NASA Technical Memorandum 89117

AN ANALYSIS OF THE EFFECT OF AEROASSIST MANEUVERS ON ORBITAL TRANSFER VEHICLE PERFORMANCE

Gregory O. Murphy and

William T. Suit

September 1987

National Aeronautics and Space Administration

Langley Research Center

Hampton, Virginia 23665

ABSTRACT

This paper summarizes a Langley Aerospace Research Summer Scholars (LARSS) research project (Summer 1986) dealing with the topic of the effectiveness of aeroassist maneuvers to accomplish a change in the orbital inclination of an Orbital Transfer Vehicle (OTV). This task was subject to OTV design constraints, chief of which were the axial acceleration (ASMG) and the aerodynamic heating rate (HEATRT) limits of the OTV. The use of vehicle thrust to replace lost kinetic energy and, thereby, to increase the maximum possible change in orbital inclination was investigated. A relation between time in the "hover" orbit and payload to LEO was established. The amount of plane change possible during this type of maneuver was checked for several runs and a possible thrusting procedure to increase the plane change and still get to LEO was suggested. Finally, the sensitivity of various target parameters to controllable independent variables was established, trades between the amount of control allowed, and payload to LEO suggested.

INTRODUCTION

The use of the earth's atmosphere to reduce the energy of a vehicle transferring from geosynchronous orbit to a low-earth orbit has been discussed by many authors; see for example reference 1. In addition to losing energy, aeroassist maneuvers can also be used for making orbital plane changes. Many different types of maneuvers can be used for braking/plane changes depending on the lift to drag ratio (L/D) of the vehicle.

In this paper, a specific maneuver for a vehicle with a maximum L/D of .45 is studied. The vehicle used is described in reference 1, and a sketch of it is shown as figure 1. During this maneuver, the vehicle descends to a perigee altitude based on an allowable maximum heating rate. When the vehicle reaches the desired perigee, the bank angle is varied so that the vehicle stays at approximately perigee altitude for a specified period of time. The vehicle will be close to maximum dynamic pressure at this altitude, and so the forces for braking or plane change will be greatest during this maneuver. After losing energy in this orbit for a specified time, the vehicle will initiate a maneuver to exit the earth's atmosphere to a specific low-earth orbit.

The purpose of this paper is to discuss the trades between time in the maneuver orbit and thrust to get to the specified low-earth orbit. The issue will be "what payload can be delivered to low-earth orbit while meeting other mission constraints?" The paper will also discuss the sensitivity of the maneuvers to the amount of thrusting available for a particular mission. These sensitivities will also indicate how accurately the maneuvers must be performed leading to specifications on guidance and instrumentation systems.

TOOLS AND METHODS OF INVESTIGATION

The computer program used in this investigation is the Program for Optimizing Simulated Trajectories (POST). This program was written in the late seventies and has been revised extensively. Details of the basic program are given in reference 2. The runs used in this investigation begin at a geosynchronous orbit, transfer through the earth's atmosphere for braking, and end in a low-earth orbit. The following scenarios and program steps are common to all runs.

The Orbital Transfer Vehicle (OTV) thrusts until ALTP (projected altitude of perigee) becomes equal to the assigned (variable) value, thus freeing the OTV from an initial circular geocentric orbit and placing it on an elliptical trajectory. Once this is accomplished, the thrusting is ceased and the angle-of-attack (ALPPC) is changed to an assigned value. The elliptical trajectory will intercept the atmosphere near orbital periapse and commence the aeroassist maneuver. The atmosphere is entered into the modeling process as soon as the OTV has descended to an altitude of 400,000 ft. The OTV is allowed to fall through the atmosphere without further manipulation until the flight path angle attains the value of zero (ideally this should occur at an altitude of approximately 250,000 ft. if the angle-of-attack has been properly chosen). Once this happens, the steering guidance option takes over temporarily to hold the flight path angle equal to zero while varying the bank angle to accommodate this. (The use of any other steering variable, other than the bank angle as the independent control variable, achieved nothing worthwhile - usually resulting in wild output as the computer "struggled" to meet its dictates).

For the thrust cases, the steering guidance phase (i.e., the "hovering" phase where the flight path angle is held to zero) lasts for a specified time and is followed by various types of thrusting/maneuvering schemes. For the nonthrust cases, the steering guidance phase lasts only so long as to allow the OTV to possess enough kinetic energy to reescape, via setting the bank angle back to zero and the angle-of-attack to a favorable number after the "hovering" phase has ceased. The details of the individual runs are described later.

PROGRAM PRINCIPLES THROUGHOUT THE USAGE OF THE POST PROGRAM

The line numbers and variables referred to are from the NAMELISTS given in the appendix. The run numbers associated with the name lists correspond to the runs summarized in Table I.

1. The name of the variable to be monitored (minimized) was "measureable acceleration" (i.e., ASMG: see line Number 26).

2. The technique used for "search/optimization" was the "accelerated projected gradient" method (see line Number 5).

3. The "constraint variables" (line Number 9) were ALTA (the projected altitude of orbital apogee) and HEATRT (the aerodynamic heating rate). Both variables were held to +/- 10 units.

4. The "control variables" (line Number 15) were CRITR (event criteria) and BNKPC (the vehicle bank angle).

5. Initial values of the following variables were always as such:

   Initial Altitude (ALTREF) = 19323 n. miles, perigee altitude (ALTP) equals the apogee altitude (ALAA)
   (i.e., the initial orbit is circular)

   Azimuth Reference (AZREF) = 90 degrees

   Vehicle Reference Area (SREF) = 153.94 square feet.

   Orbital Inclination (INC) = 0.0 degrees

Guidance Options (IGUID) = 3,0,1 (i.e.: Euler Steering)

Angle-of-Sideslip (BETPC(1)) = 0 degrees

Bank Angle (BNKPC(1)) = 0 degrees

Angle-of-Attack (ALPPC(1)) = 180 degrees

These are the conditions that exist from the assumed geosynchronous orbit.

RESULTS AND DISCUSSION

This study was developed in two phases. The first was to determine the minimum perigee altitude possible given a specified heating constraint. The second was to examine the effect of spending different amounts of time in an almost constant altitude "hover" trajectory.

The first phase of the study considered the maximum penetration into the atmosphere possible on a return from geocentric orbit (GEO) before allowable peak heating rates are reached. This penetration established the minimum perigee altitude for the aerobraking orbit during a return from GEO. The heating rate was referenced to a unit sphere, and a target heat rate of 180 btu/ft^2-sec was established with an absolute maximum of 185 btu/ft^2-sec. A fixed angle-of-attack was held during the atmospheric entry. These conditions in combination with the weight and aerodynamics of the subject vehicle resulted in the projected perigee altitudes shown in table II and figure 2.

The figure and table show qualitative trends that were predictably demonstrated in run after run for three of the POST parameters. Table II does not present every computer run that was performed, but because the same trends were uniformly and consistently observed, the displayed range of iterations will be sufficient to convey important relationships. As can be seen from figure 2, the periapse altitude is far more potent a parameter for adjusting the aerodynamic heating rate than is the angle-of-attack. It should be noted that as a control effort, all of the samples (data points) have been taken from corresponding segments of given runs where the bank angle (BNKPC) was equal to the constant value of zero.

It can be noticed from the diagram that most of the angles-of-attack were chosen less than 55 degrees or greater than 40 degrees. The reason is that angles-of-attack out of this range tended to cause several variables (especially the bank angle) to experience wild fluctuations which indicated that the computer was having difficulty satisfying those input values. It should also be pointed out that for the thrust cases, the angle-of-attack was usually chosen to be near 53 degrees. This value was the value which produced the greatest coefficient of lift and was, therefore, useful in achieving the maximum plane change from banking maneuvers. For nonthrust cases where conservation of kinetic energy was paramount, the angle-of-attack was usually chosen to be near 45 degrees. This value is the value which produces the greatest ratio of the lift coefficient to the drag coefficient and was, therefore, believed to be best for slicing through the atmosphere with minimal energy loss. As with most phenomena, however, there is a trade-off involved with this even though the OTV may be better suited aerodynamically for conserving energy utilizing the 45-degree angle. It should be remembered that the OTV penetrates significantly farther into the atmosphere than it would using angles with greater

lift coefficients. This causes the OTV to encounter an atmosphere of far greater density during the descent and could significantly exceed the allowable heat rate.

As seen, some of the combinations of angle-of-attack and projected perigee altitude resulted in braking orbits that exceeded that allowable heat rate. The exact optimal angle for the nonthrust cases was not decided upon due to time constraints, and the angle-of-attack versus heat rate trade-off is one area where further research should be conducted. Based on these results, an angle-of-attack of 53 degrees was held throughout the atmospheric pass phase of each mission. This is shown in Table II as an alpha of 53 degrees during entry and an alpha of 53 degrees during exit.

In phase two, the "hover" trajectories entered just after perigee were examined. Several mission scenarios were used. All runs began from a geocentric orbit and ultimately were to end in a low-earth orbit. However, so that the sensitivity of various parts of the trajectories could be analyzed, some of the runs were stopped when the vehicle escaped the atmosphere (400,000 ft. altitude) and the conditions were noted.

Three mission objectives were considered, and they were all related to the time the vehicle stayed in the so-called "hover" trajectory. The first mission was to determine how long the vehicle could stay in the "hover" trajectory and still get to 400,000 feet without thrusting and then how much thrust was required to get the vehicle into a LEO with a 160-nautical-mile apogee.

The second mission was to determine how long the vehicle could stay in the "hover" trajectory and still escape to a LEO with a 160-nautical-mile perigee without any thrusting. The third mission was to determine, if the vehicle stayed in the "hover" trajectory for 300 seconds, how large a plane change would be possible and how much thrust would be required to get the vehicle to a LEO with a 160-nautical-mile perigee. For all missions, the LEO must be circularized to a 160-nautical-mile orbit. The major constraints on the missions are that the heat should not exceed 185 btu/ft^2-sec and the final vehicle weight must be 10,000 pounds.

The first mission scenario will now be discussed. The summary of run 3 from table I indicates that the vehicle could stay in the "hover" trajectory for 149 seconds and still escape to the edge of the atmosphere without any thrusting. Then, with 10.6 seconds of thrusting, the vehicle could be put on a trajectory that would have an apogee of 160 nautical miles. This trajectory would require a delta velocity of 483 ft/sec for circularization, leaving a vehicle weight of 17,900 pounds. The bank angle sequence required to meet the mission requirements resulted in a plane change of 3.29 degrees.

The second mission, when thrust was used before circularization, had a "hover" time of 128 seconds. After circularization into a 160-nautical-mile LEO, the final vehicle weight was 19,288 pounds. Because of the shorter time in the "hover" orbit, the plane change that resulted was 2.86 degrees.

The third mission allowed the vehicle to stay in the "hover" orbit for 300 seconds and then thrust was required to get the vehicle to a 160-nautical-mile apogee. At apogee, thrust was again added to circularize the orbit. The thrusting to obtain a 160-nautical-mile apogee occurred in two ways. First, a single burn occurring after the 300-second "hover" was used to get the vehicle on a trajectory with a 160-nautical-mile apogee. In the second case, a two-burn sequence was used. The first burn was just long enough to get the vehicle to the edge of the atmos-

phere; then, the second burn put the vehicle on a trajectory with a 160-nautical-mile apogee. Run 11 of table I summarizes the results of the one burn mission. The energy loss associated with performing the burn in the atmosphere is apparent. The burn time is long, and, even though the vehicle gets on a trajectory with a 160-nautical-mile apogee, the orbit that the vehicle is on has less energy than those of missions 1 and 2. Therefore, a large velocity change was required for circularization. The final vehicle weight was very close to the 10,000 pound minimum acceptable weight. The longer time in the "hover" orbit resulted in a plane change of 10.84 degrees.

The two burn missions were of two types. Both burned once in the atmosphere to ensure that the vehicle would reach the edge of the atmosphere and then a second time to get the vehicle into an orbit with the desired apogee altitude. The burns were performed in two ways. In run 8, the burns were in the orbital plane and were designed to get the vehicle to a specified apogee altitude. In run 15, the burns were not only designed to achieve a specified apogee altitude but also thrusted out-of-plane to increase the plane change for that mission. The NAMELISTS showing the differences in the instructions to the computer for runs 8 and 15 are given in the appendix. Although no effort was made to optimize the vehicle attitude during run 15, this run was clearly superior to run 8. As seen from the run summaries of Table II, the burns used in run 8 actually reduced the plane change possible from the aerodynamic forces during the 300-second "hover." While the burns achieved the mission objectives, their implementation as specified in the program NAMELIST resulted in a reduced plane change. Also, even though run 15 gave an increased plane change and had a longer burn, the resulting orbit had more energy at apogee than the run 8 orbit so that the circularization thrust was less. The end result was that run 15 had a greater plane change and still delivered more weight to the 160-nautical-mile LEO. The reason for the differences between runs 8 and 15 have not been completely examined, and determining why run 15 was as successful as it was is an area for further study.

For comparison the fuel used for an impulsive maneuver was calculated. The impulsive maneuver was split into two parts for easier comparison, however, this is not an optimal transfer. The fuel required for a 10° plane change was about 3,000 pounds, where a Hohmann transfer between GEO and LEO required about 16,000 pounds of fuel. An all-impulsive transfer and 10 degree plane change could use as much as 19,000 pounds of fuel leaving 8,500 pounds of payload. However, if the transfer was done using an aeroassist maneuver and a 10 degree plane change was done impulsively, the result could be a total plane change of 12.86 degrees with over 16,000 pounds in final orbit. Additional information on the aeroassist and direct impulsive transfers are given in references 3 and 4.

A feature of POST is the calculation of the sensitivity of the target variables to variations in selected independent variables. For the missions examined, the target variables were final apogee altitude and maximum heat rate, and the independent variables considered were perigee altitude of the entry orbit and bank angle. The sensitivities are summarized in Table III. The most important fact illustrated in Table III appears to be that the fewer controls available, the more sensitive the error in perigee altitude. If perigee is missed by 1 nautical mile, then apogee would be in error by 287.8 nautical miles. More significantly, if apogee is to be attained to within 5 nautical miles, then perigee must be attained to within .058 nautical miles. The other runs where thrust is added are not sensitive to perigee altitude. These results illustrate the trade between payload delivered and system sensitivity. By adding thrust, a less accurate guidance system can be used, but at the expense of payload delivered. The heat rate is a function of perigee altitude,

and the perigee is reached before any thrusting is initiated. The table shows that a 1-nautical-mile error in perigee will result in a 10 btu/ft^2-sec change in heat rate. Halving these numbers would give a more acceptable heat rate error, and a perigee error of this magnitude is not unreasonable. The trades implied by Table III are areas for further study.

CONCLUDING REMARKS

Follow-up research continuing the work commenced within this paper can be continued along several avenues. One such avenue is experimentation with the use of criterion variables other than those which can be discontinuous (such as ALTA); another avenue of future research might be an investigation of why or how the propellant burned reaches a maximum value and then falls off when attempting to achieve the goal of plane change via thrusting (see run 15 and Table I). One more area that deserves further observation is that of devising better algorithms or "schemes" for using thrust to achieve various ends (this is related somewhat to the above suggestion that the criterion variables being used should be reconsidered). Much further research can be done concerning the best choice of variables to be included under the POST input file section entitled "CONTROL VARIABLES" (see line number 15 of any of the enclosed programs in the appendix). It has become evident that when the ideal or optimal input is not known, then one should keep the variables included in this section to a minimum. As one closes in after many iterative attempts to the desired output goal, then more variables can be safely classified as control variables.

The current study has established a relation between perigee altitude of the braking trajectory and the heat rate on the vehicle. The method of braking involved staying in a "hover" orbit, where the change in flight path angle equals zero, for specified periods of time to lose energy. The effect of plane changes was investigated. A relation between time in the "hover" orbit and payload to LEO was established. The amount of plane change possible during this type of maneuver was checked for several runs and a possible thrusting procedure to increase the plane change and still get to LEO was suggested. Finally, the sensitivity of various target parameters to controllable independent variables was established, trades between the amount of control allowed, and payload to LEO suggested.

APPENDIX

NAMELISTS FOR SELECTED RUNS

```
L$SEARCH                                                                    --    1 --
 OPT=-1,                                                                    --    2 --
 OPTVAR=6HXMAX1 ,MAXITR=1,PCTCC=.01,                                        --    3 --
  PERT=.01,.1,.1,.1,.1,                                                     --    4 --
   SRCHK   = 4,     / ACCELERATED PROJECTED GRADIENT                        --    5 --
   OPTPH   =1000,                                                           --    6 --
C     *** CONSTRAINT VARIABLES ***                                          --    7 --
   NDEPV   = 2,                                                             --    8 --
   DEPVP   = 6HALTA  ,6HHEATRT,                                             --    9 --
   DEPVAL  =160,180,                                                        --   10 --
  DEPTL =10,10,                                                             --   11 --
   DEPPH   =1000,40,                                                        --   12 --
C     *** CONTROL VARIABLES ***                                             --   13 --
   NINDV=3,                                                                 --   14 --
  INDVR=6HCRITP ,6HBNKPC1,6HCRITR ,                                         --   15 --
 U= 40.3900000,0.0,145,                                                     --   16 --
  INDPH=30,50,50,                                                           --   17 --
 $                                                                          --   18 --
L$GENDAT                                                                    --   19 --
 NPC(1)=3,                                                                  --   20 --
 NPC(15)=1,                                                                 --   21 --
 PRNT(91)=6HXMAX1 ,6HALPHI ,6HBETAI ,6HBANKI ,6HTIMREI ,5HVELAD,5HPSTOP,    --   22 --
 NPC(8)=0,                                                                  --   23 --
 NPC(5)=0,                                                                  --   24 --
 NPC(3)=5,                                                                  --   25 --
 MONX=4HASMC,                                                               --   26 --
  NPC(12)=3,ALTREF=19323,AZREF=90,                                          --   27 --
  LATREF=0,LONREF=0,                                                        --   28 --
 SREF=153.94,                                                               --   29 --
   TITLE=OH*ND17AF*,                                                        --   30 --
   EVENT=1,PRNC=10000,                                                      --   31 --
   FESN=1000,                                                               --   32 --
    DT=10,                                                                  --   33 --
   PINC=1000,                                                               --   34 --
  ALTA=19323,                                                               --   35 --
 ALTP=19323,                                                                --   36 --
  TRUAN=0,                                                                  --   37 --
 INC=0,                                                                     --   38 --
  ARGP=0,                                                                   --   39 --
  LAN=0,                                                                    --   40 --
 PGCLAT=0,                                                                  --   41 --
  WGTSG=27500.0,                                                            --   42 --
  IGUID=3,0,1,                                                              --   43 --
 ALPPC(1)=180,                                                              --   44 --
 BETPC(1)=0,                                                                --   45 --


 BNKPC(1)=0,                                                                --   46 --
 $                                                                          --   47 --
L$TBLMLT    $                                                               --   48 --
L$TAB  TABLE=3HCLT,1,5HALPHA,16,3*1,                                        --   49 --
 0,.51727,4,.48391,8,.59023,12,.56354,16,.66854,20,.80837,                  --   50 --
 24,.97468,28,1.15744,32,1.34564,36,1.52768,40,1.69200,                     --   51 --
 44,1.82750,48,1.92421,52,1.97352,56,1.96870,60,1.90314,                    --   52 --
 $                                                                          --   53 --
L$TAB  TABLE=3HCDT,1,5HALPHA,16,3*1,                                        --   54 --
 0,1.52732,4,1.63046,8,1.73721,12,1.85542,16,1.99509,20,2.16082,            --   55 --
 24,2.35749,28,2.59024,32,2.86042,36,3.16615,40,3.51087,                    --   56 --
 44,3.88398,48,4.28041,52,4.69117,56,5.10583,60,5.51361,                    --   57 --
 ENDPHS=1 $                                                                 --   58 --
L$GENDAT                                                                    --   59 --
 EVENT=20,CRITP=6HTIME   ,VALUE=20,DT=1,PINC=200,NPC(9)=1 $                 --   60 --
L$TBLMLT                                                                    --   61 --
 $                                                                          --   62 --
L$TAB                                                                       --   63 --
 TABLE=6HTVCIT ,0,46000 $                                                   --   64 --
L$TAB                                                                       --   65 --
 TABLE=6HWDOT  ,0,100,ENDPHS=1 $                                            --   66 --
L$GENDAT                                                                    --   67 --
 EVENT=30,CRITR=6HALTP   ,NPC(9)=0,DT=1000,IGUID=0,0,1,PINC=10000,          --   68 --
 NPC(2)=4,                                                                  --   69 --
  ALPPC(1)=53,ENDPHS=1 $                                                    --   70 --
L$GENDAT                                                                    --   71 --
 EVENT=35,CRITR=6HALTITD,VALUE=40000,NPC(5)=2,NPC(8)=2,PINC=10,PRNC=0,      --   72 --
 NPC(2)=1,DT=1,                                                             --   73 --
 ENDPHS=1,DTIMR=1 $                                                         --   74 --
L$GENDAT                                                                    --   75 --
 EVENT=40,CRITR=6HGAMMAI,VALUE=0,NDEPVS=1,DEPVRS=5HGAMAD,DEPVLS=0,          --   76 --
 DEPTLS=.01,US=90,ALPPC(1)=53,ENDPHS=1,INDVRS=6HBNKPC1  $                   --   77 --
L$GENDAT                                                                    --   78 --
 EVENT=50,CRITR=5HTDUMP,VALUE=145,NDEPVS=0,                                 --   79 --
 ENDPHS=1  $                                                                --   80 --
L$GENDAT                                                                    --   81 --
 EVENT=60,CRITR=6HALTITD,VALUE=40000,NPC(9)=1,ENDPHS=1  $                   --   82 --
L$GENDAT                                                                    --   83 --
 EVENT=70,CRITR=4HALTA,VALUE=160,NPC(9)=0,ENDPHS=1  $                       --   84 --
L$GENDAT                                                                    --   85 --
 EVENT=1000,CRITR=6HGAMMAI,VALUE=0,ENDPHS=1,ENDPPR=1,ENDJOB=1  $            --   86 --
```

```
 LSSEARCH                                                                -- 1 --
  OPT=-1,                                                                -- 2 --
  OPTVAR=6HXMAX1 ,MAXITR=1,PCTCC=.01,                                    -- 3 --
   PERT=.01,.1,.1,.1,.1,                                                 -- 4 --
    SRCHM   = 4,     / ACCELERATED PROJECTED GRADIENT                    -- 5 --
    OPTPH   =1000,                                                       -- 6 --
C     *** CONSTRAINT VARIABLES ***                                       -- 7 --
    NDEPV   = 2,                                                         -- 8 --
    DEPVR   = 6HALTA  ,6HHEATRT,                                         -- 9 --
    DEPVAL  =160,180,                                                    -- 10 --
   DEPTL =10,10,                                                         -- 11 --
    DEPPH   =1000,40,                                                    -- 12 --
C     *** CONTROL VARIABLES ***                                          -- 13 --
    NINDV=3,                                                             -- 14 --
   INDVR=6HCRITR ,6HBNKPC1,6HCRITR ,                                     -- 15 --
  U= 40.3900000,0.0,133,                                                 -- 16 --
   INDPH=30,50,50,                                                       -- 17 --
  $                                                                      -- 18 --
 LSGENDAT                                                                -- 19 --
  NPC(1)=3,                                                              -- 20 --
  NPC(15)=1,                                                             -- 21 --
  PRNT(91)=6HXMAX1 ,6HALPHI ,6HBETAI ,6HBANKI ,6HTIMRFI ,5HVELAD,5HPSTOP,  -- 22 --
  NPC(8)=0,                                                              -- 23 --
  NPC(5)=0,                                                              -- 24 --
  NPC(3)=5,                                                              -- 25 --
  MONX=4HASMG,                                                           -- 26 --
   NPC(12)=3,ALTREF=19323,AZREF=90,                                      -- 27 --
   LATREF=0,LONREF=0,                                                    -- 28 --
  SREF=153.94,                                                           -- 29 --
    TITLE=DH*JUL17*,                                                     -- 30 --
   EVENT=1,PRNC=10000,                                                   -- 31 --
    FESN=1000,                                                           -- 32 --
     DT=10,                                                              -- 33 --
    PINC=1000,                                                           -- 34 --
   ALTA=19323,                                                           -- 35 --
  ALTP=19323,                                                            -- 36 --
   TRUAN=0,                                                              -- 37 --
  INC=0,                                                                 -- 38 --
   ARGP=0,                                                               -- 39 --
   LAN=0,                                                                -- 40 --
  PGCLAT=0,                                                              -- 41 --
   WGTSG=27500.0,                                                        -- 42 --
   IGUID=3,0,1,                                                          -- 43 --
  ALPPC(1)=180,                                                          -- 44 --
  BETPC(1)=0,                                                            -- 45 --

  BNKPC(1)=0,                                                            -- 46 --
  $                                                                      -- 47 --
 LSTBLMLT    $                                                           -- 48 --
 LSTAB  TABLE=3HCLT,1,5HALPHA,16,3*1,                                    -- 49 --
  0,.51727,4,.48391,8,.50023,12,.56354,16,.66854,20,.80837,              -- 50 --
  24,.97488,28,1.15744,32,1.34564,36,1.52768,40,1.69200,                 -- 51 --
  44,1.82750,48,1.92421,52,1.97352,56,1.98870,60,1.90314,                -- 52 --
  $                                                                      -- 53 --
 LSTAB  TABLE=3HCDT,1,5HALPHA,16,3*1,                                    -- 54 --
  0,1.52732,4,1.63046,8,1.73721,12,1.85542,16,1.99509,20,2.16082,        -- 55 --
  24,2.35749,28,2.59024,32,2.86042,36,3.16819,40,3.51087,                -- 56 --
  44,3.88398,48,4.28041,52,4.69117,56,5.10583,60,5.51361,                -- 57 --
  ENDPHS=1 $                                                             -- 58 --
 LSGENDAT                                                                -- 59 --
  EVENT=20,CRITR=6HTIME  ,VALUE=20,DT=1,PINC=200,NPC(9)=1 $              -- 60 --
 LSTBLMLT                                                                -- 61 --
  $                                                                      -- 62 --
 LSTAB                                                                   -- 63 --
  TABLE=6HTVC1T ,0,46000 $                                               -- 64 --
 LSTAB                                                                   -- 65 --
  TABLE=6HWD1T  ,0,100,ENDPHS=1 $                                        -- 66 --
 LSGENDAT                                                                -- 67 --
  EVENT=30,CRITR=6HALTP  ,NPC(9)=0,DT=1000,IGUID=0,0,1,PINC=10000,       -- 68 --
  NPC(2)=4,                                                              -- 69 --
   ALPPC(1)=53,ENDPHS=1 $                                                -- 70 --
 LSGENDAT                                                                -- 71 --
  EVENT=35,CRITR=6HALTITD,VALUE=400000,NPC(5)=2,NPC(8)=2,PINC=10,PRNC=0, -- 72 --
  NPC(2)=1,DT=1,                                                         -- 73 --
  ENDPHS=1,DTIMR=1 $                                                     -- 74 --
 LSGENDAT                                                                -- 75 --
  EVENT=40,CRITR=6HGAMMAI,VALUE=0,NDEPVS=1,DEPVRS=5HGAMAD,DEPVLS=0,      -- 76 --
  DEPTLS=.0001,US=90,ALPPC(1)=53,ENDPHS=1,INDVRS=6HBNKPC1  $             -- 77 --
 LSGENDAT                                                                -- 78 --
  EVENT=50,CRITR=5HTDURP,VALUE=133,NDEPVS=0,                             -- 79 --
  ENDPHS=1  $                                                            -- 80 --
 LSGENDAT                                                                -- 81 --
  EVENT=60,CRITR=6HALTITD,VALUE=400000,ENDPHS=1  $                       -- 82 --
 LSGENDAT                                                                -- 83 --
  EVENT=1000,CRITR=6HGAMMAI,VALUE=0,ENDPHS=1,ENDPRB=1,ENDJOB=1  $        -- 84 --
```

```
LSSEARCH                                                                    --   1 --
 OPT=-1,                                                                    --   2 --
 OPTVAR=6HYMAX1 ,MAX1TP=3,PCTCC=.001,                                       --   3 --
  PERT=.01,.1,.1,.1,.1,                                                     --   4 --
   SRCHM   = 4,     / ACCELERATED PROJECTED GRADIENT                        --   5 --
   OPTPH   =1000,                                                           --   6 --
C     *** CONSTRAINT VARIABLES ***                                          --   7 --
   NDEPV   = 2,                                                             --   8 --
   DEPVP   = 6HALTA  ,6HHEATRT,                                             --   9 --
   DEPVAL  =78,1*0,                                                         --  10 --
  DEPTL =10,5,                                                              --  11 --
   DEPPH   =55,40,                                                          --  12 --
C     *** CONTROL VARIABLES ***                                             --  13 --
   NINDV=2,                                                                 --  14 --
  INDVP=6HCRITP ,6HBNKPC1,                                                  --  15 --
 U= 40.3900000,0.0,                                                         --  16 --
  INDPH=30,50,                                                              --  17 --
 $                                                                          --  18 --
LSGENDAT                                                                    --  19 --
 NPC(1)=3,                                                                  --  20 --
 NPC(15)=1,                                                                 --  21 --
 PRNT(91)=6HXMAX1 ,6HALPHI ,6HBETAI ,6HBANKI ,6HTIMRF1 ,5HVELAD,5HPSTOP,    --  22 --
 NPC(8)=0,                                                                  --  23 --
 NPC(5)=0,                                                                  --  24 --
 NPC(3)=5,                                                                  --  25 --
 MONX=44ASMG,                                                               --  26 --
  NPC(12)=3,ALTREF=19323,AZREF=90,                                          --  27 --
  LATREF=0,LONREF=0,                                                        --  28 --
 SPEF=153.94,                                                               --  29 --
   TITLE=0H*LAST22-ANSWERING Q NO 2A*,                                      --  30 --
   EVENT=1,PRNC=10000,                                                      --  31 --
   FESN=1000,                                                               --  32 --
    DT=10,                                                                  --  33 --
   PINC=1000,                                                               --  34 --
  ALTA=19323,                                                               --  35 --
 ALTP=19323,                                                                --  36 --
  TRUAN=0,                                                                  --  37 --
 INC=0,                                                                     --  38 --
  ARGP=0,                                                                   --  39 --
  LAN=0,                                                                    --  40 --
 PGCLAT=0,                                                                  --  41 --
  WGTSC=27500.0,                                                            --  42 --
  IGUID=3,0,1,                                                              --  43 --
 ALPPC(1)=180,                                                              --  44 --
 BFTPC(1)=0,                                                                --  45 --


 BNKPC(1)=0,                                                                --  46 --
 $                                                                          --  47 --
LSTBLMLT    $                                                               --  48 --
LSTAB  TABLE=3HCLT,1,5HALPHA,16,3*1,                                        --  49 --
 0,.51727,4,.48391,8,.50023,12,.56354,16,.66854,20,.80837,                  --  50 --
 24,.97488,28,1.15744,32,1.34564,36,1.52768,40,1.69200,                     --  51 --
 44,1.82750,48,1.92421,52,1.97352,56,1.96870,60,1.90314,                    --  52 --
 $                                                                          --  53 --
LSTAB  TABLE=3HCDT,1,5HALPHA,16,3*1,                                        --  54 --
 0,1.52732,4,1.63046,8,1.73721,12,1.85542,16,1.99509,20,2.16082,            --  55 --
 24,2.35749,28,2.59024,32,2.86042,36,3.16815,40,3.51087,                    --  56 --
 44,3.88398,48,4.28641,52,4.69217,56,5.10583,60,5.51361,                    --  57 --
 ENDPHS=1 $                                                                 --  58 --
LSGENDAT                                                                    --  59 --
 EVENT=20,CRITP=6HTIME  ,VALUE=20,DT=1,PINC=20,,NPC(9)=1 $                  --  60 --
LSTBLMLT                                                                    --  61 --
 $                                                                          --  62 --
LSTAB                                                                       --  63 --
 TABLE=6HTVC1T ,0,46000 $                                                   --  64 --
LSTAB                                                                       --  65 --
 TABLE=6HWD1T  ,0,100,ENDPHS=1 $                                            --  66 --
LSGENDAT                                                                    --  67 --
 EVENT=30,CRITP=6HALTP  ,NPC(9)=0,DT=1000,IGUID=0,0,1,PINC=10000,           --  68 --
 NPC(2)=4,                                                                  --  69 --
  ALPPC(1)=53,ENDPHS=1 $                                                    --  70 --
LSGENDAT                                                                    --  71 --
 EVENT=35,CRITP=6HALTITD,VALUE=400000,NPC(5)=2,NPC(8)=2,PINC=10,PRNC=0,     --  72 --
 NPC(2)=1,DT=1,                                                             --  73 --
 ENDPHS=1,DTIMR=1 $                                                         --  74 --
LSGENDAT                                                                    --  75 --
 EVENT=40,CRITP=6HGAMMAI,VALUE=0,NDEPVS=1,DEPVPS=5HGAMAD,DEPVLS=0,          --  76 --
 DEPTLS=.0001,US=90,ALPPC(1)=53,ENDPHS=1,INDVPS=6HBNKPC1  $                 --  77 --
LSGENDAT                                                                    --  78 --
 EVENT=50,CRITP=5HTDURP,VALUE=300,NDEPVS=0,                                 --  79 --
 ENDPHS=1,NPC(9)=1  $                                                       --  80 --
LSGENDAT                                                                    --  81 --
 EVENT=55,CRITP=6HALTA  ,VALUE=78,NPC(9)=0,ENDPHS=1  $                      --  82 --
LSGENDAT                                                                    --  83 --
 EVENT=60,CRITP=6HALTITD,VALUE=400000,NPC(9)=1,ENDPHS=1  $                  --  84 --
LSGENDAT                                                                    --  85 --
 EVENT=90,CRITP=6HALTA  ,VALUE=160,NPC(9)=0,ENDPHS=1  $                     --  86 --
LSGENDAT                                                                    --  87 --
 EVENT=1000,CRITP=6HGAMMAI,VALUE=0,ENDPHS=1,ENDJOB=1  $                     --  88 --
```

```
LSSEARCH                                                                    --    1 --
 OPT=-1,                                                                    --    2 --
 OPTVAR=6HXMAX1 ,MAXITR=3,PCTCC=.001,                                       --    3 --
  PERT=.01,.1,.1,.1,.1,                                                     --    4 --
   SRCHM    = 4,     / ACCELERATED PROJECTED GRADIENT                       --    5 --
   OPTPH    =100,                                                          --    6 --
C     *** CONSTRAINT VARIABLES ***                                          --    7 --
   NDEPV    = 2,                                                           --    8 --
   DEPVP    = 6HALTA  ,6HHEATFT,                                           --    9 --
   DEPVAL   =180,140,                                                      --   10 --
  DEPTL =1.,5,                                                             --   11 --
   DEPPH    =1000,40,                                                      --   12 --
C     *** CONTROL VARIABLES ***                                             --   13 --
   NINDV=4,                                                                 --   14 --
  INDVP=6HCPITP ,6HBNKPC1,6HALPPC1,6HALPPC1,                                --   15 --
 U= 40.3600000,0.0,55,53,                                                   --   16 --
  INDPH=30,50,40,50,                                                        --   17 --
 $                                                                          --   18 --
LSGENDAT                                                                    --   19 --
 NPC(1)=3,                                                                  --   20 --
 NPC(15)=1,                                                                 --   21 --
 PRNT(91)=6HXMAX1 ,6HALPHI ,6HRETAI ,6HBANKI ,6HTIMRF1 ,5HVELAD,5HPSTOP,    --   22 --
 NPC(8)=0,                                                                  --   23 --
 NPC(5)=0,                                                                  --   24 --
 NPC(3)=5,                                                                  --   25 --
 MONX=4HASMG,                                                               --   26 --
  NPC(12)=3,ALTREF=19323,AZREF=90,                                          --   27 --
  LATREF=0,LONREF=0,                                                        --   28 --
 SREF=153.94,                                                               --   29 --
   TITLE=6H*JUL15D*,                                                        --   30 --
   EVENT=1,PRNC=10000,                                                      --   31 --
   FESN=1000,                                                               --   32 --
    DT=10,                                                                  --   33 --
   PINC=1000,                                                               --   34 --
  ALTA=19323,                                                               --   35 --
 ALTP=19323,                                                                --   36 --
  TRUAN=0,                                                                  --   37 --
 INC=0,                                                                     --   38 --
  ARGP=0,                                                                   --   39 --
  LAN=0,                                                                    --   40 --
 PGCLAT=0,                                                                  --   41 --
  WGTSG=27500.0,                                                            --   42 --
  IGUID=3,0,1,                                                              --   43 --
 ALPPC(1)=180,                                                              --   44 --
 BETPC(1)=0,                                                                --   45 --


 BNKPC(1)=0,                                                                --   46 --
 $                                                                          --   47 --
LSTBLMLT    ¶                                                               --   48 --
 1STAB  TABLE=3HCLT,1,5HALPHA,16,3*1,                                       --   49 --
  0,.51727,4,.48391,8,.50023,12,.56354,16,.66854,20,.80837,                 --   50 --
  24,.97488,28,1.15744,32,1.34564,36,1.52768,40,1.69200,                    --   51 --
  44,1.82759,48,1.92421,52,1.97252,56,1.98870,60,1.98314,                   --   52 --
  $                                                                         --   53 --
LSTAB  TABLE=3HCDT,1,5HALPHA,16,3*1,                                        --   54 --
 0,1.52737,4,1.63046,8,1.73721,12,1.85542,16,1.99509,20,2.16082,            --   55 --
 24,2.35749,28,2.59024,32,2.86042,36,3.16815,40,3.51087,                    --   56 --
 44,3.88398,48,4.28041,52,4.69117,56,5.10593,60,5.51361,                    --   57 --
 ENDPHS=1 $                                                                 --   58 --
LSGENDAT                                                                    --   59 --
 EVENT=20,CRITP=6HTIME  ,VALUE=20,DT=1,PINC=200,NPC(9)=1 $                  --   60 --
LSTBLMLT                                                                    --   61 --
 $                                                                          --   62 --
LSTAB                                                                       --   63 --
 TABLE=6HTVC1T ,0,46000 $                                                   --   64 --
LSTAB                                                                       --   65 --
 TABLE=6HWD1T  ,0,100,ENDPHS=1 $                                            --   66 --
LSGENDAT                                                                    --   67 --
 EVENT=30,CRITP=6HALTP  ,NPC(9)=0,DT=1000,IGUID=0,0,1,PINC=10000,           --   68 --
 NPC(2)=4,                                                                  --   69 --
  ALPPC(1)=53,ENDPHS=1 $                                                    --   70 --
LSGENDAT                                                                    --   71 --
 EVENT=35,CRITP=6HALTITD,VALUE=400000,NPC(5)=2,NPC(8)=2,PINC=10,PRNC=0,     --   72 --
 NPC(2)=1,DT=1,                                                             --   73 --
 ENDPHS=1,DTIMR=1 $                                                         --   74 --
LSGENDAT                                                                    --   75 --
 EVENT=40,CRITP=6HGAMMAI,VALUE=0,NDEPVS=1,DEPVRS=5HGAMAD,DEPVLS=0,          --   76 --
 DEPTLS=.01,US=90,ALPPC(1)=53,ENDPHS=1,INDVPS=6HBNKPC1  $                   --   77 --
LSGENDAT                                                                    --   78 --
 EVENT=50,CRITP=5HTDUPP,VALUE=300,NDEPVS=0,                                 --   79 --
 ENDPHS=1,NPC(9)=1  $                                                       --   80 --
LSGENDAT                                                                    --   81 --
 EVENT=60,CRITP=5HALTA  ,VALUE=100,NPC(9)=0,ENDPHS=1  $                     --   82 --
LSGENDAT                                                                    --   83 --
 EVENT=100,CRITP=6HGAMMAI,VALUE=0,NDEPVS=1,ENDPHS=1,ENDJOB=1  $             --   84 --
```

```
L$SEARCH                                                                    --    1 --
 OPT=-1,                                                                    --    2 --
 OPTVAR=6HYMAX1 ,MAXITR=3,PCTCC=.001,                                       --    3 --
  PERT=.01,.1,.1,.1,.1,                                                     --    4 --
   SRCHM   = 4,     / ACCELERATED PROJECTED GRADIENT                        --    5 --
   OPTPH   =1000,                                                           --    6 --
C     *** CONSTRAINT VARIABLES ***                                          --    7 --
   NDEPV   =2,                                                              --    8 --
   DEPVR   =6HALTA  ,6HHEATPT,                                              --    9 --
   DEPVAL  =100,180,                                                        --   10 --
  DEPTL =100,5,                                                             --   11 --
   DEPPH   =100,40,                                                         --   12 --
C     *** CONTROL VARIABLES ***                                             --   13 --
   NINDV=3,                                                                 --   14 --
  INDVR=6HCRITP ,6HBNKPC1,6HBNKPC1,                                         --   15 --
 U= 40.3*600(C,90.0,0.0,                                                    --   16 --
  INDPH=30,50,55,                                                           --   17 --
 $                                                                          --   18 --
L$GENDAT                                                                    --   19 --
 NPC(1)=3,                                                                  --   20 --
 NPC(15)=1,                                                                 --   21 --
 PRNT(91)=6HYMAX1 ,6HALPHI ,6HBETAI ,6HBANKI ,6HTIMREF1 ,5HVELAD,5HPSTOP,   --   22 --
 NPC(8)=0,                                                                  --   23 --
 NPC(5)=0,                                                                  --   24 --
 NPC(3)=5,                                                                  --   25 --
 MUNX=4HASMG,                                                               --   26 --
  NPC(12)=3,ALTREF=19323,AZREF=90,                                          --   27 --
  LATREF=0,LONREF=0,                                                        --   28 --
 SREF=153.94,                                                               --   29 --
   TITLE=6H*DEL72R-TWO BURN DELTA I MAX*,                                   --   30 --
   EVENT=1,PRNC=10000,                                                      --   31 --
   FESN=1000,                                                               --   32 --
    DT=10,                                                                  --   33 --
   PINC=1000,                                                               --   34 --
  ALTA=19323,                                                               --   35 --
 ALTP=19323,                                                                --   36 --
  TKUAN=0,                                                                  --   37 --
 INC=0,                                                                     --   38 --
  APGP=0,                                                                   --   39 --
  LAN=0,                                                                    --   40 --
 PGCLAT=0,                                                                  --   41 --
  WGTSG=27500.0,                                                            --   42 --
  IGUID=3,0,1,                                                              --   43 --
 ALPPC(1)=100,                                                              --   44 --
 BETPC(1)=0,                                                                --   45 --


 BNKPC(1)=0,                                                                --   46 --
 $                                                                          --   47 --
L$TBLMLT    $                                                               --   48 --
L$TAB  TABLE=3HCLT,1,5HALPHA,16,3*1,                                        --   49 --
 0,.51727,4,.48391,8,.50023,12,.56354,16,.66854,20,.80837,                  --   50 --
 24,.97488,28,1.15744,32,1.34564,36,1.52768,40,1.69200,                     --   51 --
 44,1.82750,48,1.92421,52,1.97352,56,1.98670,60,1.90314,                    --   52 --
 $                                                                          --   53 --
L$TAB  TABLE=3HCDT,1,5HALPHA,16,3*1,                                        --   54 --
 0,1.52732,4,1.63046,8,1.73721,12,1.85542,16,1.99509,20,2.16082,            --   55 --
 24,2.35749,28,2.59024,32,2.86042,36,3.16815,40,3.51087,                    --   56 --
 44,3.88398,48,4.28041,52,4.69117,56,5.10583,60,5.51361,                    --   57 --
 ENDPHS=1 $                                                                 --   58 --
L$GENDAT                                                                    --   59 --
 EVENT=20,CRITR=6HTIME  ,VALUE=20,DT=1,PINC=200,NPC(9)=1 $                  --   60 --
L$TBLMLT                                                                    --   61 --
 $                                                                          --   62 --
L$TAB                                                                       --   63 --
 TABLE=6HTVC1T ,0,46000 $                                                   --   64 --
L$TAB                                                                       --   65 --
 TABLE=6HVD1T  ,0,100,ENDPHS=1 $                                            --   66 --
L$GENDAT                                                                    --   67 --
 EVENT=30,CRITR=6HALTP  ,NPC(9)=0,DT=1000,IGUID=0,0,1,PINC=10000,           --   68 --
 NPC(2)=4,                                                                  --   69 --
  ALPPC(1)=53,ENDPHS=1 $                                                    --   70 --
L$GENDAT                                                                    --   71 --
 EVENT=35,CRITR=6HALTITD,VALUE=400000,NPC(5)=2,NPC(8)=2,PINC=10,PRNC=0,     --   72 --
 NPC(2)=1,DT=1,                                                             --   73 --
 ENDPHS=1,DTMAX=1 $                                                         --   74 --
L$GENDAT                                                                    --   75 --
 EVENT=40,CRITR=6HGAMMAI,VALUE=0,NDEPVS=1,DEPVRS=5HGAMAD,DEPVLS=0,          --   76 --
 DEPTLS=.0001,US=90,ALPPC(1)=52,ENDPHS=1,INDVRS=6HBNKPC1  $                 --   77 --
L$GENDAT                                                                    --   78 --
 EVENT=50,CRITR=5HTDURP,VALUE=300,NDEPVS=0,                                 --   79 --
 ENDPHS=1,NPC(9)=1,BNKPC(1)=90  $                                           --   80 --
L$GENDAT                                                                    --   81 --
 EVENT=55,CRITR=6HWEIGHT,VALUE=161CC,ENDPHS=1,BNKPC(1)=0 $                  --   82 --
L$GENDAT                                                                    --   83 --
 EVENT=57,CRITR=5HALTA  ,VALUE=78,NPC(9)=0,ENDPHS=1  $                      --   84 --
L$GENDAT                                                                    --   85 --
 EVENT=60,CRITR=5HALTITD,VALUE=413400,NPC(9)=1,ENDPHS=1  $                  --   86 --
L$GENDAT                                                                    --   87 --
 EVENT=65,CRITR=6HALTA  ,VALUE=160,NPC(9)=0,ENDPHS=1  $                     --   88 --
L$GENDAT                                                                    --   89 --
 EVENT=70,CRITR=6HGAMMAI,VALUE=0,ENDEPS=1,ENDPHS=1,ENDDIR=1  $              --   90 --
```

REFERENCES

1. Blosser, M. L.; Scotti, S. J.; Cerro, J. A.; Powell, R. W.; Jackson, L. R.; and Cruz, C. I.: "Design Study of a Slant-Nose-Cylinder Aeroassisted Orbital Transfer Vehicle", AIAA-85-0966, AIAA 20th Thermophysics Conference, Williamsburg, VA, June 1985.

2. Braner, G. L.; Cornick, D. E.; and Stevenson, R.: "Capabilities and Applications of the Program to Optimize Simulated Trajectories (POST)", NASA CR-2770, February 1977.

3. Walberg, Gerald D.: "A Review of Aeroassisted Orbit Transfer," AIAA Paper No. 82-1378, AIAA 9th Atmospheric Flight Mechanics Conference, San Diego, CA, August 1982.

4. Mease, Kenneth D.; and Vinh, Nguyen X.: "Minimum-Fuel Aeroassisted Coplaner Orbit Transfer Using Lift Modulation," Journal of Guidance, Control, and Dynamics, Vol. 8, No. 1, January-February 1985, pp. 134-141.

TABLE I MISSION SUMMARY

Run #	Heat Rate Btu/ft^2 Sec	Time of Hover, Sec	Number of Burns	Total Burn Time, Sec	ALPHA, DEG Entry, Exit	Plane Change, Deg.	Perigee Altitude NM
3	180.0	149	1	10.6	53/53	3.29	40.38
6	180.9	128	0	0	53/53	2.86	40.28
8	180.0	300	2	40.3	53/53	6.75	40.39
11	181.1	300	1	60.24	53/53	10.84	40.38
15	180.4	300	2	42.20	53/53	13.72	40.38

Run #	Able to Circularize	Del. Vel. to Circularize ft/sec	Final Weight, lb
3	Yes	483.0	17,900.0
6	Yes	354.4	19,288.0
8	Yes	1,991.0	13,752.0
11	Yes	5,510.0	10,108.0
15	Yes	1,694.0	13,950.0

TABLE II QUALITATIVE BEHAVIOR OF PARAMETERS: HEAT RATE, PERIAPSE, AND ANGLE OF ATTACK

Projected Perigee Alt. [ALTP] Nautical Miles	Heat Rate [HEATRT] Btu/Ft.^{2}-Sec.	Angle of Attack [ALPPC] Degrees
37.29	210	55
37.29	211	53
37.29	213	50
37.29	208	60
37.29	267	20
37.29	206	65
37.29	207.3	62
37.29	209	57
38	218	40
38	216	40
38	200	60
38	209	45
38	203	50
38	199	55
38	211	45
40	189	45
40	182	55
40	189	45
40	182	55
40	185	50
40	184.5	50
40	179	60
40	184	55
40	189	45
40	194	40
40	185	50
40	194	40
40.1	182	52
40.2	181	54
40.2	181.9	52
40.3	181.2	52
40.3	180	54
40.4	179.5	54
40.4	180.4	52
40.5	178.7	54
40.5	179.6	52
40.6	177.8	54
40.6	178.7	52
42	161	55
42	160.8	60
42	163	50
42	166	45
42	170	40
45	124.9	60
45	125	65
45	125	60
45	125	55
45	126	50

TABLE II QUALITATIVE BEHAVIOR OF PARAMETERS: HEAT RATE, PERIAPSE, AND ANGLE OF ATTACK (CON'T)

Projected Perigee Alt. [ALTP] Nautical Miles	Heat Rate [HEATRT] Btu/Ft.^{2}-Sec.	Angle of Attack [ALPPC] Degrees
38	201	55
40	189	45
40	189	45
40	189	45
40.1	182.7	52
40.2	181.9	52
40.3	180.3	54
40.3	180.3	54
40.35	180.4	53
40.35	180.4	53
40.5	179.6	52
41	179.1	45
41	175.2	51

TABLE III SENSITIVITIES

Run #	$\frac{\Delta \text{ Apogee Alt.}}{\Delta \text{ Perigee Alt}}$	$\frac{\Delta \text{ Apogee Alt.}}{\Delta \text{ Bank Angle}}$	$\frac{\Delta \text{ Heat Rate}}{\Delta \text{ Perigee Alt.}}$	$\frac{\Delta \text{ Heat Rate}}{\Delta \text{ Bank Angle}}$
3	-4.9	0	-10.0	0
6	287.8	0	-10.0	0
8	0.0	0	-10.0	0
11	-14.5	0	-9.9	0
15	-.5	0	-10.0	0

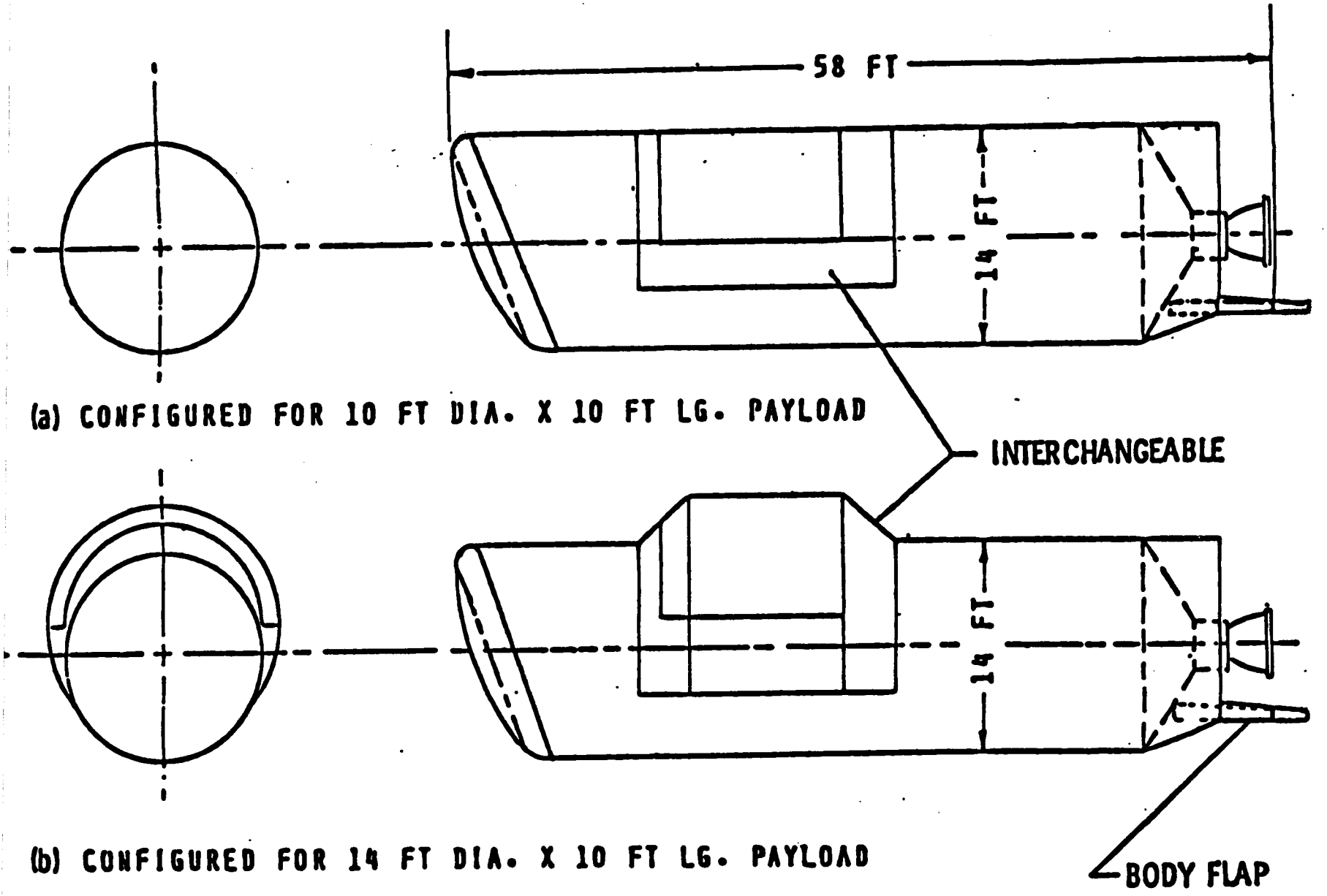

FIGURE 1. SLANTED-NOSE-CYLINDER AOTV

NASA
National Aeronautics and Space Administration

Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NASA TM-89117		

4. Title and Subtitle

An Analysis of the Effect of Aeroassist Maneuvers on Orbital Transfer Vehicle Performance

5. Report Date

September 1987

6. Performing Organization Code

7. Author(s)

Gregory O. Murphy*
William T. Suit

8. Performing Organization Report No.

10. Work Unit No.

506-46-21-01

9. Performing Organization Name and Address

NASA Langley Research Center
Hampton, VA 23665-5225

11. Contract or Grant No.

13. Type of Report and Period Covered

Technical Memorandum

12. Sponsoring Agency Name and Address

National Aeronautics and Space Administration
Washington, DC 20546-0001

14. Sponsoring Agency Code

15. Supplementary Notes

* Langley Aerospace Research Summer Scholar (LARSS)

16. Abstract

This paper summarizes a Langley Aerospace Research Summer Scholars (LARSS) research project (Summer 1986) dealing with the topic of the effectiveness of aeroassist maneuvers to accomplish a change in the orbital inclination of an Orbital Transfer Vehicle (OTV). This task was subject to OTV design constraints, chief of which were the axial acceleration (ASMG) and the aerodynamic heating rate (HEATRT) limits of the OTV. The use of vehicle thrust to replace lost kinetic energy and, thereby, to increase the maximum possible change in orbital inclination was investigated. A relation between time in the "hover" orbit and payload to LEO was established. The amount of plane change possible during this type of maneuver was checked for several runs and a possible thrusting procedure to increase the plane change and still get to LEO was suggested. Finally, the sensitivity of various target parameters to controllable independent variables was established, trades between the amount of control allowed, and payload to LEO suggested.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
Spacecraft Guidance Aeroassist Spacecraft Maneuvers	Unclassified - Unlimited Subject Category 18

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of pages	22. Price
Unclassified	Unclassified	20	A02

NASA FORM 1626 OCT 86 FOR SALE BY THE NATIONAL TECHNICAL INFORMATION SERVICE, SPRINGFIELD, VA 22161-2171