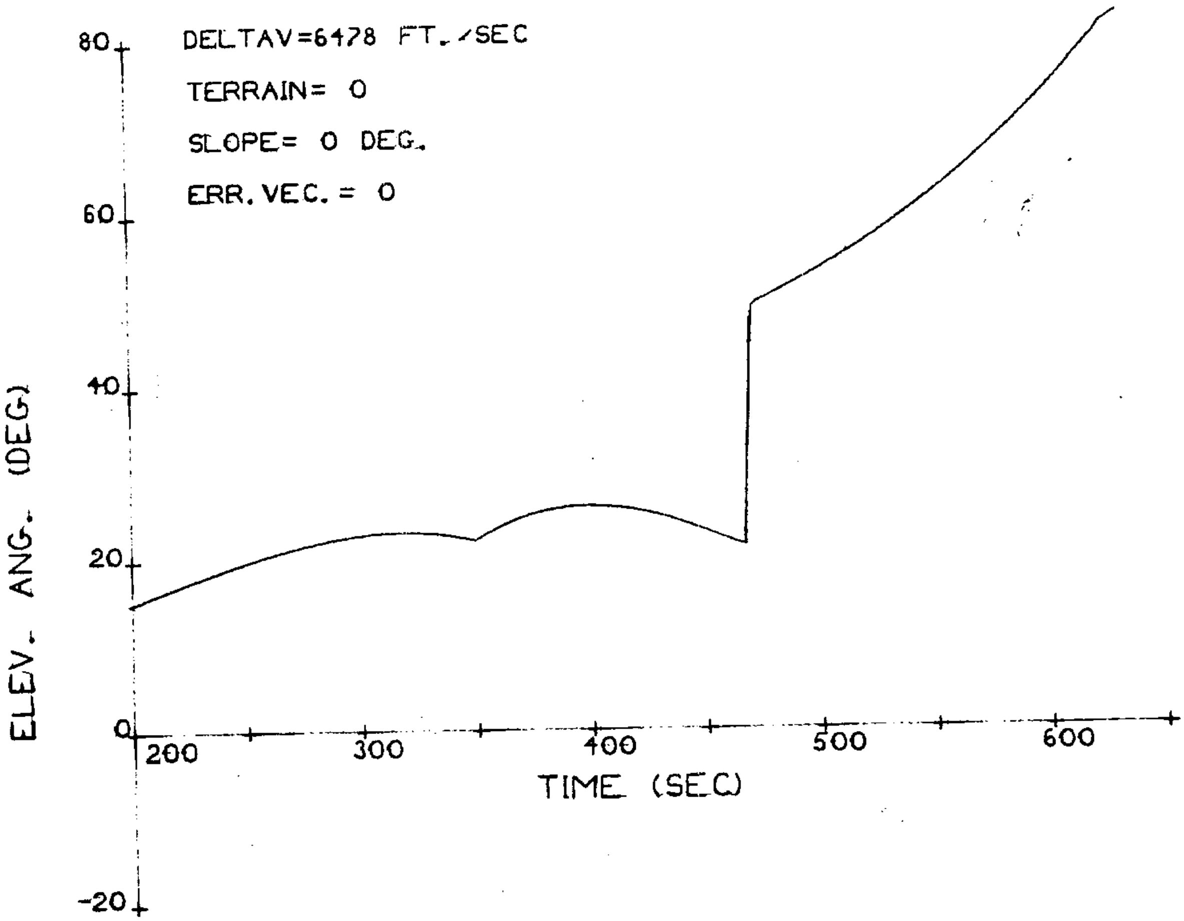
PURPOSE	Run No.	Initial Errors	IMU Errors	Terrain Vars.	Terrain Slope	Thrust Acc. Dev
(1.) Nominal	100	No	No	Smooth	0	0
(2.) Initial-Condition Errors Alone	102	+#1191	No	Smooth	0	0
	103	-#1191	No	Smooth	0	0
(3.) Terrain Variations Alone	104	No	No	III-P-11A	0	0
	105	No	No	III-P-11A	+1 deg.	0
	106	No	No	III-P-11A	-1 deg.	0
(4.) Thrust Accelerations Alone	107	No	No	Smooth	0	3-σ High
	108	No	No	Smooth	0	3-σ Low
(5.) Worst-Case Runs	109	-#1191	3-σNeg	III-P-11A	-1 deg.	3-σ High
	110	+#1191	3-σPos	III-P-11A	+1 deg.	3-σ Low

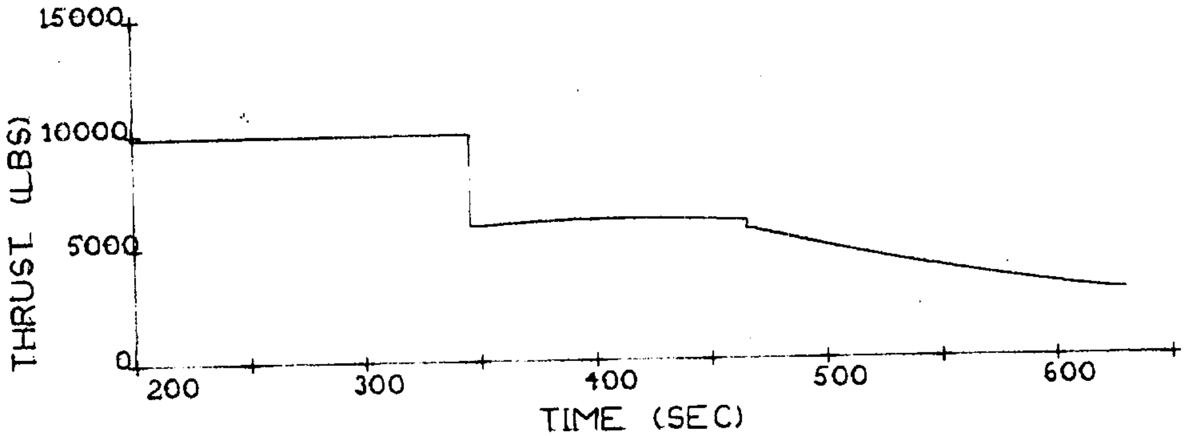
Enclosure 6

Comments on Test Runs

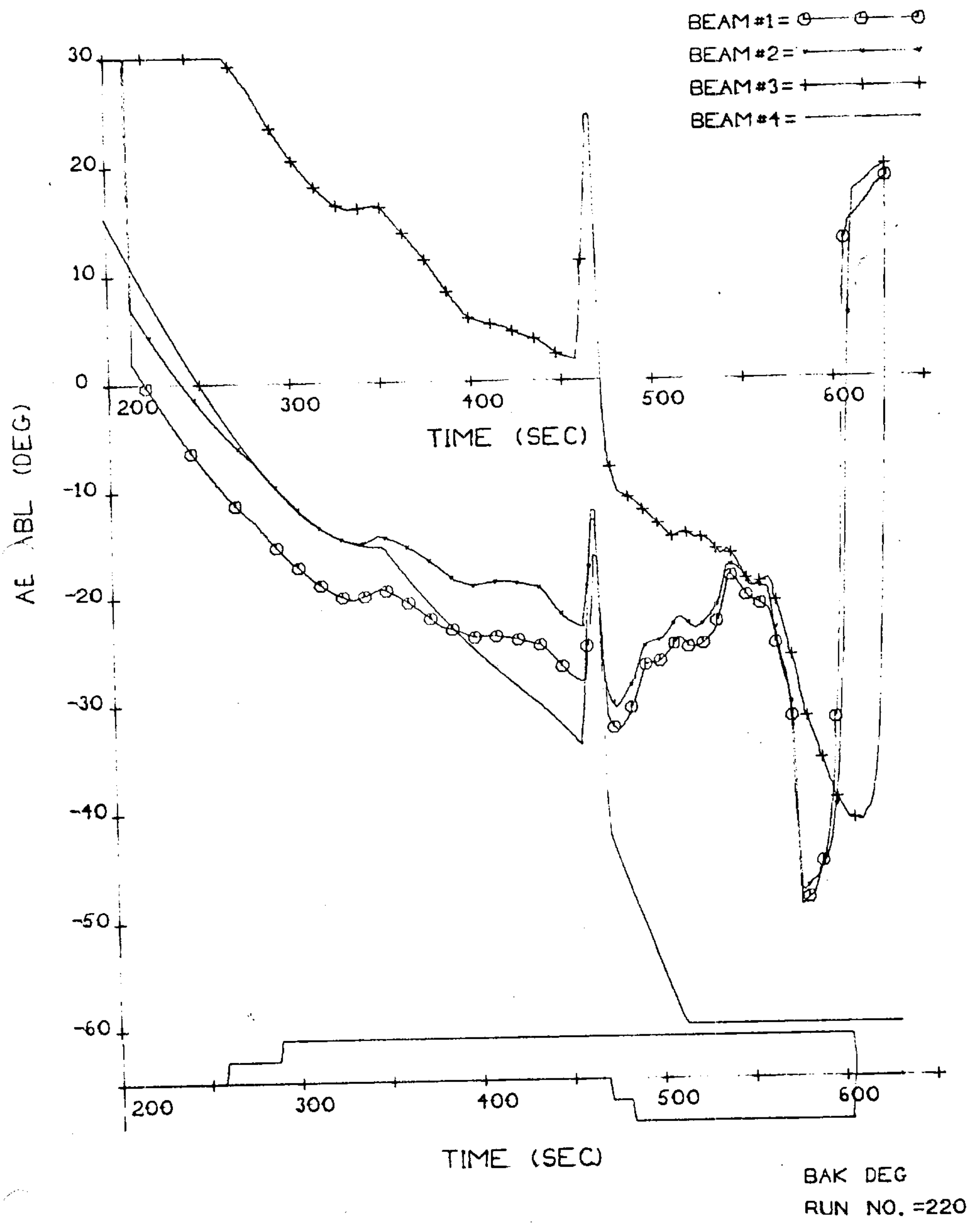
- No velocity updatings during braking phase on nominal run with assumed LR-dropout model
- Altitude and velocity data dropout 30 seconds before end of visibility phase on nominal run
- Worst-case initial-condition errors alone or 3-sigma thrust acceleration variations alone presented no difficulties
- With terrain III-P-11A, thrust-vector elevation-angle deviations are excessive during the last 50-60 sec. of the braking phase
- Run with vehicle high and slope down had no LR updatings
- Run with vehicle low, slope up, and 3-σ IMU errors had large High-Gate errors. Poor approach characteristics

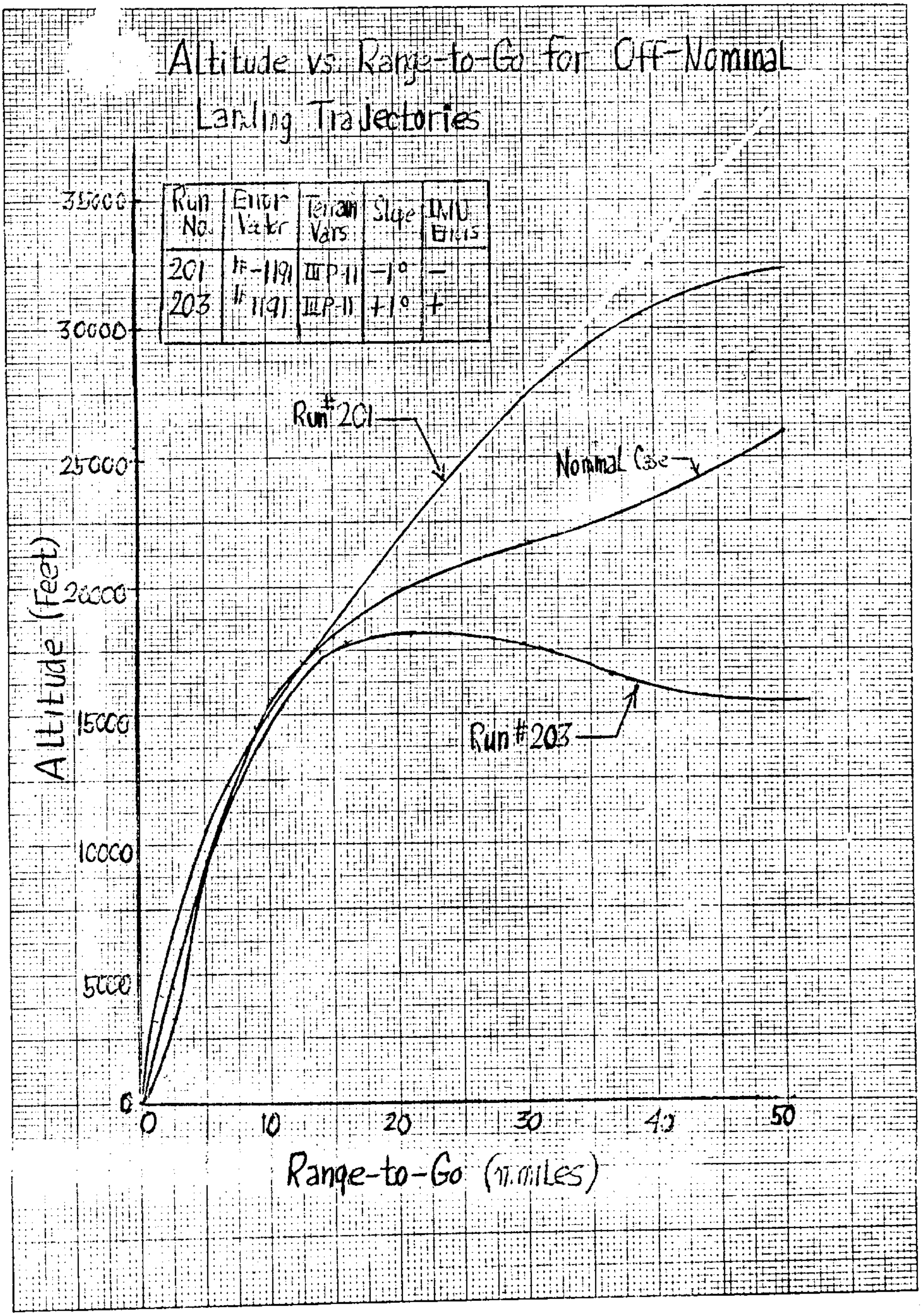
Nominal Trajectory Thrust Profiles





I-R Beam Angles on Nominal Trajectory





Run No.	Error Vctr	Terrain Vars	Slope	IMU Bias
201	IF -1191	III P-11	-1°	−
203	IF 1191	III P-11	+1°	+

Constraints to Evaluate High-Gate Errors

- Visibility interval --- 7-deg. above window edge (75 sec. min)
- Range-to-go when 4-sec deadman's curve violated
  (want to be smaller than 200 ft)
- Altitude at 2000 ft. range-to-go (30-50 % devs.)
- Flight-path angle at 2000 ft. range-to-go (30-50 % devs.)
- Pitch angle of thrust vector during Last 2000 ft.

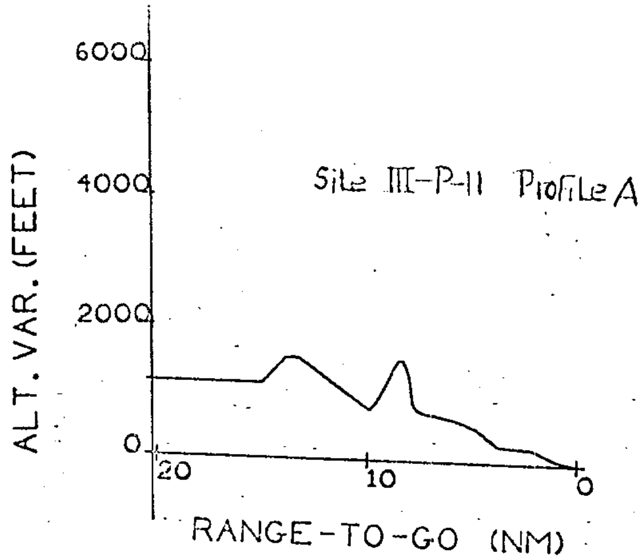
Minimization of Mean-Squared Estimation Errors

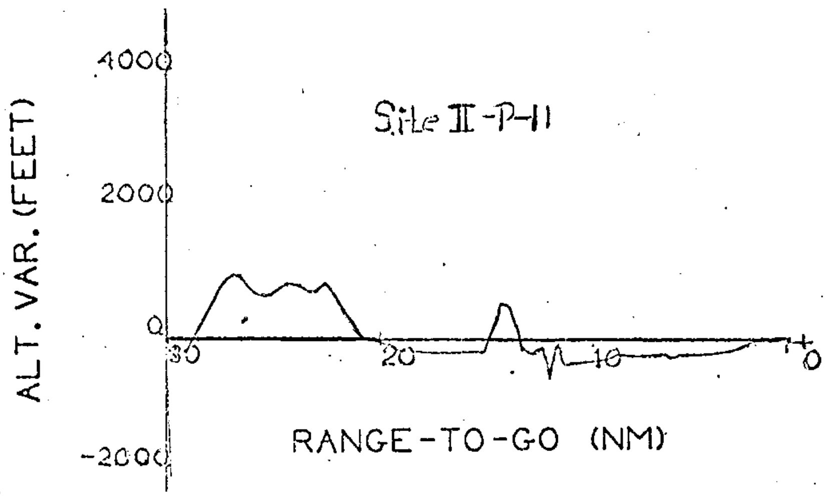
- Meet High-Gate and Low-Gate conditions accurately

- The earlier that estimation errors in altitude can be reduced, the less severe will be the required maneuvers to meet aim conditions

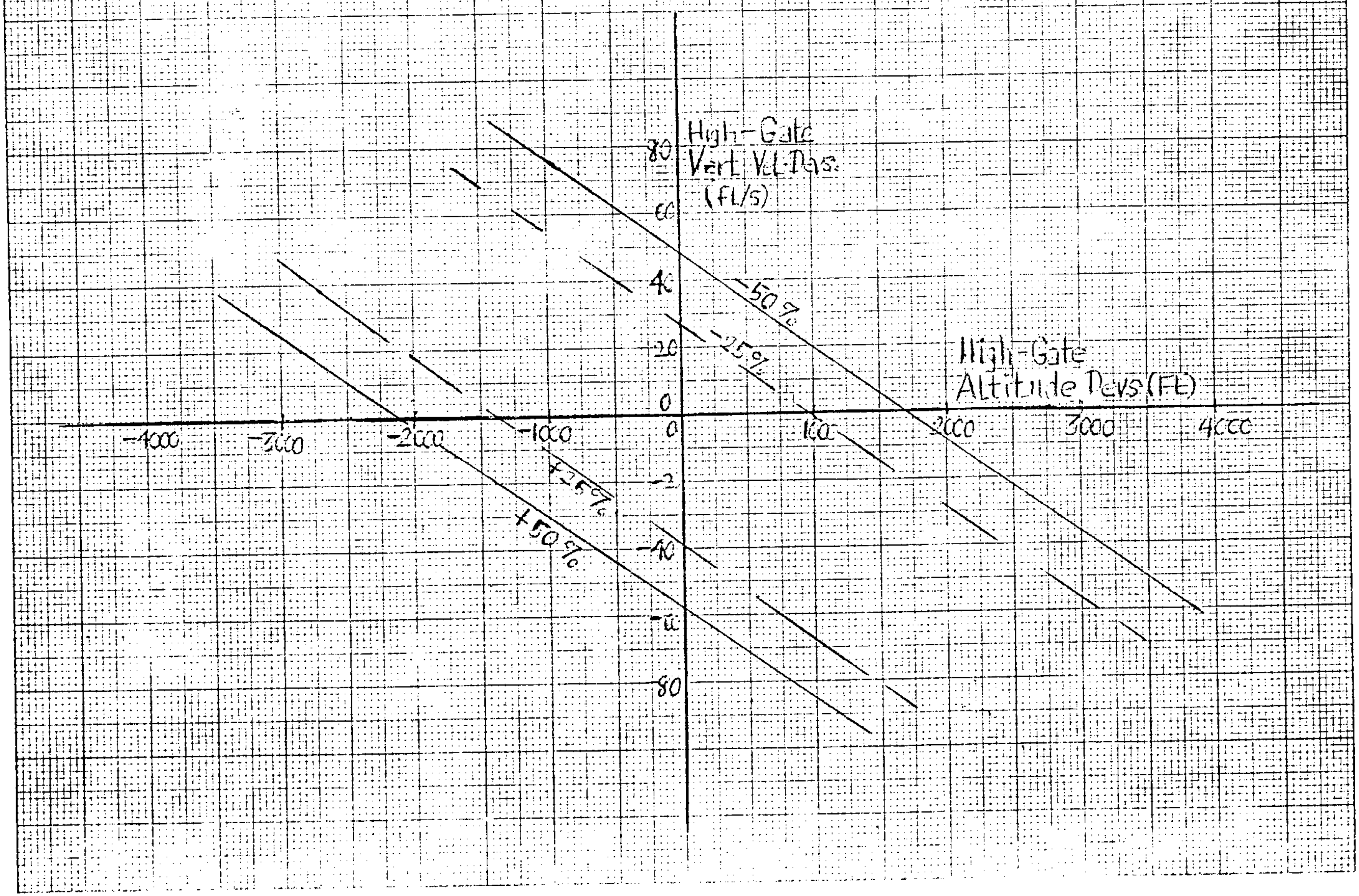
- In the event of LR dropouts during trajectory it will be best to have a minimum-error estimate prior to dropout

Lunar Terrain Variation Models

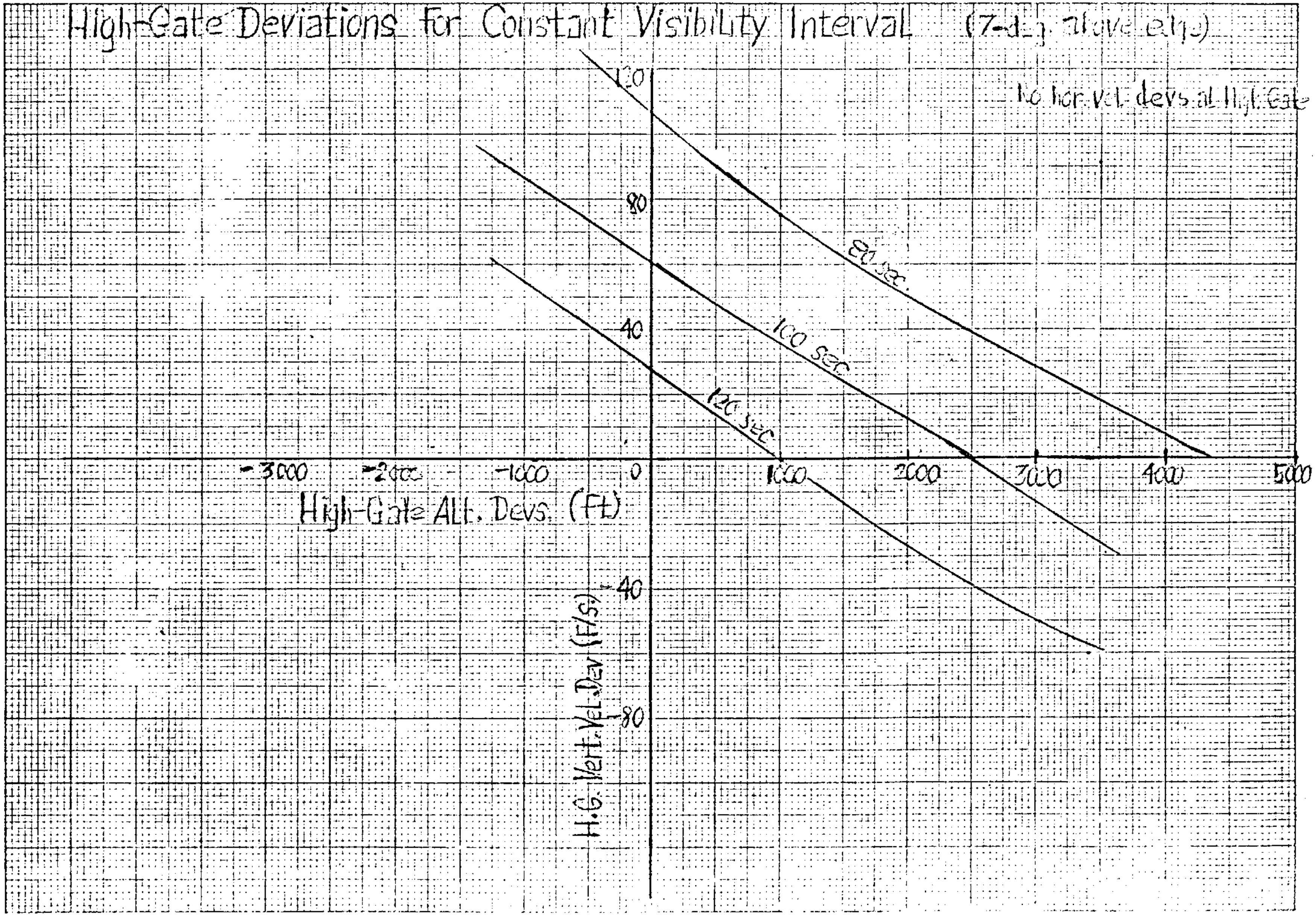




Percent Change in Flight-Path Angle at Range-to-Go of 2000 Ft. for High-Gate Devs.

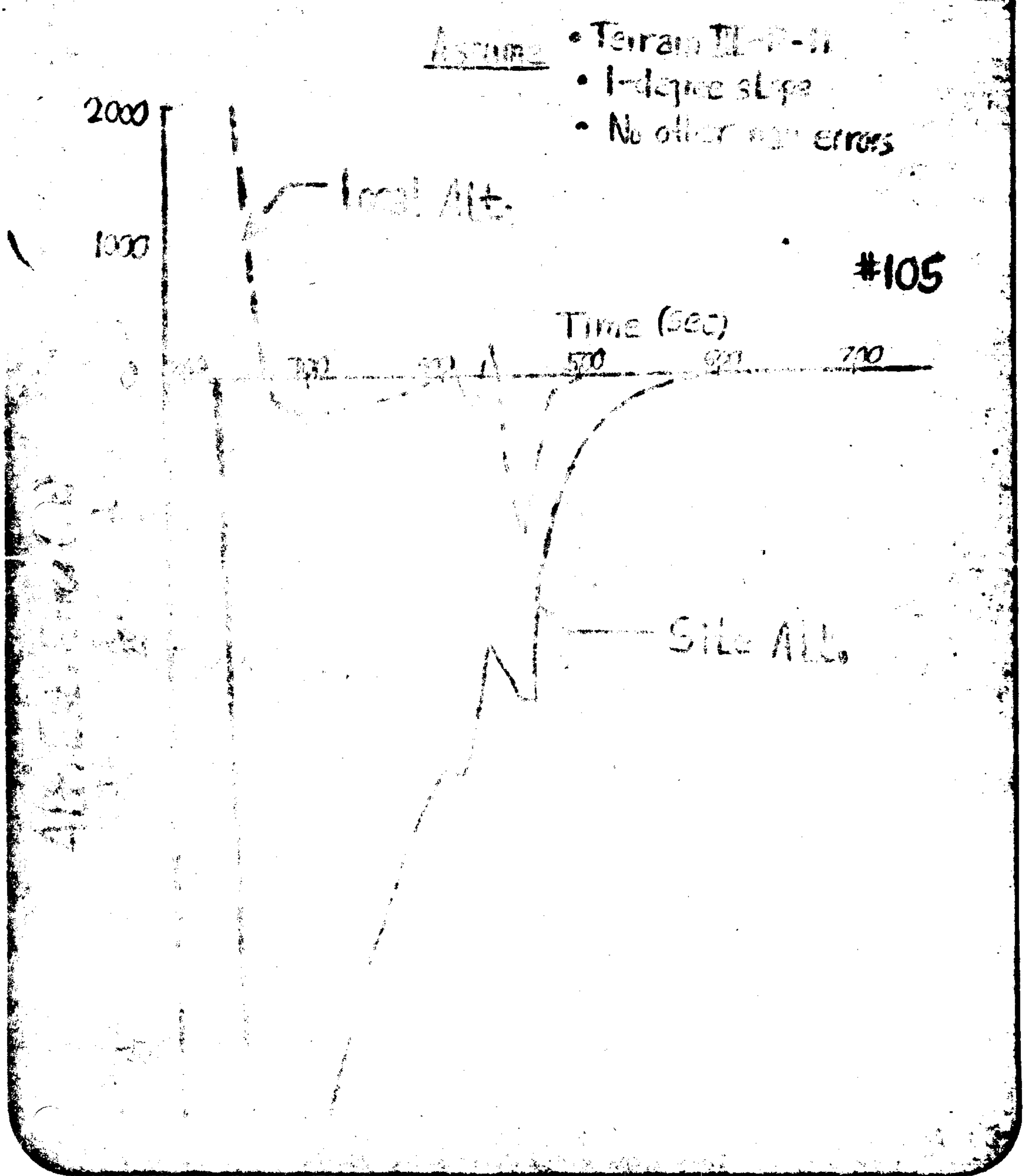


IT Graph



High-Gate Deviations for Constant Visibility Interval (7-d... above ...)
No hor. vel. devs at High Gate
120
80
40
-40
-80
-3000
-2000
-1000
0
1000
2000
3000
4000
5000
80 sec.
100 sec
120 sec
High-Gate Alt. Devs. (Ft)
H.G. Vert. Vel. Dev (F/S)

Altitude Est. Errors with Present Weighting Functions



Additional Test-Run Comments

- Terrain III-P-11A causes Large High-Gate errors

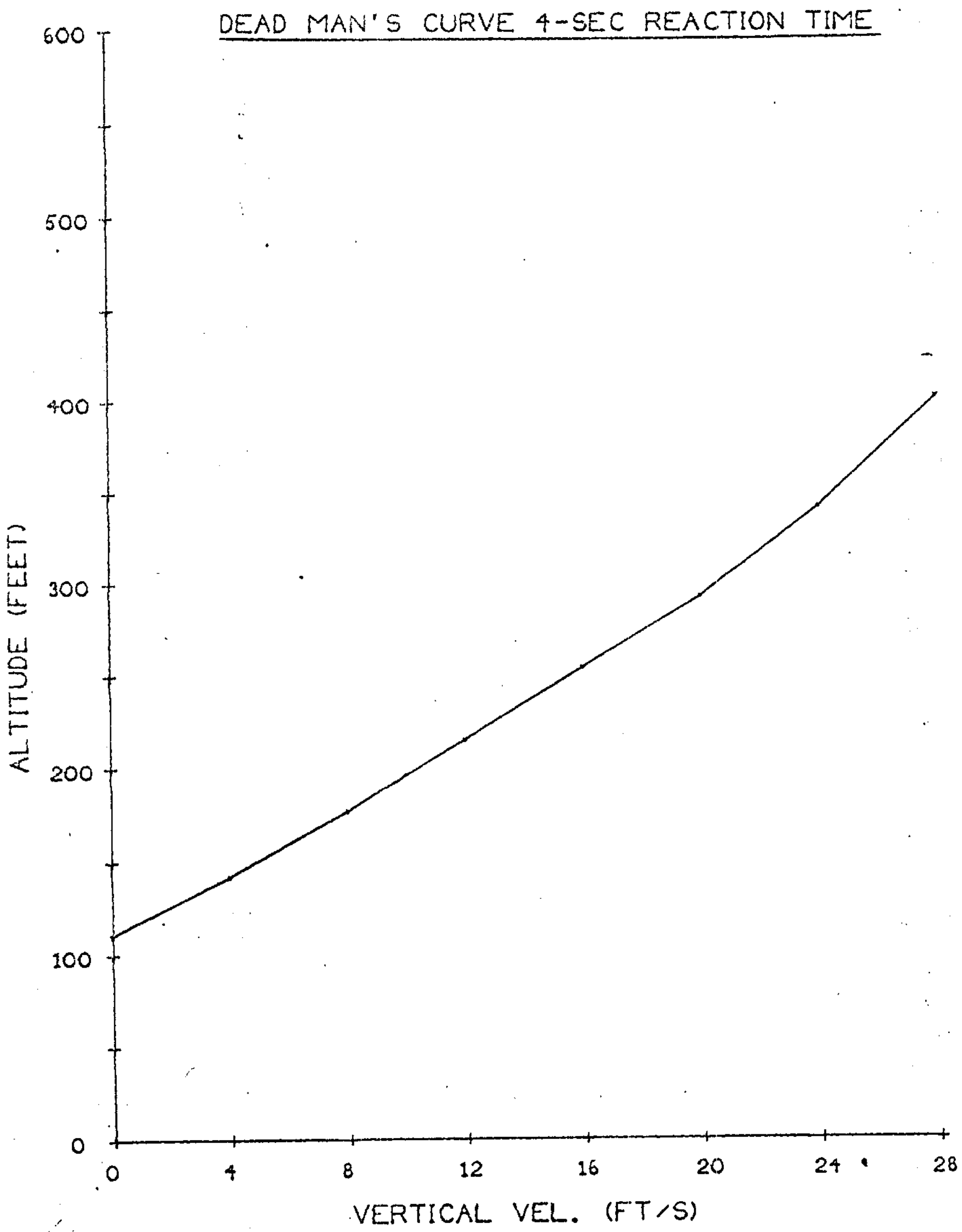
- Trajectory appears to follow terrain too early in trajectory.

- On nominal traj. LR altitude updating start at
  $h \approx 25{,}000$ ft or $t_{GO} \approx 190$ sec

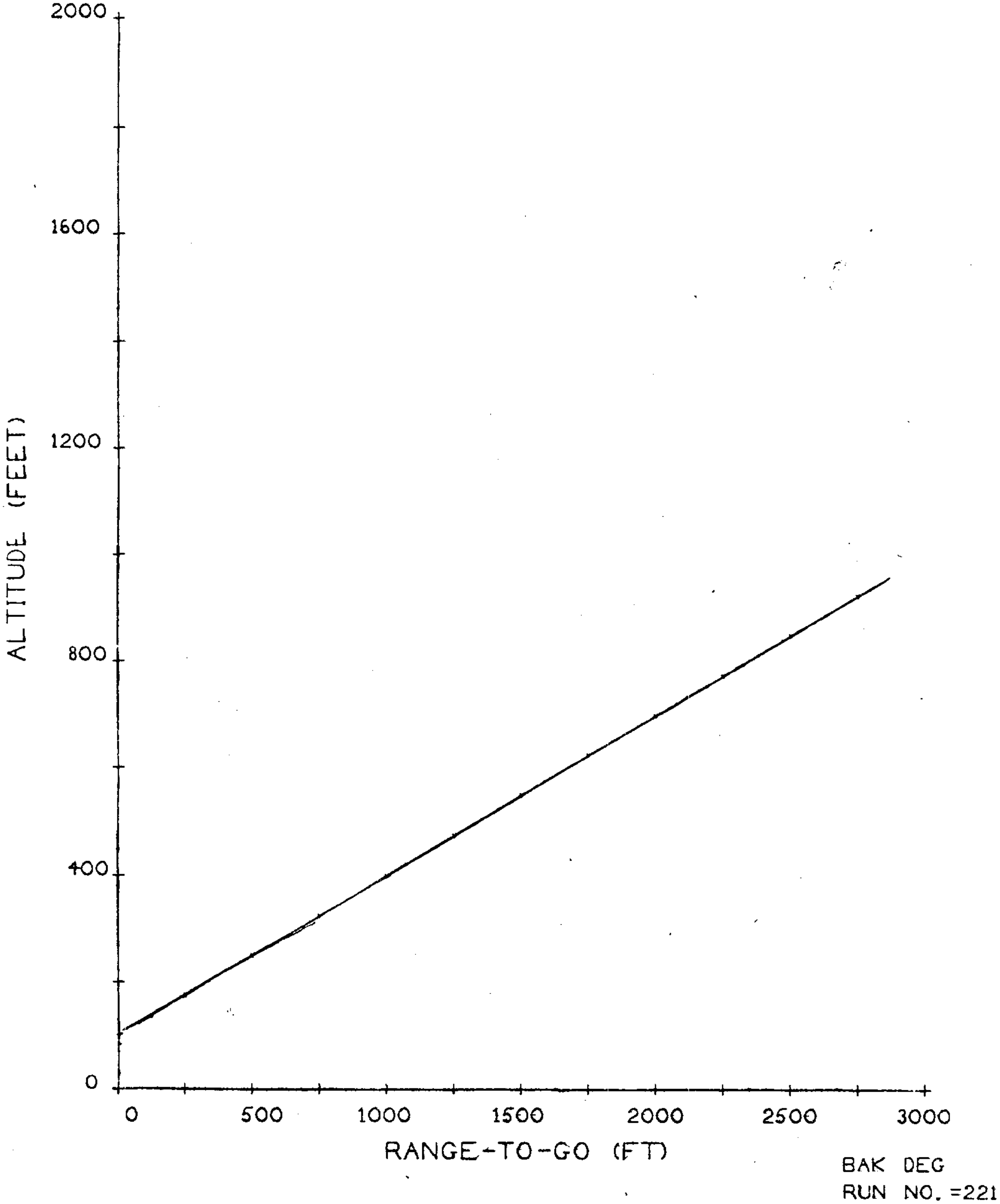
- LR antenna switched too early to Position #2

- LR dropout 30 sec [illegible]
  terrains alone [illegible]

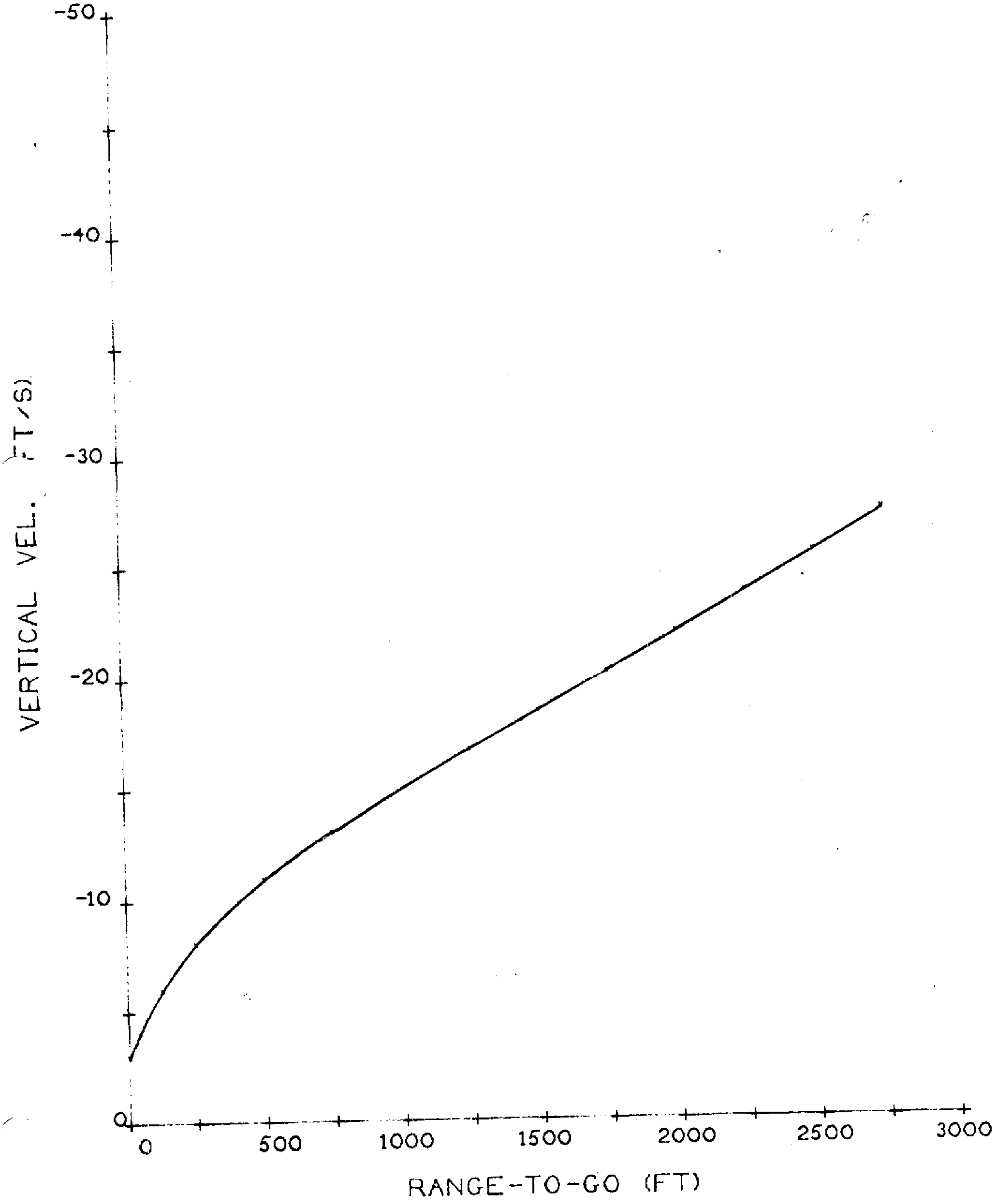
6-12


DEAD MAN'S CURVE 4-SEC REACTION TIME
600
500
400
300
200
100
0
ALTITUDE (FEET)
0
4
8
12
16
20
24
28
VERTICAL VEL. (FT/S)

Altitude Constraint Curve



Vertical-Velocity Constraint Curve



Perturbation Study Summary

Assuming:

- Ideal error-free conditions
- Visibility interval at least 90 sec.
- Stay within 50% of constraints at 2000-ft. range-to-go

Conclude:

- High-Gate errors should be limited to about 1500 ft. in altitude and 20 f/s vertical velocity
- Limiting conditions are visibility interval and flight-path angle deviation

7-16

LR Altitude Error Model

Range Measurement

Old Value: 0.5 percent $(1\text{-}\sigma) + 5$ Ft

New Values:

$25000' > h \geq 3000'$ 0.667 percent $(1\text{-}\sigma)$

$3000' > h \geq 2000'$ 1.00 percent $(1\text{-}\sigma)$

$2000' > h > 10'$ 0.5 percent $(1\text{-}\sigma) + 5$ Ft

Terrain Slope

Old Value: 100 Ft/n.m. $(1\text{-}\sigma)$

New Value: 33.3 Ft/n.m. $(1\text{-}\sigma)$

LR Velocity Error Model

Speed Measurement

Old Value: 0.33 percent (1-σ) each component
0.50 ft/s threshold each component

New Values:

$\sigma_{VXA} \approx 0.45$ percent (1-σ)

$\sigma_{VYA} \approx 0.7$ percent (1-σ) for V > 400 F/s
1.1 percent (1-σ) for V < 400 F/s

$\sigma_{VZA} \approx 0.7$ percent (1-σ)

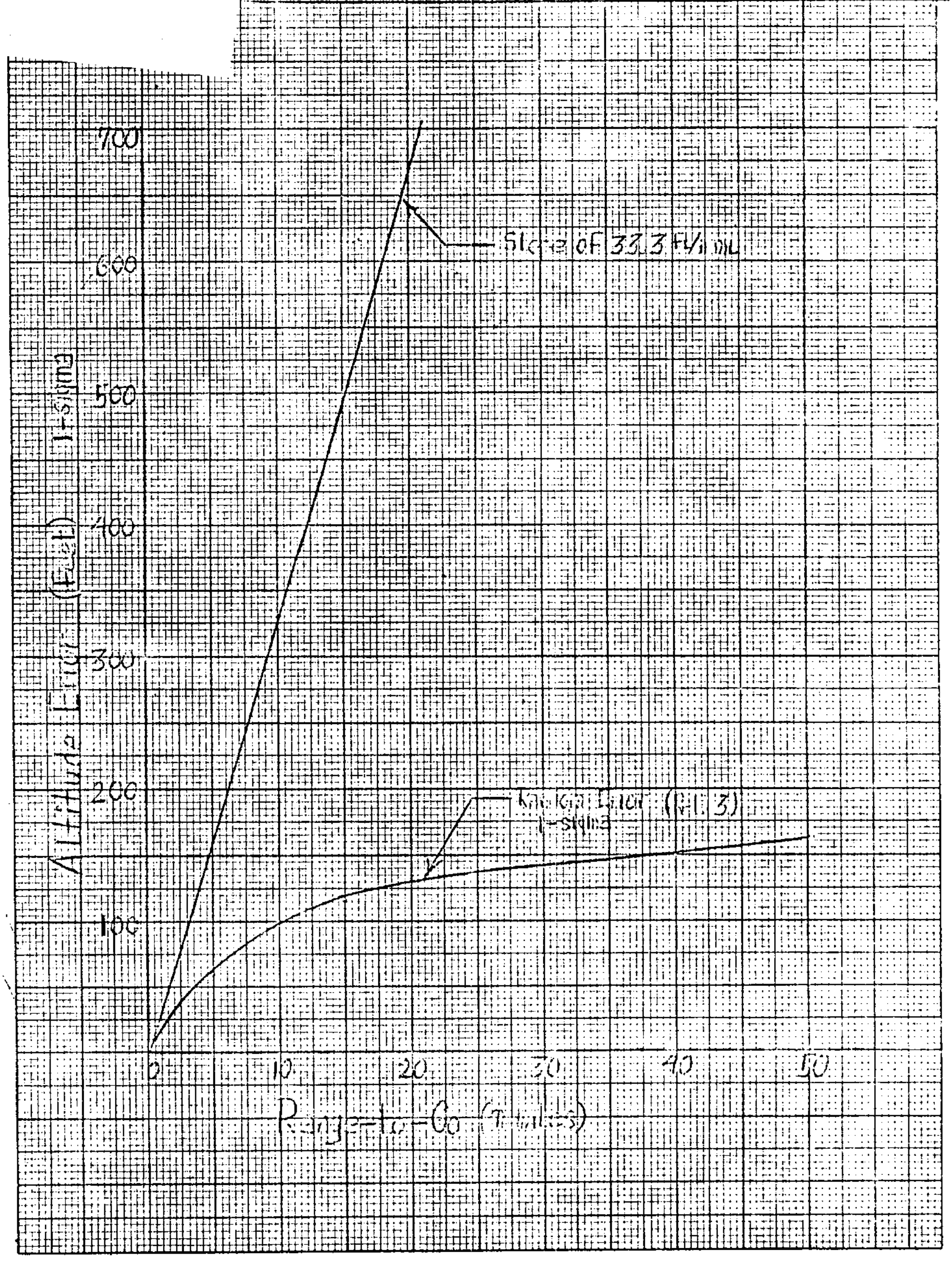
threshold -- VXA = .5 Ft/s (1-σ)
VYA = .83 Ft/s (1-σ)
VZA = .83 Ft/s (1-σ)

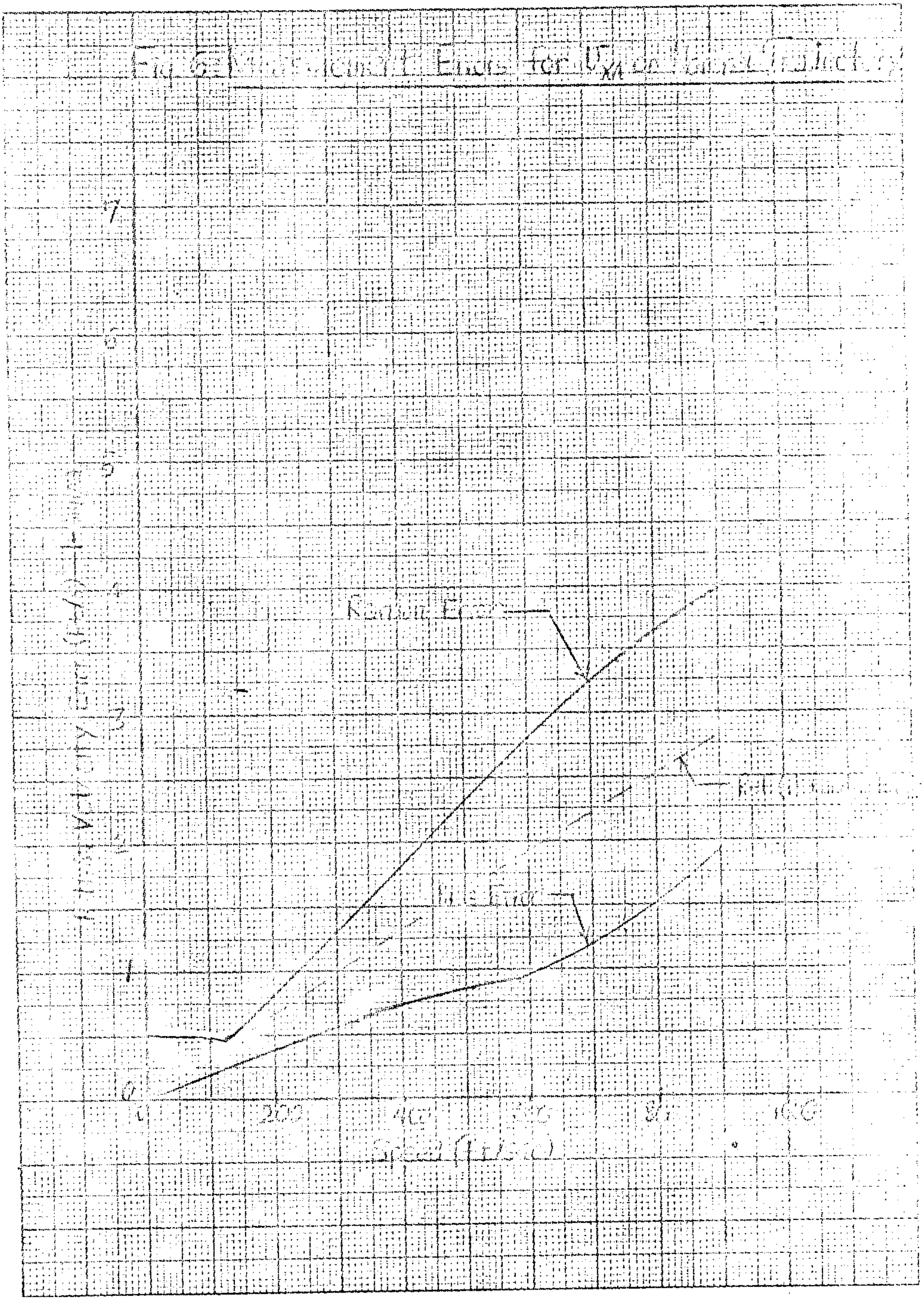
Alinement

Old Value: 6 mr (1-σ) for each axis

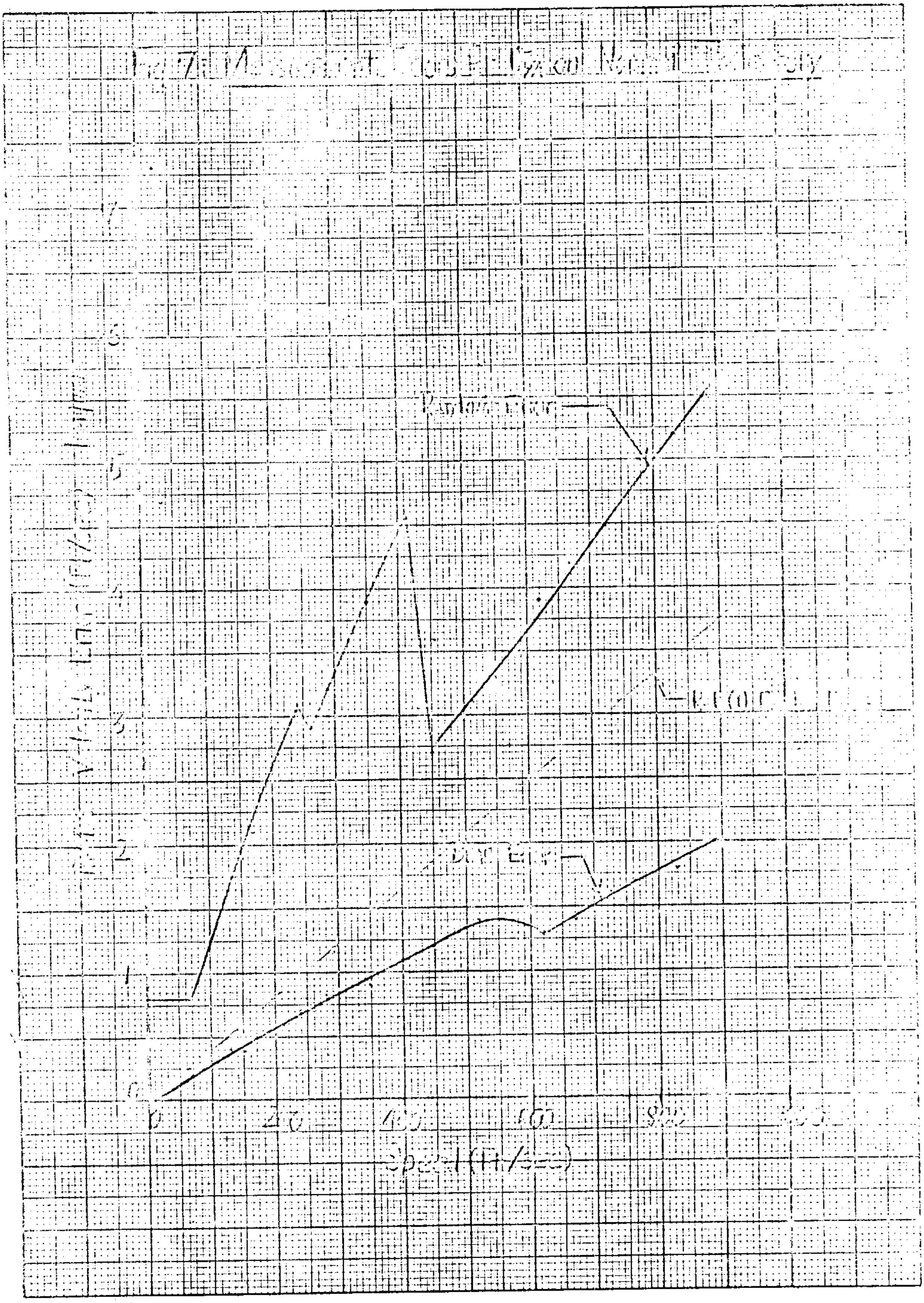
New Values: $\sigma_{XB} = 2$ mr (1-σ)
$\sigma_{YB} = 3.7$ mr (1-σ)
$\sigma_{ZB} = 3.3$ mr (1-σ)

Altitude Measurement Errors on Nominal Trajectory



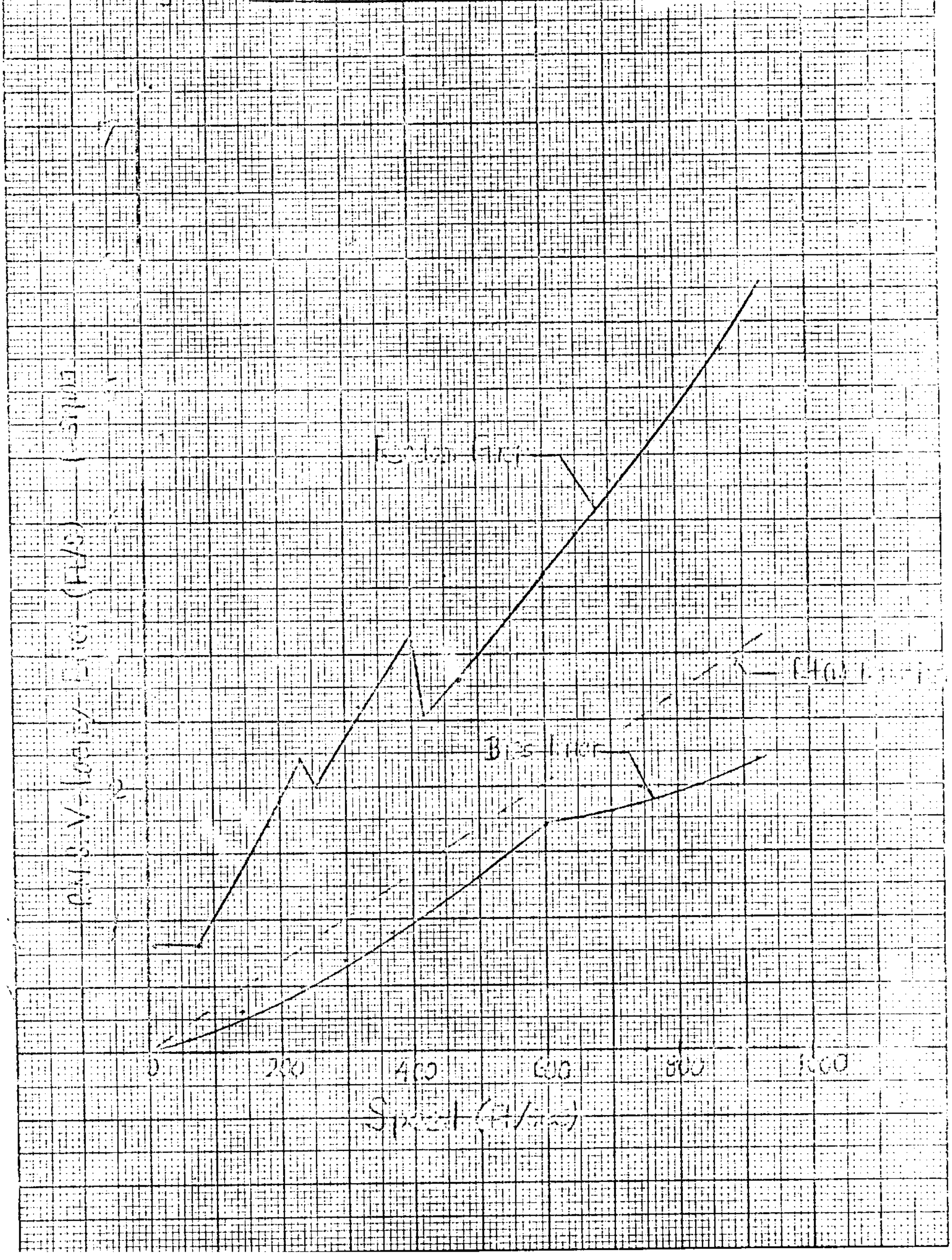


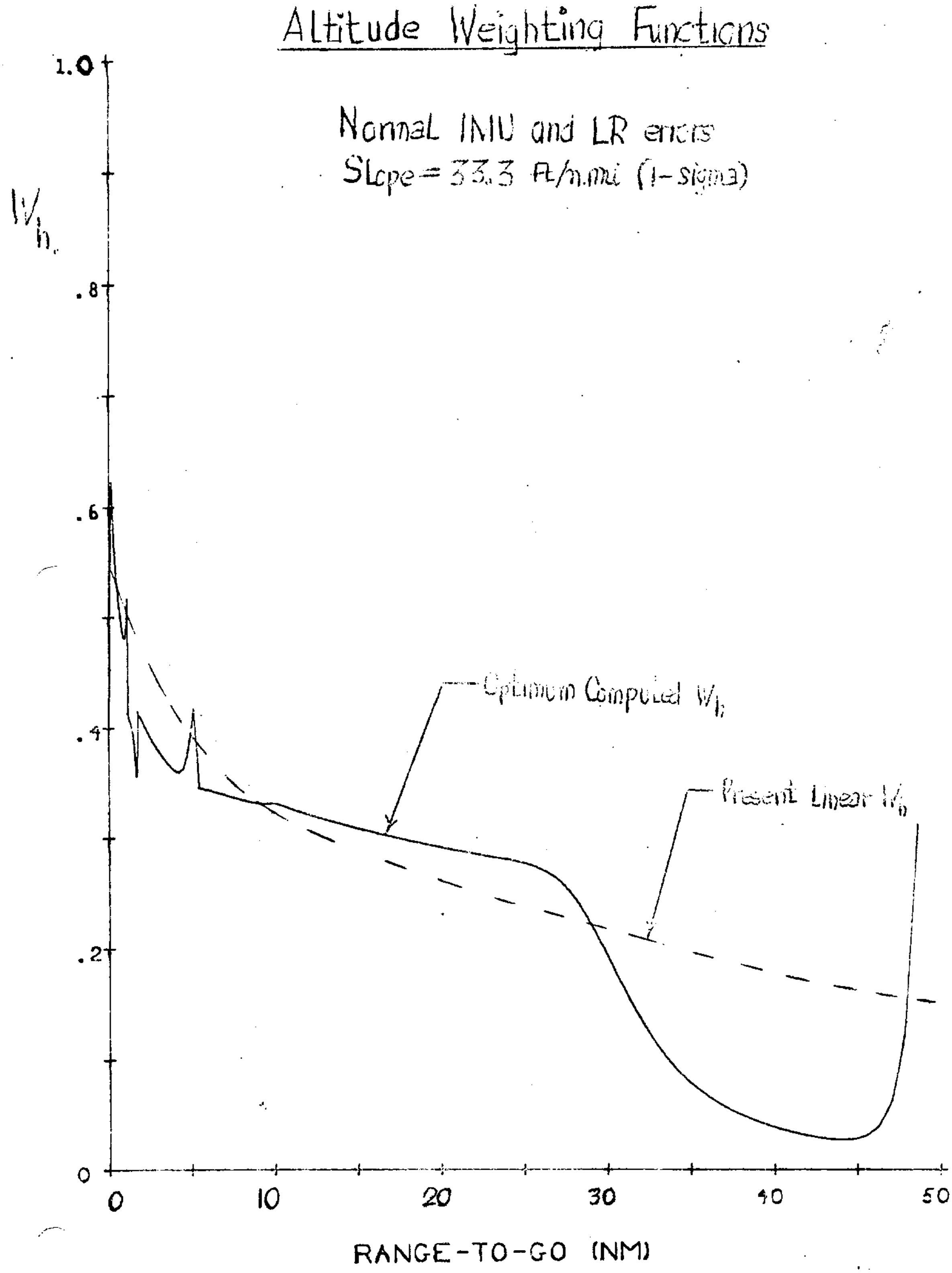
Random Error
Bias Error
0
1
200
400



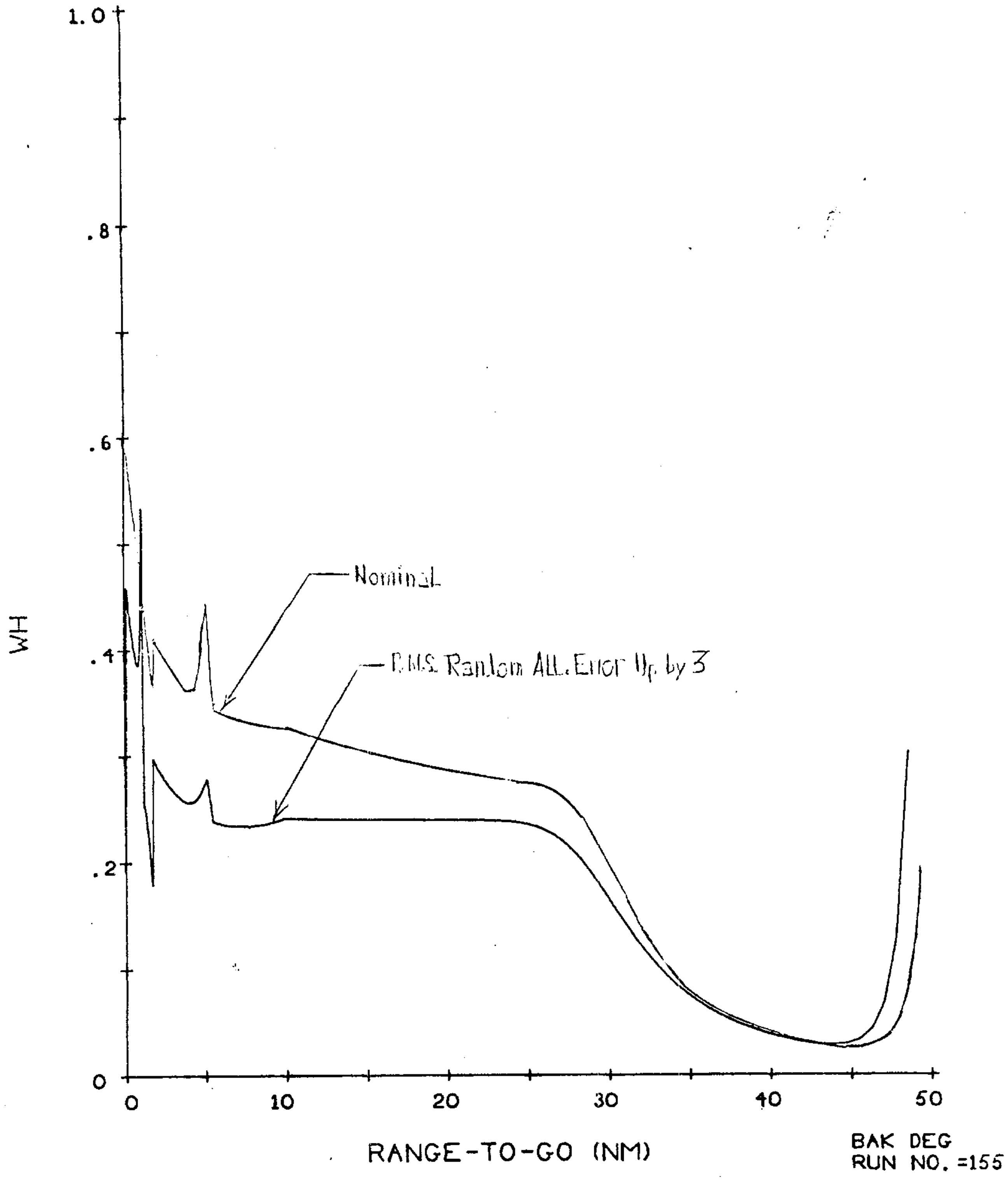
Random Error
0
1
2
3
4
5
6
7
200
400
600
800

Fig 5: Measurement Errors For V_{yA} on Nominal Trajectory




Altitude Weighting Functions
Normal IMU and LR errors
Slope = 33.3 ft/n.mi (1-sigma)
W_h
1.0
.8
.6
.4
.2
0
Optimum Computed W_h
Present Linear W_h
0
10
20
30
40
50
RANGE-TO-GO (NM)

Effect of Increased Random Altitude Measurement Error on Altitude Weighting Function



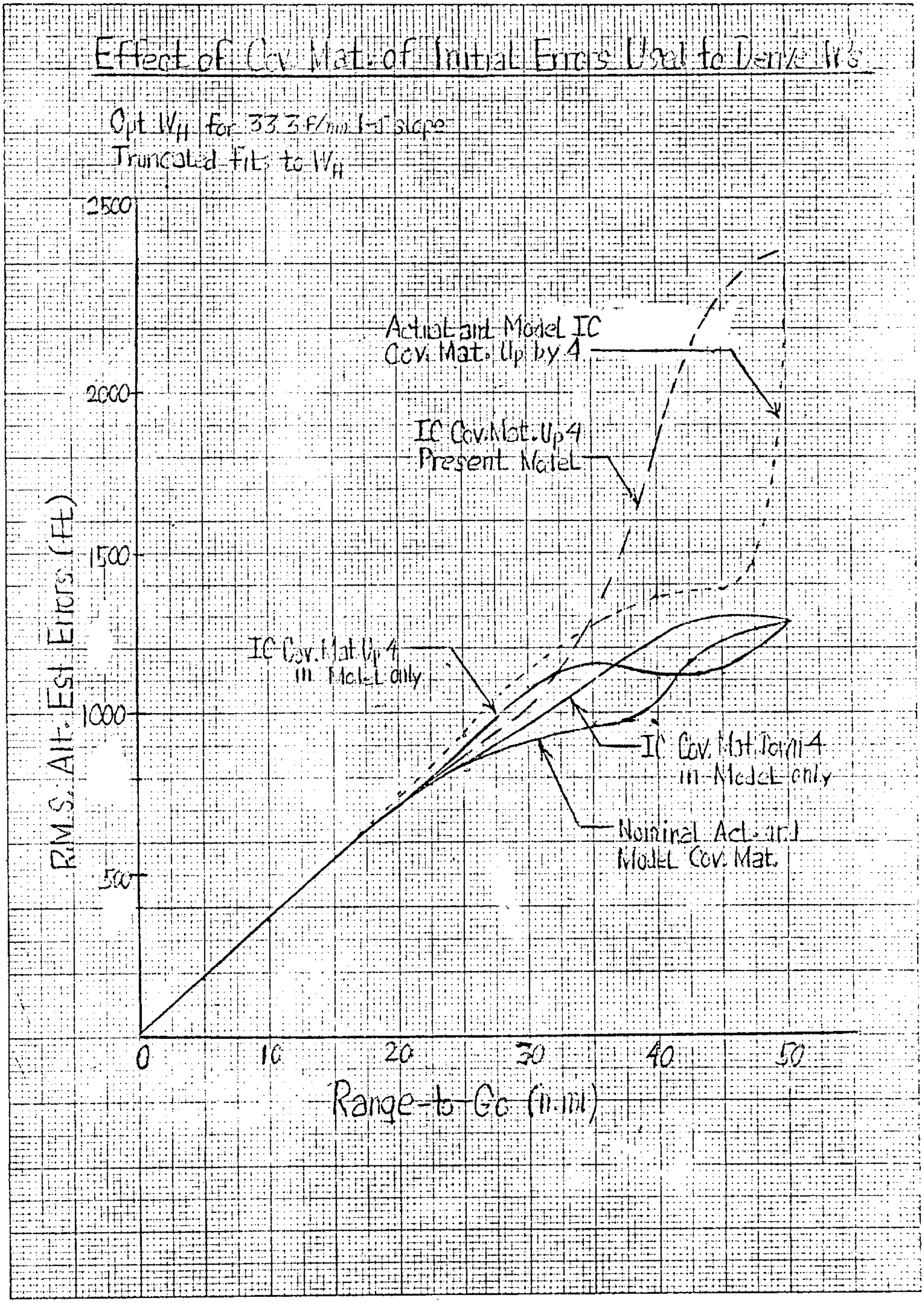
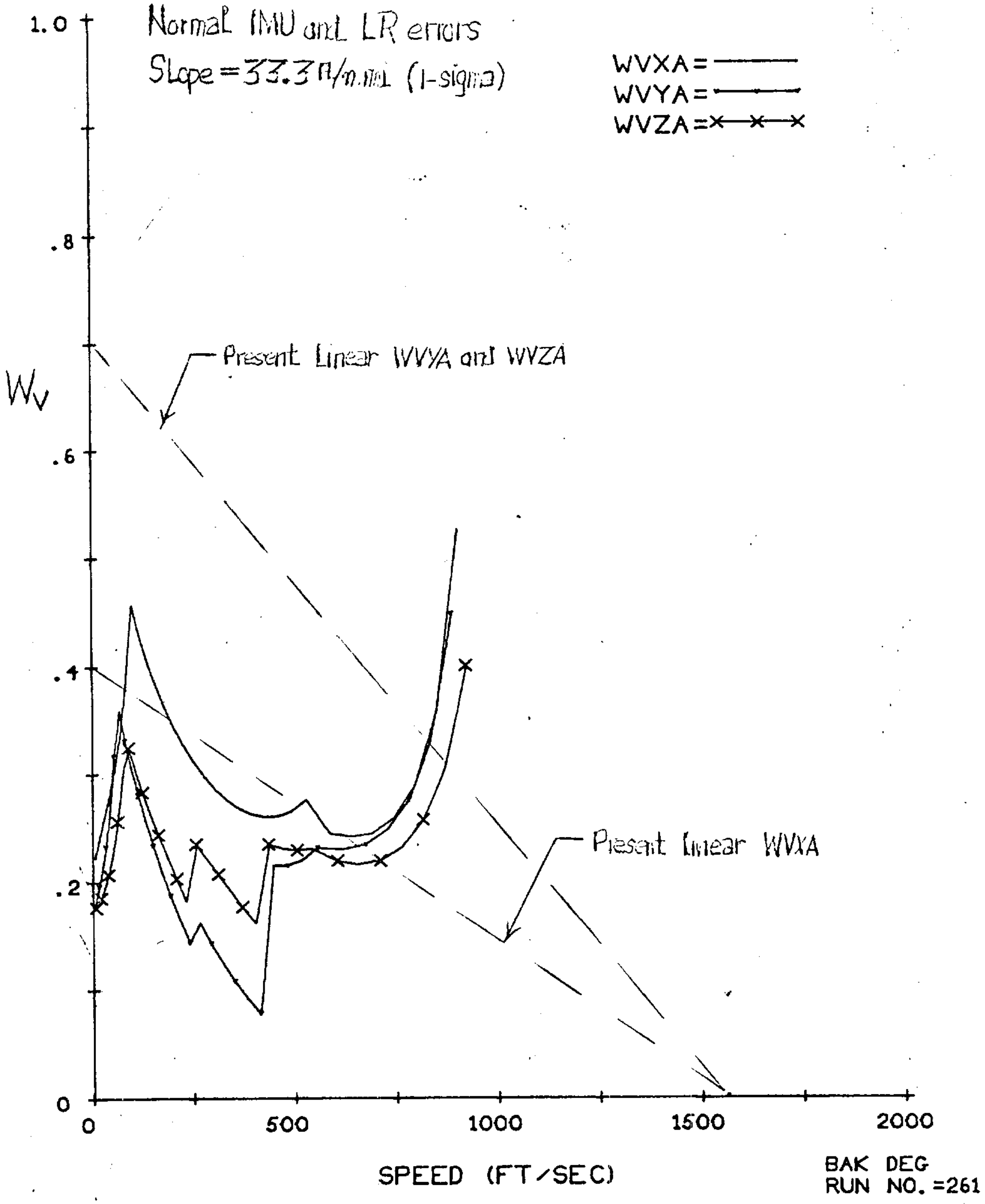
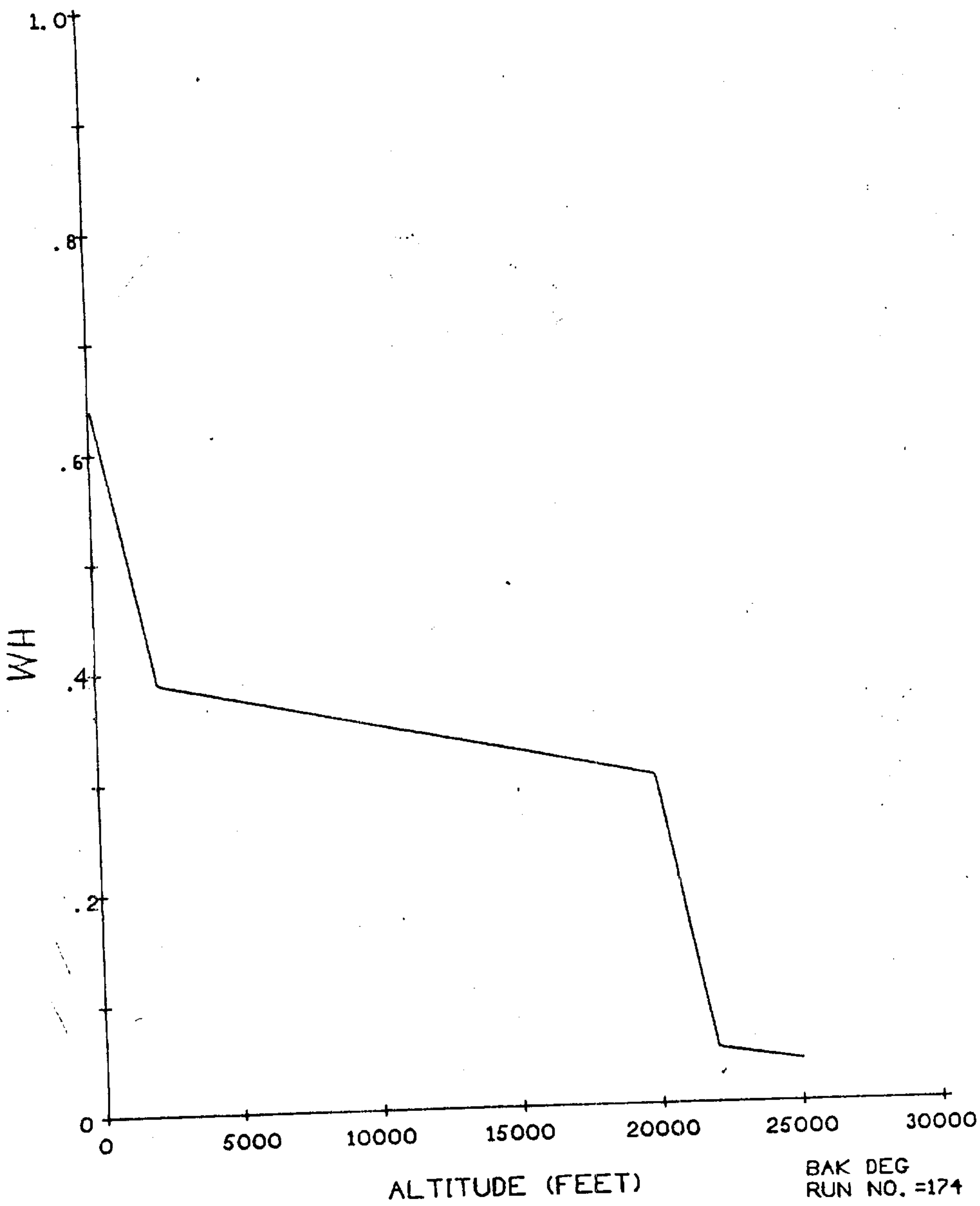

Effect of Cov. Mat. of Initial Errors Used to Derive W's
Opt W_H for 33.3 f/nm 1-σ slope
Truncated Fits to W_H
2500
2000
1500
1000
500
0
10
20
30
40
50
Actual and Model IC
Cov. Mat. Up by 4
IC Cov. Mat. Up 4
Present Model
IC Cov. Mat. Up 4
in Model only
IC Cov. Mat. Down 4
in Model only
Nominal Act. and
Model Cov. Mat.
R.M.S. Alt. Est. Errors (Ft.)
Range-to-Go (n.mi)

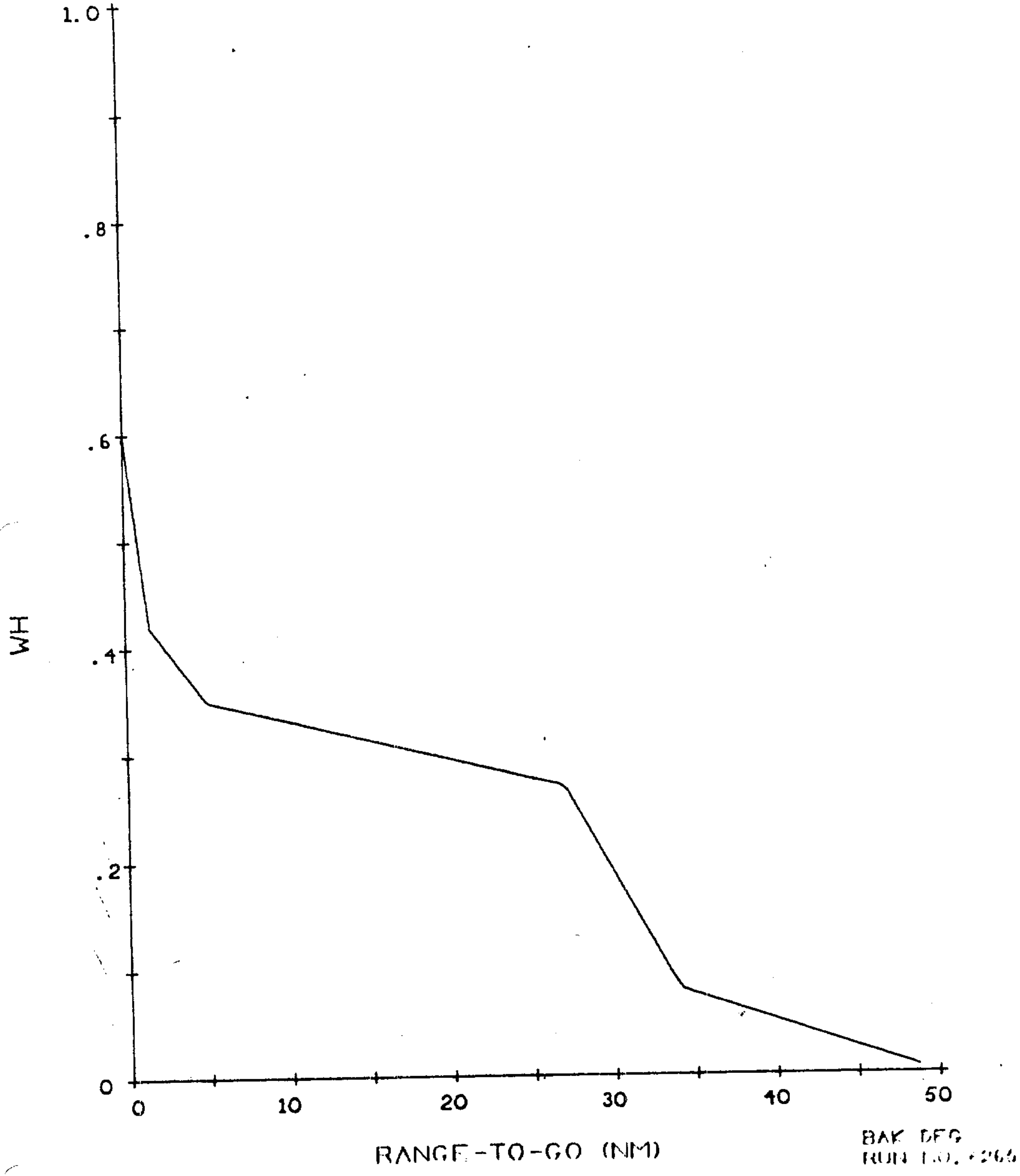
Fig. 4: Velocity-Component Weighting Functions



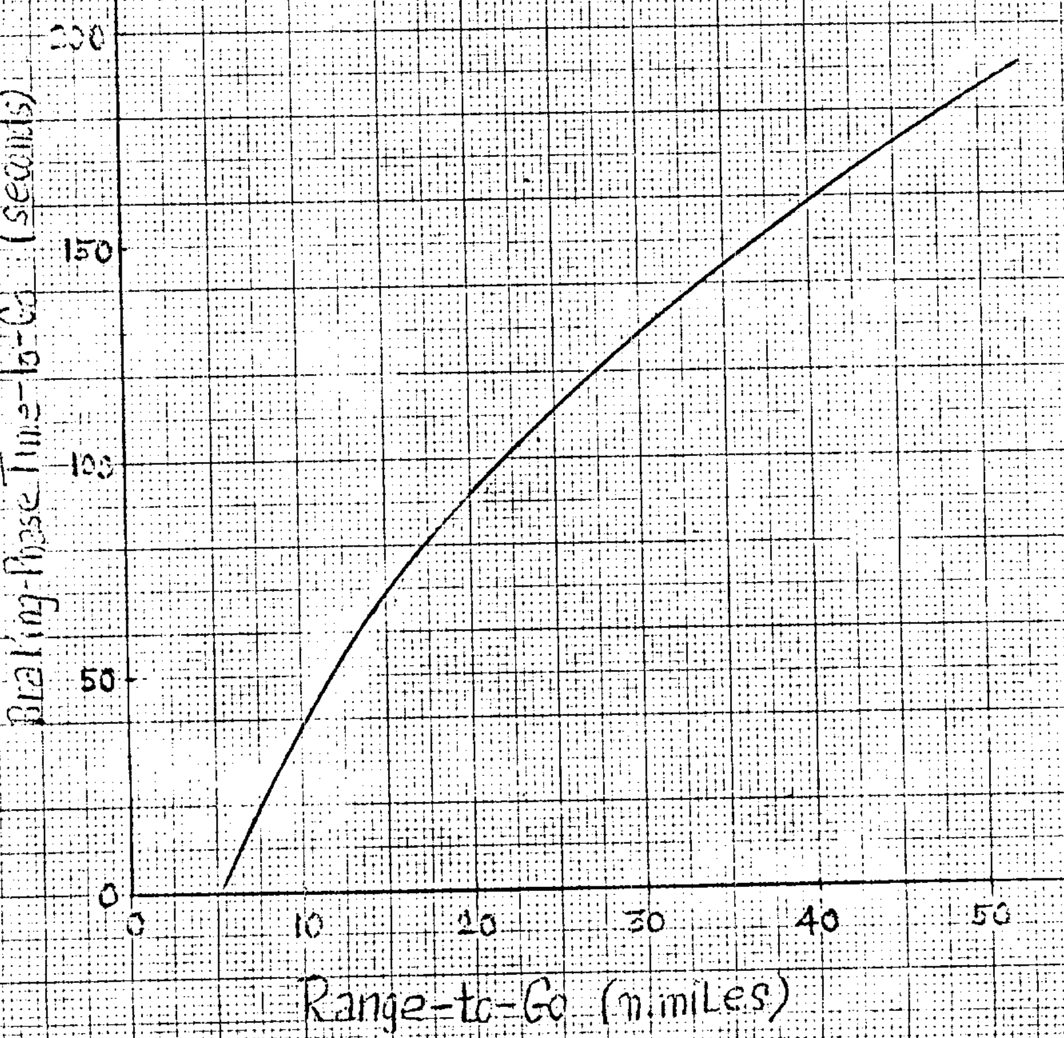
Altitude Weighting Function vs. Altitude



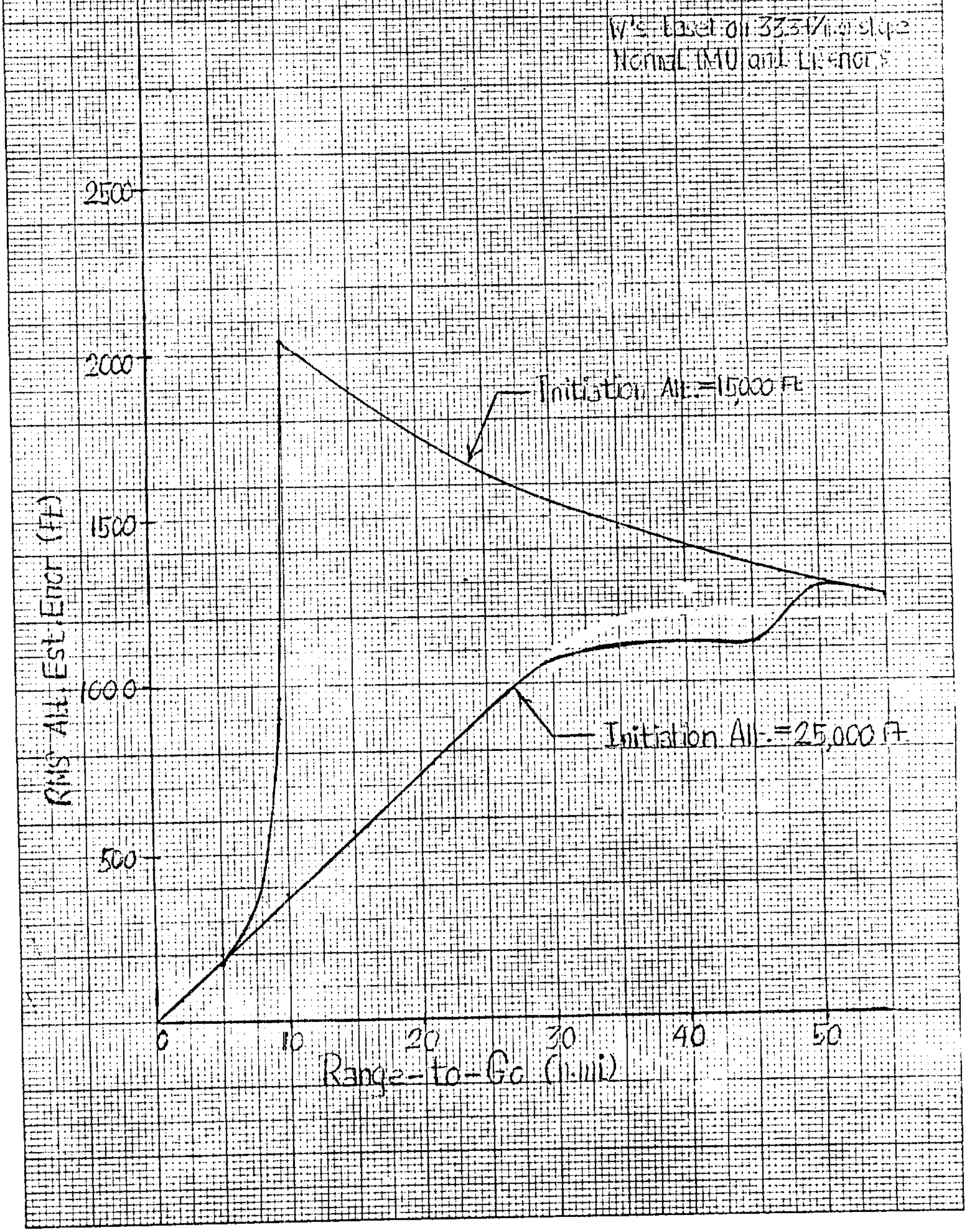
Altitude Weighting Function vs. Range-to-Go



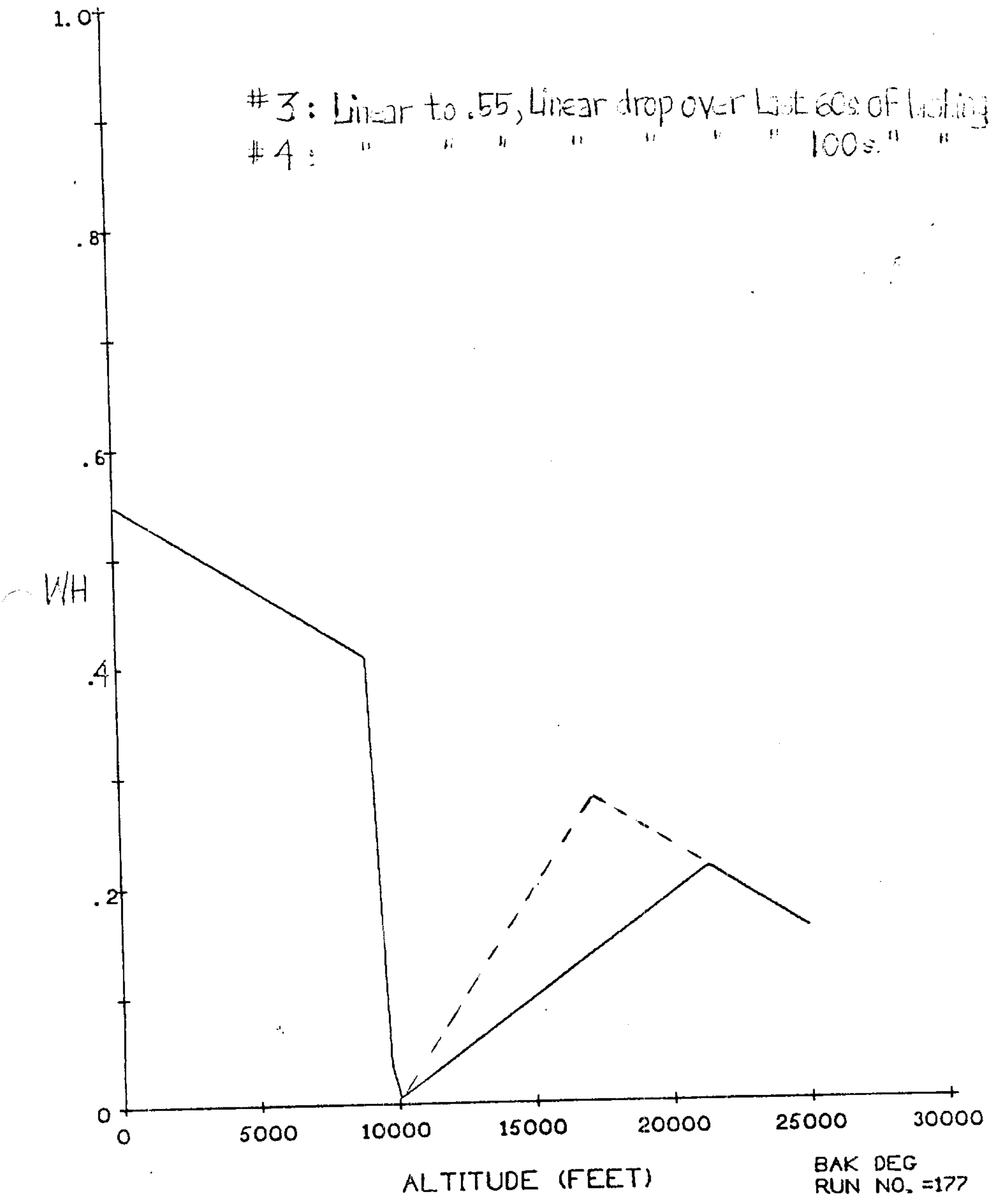
Braking-Phase Time-to-Go vs Range-to-Go for OFT-Nominal Trajectories



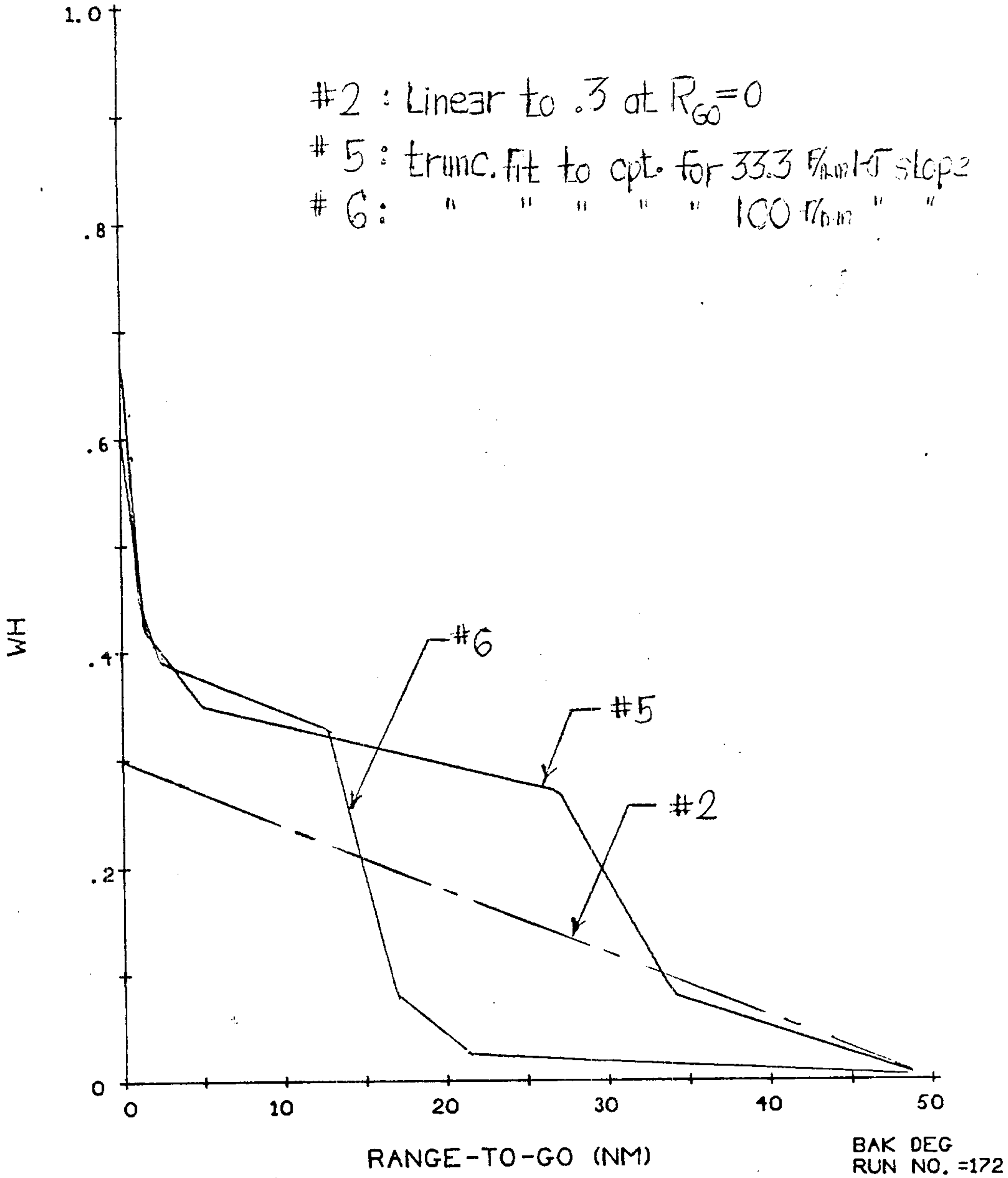
Effect of LR Starting Altitude on RMS Est. Errors



LR Altitude Weighting Functions

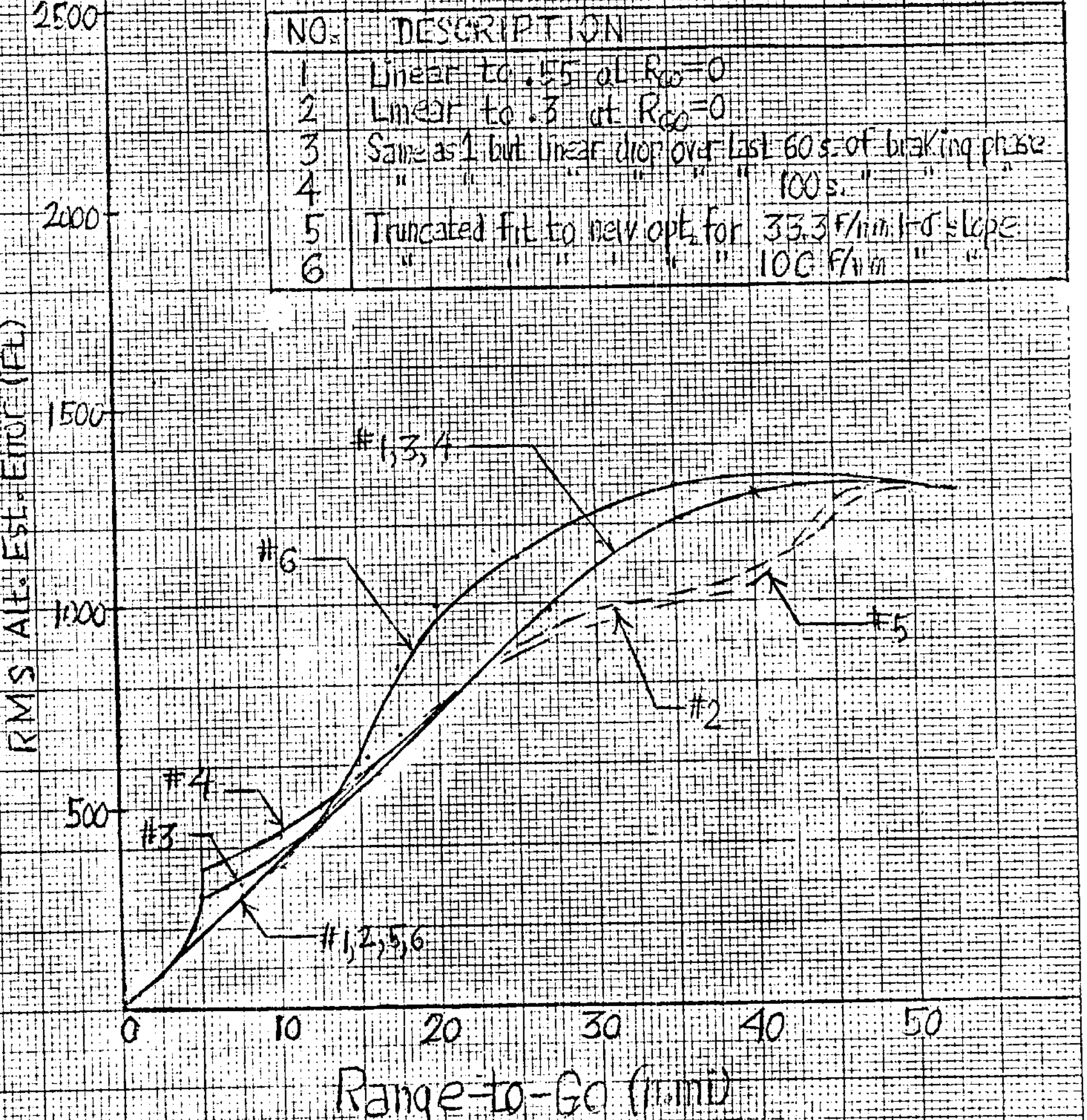


LR Altitude Weighting Functions



Effect of Altitude Weighting Function on R.M.S. Altitude Estimation Errors

NO.	DESCRIPTION
1	Linear to .55 at $R_{GO}=0$
2	Linear to .3 at $R_{GO}=0$
3	Same as 1 but linear drop over last 60 s. of braking phase
4	" " " " " " " 100 s. " " "
5	Truncated fit to new opt. for 33.3 F/nmi 1-σ slope
6	" " " " " " 100 F/nmi " "



INDEPENDENT VARIABLE USED IN ALTITUDE WEIGHTING FUNCTION

- Desire altitude with respect to site
- Dominant measurement error is terrain slope, which is a direct function of range-to-go
- Altitude vs. range-to-go will change on off-nominal trajectories
- Time-to-go vs. range-to-go same on all trajectories
- Store W_H vs. R_{GO} or t_{GO} to obtain same W_H for a given measurement error and t_{GO} before High-Gate

FURTHER PROBLEMS TO BE INVESTIGATED

1.) Minimum required LR updatings

2.) Prefiltering altitude data

3.) Effect of time updatings are started

4.) [illegible] weighting functions in [illegible] for LR dropouts

5.) [illegible] Carlo runs for recommended system [illegible] [illegible] and errors to check perform[illegible]

6.) [illegible] High-Gate [illegible]

7.) [illegible] weighting functions with [illegible]

8.) [illegible] model for statistical [illegible] slope bias.

[illegible] sites. LR [illegible]

Monte-Carlo Runs with Different Weighting Functions, Using Present Guidance System

Terrain III-P-11A, Dropout boundaries present

Weighting Function for Alt.	IC, IMU, Slope #1191 +1-σ +1deg		IC, IMU, Slope #1191 -1σ +1deg		IC, IMU, Slope #1191 +1σ -1deg	
	Δh_{HG} (ft)	ΔV_{VHG} (f/s)	Δh_{HG} (ft)	ΔV_{VHG} (f/s)	Δh_{HG} (ft)	ΔV_{VHG} (f/s)
Linear to .55	370	-84	2614	2	-590	-30
Linear to .3	445	-95	2564	-4	-422	-21
Linear to .55, drop over last 60 s.	704	-74	2645	1	-462	-20
Linear to .55, drop over last 100 s.	1536	-30	3299	-2	-649	-7
mean-squared min. 33.3 f/nm 1-σ slope	941	-50	2598	6	-400	-12
mean-squared min. 100 f/nm 1-σ slope			2368	-13	-734	-6

Monte-Carlo Runs with New Weighting Functions and Controller Fixes : High-Gate Errors

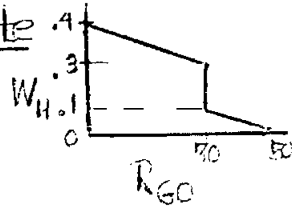
Weighting Function	Controller Fix for Last 50% of braking phase	[illegible]		[illegible]		[illegible]	
		δh (ft)	δV_V (F/s)	δh (ft)	δV_V (F/s)	δh (ft)	δV_V (F/s)
1.) Present	None	1100	84	4[illegible]6	-10[illegible]	[illegible]3	-121
2) Trunc. fit with slope = 33.3 F/min	(a.) Fixed quadratic	[illegible]	8	[illegible]	-[illegible]	2[illegible]	-10
	b.) Inhibit [illegible]	4[illegible]	-[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3.) Same as 2) but [illegible] at High Gate	(a.) Fixed quadratic	[illegible]	4	[illegible]	-[illegible]		
	[illegible]						
4.) Trunc. fit with slope = 100 F/min	(a.) Fixed quadratic						
	(b.) Inhibit [illegible]						

Recommendations

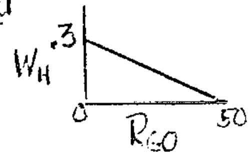
- Inhibit altitude updatings from guidance system during last 50 sec. of braking phase

- Store altitude weighting function vs range-to-go (or time-to-go)

Best to date



Goal



- Lower Y and Z velocity-component weighting functions to linearize through .25 to .30 at zero speed

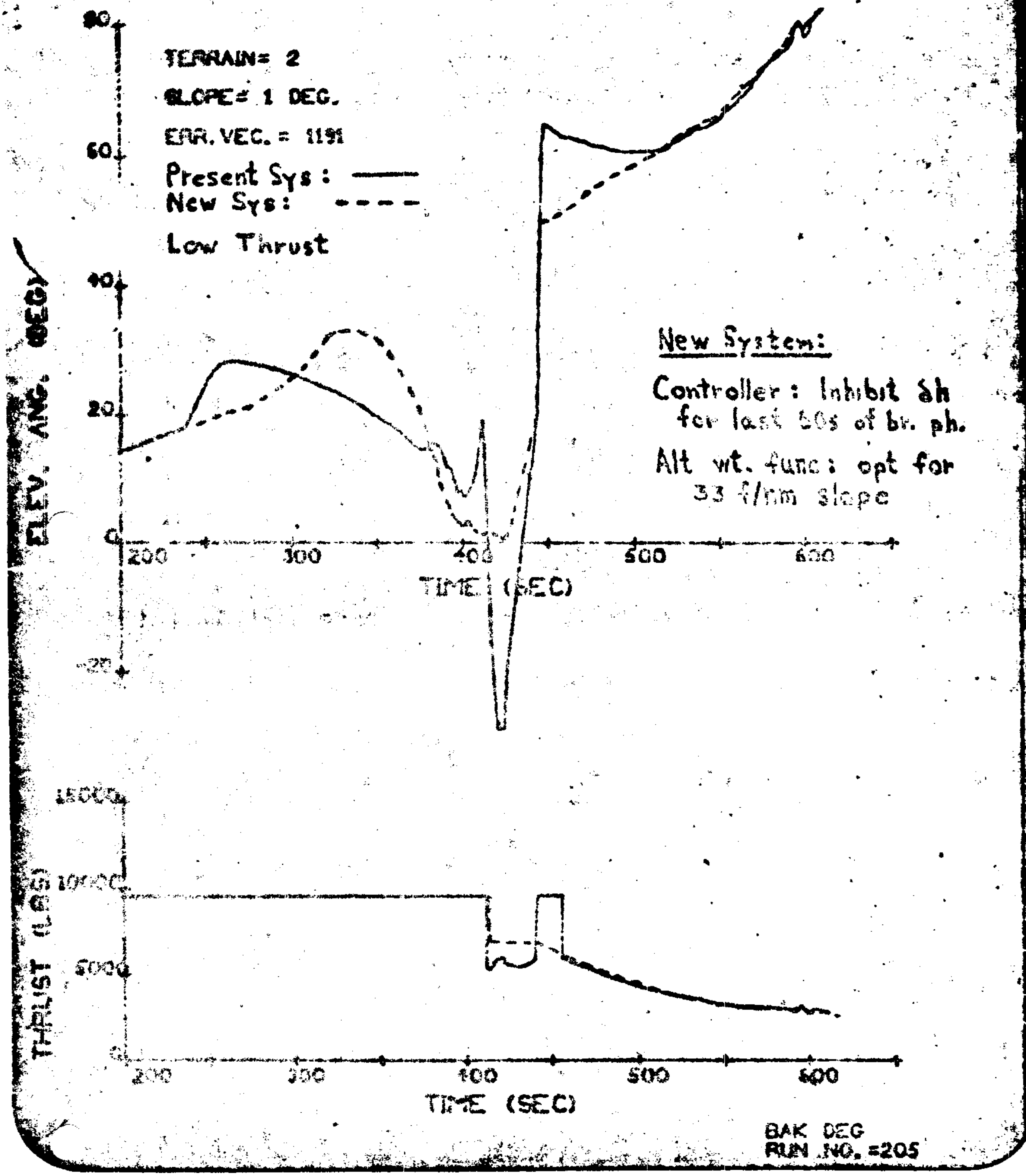
- Correct LR dropout problems on present trajectories

Monte-Carlo Runs with Different Control Schemes during Last 50-60 Seconds of Braking Phase, Using Present Weighting Function

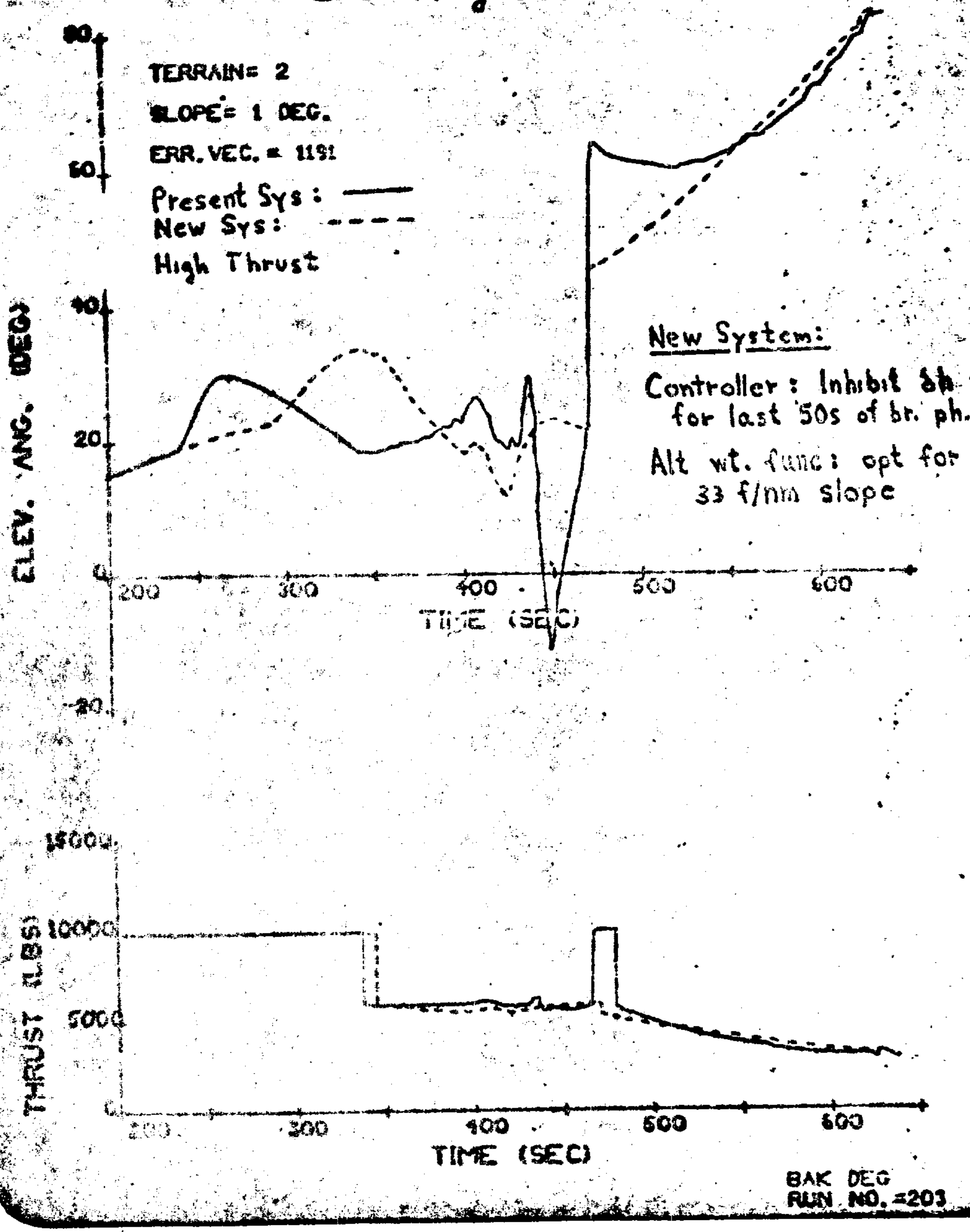
Terr. III-P-11A
No dropout boundaries

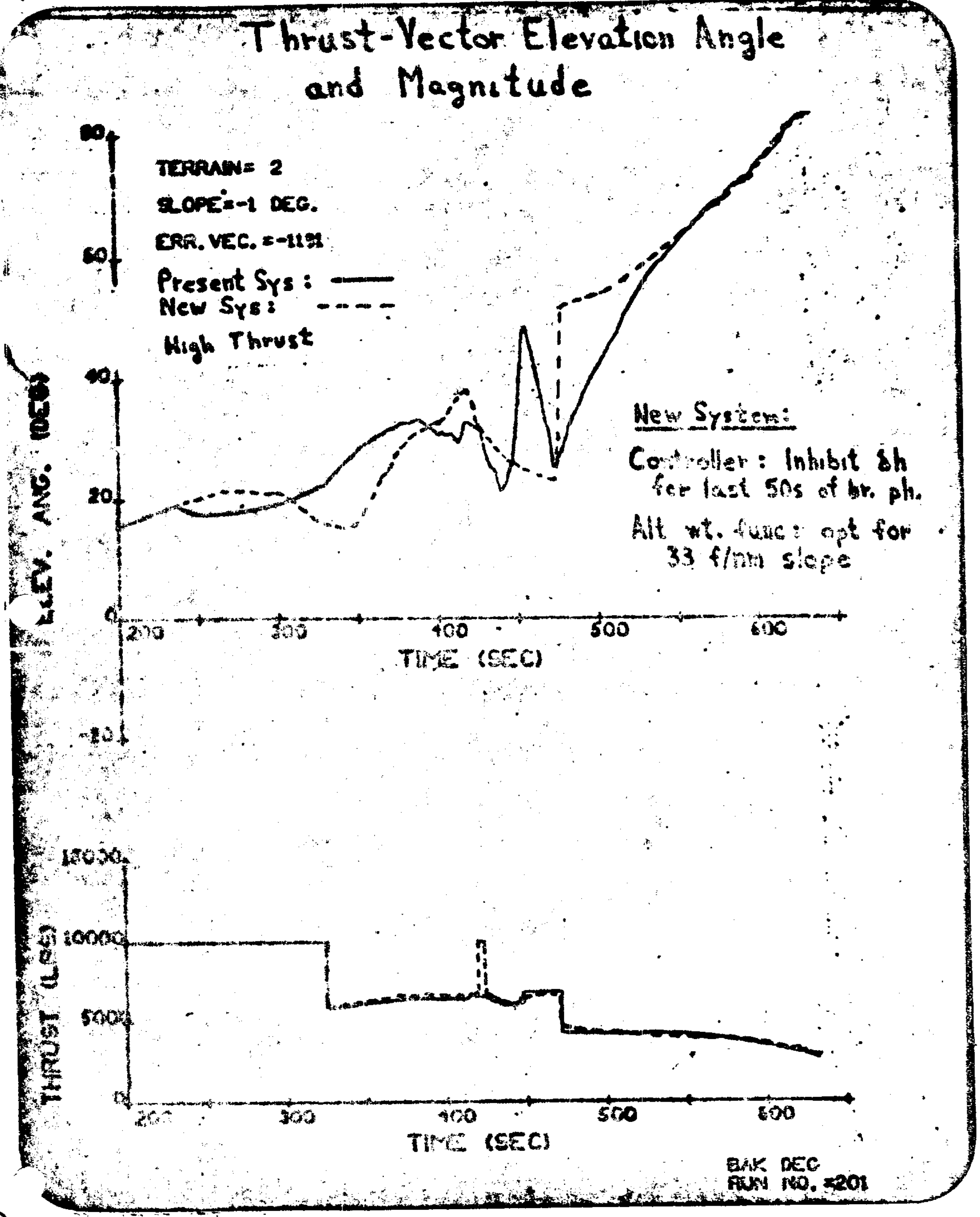
GUIDANCE SCHEME	−1191, −1 deg, −1σ IMU, +F		+1191, +1 deg, +1σ IMU, +F		+1191, +1 deg., +1σ, −F	
	ΔH_{HG}	ΔVV_{HG}	ΔH_{HG}	ΔVV_{HG}	ΔH_{HG}	ΔVV_{HG}
Present Guidance Scheme	1100 Ft	84 F/s	436 Ft	−107 F/s	83 Ft	−121 F/s
Quad. Guid. with Fixed Coeff. over Last 50 s. of braking phase	48	−2	2238	−3	2191	−5
Reduce vert. channel accel. command by $(1-20/t_{GO})$	−759	−7	1779	−23	2651	26
Inhibit alt. updatings from controller during Last 50 s. of brak. phase	365	−6	1648	5	1657	10

Thrust-Vector Elevation Angle and Magnitude



Thrust-Vector Elevation Angle and Magnitude





Thrust-Vector Elevation Angle and Magnitude
TERRAIN= 2
SLOPE=-1 DEG.
ERR. VEC.=-1191
Present Sys :
New Sys :
High Thrust
New System:
Controller : Inhibit δh for last 50s of br. ph.
Alt wt. func : opt for 33 f/nm slope
ELEV. ANG. (DEG)
80
60
40
20
0
-20
200
300
400
500
600
TIME (SEC)
THRUST (LBS)
15000.
10000.
5000.
0
200
300
400
500
600
TIME (SEC)
BAK DEC
RUN NO. #201

Enclosure 7

Table 2

Run	Thrust	Terrain	Terrain Slope	Navigation Errors	IMU Errors
727.29	Nominal	None	None	None	None
727.30	3σ low	"	"	"	"
727.31	3σ high	"	"	"	"
802.04	Nominal	2-P-8 No. 3	$+1^{\circ}$	"	"
802.05	"	"	-1°	"	"
802.26	"	"	0°	"	"
802.06	"	"	-1°	+1191	"
802.12	"	3-P-11 No. A	$+1^{\circ}$	None	"
802.13	"	"	-1°	"	"
802.16	"	"	-1°	+1191	"

ONE PHASE GUIDANCE

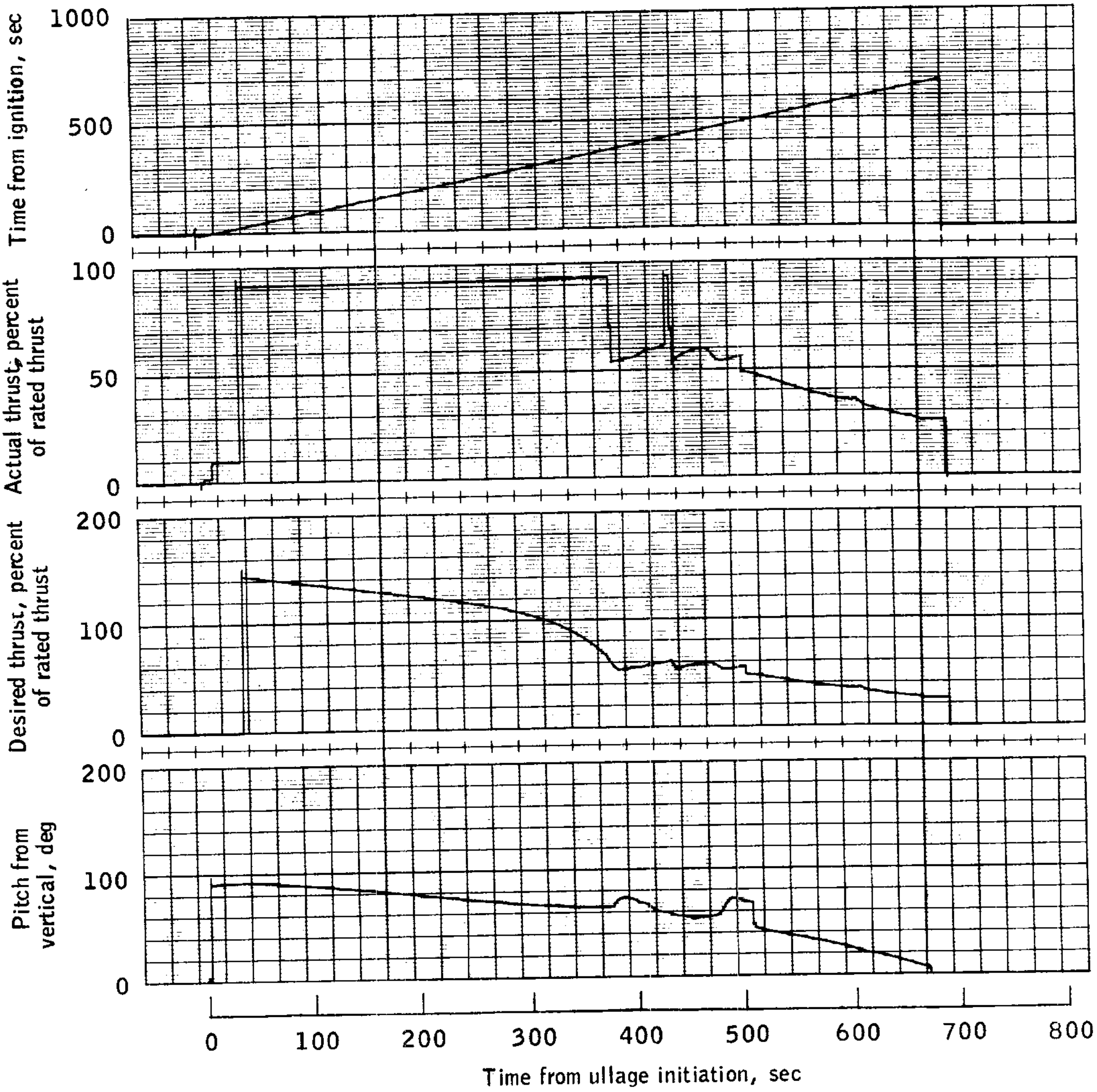
INPUT PARAMETERS FOR TRAJECTORY CASES

Run	Navigation error	IMU error	Thrust dispersion	Terrain	Terrain slope
815.01	none	none	none	none	none
815.02	+1191	none	none	none	none
815.03	-1191	none	none	none	none
815.04	none	none	none	3-P-11#A	0°
815.05	none	none	none	3-P-11#A	+1°
815.06	none	none	none	3-P-11#A	-1°
815.07	none	none	3σ low	none	none
815.08	none	none	3σ high	none	none
815.09	-1191	$+3\sigma$	3σ low	3-P-11#A	-1°
815.10	+1191	-3σ	3σ high	3-P-11#A	+1°
*815.11	-1191	$+3\sigma$	3σ low	3-P-11#A	-1°

*Includes multiplying weighting function by 1.8

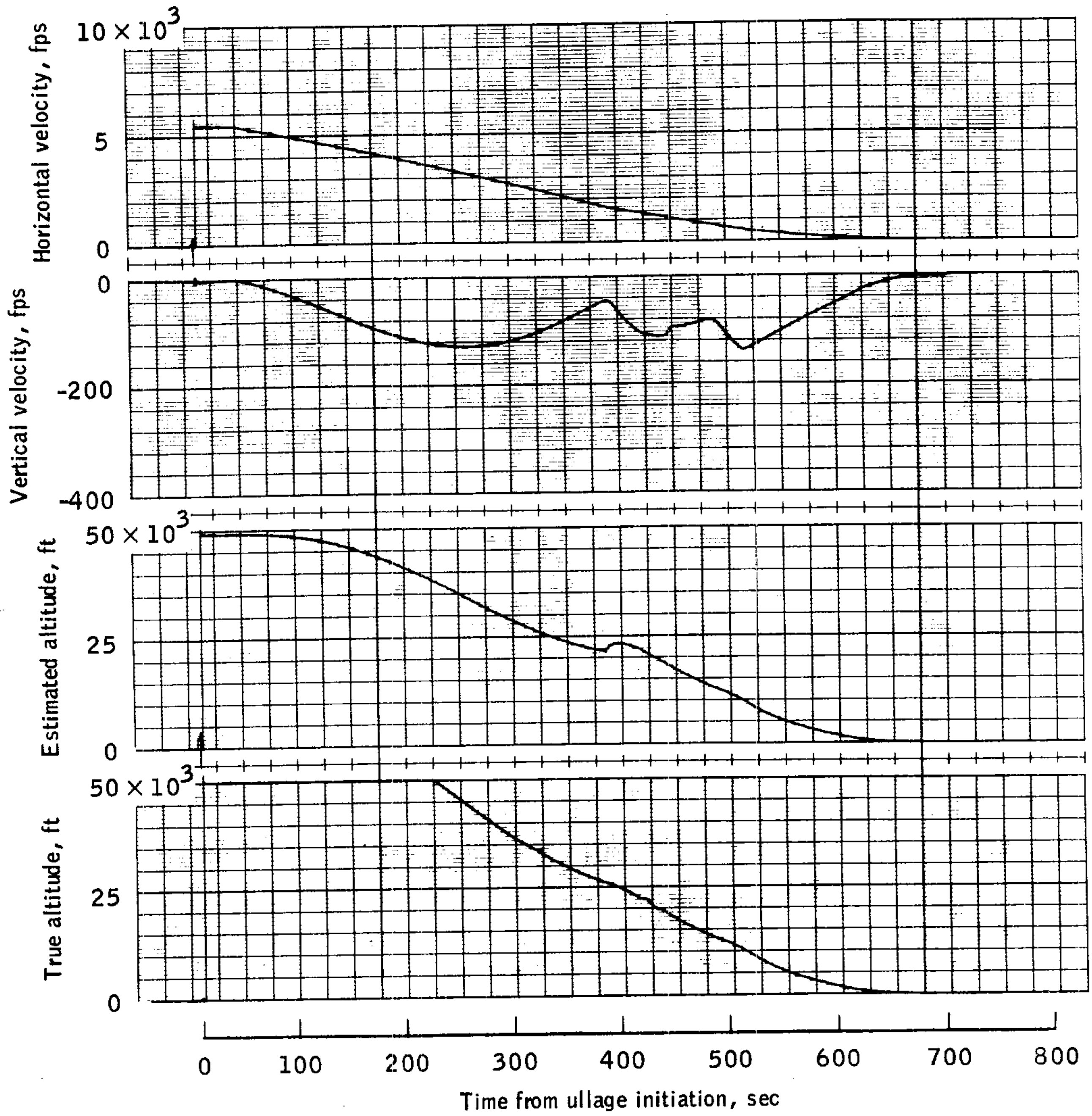
INPUT PARAMETERS FOR TRAJECTORY CASES

Run	Navigation error	IMU error	Thrust dispersion	Terrain	Terrain slope
815.12	none	none	none	none	none
815.14	+1191	none	none	none	none
815.15	-1191	none	none	none	none
815.16	none	none	none	3-P-11#A	0°
815.17	none	none	none	3-P-11#A	+1°
815.18	none	none	none	3-P-11#A	-1°
815.19	none	none	3σ low	none	none
815.22	none	none	3σ high	none	none
815.20	-1191	+3σ	3σ low	3-P-11#A	-1°
815.21	+1191	-3σ	3σ high	3-P-11#A	+1°
815.23	none	-.003 rad. misalignment	none	none	none



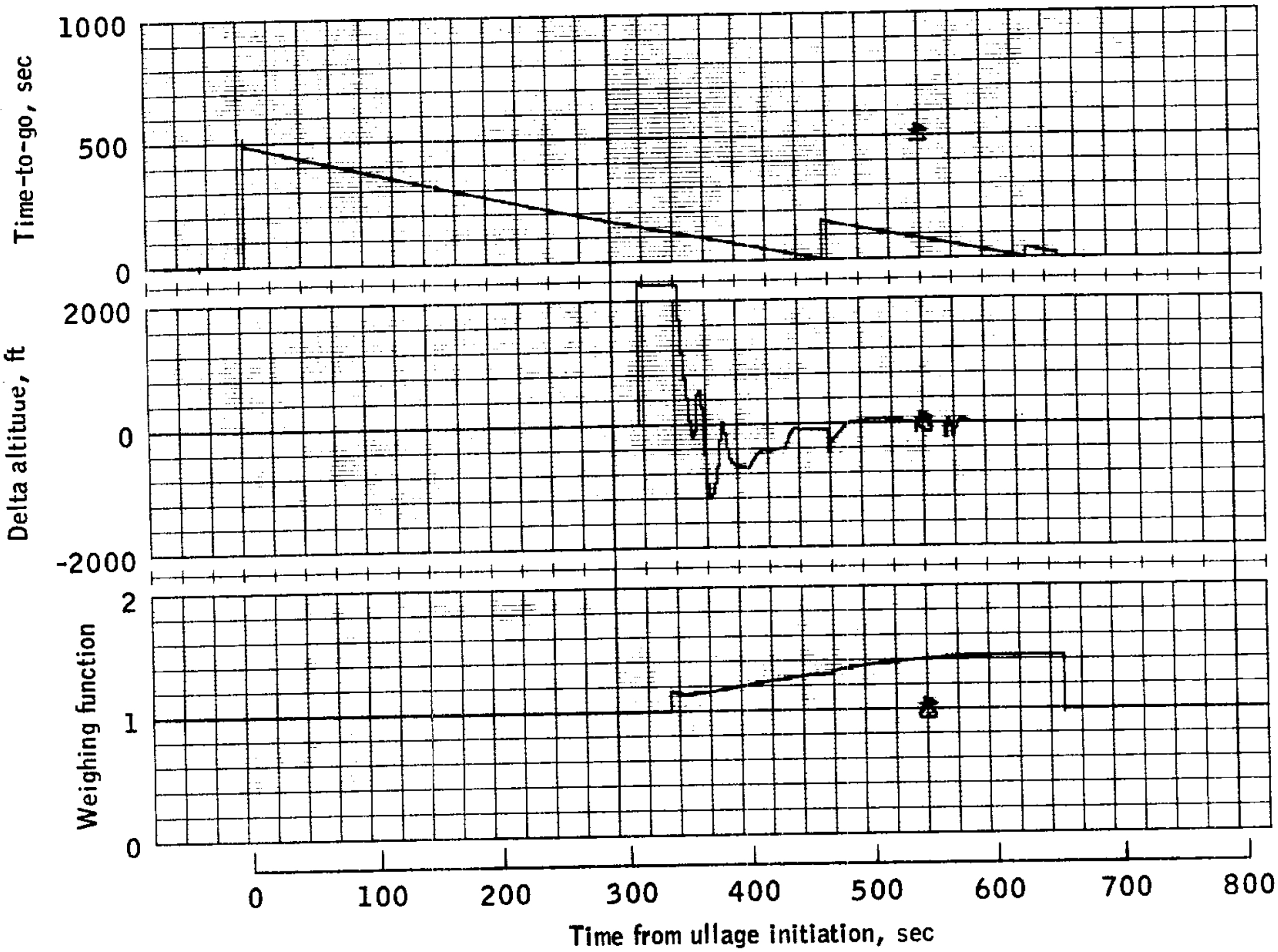
(a) Time from ignition, thrust and pitch from vertical.

Figure .- Time histories of trajectory parameters for case number 802.04.



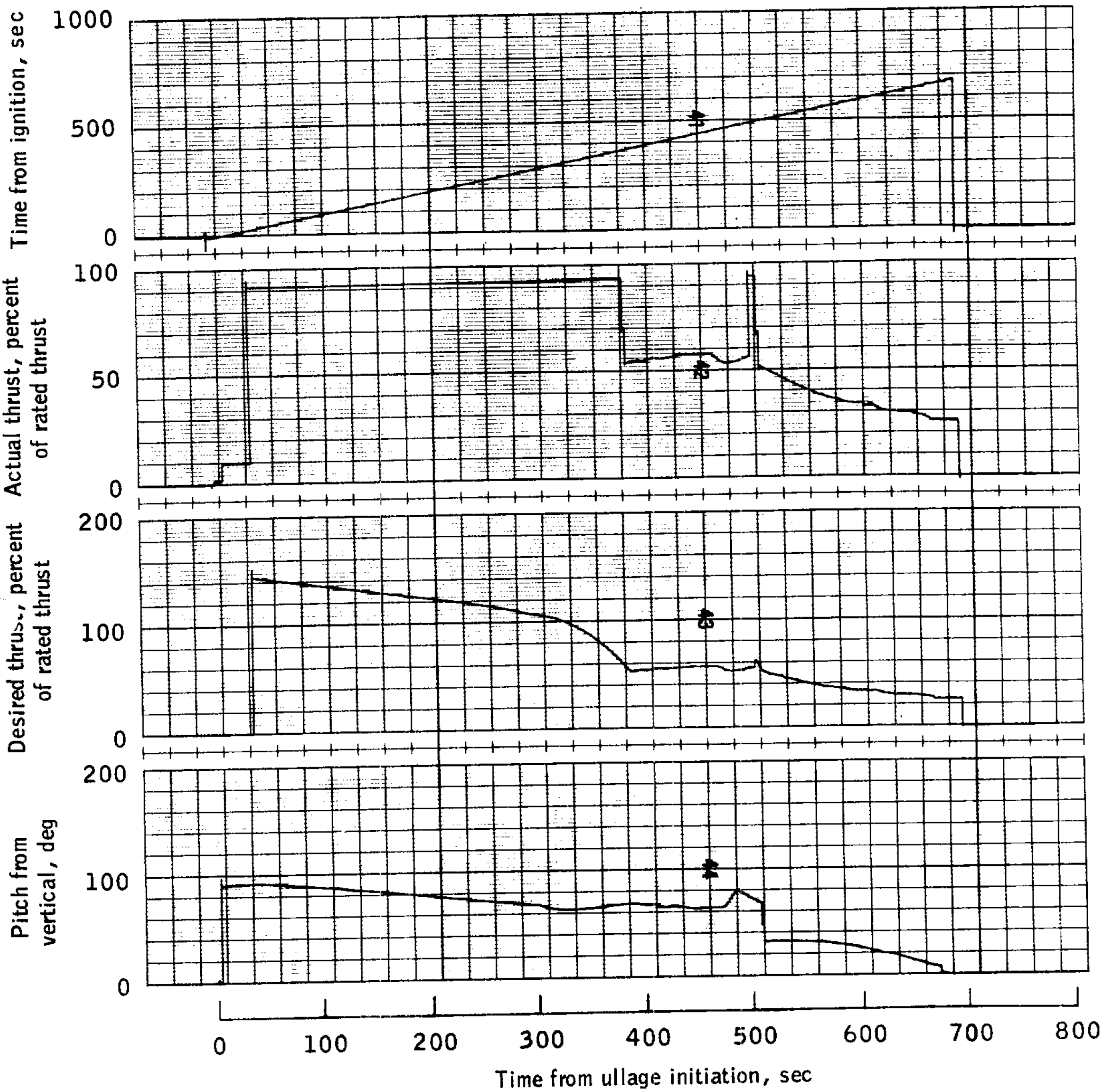
(b) Vertical velocity, horizontal velocity and altitude.

Figure .- Continued.



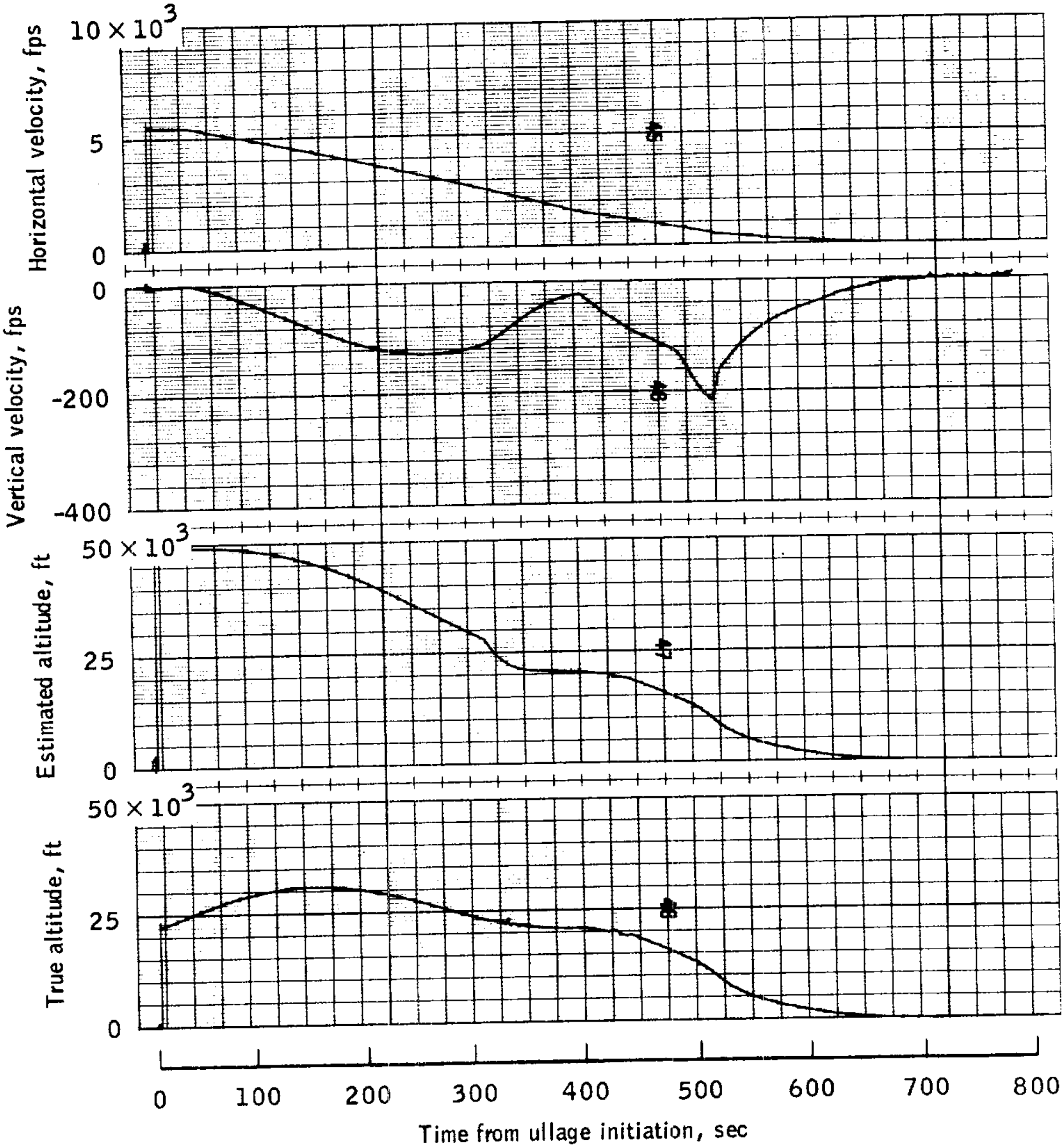
(e) Time-to-go, delta altitude and weighing function.

Figure .- Concluded.



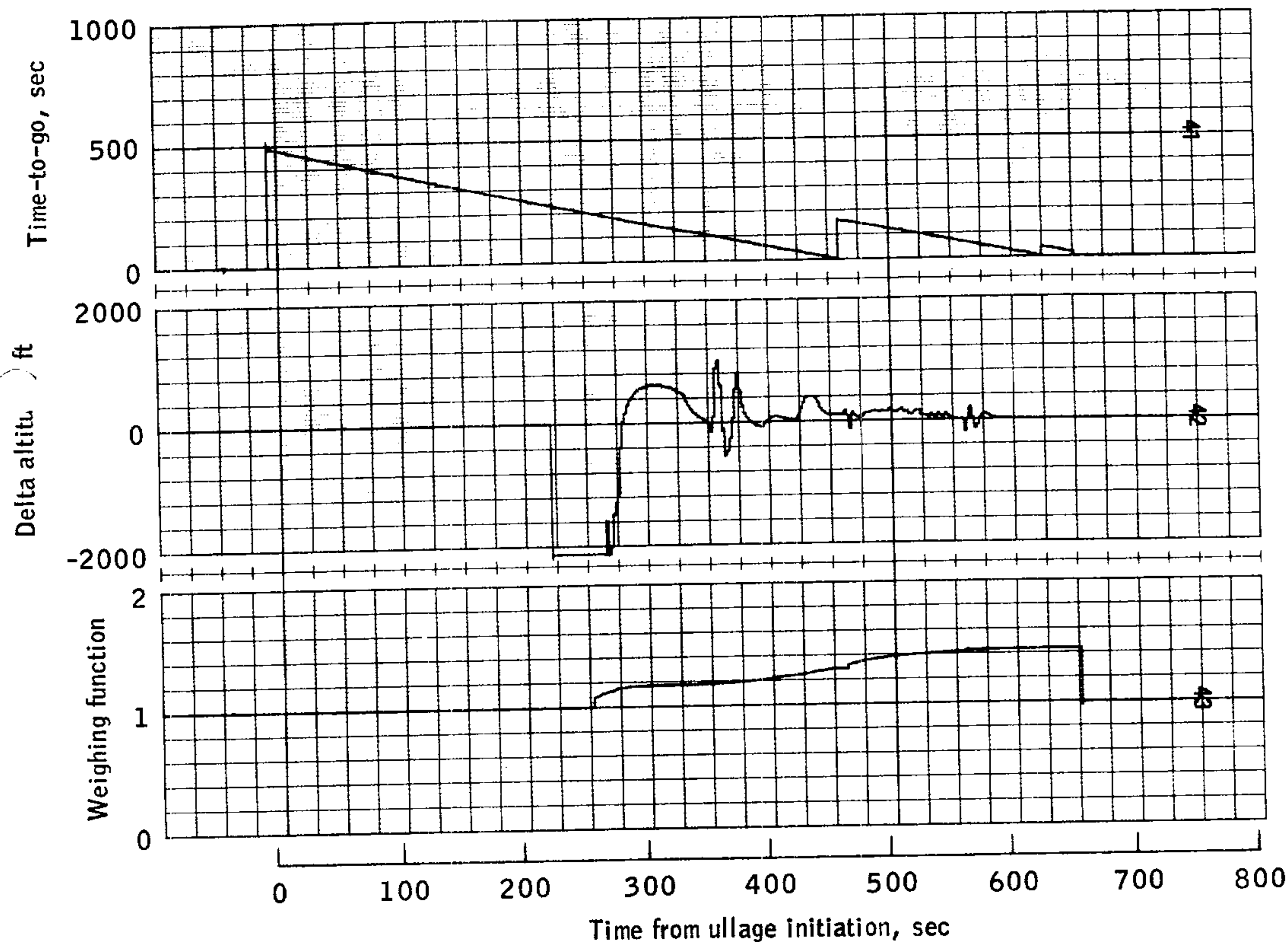
(a) Time from ignition, thrust and pitch from vertical.

Figure .- Time histories of trajectory parameters for case number 802.05.



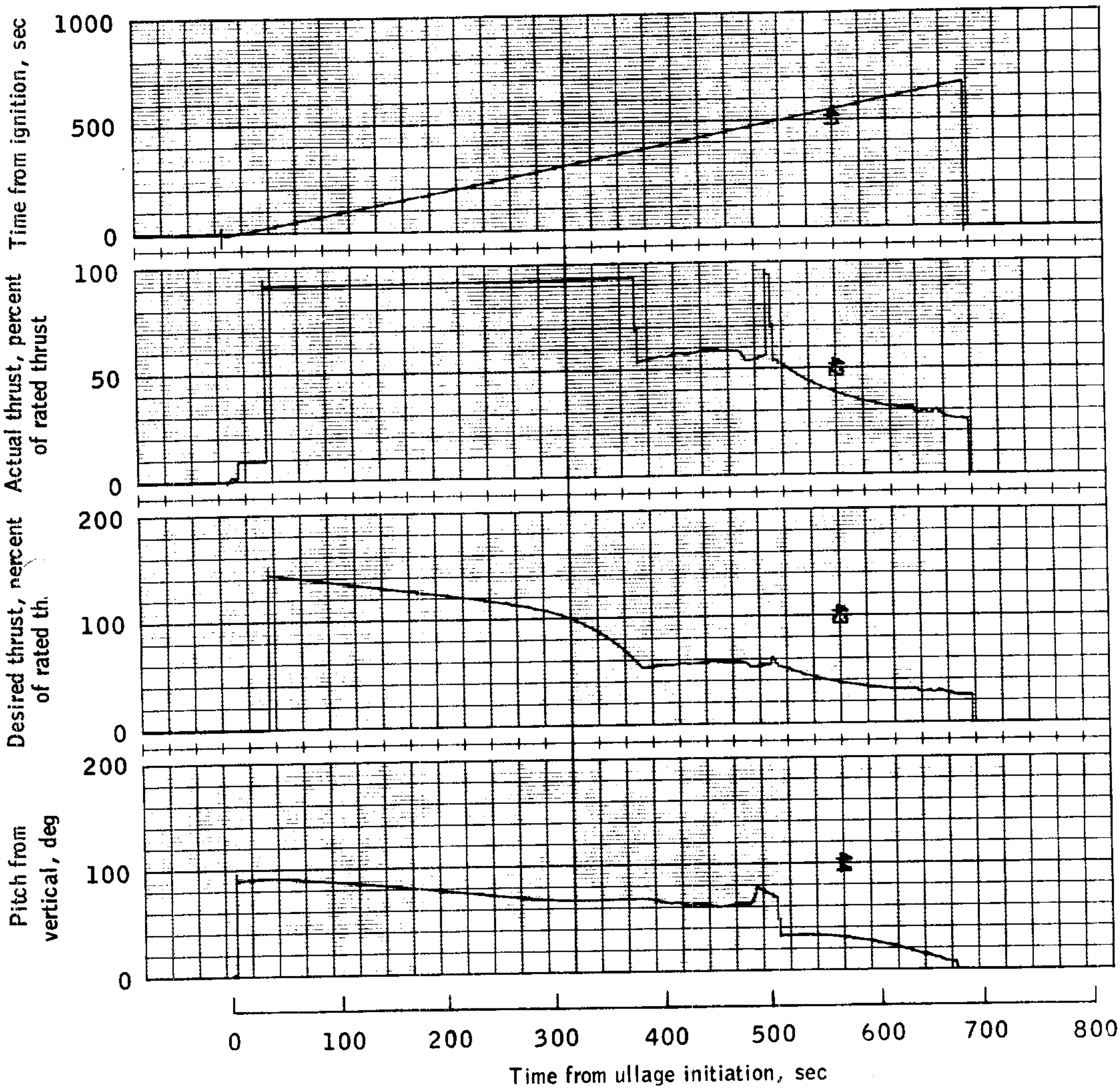
(b) Vertical velocity, horizontal velocity and altitude.

Figure .- Continued.



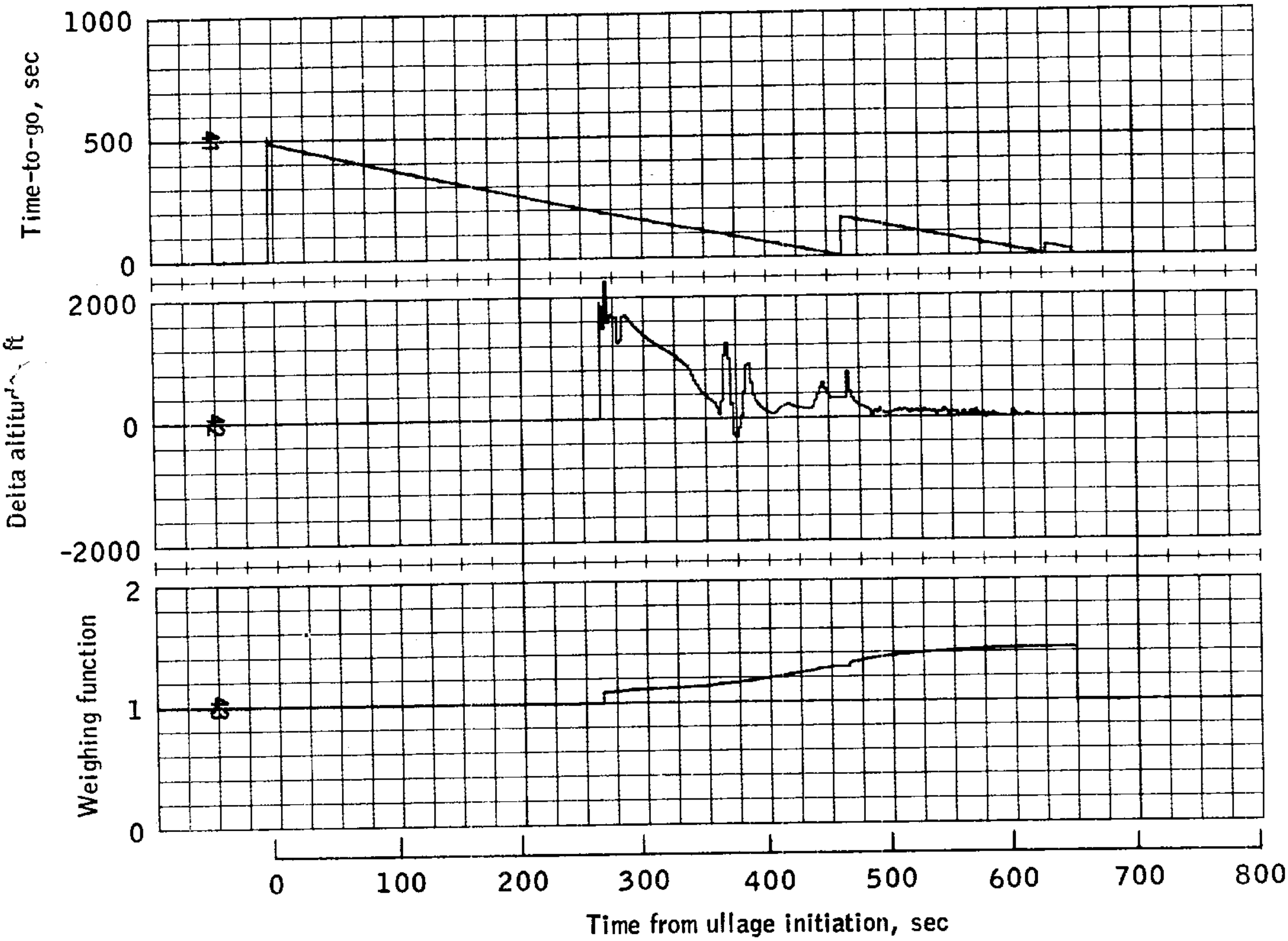
(e) Time-to-go, delta altitude and weighing function.

Figure .- Concluded.



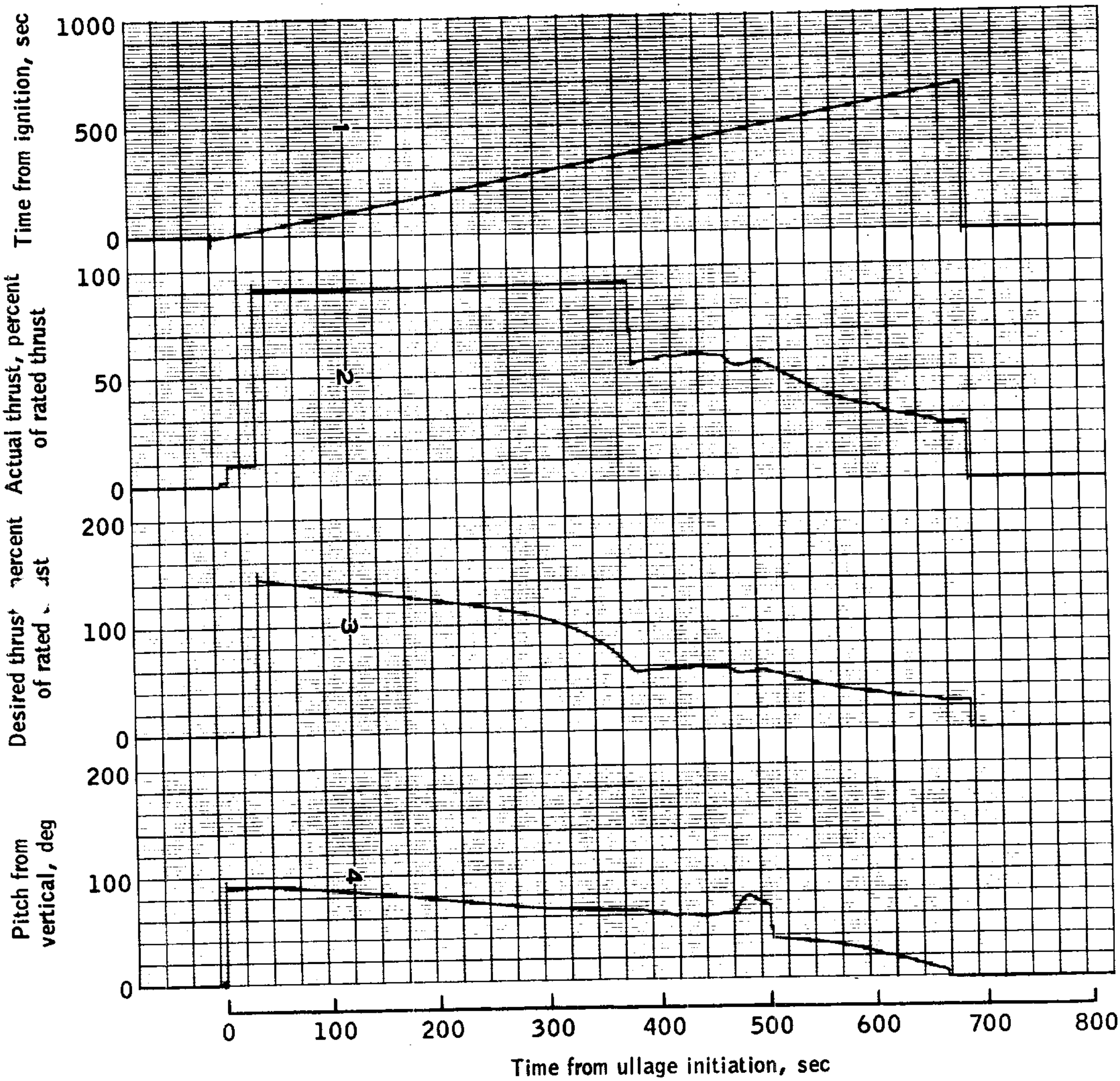
(a) Time from ignition, thrust and pitch from vertical.

Figure .- Time histories of trajectory parameters for case number 802.06.



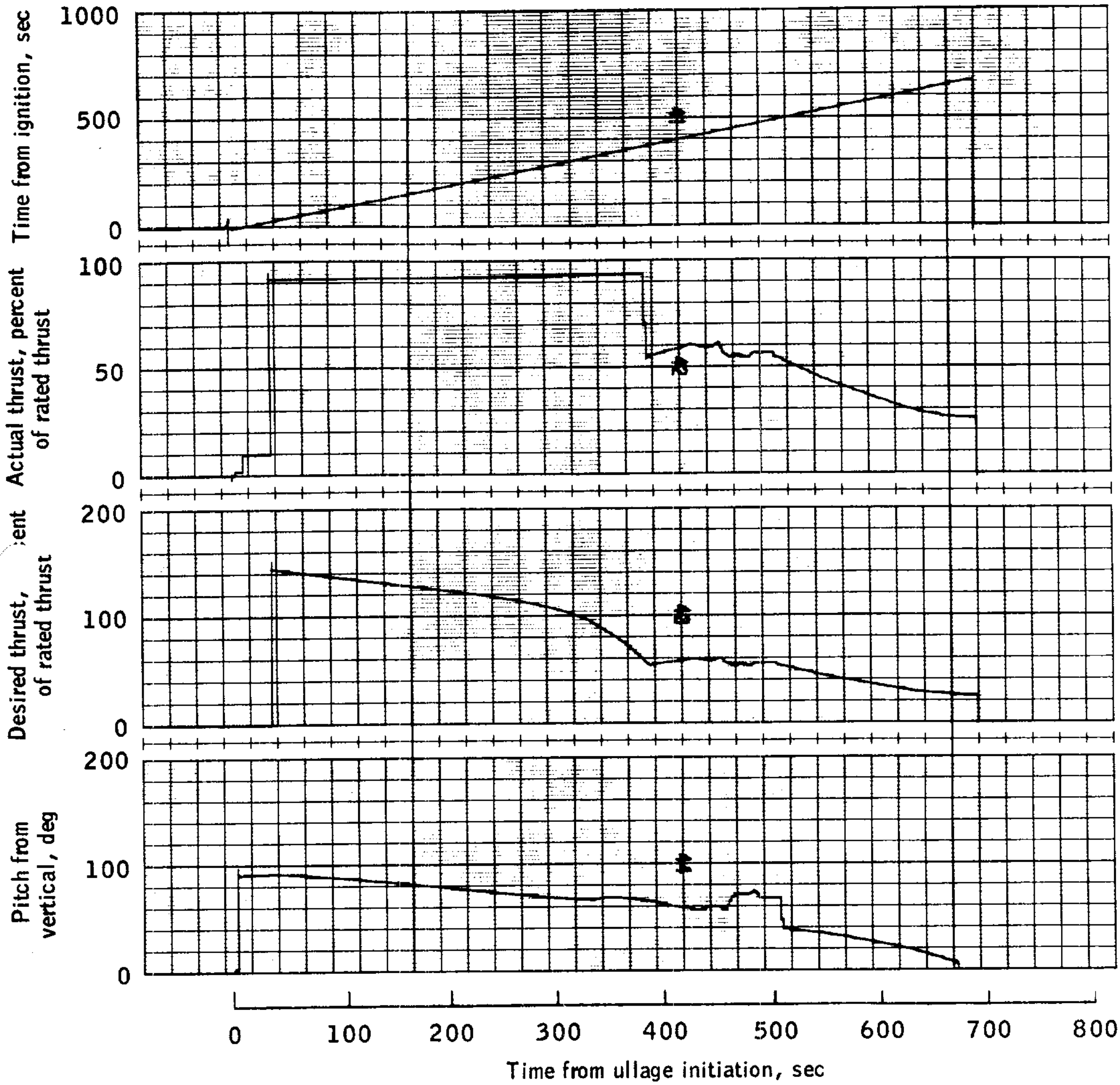
(e) Time-to-go, delta altitude and weighing function.

Figure .- Concluded.



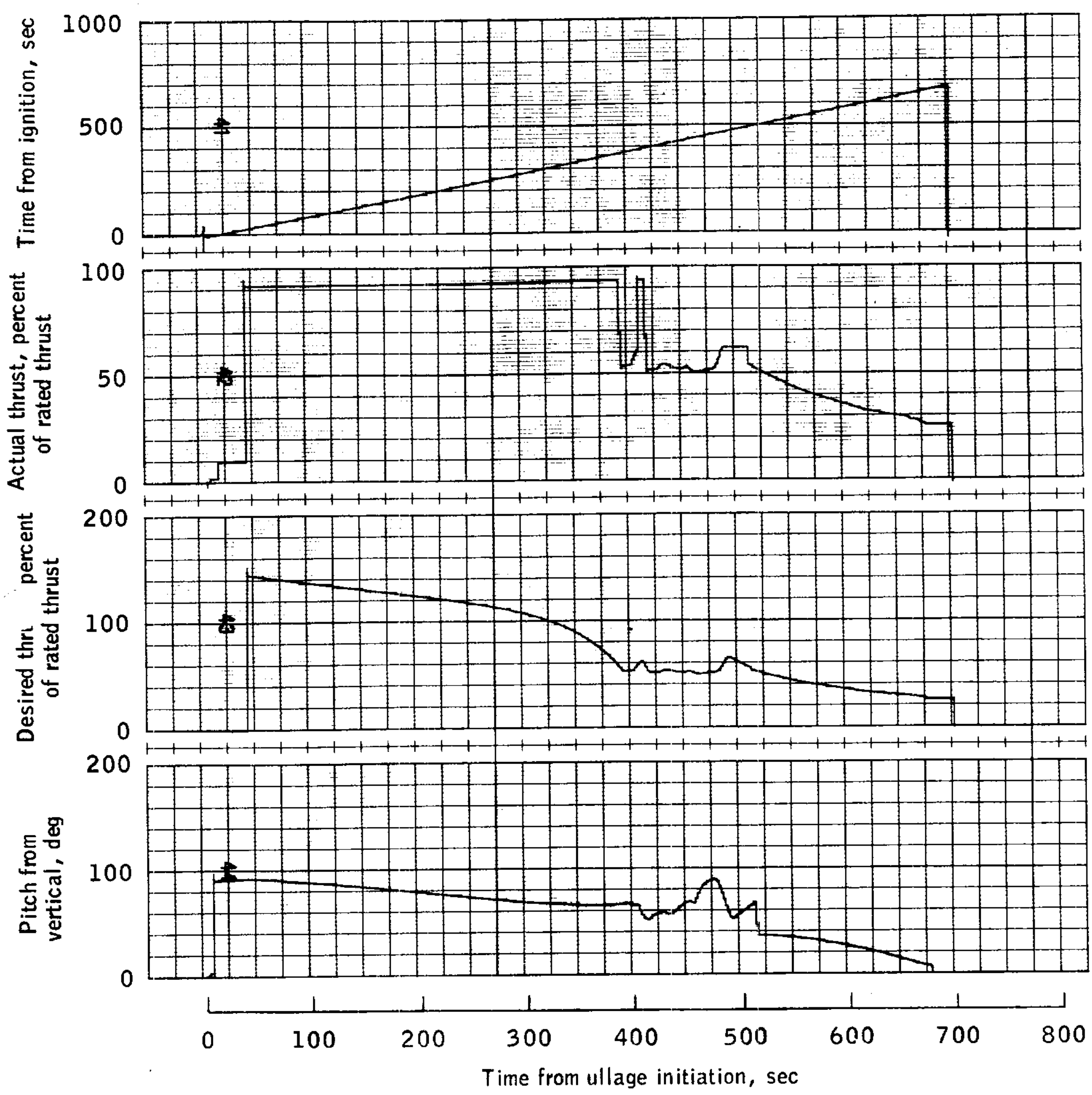
(a) Time from ignition, thrust and pitch from vertical.

Figure .- Time histories of trajectory parameters for case number 802.26.



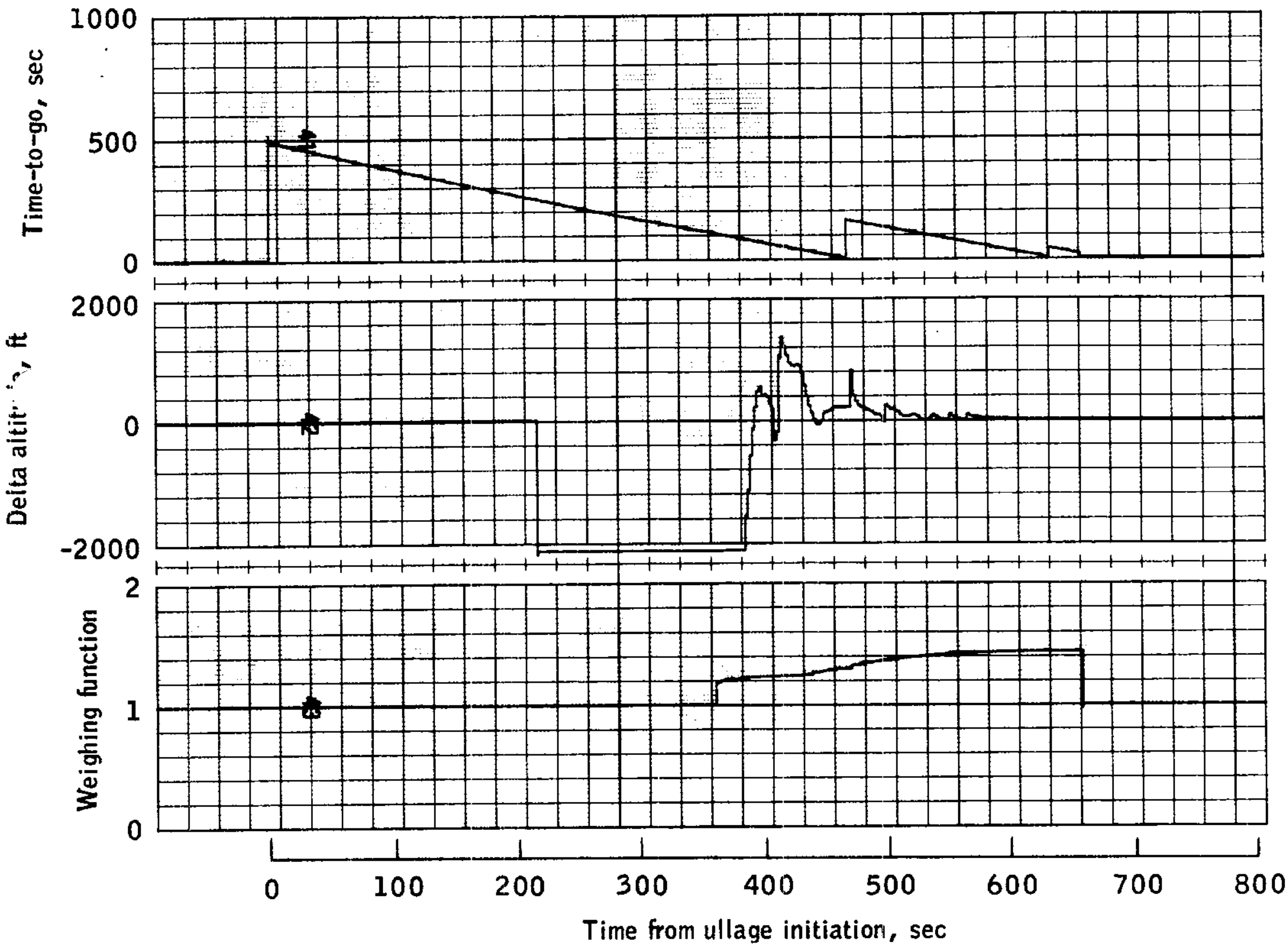
(a) Time from ignition, thrust and pitch from vertical.

Figure .- Time histories of trajectory parameters for case number 802.12.



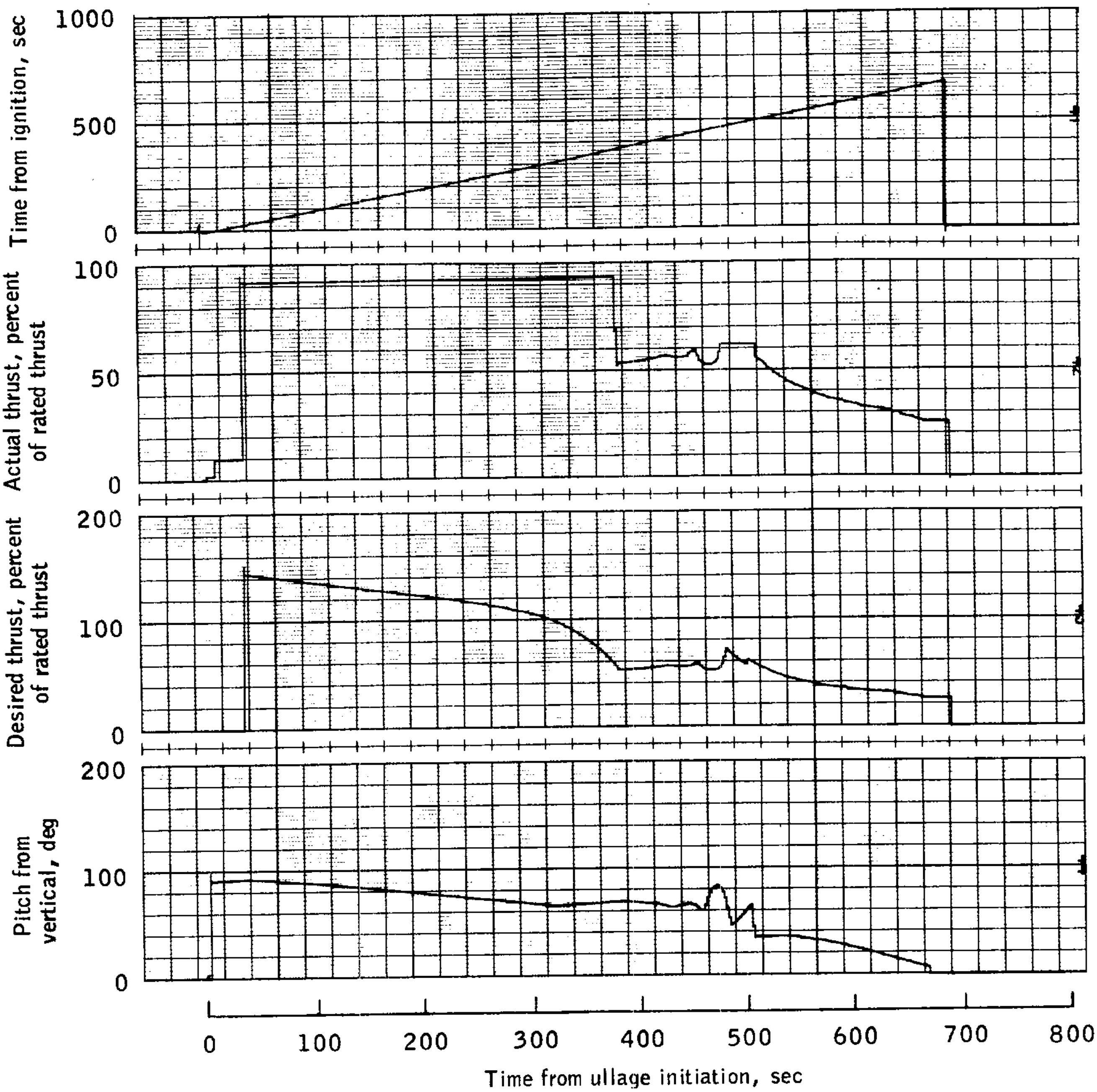
(a) Time from ignition, thrust and pitch from vertical.

Figure .- Time histories of trajectory parameters for case number 802.13.



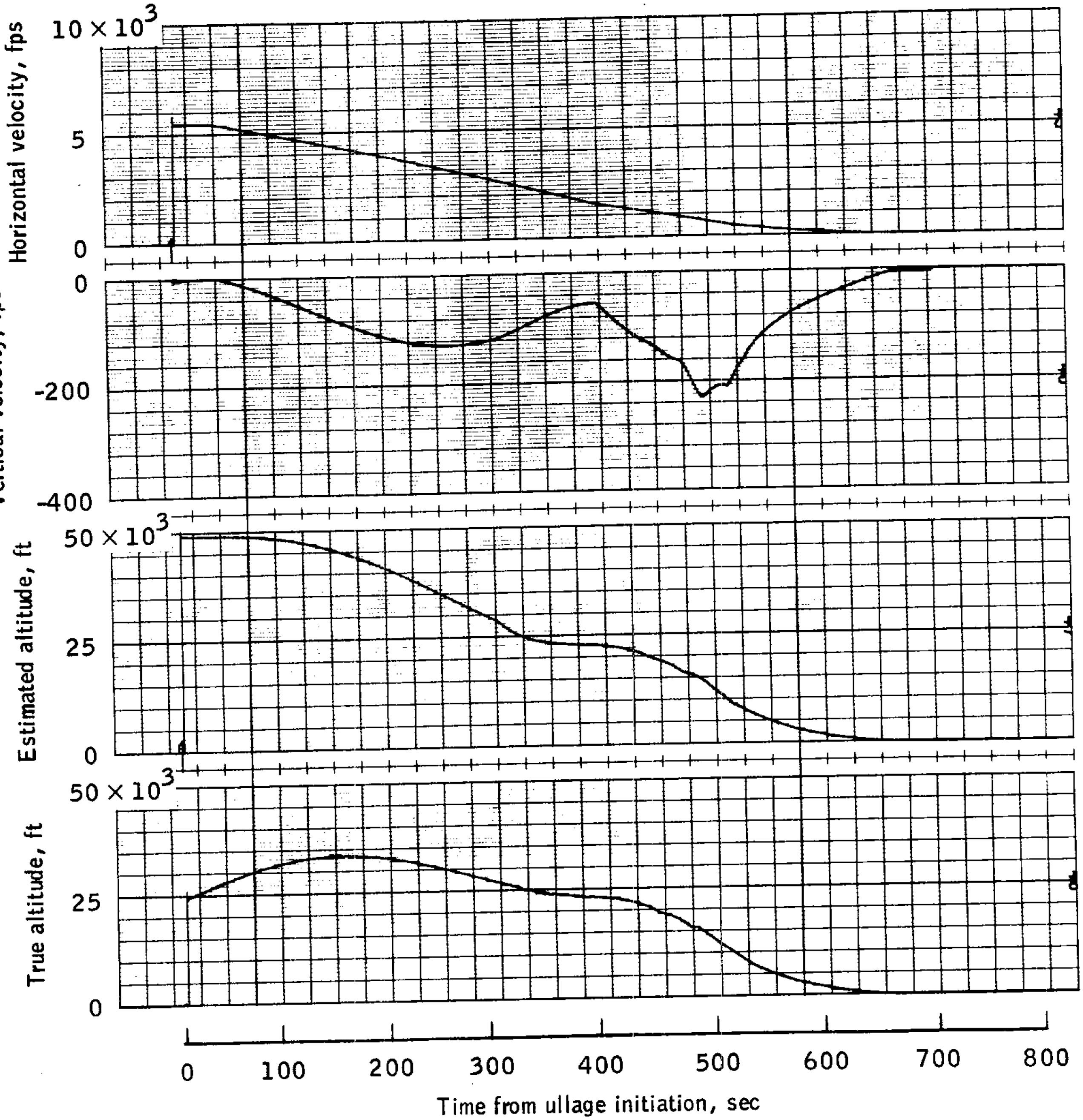
(e) Time-to-go, delta altitude and weighing function.

Figure .- Concluded.



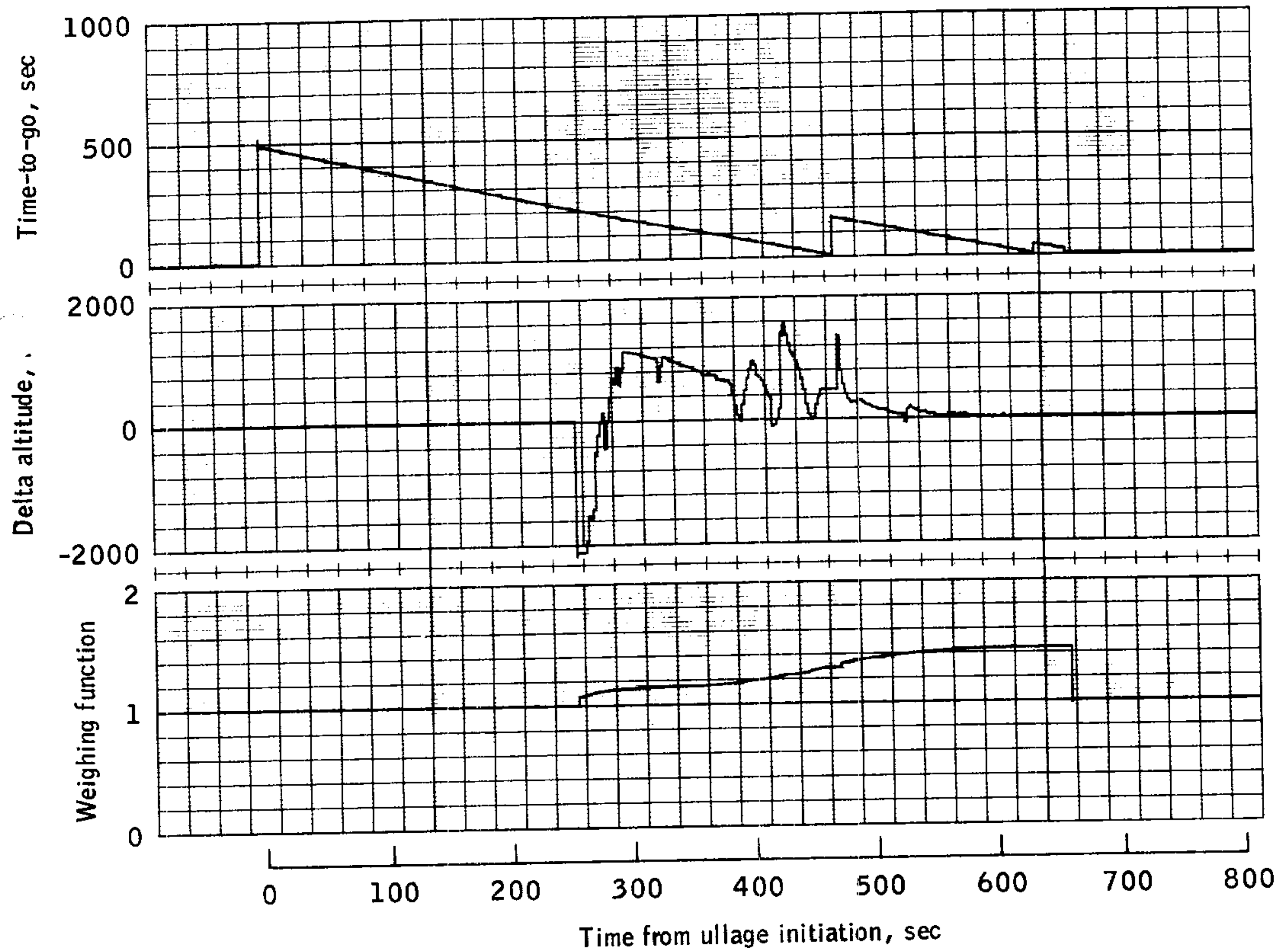
(a) Time from ignition, thrust and pitch from vertical.

Figure .- Time histories of trajectory parameters for case number 802.16.



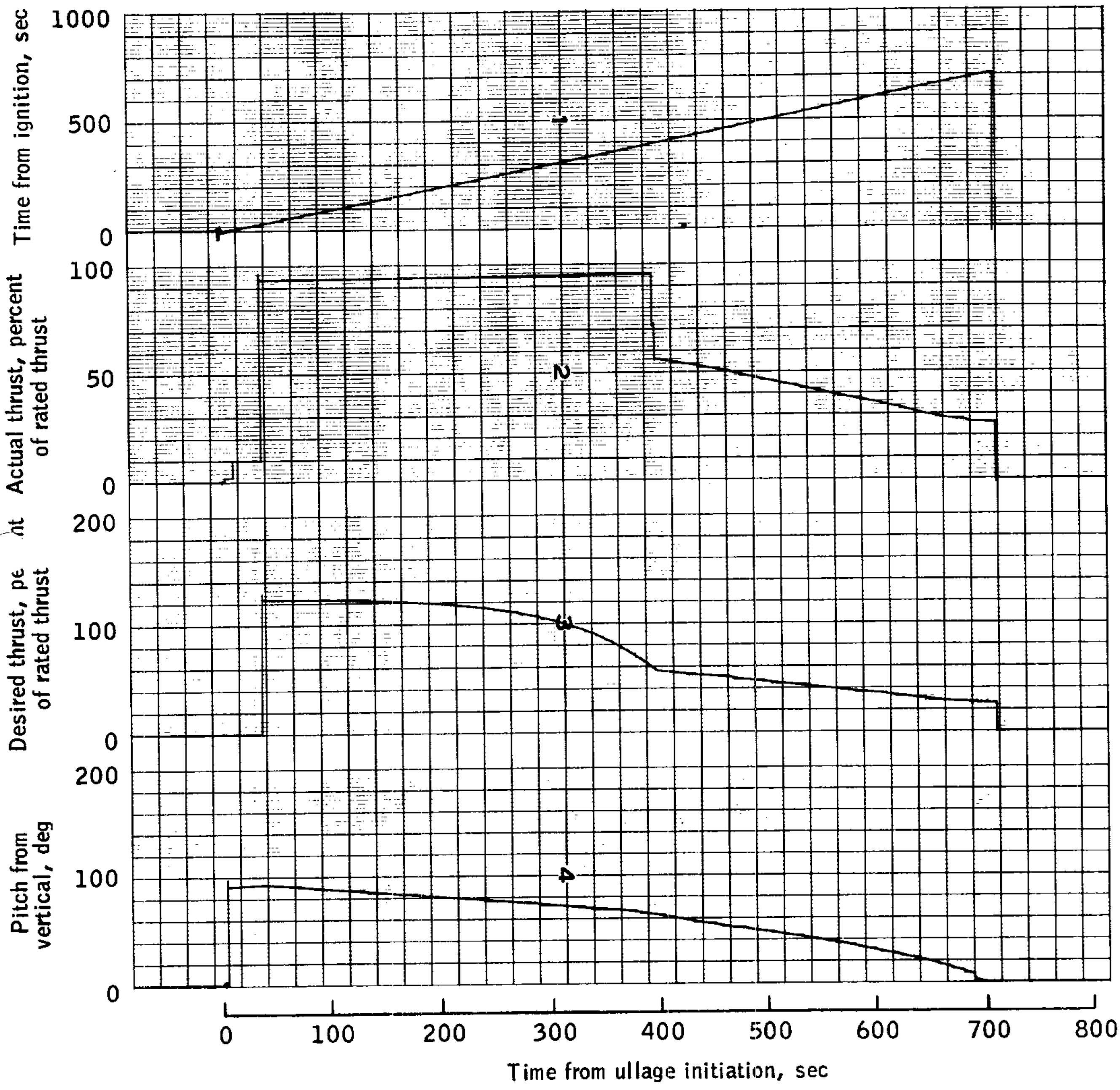
(b) Vertical velocity, horizontal velocity and altitude.

Figure .- Continued.



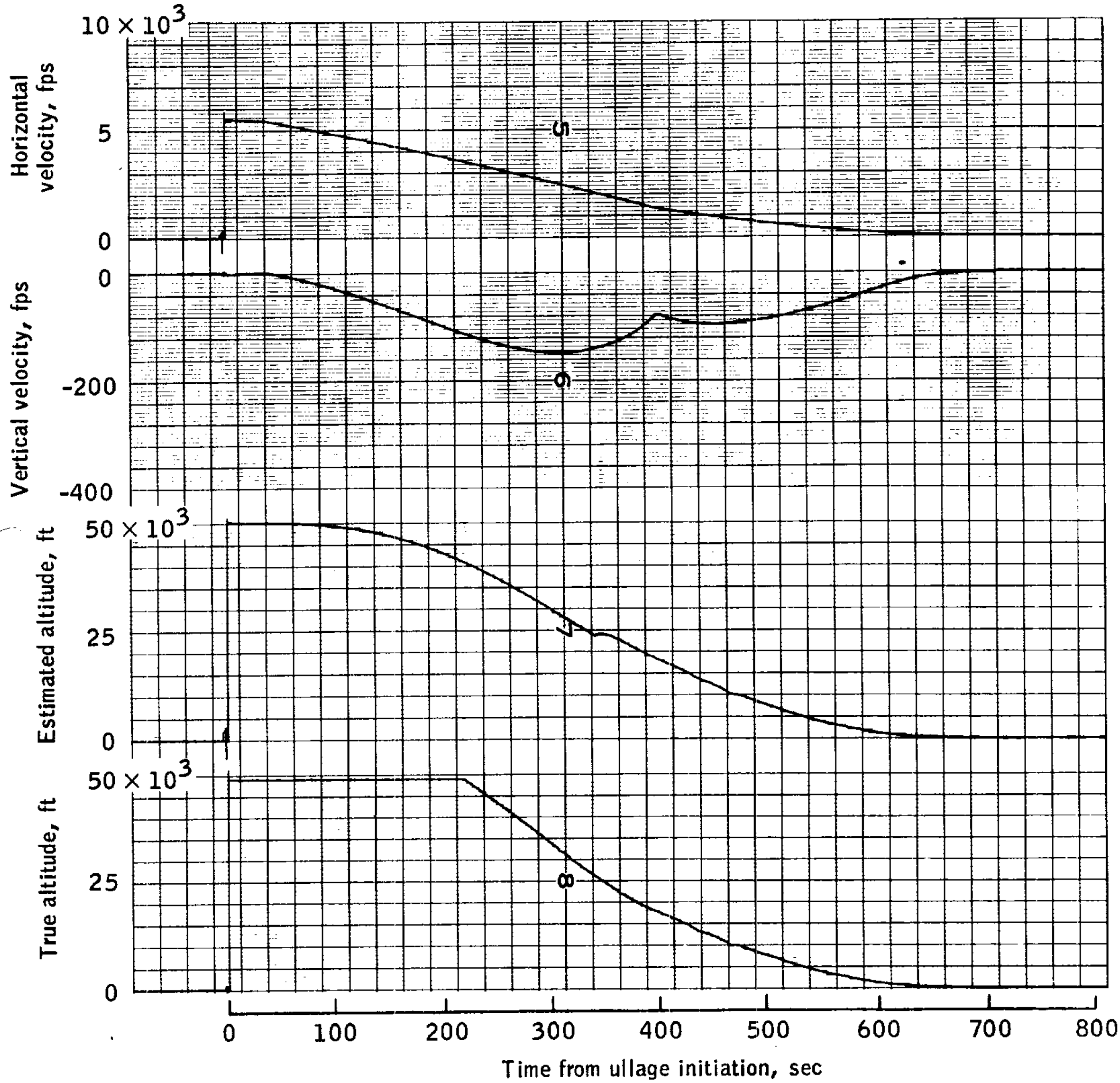
(e) Time-to-go, delta altitude and weighing function.

Figure .- Concluded.



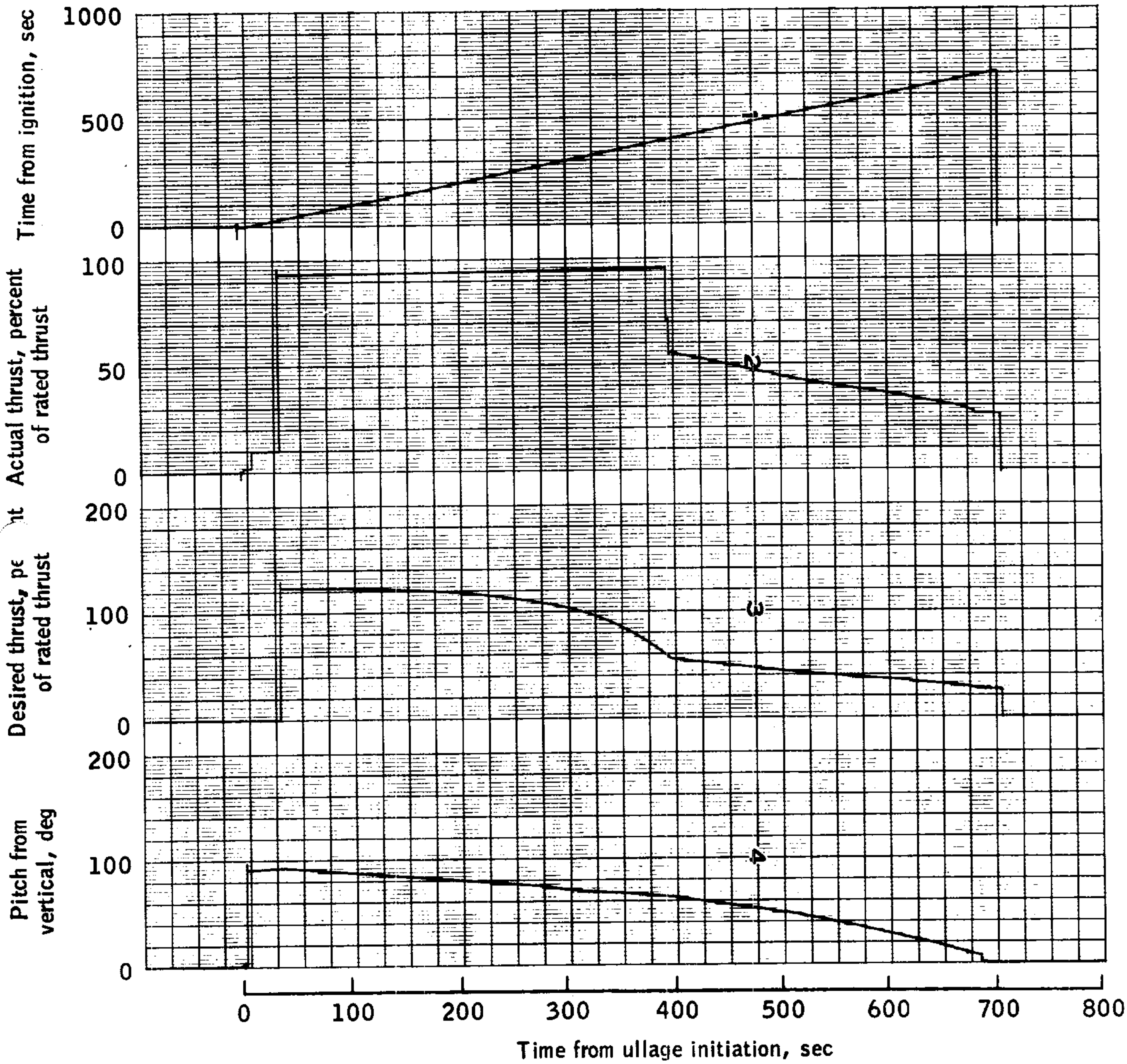
(a) Time from ignition, thrust and pitch from vertical.

Figure .- Time history of trajectory parameters for one phase guidance case 815.05.



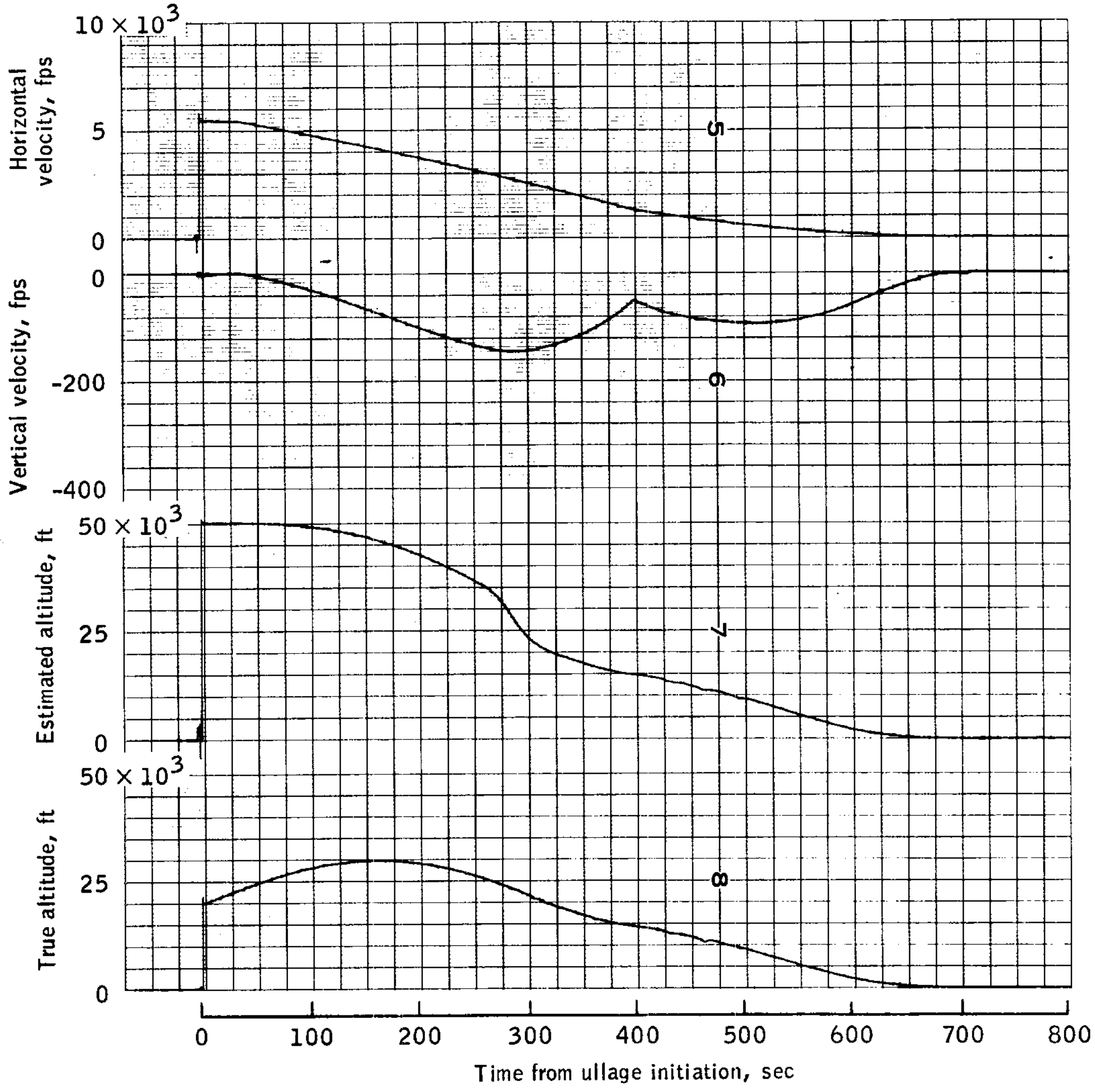
(b) Vertical velocity, horizontal velocity and altitude.

Figure .- Continued.



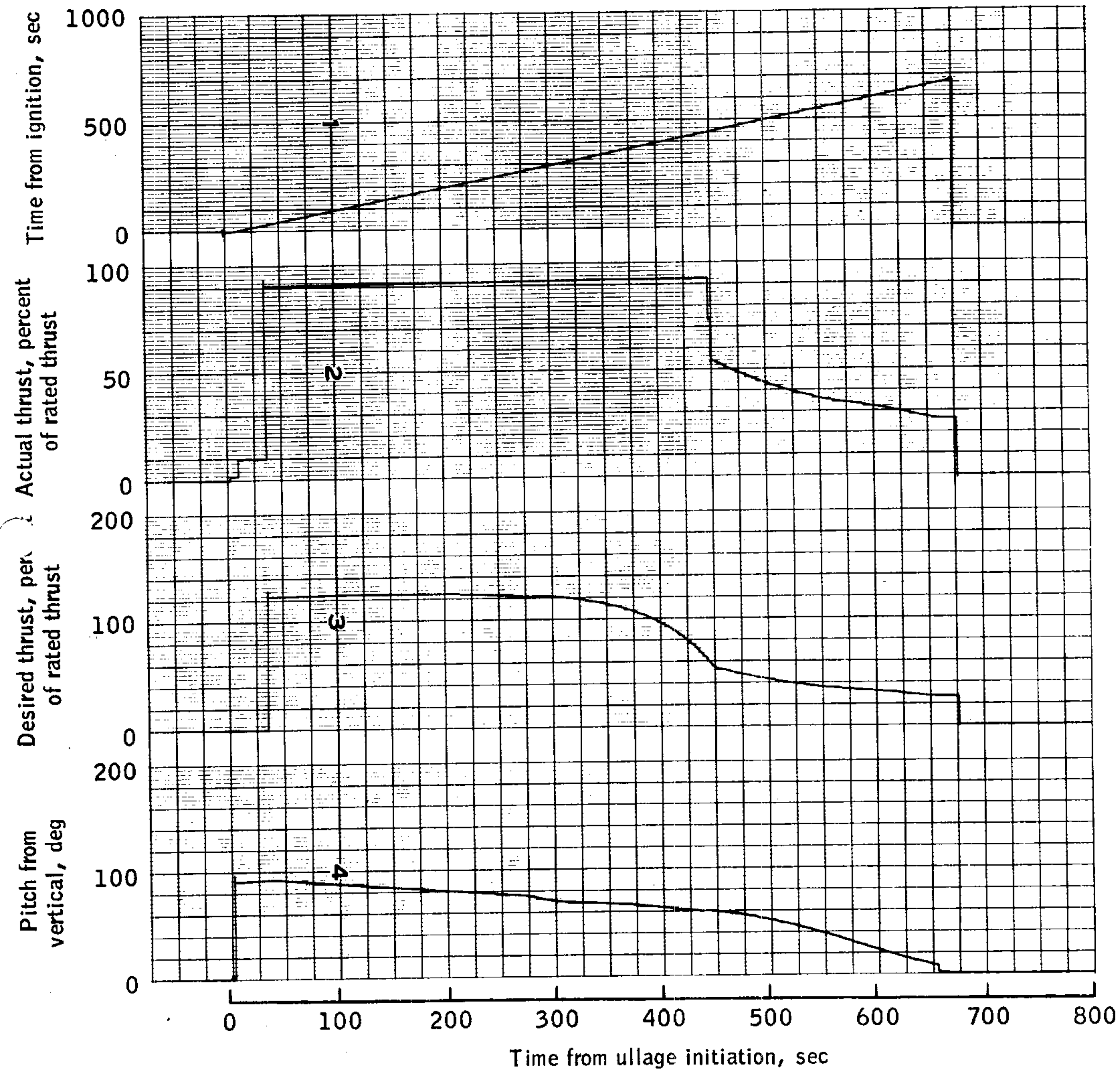
(a) Time from ignition, thrust and pitch from vertical.

Figure .- Time history of trajectory parameters for one phase guidance case 815.06.



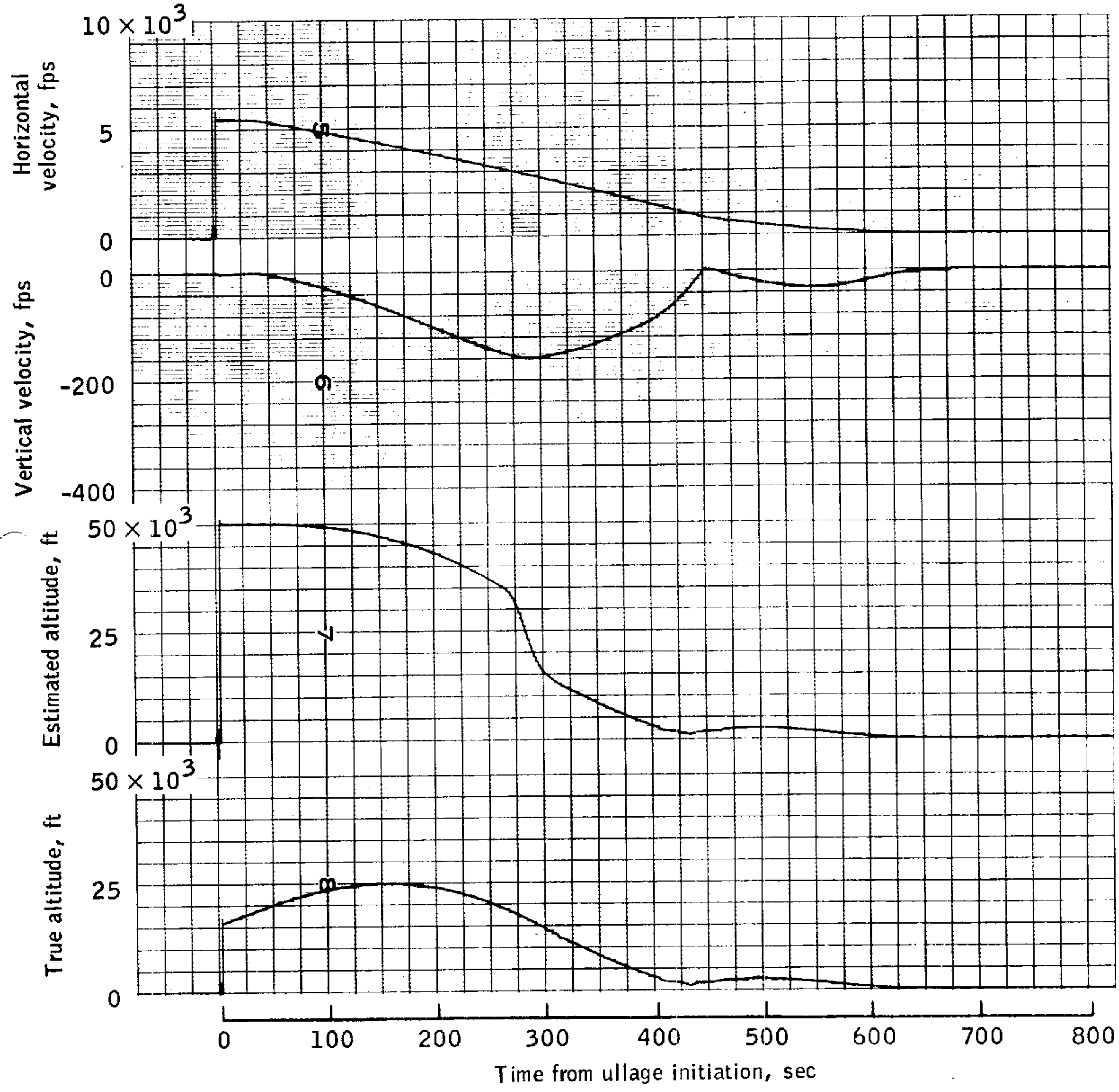
(b) Vertical velocity, horizontal velocity and altitude.

Figure .- Continued.



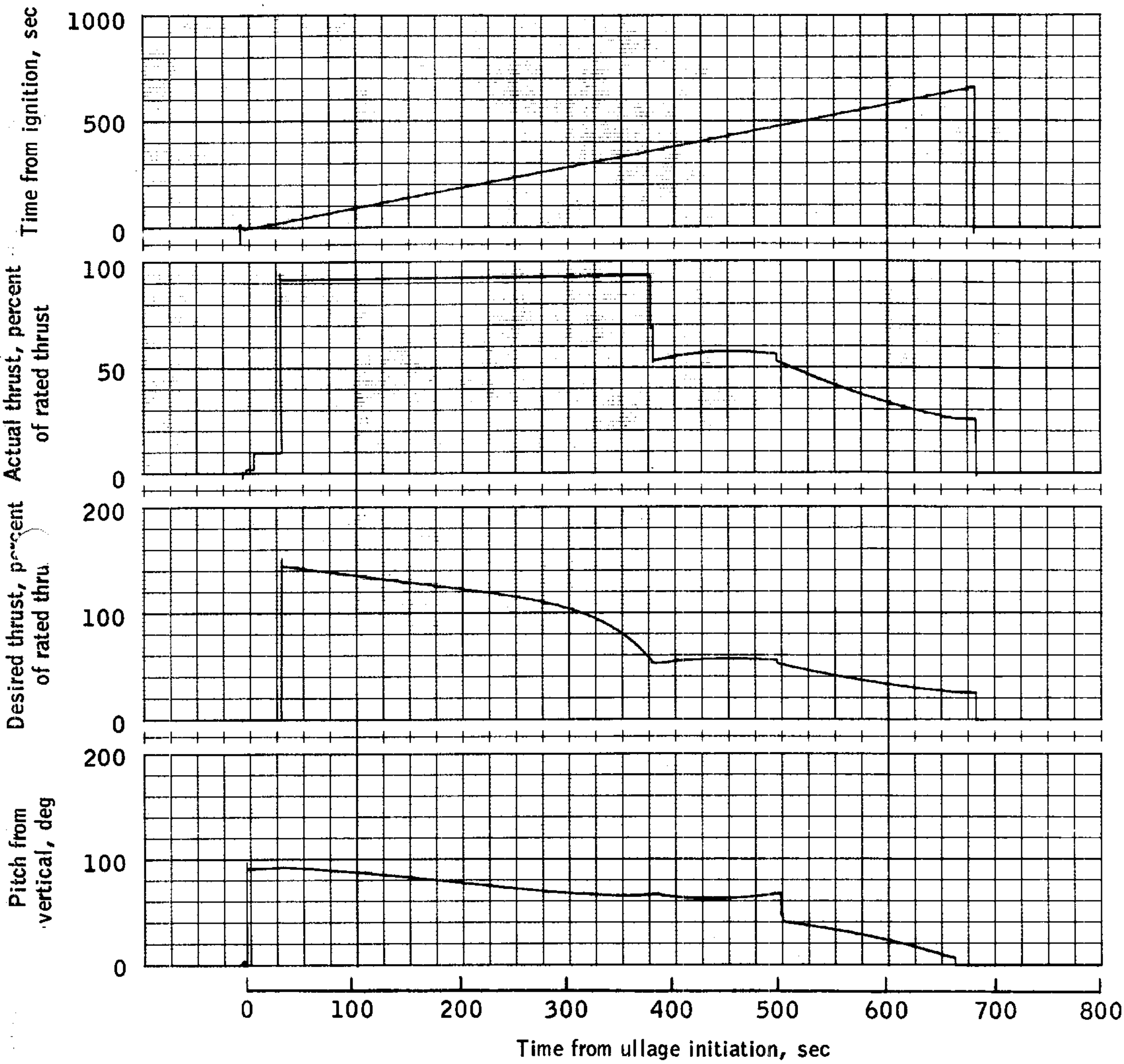
(a) Time from ignition, thrust and pitch from vertical.

Figure .- Time history of trajectory parameters for one phase guidance case 815.09.



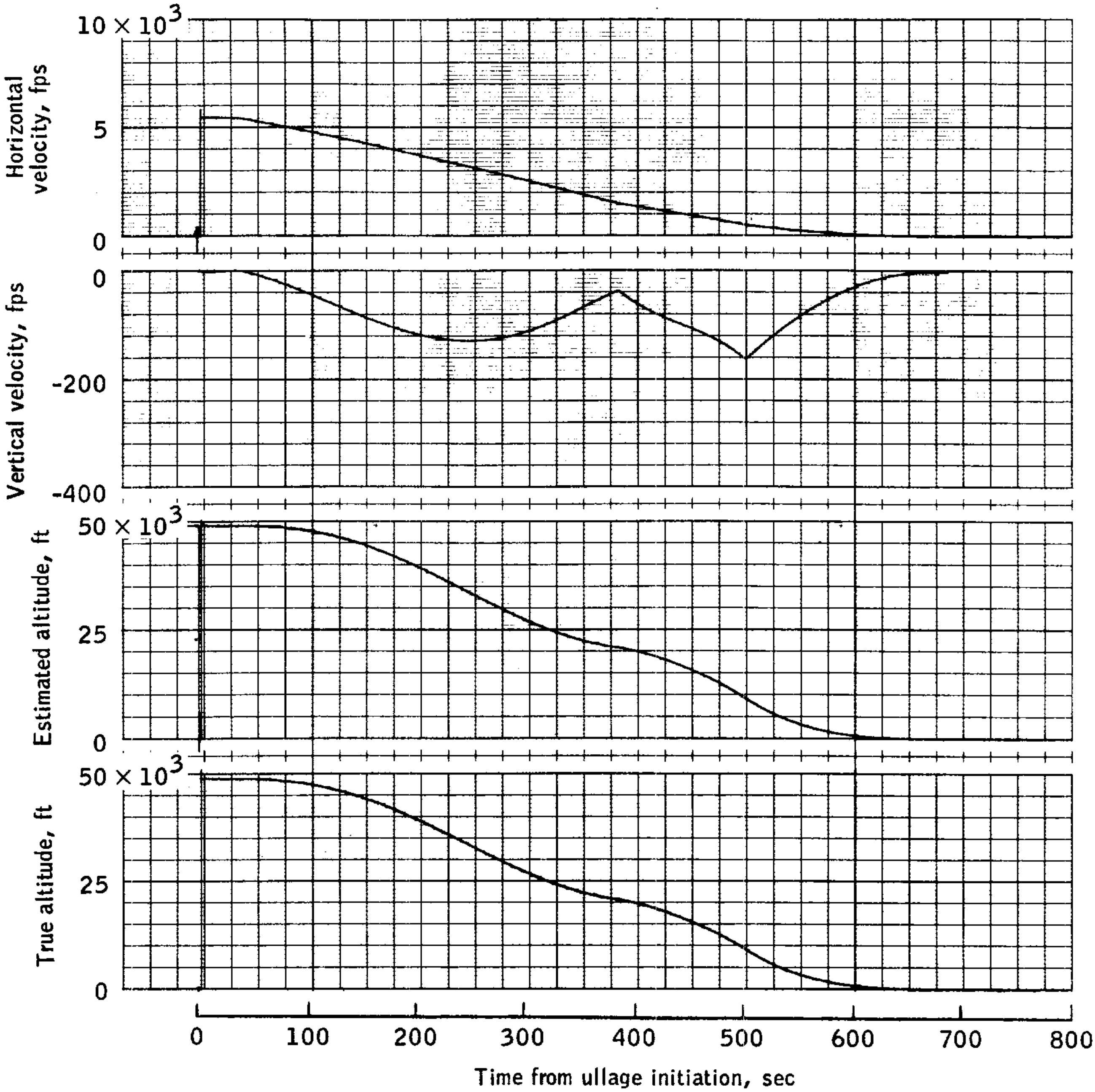
(b) Vertical velocity, horizontal velocity and altitude.

Figure .- Continued.



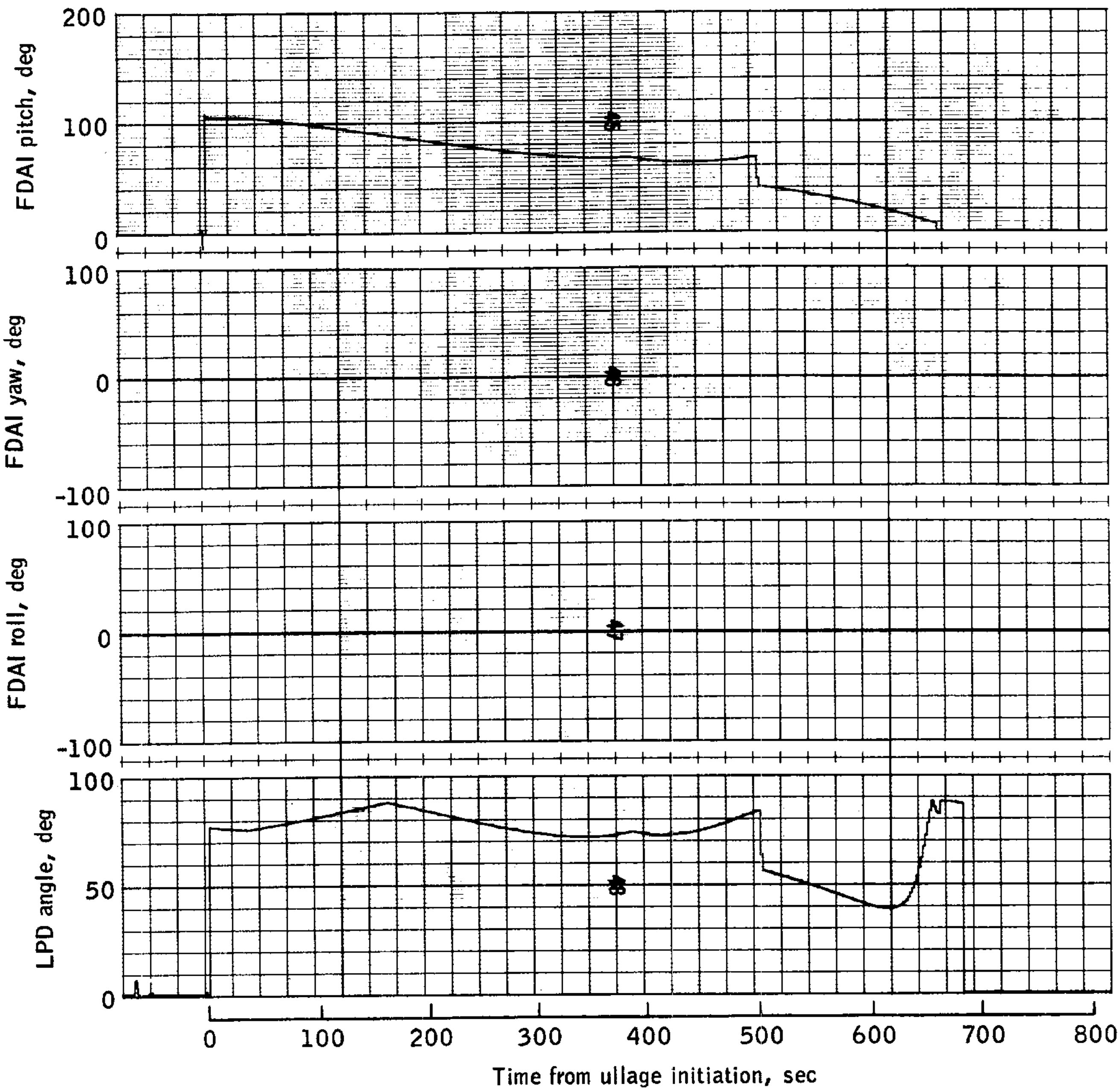
(a) Time from ignition, thrust and pitch from vertical.

Figure .- Time histories of trajectory parameters for case number 727.29.



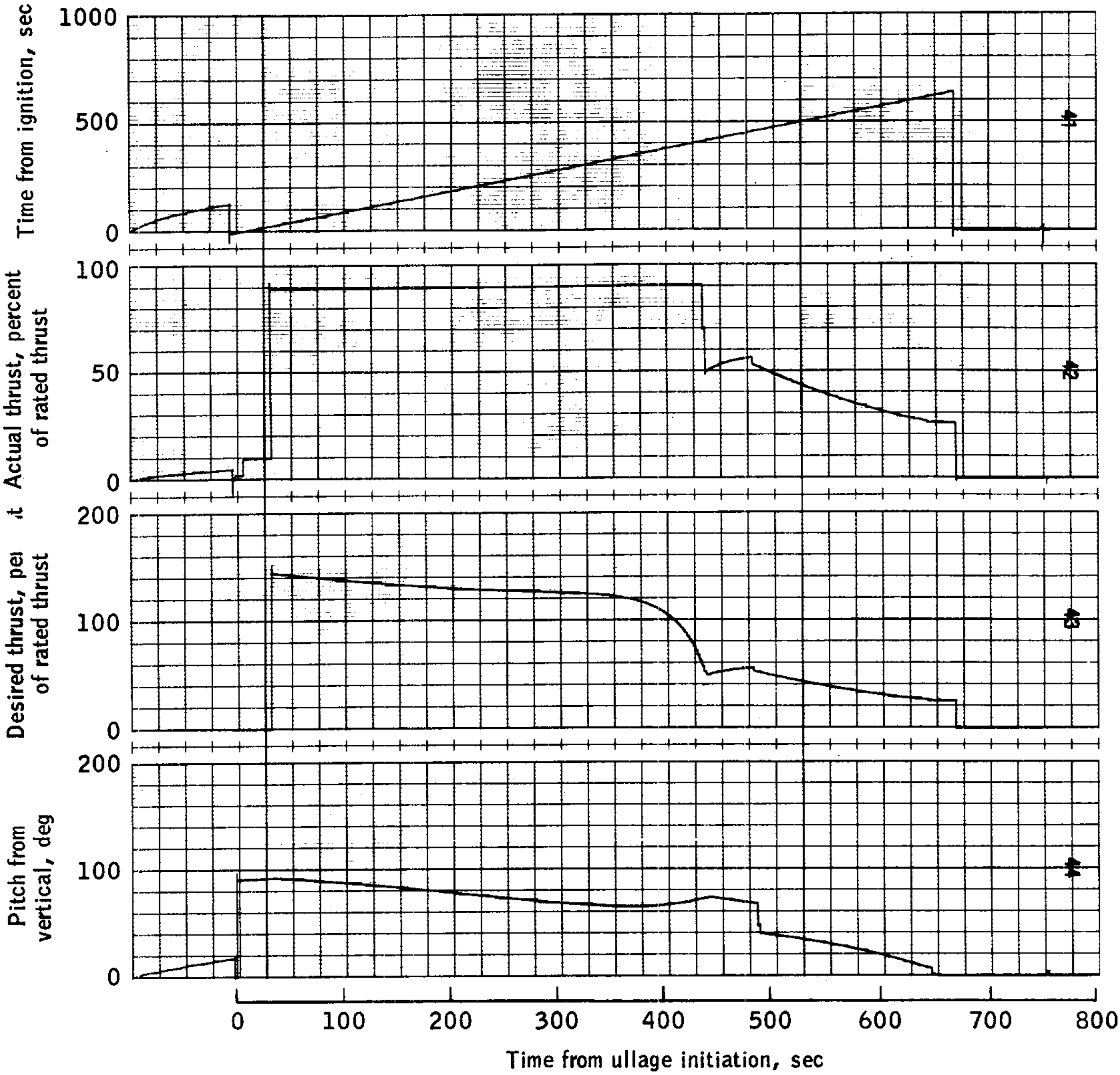
(b) Vertical velocity, horizontal velocity and altitude.

Figure .- Continued.



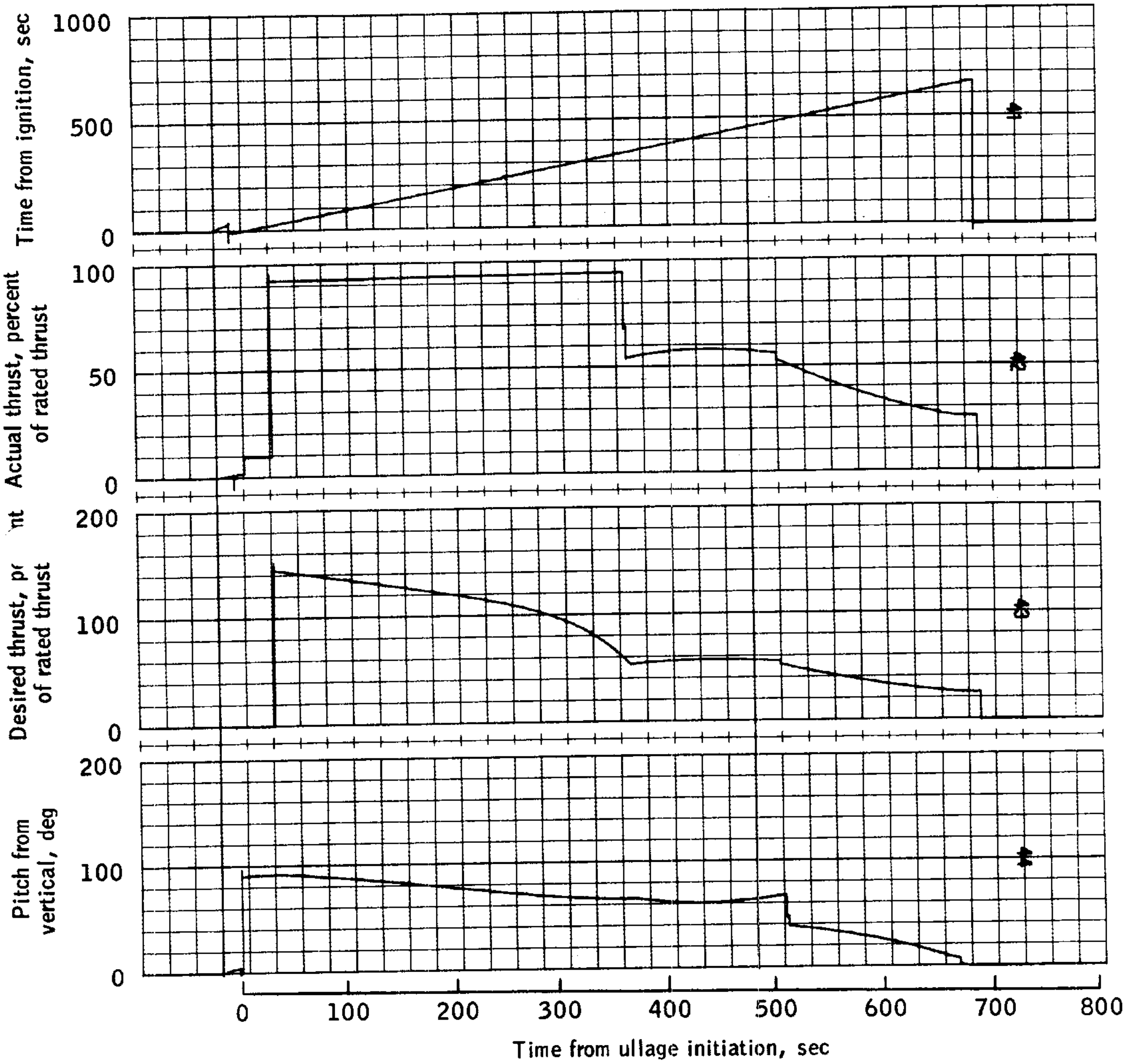
(d) FDAI pitch, yaw and roll and LPD angle.

Figure .- Continued.



(a) Time from ignition, thrust and pitch from vertical.

Figure .- Time histories of trajectory parameters for case number 727.30.



(a) Time from ignition, thrust and pitch from vertical.

Figure .- Time histories of trajectory parameters for case number 727.31.

Enclosure 8

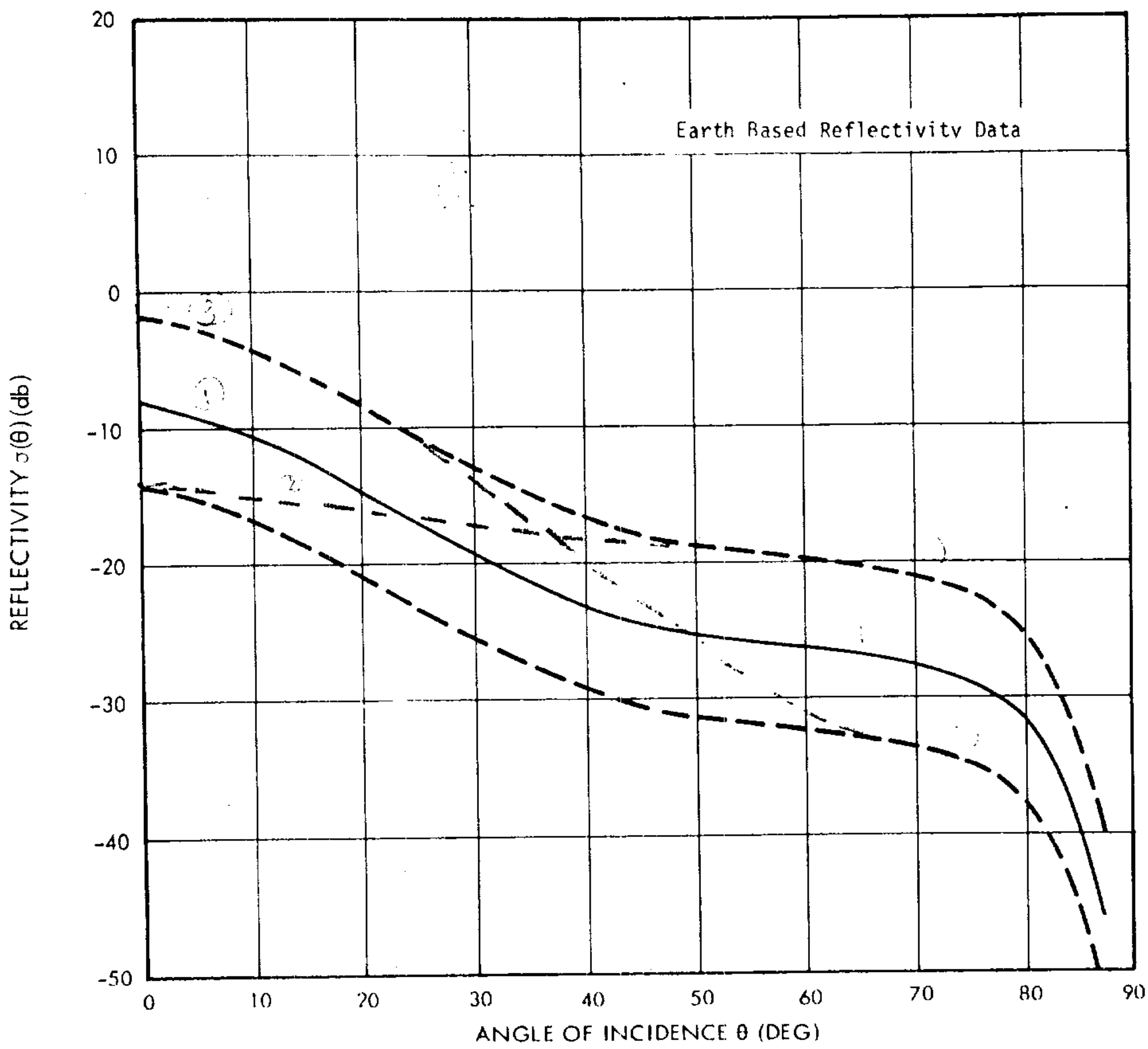


Figure 1. Recommended Interim Reflectivity Model

EVALUATE ANY CHANGES TO G&N SOFTWARE

A. CHANGES IN GUIDANCE LOGIC (e.g. NEW TARGETING)

B. CHANGES IN NAVIGATION LOGIC (e.g., DATA READ ROUTINE, WEIGHTING FUNCTIONS)

C. GENERATE STANDARD CHECK CASES

D. BEGIN 1-SEPTEMBER EG23 AND TRW

ESTIMATED COMPLETION 1-NOVEMBER

ESTABLISH LR PERFORMANCE MODEL

A. REFLECTIVITY GIVEN BY IESD (EST. AUG. 26)

B. DROP-OUT BOUNDARIES GENERATED:BY EG23

(3 MODELS - ESTIMATED COMPLETION OF:

NOMINAL - 9 SEPTEMBER

CONSERVATIVE - 23 SEPTEMBER

OPTIMISTIC - 7 OCTOBER)

REEVALUATION OF PRIME SITES AS REQUIRED WITH UPDATED REFLECTIVITY

A. DONE BY EG23 WITH TRW SUPPORT.

B. BEGIN 10 - SEPTEMBER AND CONTINUE EFFORT AS NEEDED.

(REEVALUATE III - P - 11 - R, III - P - 11 - A

WITH NOMINAL, CONSERVIATIVE AND OPTIMISTIC REFLECTIVITY).

ESTABLISH UPDATED LANDING ELLIPSE

A. USE MONTE CARLO PROGRAM TO DETERMINE "ENSEMBLE AVERAGE" TRANSITION MATRIX.

B. OBTAIN STATISTICS OF ESSENTIAL PARAMETERS SUCH AS DELTA V, VISIBILITY TIME, TOUCHDOWN VELOCITIES, ET CETERA.

C. BEGIN 1 - OCTOBER ESTIMATED COMPLETE 15 - OCTOBER*

EG23 w/ CAD

*SUBJECT TO COMPUTER AVAILABILITY.

EXAMINE G, N & C INTERACTIONS

A. SIMULATE INTEGRATED G, N & C (DAP)

B. DETERMINE PERFORMANCE CHARACTERISTICS (i.e. ASSESS POTENTIAL IMPINGEMENT PROBLEM, DETERMINE RCS FUEL REQUIREMENTS, ETC.)

C. BEGIN 15 - OCTOBER FINISH 15 - JANUARY

EG23 WITH CAD

FAILURE EFFECT ANALYSES

A. SENSOR FAILURES (i.e. LR, IMU)

B. CONTROL SYSTEM (i.e. JET FAILURES ENGINE GIMBAL ETC.)

C. EG23 WITH TRW AND CAD SUPPORT

BEGIN 1-DECEMBER COMPLETE 1 - FEBRUARY

CHECK RUNS

	RUN NO.	INITIAL ERRORS	IMU ERRORS	TERRAIN VAR.	TERRAIN SLOPE	THRUST ACC.DEV.
(1.) NOMINAL	1	NO	NO	SMOOTH	0	0
(2.) INITIAL ERRORS ALONE	2	+#1191	NO	SMOOTH	0	0
	3	-#1191	NO	SMOOTH	0	0
(3.) TERRAIN VARIATIONS ALONE	4	NO	NO	III-P-11A	0	0
	5	NO	NO	III-P-11A	$+1^{o}$	0
	6	NO	NO	III-P-11A	-1^{o}	0
(4.) THRUST ACC. VARS. ALONE	7	NO	NO	SMOOTH	0	$3-\sigma$ HIGH
	8	NO	NO	SMOOTH	0	$3-\sigma$ LOW
(5.) RUNS 4 & 5 OF REF. 5	9	+#1191	3- NEG.	III-P-11A	$+1^{o}$	$3-\sigma$ HIGH
	10	-#1191	3- POS.	III-P-11A	-1^{o}	$3-\sigma$ LOW

Enclosure 9

LM POSITION ACCURACY AT POWERED DESCENT INITIATION 3σ NM

	Radial	Down Range	Crossrange
No sextant	1.6	3.7	5.2 to 5.8
Sextant sighting	.3	3.4	.15

9-2

3. The following uvw covariance matrix was established based on current lunar orbit navigation procedures, LO3 navigation accuracies and predicted sextant landing site tracking accuracies.

	u	v	w	$\dot{u}$	$\dot{v}$	$\dot{w}$
u	$(600)^2$	0	0	0	0	0
v	0	$(6800)^2$	0	-38300	0	0
w	0	0	$(300)^2$	0	0	0
$\dot{u}$	0	-38300	0	$(6)^2$	0	0
$\dot{v}$	0	0	0	0	$(2.5)^2$	0
$\dot{w}$	0	0	0	0	0	$(9)^2$

ATTENDEES

Name	Organization
K. J. Cox	EG23
J. B. Craven	FC
G. W. Cherry	MIT/IL
B. A. Kriegsman	MIT/IL
D. E. Gustafson	MIT/IL
A. R. Klumpp	MIT/IL
O. Y. Lui	TRW
R. A. Harwood	TRW
P. C. Smith	TRW
S. G. Bales	FC
G. L. Bush	Bellcomm
I. Silberstein	Bellcomm
C. V. Whitmore	FC
T. E. Lewis	EG41
J. H. Alphin	FM2
K. G. Nickerson	TRW
R. J. Perkins	TRW
N. C. Stewart	TRW
T. E. Moore	EG27
J. Coffman	TRW
W. J. Klenk	TRW
R. Boudreau	TRW
W. L. Steele	TRW
C. McGee	TRW
D. R. Proctor	IBM
T. L. Henderson	IBM
C. T. Hackler	EG2
R. T. Neal	CF24
E. G. Dupnick	FM2
J. D. Payne	FM2
B. G. Taylor	FM2
C. R. Halliman	FM2
G. Venables	FM2
I. Johnson	MIT/IL
R. A. Larson	MIT/IL
R. W. Force	CF33
W. F. Haldeman	FM2
G. Xenakis	EG
C. A. Graves, Jr.	FM2
D. Dyer	EG23
J. H. Suddath	EG23
J. E. Greenlee	ED35
K. M. Alder	LEC
W. R. Wollenhaupt	FM4
E. D. Mitchell	CB
T. M. Lawton	EG (MIT/IL)
R. J. Labrecque	FM2
D. C. Cheatham	EG2

info

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA FPMR (41 CFR) 101-11.6

UNITED STATES GOVERNMENT

Memorandum

TO : See list attached

DATE: October 21, 1968

68-PA-T-226A

FROM : PA/Chief, Apollo Data Priority Coordination

SUBJECT: Descent Aborts

We have finally started mission techniques meetings on lunar landing descent aborts. At the risk of losing whatever confidence you might have in my judgment, I would like to describe a technique we are probably going to propose for aborts early in the descent phase. That is, within about 25 seconds of commanding the DPS to full thrust. It is a technique that Joe D. Payne and Floyd Bennett have been suggesting for quite a while, but which most of the rest of us had been unwilling to accept.

First of all, I don't think anyone will argue about what should be done between initialization of powered descent and DPS throttle up after the trim gimbal period (currently set for 26 seconds). The ΔV acquired during that period only drops the apogee down to about 40 miles so the best thing to do is probably just shut off the engine and sit tight. That is, no immediate abort maneuvers are required unless it is necessary to get away from a hazardous DPS stage.

After going to full throttle, though, there is a short period (roughly 25 seconds) during which aborts become a little difficult to handle. In this region the trajectory rapidly becomes suborbital, making an immediate abort maneuver necessary to achieve a safe orbit. The problem is that the spacecraft is oriented retrograde to perform the descent maneuver, which is exactly opposite to the direction required to get back into orbit. This causes the problem. Namely, if we want to abort on the DPS, you have a choice of:

a. Either turning off the engine, reorienting the spacecraft about 180°, and reigniting the DPS to make a posigrade burn into orbit - and no one wants to turn off the engine! or

b. Leave the DPS engine on as the spacecraft is being reoriented. Unfortunately, in order to avoid gimbal lock this attitude maneuver must be made in the pitch direction and leaving the engine on causes us to acquire a large radial velocity during the attitude maneuver which must be removed. To do this the spacecraft would go through a pretty wild pitch profile rotating almost a complete revolution from the time of abort to the time of engine shutdown. The reason for this is that attitude change is made at a rate of only 10 degrees a second, which means the engine would thrust with a component in the radial direction for a long time. As you can imagine, there are also considerable problems in the guidance equations, which would cause the engine to be shutdown prematurely under certain circumstances.

Abort Staging with the APS is not much better since it was felt necessary to provide an immediate separation maneuver (currently coded to be three seconds or 30 fps) to get away from the DPS before reorienting to posigrade attitude. And, you can't leave it running for the same reasons as the DPS. So you see, even for an APS abort, we end up turning the engine on, then off, and then back on, which we don't want to do.

Let me point out that after about 25 seconds at full throttle, the horizontal velocity required to get back into orbit when combined with the radial velocity picked up during the attitude change results in a guidance and attitude control situation considered acceptable. That is, it is not necessary to turn off the engine during the pitch over to posigrade attitude. So our only concern is with aborts during the first 25 seconds after throttle up, when it is neither acceptable to leave the engine on nor to turn it off for fear that it won't start again.

Standby for Payne's solution!

It is proposed that in the event of an abort recognized in that troublesome period to continue operating the DPS in the retrograde direction until we have reached the time it is possible to make the attitude change to the posigrade direction without turning off the engine! If the DPS is the system that isn't working and it is necessary to "Abort Stage" and use the APS, it is proposed to burn the APS in the retrograde direction as long as necessary to reach the point when we can pitch to the posigrade direction without turning off the APS.

This solution, you see, avoids the need for turning off an operating engine and makes the procedures for both DPS and APS about the same in this time period as they are after this period. The thing that takes awhile to get used to is burning in a retrograde direction lowering the orbit still farther after a need for an abort has been recognized. How do we rationalize doing a thing like that? We currently feel that the advantages of the simplified, standardized procedures and particularly of not shutting down a running engine sufficiently justify thrusting to a situation a little worse than that which existed at the time of abort recognition. And, of course, we do have a tremendous propellant surplus if we abort at this time. Furthermore, aside from some problem associated with throttle up, the probability of an abort being required in this 25 second period seems awfully remote making it very difficult to justify development of a unique set of abort procedures and training to use them. In effect, this proposal creates two rather than three abort zones. No abort maneuvers are required prior to DPS throttle up since the LM is still orbital. Procedures after throttle up are all the same. There is no discrete point in the descent required special techniques.

Formulation of the LUMINARY DPS abort program (P70) is completely compatible with this procedure. That is, for a DPS abort the crew would always delay taking abort action until 25 seconds after throttle up. A program change will be necessary to support this procedure in the APS abort program (P71) so that if the crew hits "Abort Stage," the APS will light off and separate, maintaining a retrograde attitude until 25 seconds after DPS throttle up time. Then it could go into the abort guidance as currently programmed. Specifically, the change is to have the spacecraft perform a continuous retrograde APS burn as opposed to a three second burn followed by an attitude change and reignition.

Mal Johnston of MIT was at our meeting and will discuss this with our friends in Boston. We'll talk about it some more next time after thinking it over a couple of weeks. I'd be interested in your comments.

Howard W. Tindall, Jr.

Howard W. Tindall, Jr.

PA:HWTindall, Jr.:js

AA/R. R. Gilruth
AB/G. S. Trimble
CA/D. K. Slayton
CB/A. B. Shepard
CB/ A. McDivitt
CB/N. Armstrong
CB/F. Borman
CB/M. Collins
CB/C. Conrad
CB/L. G. Cooper
CB/C. M. Duke
CB/R. F. Gordon
CB/J. Lovell
CB/R. L. Schweickart
CB/D. R. Scott
CB/T. P. Stafford
CB/E. E. Aldrin
CB/A. L. Bean
CB/H. H. Schmitt
CB/J. W. Young
CB/E. D. Mitchell
CB/E. A. Cernan
CB/J. A. Engle
CB/J. B. Irwin
CF/W. J. North
CF13/D. F. Grimm
CF212/C. Jacobsen
CF212/W. Haufler
CF212/R. P. Rudd
CF J. Bilodeau
CF22/C. C. Thomas
CF22/D. L. Bentley
CF22/R. L. Hahne
CF24/P. Kramer
CF24/M. C. Contella
CF24/D. W. Lewis
CF24/D. K. Mosel
CF3/C. H. Woodling
CF32/J. J. Van Bockel
CF32/M. F. Griffin
CF33/M. Brown
CF33/C. Nelson
CF34/E. B. Pippert
CF34/T. W. Holloway
CF34/J. V. Rivers
CF34/G. Colton
EA/M. A. Faget
EA2/J. B. Lee
EA4/J. Chamberlin
EA5/P. M. Deans
EB/P. Vavra
EE/L. Packham
EE/R. Sawyer
EE13/M. J. Kingsley
EE13/R. G. Irvin
E /R. L. Chicoine
E /G. B. Gibson
EE6/R. G. Fenner
EE6/J. R. McCown
EG/R. A. Gardiner
EG/D. C. Cheatham
EG2/M. Kayton
EG2/C. T. Hackler
EG23/K. J. Cox
EG23/E. E. Smith
EG25/T. V. Chambers
EG26/P. E. Ebersole
EG27/W. J. Klinar
EG27/H. E. Smith
EG41/J. Hanaway
EG42/B. Reina
EG43/J. M. Balfe
EG44/C. W. Frasier
EG/MIT/T. Lawton
KA/R. F. Thompson
PA/G. M. Low
PA/C. H. Bolender
PA/K. S. Kleinknecht
PA2/M. S. Henderson
PB/A. Hobokan
PC/W. H. Gray
PD/O. E. Maynard
PD/C. D. Perrine
PD12/J. G. Zarcaro
PD12/R. J. Ward
PD12/R. W. Kubicki
PD12/M. H. von Ehrenfried
PD4/A. Cohen
PD6/H. Byington
PD7/W. R. Morrison
PD8/J. Loftus
PE/D. T. Lockard
FA/C. C. Kraft, Jr.
FA/S. A. Sjoberg
FA/C. C. Critzos
FA/R. G. Rose
FC/E. F. Kranz
FC/M. P. Frank
FC/G. S. Lunney
FC/C. E. Charlesworth
FC2/J. W. Roach
FC2/H. M. Draughon
FC27/W. E. Platt (3)
FC3/A. D. Aldrich
FC35/B. N. Willoughby (4)
FC4/J. E. Hannigan
FC44/R. L. Carlton (3)
FC5/J. C. Bostick
FC5/P. C. Shaffer
FC54/J. S. Llewellyn
FC54/D. V. Massaro
FC54/C. F. Deitrich
FC54/J. E. I'Anson
FC55/E. L. Pavelka (5)
FC56/C. B. Parker (3)
FC6/H. G. Miller (4)
FL/J. B. Hammack
FS/L. C. Dunseith
FS5/J. C. Stokes
FS5/T. F. Gibson, Jr.
FS5/J. E. Williams
FS5/T. M. Conway
FS5/R. Allen
FS5/G. R. Sabionski
TH3/J. E. Dornbach
TH3/J. H. Sasser
FM/J. P. Mayer
FM/C. R. Huss
FM/D. H. Owen
FM13/R. P. Parten (9)
FM3/C. T. Hyle
FM4/P. T. Pixley (2)
FM4/R. T. Savely
FM4/W. R. Wollenhaupt
FM5/R. E. Ernull
FM5/H. D. Beck
FM6/R. R. Regelbrugge
FM6/K. A. Young
FM6/R. W. Becker (3)
FM6/R. S. Merriam
FM7/S. P. Mann
FM7/R. O. Nobles
FM7/R. H. Brown
FM2/C. A. Graves
FM2/J. C. Harpold
FM/Branch Chiefs

HA-58/R. L. Allen (Boeing)
HM-25/H. E. Dornak
HM-25/D. W. Hackbart
Bellcomm/Hqs./R. V. Sperry
Bellcomm/Hqs./G. Heffron
GAEC/Bethpage/M. Pollack
GAEC/Bethpage/J. Marino (3)
GAEC/Bethpage R. Mangulis
GAEC/Bethpage/D. Shields
GAEC/Bethpage/R. Pratt
MIT/IL/R. R. Ragan (15)
MIT/IL/E. Copps
MIT/IL/M. W. Johnston
NR/Downey/M. Vucelic (3)
NR/Downey/D. Zermuchlen
NR/Downey/B. C. Johnson, AB75
NR/Downey/W. H. Markarian, FB55
NR/Downey/E. Dimitruk, FB30
GSFC/550/F. O. Vonbun
GSFC/550/B. Kruger
KSC/CFK/R. D. McCafferty
KSC/CFK/P. Baker
NASA/Hqs./MAO/R. B. Sheridan
NASA/Hqs./MAOP/R. O. Aller (2)
TRW/Redondo Beach/R. Braslau
TRW/Houston/W. J. Klenk
TRW/Houston/R. J. Boudreau
TRW/Houston/M. Fox
TRW/Houston/K. L. Baker

info

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA FPMR (41 CFR) 101-11.6

UNITED STATES GOVERNMENT

Memorandum

TO : See list attached

DATE: October 25, 1968
68-PA-T-238A

FROM : PA/Chief, Apollo Data Priority Coordination

SUBJECT: Descent Aborts - Part II

This memo is to carry on from that three page snowflake I sent you the other day on the same subject. It turns out we have encountered one of those rare situations when in doing something to fix an undesireable situation we actually improve something else at the same time. Specifically, the rendezvous people want to target the LM to a substantially higher orbit following an early descent abort than they had previously proposed. This makes the horizontal posigrade burn following the descent abort larger, of course, and alleviates that crazy pitch profile problem which used to exist during an abort in the first 50 seconds of powered descent. The point is that by some fairly minor changes in the spacecraft computer program (LUMINARY), we can probably eliminate the special abort procedure we used to think was necessary early in descent. Changes to the DPS abort program (P70) are essentially just changes in some erasible constants. This does not impact coding but has a significant impact on testing. By that, I mean the program will work now. The APS program change noted in last week's memo is still required but is essentially achieved by a erasible constant change too. This will all be firmed up and brought to the Software Configuration Control Board in the near future for their approval or something.

Having the early abort situation under control, we pressed on to another phase of descent aborts requiring some attention - specifically, how to handle the situation when the DPS is not quite capable of getting the LM all the way back into the desired insertion orbit. In order to establish procedures, it was necessary to make some assumptions. They are:

1. We never want to "Abort Stage" and use the APS, if the DPS is still operational.

2. It is acceptable to operate the DPS to propellant depletion.*

3. We have no desire to use the APS engine again after achieving orbit (that is, during rendezvous). Of course, we intend to use the APS propellant through the RCS interconnect.

---

* This assumption must be verified by ASPO and then included in their data books.

4. The "Abort Monitor" in LUMINARY remains active following a DPS propellant depletion cutoff, which may result in a ΔV monitor alarm, even though the crew calls up the ΔV residuals.*

If we can make the above assumptions, the procedures become quite simple and standard. Namely, whenever aborting on DPS, the crew will permit that engine to operate at full thrust until either a guided cutoff is acheived or propellant depletion occurs. At that time, the crew will "proceed" to the DSKY display of ΔV residuals. If the ΔV remaining to be gained is less than 30 fps, the DPS will be manually staged and the crew will utilize the RCS to achieve the desired insertion condition by nulling the ΔV residuals. (It is probable that only the horizontal component need be trimmed if a convenient attitude reference is available. The FDAI eight ball should be good for this.) If the ΔV to be gained is in excess of 30 fps, the crew will hit "Abort Stage," automatically jettisoning the DPS and lighting off the APS to make up the ΔV deficiency. Again, only the horizontal ΔV residual need be trimmed.

It is to be noted that with the new, high apogee we will be targeting for, the RCS/APS switchover point is orbital by a substantial margin (apogee in excess of 75 miles) and so there is no problem in the use of an RCS burn whose duration is less than 30 seconds. It is also to be noted that if the ΔV required of the APS is less than 100 fps, the burn duration will be less than 10 seconds, which probably makes it unsafe to reignite the APS. There is so much mystery with what is and what is not acceptable with the APS we cannot really be sure about that. However, it does not matter since there is no problem anticipated in performing the rest of the maneuvers with RCS.

One final comment - it has been proposed that the DPS be operated at half thrust during aborts to prevent lofting when the APS is required to achieve orbit. Two miles perigee and four miles apogee are the maximum effects. Those do not significantly perturb the abort rendezvous and therefore the decision was to maintain full thrust.

---

* This assumption must be verified by me with MIT.

Howard W. Tindall, Jr.

Howard W. Tindall, Jr.

PA:HWTindall, Jr.:js

info

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA FPMR (41 CFR) 101-11.6

UNITED STATES GOVERNMENT

Memorandum

TO : See list attached

DATE: November 25, 1968
68-PA-T-257A

FROM : PA/Chief, Apollo Data Priority Coordination

SUBJECT: LM DPS low level light fixing

I think this will amuse you. It's something that came up the other day during a Descent Abort Mission Techniques meeting.

As you know, there is a light on the LM dashboard that comes on when there is about two minutes worth of propellant remaining in the DPS tanks with the engine operating at quarter thrust. This is to give the crew an indication of how much time they have left to perform the landing or to abort out of there. It compliments the propellent gauges. The present LM weight and descent trajectory is such that this light will always come on prior to touchdown. This signal, it turns out, is connected to the master alarm - how about that! In other words, just at the most critical time in the most critical operation of a perfectly nominal lunar landing mission, the master alarm with all its lights, bells, and whistles will go off. This sounds right lousy to me. In fact, Pete Conrad tells me he labeled it completely unacceptable four or five years ago, but he was probably just an Ensign at the time and apparently no one paid any attention. If this is not fixed, I predict the first words uttered by the first astronaut to land on the moon will be "Gee whiz, that master alarm certainly startled me."

As I understand it, cutting the wire to the master alarm eliminates the low level sensor light too. If nothing else can be done, this should be and we'll get along just using the propellent gauges without the light. If possible, a better fix would be to cut the wire on both sides of the master alarm and jumper the signal to the light only.

Incidentally, on the D mission the propellent levels will be low enough when we get to the DPS rendezvous maneuvers - Phasing and Insertion - that if this system is activated prior to ullage, the master alarm will likely go off. I guess it will be standard procedure to punch it off if that happens. But, where this is just an annoyance on D, it is dangerous on G.

Bill T

Howard W. Tindall, Jr.

PA:HWTindall, Jr.:js

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA FPMR (41 CFR) 101-11.6

UNITED STATES GOVERNMENT

Memorandum

info

TO : See list attached

DATE: November 25, 1968

68-PA-T-258A

FROM : PA/Chief, Apollo Data Priority Coordination

SUBJECT: Descent Aborts - Part III

We have had a couple more Descent Aborts Mission Techniques meetings resulting in substantial progress which I would like to tell you about in this memo, if you haven't already heard.

A basic ground rule we have established is that these abort procedures go into effect at the time powered descent initiation (PDI) is attempted (i.e., starting at the time of PDI TIG). The point is, if the descent burn is not attempted at all another procedure is used (TBD). But once descent is started and an abort is required, the crew will always go to P70 or P71, the DPS or APS abort programs.

As noted previously we have eliminated the special abort zone during the first 50 seconds of powered descent which used to require special procedures. A simple program change was made to LUMINARY to do this. In order to cause the system to work in an acceptable way, it is also necessary to increase the insertion apogee altitude in the PGNCS targeting. This is done by changing the value of an erasible memory constant in the LGC. (Insertion apogee altitude is now 100 n.m.; it was 60.) A preferable solution was considered for LUMINARY but must be delayed to LUMINARY II due to schedule impact. It is to have the PGNCS compute the optimum apogee insertion altitude in real time based on the phase angle between the LM and the CSM at the time of the abort. It is possible to do this such that the subsequent rendezvous sequence is almost identical to the nominal lunar landing mission rendezvous sequence - always providing a one rev rendezvous with a differential altitude of 15 n.m. This program change will likely be made in the AGS, too - perhaps even in time for the F mission since it is relatively simple. Assuming we are able to fix the PGNCS program for the lunar landing mission, it looks like we have a very good, straight forward, simple and standarized abort/rendezvous procedure.

One caution must be observed since the DPS abort program (P70) commands full throttle immediately. Therefore, if the crew decides to abort on the DPS immediately after PDI they must at least await engine stability before hitting the Abort button. I should also point out that aborts during the first 40 seconds of powered descent will currently result in a spacecraft pitch maneuver which will cause the MCC-H to lose all telemetry until the crew can realign the hi-gain antenna or switch to the omnis. A program change request for LUMINARY II has been submitted to fix this.

Another area in which we have been working is the procedure following a descent abort using the DPS engine immediately after the engine cutoff. Like any other maneuver, the standard procedure is for the crew to call up the ΔV residuals on the DSKY and check the horizontal ΔV still required. Then:

a. If the horizontal ΔV to be gained is less than 5 fps, which should be the usual case for aborts prior to about 300 seconds into powered descent, the crew will trim it with RCS without staging the DPS. Out-of-plane and radial ΔV components will be left untrimmed and their effects will be eliminated by the subsequent rendezvous maneuvers.

b. If the ΔV in the horizontal direction at the end of DPS burn is more than 5 fps but less than 30 fps, we want to stage the DPS off prior to burning into orbit with RCS since RCS plume impingement precludes dragging the DPS along. However, staging presents a problem since the PGNCS digital auto pilot (DAP) will not be aware it has happened. Since it would continue to assume the high inertia, unstaged spacecraft, it would command excessive RCS firing for altitude control. Like LM_1, it would really hose out the RCS fuel. The easiest way around this is to switch guidance control to "AGS" and attitude control to "AGS attitude hold" and then manually translate into orbit with RCS based on the PGNCS DSKY ΔV display. The procedure would be to manually stage immediately after initiation of the RCS trim burn. Again, there is no reason for trimming the out-of-plane and radial ΔV residuals.

c. If at DPS engine cutoff the ΔV residual in the horizontal direction exceeds 30 fps, the procedure is to simply hit "Abort Stage." This will automatically separate the DPS and utilize the APS to complete the maneuver required to achieve the desired orbit. The ΔV required depends on the abort time and can range from as little as 30 fps all the way to a full Ascent duration burn. The 30 fps boundary was chosen because attempts to use P71/APS for smaller maneuvers can result in very large ΔV errors, in fact as much as 60 fps. Again, only the horizontal in-plane component of ΔV need be trimmed after the main engine cutoff.

Of course, in case "a" noted above it will be necessary to separate from the DPS sometime. There was considerable discussion as to whether a special post-insertion maneuver should be made for this or if it was preferable to await the first of the scheduled rendezvous burns - CSI. We finally concluded that the most straight forward procedure was to separate the DPS at CSI in order to avoid the need for more complicated special procedures for this special situation. Separation at CSI rather than immediately at insertion also provides the peripheral advantage of an extra hour use of DPS consumables. But that is not our reason for recommending this procedure. Of course, it will be necessary for the crew to carry out certain DPS safing procedures. Specifically, they must vent the tanks just as they do after a nominal lunar landing. Onc open item in regard to this is the determination of how propulsive this venting is. If it turns out to be unacceptable we may be forced to provide some special procedure to stage the DPS at insertion. FCD has the action item of determining the magnitude of venting ΔV.

Howard W. Tindall, Jr.

Howard W. Tindall, Jr.

PA:HWTindall, Jr.:js

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA FPMR (41 CFR) 101-11.6
UNITED STATES GOVERNMENT

Memorandum

Mus

info
file

NASA Manned Spacecraft Center

TO : See list attached

DATE: July 1, 1969
69-PA-T-101A

FROM : PA/Chief, Apollo Data Priority Coordination

SUBJECT: Post-insertion alignment is lower priority than rendezvous navigation

It has been agreed that it is more important for the LM to obtain rendezvous navigation tracking data than to complete the platform realignment after insertion into orbit if problems occur which prolong it. The point is, an accurate CSI maneuver is vital but it is recognized that bad angle data does not substantially degrade that solution. Thus, even though the lunar surface platform alignment may not be red hot it should be adequate to support the rendezvous navigation; if the crew experiences difficulty in realigning, they should terminate that effort to insure they get an adequate amount of rendezvous radar data. Specifically, they should complete or terminate the P52 by 30 minutes before CSI. If they do fail to complete the alignment, they should add one into their timeline immediately after CSI and depend on the CSM for their plane change targeting.

I would like to emphasize that this is a contingency procedure since everyone anticipates that adequate time has been provided to do this alignment.

Howard W. Tindall, Jr.

PA:HWT:js

Addressees:

AA/R. R. Gilruth
AB/G. S. Trimble
A/D. K. Slayton
CB/A. B. Shepard (48)
CF/W. J. North
CF13/D. F. Grimm
CF212/C. Jacobsen
CF212/W. Haufler
CF212/W. Hinton
CF2/J. Bilodeau
CF22/C. C. Thomas
CF22/D. L. Bentley
CF22/R. L. Hahne
CF22/M. C. Gremillion
CF22/W. B. Leverich
CF22/T. H. Kiser
CF24/P. Kramer
CF24/J. Rippey
CF24/M. C. Contella
CF24/D. W. Lewis
CF24/D. K. Mosel
CF3/C. H. Woodling
CF32/J. J. Van Bockel
CF32/M. F. Griffin
CF33/M. Brown
CF33/C. Nelson
CF34/T. W. Holloway (6)
EA/M. A. Faget
EA2/R. A. Gardiner
EA4/J. Chamberlin
~~A8/J. B. Lee~~
EA8/P. M. Deans
EB/P. Vavra
EE/L. Packham
EE/R. Sawyer
EE13/M. J. Kingsley
EE13/R. G. Irvin
EE3/R. L. Chicoine
EE6/G. B. Gibson
EE6/R. G. Fenner
EE6/J. R. McCown
EP2/W. R. Hammock
EG/R. G. Chilton
EG/D. C. Cheatham
EG13/W. J. Klinar
EG2/C. T. Hackler
EG23/K. J. Cox
EG23/E. E. Smith
EG25/T. V. Chambers
EG27/W. R. Warrenburg (2)
EG27/H. E. Smith
EG41/J. Hanaway
EG42/B. Reina
EG43/A. R. Turley
EG44/C. W. Frasier
EG/MIT/T. Lawton
KA/R. F. Thompson
PA/G. M. Low
PA/C. H. Bolender
PA/K. S. Kleinknecht
PA2/M. S. Henderson
PB/A. Hobokan
PT/GAEC/K. Mountain

PC/W. H. Gray
PD/O. E. Maynard
PD/C. D. Perrine
PD/R. V. Battey
PD12/J. G. Zarcaro
PD12/R. J. Ward
PD12/R. W. Kubicki
PD12/J. Sevier
PD13/A. Cohen
PD6/H. Byington
PD7/W. R. Morrison
PE/D. T. Lockard
HA/J. P. Loftus
TJ/J. H. Sasser
TH3/J. E. Dornbach
CO7/J. Nowakowski
FA/C. C. Kraft, Jr.
FA/S. A. Sjoberg
FA/C. C. Critzos
FA/R. J. Rose
FA4/C. R. Hicks
FC/E. F. Kranz
FC/G. S. Lunney
FC/M. P. Frank
FC/C. E. Charlesworth
FC/M. Windler
FC/J. W. Roach
FC/G. D. Griffin
FC2/C. S. Harlan
FC2/H. M. Draughon
FC2/J. H. Temple
FC25/C. R. Lewis
FC27/W. E. Platt (3)
FC3/A. D. Aldrich
FC3/N. B. Hutchinson
FC35/B. N. Willoughby (3)
FC35/R. Fruend
FC4/J. E. Hannigan
FC44/R. L. Carlton (3)
FC5/J. C. Bostick
FC5/P. C. Shaffer
FC54/J. S. Llewellyn
FC54/C. F. Deiterich
FC54/J. E. I'Anson
FC55/E. L. Pavelka (6)
FC56/C. B. Parker (3)
FC6/C. B. Shelley (4)
FL/J. B. Hammack
FL2/R. L. Brown (2)
FL6/R. W. Blakley
FS/L. C. Dunseith
FS5/J. C. Stokes (10)
FM/J. P. Mayer
FM/C. R. Huss
FM/D. H. Owen
FM13/R. P. Parten (10)
FM2/C. A. Graves (3)
FM3/C. T. Hyle
FM4/E. R. Schiesser
FM4/P. T. Pixley (2)
FM4/R. T. Savely
FM4/W. R. Wollenhaupt

FM5/R. E. Ernull (5)
FM5/J. D. Yencharis (4)
FM5/H. D. Beck
FM5/R. D. Duncan
FM6/K. A. Young (6)
FM6/R. W. Becker (3)
FM7/D. A. Nelson
FM7/S. P. Mann
FM7/R. O. Nobles
FM/Branch Chiefs (7)

BOEING/Houston/R. B. McMurdo (2), HH-02
BOEING/Houston/D. Heuer, HM-08
BOEING/Houston/R. L. Allen, HA-58
BOEING/Houston/H. E. Dornak, HM-25
BOEING/Houston/D. W. Hackbart, HM-25
BELLCOMM/HQS./R. V. Sperry
BELLCOMM/HQS./MAS/A. Merritt
BELLCOMM/HQS./D. Corey
BELLCOMM/HQS./G. Heffron
GAEC/Bethpage/W. Obert-Thorn
GAEC/Bethpage/R. Schendwolf (3)
GAEC/Bethpage/R. Mangulis
GAEC/Bethpage/R. Pratt
GAEC/Bethpage/Consulting Pilot's Office
GAEC/Bethpage/B. O'Neal
GAEC/Houston/G. Kingsley
MIT/IL/R. R. Ragan (25)
MIT/IL/M. W. Johnston, IL 7-279
NR/Downey/M. Vucelic, FB84
NR/Downey/A. Sohler, AE23
NR/Downey/J. E. Roberts, AE23
NR/Downey/B. C. Johnson (4), AB46
NR/Downey/W. H. Markarin, AE23
NR/Downey/J. Jansz, BB48
NR/Downey/M. B. Chase, AB33
NR/Downey/D. W. Patterson, AC50
MITRE/Houston/W. P. Kincy
GSFC/500/F. O. Vonbun
NASA/HQS./MAO/R. B. Sheridan
NASA/HQS./MAOP/R. O. Aller (2)
NASA/HQS./XS/R. Sherrod
KSC/CFK/R. D. McCafferty
KSC/CFK/P. Baker
KSC/CFK/C. Floyd
KSC/CFK/M. Walters
KSC/CFK/MIT/R. Gilbert
TRW/Redondo Beach/R. Braslau
TRW/Houston/W. J. Klenk
TRW/Houston/B. J. Gordon
TRW/Houston/R. J. Boudreau
TRW/Houston/C. R. Skillern
TRW/Houston/M. Fox
TRW/Houston/K. L. Baker
TRW/Houston/W. Hill
IBM/Houston/G. Carlow, D70

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA FPMR (41 CFR) 101-11.6

Check

info file

UNITED STATES GOVERNMENT

Memorandum

NASA Manned Spacecraft Center

TO : See list attached

DATE: June 24, 1969

69-PA-T-95A

FROM : PA/Chief, Apollo Data Priority Coordination

SUBJECT: Post Insertion CSM P52 is optional

Dick Gordon and Pete Conrad called the other day to ask how important we feel the CSM platform alignment is just after LM insertion into orbit. As I recall, this alignment is a carry-over from the time we planned to do the CSM plane change just prior to lift-off rather than just after landing as we currently plan to do. We didn't have pulse torquing then either. Given these changes I don't really see why it is needed anymore, particularly if we have been monitoring the IMU for several days inflight and if necessary, have compensated it. As a matter of fact, if it is not too late it might be reasonable to consider dropping this CSM platform alignment from the G Flight Plan too. The main advantage is that it would permit CSM to remain in an attitude compatible with rendezvous radar tracking by the LM as soon as they finish with their P52. Any comments anyone?

Howard W. Tindall, Jr.

PA:HWT:js

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA GEN. REG. NO. 27 5010-107

UNITED STATES GOVERNMENT

Memorandum

EA5//P. M. Deans
info

TO : See list below DATE: MAY 10 1968

68-PA-T-100A

FROM : PA/Chief, Apollo Data Priority Coordination

SUBJECT: No special visual reference will be provided for the final tranearth midcourse correction maneuver

1. On May 7 we reviewed the need for an RTCC program change to provide a special visual reference for the crew during the last transearth midcourse correction maneuver on a lunar mission. We concluded it is not needed and that no new programming or displays are required.

2. The final transearth midcourse correction maneuver has the following characteristics. It is scheduled to occur two hours before entry. At that time, the spacecraft is located approximately on the earth-moon line about 20,000 miles from the earth. The maneuver is essentially horizontal with respect to the earth - perpendicular to the earth-moon line.

3. The primary subject under consideration was the use of the earth or the moon as a visual reference. This is partly a carry-over from using the horizon as a reference during the retrofire maneuver on earth orbital missions since they are similiar maneuvers in a way - both set-up the reentry trajectory. Unfortunately located as they are with respect to a horizontal burn, the earth and moon are both located in the worst possible places for use as a burn attitude reference. Accordingly, we concluded that our best course of action is to use standard burn attitude checks such as comparison with a properly aligned SCS and stars if they are visable.

4. It should be pointed out that large orientation errors have relatively little effect on this unique maneuver since components of delta V perpendicular to the one we are trying to achieve don't do anything. Thus, misalignment merely reduces the effective magnitude of the maneuver by the cosine of the misalignment angle.

Howard W. Tindall, Jr.

Howard W. Tindall, Jr.

Addressees:
(See list attached)

PA:HWTindall, Jr.:js

Addressees:
AA/R. R. Gilruth
AB/G. S. Trimble
CA/D. K. Slayton
CB/A. B. Shepard
J. A. McDivitt
N. Armstrong
F. Borman
M. Collins
C. Conrad
L. G. Cooper
C. Duke
R. Gordon
J. Lovell
R. L. Schweickart
D. R. Scott
T. P. Stafford
W. R. Pogue
W. M. Schirra
D. F. Eiselle
CF/W. J. North
CF13/D. F. Grimm
CF2/J. Bilodeau
CF212/C. Jacobsen
CF22/C. C. Thomas
CF24/P. Kramer
M. C. Contella
D. K. Mosel
D. W. Lewis
CF3/C. H. Woodling
CF32/J. J. Van Bockel
CF33/C. Nelson
M. Brown
CF34/T. Guillory
T. W. Holloway
EA/M. A. Faget
EA1/J. Chamberlin
EA2/J. B. Lee
EA5/P. M. Deans
EB/P. Vavra
EE/R. Sawyer
L. Packham
EE13/M. J. Kingsley
R. C. Irvin
EE3/E. L. Chicoine
EE6/G. B. Gibson
R. G. Fenner
EG/R. A. Gardiner
EG2/D. C. Cheatham
EG27/W. J. Klinar
H. E. Smith
EG41/J. Hanaway
EG42/B. Reina

EG43/J. M. Balfe
EG44/C. W. Frasier
KA/R. F. Thompson
PA/G. M. Low
C. H. Bolender
K. S. Kleinknecht
PA2/M. S. Henderson
PD/O. E. Maynard
PD12/J. G. Zarcaro
R. J. Ward
R. W. Kubicki
M. H. von Ehrenfried
PD4/A. Cohen
PD6/H. Byington
PD7/W. R. Morrison
PD8/J. Loftus
PE7/D. T. Lockard
FA/C. C. Kraft, Jr.
S. A. Sjoberg
C. C. Critzos
R. G. Rose
FC/J. D. Hodge
E. G. Kranz
D. H. Owen
D. B. Pendley
M. P. Frank
FC2/J. W. Roach
FC3/A. D. Aldrich
G. E. Coen
B. N. Willoughby
G. P. Walsh
FC4/J. B. Craven
R. L. Carlton
J. C. Elliott
FC5/G. S. Lunney
J. S. Llewellyn
J. C. Bostick
D. Massaro
C. B. Parker
C. E. Charlesworth
C. F. Deiterich
S. L. Davis
W. E. Fenner
G. E. Paules
W. S. Presley
H. D. Reed
P. C. Shaffer
J. H. Greene
K. W. Russell
S. G. Bales
FL/J. B. Hammack
FS/L. C. Dunseith

FS5/J. C. Stokes
T. F. Gibson, Jr.
G. R. Sabionski
J. E. Williams
T. M. Conway
TH3/J. E. Dornbach
J. H. Sasser
FM/J. P. Mayer
C. R. Huss
M. V. Jenkins
FM12/R. R. Ritz
FM13/R. P. Parten
J. R. Gurley
E. D. Murrah
A. Nathan
FM3/M. Collins
FM4/P. T. Pixley
R. T. Savely
FM5/R. E. Ernull
FM6/R. R. Regelbrugge
K. A. Young
FM7/S. P. Mann
R. O. Nobles
FM/Branch Chiefs

HE-03/H. E. Cormak
D. W. Hackbart
Bellcomm (Hqs.)/R. V. Sperry
G. Heffron
GAEC (Bethpage)/J. Marino
MAC (Houston)/W. Haufler
MIT/IL/R. R. Ragan
NR (Downey)/M. Vucelic
J. Zermuehlen
L. Dimitruk, FSSO
TRW (Houston)/R. Boudreau
M. Fox
C. Pittman
W. R. Lee, Jr.
T. V. Harvey
TRW (Redondo Beach)/B. [illegible]
GSFC/F. O. Vonbun, 550
B. Kruger, 550
KSC/R. D. McCafferty (CFK)
P. Baker (CFK)
NASA (Hqs.)/A. [illegible], MAO

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA FPMR (41 CFR) 101-11.6
UNITED STATES GOVERNMENT

EA5/P. M. Dean

info

Memorandum

TO : See list below

DATE: JUN 3 1968

68-PA-T-111A

FROM : PA/Chief, Apollo Data Priority Coordination

SUBJECT: Transearth midcourse correction philosophy - a major operational break through!

1. In trying to establish mission techniques for the midcourse correction maneuvers on the way back from the moon, we reached a point beyond which we could not progress without first establishing some sort of maneuver philosophy, like:

a. Should the MCC's be carried out on a fixed or real time selected schedule?

b. Which propulsion system should be used?

c. Are these things dependent upon propellent available?

d. In fact, what should we be trying to accomplish with the MCC's?

Accordingly, on May 17, Ron Berry, Aaron Cohen, Harry Byington, Jon Harpold, Stan Mann, Harold Granger, and I got together to see if we could find some logical way to handle these maneuvers. Since then I've talked to others who agree with what we came out with. Personally I think it's just great and I hope you do too. I assume you'll let me know if it makes you unhappy.

2. In summary there are only two things to be accomplished through the use of the transearth midcourse corrections (MCC). The first and most important is to guide the spacecraft into the entry corridor. The second is to help to control the location of the landing point on the earth's surface. We quickly concluded that the latter is unnecessary after the first MCC. If we want the recovery force in the center of the reentry footprint, move the ships there rather than making spacecraft maneuvers to adjust location of the footprint. So, that leaves corridor control as the only MCC objective. We feel that the best way to do this is to make as many as eight small RCS burns whenever their need becomes apparent. It is our estimate that they would occur no more often than every 10 or 12 hours, would be less than 1 fps each and would be made using the SCS control system. Thus, the total transearth MCC cost should not exceed about 8 fps (aside from alignment and altitude requirements) and we would never use the SPS or the G&N on the way back except in some low probability contingency situation. Therefore, this procedure would really provide a minimum delta V return and would be consistent with a non-G&N situation

which simplifies the decision logic and standardizes procedures. That is, we would use the same techniques regardless of the status of the propulsion systems, the G&N, and/or the amount of propellants remaining. How could anyone ask for anything more than that!

3. The rest of this memo just gives the rationale and some interesting comments for the record. If you're busy, you should stop here.

4. Landing Point Control

The first midcourse correction has always been scheduled at about five or six hours after the Transearth Injection (TEI) maneuver which is near the sphere-of-influence of the moon. This maneuver is primarily to correct whatever dispersions have occurred during TEI but will unquestionably be primarily for landing point control. This is due to the fact that the MSFN is able to determine the spacecraft trajectory characteristics pretty well along the line-of-sight, but is relatively weak perpendicular to the line-of-sight at that point in the mission. It is the line-of-sight components that have the greatest influence on the transient time, which in turn controls where the entry footprint is located on the earth. Therefore, it is anticipated that this maneuver should do a pretty good job of setting up the entry footprint where we want it over the recovery force. It is our opinion that after this time the task of maintaining the desired relative location of the entry footprint with respect to the recovery ships should be handled by moving the ships to wherever you want them in the footprint rather than maneuvering the spacecraft to move the footprint. A single exception to all this is the possible need for spacecraft maneuvers to insure that the non-G&N recovery area is free of bad weather. This will be discussed in more detail later.

5. Entry Corridor Control

As noted previously, we came to a very interesting and startling conclusion with regard to how we should control the trajectory to hit the entry corridor. But, in order to understand how you arrive at this conclusion it is important to first understand something of the character of corridor control midcourse maneuvers. Control of the flight path angle at the entry interface (i.e., corridor control) is achieved by almost exactly horizontal maneuvers with respect to the earth. Very small maneuvers in this direction have a very large effect. The following table illustrates this point:

Time of MCC	Delta V
EI - 2 hours	4 fps
EI - 15 hours	1.2 fps

Time of MCC (cont'd)	Delta V
EI - 20 hours	1.0 fps
EI - 25 hours	.8 fps
EI - 80 hours	Teensy weensy

(The delta V listed is that required to change the flight path angle at the entry interface (EI) 0.36°. This is a typical value for "corridor width," i.e., the maximum acceptable dispersion from the center.)

6. You will notice that dispersions (even 0.1 fps) at TEI and MCC1 will certainly make corridor control maneuvers necessary. But, you will also notice that even as late as 15 to 25 hours out from the earth an 0.8 fps error would only require a corrective MCC of 1.2 fps after a 10 hour propagation period, and further out it is much less. Therefore, intuition says that a sequence of maneuvers throughout the transearth coast should be capable of maintaining continuous corridor control at very little RCS cost - individually and collectively. Also, it is evident that misalignment during these maneuvers can only hurt to the extent the desired maneuver magnitude is reduced - a cosine effect. Very coarse orientation is good enough - even 30° error or more is acceptable. For example, suppose we want 1 fps and only get 3/4 fps. This should become apparent via MSFN tracking over the next 10 to 12 hours and can be corrected at a cost very little more than the 1/4 fps error just incurred. It doesn't hurt very much to do the wrong thing. Duration of the burn is not critical either for the same reason making it reasonable to control delta V by time (a clock) rather than with accelerometers. Therefore, there is no need to bring the G&N on line. SCS is good enough. Rather than scheduling two maneuvers (currently at two hours and 20 hours prior to entry) we tentatively propose that as many as eight RCS burns be planned, all of which should be less than one foot a second to be scheduled at intervals of about 12 hours apart throughout the transearth coast. Of course, any one would be omitted if its computed magnitude were so small that the "noise" in the targeting obscures it. The advantages to be gained by this technique are:

a. It continuously maintains a trajectory intercepting the center of the entry corridor which is advantageous from both a psychological and communication loss standpoint.

b. The procedure is the same as the one to be used in the case of G&N failure.

c. The G&N need not be brought on line which simplifies procedures and reduces consumable consumption.

d. The SPS engine need not be used simplifying the maneuver procedures and eliminating concern over whether or not it will restart and perform properly.

e. The real time logic is very simple.

f. It is anticipated to be a minimum delta V technique or close to it, which means that the procedures and logic will not depend on the propellent situation.

In addition to the analysis currently underway to learn more about this technique, it is necessary to investigate the RCS cost associated with SCS alignment, maneuver control, etc. It is anticipated that with a little study, techniques may be developed which couple this with other activities such as spacecraft thermal control, which will minimize total delta V requirements.

7. Something else came out of this discussion that hadn't occurred to me before dealing with the problem of bad weather avoidance in the recovery area. All systems design and analysis have been based on providing adequate L/D reentry maneuverability to assure good weather at the landing point area without the need for maneuvering on the way back. As I understand it, that is where the thousand mile long footprint came from. However, it is also necessary to make sure that good weather is available in the recovery area to which the spacecraft would go in the event of a G&N failure. You recall, the entry mode for this situation is to fly a constant range (1200 n.m.), constant "g" reentry. It is evident that the lifting reentry cannot help us here. Hence, it is not the prime area but rather it is this non-G&N area which must be protected for weather, if indeed either must be. Accordingly, it is proposed that one or two days prior to entry, based on the weather prediction for that area, it will be determined whether or not a midcourse correction maneuver should be made for that purpose. It certainly must be made if the weather is unacceptable and the G&N is busted; it probably should be made even if it is still working. If the maneuver were made 20 hours before entry, it should not exceed 170 fps. This is the amount required to move the entry footprint 300 miles, which is Recovery's estimate of weather disturbance radius including prediction uncertainties. Based on a trade-off of weather prediction uncertainties, which deminish with time, versus maneuver magnitude, which grows with time, it may be found cheaper to make the maneuver earlier than that. The number given is to give you a feel for the situation. If such an SPS burn were made, it would have to be followed by corridor correction maneuvers as described above, perhaps carried out at a greater frequency.

9. In summary, the first midcourse correction is likely to be an SPS burn compensating for whatever dispersions occurred in TEI. After that, all the rest of the midcourse corrections will be made solely for corridor control consisting of many very small RCS burns using the SCS. The "landing point footprint" would be accepted as is and the recovery force would be moved to compensate for its dispersions. The only exception would be to add a midcourse correction maneuver if necessary to provide good weather in the non-G&N recovery area if that is a requirement.

Howard W. Tindall, Jr.

Howard W. Tindall, Jr.

Addressees:
(See list attached)

PA:HWTindall, Jr.:js

Addressees:
A/R. R. Gilruth
AB/G. S. Trimble
CA/D. K. Slayton
CB/A. B. Shepard
J. A. McDivitt
N. Armstrong
F. Borman
M. Collins
C. Conrad
L. G. Cooper
C. Duke
R. Gordon
J. Lovell
R. L. Schweickart
D. R. Scott
T. P. Stafford
W. R. Pogue
W. M. Schirra
D. F. Eiselle
A. L. Bean
CF/W. J. North
CF13/D. F. Grimm
CF2/J. Bilodeau
CF212/C. Jacobsen
CF22/C. C. Thomas
CF24/P. Kramer
M. C. Contella
D. K. Mosel
D. W. Lewis
CF3/C. H. Woodling
CF32/J. J. Van Bockel
CF33/C. Nelson
M. Brown
CF34/T. Guillory
T. W. Holloway
EA/M. A. Faget
EA1/J. Chamberlin
EA2/J. B. Lee
EA5/P. M. Deans
EB/P. Vavra
EE/R. Sawyer
L. Packham
EE13/M. J. Kingsley
R. G. Irvin
EE3/E. L. Chicoine
EE6/G. B. Gibson
R. G. Fenner
EG/R. A. Gardiner
D. C. Cheatham
EG2/M. Kayton
C. T. Hackler
EG23/K. J. Cox
E. E. Smith
EG25/T. V. Chambers
EG26/P. E. Ebersole
EG27/W. J. Klinar
H. E. Smith
EG41/J. Hanaway
EG42/B. Reina
EG43/J. M. Balfe
EG44/C. W. Frasier
KA/R. F. Thompson
PA/G. M. Low
C. H. Bolender
K. S. Kleinknecht
PA2/M. S. Henderson
PD/O. Maynard
PD12/J. G. Zarcaro
R. J. Ward
R. W. Kubicki
M. H. von Ehrenfried
PD4/A. Cohen
PD6/H. Byington
PD7/W. R. Morrison
PD8/J. Loftus
PE/D. T. Lockard
FA/C. C. Kraft, Jr.
S. A. Sjoberg
C. C. Critzos
R. G. Rose
FC/E. G. Kranz
D. H. Owen
D. B. Pendley
M. P. Frank
FC2/J. W. Roach
FC3/A. D. Aldrich
G. E. Coen
B. N. Willoughby
G. P. Walsh
FC4/J. B. Craven
R. L. Carlton
J. C. Elliott
FC5/G. S. Lunney
J. S. Llewellyn
J. C. Bostick
C. B. Parker
D. Massaro
C. E. Charlesworth
C. F. Deiterich
S. L. Davis
W. E. Fenner
G. E. Paules
W. S. Presley
H. D. Reed
P. C. Shaffer
J. H. Greene
FC5/K. W. Russell
S. G. Bales
FL/J. B. Hammack
FS/L. C. Dunseith
FS5/J. C. Stokes
T. F. Gibson, Jr.
G. R. Sabionski
J. E. Williams
T. M. Conway
TH3/J. E. Dornbach
J. H. Sasser
FM/J. P. Mayer
C. R. Huss
FM12/R. R. Ritz
FM13/R. P. Parten
J. R. Gurley
E. D. Murrah
A. Nathan
FM3/M. Collins
FM4/P. T. Pixley
R. T. Savely
FM5/R. E. Ernull
FM6/R. R. Regelbrugge
K. A. Young
FM7/S. P. Mann
R. O. Nobles
FM/Branch Chiefs

HE-03/H. E. Dornak
D. W. Hackbart
Bellcomm (Hqs.)/R. V. Sperry
G. Heffron
GAEC (Bethpage)/J. Marino
MAC (Houston)/W. Haufler
MIT/IL/R. R. Ragan
NR (Downey)/M. Vucelic
D. Zermuchlen
E. Dimitruk, FB30
TRW (Houston)/R. Boudreau
M. Fox
B. J. Gordon
W. R. Lee, Jr.
T. V. Harvey
TRW (Redondo Beach)/R. Braslou
GSFC/F. O. Vonbun, 550
B. Kruger, 550
KSC/R. D. McCafferty (CFK)
P. Baker (CFK)
NASA (Hqs.)/A. Merritt, MAS

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA FPMR (41 CFR) 101-11.6
UNITED STATES GOVERNMENT

Memorandum

EA5/ P.M. Deans

TO : See list below

DATE: JUN 1 8 1968

68-PA-T-126A

FROM : PA/Chief, Apollo Data Priority Coordination

SUBJECT: Transearth midcourse maneuvers are getting easier and cheaper all the time

1. On June 6 we had a Transearth Midcourse Maneuver Mission Techniques meeting at which we discussed implementation of the philosophy as described in my June 3 memo. The technique proposed, you recall, involves making a number of small RCS burns using the SCS, solely for the purpose of corridor control. I have discussed this with quite a few people since then and everyone agrees that it is a good way to go. One thing apparently was not clear in that last memo. I would like to emphasize that most of the maneuvers need not be made at fixed times, but should be scheduled consistant with the other spacecraft/crew activity, namely the work/rest cycle, attitude control for meeting spacecraft thermal constraints, etc. That is, nothing is lost by making the midcourse maneuvers at the most convenient time based on other considerations - scheduled in real time if desired.

2. At this meeting we pinned down a few ground rules which I have listed below:

a. The first and last MCC's will be scheduled at fixed times.

(1) The first MCC will be a fixed time from TEI (currently about ten hours) and will be made only if location of the entry footprint is unacceptable to Recovery and/or obvious corridor control is needed. It probably won't be!! (See paragraph No. 3)

(2) The last MCC is at a fixed time, specifically, two hours before entry interface and will be made if it exceeds 1 fps. This is also a corridor control maneuver only and most likely will be required. G&N will be aligned in preparation for entry.

b. All other MCC maneuvers shall be made for corridor control only as their need becomes apparent consistant with other spacecraft/crew activity.

c. If the G&N is in operation anyway, use it. However, if it is not, use SCS, timed burns with two jet RCS. An exception is that any SPS maneuver will be G&N controlled. Also, SPS will have ΔV residual trimming. Any G&N burn shall use the CMC External ΔV guidance mode.

d. As a standard procedure for maintaining the best possible state vector in the CMC through the MCC's performed with no IMU, the Mission Control Center will send a postburn state vector to the spacecraft. The preburn state vector will be stored in CMC memory locations used for the LM state vector.

3. Regarding paragraph 2.a.(1), it is anticipated that Recovery requirements can be made quite loose. For example, TEI dispersions may move the footprint from its targeted location as much as 5° or 10° (300 - 600 n.m.). However, this is well within the ship's capability to move during the transearth coast. Therefore, if land impact (of CM or SM), bad weather, or excessive return-to-base time do not result, a CSM maneuver will probably not be required. It apparently has not been recognized generally that by taking advantage of Recovery's flexibility, we should be able to eliminate an SPS burn from a nominal transearth phase. In other words, ordinarily all MCC's will be for corridor control only. Interesting, don't you think?

4. Some other things affected by the new approach are:

a. The prime mode for "return-to-earth" targeting in the RTCC was for landing point control. The new way is really the "minimum ΔV" approach which had previously been treated as a low probability contingency mode. As a result it was not automated but required flight controllers to manually iterate for the burns. Since this is now the prime mode and will be exercised frequently during each flight, the formulation is being reworked to eliminate the manual operations and make it truly optimum. This change will have to be negotiated with Flight Software people and IBM, I suppose.

b. The analysis which has been conducted for purposes of establishing ΔV budgets and probability of maneuvers shall have to be done differently for the same reason. It should result in a reduced ΔV for both SPS and RCS.

5. I have attached to this memo an agenda for the June 20 meeting which also serves to define some action items which were assigned. I hope and expect we can ice this whole business down within the next several weeks.

Howard W. Tindall

Howard W. Tindall, Jr.

Enclosure

Addressees:
(See list attached)

PA:HWTindall, Jr.:js

LUNAR ENTRY AND TRANSEARTH MIDCOURSE CORRECTION (MCC)

MISSION TECHNIQUES MEETING

June 20 9:00 a.m. Room 3068, Building 30

AGENDA

1. Establish MCC threshold valves governing whether to make the maneuver now or to wait.

   (a) MPB to present MSFN uncertainties as a function of time.

   (b) GPB to present maneuver dispersions.

   (c) MPD to define computational uncertainties particularly associated with small RCS/SCS maneuvers.

   (d) GPB to present RCS ΔV costs for activity associated with small RCS/SCS maneuvers.

2. Establish preferred time to make a non-G&N reentry landing point control maneuver for weather avoidance if it is necessary.

   (a) LRD to present weather prediction uncertainty as a function of time.

   (b) MAB to present ΔV cost to make these maneuvers as a function of time.

3. FDB is to establish SCS alignment technique consistant with small transearth MCC requirements (i.e., crude is good enough if it saves anything).

4. MAB to present estimate of RCS ΔV cost using the multi SCS transearth MCC philosophy currently planned, assuming corridor control only.

5. Establish logic defining need for an MCC (soon after TEI) to control location of the landing footprint.

   (a) LRD to define acceptable displacement of the footprint from nominal.

   (b) MPB to present anticipated TEI uncertainties due to MSFN accuracy which influence location of the footprint.

   (c) MPB to define ΔV required at MCC1 to move the footprint.

6. Establish preferred time for the first MCC based on MSFN tracking requirements, Colossus limitations, crew work/rest timeline, etc.

7. Review Mission Techniques Flow diagrams & rationale.

MAY 1962 EDITION
GSA FPMR (41 CFR) 101-11.6
UNITED STATES GOVERNMENT

Memorandum

NASA Manned Spacecraft Center

info

TO : See list attached

DATE: July 17, 1969

69-PA-T-112A

FROM : PA/Chief, Apollo Data Priority Coordination

SUBJECT: Gyro calibration and accelerometer bias update and redline values

Chuck Wasson wrote a memo, dated June 27, 1969, to Gene Kranz and me defining in detail the Guidance and Control Division's (G&CD's) position on "in-flight gyro calibration and accelerometer bias update and redline values." In it he pointed out that both the Mission Rules and the Mission Techniques Documents should be brought into agreement with his recommendations. Actually this subject has been discussed endlessly in the Mission Techniques meetings and elsewhere and so there were no surprises in the values and techniques proposed. However, his memo does again draw our attention to the minor differences in official documentation and reminds us that that is a sloppy way to do business. I talked it over with Cliff Charlesworth (FCD) and Mal Johnston (MIT) and we all concurred that the numbers Chuck Wasson proposes are as good as any and we have taken steps to comply with his recommendation. Namely, future issues of Mission Rules and Mission Techniques Documents will conform with the G&CD's recommendations as listed in the referenced memo.

Howard W. Tindall, Jr.

PA:HWT:js

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA FPMR (41 CFR) 101-11.6

UNITED STATES GOVERNMENT

Memorandum

NASA Manned Spacecraft Center

TO : See list attached

DATE: May 1, 1969

69-PA-T-67A

FROM : PA/Chief, Apollo Data Priority Coordination

SUBJECT: Descent Aborts and subsequent Rendezvous Mission Techniques

On April 28, 1969 we reviewed the Descent Aborts and subsequent Rendezvous Mission Techniques with the crew and the rest of the world. I think most of this is quite complete and agreeable to everyone concerned, with one major exception. I was shocked and ashamed to find that I had badly misunderstood the situation regarding the CSM rescue techniques and, although there were plenty of ideas, the detailed techniques were not at all firm at that time. Subsequently, (April 30) a much smaller group of us beat that into the ground too. Therefore, this memo is to document my understanding of the agreements we reached at both of these sessions. I'm sorry it's so long - just a big subject, I guess.

1. Abort after separation if there is to be no DOI

During our meeting we inadvertently got into a lengthy discussion on conditions governing whether or not DOI should be attempted on the first or second opportunity. That, of course, is important but was not our real purpose at this meeting. We did finally conclude that in the event no attempt is made at DOI, the LM should use the brute force, immediate return technique for getting back to the CSM. The point is the separation velocity setting up the equal period mini-ball orbit is so small that automatic closure is by no means certain. Accordingly, when it is decided to abort, the crew should take positive action to establish a fairly substantial closing rate. The present recommendation is that they should set up a closing rate which in feet per second is equal to eight times the current range expressed in nautical miles. This is the same procedure that should be used for fouled up DOI maneuvers. It is useable until about ten minutes after DOI.

Some of the crew present expressed a concern that the factor "eight" seems excessive under certain circumstances and requested that somebody make sure it is really the best value. I guess this is your job, Mr. Lineberry, if you can find time between now and July to handle it. I think we should all realize, however, that simplicity in procedures may prohibit using the value that is optimum under all circumstances.

2. Abort if no attempt is to be made to initiate powered descent

At one time it was considered impractical to go an extra rev and attempt PDI two hours late, primarily due to fear of an unacceptable rendezvous/abort situation. This has proven to be unfounded. The same rendezvous abort procedures work after an extra rev, although there is an extra cost of about 70 fps for insertion from descent aborts. The extra insertion velocity does make APS propellant depletion more likely for late aborts, but the RCS can be used to make up the difference. Time required to complete a CSM rescue can be increased up to 12 hours and at a cost of 800 fps. This is used to put the CSM in a dwell orbit. But, this is only necessary if the LM experiences many failures and does not seem sufficient justification to scrub the landing attempt. Eight LGC descent abort coefficients for P70/P71 and one for the AGS must be updated in real time. (Incidentally, the current plan is to update these in real time on the nominal mission to account for dispersions in the CSM orbit.) A platform alignment should be performed by the LM prior to the second PDI attempt. The major open item is for the Flight Dynamics people to establish what Pad and command messages must be sent to the spacecraft and when. (There is also some question of accuracy of the revised descent targeting.) The primary concern deals with time available to do this. Incidentally, these same techniques <u>may</u> also be useable for a DOI maneuver delayed one rev.

3. PDI Abort

A PDI abort is only used if it is known that PDI will not be attempted or possibly, if the DPS engine does not ignite. Considerable thought was given to using an onboard capability for targeting this maneuver. Specifically, the technique was for the crew to initiate the powered descent programs following the nominal timeline through engine ignition and then hitting either the Abort or Abort Stage button to utilize the DPS or APS Descent Abort programs which automatically target the abort maneuver. It was finally concluded, however, that this technique by itself was not really adequate because spacecraft systems problems could occur at PDI time which would make it highly desirable not to have to commit instantaneously either to aborting, nor to going around another rev. That is, it seemed almost mandatory to provide an abort opportunity a short time after PDI to provide a little time to think over the situation and decide what to do - go around and try PDI again, or to abort now. Since the delayed abort opportunity was considered a requirement for this purpose, the question boiled down to whether the crew and everyone else should learn and be prepared to use the instantaneous PDI abort technique <u>as well</u>. Since there are some problems not yet worked out with it and <u>special</u> procedures are required, we concluded that it was best to drop use of the onboard technique and to provide a ground targeted abort opportunity at PDI plus 10 minutes. This abort would utilize the standard pre-thrust and thrust programs (that is, P30 and P40 or P42) and PDI Abort Pad message voiced to the crew before DOI. Since this maneuver assumes nominal conditions coming into PDI, the targeting for this burn is essentially known today. Accordingly, Ed Lineberry is to supply the ΔVg values to FCSD to be included in the crew's checklist. Simulations and experience may eventually prove that the Pad message need not be sent.

Incidentally, if DPS ignition does not occur at PDI there is no need for the crew to remove ullage since it is so small.

4. Aborts from Powered Descent

It has been established that a trim maneuver (we've been calling it the "tweak") is necessary after LM insertion into orbit in order to compensate for known errors in the LGC abort target coefficients and measured dispersions in the insertion conditions. Tweak targeting will be carried out by the MCC (not onboard) based on the best available data source for cutoff state vector - ordinarily the LM PGNCS - and will be relayed to the crew within $1\frac{1}{2}$ minutes after main engine cutoff. The tweak burn is nominally horizontal but spacecraft attitude can be substantially in error with negligible results.

I think everyone agreed to the necessity of the tweak burn but there was considerable discussion on how the post-insertion situation should be handled. We finally recognized that the thing that most confused the issue was the DPS. For example, plume impingement precludes making large burns while docked, making jettison procedures necessary under certain ΔV circumstances. Systems problems might make it mandatory that the DPS not be jettisoned, meaning that procedures were needed for both cases - staged and unstaged and so forth. There appeared to be minimal problems associated with the situation if the LM had to stage the DPS in order to achieve orbit. This led us to the final resolution, namely:

a. If the LM achieves orbit using the DPS and the V_{go} is less than 30 fps, the CSM will make the tweak maneuver at DPS cutoff plus 12 minutes. This maneuver will be under GNCS control using the SPS or RCS, whichever is called for. In this case, the LM can carry the DPS as far as docking with the CSM if that is considered desirable or it may be jettisoned at any convenient time, provided the act of jettison is carried out without any perturbation to the trajectory. If the DPS is carried along, it may be used for some of the rendezvous maneuvers.

b. If the LM insertion into orbit is on the APS, the LM makes the tweak burn as soon as possible, probably within two minutes after engine cutoff using the RCS and the "average G" program (P47).

c. The significance of "V_{go} less than 30 fps" mentioned above is that if the DPS cutoff occurs with more than 30 fps left to be gained, the crew is supposed to Abort Stage and finish the maneuver on the APS. This is a rule we have agreed to for a long time.

d. The LM does not trim any ΔV residuals after main engine cutoff for any descent abort unless the MCC fails to advise the crew within 30 seconds after cutoff that the MCC targeting will be available. The point here is that if the MCC has lost communication, which includes even the high-bit rate telemetry needed for targeting, the course of action is for the crew to trim the residuals as soon as possible. On the other hand, it is advantageous to wait if they are going to make the MCC targeted tweak burn. They should know within 30 seconds after cutoff which of these situations exist.

e. The voice message from MCC consists of only two parameters - TIG and ΔV_x.

f. Just as in a nominal mission, the MCC will always update the LM state vector in the CMC based on LM telemetry data regardless of which vehicle makes the tweak burn. However, if the CSM is the active vehicle, the LM crew must update the CSM state vector in the LGC using the target ΔV program, P76.

5. Late Aborts from Powered Descent

Aborts during the first 10 minutes of powered descent utilize variable insertion velocity targeting in the LM guidance computers - both PGNCS and AGS. The subsequent rendezvous sequence is essentially the same as a nominal rendezvous. As a result, standard CSM mirror image targeting can be used to backup the LM and no special procedures are required aside from the tweak burn noted above. However, after approximately ten minutes into powered descent the variable insertion targeting would result in an apogee less than 30 n.mi., which we consider too low. Therefore, aborts after that time are targeted for a standard low orbit - 9 by 30 n.mi. and the rendezvous situation begins to degrade. That is either the terminal phase lighting conditions or the coelliptic differential altitude becomes undesirable. It is recognized that for aborts occurring during an additional 40 seconds into descent the standard rendezvous sequence can be continued since we consider the resultant increase in differential altitude up to 20 n.mi. acceptable. After that point, something else must be done. The something else is as follows - in order to maintain nominal lighting and ΔH, an extra rev is required. Two extra maneuvers are required in the subsequent rendezvous sequence costing a total extra ΔV of as much as 80 fps. (This extra ΔV cost diminishes to zero as the abort is delayed.) The first extra maneuver, called "Phasing," occurs about 50 minutes* after insertion and is targeted by MCC to establish the nominal ΔH and TPI time. The Phasing maneuver is horizontal; its ΔV is a function of abort time. It will be transmitted by voice using the standard External ΔV Pad format. CSI_1 is the other extra maneuver and occurs 180° after Phasing. It is targeted onboard using an MCC supplied TIG. Following these two extra maneuvers, the spacecraft goes through the standard CSI/CDH/TPI sequence. All of these maneuvers are, of course, computed onboard.

The CSM performs standard mirror image targeting as usual with one exception. Since the Phasing burn could be excessively retrograde, the CSM backup of Phasing must be limited to about 50 fps. If this occurs and the CSM must execute it, the crew must use some special P32 procedures for CSI_1 to compensate for the inadequate Phasing adjustments. (The complete procedures are being documented thoroughly by MPAD and FCSD.

That's long and maybe confusing. In summary, let me point out the key things. Our problem - the one that took a day to resolve - was to figure out some way to work with both spacecraft so that:

a. The rendezvous situation would be completely acceptable - particularly the lighting and adequate tracking time and

b. That at any point, either spacecraft could take over the active role as the situation dictates and

c. That the technique be relatively simple - especially not loaded with special procedures that differ from nominal.

The solution satisfies these things very well much to the credit of Jerry Bell, Ed Lineberry, H. David Reed, Milt Contella, and probably some others.

The tasks to clean this up are:

a. OMAB - Pin down the precise timeline, ΔV's and TIGs, lighting, ranges, rates and angles - that is the reference trajectory for a few key descent aborts.

b. MPB - Establish the rendezvous navigation tracking schedule and all that goes with it.

---

* Phasing shall actually occur at a fixed GET corresponding to the CSI time for an abort occurring at 10 minutes into powered descent. This GET time will be on a pre-DOI Pad.

c. FCSD - Prepare the detailed crew procedures - particularly CSM - and identify which specific parts should be given highest simulation priority if the crew can give any attention to them preflight.

d. OMAB - Compute the rendezvous maneuver biases which must be applied to one spacecraft solution for use by the other for the various abort modes.

6. Aborts After Touchdown

Current planning includes two "preferred" times for aborts after touchdown. "Preferred" is misleading in that for the first stay/no-stay period, it is preferable to Abort Stage as soon as its need is recognized and then to carry out the rendezvous sequence precisely as described above in Section 5.

Since it is considered undesirable to remain in the insertion orbit through perigee, it was decided to establish a minimum Phasing burn of 10 fps which will always be executed by the LM to raise perigee. This, of course, changes the stay/no-stay decision time about 30 seconds earlier and the second preferred abort time one minute earlier since it reduces the catch-up rate in the parking orbit.

7. Here are some odds and ends of interest to me:

a. All rendezvous navigation, both nominal and following aborts in both spacecraft, will be operated to update the LM state vector regardless of which vehicle is active. This is done because the CSM state vector is known better inertially than the LM.

b. It is important to recognize that after a descent abort there is a very good chance the LM will have a substantial DPS and/or APS capability remaining - particularly the latter. Some of these rendezvous maneuvers can be very large - up to 120 fps. The MCC must be prepared to assess and assist the crew in choosing which engine should be used to avoid all the many constraints the LM has regarding plume impingement and APS restarts. Also, regarding PGNCS minimum burn accuracy and how to use the interconnect, etc.

8. That's it!

Howard W. Tindall, Jr.

Howard W. Tindall, Jr.

PA:HWTindall, Jr.:js

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA FPMR (41 CFR) 101-11.6
UNITED STATES GOVERNMENT

Memorandum

NASA Manned Spacecraft Center

TO : See list attached

DATE: May 5, 1969
69-PA-T-70A

FROM : PA/Chief, Apollo Data Priority Coordination

SUBJECT: Descent Monitoring Mission Techniques - a status report

I think we are beginning to see the light at the end of the Descent Monitoring Mission Techniques tunnel. At the April 24 meeting on that subject we thoroughly discussed the integration of the onboard techniques with the activity at the MCC during powered descent and I feel the resultant is as reasonable and complete as possible, consistent with practical operational constraints.

One thing we have finally been able to get under control was this squirmy idea that there is some way for the crew to compare the output of the AGS and PGNCS onboard the spacecraft with the objective of making abort and/or switchover decisions. Obviously there is no question that a massive system failure will be obvious to them and their course of action will be clear. Obvious too, is the fact that the crew will be monitoring both of these systems as well as many other data sources throughout powered descent. But, now known to everyone, is the fact that there is no way for the crew to compare AGS and PGNCS such that they are able to detect which system is malfunctioning, if that malfunction is of a slow drift degradation type, at least not with the assurance necessary to take any action. Therefore, just as in the case of ascent, not only is the MCC prime for carrying out the task of slow drift malfunction monitoring, but we now recognize that MCC is the <u>only</u> place this can be done. That, my friends, is a fantastic event - the death of a myth we have been haunted by for two years. Don't get the idea I'm happy with the situation. What I am pleased about is that everyone now agrees it <u>is</u> the situation.

There is another thing about powered descent crew procedures that has really bugged me. Maybe I'm an "Aunt Emma" - certainly some smart people laugh at this concern, but I just feel that the crew should not be diddling with the DSKY during powered descent unless it is absolutely essential. They'll never hit the wrong button, of course, but if they do, the results can be rather lousy. Therefore, I have been carrying on a campaign aimed at finding some way to avoid the necessity of the crew keying up the on-call displays. This campaign has not been altogether successful. I guess partly because not everyone shares my concern.

Although, I started out by saying the end is in sight, we still have quite a batch of unresolved issues which I would like to list here so that everyone can continue to think about them.

a. There is still a wide open question concerning what is considered our real time minimum landing radar data requirement in order that descent can be continued. There are many of us who feel that failure to obtain a certain amount of good landing radar data by some point in the powered descent is sufficient justification to abort - for example, landing radar altitude updating by 13,000 feet has been suggested as a requirement. The crew apparently feels that this constraint is not real and that their observations - visual, I suppose - are an adequate substitute. Just how we are able to integrate in these real time crew observations to overcome the landing radar deficiency has not been established yet and I am not sure who, if anyone, is working on it.

b. Although, a month or so ago, the decision was made that the crew is to manually backup the automatic switching of the landing radar antenna position during a nominal descent, there is still substantial concern that this is not the right thing to do. For example, the LM systems people point out that the switch the crew uses to do this must be cycled from "auto" through the old landing radar position to get to the new landing radar position and a switch failure could override a perfectly operating automatic signal and send the antenna scurrying back to the position it just came from.

c. I am still not content with the AGS altitude update techniques. That is, how many times and when during powered descent should this be done?

d. There is some point in powered descent after which it should be possible to continue the landing with an inoperative gimbal drive actuator. Procedures for handling this situation in real time remain to be established.

Howard W. Tindall, Jr.

Howard W. Tindall, Jr.

PA:HWTindall, Jr.:js

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA FPMR (41 CFR) 101-11.6
UNITED STATES GOVERNMENT

Memorandum

NASA Manned Spacecraft Center

TO : See list attached

DATE: April 15, 1969

69-PA-T-61A

FROM : PA/Chief, Apollo Data Priority Coordination

SUBJECT: Let's drop one of the lunar surface RR tests

During our review of the G Mission Lunar Surface Mission Techniques Document on April 10, we came to a conclusion which may interest you. It deals with the need, or really lack of need, for the crew to do some things that are in the current flight plan. Specifically, in the crew LM timeline, we have included two periods of LM rendezvous radar tracking of the command module - the first is two hours after landing and the second is two hours before lift-off. Neither of these periods are really needed although it may be interesting to try it once. On the other hand, it does require crew activity, uses electrical power, wears out the radar, and so forth and may even place a constraint on command module attitude during his sextant tracking of the LM. It was our conclusion that at least one of these periods of tracking should be eliminated and we are recommending that it be the first. The reason for deleting the first is that it interferes with the crew countdown demonstration (CDDT) for ascent, which is synchronized with the first CSM passage over the LM. If the crew were to perform rendezvous radar tracking, the CDDT would have to be terminated about 15 minutes before "lift-off." By eliminating the rendezvous radar test, the CDDT can and should be run until about TIG minus one minute.

Although we are not proposing to delete it yet, it should be noted that the CDDT itself is of marginal importance and if it interferes with other more important activity, it could also be eliminated. It is not a precise countdown, anyway, since obviously the crew must not fire pyros, bring the APS batteries on line, pressurize tanks, and so forth, unless they really intend to lift-off. This CDDT should certainly be eliminated from lunar landing missions after the first.

As noted in a previous memo, the command module sextant tracking of the LM is not mandatory either, although the flight controllers will use the data if they get it to reinforce confidence in their other data sources. And, of course, the post-flight people will undoubtedly find it interesting. Here again, though, it may be worthwhile to consider omitting one of the two sextant tracking periods. We are not proposing this yet either.

Howard W. Tindall, Jr.

PA:HWTindall, Jr.:js

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA FPMR (41 CFR) 101-11.6

UNITED STATES GOVERNMENT

Memorandum

TO : See list attached

DATE: November 4, 1968

68-PA-T-241A

FROM : PA/Chief, Apollo Data Priority Coordination

SUBJECT: When is the rendezvous radar designate routine (R29) needed?

George Cherry (MIT) asked if it is possible to drop the rendezvous radar designate routine (R29) out of the descent abort programs (P70 and P71). He gave me the impression that to do so now would significantly reduce their work and permit concentration in testing in more profitable areas. I don't know when the next Software Board meeting is - soon I hope. Perhaps this would be a suitable subject to bring up at that time.

Howard W. Tindall, Jr.

PA:HWTindall, Jr.:js

EA/M. A. Faget

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA GEN. REG. NO. 27
5010-107

UNITED STATES GOVERNMENT

Memorandum

TO : See list below

DATE: MAR 18 1968
68-PA-T-63A

FROM : PA/Chief, Apollo Data Priority Coordination

SUBJECT: Lunar rendezvous abort summary

1. A great deal of work has gone on over the years on the subject of lunar abort rendezvous, spearheaded by Morris Jenkins, Ed Lineberry, Buzz Aldrin and others. The results of some of this work have already been documented and more detailed reports are in the works. The primary reason I'm writing this note is to give you a layman's summary of the situation as I understand it. Basically, it is not as complicated a subject as you may have been led to believe. Also, I want to make you aware that current planning involves substantial use of the command module, more than you may have thought, since that's a rather important thing. And, finally, I'd like to point out several places where inflight abort preparations influence the nominal operations.

2. First of all, I'd like to emphasize one simple, very significant feature of these operations. All lunar rendezvous---nominal, contingency, abort---are essentially the same operation. The only two things that influence how it will be performed are:

(a) The phasing situation at the start; that is, which vehicle is ahead of the other and how far, and

(b) which spacecraft is to do the various maneuvers.

Perhaps they are so obvious and simple that they're not worth pointing out but it turns out everything we do is based on them. It is to be emphasized that current plans do not include exotic, special maneuver sequences, spacecraft or ground computer programs, operational techniques, etc. In fact, all lunar rendezvous----from (a) Hohmann descent following DOI, (b) powered descent and hover, (c) lunar surface, both nominal and abort, and (d) CSM rescue---are carried out using the standard four maneuver, rendezvous sequence---CSI/CDH/TPI/TPF. (For those who don't recall what that means, see footnote.) The variables to bring about rendezvous are the timing and magnitude of those four maneuvers, constrained to occur within a limited

---

1 Coelliptic Sequence Initiation (CSI) is a maneuver which establishes the proper phasing and differential altitude conditions at the Constant Differential Altitude (CDH) maneuver point where the orbits are made coelliptic. Terminal Phase Initiation (TPI) establishes an intercepting trajectory of one spacecraft with the other, and the Terminal Phase Final (TPF) braking maneuver stops them from impacting each other.

number of revolutions (primarily due to LM systems constraints) and differential altitude constrained to be between 10 and 25 miles. Unfortunately, the final approach often ends up being above instead of below as we would prefer. This sequence is sometimes preceded by a CSM Hohmann transfer to a low orbit but only if the CSM is behind the LM at the time of abort and must assist in the rendezvous. Accordingly, standard maneuver logic is all that is needed in the RTCC/MCC and spacecraft computer programs.

3. Let's first discuss the situation after the LM has executed the Descent Orbit Insertion (DOI) maneuver and an abort is required. (Nominally the CSM is in a 60 nm circular orbit and the LM is in an 8.5/60 nm orbit.)

(a) During this mission phase and even to a point 30 minutes past nominal powered descent initiation (PDI), the LM can perform the rendezvous without CSM assistance within $2\frac{1}{2}$ revolutions. Since the LM quickly moves ahead of the CSM during this mission phase, it must transfer to a higher orbit than the CSM to get back. Accordingly, a LM active rendezvous will always be from above the CSM. Since the TPI times are solely dependent upon the CSM orbit to give optimum lighting conditions, it is possible and should be a standard procedure prior to DOI to relay to the LM crew these values for a 1 and 2 revolution rendezvous so that they are readily available for onboard targeting of the maneuver sequence, if needed. CSI is the LM's abort maneuver and it will always be posigrade and horizontal to raise the LM's orbit above the CSM's.

(b) If the LM is passive, the CSM must catch up by dropping to a lower orbit than the LM. Ed Lineberry's people have chosen a 20 nm circular orbit into which the CSM drops by making 2 canned Hohmann transfer burns of about 60 fps each. The first is executed one-half revolution after DOI and the second one-half revolution after that. (Incidentally, the rendezvous people are convinced that this CSM orbit and maneuver execution time is as good or better than any other, regardless of the time an abort situation is recognized in this mission phase.) The CSM then carries out the standard CSI/CDH/TPI rendezvous sequence finally arriving about $9\frac{1}{4}$ hours after DOI. One somewhat significant feature about all CSM active LM rescues is that since the LM has a perigee of only 8 or 10 miles, it is impossible to perform a coelliptic rendezvous from below. We can't fly the CSM lower than that in a coelliptic orbit. So all CSM active rendezvous are from above. In this particular abort case, it is necessary for the CSM to stay in the 20 nm catchup orbit long enough to actually pass the LM and set up proper phasing for a final approach from above. Accordingly, whenever possible the LM should at least do the braking---not only to save CSM RCS fuel but because of its more favorable approach conditions visually.

(c) If the LM's Descent Propulsion System (DPS) doesn't work when the abort is initiated, or abort is due to DPS failure to start at PDI, it is our proposal to make the CSM active as outlined in (b) in order to avoid staging the DPS with all its nice consumables. This would keep the whole process non-time critical. Of course, the LM should stage and become active at TPI or braking once everything is under control and rendezvous is assured.

Total CSM delta V required to do this does not exceed about 180 fps in the worst phasing case (all SPS, except ullage). This introduces an important concept. The nominal CSM timeline during LM descent should include targeting and preparing for the Hohmann transfer maneuver so it can do it if it needs to. It would countdown to go a little more than one hour after DOI.

4. Now let's discuss aborts from early Powered Descent (PD). During about the first 8 minutes of PD, or until about hi-gate, almost the same procedures would be followed as above, since the phasing at abort is the same---LM in front of the CSM. However, there are two significant differences:

(a) The LM using just the DPS is only able to achieve orbit for the first 5 minutes of PD. After that the LM must stage and use some APS fuel.

(b) The LM abort insertion orbit is currently targeted for only 10/30 nm whereas the post-DOI orbit is about 8.5/60 nm. This means the CSM cannot get into a smaller (shorter period) orbit to do a rescue. That is, if the CSM circularizes at 20 nm it will have the same period as the LM and will not catch up. This prompts a current program change request for the LM program (Luminary), namely, to change early abort targeting in the DPS abort (P-70) and APS Abort (P-71) programs to insert into a 10/60 nm orbit to permit CSM rescue if necessary. Without this we don't have a CSM rescue capability for this situation.

(c) If the LM does not have to stage to reach the 10/60 nm orbit, we again propose the CSM perform the rendezvous just as described in paragraph 3 in order to save LM consumables. Of course, if the LM must stage due to DPS failure or late abort (after 5 minutes into PD), it might as well go ahead and do the rendezvous, i.e., active LM and passive CSM.

5. During the rest of PD (approximately after hi-gate) through hover and even for the first few minutes on the lunar surface, the phasing has changed such that if the LM aborts it will be trailing the CSM when it gets into orbit again. That is, during PD the CSM overtakes the LM and proceeds ahead of it such that roughly after hi-gate, the LM should insert into the standard 10/30 orbit and, using the standard maneuver sequence, will rendezvous from below the CSM. CSI will occur 30 minutes after insertion just like a nominal rendezvous. Conversely, if after insertion (using the APS, of course), a CSM rescue of the LM is required, the phasing is right for the CSM to perform the standard maneuver sequence---essentially "mirror image" of the LM maneuvers---to reach the LM from above. In either case, the rendezvous can be accomplished within two revolutions.

6. Note then, that during the LM's Hohmann descent after DOI, the CSM traills the LM by an increasing amount making the phasing situation progressively worse. This trend reverses during PD until at some instant shortly after hi-gate the phasing is perfectly nominal (when the LM achieves orbit following an abort). After that, the phasing degrades again but this time with the CSM leading the LM, such that the rendezvous by the LM is as we prefer---from below. The only thing is that the later we abort the longer it takes.

One thing is evident from this. From an abort trajectory standpoint there is a "preferred" period to abort. Therefore, if possible, we should attempt to select the "Go/No Go for landing" time inPD within this period. Of course, many other considerations are involved in this choice, too.

7. Finally, I'd like to discuss aborts from the lunar surface. Much has been said about "anytime lift off" and a great deal of work has gone and is going into it. Personally, I feel it's time we knocked that off, and I'll explain why and what we should do instead. But, first I'd like to point out a remarkable similarity of the LM's lunar surface situation to any of our manned earth orbital missions. On the latter, immediately after insertion into earth orbit, critical parameters are checked and a Go/No Go for one revolution is given. And the spacecraft either aborts or goes one revolution. After that Go/No Go's for more interger revolutions are given at logical times---Go for six, Go for 16, etc. Reentry at these times is seriously prepared for and that's where the effort goes. Of course, some consideration is given to coming down in between these planned recovery areas due to critical systems failures but not much. It can be done but "anytime reentry" would be BAD NEWS! We have the same situation with the LM on the lunar surface. Immediately after the DPS is shut off after landing, the spacecraft should be maintained in the same state as during hover for about three more minutes. That is, the guidance system remains in the same program as used during terminal descent and everything remains prepared to "abort stage." During this three minutes (or whatever) the crew and the ground make a rapid check of all critical systems and spacecraft state (such as tilt, etc.). Then a "Go/No Go for two hours lunar stay" is given. If it's No Go--- "abort stage" into orbit and follow the standard rendezvous procedures noted above. If it's a Go for 2 hours lunar stay---stay and start preparing to lift off in 2 hours, if necessary. This includes platform alignments, guidance system targeting, etc., and all the rest of it. From here on is a series of Go/No Go's for more integer revolutions (CSM's) on some logical basis and serious preparations (targeting, etc.) should be carried out for them. That's where the effort should go. That is, if things go bad, launch when the CSM comes over again with nominal phasing. Special provisions should not be made to support a true "anytime launch" capability. That's BAD NEWS, too! Of course, MCC/RTCC programs and displays are available to handle the situation if it were to occur, but on a low probability contingency basis. Under some phasing situations, propellant requirement and spacecraft failures, etc., rendezvous would not result.

8. Furthermore, just like for reentry, I propose discrete lift off times for the nominal LM lift off. The countdown should include adequate time, built-in holds, etc., to insure being ready to go on time---once per CSM revolution. If that opportunity is missed wait two hours and get the problem that delayed lift off straightened out. What I'm saying is---all planning, procedures, ground rules, training and simulations, etc., should be oriented to those "probable" lift off times (i.e., 3 minutes after TD and on-time once per CSM revolution), just like we do for earth orbital reentry.

9. Well---that was a lot of reading. I hope it helped straighten out for you what lunar rendezvous aborts are all about. If you still don't understand it's not because it's complicated, but rather because I didn't explain it well enough. So give me a call. Or the people who are really doing the work.

Howard Tindall Jr.

Howard W. Tindall, Jr.

Addressees:
(See attached list)

UNITED STATES GOVERNMENT

Memorandum

NASA - Manned Spacecraft Center
Mission Planning & Analysis Division

EA5 / P.M. Deans

TO : See list below

DATE: AUG 5 1968

File No. 68-FM13-445

FROM : FM/Chief, Mission Planning and Analysis Division

SUBJECT: Data requirements during rendezvous sequence

The purpose of this memorandum is to establish a requirement for high bit rate (HBR) telemetry data during the mission "C" rendezvous sequence.

In a recent postflight analysis meeting between GCD and MPAD, it was discovered that, based on the current flight plan, the onboard recorder was to be on a low bit rate (LBR) for the final phase of the rendezvous (from TPI through TPF). Since the final phase will take place largely out of sight of ground tracking stations, if only LBR recorded telemetry data is recovered, a thorough analysis of the rendezvous systems, ground as well as onboard, will be impossible.

The standard used to evaluate performance of both the RTCC and the G&N system is the Best Estimate Trajectory (BET). The BET is generated postflight from a best fit of all available tracking data, augmented during maneuvers by velocity time histories recorded by the G&N system. When a number of maneuvers will be made between stations, as in the rendezvous sequence, the G&N data will be mandatory for valid trajectory reconstruction. In the LBR record mode, the time history of G&N velocity cannot be recovered from the data.

Therefore, it is requested that DTO 20.13 be changed to make HBR recorded telemetry data mandatory for the terminal phase of the rendezvous, and that the crew procedures and flight plan reflect this change. As a minimum, the DSE should be switched to HBR 10 seconds prior to each maneuver and held there until 10 seconds after the maneuver (and any residual nulling) is completed.

for D H Owen
John P. Mayer
Chief, Mission Planning
and Analysis Division

RPP

Addressees:
CA/D. Slayton
PD/O. E. Maynard
FC/E. F. Kranz

cc: (see attached list)

EA5 / T. Deans
info

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA FPMR (41 CFR) 101-11.6

UNITED STATES GOVERNMENT

Memorandum

TO : See list attached

DATE: JUL 2 1968

68-PA-T-147A

FROM : PA/Chief, Apollo Data Priority Coordination

SUBJECT: Lunar rendezvous shaping up

1. On June 26 we took another wack at the "G" Rendezvous Mission Techniques. I think we now have most of the basic things squared away so that we can get into the detail with some confidence. The most significant decisions were:

a. To make the new plane change maneuver discussed in the last report with the LM as long as RCS propellant is adequate.

b. To add IMU fine alignments into both the LM and CSM timelines right after LM insertion.

c. To increase the time between LM insertion and the CSI maneuver to 50 minutes.

d. Since that decreases the CDH/TPI Δt and increases the CSI/CDH Δt, to move the new plane change maneuver from 30 minutes after CDH to 30 minutes before CDH.

2. It is interesting to note that the timeline now is very similar to the second half of the "D" mission rendezvous and not so darned crowded as it used to be. It looks like this now:

INS	CSI	PC	CDH & PC	TPI
	50	20	30	47
	50	70	100	147

3. Ed Lineberry and his guys have done some good work since our last meeting, which led to their proposal to make CSI 50 minutes after LM insertion into orbit. This not only reduces the timeline crowding in that busy period, but improves the CSM rendezvous navigation. You see, since we moved TPI about 45 minutes later (to midpoint of darkness), the relative range at insertion increased to about 320 nautical miles. By delaying CSI, we maintain the range at about 150 nautical miles at CSI

as it was before. This also makes it possible to add the IMU alignments of both the LM and CSM into the nominal timeline after insertion. We feel this is quite an advantage since the LM really needs one after Ascent, prior to rendezvous navigation - and the CSM alignment would have been over four hours old at TPI. And we would have been forced to add it in as a contingency procedure if the LM crew couldn't see stars through the AOT in the lunar surface.

4. Shifting CSI later forces CDH to move also, as shown above. This leads to the "final" change - moving the plane change to before rather than after CDH. Although we had previously been inclined toward making this burn with the CSM, everyone agreed that as long as the LM has the fuel it can do it with the least impact on everything. This is because the LM lateral thrusters are pretty well aligned through the c.g. at this time in the mission so we can use them making an IMU alignment unnecessary. In fact, we are so anxious to avoid realigning that CSM three gimbal IMU we concluded that if the LM fuel becomes marginal we should do CSI, CDH, and TPI all with the CSM if that permits the LM to do the plane change. Tradeoff of CSM maneuvering rather than the LM will be based on LM RCS propellant remaining, red line values established pre-flight. (Action item for Guidance and Performance Branch)

5. Some associated ground rules follow:

a. The plane change will be made by the LM no matter how small - i.e., there is no minimum threshold.

b. The CSM does mirror image targeting for all LM burns except the planechange (to avoid the out-of-plane alignment).

c. If the LM becomes passive before CSI, the CSM will use the maneuver sequence illustrated above including an out-of-plane alignment for the plane change.

d. If the LM becomes passive at the plane change, the CDH will be targeted to force a node 20 minutes after CDH to insure adequate time for TPI preparation. This is a little more expensive than 30 minutes, which is the "natural node," but is worth it to avoid a jam up at TPI.

6. MPAD will prepare and distribute a memo defining the many parameters of interest based on this new timeline. At our next meeting we'll review that and the rendezvous navigation tracking schedule. We will also start the tradeoff of the various guidance systems. You know - shall we put rendezvous radar data in the AGS? etc.

Howard W. Tindall, Jr.

Howard W. Tindall, Jr.

PA:HWTindall, Jr.:js

EA 5/ [illegible] info

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA FPMR (41 CFR) 101-11.6

UNITED STATES GOVERNMENT

Memorandum

TO : See list below

DATE: JUN 21 1968
68-PA-T-131A

FROM : PA/Chief, Apollo Data Priority Coordination

SUBJECT: Let's add a plane change into the lunar rendezvous timeline

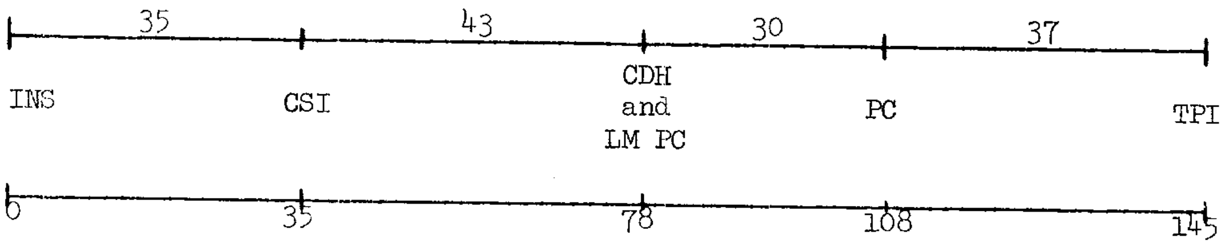
The June 13 Lunar Rendezvous Mission Techniques meeting was devoted to how to handle the plane change. As noted in my last bulletin, this problem had to be solved before we could do any meaningful work in the development of lunar rendezvous mission techniques. In my opinion a pretty good approach has been agreed to. It involves the addition of a new maneuver in the timeline, specifically, for cleaning up the out-of-plane situation. Although it is not certain, I expect this maneuver, which will occur at a fixed time - 30 minutes after CDH - will be performed by the CSM. It is almost mandatory to schedule this burn at a fixed time on such a short rendezvous as this in order to prevent it from interfering with the other maneuvers and the rendezvous navigation. However, as you know, unless it's controlled somehow, a plane change (i.e., the node) might naturally occur anywhere. Therefore, several other things also had to be settled to permit this particular approach. They are:

1. The LM shall burn whatever out-of-plane velocity is known to exist at the CDH time as part of the CDH maneuver. This will force a node 90° (i.e., about 30 minutes) later. Both the LM and the CSM have the onboard capability of computing this parameter using Routine 36, and the CM crew can input it into the CDH targeting. (The CSM will use the same routine to target its plane change 30 minutes later.)

2. In order to keep the out-of-plane component of the CDH maneuver within reasonable limits, it is necessary to set up a nominally in-plane situation at LM insertion. If this is done, the CDH out-of-plane will only be due to MSFN Ascent Targeting error and LM PGNCS dispersions during Ascent. These together are estimated to be no more than 35 fps which is approximately equal to the in-plane component. This means we shouldn't have a LM gimbal lock problem there.

3. There are two ways of doing this. Either the CSM must make a plane change prior to LM Ascent or if the required plane change is less than 50 fps, we can yaw steer the LM into the CSM plane during Ascent. That is, if the pre-Ascent plane change required is that small, we can probably simplify the operation by "dog legging" the LM Ascent and omitting the pre-Ascent CSM plane change.

4. TPI was scheduled to occur 20 minutes before darkness. However, in order to provide time for this extra maneuver, FCSD has agreed that TPI can be moved later. Their second preference is a good one - midpoint of darkness. This gives at least 67 minutes between CDH and TPI which makes the new plane change maneuver fit in nicely. The timeline looks like this now. (All the numbers are minutes.)



5. Note that we have moved CSI from 30 to 35 minutes after insertion and I've asked Ed Lineberry to see if we can move it even later. The pre-CSI timeline is quite crowded and if the LM has to do an IMU alignment after insertion, they will not get much rendezvous tracking in.

6. To do the plane change, the CSM (or LM) will have to reorient the IMU, probably by pulse torquing. In order to minimize the induced error which is proportional to the extent of the reorientation we should probably only move the platform the amount necessary to avoid gimbal lock - say 20 or 30 degrees. This would mean the crew will not have the FDAI ball at 0,0,0 for the burn.

7. If the CSM does the plane change, it may be preferable to omit all subsequent sextant tracking and to rely on VHF ranging only. With the new TPI time, there is likely to be some sun interference anyway and it sure simplifies the CSM pilot's task.

At the next meeting we'll pin down which vehicle should make the plane change, review the rendezvous navigation tracking schedule for both vehicles, and begin to fill in the details.

Howard W. Tindall, Jr.

Enclosure
List of Attendees

Addressees:
(See list attached)

PA:HWTindall, Jr.:js

ATTENDEES

Howard W. Tindall, Jr.	PA
E. C. Lineberry	FM
J. Shreffler	FM
R. T. Savely	FM
P. T. Pixley	FM
G. C. Guthrie	FC
W. G. Weppner	FC
L. J. Riche	CF
M. C. Contella	CF
K. Baker	TRW
J. W. Wright	TRW
H. Klein	TRW
J. E. Scheppan	TRW
W. O. Covington	Bellcomm
W. T. Musial	McDonnell

Enclosure 1

info

EA5/P. M. Deans

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA FPMR (41 CFR) 101-11.6

UNITED STATES GOVERNMENT

Memorandum

TO : See list below

DATE: JUN 3 1968

68-PA-T-114A

FROM : PA/Chief, Apollo Data Priority Coordination

SUBJECT: Lunar Rendezvous Mission Techniques

1. On May 28 we finally kicked off the Lunar Rendezvous Mission Techniques business. Because of the imminence of missions "D" and "E", we started on those first some months ago. Now I wish we hadn't because they are so darned complicated. I have a feeling the lunar rendezvous can be finished up quicker than they can and, of course, some of the things we are planning to do in the lunar operation should influence how to go on the development flights.

2. This meeting was devoted to establishing some ground rules upon which we can base our work as well as making a cursory survey of anticipated problem areas requiring special attention. This memo will do little more than list these items. Some of the assumptions are debateable, of course, and if ultimately proven wrong, will require changing some things. However, we have got to get started somewhere.

3. The following is a list of the ground rules we established:

a. Assume Luminary (the LM spacecraft computer program) will remain as designed today for the lunar missions.

b. Assume Colossus (the command module spacecraft computer program) will be the same as designed today, plus the addition of the CSI and CDH rendezvous targeting programs and the addition of IMU pulse torquing.

c. Assume the VHF ranging device on the command module is operational.

d. Assume the "G" mission lunar rendezvous operation is as currently planned. That is, it should be completed within approximately one revolution. The coelliptic differential altitude is 15 n.m. and the terminal phase transfer angle is 130°.

e. Assume LM liftoff shall be on-time only. That is, there is no launch window.

f. Assume MSFN rendezvous assistance (that is, participation) is minimal as long as the situation remains essentially nominal.

g. Assume all in-orbit LM maneuvers will be made with the RCS propulsion system.

h. Assume both spacecraft will update the LM state vector based on their rendezvous navigation.

i. Assume that if an out-of-plane situation exists after LM ascent, all necessary maneuvers will be made prior to TPI to establish an in-plane rendezvous situation during terminal phase.

j. Assume all plane change maneuver targeting to be executed by either vehicle will be done by the CSM based on its sextant tracking.

4. The following is a list of problem areas, some large and some rather trivial for which we must seek answers:

a. By far the most significant is the problem of how to handle the out-of-plane situation. More on this later in the memo.

b. What is the source of the LM state vector in the command module computer after LM insertion?

c. Should frequent VHF range ambiguity tests be made by the crew as a standard procedure?

d. Should we include onboard determination of radar angle bias in the PGNCS?

e. Should rendezvous radar data be input to the AGS?

f. Should in-orbit platform alignments be performed by either spacecraft after LM insertion into orbit?

g. Should the CSM be targeted for a Holman Transfer to protect against a low LM insertion orbit as a standard (that is, nominal) procedure?

5. I believe for the first time the question of how to handle the out-of-plane situation on the lunar rendezvous is being attacked. Primarily as a result of our beloved three gimbal platform (choke) any difference in the LM and CSM orbital planes becomes difficult to handle. Current estimates of MSFN targeting uncertainty for the LM ascent plus LM PGNCS errors during ascent assure us that an out-of-plane situation will exist. Therefore, a basic question to be resolved is - should we plan as a nominal procedure in the timeline to make a maneuver specifically for getting the two vehicles into the same plane. The alternate, of course, is somehow to pick up pieces of the out-of-plane by incorporating out-of-plane components into the CSI/CDH/TPI burns as much as we can and

then take care of the rest of it in the terminal phase midcourse maneuvers. Most of us are inclined to think we should provide a special maneuver probably using the command module. Of course, this idea immediately leads to another, namely why not eliminate the command module plane change prior to LM ascent and incorporate both that and the dispersions picked up during ascent into a single burn performed after sufficient in-orbit rendezvous navigation to determine the actual situation. There is a sort of philosophical question here since if everything worked perfectly, no post-ascent plane change would be required if we made the CSM maneuver before ascent. It was the opinion of the majority, I think, that we would be naive to think that everything will work perfectly. Some of the basic questions to be answered in order to make this important decision deal with its effect on rendezvous navigation and the impact of an extra maneuver on the timeline. For example:

a. How does this effect rendezvous radar navigation?

b. How does this effect VHF rendezvous navigation?

c. If we pulse torque the platforms, will that introduce unacceptable errors in the rendezvous?

d. What platform orientation should be used in the CSM before and after the plane change?

e. How does this effect the command module mirror image maneuver targeting?

f. What is the maximum plane change delta V which can be left until terminal phase? (This also has implications on RCS delta V residual trimming and possible use of SPS only.)

g. Should the out-of-plane maneuver be made at its natural node or should two burns be planned instead?

h. Should we plan any out-of-plane yaw steering during ascent?

i. One important matter which Ed Lineberry will discuss with Milton Contella (FCSD) prior to the next meeting regards selection of optimum TPI time, currently set at 20 minutes before darkness. The question is how undesirable from a lighting standpoint is it to move nominal TPI time later - perhaps even to midpoint of darkness - in order to give more time in the rendezvous sequence to perform the plane change maneuvers.

6. Well, there are a lot of questions and few answers. As I noted previously, its impact is so great on everything, we really must decide what to do about the plane change before we can get anywhere. So that's what we'll talk about at the next meeting - June 12th.

Howard W. Tindall, Jr.

Addressees:
(See list attached)

PA:HWTindall, Jr.:js

Addressees:
/R. R. Gilruth
AB/G. S. Trimble
CA/D. K. Slayton
CB/A. B. Shepard
J. A. McDivitt
N. Armstrong
F. Borman
M. Collins
C. Conrad
L. G. Cooper
C. Duke
R. Gordon
J. Lovell
R. L. Schweickart
D. R. Scott
T. P. Stafford
W. R. Pogue
W. M. Schirra
D. F. Eisele
A. L. Bean
CF/W. J. North
CF13/D. F. Grimm
CF2/J. Bilodeau
CF212/C. Jacobsen
CF22/C. C. Thomas
CF24/P. Kramer
M. C. Contella
D. K. Mosel
D. W. Lewis
CF3/C. H. Woodling
CF32/J. J. Van Bockel
CF33/C. Nelson
M. Brown
CF34/T. Guillory
T. W. Holloway
EA/M. A. Faget
EA1/J. Chamberlin
EA2/J. B. Lee
EA5/P. M. Deans
EB/P. Vavra
EE/R. Sawyer
L. Packham
EE13/M. J. Kingsley
R. G. Irvin
EE3/E. L. Chicoine
EE6/G. B. Gibson
R. G. Fenner
EG/R. A. Gardiner
D. C. Cheatham
EG2/M. Kayton
C. T. Hackler
EG23/K. J. Cox
E. E. Smith
EG25/T. V. Chambers
EG26/P. E. Ebersole
EG27/W. J. Klinar
H. E. Smith
EG41/J. Hanaway
EG42/B. Reina
EG43/J. M. Balfe
EG44/C. W. Frasier
KA/R. F. Thompson
PA/G. M. Low
C. H. Bolender
K. S. Kleinknecht
PA2/M. S. Henderson
PD/O. Maynard
PD12/J. G. Zarcaro
R. J. Ward
R. W. Kubicki
M. H. von Ehrenfried
PD4/A. Cohen
PD6/H. Byington
PD7/W. R. Morrison
PD8/J. Loftus
PE/D. T. Lockard
FA/C. C. Kraft, Jr.
S. A. Sjoberg
C. C. Critzos
R. G. Rose
FC/E. G. Kranz
D. H. Owen
D. B. Pendley
M. P. Frank
FC2/J. W. Roach
FC3/A. D. Aldrich
G. E. Coen
B. N. Willoughby
G. P. Walsh
FC4/J. B. Craven
R. L. Carlton
J. C. Elliott
FC5/G. S. Lunney
J. S. Llewellyn
J. C. Bostick
C. B. Parker
D. Massaro
C. E. Charlesworth
C. F. Deiterich
S. L. Davis
W. E. Fenner
G. E. Paules
W. S. Presley
H. D. Reed
P. C. Shaffer
J. H. Greene
FC5/K. W. Russell
S. G. Bales
FL/J. B. Hammack
FS/L. C. Dunseith
FS5/J. C. Stokes
T. F. Gibson, Jr.
G. R. Sabionski
J. E. Williams
T. M. Conway
TH3/J. E. Dornbach
J. H. Sasser
FM/J. P. Mayer
C. R. Huss
FM12/R. R. Ritz
FM13/R. P. Parten
J. R. Gurley
E. D. Murrah
A. Nathan
FM3/M. Collins
FM4/P. T. Pixley
R. T. Savely
FM5/R. E. Ernull
FM6/R. R. Regelbrugge
K. A. Young
FM7/S. P. Mann
R. O. Nobles
FM/Branch Chiefs

HM-31/H. E. Dornak
D. W. Hackbart
Bellcomm (Hqs.)/R. V. Sperry
G. Heffron
GAEC (Bethpage)/J. Marino
MAC (Houston)/W. Haufler
MIT/IL/R. R. Ragan
NR (Downey)/M. Vucelic
D. Zermuchlen
E. Dimitruk, FB30
TRW (Houston)/R. Boudreau
M. Fox
B. J. Gordon
W. R. Lee, Jr.
T. V. Harvey
TRW (Redondo Beach)/R. Braslou
GSFC/F. O. Vonbun, 550
B. Kruger, 550
KSC/R. D. McCafferty (CFK)
P. Baker (CFK)
NASA (Hqs.)/A. Merritt, MAS

UNITED STATES GOVERNMENT

Memorandum

TO : See list attached

DATE: October 15, 1968

68-PA-T-219A

FROM : PA/Chief, Apollo Data Priority Coordination

SUBJECT: Lunar Rendezvous Mission Techniques

A number of people who know about the rendezvous radar (Myron Kayton, Richard Broderick, etc.) came to our little Lunar Rendezvous Mission Techniques meeting October 2 and assuaged our anxieties regarding the possibility of poor shaft angle measurements when the line-of-sight to the command module passes close to the lunar horizon. According to the data they presented, the error introduced by multi-path in the rendezvous radar data is essentially lost in the noise for elevation angles above 10° from the horizon. (During the nominal lunar rendezvous tracking begins at approximately 10° elevation and approaches 20° at CSI.)

Ed Lineberry's people have made sufficient runs to show that it is possible to use the same CSI targeting data computed in the CMC for LM maneuver solution comparison (properly biased) and for CSM mirror image maneuver targeting. We are currently recommending that the CMP use P32 rather than P72 since this would avoid the necessity of going through two pre-thrust programs.

One of the most significant things coming from the meeting, I think, was a report by the Math Physics Branch people to the effect that the rendezvous radar data is not expected to be of sufficient accuracy to target plane change maneuvers prior to terminal phase. The estimated errors are simply too great (e.g., 11 fps, one sigma). Accordingly, all plane change targeting prior to terminal phase must come from the CSM which can do an excellent job given as little as 10 minutes worth of sextant tracking (0.5 fps, one sigma). This does introduce sort of a problem since the technique for determining the magnitude of the plane change maneuver is to input the time of interest into the R36 routine. Unfortunately, if we put in the time of the LM maneuver, the solution would apply to the out-of-plane the command module should make at a substantially different place in orbit. For example, at CSI the command module is leading the LM by as much as 12°. Of course, the CMP could go through some "mickey mouse" to bias this time as a function of this phase angle based on some charts or something. However, he is already pretty well bogged down with other work and so we are going to put in a program change request for COLOSSUS II giving us a solution based on the LM state vectors rather than the CSM state vectors somewhat as the 70 series programs compliment the 30 series.

Jack Wright, TRW, had an interesting idea regarding the technique for checking the validity of the VHF range data. It is his impression that the rendezvous radar range and range rate measurements are essentially independent of one another, in effect providing two data sources for comparison with the VHF. Agreement of either of these with the VHF would provide confidence in its use. The crew display of raw VHF data is not really accessible to the CMP in the lower equipment by and, of course, does not provide range rate at all. Therefore, the comparison must be against the DSKY display of range and range rate based on the navigated state vectors which include the sextant observations. It seems to us, in lieu of real data that this is probably a valid test of the VHF since it probably overwhelms the sextant data in the determination of navigated range and range rate. I would like to emphasize that this is a proposal requiring verification and may prove to be not useable. However, I thought it interesting enough to pass on to you.

Howard W. Tindall, Jr.

PA:HWTindall, Jr.:js

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA FPMR (41 CFR) 101-11.6

UNITED STATES GOVERNMENT

Memorandum

NASA Manned Spacecraft Center

info

TO : See list attached

DATE: July 14, 1969

69-PA-T-109A

FROM : PA/Chief, Apollo Data Priority Coordination

SUBJECT: How we will handle the effect of mascons on the LM lunar surface gravity alignments

What do we do if one of those big damn lumps of gold is buried so near the LM that it screws up our gravity alignment on the lunar surface? Without exception, the calculations of all the various far-flung experts predict that mascons should have no significant effect on our lunar surface gravity alignments. In fact, based on this we have chosen to use gravity alignments nominally as opposed to star alignments. They are easier to do and probably more accurate. A few of us got together the other day, though, to figure out what to do if, contrary to expectation, some sort of weird gravity effect is noted, which appears to be acting on the LM on the lunar surface. This memo is to tell you about that.

As you know we have several sources of data for determining the LM's position on the lunar surface (RLS). One of these is through the use of data obtained from LM platform measurements of the direction of the lunar gravity and from AOT observations of the stars. If this determination, using the LM data, disagrees substantially with the other data sources, we must consider the possibility that it's due to gravity anomalies. The sort of difference we are willing to tolerate is 0.3° in longitude, which is more or less equivalent to 0.3° pitch misalignment in the platform. True alignment errors in excess of that could present ascent guidance problems. Since 0.3° is equivalent to about five miles, you'd expect the crew's estimate of position could probably be useful in determining the true situation. All they'd have to do is tell us they are short or over-shot the target point a great deal.

If uncertainty still persists, it seems we must believe the gravity and use it for our alignments - both PGNCS and AGS. That is, we have more faith in it than in our other sources of RLS determination. However, if examination of all these sources convince us that the gravity does have some funnies greater than 0.3° associated with it, we would have to modify the crew procedures in real time such that the ascent platform alignment is done using the stars (Alignment Technique 2) rather than gravity.

Consideration was given to hedging our bet by aligning the PGNCS to the stars and using the lunar gravity alignment in the AGS. Further consideration, however, revealed an interesting and somewhat sad thing. What we actually discovered was that the ground trajectory processing during ascent is also affected by downrange position error - that old demon that seems to be plaguing us in so many ways recently. The fact is that throughout ascent we would never know which system was right and so we would never have the intelligence to switch over from one system to the other. In other words, there is no point in using different Alignment Techniques for the two guidance systems.

The problem noted above is primarily in support of Ascent 1 rev after landing. After that, additional very accurate sources of RLS determination become available. Specifically CSM sextant tracking of the LM is always the prime source and if Mike has trouble on one try, he should try again on later revs - there are plenty of opportunities and little else to do. If he still fails and the uncertainty noted above exists, we have the situation in which LM rendezvous radar tracking of the CSM becomes mandatory. You recall we deleted this from the timeline with the understanding it would be reinserted if we could determine RLS in no other way and this is that case. We sure don't expect this to happen, but if it does RR will be needed.

In summary then:

a. We should always align both AGS and PGNCS to the same data source, gravity or stars.

b. We use gravity unless we have some concrete reason to question it - such as all data sources including the crew estimate of RLS are in disagreement with it by more than 0.3^{o} in longitude (pitch). In that case, use tne stars (both AGS and PGNCS).

c. Naturally longitude initialization error louses up the ground ascent trajectory monitoring just like it does descent.

d. If RLS uncertainty persists, either CSM sextant or LM RR tracking of the other vehicle becomes mandatory.

Howard W. Tindall, Jr.

Howard W. Tindall, Jr.

PA:HWT:js

UNITED STATES GOVERNMENT

Memorandum

NASA Manned Spacecraft Center

Dnit

info

TO : See list attached

DATE: July 10, 1969

69-PA-T-105A

FROM : PA/Chief, Apollo Data Priority Coordination

SUBJECT: Tweak burns

If you can stand it I would like for you to hear the latest on tweak burns - the trim maneuvers made after LM insertion from a descent abort. I thought we had this settled and on ice a couple of months ago but some things have happened which probably make it logical to revise the tweak rules. The things that have happened are:

a. The LM RCS plume impingement constraints have been substantially reduced.

b. Simulations have shown that the Flight Dynamics Officer (FDO)/ RTCC capability of computing the tweak maneuvers on a timely basis is much better than anticipated.

Some FCSD, FCD, and MPAD guys got together July 8 and came up with the following:

a. Our previous rule was quite simple; if the LM inserted into orbit with the DPS attached, the command module would make the burn; if the LM had staged, the LM would make the maneuver. Now that the LM has been modified with plume deflectors and additional thermal protection, it has the capability of performing any tweak maneuver we foresee. Accordingly, the rule is being modified to say that for all descent aborts prior to PDI + 10 minutes the LM will perform the tweak provided it is within the RCS plume impingement constraint, regardless of whether the LM has staged or not. If for some abnormal reason the LM capability is exceeded, the CSM will perform it; the LM should not stage the DPS just to provide a greater RCS capability. Also, the LM should not trim insertion conditions.

b. As you recall, aborts after PDI + 10 minutes require an extra rev in addition to a phasing maneuver, which makes the tweak burn unnecessary. We have also stated that trimming the insertion conditions is necessary. However, if the crew wishes to trim +x there is no objection to that and obviously if the +x required is large, there is no choice. It must be trimmed.

c. I would like to emphasize another rule which has been on the books for a long time but which may not have been clear to the crew. Namely, if the DPS shuts down with a ΔV required to reach the insertion conditions greater than 30 fps, the crew should utilize the APS and P71 to achieve orbit. We have recommended that automatic Abort Stage sequence to achieve this.

Howard W. Tindall, Jr.

PA:HWT:js

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA FPMR (41 CFR) 101-11.6

UNITED STATES GOVERNMENT

Memorandum

NASA Manned Spacecraft Center

TO : See list attached

DATE: April 4, 1969
69-PA-T-55A

FROM : PA/Chief, Apollo Data Priority Coordination

SUBJECT: AGS alignments in lunar orbit and operations on the lunar surface

On April 2 we finally got around to establishing how to operate the AGS on the lunar landing mission. The two basic subjects for discussion were how to handle CDU transient problems when aligning the AGS to the PGNCS in lunar orbit and how to operate the AGS in total while on the lunar surface.

I am certainly no authority on CDU transients and only attempt the following brief description so that the rest of the memo will make some sense to you. If you are interested in what CDU transients really are, I recommend that you find an authority on them. There are lots of 'em - and as many versions. As you know, the AGS uses the PGNCS as the primary reference in its alignments. As I understand it, CDU transients have something bad to do with the electronics in the PGNCS which are used to generate the data transmitted to the AGS which the AGS uses in its alignments. Unless certain precautions are taken, CDU transients can occur and are not ordinarily obvious to the crew. I gather that they can result in errors in the AGS alignments of up to $1\frac{1}{2}$ degrees or so. During much of the operation even the largest misalignment errors would not particularly concern us. On other occasions, such as during descent, they would essentially disable the AGS as a useful guidance and control system.

I will go through each of the AGS alignments:

a. <u>LM Activation before Undocking</u>

The command module should be used to orient the spacecraft to a so-called AGS calibration attitude which is essentially just displacing all three spacecraft axes at least $11\frac{1}{2}$ degrees away from zero or multiples of 45 degrees from the IMU principle axes. This action, it is said, will permit the AGS alignment and calibration to be carried out free of CDU transients.

b. <u>Pre-DOI after Undocking</u>

The AGS is aligned to the PGNCS after its AOT alignment in preparation of DOI. Since AGS alignment errors do not create a problem but are more of an annoyance in the AGS monitoring of the DOI burn, no precautions will be taken to avoid CDU transients.

c. Pre-PDI

This alignment in preparation for descent is most critical. The AGS must be aligned accurately and, in order to minimize drift, it must be aligned to the PGNCS very late before PDI. The choices here were to add special crew procedures into an already crowded timeline to avoid CDU transients vs. taking no precautions against their occurring, but being prepared to redo the alignment if the MCC detects a CDU transient alignment error has occurred. Either of these two approaches were considered acceptable and are almost a toss-up. It was finally decided to avoid the special procedures and to take a chance on the transient. If the MCC determines that a CDU transient has occurred, the crew will be informed within 30 seconds and they must then rezero the CDU's and repeat the alignment. This procedure is felt to be simpler for the crew and, in particular, it avoids attitude maneuvers which are part of the CDU transient avoidance procedure.

d. Post-Insertion Alignments

After insertion into orbit the AGS should then be aligned to the PGNCS. Again in this non-critical period it was decided to take a chance on a CDU transient occurring, particularly since this alignment is carried out within sight of the earth and the MCC is in a position to advise the crew if a realignment is necessary.

Attached to this memo is a detailed sequential list of AGS options on the lunar surface at each step of which it is assumed the PGNCS is still operational. In other words, it is the nominal sequence. If the PGNCS becomes broken on the lunar surface, different and more extensive operations will be required, which we have yet to define. In the development of the attached sequences, some items of interest and action items popped out which I would like to add here.

a. Whenever RLS is updated in the PGNCS, it should be standard procedure to update the AGS lunar launch site radius (Address 231). This update will be based on a voice relay from the MCC of the value to be input via the AGS DEDA by the crew.

b. With regard to CDU transients during AGS alignments on the lunar surface, it was decided that we would rely on the MCC to monitor and advise the crew if a CDU transient has occurred. That is, the crew would follow no special procedure to determine if one had occurred except in the case of no communication.

c. Guidance and Control Division and TRW were requested to advise what timetag should be associated with the CSM state vector voiced to the crew for input into the AGS in the event the PGNCS has failed.

d. MPAD was asked to determine if it is acceptable to input state vectors into the AGS 15 minutes or more prior to PDI. The question here really is whether or not the AGS numerical integration causes unacceptable state vector errors for descent aborts if the state vectors are loaded too early. Early loading, of course, is desirable to reduce crew activity just before PDI.

All of this AGS jazz will be added to the Lunar Surface Mission Techniques Document. I think it's the last chunk. We will review the whole subject of lunar surface activity next week and then can forget it - I hope.

Howard W. Tindall, Jr.

Howard W. Tindall, Jr.

Enclosure

PA:HWTindall, Jr.:js

April 2, 1969

First Two Hours on the Lunar Surface
After Touchdown and First Stay Decision

1. PGNCS goes to P68
2. 413 + 10,000 Lunar Surface flag to store azimuth and terminate average g
3. 414 + 10,000 State vector update (V47) after verification of PGNCS
4. 400 + 30,000 AGS align to PGNCS
5. 400 + 10,000 Initialize for Ascent
6. 413 + 10,000 Store better azimuth
7. Stay for two hours decision
8. Crew readout to MCC addresses 047 and 053
9. 400 + 60,000 AGS gyro calibration [5 minutes required]
10. Load $J_8 = J_9$ = "45 n.mi. apogee"
11. Verify Ins $\dot{H}$ = 32 fps and H = 60,000 ft.
12. PGNCS Option 1 alignment
13. 400 + 40,000 Lunar Surface align [3 minute system test]
14. PGNCS Option 2 alignment
15. 400 + 30,000 AGS to PGNCS align
16. 413 + 10,000 Store best azimuth
17. Crew readout addresses 047 and 053 to MCC
18. Pause
19. Receive Ascent Pad
20. Load AGS azimuth [Address 047 and 053] with values for MCC
21. Pause
22. PGNCS Option 3 alignment
23. 414 + 10,000 State vector update

24. Pause

25. 400 + 30,000 Align to PGNCS

26. 400 + 10,000 Initialize for Ascent

27. Verify 410 is "+00000" [Ascent Program]

28. Exit lunar CDDT and switch AGS to "off" [warm-up mode]

April 2, 1969

Normal Ascent

1. Power up AGS [25 minutes required]
2. AGS System Tests (?)
3. Initialize AGS time [K = 90 hours]
4. 414 + 10,000 CDU zero [by state vector update] (V47)
5. PGNCS Option 3 align to REFSMMAT
6. 400 + 30,000 AGS to PGNCS align
7. 400 + 60,000 AGS gyro calibration [5 minutes]
8. 400 + 30,000 AGS to PGNCS align
9. Pause including RR Track of CSM
10. Receive Ascent Pad
11. Load AGS azimuth [Address 047 and 053] with value from MCC-H
12. Pause
13. PGNCS Option 3 alignment
14. 414 + 10,000 state vector update
15. Pause
16. 400 + 30,000 align to PGNCS
17. 400 + 10,000 Initialize for Ascent
18. Verify 410 is "+00000" [Ascent Program]

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA FPMR (41 CFR) 101-11.6
UNITED STATES GOVERNMENT

Memorandum

NASA Manned Spacecraft Center

TO : See list attached

DATE: April 1, 1969

69-PA-T-52A

FROM : PA/Chief, Apollo Data Priority Coordination

SUBJECT: PGNCS operations while on the lunar surface

During our March 27 Lunar Surface Mission Techniques meeting I think we finally settled how we think the PGNCS should be operated. How many times have I said that before? This memo is to broadcast a few new items that might be of general interest.

MIT has recently made a significant change in the PGNCS lunar surface alignment program (P57). They have added a new alternative governing the orientation to which the IMU can be aligned. Specifically, before this change there were only two alternatives - a "preferred" alignment associated with lift-off time computed by the LGC and an alignment to a REFSMMAT uplinked from the Mission Control Center. The new alternative provides the capability of an alignment to the stored REFSMMAT - that is, the same REFSMMAT to which the IMU was aligned the last time. This program change significantly simplifies crew procedures and since it will be used several times during the lunar stay you should be aware of it.

We have finally converged on the sequence of P57 options to be used on the lunar surface. They are described in considerable detail in the attachment. Briefly the sequence is:

a. A gravity alignment (Option 1) to determine the direction of the gravity vector.

b. An AOT star alignment (Option 2) to establish an inertial reference which can be used with the gravity vector to determine the LM's position on the lunar surface. This alignment will also provide a drift check on the IMU since the pre-DOI AOT star alignment.

c. A gravity and star alignment (Option 3) in preparation for lift-off at the end of two hours stay, if that is necessary, and to initialize the system for a sustained IMU drift check.

d. Two Option 3's in the nominal ascent countdown. The first, which completes the drift check, also sets up the system for the rendezvous radar tracking of the command module two hours before the lift-off. The second supports the Ascent itself.

This sequence not only provides all of the data needed to support the actual operation but also exercises all of the options which makes the engineers happy. The consensus was that we have trimmed this activity just about to a minimum and it should be fairly easy to include in the crew timeline.

Flight Dynamics' flight controllers were requested to select the stars to be used for the lunar surface alignment on the nominal G mission as soon as possible.

It is our understanding and recommendation that the IMU will remain powered up throughout the lunar stay. We should emphasize that it is also necessary that the LGC remain powered up as in order to maintain gyro compensation in the IMU as well as to provide the downlink data continuously to the Mission Control Center. Apparently there was some uncertainty about this.

After considerable discussion it was decided that our best course of action is to update both the LM position on the lunar surface (RLS) and command module state vector in the LGC during the first two hours on the lunar surface to support an ascent at that time, if it is necessary. The RLS will be based on the AOT alignment and gravity vector data as well as crew observations during the landing and perhaps on data gathered prior to DOI. (The exact manner in which the Mission Control Center will do this job is the subject of a meeting next week.) The CSM state vector will be the best MSFN estimate at the time of the update. This is such an obvious choice you must wonder how we wasted our time. The only point we were concerned with was making sure that the RLS and CSM vectors were compatible enough to support ascent guidance at the end of a two hour stay. We feel that this technique will probably provide that, but we may want to reconsider after obtaining F mission experience.

In addition to the Data Select business noted above about how to establish RLS, we are also scheduling a meeting specifically to discuss the AGS operation on the lunar surface next week. After incorporating the results of those meetings into the Mission Techniques Document for Lunar Surface Operation, we will review and finally publish that document a couple of weeks later. Hopefully, at that time this mission phase should be fairly well closed out.

Howard W. Tindall, Jr.

Howard W. Tindall, Jr.

Enclosure

PA:HWTindall, Jr.:js

LM IMU ALIGNMENT SEQUENCE

1. Pre-undock - align to Mission Control Center REFSMMAT

2. Pre-DOI - P52 AOT align to REFSMMAT (stored)

3. Post Touchdown

   a. Option 1 to REFSMMAT to obtain the g vector

      Do not torque the IMU - specifically, the crew should recycle (V32E) out of the program at the V06N93 torquing angle display

   b. Option 2* to REFSMMAT - to obtain IMU drift since pre-DOI alignment. Given the g vector of Option 1 this supplies all data required for LM position determination on the lunar surface both onboard and at the Mission Control Center.

   c. Update RLS and CSM state vector in the LGC based on best sources of data available - no attempt is made to make these "consistent."

4. Touchdown plus $1\frac{1}{4}$ hr to prepare for RR track or lift-off after first CSM rev.

   Option 3* to landing site - using updated lift-off time from the Mission Control Center.

5. During lunar stay (about 19 hours duration) monitor CDU angles continuously at the Mission Control Center.

6. Lift-off - $2\frac{1}{2}$ hours

   Option 3* to REFSMMAT to obtain drift and to align for RR tracking.

7. Update CSM state vector in LGC. Optional update of RLS.

8. Lift-off - 45 minutes

   Option 3* to landing site for Ascent.

   *(a) If attempt at Option 2 fails because stars are not visible, replace with Option 3 using sun or earth if possible.

   (b) If attempts at Option 3 fail (even with sun or earth) replace with Option 1's.

   Note: Unset REFSMMAT flag before #6 above if using Option 1 to eliminate drift effect over long lunar stay.

Enclosure

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA FPMR (41 CFR) 101-11.6
UNITED STATES GOVERNMENT

Memorandum

NASA Manned Spacecraft Center

DATE: April 4, 1969
69-PA-T-54A

TO : See list attached

FROM : PA/Chief, Apollo Data Priority Coordination

SUBJECT: RLS Determination

On April 2 we had a Mission Techniques meeting to discuss how we should handle the determination of the LM's position on the lunar surface (RLS). Specifically, we were concerned with how to determine its values and, after improved values are determined, when they should be loaded into the spacecraft computer. One obvious conclusion, if anything can be called obvious coming from this discussion, is that we have many excellent data sources for determining RLS, each of which is estimated to be of a quality much better than we need to support the operation.

"RLS" is actually the LM position vector on the lunar surface consisting of three components. It is moon fixed - that is, rotates with the moon - and is simply the latitude, longitude, and radial distance of the LM from the moon's center.

Prior to landing it is necessary to establish the values of RLS to be used in Descent targeting. For the first lunar landing, where the F mission will have thoroughly surveyed the landing site, the consensus is that we should use the RLS determined on the F mission and only use in-flight mission G measurements as a system check similar to the horizon check made before retrofire. For landings at sites which have not been surveyed previously, the RLS must be determined in real time based on the MSFN/sextant tracking done pre-DOI. The Math Physics Branch (MPB) of MPAD proposes that this be handled in the following way and I think everyone finally agreed it was logical, at least pending results of the F mission:

a. The CSM/LM state vectors will be a so-called single pass MSFN solution based solely on data obtained during the sextant tracking pass. Orientation of the orbital plane of this solution will be constrained by the pre-LOI plane plus confirmed maneuvers. (In fact, MPB proposed that we use this technique throughout lunar orbit from LOI through TEI. Data Select and MPB people have the task of establishing the technique for monitoring rev by rev single pass solutions with the orbital plane unconstrained to confirm that the pre-LOI value falls within the scatter of these determinations and of establishing the limits beyond which they would abandon the pre-LOI plane orientation.)

way, it would have to be added back in at that time. In fact, I should emphasize that we are not proposing that it be dropped from the timeline, but rather that it could be dropped if necessary - so can the sextant tracking for that matter, although no reason for dropping it occurred to us.

In summary, we have many excellent data sources for RLS determination. How we will use them will be established after the F mission. Rendezvous radar tracking by the LM on the lunar surface is no longer a requirement. And, a couple of new MSFN facts are that a short arc solution yields a good position vector and it is proposed that the pre-LOI determined orbital plane plus confirmed maneuvers be used throughout the lunar orbit activity.

Howard W. Tindall, Jr.

Howard W. Tindall, Jr.

PA:HWTindall, Jr.:js

info

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA FPMR (41 CFR) 101-11.6

UNITED STATES GOVERNMENT

Memorandum

TO : See list attached

DATE: February 5, 1969
69-PA-T-14A

FROM : PA/Chief, Apollo Data Priority Coordination

SUBJECT: Two-stage LOI looks good after C'

Just like in other fields of endeavor, it always seems possible to use actual flight results to prove how smart you were before the flight. I am writing this note to crow about how C' proved we "done right" in planning a two-stage LOI.

As you recall we originally considered manually backing up the GNCS during LOI to avoid an overburn using both burn duration AND the EMS ΔV counter. However, when we got down to detailed planning on how to do this, we concluded that we had insufficient confidence in the ΔV counter to wait for it to clock out since the consequences of an overburn are catastrophic. Furthermore, although it sounds simple, monitoring three data sources simultaneously and taking proper action at this critical time turned out to be messy. As a result, the final C' procedure was to backup the GNCS by manually shutting down the SPS if it exceeded the LOI_1 estimated burn duration by more than six seconds. This value was consistent with the 60 x 170 n.m. initial lunar orbit. If we had been using a one-stage LOI our rule would have had to be for the crew to shut down manually just about at the nominal burn duration (no delay) in order to avoid an unsafe pericynthion in the event of a high thrust engine.

On C' LOI_1 we actually experienced a burn duration 4.9 seconds in excess of that expected. Therefore, given a one-stage LOI on C' the crew would have shut down the SPS manually even though the G&N was operating properly and then they would have had to make a second burn of about five seconds duration to finish it off. (In addition to that, we would have been unable to utilize the flexibility of the two-burn LOI targeting to compensate for the trajectory dispersion following the last translunar midcourse correction and we would have ended up with a 64 mile altitude on the back of the moon rather than a 60 circular orbit.)

Incidentally, our other pre-flight conclusion, that is, lack of confidence in the ΔV counter was also proven correct on this flight by several in-flight anomalies including an erratic accelerometer!

Weren't we smart?

Howard W. Tindall, Jr.

Howard W. Tindall, Jr.

PA:HWTindall, Jr.:js

info

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA FPMR (41 CFR) 101-11.6

UNITED STATES GOVERNMENT

Memorandum

NASA Manned Spacecraft Center

TO : See list attached

DATE: February 24, 1969

69-PA-T-32A

FROM : PA/Chief, Apollo Data Priority Coordination

SUBJECT: Some things about MSFN orbit determination

A couple of interesting things came out of our Data Selection Mission Techniques meeting of February 19.

There had been concern that the last translunar midcourse correction (MCC_4) was being scheduled too late before LOI. You recall that it is at LOI - 5 hours. Math Physics Branch reported that the MSFN 1 sigma perigee prediction uncertainty at the time of LOI targeting (at LOI - 2 hours) is 1.4 n.m., assuming MCC_4 is executed to within .2 fps. It was also reported that if it was unnecessary to perform MCC_4 the uncertainty in perigee prediction is essentially constant from LOI - 5 hours through LOI - 2 hours; the 1 sigma value being .4 n.m. The significance of this, of course, is that our current midcourse correction logic makes it probable that MCC_4 will not be required and, therefore, it should be possible to perform LOI targeting as much as 5 hours before LOI without any additional error if it is operationally desirable to do so.

If you recall, on the C' mission we stated that MSFN ranging while the spacecraft was in lunar orbit was unnecessary unless orbit determination problems cropped up, which they never did. This same procedure applies to the F mission with one significant exception. In order to give us the greatest chance of solving our current lunar orbit determination and lunar gravitational problems, we would like to obtain as much MSFN ranging as possible during the landmark tracking exercise to be carried out on TEI day. Although not mandatory, we would like to assign it a priority high enough that it would be obtained even at some cost of voice communications and/or other things that might conflict with it. In other words, it is not trivial.

Bill

Howard W. Tindall, Jr.

PA:HWTindall, Jr.:js

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA FPMR (41 CFR) 101-11.6

UNITED STATES GOVERNMENT

Memorandum

NASA Manned Spacecraft Center

TO : See list attached

DATE: February 28, 1969
69-PA-T-40A

FROM : PA/Chief, Apollo Data Priority Coordination

SUBJECT: There will be no VHF ranging data collected while tracking the LM on the lunar surface

It has been suggested that, in addition to optics and rendezvous radar tracking one spacecraft of the other while the LM is on the lunar surface, we should also utilize VHF ranging. This data would certainly be useful for post-flight analysis if not in real time. I have attempted to resolve the situation with regard to obtaining this data and have come to the conclusion that it is too late to get it, as unfortunate as that may be. The basic problem is in the formulation of the RTCC program. And, the program changes required appear to be too large for obtaining data which at best must be labeled "desirable."

Through the years our plans for CSM tracking of the LM while on the lunar surface have all been based on just using the sextant. Obviously, we intended to use the Lunar Orbital Navigation program (P22), which not only provides automatic optics tracking but also complies the desired optical data, time tags, spacecraft attitude and landmark I.D. in a special downlist package for transmission to the MCC-H. The RTCC programs have been formulated to accept this data in that format and process it in real time.

First indications are that the spacecraft Rendezvous Navigation program (P20) would serve the crew as well as P22 for tracking the LM on the lunar surface with regard to automatic optics, and would have the additional advantage of including VHF ranging data on the downlist. Unfortunately, though, the P20 downlist format is substantially different than the P22 downlist and would require rather extensive changes in the RTCC program. For example, the sextant data is not stored in a batch of five observations as in P22 but would have to be stripped out one at a time as the observations are obtained. This could easily cause us to miss some points. But more important, the RTCC would have to be coded to store them for processing. Finally, it is to be noted that P20 only collects a VHF data point once per minute - almost not worth the effort! Implicit in the above is that VHF telemetry via the CMC is the only source; raw VHF does not come down directly.

In summary, we are abandoning efforts to get VHF for the G flight. It may be worthwhile to put in a PCR to add VHF sampling to the P22 program and its downlist at a reasonable data rate. Jim McPherson - would you take the action on this, if it seems reasonable to you?

Howard W. Tindall, Jr.

PA:HWTindall, Jr.:js

info

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA FPMR (41 CFR) 101-11.6
UNITED STATES GOVERNMENT

Memorandum

NASA Manned Spacecraft Center

TO : See list attached

DATE: March 12, 1969

69-PA-T-45A

FROM : PA/Chief, Apollo Data Priority Coordination

SUBJECT: Simplification to the pre-PDI abort procedure

As a result of a passing comment in one of my previous notes, Tommy Gibson and George Cherry looked into what it would take to provide automatic PGNCS targeting for LM aborts at initiation of powered descent (PDI). They found the capability already exists in the LUMINARY program. How's that for great!

The situation I am discussing is when the need for abort is recognized after DOI and before PDI on a lunar landing mission. The ideal procedure, of course, is for the LM to make a maneuver at about PDI time which will set up a nominal rendezvous sequence with CSI $\frac{1}{2}$ rev later. This is exactly what the DPS and APS abort programs (P70 and P71) do automatically, but it was thought these programs could only be used if powered descent was actually started and we certainly didn't want to start powered descent - a retrograde maneuver when the abort maneuver must be posigrade. That would make it necessary to execute a large attitude change while thrusting. It turns out that the crew may obtain automatic targeting for an abort maneuver by proceeding into the descent program (P63) just as if intending to land, except that he must maneuver the spacecraft manually into the posigrade abort direction prior to PDI time. He actually starts the DPS burn in P63 but since P63 does not start descent guidance until the engine is throttled up, it will automatically maintain the abort attitude the crew has established. After achieving engine stability at about TIG plus five seconds, the crew can press the Abort button which will automatically call up the DPS Abort program (P70) to compute the abort maneuver targets, immediately throttle up to full thrust, and control the burn.

This certainly seems like a straightforward procedure, completely consistent with standard descent procedures, and aborts immediately after PDI. I think we should establish this as our primary abort technique for this mission period.

Great work, Tom and George. Keep that up and I predict you'll go places.

Bill T

Howard W. Tindall, Jr.

PA:HWTindall, Jr.:js

info

UNITED STATES GOVERNMENT

Memorandum

TO : See list attached

DATE: October 25, 1968

68-PA-T-237A

FROM : PA/Chief, Apollo Data Priority Coordination

SUBJECT: X-axis or z-axis for LM TPI?

This memo is in response to a question that came up at the October 21 D Rendezvous Mission Techniques meeting. The question was: What is the additional LM RCS propellant cost if we use the z-axis RCS translation rather than the x-axis for TPI? Chuck Pace checked with the MPAD Consumable people who figured the x-axis would cost about 15 lbs. (taking into account the required attitude changes and use of the APS interconnect) and the z-axis will use at least 31 lbs. of RCS propellant (assuming the best CG location). These numbers are based on current spacecraft data book information. They intend to verify them through use of a 6D simulation program in the near future and will document the results.

In the meantime, we can probably use these estimates to decide which to use - x-axis which costs less RCS or z-axis which avoids breaking radar lock on.

Howard W. Tindall, Jr.

PA:HWTindall, Jr.:js

EA/Dr. Faget

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA FPMR (41 CFR) 101-11.6

UNITED STATES GOVERNMENT

Memorandum

TO : PA/Manager, Apollo Spacecraft Program

DATE: AUG 5 1968

68-PA-T-186A

FROM : PA/Chief, Apollo Data Priority Coordination

SUBJECT: Recommendation to retain the Two-Stage Lunar Orbit Insertion (LOI) Maneuver

This memorandum documents the results of our review of the two-stage LOI maneuver which you requested as a result of a recent OMSF suggestion that it might be preferable to return to a single burn plan. Participation in this review involved all operational elements of MSC concerned in this matter. The conclusions are unanimous.

Summary - It is recommended that the two-stage LOI be retained in the mission plan for the first flight to the moon. The justification cannot be based on numerical results of analyses. In fact, if you believe in "Three Sigma" system performance and/or that nothing unexpected will happen, it can be shown that a single LOI burn is safe and that a subsequent trim maneuver will not be needed. Except for the 30 pound RCS cost, no advantage or disadvantage can be assigned a specific value. That is not to imply that they are valueless, however. There are very significant considerations and it is our belief the advantages of a two-burn LOI substantially outweigh the disadvantages - including the 30 pounds of RCS.

Background - To insert into a 60 n.m. circular orbit it is necessary to make a LOI maneuver of about 3200 fps which requires an SPS burn of about 380 seconds duration. The acceleration at the end of this maneuver is approximately 10 fps/sec., which reduces the orbital altitude about 7 n.m/sec. of burn time. This maneuver can be accomplished in one continuous maneuver or can be discontinuous - that is, performed in two steps. The first stage of the two-stage LOI in the present lunar mission plan accomplishs all but about 150 fps (15 second burn duration) of the LOI resulting in orbital altitudes of 60 by 170 n.m.; the second stage completes the process of achieving a 60 n.m. circular orbit. The second stage is performed entirely in-plane and, with targeting based on lunar orbit MSFN navigation, will reduce the dispersion of the in-plane orbital elements significantly.

Monitoring procedures can be established for a single-burn LOI, which vote two systems out of three to assure a safe pericynthion. Therefore, if at least two systems out of three are working, we are assured a safe maneuver. Based on current estimates of systems performance (G&N, ΔV counter, and SPS engine), the monitoring procedure would cause the crew to shut off the SPS manually, unnecessarily about 20% of the time - that is, before a satisfactorily operating G&N sends "Engine Off." However, assuming that we can tolerate a dispersion of about $\pm$ 10 n.m. around the nominal 60 n.m. circular orbit, in no case (out of 100 runs) was an in-plane trim maneuver required. In fact, the manual intervention often improved the situation, providing a more nominal orbit than the G&N would have achieved. Furthermore, current estimates of systems performance (pre-LOI MSFN, G&N during LOI, and DPS during powered descent) assure us that no out-of-plane trim maneuver will ever be needed in lunar orbit prior to descent. (See comment no. 1)

The following is a list of advantages of a one-stage LOI:

1. It nominally saves about 30 pounds of RCS propellant which would be used during LOI_2 for ullage, alignment, and attitude hold.

2. Approximately half the time it reduces the number of SPS burns in a lunar mission by one. (See comment 3a)

3. It reduces the nominal lunar timeline approximately one revolution (two hours).

4. It reduces terminal supercritical helium pressure build up by about 20 psi. (See comment 3b)

5. It reduces cryogenic hydrogen and oxygen consumption about 0.5 pounds and 5 pounds respectively.

The following are advantages of a two-stage LOI:

1. Crew Safety

a. Protects against double failure including undetected systems degradation beyond three sigma.

b. Protects against the unexpected. This is the first attempt to insert into lunar orbit and experience has shown that the unexpected is likely to occur, particularly on first attempts.

c. Provides a more nearly nominal lunar operating orbit, thereby decreasing the ranges of conditions in Descent, Rendezvous, and Abort for which the crew must train.

2. Other considerations

a. Makes lunar operations more nearly nominal by assuring achievement of the pre-planned oribt. (See comment no. 2)

(1) Simplifies procedures - for example, permits use of pre-mission "canned" CSM LM rescue maneuvers and descent abort switchover points.

(2) Reduces dispersions on such things as DOI and CDH burn attitude.

(3) Helps in development and simplifies crew charts and similar operational aids.

(4) Reduces DPS budget a little bit.

b. Keeps timeline constant in the event a trim burn becomes necessary.

c. Makes the mission plan and crew procedures less sensitive to changes in systems performance estimates, development flight experience, etc.

d. Assures two good (i.e., complete) G&N tests as opposed to about an 80% probability of getting one.

e. Avoids a change in the mission plan and all it affects. That is, everyone has been going and thinking two-stage LOI for eight months.

The basic problem, of course, is in weighing these lists of advantages because none of the items on either list is overwhelming. Certainly, the extra consumable costs and the lower supercritical helium pressure margin of a two-stage LOI are affordable; on the other hand, it certainly cannot be said the added risk and greater in-orbit dispersions of a one-burn LOI are unacceptable. These things do not dictate the decision of which way to go. Nor does the nebulous added risk of an extra SPS restart. This system's reliability will have been proven more than adequately in-flight prior to this mission - certainly to the extent that a five-burn mission is not significantly more dangerous than a four-burn. This must be true since a relatively high probability, contingency situation requires as many as four or five extra SPS burns for CSM rendezvous maneuvers to rescue the LM.

It seemed to the review team that the one vs two-burn LOI decision must be based primarily on operational considerations - primarily the significant advantage of close-to planned conditions as they influence both a nominal flight and ones conducted under degraded conditions. For example, assurance of a nominal CSM parking orbit will help immeasurably in effecting the rendezvous and will substantially reduce the ΔV costs. (Add in a system failure - the rendezvous radar or (beacon) for example - and the advantages multiply.) AND, it reduces communication requirements on a nominal mission. AND, it simplifies everyone's job pre-flight and in-flight at least a little - sometimes a lot.

But most important of all is our concern for the consequences of the many things we will not have thought about but will encounter on the first lunar flight. Anything that can be done to keep the dispersions small and the procedures simple provides that much more tolerance for the unexpected and that much more time and attention that can be devoted to handling them. It seemed to us, the cost of the two-stage LOI is a small price to pay for these intangible but important benefits.

Howard W. Tindall, Jr.

Howard W. Tindall, Jr.

Enclosure

cc:
AA/R. R. Gilruth
CA/D. K. Slayton
FA/C. C. Kraft, Jr.
EA/M. A. Faget

PA:HWTindall, Jr.:js

COMMENTS

This appendix consists of a number of comments which amplify or explain statements made in the main body of this memorandum. They are separated into three categories: 1) How the out-of-plane is handled, 2) The in-plane situation, and 3) Consumables and other things.

1. How the out-of-plane is handled

We plan to make no plane change in lunar orbit prior to descent. It is expected the pre-LOI MSFN navigation and targeting plus G&N performance during LOI_1 will provide a more desirable orbital plane than could be obtained by a trim maneuver based on lunar orbit MSFN navigation and targeting. That is, after insertion into orbit no new information, upon which we would be willing to act, will be available until the sextant observations of the landing site are obtained on DOI day. But more important than that, there is no need to make a plane change prior to powered descent.

a. The three sigma out-of-plane dispersion of the LOI maneuver is currently estimated to be about 0.3°. Major contributors are pre-LOI MSFN navigation and targeting and G&N control through LOI which have been RSS'ed to obtain that value.

b. DPS ΔV required to perform an out-of-plane maneuver is almost exactly proportional to the square of the landing site displacement from the orbital plane. One half degree costs 10 fps by itself; however, when RSS'ed with other descent dispersions, it contributes only about 2 fps to the DPS budget.

Therefore, it is clear the LM has considerably more capability than is needed to handle the out-of-plane situation which will actually become known only when the sextant observations are made - even if MSFN is two or three times worse than we expect today. And, of course, we are extremely anxious to avoid this extra SPS burn in order to avoid impacting the DOI day timeline which is almost unacceptably crowded without it.

2. The in-plane situation

The problems in-plane are quite different. Although the mission techniques are nominally tolerant of fairly large ($\pm$ 10 n.m.) dispersions in orbital altitude, these dispersions have a highly undesirable affect on the flight from an operational standpoint.

a. Current estimate of the in-orbit dispersion due to pre-LOI MSFN navigation and targeting and G&N performance is in excess of 7 n.m. (three sigma). This could be reduced to about 2 n.m. (three sigma) based on post-LOI MSFN navigation and targeting and G&N performance through the short LOI_2 burn.

b. It may be argued that without actual experience we have no assurance the in-lunar orbit MSFN navigation and targeting will be of a quality to reduce the altitude dispersions as noted above. It is true the analysis that yielded those results is solely based on Langley Lunar Orbitor data whose orbit was not the same as that planned for Apollo. However, if it is not of that quality, the lunar landing is in jeopardy anyway. It is important to realize that MSFN is a vital in-line part of the G&N system - not a backup - and its failure would force switching to an alternate non-landing mission. The point is it either works that well or we don't land.

c. Considering the problems associated with determining the lunar potential, no plans are being made to make improvements in it during the operation. The point is MSFN performance in lunar orbit should remain essentially constant - not significantly better after a day than during the first revolution, although by then we should at least know how well it is working.

3. Consumables and other things

a. It can be shown that by taking advantage of the two-stage LOI targeting flexibility it is possible to eliminate one of the SPS translunar midcourse correction (MCC) maneuvers approximately half the time. Of course, avoiding this maneuver does not save ullage RCS since the MCC does not require ullage.

b. DPS supercritical helium pressure builds up continually from time of loading before launch until the DPS is used for Powered Descent. The loading technique is fixed and the pressure rises thereafter with no external control toward its red line value as a function of time at a rate of approximately 8 to 10 psi/hour. Assuming the higher rate and one complete extra orbit, the pressure increase is 20 psi.

c. Assuming a 90 amp load, the extra hydrogen consumed will be less than 0.5 pounds during the extra revolution. The oxygen used for power will be less than 4 pounds; adding metabolic and cabin leak oxygen of less than 0.5 pounds each, the total extra oxygen consumed in this revolution is less than 5 pounds.

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA FPMR (41 CFR) 101-11.6

UNITED STATES GOVERNMENT

Memorandum

TO : See list attached

DATE: JUL 30 1968

68-PA-T-173A

FROM : PA/Chief, Apollo Data Priority Coordination

SUBJECT: Pulse Torquing to Achieve IMU Realignments

This memo is to describe the gyro pulse torque realign capability being added to the IMU Realign Program in Luminary and Colossus, Jr. Most of it is quoted word for word from a memo Steve Copps (MIT) wrote last February proposing it.

"The purpose of the program is to provide the capability of moving the stable member from one orientation to another without losing inertial reference. The actual program change is an addition to the IMU Realign Program (P52). Presently a display comes on showing V06N22 and the gimbal angles which will be achieved by coarse aligning the gimbals. This display is being changed to provide the navigator the option of achieving the new orientation by coarse aligning <u>or</u> by pulse torquing ('enter' achieves one and 'proceed' the other).

"Obviously the most accurate method of realigning the IMU is to use star sightings, and if star sightings will be taken there is probably not much advantage to pulse torquing. However, if there is some doubt as to one's ability to acquire and mark on stars, or the inertial reference accuracy required in the next orientation is less than the error induced by pulse torquing, then this option has great value.

"The time to pulse torque to a new orientation is a consideration. The maximum time to coarse align is 15 seconds. The time to pulse torque is much longer. Since only one gyro is torqued at a time, the total changes in angle for each axis is summed together and that total angle is multiplied by 2 (torquing rate is approximately 1/2 degree per second) to obtain an estimate of realignment time.

"The induced error is directly proportional to the sum of the angles that each gyro is pulse torqued through. An estimate of the error induced is obtained by multiplying the sum total of change in angle by .002.

"So a single 90° yaw reorientation would take three minutes and would induce an error of .180 degrees. The time to pulse torque is alleviated by the fact that no star sightings are required following the alignment.

"It should be noted that during pulse torquing there is no need to hold the spacecraft in a fixed orientation since the IMU is always inertial. However, there is a possibility of pulse torquing the middle gimbal into gimbal lock. It was decided to do nothing about this problem and leave it to the astronaut to monitor the FDAI or N20 and maneuver if required."

The significant point to be made is that the change is being mechanized as an option in P52 - the IMU Realignment Program - and so the controls for achieving the new alignment are the same as exist for that program. That is, there is no direct way for the crew to tell the system to move 90°. Of course, he can probably fake it out by targeting an External ΔV maneuver he has no intention of making - say out-of-plane to get a preferred REFSMMAT and then go into P52 to realign the IMU to an out-of-plane orientation. This last paragraph is my comment. Don't call Steve if its nutty - or me either for that matter.

Bill

Howard W. Tindall, Jr.

PA:HWTindall, Jr.:js

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA FPMR (41 CFR) 101-11.6

EA5/P. M. Deans

UNITED STATES GOVERNMENT

Memorandum

TO : See list below

DATE: JUN 7 1968

68-PA-T-119A

FROM : PA/Chief, Apollo Data Priority Coordination

SUBJECT: Some alternate ways of figuring out where the LM is on the moon will be available

For some months we have been concerned with the problem of determining the LM's location after its landing on the lunar surface. This information is essential in order to do a decent job of Ascent targeting and, in fact, a significant error can even influence crew safety. Primary modes already implemented in the Control Center/RTCC for determining LM location utilize observations of the LM with the CSM sextant and/or observation of the CSM with the LM rendezvous radar. In each case, these observations are combined with a knowledge of CSM location as determined by the MSFN to permit locating the LM. Another rather simple technique we have developed essentially uses procedures and computer programs already available to do the job in the same way a sailor at sea does. That is, we are able to determine the LM's location on the moon quite accurately by making an AOT platform alignment using the stars and by doing a gravity alignment which in effect establishes direction of local gravity and by then combining the information obtained. MPAD is in the process of formulating the equations to provide this capability in the RTCC and Charley Parker of the Flight Control Division will submit a request for the RTCC program change through the regular channels. We will also initiate a PCR to implement something similar in the Luminary computer program if it's as easy to do as we expect.

This not only gives a completely independent means (i.e., data source) for doing this job which is valuable for cross checking the prime techniques, but it also could become the prime mode under certain circumstances. For example, if it is necessary to abort one CSM revolution after landing, we would likely use this technique for determining LM location to target Ascent, since by that time neither sextant nor rendezvous radar data will be available to do the job.

Howard W. Tindall

Howard W. Tindall, Jr.

Addressees:
(See list attached)

PA:HWTindall, Jr.:js

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA FPMR (41 CFR) 101-11.6

UNITED STATES GOVERNMENT

Memorandum

info
CA S/P. M. Deans

TO : See list below

DATE: MAY 29 1968

68-PA-T-108A

FROM : PA/Chief, Apollo Data Priority Coordination

SUBJECT: Spacecraft computer program - things dealing with lunar descent and aborts from it

1. I spent an interesting morning at MIT on May 16 with George Cherry, Dan Lickly, Norm Sears, and Craig Shulenberg talking about Luminary - how it works and some things that really haven't been defined yet. It primarily dealt with lunar descent and aborts from lunar descent.

2. Powered Descent Braking Phase (P63)

There is a question in MIT's cumulative mind as to whether the x-axis override logic is consistant with the current landing radar utilization logic. Recently a PCR was approved to permit use of landing radar data earlier in powered descent but no changes were made in the x-axis override logic. MIT questioned if this is consistant. However, more basic than that, there is the question of whether or not any of these things should be keyed to navigated altitude as they currently are, rather than time of initiation from powered descent or simply crew choice. I believe we all are concerned that using navigated altitude as the system is currently designed may cause the system to be locked out from doing the right thing. Specifically, if the PGNCS has computed the wrong altitude for some reason, even though the crew may know they are getting true altitude from the landing radar, there is no way to get the PGNCS to accept it. Although this probably won't happen, the consequences are so serious that none of us could see any reason for designing the system in this inflexible way. The way the guidance system currently weighs the landing radar data precludes its use above 35,000 feet based on some sort of radar specifications. Even if the navigated altitude were correct, we may be making a mistake providing this data lockout in the computer program at this early point in program development.

3. MIT would like to make a design change in the Powered Descent Landing Phase programs P65/P66/P67. As currently designed, the crew exits these final descent programs by hitting "Proceed," which causes the LGC to do such things as storing gimbal angles and LM position, turning off average "g," turning off the DAP, turning off the abort monitor (which prevents PGNCS recognition of an Abort and Abort Stage discrete), sets the lunar surface flag, displays LM position to the crew, etc. This procedure is enabled when the computer thinks the spacecraft is within 50 feet of the

lunar surface. There are two potential problems here. First of all the crew is within one "Proceed" of catastrophy if he prematurely hits the button inadvertently. This is unlikely but is also unnecessary since there is no need to terminate that program by a single key stroke. Worse than that, if for some reason the PGNCS never realizes the altitude is less than 50 feet, there is no way for the crew to terminate the program in such a way that all those important functions are carried out. It is MIT's proposal to change the design by adding a new program (P68) which would be called in a standard way via Verb 37. This program would do all the things previously done following the "Proceed" in the final descent program and could be exited directly to any callable program crew procedures dictate such as Ascent (P12) or IMU Alignment (P57). I think it is a good idea that they do that. P68 would not be called til several minutes after the lunar landing, of course, in order to maintain the PGNCS in a state of readiness to Abort Stage from the lunar surface, if that unlikely event were necessary.

4. I learned some interesting things with regard to the APS Abort program (P71) - answers to questions noted in last week's bulletin on aborts from powered descent. Specifically, P71 does not have any so-called short burn logic. That is, if P71 is called when the duration of an APS burn required to fulfill the targeting requirements is less than four or five seconds, the PGNCS will not provide a well controlled cutoff. Actually, what it will do following Abort Stage is to turn off the APS as soon as it sees what is going on, which will be late. I asked MIT to look this over and tell us exactly what will happen in this unlikely event - for example, how big an overburn will we get? I'm sure this is an acceptable situation and the procedures we outlined in last week's memo are still okay. Of course, it may mean that RCS trimming is needed but at least the spacecraft would be in a safe orbit while it's doing it. (Incidentally, if the crew wants to do four jet RCS trimming following an abort, they will have to call up the DAP data load (R03) and reset it from the two jet logic used in preparation for powered descent.)

5. Finally, MIT people noted that there are two ways of calling up the abort programs (P70 and P71). The preferable way, of course, is through the use of the Abort and Abort Stage buttons. The alternate means is using Verb 37. They noted that program coding and testing could be carried out more efficiently if we were to delete the Verb 37 mode. None of us could think of an occassion for using Verb 37 as the primary technique. In fact, the only contingency conceivable would be to backup the abort discrete. At the time, I was inclined to think that this was unnecessary but after further reflection, I am now reluctant to see that discrete backup removed, particularly in the wake of our stage verify discussions.

6. I expect to see some PCR's or PCN's in the near future on some of the things noted above. Maybe this note will give you a little time to think about them.

Howard W. Tindall, Jr.

Addressees:
(See list attached)

PA:HWTindall, Jr.:js

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA FPMR (41 CFR) 101-11.6

UNITED STATES GOVERNMENT

Memorandum

EA5/ P. M. Deans

TO : See list below

DATE: MAY 24 1968

68-PA-T-106A

FROM : PA/Chief, Apollo Data Priority Coordination

SUBJECT: Spacecraft computer program newsletter

1. I learned some things at MIT last week that seemed interesting enough to justify this note. Of course, it deals primarily with the spacecraft computer programs and their influence on the mission techniques we are developing.

2. Pete Conrad reported that during their KSC LMS simulation, they have experienced an apparent deficiency in Sundance when making a docked DPS burn. He says that the DPS engine gimbal angles do not get changed at all during that low thrust period at the beginning of the burn which was provided specifically for trimming them. MIT looked into this problem and agreed that for some reason the program does appear to work - or not work - like Pete says. Their preliminary guess as to the course of this is that with low thrust and high inertial the gimbal trim estimator may be experiencing underflow. That is, the computer is simply not able to determine that a movement of the trim gimbal is necessary as it is currently coded. Of course, the RCS jets are very active both before and after throttle up.

3. Our requirements for getting rendezvous radar (RR) data on the downlink while the LM is on the lunar surface was discussed again, and I am afraid I really blew it. MIT has resisted the program change we requested and I am beginning to think they may very well be right. That is, I am not so darn sure any more that the program as currently designed and coded is not good enough. In any case, George Cherry now proposes to look into a very simple change which can be made in the lunar surface navigation program (P22), which would substantially increase the frequency of RR data on the downlink. All that it amounts to is to remove the delay after the previous computations before the computer collects another batch of RR data. Right now this delay is 15 seconds. If we eliminate this delay and operate P22 in the "no state vector update" mode, the computer should cycle very fast. George Cherry is going to make an estimate of what this RR downlink frequency would be as well as evaluating the schedule impact for this change. I would be surprised if it is not acceptable to MSC even if it is not perfect - whatever perfect is.

4. As Colossus is currently designed, the crew is required to press the "Proceed" button during the period of maximum reentry G's to obtain a DSKY display change. A PCR had been submitted to make this procedure

automatic. However, on future consideration, we are not so sure that it is a good thing to do. The initial display parameter in P65 are used in the primary go/no go logic employed by the crew in evaluating the G&N performance to decide whether to stay on it or to go with the EMS backup. It is essential that they see these parameters and an automatic "Proceed" could wipe them out before they have seen and digested them under certain circumstances. Accordingly, I suspect we should delete our request. The discussions have revealed, however, that some modification in the coding will probably be needed to make sure the system will work throughout the rest of the entry even if the crew does not provide the "Proceed" signal.

5. Here is one more note in the continuing "Stage Verify" story. According to John Norton the lunar ascent program (P12) no longer checks stage verify. That strikes me as a real improvement in the program but it mystifies me as how it go changed without a PCR or PCN, or even letting anyone know. Norton, of course, uncovered it by going meticulously through the program listing.

Howard W. Tindall

Howard W. Tindall, Jr.

Addressees:
(See list attached)

PA:HWTindall, Jr.:js

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA GEN. REG. NO. 27

5010-107

UNITED STATES GOVERNMENT

Memorandum

EA/M.A.-Faget

TO : See list below

DATE: MAR 13 1968

68-PA-T-60A

FROM : PA/Chief, Apollo Data Priority Coordination

SUBJECT: Lunar Reentry Mission Techniques meeting - March 7

1. On March 7 we had a Data Priority Mission Techniques meeting on lunar reentry. This was the first on this mission phase with contractor participation. Our objective was to understand the current status of the business and to begin pinning down the operational procedures to be used onboard the spacecraft and on the ground. We were particularly interested in data flow, decision points and logic, and the actual detailed techniques to be used during this phase of the mission. Although we intended for it to start just prior to the final (third) midcourse correction on the way back from the moon, it turned out the discussion unavoidably included activities earlier in the flight, starting with the Transearth Injection (TEI) maneuver itself. Generally speaking, I would say this mission phase is better understood and more completely developed than any other in the lunar mission. A reasonable set of mission techniques is more or less in hand right now. Of course, there is no question that significant changes will be made based on further analysis and actual flight experience.

------ Paragraphs 2 through 5 deal with the midcourse correction maneuvers ------

2. Jerry Yencharis (MPAD) briefly discussed the second midcourse correction maneuver (MCC2). It is a maneuver to be made entirely in-plane designed to achieve specific entry interface conditions consistent with a safe reentry and controlled landing point. Analysis summarized in Figure 1 has shown that this maneuver can be made efficiently anytime in the period between 15 and 25 hours before entry, and so it should probably be scheduled to fit the crew work/rest cycle. However, some consideration is being given to rescheduling it in real time based on its magnitude. Obviously, both the nominal time and real time decision logic must be worked out before that (i.e., now). One question to be resolved involves basic "small maneuver" philosophy. Specifically, should maneuvers of a magnitude less than the targeting uncertainty be made? We have generally said that they would be so that dispersions would be equally distributed plus and minus. This, however, is not the currently proposed technique for these midcourse corrections, and deserves further examination. It is clear that if this maneuver is made we'll use the External Delta V guidance mode with the SPS engine (if it is in excess of 8 fps). And it will be targeted from the ground. Platform orientation can be determined either onboard or on the ground; this appears to be pretty much a crew preference, and we'll be interested in their decision.

3. A third midcourse correction (MCC3) is scheduled in the timeline 2 hours prior to entry. The real time decision as to whether or not this maneuver need be made is carried out as follows: The desired flight path angle at the entry interface is compared to the predicted value assuming no MCC3. Only if the difference in these two exceeds $.36^{\circ}$ will the maneuver be executed. This limit has been selected to insure a safe reentry but is large enough to make the need for this maneuver extremely small. For example, a 200 sample Monte Carlo study was made, and in no case was the MCC3 required. In fact, the largest flight path angle difference was only about $.25^{\circ}$ (see Figure 1). It has been established that this maneuver will be entirely inplane, targeted from the ground to achieve the desired flight path angle and will utilize the External Delta V guidance mode. Of course, the inertial platform must be aligned prior to this maneuver. Its orientation will not be constrained to provide any particular pitch attitude display on the FDAI 8-ball during the burn. Of course, the ORDEAL could be used to give all zeros on the 8-ball. The actual REFSMMAT to be used during the MCC3 and reentry will be computed and relayed to the crew from the ground to provide 0, 0, 0 on the ball at 400,000 feet altitude when the spacecraft is in a heads down, in-plane, horizontal, wings level attitude, heat shield forward.

4. It has also been established that preparations for all maneuvers are begun 2 hours and 40 minutes before time of ignition to allow sufficient time to activate the systems from a standby state, to get all of the initialization data input into the system and to make all of the various checks to develop confidence that the burn will be made properly. It was also decided that the same timeline for bringing up the system, aligning the platform, etc., would be utilized regardless of whether the MCC3 maneuver is made or not. FCSD people involved in crew timeline development took the action item of making sure this is an acceptable approach.

5. Although major emphasis at this meeting was devoted to nominal reentry procedures with all systems working properly, we did depart long enough to discuss briefly current plans for handling communications failure occurring at about the time of the second midcourse correction or later. Specifically, it was stated that if the ground has transmitted to the spacecraft its MCC2 state vector and targeting command load prior to communications failure, there should be no attempt made onboard the spacecraft to perform onboard navigation using the sextant. The point is that onboard navigation can foul up the state vector and some of us intuitively feel it better to stick with the last set sent from the ground for entry if it is that current. Various people did not agree with this rule, of course, and so an action item was promptly levied upon them to determine a superior alternate approach in detail. In the meantime, we will continue on as described above.

------Paragraphs 6 through 12 deal with
entry preparation------

6. At present the reentry guidance philosophy includes two planned landing areas (PLA) which are illustrated in Figure 2. (All figures attached are courtesy of MPAD's Lunar Mission Analysis Branch.) PLA 1 is a thousand mile band including the primary landing point and giving the capability of bad weather avoidance. In the event of PNGCS failure a shorter range landing point, PLA 2, is designated consistent with a no skip, constant g reentry which is the planned backup reentry mode. Efforts are being made to determine if the PLA 1 range can be made to include PLA 2 with current PNGCS hardware and software implementation. If so, it is probable PLA 2 would be selected as the primary recovery area in order to make PNGCS, EMS and backup techniques all compatible.

7. With regard to the constant g reentry, the MPAD reentry people have the action item of preparing and delivering updated constant g reentry load factor profiles to FCOD for their evaluation and, hopefully, buy off. We anticipate no problem on this. Typically, they are a 4 g reentry with a 4 minute duration or a 3 g reentry with a 5 minute duration, sometimes preceded by a high acceleration, short duration spike (See Figure 3).

8. It was established that as long as communications exist with the ground, MSFN data will be used for EMS initilization. This activity will be scheduled at some convenient time, probably an hour or so before entry, since it is not time critical. Although the PNGCS computer is programmed to provide this data, there is no need to pay any attention to it unless communications prevent receipt of the ground update.

9. Command module/service module separation will be carried out using manual attitude control and will occur approximately 15 minutes before EI. It was stated that the Descent program (P-61) will be called up approximately 2 minutes prior to that event. This will enable the PNGCS to accept accelerometer inputs making it aware of any small spacecraft translations due to separation itself and/or due to subsequent attitude control. (Recall command module attitude control is not done with balanced couples.) Since accelerometer bias could accumulate over a period of time as a significant contributor to missing the landing point, we spent some time discussing the question of whether or not allowing the guidance system to accept accelerometer input for 20 or 30 minutes prior to entry interface is acceptable. According to recent analysis (summarized in Figure 4), down range miss distance due to a 3 sigma accelerometer bias (calibrated inflight) would be about 10 miles, and cross range would be about half that much, even if Average G is enabled by the Descent program (P-61) 30 minutes prior to entry. Some consideration is apparently being given to adding an accelerometer threshold limit into the computer program to avoid this small error. Since this worst case error is really quite acceptable, I would oppose any such program change which I assume would only be made after approval of a formal program change request.

10. Claude Graves' people presented some data to show the magnitude of landing point miss due to platform misalignment, the major contributor (see Figure 5). He showed that with 3 sigma gyros the miss distance was nearly linear at the rate of about .6 of a mile down range and 3 miles cross range for each hour spent between the last platform alignment and the entry interface. Since a 3 or 4 hour period of drift would only result in about 12 miles miss at the worst, we felt it unnecessary to make any further platform alignments after the third midcourse correction.

11. Some thought was given to making a spacecraft attitude check using the sextant prior to reentry; however, it was concluded that this really accomplishes very little. Confidence has been developed in the PNGCS prior to the MCC3 maneuver and so we would only be uncovering failure subsequent to that. Furthermore, there are a whole series of PNGCS performance evaluation tests associated with the reentry itself made before committing to the PNGCS and there is nothing that could be done to fix the system if it has failed in that short time. All of which says, the test is useless. Accordingly, although FCSD has not completed the detailed timeline yet, as of now there is no known reason for the crew to leave their couches after MCC3.

12. We had a lengthy discussion with regard to initialization and use of the EMS roll stability indicator (RSI), also known as the roll attitude indicator and lift vector indicator. Apparently, this device is merely a repeater from the FDAI roll bug driven by the GDC. It was originally included in the EMS when there was only one FDAI in the spacecraft. However, now that there are two FDAI's its purpose and value are rather nebulous. Actually, the discussion took a surprising turn. We started out trying to figure out how to initialize the damn thing and after much emotional, confused talk we seemed to arrive at the conclusion that it really has very little value. Mike Collins intends to obtain a crew position on this, and Clyde Paulk was requested to pulse G&C on the same subject. The thing that bugged several of us is that we shouldn't have something displaying wrong information in the cockpit, and so we should either cover it up with masking tape or else we should line it up properly, no matter how useless it is. The problem is that the way the PNGCS controls attitude is not consistent with the RSI alignment procedure. Therefore, it requires the crew to control spacecraft attitude manually until .05 g. Actually, I am not so sure if that ought not to be the procedure anyway, in order to utilize the horizon as an independent check that the spacecraft is in proper pitch trim attitude to insure aerodynamic capture of the spacecraft in the proper attitude. Left unresolved was whether we should submit a program change request to make the Colossus lunar return reentry program compatible with that procedure.

5

------Paragraphs 13 through 19 deal with------
entry proper

13. The remainder of this meeting dealt with reentry procedure based on Figures 6 and 7 which are attached to this memorandum. Generally speaking, these procedures for monitoring a nominal reentry and carrying out a backup reentry seem to be well thought out and complete. Obviously, there are still a number of relatively minor refinements or changes which have to be made. Some of these are the items reported in the following paragraphs.

14. Probably the most important decision to be made during reentry occurs when the reentry program changes from P-64 to P-65 which occurs just about at the time of peak g's. At this time, a display of predicted exit velocity and drag level (VL and DL) appears on the DSKY. The crew must determine if these values are within limits determined by the ground and relayed to the crew as part of the standard entry preparation procedure. If they are within bounds, the crew commits to the PNGCS. If they are outside, the PNGCS has failed and the crew takes over and flies constant g reentry to PLA2. An important point to be made here is that the primary PNGCS Go/No Go check is based on a comparison with the ground and that this is considered absolute! Of course, the crew does monitor the EMS for scroll line violation which also could result in abandoning the PNGCS, but that is not a comparison of one system against the other for performance evaluation. The criteria on which this test is based is expected to be tied to the accuracy with which the ground is able to predict these parameters as opposed to being selected to establish such things as 3 sigma PNGCS performance, assurance of landing within some specified distance of the recovery force, or assuring reentry itself---although it better do at least that! Graves' people are in the process of determining values for these limits and then we will know what sort of reentry may be assured. They expect this work to be completed at least six months prior to the "E" mission.

15. It was noted in this discussion that a second set of DSKY display parameters are available in P-65 by a crew input of "proceed" to the computer. It is evident that the crew is not likely to perform that operation while experiencing 5 g's, so Graves was given the action item of determining whether these display parameters (inertial velocity and altitude rate) are of any real use to the crew. If they are, it will be necessary to submit a Colossus program change request to make their appearance automatic probably after display of VL and DL for a fixed length of time.

16. Another PCR Graves intends to submit for Colossus No. 2 would make PNGCS control of attitude be lift vector up until .2 g's during "second entry" following a skip. This is felt to be mandatory since a pitch trim attitude check on the horizon is critically needed at this time. At present the computer program will drive the spacecraft attitude to whatever bank angle is consistent with the reentry guidance objectives even though prior to .2 g's the aerodynamic forces contribute very little to landing point control.

17. Graves' people were requested to examine the EMS scroll lines to make sure no EMS line violation during the second entry would cause the crew to take over from a perfectly operating PNGCS. That is, we want to make certain that sufficient margin is provided to prevent this from happening.

18. Both MPAD and G&C were requested to develop some sort of tests to be included in the reentry procedure to determine if the EMS is performing properly. NR will probably do some work on this, too. The point is, it was apparent from our discussion that all performance evaluation was centered on examination of the PNGCS with switchover to the EMS in the event of its failure. What seemed to be missing was performance evaluation tests of some sort to make sure the EMS was working well enough to be used.

19. Based on this day's discussion TRW will prepare a mission techniques flow diagram to start the review cycle on this mission phase. After a couple of internal MSC meetings, I expect we will again call in MIT and NR and see if we can't put this business on ice.

Howard W. Tindall, Jr.

Howard W. Tindall, Jr.

Enclosures 8

Addressees:
(See attached list)

GSA FPMR (41 CFR) 101-11.6

UNITED STATES GOVERNMENT

Memorandum

MAY 17 1967

TO : See list

DATE: MAY 1 7 1967
67-FM1-39

1/2

FROM : FM/Deputy Chief

SUBJECT: A new spacecraft computer program development working philosophy is taking shape

It's becoming evident that we are entering a new epoch regarding development of spacecraft computer programs, and I thought I'd try to put my impression relating to this into words and get them out in the open.

Until a few months ago, our most basic problem was getting the spacecraft computer programs - and ultimately the flight ropes - completed in time to support the official flight schedule. This presented such a challenge to the people involved that intense reluctance was created to making changes and, after a certain point, even correcting known deficiencies in the programs. Where necessary, work around procedures were invented as the only possible solution. Since the January accident the situation has changed considerably in two ways. First of all, the flight schedule has slipped to an extent that computer program development no longer paces the flights in any way (including crew training and system tests) and, secondly, the value of quality has become supreme. These things are most clearly evident right now on LM-1 where it's almost unthinkable to fly with any known deficiencies in the program - even those which would only affect very low probability contingency situations - in spite of the fact that the flight ropes have already been manufactured. I feel it's quite likely the decision will be made to rework the LM-1 program and remanufacture ropes regardless of impact on any of MIT's program development work, including delivery of the manned mission computer programs. In fact, we have asked MIT to determine the extent of this across-the-board impact assuming all of the known deficiencies in the LM-1 program are removed, no matter how minor. Much more significant, however, is that without doubt this situation is forcing us to adopt a new working philosophy which should be recognized and included in all of our planning - program development schedules, man loading, crew training, spacecraft systems tests, etc. It is clear that, as Ed Copps puts it, program "shelf life" is very short. That is, it is extremely unlikely we will ever fly with ropes manufactured substantially in advance of the mission; instead of releasing the flight program for rope manufacture at the earliest possible date we should release it at the latest possible date.

The next question to be answered is - how far should the work on these assemblies proceed before being frozen (if you call slush "frozen") and put on the shelf until some key milestone associated with spacecraft flight readiness? Should complete flight qualification Level 5 testing be carried out with the realization that changes will come along forcing us to revise the program and thus to repeat substantial portions of the flight verification? Or should we merely carry the program development through Level 4 testing, resulting in an assembly on the shelf which is bug free as far as we know, but which has not been completely flight qualified? There are arguments for both positions. We have asked MIT to consider this subject - program development working philosophy - and to recommend their preference. We here at MSC will do the same and within a month will be prepared to adopt what appears to be the best over-all compromise. In any case, I'm sure it will force us to maintain a larger MIT staff and more program development facilities in order to be in a position to maintain and modify these programs until we finally release them. And we are less likely to have to throw sets of ropes in the garbage can so often.

I'm not trying to flag this all out as a big problem area. It should certainly be easier to handle than our previous "schedule is king - anything is better than nothing" type of problem. But I'm sure what we do will have some fairly significant implications on everyone involved in the business of program development as well as the various users of their product and I thought it worthwhile to bring it to your attention.

Howard W. Tindall

Howard W. Tindall, Jr.

Addressees:
(see page attached)

67-FM1-39 2/2

First page of this memo retyped and italic text included by David T. Craig (736 Edgewater, Wichita, Kansas 67230) on 10 April 1991 to make the memo physically readable and to clarify the facts of this memo

United States Government
Memorandum

TO: See list below — DATE: OCT 18 1967

FROM: FM / Deputy Chief (*Howard W. Tindall, Jr.*) — 67-FM-T-85 1/2

SUBJECT: Spacecraft computer program development improvements to be utilized by MIT (*Massachusetts Institute of Technology, Draper Labs*)

1. Just for the record, I would like to record a list of program development improvement ideas which MIT plans to incorporate. This list was gleaned from discussions by Ed Copps (*Edward M. Copps*), Fred Martin (*Frederick H. Martin*), and Alex Kosmala (*Albrecht L. Kosmala*) during the week of October 2, 1967.

a) Much more complete program structure design work will be done prior to program integration. This includes more precise definition of the program module interfaces. And I suppose things like allotment of computer memory.

b) Control of program constants will be *exercised* (?) to insure their accuracy and to avoid duplication from one procedure into another.

c) In order to avoid the problem of erasable memory conflicts a panel is being established to manage the use of erasable memory.

d) MIT proposes to initiate a series of periodic internal program design reviews.

e) Approved program changes will be considered by MIT as they arrive from MSC (*Manned Spacecraft Center, Houston, Texas [a.k.a. JSC]*) but will be added into the flight program assemblies in blocks periodically as opposed to randomly as in the past.

f) Much tighter assembly control will be exercised with all program modifications being monitored and reviewed by a higher level of MIT management. Only those changes really necessary will be permitted. New assemblies will only be produced once a week as opposed to the much higher frequency hitherto.

g) Associated with assembly control, specific processors will be "sealed" internally in the assembly as they become operational as opposed to the current practice of putting the entire program under configuration control when all components are working.

h) It is my understanding that at present digital autopilots (DAP) are available for both the LM and command module. On the other hand, design improvements will probably be necessary on a fairly continuous basis. All modifications in the DAP's will be made and checked out in some program other than the current flight program assembly used by the rest of the program development personnel. Modified DAP's will only be added to this working assembly when they are running properly.

i) Much more coordination and communication between the various groups involved in software development is essential. It is Martin's intention to establish standing committees with periodic meetings for this purpose. These meetings will also be used for consideration and coordination of proposed changes.

j) Apparently, in the past development of program test plans has been carried out by a small group without much assistance, advice or coordination with other interested parties. Wider participation in this effort both at MIT and MSC is planned.

k) MIT has finally decided to utilize discrepancy reporting like we have requested for well over a year and which has recently proven to be of great value to them in the latter stages of the SUNDISK development. They intend to utilize this from the beginning on the remaining programs.

l) Associated with the discrepancy reporting, MIT will maintain an up-to-date operational constraint list. Obviously, one way in which discrepancies may be eliminated is by establishing work around procedures or operational constraints on program usage.

m) Steps are being taken to make sure that as problems are found and corrected in one major program these same flaws are corrected in the other programs (e.g., SUNDANCE and COLOSSUS).

n) Slow response in the exchange of data, particularly spacecraft characteristics, has delayed MIT previously. Steps are being taken at both MIT and MSC to provide faster response. When necessary, in lieu of answers from MSC, MIT proposes to state their assumptions and proceed ahead with program development to avoid delays of this type.

2. As you can see, nothing particularly startling here but I believe everyone would agree those are all good things to do, that is, they should improve the quality of the program itself and should certainly result in getting the job done faster. MIT has recently reorganized their personnel somewhat, hopefully in a way that will allow them to implement these ideas effectively.

Howard W. Tindall, Jr.

Addressees:
(See attached list)

67-FM-T-85 2/2