RESEARCH MEMORANDUM

PRELIMINARY STUDIES OF MANNED SATELLITES

WINGLESS CONFIGURATION: NONLIFTING

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and James J. Buglia

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SUMMARY

This paper is concerned with the simple nonlifting satellite vehicle which follows a ballistic path in reentering the atmosphere. An attractive feature of such a vehicle is that the research and production experiences of the ballistic-missile programs are applicable to its design and construction, and since it follows a ballistic path, there is a minimum requirement for autopilot, guidance, or control equipment. After comparing the loads that would be attained with man's allowable loads, and after examining the heating and dynamic problems of several specific shapes, it appears that, insofar as reentry and recovery is concerned, the state of the art is sufficiently advanced so that it is possible to proceed confidently with a manned-satellite project based upon the ballistic reentry type of vehicle.

INTRODUCTION

This paper is concerned with the simple nonlifting satellite vehicle which follows a ballistic path in reentering the atmosphere. An attractive feature of such a vehicle is that the research and production experiences of the ballistic-missile programs are applicable to its design and construction.

The ballistic reentry vehicle also has certain attractive operational aspects which should be mentioned. Since it follows a ballistic path there is a minimum requirement for autopilot, guidance, or control equipment. This condition not only results in a weight saving but also eliminates the hazard of malfunction. In order to return to the earth from orbit, the ballistic reentry vehicle must properly perform only one maneuver. This maneuver is the initiation of reentry by firing the retrograde rocket. Once this maneuver is completed (and from a safety standpoint alone it need not be done with a great deal of precision), the vehicle will enter the earth's atmosphere. The success of the reentry is then dependent only upon the inherent stability and structural integrity of the vehicle. These are things of a passive nature and should be thoroughly checked out prior to the first man-carrying flight. Against these advantages the disadvantage of large area landing by parachute with no corrective control during the reentry must be considered.

In reference 1, Dean R. Chapman has shown that the minimum severity of the deceleration encountered during a ballistic reentry is related to the fundamental nature of the planet. Thus it can be considered a fortunate circumstance that man can tolerate this deceleration with sufficient engineering margin.

SYMBOLS

L lift

D drag

W weight

C_D drag coefficient

A cross-sectional area (frontal)

C_{N_α} normal-force coefficient slope per radian

C_{L_α} lift-coefficient slope per radian

C_{m_α} pitching-moment coefficient slope per radian, based on maximum diameter

I moment of inertia (general)

m mass

P period

a_n normal acceleration

a_X acceleration (longitudinal)

R_d Reynolds number based on diameter

T_j thrust of jet

M Mach number

C_m pitching-moment coefficient

C_N normal-force coefficient

d diameter

y distance

For aerodynamic coefficients, the frontal area is the reference area and the diameter is the reference length.

DISCUSSION

Figure 1 shows man's approximate tolerance to "g" loads for several positions in which he may be supported. The information shown was obtained from reference 2. It should be noted that the tolerance to acceleration varies for different individuals and that figure 1 does not give a complete picture of the problem. It does, however, neatly establish an approximate basis for consideration of the acceleration loads to be described.

The deceleration history of a typical reentry is presented in figure 2. For this case the reentry angle is -0.8° and results in a maximum deceleration of 8.5g. It should be noted that the buildup in deceleration is very gradual and that the overall severity is well within human tolerances. In fact, larger reentry angles resulting in a more severe deceleration history should be tolerable.

The acceleration loads which may be encountered during launching are presented in figure 3. The acceleration history shown was calculated by using elements of a present-day ballistic-missile propulsion system as a basis. The severity of this acceleration history is approximately the same as the deceleration history in figure 2 and is well within the human tolerance limit.

The one maneuver which the ballistic reentry vehicle must perform is the retrograde maneuver. This maneuver consists of deflecting the orbit by the proper application of an impulse provided by the retrorocket.

The performance required from the retrorocket to initiate reentry from a circular orbit of 800,000 feet altitude is shown in figure 4. This figure shows the flight-path angle that would be obtained at the 350,000-foot level when the retrorocket "kicks" the satellite with various velocity changes. It can be seen that use of a rearward impulse is much more effective than a downward one. The downward one has some merit, however, in that it would cause reentry to occur much sooner after the impulse was applied. With a rearward impulse the satellite would travel approximately halfway around the earth before reentering the atmosphere; with a downward impulse the satellite would travel only about one-fourth of the way around before reentry.

There are some particular advantages to be gained if reentry is made from an elliptical orbit. Figure 5 is a schematic drawing of an elliptical orbit and will help illustrate this. The elliptical orbit has a perigee point where it passes close to the earth's surface and an apogee point which is 180° away and is the point of highest altitude. Inasmuch as the satellite is closest to the earth at the perigee, the perigee forms a bucket as far as determining the landing point is concerned. Since the landing point naturally tends to be in vicinity of perigee, the accuracy of the reentry maneuver is improved when the landing point is purposely made in the vicinity of the perigee.

Inspection of figure 5 suggests an interesting possibility. If the satellite is given a moderate rate of spin about its longitudinal axis at last-stage burnout, it can be attitude-stabilized in space and will be traveling exactly backward at the apogee in the correct attitude for firing the retrorockets. Also at the perigee it will be in the correct nose-first attitude for entry. The required spin rates are well within the tolerance of a supine or prone pilot. This technique of spin stabilization might simplify considerably the guidance and control equipment necessary for attitude stabilization.

Figure 6 shows the required performance of the retrorocket when used in initiating reentry from the apogee of an elliptical orbit. It can be seen that increasing the height of the apogee decreases the amount of impulse required to produce a given reentry path angle.

During the last several years the National Advisory Committee for Aeronautics has been intensively studying the important aerodynamic aspects of ballistic-missile reentry bodies. Much of this work is directly applicable to the problem at hand. Thus, fairly well established information is available to help in the choice of the configuration for the ballistic reentry vehicle. Table I summarizes some aerodynamic characteristics for four different types of nose shapes.

The nose shapes shown in table I are compared on a basis of equal weight and diameter. A weight of 2,000 pounds was chosen as being reasonable for the ballistic reentry satellite. A diameter of 7 feet was chosen as being adequate for the occupant supported in the prone or supine position. The aerodynamic characteristics shown in the table are those associated with the forebodies (shown by the solid lines). The afterbodies are arbitrary shapes. Four different nose shapes are shown. They are a hemisphere, a heavily blunted 15° cone, a 53° cone, and a nearly flat nose consisting of a spherical segment. The position of the neutral point and an arbitrary center-of-gravity location are indicated for each of these noses.

Values of W/C_DA, total heating load, and maximum heating rate are also listed for these noses. The heating was computed for reentry starting at 350,000 feet with a path angle of -0.8°. Computations were based upon the methods shown in references 3 and 4 and the experimental data presented in reference 5. It should be noted that the heating is dependent upon both the shape and the W/C_DA. The peak-heating rates are of an order of magnitude less than those experienced by ballistic missiles. The other aerodynamic derivatives shown are of interest when the motion of the body during reentry is considered.

The heating shown is based on the assumption that laminar flow exists over the entire face of the nose. This assumption at least seems to be justified for the nearly flat nose and is illustrated in figure 7. Figure 7 shows the variation of Reynolds number based on nose diameter with Mach number for several possible reentry paths in which the initial path angle is varied from -0.5° to -2.5°. Also shown are two flights of rocket-powered models (refs. 6 and 7) in which laminar flow was measured over the entire flat nose of the model. Although these flights do not indicate the maximum Reynolds number which could be obtained with laminar flow, they do show that laminar flow does exist at Reynolds numbers greater than those which would be expected during the reentry.

Based upon the foregoing statements, a specific configuration was chosen in order to bring into focus some of the more detailed reentry problems. This configuration is shown in figure 8. This space capsule is conceived of as traveling in two directions. During launching it would provide a fairly low-drag nose for the boosting system, but during reentry it would have the desired heat shield in the front. This reversal in attitude also simplifies the support system for the occupant, since the same couch is properly alined for both the acceleration and deceleration phases of the flight. The heat shield chosen is the one with the lowest heating of the four shapes studied.

During reentry the attitude control system will be used to aline the vehicle with the flight path. Although this alinement should usually be accomplished with sufficient precision, one can expect that either through error or malfunction the capsule will occasionally enter the atmosphere with an attitude error. It is assumed that, if no corrective control is applied, the capsule will develop a pitching and yawing oscillation.

In reference 8, John D. Bird has shown that the limit envelope of this oscillation is not affected by the degree of static stability and is independent of dynamic stability down to the point of maximum deceleration. From this framework it is easy to study the violence of the residual oscillation at maximum g. Figure 9 shows the period and normal acceleration that would be encountered during an oscillating reentry. The equations shown for P and a_n were developed by simply substituting $q = \frac{a_X m}{C_D A}$ into the standard expression for these quantities.

Inspection of the resulting equation shows that the length of the period is directly proportional to the square root of C_D/C_{m_α}. Thus to decrease the severity of the oscillation, the period may be lengthened by choosing a shape having a high value of C_D/C_{m_α}. Similarly, the severity of the oscillation may be decreased by reducing the resulting normal acceleration for a given angle of attack. Here it is desired to have a large ratio of C_D to C_{N_α}. It can be seen that from both these considerations the nearly flat nose is very favorable. It is estimated that this configuration would have a period of roughly 1 second at maximum deceleration and that, with an initial attitude error of 10° at the start of reentry, the maximum normal acceleration would be approximately 0.1g.

The particular configuration shown may have negative damping and, as shown in reference 8, this situation will result in a buildup in the oscillation amplitude after the point of maximum deceleration is passed. This amplitude will approximately equal the initial attitude error of reentry when sonic velocity is reached. In order to determine the limit that the oscillation might build up to in the subsonic region, some tests (unpublished) were carried out in the Langley 20-foot free-spinning tunnel. These tests showed that the configuration oscillated at an amplitude of approximately 45°. The use of a small drogue chute about one-half the diameter of the capsule reduced the amplitude of the oscillation to about 20°. An extendable flared skirt originating at the maximum diameter essentially eliminated any oscillatory motion. However, such a device may be unduly complicated to be practical. An alternate configuration, the 53° cone shape, was tested and proved to have very little oscillatory motion.

It appears very likely that, after initial flights of the ballistic reentry type of satellite, the need to reduce the size of landing area which must be kept under surveillance may result in the desire to improve the landing-point accuracy. For this reason several simple means of producing small amounts of lift have been investigated. Figure 10 illustrates three such schemes.

The use of the attitude jets provide a simple method since they would already be in existence. Because of a low value of C_{m_α}, a high moment arm, and a high negative C_{L_α}, these jets appear to be fairly effective in producing lift. With this arrangement an L/D of 0.1 could be produced during the entire reentry deceleration with an expenditure of approximately 80 pounds of H_2O_2. A drag flap is shown to be very effective by some tests carried out in the Langley 11-inch hypersonic tunnel. (See ref. 9.) A trimmed L/D of 0.2 may be obtained with a flap area 4.5 percent of the frontal area. Similarly, a small center-of-gravity shift is also very effective in producing lift.

Figure 11 illustrates the effect of a small amount of lift during reentry. It is seen that with a lift-drag ratio of 0.2 the maximum deceleration is roughly half of that with no lift. This value will also stretch the range by 280 miles. Similarly, the landing point may be deflected to the side by the use of lift. A 90° bank angle, for instance, will provide a lateral displacement of roughly 60 miles with a lift-drag ratio of 0.1.

These possibilities of variations in range or lateral displacement of the landing point may be looked upon in two ways. As previously stated it may be considered as a useful method of correcting errors in the ballistic path.

However it should be pointed out that this condition should also be considered as an indication that, in the case where a pure ballistic reentry trajectory is desired, the ballistic path will be highly sensitive to small aerodynamic misalinements and center-of-gravity displacements. The employment of a slow rate of spin to produce an averaging effect may prove to be a necessity in order to avoid this difficulty. The use of a shape which is incapable of producing lift such as the sphere would also avoid this difficulty.

CONCLUSION

In conclusion it appears that, insofar as reentry and recovery is concerned, the state of the art is sufficiently advanced so that it is possible to proceed confidently with a manned satellite project based upon the ballistic reentry type of vehicle.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., March 18, 1958.

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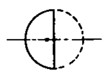
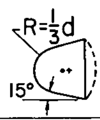
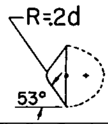
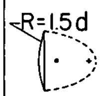
TABLE I

COMPARISON OF NOSE SHAPES
WEIGHT, 2,000 LB; DIAMETER, 7 FT

NOSE SHAPE				
W/C_DA	57	104	37	33
TOTAL HEAT INPUT, BTU	338,000	414,000	293,000	256,000
MAXIMUM HEATING RATE AT STAG POINT BTU/(SQ FT) (SEC)	125	215	166	64.5
C_{N_α}	.92	.97	.69	.24
C_{L_α}	0	.47	-.71	-1.32
C_{m_α}	-.16	-.09	-.22	-.13

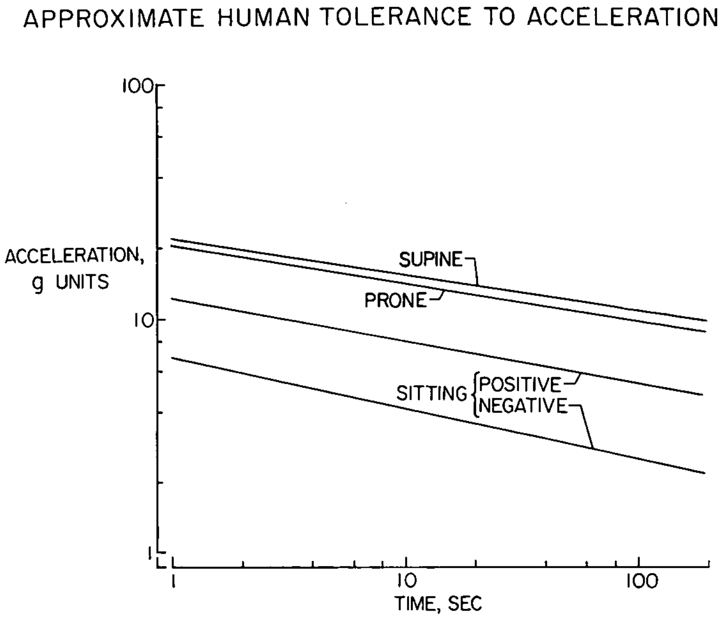


Figure 1

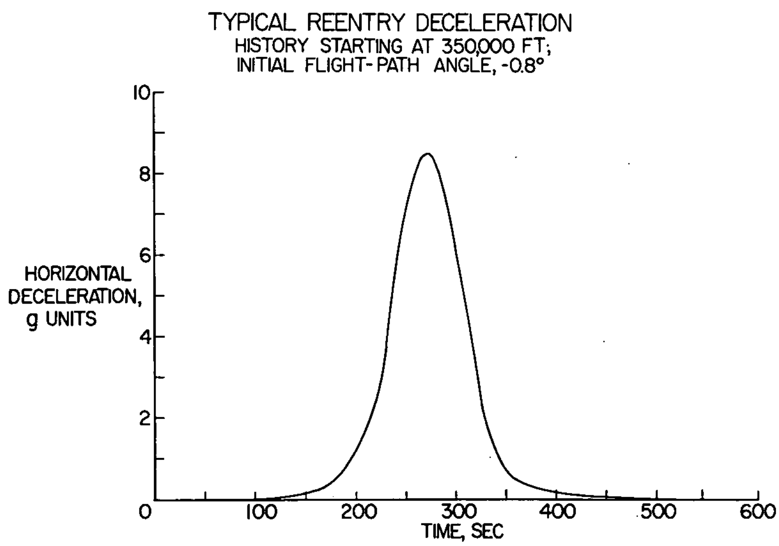


Figure 2

ACCELERATION HISTORY DURING LAUNCHING

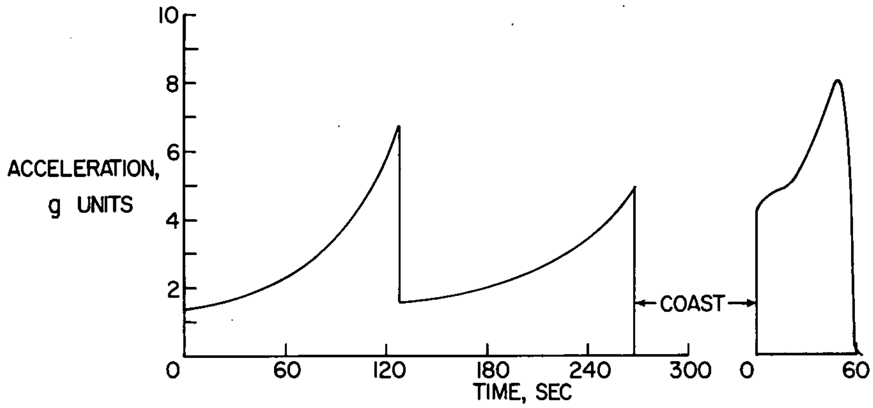


Figure 3

DESCENT MANEUVER FROM CIRCULAR ORBIT AT 800,000 FT

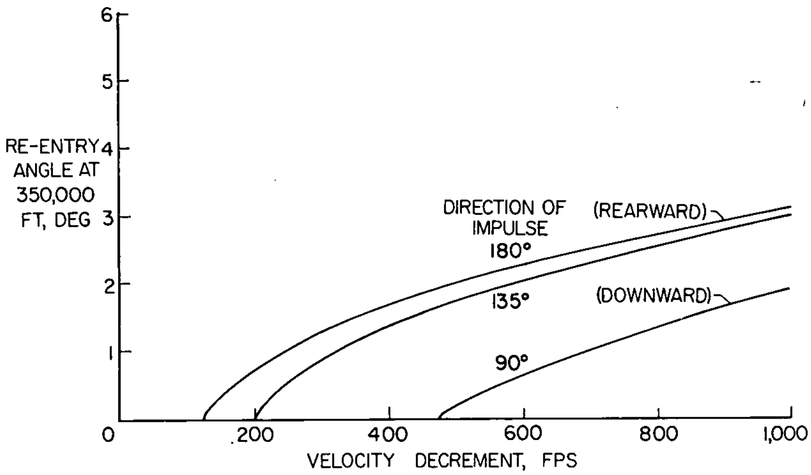


Figure 4

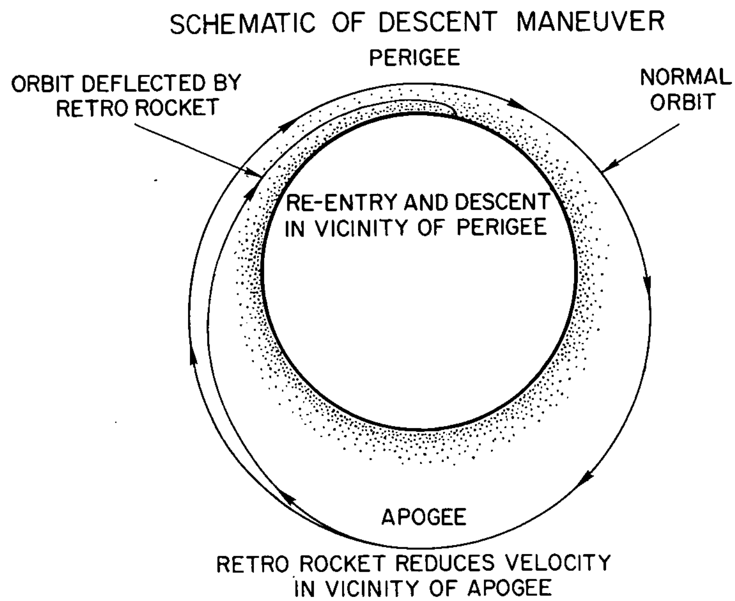


Figure 5

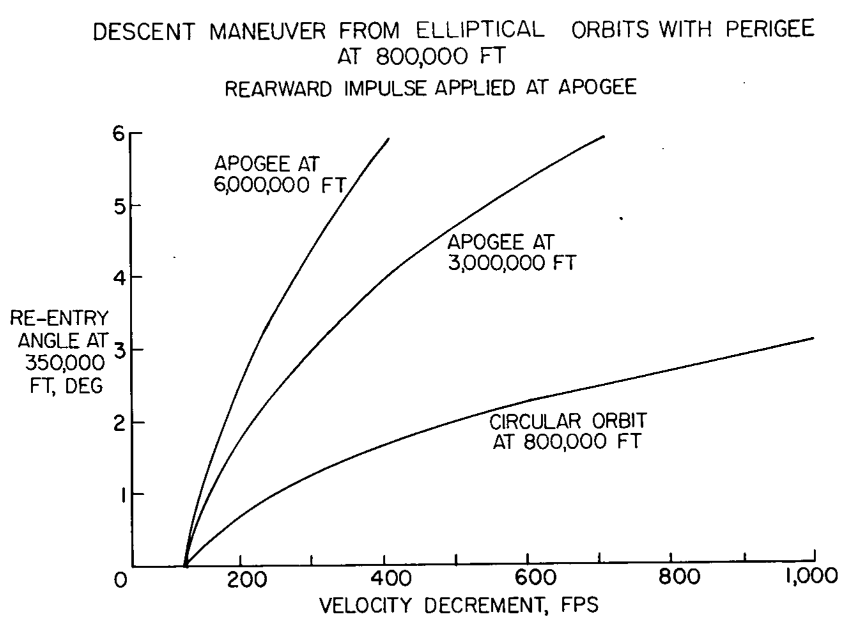


Figure 6

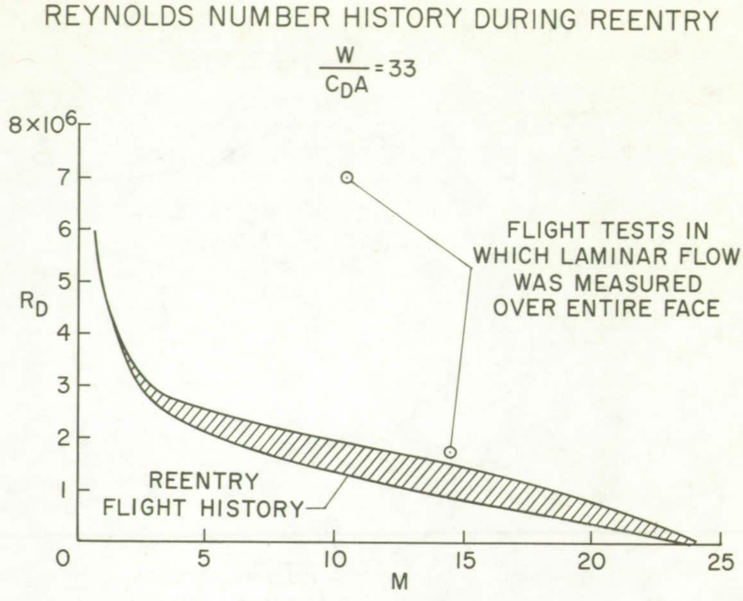


Figure 7

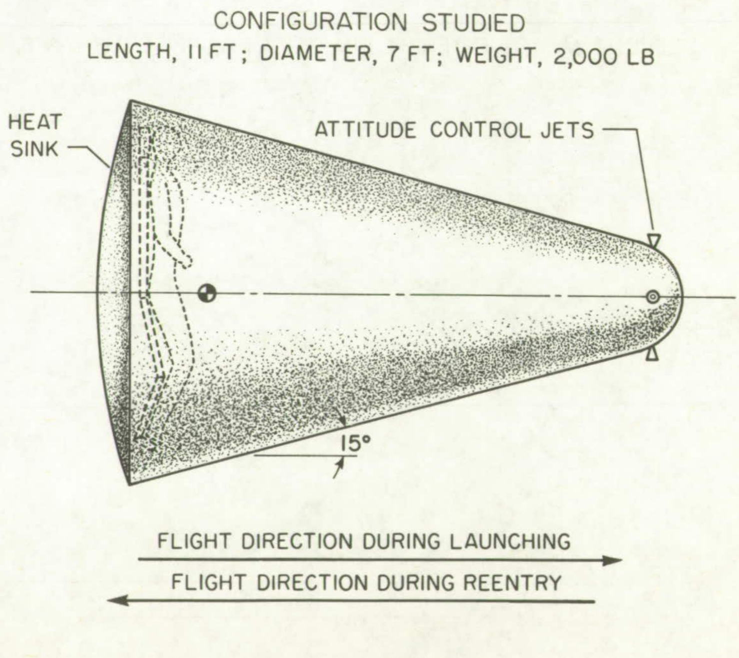
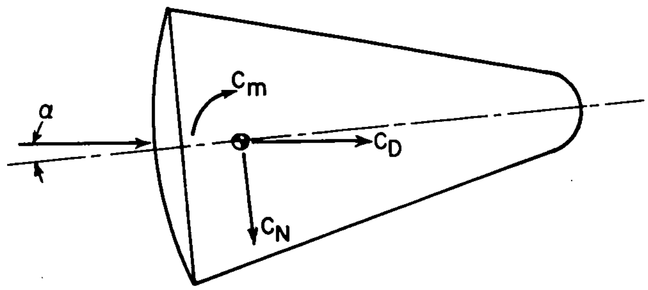


Figure 8

NORMAL ACCELERATION AND PERIOD
DURING OSCILLATORY REENTRY



$$P \approx 2\pi \sqrt{\frac{I\, C_D}{m\, a_X\, C_{m_\alpha} d}}$$

$$a_n = \frac{a_X\, \alpha\, C_{N_\alpha}}{C_D}$$

Figure 9

METHODS FOR PRODUCING LIFT

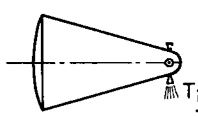
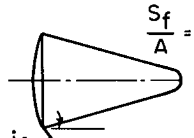
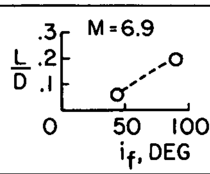
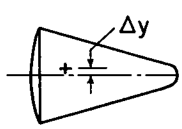
CONTROL METHOD	PERFORMANCE
 REACTION JET	$L = 12\ T_j$
$\frac{S_f}{A} = 0.045$  DRAG FLAP	
 C. G. SHIFT	$\frac{L}{D} = 10.1\ \frac{\Delta y}{d}$

Figure 10

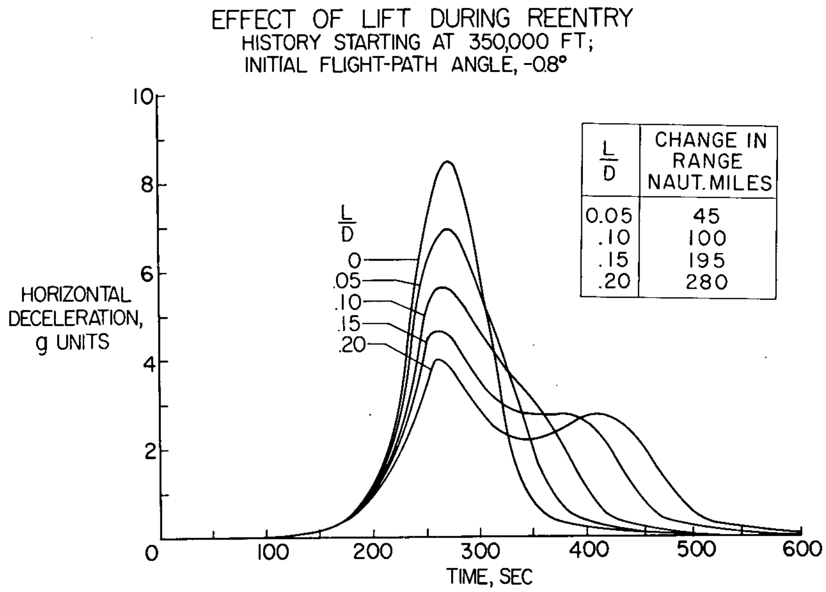

EFFECT OF LIFT DURING REENTRY
HISTORY STARTING AT 350,000 FT;
INITIAL FLIGHT-PATH ANGLE, -0.8°
HORIZONTAL DECELERATION, g UNITS
TIME, SEC
L/D
0
.05
.10
.15
.20
L/D | CHANGE IN RANGE NAUT. MILES
0.05 | 45
.10 | 100
.15 | 195
.20 | 280
0
100
200
300
400
500
600
2
4
6
8
10

Figure 11