R. Larson

Mission Techniques Memo #39A

TO: Distribution
FROM: Malcolm W. Johnston
DATE: October 2, 1969
SUBJECT: "H" Odds and Ends - Some Important!

1. Several LOI abort procedures call for docked, manually guided "DPS or APS pushing CSM" burns! MIT has not investigated the consequences of such procedures . . . dynamic stability etc !!

2. To stay in P40 (N85 display) after a guided DPS burn has been interrupted by a manual APS burn (LOI Mode IIA abort), must reset the thrust fail routine after the APS thrust has built up .. .. via enter/enter on V97/V99! This procedure will result in the software issueing an engine off signal, therefore, a manual "Engine Start" must be exercised first to inhibit receipt of this engine-off discrete. (See item #25).

3. Some contingency situations call for an SPS guided burn while docked with a full APS. (LOI abort where SPS was shutdown on loose limits, DPS exhausted, and SPS called upon to finish abort ... rather than immediately asking for an APS burn). What should DAP configuration be? Any problems?

   Ans. Same as for SPS pushing an empty APS (i.e., "CSM only" option and correct mass loading).

4. An intermediate throttle up of the LM DPS during a docked burn is still required. See enclosed Luminary Memo #93 by J. Jones.

5. A new ORBRATE routine (R64 is described in the enclosed Colossus Memos #203 and #217 by J. Turnbull.

6. The enclosed Colossus Memo #213, by W. Ostanek, describes a procedure for replacing a bad "other vehicle" state vector without ground update.

7. What is the best procedure for exiting the average "G" routine in a hurry after a burn (to avoid effects of pipa bias), and still obtain the burn residuals on the downlink? For both CSM and LM!

   Ans. The residuals are on the LM Coast and Align downlist, therefore can exit burn program immediately ... to Poo. For the CSM, again exit to Poo, then call N85 which will display these residuals in body coordinates. (i.e., PRO, PRO, 00, enter, call N85).

8. As in "G", up to 5° platform misalignment from the nominal landing site orientation (not alignment uncertainty) can be tolerated and still not degrade the landing accuracy significantly. MSC has said such a misalignment from nominal, of about 1°, would result if a second PDI opportunity was required. (See MTM# 29A, item #4).

9. For Apollo #13 the LM will be undocked one rev earlier than on #11 and #12, thereby allowing two back-to-back AOT alignments (separated by one rev) prior to descent. For Apollo #12, we will still determine IMU drift via comparison of the docked alignment and the single, pre-DOI AOT alignment. The docked alignment uncertainty, however, will be considerably less than on "G" due to incorporation of R. White's ground procedures . . . unfortunately, these will be dropped for Apollo #13. In fact, it may be better to depend on the docked alignment and use the subsequent AOT sightings (don't torque

gyros) only as a check. (Docked LM drift determination now seems possible). Of course schemes must be worked out to anticipate the PDI misalignment and bias RLS accordingly, or to update the gyro compensation or torque the gyros to insure proper PDI alignment. This investigation seems worthwhile though . . . because IMU alignment error at PDI is extremely important for pinpoint landings!

A 1 mr out-of-plane alignment error at PDI causes a 1400 ft cross-track error. A 3 sigma PGNCS could easily cause twice this misalignment. Moreover, the present plans for drift and alignment accuracy determination for both Apollo #12 and #13 could not detect such a misalignment.

10. Several questions concerning the above have been raised: How accurate will the drift and alignment determination be? Could (should) we update gyro compensation or RLS. What should the pre-DOI drift "Go/No Go" limits be?

Ans. AOT alignment accuracy is about 2 mr / axis (3σ). Two alignments, about 2 hrs apart, result in a drift indication uncertainty of roughly ±0.075°/hr. (This is a conservative number when applied to Apollo 12 where the first AOT alignment is replaced by R. White's more accurate alignment determination). If drift indications are less than about 0.25°/hr DOI should be Go. If not, NoGo DOI and get another AOT alignment. May update gyro compensation after this second drift check, if data is consistant, to get below our 0.25°/hr limit. However, RLS or gyro compensation updates to meet pinpoint landing requirements could not be made with much certainty.

Note: The pre-DOI Go/NoGo limit of 0.25°/hr depends on a single AOT alignment. If this is improperly performed . . . DOI will be "NoGo"; procedurally, it is nearly certain that a gyro compensation update will have to precede the subsequent AOT alignment (contrary to our request above), therefore, this update will be in error; the following AOT alignment will be confusing as a result; and the landing will most likely be aborted. In other words, that AOT alignment is sort of a "single point failure"! Isn't it possible to squeeze that Apollo #12 AOT alignment 10 minutes earlier so that it may quickly be repeated if the torquing angle limits are exceeded??

11. R. White's docked alignment determination is sensitive to excessive time separating the required attitude maneuvers. However, the entire four sets of gimbal angles for "H" will be obtained in about 30 minutes. Even this effect may be eliminated by iteration . . . it's now being investigated.

12. The enclosed STG memo #1409 by R. Lones contains MIT's recommendation for handling gyro compensation updates when sign changes are involved.

13. For all AOT platform alignments the crew plans the following sequence: Spiral - Mark - Cursor - Load - Cursor - Mark - Spiral - Load - Spiral - Mark - Cursor - Load! O.K.?

    Ans. O.K.! Though probably as time consuming as the "G" technique, this procedural time will not degrade alignment accuracy as much.

14. The pre-PDI LR test utilizing R77 has been deleted!

15. Minimum impulse limit cycle (not MIC) attitude control by the CSM DAP utilizes balanced couples, while the LM DAP does not. However, due to the thrust unbalance caused by the LM deflectors a logical argument can show that more delta V impartation would result if the LM DAP logic were changed to utilize balanced couples. In either case this velocity would be on the order of 0.01 to 0.02 ft/sec/hr (assumed 0.3° deadband).

16. The crew plans to continue the landing (proceed at the 523 alarm) if the LR antenna fails to reposition at High Gate. (Worst case would be if the antenna stuck just out of position #1). O.K.?

    Ans. Preliminary studies indicate this is O.K.! (Mission Simulation Memo #28-69 by Kriegsman and Gustafson). However, it appears that the last 500 - 700 ft would have to be flown manually.

    Additional descent analysis for the "H" mission is contained in Mission Simulation Memos #26-69 and #27-69, by Kriegsman and Gustafson, and Space Guidance Analysis Memo #7-69, by Klumpp and Pippenger. All of these memos have been distributed under separate cover.

17. ROD dynamic response via the LLRF was excellent according to Pete Conrad. D. Hewes and T. Obrian (Langley), T. Hoekstra (Bellcomm), and B. McCoy (MIT) agreed via phone that the Langley facility does indeed utilize a model that accurately represents the MIT software. Neil Armstrong's comments on the ROD mode corroborates this. (i.e., Pete's favorable LLRF experience was representative of actual LM response).

18. The crew has noticed that early P70 aborts (right after throttle - up) result in unsafe orbits. The problem has been traced to improper abort targets ... not the old "pitchover - short burn" problem. See enclosed Luminary Memo #111, by B. McCoy. This memo also summarizes the level 6 testing. The N69 (ΔRLS) exercises, though not finished, show no signs of trouble!

19. Some CSM rescues could require targetting maneuvers that put the CSM below 35,000 ft. O.K. ?

Ans. No! The CSI targetting program will not work unless a work-a-round procedure is employed. (See Don Reinke - MIT/IL). P30 - P40 will work, as will the normal orbital parameter display (V82).

20. To avoid jet firings on the surface, P68 sets the V76 (minimum impulse) bit. P12 (and P40, 41, 42 and 63) have now been changed such that the V77 (attitude Hold) bit is set at TIG. (i.e., unless the T2 abort countdown is not terminated before TIG, the "pulse" mode will still be in effect for jet firing avoidance ... V76 need not be recalled).

21. Large yaw angles (like 50° - 60°) don't seem to be taken out before pitchover in P12, according to Pete Conrad's LMS experience. Is this expected from the program?

Ans. Yes! Pitchover will commence when an upward velocity of 40 fps is exceeded. A yaw maneuver can continue through pitchover, up to return of x-axis override. This occurs about 10 secs after pitchover is completed. An MIT simulation, starting with 175° yaw, showed that only 57° had been completed at the start of pitchover. In this case the yaw was never completed as x-axis override was returned with 18° to go.

22. It has been suggested to yaw right 20° at liftoff + 4 min to maintain S-Band coverage! O.K. ?

<u>Ans.</u> O.K.! When the x - axis override capability is returned to the crew the PGNCS must be able to live with the above adjustment, or any other the crew may choose.

23. As of September 26, 1969, the following Navigation decisions have been reached between MIT and MPAD (Pixley, Lineberry, McPherson etc.). W-matrix re-initializations during rendezvous, subsequent to burns, will take place after three marks have been taken ... both LM and CSM; TPI velocity solution comparisons (CSM and LM) will be based on the elevation angle (E) option; SXT calibration (cis-lunar) should still be performed every 30 minutes in a "no - comm" situation. (Additional information concerning optics operation is enclosed as Colossus Memos #206 and #212 by S. Copps).

24. Pete Conrad has suggested that he can continue rendezvous tracking up to 8 minutes prior to a burn (previous limit was 12 minutes). Though desireable, this is <u>not</u> an MIT requirement.

25. Several questions have been raised concerning the use and validity of the N85 (VG) display after normal or prematurely terminated burns. (P12, 40, 41, 42, 70 and 71).

All these programs will provide displays that are being recomputed (refreshed) in the above situations, however, slight degradation in display accuracy occurs in some cases (burn rotation based on wrong engine etc.). As a general rule, any trimming or burn completion should be accomplished ASAP. The enclosed memo by L. Berman expands on the more interesting P12, P70, and P71 cases. (See item #2).

Malcolm W. Johnston

Malcolm W. Johnston

Massachusetts Institute of Technology
Instrumentation Laboratory
Cambridge, Massachusetts

LUMINARY Memo #93

TO: Distribution
FROM: J. E. Jones
DATE: 14 July 1969
SUBJECT: Intermediate Throttle-up of LM DPS During CSM-docked Burn

Astronaut procedures for Apollo 9 included a manual throttle-up to 40% thrust a few seconds after ignition during the CSM-docked burn. This intermediate thrust level was added to alleviate a GTS computational underflow which occurred in the CSM-docked configuration at low thrust levels.

In LUMINARY 1A, the GTS was rescaled to eliminate this underflow problem. It is recommended, however, that the intermediate throttle-up procedure be retained during DPS docked burns for future LUMINARY flights when the trimming of the DPS-engine bell at ignition is expected to be accurate. (Such was the case in Apollo 9, SUNDANCE Mission "D".) For small initial mistrims, the presence of the intermediate thrust level significantly reduces the magnitude of the attitude state transients which occur at automatic throttle-up to FTP (Fixed Throttle Position, about 93%), 26 seconds after ignition. These transients are due to two factors associated with the abrupt thrust increase: the roughly proportional thrust-dependent misalignment (compliance) of the engine mount; and, more significantly, the proportional instantaneous increase in the angular acceleration magnitude when the thrust vector is displaced from the c. g. at throttle-up. The simulation results which follow support the above recommendation.

Two simulations were made to determine the effect of the 40% intermediate throttle-up level upon performance during a CSM-docked DPS burn with small initial gimbal mistrims. Run NOTHROTL remained at 10% thrust until automatic throttle-up at 26 seconds. Run 40THROTL ignited to 10% thrust, throttled to 40% thrust 5 seconds after ignition, and automatically throttled to FTP 21 seconds later. The engine bell was initially trimmed such that the thrust vector would point through the c. g. after compliance at

10% thrust in NOTHROTL and 40% in 40THROTL. Both simulations modelled bending, slosh, and compliance, and shared the following programs, environment data files, and initialization:

Program:	LUMINARY Revision 097		
Subprograms:	COMMON. LEM	6/4/69	15:12
	COMMON. UNIVERSE	2/3/69	9:47
Data Files:	UNIV. EPHM 6869	11/24/69	14:23
	LEM 5. NOMINAL	6/4/69	11:21
Fuel Loadings:	DPS - 0.835		
	APS - 1.000		
	SPS - 0.250		
	RCS - 1.000		
Noise Level:	2 Bits		
Engine and RCS Misalignments:	3 - σ Errors		

Figures 1 and 2 show the P, Q, and R attitude errors for runs NOTHROTL and 40THROTL respectively. The large (about -26 degrees) attitude error excursion shortly after throttle-up in NOTHROTL is due primarily to the factor of about 9 instantaneous increase in GTS control authority when throttling from 10% thrust to FTP. (The thrust vector, steering out attitude errors at low thrust, was displaced from the c.g. primarily along the Q-axis at throttle-up.) Throttling from 40% thrust to FTP as in 40THROTL causes an instantaneous acceleration increase of only about a factor of 2. Resulting attitude excursions are small: about 3.5 degrees in R and about -1.5 degrees in Q. These compare very well with transient throttle-up attitude error magnitudes observed during the docked DPS burn of Apollo 9 (see J. E. Jones, Post - Flight Data Analysis Memo #21, June 4, 1969).

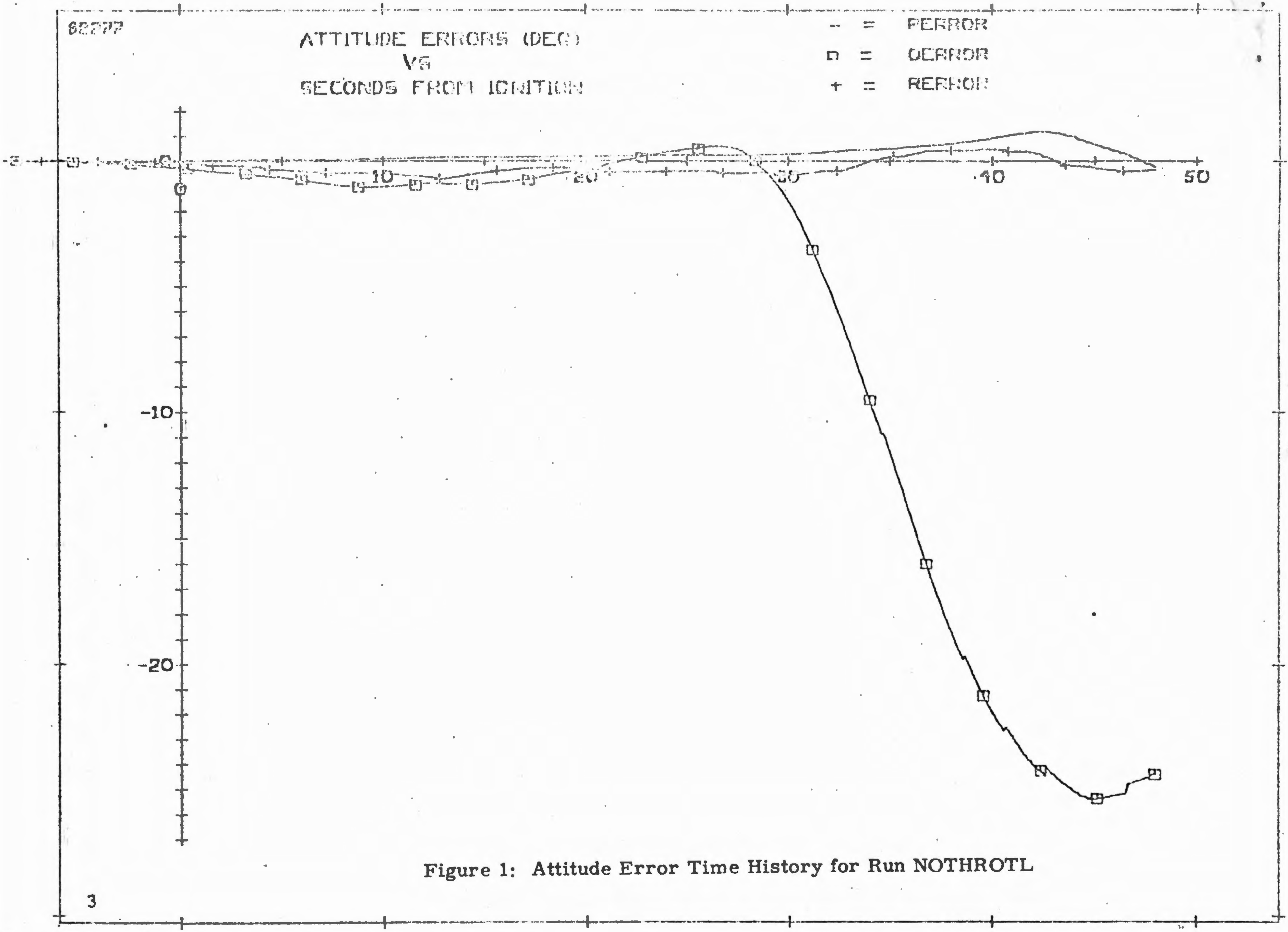


Figure 1: Attitude Error Time History for Run NOTHROTL

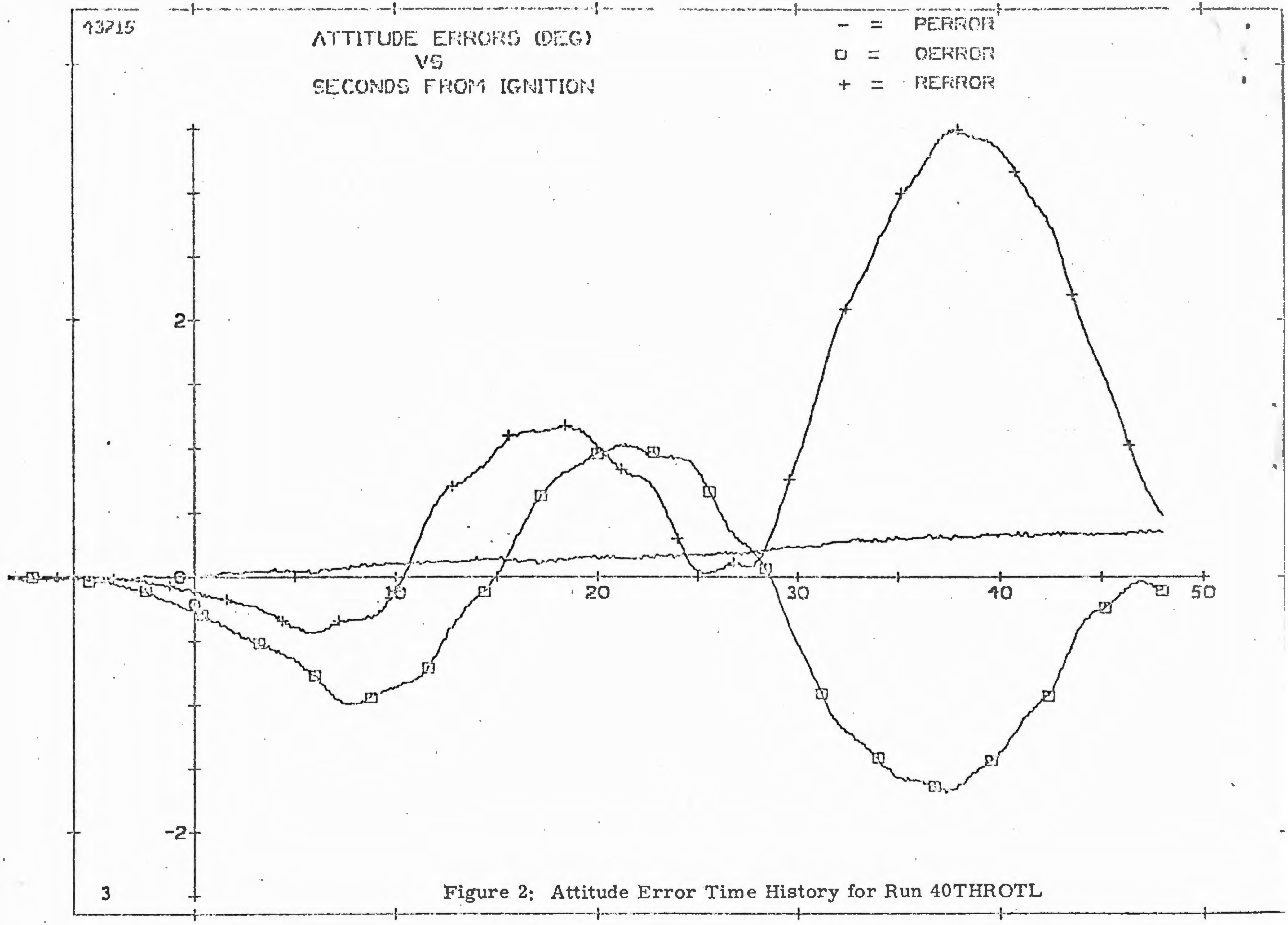


Figure 2: Attitude Error Time History for Run 40THROTL

Massachusetts Institute of Technology
Instrumentation Laboratory
Cambridge, Massachusetts

32

COLOSSUS Memo #203, Spacecraft Autopilot Development Memo # 28-69

TO: Distribution
FROM: J. F. Turnbull
DATE: July 31, 1969
SUBJECT: PCR815/V79/R64/PTC - ORBRATE Routine

In response to PCR815, a new routine, R64, has been added to COLOSSUS 2C. This routine enables the crew to perform PTC (X AXIS roll), a restricted form of ORB RATE, and deadband changing without having to do direct erasable loading. The restriction on ORB RATE is that CDUX should be close to 7.25 deg and CDUZ should be close to zero. If these two conditions are met, the Y RCS control axis and the CDUY axis (i.e. inner gimbal axis) will be aligned. Such an alignment is necessary because the ORB RATE option is implemented by incrementing the desired CDUY value every DAP cycle and commanding a corresponding rate about the Y RCS control axis.

R64 will be described as an operational mode in Section 4 of the COLOSSUS 2C GSOP. Briefly the routine is as follows:

> If no other extended verb is active, keying V79E results in flashing V06 N79 display. N79 has three decimal components.
>
> The first component of N79 is rate displayed to .0001 deg/sec. The second component is deadband displayed to .01 deg. The third component is axis code. ±00000 implies X axis (i.e. PTC option), non-zero implies Y axis (i.e. ORB RATE option).
>
> The erasable locations used for N79 are shared locations so data in N79 is not necessarily saved from the previous use of V79. Therefore, in general, it will be necessary to load data using

V25. Once N79 is configured as desired, PROCEEDing on the flashing V06N79 will:

1) change the DAP deadband to that specified by component two of N79;
2) a) if PTC option is selected, generate a commanded rate about the vehicle X axis equal to that specified in component one of N79 and also generate the appropriate increment to be added every DAP cycle to desired CDUX, or
   b) if ORBRATE option is selected, generate a commanded rate about the Y RCS control axis equal to that specified in component one of N79 and also generate the appropriate increment to be added every DAP cycle to desired CDUY; and
3) configure a DAP erasable location such that,
   a) if the PTC option is selected, a roll firing will be forced during the next DAP cycle independent of whether the DAP phase plane point is outside the roll deadzone, or
   b) if the ORB RATE option is selected, a pitch firing will be forced during the next DAP cycle independent of whether the DAP phase plane point is outside the pitch deadzone.

As is the case with all routines and programs involving automatic maneuvering, the maneuvering commands will be communicated to the DAP only if the S/C CONT switch is in CMC and the CMC MODE switch is in AUTO. If such is the case, the physical response to PROCEEDing on V06N79 will be an immediate forced roll or forced pitch firing (depending on the axis option in N79) which will reduce the difference between commanded rate and actual rate by about 80%. Additional firings to further refine the S/C rate will be commanded when the phase plane point eventually leaves the deadzone. If a large deadband has been chosen the time between the initial forced firing and the first additional firing may be very long - perhaps 10 or 20 minutes.

When component one of N79 is zero, the commanded rates and CDU increments generated by PROCEEDing on V06N79 are identically zero. In this situation the effect of doing R64 will be to set the deadband to the value specified in the second component of N79.

Having once executed R64, the mode of operation established by it can be altered in various ways. In Table I the possible actions and their respective effects are presented.

	Zero Commanded Rate	Return to Deadband Specified by Rate 03	Zero DAP Attitude Error
V46E	√	√	√
S/C Control Switch cycled CMC—SCS—CMC	√	√	√
CMC Switch to Hold	√		√
Rotational Hand Controller Activity	√		√
V37E XXE	√	√	
KALCMANU	*		√

* KALCMANU generates new commanded rates.

Operationally, several potential uses of R64 are envisioned.

1) Automatic PTC Initiation.

The availibility of R64 means that direct loading of erasable memory in order to initiate PTC or widen deadband is no longer necessary. Also, the V49 auto maneuver to PTC attitude, which in addition to maneuvering the S/C assured that various erasables were properly configured prior to direct erasable loading, is no longer essential since R64 properly initializes all the necessary erasable locations. Still required, however, is the wait period between maneuvering to PTC attitude and PTC initiation so that residual rates will be damped out before PTC is begun.

The roll forced firing will bring the S/C up to about 80% of the rate specificed in component one of N79. If a wide deadband is used, it will be a long time before the next roll firing occurs. Consequently, it may be desirable procedurally to load a rate in N79 25 to 30 percent higher than the desired PTC rate. The single forced firing then should produce a rate rather close to the actually desired PTC rate. The rest of the PTC checklist (disabling roll jets, etc) can then be executed without waiting for additional firings to bring the S/C up to desired rate.

2. Deadband Changing.

If all zeros are loaded in N79, the effect of executing R64 will be to change the DAP deadband to that specified in component two of N79. R64 does not change the attitude reference, thus if R64 were used to decrease the deadband, an attitude maneuver would result, in general, to get the S/C to within the new decreased deadband of the reference.

Also, the logic involved with R64 will produce one forced firing about either the roll or pitch axis (depending on the axis option in N79) even if the command rate is zero. This forced firing can be inhibited external to the DAP by switching the roll or pitch MANUAL ATTITUDE switch to ACCEL CMD before PROCEEDing on V06N79. The switch can be returned to RATE CMD almost immediately (0. 1 sec) after keying PROCEED.

3. Y Axis Rate Drive.

Program COLOSSUS does not have a local vertical tracking routine. As a substitute for such a routine, R64 can be used to drive the S/C at orbital rate. The long term integrated accuracy of the drive at orbital rate is influenced by several factors which are more appropriately discussed with reference to a particular use of R64 for driving at orbital rate. Use of R64 to control a Y axis rate may also be of help elsewhere as for example for landmark tracking during P22.

Verification of R64.

Four all digital simulations using COMANCHE, Rev. 65 were set up and run successfully. One simulation, run by John Laird, used the X axis option with a .15 deg/sec commanded rate and 30 deg deadband. The three other simulations, run by Roy Whittridge, used the Y axis option at 4 deg/sec with a 2 deg deadband, 0.3 deg/sec with a 1 deg deadband and 0.05 deg/sec with a 0.8 deg deadband.

These simulations demonstrated that the axis selection, rate command, deadband changing, and forced firing aspects of R64 all functioned as desired.

In addition, I ran an afternoon of hybrid testing on R64 using COMANCHE Rev. 67. This testing independently verified those aspects already verified in the all digital simulations and in addition verified that the effects of various actions subsequent to R64 is as presented in Table 1.

Massachusetts Institute of Technology
Instrumentation Laboratory
Cambridge, Massachusetts

COLOSSUS MEMO #217

TO: Cmdr. Richard Gordon
FROM: J. F. Turnbull
DATE: September 24, 1969
SUBJECT: Performance of R64 Y axis option at a rate = .0507 with CDUX = 180 deg.

The Y axis option of Routine 64 (V79) was designed to be used with the restrictions that CDUX be close to 7.25 deg. and CDUZ be zero. If these conditions are met, the positive Y stable member axis and the positive Y RCS control axis are parallel and point in the same direction. This is important because of the way the Y axis option is implemented in the computer. Basically the situation is that sufficient storage was not available when R64 was coded to make the command rate a function of CDUX.

The easiest way to explain the effect of this is to consider a specific example. Let us assume that register 1 of N79 is loaded with a rate of -0.05 deg/sec. Routine 64 will give two commands to the DAP. One will be a commanded increment for CDUY to be added every 0.1 sec. For the case we are considering, the increment will be a negative number, -0.005 deg. The second command will be the commanded rate about the Y RCS control axis. For our example, that will be -0.05 deg/sec. If CDUX = 7.25 and CDUZ = 0, then both commands will be negative about axes which point in the same direction so everything is coordinated. If, however, CDUX = 180 deg and CDUZ = 0 both commands will still be negative but about axes that point in roughly opposite directions so that the effect is that of having the commanded gimbal angle increment in one direction and the commanded rate in the opposite direction. This obviously is a contradictory situation.

The question is what penalty do you pay for flying in a "heads down" (CDUX = 180 deg.) configuration? To answer this question two simulations were run on the MIT all digital simulator. Both simulations used the Y axis option of R64 with a rate of -0.0507 deg/sec and a deadband of 0.5 deg loaded in N79. The sequence of astronaut actions executed in both simulations is the same and is listed in Table 1. The difference between the two runs is that one simulation, referred to as "heads up", starts from initial gimbal angles CDUX = 0, CDUY = 0, and CDUZ = 0, which nearly meet the restrictions of the R64 Y axis option. The other run, referred to as "heads down", starts from initial gimbal angles CDUX = 180, CDUY = 0, and CDUZ = 0 which violates the CDUX restriction by 172 degrees.

Figure 1 is a plot of CDUY for the HEADS UP run. As can be seen, CDUY is a smoothly decreasing function of time. Figure 2 is a plot of CDUY for the HEADS DOWN run. The plot in this case has a saw tooth nature. What is important is that, despite the fact that CDUY does not decrease smoothly, its average rate of decrease, over the long term, is correct.

Figure 3 is a plot of the Y component in body axes of S/C angular velocity for the HEADS UP run. It is not a constant, but it does remain in the vicinity of -.05 as is desired. Figure 4 is a plot of Y body rate for the HEADS DOWN run. Keep in mind that with CDUX = 180 a positive Y body rate implies a negative rotation about Y stable member. As can be seen, R64 starts by producing a negative body rate which is the wrong direction since a negative rotation about Y stable member is desired. After a brief time the DAP drives the rate positive. This type of behavior has been observed on the Command Module Simulator and is understandable from the way R64 is programmed. The positive rate achieved is too high and eventually the DAP slows the vehicle down, so much so that the rate is actually driven negative. After a brief time, the rate is again driven positive. This cycle can be seen to repeat as time passes and is the rate history that corresponds to the saw tooth CDUY history of Figure 2. All the changes in rate shown in Figure 4 are, of course, the result of jet firing.

One indicator of the efficiency of DAP operation is the phase plane. Figure 5 is the Y phase plane for the HEADS UP run showing a nice small limit cycle centered near the horizontal axis. Figure 6, on the other hand, is the Y phase plane for the HEADS DOWN run. Here the height of the limit cycle is much greater and is centered considerably above the horizontal axis indicating less efficient operations.

Of course the most important criterion for judging efficiency is fuel consumption. Table 2 is a summary of jet activity and fuel usage for the HEADS UP run. Total firings is 22 and total fuel is 0.17 lbs. The same summary for the HEADS DOWN run, Table 3, shows total firings to be 90 and total fuel to be 1.02 lbs. Both runs are of exactly the same length.

CONCLUSION

Analysis of the simulation runs indicates that flying heads down in R64 at -0.0507 deg/sec will work but at a penalty in smoothness and efficiency. The S/C motion will be considerably more jerky than flying heads up in R64. The S/C will fly in the correct direction for a while at too high a rate then briefly reverse its direction and effectively back up a bit then start forward again and so on. Fuel usage will be considerably higher for heads down operation. Comparison of the two simulations discussed in this memo shows fuel usage to be increased by a factor of six. Actual increase in flight may be greater or less depending on what disturbances the S/C experiences.

TABLE 1

Astronaut sequence for both simulation runs.

```
T = 5 V 48E
IF V 04 N 46 THEN PROCEED
IF V 06 N 47 THEN PROCEED
IF V 06 N 48 THEN PROCEED
T = 15 V 46 E
T = 17 V 79 E
IF V 06 THEN  V 25 E
IF V 21 THEN -00507 E
IF V 22 THEN +00050 E
IF V 23 THEN +11111 E
WAIT 2 PROCEED
```

TABLE 2

Jet firing and fuel consumption table for HEADS UP simulation run

RCS JET #	TIME ON	# FIRINGS	FUEL USED
1	0.01	1	0.00
2	0.05	3	0.02
3	0.01	1	0.00
4	0.05	3	0.02
5	0.01	1	0.00
6	0.02	2	0.01
7	0.01	1	0.00
8	0.02	2	0.01
9	0.00	0	0.00
10	0.00	0	0.00
11	0.00	0	0.00
12	0.00	0	0.00
13	0.02	2	0.01
14	0.02	2	0.01
15	0.02	2	0.01
16	0.02	2	0.01
ALL JETS	0.28	22	0.17

Jet firing and fuel consumption table for HEADS DOWN simulation run

RCS JET #	TIME ON	# FIRINGS	FUEL USED
1	0.45	31	0.26
2	0.47	7	0.19
3	0.45	31	0.26
4	0.47	7	0.19
5	0.02	2	0.01
6	0.01	1	0.00
7	0.02	2	0.01
8	0.01	1	0.00
9	0.00	0	0.00
10	0.00	0	0.00
11	0.00	0	0.00
12	0.00	0	0.00
13	0.02	2	0.01
14	0.02	2	0.01
15	0.02	2	0.01
16	0.02	2	0.01
ALL JETS	2.00	90	1.02

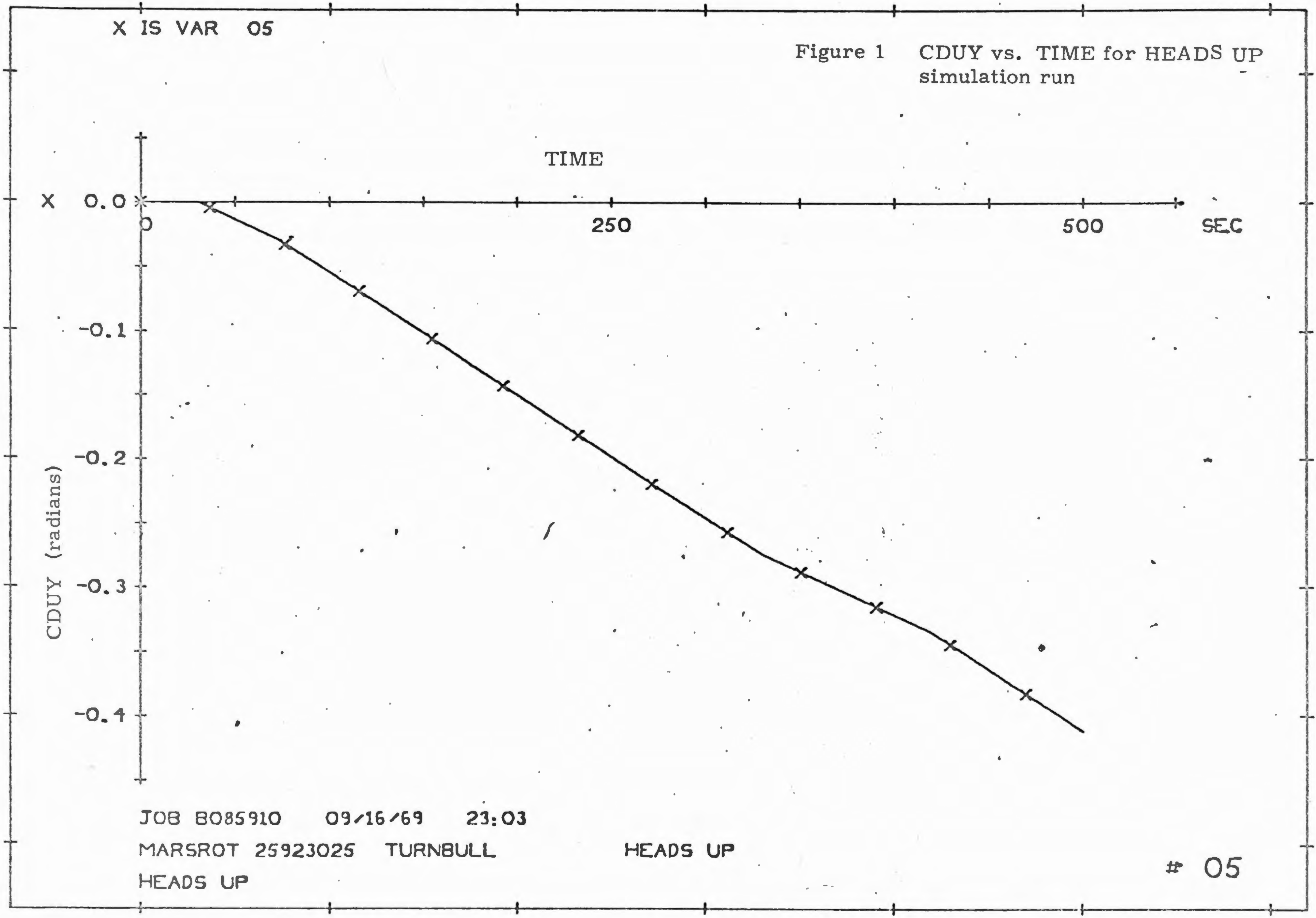


Figure 1 CDUY vs. TIME for HEADS UP simulation run

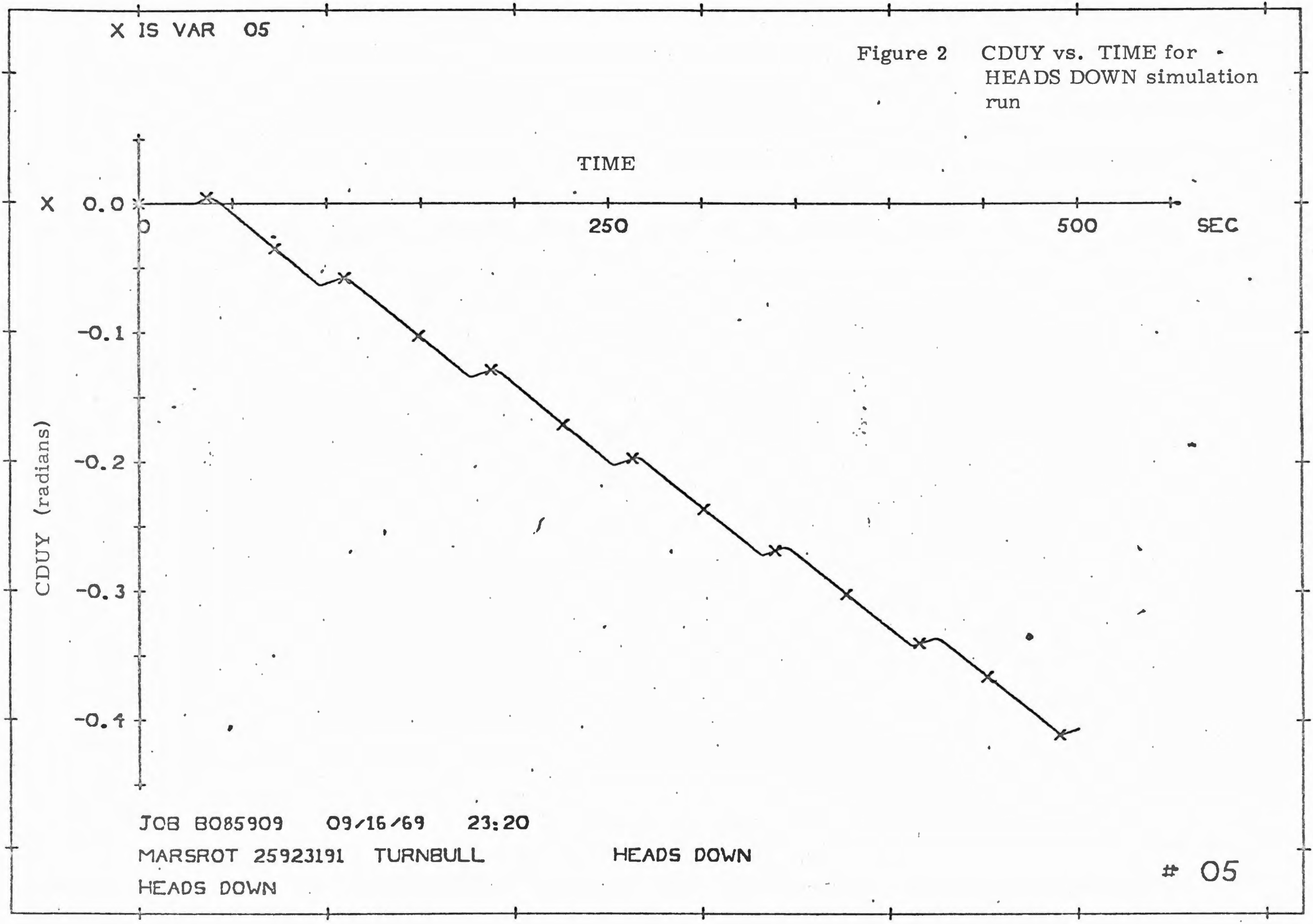


Figure 2 CDUY vs. TIME for HEADS DOWN simulation run

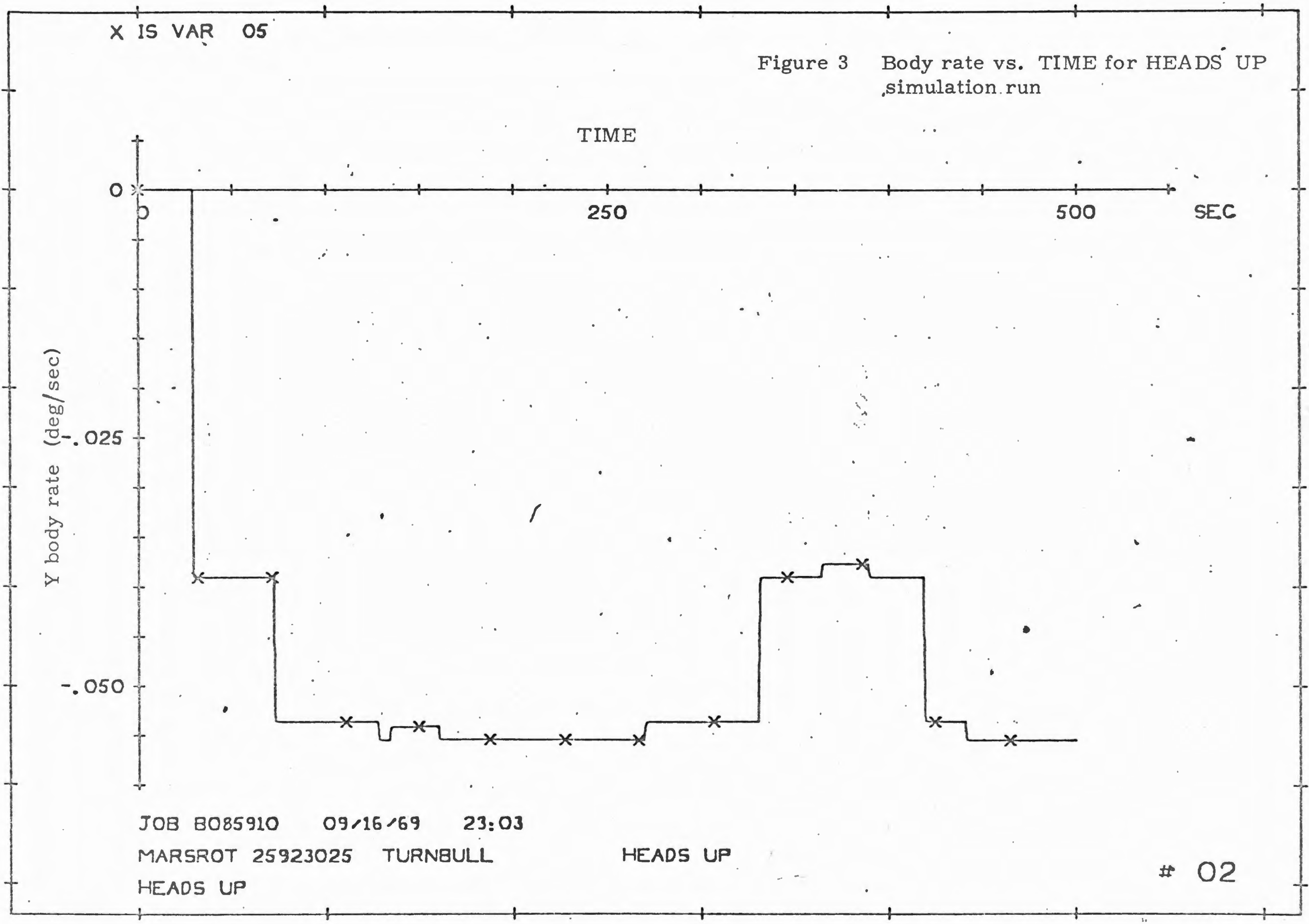


Figure 3 Body rate vs. TIME for HEADS UP simulation run

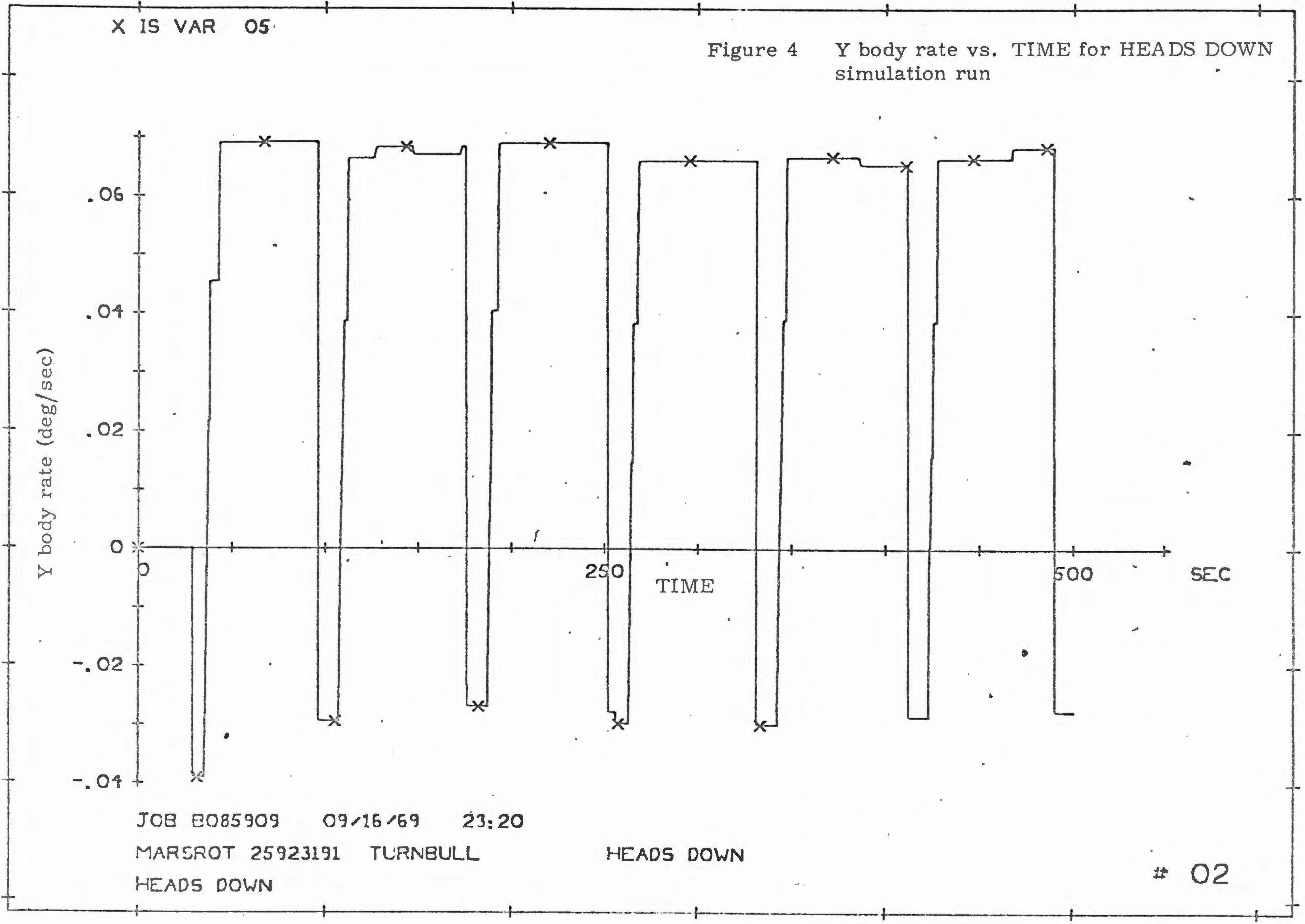


Figure 4 Y body rate vs. TIME for HEADS DOWN simulation run

Figure 5 Y phase plane for HEADS UP simulation run

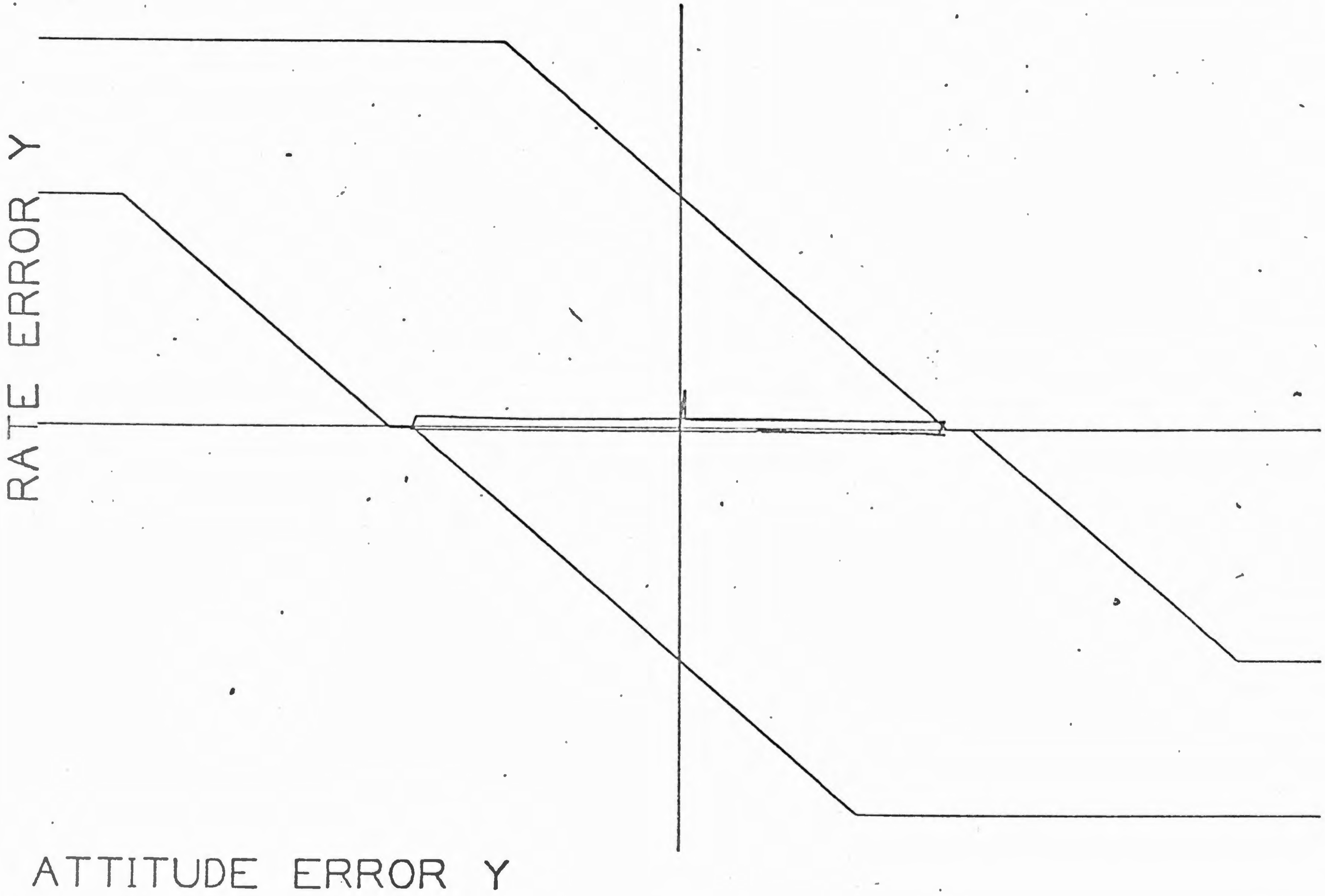
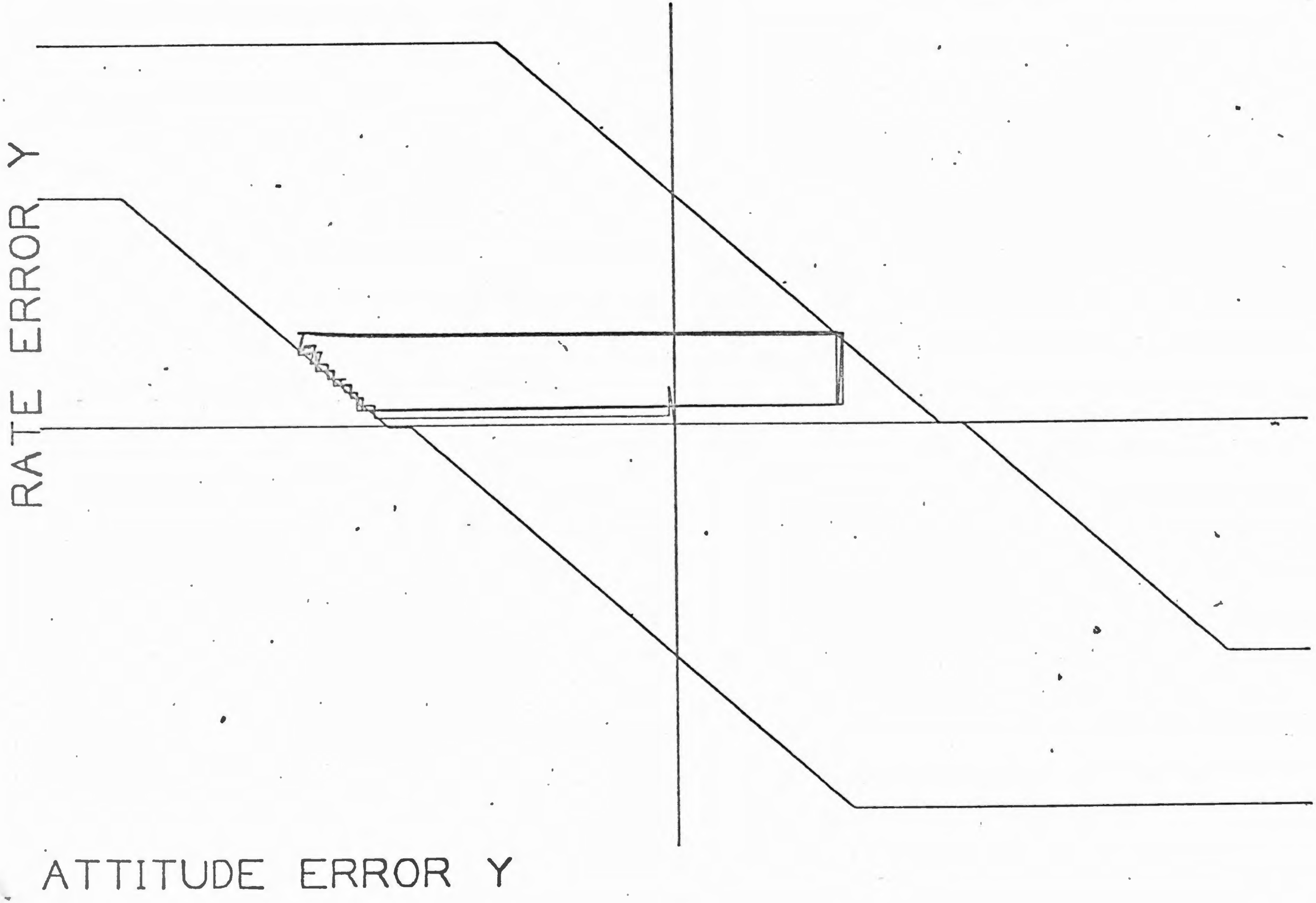


Figure 6 Y phase plane for HEADS DOWN simulation run



Massachusetts Institute of Technology
Instrumentation Laboratory
Cambridge, Massachusetts

COLOSSUS Memo #213 LUMINARY Memo #110

TO: Distribution
FROM: W. F. Ostanek
DATE: 10 September 1969
SUBJECT: Bad Other Vehicle State Vector

This memo describes a method of replacing a bad state vector for the other vehicle without ground update. The bad state vector probably results from erroneous use of P76.

This method involves use of V71 state vector update and a program or routine which leaves available in erasable a rectified state vector scaled appropriately for earth or lunar orbit. Rectified this and other state vectors are available in both spacecraft (RN, VN, PIPTIME; R-OTHER, V-OTHER, T-OTHER) but cannot be loaded directly via V71 because of incorrect scaling when lunar centered.

However, routines R31 (V83), R34 (V85) and program P21 with other vehicle option integrate the state vector to some base time and save the rectified state vector in the proper scaling for that base time.

Procedure:

In the Command Module

When it recognizes it has a bad LM state vector, the CM asks the LM for his state vector. In the LM, with rendezvous navigation programs, V83 is entered and following the N54 the following registers are readout via V1N1:

$\bar{R}$	BASETHP	E4,1567	2167-2174	
$\bar{V}$	BASETHV	E4,1504	2104-2111	(LUMINARY 116)
T	BASETIME	E4,1513	2113-2114	

If rendezvous navigation is not being done, P21 may be used with this vehicle option and readout of the following registers after N43:

$\bar{R}$	P21BASER	E7,1675	3675-3702	
$\bar{V}$	P21BASEV	E7,1703	3703-3710	(LUMINARY 116)
T	P21TIME	E7,1762	3762-2763	

The 14 registers comprising $\bar{R}$, $\bar{V}$, T are voiced in that order to the CM. The CM copies the registers, then selects P00 and enters V71E, 21E, 1501E, 77775 (77776 for earth orbit) and then $\bar{R}$, $\bar{V}$, T. Proceed on FLV21 N02 causes the state vector to be loaded. Since the state vector was obtained from the LM and the LM burn has already taken place, the CM does not use P76 again until the next LM burn.

The W matrix and state vectors will not be synchronized following this procedure. The W-matrix is invalidated by the state vector update. P00 should be reselected so that P00 will immediately synchronize the state vectors.

In the Lunar Module

If the LM has a bad CM state vector, the procedure above is used except the CM calls up V83 or P21 with this vehicle option. The CMC locations for the V83 state vector is:

$\bar{R}$	BASETHP	E4,1624	2254-2261	
$\bar{V}$	BASETHV	E4,1640	2262-2267	(COMANCHE 67)
T	BASETIME	E4,1742	2342-2343	

For P21:

$\bar{R}$	P21BASER	E7,1604	3604-3611	
$\bar{V}$	P21BASEV	E7,1612	3612-3617	(COMANCHE 67)
T	P21TIME	E4,1715	2315-2316	

The LM uses the same P27 block update procedure except the third entry after V71E is 2 (1 for earth orbit).

Johnston

MIT/IL
Apollo Guidance and Navigation
System Test Group Memo #1409

To: Distribution
From: R. Lones
Subject: Gyro Drift Compensation
Ref: ISS Memo #846 31 July 1969
Date: 2 October 1969

A. Gyro Drift (NBD) Model.

The gyro drift (NBD) as a function of "NBD Only" compensation can be approximately modeled as shown in Figure 1A. If we knew ΔD exactly we could compute the required compensation exactly. ΔD is the shift in gyro bias drift as a result of a change in pulse torquing polarity. However, since the required test time and procedure changes to determine the three values of ΔD for each platform will probably keep us from actually running the test an average value of ΔD will be selected. Based on the limited sample of Apollo 11 (2.1 meru for X and 1.6 meru for Y) an average value of $\Delta D = 1.8$ meru will be selected for use with the method described in section B. Also minimum compensation is arbitrarily selected to be .1 meru for use in this same method.

B. A method to correct NBD Compensation.

1. Compute $GD = MD + NBD_C$

where GD = Gyro Drift (meru)
MD = Measured Compensated Drift (meru)
NBD_C = Current NBD Compensation (meru)

2. Case I. Sign GD = sign NBD_C

Load:

New $NBD_C = GD$

3. Case II Sign $GD \neq$ sign NBD_C
then a, orb, or c

a. For $|GD| > |\Delta D|$

Load:

New $NBD_C = GD + K\,\Delta D$

where $K = +1$ Current $NBD_C = +$
$K = -1$ " " $= -$

b. For $|\Delta D| > |GD| > \left|\frac{\Delta D}{2}\right|$

Load:

New NBD_C = Minimum Compensation with opposite sign from NBD_C

c. For $|GD| < \left|\frac{\Delta D}{2}\right|$

Load:

New NBD_C = Minimum Compensation with same sign as NBD_C

C. Some Possible Errors.

1. Actual ΔD different from average ΔD - This will cause an error (when the polarity of compensation is changed) dependent on the actual ΔD but could be worked around by a second pass at adjusting compensation using an acutal ΔD determined from the MD measured with the previous compensation and with the current compensation.

2. ΔD centered around zero drift.

Using the straight line model in Figure 1A the minimum compensation error in this case would be ΔD/2. Intuitively, I would expect the model to look more like Figure 1B although not necessarily centered around zero drift. If so, the minimum compensation error should approach ±D min.

D. Some Unanswered Questions.

1. The model postulated with Figure 1B should be verified or corrected.
2. After pulse torquing for some time I would expect that it takes some time for the drift to decay to ± D min. This time constant should be determined.
3. The number of pulses required to reach steady state drift with low pulse rates (NBD compensation program puts in X pulses every 82 seconds) should be determined. The above compensation scheme assumes very few pulses are needed to switch states.

R. Lones
Robert Lones

RL:jdg
Distribution:

MIT/MSC (2)
MIT/KSC
G. Silver
A. Laats
V. Megna
R. Sheridan
R. Booth
E. Grace
W. Prince
J. Gilmore
J. Feldman
M. Johnston
G. Edmonds

S.G. MEMO # 140

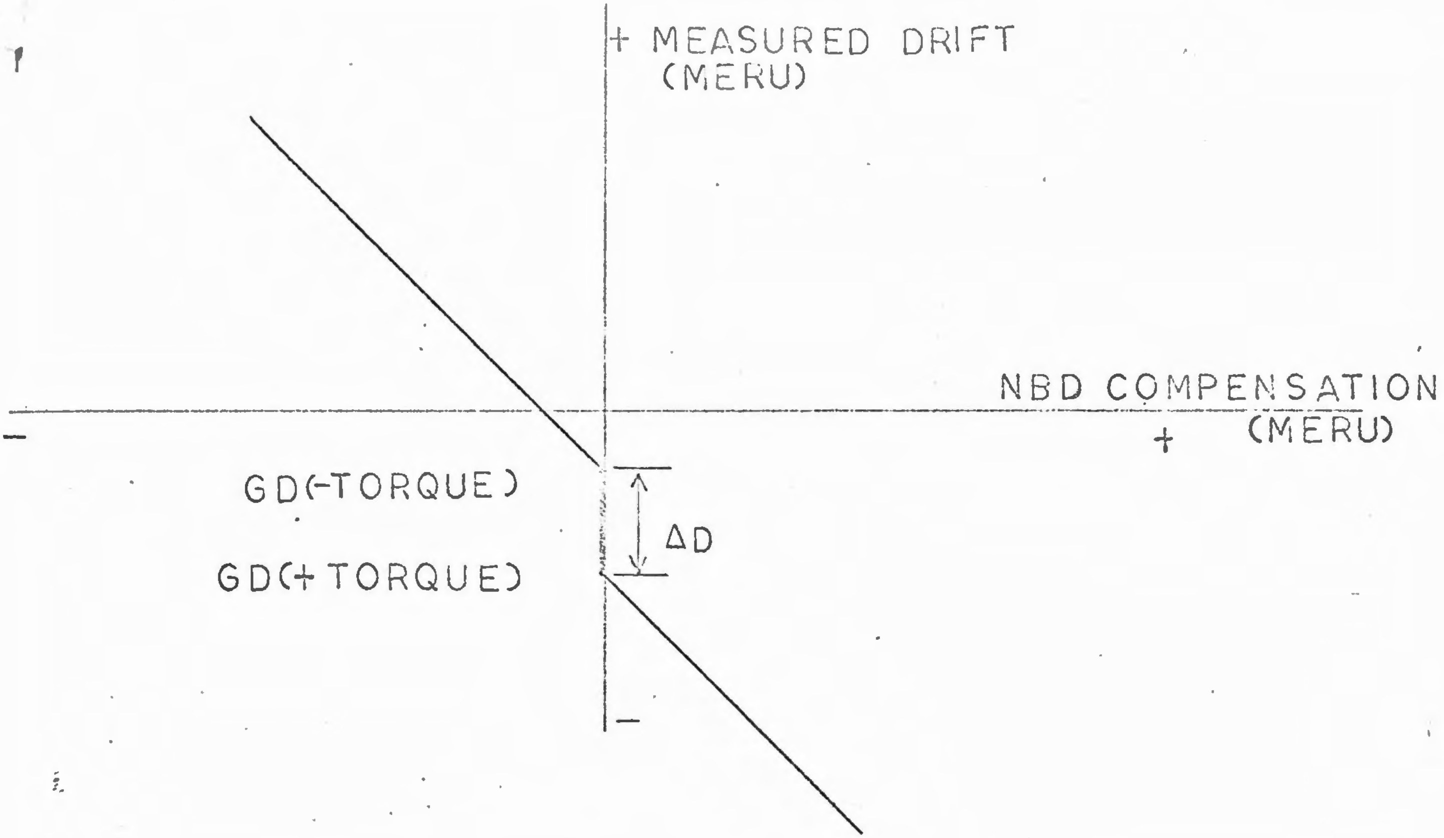


FIGURE 1A

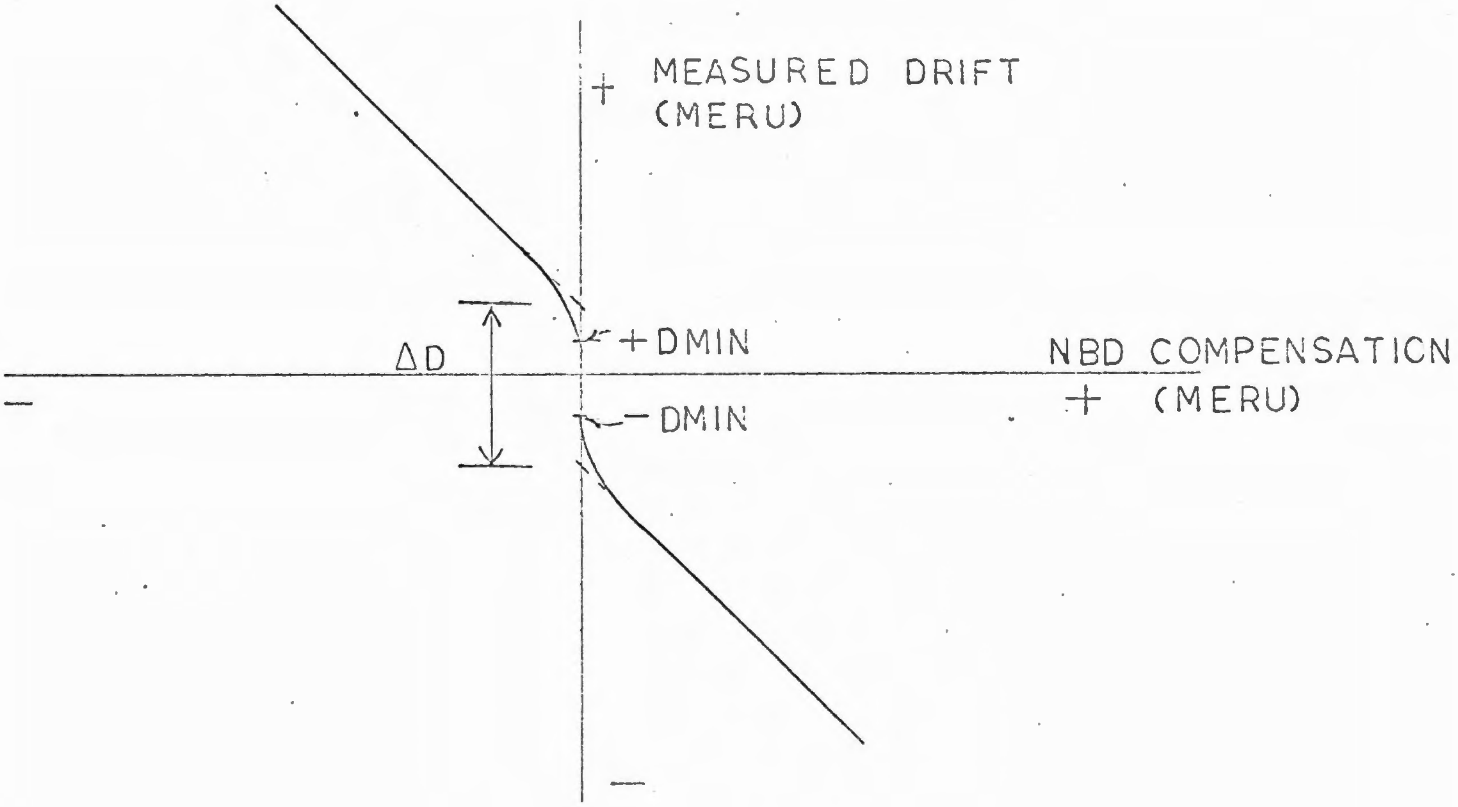


FIGURE 1B

Massachusetts Institute of Technology
Instrumentation Laboratory
Cambridge, Massachusetts

LUMINARY Memo #111

To: Distribution
From: B. McCoy
Date: 19 September 1969
Subject: Level 6

The Level 6 testing is now underway. It is designed to test the new features of Luminary 1B and the particulars offered by Apollo 12. The test runs are divided into 4 groups and described as follows:

1. Rendezvous
   LM Active-Nominal
      P00, P52, P20, P32, P41, P30, P41, P33, P41, P34, P41, P35, P41, P35, P41, P47
   Abort Insertion Profile to Rendezvous
      P00, P52, P20, P32, P41, P32, P41, P33, P41, P34, P41, P35, P41, P35, P41
2. Lunar Surface and Ascent
      P68, P00, P12, P57 (2 stars), P06, P57 (gravity/star), P57 (gravity/refsmmat), P22, P12, P20, P32 (initialized with 5° pitch, 15° yaw)
3. Aborts from Descent
      Early - P00, P63, P70 (at 30 kft), P20 (11 mks), P32 (one soln)
      Mid - P00, P63, P70 (at 10 kft), P71 (at FV97), P20 (11 mks), P32 (one soln)
      Late - P00, P63/P64, P71 (at 500 ft), P20 (11 mks), P32 (one soln)
4. Landing
   a) Enter P66 at 700 ft altitude; null all velocity components

b) Redesignations and NOUN 69 Delta's

case	NOUN 69 load at	Range Down	Cross	Redesignations Range Down	Cross
1	PDI + 3m	+5K	+5K	NONE	NONE
2	"	+35K	+10K	-3K	-5.2K
3	PDI - 3m	+25K	+5K	+8K	+10K
	PDI + 3m	+10K	+5K		
4		NONE		+5K	-5K
5	+ 3m	-35K	-10K	-3K	-10K

- check fuel consumption, visibility, and throttle behavior
- use state vectors for hi/lo trajectories
- enter P66 at 500 ft and null velocities

c) Nominal Error-Free (Automatic)

- check weighting functions for vel/alt

d) LR Position Check

- LR placed in Position 1 but channel bits don't indicate either position
- P64 gives 523 alarm; PRO to assume Position 2
- enter P66 at 500 ft and null velocities

Forthcoming is an anomaly that results in the X-pointers being disabled during descent. If the RR mode switch is placed in and out of LGC position during descent the RR Error Counter Enable (C1262) is reset; R10 does not subsequently set the bit back to allow velocity information to reach the CDU error counters to display on the X-pointers. The recovery is to cycle the MODE SELECT switch out of and back into PGNS.

Evidence was reported from the LMS (KSC) of an early shutdown of the engines during a very early abort (PDI + 28 sec). We have found on our simulators that it is possible to have such a case with an improper erasable pad load. However, using the proper load there is no evidence of early shutdown aborting at any point in the descent.

Massachusetts Institute of Technology
Instrumentation Laboratory
Cambridge, Massachusetts

COLOSSUS Memo #206

TO: Distribution
FROM: Stephen L. Copps 8/12/69
DATE: August 11, 1969
SUBJECT: Optics Calibration for P23

It has been the practice for all lunar flights to date to use stars for optics calibration. The CMC does not presently aid the astronaut in acquiring his chosen star in the LLOS field of view.

For Colossus 3 a PCR has been written to provide automatic acquisition. In the meantime it may be helpful to acquire stars by use of the Auto Optics routine shaft and trunnion DSKY display.

If the astronaut achieves a desired trunnion angle of zero degrees in Auto Optics he has in fact placed the star along LLOS. A fairly straightforward procedure for accomplishing this is described below.

1. Key V37E 52E.
2. at V04 N06 set R2 = 3 and PRO.
3. at V50 N25 00015 ENTR.
4. at V01 N70 load the star code of the specified calibration star.
5. observe non-flashing V06 N92 or, if FL V51, key V16 N92E.

    The objective here is to achieve a desired trunnion angle of zero degrees in two predictable maneuvers. In order to visualize the polarity involved picture the LLOS to be colinear with the $+Z_{SC}$ axis and the shaft rotation to be positive starting from the $+X_{SC}$.

The first maneuver is performed to place the star in the XZ plane by applying pure roll. If R1 lies between 0 and 180 degrees then apply left roll and if it lies between 180 and 360 degrees apply right roll stopping when R1 is either 0 or 180 degrees.

The second maneuver is a pure pitch maneuver to change R2 to 0 degrees. If shaft reads 0 degrees then pitch up and if it reads 180 degrees then pitch down.

6. Key V37E23E.

Massachusetts Institute of Technology
Instrumentation Laboratory
Cambridge, Massachusetts

COLOSSUS Memo # 212

TO: Distribution
FROM: Stephen L. Copps
DATE: August 27, 1969
SUBJECT: New Requirement for Performing ZERO OPTICS

In the Apollo 11 technical debriefing Astronaut Collins stated that, following CSI, he had to perform an unscheduled ZERO OPTICS in order to acquire the LM in the SXT field of view. Post flight analysis has shown that the trunnion CDU was in fact in error and that the zeroing was required.

As I understand it the trunnion error was due to an unexpectedly large servo drift during the time that the optics DAC's were being used in P40 to control the SPS bell (following response to V50 N25 204 until he exited P40). The actual drift was apparently quite large and whether it behaved within spec. values is not clear as yet.

In any case this event introduces a requirement to always either place the OPTICS ZERO switch to ZERO prior to P40 or to cycle the switch following P40, perferably the former.

Massachusetts Institute of Technology
Instrumentation Laboratory
Cambridge, Massachusetts

MEMO

To: M. Johnston
From: L. Berman
Date: 6 October 1969
Subject: Ascent Guidance Nominal Trim and Engine Fail Procedure

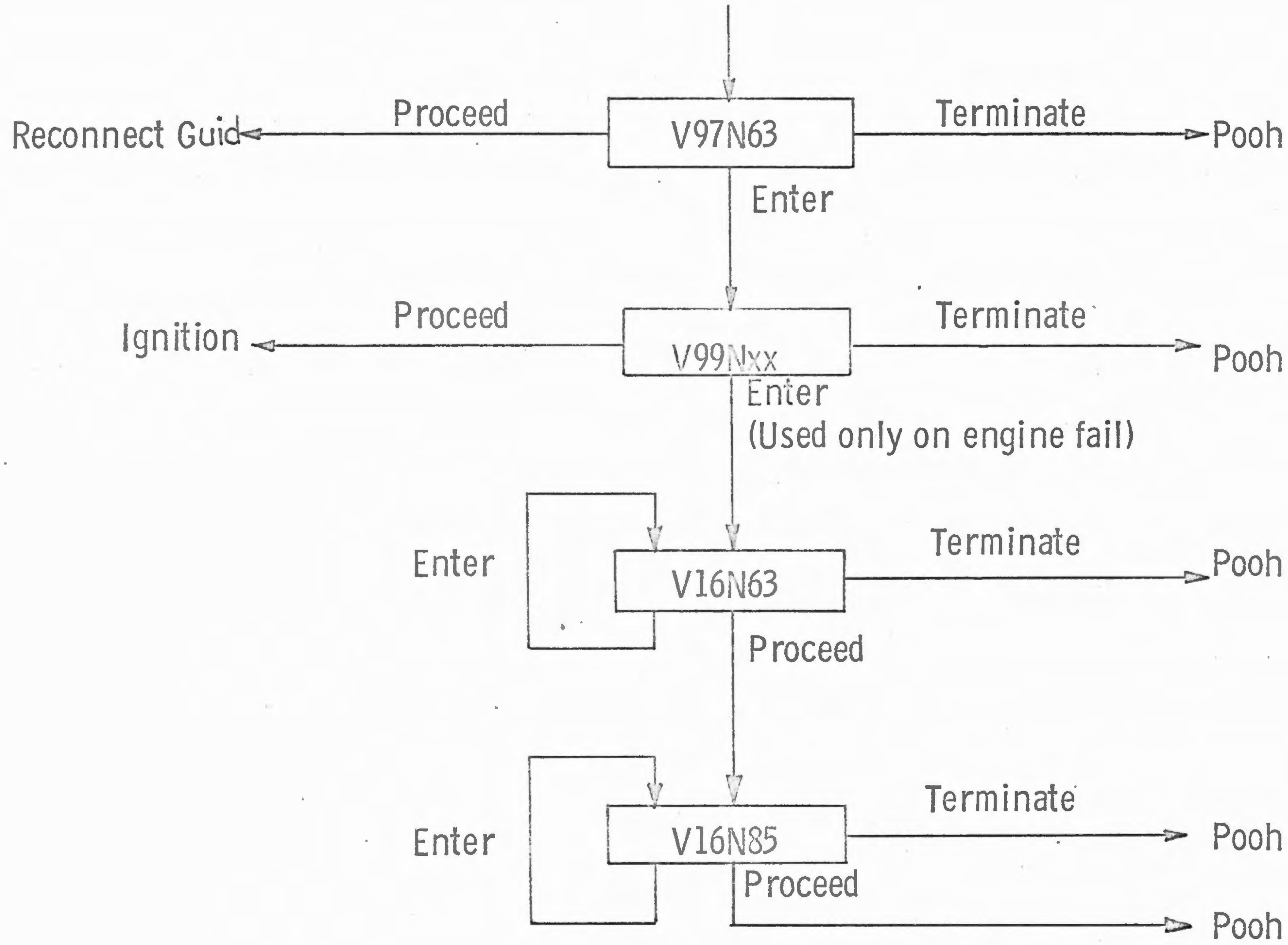
During Ascent Guidance (P70, P71, or P12) a standard procedure is built into the guidance equations for use in case of engine failure. This procedure is shown in the attached figure.

The V99 display logic is the same as is used at ignition time, and if re-ignition is to be attempted, the same action, PROCEED, is followed. The V16 N63 logic is the same as for normal cutoff; hence the crew is in exactly the same logical situation as at nominal cutoff. Physically, however, they are in a different situation with much larger $\underline{V}g$.

The crew has the choice of N63 or N85 display. In the case of the P70's, the continuous explicit targeting is still operating so that N85 ($\underline{V}g$) is correct, with compensation for the added burn time and attitude error due to RCS use. In the case of P12, the velocity targets are fixed and are not compensated for the overshoot in altitude. Typically for engine fail at Tgo = 20 sec, the error will be 10,000 ft. However, when V > 5077 fps, (Tgo ≈ 22 sec), the range rate becomes negative. The longer burn means that cutoff will come at a smaller LM-CSM phase angle.

The altitude overshoot requires a lower injection speed, (1 fps/1000 ft) while the smaller phase angle requires a higher speed (5 fps/degree). Thus the two effects, at least partially, offset each other.

For an engine fail at Tgo = 20 sec, the maximum error in $\dot{Z}_D$ (assuming no help from the reduced LM-CSM phase angle) is 10 fps. Hence the use of N85 to monitor injection in P12 is satisfactory. Since N85 is superior to N63 for P70/P71, N85 should be the common procedure for both situations.


Proceed
Reconnect Guid
V97N63
Terminate
Pooh
Enter
Proceed
Ignition
V99Nxx
Terminate
Pooh
Enter
(Used only on engine fail)
Enter
V16N63
Terminate
Pooh
Proceed
Enter
V16N85
Terminate
Pooh
Proceed
Pooh