Massachusetts Institute of Technology
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DG Memo No. 1475

TO: R. Larson

FROM: S. Davis

DATE: November 10, 1969

SUBJECT: LMA Deorbit Burn

Summary: A procedure for the flight controllers is recommended (Section I-B). Other methods are discussed and a strip chart history of a typical "Ullage Burn" is presented.

A request was received last week to look into several aspects of the planned LMA Deorbit Burn. This unmanned burn will be made to put the LM ascent stage into a lunar impact orbit as a test of the seismometer and will be made using the auto ullage feature of P42.

I. Procedures

The burn will be under ground control. The procedures are summarized as follows:

Rendezvous
:
P30 - with pad
R03 - 5 deg deadband
P00
Mode control to Auto (from free)
CM SEP
Gnd call P42
Auto trim (R60)
Enter on FL V99 when burn cutoff criteria reached

As it is desirable to have Lunar impact at a specified location the point at which the flight controller ENTERS on the flashing Verb 99 becomes critical. The problem is further complicated by the fact that there is a signal transit time of nearly 2 seconds each way and the flight controller, for all practical purposes, has only the downlinked DSKY display (N40) to guide him. The remainder of this section discusses several criteria the flight controller may use.

A: using VG or ΔV (R2 and R3 of N40)

One criteria for "Entering" would be when either VG, the remaining velocity to be gained, or ΔV measured reached a given value. An inherent problem in using either variable as a criteria is that the display is updated only once every 2 seconds, making any estimations difficult. A typical delta V gained in 2 seconds with 4 jet ullage is 4.8 fps for an almost empty LMA.

Any cross axis accelerations will affect the VG and ΔV displays. These may cause the flight controller to err. To illustrate, due to the vehicle dynamics there is a cross axis acceleration during ullage results in a ΔV_y of about 5 fps per minute. Being unaware of this at the time, the author made a run using the criteria of VG being less than 5 fps. Since VG never went below 5.4 fps, the "ENTER" was not made at the proper time resulting in residuals (N85) of -9.6, 5.5, and 0.7 fps. In the mission the targets will be biased for this cross axis acceleration, but biasing the targets will not remove the effect of the cross axis acceleration on the DSKY display (N40). Assuming the flight controller is aware of the situation, the fact that VG does not approach zero, but some function of time, may degrade his performance.

As indicated the author found it difficult to keep the residuals small using a velocity criteria. In six or seven runs made using this criteria and with 4 jet ullage the average magnitude of the X axis residual was about 7 fps. Perhaps with more practice and concentration the error could be reduced, but the author still does not recommend this method.

B: Time criteria (R1 of N40)

This criteria would be to Enter on some value of TFI (R1 of N40). In this method the flight controller would determine the burn duration and bias it by the signal transit time and the 3 1/2 seconds ullage starts before TIG. It should be noted that TFI is incremented every second (If no PRO on V99) and that estimations of fractions of a second are not difficult to make.

The calculation of the value of TFI to Enter on could be made before hand on the basis of vehicle weight and RCS thruster data. Or it could be calculated during the burn by the following method

1. Find the ΔV gained during 2 seconds. This can be calculated before hand or found by subtracting any two successive displays of ΔV (R3 or N40) which will be small and easy to handle at TIG.
2. Look up DSKY display time the "Enter" should be made at using the graph given in figure 1 (or 1A) or a similar one based on perhaps more accurate data.

The plot given in figures 1 and 1A takes into account the 3 1/2 seconds of ullage before TIG and supposes a 3 second total transit time.

The flight controller should have no difficulty in using this method, including the ΔV calculation, as he will have at least one full minute before having to take action.

The author has made several runs using this method and has had very satisfactory results. The VX residuals have all been less than 3.5 fps.

A word of caution, if you will excuse my being presumptious, would be to make sure the Auto trim maneuver (R60) is exercised at least once. In past missions APS to depletion burns have been made by the CSM maneuvering the LMA to the burn attitude prior to separation and the trim maneuver in P42 being bypassed. This meant that the LM could have an attitude error at ignition of as much as 5 deg per axis (at SEP the LMA is in a 5 deg deadband. When P42 is entered, it sets the deadband to 1 deg about the angles it found until the trim maneuver is performed.) However, once the APS was lit, the DAP steered the LMA to the proper attitude. In this case, though, no such steering will occur and a reasonably large burn error may result.

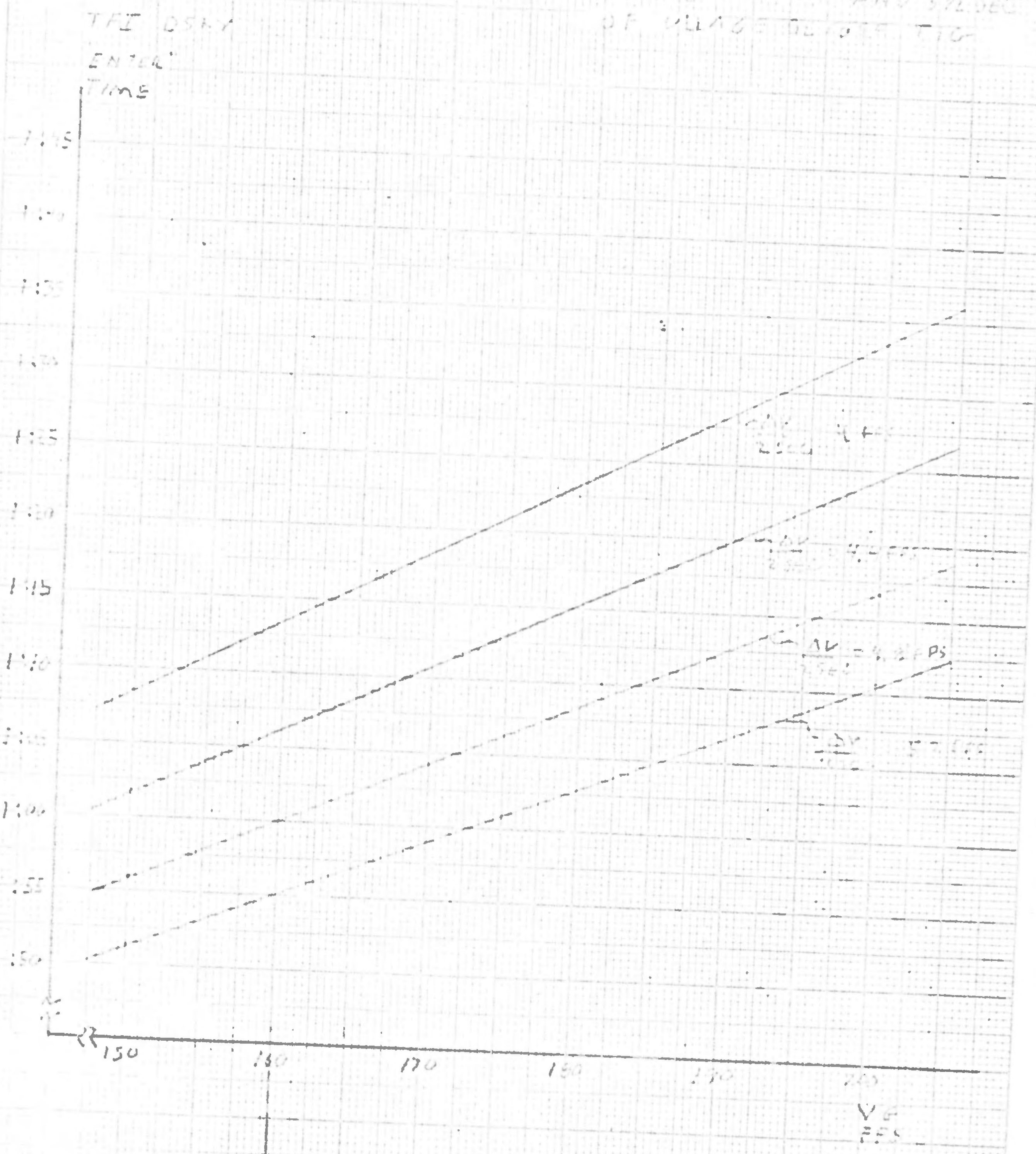
II. Performance

Due to the time limitations a detailed analysis of the LM performance during an "ullage burn" has not been made. Enough tests have been made, however, to show that such a burn will give satisfactory results.

For demonstration purposes a 200 fps ullage burn was made on the Hybrid. The platform was aligned such that at ignition the gimbal angles were close to zero. A strip chart history of the run is presented in Fig. 2. During the burn the platform angles remained within the 1 deg deadband. The drifting off of the gimbal angles after the burn is accounted for by the DAP being reset to the 5 deg deadband. The burn was terminated using the method suggested above. The residuals were (N85) 0.9, 5.4, and 0.4 fps body axis X, Y, and Z respectively. It should be noted that in all the runs performed a VY body axis residual of about 5 feet per second occurred and that this is attributable to the dynamics of the extremely light vehicle.

FIG. 1

[illegible]
[illegible]
[illegible] AND 3½ SEC
[illegible]



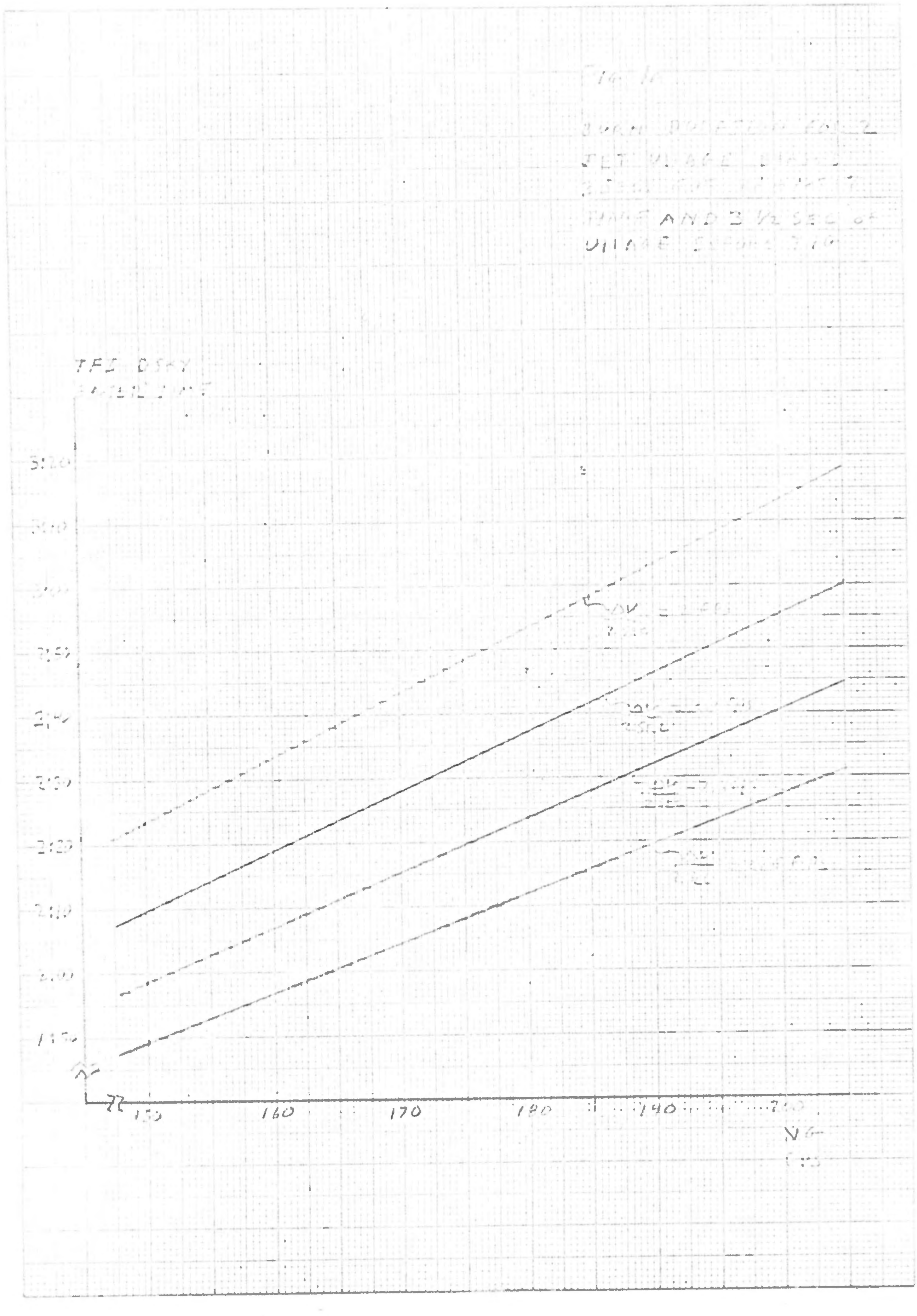

AND 3 ½ SEC OF
150
160
170
180
190

Fig 2.

200 FPS "Ullage Burn"