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THE APPLICATION OF SOME LIFTING-BODY REENTRY CONCEPTS TO MISSILE DESIGN

M. LEROY SPEARMAN

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NASA
National Aeronautics and
Space Administration

Langley Research Center
Hampton, Virginia 23665

SUMMARY

The aerodynamic characteristics of some lifting-body concepts have been examined with a view to the applicability of such concepts to the design of missiles. The concepts considered include right triangular pyramidal configurations, a lenticular configuration, and various 75-degree triangular planform configurations with variations in body camber and control systems.

The aerodynamic features were generally satisfactory with some concepts indicating inherent static stability characteristics. In addition, some potential advantages were noted relative to other factors such as heat transfer, structures, carriage, observability, propulsion, and volumetric efficiency.

INTRODUCTION

In the early 1950's, some NASA investigations were underway to study the possibility of reentering the atmosphere with manned space vehicles. These vehicles were required to operate over a large angle of attack range and a large Mach number range with satisfactory stability and control characteristics. In addition, attention was given to such factors as volumetric efficiency, structural integrity, and heat transfer.

Many of the concepts that satisfied the manned reentry requirements should also provide features desired in many missile concepts. These features include a wide range of speed and altitude options for varied mission requirements, volumetric efficiency, ease of stowage and carriage, reduced observability, and good stability and control characteristics. It is the purpose of this paper to consider some of the lifting-body characteristics and explore the possible applications to missile design.

SYMBOLS

C_L	lift coefficient
C_m	pitching-moment coefficient
C_{l_β}	effective dihedral parameter
C_{n_β}	directional stability parameter
L/D	lift-drag ratio

M	Mach number
c	chord length
l	body length
t	thickness
c.g.	center of gravity
c.p.	center of pressure
α	angle of attack, deg.
δ	control deflection, deg.
Λ	sweep angle, deg.

Coefficients for the configurations presented herein are nondimensionalized in various ways. Detailed information for the configurations may be found in the referenced papers. The numerical value of the coefficients, however, does not affect the interpretation of the results.

DISCUSSION

Pyramidal Body Concept

Early studies of long-range hypersonic gliders indicated that the wing leading-edge presented an area of major heating (ref. 1). It was found that large positive dihedral had a significant effect on wing leading-edge heat transfer by shifting the heating problem to the axis of symmetry ridge line where greater mass was available to absorb the heat. By filling in the upper region of a high dihedral (45°) highly swept wing, the flat-top right-triangular pyramidal concept evolved. The basic concept is illustrated in figures 1 and 2 and some studies related to the concept are reported in references 1 to 11. Some results excerpted from these references are shown in figures 3 to 5.

A summary of some longitudinal characteristics of the pyramidal body over the Mach number range (fig. 3) indicates a c.p. location at about 70 percent of the body length that is essentially invarient in the supersonic Mach number range. Such a characteristic should facilitate the attainment of good stability and control characteristics. Reasonably good lift-to-drag characteristics are also indicated with the ratio of lift-to-drag increasing from about 2 to about 3 over the supersonic range shown. The boattailed configuration indicates characteristics slightly better than those for the basic body.

Longitudinal trim for the basic pyradimal body as obtained with a body flap is illustrated in figure 4 for a Mach number of 2.9 and a center of gravity location at 60 percent of the body length. These results translate into the potential for a vehicle a little over 30 feet in length to support a weight of about 22,000 pounds in level flight (1g) at an altitude of about 82,000 feet. Such a vehicle, supporting the same weight, could provide an instantaneous g of about 10 at 32,000 feet and about 20 at 23,000 feet. Near sea level at M = 2.9 an instantaneous g in excess of 30 is potentially available. The aerodynamic leading and thermal environment encountered under such conditions is considerably relieved by the geometry of the pyramidal configuration.

The lateral-directional stability characteristics for the pyramidal body at M = 2.9 and c.g. at 0.60 l (fig. 5) indicate a positive dihedral effect and positive directional stability, both of which increase with increasing angle of attack up to at least 28 degrees. The directional stability for the boattail configuration is higher than that for the basic configuration because of the further aft c.p. location as indicated in the longitudinal summary. The angle of attack range shown is sufficient to encompass the longitudinal operational envelope discussed.

Thus, the pyramidal shape appears to offer a geometrically simple configuration that inherently provides both longitudinal and lateral-directional static stability. In addition, the shape is such that stowage and carriage may be simplified.

Blunted Pyramidal Body

Further investigations were conducted with a pyramidal body having a blunter nose and a more rounded ridge line. The basic concept is shown in figure 6 and two variations of control--body flaps and nose incidence--are shown in figure 7. The results shown in figure 8 for M = 3.05 (ref. 12) indicate somewhat higher values of L/D than the more pointed pyramidal body. The aft body flap is shown to be effective in trimming to maximum L/D with only a slight loss due to trimming. Additional control power is available for maneuvering or trimming to higher values of lift.

Results for the blunted pyramidal body are shown in figure 9 for M = 6.2 (ref. 13). Reasonably high values of L/D are indicated and the deflection of the nose is effective in providing trim and control.

Some tests were conducted in the subsonic and transonic speed range for the blunted pyramidal body with the addition of variable-sweep wing panels (ref. 9). The effects of wing sweep on the maximum lift-drag ratio (fig. 10) indicate substantial increases at the lower Mach numbers as the wing panels are extended. Such increases, of course, could be translated into considerable increases in range at subsonic speeds. The body with the wings fully retracted ($\Lambda = 80°$) reaches a minimum value of L/D at M = 1 and then begins to increase toward the values previously shown at M = 3.05 and 6.2. Other results contained in reference 9 indicate that the aft body flap is effective in producing trim and control throughout the test angle of attack range of 25 degrees.

Lenticular Body

Among the body shapes proposed for a manned lifting reentry vehicle was the lenticular shape. Such a body shape was intended for high angle of attack reentry to minimize aerodynamic heating and, as the velocity decreases, the angle of attack would be decreased, tails would be deployed, and horizontal flight or cross-range capability would be achievable. Results of investigations of this type vehicle may be found in references 14 to 22. Some of these results are presented in figures 12 to 14. The longitudinal characteristics at M = 2 and M = 3.5 (fig. 12) indicate relatively low values of maximum L/D (on the order of 1) that might be expected for this particular kind of shape. The longitudinal stability and control features are of interest, however, in that positive static stability is maintained with the c.g. at 45 percent l, self-trimming capability is indicated due to the positive values of C_m at zero angle of attack, and controllability is easily accomplished up to at least $\alpha = 40°$. The trim values of L/D at M = 2 (fig. 13) indicate no loss due to trimming at the maximum value of L/D. The lateral-directional characteristics for M = 3.5 (fig. 14) indicate positive effective dihedral and positive static directional stability even with the tails removed up to the maximum angle of attack of 40 degrees.

Thus the lenticular shape offers a relatively large volume within its geometric constraints along with good static stability and control characteristics. Other features of the lenticular shape, some of which were explored in a study by Mr. Fred Howard at Eglin Air Force Base, Florida in the late 1950's are:

- o Ease of stowage and carriage when stacked in a tube.
- o Possibility of omni-directional launch.
- o Lenticular drag generally less than that of a cone-cylinder having equivalent volume and carriage constraints.
- o Alleviation of heating and structural problems.
- o Low moments of inertia.

75° Triangular Planforms

Several configurations having triangular planforms to provide lift during atmospheric entry have been proposed and investigated (refs. 23 to 29). Some of these configurations, extracted from reference 29, are shown in figure 15. These all have 75-degree triangular planforms and include an elliptical body, a flat wing with a semiconical upper body, and a modified elliptical wing with a semiconical upper body.

Some results from reference 29 are presented in figure 16 for these three configurations at M = 2.94 and 4.78. The L/D values are lowest for the elliptical body but this body also provides the greatest volume. No control system was investigated for this configuration. However, the elliptic body shape is quite similar to one that was used in the Up Stage (Upper Stage Acceleration and Guidance Experiment) flight demonstration vehicle in the early 1970's. The Up Stage vehicle was designed as an interceptor missile for defense against a maneuvering RV and, using either external burning or jet interaction for control, successfully demonstrated that the elliptical body could achieve a very small miss distance with a rapid response time and a very high maneuver level (about 300-400 g's).

The flat bottom configuration and the modified elliptical configuration (fig. 16) both provided somewhat higher values of L/D than the ellipse but, of course, with a reduced volume. Pitch control effectiveness is shown only for the flat bottom configuration with triangular tip controls and indicates that trim can easily be maintained at maximum L/D and that maneuver potential to high angles of attack is achievable. The tip control was less effective for the modified ellipse. However, the asymmetrical shape of the modified ellipse provided positive lift at zero angle of attack and maximum values of L/D of 4 or greater were obtained at $\alpha = 0°$ which could result in some benefits in trim control requirements and cruise flight efficiency.

Cambered Bodies

Other studies (unpublished) have been made with a basic 75-degree planform to determine the effects of various types of upper and lower surface camber. The purpose of the cambered body study was to explore means for increasing body volume in an aerodynamically sound manner.

Some of the cambered bodies studied are shown in figure 17. The basic model was a 75-degree triangular flat plate with a strain gage balance housing attached to the upper surface. The additions included a 10-percent thick cambered body with the maximum thickness located at the 30-percent centerline chord station that was investigated both as an upper surface addition (flat bottom) and a lower surface addition (flat top). Flat top configurations were also investigated that had lower surface additions with 20 percent maximum thickness located at either 30 percent or 50 percent of the centerline chord. A comparison of the flat bottom and the flat top configuration with the addition of the cambered body having 10-percent thickness at the 30 percent chord station is shown in figure 18 for M = 2.3 and the c.g. at 0.53 l. Although the flat bottom configuration provided higher values of L/D, the upper surface camber caused a negative pitching moment at zero α and the configuration could not be trimmed without the application of some form of pitch control. The flat top configuration with lower surface camber, however, resulted in a positive pitching moment at zero α and, even though the L/D was slightly less than that with the flat bottom, the configuration could be trimmed at maximum L/D without any control application.

A further look at lower surface camber effects with the flat top configuration at M = 2.3 is shown in figure 19 where lower surface camber addition is increased in thickness to 20 percent of the chord with the maximum thickness locations at 30 percent c and at 50 percent c. Both of the increased thickness additions resulted in a substantial reduction in L/D although there is a considerable increase in volume. However, the increased lower surface camber also caused an increase in positive pitching moment at all angles of attack such that longitudinal trim or control at positive angles of attack could be accomplished with an aft control producing positive lift--a potential advantage for aerodynamic efficiency and maneuverability.

The lateral-directional stability characteristics for these cambered bodies at M = 2.3 are shown in figure 20. The results for the addition of the body with t/c = 0.10 at 0.3c indicate that the flap top configuration (lower surface camber) is somewhat better than the flat bottom configuration in that the level of directional instability is less and the effective dihedral remains positive over the angle of attack range. The directional instability could be corrected to some extent by a forward movement of the c.g. or, more likely, by the addition of some aft directional surfaces. The addition of increased camber (volume) to the lower surface resulted in an increase in the level of directional instability with the effect being less for the more rearward distribution of volume. With the increase in lower surface camber, the effective dihedral remained positive throughout the angle of attack range although the magnitude was reduced some at the higher angles. The generally more favorable lateral-directional stability characteristics for the flat top configuration is in harmony with the favorable longitudinal characteristics that also occurred.

A summary of the longitudinal characteristics for the cambered bodies over the Mach number range from 2.3 to about 4.6 is shown in figure 21. The results are generally consistent over the Mach number range; that is, the flat bottom configuration displays the highest values of maximum L/D but also indicates negative values of pitching moment at zero angle of attack (C_{m_o}) that present a trimming problem, whereas the flat top configuration indicates lower values of maximum L/D but maintain positive values of C_{m_o} that could prove to be beneficial.

CONCLUDING REMARKS

It has been the purpose of this paper to review the aerodynamic characteristics of some lifting-body concepts with a view to the possible application to the design of missile systems.

Some concluding observations are:

o Design features from several lifting-body reentry concepts appear to have some application to the design of missiles.

o A flat-top, right-triangular pyramidal body offers good structural and heat transfer features, together with inherent static longitudinal and lateral directional stability, and the potential for some advantages in stowage, carriage, and observability.

o A lenticular shape offers good structural and heat transfer characteristics, inherent static stability, large volume within given geometric constraints, the possibility of omnidirectional launch, possibility of ease in stowage and carriage, possible advantages in observability.

o Some 75-degree triangular planforms offered a variety of trade possibilities between volume requirements and aerodynamic behavior. In general, a family of cambered bodies suggested that flat-top configurations with lower surface camber, when compared to a flat-bottom configuration, offered possible advantages in trim, control, stability, and maneuver potential despite some degradation in lift-drag ratio.

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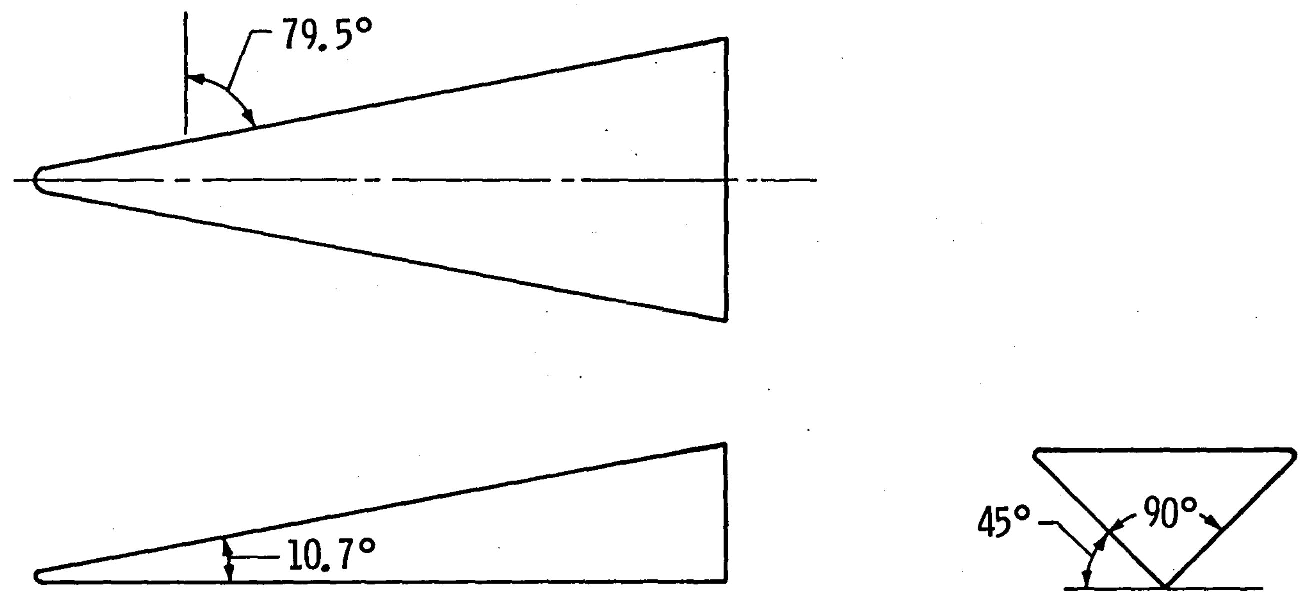

Figure 1. - Pyramidal body.

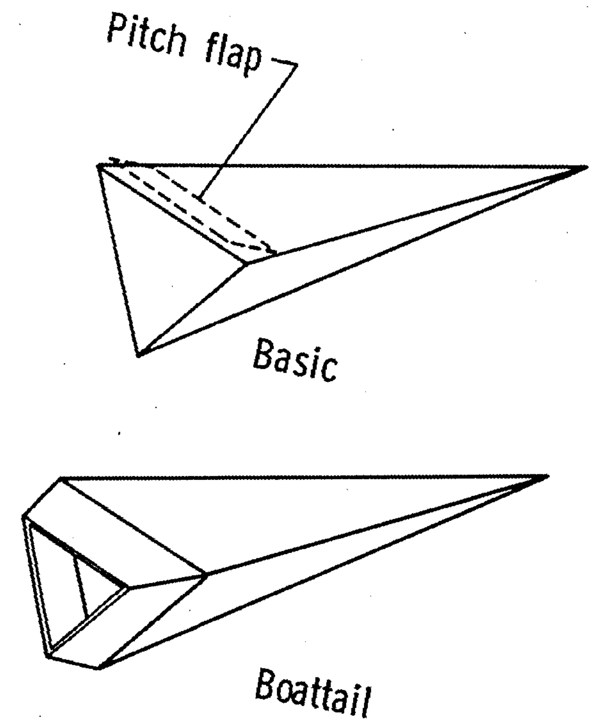

Figure 2. - Pyramidal body variations.

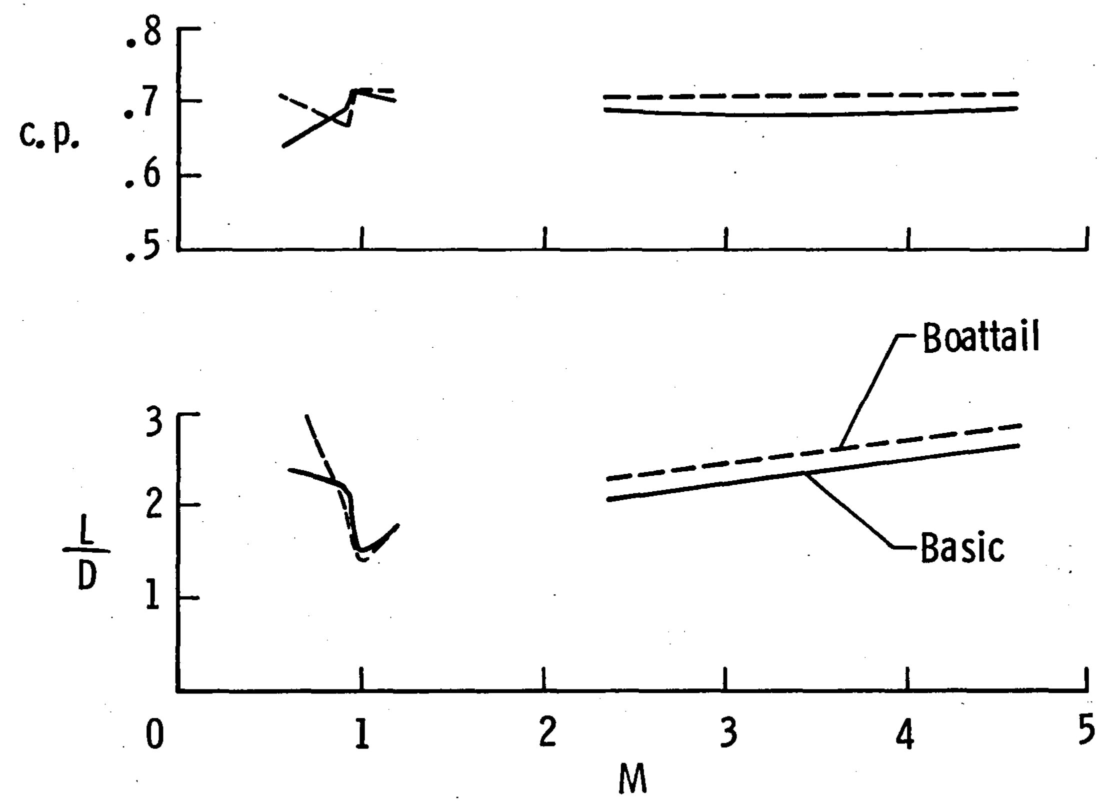

Figure 3. - Longitudinal summary, pyramidal body.

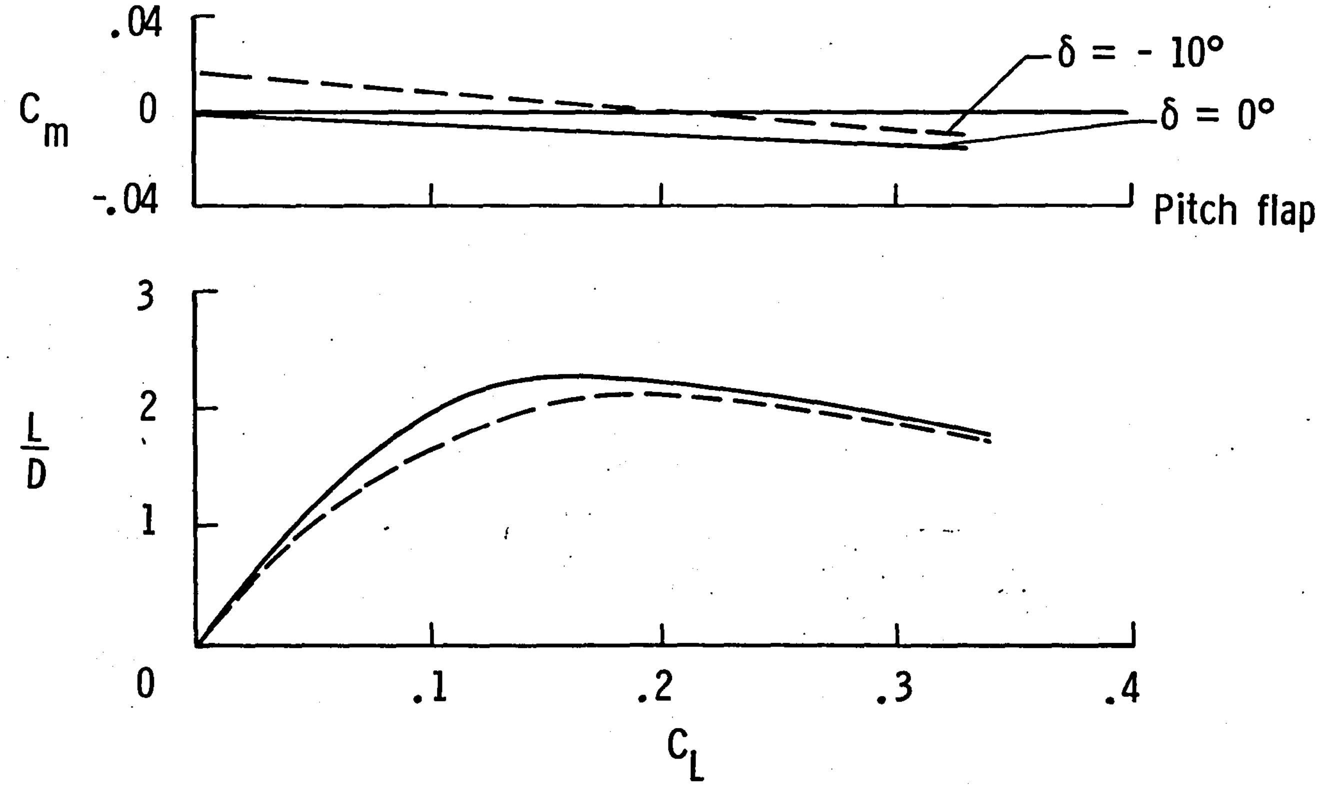

Figure 4. - Longitudinal trim for basic pyramidal body.
M = 2.9, c.g. = 0.60ι.

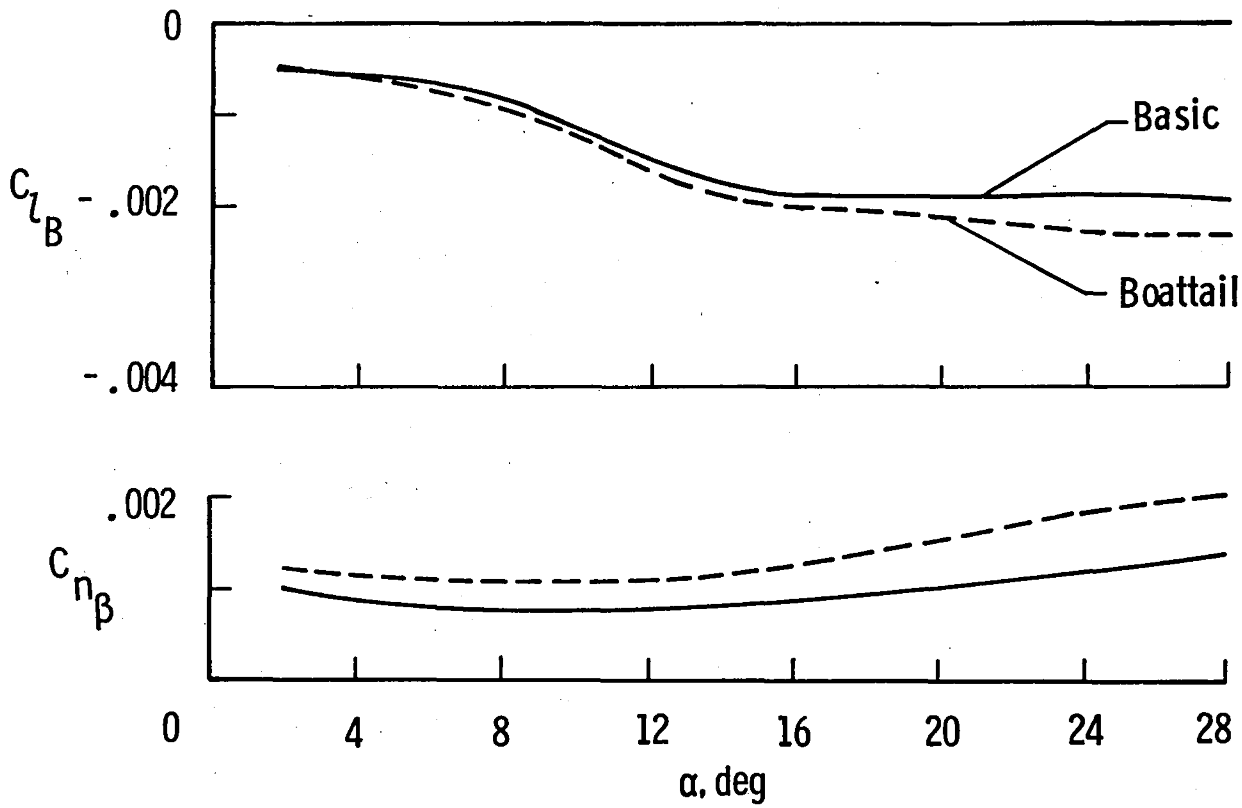

Figure 5. - Lateral-directional stability for pyramidal body.
M = 2.9, c.g. = 0.60l.

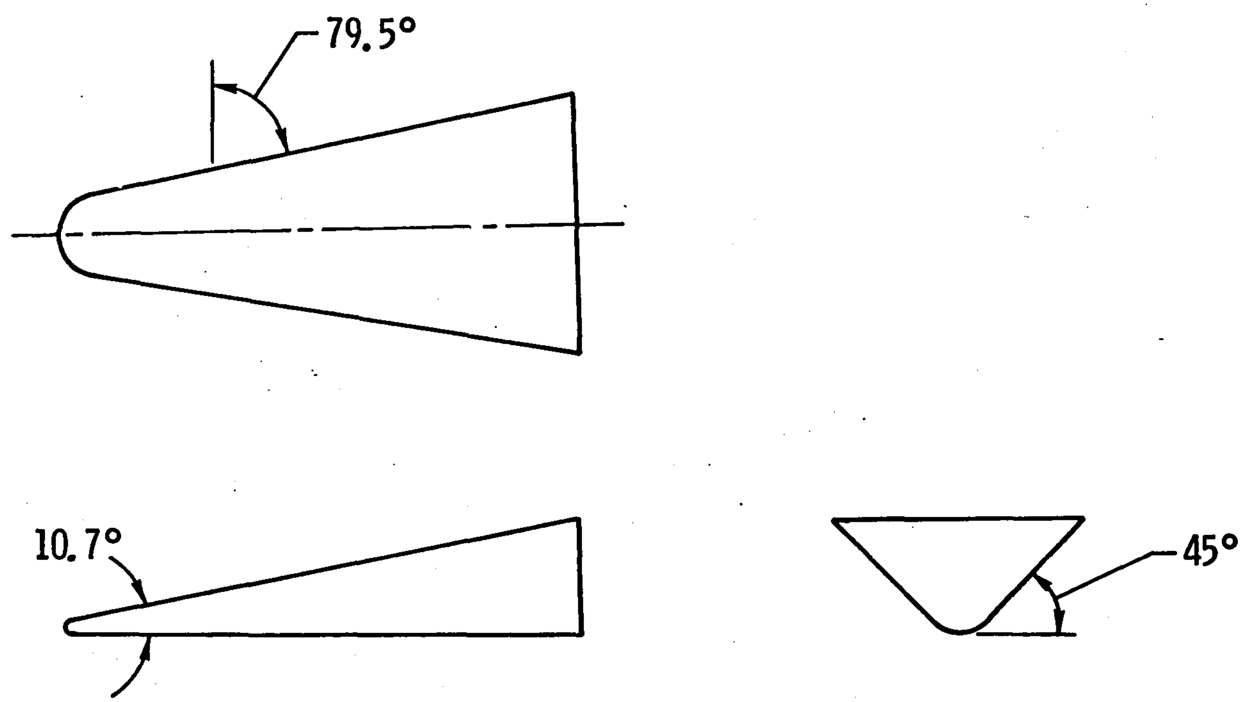

Figure 6. - Blunted pyramidal body.

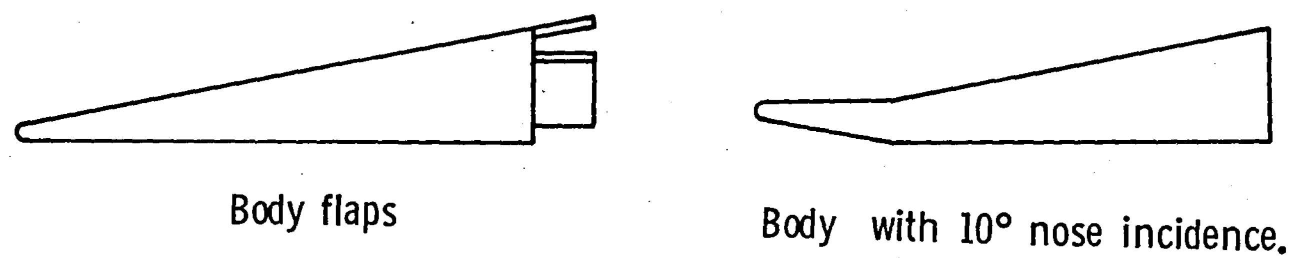

Figure 7. - Blunted pyramidal body variations.

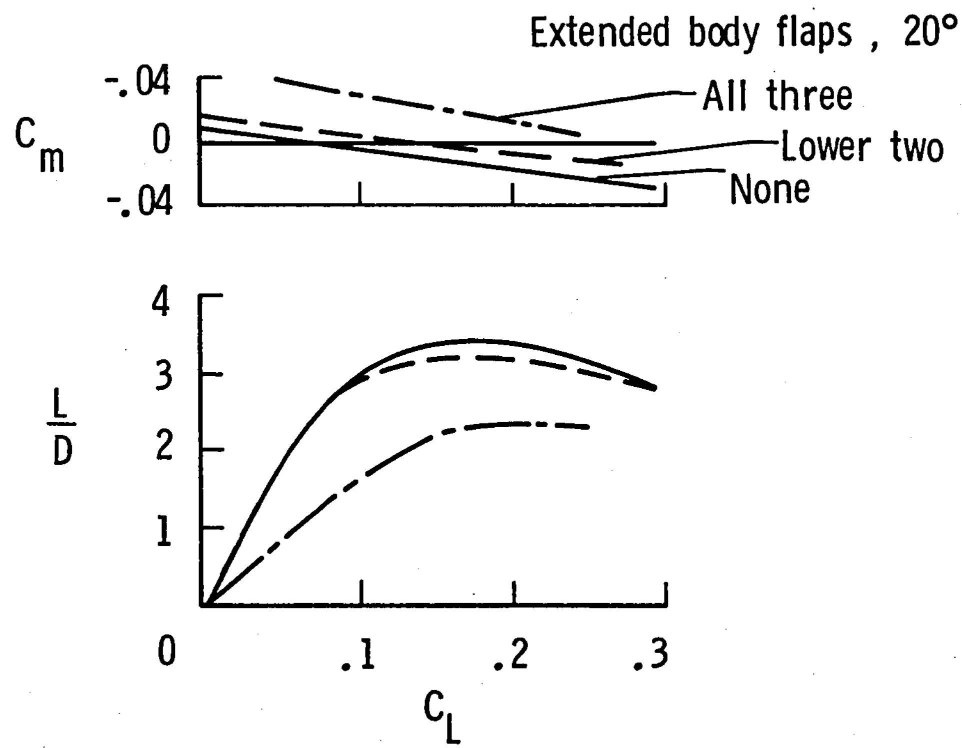

Figure 8. - Longitudinal characteristics for blunted pyramidal body. M = 3.05, c.g. = 0.57l.

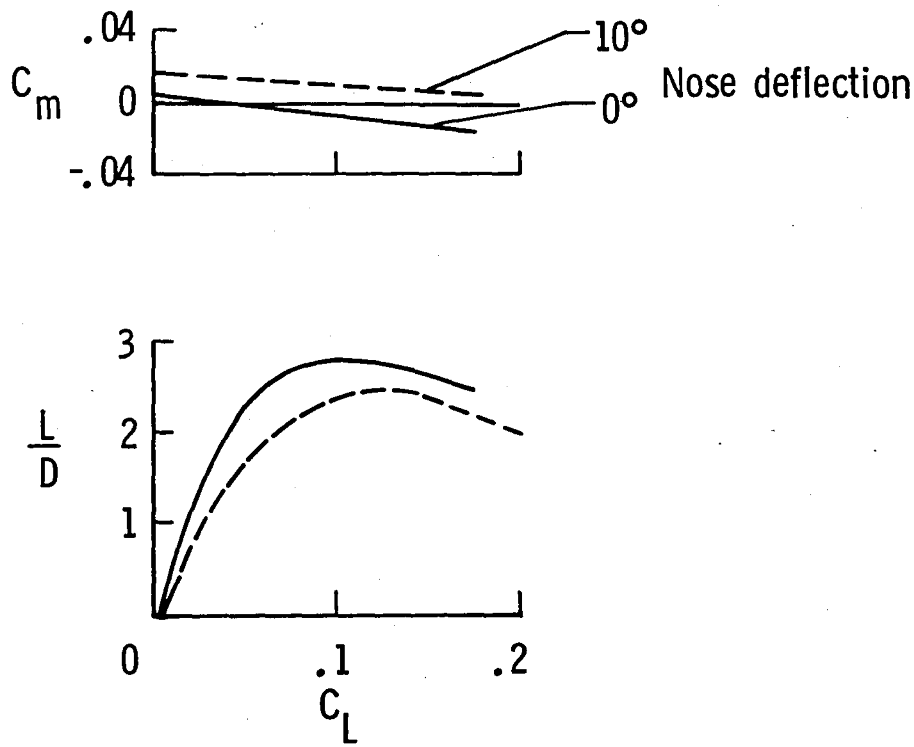

Figure 9. - Longitudinal characteristics for blunted pyramidal body.
M = 6.2, c.g. = 0.57l.

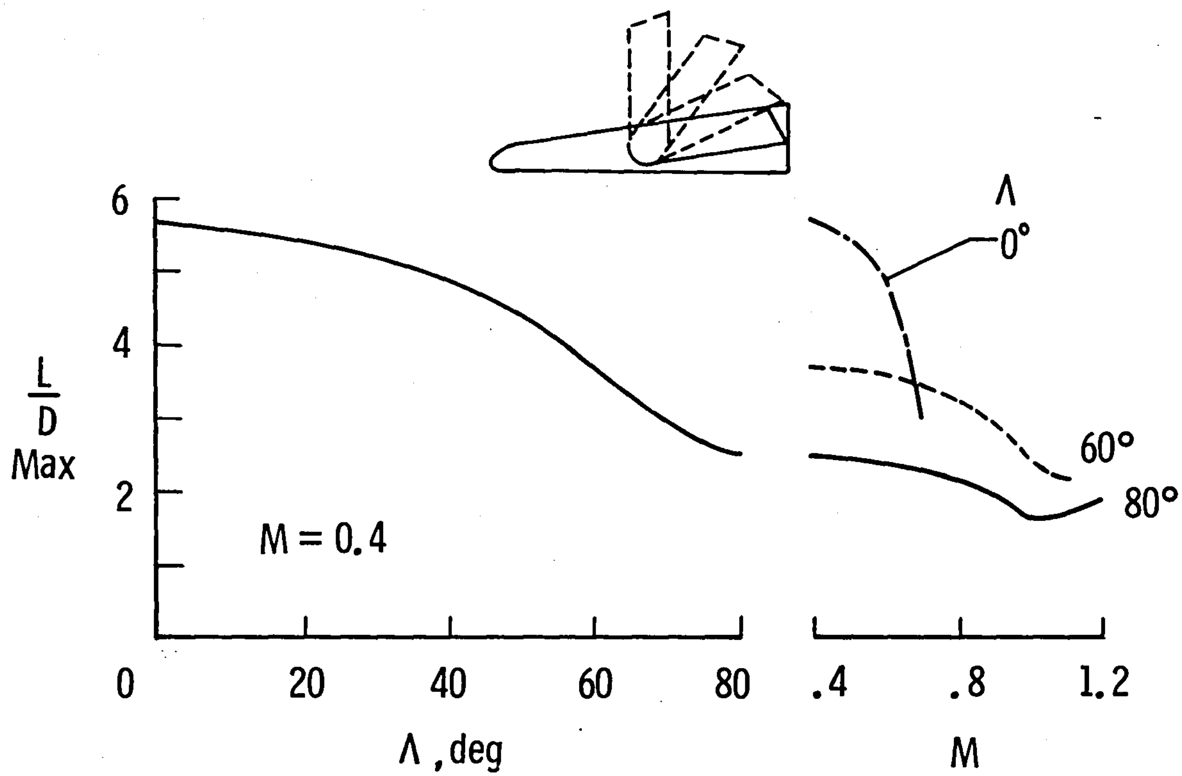

Figure 10. - Effect of variable-sweep wings on blunted pyramidal body.

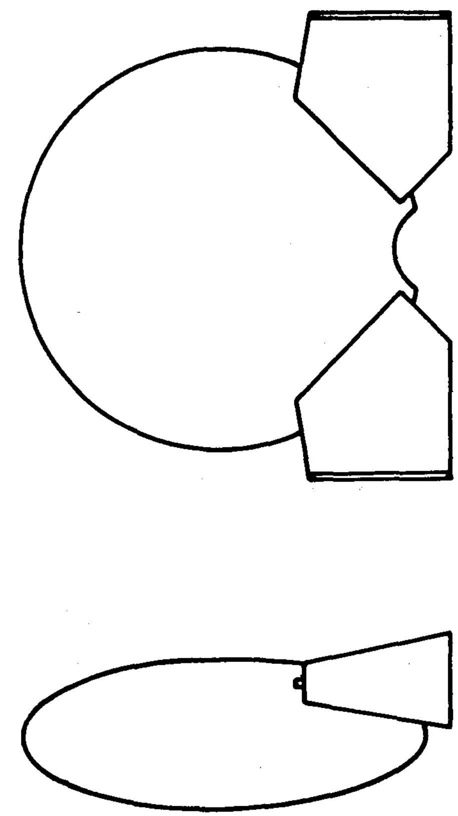

Figure 11. - Lenticular body.

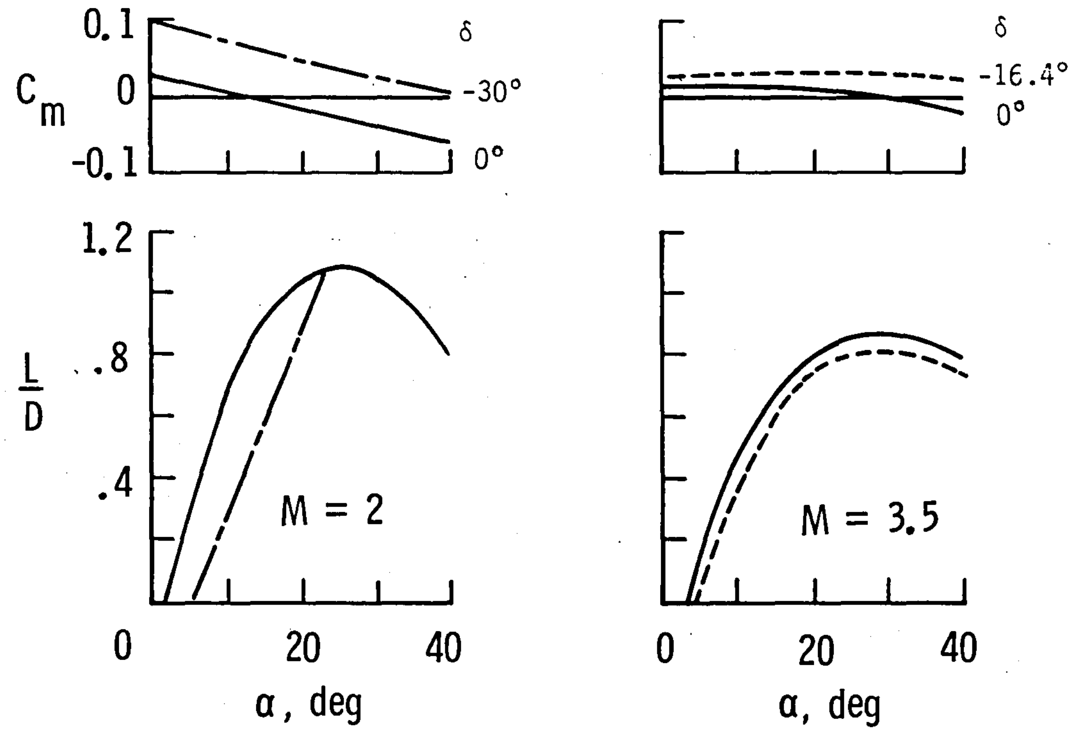

Figure 12. - Longitudinal characteristics, lenticular body with c.g. at 0.45l.

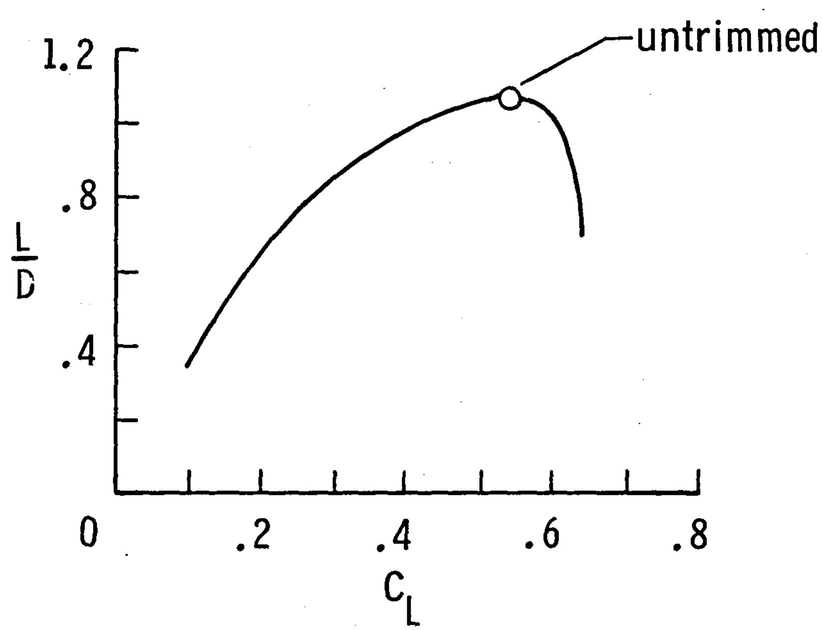

Figure 13. - Trim characteristics for lenticular body.
$M = 2$, c.g. = $0.45l$.

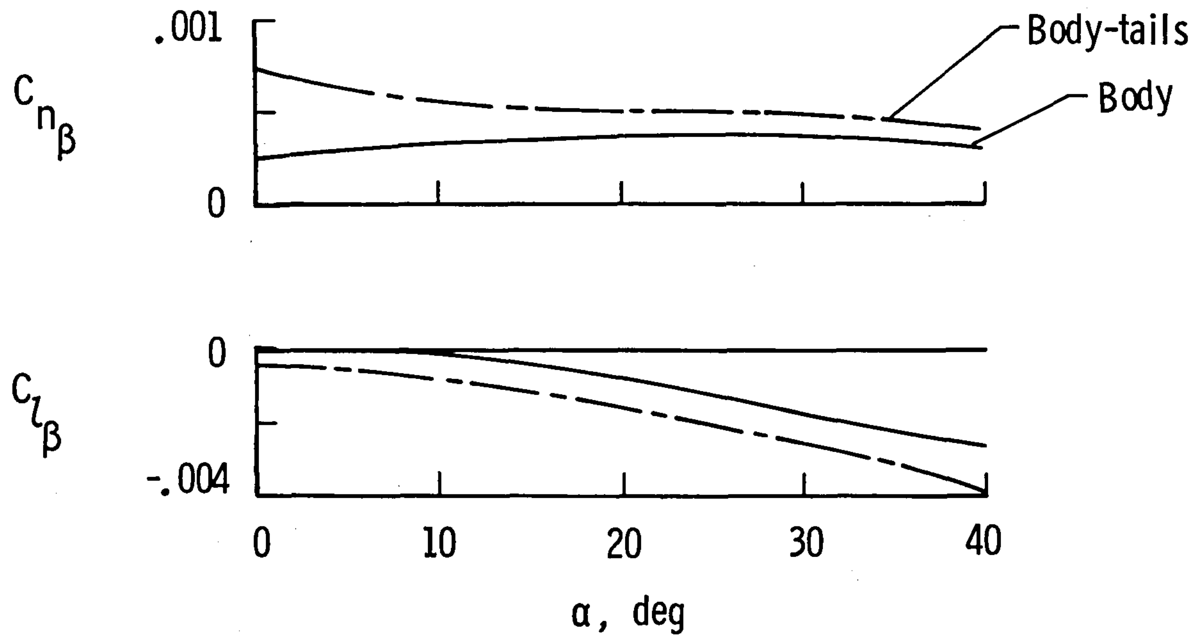

Figure 14. - Lateral-directional stability for lenticular body. M = 3.5, c.g. = 0.45l.

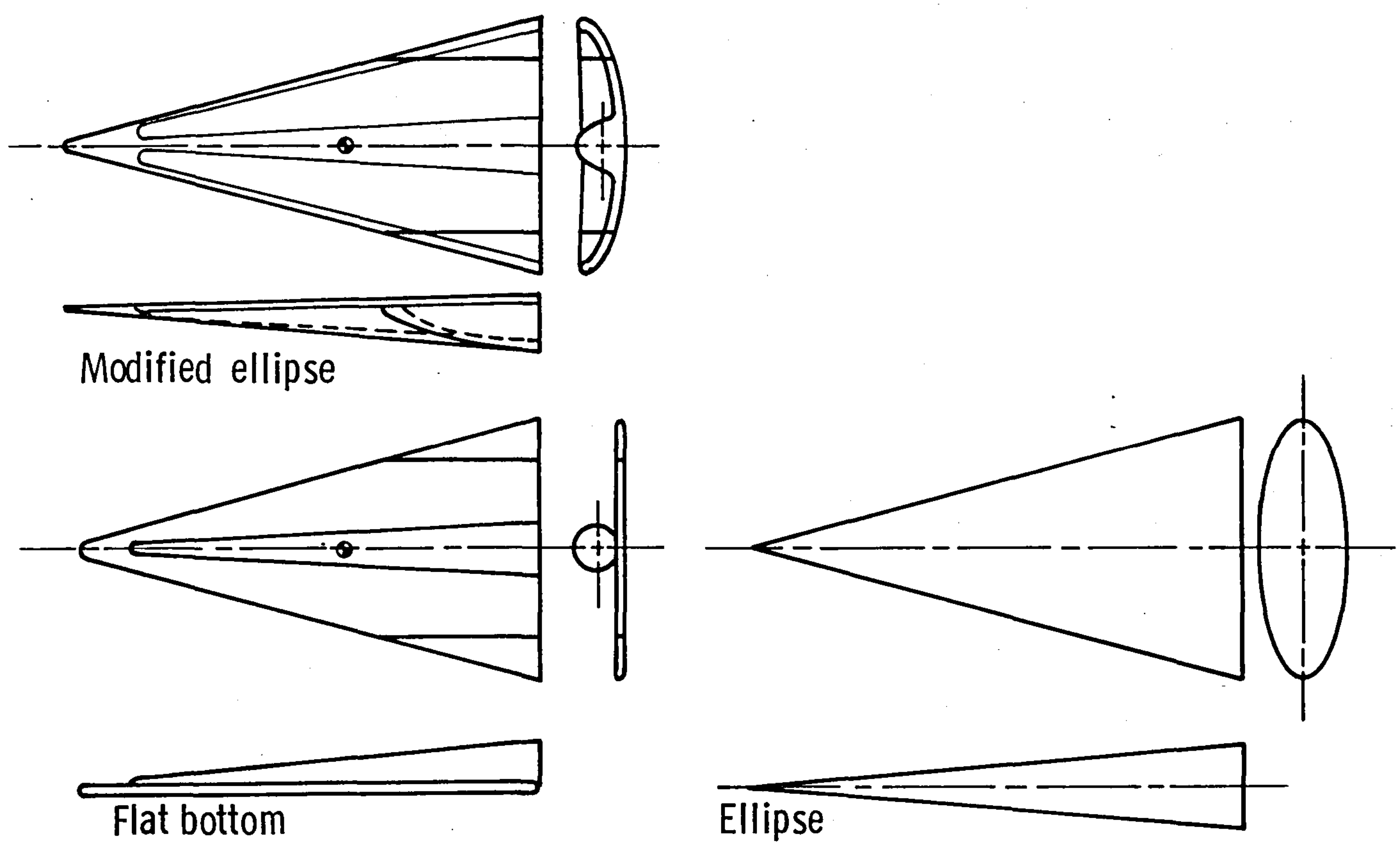

Figure 15. - Concepts with 75° triangluar planforms.

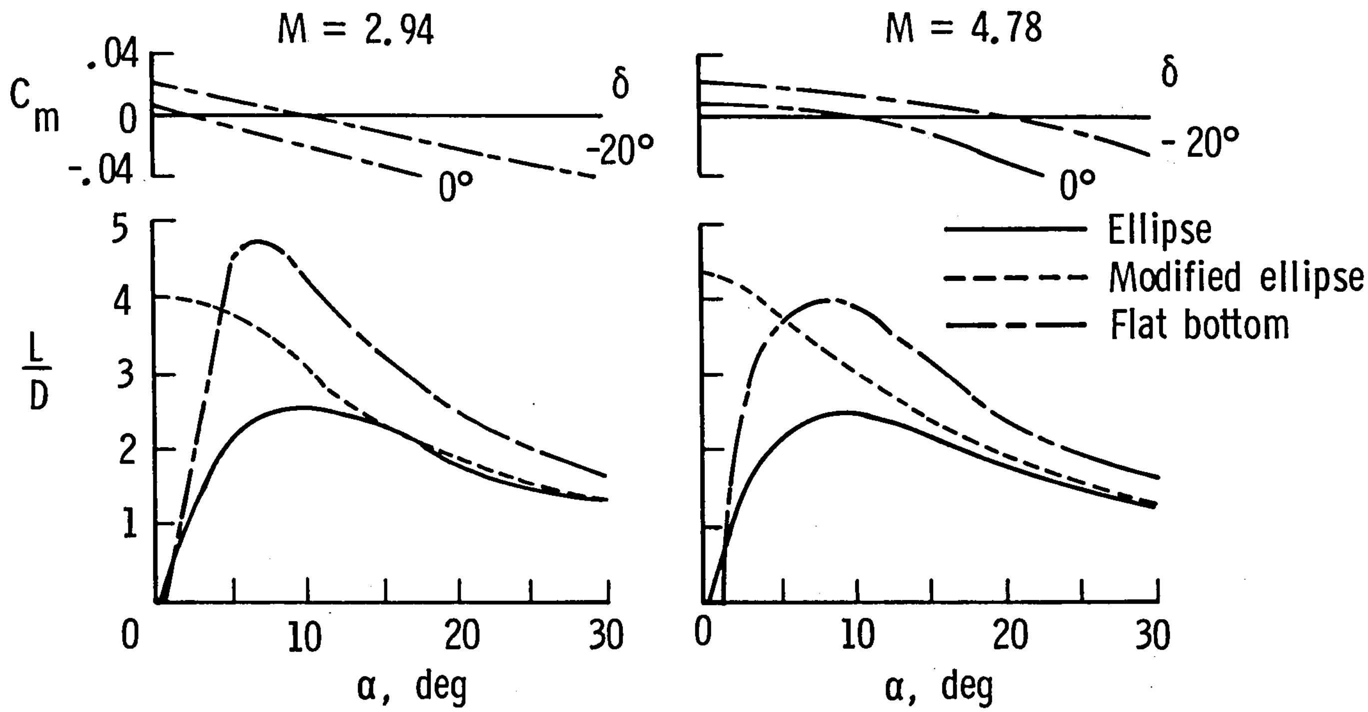

Figure 16. - Longitudinal characteristics for 75° triangular planform concepts. c.g. = 0.60l.

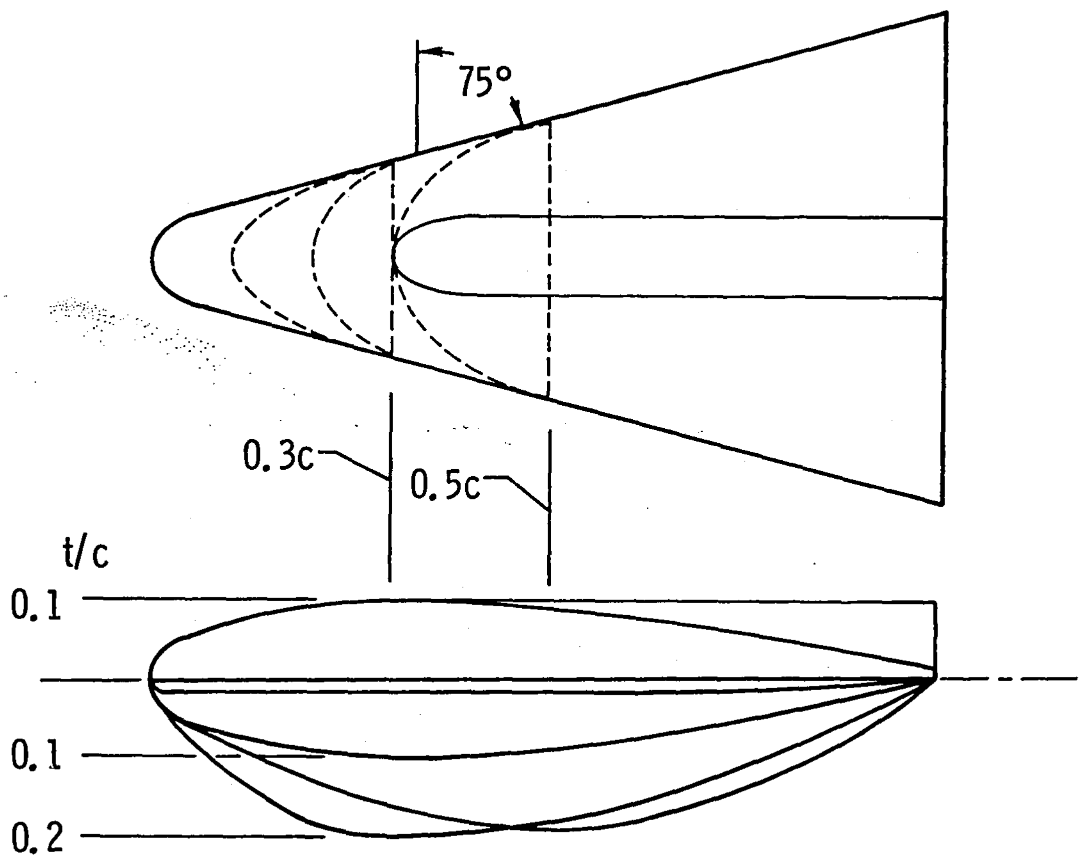

Figure 17. - Cambered bodies, 75° triangular planform.

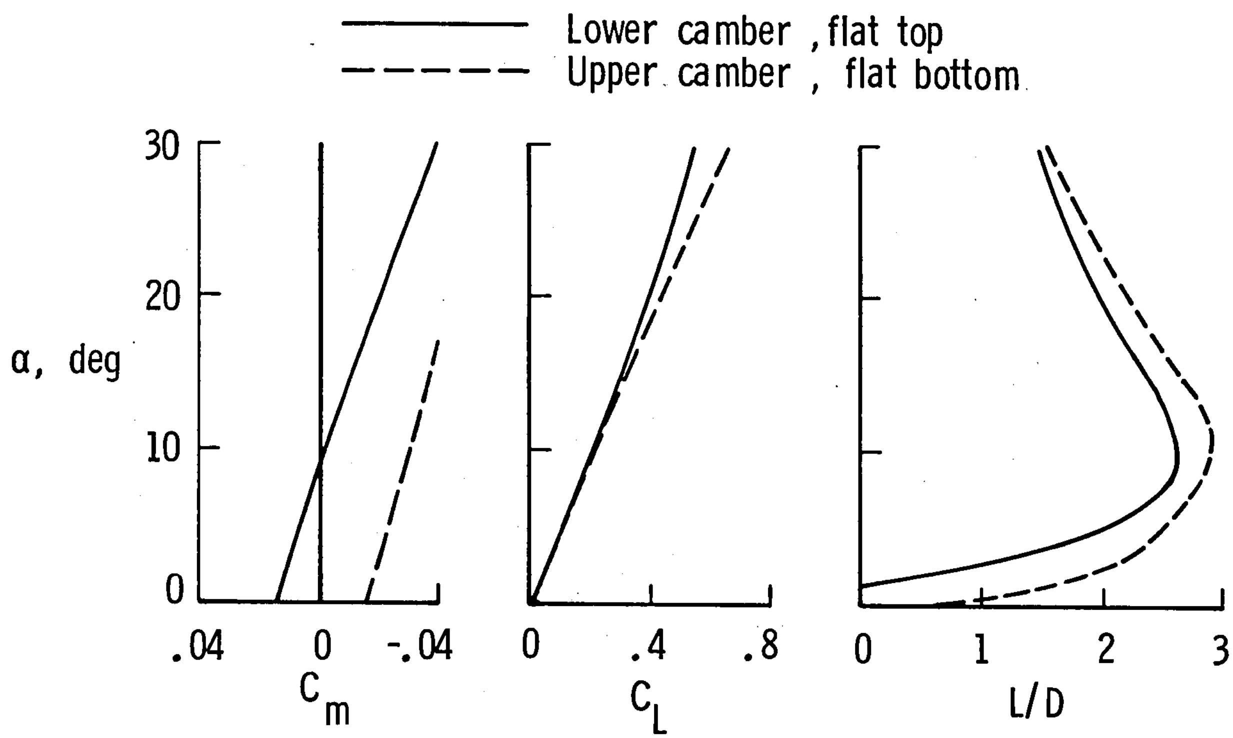

Figure 18. - Effect of camber addition to flat plate with 75° triangular planform. M = 2.3, c.g. = 0.53l, t/c = 0.10 at 0.3c.

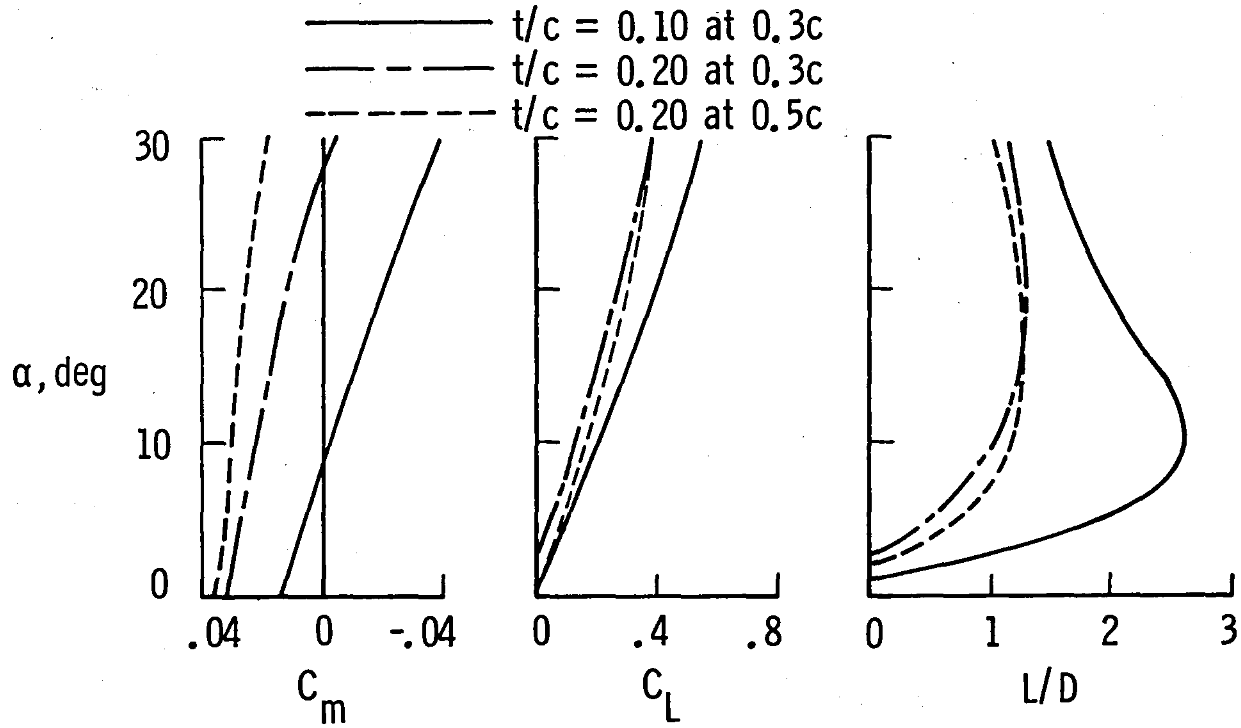

Figure 19. - Lower surface camber additions to flat top 75° triangular planform. M = 2.3, c.g. = 0.53l.

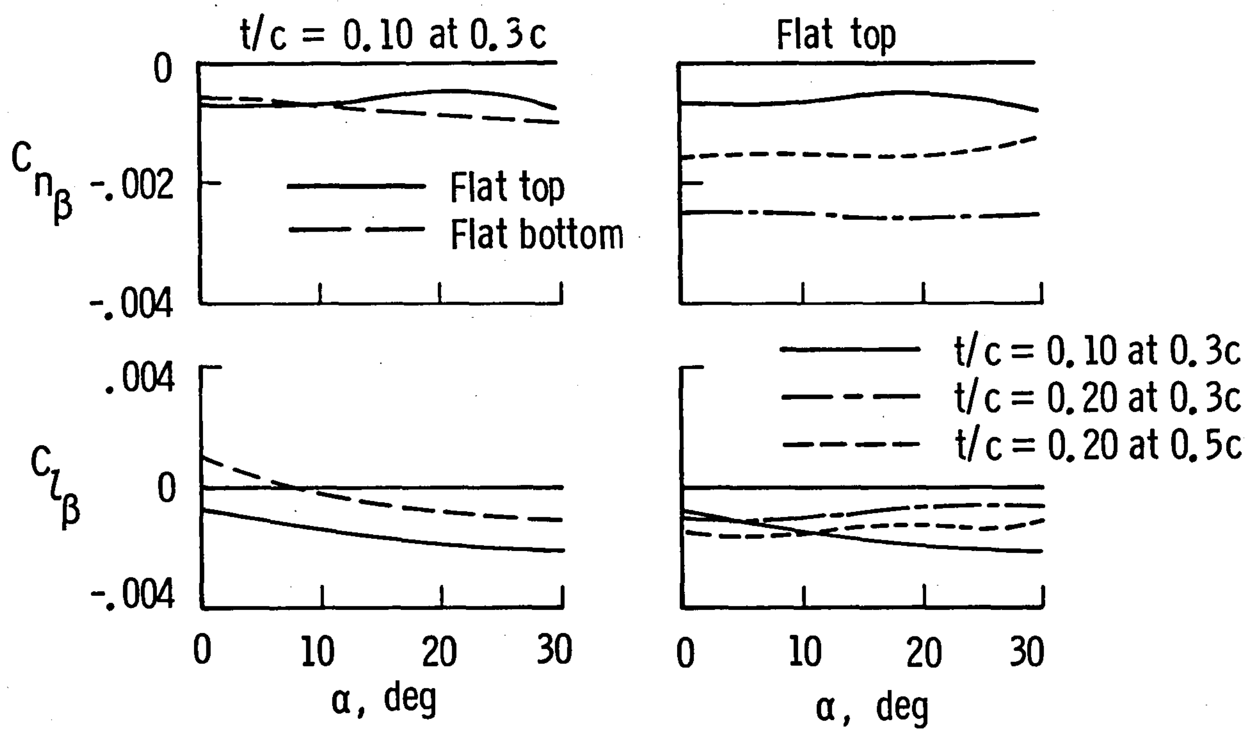

Figure 20. - Lateral-directional stability for cambered bodies with 75° triangular planform. M = 2.3, c.g. 0.53l.

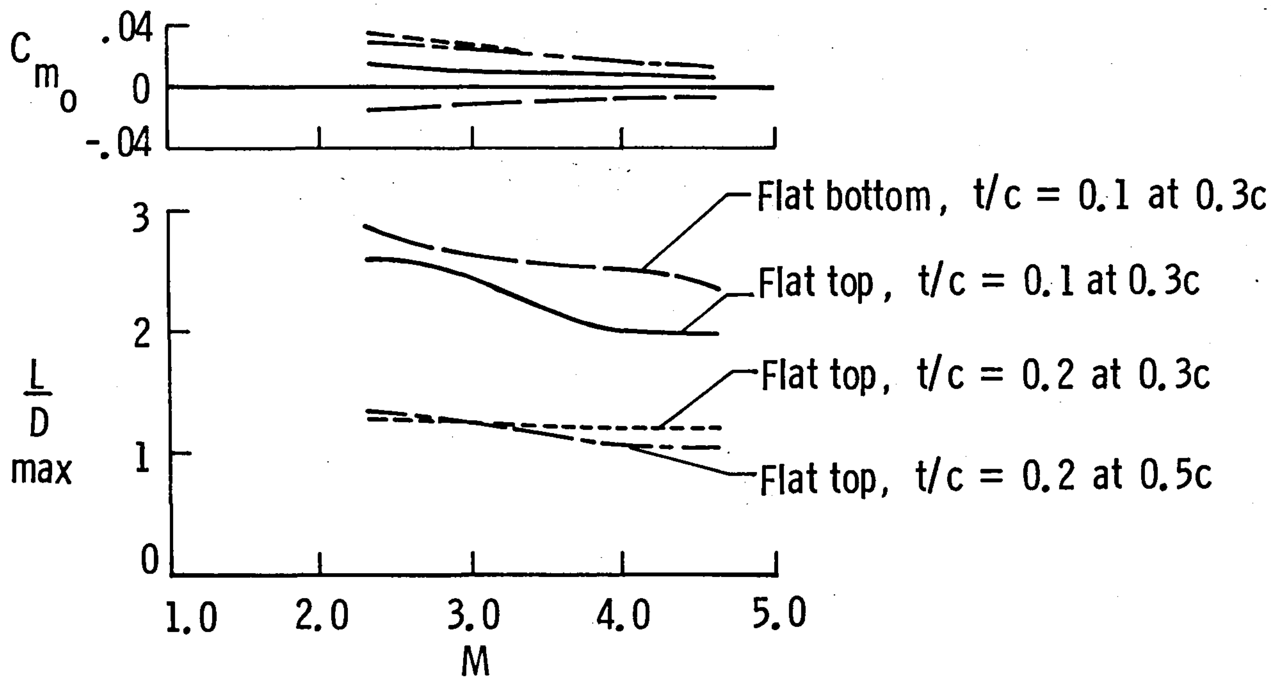

Figure 21. - Longitudinal summary for cambered bodies with 75° triangular planform.

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16. Abstract

The aerodynamic characteristics of some lifting-body concepts are examined with a view to the applicability of such concepts to the design of missiles. A considerable amount of research has been done in past years with vehicle concepts suitable for manned atmospheric-entry and atmospheric flight. Some of the concepts appear to offer some novel design approaches for missiles for a variety of missions and flight profiles. The concepts considered include right triangular pyramidal configurations, a lenticular configuration, and various 75-degree triangular planform configurations with variations in body camber and control systems. The aerodynamic features are emphasized but some observations are also made relative to other factors such as heat transfer, structures, carriage, observability, propulsion, and volumetric efficiency.

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