

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

# APOLLO

## GUIDANCE, NAVIGATION AND CONTROL

R-532

Volume I of II

### REENTRY GUIDANCE FOR APOLLO

by

Raymond Morth

January 1966

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# APOLLO

## GUIDANCE AND NAVIGATION

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R-532  
 Volume I of II  
 REENTRY GUIDANCE  
 FOR APOLLO

by  
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R-532

## REENTRY GUIDANCE FOR APOLLO

### ABSTRACT

The design of the reentry steering for the Apollo spacecraft is discussed in detail.

Error performance is the critical design factor. A great deal of effort has been spent to find a system that would steer properly in spite of navigation errors. The most significant error is in the initial indicated rate-of-climb. To achieve this error performance a computed reference trajectory is used during the critical supercircular phase, with control gains that have been chosen on a statistical basis to minimize the miss distance.

The many other factors which affected the design are presented. Some of these are requirements on the trajectory by the heat shield and monitor system, and limitations on the attitude maneuvers by the roll control system fuel.

The performance of the automatic self-contained system using a digital computer is presented. Guidance to all possible points throughout the entry corridor is demonstrated.

The detailed computer logic for the Apollo Guidance Computer is also presented.

by Raymond Morth  
January 1966

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### Volume II of II (Separately bound classified document)

#### Instrument Error Performance



## PROLOGUE

Since "Apollo Reentry Guidance", R-415, was written several changes have occurred. These changes as well as more complete performance data are the subject of this report.

The most significant change is the reduction of the lift-to-drag ratio (L/D) of the Apollo command module from .5 to .3. This is a profound change in that the vehicle's performance characteristics have been sharply reduced. No longer is a 5000 nautical mile range possible for entries near the undershoot (10 g) limit. The maximum range possible for a .3 L/D vehicle is about 2500 nautical miles in this case. This reduced range capability affects the entire Apollo mission, putting stronger requirements on such things as the number of landing sites, and the time of the lunar month for return to earth. The entry steering design is also affected, with more accurate ranging required in the early phases because the final phase has less capability to correct for deviations.

It was felt since R-415 is essentially out of date, that this report should be made self-contained, repeating some of the material in R-415.

## I INTRODUCTION

A large amount of experience in reentry from orbit has been gained in the Mercury and Gemini programs. To date, there has been essentially no guidance during the reentry phase, though the Gemini spacecraft has a reentry guidance system, yet the results have been satisfactory. This raises the question: Is reentry guidance necessary for the Apollo mission? The answer is an emphatic yes. The main reason lies in the dynamics of reentry at escape velocity. Although escape velocity is only 40% greater than orbital velocity, the sensitivity of reentry range to variations in the reentry flight path angle is several orders of magnitude greater than that for the orbital case. (See Section II for a detailed discussion.) Thus a ballistic entry or a constant L/D entry would impose unreasonable accuracy requirements on the preceding phase. Further, even if such accuracy were possible, large landing point errors would be caused by non-standard atmospheric conditions and variations in the spacecraft aerodynamic characteristics. Because, here again, the range sensitivity to these variations is significantly higher than in the orbital case.

The guidance system must be self-contained because of radio black-out which is caused by an ion sheath surrounding the vehicle. Though there are means of penetrating this sheath such as by injecting water and using extremely high radio frequencies, these methods are as yet unproved, and it would be unwise to rely on their timely development.

The two objectives of the reentry guidance are, in order of importance:

1. safe return to the surface of the earth, and
2. landing point control.

These objectives must be achieved in spite of non-ideal equipment performance and non-standard environmental conditions.

To achieve a safe return the vehicle must be in the reentry "corridor", i.e. the entry angle must be large enough so that capture by the atmosphere



is assured but not so large so that excessive acceleration will result, (see fig. 1-1.) The midcourse guidance phase has first responsibility to attain this corridor.

The reentry guidance then must achieve the landing site while avoiding excessive g-loads at one extreme and a prolonged ballistic flight at the other. There is a real chance of the latter since longer ranges are attained by exiting from the atmosphere at slightly less than satellite velocity. Should this exit velocity exceed satellite velocity there would be an extended elliptical flight from half way to almost all the way around the earth. This would be highly undesirable since there are limited supplies of power and oxygen, to say nothing about the recovery problem from an unpredictable point on the earth.

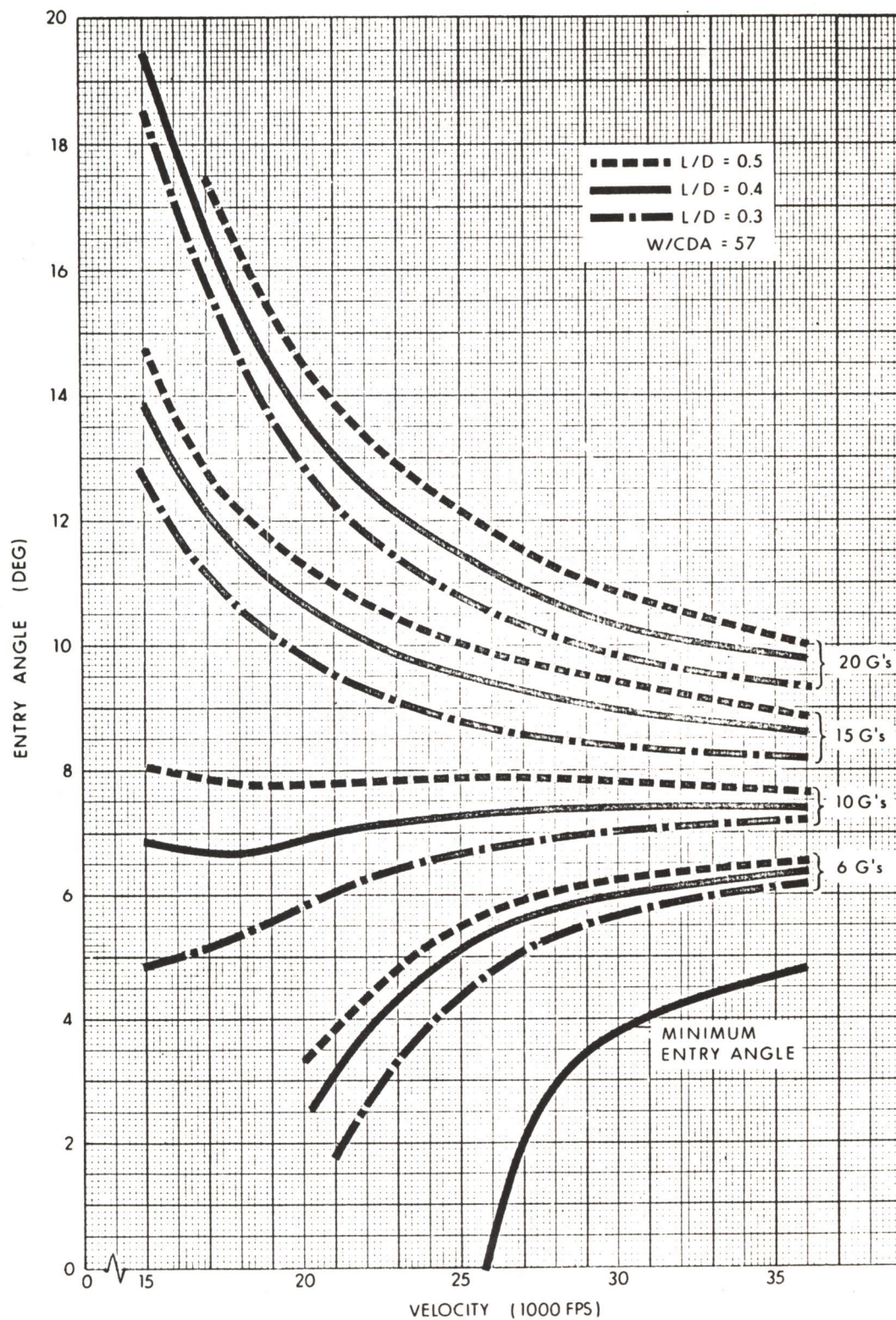


Fig. H Limit entry angle.



## II CAPABILITIES AND REQUIREMENTS

The Apollo command module is a wingless, axially symmetric reentry vehicle constructed so that its center of gravity is displaced from its axis of symmetry. The c.g. offset causes the vehicle to trim to a low angle of attack, about 20 degrees, providing the lift for trajectory control. The trajectory is controlled by rolling the vehicle about the wind axis with hypergolic reaction control jets, so that the lift may be directed anywhere in a plane perpendicular to the velocity vector.

A major vehicle design problem has been to provide sufficient center of gravity offset so that the vehicle lift-to-drag ratio,  $L/D$ , will be large enough. At present the  $L/D$  is about .3. As the following charts will show, further reduction of the  $L/D$  would seriously degrade the mission.

Shown in fig. 2-1 are maximum range capabilities for a series of low  $L/D$  vehicles which hold lift up throughout the reentry trajectory. Range is plotted against the initial flight path angle. The first point to note from this figure is that long range capability is due more to initial energy than to lifting capability. All vehicles, even the ballistic vehicle ( $L/D = 0$ ), can achieve a very large range if they enter at the right flight path angle. But the sensitivity of range to initial flight path angle is very large as seen by the slopes of the solid lines. For example, a ballistic vehicle going 4000 nautical miles has a sensitivity of about 10,000 nautical miles per milliradian. This sensitivity decreases with both increasing  $L/D$  and decreasing range, but for ranges greater than 1500 n.m. the sensitivities are too great to permit an open-loop guidance system.

The dotted line in fig. 2-1 shows the cases which have a maximum acceleration of 10 g's. This line shows the increase in allowable initial flight path angle with increasing  $L/D$ . Further, the figure shows the range penalty for decreasing  $L/D$ . At the 10 g limit, about 2500 n.m. is the maximum possible range with an  $L/D$  of .3 while over 6000 n.m. is possible with an  $L/D$  of .4.

The minimum possible range is determined by the maximum g level that can be tolerated as well as by the initial entry angle. Figure 2-2 shows



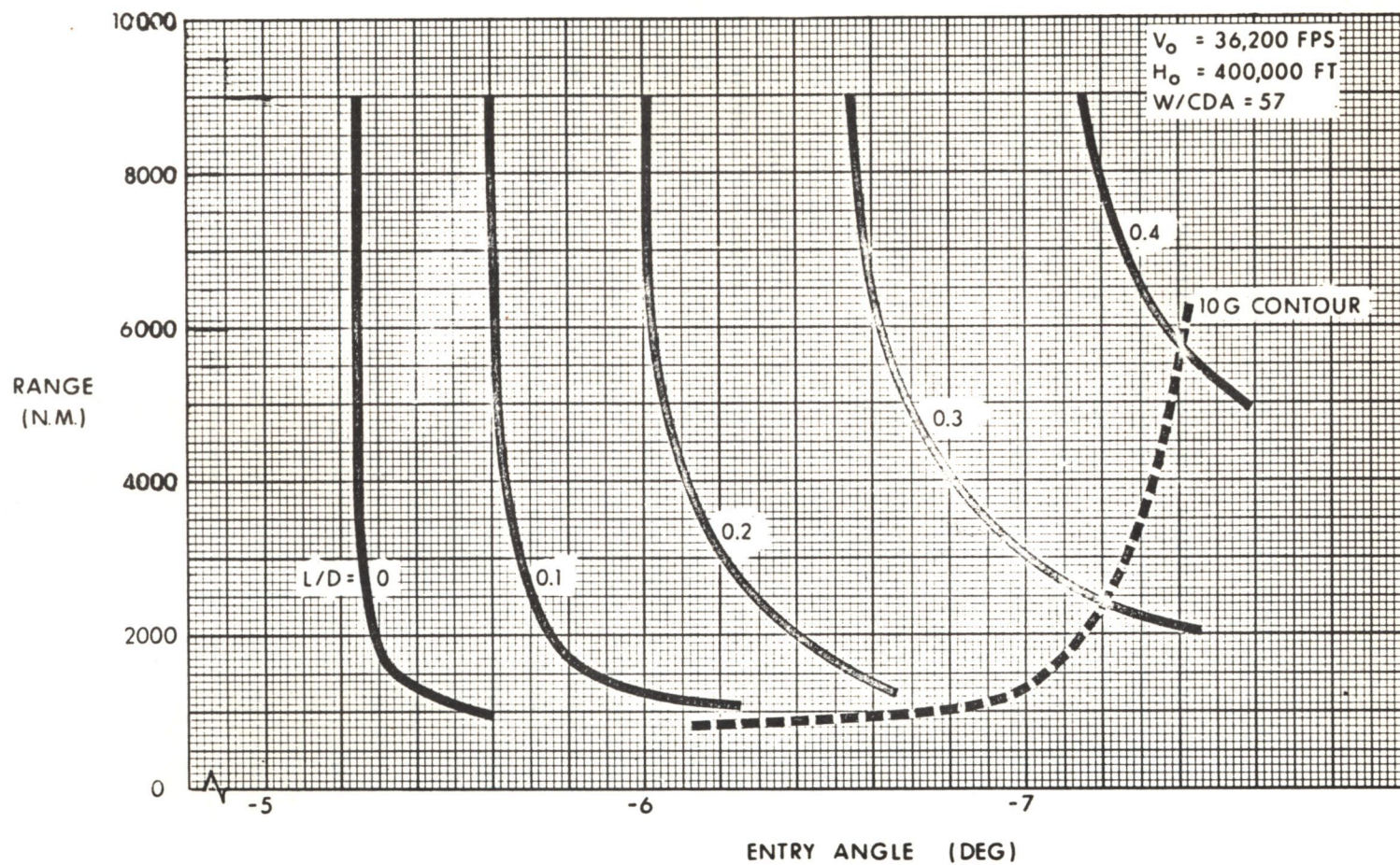


Fig. 2-1 Range for constant 4/0 entry.

a measure of this minimum range. This range was attained by directing the lift down after the initial pull-out modulating this lift direction by a g-limiter logic so that a 10 g limit will not be exceeded.

The maximum lateral range is shown in fig. 2-3 which plots the entry "foot print" for three values of L/D. That the lateral range is quite small emphasizes the fact that ranging capability is due to initial velocity (or energy) rather than aerodynamic characteristics. Note that the lateral range capability for  $L/D = .3$  is roughly half that for  $L/D = .4$ .

The next three charts show the vehicle capabilities for initial velocities less than satellite velocity. The curve for  $L/D = .3$  can be considered a maximum range capability and the  $L/D = 0$  curve can be considered a minimum range capability. At these velocities there is not a significant range reduction attained by lifting down. The next curve shows the time of flight for the  $L/D = .3$  cases. These curves have been useful to the designer of the powered steering for the abort cases.

### Design Requirements

The several requirements on the guidance system are listed below

1. Guide to all possible landing sites over the entry corridor
2. Do this with a 3 sigma accuracy of 15 n.m. in track and range
3. Choose those trajectories recognizable by a simple monitor
4. Choose trajectories that are compatible with the heat shield
5. Use only vehicle lift directed by a reaction control system with limited fuel
6. Do all this with a self-contained system, because of radio black-out

Vehicle capabilities dictate a range requirement of 2500 n.m. maximum, and 1500 n.m. minimum for all entry angles. Note again that this maximum range is reduced from the previous 5000 n.m. value which was possible with the higher L/D.



The accuracy requirement is largely a requirement on the initial condition uncertainties. The errors accumulated during entry due to both the steering and navigation meet this requirement easily. There is some possibility of reducing unusually large initial errors by monitoring the drag build-up. This is discussed in Appendix E.

The monitor function is to detect a guidance system failure. This is particularly difficult in some cases where the failure might result in a ballistic phase starting at just above satellite velocity. Since the monitor system has simple instruments which are supposed to be more reliable, the guidance system is constrained to generate trajectories in which "good" and "bad" is more easily detected.

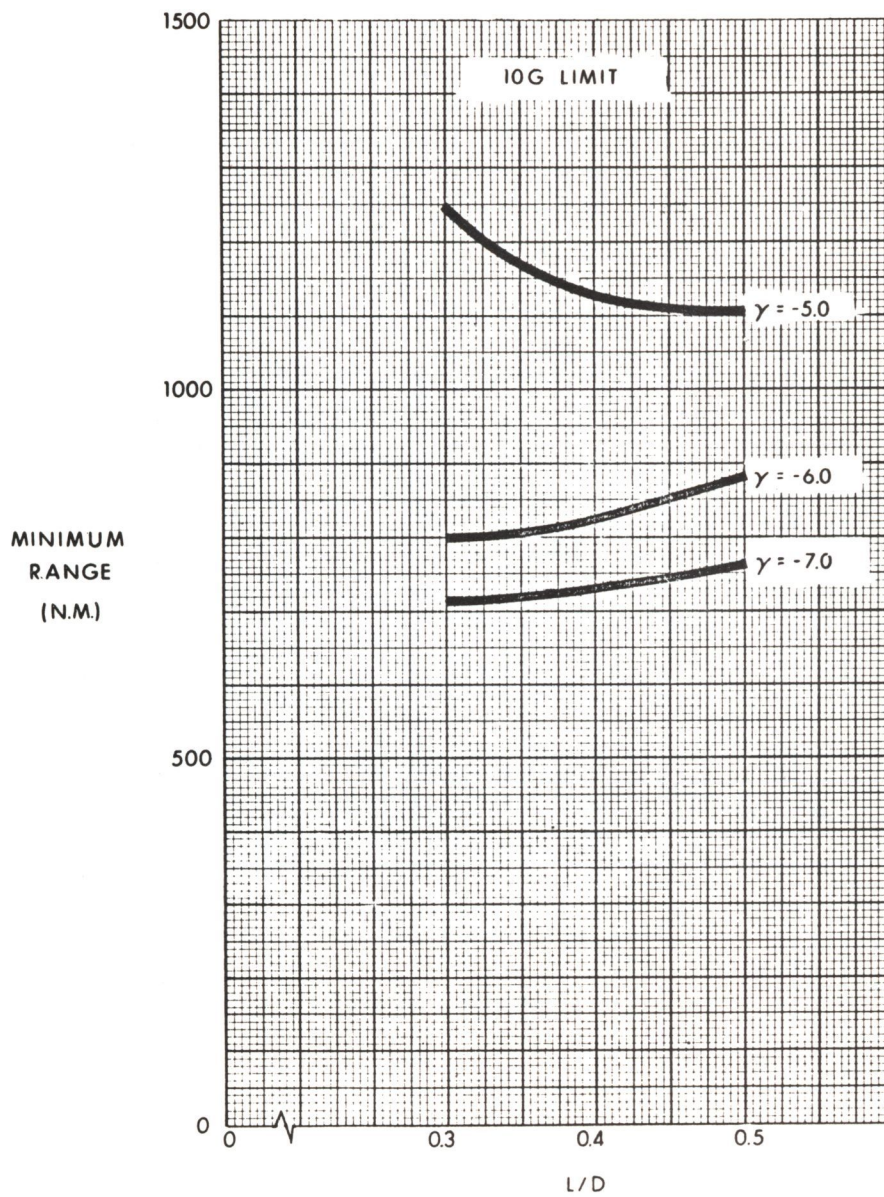


Fig. 2-2 Minimum possible range.



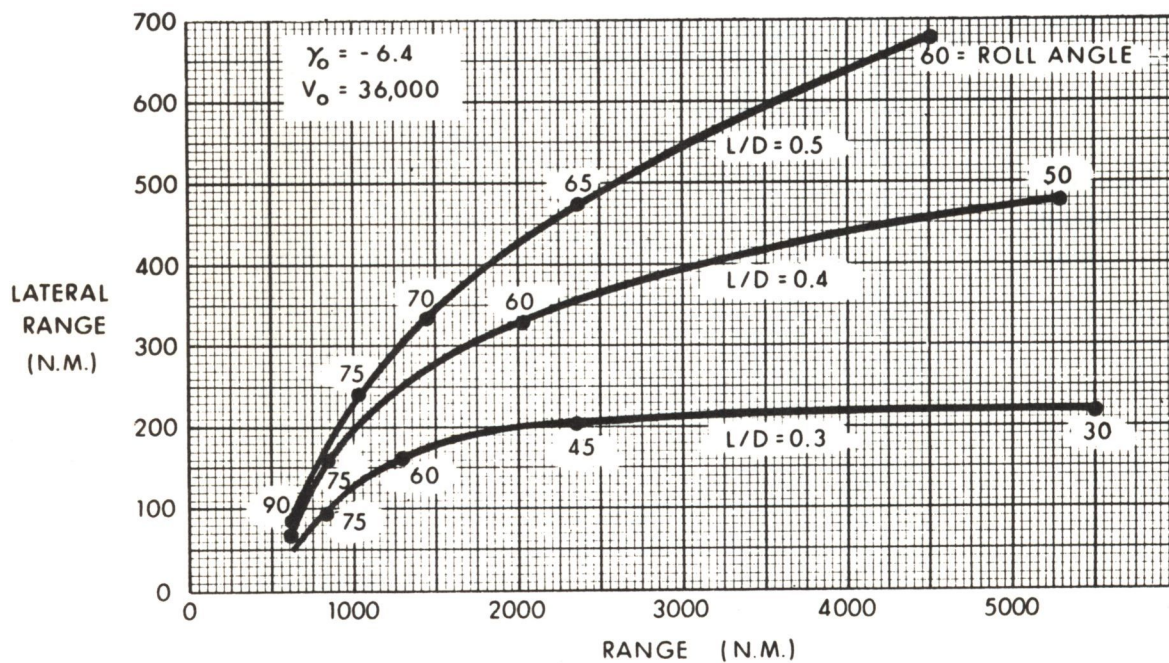


Fig. 2-3 Maximum lateral range.

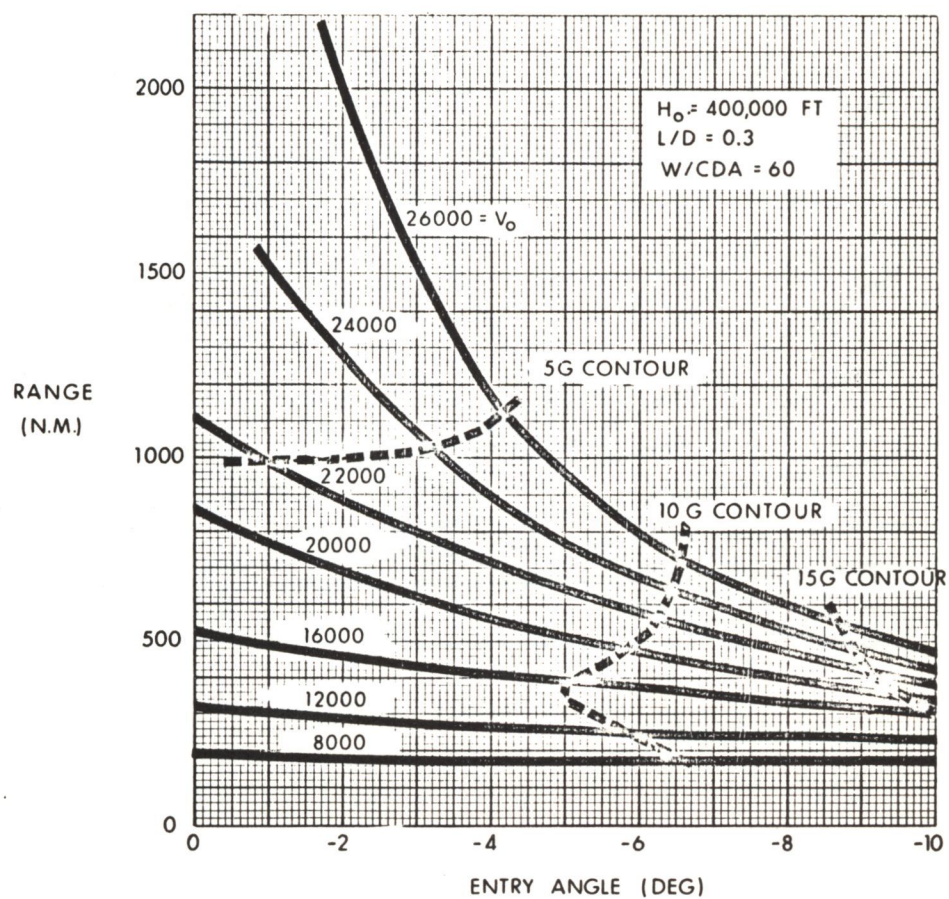


Fig. 2-4 Maximum Range for  $L/O = 0.3$



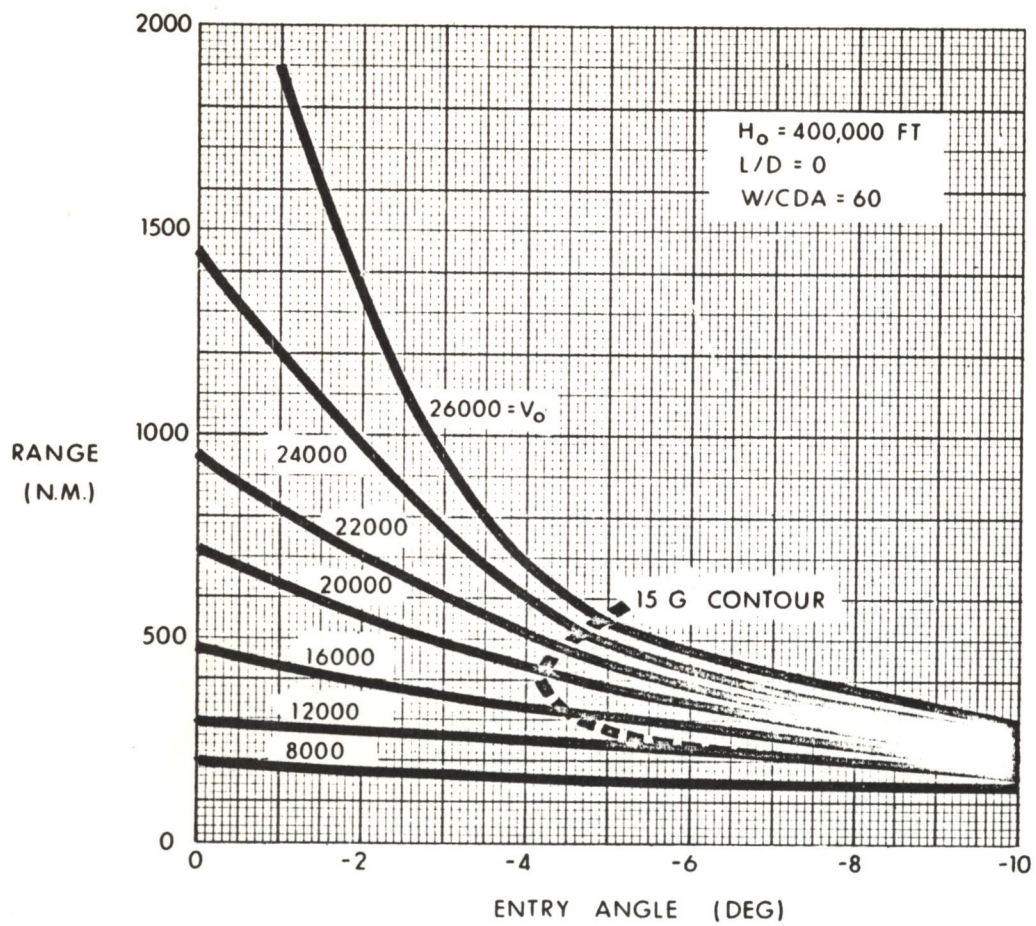


Fig. 2-5 Ballistic Range.

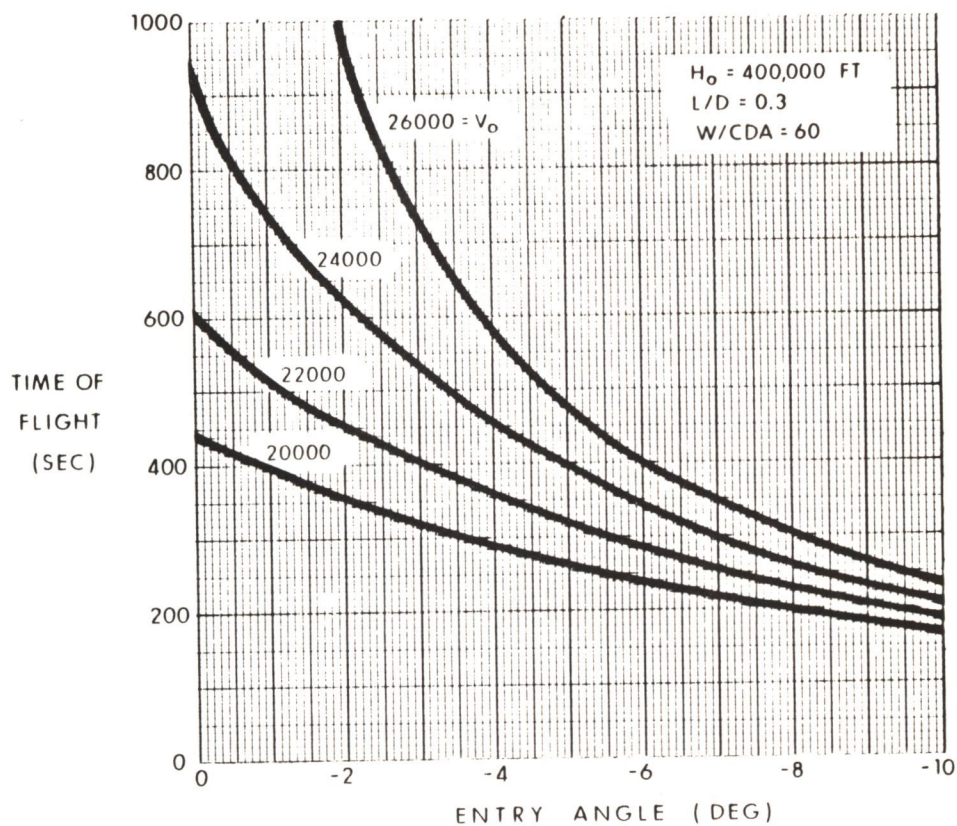


Fig. 2-6 Time of Flight



### III DESIGN GOALS

To meet these requirements several goals were set forth to evaluate the various designs that evolved. These are

1. Have large error handling capability
2. Use explicit techniques where possible
3. Adapt to the digital computer which is shared with several other mission phases

The main design goal was to synthesize a system which would steer correctly in spite of large errors in the form of initial condition uncertainties and gyro and accelerometer errors, as well as adapt to large deviations in the atmosphere and vehicle aerodynamic characteristics. Two distinct types of errors are encountered. The first is a navigation error, or lack of knowledge of position and velocity. This type of error is largely uncontrollable. That is, there is not much chance of reducing the position or velocity error without more measurements. The final miss will be at least the initial uncertainty propagated through the entry trajectory by the navigation equations. However, as described in Appendix E, very large uncertainties can be reduced by monitoring the acceleration build-up.

A second and more serious error is designated a "steering error". This error is a miss of the indicated target due to improper control action based on imperfect data. Early in the flight, more particularly in the critical up-control phase, an imperfect altitude rate signal, for example, will cause a range deviation so large that the final phase cannot correct for it. That is, in the critical early portion of the flight an error will cause the vehicle to fall outside the "foot print" and a huge miss results.

The central goal of this steering design was to find a scheme to reduce this "steering error". As will be described, a self-generated reference trajectory in the critical up-control phase has this effect. The reference trajectory in a sense weights all the input variables, thus not allowing any one variable to cause a large deviation.

Secondly, gains to control to this reference trajectory have been chosen to minimize the miss distance in the presence of noisy inputs. This is done on a statistical basis and is described in more detail in Reference 8. This type of performance criterion, i.e. maximum adaptability to errors, would appear to be more desirable than most of the criteria seen in the optimal control literature today. Much more work can be done along these lines on the entry problem.



## IV GUIDANCE DESCRIPTION

### General

A typical entry is shown in fig. 4-1 to illustrate the main features of the steering design. This is an acceleration versus velocity plot such as has been proposed for the monitor display.

Initially the vehicle is at point (1). Starting at point (1), the lift is directed up. Then the acceleration builds up and the velocity decreases until a point near peak acceleration, detected by a threshold altitude rate, is reached, point (2). Variations in this initial policy will be described in the detailed discussion. At point (2) a constant drag control is started. At the same time a range prediction is made. This calculates the range for constant L/D flight starting at present drag and velocity, and continuing the flight at constant L/D. Constant drag control is maintained until the range prediction is within 25 n.m. of the desired range. When this occurs, point (3), control is shifted to a self-generated reference trajectory that goes to the edge of the atmosphere, point (4). A ballistic phase is then maintained until the acceleration again builds up, point (5). Finally, steering to the landing site is accomplished by using a prestored reference trajectory, shown as a dotted line.

Very short ranges omit the up-control portion, and very long ranges omit the constant drag portion. Special cases such as an abort from orbit would start directly in the final phase.

Heating and monitor considerations led to selecting this type of trajectory. A high heating rate is desirable because it leads to a low integrated heat load, and the heat load sizes the heat shield. A trajectory with a constant drag portion tends to have a high heat rate because the initial stay in the atmosphere is prolonged. The reduction in heat load is more dramatic in the shallow entries where the constant drag level is larger than the drag at pull-out. In the limit, a trajectory in which the up-control portion is delayed as long as possible would have the least heat load. This extreme delay is not practical, of course, since there would be great danger of falling short of the target.

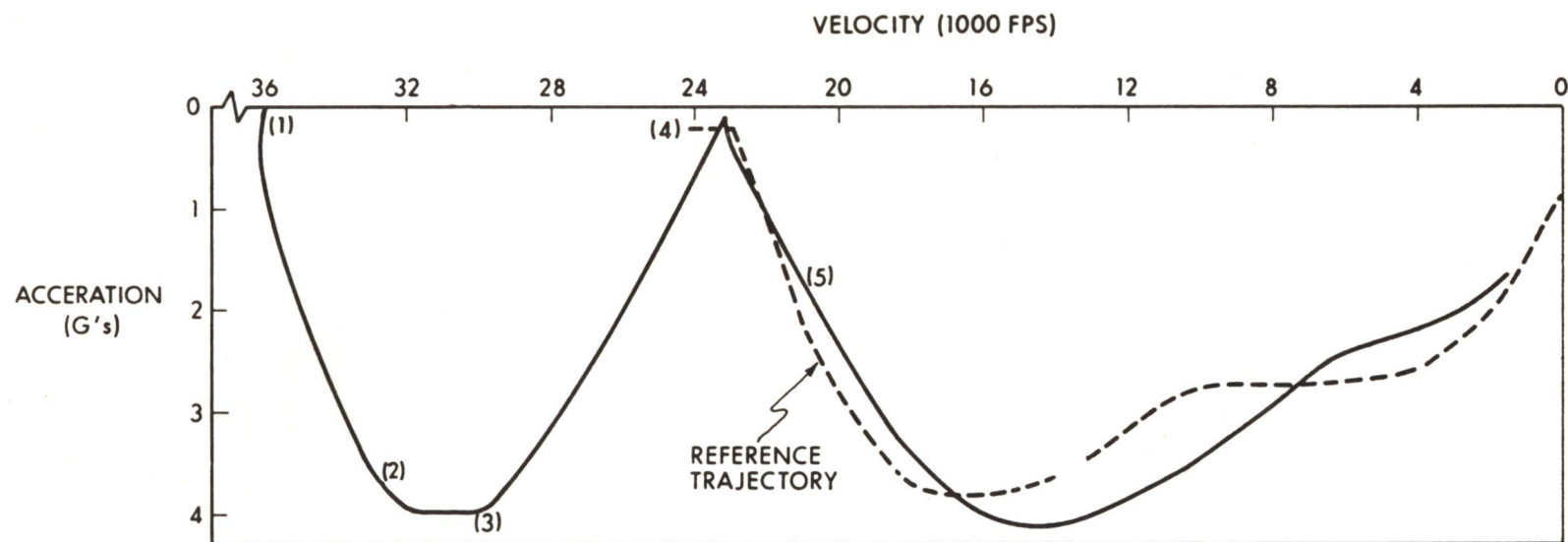


Fig. 4-1 Typical entry trajectory.



The monitor function is to detect uncontrolled skip-outs at greater than satellite velocity. The trajectory in which the up-control portion has been delayed is more easily distinguished from an uncontrolled skip-out than is one with no delay. This is true whether the monitoring function is accomplished by means of a trace on an acceleration-velocity plot as has been proposed by North American Aviation, or by a meter displaying rate of change of acceleration with velocity,  $dA/dV$ , as has been proposed by the Ames laboratory of NASA. Since the maximum range has been decreased to 2500 n.m., the monitor task has been greatly simplified. This is because the exit velocity for a 2500 n.m. trajectory is much less than that for a 5000 n.m. trajectory.

#### Input Variables

The input variables to the steering equations are fixed by the inertial measurement unit which is shared with other mission phases. The basic input is integrated acceleration generated by the PIPA-s (Pulsed Integrating Pendulous Accelerometers). This along with the initial condition of position and velocity, the target location, and the location of the earth North Pole vector,  $\bar{U}_Z$ , are the basic inputs.\*

There are several choices on how to rearrange these basic inputs. The derived variables that have been chosen are:

- D = total acceleration
- T = time from start of entry
- $\bar{R}$  = position vector
- $\bar{V}$  = velocity vector
- $\bar{R}_T$  = target vector
- $\dot{R}$  = altitude rate

Acceleration is preferred to altitude. The acceleration provides a measure of the pressure altitude, and is less susceptible to variations in atmospheric density and vehicle aerodynamic characteristics. Also, no requirement is made on the inherently divergent altitude channel of the inertial measurement unit.

---

\* Notation peculiar to this report is in Appendix I.

All the other choices are straight-forward except for that of altitude rate. The altitude rate signal is subject to large biases because the direction of the position vector is not known precisely. See the detailed discussion in Appendix D. The alternative, rate of change of drag with velocity ( $dA/dV$ ) is a noisy signal. The noise is due both to vehicle oscillations and the quantization in the PIPA-s. Shown in fig. 4-2 is an estimate of this noise level due to vehicle oscillations. The amplitude of the oscillation is mainly a function of the dead zone in the rate damper channel of the Stabilization and Control System (SCS).

Altitude rate is chosen as the lesser of two evils. The steering equations have been designed to accomodate large biases in this signal. Many schemes that were studied would have a large miss because of this error. The drag rate signal did not cause unusually large steering errors but did cause excessive roll control system fuel consumption particularly at the lower drag levels. The vehicle would alternate between zero and 180 degrees roll angle following the noise on the drag signal. A fairly sophisticated filter was required to smooth this signal.

The drag rate information is better used to correct the bias in the smoother altitude rate signal. One possibility for this is described in Appendix F.

### Computer Logic

The flow graph in fig. 4-3 shows the computer logic. This logic is entered every two seconds, and flow is directed to the appropriate branch by the mode selector. The final result is a roll command sent to the SCS by means of the coupling and display unit (CDU).

The Initialization Section, entered once at the start of entry, does the necessary initialization of variables, switches, etc.

The Navigation Section updates the position and velocity vectors with acceleration data by using the so-called "average-g" integration.

The Targeting Section calculates the range and lateral range to the landing site which is projected ahead by the earth rotating through an estimated time of flight.

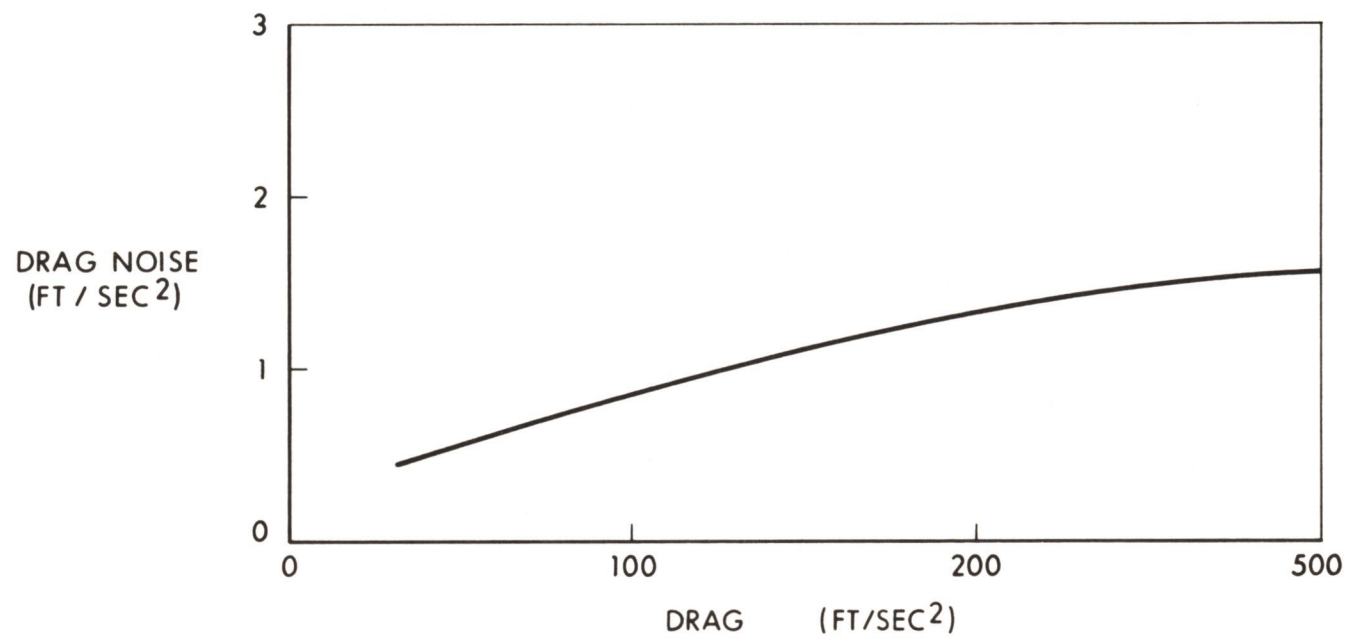


Fig. 4.2. Drag noise due to angle of attack oscillations



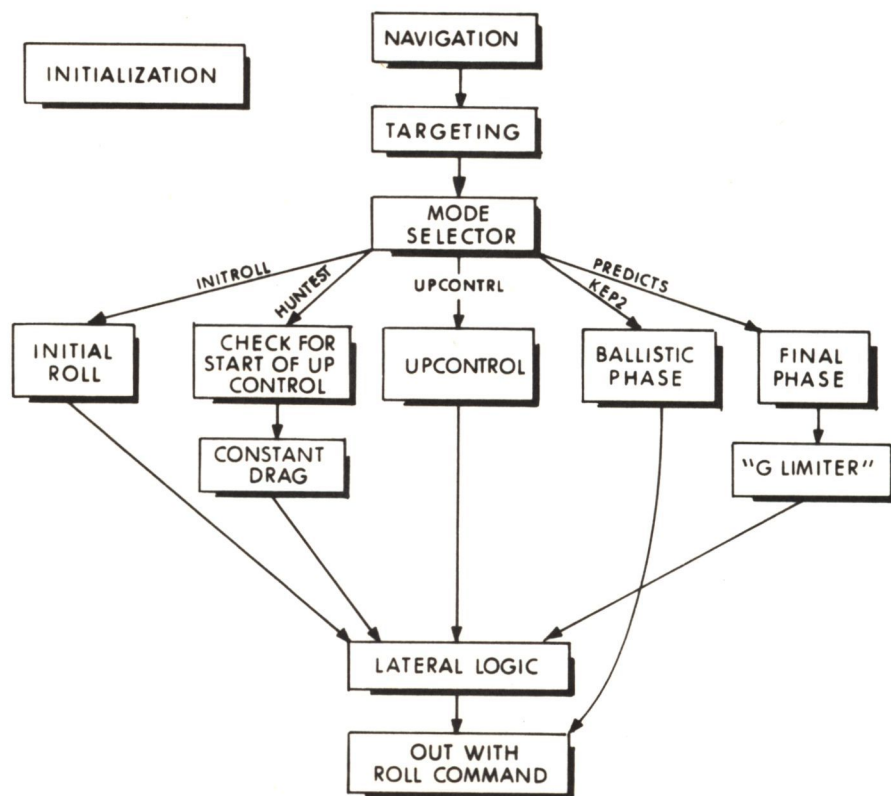


Fig. 4.3. Computer Logic

The Mode Selector selects the appropriate branch. In the diagram, the branches are arranged from left to right as they would be selected in time-sequence by the Mode Selector.

The Initial Roll Section holds constant roll angle, down-lift for shallow entries and up-lift for steep entries, until safe capture by the atmosphere is assured and ranging starts.

The Hunttest Section checks to see if the predicted range of a constant L/D flight from present velocity and acceleration equals the desired range. If the predicted range is long, the Constant Drag section is entered. If the predicted range is within 25 n.m. of the desired range, the Up-control Section is entered.

In the Up-control Section the vehicle is steered to the edge of the atmosphere by using a self-generated reference trajectory.

The Constant Drag Section holds constant acceleration with a simple linear proportional control.

The Ballistic Phase Section holds a constant roll command. Pitch and yaw commands are also generated because the aerodynamic stability is inadequate in this low dynamic pressure region.

The Final Phase Section steers to the landing site by using a prestored reference trajectory.

The G-Limiter Section modifies the roll commands where needed so that the limit acceleration will not be exceeded.

The Lateral Logic Section periodically switches the roll command from one side to the other so that one control variable, roll angle, can control both range and lateral range.

### Initialization

The Initialization Section sets up the computation cycle by setting certain initial variables and branches in the logic. The input to this section are the initial position and velocity vectors, the initial target vector all in earth-centered inertial coordinates, and the corresponding timing mark. Also as an input is an initial estimate of the entry angle so that the initial roll attitude may be set.

The vectors  $\bar{RTE}$ ,  $\bar{UTR}$ , and  $\bar{WE}$  are calculated so that the target position may be updated with the earth's rotation. Also, an initial calculation is made of the range,  $\theta$ , and the lateral range,  $LATANG$ .

The lateral logic parameter is set so that the initial lift will be toward the target.

$$K2ROLL = -SGN(LATANG)$$

The address of the starting phase is set to  $INITROLL$ . At  $INITROLL$  the decision is made if the particular trajectory is an abort case.

Other parameters are set to their initial values of zero. These are all the switches and  $K1ROLL$ .

#### Navigation

The "average-g" method of navigation is used to update position and velocity. The main idea is that the average gravity acceleration over the time interval is used to incorporate the velocity increment measured by the PIPA-s.

The computation cycle proceeds as follows: first the velocity increment is read as  $\bar{DELV}$ . Then the position vector is updated by using the gravity acceleration corresponding to the position vector at the start of the computation cycle.

$$\bar{R} = \bar{R} + \bar{TEM} DT$$

where

$$\bar{TEM} = \bar{V}_I + DT \bar{G}/2 + \bar{DELV}/2$$

The gravity acceleration at the end of computation cycle is then computed using this position vector.



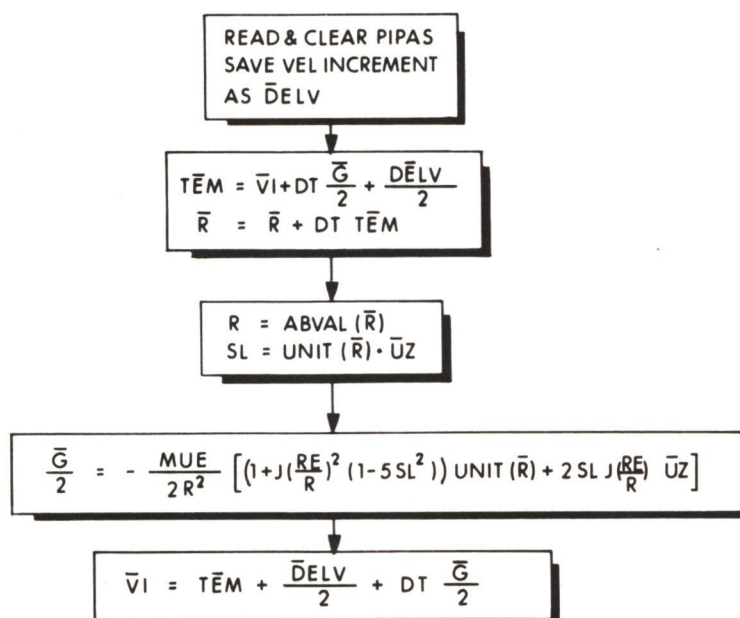


Fig. 4.4. "Average-g" Navigation

$$\bar{G} = -\mu E/2 R^2((1 - J(RE/R)^2 (1-5 SL^2)) \text{UNIT}(\bar{R}) + 2 SL J(RE/R^2 \bar{U}Z)$$

where

$$R = \text{ABVAL}(\bar{R})$$

SL = sine of Geocentric Latitude

$$= \text{UNIT}(\bar{R}) \cdot \bar{U}Z$$

Note that the second spherical harmonic coefficient, J, is used to represent the oblate earth. Finally, the velocity is calculated using the average of the two gravity acceleration vectors by

$$\bar{V}I = \bar{T}EM + \bar{D}ELV/2 + DT \bar{G}/2$$

A thorough discussion of this method is given by R. Bairnsfather in Reference 7, where he presents the effects of round-off and truncation on computational accuracy. The errors due to these effects are shown to be in the order of a few feet for the average entry trajectory.

He also shows that the errors introduced in computing velocity by the approximate representation of the oblate earth are less than the eight decimal digit precision of a double precision AGC number.

### Targeting

This section processes the position and velocity vectors generated by the Navigation Section to get the range and lateral range to the landing site as well as certain control parameters.

The control parameters are

$$V = \text{ABVAL}(\bar{V}), \text{ total velocity either relative or inertial}$$

$$VSQ = V^2/VSAT^2, \text{ normalized square of velocity}$$

$$LEQ = (VSQ - 1) GS, \text{ gravity plus centripetal accelerations}$$

$\bar{D} = ABVAL(DELV)/DT$ , total acceleration

$\dot{\bar{R}} = \bar{V} \cdot \text{UNIT}(\bar{R})$ , altitude rate

$\bar{U}_{NI} = \text{UNIT}(\bar{V} * \text{UNIT}(\bar{R}))$ , unit normal to trajectory plane

Initially the velocity vector is calculated as the inertial value,  $V_I$ . But late in the flight, when  $V$  is less than  $V_{MIN}$ , the velocity vector is calculated as a velocity relative to a fixed altitude above the rotating earth by

$$\bar{V} = \bar{V}_I - KWE \bar{U}_Z * \text{UNIT}(\bar{R})$$

This decision is marked by the switch RELVELSW. At the same time, the target is no longer projected ahead through an estimated time of flight, but the range is calculated to the instantaneous location of the target. At these low velocities it does not make sense to chase a target going at earth rate, but rather we steer in coordinates fixed to the rotating earth.

The target vector is rotated through an angle  $WT$  by the equation

$$\bar{U}_{RT} = \bar{U}_{RT0} + \bar{U}_{TR} (\cos WT - 1) + \bar{R}_{TE} \sin WT$$

where

$\bar{U}_{RT0}$  = initial target vector

$\bar{R}_{TE} = \bar{U}_Z * \bar{U}_{RT0}$

$\bar{U}_{TR} = \bar{R}_{TE} * \bar{U}_Z$

Figure 4-6 is the appropriate diagram.  $\bar{U}_{RT0}$ ,  $\bar{U}_{TR}$ , and  $\bar{R}_{TE}$  are set up in the Initialization Section.

The angle,  $WT$ , through which the initial target vector is rotated is based on the time of flight which is estimated in one of three different ways. Initially, at supercircular velocities

$$WT = WIE (KTETA \text{ THETA} + T)$$



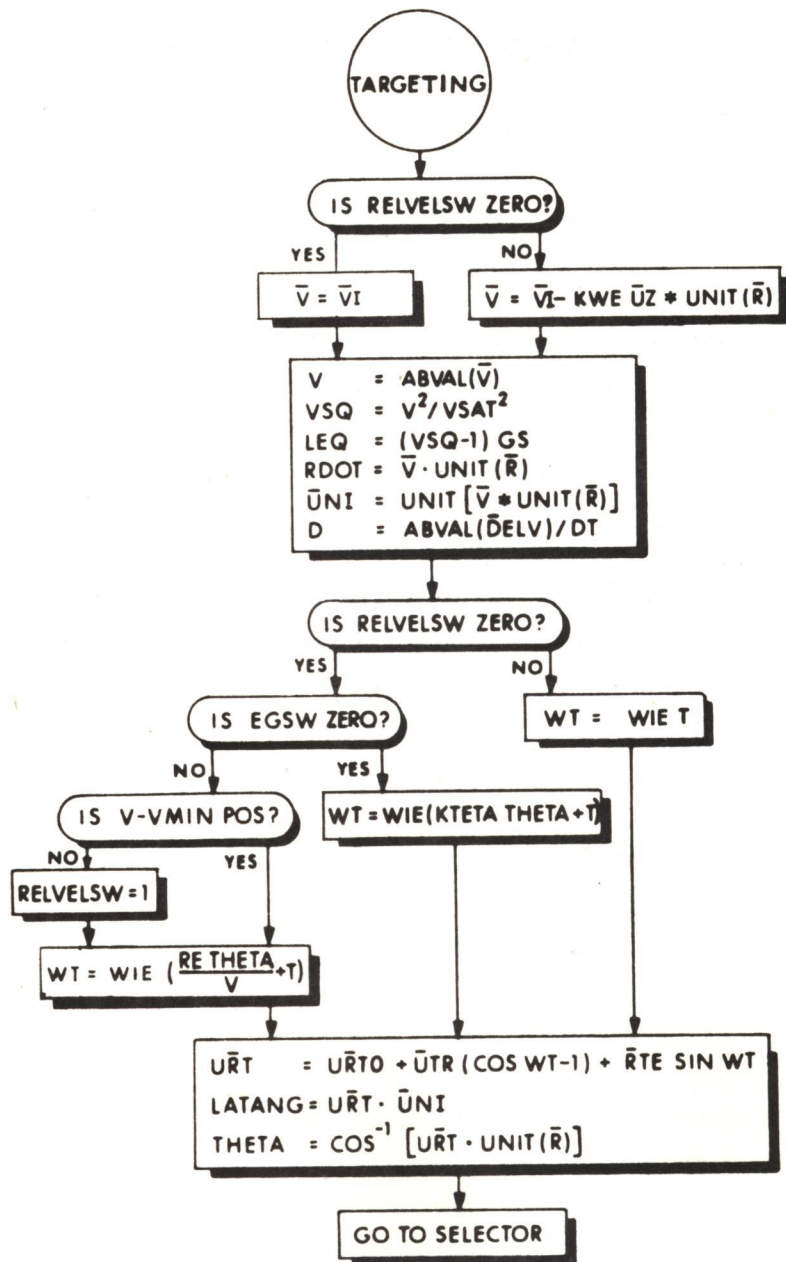


Fig. 4.5. Targeting

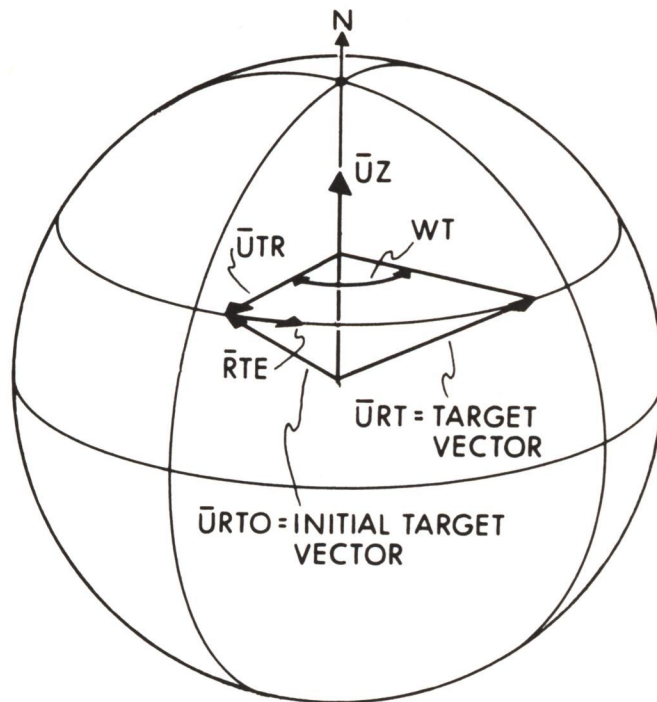


Fig. 4-6 Projection of target vector through estimated time of flight.

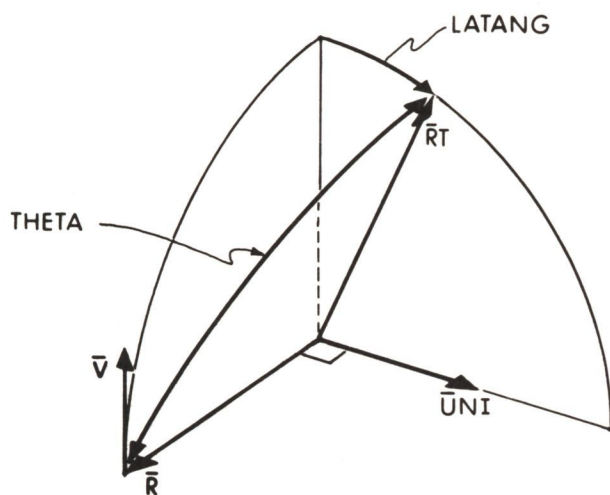


Fig. 4-7 Range and lateral range.

The time of flight is approximately proportional to the range-to-go. This assumes flight at constant velocity,  $KTETA$  approximately equals  $RE/VSAT$ . An examination of the guided trajectories in Section V shows that this assumption is reasonable.

During the first part of the final phase

$$WT = WIE (THETA RE/V + T)$$

The time of flight is calculated assuming the rest of the flight will be at the present velocity. It is no longer fair to assume flight at satellite velocity.

Finally, when relative velocity is used near the very end of the flight, the target is not projected ahead. That is, we steer the present position of the target by using  $WT = WIE T$ .

The lateral range is calculated by

$$LATANG = \bar{U}RT \cdot \bar{U}NI$$

Small angles are assumed since the right hand side of the above equation defines the sine of the lateral range.

The range is calculated by

$$THETA = ARCCOS(\bar{U}RT \cdot UNIT(\bar{R}))$$

See fig. 4-7. If we go past the target, detected by  $\bar{R}T \cdot \bar{R} \cdot \bar{U}NI$  less than zero, the steering is disabled and a 180 degree roll is called. This logic is performed only in the final phase.

The range formula is unambiguous for ranges up to 180 degrees. If ranges greater than half way around the earth are ever contemplated, additional logic would be required to allow for this possibility. Likewise the lateral logic would have to be changed since all great circles converge at a point 180 degrees away from the present point.



The ARCCOS function is not very accurate for arguments near one. The algorithm for this function has been modified to improve the accuracy by making use of the triple precision result of a double precision multiplication. Let  $x$  equal the argument of the ARCCOS. If  $1-x$  is less than  $1/16384$ , i.e. the high order part is zero, the quantity  $1-x$  is shifted left 13 places and the ARCCOS is approximated by

$$\text{ARCCOS}(x) = \text{SQRT}(2(1-x))$$

### Initial Roll

The Initial Roll Section holds a constant roll attitude until the sensible atmosphere is detected (at .05 g). At this time INRLSW is set to one so that this branch will not be entered again. Then up-lift is called and the final phase is entered if the velocity is low, less than VFINAL. If the velocity is high, a test is made to determine the position in the entry corridor. Down-lift is called if the entry is shallow. This is detected when the velocity is greater than

$$V_{\text{FINAL}} - K_{44} (\dot{R}/V)^3$$

This curve, shown in fig. 4-8a, is parallel to the overshoot boundary curve defined at the .05 g level.

As described in Appendix D, a shallow entry angle is accompanied by a positive  $\dot{R}$  error. This error would indicate an even shallower entry. The test, therefore, would call for the proper lift direction even in the presence of very large errors.

This lift direction is then maintained until the acceleration exceeds  $K_A$ . Then the L/D command is set to LAD. This command is held until the altitude rate is less than a threshold altitude rate, VRCONTROL, at which time the next phase is started.

$K_A$  is fixed at 2 g's for lunar entries and .2 g's for the 202 case, but may vary for some of the other flight tests.

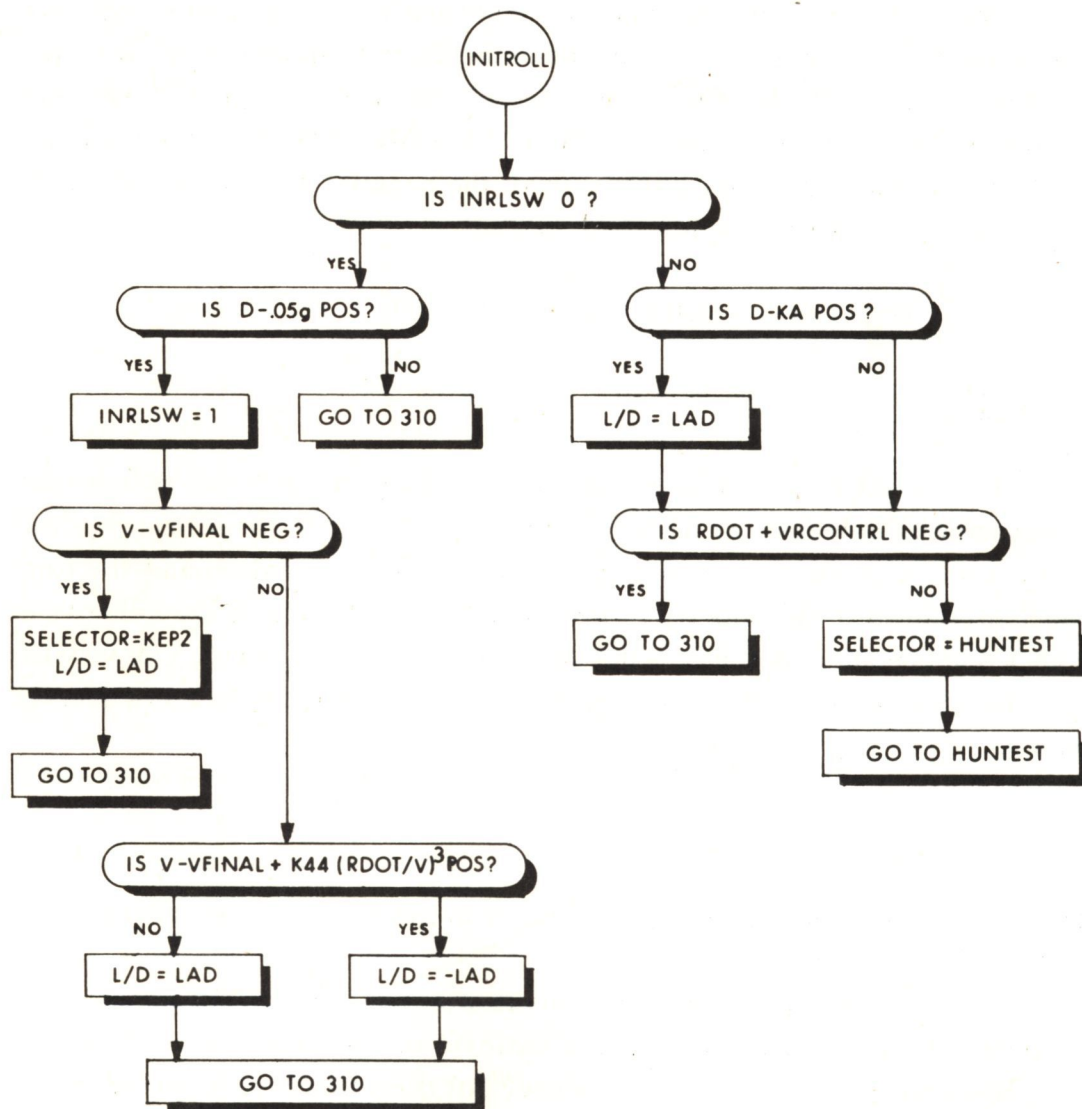


Fig. 4.8. Initial Roll

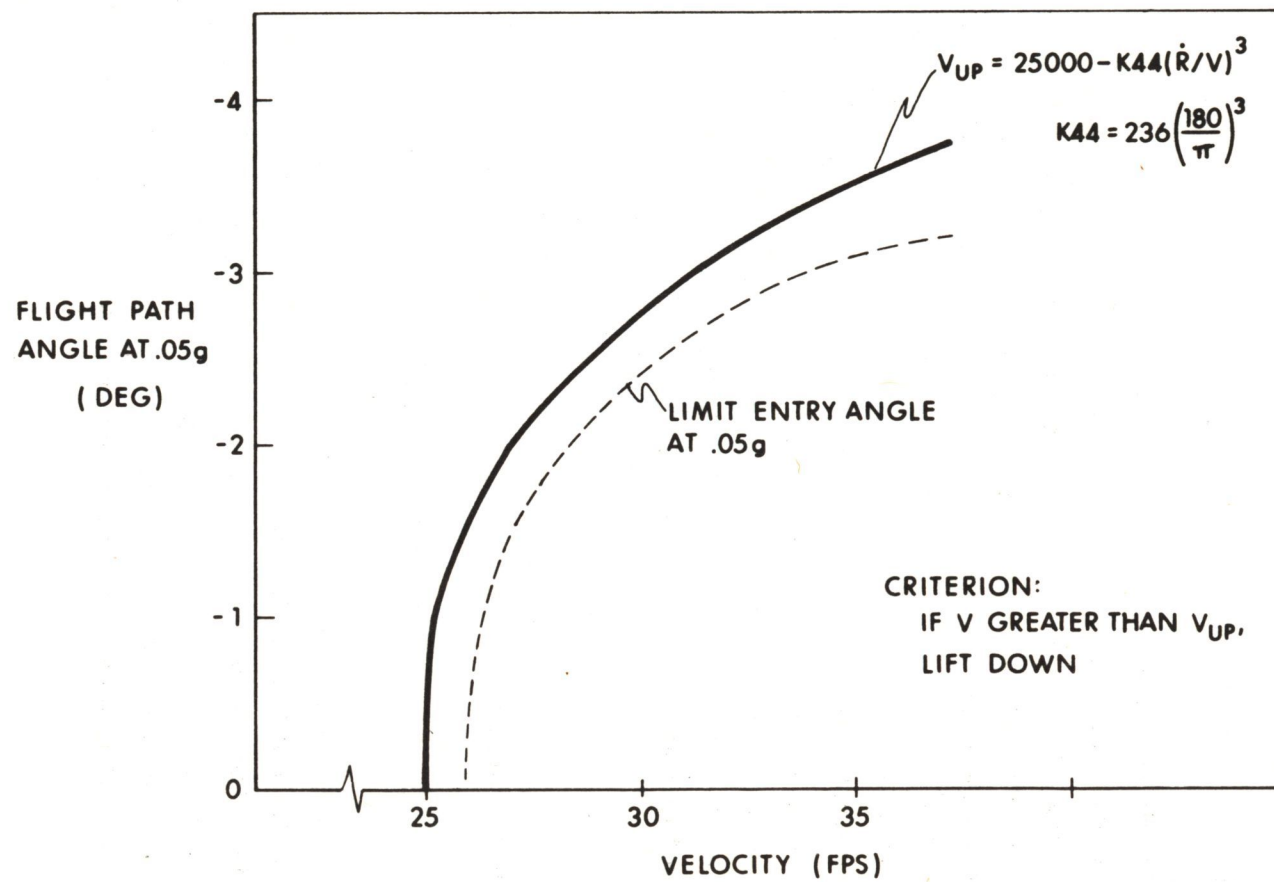


Fig. 4-8a. Criterion for Up- or Down-Lift



A more sophisticated policy is being considered for this phase. This policy would examine the acceleration build-up to determine where the vehicle is in the entry corridor, and then direct the lift accordingly. So far however, the simple roll policy appears to be adequate.

### Huntest

The Huntest Section checks to see if a constant L/D policy from present conditions will give the desired range. If so, range control is started using a self-generated reference trajectory. If the range is longer than the desired range, control is shifted to a constant drag controller. The reference trajectory, which approximates constant L/D flight, is a parabola relating drag and velocity. The predicted ranges are represented by simple approximate formulae.

The first "subtask" of this section is to project ahead from present conditions to a point having zero altitude rate. This point is a possible starting point for the up-control phase and has a starting velocity V1, and a starting acceleration A0. If R is negative the starting velocity is calculated assuming flight at maximum L/D until  $\dot{R} = 0$ .

$$V1 = V + \dot{R}/LAD$$

The same assumption is used to calculate A0, see Appendix A.

$$A0 = (V1/V)^2 (D + \dot{R}^2/(2 HS LAD))$$

If R is positive, flight at nominal L/D is assumed from zero  $\dot{R}$ , and LEWD is used in place of LAD in the two equations above.

This refinement was needed for the 202 mission in which this part of the trajectory is flown at low dynamic pressure and hence for a long time period. The nominal entry for a lunar mission is at a much higher dynamic pressure, and in this case these corrections will be quite small.

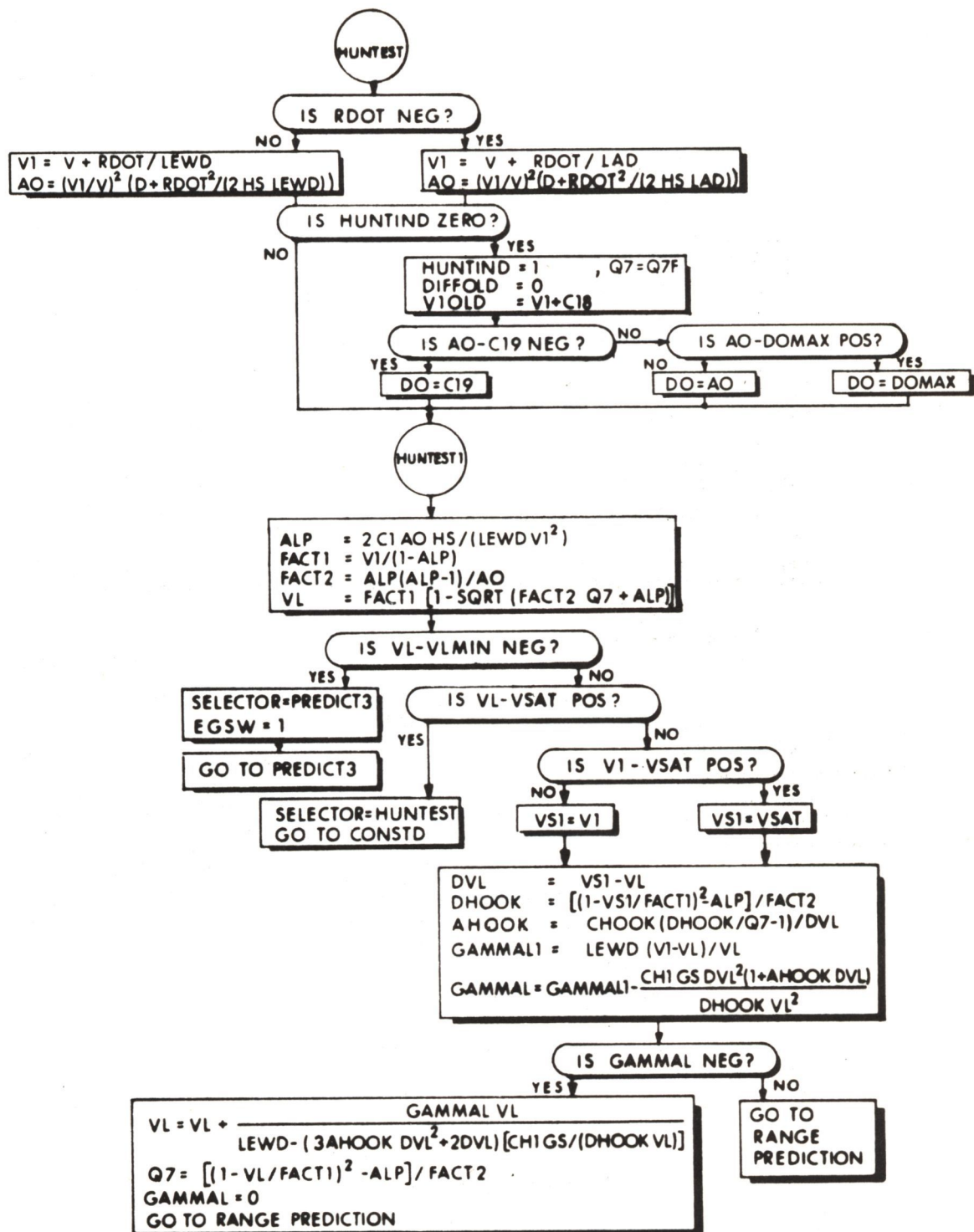


Fig. 4-9. Hunttest

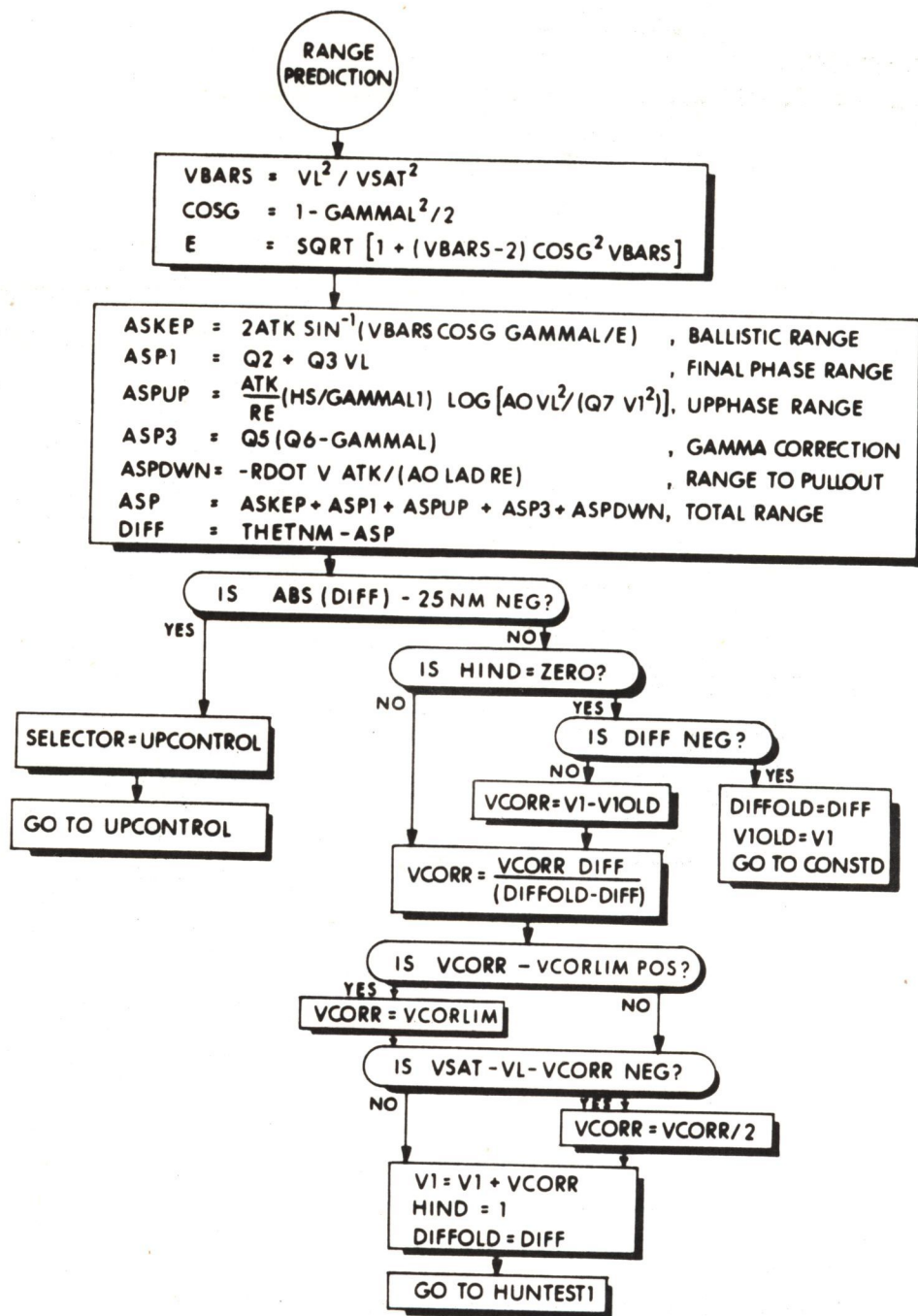


Fig. 4-10. Range Prediction



The next "subtask" of this section is to establish the drag level for the constant drag controller. This is D or C19, whichever is larger, with a maximum value of D0MAX. HUNTIND is a switch to allow this calculation only one time, the first pass through this section. Very short ranges could call for a higher drag level than C19, and logic has been written to allow for this possibility. So far, the logic has not been needed and therefore has not been included.

Next, the exit velocity, VL, is related to the initial velocity and the initial and final drag levels by the relation

$$VL = FACT1(1 - \sqrt{FACT2 Q7 + ALP})$$

where

$$ALP = 2 C1 A0 HS / (LEWD V1^2)$$

$$FACT1 = V1 / (1 - ALP)$$

$$FACT2 = ALP(ALP - 1) / A0$$

$$C1 = \text{shaping constant}$$

As shown in Appendix A, this relation holds for constant L/D flight if the gravity plus centripetal acceleration is negligible, a good approximation near satellite velocity.

If the exit velocity is too low, less than VLMIN, the program control is shifted to the final phase, PREDICT3. If the exit velocity is greater than satellite velocity, VSAT, program control is shifted to the constant drag controller.

The altitude rate at exit is calculated by a simple linear relation with velocity, with a correction to allow for the neglected centripetal and gravity accelerations.

$$GAMMAL = LEWD(V1 - VL) / VL - CH1 GS DVL^2 (1 + AHOOK DVL) / (DHOOK VL^2)$$

where

$$DHOOK = ((1 - VS1 / FACT1)^2 - ALP) / FACT2$$

$$AHOOK = CHOOK(DHOOK / Q7 - 1) / DVL$$

$$DVL = VS1 - VL$$

$$VS1 = VSAT \text{ or } V1, \text{ whichever is lower}$$

$$CH1, CHOOK = \text{shaping constants}$$

If the gravitation acceleration effect is too great, GAMMAL can be negative, indicating that the desired exit condition cannot be reached. In this case, the exit velocity, VL, is adjusted to the zero flight path angle condition by

$$VL = VL + GAMMAL VL / (d\dot{R}/dV)$$

where

$$d\dot{R}/dV = LEWD - CH1 GS(3 AHOOK DVL^2 + 2 DVL) / (DHOOK VL)$$

And the acceleration at exit, Q7, is adjusted to correspond to this new VL by

$$Q7 = ((1 - VL/FACT1)^2 - ALP) / FACT2$$

These two variables (GAMMAL and VL) are enough to calculate the predicted range ASP as the sum of five components, each represented by simple approximate formulae, derived in Appendix G.

$$ASP = ASPDWN + ASPUP + ASKEP + ASP1 + ASP3$$

$$\begin{aligned} ASPDWN &= \text{range to pull-out (where } R = 0) \text{ in n.m.} \\ &= -R V ATK / (A0 LAD RE) \end{aligned}$$

$$\begin{aligned} ASPUP &= \text{range to exit in n.m.} \\ &= (ATK HS / (RE GAMMAL1)) \ln(A0 VL^2 / (Q7 V1^2)) \end{aligned}$$

$$\begin{aligned} ASKEP &= \text{ballistic range in n.m.} \\ &= 2 \arcsin(VBARS \cos G GAMMAL / E) \end{aligned}$$

where

$$VBARS = VL^2 / VSAT^2, \text{ normalized exit velocity squared}$$

$$\cos G = 1 - GAMMAL^2 / 2$$

$$E = \sqrt{1 + (VBARS - 2) \cos G^2 VBARS}$$

$$\begin{aligned}\text{ASP1} &= \text{final phase range in n.m.} \\ &= Q2 + Q3 \text{ VL}\end{aligned}$$

$$\begin{aligned}\text{ASP3} &= \text{correction to final phase for flight path angle in n.m.} \\ &= Q5(Q6 - \text{GAMMAL})\end{aligned}$$

If the difference between the predicted and desired ranges, DIFF, is less than 25 n.m., control is shifted to the up-control section. If no iteration has been called, HIND = 0, and the predicted range is too great, DIFF is negative, then control is shifted to the constant drag controller. DIFF and V1 are saved to aid in a possible future iteration.

If HIND = 1, an iteration has been indicated. This iteration is started when the desired range is more than 25 n.m. greater than the predicted range. In this case the starting velocity, V1, is altered to cause the predicted and desired range to agree.

$$V1 = V1 + \text{VCORR}$$

where

$$\text{VCORR} = \text{VCORR DIFF} / (\text{DIFFOLD} - \text{DIFF})$$

The VCORR on the right hand side of the last equation is either the last velocity correction or V1OLD - V1 on the first pass through the iteration. No correction greater than 1000 fps is allowed so that the iteration will be well-behaved. Also, the velocity correction is halved if it appears that the exit velocity may exceed satellite velocity on the next pass through the iteration.

Usually no iteration is involved. It is only on the steep entry long range case that an iteration is called. In this case, the very first pass through this section gives too short a predicted range, and V1 must be increased until the range is great enough.

There is some consideration of changing the iteration cases to an iteration on LEWD rather than V1. It is more reasonable to raise the nominal L/D at the present starting point than to find a different starting point where we should have been. At this time it is not decided if the additional programming required is warranted.



## Up-control

The Up-control Section steers the vehicle along a self-generated reference to suitable conditions at the edge of the atmosphere. In this section, sensitivity to errors was the determining design factor. The reference trajectory technique was found to be less sensitive to altitude rate errors. This reference is self-generated allowing the desired flexibility. Optimum gains were chosen on a statistical basis to follow this reference. These optimum gains were chosen to minimize the effects of errors.

Drag is the independent variable of this reference. Other designs had velocity as the independent variable. There is no double value in the reference near exit velocity if drag is the independent variable. A second advantage is that the system response is faster to a commanded velocity than to a commanded drag level, thus a tighter control can be maintained.

Also, there is no iteration in most cases to get this reference. This gives better response than did previous systems because the actual starting condition for the up-control phase is closer to the reference starting condition.

The central equation is

$$L/D = LEWD - KB2 F1(KB1 F1 (\dot{R} - RREF) + V - VREF)$$

where

$L/D$  = commanded lift-to-drag ratio in vertical plane

$LEWD$  = reference  $L/D$

$KB1, KB2$  = optimum constant gains

$F1 = (D - Q7)/(A0 - Q7)$

$VREF = FACT1(1 - \sqrt{FACT2 D + ALP})$

$RREF = LEWD(V1 - VREF) + RCORR$

$RCORR = CH1 GS((VS1 - VREF)^2 + AHOOK(VS1 - VREF)^3)/(DHOOK VREF)$

Prior to implementing this equation certain tests are made. First, as is common programming practice, tests are made at the start to see if the phase is over. If the drag is less than  $Q7$ , the minimum drag, the ballistic

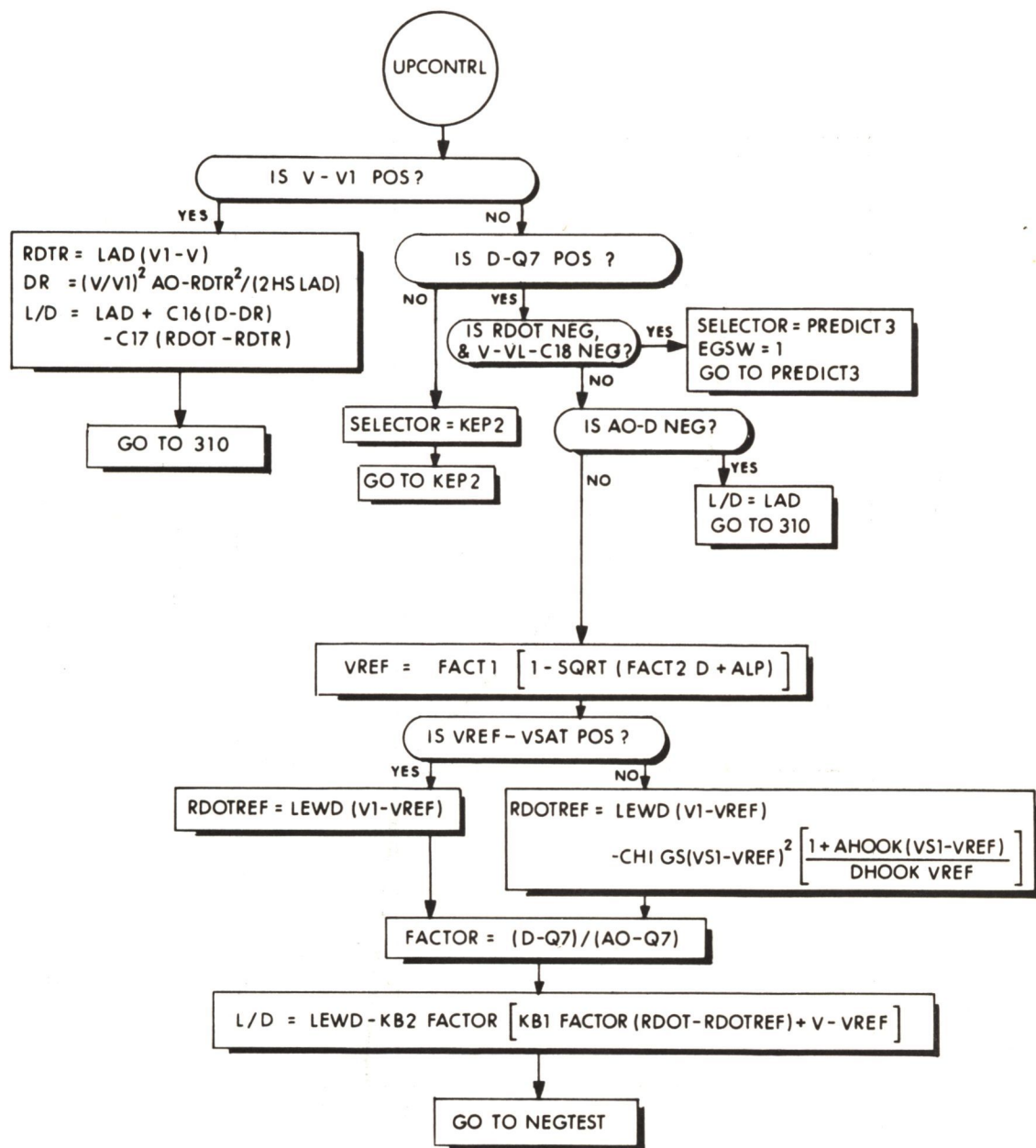


Fig. 4-11. Up-control

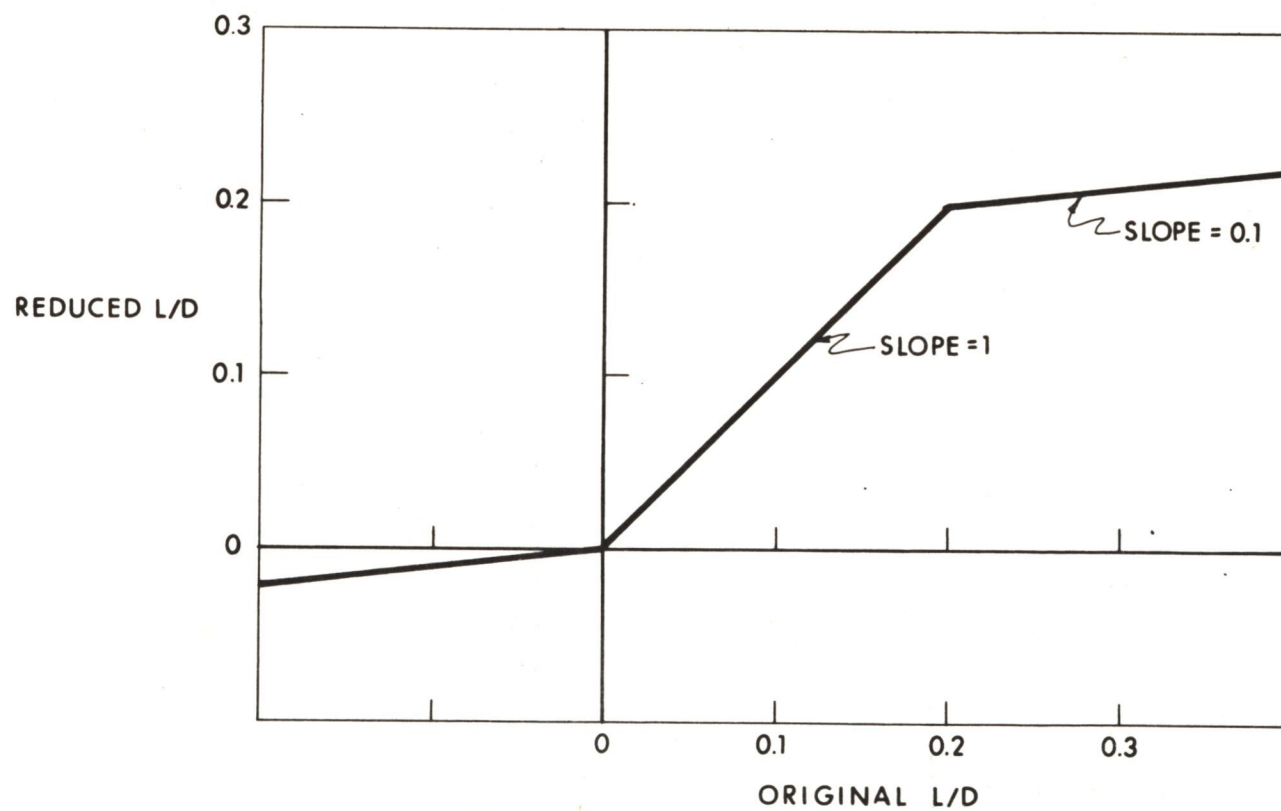


Fig. 4-12. Circuit to Reduce Gain for Large Commands



phase is started. If the altitude rate is negative and the velocity less than  $V_L + C18$ , the final phase is started. Other tests call for full positive lift if the drag is greater than the starting drag,  $A0$ , because the reference is not defined at these high drag levels.

The method used to determine the optimum form of Eq. 1, along with the optimum gain parameters,  $KB1$ , and  $KB2$ , is described in detail in Reference 8. The objective was to find varying gains, multiplying  $(\dot{R} - RREF)$  and  $(V - VREF)$  so that exit conditions would result in minimum dispersion at the target. The sources of error considered were uncertainties in altitude rate and velocity and deviations in atmospheric scale height. The optimization procedure consisted of the following four steps. First, an approximate set of equations of motion were derived, in which drag, rather than time, is the independent variable. Second, these approximate equations were linearized about a reference trajectory. Third, a set of linear equations (variance equations) which describe the statistical behavior of the system for an ensemble of cases were derived from the former set. Finally, a computer program containing the variance equations was used to vary the gains in an iterative, steepest-descent, fashion so that the projected dispersion at the target was minimized. The resulting gains are optimal for one particular range (2500 n.m.), but work well for all ranges.

The optimum gains are high values and can lead to a roll angle history with several switches between zero and 180 degrees. To smooth this response, reduced gains are used for large error signals. Figure 4-8 shows the nonlinear circuit that is used.

A short segment of control is made if the velocity is above the starting velocity  $V1$ . This causes the vehicle to follow a trajectory as if the  $L/D$  were  $LAD$ , the maximum value. This is done so that there will be no long open loop segment at maximum  $L/D$ , a possible problem at the lower drag levels. The control is very similar to the constant drag control.

$$L/D = LAD + C16 (D - DR) - C17 (\dot{R} - RDTR)$$

where

$$RDTR = LAD (V - V1)$$

$$DR = (V1/V)^2 A0 - (V - V1)^2 LAD / (2 HS)$$

Still another test, NEGTEST, will not allow L/D to be negative if the drag level exceeds C20. This is to preclude a lateral switch, rolling through the full down-lift attitude. At these high drag levels, such a maneuver could cause the vehicle to fall short of the target.

### Constant Drag

The constant drag controller holds the drag level to D0 with three terms,

$$L/D = -LEQ/D0 + C16 (D - D0) - C17 (\dot{R} + 2 HS D0/V)$$

The first term,  $-LEQ/D0$ , is the L/D required for equilibrium. The second term,  $C16(D - D0)$ , is a constant gain on the drag difference. The third term,  $-C17 (\dot{R} + 2 HS D0/V)$ , is a constant gain on the difference between R and R for constant drag.

The gain C16 is designed to give a 90 second period to the equivalent second order system. For fixed frequency this gain should be inversely proportional to the square of drag. The damping gain, C17, is designed to give a damping ratio of .7. This gain should be inversely proportional to the drag level for fixed damping ratio. The governing equation by which these gains were derived can be found by taking perturbations about equilibrium of the constant drag level and neglecting certain terms. See Appendix F. The perturbation equation is

$$\delta \ddot{D} + (2D/V + C17 D) \delta \dot{D} + (C16 \beta D^2 - \beta(V^2/R - G)) \delta D = 0$$

where

$$\delta D = D - D0$$

The natural divergence at supercircular velocities can be noted, as well as the drag dependence of the natural frequency and damping ratio.

Should constant drag control be desired over a wide range of constant drag levels, this drag dependence of the gains could be used.

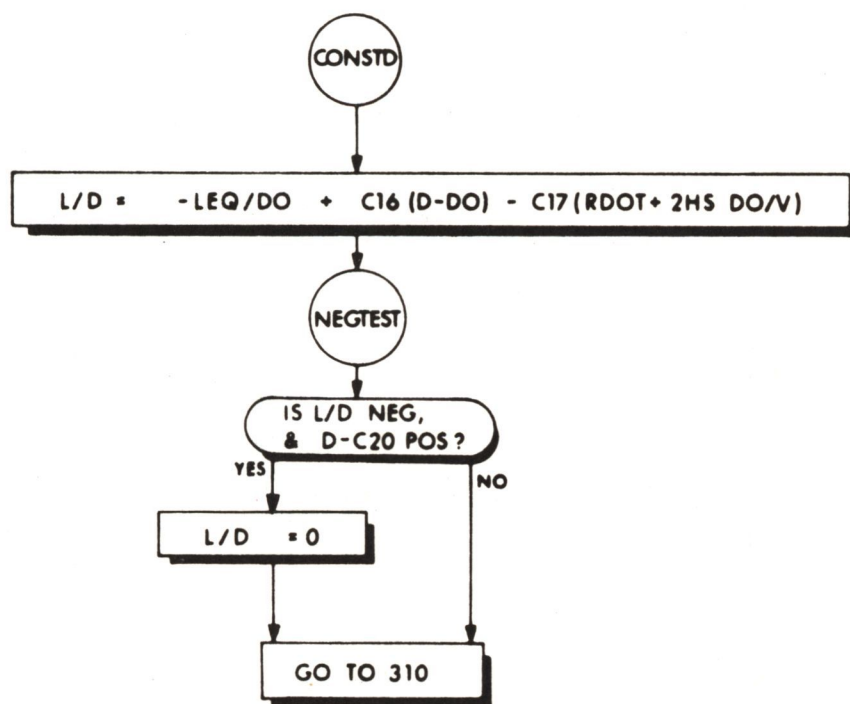


Fig. 4-13. Constant Drag Control



### Ballistic Phase

The ballistic phase controls the vehicle attitude in all three axes by commanding gimbal angles. The last roll command generated in the previous phase is held constant. The pitch is commanded to an assumed 20 degree angle of attack with respect to a calculated relative velocity vector. Yaw is commanded to zero sideslip angle with respect to the relative velocity vector. These pitch and yaw commands are generated continuously throughout entry. But the SCS ignores the pitch and yaw commands if the acceleration exceeds .05 g's.

A triad at the relative velocity vector is calculated by

$$\bar{U}VA = \text{UNIT}(\bar{V} - KWE \bar{U}Z * \text{UNIT}(\bar{R}))$$

$$\bar{U}YA = \text{UNIT}(\bar{U}VA * \bar{R})$$

$$\bar{U}NA = \text{UNIT}(\bar{U}YA * \bar{U}VA)$$

A triad at the navigation base is then calculated by

$$\bar{U}BY = \bar{U}YA \cos(\text{ROLLC}) + \bar{U}NA \sin(\text{ROLLC})$$

$$\bar{U}BX = -\text{UNIT}(\bar{U}BY * \bar{U}VA) \sin(13) - \bar{U}VA \cos(13)$$

$$\bar{U}BZ = \bar{U}BX * \bar{U}BY$$

See fig. 4-14.

This triad ( $\bar{U}BX, \bar{U}BY, \bar{U}BZ$ ) is supplied to the subroutine CALCGTA which generates the gimbal angle commands (OGC, MGC, IGC). See Reference 11.

The final phase is started when the acceleration exceeds  $Q7 + .5$  fps.

### Final Phase

The final phase is based on a stored nominal trajectory. This nominal is made up of six fifteen point tables with velocity as the independent variable. As stated before, the analytic approach is preferred because it has greater

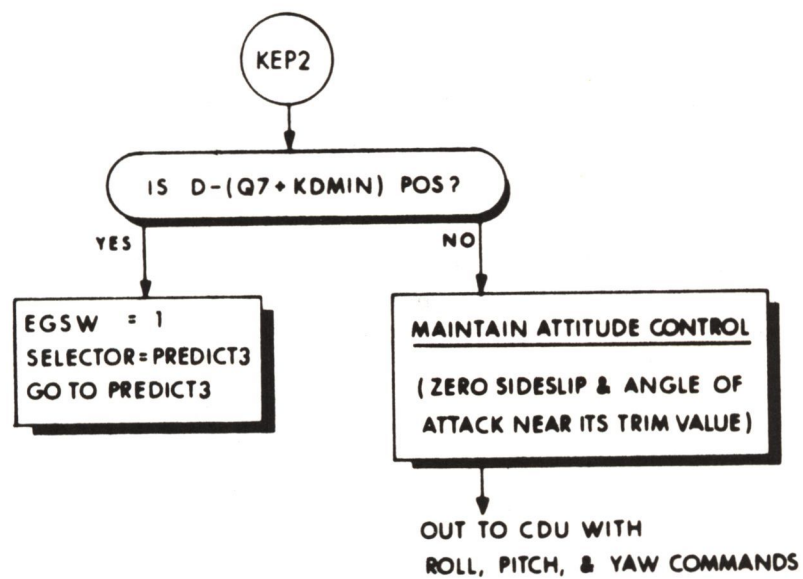


Fig. 4-14. Ballistic Phase

## ATTITUDE CONTROL PHASE

Calculates commanded gimbal angles (OGC, MGC, IGC) by computing desired orientation of Nav Base with respect to relative velocity vector.

$$\bar{U}VA = \text{UNIT} (\bar{V} - KWE \bar{U}Z * \text{UNIT} (\bar{R}))$$

$$\bar{U}YA = \text{UNIT} (\bar{U}VA * \bar{R})$$

$$\bar{U}NA = \text{UNIT} (\bar{U}YA * \bar{U}VA)$$

$$\bar{U}BY = \bar{U}YA \cos(\text{ROLLC}) + \bar{U}NA \sin(\text{ROLLC})$$

$$\bar{U}BX = -\text{UNIT} (\bar{U}BY * \bar{U}VA) \sin(13) - \bar{U}VA \cos(13)$$

$$\bar{U}BZ = \bar{U}BX * \bar{U}BY$$

Call CALGTA with ( $\bar{U}BX, \bar{U}BY, \bar{U}BZ$ )

Return with (OGC, IGC, MGC).

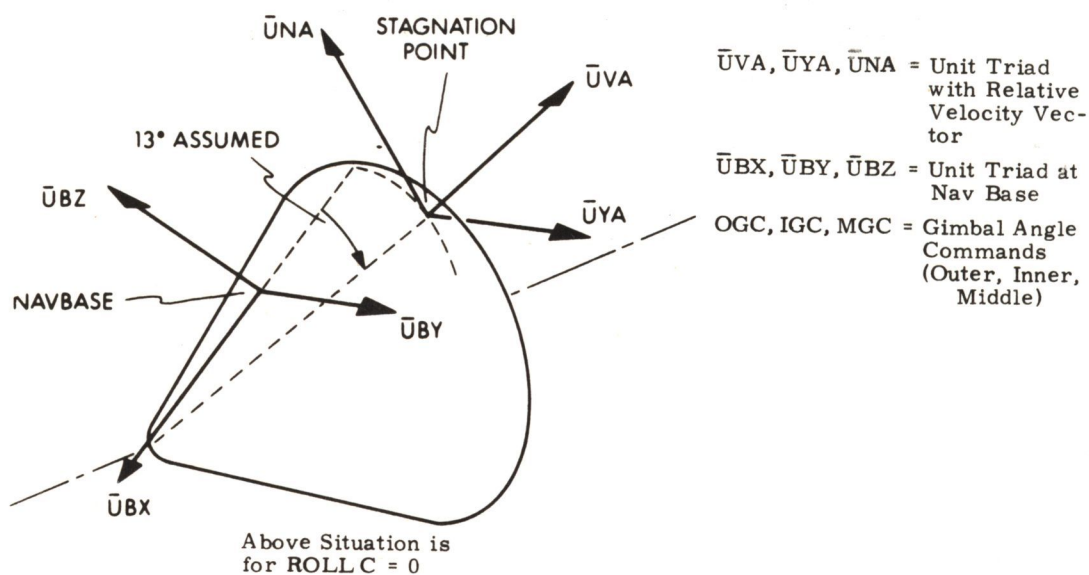


Fig. 4-15



flexibility in adapting to off-design conditions. As a matter of fact, previous designs used simple analytic formulae based on the equilibrium glide concept. but with the present low L/D, equilibrium glide flight is no longer a good approximation. Were some analysis available to represent a near-ballistic vehicle as is the Apollo command module, this would certainly be preferred.

On the other hand, the range calculation is simpler for a vehicle of low capability. Since the vehicle has a smaller band of possible ranges, the analysis need only represent this smaller band. That is, the linear perturbation theory is pushed less far out of the linear range.

The central equation is

$$L/D = LOD + 4 (THETNM - PREDANGL)/F3$$

where

LOD = nominal L/D = .18

THETNM = desired range in n.m.

PREDANGL = predicted range in n.m.

F3 = dRANGE/d(L/D)

The predicted range, PREDANGL, is obtained from a stored table with corrections for drag and altitude rate.

$$PREDANGL = RTOGO(V) + F2(V)(R - RDOTREF(V)) + F1(V)(D - DREF(V))$$

The prestored tables are shown in fig. 4-16. The details of the reference generation are described in Appendix F. Essentially, the reference is a two-dimensional trajectory over a spherical non-rotating earth. The reference L/D is chosen at .18 so as to be in the center of capability for a .3 L/D vehicle. The partial derivatives to provide the drag and altitude rate corrections are solved from linear perturbation equations (the adjoint set) also described in Appendix C. Linear interpolation is used between the stored points. A dummy point is stored at each end to guarantee good behavior of the interpolation. The last eight points of F3 = dRANGE/d(L/D) are multiplied by two. This is to provide reduced gain near the end of the

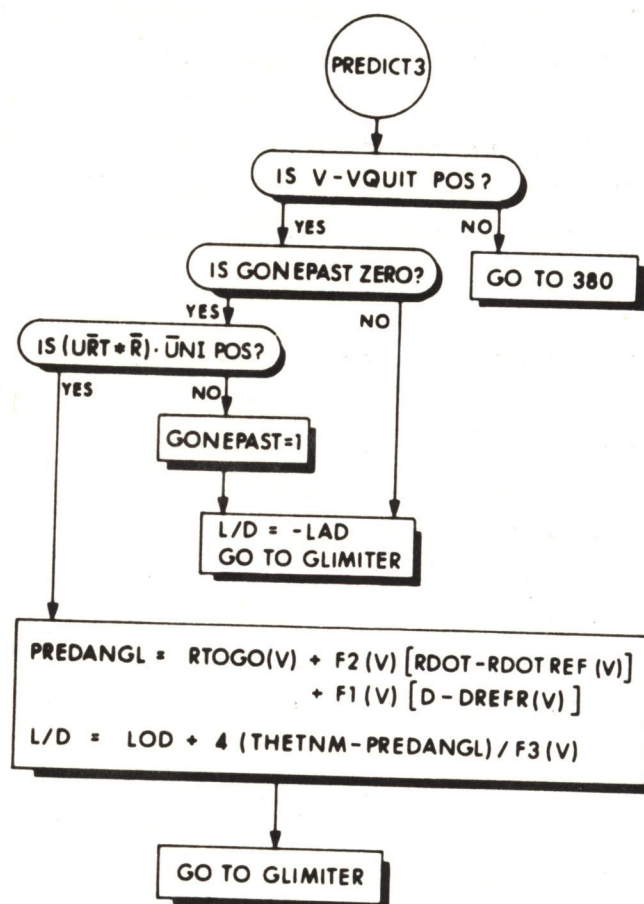


Fig. 4-16. Final Phase

| VREF  | RDOTREF | DREFR | DR/DRDOT<br>F2 | DR/DA<br>F1   | RTOGO | DR/DL/D<br>F3 |
|-------|---------|-------|----------------|---------------|-------|---------------|
| FPS   | FPS     | FPSS  | NM/FPS         | NM/FPSS       | NM    | NM            |
| 0     | -331    | 34.1  | 0              | -.02695       | 0     | 1             |
| 337   | -331    | 34.1  | 0              | -.02695       | 0     | 1             |
| 1080  | -693    | 42.6  | .002591        | -.03629       | 2.7   | 6.44 x 2      |
| 2103  | -719    | 60.   | .003582        | -.05551       | 8.9   | 10.91 x 2     |
| 3922  | -694    | 81.5  | .007039        | -.09034       | 22.1  | 21.64 x 2     |
| 6295  | -609    | 93.9  | .01446         | -.1410        | 46.3  | 48.35 x 2     |
| 8531  | -493    | 98.5  | .02479         | -.1978        | 75.4  | 93.72 x 2     |
| 10101 | -416    | 102.3 | .03391         | -.2372        | 99.9  | 141.1 x 2     |
| 14014 | -352    | 118.7 | .06139         | -.3305        | 170.9 | 329.4         |
| 15951 | -416    | 125.2 | .07683         | -.3605        | 210.3 | 465.5         |
| 18357 | -566    | 120.4 | .09982         | -.4956        | 266.8 | 682.7         |
| 20829 | -781    | 95.4  | .1335          | -.6483        | 344.3 | 980.5         |
| 23090 | -927    | 28.1  | .2175          | -2.021        | 504.8 | 1385          |
| 23500 | -820    | 6.4   | .3046          | <b>-3.354</b> | 643.0 | 1508          |
| 35000 | -820    | 6.4   | .3046          | <b>-3.354</b> | 643.0 | 1508          |

Fig. 4-17. Final Phase Reference



flight to conserve reaction jet fuel. The higher gain is needed at the start of the phase to control large deviations from the nominal. Linear perturbation theory underestimates the range contribution of large positive deviations of  $\dot{R}$ . A high gain is needed at the start of this phase to control these cases. An alternate way that has been considered is to include an additional range term proportional to  $\dot{R}^2$ .

The steering is disabled when the velocity is very low, less than VQUIT. This again is to conserve reaction jet fuel.

### Lateral Logic

The lateral logic shifts the lift vector from one side of the vertical to the other. This is done so that one control variable, roll angle, can control both lateral and longitudinal range. A variable dead-zone is calculated of allowable lateral range at the target. Then if this dead-zone is exceeded, the lift is directed to the other side so as to decrease the lateral range.

To this end, the lateral range dead-zone is calculated by the simple approximation  $Y = K_{LAT} VSQ$ .  $K_{LAT}$  is chosen so that  $Y$  represents about half the vehicle's lateral range capability.

A bias term,  $Y_{BIAS}$ , is added to  $Y$  so that there are fewer switches near the end of the flight. When the vehicle's projected lateral range at the target,  $LATANG$ , exceeds this  $Y$  and is increasing, lift is directed to the other side by changing the sign of  $K2ROLL$ . The sign convention is such that positive roll angle causes positive lateral range.

A special case occurs when the roll angle is within 15 degrees of full positive or full negative lift. In this case, a 15 or 165 degree roll is called if the roll would decrease the lateral range. In this case also, there is a switch if  $LATANG$  exceeds  $Y/2$ .

Also, special provision is made to roll in the shortest direction during a switch. This condition is detected by a negative  $L/D$ , and is accomplished by using  $K1ROLL$ .

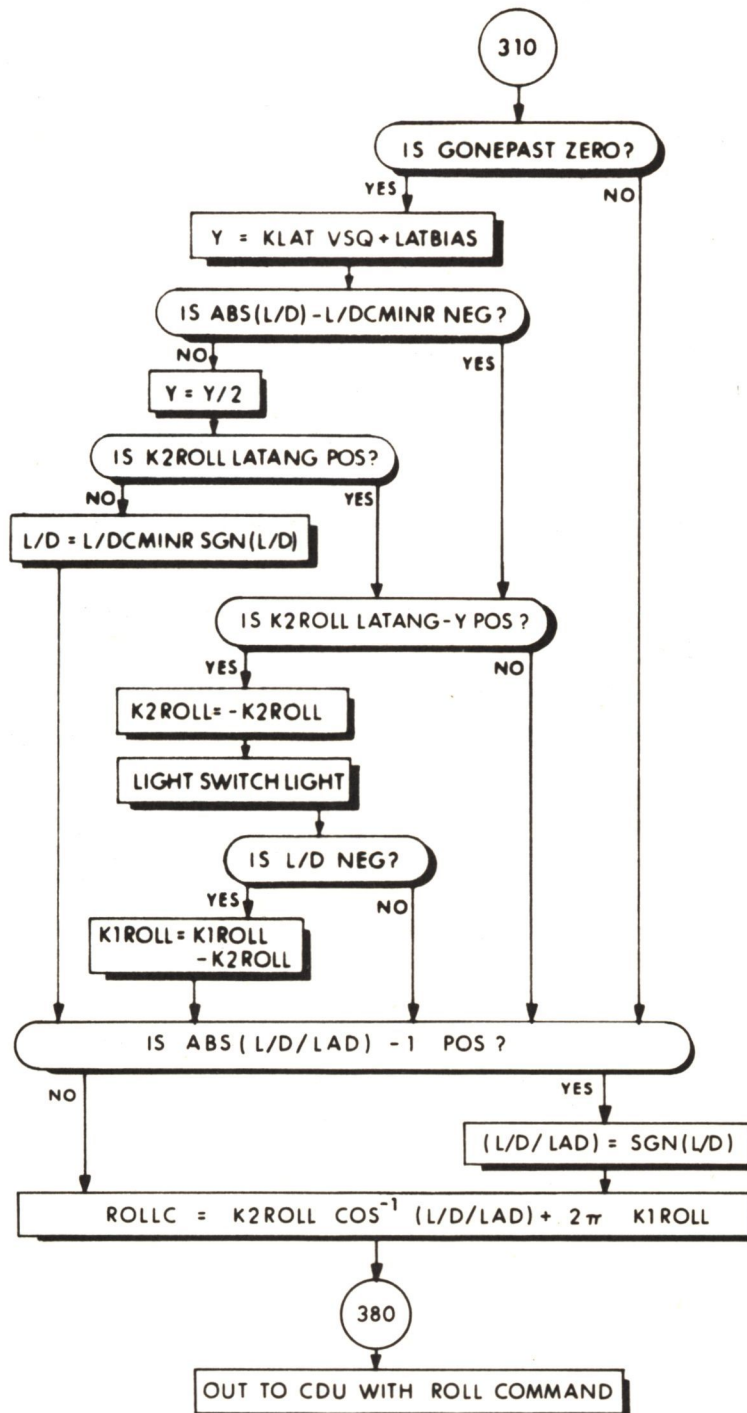


Fig. 4-18. Lateral Logic

In the lateral logic the effect of the low vehicle L/D is also seen. The dead-zone Y must be designed for the minimum expected L/D, and with a higher L/D more lateral switches will occur.

#### G-Limiter

The g-limiter overrides the commanded roll angle if the g-limit will be exceeded. If the altitude rate exceeds a limit altitude rate,  $\dot{R}_1$ , full positive lift is called. This limit altitude rate, derived in Appendix H, is

$$\dot{R}_1 = -\text{SQRT}((2 \text{ HS GMAX}/V)^2 + 2 \text{ HS LAD}(\text{GMAX}-D) + 2 \text{ HS LEQ}(\text{GMAX}-D)/\text{GMAX})$$

If the vehicle has this limit altitude rate full positive lift will result in a peak acceleration of GMAX.

No test for g-limiting is made if the drag is less than GMAX/2. And of course full positive lift is called if the drag is greater than GMAX.



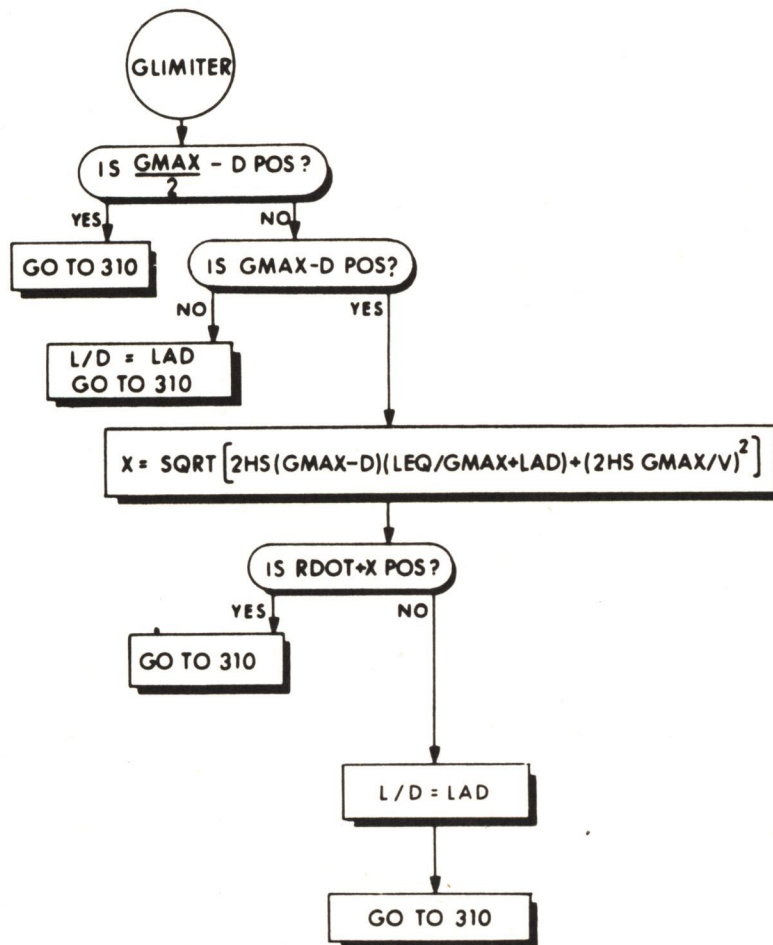


Fig. 4-19. G-limiter

## V GUIDANCE PERFORMANCE

### Steering Performance

Shown in fig. 5-1 is the guided entry for the nominal reentry for the lunar mission.

The initial conditions are

$$H_0 = 400,000 \text{ ft.}$$

$$V_0 = 36,200 \text{ fps}$$

$$\gamma_0 = -6 \text{ degrees}$$

$$\text{Range} = 2000 \text{ n.m.}$$

$$\text{Latitude} = -12.7 \text{ degrees}$$

$$\text{Longitude} = 122.9 \text{ degrees East}$$

$$\text{Azimuth} = 61 \text{ degrees}$$

The trajectory is terminated at 25,000 ft. near the point of chute deployment.

The vehicle is described by  $L/D = .34$ ,  $W/CDA = 66 \text{ psf}$ .

The 1962 ICAO model atmosphere is used. The trajectory is generated with a 4 degree of freedom simulation. The SCS model is the North American Aviation design which includes a 20 deg/sec limit roll rate. The guidance parameters are tabulated in fig. 6-1.

Figure 5-1a shows the altitude, velocity, acceleration and range from start of entry as a function of time.

More interesting is fig. 5-1b which shows the roll angle, lateral range = LATANG, lateral switch limit = Y, and reaction control fuel for the roll channel.

The roll angle time history is the key to the significant events. At point (1), the start of entry, a roll to -15 degrees is made to decrease the initial LATANG which was about 80 n.m. Initially the trajectory plane contained the target, but the target was calculated to rotate about 80 n.m. out of this plane during the estimated time of entry.

At point (2) the altitude rate is less than 700 fps and the constant drag control is started.

At point (3) the reference trajectory has been established and zero roll is called to null out the negative altitude rate that was a part of the constant drag phase.

Point (4) is the start of the reference trajectory.

Point (5) is the first lateral switch. LATANG is seen to change direction. This is after an intersection with the -Y curve which is not shown.

Point (6) marks the start of the final phase. There is a slight discontinuity in LATANG as a different calculation is made of the estimated time of flight.

Points (7), (9), (10), and (11) are lateral switches in the final phase.

Point (8) marks the start of using relative velocity rather than inertial velocity. The limit cycle operation of the SCS can be seen here as well as between points (5) and (6).

The total roll fuel is about 60 seconds of burn.

Eight other trajectories are shown in figs. 5-2 to 5-9 completing a set of three entry angles and three ranges.

The maximum range of 2350 n.m. corresponds to a total range traversed 2500 n.m. when the effect of the earth rotation is included. The minimum range of 1500 n.m. is close to the minimum possible for a shallow entry into a thin atmosphere. The shallow entry angle of -5.2 degrees is near the skip-out boundary for a .3 L/D vehicle entering a thin atmosphere. The steep entry angle of -6.7 degrees is dictated by a maximum possible range for a .3 L/D vehicle entering a more-dense atmosphere.

Tabulated are summaries of these trajectories plus the trajectories with L/D variations to .3 and .4 and with altitude rate errors of  $\pm 200$  fps. The extreme atmosphere cases of shallow entry into a thin atmosphere and steep entry into a thick atmosphere are also tabulated. Other trajectories with atmospheric variations are not shown since the entry angle variation has the same effect as the atmospheric variation.

The significant parameters that are tabulated are

RANGE = inertial range from start of entry n.m.

VEL. = velocity at start of entry, fps

GAMMA = flight path angle at start, deg.

ERV = altitude rate error, held constant, fps

SQA = atmospheric density factor, see NASA TN D-612

MISS = steering miss only, n.m.



FUEL = roll fuel for dual system, seconds

dQCONV/dT = convective heat rate at stagnation point

Btu/sq.ft/sec

$$= .79323374 \text{ RN}^{-1/2} (\rho / \rho_o)^{3/2} (\text{VA}/1000)^{3.15}$$

dQRAD/dT = radiative heat rate at stagnation point,

Btu/sq.ft/sec

$$= 7.5 \text{ RN} (\rho / \rho_o) (\text{VA}/10000)^{12.5}$$

RN = nose radius = 1 ft

VA = relative velocity, fps

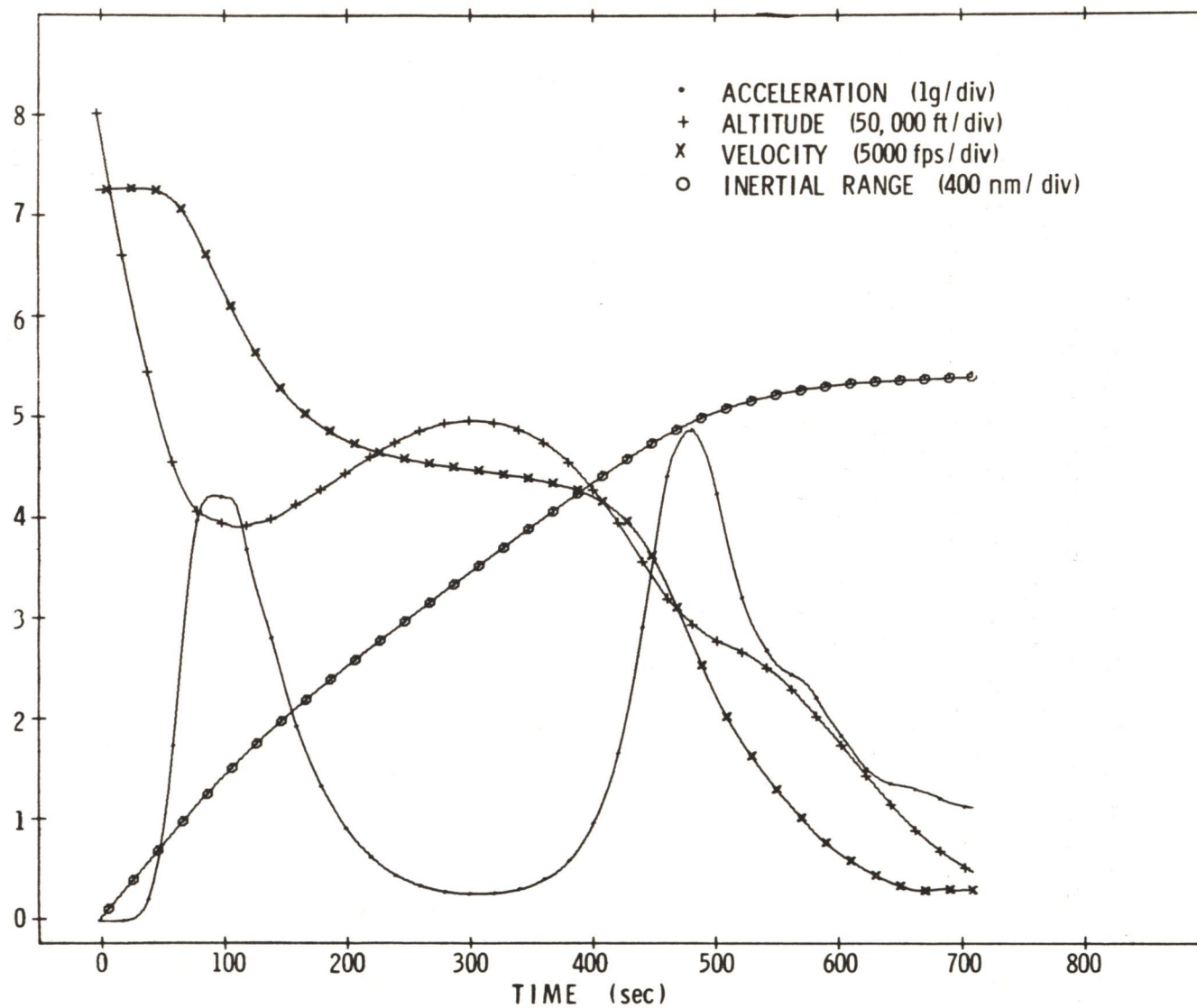


Fig. 5-1a 2000 n.m., - 6 Degree Entry

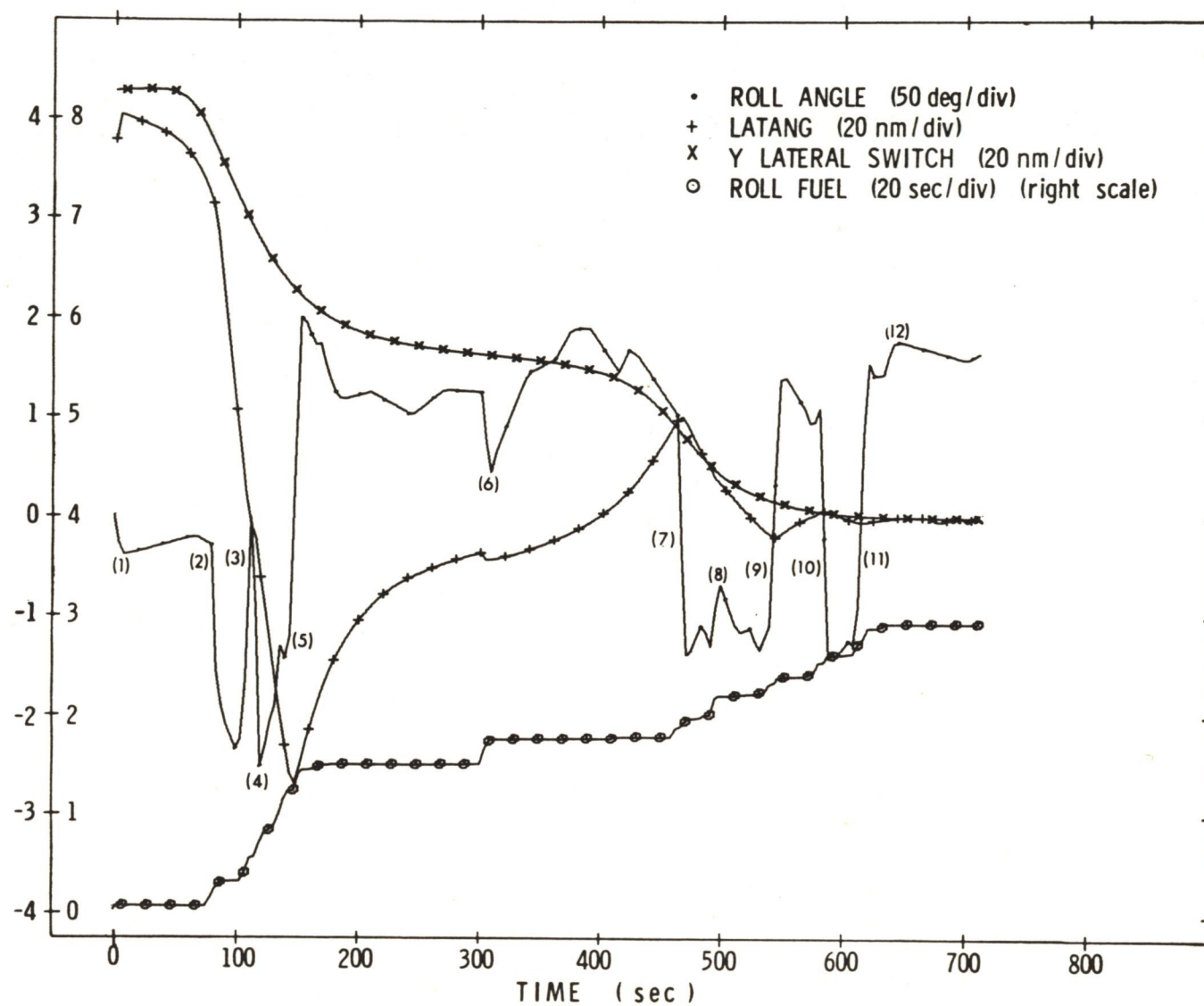


Fig. 5-1b 2000 n.m., -6 Degree Entry



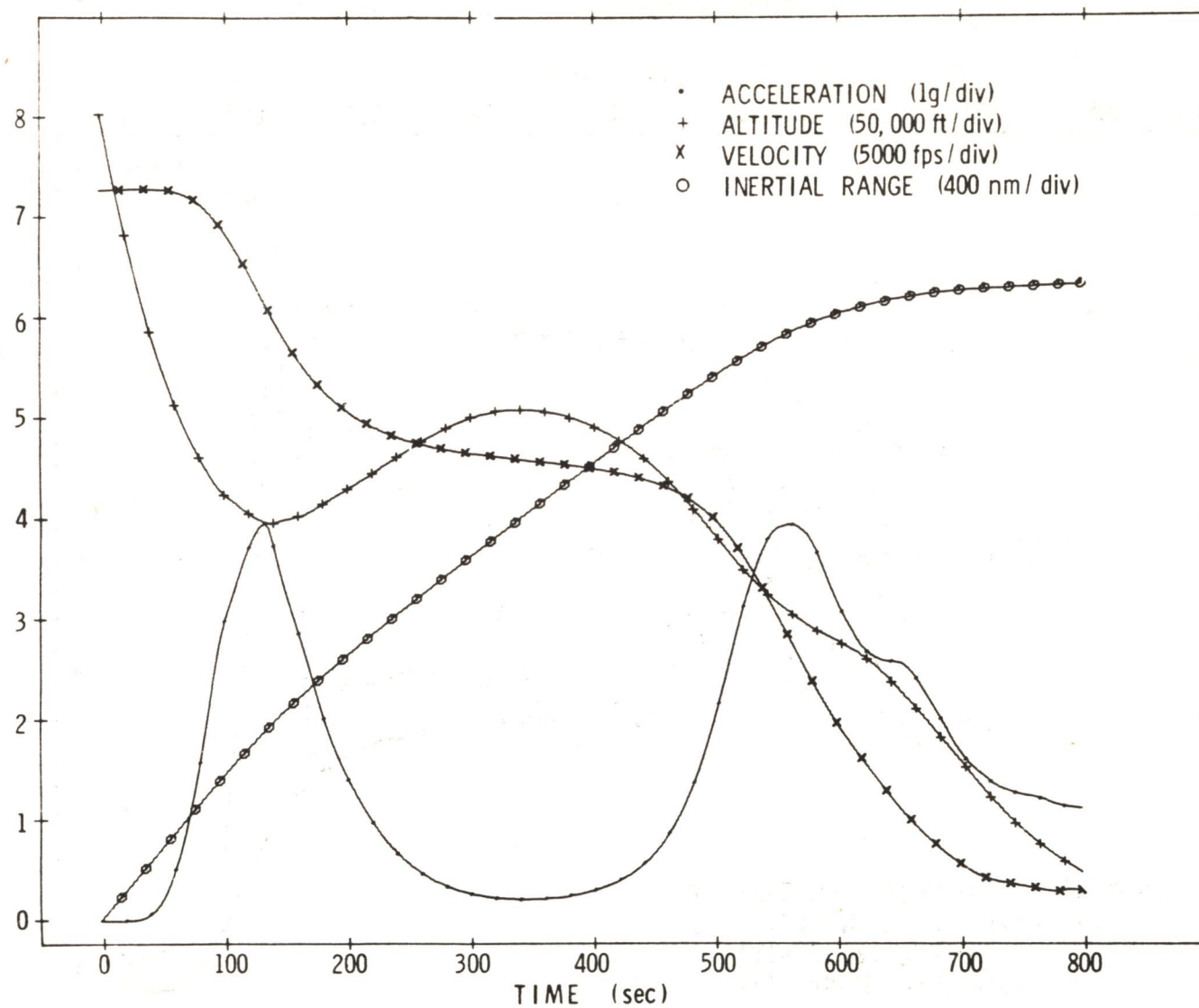


Fig. 5-2a 2350 n.m., -5.2 Degree Entry

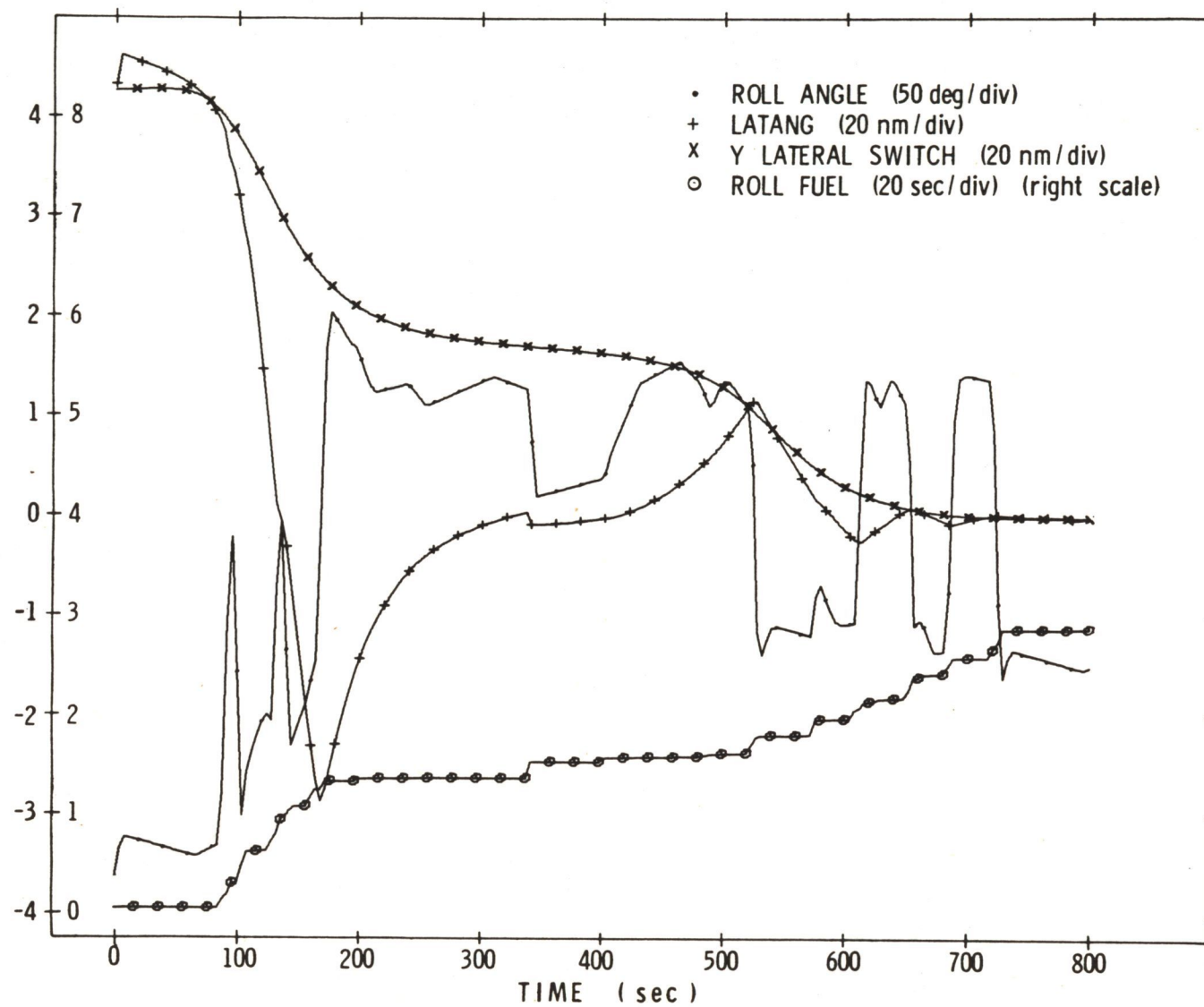


Fig. 5-2b 2350 n.m., -5.2 Degree Entry

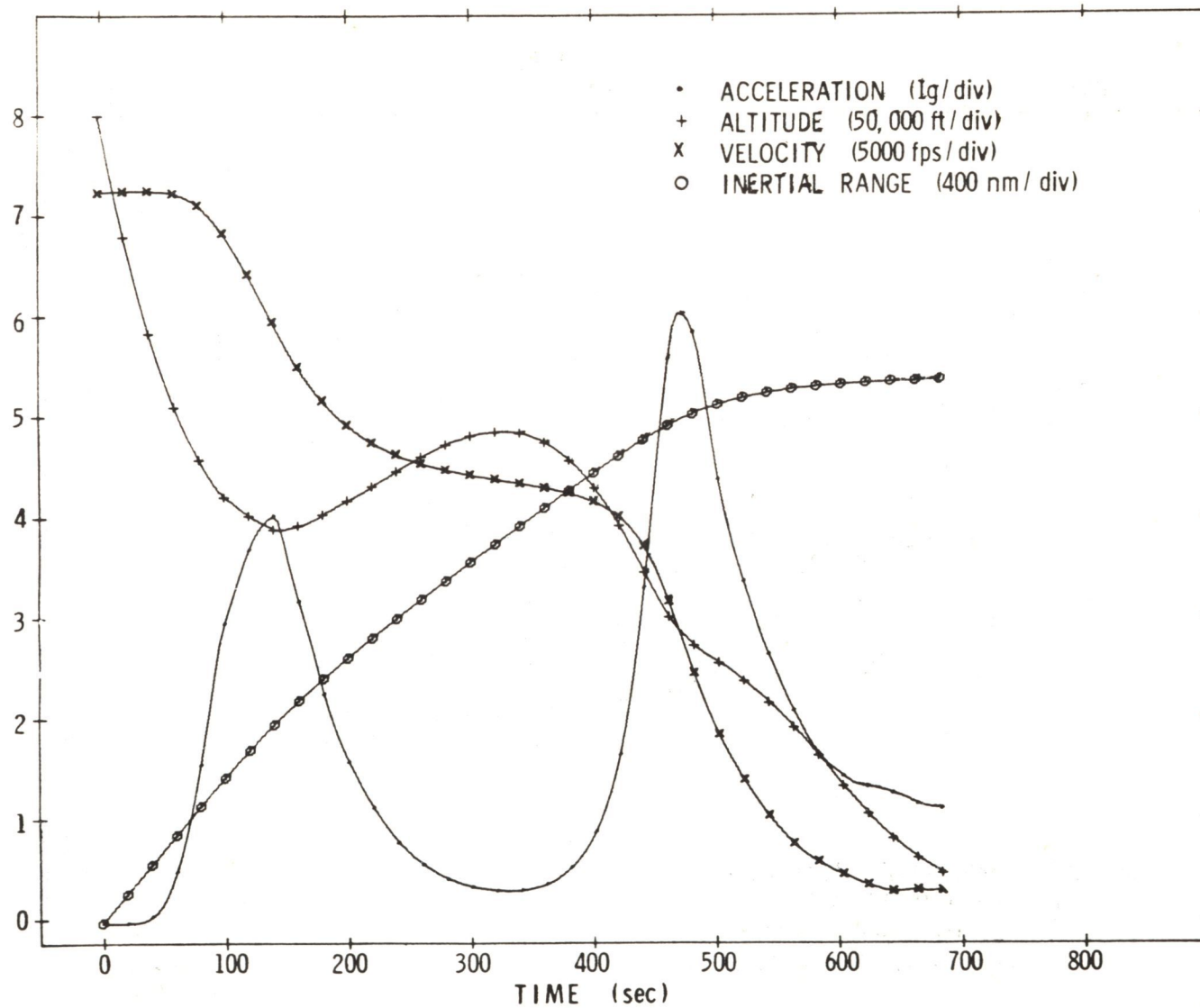


Fig. 5-3a 2000 n. m., -5.2 Degree Entry



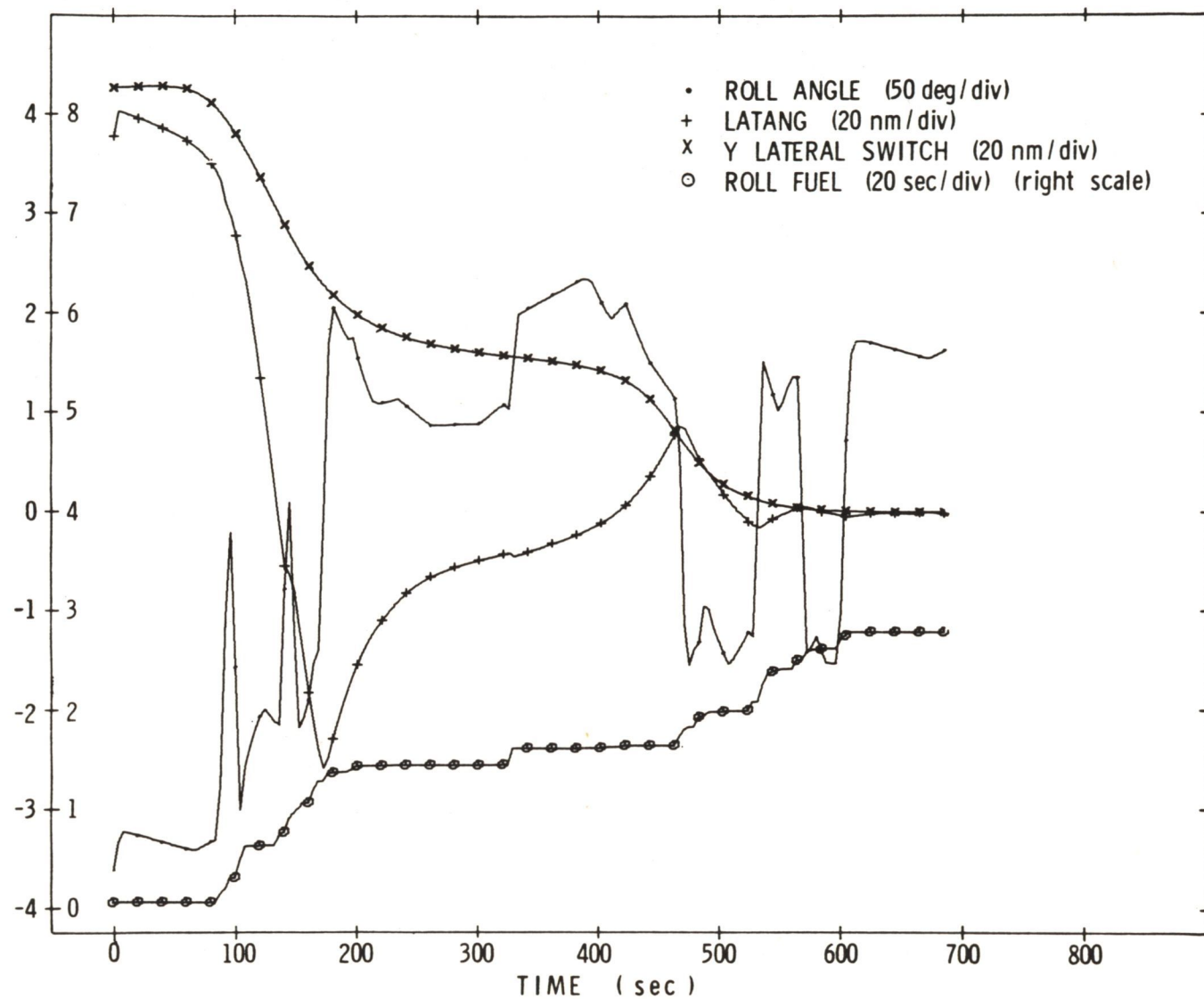


Fig. 5-3b 2000 n.m., -5.2 Degree Entry

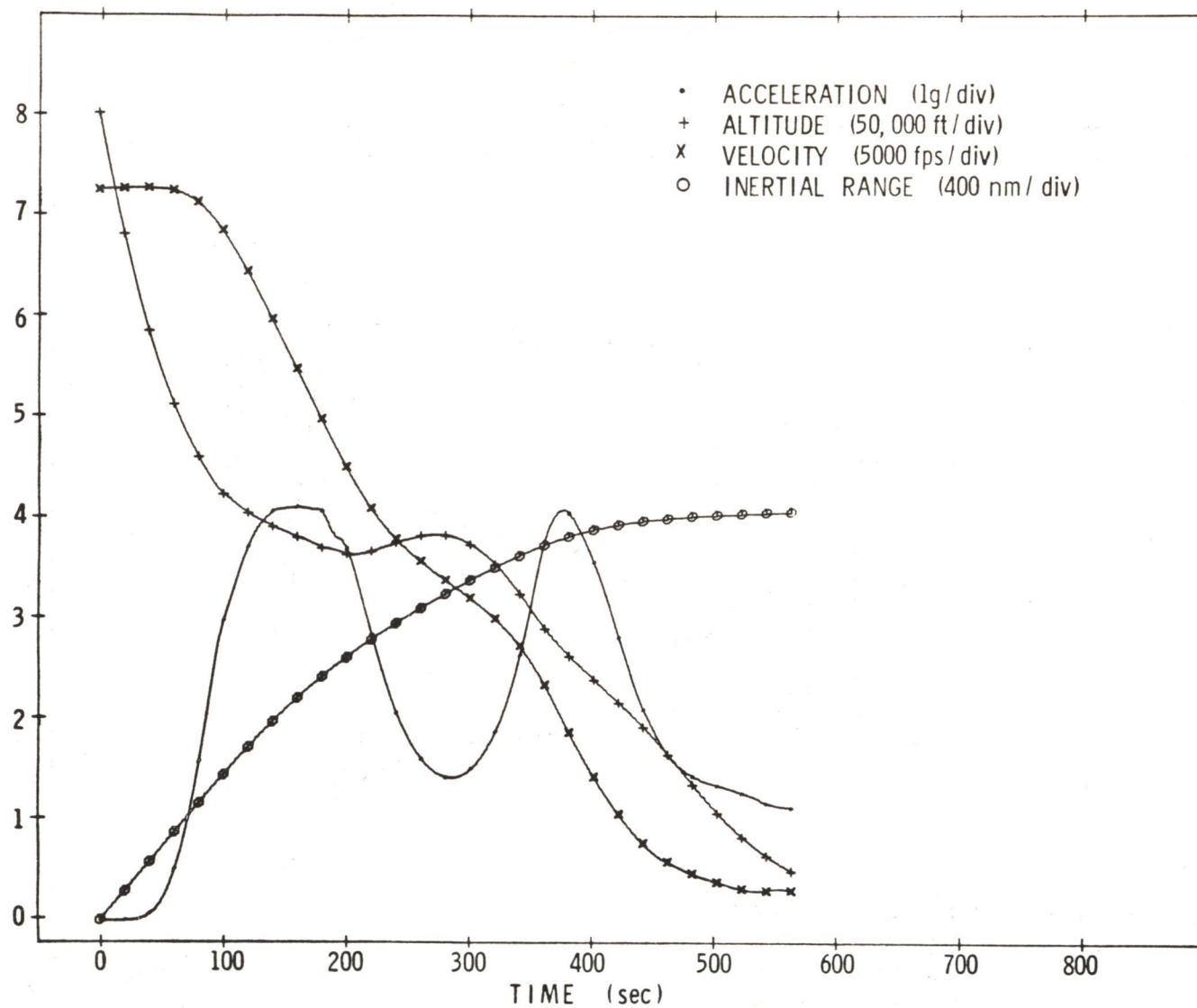


Fig. 5-4a 1500 n.m., -5.2 Degree Entry

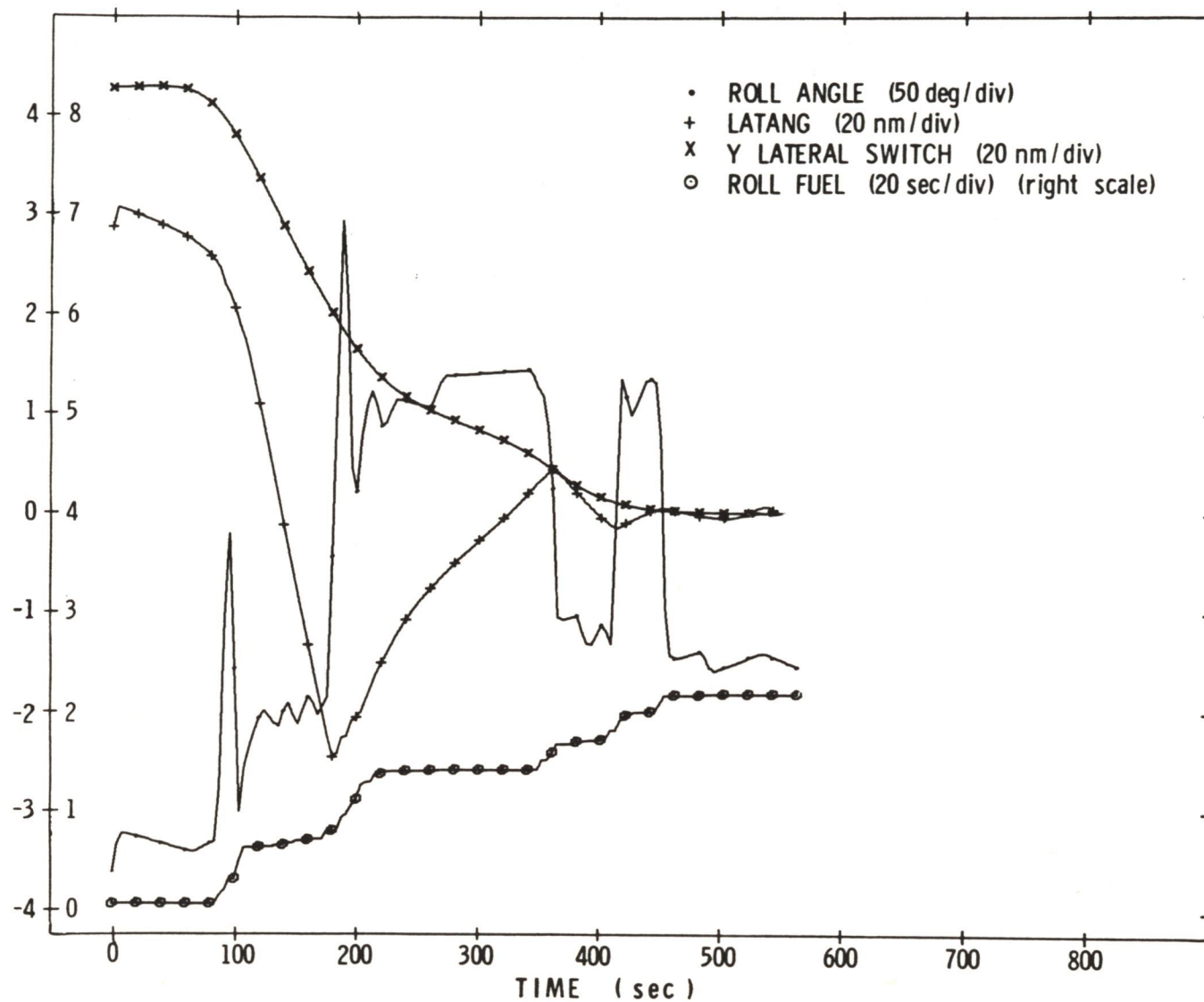


Fig. 5-4b 1500 n.m., -5.2 Degree Entry



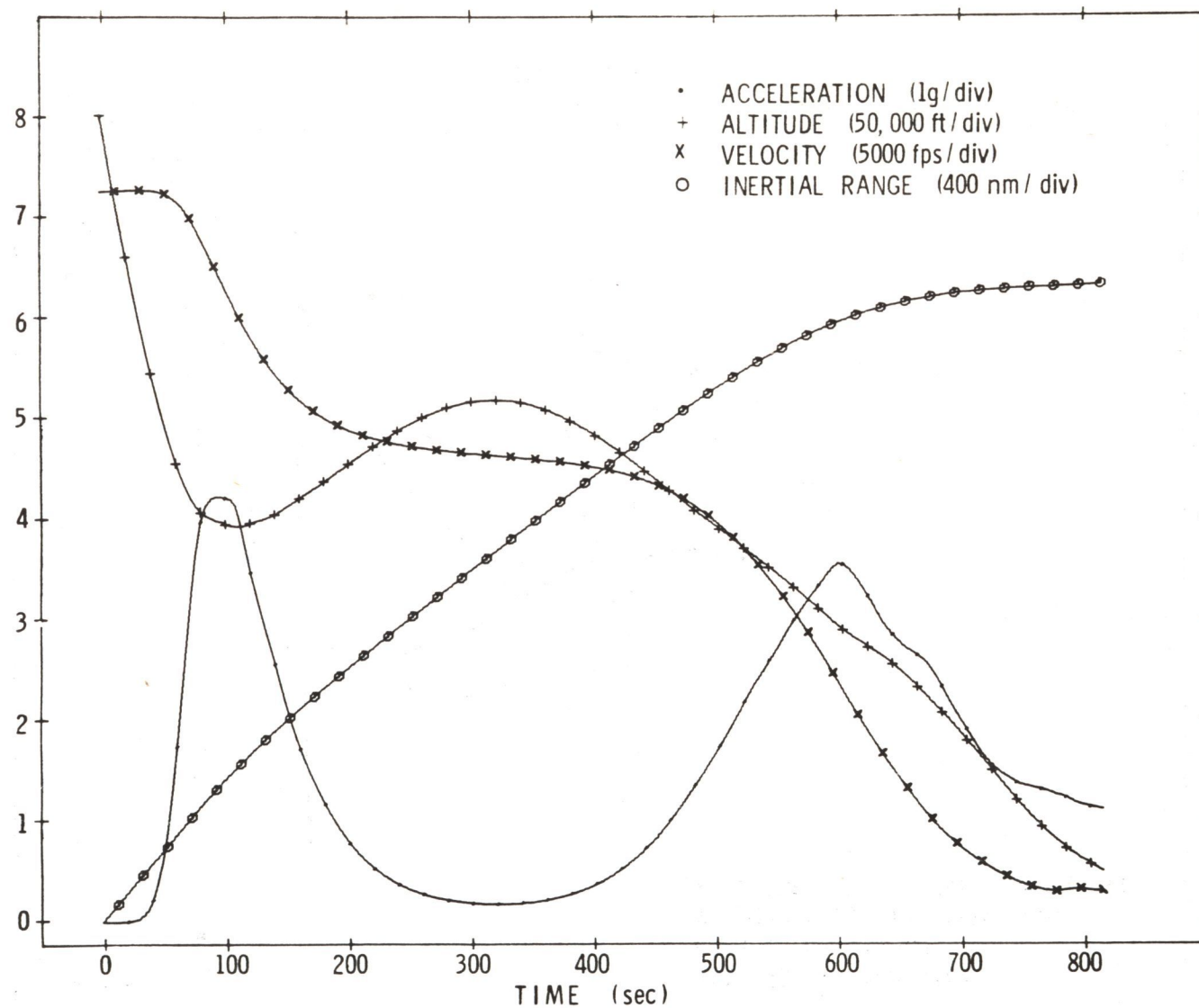


Fig. 5-5a 2350 n.m., -6 Degree Entry

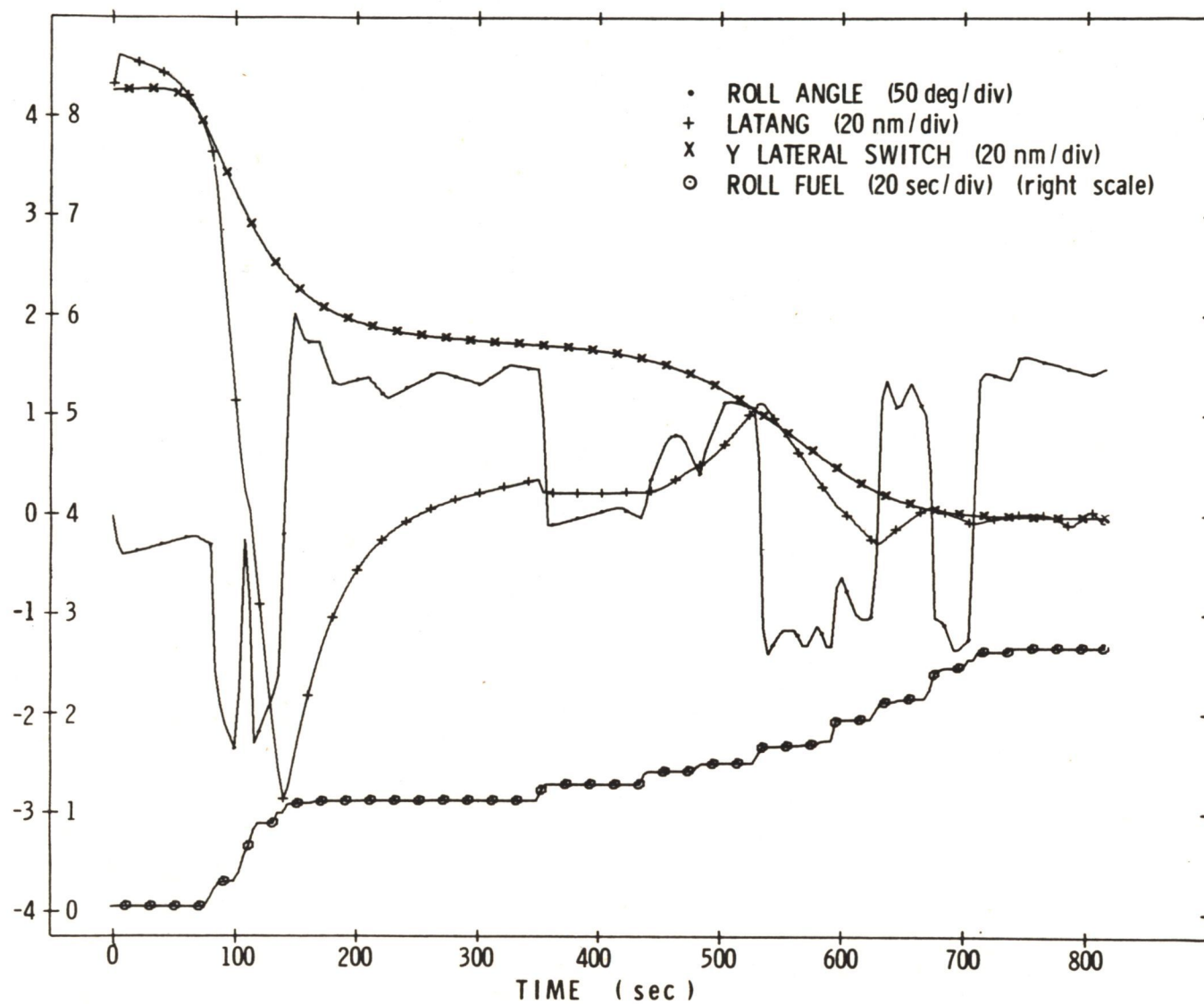


Fig. 5-5b 2350 n.m., -6 Degree Entry

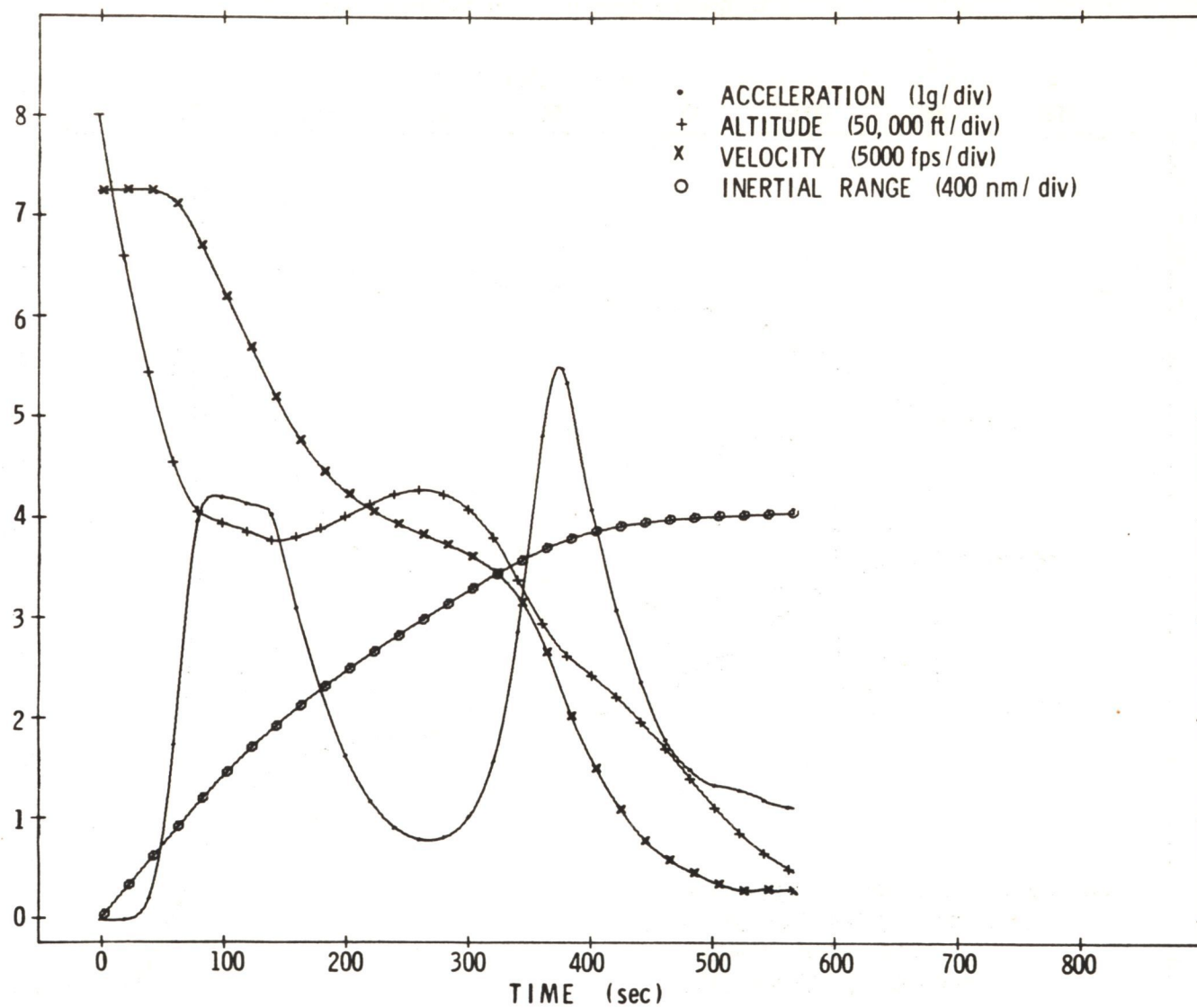


Fig. 5-6a 1500 n.m., -6 Degree Entry



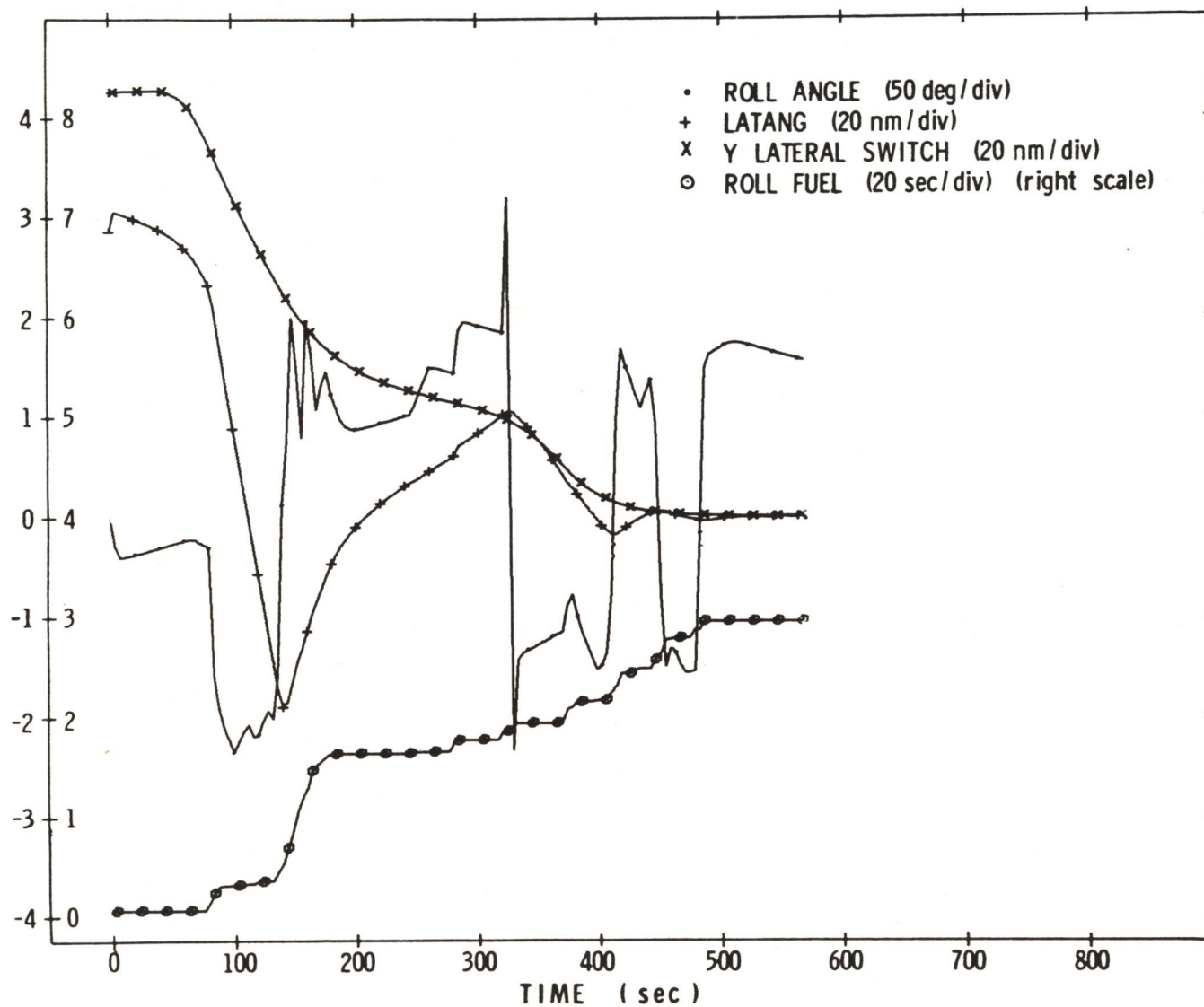


Fig. 5-6b 1500 n.m., -6 Degree Entry

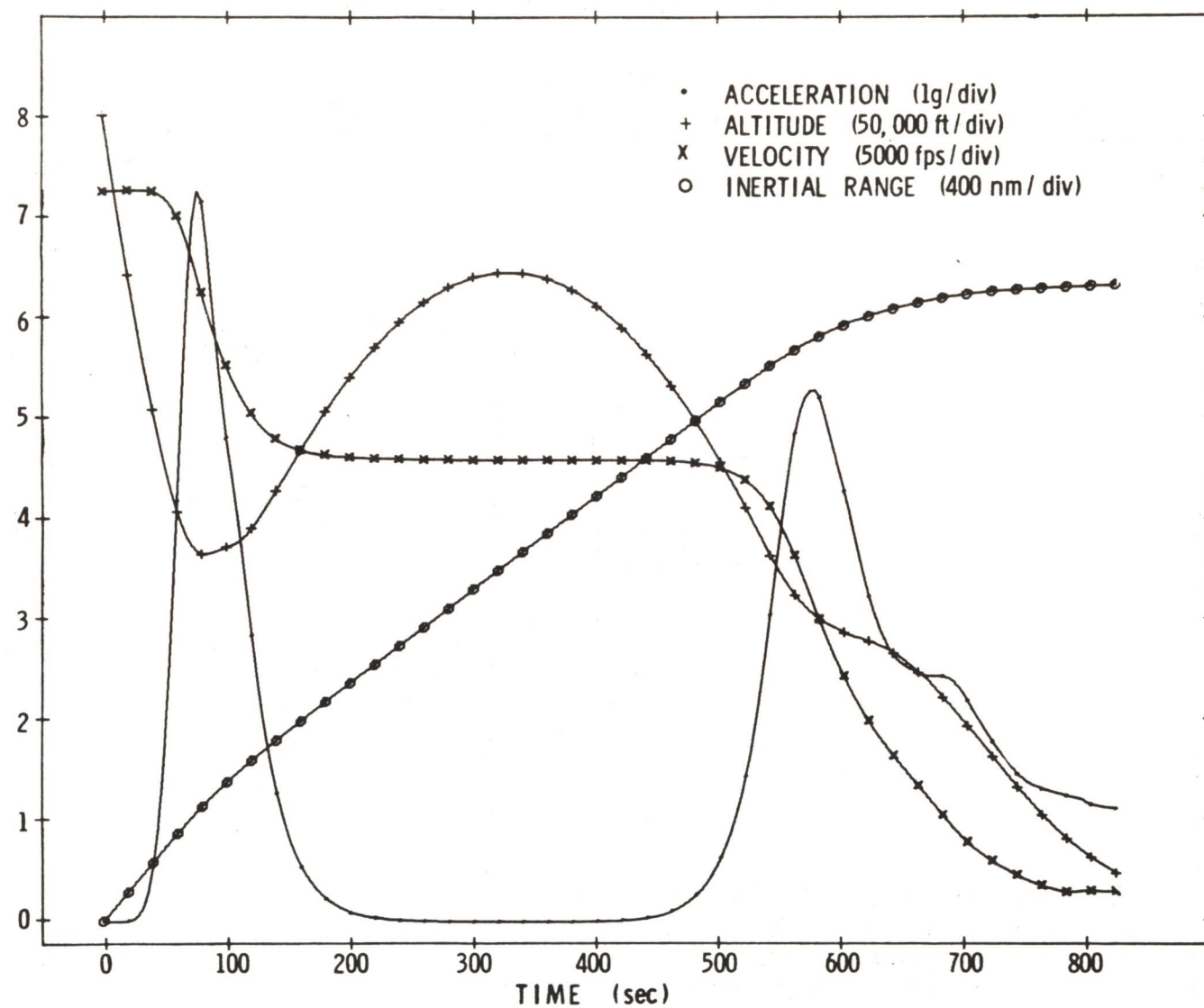


Fig. 5-7a 2350 n.m., -6.7 Degree Entry

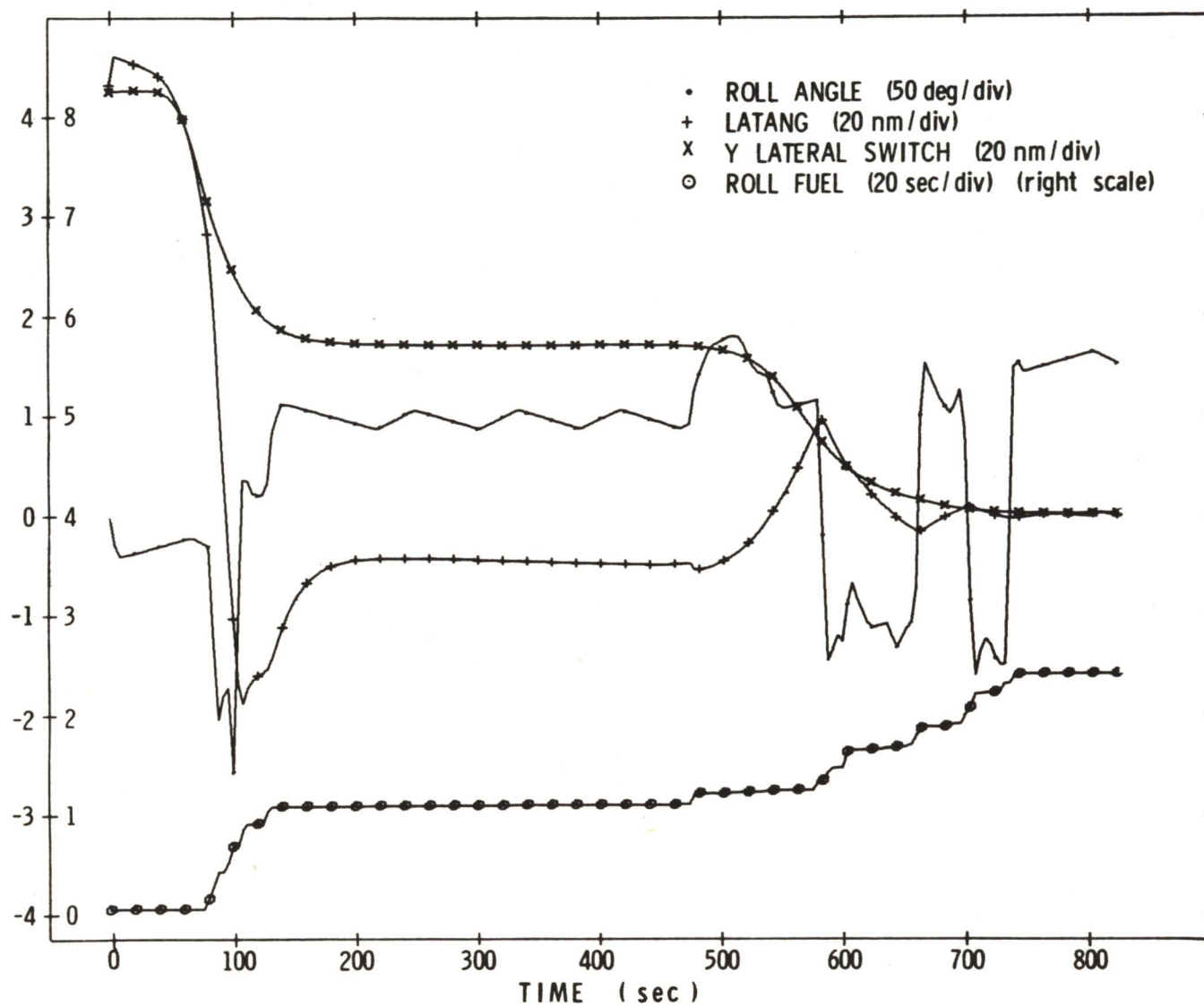


Fig. 5-7b 2350 n.m., -6.7 Degree Entry



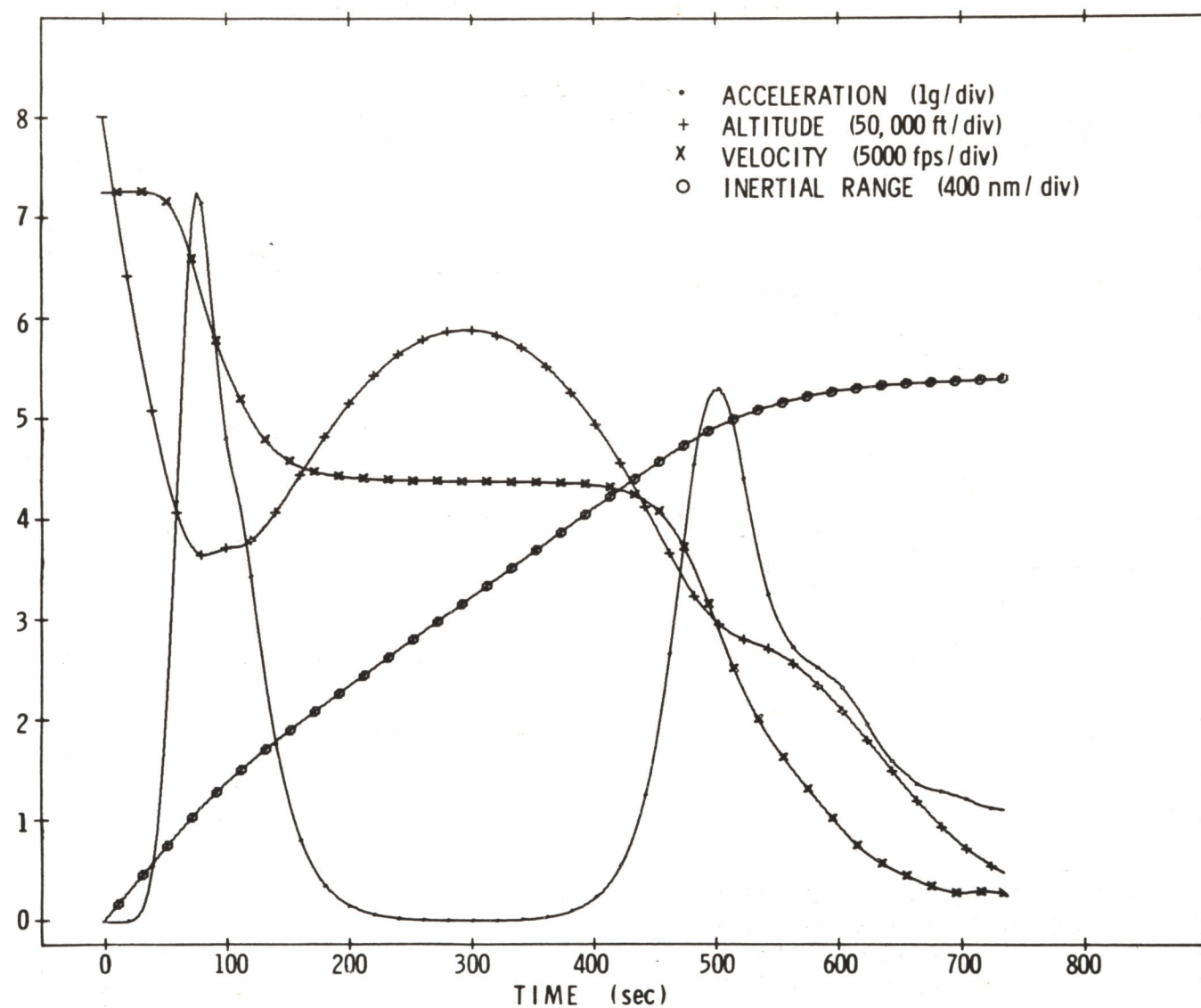


Fig. 5-8a 2000 n.m., -6.7 Degree Entry

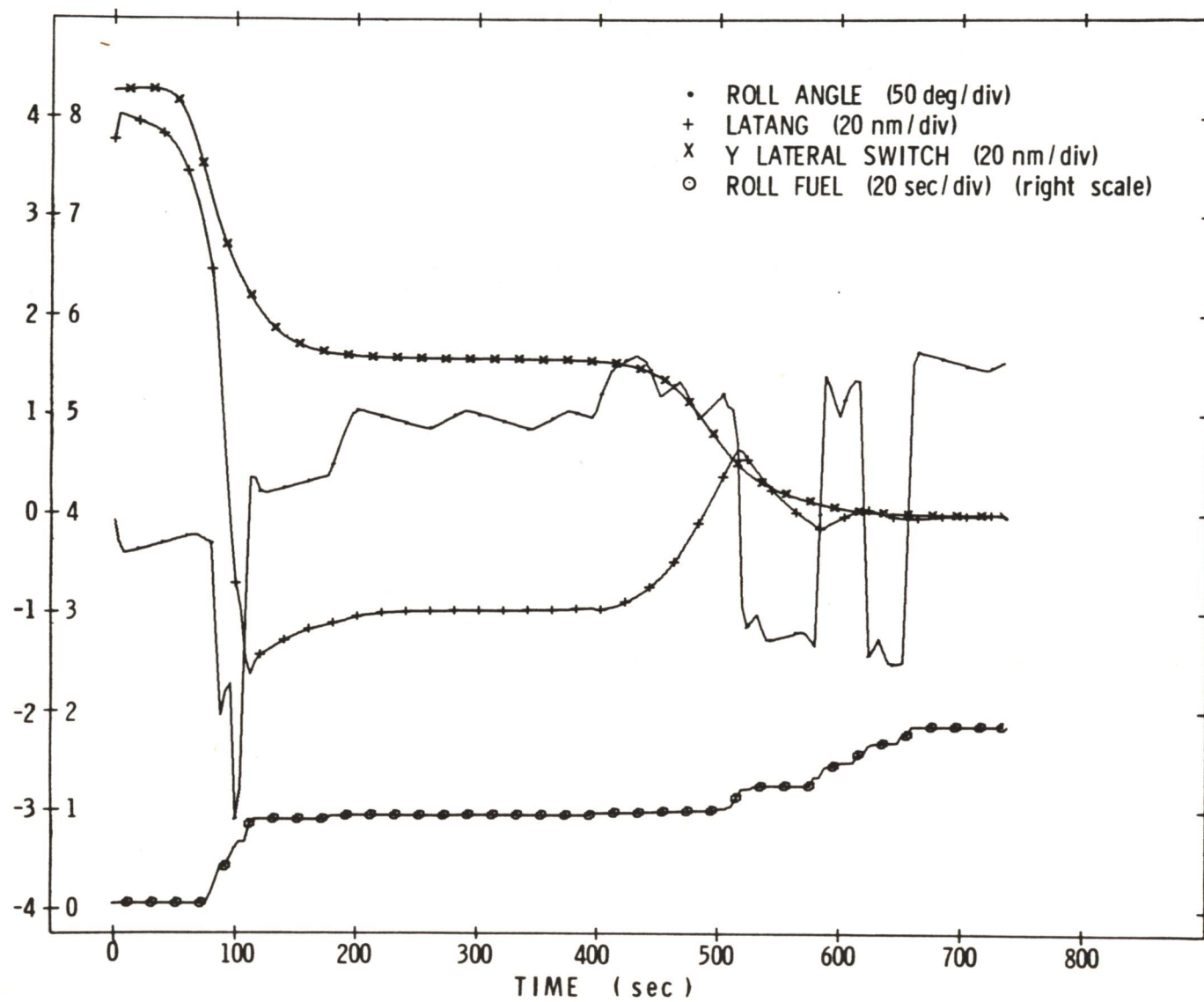


Fig. 5-8b 2000 n.m., -6.7 Degree Entry

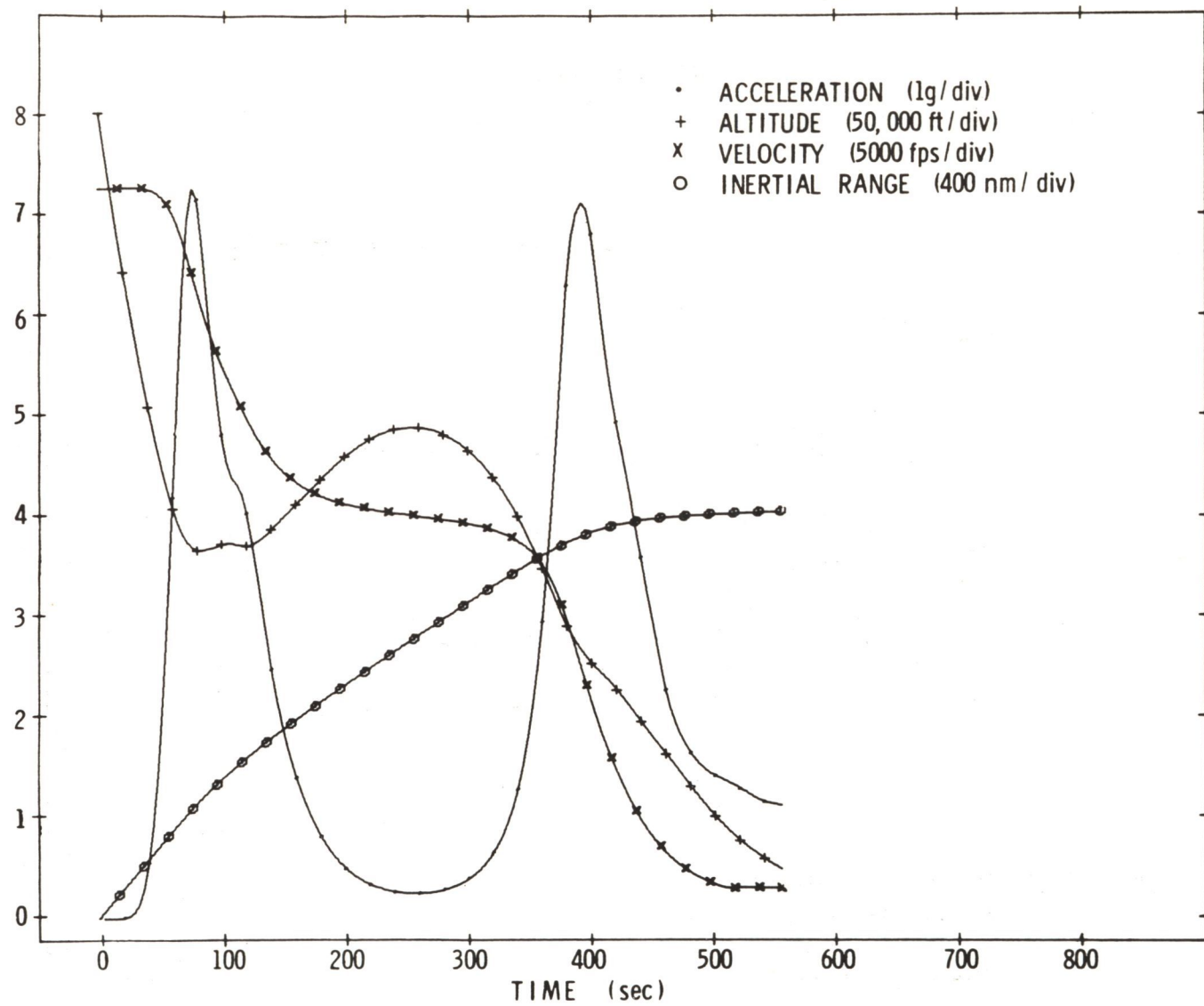


Fig. 5-9a 1500 n. m., -6.7 Degree Entry



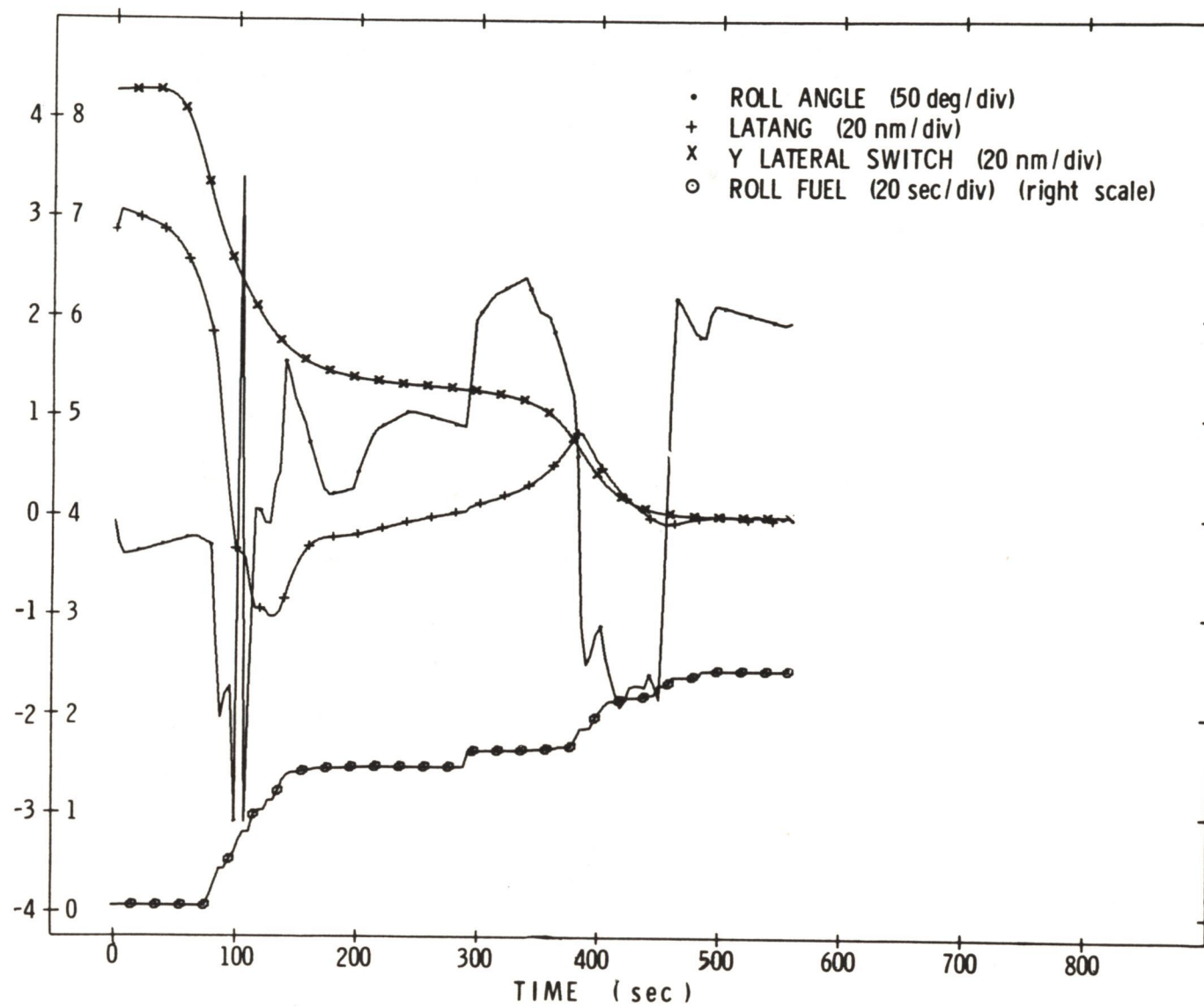


Fig. 5-9b 1500 n.m., -6.7 Degree Entry

MAC RUN 284198

5.2-- L/D = .3

(7/30/65)

| RANGE<br>NM | L/D | VEL.<br>FPS | GAMMA<br>DEG. | ERV<br>FPS | SQA | MISS<br>NM | MAX-G<br>G-S | FUEL<br>SEC. | QCONV<br>BTU/SQFT | GRAD<br>BTU/SQFT |
|-------------|-----|-------------|---------------|------------|-----|------------|--------------|--------------|-------------------|------------------|
| 2350        | .30 | 36200       | -5.20         | 200        | 0   | 1.14       | 4.41         | 71.4         | 99006             | 2342             |
| 2350        | .30 | 36200       | -5.20         | 0          | 0   | 0.15       | 3.94         | 74.6         | 102884            | 2270             |
| 2350        | .30 | 36200       | -5.20         | -200       | 0   | 0.78       | 4.84         | 69.9         | 105125            | 2207             |
| 2000        | .30 | 36200       | -5.20         | 200        | 0   | 0.73       | 6.50         | 71.1         | 93223             | 2370             |
| 2000        | .30 | 36200       | -5.20         | 0          | 0   | 0.86       | 5.98         | 66.1         | 96411             | 2297             |
| 2000        | .30 | 36200       | -5.20         | -200       | 0   | 0.61       | 5.78         | 66.2         | 98853             | 2231             |
| 1500        | .30 | 36200       | -5.20         | 200        | 0   | 0.95       | 4.80         | 58.9         | 82928             | 2414             |
| 1500        | .30 | 36200       | -5.20         | 0          | 0   | 0.07       | 4.24         | 50.4         | 84923             | 2345             |
| 1500        | .30 | 36200       | -5.20         | -200       | 0   | 0.68       | 3.77         | 46.9         | 86612             | 2280             |

Fig. 5-10 Shallow entry, L/D = .3

MAC RUN 284202

5.2--- L/D = .34

(7/30/65)

| RANGE<br>NM | L/D | VEL.<br>FPS | GAMMA<br>DEG. | ERV<br>FPS | SOA | MISS<br>NM | MAX-G<br>G-S | FUEL<br>SEC. | QCONV<br>BTU/SQFT | QRAD<br>BTU/SQFT |
|-------------|-----|-------------|---------------|------------|-----|------------|--------------|--------------|-------------------|------------------|
| 2350        | .34 | 36200       | -5.20         | 200        | 0   | 0.94       | 4.42         | 64.6         | 99236             | 2339             |
| 2350        | .34 | 36200       | -5.20         | 0          | 0   | 0.22       | 3.95         | 57.9         | 102842            | 2284             |
| 2350        | .34 | 36200       | -5.20         | -200       | 0   | 1.33       | 5.37         | 70.2         | 104334            | 2218             |
| 2000        | .34 | 36200       | -5.20         | 200        | 0   | 1.01       | 6.56         | 75.0         | 93595             | 2368             |
| 2000        | .34 | 36200       | -5.20         | 0          | 0   | 0.20       | 6.02         | 56.1         | 96278             | 2311             |
| 2000        | .34 | 36200       | -5.20         | -200       | 0   | 1.19       | 5.93         | 67.2         | 98653             | 2240             |
| 1500        | .34 | 36200       | -5.20         | 200        | 0   | 1.02       | 5.22         | 69.2         | 82993             | 2415             |
| 1500        | .34 | 36200       | -5.20         | 0          | 0   | 1.45       | 4.10         | 43.9         | 84912             | 2358             |
| 1500        | .34 | 36200       | -5.20         | -200       | 0   | 1.33       | 3.83         | 52.5         | 86720             | 2289             |

Fig. 5-11 Shallow entry, L/D = .34



MAC RUN 283918

5.2--- L/D = .4

(7/29/65)

| RANGE<br>NM | L/D | VEL.<br>FPS | GAMMA<br>DEG. | ERV<br>FPS | SQA | MISS<br>NM | MAX-G<br>G-S | FUEL<br>SEC. | QCONV<br>BTU/SQFT | GRAD<br>BTU/SQFT |
|-------------|-----|-------------|---------------|------------|-----|------------|--------------|--------------|-------------------|------------------|
| 2350        | .40 | 36200       | -5.20         | 200        | 0   | 1.04       | 5.74         | 86.1         | 97315             | 2375             |
| 2350        | .40 | 36200       | -5.20         | 0          | 0   | 0.08       | 4.47         | 78.1         | 101515            | 2307             |
| 2350        | .40 | 36200       | -5.20         | -200       | 0   | 1.23       | 6.03         | 70.7         | 103887            | 2238             |
| 2000        | .40 | 36200       | -5.20         | 200        | 0   | 1.43       | 7.14         | 79.4         | 92813             | 2401             |
| 2000        | .40 | 36200       | -5.20         | 0          | 0   | 0.28       | 6.40         | 70.3         | 95647             | 2333             |
| 2000        | .40 | 36200       | -5.20         | -200       | 0   | 2.00       | 6.25         | 64.3         | 98295             | 2265             |
| 1500        | .40 | 36200       | -5.20         | 200        | 0   | 0.72       | 6.78         | 84.0         | 82763             | 2448             |
| 1500        | .40 | 36200       | -5.20         | 0          | 0   | 0.47       | 4.66         | 67.0         | 84778             | 2382             |
| 1500        | .40 | 36200       | -5.20         | -200       | 0   | 0.66       | 4.11         | 55.3         | 86569             | 2315             |

FIG. 5-12 SHALLOW ENTRY, L/D = .4

MAC RUN 284723

6.0 --- L/D = .3

(8/02/65)

| RANGE<br>NM | L/D | VEL.<br>FPS | GAMMA<br>DEG. | ERVR<br>FPS | SQA | MISS<br>NM | MAX-G<br>G-S | FUEL<br>SEC. | QCONV<br>BTU/SQFT | GRAD<br>BTU/SQFT |
|-------------|-----|-------------|---------------|-------------|-----|------------|--------------|--------------|-------------------|------------------|
| 2350        | .30 | 36200       | -6.00         | 200         | 0   | 0.92       | 4.69         | 56.6         | 95543             | 2621             |
| 2350        | .30 | 36200       | -6.00         | 0           | 0   | 0.29       | 4.39         | 71.6         | 99411             | 2568             |
| 2350        | .30 | 36200       | -6.00         | -200        | 0   | 0.58       | 4.34         | 73.3         | 101231            | 2536             |
| 2000        | .30 | 36200       | -6.00         | 200         | 0   | 0.87       | 5.29         | 47.4         | 90538             | 2641             |
| 2000        | .30 | 36200       | -6.00         | 0           | 0   | 0.18       | 4.92         | 65.4         | 93381             | 2589             |
| 2000        | .30 | 36200       | -6.00         | -200        | 0   | 0.59       | 5.44         | 56.9         | 94954             | 2556             |
| 1500        | .30 | 36200       | -6.00         | 200         | 0   | 1.33       | 5.79         | 59.8         | 82011             | 2681             |
| 1500        | .30 | 36200       | -6.00         | 0           | 0   | 0.32       | 6.48         | 63.3         | 83503             | 2632             |
| 1500        | .30 | 36200       | -6.00         | -200        | 0   | 0.94       | 5.52         | 54.0         | 84511             | 2606             |

Fig. 5-13 Mid entry, L/D = .3

MAC RUN 284604

6.0 --- L/D = .34

(8/02/65)

| RANGE<br>NM | L/D | VEL.<br>FPS | GAMMA<br>DEG. | ERV<br>FPS | SOA | MISS<br>NM | MAX-G<br>G-S | FUEL<br>SEC. | QCONV<br>BTU/SQFT | QGRAD<br>BTU/SQFT |
|-------------|-----|-------------|---------------|------------|-----|------------|--------------|--------------|-------------------|-------------------|
| 2350        | .34 | 36200       | -6.00         | 200        | 0   | 0.91       | 4.68         | 75.2         | 95806             | 2591              |
| 2350        | .34 | 36200       | -6.00         | 0          | 0   | 1.36       | 4.22         | 54.0         | 100575            | 2532              |
| 2350        | .34 | 36200       | -6.00         | -200       | 0   | 0.53       | 4.81         | 67.0         | 100887            | 2489              |
| 2000        | .34 | 36200       | -6.00         | 200        | 0   | 0.88       | 5.62         | 65.8         | 90901             | 2613              |
| 2000        | .34 | 36200       | -6.00         | 0          | 0   | 0.72       | 4.86         | 58.9         | 94248             | 2551              |
| 2000        | .34 | 36200       | -6.00         | -200       | 0   | 0.58       | 5.84         | 67.7         | 95539             | 2510              |
| 1500        | .34 | 36200       | -6.00         | 200        | 0   | 0.82       | 6.80         | 58.3         | 82373             | 2654              |
| 1500        | .34 | 36200       | -6.00         | 0          | 0   | 0.19       | 5.51         | 59.2         | 84041             | 2598              |
| 1500        | .34 | 36200       | -6.00         | -200       | 0   | 1.79       | 5.39         | 47.9         | 84803             | 2560              |

Fig. 5-14 Mid entry, L/D = .34

MAC RUN 284726

6.0 --- L/D = .4

(8/02/65)

| RANGE<br>NM | L/D | VEL.<br>FPS | GAMMA<br>DEG. | ERV<br>FPS | SQA | MISS<br>NM | MAX-G<br>G-S | FUEL<br>SEC. | QCONV<br>BTU/SQFT | QGRAD<br>BTU/SQFT |
|-------------|-----|-------------|---------------|------------|-----|------------|--------------|--------------|-------------------|-------------------|
| 2350        | .40 | 36200       | -6.00         | 200        | 0   | 0.82       | 4.67         | 68.8         | 95902             | 2563              |
| 2350        | .40 | 36200       | -6.00         | 0          | 0   | 0.28       | 4.17         | 69.5         | 100033            | 2490              |
| 2350        | .40 | 36200       | -6.00         | -200       | 0   | 0.74       | 5.09         | 72.4         | 101920            | 2436              |
| 2000        | .40 | 36200       | -6.00         | 200        | 0   | 1.47       | 6.97         | 80.6         | 90111             | 2587              |
| 2000        | .40 | 36200       | -6.00         | 0          | 0   | 0.30       | 5.73         | 68.8         | 93987             | 2513              |
| 2000        | .40 | 36200       | -6.00         | -200       | 0   | 0.78       | 6.22         | 63.9         | 96381             | 2456              |
| 1500        | .40 | 36200       | -6.00         | 200        | 0   | 1.41       | 7.08         | 54.3         | 82334             | 2628              |
| 1500        | .40 | 36200       | -6.00         | 0          | 0   | 0.18       | 5.95         | 53.0         | 84141             | 2564              |
| 1500        | .40 | 36200       | -6.00         | -200       | 0   | 1.53       | 5.58         | 61.7         | 85373             | 2512              |

Fig. 5-15 Mid entry, L/D = .4



MAC RUN 283389

6.7 L/D=.3, YULTEST

(7/28/65)

| RANGE<br>NM | L/D | VEL.<br>FPS | GAMMA<br>DEG. | ERV<br>FPS | SQA | MISS<br>NM | MAX-G<br>G-S | FUEL<br>SEC. | QCONV<br>BTU/SQFT | QGRAD<br>BTU/SQFT |
|-------------|-----|-------------|---------------|------------|-----|------------|--------------|--------------|-------------------|-------------------|
| 2350        | .30 | 36200       | -6.70         | 200        | 0   | 0.84       | 7.63         | 47.1         | 80863             | 3198              |
| 2350        | .30 | 36200       | -6.70         | 0          | 0   | 0.26       | 7.63         | 60.7         | 83553             | 3185              |
| 2350        | .30 | 36200       | -6.70         | -200       | 0   | 20.12      | 7.63         | 111.7        | 85959             | 3180              |
| 2000        | .30 | 36200       | -6.70         | 200        | 0   | 1.68       | 7.63         | 39.6         | 79388             | 3202              |
| 2000        | .30 | 36200       | -6.70         | 0          | 0   | 0.87       | 7.63         | 40.7         | 81058             | 3195              |
| 2000        | .30 | 36200       | -6.70         | -200       | 0   | 0.65       | 7.63         | 43.2         | 80415             | 3187              |
| 1500        | .30 | 36200       | -6.70         | 200        | 0   | 1.31       | 7.63         | 25.6         | 75706             | 3214              |
| 1500        | .30 | 36200       | -6.70         | 0          | 0   | 1.41       | 7.63         | 42.1         | 76358             | 3204              |
| 1500        | .30 | 36200       | -6.70         | -200       | 0   | 0.70       | 7.63         | 43.2         | 77846             | 3195              |

Fig. 5-16 Steep entry, L/D = .3

MAC RUN 283301

6.7 L/D=.34,YULTEST

(7/28/65)

| RANGE<br>NM | L/D | VEL.<br>FPS | GAMMA<br>DEG. | ERVR<br>FPS | SQA | MISS<br>NM | MAX-G<br>G-S | FUEL<br>SEC. | QCONV<br>BTU/SQFT | GRAD<br>BTU/SQFT |
|-------------|-----|-------------|---------------|-------------|-----|------------|--------------|--------------|-------------------|------------------|
| 2350        | .34 | 36200       | -6.70         | 200         | 20  | 0.99       | 7.77         | 46.5         | 79499             | 3220             |
| 2350        | .34 | 36200       | -6.70         | 0           | 0   | 0.39       | 7.24         | 48.2         | 81262             | 3125             |
| 2350        | .34 | 36200       | -6.70         | -200        | 0   | 0.64       | 7.24         | 50.1         | 86636             | 3108             |
| 2000        | .34 | 36200       | -6.70         | 200         | 0   | 0.92       | 7.24         | 77.0         | 81335             | 3142             |
| 2000        | .34 | 36200       | -6.70         | 0           | 0   | 0.12       | 7.24         | 37.6         | 80347             | 3132             |
| 2000        | .34 | 36200       | -6.70         | -200        | 0   | 4.20       | 8.15         | 43.7         | 79953             | 3122             |
| 1500        | .34 | 36200       | -6.70         | 200         | 0   | 1.10       | 7.49         | 48.2         | 75709             | 3152             |
| 1500        | .34 | 36200       | -6.70         | 0           | 0   | 0.55       | 7.24         | 49.4         | 77302             | 3139             |
| 1500        | .34 | 36200       | -6.70         | -200        | 0   | 1.45       | 7.24         | 55.0         | 78428             | 3131             |

Fig. 5-17 Steep Entry, L/D = .34

MAC RUN 283224

6.7 L/D=.4 YULTEST

(7/28/65)

| RANGE<br>NM | L/D | VEL.<br>FPS | GAMMA<br>DEG. | ERVR<br>FPS | SQA | MISS<br>NM | MAX-G<br>G-S | FUEL<br>SEC. | QCONV<br>BTU/SQFT | QGRAD<br>BTU/SQFT |
|-------------|-----|-------------|---------------|-------------|-----|------------|--------------|--------------|-------------------|-------------------|
| 2350        | .40 | 36200       | -6.70         | 200         | 0   | 1.30       | 6.78         | 66.1         | 80186             | 3060              |
| 2350        | .40 | 36200       | -6.70         | 0           | 0   | 2.15       | 9.14         | 49.4         | 79772             | 3040              |
| 2350        | .40 | 36200       | -6.70         | -200        | 0   | 0.87       | 6.78         | 60.4         | 88314             | 3009              |
| 2000        | .40 | 36200       | -6.70         | 200         | 0   | 0.72       | 7.63         | 77.6         | 79550             | 3060              |
| 2000        | .40 | 36200       | -6.70         | 0           | 0   | 0.54       | 8.78         | 42.0         | 80256             | 3045              |
| 2000        | .40 | 36200       | -6.70         | -200        | 0   | 0.74       | 6.78         | 50.6         | 84785             | 3022              |
| 1500        | .40 | 36200       | -6.70         | 200         | 0   | 1.34       | 8.99         | 59.7         | 76115             | 3077              |
| 1500        | .40 | 36200       | -6.70         | 0           | 0   | 4.95       | 8.68         | 51.0         | 77344             | 3061              |
| 1500        | .40 | 36200       | -6.70         | -200        | 0   | 2.22       | 6.78         | 73.5         | 79635             | 3039              |

Fig. 5-18 Steep entry, L/D = .4

MAC RUN 283585

6.7 L/D=.3, THICK, YULTEST (7/29/65)

| RANGE<br>NM | L/D | VEL.<br>FPS | GAMMA<br>DEG. | ERV<br>FPS | SQA | MISS<br>NM | MAX-G<br>G-S | FUEL<br>SEC. | QCONV<br>BTU/SQFT | QGRAD<br>BTU/SQFT |
|-------------|-----|-------------|---------------|------------|-----|------------|--------------|--------------|-------------------|-------------------|
| 2350        | .30 | 36200       | -6.70         | 200        | 20  | 0.54       | 8.16         | 46.7         | 78099             | 3287              |
| 2350        | .30 | 36200       | -6.70         | 0          | 20  | 0.19       | 8.16         | 53.1         | 80105             | 3279              |
| 2350        | .30 | 36200       | -6.70         | -200       | 20  | 0.52       | 8.16         | 41.0         | 80486             | 3272              |
| 2000        | .30 | 36200       | -6.70         | 200        | 20  | 1.67       | 8.16         | 49.2         | 77345             | 3291              |
| 2000        | .30 | 36200       | -6.70         | 0          | 20  | 0.22       | 8.16         | 53.6         | 78961             | 3283              |
| 2000        | .30 | 36200       | -6.70         | -200       | 20  | 0.65       | 8.16         | 56.9         | 81327             | 3278              |
| 1500        | .30 | 36200       | -6.70         | 200        | 20  | 63.70      | 8.16         | 53.1         | 73729             | 3303              |
| 1500        | .30 | 36200       | -6.70         | 0          | 20  | 1.14       | 8.16         | 41.5         | 75499             | 3294              |
| 1500        | .30 | 36200       | -6.70         | -200       | 20  | 21.63      | 8.16         | 72.7         | 75119             | 3287              |

Fig. 5-19 Steep entry, thick atmosphere, L/D = .3



MAC RUN 285193

5.2--- L/D = .3, THIN

(8/03/65)

| RANGE<br>NM | L/D | VEL.<br>FPS | GAMMA<br>DEG. | ERV<br>FPS | SOA | MISS<br>NM | MAX-G<br>G=5 | FUEL<br>SEC. | QCONV<br>BTU/SQFT | GRAD<br>BTU/SQFT |
|-------------|-----|-------------|---------------|------------|-----|------------|--------------|--------------|-------------------|------------------|
| 2350        | .30 | 36200       | -5.20         | 200        | -20 | 1.61       | 4.25         | 61.1         | 103887            | 2094             |
| 2350        | .30 | 36200       | -5.20         | 0          | -20 | 0.59       | 4.64         | 66.1         | 105513            | 2067             |
| 2350        | .30 | 36200       | -5.20         | -200       | -20 | 0.61       | 5.64         | 50.5         | 106979            | 2033             |
| 2000        | .30 | 36200       | -5.20         | 200        | -20 | 0.68       | 8.09         | 76.2         | 97359             | 2117             |
| 2000        | .30 | 36200       | -5.20         | 0          | -20 | 0.23       | 7.71         | 65.6         | 98687             | 2095             |
| 2000        | .30 | 36200       | -5.20         | -200       | -20 | 0.57       | 6.20         | 52.5         | 99992             | 2070             |
| 1500        | .30 | 36200       | -5.20         | 200        | -20 | 0.24       | 4.61         | 49.9         | 85178             | 2161             |
| 1500        | .30 | 36200       | -5.20         | 0          | -20 | 1.47       | 4.28         | 48.4         | 86275             | 2139             |
| 1500        | .30 | 36200       | -5.20         | -200       | -20 | 0.53       | 5.12         | 46.8         | 87603             | 2105             |

Fig. 5-20 Shallow entry, thin atmosphere, L/D = .3

## VI AGC PROGRAM

The detailed reentry program is shown in succeeding pages. Both basic and interpretative programming have been used. These are described in References 3 and 4.

The program speed and size is summarized in fig. 6-1. The program is roughly 1500 words long and the computation time varies from .5 to 1.0 second depending on the program mode.

The program is listed in the form ready for the YUL assembler. The right half of the list (column 41 on the card) contains comments to aid in reading the program.

It is assumed here that prior to entry the vehicle is in the entry attitude and that the SCS, IMU, and CDU are all in the entry mode. Further it is assumed that the mission control program (not described) has put a 2 second call to the "Wait List"\* for the PIPUP routine, and the entry calculations have been started in the Initialization Section, STARTENT.

This section starts the attitude control job by assigning a priority of 14 to the job UPTHETA1. The various quantities are initialized in STARTENT, then the program waits until the next cycle to start the normal entry calculations.

Further entries to the main computation are made through the PIPA reading routine, PIPUP. This routine reads the PIPA-s by calling PIPASR by way of ISWCALL. ISWCALL is a routine to call a subroutine in a different switchable bank from the one currently being executed. (It is equivalent to SWCALL except it may be used in the interrupt mode.) The PIPUP routine then perpetuates itself by giving a two second call to the Wait List. It also sets up the INTERPIP routine with a .5 second call to the Wait List. INTERPIP is a routine to read the PIPA-s in a finer time interval to give a more detailed acceleration history. The main computational cycle is then set up by giving a priority of 16 to the program starting at ENTRYTOP.

---

\*Details of the "wait list" and program control are in Ref. 6.

The UPTHETA1 job calls itself by putting a two second call to the Wait List for UPTHETA3, and UPTHETA3 calls UPTHETA with a priority of 14.

The computer variables are listed in fig. 6-2. The maximum value shows the value of the variable if the scaled variable had a value of one. (The real maximum is one bit less than this - 1 part in  $2^{28}$  for double-precision variables.)

The unscaled constants are listed in fig. 6-3. The scaled constants, of course, appear in the AGC program listing.

|                                                | TIME<br>SEC  | SIZE<br>WORDS |
|------------------------------------------------|--------------|---------------|
| INITIALIZE                                     | .117         | 57            |
| READ PIPA-S                                    | .001         | 105           |
| NAVIGATE                                       | .230         | 147           |
| TARGETING                                      | .270         | 147           |
| MODE SELECTOR                                  | .001         | 2             |
| INITIAL ROLL                                   | .015<br>.053 | 63            |
| HUNTEST                                        | .301<br>.350 | 316           |
| CONSTANT DRAG CONTROL                          | .067         | 56            |
| UP-CONTROL                                     | .106<br>.136 | 111           |
| BALLISTIC PHASE<br>(INCLUDES ATTITUDE CONTROL) | .371         | 71            |
| FINAL PHASE                                    | .043         | 190           |
| G-LIMITER                                      | .009<br>.037 | 38            |
| LATERAL LOGIC                                  | .061         | 82            |
| CONSTANTS                                      | ---          | 131           |

Fig. 6-1 Program speed and size.



| VARIABLE<br>----- | DESCRIPTION<br>-----             | MAXIMUM VALUE<br>-----  | COMPUTER NAME<br>----- |
|-------------------|----------------------------------|-------------------------|------------------------|
| URTO              | INITIAL TARGET VECTOR            | 2 (UNIT VECTOR)         | = RTINIT               |
| UZ                | UNIT VECTOR NORTH                | 2                       | = (UZ) OR UNITW        |
| V                 | VELOCITY VECTOR                  | 2 VSAT                  | = (V)                  |
| R                 | POSITION VECTOR                  | 2 EXP 29 METERS         | = RM                   |
| VI                | INERTIAL VELOCITY                | 128 M/CENTISEC          | = VPIP                 |
| RTE               | VECTOR EAST AT INITIAL TARGET    | 2                       | = RTEAST               |
| UTR               | NORMAL TO RTE AND UZ             | 2                       | = RTNORM               |
| URT               | TARGET VECTOR                    | 2                       | = (RT)                 |
| UNI               | UNIT NORMAL TO TRAJECTORY PLANE  | 2                       |                        |
| DELV              | INTEGRATED ACCEL. FROM PIPAS     | 5.85 16384 CM/S         |                        |
| G                 | GRAVITY VECTOR                   | 1/32 M/CS/CS            | = GRAVITY              |
| A0                | INITIAL DRAG FOR UPCONTRL        | 805 FPSS                | FPSS=FT/SEC/SEC        |
| AHOOKDV           | TERM IN GAMMAL CALC. = AHOOK DVL | 805/16 VSAT<br>FPS FPSS |                        |
| ALP               | CONST FOR UPCONTRL               | 1                       |                        |
| ASKEP             | KEPLER RANGE                     | 21600 NM                | NM = NAUTICAL MILE     |
| ASP1              | FINAL PHASE RANGE                | 21600 NM                |                        |
| ASPUP             | UP-RANGE                         | 21600 NM                |                        |
| ASP3              | GAMMA CORRECTION                 | 21600 NM                |                        |
| ASPDWN            | RANGE DOWN TO PULL-UP            | 21600 NM                |                        |
| ASP               | PREDICTED RANGE                  | 21600 NM                |                        |
| COSG              | COSINE(GAMMAL)                   | 2                       | = COSG/2               |
| D                 | TOTAL ACCELERATION               | 805 FPSS                |                        |
| D0                | CONTROLLED CONST. DRAG           | 805 FPSS                |                        |
| DHOOK             | TERM IN GAMMAL COMPUTATION       | 805 FPSS                |                        |
| DIFF              | THETNM-ASP (RANGE DIFFERENCE)    | 21600/16 NM             |                        |
| DIFFOLD           | PREVIOUS VALUE OF DIFF           | 21600/16 NM             |                        |
| DR                | REFERENCE DRAG FOR DOWNCONTROL   | 805 FPSS                |                        |
| DREFR             | REFERENCE DRAG                   | 805 FPSS                |                        |
| DVL               | VS1-VL                           | 2 VSAT                  |                        |
| E                 | ECCENTRICITY                     | 4                       |                        |
| F1                | DRANGE/D DRAG (FINAL PHASE)      | 2700/805                |                        |
| F2                | DRANGE/D RDOT (FINAL PHASE)      | 2700/2VS NM/FPS         |                        |
| F3                | DRANGE/D (L/D)                   | 2700 NM                 |                        |
| FACT1             | CONST FOR UPCONTRL               | 2 VSAT                  |                        |
| FACT2             | CONST FOR UPCONTRL               | 1                       |                        |
| FACTOR            | USED IN UPCONTRL                 | 1                       |                        |
| GAMMAL            | FLIGHT PATH ANGLE AT VL          | 1 RADIAN                |                        |
| GAMMAL1           | SIMPLE FORM OF GAMMAL            | 1 RADIAN                |                        |

Fig. 6-2 Computer Variables

| VARIABLE<br>----- | DESCRIPTION<br>-----                           | MAXIMUM VALUE<br>----- | COMPUTER NAME<br>----- |
|-------------------|------------------------------------------------|------------------------|------------------------|
| K1ROLL            | INDICATOR FOR ROLL SWITCH                      |                        |                        |
| K2ROLL            | INDICATOR FOR ROLL SWITCH                      |                        |                        |
| LATANG            | LATERAL RANGE                                  | 4 RADIANS              |                        |
| LEQ               | EXCESS C.F. OVER GRAV=(VSQ-V)GS                | 128.8 FPSS             |                        |
| L/D               | DESIRED LIFT TO DRAG RATIO (VERTICAL PLANE)    |                        |                        |
| PREDANGL          | PREDICTED RANGE (FINAL PHASE)                  | 2700 NM                |                        |
| Q7                | MINIMUM DRAG FOR UPCONTROL                     | 805 FPSS               |                        |
| RDOT              | ALTITUDE RATE                                  | 2 VSAT                 |                        |
| RDOTREF           | REFERENCE RDOT FOR UPCONTROL                   | 2 VSAT                 |                        |
| RDTR              | REFERENCE RDOT FOR DOWNCONT                    | 2 VSAT                 |                        |
| ROLLC             | ROLL COMMAND                                   | 8 REVOLUTIONS          |                        |
| RTOGO             | RANGE TO GO (FINAL PHASE)                      | 2700 NM                |                        |
| SL                | SINE OF LATITUDE                               | 1                      |                        |
| T                 | TIME                                           | 16384 SEC              | = TENTRY               |
| THETA             | DESIRED RANGE (RADIAN)                         | 2 PI RADIAN            | = THETAH               |
| THETNM            | DESIRED RANGE (NM)                             | 21600 NM               |                        |
| V                 | VELOCITY MAGNITUDE                             | 2 VSAT                 |                        |
| V1                | INITIAL VELOCITY FOR UPCONTROL                 | 2 VSAT                 |                        |
| V1OLD             | PREVIOUS VALUE OF V1                           | 2 VSAT                 |                        |
| VCORR             | VELOCITY CORRECTION FOR UPCONTROL              | 2 VSAT                 |                        |
| VL                | EXIT VELOCITY FOR UPCONTROL                    | 2 VSAT                 |                        |
| VREF              | REFERENCE VELOCITY FOR UPCONTROL               | 2 VSAT                 |                        |
| VS1               | VSAT OR V1, WHICHEVER IS SMALLER               | 2 VSAT                 |                        |
| VBARS             | $\frac{VL^2}{VSAT^2}$                          | 4                      |                        |
| VSQ               | NORMALISED VEL. SQUARED = $\frac{V^2}{VSAT^2}$ | 4                      | = VSQUARE              |
| WT                | EARTH RATE TIMES TIME                          | 1 REVOLUTION           | = WIE (DTEAROT)        |
| X                 | INTERMEDIATE VARIABLE IN G-LIMITER             |                        |                        |
| Y                 | LATERAL MISS LIMIT                             | 4 RADIANS              |                        |

Fig. 6-2a Computer Variables (cont'd)

-----  
 EXTRA COMPUTER ERASABLE LOCATIONS NOT SHOWN ON FLOW CHARTS  
 -----

| VARIABLE<br>----- | DESCRIPTION<br>-----                 | MAXIMUM VALUE<br>-----           |
|-------------------|--------------------------------------|----------------------------------|
| C/D0              | SCALED RECIPROCAL OF D0              |                                  |
| GOTOADDR          | ADDRESS SELECTED BY SEQUENCER        |                                  |
| XPIBUIF           | BUFFER TO STORE X PIPA COUNTS        |                                  |
| YPIBUIF           | BUFFER TO STORE Y PIPA COUNTS        |                                  |
| ZPIBUIF           | BUFFER TO STORE Z PIPA COUNTS        |                                  |
| PIPCTR            | COUNTS PASSES THRU PIPA READ ROUTINE |                                  |
| JJ                | INDEX IN FINAL PHASE TABLE LOOK-UP   |                                  |
| M1                | INDEX IN FINAL PHASE TABLE LOOK-UP   |                                  |
| GRAD              | INTERPOLATION FACTOR IN FINAL PHASE  |                                  |
| FX                | DRANGE/D L/D = F3                    | 2700 NM                          |
| FX + 1            | AREF                                 | 805 FPSS                         |
| FX + 2            | RTOGO                                | 2700 NM                          |
| FX + 3            | RDOTREF                              | VSAT/4                           |
| FX + 4            | DRANGE/D RDOT = F2                   | 21600/2VS NM/FPS                 |
| FX + 5            | DRANGE/D DRAG = F1                   | 2700/805 NM/FPSS                 |
| UNITV             | UNIT V VECTOR                        | 2                                |
| UNITR             | UNIT R VECTOR                        | 2                                |
| TEMP1B            | TEMPORARY LOCATION                   |                                  |
| SWITCHES<br>----- |                                      |                                  |
| (6)               | GONEPAST                             | INDICATES OVERSHOOT OF TARGET    |
| (7)               | RELVELSW                             | RELATIVE VELOCITY SWITCH         |
| (8)               | EGSW                                 | FINAL PHASE SWITCH               |
| (9)               | HUNTIND                              | INITIAL PASS THRU HUNTEST        |
| (10)              | HIND                                 | INDICATES ITERATION IN HUNTEST   |
| (11)              | INRLSW                               | INDICATES INIT ROLL ATTITUDE SET |

Fig. 6-2b Computer Variables (cont'd)

## CONSTANTS AND GAINS

## VALUE

|          |                                                |          |        |
|----------|------------------------------------------------|----------|--------|
| C1       | FACTOR IN ALP COMPUTATION                      | 1.25     |        |
| C16      | CONSTD GAIN ON DRAG                            | .01      |        |
| C17      | CONSTD GAIN ON RDOT                            | .001     |        |
| C18      | BIAS VEL. FOR FINAL PHASE START                | 500      | FPS    |
| C19      | MINIMUM CONST DRAG                             | 130      | FPSS   |
| C20      | MAX DRAG FOR DOWN-LIFT                         | 175      | FPSS   |
| CHOOK    | FACTOR IN AHOOK COMPUTATION                    | .25      |        |
| CH1      | FACTOR IN GAMMAL COMPUTATION                   | .75      |        |
| DOMAX    | MAX CONST DRAG                                 | 175      | FPSS   |
| DT       | COMPUTATION CYCLE TIME INTERVAL                | 2        | SEC.   |
| GMAX     | MAXIMUM ACCELERATION                           | 322      | FPSS   |
| KA       | DRAG TO ROLL UP IF DOWN INITIALLY (=KAT)       | 64.4     | FPSS   |
| KB1      | OPTIMIZED UPCONTROL GAIN                       | 3.4      |        |
| KB2      | OPTIMIZED UPCONTROL GAIN                       | .0034    |        |
| KDMIN    | INCREMENT ON Q7 TO DETECT END OF KEPLER PHASE  | .5       | FPSS   |
| KLAT     | LATERAL SWITCH GAIN                            | .0125    |        |
| KTETA    | TIME OF FLIGHT CONSTANT                        | 1000     |        |
| K44      | GAIN USED IN INITIAL ROLL SECTION              | 44389312 | FPS    |
| LAD      | MAX L/D (MIN ACTUAL VEHICLE L/D)               | .3       |        |
| LATBIAS  | LATERAL SWITCH BIAS TERM                       | .4       | NM     |
| L/DCMINR | LAD COS(15 DEG)                                | .2895    |        |
| LEWD     | UPCONTROL L/D                                  | .1       |        |
| L0D      | FINAL PHASE L/D                                | .18      |        |
| Q2       | FINAL PHASE RANGE - 23500 Q3                   | -1002    | NM     |
| Q3       | FINAL PHASE DRANGE/D V                         | .07      | NM/FPS |
| Q5       | FINAL PHASE DRANGE/ D GAMMA                    | 7050     | NM/RAD |
| Q6       | FINAL PHASE INITIAL FLIGHT PATH ANGLE          | .0349    | RAD    |
| Q7F      | MIN DRAG FOR UPCONTROL                         | 6        | FPSS   |
| VFINAL   | VELOCITY TO START FINAL PHASE ON INITIAL ENTRY | 25000    | FPS    |
| VLMIN    | MINIMUM VL                                     | 18000    | FPS    |
| VMIN     | VELOCITY TO SWITCH TO RELATIVE VEL             | VSAT/2   |        |
| VRCONTRL | RDOT TO START INTO HUNTEST                     | 700      | FPS    |
| VCORLIM  | MAX VALUE OF VCORR                             | 1000     | FPS    |
| 25NM     | TOLERANCE TO STOP RANGE ITERATION              | 25       | NM     |
| VQUIT    | VELOCITY TO STOP STEERING                      | 1000     | FPS    |

(10 G-S)

## CONVERSION FACTORS AND SCALING CONSTANTS

|      |                              |                |                       |
|------|------------------------------|----------------|-----------------------|
| ATK  | ANGLE IN RAD TO NM           | 3437.7468      | NM/RAD                |
| GS   | NOMINAL G VALUE FOR SCALING  | 32.2           | FPSS                  |
| HS   | ATMOSPHERE SCALE HEIGHT      | 28500          | FT                    |
| J    | GRAVITY HARMONIC COEFFICIENT | .00162345      |                       |
| KWE  | EQUATORIAL EARTH RATE        | 1546.70168     | FPS                   |
| MUE  | EARTH GRAVITATIONAL CONSTANT | 3.986032233    | E 14 CUBIC M/ SEC SEC |
| RE   | EARTH RADIUS                 | 21202900       | FT                    |
| VSAT | SATELLITE VELOCITY AT RE     | 25766.1973     | FPS                   |
| WIE  | EARTH RATE                   | .0000729211505 | RAD/SEC               |

Fig. 6-3 Constants, Gains and Conversion Factors



# RE-ENTRY CONTROL

```

0001          SETLOC 56000

R0002          THE PIPUP SECTION IS A TASK WHICH READS THE PIPAS EVERY .5
R0003 SECONDS. ACCELERATION HISTORY OVER THE LAST TWO SECONDS (FOUR READINGS)
R0004 IS MAINTAINED IN THE XPIPBUF, YPIPBUF, AND ZPIPBUF REGISTERS. EACH PIPA
R0005 READING IS SUMMED INTO THE XPIPSUM ETC. REGISTERS, AND EVERY FOURTH READ
R0006 ING AVERAGE G IS CALLED TO USE THE SUMMED READINGS TO UPDATE POSITION
R0007 AND VELOCITY AND SET THE PIPSUM REGISTERS TO ZERO.

R0008          GOES THRU PIPUP ONLY EVERY 2 SEC. (ELSEWHERE MORE OFTEN.)

0009          CADR      REPIPASR
0010 REPIPUP    CAF      -1
0011          TC        PIPUP + 1          REREAD PIPAS IF NECESSARY.

0012          CADR      PIPASR
0013 PIPUP     CAF      -1
0014          TC        ISWCALL          GO TO PIPAREAD SUBROUTINE.

0015          CAF      THIRTN          PICK UP AT RED05.13
0016          TC        NEWPHASE
0017          OCT      5          5.13 RESTART. (NO TIME CALL.)

0018 RED05.13  CAF      DT
0019          TC        WAITLIST
0020          CADR      PIPUP

0021          CS        PIPTIME + 1
0022          TS        TBASE5          SAVE NEW TIME.

0023          CAF      IPIPDT
0024          TC        WAITLIST
0025          CADR      INTERPIP          READ ACCELERATION MORE OFTEN.

0026          CAF      PRI016
0027          TC        FINDVAC
0028          CADR      ENTRYTOP

0029          CAF      TWO
0030          TS        PIPCTR

0031          CAF      FOURTN          THIS WILL PICK UP AT ENTRYTOP + 3.
0032          TC        NEWPHASE
0033          OCT      5          5.14 RESTART.

0034          TC        TASKOVER

0035 IPIPDT    DEC      50

```

# RE-ENTRY CONTROL

|       |                                                                |      |                                                                                                  |
|-------|----------------------------------------------------------------|------|--------------------------------------------------------------------------------------------------|
| P0036 | JOB WHICH PROCESSES PIPA READINGS TO UPDATE POSITION AND VELOC |      |                                                                                                  |
| 0037  | ENTRYTOP                                                       | XCH  | TENTRY                                                                                           |
| 0038  |                                                                | AD   | TWO                                                                                              |
| 0039  |                                                                | XCH  | TENTRY                                                                                           |
|       |                                                                |      | UPDATE ENTRY TIME.                                                                               |
|       |                                                                |      | IN SECS SINCE START OF ENTRY.                                                                    |
| 0040  |                                                                | CAF  | ONE                                                                                              |
| 0041  |                                                                | TS   | PIPAGE                                                                                           |
| 0042  |                                                                | CS   | DELVX                                                                                            |
| 0043  |                                                                | TS   | XPIPBUF + 3                                                                                      |
| 0044  |                                                                | CS   | DELVY                                                                                            |
| 0045  |                                                                | TS   | YPIPBUF + 3                                                                                      |
| 0046  |                                                                | CS   | DELVZ                                                                                            |
| 0047  |                                                                | TS   | ZPIPBUF + 3                                                                                      |
|       |                                                                |      | SAVE PIP COUNTS.                                                                                 |
| 0050  |                                                                | TC   | PHASCHNG                                                                                         |
| 0051  |                                                                | OCT  | 01705                                                                                            |
| 0052  |                                                                | TC   | BANKCALL                                                                                         |
| 0053  |                                                                | CADR | 1/PIPA                                                                                           |
|       |                                                                |      | 5.15 RESTART PICKS UP AT REFAZE4.<br>COMPENSATE THE PIPA DATA                                    |
| 0054  | REFAZE4                                                        | TC   | INTPRET                                                                                          |
| 0055  |                                                                | ITC  | 0                                                                                                |
| 0056  |                                                                |      | CALCRVG                                                                                          |
| A0057 |                                                                |      | GO TO AVERAGE G INTEGRATION ROUTINES TO<br>USE PIPA READINGS TO UPDATE POSITION AND<br>VELOCITY. |
| 0058  |                                                                | TC   | PHASCHNG                                                                                         |
| 0059  |                                                                | OCT  | 02105                                                                                            |
|       |                                                                |      | 5.17 RESTART AT REFAZE8.                                                                         |
| 0060  | REFAZE8                                                        | TC   | INTPRET                                                                                          |

# RE-ENTRY CONTROL

```

P0061    PROCESS AVERAGE G OUTPUT...SCALE IT AND GET INPUT DATA

0062    SCALEPOP VXSC    0
0063                VPIP
0064                KVSCALE
0065                STORE (V)
                                KVSCALE = (12800/.3048)0(25766.1973 X2)
                                KVSCALE = .81491944
                                V VECTOR

0066                TEST    2
0067                VXV    VXSC
0068                VAD
                                (VREL) = (V) + KWE UNITR*UNITW
0069                RELVELSW
                                SWITCH NUMBER.
0070                GETUNITV
0071                UNITR
0072                UNITW
0073                KWE
0074                (V)
0075                STORE (V)
                                NEW V VECTOR IS RELATIVE.

0076    GETUNITV NOLOD    1
0077                UNIT
0078                STORE UNITV
                                HALF MAX. OF COURSE.

0079                TSLT    0
0080                28D
0081                2
0082                STORE VSQUARE
                                RESCALE MAGNITUDE SQUARED.
                                SHIFT COUNT. (2 BECAUSE HALF-LEN SQRD
                                VELOCITY SQUARED. (NORMAL SCALING)

0083                DSU    0
0084                VSQUARE
0085                FOURTH
0086                STORE LEQ
                                LEQ = VSQUARE-1
                                4 G-S FULL SCALE

0087                TSLT    0
0088                30D
0089                1
0090                STORE V

0091                DOT    1
0092                TSLT
0093                (V)
0094                UNITR
0095                1
0096                STORE RDOT
                                RDOT = V.UNITR
                                AND SCALE BACK UP. UNITS ARE 1/2.

```

# RE-ENTRY CONTROL

|       |                                                                       |       |          |                                       |
|-------|-----------------------------------------------------------------------|-------|----------|---------------------------------------|
| 0097  |                                                                       | DMOVE | 0        | SAVE OLD DRAG VALUE.                  |
| 0098  |                                                                       |       | D        |                                       |
| 0099  |                                                                       | STORE | DOLD     |                                       |
| 0100  |                                                                       | ABVAL | 2        |                                       |
| 0101  |                                                                       | TSLT  | DMP      |                                       |
| 0102  |                                                                       | BZF   |          |                                       |
| 0103  |                                                                       |       | DELV     | KASCALE=5.85 16384/(4 .3048 805 100)  |
| 0104  |                                                                       |       | 2        | 2 FOR 2 SEC, 3 FOR 1 SEC, 4 FOR .5 -- |
| 0105  |                                                                       |       | KASCALE  | = 3. /4 /25                           |
| 0106  |                                                                       |       | SETMIND  |                                       |
| 0107  |                                                                       | STORE | D        | ACCELERATION (DRAG, ALMOST)           |
| 0108  | GETUNI                                                                | VXV   | 1        | UNI = UNIT(V*R)                       |
| 0109  |                                                                       | UNIT  |          |                                       |
| 0110  |                                                                       |       | (V)      | COULD USE UNITV.                      |
| 0111  |                                                                       |       | UNITR    |                                       |
| 0112  |                                                                       | STORE | UNI      | INERTIAL OR RELATIVE AS IS (V).       |
| R0113 | SOME OF THE FOLLOWING TARGETTING MIGHT BE DONE LESS OFTEN THAN ABOVE. |       |          |                                       |
| 0114  |                                                                       | TEST  | 1        | THIS TEST MIGHT BE COMBINED WITH THE  |
| 0115  |                                                                       | DMOVE |          | PREVIOUS ONE IF ALL CALCULATIONS ARE  |
| 0116  |                                                                       |       | RELVELSW | DONE EVERY CYCLE.                     |
| 0117  |                                                                       |       | GETETA   |                                       |
| 0118  |                                                                       |       | PIPTIME  |                                       |
| 0119  |                                                                       | STORE | DTEAROT  |                                       |



# RE-ENTRY CONTROL

|       |          |       |          |                                         |
|-------|----------|-------|----------|-----------------------------------------|
| 0120  | UPDATERT | ITC   | 0        | UPDATE PREDICTED TARGET VECTOR RT       |
| 0121  |          |       | EARROT2  |                                         |
| 0122  |          | NOLOD | 1        |                                         |
| 0123  |          | DOT   | RTB      | SINCE (RT) UNIT VEC, THIS IS 1/4 MAX.   |
| 0124  |          |       | UNI      | LATANG = RT.UNI                         |
| 0125  |          |       | FRESHPD  |                                         |
| 0126  |          | STORE | LATANG   | LATANG = MAC LATANGLE/4 (NO 2 PI)       |
| A0127 |          |       |          | UNUSUAL SCALING FOR LATANG. ( = ASIN L. |
| 0128  | GETANGLE | DOT   | 3        | THETA = ARCCOS(RT.UNITR)                |
| 0129  |          | DSU   | BPL      | RT IS UNIT VECTOR                       |
| 0130  |          | DAD   | TSLT     |                                         |
| 0131  |          | ACOS  |          |                                         |
| 0132  |          |       | RT       |                                         |
| 0133  |          |       | UNITR    |                                         |
| 0134  |          |       | NEAR1/4  | TO IMPROVE ACCURACY, CALC RANGE BY      |
| 0135  |          |       | TINYTHET | TINYTHET IF HIGH ORDER PART OF          |
| 0136  |          |       | NEAR1/4  | ARCCOS ARGUMENT IS ZERO                 |
| 0137  |          |       | 1        |                                         |
| 0138  |          | STORE | THETAH   |                                         |
| 0139  |          | EXIT  | 0        |                                         |
| 0140  | REFAZE10 | TC    | PHASCHNG |                                         |
| 0141  |          | OCT   | 02205    | 5.18 RESTART AT REFAZE10                |
| 0142  |          | TC    | INTPRET  |                                         |

# RE-ENTRY CONTROL

P0143 JUMP TO PARTICULAR RE-ENTRY PHASE.

0144 SEQUENCE ITCI 0 BRANCHES TO VARIOUS CONTROL PHASES.  
0145 GOTOADDR ADDRESS OF PHASE EQS STORED HERE.

R0146 GOTOADDR CONTAINS THE ADDRESS OF THE ROLL COMMAND EQUATIONS  
R0147 APPROPRIATE TO THE CURRENT PHASE OF RE-ENTRY. SEQUENCING IS AS FOLLOWS:

R0148 INITROLL SET HERE INITIALLY. HOLDS INITIAL ROLL ATTITUDE UNTIL KAT EX-  
R0149 CEDED. THEN HOLDS NEW ROLL ATTITUDE UNTIL VRTHRESH EXCEEDFD.  
R0150 THEN BRANCHES TO

R0151 HUNTEST THIS SECTION CHECKS TO SEE IF THE PREDICTED RANGE AT NOMINAL  
R0152 L/D FROM PRESENT CONDITIONS IS LESS THAN THE DESIRED RANGE  
R0153 IF NOT-- A ROLL COMMAND IS GENERATED BY THE CONSTANT DRAG  
R0154 CONTROLLER.  
R0155 IF SO-- CONTROL AND GOTOADDR ARE SET TO UPCONTRL  
R0156 USUALLY NO ITERATION IS INVOLVED EXCEPT IF THE RANGE DESIRED IS  
R0157 TOO LONG ON THE FIRST PASS THRU HUNTEST.

R0158 UPCONTRL CONTROLS ROLL DURING THE SUPER-CIRCULAR PHASE. UPCONTRL IS TERM-  
R0159 INATED EITHER (A) WHEN THE DRAG (AS MEASURED BY THE PIPAS)  
R0160 FALLS BELOW Q7 OR (B) IF RDOT IS NEGATIVE AND REFERENCE VL  
R0161 EXCEEDS V. IN CASE (A), GOTOADDR IS SET TO KEP2 AND IN (B) TO  
R0162 PREDICT3, SKIPPING THE KEPLER PHASE OF ENTRY.

R0163 KEP2 GOTOADDR IS SET HERE DURING THE KEPLER PHASE TO MONITOR DRAG.  
R0164 SPACECRAFT IS INSTANTANEOUSLY TRIMMED IN PITCH AND YAW TO THE  
R0165 COMPUTED RELATIVE VELOCITY VECTOR. THE LAST COMPUTED ROLL  
R0166 ANGLE IS MAINTAINED. WHEN THE MEASURED DRAG EXCEEDS Q7+.5,  
R0167 GOTOADDR IS SET TO

R0168 PREDICT3 THIS CONTROLS THE FINAL SUB-ORBITAL PHASE. ROLL COMMANDS CEASE  
R0169 WHEN V IS LESS THAN VQUIT. AN EXIT IS MADE TO TERMALT WHEN  
R0170 TERMINAL ALTITUDE IS REACHED.

# RE-ENTRY CONTROL

P0171 OUT OF SEQUENCE SUBSECTION TO COMPUTE ETA.

0172 BOOKMARK EQUALS

0173 SETLOC ENDRTHSS

0174 GETETA TEST 1

0175 DMP

0176 EGSW

0177 SUBETA

0178 THETAH

0179 KTETA

0180 STORE ETA

NOT USED AT LOW VEL WHERE THETA NEG.

BRANCHES IF INTO EQ. GLIDE PHASE.

=  $1000 \times 2\pi / (2) E1, 163.84$

DONT REALLY WANT IT, BUT NO PUSH WANTED

0181 GETETA2 NOLOD 1

0182 DAD

0183 PIPTIME

0184 STORE DTEAROT

0185 ITC 0

0186 UPDATERT

0187 SUBETA DSU 1

0188 BPL SWITCH

0189 V

0190 FOURTH

0191 SUBETA2

0192 RELVELSW

SWITCH FROM INERTIAL TO RELATIVE  
VELOCITY WHEN V LESS THAN .5 VSAT.

SHOULD CHANGE TO OFF (NON-BRANCH) STATE

0193 SUBETA2 DMP 1

0194 DDV ITC

0195 THETAH

0196 KT

0197 V

0198 GETETA2

$KT = RE(2 \pi) / 2 VS 16384 163.84$   
/2 VSAT

0199 SETMIND DMOVE 0

0200 1BITDP

0201 STORE D

MAKE D NON-ZERO.

0202 ITC 0

0203 GETUNI

0204 TINYTHET NOLOD 3

0205 DSU ABS

0206 TSLT SQRT

0207 DMP

0208 1BITDP + 1

0209 13D

0210 KACOS

0211 STORE THETAH

ENTER WITH X=.249

GET 1/4 - MPAC

SCALE UP BEFORE SQRT.

HAS FACTOR FOR UP SCALING.

$X = \text{SQRT}(2(1-\text{COSX}))$ , IN RADIANS

$X/2\pi = (1/64\pi) (\text{SQRT}(((1-\text{COSX})/4)2\text{EXP13}))$

0212 RTB 0

0213 REFAZE10

OFF TO PRE-SEQUENCER...

# RE-ENTRY CONTROL

P0214 MAINTAINS INITIAL ROLL UNTIL D = KAT, GOES INTO HUNTEST WHEN  
R0215 RDOT = VRCONT.

0216 BOOKMRK1 EQUALS  
0217 SETLOC BOOKMARK

0218 HUNTCADR CADR HUNTEST

0219 INITROLL TEST 2 IF D-.05 G NEG, GO TO LIMITL/D  
0220 DSU BMN IF NOT, SET .05 G SWITCH FOR SCS  
0221 EXIT  
0222 INRLSW  
0223 INITRL1  
02231 D  
02232 .05G  
02233 LIMITL/D

0224 TC RELAYON SEND .05 G SIGNAL TO SCS.  
0225 OCT 40100  
0226 TC NEWMODE SET MODE TO AFTER .05 G STATE.  
0227 OCT 00064  
0228 TC INTERPRET

022802 DMOVE 0  
022804 LAD  
022806 STORE L/D

022808 SWITCH 2 IF V-VFINAL NEG, GO TO FINAL PHASE  
02281 DSU BPL  
022812 RTB  
022814 INRLSW  
022816 V  
022818 VFINAL  
02282 UPDWNTST

022822 CAF KEPCADR  
022824 TS GOTOADDR  
022826 TC INTERPRET

022828 ITC 0  
02283 LIMITL/D

022832 UPDWNTST DDV 0  
022834 RDOT  
022836 V RESULT INTO PD

022838 NOLOD 5 IF V-VFINAL+K(RDOT/V)CUBED POS,L/D=-LAD  
02284 DSQ DMP  
022842 DDV DSU  
022844 DAD BOV  
022846 BMN LODON  
022848 DSU  
02285



# RE-ENTRY CONTROL

|        |         |          |          |                                      |
|--------|---------|----------|----------|--------------------------------------|
| 022854 |         |          | K44      |                                      |
| 022856 |         |          | VFINAL   |                                      |
| 022858 |         |          | V        |                                      |
| 02286  |         |          | LIMITL/D |                                      |
| 022862 |         |          | LIMITL/D |                                      |
| 022864 |         |          | LAD      |                                      |
| 022866 | STORE   |          | L/D      |                                      |
| 022868 | ITC     | 0        |          |                                      |
| 02287  |         | LIMITL/D |          |                                      |
| 022872 | INRLSW  | EQUALS   | LATSW    |                                      |
| 0229   | INITRL1 | DSU      | 2        | IF KAT-D POS, GO TO OUT WITH COMMAND |
| 0230   |         | BPL      | LODON    | IF NEG, L/D = LAD                    |
| 0231   |         | DMOVE    |          |                                      |
| 0232   |         | KAT      |          |                                      |
| 0233   |         | D        |          |                                      |
| 0234   |         | VRTHRES  |          |                                      |
| 0236   |         | LAD      |          | WHEN D GREATER THAN KAT, L/D = LAD   |
| 0237   | STORE   | L/D      |          |                                      |
| 0238   | VRTHRES | DAD      | 1        | IF RDOT + VRCONT NEG, GO TO STEER    |
| 0239   |         | BMN      | EXIT     | IF POS, SET SELECTOR TO HUNTEST.     |
| 0240   |         |          | RDOT     |                                      |
| 0241   |         |          | VRCONT   |                                      |
| 0242   |         |          | LIMITL/D | DO LATERAL CONTROL IF NEEDED.        |
| A0243  |         |          |          | SPACER.                              |
| 0244   | CAF     | HUNTCADR |          |                                      |
| 0245   | TS      | GOTOADDR |          | AND FALL THRU INTO HUNTEST1.         |

# RE-ENTRY CONTROL

P0246 ... HUNTEST SECTION... CHECKS TO SEE WHEN PREDICTED RANGE = DESIRED ONE

|        |         |       |          |                                               |
|--------|---------|-------|----------|-----------------------------------------------|
| 0247   | PREHUNT | TC    | INTPRET, |                                               |
| 0248   | HUNTEST | DMOVE | 0        | IF RDOT POS, TEM1B = LAD                      |
| 0249   |         |       | I AD     |                                               |
| 0250   |         | STORE | TEM1B    |                                               |
| 0251   |         | BMN   | 1        |                                               |
| 0252   |         | LODON | DMOVE    |                                               |
| 0253   |         |       | RDOT     |                                               |
| 0254   |         |       | AOCALC   |                                               |
| 0255   |         |       | LEWD     |                                               |
| 0256   |         | STORE | TEM1B    |                                               |
| 0257   | AOCALC  | DDV   | 1        | $V1 = V + RDOT/TEM1B$                         |
| 0258   |         | DAD   |          |                                               |
| 0259   |         |       | RDOT     |                                               |
| 0260   |         |       | TEM1B    |                                               |
| 0261   |         |       | V        |                                               |
| 0262   |         | STORE | V1       |                                               |
| 0263   |         | DSQ   | 3        | $A0 = (V1/V)SQ(D0 + RDOT SQ/(TEM1B^2 C1 HS))$ |
| 0264   |         | DDV   | DDV      |                                               |
| 0265   |         | DAD   | DMP      |                                               |
| 0266   |         | DMP   | DDV      |                                               |
| 02661  |         |       | RDOT     |                                               |
| 02662  |         |       | TEM1B    |                                               |
| 02663  |         |       | 2C1HS    |                                               |
| 02664  |         |       | D        |                                               |
| 02665  |         |       | V1       |                                               |
| 02666  |         |       | V1       |                                               |
| 02667  |         |       | VSQUARE  |                                               |
| 02668  |         | STORE | A0       |                                               |
| 0267   | TESTHSW | TEST  | 1        | IF HUNTSW1 ON (BRANCH), GO TO HUNTEST1        |
| 0268   |         | DMOVE | SWITCH   | HUNTSW1 = HUNTIND                             |
| 0269   |         |       | HUNTSW1  |                                               |
| 0270   |         |       | HUNTEST1 |                                               |
| 0271   |         |       | A0       |                                               |
| 0272   |         |       | HUNTSW1  | $D0 = A0$                                     |
| 0273   |         | STORE | D0       |                                               |
| 0274   |         | DSU   | 1        | IF C19-D POS, D0 = C19                        |
| 0275   |         | BMN   | DAD      |                                               |
| 0276   |         |       | C19      |                                               |
| 0277   |         |       | D0       |                                               |
| 0278   |         |       | MAXTST1  |                                               |
| 0279   |         |       | D0       |                                               |
| 0280   |         | STORE | D0       |                                               |
| 02801  | MAXTST1 | DSU   | 1        | IF D0-DOMAX POS, D0=DOMAX                     |
| 02802  |         | BPL   | DAD      |                                               |
| 02803  |         |       | DOMAX    |                                               |
| 02804  |         |       | D0       |                                               |
| 028045 |         |       | HUNTEST2 |                                               |

# RE-ENTRY CONTROL

|       |              |          |                                                       |
|-------|--------------|----------|-------------------------------------------------------|
| 02805 |              | D0       |                                                       |
| 02806 | STORE        | D0       |                                                       |
| 0281  | HUNTEST2 DDV | 0        |                                                       |
| 0282  |              | C001     |                                                       |
| 0283  |              | D0       |                                                       |
| 0284  | STORE        | C/D0     |                                                       |
| 0285  | DMOVE        | 0        | ZERO DIFFOLD THE FIRST TIME THRU.                     |
| 0286  |              | 3ZEROS   |                                                       |
| 0287  | STORE        | DIFFOLD  |                                                       |
| 0288  | DAD          | 0        | $V1OLD = V1 + C18 \text{ (500FPS)}$                   |
| 0289  |              | V1       | MAKES OLD V CORR -500 AND NEW +500 ..                 |
| 0290  |              | C18      | INITIAL VALUE ON V CORR = -500 FPS 50                 |
| 0291  | STORE        | V1OLD    | (INITIAL VALUES IF NEEDED ON 1ST PASS)                |
| 0292  | DMOVE        | 0        |                                                       |
| 0293  |              | Q7F      | $Q7 = Q7F$                                            |
| 0294  | STORE        | Q7       |                                                       |
| 0295  | HUNTEST1 DMP | 2        |                                                       |
| 0296  | DDV          | RTB      | $ALP = A0 \text{ 2HSD/LWD} / V1 \text{ V1}$           |
| 0297  | DDV          |          |                                                       |
| 0298  |              | A0       |                                                       |
| 0299  |              | 2HSD/LWD |                                                       |
| 0300  |              | V1       |                                                       |
| 0301  |              | FRESHPD  |                                                       |
| 0302  |              | V1       |                                                       |
| 0303  | STORE        | ALP      |                                                       |
| 0304  | NOLOD        | 1        |                                                       |
| 0305  | BDSU         | BDDV     |                                                       |
| 0306  |              | NEARONE  | $FACT1 = V1 / (1 - ALP)$                              |
| 0307  |              | V1       |                                                       |
| 0308  | STORE        | FACT1    |                                                       |
| 0309  | DSU          | 1        |                                                       |
| 0310  | DMP          | DDV      | $FACT2 = ALP(ALP - 1) / A0$                           |
| 0311  |              | ALP      |                                                       |
| 0312  |              | NEARONE  |                                                       |
| 0313  |              | ALP      |                                                       |
| 0314  |              | A0       |                                                       |
| 0315  | STORE        | FACT2    |                                                       |
| 0316  | DMP          | 2        | $VL = FACT1(1 - \text{SQRT}(ALP + Q7 \text{ FACT2}))$ |
| 0317  | DAD          | SQRT     |                                                       |
| 0318  | BDSU         | DMP      |                                                       |
| 0319  |              | Q7       |                                                       |
| 0320  |              | FACT2    |                                                       |
| 0321  |              | ALP      |                                                       |
| 0322  |              | NEARONE  |                                                       |
| 0323  |              | FACT1    |                                                       |
| 0324  | STORE        | VL       |                                                       |

# RE-ENTRY CONTROL

|       |          |          |                                      |
|-------|----------|----------|--------------------------------------|
| 0325  | NOLOD    | 2        | GAMMAL = LEWD(V1-VL)/VL              |
| 0326  | BDSU     | DMP      |                                      |
| 0327  | DDV      |          |                                      |
| 0328  |          | V1       |                                      |
| 0329  |          | LEWD     |                                      |
| 0330  |          | VL       |                                      |
| 0331  | STORE    | GAMMAL1  | GAMMAL1 USED IN UPCTRL               |
| 0332  | DSU      | 1        | IF VL-VMIN NEG, GO TO SHORT          |
| 0333  | BMN      |          |                                      |
| 0334  |          | VL       |                                      |
| 0335  |          | VMIN     |                                      |
| 0336  |          | PREFINAL | PREFINAL = SHORT                     |
| 0337  | DSQ      | 0        | VRARS = VL VL                        |
| 0338  |          | VL       |                                      |
| 0339  | STORE    | VBARS    |                                      |
| 0340  | DSU      | 1        | IF VSAT - VL NEG, GO TO CONSTD.      |
| 0341  | BMN      |          |                                      |
| 0342  |          | HALVE    | VSAT = .5                            |
| 0343  |          | VL       |                                      |
| 0344  |          | BECONSTD | GOTOADDR MAY BE SIDETRACKED.         |
| 0345  | STORE    | DVL      | DVL = VSAT - VL                      |
| 0346  | DMOVE    | 0        |                                      |
| 0347  |          | HALVE    | VS = VSAT                            |
| 0348  | STORE    | VS       |                                      |
| 0349  | NOLOD    | 2        |                                      |
| 0350  | DSU      | BMN      | IF V1 GREATER THAN VSAT, GO ON.      |
| 0351  | BDSU     |          |                                      |
| 0352  |          | V1       |                                      |
| 0353  |          | GETDHOOK |                                      |
| 0354  |          | DVL      | DVL = DVL - (VSAT-V1) = V1 - VL      |
| 0355  | STORE    | DVL      |                                      |
| 0356  | DMOVE    | 0        |                                      |
| 0357  |          | V1       |                                      |
| 0358  | STORE    | VS       | VS = V1                              |
| 0359  | GETDHOOK | TSRT 3   | DHOOK = ((1-VS/FACT1)SQ - ALP)/FACT2 |
| 0360  |          | DDV BDSU |                                      |
| 0361  |          | TSLT DSQ |                                      |
| 0362  |          | DSU DDV  |                                      |
| 0363  |          | VS       |                                      |
| 0364  |          | 1        |                                      |
| 0365  |          | FACT1    |                                      |
| 03655 |          | HALVE    |                                      |
| 0366  |          | 1        |                                      |
| 0367  |          | ALP      |                                      |
| 0368  |          | FACT2    |                                      |
| 0369  | STORE    | DHOOK    |                                      |
| 0370  | TSRT     | 1        | RESCALE BY 32.                       |
| 0371  | DDV      | DSU      |                                      |



# RE-ENTRY CONTROL

|      |       |         |
|------|-------|---------|
| 0372 |       | DHOOK   |
| 0373 |       | 5       |
| 0374 |       | Q7      |
| 0375 |       | CHOOK   |
| 0376 | STORE | AHOOKDV |
| 0377 | NOLOD | 4       |
| 0378 | DAD   | DMP     |
| 0379 | DMP   | DMP     |
| 0380 | DDV   | DDV     |
| 0381 | BDSU  | BMN     |
| 0382 |       | 1/8TH   |
| 0383 |       | CH1     |
| 0384 |       | DVL     |
| 0385 |       | DVL     |
| 0386 |       | DHOOK   |
| 0387 |       | VBARS   |
| 0388 |       | GAMMAL1 |
| 0389 |       | NEGAMA  |
| 0390 | STORE | GAMMAL  |

GAMMAL = GAMMAL1-CH1 DVL50(1+AHOOK DVL  
/DHOOK VBARS

FIND CONDITIONS FOR GAMMAL = 0.

# RE-ENTRY CONTROL

P0391      ... PREDICT RANGES FOR EACH PHASE OF TRAJECTORY...

|      |        |       |         |                                            |
|------|--------|-------|---------|--------------------------------------------|
| 0392 | RANGER | DSQ   | 1       |                                            |
| 0393 |        | TSRT  | BD5U    | COSG = 1-GAMMAL SQ/2 , TRUNCATED SERIES    |
| 0394 |        |       | GAMMAL  |                                            |
| 0395 |        |       | 2       |                                            |
| 0396 |        |       | HALVE   |                                            |
| 0397 |        | STORE | COSG/2  |                                            |
| 0398 |        | DSU   | 3       |                                            |
| 0399 |        | DMP   | DMP     | E=SQRT(1+VBARS-2)VBARS COSG COSG)          |
| 0400 |        | DMP   | TSLT    |                                            |
| 0401 |        | DAD   | SQRT    |                                            |
| 0402 |        |       | VBARS   |                                            |
| 0403 |        |       | HALVE   |                                            |
| 0404 |        |       | VBARS   |                                            |
| 0405 |        |       | COSG/2  |                                            |
| 0406 |        |       | COSG/2  |                                            |
| 0407 |        |       | 2       | MULT BY 4                                  |
| 0408 |        |       | C1/16   | E (E/4 REALLY) INTO PD.                    |
| 0409 |        | DMP   | 2       | ASKEP/2 = ARCSIN(VBARS COSG SING/E)        |
| 0410 |        | DMP   | DDV     |                                            |
| 0411 |        | ASIN  | TSLT    |                                            |
| 0412 |        |       | VBARS   |                                            |
| 0413 |        |       | COSG/2  |                                            |
| 0414 |        |       | GAMMAL  |                                            |
| 0415 |        |       | -       | E FROM PD.                                 |
| 0416 |        |       | 1       | ASKEP INTO PD.                             |
| 0417 |        | DMP   | 1       | ASP1 = Q2 + Q3(VL-Q4) = Q2' + Q3 VL        |
| 0418 |        | DAD   | DAD     |                                            |
| 0419 |        |       | VL      |                                            |
| 0420 |        |       | Q3      |                                            |
| 0421 |        |       | Q2      | ASP1 + ASKEP INTO PD.                      |
| 0422 |        | DSQ   | 3       | ASPUP = -C12 LOG(V1 V1 Q7/VBARS D)/GAMMAL1 |
| 0423 |        | DMP   | DDV     |                                            |
| 0424 |        | DDV   | RTB     |                                            |
| 0425 |        | DMP   | DDV     |                                            |
| 0426 |        |       | V1      |                                            |
| 0427 |        |       | Q7      |                                            |
| 0428 |        |       | VBARS   |                                            |
| 0429 |        |       | A0      |                                            |
| 0430 |        |       | LOG     |                                            |
| 0431 |        |       | C12     |                                            |
| 0432 |        |       | GAMMAL1 | ASPUP UNTO PD                              |
| 0433 |        | DMP   | 1       | ASPDWN = KC3 RDOT V / A0                   |
| 0434 |        | DMP   | DDV     |                                            |
| 0435 |        |       | KC3     |                                            |
| 0436 |        |       | RDOT    |                                            |
| 0437 |        |       | V       |                                            |
| 0438 |        |       | A0      | ASPDWN INTO PD.                            |

# RE-ENTRY CONTROL

|      |         |          |                                          |
|------|---------|----------|------------------------------------------|
| 0439 | DSU     | 2        | ASP3 = Q5(Q6-GAMMAL)                     |
| 0440 | DMP     | DAD      |                                          |
| 0441 | DAD     | DAD      |                                          |
| 0442 |         | Q6       |                                          |
| 0443 |         | GAMMAL   | ASP = ASP1+ASKEP+ASPUP+ASP3              |
| 0444 |         | Q5       | ASP INTO PD                              |
| 0445 | NOLOD   | 1        |                                          |
| 0446 | BDSU    | TSRT     |                                          |
| 0447 |         | THETAH   |                                          |
| 0448 |         | 4        | DIFF = (ASP-THETA)/16                    |
| 0449 | STORE   | DIFF     | END OF TEST                              |
| 0450 | NOLOD   | 4        |                                          |
| 0451 | ABS     | DSU      | IF ABS((THETAH-ASP) - 25NM NEG,GOTOUPSY  |
| 0452 | BMN     | TEST     | IF HIND SET, GO TO GET LV THE REPEATWAY  |
| 0453 | LODON   | BMN      | IF DIFF NEG, GO TO CONSTD                |
| 0454 | LODON   | DSU      | VCORR = V1 - V1OLD                       |
| 0455 |         | 25NM     |                                          |
| 0456 |         | GOTOUPSY |                                          |
| 0457 |         | HIND     |                                          |
| 0458 |         | GETVCOR  |                                          |
| 0459 |         | DIFF     |                                          |
| 0460 |         | DCONSTD  | SETTING UP DIFFOLD ON THE WAY            |
| 0461 |         | V1       |                                          |
| 0462 |         | V1OLD    | VCORR = V1 - V1OLD                       |
| 0463 | STORE   | VCORR    |                                          |
| 0464 | GETVCOR | DSU      |                                          |
| 0465 |         | DDV      |                                          |
| 0466 |         | BDDV     | VCORR = VCORR(DIFF/(DIFFOLD-DIFF))       |
| 0467 |         | DIFFOLD  |                                          |
| 0468 |         | DIFF     |                                          |
| 0469 |         | VCORR    |                                          |
| 0470 | STORE   | DIFF     |                                          |
| 0471 | EXIT    | 0        |                                          |
| 0472 | TC      | PHASCHNG | HAVE GROUP 3 PICK UP AT PREHUNT.         |
| 0473 | OCT     | 02003    | 3.16 RESTART.                            |
| 0474 | CAF     | ADENEXT  | SIDETRACK NEXT PASS UNTIL THIS ONE DONE. |
| 0475 | TS      | GOTOADDR | ONLY AFTER RESTART IS LEFT AFTER DETOUR. |
| 0476 | TC      | INTPRET  |                                          |
| 0477 | NOLOD   | 2        |                                          |
| 0478 | BDSU    | BPL      | IS VCORR - 1000 POS,                     |
| 0479 | DAD     |          | VCORR = 1000                             |
| 0480 |         | VCORLIM  |                                          |
| 0481 |         | CHKVL    |                                          |
| 0482 |         | VCORR    | LEAVING VCORLIM IN MPAC                  |
| 0483 | STORE   | VCORR    |                                          |

# RE-ENTRY CONTROL

|      |         |        |          |                                           |
|------|---------|--------|----------|-------------------------------------------|
| 0484 | CHKVL   | DAD    | 2        |                                           |
| 0485 |         | DSU    | BMN      | IF VL + V CORR - VSAT POS, V CORR=V CORR/ |
| 0486 |         | LODON  | TSRT     |                                           |
| 0487 |         |        | VCORR    |                                           |
| 0488 |         |        | VL       |                                           |
| 0489 |         |        | HALVE    |                                           |
| 0490 |         |        | GETNUV1  |                                           |
| 0491 |         |        | VCORR    |                                           |
| 0492 |         |        | 1        |                                           |
| 0493 |         | STORE  | VCORR    |                                           |
| 0494 | GETNUV1 | DAD    | 0        |                                           |
| 0495 |         |        | V1       |                                           |
| 0496 |         |        | VCORR    |                                           |
| 0497 |         | STORE  | V1       |                                           |
| 0498 |         | DMOVE  | 0        | SAVE OLD VALUE OF ASP                     |
| 0499 |         |        | DIFF     |                                           |
| 0500 |         | STORE  | DIFFOLD  |                                           |
| 0501 |         | TEST   | 1        | SET HIND AND GO TO HUNTEST1               |
| 0502 |         | SWITCH | ITC      |                                           |
| 0503 |         |        | HIND     |                                           |
| 0504 |         |        | HUNTEST1 |                                           |
| 0505 |         |        | HIND     |                                           |
| 0506 |         |        | HUNTEST1 |                                           |
| 0507 | NEGAMA  | NOLOD  | 1        | ENTER WITH GAMMAL IN MPAC                 |
| 0508 |         | DMP    | DMP      | FIND GAMMAL VL / 3                        |
| 0509 |         |        | VL       |                                           |
| 0510 |         |        | 1/3RD    | .. AND PUSH DOWN PARTIAL RESULT..         |
| 0511 |         | DAD    | 3        |                                           |
| 0512 |         | DMP    | DMP      | DEL VL = GAMMAL VL/3)/(LEWD/3 - DVL(2/3   |
| 0513 |         | DDV    | DDV      | + AHOOKDV)(CH1 GS/DHOOK VL))              |
| 0514 |         | BDSU   | BDDV     |                                           |
| 0515 |         |        | AHOOKDV  |                                           |
| 0516 |         |        | 1/12TH   |                                           |
| 0517 |         |        | DVL      |                                           |
| 0518 |         |        | CH1      |                                           |
| 0519 |         |        | DHOOK    |                                           |
| 0520 |         |        | VL       |                                           |
| 0521 |         |        | LEWD/3   | OUT OF AND BACK INTO PD.                  |
| 0522 |         | DAD    | 0        |                                           |
| 0523 |         |        | VL       |                                           |
| 0524 |         | STORE  | VL       | VL = VL + DEL VL                          |
| 0525 |         | NOLOD  | 3        | VL IS IN MPAC                             |
| 0526 |         | DDV    | BDSU     | Q7 = ((1-VL/FACT1)SQ - ALP)/ FACT2        |
| 0527 |         | DSC    | DSU      |                                           |
| 0528 |         | DDV    |          |                                           |
| 0529 |         |        | FACT1    |                                           |



# RE-ENTRY CONTROL

|       |          |       |          |                                         |
|-------|----------|-------|----------|-----------------------------------------|
| 0530  |          |       | NEARONE  |                                         |
| 0531  |          |       | ALP      |                                         |
| 0532  |          |       | FACT2    |                                         |
| 0533  |          | STORE | Q7       |                                         |
| 05332 |          | DSQ   | 0        | GET NEW VBARS.                          |
| 05334 |          |       | VL       |                                         |
| 05336 |          | STORE | VBARS    |                                         |
| 0534  |          | DMOVE | 0        |                                         |
| 0535  |          |       | 3ZEROS   |                                         |
| 0536  |          | STORE | GAMMAL   | GAMMAL = 0                              |
| 0537  |          | ITC   | 0        |                                         |
| 0538  |          |       | RANGER   |                                         |
| 0539  | UPCADR   | CADR  | UPCONTRL |                                         |
| 0540  | GOTOUPSY | EXIT  | 0        | BACK TO BASIC.                          |
| 0541  | HUNTDUMP | CAF   | UPCADR   | RESET GOTOADDR                          |
| 0542  |          | TS    | GOTOADDR |                                         |
| 0543  |          | TC    | NEWMODE  | CHANGE MODE TO SIGNAL END OF HUNT-TEST. |
| 0544  |          | OCT   | 00065    |                                         |
| 0545  |          | CS    | ONE      | MAKE GROUP 3 INACTIVE WHEN DONE WITH    |
| 0546  |          | TC    | NEWPHASE | THE ITERATIONS.                         |
| 0547  |          | OCT   | 3        | GROUP 3.                                |
| 0548  |          | TC    | INTPRET  | ... AND GO INTO UPCONTROL...            |

# RE-ENTRY CONTROL

P0549 THIS SECTION IS THE UPCONTROL FOR THE SUPERCIRCULAR PHASE

|      |          |       |           |                                          |
|------|----------|-------|-----------|------------------------------------------|
| 0550 | UPCONTRL | DSU   | 3         | IF V-V1 POS, GO TO DOWNCONTROL           |
| 0551 |          | BPL   | LODON     | IF D-Q7 NEG, GO TO KEP                   |
| 0552 |          | DSU   | BMN       |                                          |
| 0553 |          | LODON | BMN       | IF RDOT NEG, GO TO VLTEST                |
| 0554 |          |       | V         | VLTEST TESTS FOR START OF FINAL PHASE    |
| 0555 |          |       | V1        |                                          |
| 0556 |          |       | DOWNCNTRL |                                          |
| 0557 |          |       | D         |                                          |
| 0558 |          |       | Q7        |                                          |
| 0559 |          |       | KEP       | SET CONSTS, ETC FOR BALLISTIC PHASE.     |
| 0560 |          |       | RDOT      |                                          |
| 0561 |          |       | VLTEST    |                                          |
| 0562 | CONT1    | DSU   | 1         |                                          |
| 0563 |          | BPL   |           |                                          |
| 0564 |          |       | D         | IF D-A0 NEG, L/D=LAD, GO TO 310          |
| 0565 |          |       | A0        |                                          |
| 0566 |          |       | GOPOSLAD  |                                          |
| 0567 |          | DMP   | 2         | $VREF = FACT1(1 - \sqrt{FACT2 D + ALP})$ |
| 0568 |          | DAD   | SQRT      |                                          |
| 0569 |          | BDSU  | DMP       |                                          |
| 0570 |          |       | D         |                                          |
| 0571 |          |       | FACT2     |                                          |
| 0572 |          |       | ALP       |                                          |
| 0573 |          |       | NEARONE   |                                          |
| 0574 |          |       | FACT1     |                                          |
| 0575 |          | STORE | VREF      |                                          |
| 0576 |          | NOLOD | 1         | $RDOTREF = LEWD(V1 - VREF)$              |
| 0577 |          | BDSU  | DMP       |                                          |
| 0578 |          |       | V1        |                                          |
| 0579 |          |       | LEWD      |                                          |
| 0580 |          | STORE | RDOTREF   |                                          |
| 0581 |          | DSU   | 1         | IF VSAT - VREF NEG, GO TO CONTINU2       |
| 0582 |          | BMN   | NOLOD     | NOLOD TO PUSH DOWN (HALVE-VREF)          |
| 0583 |          |       | VS        |                                          |
| 0584 |          |       | VREF      | NO RDHOOK UNTIL VREF LESS THAN VSAT.     |
| 0585 |          |       | CONTINU2  | PUSHING DOWN IF NO BRANCH.               |
| 0586 |          | NOLOD | 5         | $RDHOOK = CH1(AHOOKDVL/DVL(DV+1))DV$     |
| 0587 |          | DMP   | DDV       | $/DHOOK VREF$                            |
| 0588 |          | DAD   | DMP       | WHERE $DV = VS - VREF$                   |
| 0589 |          | DMP   | DMP       |                                          |
| 0590 |          | DDV   | DDV       |                                          |
| 0591 |          | BDSU  |           |                                          |
| 0592 |          |       | AHOOKDV   |                                          |
| 0593 |          |       | DVL       |                                          |
| 0594 |          |       | 1/8TH     |                                          |
| 0595 |          |       | CH1       |                                          |
| 0596 |          |       | 0         | ABOVE SHOULD HAVE PUSHED INTO LOC 0.     |
| 0597 |          |       | -         |                                          |
| 0598 |          |       | DHOOK     |                                          |

# RE-ENTRY CONTROL

|        |          |       |          |                                      |
|--------|----------|-------|----------|--------------------------------------|
| 0599   |          |       | VREF     |                                      |
| 0600   |          |       | RDOTREF  |                                      |
| 0601   |          | STORE | RDOTREF  | RDOTREF = RDOTREF - RDHOOK           |
| 0602   | CONTINU2 | DSU   | 0        |                                      |
| 0603   |          |       | A0       | FACTOR = (D-Q7/(A0-Q7)               |
| 0604   |          |       | Q7       | PARTIAL RESULT IN PD                 |
| 0605   |          | DSU   | 1        |                                      |
| 0606   |          | DDV   |          |                                      |
| 0607   |          |       | D        |                                      |
| 0608   |          |       | Q7       | FACTOR INTO PD                       |
| 0610   |          | DSU   | 3        | L/D = LEWD                           |
| 0611   |          | DMP   | DDV      | -((PDOT-RDOTREF)F1/KB1+V-VREF)F1/KB2 |
| 0612   |          | DAD   | DSU      |                                      |
| 0613   |          | DMP   | DDV      |                                      |
| 0614   |          |       | RDOT     |                                      |
| 0615   |          |       | RDOTREF  |                                      |
| 0616   |          |       | 0        |                                      |
| 0617   |          |       | KB1      |                                      |
| 0618   |          |       | V        |                                      |
| 0619   |          |       | VREF     |                                      |
| 0620   |          |       | -        | KB2 IS NEGATIVE                      |
| 0621   |          |       | KB2      | DELTA L/D INT PD                     |
| 0622   |          | BOV   | 3        | NON-LINEAR CIRCUIT FOR REDUCING HIGH |
| 0623   |          | ABS   | DSU      | GAINS HERE                           |
| 0624   |          | BMN   | DMP      |                                      |
| 0625   |          | DAD   | SIGN     |                                      |
| 0626   |          |       | GOMAXL/D |                                      |
| 0627   |          |       | 0        |                                      |
| 0628   |          |       | POINT1   |                                      |
| 0629   |          |       | NEXT1    |                                      |
| 06291  |          |       | POINT1   |                                      |
| 06292  |          |       | POINT1   |                                      |
| 06293  | NEXT1    | DAD   | 1        |                                      |
| 06294  |          | BOV   |          |                                      |
| 06295  |          |       | LEWD     |                                      |
| 06296  |          |       | -        |                                      |
| 06297  |          |       | GOMAXL/D |                                      |
| 06298  |          | STORE | L/D      |                                      |
| 062991 | NEGTESTS | NOLOD | 3        | IF L/D NEG, AND D-C20 POS, L/D = 0   |
| 062992 |          | BPL   | LODON    |                                      |
| 062993 |          | DSU   | BMN      |                                      |
| 062994 |          | DMP   |          |                                      |
| 0630   |          |       | LIMITL/D |                                      |
| 0631   |          |       | D        |                                      |
| 0632   |          |       | C20      |                                      |
| 0633   |          |       | LIMITL/D |                                      |
| 0635   |          |       | 3ZEROS   | L/D = 0 (NO NEG LIFT)                |
| 0636   |          | STORE | L/D      |                                      |
| 0637   |          | ITC   | 0        |                                      |
| 0638   |          |       | LIMITL/D |                                      |

# RE-ENTRY CONTROL

|       |          |       |                          |                                       |
|-------|----------|-------|--------------------------|---------------------------------------|
| P0639 |          |       | CONSTANT DRAG CONTROLLER |                                       |
| 0640  | DCONSTD  | DMOVE | 0                        |                                       |
| 0641  |          |       | DIFF                     | SAVE OLD VALUE OF DIFF FOR NEXT PASS. |
| 0642  |          | STORE | DIFFOLD                  |                                       |
| 0643  |          | DMOVE | 0                        |                                       |
| 0644  |          |       | V1                       | V1OLD = V1                            |
| 0645  |          | STORE | V1OLD                    |                                       |
| 0646  | BECONSTD | AXT+1 | 1                        |                                       |
| 0647  |          | SXA+1 |                          | RESETS GOTOADDR TO GO TO HUNTEST      |
| 0648  |          |       | HUNTEST                  |                                       |
| 0649  |          |       | GOTOADDR                 |                                       |
| 0650  | CONSTD   | DMP   | 0                        |                                       |
| 0651  |          |       | LEQ                      |                                       |
| 0652  |          |       | C/D0                     | C/D0 LEQ INTO PD                      |
| 0653  |          | DMP   | 2                        |                                       |
| 0654  |          | DDV   | DAD                      |                                       |
| 0655  |          | DMP   | DAD                      |                                       |
| 0656  |          |       | 2HS                      | RDOTREF = - 2 HS D0/V                 |
| 0657  |          |       | D0                       |                                       |
| 0658  |          |       | V                        |                                       |
| 0659  |          |       | RDOT                     |                                       |
| 0660  |          |       | K2D                      | C/D0 LEQ + K2D(RDOT-RDOTREF) INTO PD  |
| 0661  |          | DMOVE | 0                        |                                       |
| 0662  |          |       | D0                       | D0 INTO PD                            |
| 0663  | CONSTD1  | DSU   | 2                        |                                       |
| 0664  |          | DMP   | DAD                      |                                       |
| 0665  |          | TSLT  | BOV                      |                                       |
| 0666  |          |       | D                        |                                       |
| 0667  |          |       | -                        |                                       |
| 0668  |          |       | K1D                      |                                       |
| 0669  |          |       | -                        |                                       |
| 0670  |          |       | 8D                       |                                       |
| 0671  |          |       | GOMAXL/D                 |                                       |
| 0672  |          | STORE | L/D                      |                                       |
| 0673  |          | ITC   | 0                        |                                       |
| 0674  |          |       | NEGTESTS                 |                                       |
| 0675  | DOWNCNL  | DSU   | 2                        | RDTR = LAD(V1-V)                      |
| 0676  |          | DMP   | DAD                      |                                       |
| 0677  |          | DMP   | DAD                      |                                       |
| 0678  |          |       | V                        |                                       |
| 0679  |          |       | V1                       |                                       |
| 0680  |          |       | LAD                      |                                       |
| 0681  |          |       | RDOT                     |                                       |
| 0682  |          |       | K2D                      |                                       |
| 0683  |          |       | LAD/256                  | LAD + K2D(RDOT-RDTR) INTO PD          |
| 0684  |          | DSU   | 1                        |                                       |



# RE-ENTRY CONTROL

|       |          |        |          |                                        |
|-------|----------|--------|----------|----------------------------------------|
| 0685  |          | DSQ    | DDV      |                                        |
| 0686  |          |        | V1       |                                        |
| 0687  |          |        | V        |                                        |
| 0688  |          |        | 2C1HSLAD | (V1-V)SQ/(2 C1 HS/LAD) INTO PD         |
| 0689  |          | DSQ    | 2        |                                        |
| 0690  |          | DDV    | BDDV     | DREF = (V/V1)SQ AD - PD                |
| 0691  |          | DSU    |          |                                        |
| 0692  |          |        | V1       |                                        |
| 0693  |          |        | VSQUARE  |                                        |
| 0694  |          |        | A0       |                                        |
| 0695  |          | ITC    | 0        |                                        |
| 06951 |          |        | CONSTD1  |                                        |
| 0696  | KEP      | EXIT   | 0        |                                        |
| 0697  |          | CAF    | KEPCADR  | SET GOTOADDR TO KEPLER PHASE.          |
| 0698  |          | TS     | GOTOADDR |                                        |
| 0699  |          | TC     | NEWMODE  | SET MODE TO KEPLER PHASE.              |
| 0700  |          | OCT    | 00066    |                                        |
| 0701  |          | TC     | INTPRET  |                                        |
| 0702  | KEP2     | DAD    | 1        | IF Q7+KDMIN - D NEG, GO TO FINAL PHASE |
| 0703  |          | DSU    | BMN      |                                        |
| 0704  |          |        | Q7       | MIN DRAG = Q7 + .5 FT/SEC/SEC          |
| 0705  |          |        | KDMIN    |                                        |
| 0706  |          |        | D        |                                        |
| 0707  |          |        | PREFINAL | FALL THRU IF POS.                      |
| 0708  | ENDEXIT  | EXIT   | 0        | GOTOADDR IS SET HERE DURING VLHUNT.    |
| 0709  |          | TC     | OVERNOUT |                                        |
| 0710  | KEPCADR  | CADR   | KEP2     |                                        |
| 0711  | P3CADR   | CADR   | PREDICT3 |                                        |
| 0712  | VLTEST   | DSU    | 1        | IF V-VL-C18 NEG,EGSW=1,SELECTOR=PREDIC |
| 0713  |          | DSU    | BPL      | GO TO PREDICT3                         |
| 0714  |          |        | V        |                                        |
| 0715  |          |        | VL       |                                        |
| 0716  |          |        | C18      |                                        |
| 0717  |          |        | CONT1    |                                        |
| 0718  | PREFINAL | SWITCH | 1        |                                        |
| 0719  |          | EXIT   |          |                                        |
| 0720  |          |        | EGSW     |                                        |
| 0721  |          | CAF    | P3CADR   |                                        |
| 0722  |          | TS     | GOTOADDR | SET TO PREDICT3 PHASE.                 |
| 0723  |          | TC     | NEWMODE  |                                        |
| 0724  |          | OCT    | 00067    |                                        |
| 0725  |          | TC     | INTPRET  | ... AND FALL INTO PREDICT3...          |

# RE-ENTRY CONTROL

P0726 SUBORBITAL CONTROL (REFERENCE TRAJECTORY BY TABLE LOOK-UP.)

|      |          |        |            |                                         |
|------|----------|--------|------------|-----------------------------------------|
| 0727 | PREDICT3 | DSU    | 4          |                                         |
| 0728 |          | BMN    | LODON      | IF V - VQUIT NEG, STOP STEERING         |
| 0729 |          | TEST   |            |                                         |
| 0730 |          | VXV    | DOT        | IF (RT)*UNITR.UNI NEG, SET GONEPAST     |
| 0731 |          | BMN    | EXIT       |                                         |
| 0732 |          |        | V          |                                         |
| 0733 |          |        | VQUIT      |                                         |
| 0734 |          |        | STEER      |                                         |
| 0735 |          |        | GONEPAST   |                                         |
| 0736 |          |        | GONEGLAD   |                                         |
| 0737 |          |        | RT         |                                         |
| 0738 |          |        | UNITR      |                                         |
| 0739 |          |        | UNI        | (MIGHT SAVE THIS FROM EARLIER..         |
| 0740 |          |        | SETGPAST   |                                         |
| 0741 |          | CS     | NEG14      |                                         |
| 0742 | BACK     | TS     | JJ         |                                         |
| 0743 |          | CS     | V          |                                         |
| 0744 |          | INDEX  | JJ         |                                         |
| 0745 |          | AD     | VREFER     | VREF - V, HIGHEST VREF AT END OF TABLE. |
| 0746 |          | CCS    | A          | IF VREF-V POS LOOP BACK                 |
| 0747 |          | CCS    | JJ         | DECREMENT JJ, JJ CANNOT BE ZERO         |
| 0748 |          | TC     | BACK       |                                         |
| 0749 |          | AD     | ONE        |                                         |
| 0750 |          | TS     | TEM1B      | V-VREF IN TEM1B (MUST BE POSITIVE NUM)  |
| 0751 |          | INDEX  | JJ         |                                         |
| 0752 |          | CS     | VREFER     |                                         |
| 0753 |          | INDEX  | JJ         |                                         |
| 0754 |          | AD     | VREFER + 1 | $V(K+1) - V(K)$ (POS NUM)               |
| 0755 |          | XCH    | TEM1B      |                                         |
| 0756 |          | EXTEND |            |                                         |
| 0757 |          | DV     | TEM1B      |                                         |
| 0758 |          | TS     | GRAD       | $GRAD = (V-VREF)/(VK+1 - VK)$ (POS NUM) |
| 0759 |          | CAF    | FIVE       |                                         |
| 0760 | BACK2    | TS     | M1         |                                         |
| 0761 |          | CAF    | DEC15      |                                         |
| 0762 |          | AD     | JJ         |                                         |
| 0763 |          | TS     | JJ         |                                         |
| 0764 |          | INDEX  | A          |                                         |
| 0765 |          | CS     | VREFER     |                                         |
| 0766 |          | INDEX  | JJ         |                                         |
| 0767 |          | AD     | VREFER + 1 | $X(K+1) - X(K)$                         |
| 0768 |          | EXTEND |            |                                         |
| 0769 |          | MP     | GRAD       |                                         |
| 0770 |          | INDEX  | JJ         |                                         |
| 0771 |          | AD     | VREFER     |                                         |
| 0772 |          | INDEX  | M1         |                                         |
| 0773 |          | TS     | FX         | $FX = AK + GRAD (AK+1 - AK)$            |
| 0774 |          | CCS    | M1         |                                         |

# RE-ENTRY CONTROL

|      |           |          |                               |
|------|-----------|----------|-------------------------------|
| 0775 | TC        | BACK2    |                               |
| 0776 | CAF       | ZERO     | ZERO FX + 1                   |
| 0777 | XCH       | FX + 1   | DREFR                         |
| 0778 | AD        | D        |                               |
| 0779 | EXTEND    |          |                               |
| 0780 | MP        | FX + 5   | F1                            |
| 0781 | TS        | TEM1B    | TEM1B= F1(D-DREF)             |
| 0782 | CS        | RDOT     | FORM RDOTREF - RDOT           |
| 0783 | DOUBLE    |          |                               |
| 0784 | DOUBLE    |          | SCALE UP BY 8 FOR THIS PHASE. |
| 0785 | DOUBLE    |          |                               |
| 0786 | AD        | FX + 3   | RDOTREF                       |
| 0787 | EXTEND    |          |                               |
| 0788 | MP        | FX + 4   | F2                            |
| 0789 | AD        | TEM1B    | ADD F2(DADV1-DADVR)           |
| 0790 | AD        | FX + 2   | RTOGO                         |
| 0791 | XCH       | PREDANG  | NO OVERFLOW SKIP PLEASE.      |
| 0792 | TC        | INTPRET  |                               |
| 0793 | SMOVE     | 4        |                               |
| 0794 | TSRT      | BDSU     | THETAH - PRED ANGLE           |
| 0795 | DDV       | TSLT     |                               |
| 0796 | BOV       | DAD      | L/D = LOD + (THET-PA)/Y       |
| 0797 | BOV       |          |                               |
| 0798 |           | PREDANG  |                               |
| 0799 |           | 3        |                               |
| 0800 |           | THETAH   |                               |
| 0801 |           | FX       | FX = DRANGE/D L/D = Y         |
| 0802 |           | 5        |                               |
| 0803 |           | GOMAXL/D |                               |
| 0804 |           | LOD      |                               |
| 0805 |           | GOMAXL/D |                               |
| 0806 | STORE     | L/D      |                               |
| 0807 | ITC       | 0        |                               |
| 0808 |           | GLIMITER |                               |
| 0809 | GOPOS LAD | DMOVE 0  |                               |
| 0810 |           | LAD      |                               |
| 0811 | STORE     | L/D      |                               |
| 0812 | ITC       | 0        |                               |
| 0813 |           | LIMITL/D |                               |
| 0814 | SETGPAST  | SWITCH 0 | SHOULD BE BY TARGET IF HERE.  |
| 0815 |           | GONEPAST |                               |
| 0816 | GONEGLAD  | COMP 0   |                               |
| 0817 |           | LAD      | L/D = - LAD                   |
| 0818 | STORE     | L/D      |                               |
| 0819 | ITC       | 0        |                               |
| 0820 |           | GLIMITER |                               |

# RL-ENTRY CONTROL

```

0821 GOMAXL/D RTB 1
0822 DMP
0823 SIGNMPAC
0824 LAD
0825 STORE L/D

0826 GLIMITER DSU 2
0827 BPL DAD
0828 BMN DMP
0829 GMAX/2
0830 D
0831 LIMITL/D
0832 GMAX/2
0833 GOPOSLAD
0834 ZHS

0835 DMP 1
0836 DAD DMP
0837 LEQ
0838 1/GMAX
0839 LAD

0840 DDV 3
0841 DAD SQRT
0842 DAD BMN
0843 ROUND
0845 VSQUARE
0846 -
0848 GOPOSLAD

```

L/D = LAD SIG(MPAC)

AND FALLS INTO LIMITL/D SECTION.

IF GMAX/2-D POS, GO TO LIMITL/D  
IF GMAX-D NEG, GO TO GOPOSLAD

2HS(GMAX-D) INTO PD

2HS(GMAX-D) (LEQ/GMAX+LAD) INTO PD

XLIM = SQRT(PD+(2HSGMAX/V)SQ)  
IF RDOT+XLIM NEG, L/D=LAD  
L/D = (RDOT+XLIM+KGLIM1 LEQ)/(KGLIM2 D



# RE-ENTRY CONTROL

P0859 COMES HERE TO COMPUTE ROLL COMMAND, CHECK LATERAL ERRORS, AND STEER

|      |          |       |          |                                          |
|------|----------|-------|----------|------------------------------------------|
| 0860 | LIMITL/D | TEST  | 1        | NO LATERAL CONTROL IF PAST TARGET        |
| 0861 |          | DMP   | DAD      | $Y = KLAT \cdot VSQUARE + LATBIAS$       |
| 0862 |          |       | GONEPAST |                                          |
| 0863 |          |       | L355     |                                          |
| 0864 |          |       | VSQUARE  |                                          |
| 0865 |          |       | KLAT     |                                          |
| 0866 |          |       | LATBIAS  |                                          |
| 0867 |          | STORE | Y        |                                          |
| 0868 | L350     | ABS   | 4        | IF $ABS(L/D) - L/DCMINR$ NEG, GO TO L353 |
| 0869 |          | DSU   | BMN      |                                          |
| 0870 |          | LODON | SIGN     | IF K2ROLL LATANG NEG, GO TO L357         |
| 0871 |          | BMN   | LODON    |                                          |
| 0872 |          | TSRT  |          | $Y = Y/2$                                |
| 0873 |          |       | L/D      |                                          |
| 0874 |          |       | L/DCMINR |                                          |
| 0875 |          |       | L353     |                                          |
| 0876 |          |       | LATANG   |                                          |
| 0877 |          |       | K2ROLL   |                                          |
| 0878 |          |       | L357     |                                          |
| 0879 |          |       | Y        |                                          |
| 0880 |          |       | 1        |                                          |
| 0881 |          | STORE | Y        |                                          |
| 0882 | L353     | SIGN  | 2        | IF LATANG SIGN(K2ROLL) - Y POS, SWITCH   |
| 0883 |          | DSU   | BMN      |                                          |
| 0884 |          | RTB   |          |                                          |
| 0885 |          |       | LATANG   |                                          |
| 0886 |          |       | K2ROLL   |                                          |
| 0887 |          |       | Y        |                                          |
| 0888 |          |       | L355     |                                          |
| 0891 |          |       | BL361    |                                          |
| 0892 | L355     | DDV   | 2        | $ROLLC = ACOS((L/D)/LAD)$                |
| 0893 |          | TSRT  | ACOS     |                                          |
| 0894 |          | SIGN  |          | $ROLLC = ROLLC \cdot SIGN(K2ROLL)$       |
| 0895 |          |       | L/D      |                                          |
| 0896 |          |       | LAD      |                                          |
| 0897 |          |       | 1        |                                          |
| 0898 |          |       | K2ROLL   |                                          |
| 0899 |          | STORE | ROLLC    |                                          |

# RE-ENTRY CONTROL

|      |          |        |          |                                          |
|------|----------|--------|----------|------------------------------------------|
| 0900 | STEER    | EXIT   | 0        |                                          |
| 0904 | STEER2   | CS     | ROLLC    | SCALE ROLL OUTPUT FOR 16 SPEED.          |
| 0905 |          | EXTEND |          |                                          |
| 0906 |          | MP     | NEG1/8   | ROLL = ROLLC/8 + K1ROLL                  |
| 0907 |          | AD     | K1ROLL   |                                          |
| 0908 |          | TS     | MPAC     | AFRAID TO STORE POSS BAD NUM IN THETAD   |
| 0909 |          | TC     | +4       | SKIPS ON OVERFLOW                        |
| 0910 |          | INDEX  | A        |                                          |
| 0911 |          | CAF    | LIMITS   | ALLOW OVERFLOW (GO TO NEGMAX FROM POSMX) |
| 0912 |          | AD     | MPAC     |                                          |
| 0913 |          | INHINT |          |                                          |
| 0914 |          | TS     | THETAD   | THETAD = X CDU = ROLL                    |
| 0915 |          | CS     | BIT3     |                                          |
| 0916 |          | MASK   | TMMARKER |                                          |
| 0917 |          | AD     | BIT3     | SET BIT 3 IN TMMARKER WHEN THETAD COMP   |
| 0918 |          | TS     | TMMARKER |                                          |
| 0919 | OVERNOUT | TC     | PHASCHNG | RECYCLE GROUP 5 TO PIPUP WAIT STATE.     |
| 0920 |          | OCT    | 01405    | 5.12 RESTART. (PIPUP SYNCED WITH 2 SEC)  |
| 0921 |          | TC     | ENDOFJOB |                                          |
| 0922 | BL361    | CS     | K2ROLL   | K2ROLL = - K2ROLL                        |
| 0923 |          | TS     | K2ROLL   |                                          |
| 0924 |          | CCS    | L/D      | IF L/D POS, EXIT                         |
| 0925 |          | TC     | RE-ENTER | SO IT WONT STORE IN PUSH LIST.           |
| 0926 |          | TC     | RE-ENTER |                                          |
| 0927 |          | TC     | +2       |                                          |
| 0928 |          | TC     | RE-ENTER |                                          |
| 0929 |          | CCS    | K2ROLL   | K1ROLL = K1ROLL + K3ROLL SIGN(K2ROLL)    |
| 0930 |          | CAF    | K3ROLL   | K3ROLL = - .125                          |
| 0931 |          | TC     | +2       |                                          |
| 0932 |          | CS     | K3ROLL   |                                          |
| 0933 |          | AD     | K1ROLL   |                                          |
| 0934 |          | TS     | K1ROLL   |                                          |
| 0935 |          | TC     | RE-ENTER | SKIPS THIS ON OVERFLOW.                  |
| 0936 |          | INDEX  | A        | POSMAX + 1 = NEGMAX ETC.                 |
| 0937 |          | CAF    | LIMITS   | NO LIMIT ON NUMBER OF ROLL REVS DURING   |
| 0938 |          | AD     | K1ROLL   | ENTRY. (ROUTINE IS GENERAL.)             |
| 0939 |          | TS     | K1ROLL   | STILL DOESNT WORRY ABOUT 2SCOMP, THO.    |
| 0940 |          | TC     | RE-ENTER |                                          |
| 0941 | L357     | SIGN   | 0        |                                          |
| 0942 |          |        | L/DCMINR | L/D = L/DCMINR SIGN(L/D)                 |
| 0943 |          |        | L/D      |                                          |
| 0944 |          | STORE  | L/D      |                                          |
| 0945 |          | ITC    | 0        |                                          |
| 0946 |          |        | L355     |                                          |
| 0947 | ENDSTR   | EQUALS |          |                                          |

# RE-ENTRY CONTROL

P0951 ROUTINE TO PREDICT AND SET PITCH ANGLE FOR 2ND ENTRY CONDITIONS.

|       |          |        |            |                                       |
|-------|----------|--------|------------|---------------------------------------|
| 09515 |          | SETLOC | PFS25/1    | IN BANK 25 TO MAKE ROOM IN BANK 27    |
| 0952  | UPTHETA3 | CAF    | PRI014     |                                       |
| 0953  |          | TC     | FINDVAC    |                                       |
| 0954  |          | CADR   | UPTHETA1   |                                       |
| 0955  |          | TC     | TASKOVER   |                                       |
| 0956  | UPTHETA1 | TC     | INTPRET    | STARTS OFF IN BASIC                   |
| 0957  | UPTHETA  | ITC    | 0          | FIND DESIRED SPACECRAFT ORIENTATION.  |
| 0958  |          |        | GETUNB     |                                       |
| 0959  |          | ITC    | 0          | GET OGC, IGC, MGC, GIMBAL COMMANDS    |
| 0960  |          |        | CALCGTA    |                                       |
| 0961  |          | EXIT   | 0          |                                       |
| 0962  |          | CS     | IGC        |                                       |
| 0963  |          | COM    |            |                                       |
| 0964  |          | DOUBLE |            |                                       |
| 0965  |          | TS     | THETAD + 1 | COMMAND PITCH ANGLE                   |
| 0966  |          | CS     | MGC        |                                       |
| 0967  |          | COM    |            |                                       |
| 0968  |          | DOUBLE |            | CHANGE FORM INTERP SCALING TO CDU.    |
| 0969  |          | TS     | THETAD + 2 | COMMAND YAW ANGLE                     |
| 0970  |          | INHINT |            |                                       |
| 0971  |          | CAF    | PITCHDT    | CALL UP ATTITUDE CONTROL LOOP PITCHDT |
| 0972  |          | TC     | WAITLIST   | SECONDS AFTER FINISHING THIS TIME.    |
| 0973  |          | CADR   | UPTHETA3   |                                       |
| 0974  | UPNOVER  | TC     | ENDOFJOB   |                                       |
| 09745 | PITCHDT  | DEC    | 200        |                                       |
| 09747 | IPIPDT1  | DEC    | 50         |                                       |

# RE-ENTRY CONTROL

P0975 PIPAS ARE READ (BUT NOT CLEARED) AT A HIGHER RATE HERE.

|      |          |       |          |
|------|----------|-------|----------|
| 0976 | INTERPIP | CS    | PIPA     |
| 0977 |          | INDEX | PIPCTR   |
| 0978 |          | TS    | XPIBUE   |
| 0979 |          | CS    | PIPA     |
| 0980 |          | INDEX | PIPCTR   |
| 0981 |          | TS    | YPIBUE   |
| 0982 |          | CS    | PIPA     |
| 0983 |          | INDEX | PIPCTR   |
| 0984 |          | TS    | ZPIBUE   |
| 0985 |          | CCS   | PIPCTR   |
| 0986 |          | TC    | +4       |
| 0987 |          | CAF   | TWO      |
| 0988 |          | TS    | PIPCTR   |
| 0989 |          | TC    | TASKOVER |
| 0990 |          | TS    | PIPCTR   |
| 0991 |          | CAF   | IPIPT1   |
| 0992 |          | TC    | WAITLIST |
| 0993 |          | CADR  | INTERPIP |
| 0994 |          | TC    | TASKOVER |

0996 ENDUPTHT EQUALS



# RL-ENTRY CONTROL

P1000 DETERMINE TIME TO OPEN CHUTE HERE IF NEEDED

|       |       |        |        |               |
|-------|-------|--------|--------|---------------|
| 10015 |       | SETLOC | ENDSTR |               |
| 1002  | DT    | DEC    | 200    | MAIN LOOP DT. |
| 1003  | DEC15 | DEC    | 15     |               |

|      |          |      |         |
|------|----------|------|---------|
| 1004 | K3ROLL   | DEC  | -.125   |
| 1005 | ADENDEXT | CADR | ENDEXIT |

R1006 DEFINED BY EQUALS

|      |         |        |         |                       |
|------|---------|--------|---------|-----------------------|
| 1007 | HIND    | EQUALS | HIND2SW | HUNT INDICATOR SWITCH |
| 1008 | ASP     | EQUALS | 0       |                       |
| 1009 | Y       | EQUALS | 20D     | TEMP                  |
| 1010 | GAMMAL1 | EQUALS | 22D     |                       |

# RE-ENTRY CONTROL

P1011      TABLE USED FOR SUB-ORBITAL REFERENCE TRAJECTORY CONTROL.

|      |        |     |            |                                         |
|------|--------|-----|------------|-----------------------------------------|
| 1012 | VREFER | DEC | 0          | REFERENCE VELOCITY SCALED V/51552.3946  |
| 1013 |        | DEC | .006539    | 15 POINTS ARE STORED AS THE INDEPENDENT |
| 1014 |        | DEC | .020958    | VARIABLE AND THEN SIX 15 POINT FUNC-    |
| 1015 |        | DEC | .040809    | TIONS OF V ARE STORED CONSECUTIVELY     |
| 1016 |        | DEC | .076107    |                                         |
| 1017 |        | DEC | .122156    |                                         |
| 1018 |        | DEC | .165546    |                                         |
| 1019 |        | DEC | .196012    |                                         |
| 1020 |        | DEC | .271945    |                                         |
| 1021 |        | DEC | .309533    |                                         |
| 1022 |        | DEC | .356222    |                                         |
| 1023 |        | DEC | .404192    |                                         |
| 1024 |        | DEC | .448067    |                                         |
| 1025 |        | DEC | .456023    |                                         |
| 1026 |        | DEC | .67918     | HIGH VELOCITY FOR SAFETY                |
| 1027 |        | DEC | -.008035   | DRANGE/DA      SCALED DRDA/(2700/805)   |
| 1028 |        | DEC | -.008035   |                                         |
| 1029 |        | DEC | -.010820   |                                         |
| 1030 |        | DEC | -.016550   |                                         |
| 1031 |        | DEC | -.026935   |                                         |
| 1032 |        | DEC | -.042039   |                                         |
| 1033 |        | DEC | -.058974   |                                         |
| 1034 |        | DEC | -.070721   |                                         |
| 1035 |        | DEC | -.098538   |                                         |
| 1036 |        | DEC | -.107482   |                                         |
| 1037 |        | DEC | -.147762   |                                         |
| 1038 |        | DEC | -.193289   |                                         |
| 1039 |        | DEC | -.602557   |                                         |
| 1040 |        | DEC | -.99999    |                                         |
| 1041 |        | DEC | -.99999    |                                         |
| 1042 |        | DEC | 0          | -DRANGE/DRDOT                           |
| 1043 |        | DEC | 0          | SCALED((2VS/8 2700) DR/DRDOT)           |
| 1044 |        | DEC | -.0494520  | B-3                                     |
| 1045 |        | DEC | -.0683663  | B-3                                     |
| 1046 |        | DEC | -.1343468  | B-3                                     |
| 1047 |        | DEC | -.2759846  | B-3                                     |
| 1048 |        | DEC | -.4731437  | B-3                                     |
| 1049 |        | DEC | -.6472087  | B-3                                     |
| 1050 |        | DEC | -1.171693  | B-3                                     |
| 1051 |        | DEC | -1.466382  | B-3                                     |
| 1052 |        | DEC | -1.905171  | B-3                                     |
| 1053 |        | DEC | -2.547990  | B-3                                     |
| 1054 |        | DEC | -4.151220  | B-3                                     |
| 1055 |        | DEC | -5.813617  | B-3                                     |
| 1056 |        | DEC | -5.813617  | B-3                                     |
| 1057 |        | DEC | -.00642065 | B3      RDOTREF      SCALED (8 RDT/2VS) |
| 1058 |        | DEC | -.00642065 | B3                                      |
| 1059 |        | DEC | -.0134426  | B3                                      |

# RE-ENTRY CONTROL

|      |     |            |    |
|------|-----|------------|----|
| 1060 | DEC | -.013947   | B3 |
| 1061 | DEC | -.013462   | B3 |
| 1062 | DEC | -.011813   | B3 |
| 1063 | DEC | -.0095631  | B3 |
| 1064 | DEC | -.00806946 | B3 |
| 1065 | DEC | -.006828   | B3 |
| 1066 | DEC | -.00806946 | B3 |
| 1067 | DEC | -.0109791  | B3 |
| 1068 | DEC | -.0151496  | B3 |
| 1069 | DEC | -.0179817  | B3 |
| 1070 | DEC | -.0159061  | B3 |
| 1071 | DEC | -.0159061  | B3 |

|      |     |          |
|------|-----|----------|
| 1072 | DEC | 0        |
| 1073 | DEC | 0        |
| 1074 | DEC | .00100   |
| 1075 | DEC | .0032963 |
| 1076 | DEC | .0081852 |
| 1077 | DEC | .017148  |
| 1078 | DEC | .027926  |
| 1079 | DEC | .037     |
| 1080 | DEC | .063296  |
| 1081 | DEC | .077889  |
| 1082 | DEC | .098815  |
| 1083 | DEC | .127519  |
| 1084 | DEC | .186963  |
| 1085 | DEC | .238148  |
| 1086 | DEC | .238148  |

RANGE TO GO SCALED RTOGO/2700

2.7 NM  
8.9  
22.1

|      |     |          |
|------|-----|----------|
| 1087 | DEC | -.042360 |
| 1088 | DEC | -.042360 |
| 1089 | DEC | -.052919 |
| 1090 | DEC | -.074534 |
| 1091 | DEC | -.101242 |
| 1092 | DEC | -.116646 |
| 1093 | DEC | -.122360 |
| 1094 | DEC | -.127081 |
| 1095 | DEC | -.147453 |
| 1096 | DEC | -.155528 |
| 1097 | DEC | -.149565 |
| 1098 | DEC | -.118509 |
| 1099 | DEC | -.034907 |
| 1100 | DEC | -.007950 |
| 1101 | DEC | -.007950 |

-AREF SCALED AREF/805

|      |     |         |
|------|-----|---------|
| 1102 | DEC | .000371 |
| 1103 | DEC | .000371 |
| 1104 | DEC | .004770 |
| 1105 | DEC | .008081 |
| 1106 | DEC | .016030 |
| 1107 | DEC | .035815 |
| 1108 | DEC | .069422 |
| 1109 | DEC | .104519 |
| 1110 | DEC | .122    |
| 1111 | DEC | .172407 |

DRANGE/D L/D SCALED Y/2700

RE-ENTRY CONTROL

|      |     |         |
|------|-----|---------|
| 1112 | DEC | •252852 |
| 1113 | DEC | •363148 |
| 1114 | DEC | •512963 |
| 1115 | DEC | •558519 |
| 1116 | DEC | •558519 |

END OF STORED REFERENCE

1117    ENDREENS EQUALS



# RE-ENTRY CONTROL

P1118 CONTINUATION OF RE-ENTRY SECTION IN 2ND BANK. (CONSTANTS AND M923=8

1119 SETLOC BOOKMRK1

1120 NEARONE 2DEC .999999999  
1121 1/3RD 2DEC .333333333 ONE THIRD  
1122 1/12TH 2DEC .083333333 ONE TWELFTH

R1123 VSAT = 25766.1973 FT/SEC.

R1124 RE = 21,202,900 FEET

|       |          |        |                     |                                         |
|-------|----------|--------|---------------------|-----------------------------------------|
| 1125  | LEWD     | 2DEC   | .1                  |                                         |
| 1126  | LEWD/3   | 2DEC   | .033333333          | LEWD/3 (LEWD = .1)                      |
| 1127  | FOURTH   | 2DEC   | .25                 |                                         |
| 1128  | 3ZEROS   | 2DEC   | 0                   |                                         |
| 1129  | 1BITDP   | 2OCT   | 00000 00001         | DOUBLE PREC 1 BIT                       |
| 1130  |          | DEC    | 0                   |                                         |
| 1131  | NEAR1/4  | 2OCT   | 07777 00000         | 1/4 LESS 1 BIT IN UPPER PART.           |
| 1132  | C18      | 2DEC   | .0097026346         | 500/2VS                                 |
| 1133  | KDMIN    | 2DEC   | .00062111801        | .5/805                                  |
| 1134  | C1/16    | 2DEC   | .0625               | 1/16                                    |
| 1135  | 2HSD/LWD | 2DEC   | .16278661           | 2(1.0) 28500 805/ .1 (2VS) SQ           |
| 1136  | Q2       | 2DEC   | -.046388889         | -1002/21600 = (643/21600-Q2(23500/2VS)) |
| 1137  | Q3       | 2DEC   | .167003132          | .07 2VS/21600                           |
| 1138  | Q5       | 2DEC   | .326388889          | .3 23500/21600                          |
| 1139  | Q6       | 2DEC   | .034893617          | 820/23500                               |
| 1140  | Q7F      | 2DEC   | .0074534161         | 6/805 (VALUE OF Q7 IN FIXED MEM.)       |
| 1141  | VMIN     | 2DEC   | .34929485           | 18000/2VS                               |
| 1142  | C12      | 2DEC   | .00684572901        | 32 28500/(21102900 2 PI)                |
| 1143  | GS       | 2DEC   | -.16                |                                         |
| 1144  | KB1      | 2DEC   | .29411765           | 1/3.4                                   |
| 1145  | KB2      | 2DEC   | -.0057074322        | -1/(.0034 2 VS)                         |
| 1146  | C19      | 2DEC   | .16149068           | 130/805                                 |
| 1147  | VCORLIM  | 2DEC   | .019405269          | 1000/2VS                                |
| 1148  | VQUIT    | EQUALS | VCORLIM             | BOTH ARE 1000 FT/SEC                    |
| 1149  | KAFIX    | 2DEC   | .08                 | 64.4/805 (2 G-5)                        |
| 1150  | C20      | 2DEC   | .21739130           | (175 FPSS) LIFT UP IF ABOVE C20         |
| 11505 | DOMAX    | EQUALS | C20                 |                                         |
| 1151  | 25NM     | 2DEC   | .0011574074 B-4     | 25/(21600 16) (25 NAUT MILES)           |
| 1152  | K1D      | 2DEC   | .0314453125         | .01 805/256                             |
| 11525 | K2D      | 2DEC   | -.201298418         | -.001 2VS/256                           |
| 1153  | KVSCALE  | 2DEC   | .81491944           | 12800/(2 VS .3048)                      |
| 1154  | KASCALE  | 2DEC   | .97657358           | 5.85 16384/(4 .3048 100 805)            |
| 1155  | KTETA    | 2DEC*  | .383495203 E2 B-14* | 1000 2PI/16384(163.84)                  |
| 1156  | KI       | 2DEC*  | .157788327 E2 B-14* | RE(2PI)/2VS(16384)163.84                |
| 1157  | .05G     | 2DEC   | .002                | .05/25                                  |
| 1158  | LAD      | 2DEC   | .3                  |                                         |
| 1159  | LAD/256  | 2DEC   | .001171875          | .3/256                                  |
| 1160  | KLAT     | 2DEC   | .0125               |                                         |
| 1161  | LATBIAS  | 2DEC   | .00003              | APPRX .5 NM/ 4(21600/2 PI)              |
| 1162  | KWE      | 2DEC   | .120056652          |                                         |
| 1163  | KACOS    | 2DEC   | .004973592          | 1/32(2PI)                               |

# RE-ENTRY CONTROL

|       |                                  |        |               |                                        |
|-------|----------------------------------|--------|---------------|----------------------------------------|
| 1164  | LAD/KC1                          | 2DEC   | .375          | LAD/KC1 = .3/.8                        |
| 1165  | OKC2                             | 2DEC   | .0074051405   | 2HS LAD(32.2)25/KC2(2VS)SQ (KC2=.7)    |
| 1166  | CHOOK                            | 2DEC   | 1 B-5         | .25/8                                  |
| 1167  | 1/8TH                            | 2DEC   | .125          |                                        |
| 1168  | CH1                              | 2DEC   | .24           | 8 CH1/ 25 (CH1 = .75)                  |
| 1169  | KC3                              | 2DEC   | -.082540747   | KC3 (2VS)SQ /2PI 25 32.2 LAD R         |
| 1170  | LOD                              | 2DEC   | .18           |                                        |
| 1171  | VRCONT                           | 2DEC   | .0135836886   | 700/2 VSAT                             |
| 1172  | HALVE                            | 2DEC   | .5            |                                        |
| 1173  | NEG1/8                           | EQUALS | K3ROLL        | ONLY A SINGLE PRECISION NUMBER.        |
| 1174  | L/DCMINR                         | 2DEC   | .2895         | LAD COS(15 DEG)                        |
| 1175  | C001                             | 2DEC   | -.000625      | -(4/25) / 256 (LEQ/DO CONST)           |
| 1178  | GMAX/2                           | 2DEC   | .2            | 5/25                                   |
| 1179  | 1/GMAX                           | 2DEC   | .4            |                                        |
| 1180  | 2HS                              | 2DEC   | .0172786611   | 2 28500 25 32.2/(4 VS VS)              |
| 1181  | 2HSGMXSQ                         | 2DEC   | .000047768341 | ((2 28500 322/(4VS VS))SQ              |
| 1182  | KWIEM                            | 2DEC   | .147323336    | RESULT IN METERS OVER 12800            |
| 1183  | COS(13)                          | 2DEC   | .9763         | REAL COS OF 12.5 DEG. NOT 1/2 COSINE.  |
| 1184  | -SIN(13)                         | 2DEC   | -.21644       | REAL SIN OF 12.5 DEG. NO FACTOR OF 1/2 |
| 11841 | 2C1HS                            | 2DEC   | .0215983264   | 2 1.25 28500 805/(2 VS)SQ              |
| 11842 | 2C1HSLAD                         | 2DEC   | .071994421    | 2 1.25 28500 805/(.3 4 VS VS)          |
| 11843 | POINT1                           | 2DEC   | .1            |                                        |
| 11844 | K44                              | 2DEC   | .00116091912  | 2 VS/(236 57.3 57.3 57.3)              |
| 11845 | VFINAL                           | 2DEC   | .48513173     | 25000/2 VS                             |
| 11846 | KAT                              | 2DEC   | .08           | 2 G-S (2/25)                           |
| R1185 | ... END OF RE-ENTRY CONSTANTS... |        |               |                                        |

# RE-ENTRY CONTROL

R1186 CLOSED SUBROUTINE TO COMPUTE DESIRED NAV BASE ORIENTATION  
R1187 NEEDED DURING ENTRY PHASE.

R1188 ENTER WITH VN, UNITR, UNITW, AND ROLLC  
R1189 COMPUTES UXNB, UYNB, AND UZNB. (NAV BASE UNIT VECTORS)

|      |        |       |          |                                      |
|------|--------|-------|----------|--------------------------------------|
| 1190 | GETUNB | RTB   | 3        | RESET PUSH COUNTER.                  |
| 1191 |        | VXV   | VXSC     | GET VELOCITY OF ATMOSPHERE           |
| 1192 |        | VAD   | UNIT     | GET UVA., RELATIVE VELOCITY          |
| 1193 |        | VXSC  |          | RESOLVE BY COS OF 13 DEG.            |
| 1194 |        |       | FRESHPD  |                                      |
| 1195 |        |       | UNITR    |                                      |
| 1196 |        |       | UNITW    | NEG OF REAL VEL.                     |
| 1197 |        |       | KWIEM    | EARTH RATE CONST IN METERS X 4.      |
| 1198 |        |       | VN       |                                      |
| 1199 |        |       | COS(13)  | UVA COS(13) INTO PD.                 |
| 1200 |        | NOLOD | 1        |                                      |
| 1201 |        | VXV   | UNIT     | UYA = UNIT(VA*RN)                    |
| 1202 |        |       | UNITR    |                                      |
| 1203 |        | STORE | 16D      | UYA INTO LOC 16 OF VAC AREA.         |
| 1204 |        | COS   | 1        | COS (ROLLC)                          |
| 1205 |        | VXSC  |          | GET UYA COS(ROLLC). PUSH INTO LOC 6. |
| 1206 |        |       | ROLLC    |                                      |
| 1207 |        |       | 16D      | AND PUSH.                            |
| 1208 |        | SIN   | 0        |                                      |
| 1209 |        |       | ROLLC    | SIN (ROLLC) INTO PD AT LOC 12        |
| 1210 |        | VXV   | 2        | UNA = UNIT(UYA*UVA)                  |
| 1211 |        | UNIT  | VXSC     | UNB = UYA COS(ROLL) + UNA SIN(ROLL)  |
| 1212 |        | VAD   | UNIT     | UNIT COULD BE REPLACED BY VSLT 1.    |
| 1213 |        |       | 16D      | UYA STORED AT LOC 16                 |
| 1214 |        |       | 0        | UVA FIRST ITEM INTO PUSH LIST        |
| 1215 |        | STORE | UYNB     | 1 SCAL AND 1 VEC FROM PD.            |
| 1216 |        | NOLOD | 2        |                                      |
| 1217 |        | VXV   | UNIT     | UN = UNIT (UYNB*UVA)                 |
| 1218 |        | VXSC  | VSU      | UXNB = -UN SIN(13) - UVA COS(13)     |
| 1219 |        |       | 0        |                                      |
| 1220 |        |       | -SIN(13) | PULLS UVA COS(13) FROM PD.           |
| 1221 |        | STORE | UXNB     |                                      |
| 1222 |        | NOLOD | 1        |                                      |
| 1223 |        | VXV   | VSLT     | UZNB = UXNB*UYNB                     |
| 1224 |        |       | UYNB     |                                      |
| 1225 |        |       | 1        |                                      |
| 1226 |        | STORE | UZNB     |                                      |
| 1227 |        | ITCQ  | 0        | AND RETURN.                          |



# RE-ENTRY CONTROL

P1228 SUBROUTINE TO READ PIPA COUNTERS, TRYING TO BE VERY CAREFUL SO THAT  
R1229 IT WILL BE RESTARTABLE.

R1230 (ARRIVE IN INTERRUPTED STATE OR INHIBITED AFTER RESTART.)  
R1231 (EXIT IS THRU ISWRETRN)

|      |         |      |              |                                        |
|------|---------|------|--------------|----------------------------------------|
| 1232 | PIPASR  | CS   | ZERO         | PUT THESE INTO THE IMPOSSIBLE STATE    |
| 1233 |         | TS   | TEMX         | FOR THEIR INITIAL VALUES.              |
| 1234 |         | TS   | TEMY         |                                        |
| 1235 |         | TS   | TEMZ         |                                        |
| 1236 |         | CAF  | ZERO         |                                        |
| 1237 |         | TS   | DEL VX + 1   |                                        |
| 1238 |         | TS   | DEL VY + 1   | PIP COUNTERS MAY NOT HAVE POS ZERO IN  |
| 1239 |         | TS   | DEL VZ + 1   |                                        |
| 1240 |         | TS   | PIPAGE       | ZERO THIS TO INDICATE IN PIPA READING. |
| 1241 | REPIP1  | TC   | READTIME + 1 | PROBABLY NOT NEEDED SINCE NOT MUCH     |
| 1242 |         | CS   | RUPTSTOR + 1 | CHANCE OF TIME1 OVERFLOWING NOW. (BUT  |
| 1243 |         | TS   | PIPTIME + 1  | JUST POSSIBLE IF MANY RESTARTS.        |
| 1244 |         | CS   | RUPTSTOR     |                                        |
| 1245 |         | TS   | PIPTIME      |                                        |
| 1246 |         | CS   | PIPAX        |                                        |
| 1247 |         | TS   | TEMXY        |                                        |
| 1248 |         | XCH  | TEMX         | PUT NEGZERO INTO PIPACTRS AS READ.     |
| 1249 |         | XCH  | PIPAX        |                                        |
| 1250 | REPIP1B | TS   | DEL VX       |                                        |
| 1251 |         | TS   | DEL VX + 1   | DOUBLE SAVE.                           |
| 1252 | REPIP2  | CS   | PIPAY        |                                        |
| 1253 |         | TS   | TEMXY        |                                        |
| 1254 |         | XCH  | TEMY         |                                        |
| 1255 |         | XCH  | PIPAY        |                                        |
| 1256 | REPIP2B | TS   | DEL VY       |                                        |
| 1257 |         | TS   | DEL VY + 1   |                                        |
| 1258 | REPIP3  | CS   | PIPAZ        | REPEAT PROCESS FOR 2 PIPA.             |
| 1259 |         | TS   | TEMXY        | SAVE NEG OF PIPA READ                  |
| 1260 |         | XCH  | TEMZ         | SAVE HERE AS PICK UP NEGZERO           |
| 1261 |         | XCH  | PIPAZ        | RESETTING PIPA AS READ OUT)            |
| 1262 | REPIP3B | TS   | DEL VZ       | AND STORE IN Z.                        |
| 1263 |         | TS   | DEL VZ + 1   | SHOWS THAT IT REALLY MADE IT.          |
| 1264 | REPIP4  | CS   | ZERO         | LEAVE THESE AT NEGZERO                 |
| 1265 |         | TS   | DEL VX + 1   |                                        |
| 1266 |         | TS   | DEL VY + 1   |                                        |
| 1267 |         | TS   | DEL VZ + 1   |                                        |
| 1268 |         | CS   | BIT1         |                                        |
| 1269 |         | MASK | TMARKER      |                                        |
| 1270 |         | AD   | BIT1         | SET BIT 1 IN TM MARKER.                |
| 1271 |         | TS   | TMARKER      |                                        |
| 1272 |         | TC   | ISWRETRN     | AND EXIT. SHOULD HAVE COME THRU ICALL  |



# RE-ENTRY CONTROL

P1273 ROUTINE TO RESTART IF READING PIPA COUNTERS.

|      |          |     |           |                                         |
|------|----------|-----|-----------|-----------------------------------------|
| 1274 | REIPASR  | CCS | PIPAGE    | WAS I READING PIPS.                     |
| 1275 |          | TC  | PIPASR    | NO.. PIPAGE = PLUS CONST.               |
| 1276 |          | CCS | DELVZ + 1 | PIPAGE = 0 (I WAS READING PIPS.)        |
| 1277 |          | TC  | REPIP4    | Z WAS READ OK.                          |
| 1278 |          | TC  | +3        | Z NOT DONE, CHECK Y.                    |
| 1279 |          | TC  | REPIP4    |                                         |
| 1280 |          | TC  | REPIP4    |                                         |
| 1281 |          | CCS | DELVY + 1 | HAS IT CHANGED FROM ITS +ZERO INIT VALU |
| 1282 |          | TC  | +3        | YES, Y DONE. TRY TO REDO Z.             |
| 1283 |          | TC  | CHKDELVX  | NO, GO LOOK AT X.                       |
| 1284 |          | TC  | +1        | YES.                                    |
| 1285 |          | CCS | TEMZ      | DOES TEMZ STILL = -0.                   |
| 1286 |          | TC  | +4        | NO TRY TO RESTORE                       |
| 1287 |          | TC  | +3        |                                         |
| 1288 |          | TC  | +2        |                                         |
| 1289 |          | TC  | REPIP3    | YES, GO BACK AND READ Z AGAIN.          |
| 1290 |          | CS  | TEMXY     | MUCH MORE LOGIC COULD BE INCORPORATED   |
| 1291 |          | TC  | REPIP3B   | TO CHECK PIPA CTR FOR SIZE.             |
| 1292 | CHKDELVX | CCS | DELVX + 1 | HAS THIS CHANGED.                       |
| 1293 |          | TC  | +3        | YES                                     |
| 1294 |          | TC  | CHKTEMX   | NO.                                     |
| 1295 |          | TC  | +1        | YES                                     |
| 1296 |          | CCS | TEMY      |                                         |
| 1297 |          | TC  | +4        |                                         |
| 1298 |          | TC  | +3        |                                         |
| 1299 |          | TC  | +2        |                                         |
| 1300 |          | TC  | REPIP2    |                                         |
| 1301 |          | CS  | TEMXY     |                                         |
| 1302 |          | TC  | REPIP2B   |                                         |
| 1303 | CHKTEMX  | CCS | TEMX      | HAS THIS CHANGED.                       |
| 1304 |          | TC  | +4        | YES                                     |
| 1305 |          | TC  | +3        | YES                                     |
| 1306 |          | TC  | +2        | YES                                     |
| 1307 |          | TC  | REPIP1    | NO                                      |
| 1308 |          | CS  | TEMXY     |                                         |
| 1309 |          | TC  | REPIP1B   |                                         |

# RE-ENTRY CONTROL

P1310 ENTRY INITIALIZATION ROUTINE.  
R1311 -----

|      |          |        |          |                                          |
|------|----------|--------|----------|------------------------------------------|
| 1312 | STARTENT | TC     | PHASCHNG | KEEP UPTHETA RUNNING IN CASE OF RESTART. |
| 1313 |          | OCT    | 03204    | 4.26 RESTART.                            |
| 1314 |          | TC     | PHASCHNG | PICK UP CURRENT STRING AT NEWMODE63.     |
| 1315 |          | OCT    | 02305    | 5.19 RESTART. RESYNCING PIPUP ALSO.      |
| 1316 |          | INHINT |          |                                          |
| 1317 |          | CAF    | PRI014   | ESTABLISH UPTHETA FOR 1ST TIME.          |
| 1318 |          | TC     | FINDVAC  |                                          |
| 1319 |          | CADR   | UPHETA1  | START UPTHETA JOB.                       |
| 1320 |          | RELINT |          |                                          |
| 1321 | NUMODE63 | TC     | NEWMODE  |                                          |
| 1322 |          | OCT    | 00063    | ENTRY PHASE = MODE 63                    |
| 1323 |          | CAF    | INITCADR |                                          |
| 1324 |          | TS     | GOTOADDR |                                          |
| 1325 |          | CAF    | EARGCADR |                                          |
| 1326 |          | TS     | CALCG    |                                          |
| 1327 |          | CAF    | ZERO     |                                          |
| 1328 |          | TS     | TENTRY   |                                          |
| 1329 |          | CAF    | NUDELTAT |                                          |
| 1330 |          | TS     | DELTAT   |                                          |
| 1331 |          | CAF    | NU/PIPD  |                                          |
| 1332 |          | TS     | 1/PIPADT |                                          |
| 1333 |          | CS     | ENTMASK  | INITIALIZE SWITCHES(BITS 6-11 IN STATE)  |
| 1334 |          | MASK   | STATE    | 6=GONEPAST, 7= RELVELSW, 8= EGSW,        |
| 1335 |          | AD     | ENTRYSW  | 9=HUNTSW1, 10=HIND, 11=INRLSW.           |
| 1336 |          | TS     | STATE    | ALL BUT RELVELSW SET TO NON-BRANCH (1)   |
| 1340 |          | TC     | INTPRET  |                                          |
| 1341 |          | RTB    | 2        | SET CDUX AGAIN JUST IN CASE.             |
| 1342 |          | VXV    | DOT      |                                          |
| 1343 |          | COMP   | RTB      |                                          |
| 1344 |          |        | CDUXFIX  |                                          |
| 1345 |          |        | VN       |                                          |
| 1346 |          |        | UNITR    |                                          |
| 1347 |          |        | RTINIT   | THIS GIVES LATANG.                       |
| 1348 |          |        | SIGNMPAC | GETS SIGN OF MPAC                        |
| 1349 |          | STORE  | K2ROLL   | K2ROLL = - SIGN(LATANG)                  |
| 1350 |          | DOT    | 1        |                                          |
| 1351 |          | TSLT   | ACOS     |                                          |
| 1352 |          |        | UNITR    |                                          |
| 1353 |          |        | RTINIT   |                                          |
| 1354 |          |        | 1        |                                          |
| 1355 |          | STORE  | THETAH   |                                          |
| 1356 |          | VMOVE  | 0        |                                          |
| 1357 |          |        | RT       |                                          |
| 1358 |          | STORE  | RTINIT   |                                          |

# RE-ENTRY CONTROL

|      |       |          |
|------|-------|----------|
| 1359 | COMP  | 0        |
| 1360 |       | DTEAROT  |
| 1361 | STORE | DTEAROT  |
| 1362 | ITC   | 0        |
| 1363 |       | EARROT1  |
| 1364 | RTB   | 0        |
| 1365 |       | OVERNOUT |

EXIT SETTING RESTART BITS TO 5.12 FOR EN

|      |          |        |          |
|------|----------|--------|----------|
| 1366 | INITCADR | CADR   | INITROLL |
| 1367 | EARGCADR | CADR   | CALCGEAR |
| 1368 | NUDELTAT | DEC    | 200 B5   |
| 1369 | NU/PIPD  | DEC    | 200 B6   |
| 1370 | ENTMASK  | OCT    | 01760    |
| 1371 | ENTRYSW  | OCT    | 01360    |
| 1372 | ENDD202S | EQUALS |          |

# AVERAGE G INTEGRATOR

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R0001 ROUTINE CALCRVG INTEGRATES THE EQUATIONS OF MOTION BY AVERAGING THE
R0002 GRAVITATIONAL ACCELERATION OVER A TIME INTERVAL, DELTAT, AND INCLUDING
R00025 THE VELOCITY INCREMENT AS MEASURED BY THE PIPAS.
R0003 FOR THE EARTH-CENTERED GRAVITATIONAL FIELD THE PERTURBATION DUE TO
R0004 OBLATENESS IS COMPUTED TO THE SECOND HARMONIC COEFFICIENT J.
R0005 ROUTINE NORMALISE MUST BE CALLED PRIOR TO THE FIRST ENTRY INTO
R0006 CALCRVG. IT REQUIRES RN SCALED TO 2(+29)M IT LEAVES RN NORMALISED, SO
R0007 THAT THE SCALED MAGNITUDE OF THE VECTOR CONTAINS ONE LEADING ZERO, BY
R0008 SHIFTING THE VECTOR LEFT N BINARY PLACES.
R0008 ROUTINE CALCRVG REQUIRES
R0009 1) THRUST ACCELERATION INCREMENTS IN DELV SCALED SAME AS PIPAX,Y,Z
R0010 2) VN SCALED AT 2(+7) M/CS
R0011 3) ADDRESS OF CALGCLUN OR CALCGEAR IN CALCG
R0012 4) DELTAT SCALED AT 2(+9) CS
R0013 5) PUSH-DOWN COUNTER SET TO ZERO
R0014 IT LEAVES UPDATED RN, SCALED AT 2(29-N) M, VN, AND GRAVITY SCALED AT
R0015 2(-5) M/CS/CS
0021 SETLOC ENDINFSS

0022 NORMLISE ABVAL 3 COUNT NUMBER OF LEADING ZEROS IN
0023 TSLC INCR,1 ABVAL (RN) AND STORE -N(=2-M) IN NSHIFT
0024 SXA,1 INCR,1 RN MUST BE SCALED AT 2(+29)M
0025 SXA,1 ITA
0026 RN
0027 X1
0028 2
0029 NSHIFT SAVE C(X1)=-N
0030 14D
0031 XSHIFT SAVE C(X1) =14-N
0032 S2

0033 VMOVE 1
0034 VSLT*
0035 RN
0036 14D,1
0037 STORE RN RN SCALED AT 2(29-N)METRES

0038 ITC 0
0039 CALCGRAV

0040 ITCI 0
0041 S2

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# AVERAGE G INTEGRATOR

|        |                                                                        |        |          |                                          |
|--------|------------------------------------------------------------------------|--------|----------|------------------------------------------|
| 0042   | CALCRVG                                                                | VXSC   | 0        |                                          |
| 0043   |                                                                        |        | DELV     |                                          |
| 0044   |                                                                        |        | KPIP     | DV TO PD SCALED AT 2(+4)M/CS             |
| 0045   |                                                                        | VXSC   | 1        |                                          |
| 0046   |                                                                        | LXA.1  | BVSU     |                                          |
| 0047   |                                                                        |        | GRAVITY  |                                          |
| 0048   |                                                                        |        | DELTAT   |                                          |
| 0049   |                                                                        |        | XSHIFT   |                                          |
| 0050   |                                                                        |        | 0        | (DV-(OLD GDT))/2 TO PD SCALED 2(+3)M/CS  |
| 0051   |                                                                        | NOLOD  | 3        |                                          |
| 0052   |                                                                        | VSRT   | VAD      |                                          |
| 0053   |                                                                        | VXSC   | VSLT*    |                                          |
| 0054   |                                                                        | VAD    | ITA      |                                          |
| 0055   |                                                                        |        | 4        |                                          |
| 0056   |                                                                        |        | VN       |                                          |
| 0057   |                                                                        |        | DELTAT   |                                          |
| 0058   |                                                                        |        | 1.1      |                                          |
| 0059   |                                                                        |        | RN       |                                          |
| 0060   |                                                                        |        | S2       |                                          |
| 0061   |                                                                        | STORE  | RN1      | SCALED AT 2(29-N) METERS                 |
| 0062   |                                                                        | ITC    | 0        |                                          |
| 0063   |                                                                        |        | CALCGRV  |                                          |
| 0064   |                                                                        | NOLOD  | 3        |                                          |
| 0065   |                                                                        | VXSC   | BVSU     |                                          |
| 0066   |                                                                        | VAD    | VSRT     |                                          |
| 0067   |                                                                        | VAD    |          |                                          |
| 0068   |                                                                        |        | DELTAT   |                                          |
| 0069   |                                                                        |        | -        | (DV-(OLD GDT))/2                         |
| 0070   |                                                                        |        | -        | DV/2                                     |
| 0071   |                                                                        |        | 4        |                                          |
| 0072   |                                                                        |        | VN       |                                          |
| 0073   |                                                                        | STORE  | VN1      | SCALED AT 2(+7) MET/CS                   |
| R00731 | IN AVERAGE G, UP THE PHASE BITS BY 2 OF ACTIVE PROG BEFORE COPY CYCLE. |        |          |                                          |
| 00732  |                                                                        | EXIT   | 0        |                                          |
| 007322 |                                                                        | INDEX  | FIXLOC   |                                          |
| 007324 |                                                                        | CS     | S2       | SAVE NEG RETURN ADDRESS IN NON-VAC AREA. |
| 007326 |                                                                        | TS     | AVGRETRN | SAVE NEG OF RETURN ADDRESS.              |
| 00733  |                                                                        | TC     | BANKCALL |                                          |
| 007335 |                                                                        | CADR   | INCPHAS2 |                                          |
| 00734  | REFAZE6                                                                | INHINT |          |                                          |
| 007343 |                                                                        | CAF    | ELEVEND  |                                          |
| 007347 |                                                                        | TS     | MPAC     | USE MPAC FOR LOOP COUNTER.               |
| 00735  |                                                                        | INDEX  | MPAC     |                                          |
| 007353 |                                                                        | CS     | RN1      | RN1 AND VN1 MUST BE IN ORDER.            |
| 007357 |                                                                        | COM    |          | LEAVE RN1 ALONE IN CASE OF RESTARTS.     |
| 00736  |                                                                        | INDEX  | MPAC     | SELECT THE RIGHT TERM.                   |

# AVERAGE G INTEGRATOR

|         |          |             |         |                                  |
|---------|----------|-------------|---------|----------------------------------|
| 007363  | TS       | RN          | ...     | AND GO THRU COPY CYCLE.          |
| 007367  | CCS      | MPAC        |         | ARE WE DONE..                    |
| 00737   | TC       | REFAZE6 + 2 |         | NO, NOT YET.                     |
| 007373  | CS       | BIT2        |         | YES, MPAC = 0.                   |
| 007377  | MASK     | TMMARKER    |         |                                  |
| 00738   | AD       | BIT2        |         | SET BIT 2 TO ONE IN TMMARKER.    |
| 007382  | TS       | TMMARKER    |         |                                  |
| A007385 |          |             |         | WHAT ABOUT GRAVITY FOR RESTART.. |
| 007387  | RELINT   |             |         |                                  |
| 00739   | CS       | AVGRETRN    |         | NEG OF ADDRESS WAS STORED.       |
| 0074    | TC       | BANKJUMP    |         |                                  |
| 0075    | ELEVEND  | DEC         | 11      | 11D (ELEVEN DECIMAL, OF COURSE.) |
| 0076    | CALCGRAV | NOLOD       | 1       |                                  |
| 0077    |          | UNIT        |         |                                  |
| 0078    |          | STORE       | UNITR   |                                  |
| 00782   |          | DMOVE       | 0       |                                  |
| 00784   |          |             | 30D     |                                  |
| 00786   |          | STORE       | RMAG    | SCALED AT 2(30-N)M               |
| 0079    |          | TSLT        | 0       |                                  |
| 0080    |          |             | 28D     |                                  |
| 0081    |          |             | 3       |                                  |
| 0082    |          | STORE       | RMAGSQ  | SCALED AT 2(57-2N)M(+2)          |
| 0083    |          | ITA         | 1       |                                  |
| 0084    |          | XAD,1       | ITCI    |                                  |
| 0085    |          |             | 27D     |                                  |
| 0086    |          |             | NSHIFT  |                                  |
| 0087    |          |             | CALCG   |                                  |
| 0088    | CALCGEAR | DOT         | 0       |                                  |
| 0089    |          |             | UNITR   |                                  |
| 0090    |          |             | UNITW   |                                  |
| 0091    |          | STORE       | 25D     |                                  |
| 0092    |          | NOLOD       | 2       |                                  |
| 0093    |          | DSQ         | DMP     |                                  |
| 0094    |          | TSLT        | BDSU    |                                  |
| 0095    |          |             | DP(5/8) |                                  |
| 0096    |          |             | 4       |                                  |
| 0097    |          |             | DP2(-3) |                                  |
| 0098    |          | DDV         | 1       |                                  |
| 0099    |          | TSLT*       |         |                                  |
| 0100    |          |             | J(RE)SQ | SCALED AT 2(+40) M(+2)           |
| 0101    |          |             | RMAGSQ  |                                  |

# AVERAGE G INTEGRATOR

|      |          |        |             |                                        |
|------|----------|--------|-------------|----------------------------------------|
| 0102 |          |        | 0.1         |                                        |
| 0103 |          | STORE  | 23D         | J(RE/RM) SQ SCALED AT 2(-3)            |
| 0104 |          | NOLOD  | 2           |                                        |
| 0105 |          | DMP    | VXSC        |                                        |
| 0106 |          | VAD    |             |                                        |
| 0107 |          |        | -           |                                        |
| 0108 |          |        | UNITR       |                                        |
| 0109 |          |        | UNITR       |                                        |
| 0110 |          | DMP    | 1           |                                        |
| 0111 |          | VXSC   | VAD         |                                        |
| 0112 |          |        | 23D         |                                        |
| 0113 |          |        | 25D         |                                        |
| 0114 |          |        | UNITW       |                                        |
| 0115 |          | DMOVE  | 1           |                                        |
| 0116 |          | ITC    |             |                                        |
| 0117 |          |        | MUEARTH     |                                        |
| 0118 |          |        | MU/RSQ      |                                        |
| 0119 | CALCGLUN | VMOVE  | 0           |                                        |
| 0120 |          |        | UNITR       |                                        |
| 0121 |          | DMOVE  | 1           |                                        |
| 0122 |          | INCR,1 |             |                                        |
| 0123 |          |        | MUMOON      |                                        |
| 0124 |          |        | 6           |                                        |
| 0125 | MU/RSQ   | NOLOD  | 2           |                                        |
| 0126 |          | DDV    | TSLT*       |                                        |
| 0127 |          | VXSC   |             |                                        |
| 0128 |          |        | RMAGSQ      | C(X1)=14-2N (EARTH)                    |
| 0129 |          |        | 5.1         | =20-2N (MOON)                          |
| 0130 |          | STORE  | GRAVITY     | SCALED AT 2(-5) M/CS/CS                |
| 0131 |          | ITCI   | 0           |                                        |
| 0132 |          |        | 27D         |                                        |
| 0133 | KPIP     | ZDEC   | 0.59904     |                                        |
| 0134 | DP2(-3)  | ZDEC   | 0.125       |                                        |
| 0135 | DP(5/8)  | ZDEC   | 0.625       |                                        |
| 0136 | MUEARTH  | ZDEC   | 0.009063188 | 5.58603223 114 50.1 2(+42)M(+3)/CS(+2) |
| 0137 | MUMOON   | ZDEC   | 0.007134481 | 4.90277800 114 50.1 2(+36)M(+3)/CS(+2) |
| 0138 | JRETS    | ZDEC   | 0.07006663  | 2(+40)M(+3)                            |
| 0139 |          |        |             |                                        |

# POWERED FLIGHT SUBROUTINES

P1240 THIS CODING APPEARS IN THE POWERED FLIGHT SECTION.

R12405 THIS ROUTINE RESOLVES THE VECTOR IN RTINIT THROUGH AN ANGULAR ROTAT-  
 R1241 ION WIE (DTEAROT) SCALED AT ONE REVOLUTION ABOUT THE UNIT POLAR AXIS  
 R1242 UNITW. IT REQUIRES DTEAROT SCALED AT 2(+28)CS. IT LEAVES THE RESOLVED  
 R1243 VECTOR IN RT WITH EASTERLY AND NORMAL COMPONENTS IN RTEAST AND RTNORM  
 R1244 RESPECTIVELY, AT THE SAME SCALING. FOR CONTINUOUS UPDATING ONLY ONE  
 R1245 ENTRY AT EARROT1 IS REQUIRED. WITH SUBSEQUENT ENTRIES AT EARROT2.

|       |          |       |          |                                   |
|-------|----------|-------|----------|-----------------------------------|
| 1248  | EARROT1  | VXV   | 1        |                                   |
| 1249  |          | VSLT  |          |                                   |
| 1250  |          |       | UNITW    |                                   |
| 1251  |          |       | RTINIT   |                                   |
| 1252  |          |       | 2        |                                   |
| 1253  |          | STORE | RTEAST   |                                   |
| 1254  |          | NOLOD | 1        |                                   |
| 1255  |          | VXV   | VSLT     |                                   |
| 1256  |          |       | UNITW    |                                   |
| 1257  |          |       | 1        |                                   |
| 1258  |          | STORE | RTNORM   |                                   |
| 1259  | EARROT2  | STZ   | 1        | BRANCH TO OVERADAY UNTIL DTEAROT  |
| 1260  |          | DDV   | BOV      | LESS THAN ONE SIDEREAL DAY        |
| 1261  |          |       | OVFINO   |                                   |
| 1262  |          |       | DTEAROT  |                                   |
| 12622 |          |       | 1/WIE    | TIME FOR ONE SIDEREAL REVOLUTION  |
| 12624 |          |       | OVERADAY |                                   |
| 12626 |          | STORE | 30D      |                                   |
| 1263  |          | NOLOD | 2        |                                   |
| 1264  |          | COS   | DSU      |                                   |
| 1265  |          | VXSC  |          |                                   |
| 1266  |          |       | DP2(-1)  | DP2(-1)= DOUBLE PREC. .5          |
| 1267  |          |       | RTNORM   |                                   |
| 1268  |          | SIN   | 2        |                                   |
| 1269  |          | VXSC  | VAD      |                                   |
| 1270  |          | VAD   |          |                                   |
| 1271  |          |       | 30D      |                                   |
| 1272  |          |       | RTEAST   |                                   |
| 1273  |          |       | RTINIT   |                                   |
| 1274  |          | STORE | RT       |                                   |
| 1275  |          | ITCQ  | 0        |                                   |
| 12751 | OVERADAY | SIGN  | 1        |                                   |
| 12752 |          | BDSU  |          |                                   |
| 12753 |          |       | 1/WIE    |                                   |
| 12754 |          |       | DTEAROT  |                                   |
| 12755 |          |       | DTEAROT  |                                   |
| 12756 |          | STORE | DTEAROT  |                                   |
| 12757 |          | BPL   | 0        | GO BACK WITHOUT DISTURBING OPRET. |



# POWERED FLIGHT SUBROUTINES

127575  
12758

1/WIE  
EARROT2

ANY POSITIVE CONSTANT WILL DO.

1276 WIE 2DEC 0.190148570  
12765 1/WIE 2DEC 0.032098670  
1277 ENDPFLSS EQUALS

EARTH RATE SCALED AT 2(-14) REV/SEC  
8.61642098 E4 SECS SCALED AT 2(+28) CS

## APPENDIX A

### DERIVATION OF THE UP-CONTROL REFERENCE, $V = f(D)$

Start with the equations of motion of a point mass assuming small flight path angle

$$dV/dT = -D \quad (D \text{ and } L \text{ are accelerations}) \quad (A-1)$$

$$d\dot{R}/dT = V^2/R - G + L \quad (A-2)$$

$$dH/dT = \dot{R} \quad (A-3)$$

If the centripetal and gravity accelerations are neglected,  $V^2/R - G = 0$ , we can write dividing (A-2) by (A-1)

$$d\dot{R}/dV = -L/D$$

which can be integrated starting at  $V = V_1$ ,  $\dot{R} = 0$

$$\dot{R} = L/D (V_1 - V) \quad (A-4)$$

Now we can solve for H as a function of V by combining (A-1), (A-3), and (A-4) to eliminate time

$$dH/dV = -L/D (V_1 - V)/D \quad (A-5)$$

Relate drag to velocity by

$$D = 1/2 \rho V^2 (SCD/m) \quad (A-6)$$

and  $\rho$  to H by assuming an exponential variation of density with altitude

$$\rho = \rho_1 e^{-\beta(H-H_1)} \quad (A-7)$$

Substitute (A-6) and (A-7) into (A-5) to get

$$dH/dV = -L/D (V_1 - V)(1/2 \rho_1 e^{-\beta(H-H_1)} V^2 \text{SCD}/m) \quad (\text{A-8})$$

Equation (A-8) integrates directly to

$$(\text{SCD}/m)/(\beta L/D)(-1/2 \rho_1 e^{-\beta(H-H_1)} + 1/2 \rho_1) = -\text{LN}(V_1/V) + V_1/V - 1$$

or

$$(\text{SCD}/m)/(\beta L/D)(-1/2 \rho + 1/2 \rho_1) = -\text{LN}(V_1/V) + V_1/V - 1 \quad (\text{A-9})$$

The log function can be expanded in a series

$$\text{LN}(1 + w) = w - w^2/2 + \dots$$

so

$$\text{LN}(V_1/V) + V_1/V - 1 = (V_1/V - 1)^2/2$$

Put the result back into (A-9)

$$(\text{SCD}/m)/(\beta L/D)(-1/2 \rho + 1/2 \rho_1) = 1/2 ((V_1 - V)/V)^2 \quad (\text{A-10})$$

To solve for V in terms of D, regroup Eq. (A-10) into a quadratic in V.

$$V^2 (2 D_1/(\beta V_1^2) - L/D) + 2 L/D V_1 V - 2 D/\beta - L/D V_1^2 = 0$$

Rewrite this equation

$$X^2 L/D(\alpha - 1) + 2 L/D X - L/D(\beta D/D_1 + 1) = 0$$

where

$$X = V/V_1$$

$$\alpha = 2 D_1/(\beta V_1^2 L/D)$$

Solve this equation with the quadratic formula noting that the positive sign on the square root is appropriate

$$X = -1/(\alpha - 1) + \sqrt{(1/(\alpha - 1))^2 + \alpha (D/D1 + 1)/(\alpha - 1)}$$

This can be simplified to

$$X = (1/(1 - \alpha))(1 - \sqrt{(\alpha - 1)\alpha D/D1 + \alpha}) \quad (A-11)$$

Finally, summarize by rewriting the result in the form used in the AGC

$$V = F1 (1 - \sqrt{F2 D + \alpha}) \quad (A-12)$$

where

$$\alpha = 2 D1 / (\beta V1^2 L/D)$$

$$F1 = V1/(1 - \alpha)$$

$$F2 = \alpha (\alpha - 1)/D1$$



## APPENDIX B

### HOOK ON ALTITUDE RATE

This derivation is to allow for the previously neglected gravity and centripetal accelerations in the reference path for the up-control phase. When the L/D slipped to its present value, this refinement was necessary since the neglected acceleration became a larger part of the total acceleration.

Start again with the basic equations for a point mass, this time including the gravity and centripetal accelerations.

$$dV/dT = -K_1 e^{-\beta H} V^2 \quad (B-1)$$

$$dR/dT = K_2 e^{-\beta H} V^2 + (V^2/VS^2 - 1) G \quad (B-2)$$

$$dH/dT = \dot{R} \quad (B-3)$$

Divide (B-2) by (B-1) to eliminate time

$$d\dot{R}/dV = -K_2/K_1 + (G/(K_1 e^{-\beta H}))(1/V^2 - 1/VS^2) \quad (B-4)$$

Note that  $K_2/K_1 = L/D$ . This time (B-3) and (B-4) are a non-linear set and cannot be integrated directly as was the case in Appendix A.

The key approximation needed to integrate this set of equations is to assume at straight line variation of the density ratio  $e^{\beta H}$  with velocity.

$$e^{\beta H} = 1 + AH(VS - V)$$

The constant AH is yet to be determined. This approximation yields for Eq. (B-4).

$$d\dot{R}/dV = -L/D + G/K_1 (1 + AH(VS - V)) (1/V^2 - 1/VS^2) \quad (B-5)$$

This readily integrated from VS to V

$$\begin{aligned} \dot{R} = \dot{R}_0 + L/D(VS - V) + G/K1 ((1 + AH VS)(-1/V + 1/VS) - AH \ln(V/VS)) \\ + G/K1 ((1 + AH VS)(1/VS - V/VS^2) + AH V^2/(2VS^2) - AH/2) \quad (B-6) \end{aligned}$$

We can simplify (B-6) by making a series approximation for the logarithm

$$\ln(V/VS) = (V - VS)/VS - .5 ((V - VS)/VS)^2$$

This substitution gives after some algebra

$$\dot{R} = \dot{R}_0 + L/D(VS-V) + (G/(DHOOK V))(-(VS-V)^2 - AH(VS-V)^3) \quad (B-8)$$

where

$$DHOOK = \text{drag at VS}$$

Note that

$$\dot{R}_0 + L/D (VS - V) = LEWD (V_1 - V)$$

Now return to determining AH.

The drag is assumed to vary parabolically with velocity (as calculated in Appendix A), with no gravity correction. This yields an exit velocity, VL, at the exit drag, Q7. A straight line is drawn between the acceleration at VS (DHOOK) and the acceleration at VL (Q7). The desired slope of the density variation is then

$$AH = ((DHOOK - Q7)/Q7)/(VS - VL)$$

This assumes that the velocity is constant over this time period, a small approximation compared to some of the others.

The square and cube terms of (VS-V) in Eq. (B-8) give the general shape of  $\dot{R}$  versus velocity shown in fig. B-1. Of some importance is  $V^2$ , the

velocity at which  $\dot{R}$  becomes zero. This signifies a peak altitude for the up-control phase and that the exit acceleration,  $Q7$ , cannot be reached, because the gravity acceleration is too great. To allow for this effect the following is done. If  $\dot{R}$  is negative on the particular computation cycle, the derivative  $d\dot{R}/dV$  is approximated at  $V_L$  by

$$d\dot{R}/dV = (-3 A_H DVL^2 - 2 DVL) G / (DHOOK V_L) + LEWD \quad (B-9)$$

where

$$DVL = V_S - V_L$$

Then  $V_2$  is calculated using this derivative

$$V_2 = V_L + \dot{R}_L / (d\dot{R}/dV) \quad (B-10)$$

This  $V_2$  is set equal to the exit velocity  $V_L$ , and a new exit acceleration is calculated by using the usual parabolic relation

$$Q7 = ((1 - V_L/F1)^2 - \alpha) / F2$$

Remember

$$\alpha = 2 A_0 H_S / (LEWD V_1^2)$$

$$F1 = V_1 / (1 - \alpha)$$

$$F2 = \alpha (\alpha - 1) / A_0$$

This  $Q7$  is used for reference trajectory calculation in future computation cycles.

This rather simple scheme for calculating  $V_2$  works because the exit altitude rate is only slightly different from zero the first time it becomes negative. Thus only one pass through this Newtonian type iteration is required.

B-4

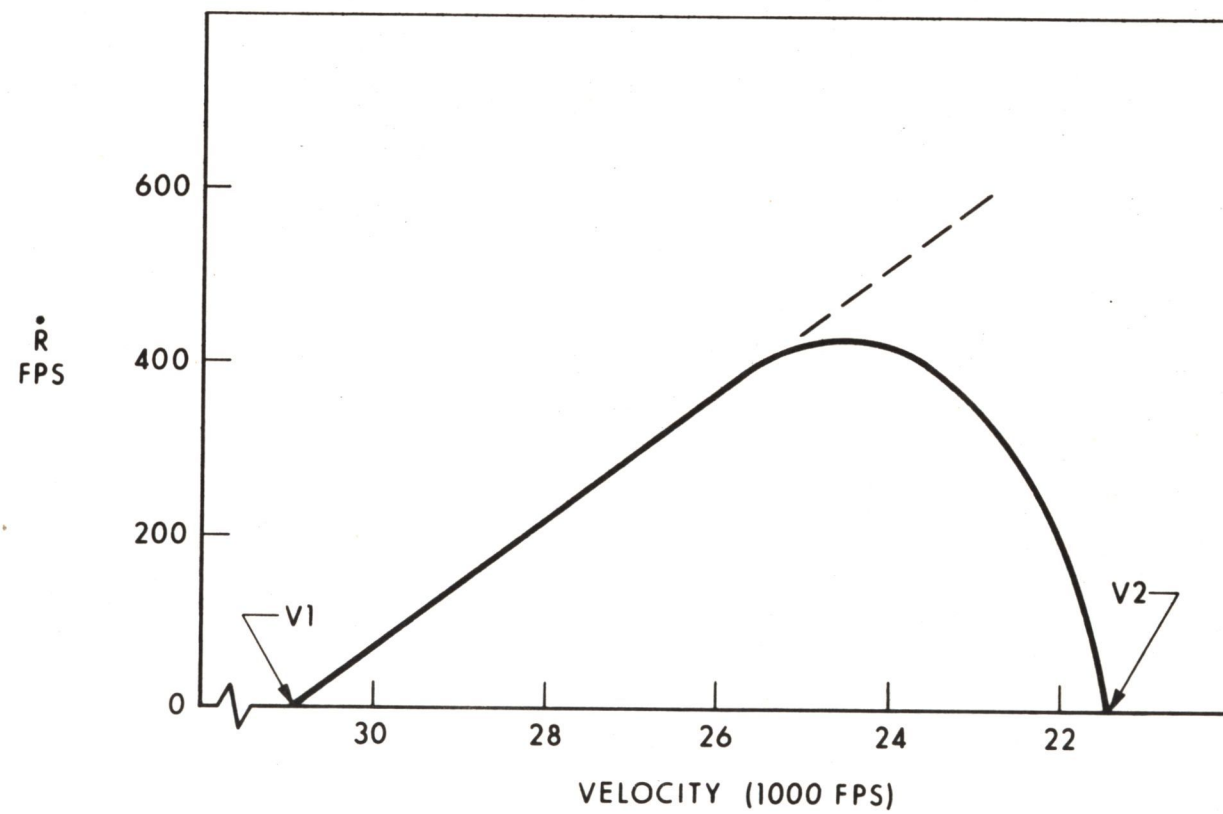


Fig. B-1. "Hook" on Altitude Rate



## APPENDIX C

### THE FINAL PHASE REFERENCE

The final phase reference is generated by these equations

$$\begin{aligned}\dot{X} &= V \text{ COSG} \\ \dot{Y} &= -Q \text{ SCD} - G \text{ SING} \\ \dot{\gamma} &= -V/(RE+H) - G/V \text{ COSG} + Q \text{ SCL}/V \\ \dot{H} &= V \text{ SING}\end{aligned}$$

where

$$\begin{aligned}\text{SING} &= \sin\gamma, \text{ COSG} = \cos\gamma \\ \text{SCD} &= G/(W/CDA), \text{ SCL} = \text{LOD SCD} \\ Q &= 1/2 \rho V^2\end{aligned}$$

These equations represent flight over a spherical non-rotating earth. The atmospheric density,  $\rho$ , is defined by the 59 ARDC standard atmosphere, as is the rate of change of density with altitude,  $\text{DRDZ}$ , and the scale height,  $\text{HS} = -\text{DRDZ}/\rho$ .

The adjoint to the set of linearized perturbation equations of the above set are then solved. This set is

$$\begin{aligned}\dot{L}_2 &= -\text{COSGL}_1 + (2 Q \text{ SCD}/V) L_2 \\ &\quad + ((-1/RE - G/V^2) \text{ COSG} - Q \text{ SCL}/V^2) L_3 - \text{SING} L_4 \\ \dot{L}_3 &= V \text{ SING} L_1 + G \text{ COSG} L_2 + (V/RE - G/V) \text{ SING} L_3 \\ &\quad - V \text{ COSG} L_4 \\ \dot{L}_4 &= 1/2 V^2 \text{ SCD DRDZ} L_2 - 1/2 V \text{ SCL DRDZ} L_3 \\ \dot{L}_5 &= -Q L_3 \text{ SCD}/(V 6080)\end{aligned}$$

These are solved with time running backwards, and with  $V, \gamma, H$ , and  $X$  generated from the first set. The appropriate boundary conditions are  $L1(T) = 1, L2(T) = 0, L3(T) = 0, L4(T) = 1/(\tan(\gamma(T))), L5(T) = 0$ .

These equations generate the required derivatives which may be identified

$$\begin{aligned}dX/dV &= L2, && \text{ft/fps} \\dX/d\dot{R} &= L3/V, && \text{ft/fps} \\dX/dH &= L4, && \text{ft} \\dX/d(L/D) &= L5, && \text{n.m.}\end{aligned}$$

If we assume the change in drag is due to a change in altitude we may write

$$dX/dD = -HS L4/D, \quad \text{ft/fps}$$

This technique is well established and may be found in Reference 3 among others.

## APPENDIX D

### ERROR CHARACTERISTICS

#### Initial Condition Deviations and Uncertainties

It is important to give a detailed discussion of the initial condition deviations and uncertainties since these pose the most significant design problem for the entry steering. The uncertainties, lack of knowledge of our position are by far more important than are the deviations, differences from our planned position; both will be discussed here.

The most important uncertainty is our lack of knowledge of altitude rate. This uncertainty has two components corresponding to the estimated inertial velocity vector and the estimated direction toward the center of the earth. These two components are highly correlated. Shown in fig. D-1 is a typical situation. We are at position 2, corresponding to perigee, while we think we are at position 1 before perigee. At parabolic speeds the range angle,  $\text{THETA}$ , is twice the flight path angle,  $\gamma$ . Our indicated inertial velocity is off by  $+\gamma$ , while the indicated direction of down is off by  $\text{THETA} = -2\gamma$ . The net result is that the error in flight path angle is  $-\gamma$ . In other words, a positive  $R$  uncertainty becomes a negative  $\dot{R}$  uncertainty when the correlated range uncertainty is included. Further, positive altitude rate uncertainties, which tend to cause the vehicle fall short, are accompanied by negative range uncertainties which also tend to cause the vehicle to fall short.

All this correlation is possible because of the following observation. The perigee has a fixed angle in space. The reason for this is not known, but it is suspected that the small velocity corrections made near the end of the Midcourse phase cannot change this angle by an appreciable amount, but can only change the altitude at perigee. Moreover, the equations of the Midcourse section allow for this fact, so that the calculated perigee direction is also fixed. This being true, the entry angle deviation is equal to the range uncertainty at the time of the last velocity correction. Of course, the range uncertainty can be improved with further observations. Summarizing then, the entry angle deviation is equal to the flight path uncertainties if no observations have improved that uncertainty.



### Error Propagation

Fortunately, the altitude rate uncertainty decreases with time. This can be seen by considering the following equation for altitude rate,

$$\dot{R} = \bar{V} \cdot \bar{U}R$$

Perturbing this equation, we can write for the error in altitude rate,

$$\delta \dot{R} = \delta \bar{V} \cdot \bar{U}R + \bar{V} \cdot \delta \bar{U}R$$

We have shown previously, for parabolic entry velocities that if  $\dot{\delta R} = 1$ , then

$$\delta \bar{V} \cdot \bar{U}R = -1 \text{ and } \bar{V} \cdot \delta \bar{U}R = 2$$

During the critical time of entry,  $\delta \bar{V}$  and  $\delta \bar{U}R$  are almost constant, varying with the Schuler period. Also  $\bar{V}$  is almost parallel to  $\delta \bar{U}R$ . So we may write

$$\delta \dot{R} / \dot{\delta R} = 2 V / V_0 - 1$$

where  $\delta R_0$  and  $V_0$  are the initial values. Figure D-2 dramatizes this relation. Shown is the actual altitude rate uncertainty history for a typical entry plotted next to this formula. Of course, the variation in  $\delta \bar{V}$  and  $\delta \bar{U}R$  will introduce further variations in  $\delta \dot{R}$ , as will the instrument and platform errors. All of which are not included here. But all of these effects are secondary over the critical up-control phase. More important is the assumed correlation between the two contributors to  $\delta \dot{R}$ . The correlation of

$$\bar{V} \cdot \delta \bar{U}R / \delta \bar{V} \cdot \bar{U}R = -2$$

is quite good at parabolic velocities, but must be redetermined for other velocities. The point of all this is that should we be able to determine the altitude rate error by independent means, we would be able to determine the correlated range error and thereby reduce our position uncertainty.



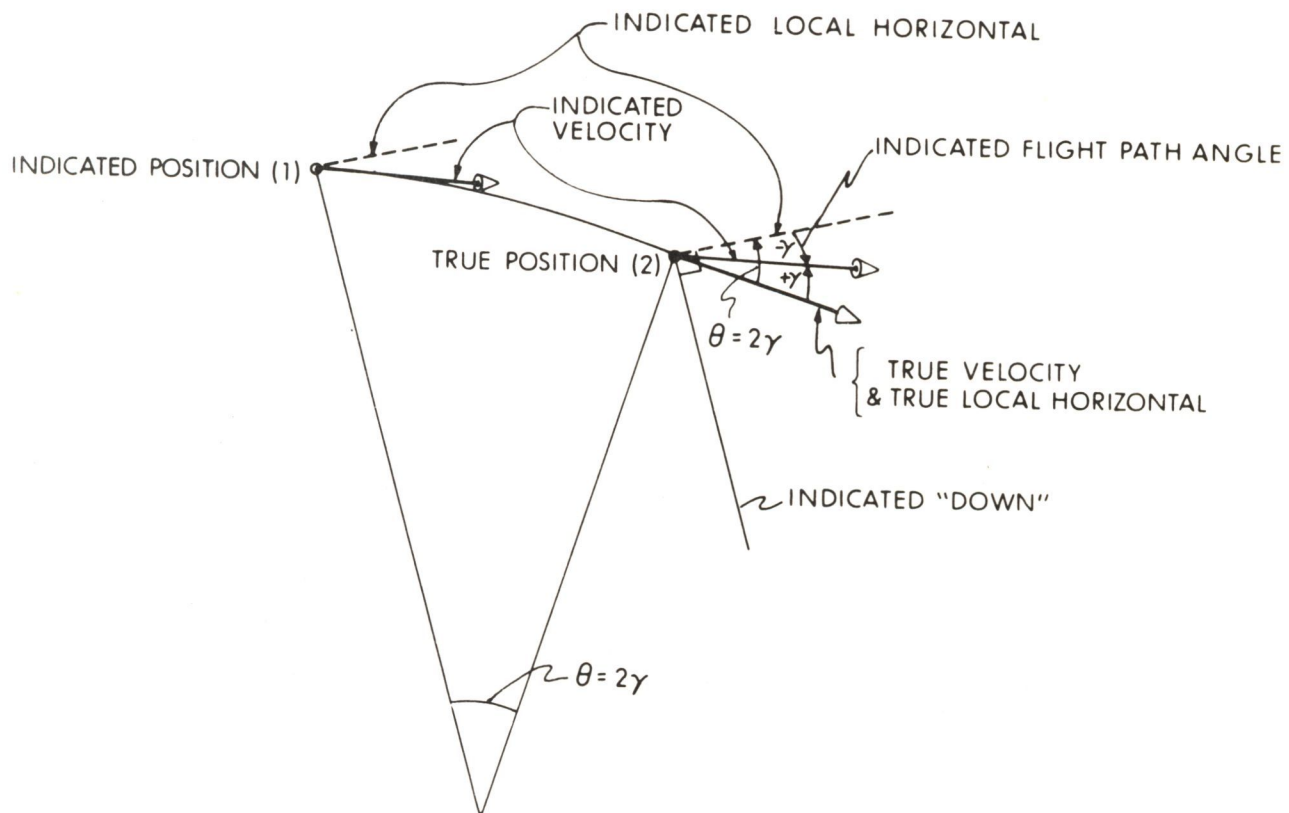


Fig. D-1. Correlation of Range and Velocity

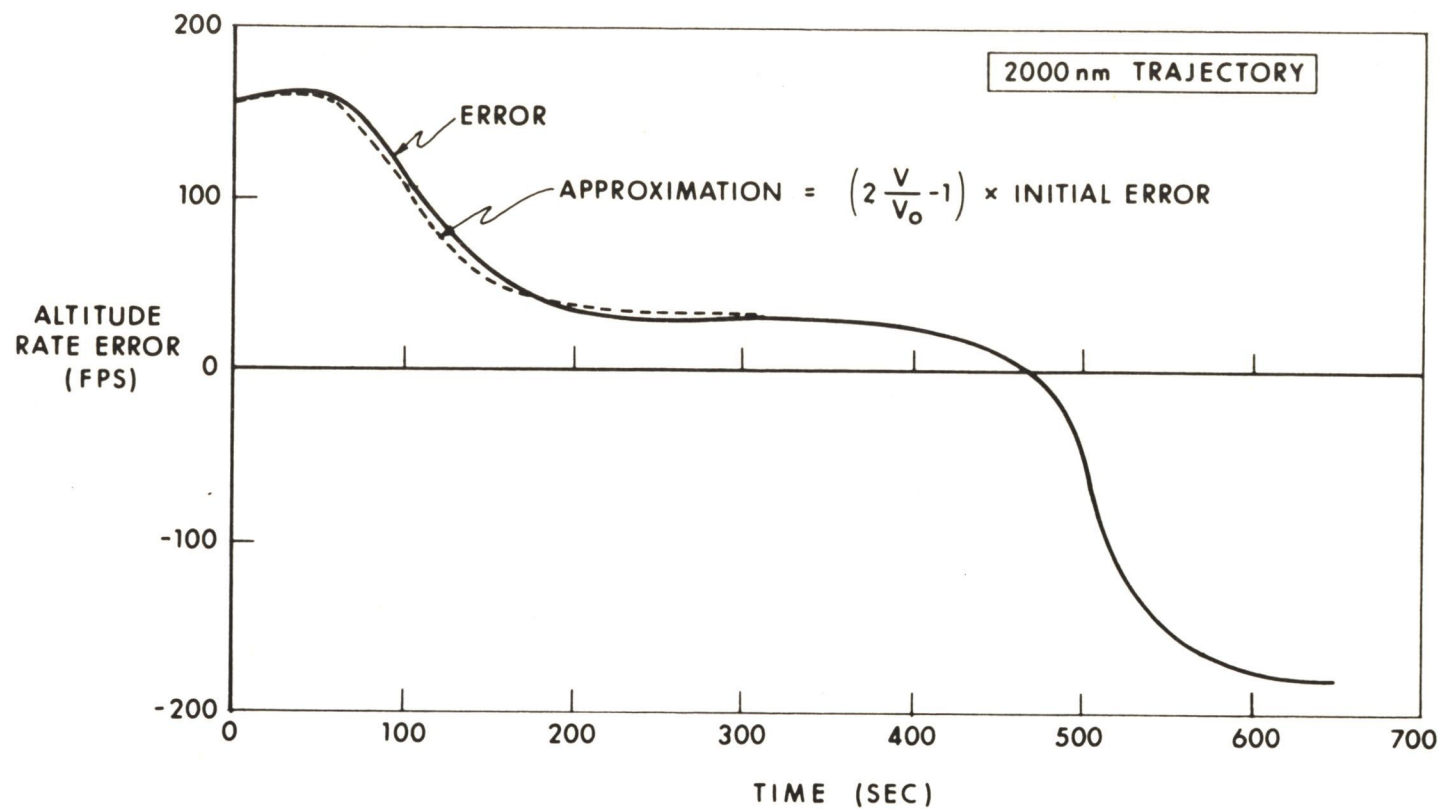


Fig. D-2. Propagation of Altitude Rate Error During Entry

## APPENDIX E

### ALTITUDE RATE CALCULATION

The equation of interest is that for drag acceleration.

$$D = 1/2 \rho V^2 SCD/m$$

If assume an exponential atmosphere,  $\rho = \rho_0 e^{-H/HS}$ , we can write for the rate of change of altitude.

$$\dot{H} = HS(2 \dot{V}/V - \dot{D}/D)$$

Use the  $\dot{H}$  notation to distinguish it from the measured  $\dot{R}$ . Since we measure only differences in drag and velocity we write the equivalent difference equation,

$$\dot{H}_{i-3/2} = 2 HS/DT (2(V_{i-1} - V_{i-2})/(V_{i-1} + V_{i-2}) - (D_{i-1} - D_{i-2})/(D_{i-1} + D_{i-2}))$$

The subscript i refers to present time, i.e. multiply the subscript by the time increment to get the time of the sample. We "smooth" the drag acceleration by averaging the last three points,

$$\hat{D}_{i-1} = (D_i + D_{i-1} + D_{i-2})/3$$

This corresponds to a least square fit through the last three points. Substituting the "smoothed" values for the D's we get

$$\begin{aligned} \dot{H}_{i-3/2} = & 2 HS/DT (2(V_{i-1} - V_{i-2})/(V_{i-1} + V_{i-2}) \\ & - (D_i - D_{i-3})/(D_i + 2 D_{i-1} + 2 D_{i-2} + D_{i-3})) \end{aligned}$$

We seek the time at which  $\dot{H} = 0$ , at which time we will set the indicated  $\dot{R}$  to zero. We do this by looking for a change in the sign of  $\dot{H}$ . When this occurs, we make a correction to  $\dot{R}$  by

$$\dot{R} = \dot{R} + \dot{R}CORR$$

where

$$\dot{R}CORR = -(X \dot{R}_{i-2} + (1 - X) \dot{R}_{i-1})$$

$$X = \dot{H}_{i-3/2} / (\dot{H}_{i-3/2} - \dot{H}_{i-5/2}) + .5$$

The error in this calculation is due mainly to a random error in the drag due to vehicle oscillations. This was shown to be about 1 fpss in Section II. The worst case will arise when one sample is +1 and the next sample is -1. In this case, the error in  $\dot{H}$  is

$$2 HS^2 / (DT^6 D)$$

If  $DT = 2$  seconds, a large  $DT$  is desirable, and  $D = 150$  fpss, the error in  $\dot{H}$  is 56 fps.

The results of the previous section show that this corresponds to a range error of 10 n.m. The rms error of course is less than this worst case and is 5 n.m..

This correction is not incorporated into the logic at this time. This is because of the uncertainty in the estimation of the drag noise. The early flights should improve this uncertainty.



## APPENDIX F

### CHARACTERISTICS OF THE CONSTANT DRAG CONTROLLER

The same assumptions as in Appendix E lead to this equation for the rate of change of drag.

$$\begin{aligned}\dot{D} &= -\beta D \dot{R} - 2D^2/V \\ &= 0, \text{ for constant drag}\end{aligned}$$

The second derivative is

$$\begin{aligned}\ddot{D} &= -\beta D \ddot{R} - \beta \dot{R} \dot{D} - (4D/V) \dot{D} - D^2/V^2 \dot{V} \\ &= 0, \text{ for constant drag.}\end{aligned}$$

Let  $\delta D = D - D_0$ , where  $D_0$  is the constant drag value and

$$\delta \dot{R} = \dot{R} - 2HS D/V$$

then

$$\delta \ddot{D} = -\beta D \delta \ddot{R} - \beta \dot{R} \delta \dot{D} + (4D/V) \delta \dot{D} - D^2/V^2 \delta D - \beta D^2 \delta(L/D)$$

This can be simplified by neglecting  $-D^2/V^2 \delta D$  and recognizing

$$\delta \ddot{R} = L/D \delta D$$

and  $L/D = -(V^2/R - G)/D$

and  $\beta \dot{R} = -2D/V$

and  $\delta(L/D) = C16 \delta D - C17 \delta \dot{R}$

and  $\delta \dot{R} = -\delta \dot{D}/(\beta D)$

The final result is

$$\ddot{D} + (2D/V + C17 D) \delta \dot{D} + (C16 D^2 - \beta(V^2/R - G)) \delta D = 0$$

## APPENDIX G

### RANGE CALCULATIONS FOR THE UP-CONTROL SECTION

#### ASPDWN

To calculate the range from the start of up-control to pull-out ( $R = 0$ ) assume constant velocity and constant acceleration over this short period. The range is then the product of velocity and time, where time is  $-R/(LAD A0)$ .

$$\begin{aligned} \text{ASPDWN} &= -R V / (LAD A0), \quad \text{ft} \\ &= -R V \text{ ATK} / (A0 LAD RE), \text{ n.m.} \end{aligned}$$

#### ASPUP

To calculate the range from pull-out to exit, assume constant  $\dot{R} = \dot{R}_L$ , the exit value with no velocity correction, and constant velocity  $V_L$ . The range is the product of velocity and time. In this case the time is the change of altitude divided by  $\dot{R}$ . The change in altitude is calculated assuming an exponential change of density with altitude

$$H = H_S \text{ LN}(\rho_1 / \rho_L)$$

where

$$\rho_1 = \text{initial density} = K A0 / V_1^2$$

$$\rho_L = \text{final density} = K Q7 / V_L^2$$

Summarizing

$$\begin{aligned} \text{ASPUP} &= (H_S V_L / R_L) \text{ LN}(A0 V_L^2 / (Q7 V_1^2)), \quad \text{ft} \\ &= (H_S \text{ ATK GAMMAL1} / RE) \text{ LN}(A0 V_L^2 / (Q7 V_1^2)), \text{ n.m.} \end{aligned}$$

#### ASKEP

The kepler range is a straight-forward application of conic sections. The derivation is included here for completeness.

From the polar form of the ellipse we can write

$$\cos f = (1 - \ell/R)/E$$

where

$f$  = true anomaly

$$\begin{aligned} \ell/R &= \text{semilatus rectum}/R \\ &= \bar{V}^2 \cos^2 \gamma \end{aligned}$$

$E$  = eccentricity

$$= 1 - 2 \bar{V}^2 \cos^2 \gamma + \bar{V}^4 \cos^2 \gamma$$

$\gamma$  = flight path angle

$\bar{V}$  = normalized velocity

$$= V/VSAT$$

The ballistic range is  $2f$ .

It is more convenient to solve for the sine of the true anomaly which is in view of the above relations

$$\sin f = V^2 \cos \gamma \sin \gamma / E$$

Since the flight path angle is small, these approximations are made

$$\cos \gamma = \text{COSG} = 1 - \text{GAMMAL}^2/2$$

$$\sin \gamma = \text{GAMMAL}$$

We have then the final result

$$\text{ASKEP} = 2 \text{ ATK } \sin^{-1}(\text{VBARS COSG GAMMAL}/E), \text{ n.m.}$$

where

$$\text{VBARS} = \text{VL}^2/\text{VSAT}^2$$

### ASP1

The final phase range is a linear correction to the reference range at the start of the final phase reference trajectory.

$$ASP1 = Q2 + Q3 VL$$

### ASP3

The flight path angle correction to the final phase range uses the initial values of the reference trajectory altitude rate and rate of change of range with altitude rate

$$ASP3 = Q5(Q6 - GAMMAL)$$



## APPENDIX H

### LIMIT ALTITUDE RATE FOR G-LIMITER

If the vehicle is at the limit altitude rate,  $R_1$ , full positive lift will just cause the  $g$ -level to become tangent to the maximum  $g$ -level. This limit altitude rate is derived as follows.

Start with the equation for rate of change of altitude rate.

$$\dot{R}/dT = V^2/R - G + 1/2 \rho V^2 SCL/m$$

Eliminate time by using  $dH/dT = R$

$$\dot{R} d\dot{R} = (LEQ + L) dH$$

where

$$LEQ = V^2/R - G$$

$$L = 1/2 \rho V^2 SCL/m e^{-H/HS}$$

Integrate from point 1 (present conditions) to point 2 (at maximum  $g$ ) assuming constant velocity

$$\dot{R}_2^2 - \dot{R}_1^2 = 2 LEQ (H_2 - H_1) - 2 HS (L_2 - L_1)$$

but  $\dot{R}_2^2 = (2 HS GMAX / V)^2$

and  $H_2 - H_1 = HS \ln(L_1/L_2) = HS \ln(D/GMAX)$

and  $L = L/D \quad D = LAD \quad D$

So we can write

$$\dot{R}_1^2 = (2 HS GMAX/V)^2 - 2 HS LEQ \ln(D/GMAX) + 2 HS LAD (GMAX - D)$$

Represent the log function by a truncated series

$$\begin{aligned}\text{LN}(D/\text{GMAX}) &= \text{LN}(1 + (D - \text{GMAX})/\text{GMAX}) \\ &= (D - \text{GMAX})/\text{GMAX}\end{aligned}$$

So we can write

$$\dot{R}_1^2 = (2 \text{ HS GMAX}/V)^2 + 2 \text{ HS LAD}(\text{GMAX} - D) + 2 \text{ HS LEQ}(\text{GMAX} - D)/\text{GMAX}$$

Finally we take the negative square root

$$\dot{R}_1 = -\text{SQRT}(\dot{R}_1^2)$$

# APPENDIX I

## NOMENCLATURE

|                         |                                                                                           |
|-------------------------|-------------------------------------------------------------------------------------------|
| $\bar{A}$               | Vector with 3 components                                                                  |
| $\bar{A} * \bar{B}$     | Vector cross product of $\bar{A}$ and $\bar{B}$                                           |
| $\bar{A} \cdot \bar{B}$ | Vector dot product of $\bar{A}$ and $\bar{B}$                                             |
| SQRT                    | Square root                                                                               |
| ABVAL                   | Absolute value of vector only                                                             |
| =                       | Is replaced by. e. $A = B + C$ means quantity labeled A is replaced by the sum of B and C |
| $\dot{A}$               | Time derivative of A                                                                      |
| $\delta$                | Variation                                                                                 |
| ARCCOS                  | Arccosine function                                                                        |
| LOG                     | Logarithm to Naperian base                                                                |
| SGN                     | Signum function = +1 for pos arg,<br>= 0 for 0 arg, = -1 for neg arg.                     |

## APPENDIX J

Between the time this report was prepared and it was ready for publication, certain improvements were made in the steering logic. These changes are minor but lead to a significant improvement in performance in some of the more difficult parts of the design envelope. In view of this, they are included here rather than adopted into the main body of the report so that the description and results in the report may be consistent.

The first change, shown in revised diagram of HUNTEST, allows for a change in the reference L/D for the Up-control phase, LEWD. If the drag is greater than D2, LEWD = LEWD2. Otherwise LEWD = LEWD1.  
(LEWD2 = .2, LEWD1 = .1, D2 = 175 fpss)

The second change shown in the same diagram fixes the constant drag value, D0, at one value (130 fpss) for all entry angles.

The third change uses the weighted average of GAMMAL and GAMMAL1 rather than GAMMAL1 in the calculation of ASPUP.

$$\text{GAMMAL1} = (1 - Q19) \text{GAMMAL1} + Q19 \text{GAMMAL} \dots (Q19 = .2)$$

The revised diagram for the Up-control section shows the next change. In this phase Q7MIN is now used in calculating FACTOR. This is done so that the gains in the Up-control phase will not decrease to zero as the drag approaches Q7. (Q7MIN = 35 fpss) Also, A1 is used instead of A0 in calculating FACTOR. A1 is calculated to be either A0 or D in the HUNTEST section depending on the sign of  $\dot{R}$ . This last calculation is made so that FACTOR will be near one at the start of the Up-control phase so that the full effect of the gains will be had.

Finally, K44 is decreased from 236 to 156 so that down-lift will be held for all entries shallower than mid-entry. This factor has considerable latitude, since there is a large band of entry angles for which the initial lift may be either down or up.



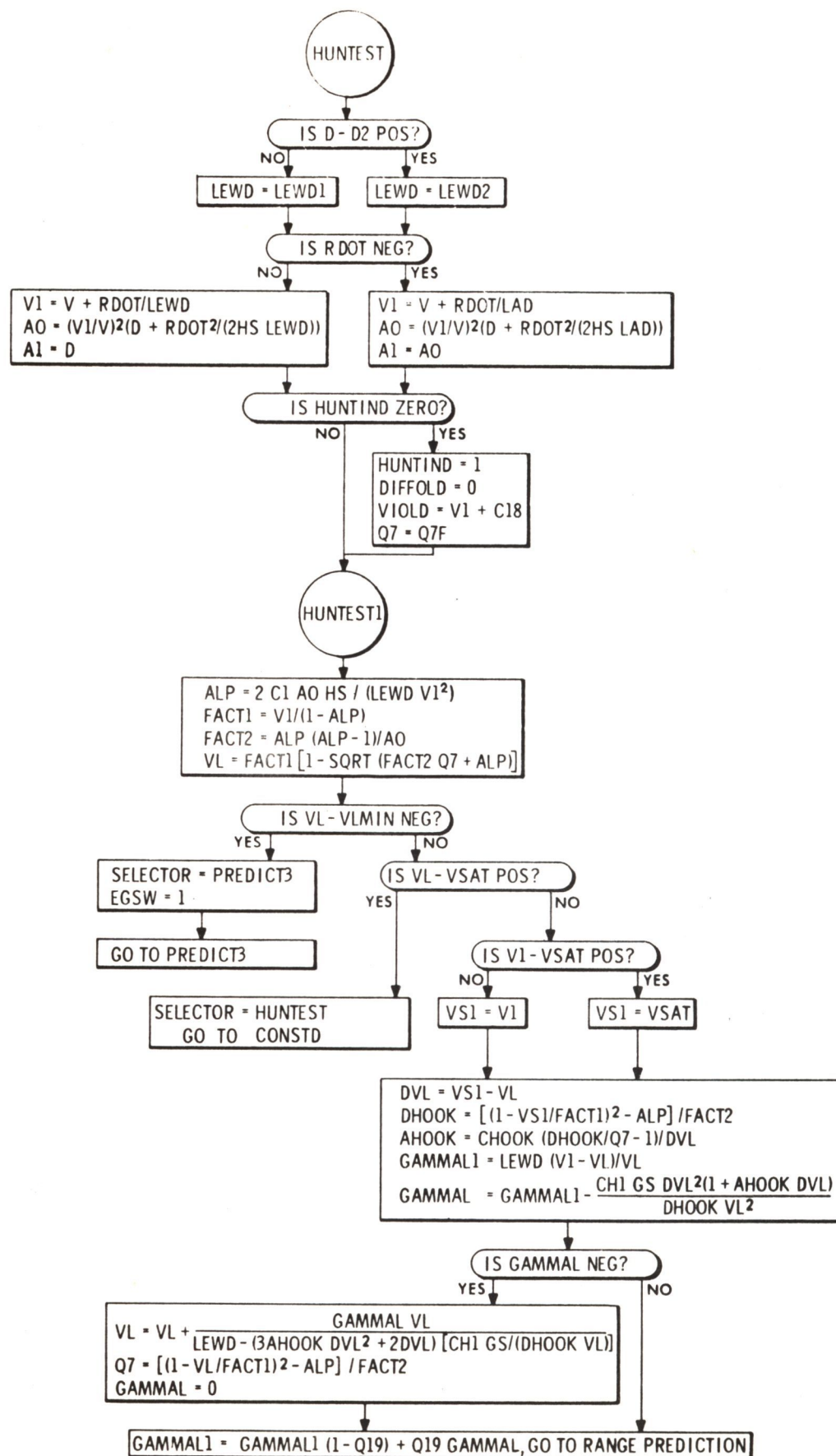


Fig. J-1 Hunttest Section (revised)

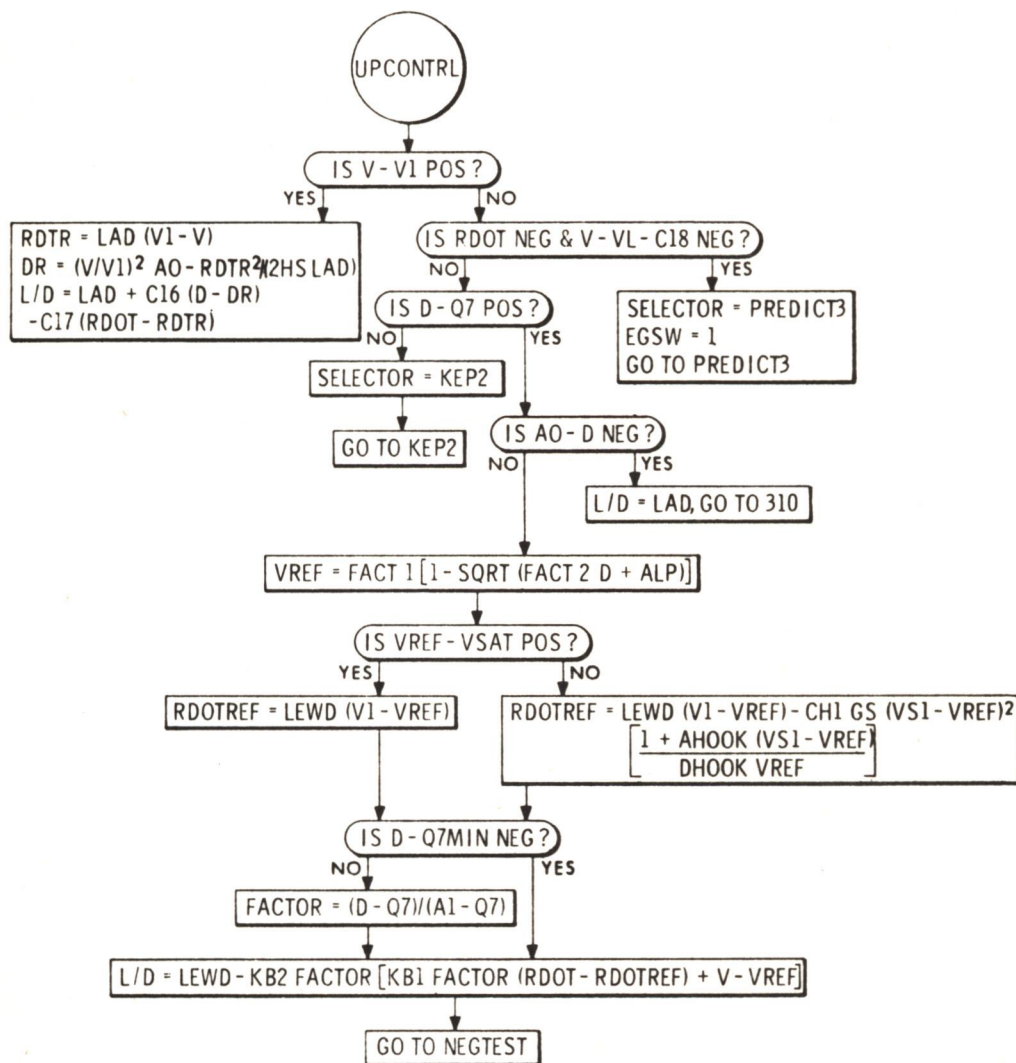


Fig. J-2 Up-control Section (revised)

APPENDIX K  
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