A PARAMETRIC STUDY OF THE DYNAMIC
MOTION OF A SPINNING AND NON-SPINNING RE-ENTRY
VEHICLE WITH NON-LINEAR AERODYNAMIC CHARACTERISTICS

F. Y. Horiuchi
Lockheed Missiles and Space Company
A Division of Lockheed Aircraft Corporation
Sunnyvale, California

Abstract

A parametric study was made of the effects of initial
conditions and various mass and aerodynamic parameters on the
dynamic motion of a typical re-entry vehicle. Non-linear aero-
dynamic characteristics were used and both spinning and non-
spinning re-entry at high angles of attack were examined. The
angle-of-attack convergence of a spinning re-entry vehicle was
found to be much more predictable than that of a non-spinning
vehicle principally due to the latter's extreme sensitivity to
initial conditions.

Introduction

The dynamic motion of a non-lifting re-entry vehicle
descending through the atmosphere has been the subject of many
investigations, (1) through (6). The approach of Friedrich and
Dore (1) was to separate the equations of motion into a set of
"static" trajectory equations describing the motion of the
center of gravity and a set of "rotational" equations describ-
ing the oscillatory motion of a vehicle about its center of
gravity. The static equations are solved to describe the time
history of the static trajectory parameters. The rotational
equations are then solved at any point along the static trajec-
tory to define the envelope of angle of attack and the motion
during a cycle.

The problem treated by Tobak and Allen (2) was that of
defining the oscillatory motion of a vehicle traversing the
ascending and descending paths through the atmosphere. The
specific case considered was that of a lifting vehicle descend-
ing on a skip trajectory, executing a turn, and then exiting
from the atmosphere. The general method of analysis was the
same as that of Friedrich and Dore.
The analysis of Sommer and Tobak (3) is an extension of the work of Tobak and Allen. Expressions were derived to describe the oscillatory motion of vehicles traversing arbitrarily prescribed trajectories. In this treatment the assumption of constant aerodynamic coefficients and the necessity of breaking the trajectory into straight line segments as required in (2) were eliminated. The resulting equations were applied to study the motion of manned re-entry vehicles.

The problem of a spinning vehicle entering the atmosphere at small angles of attack was investigated by Leon (4). The analysis was limited to the initial high-altitude portion of the re-entry trajectory where a center-of-gravity trajectory of constant velocity and constant flight path angle was assumed. This restriction was based on the work of Friedrich and Dore. Using the straight-line trajectory parameters, the rotational equations of motion were solved to derive a relation for the angle-of-attack envelope as a function of a spin parameter. The convergence of this envelope was then studied for both low and high spin rates.

These analyses are all limited in that the applicability of linear aerodynamics is assumed. The motion is therefore restricted to small angles of attack which precludes the consideration of the effects of initial angular rates on the motion of the vehicle as it descends through the atmosphere. These effects can be very significant. The presence of an initial pitch rate in the high-altitude region would drive a non-spinning vehicle into the non-linear aerodynamic regime before the aerodynamic restoring moments can initiate the convergence motion.

A study of the problem presented by the consideration of initial angular rates was made using the 6-degree-of-freedom equations of motion with the inclusion of non-linear aerodynamic characteristics. The three rotational equations of motion were coupled with the translational equations in this study. The solution of these equations using a high-speed computing machine program, (7) and (8), provides a detailed description of the vehicle motion history throughout the re-entry trajectory.

Initial Conditions

The re-entry vehicle analyzed in this study is a blunt cylindrical body with a spherical nose cap having a fineness ratio of 1.14. A sketch of the body and hypersonic aerodynamics characteristic of this type of body are shown in Fig. 1.

Due to the difficulty in defining the damping in pitch coefficient, \( C_{mq} + C_{p} \), by theoretical or experimental means, the analysis is made nominally assuming no damping in pitch.
Fig. 1. Hypersonic Aerodynamic Characteristics of a Typical Re-entry Body.
The effect of this term is analyzed by the input of constant values of the damping derivative.

The mass characteristics considered in this study are:

<table>
<thead>
<tr>
<th>Mass Characteristic</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$W/C_pA$</td>
<td>50 lb/ft$^2$</td>
</tr>
<tr>
<td>Center of gravity</td>
<td>36% of vehicle length</td>
</tr>
<tr>
<td>Roll inertia</td>
<td>250 slug-ft$^2$</td>
</tr>
<tr>
<td>Pitch inertia</td>
<td>400 slug-ft$^2$</td>
</tr>
<tr>
<td>Yaw inertia</td>
<td>400 slug-ft$^2$</td>
</tr>
<tr>
<td>Products of inertia</td>
<td>0 slug-ft$^2$</td>
</tr>
</tbody>
</table>

The dynamic motion of the re-entry vehicle descending through the atmosphere is represented by the convergence of its angle-of-attack envelope. Typical angle-of-attack histories for a non-spinning vehicle having an initial angular rate are shown in Fig. 2. The convergence can be judged by the amplitude of the envelope of the angle of attack at various altitudes in the re-entry trajectory. The altitudes considered are 200,000 feet (approximately peak heating) and 85,000 feet (Mach number = 2).

**Atmospheric Re-entry for a Non-Spinning Vehicle**

In this analysis of the non-spinning vehicle re-entering the atmosphere, the initial angular rates applied to the vehicle were restricted to the plane of the re-entry trajectory. Since the effect of atmospheric winds are neglected the oscillatory motion of the vehicle is also restricted to the plane of the re-entry trajectory. The presence of an initial pitch rate on a non-spinning vehicle causes a large amplitude of angle-of-attack oscillation in the high-altitude region where the restoring aerodynamic moments are very small. As the vehicle descends further into the atmosphere the increasing density results in greater aerodynamic moments causing the envelope of the angle-of-attack oscillation to converge. This convergence continues as the dynamic pressure builds up. Divergence of the envelope occurs as the dynamic pressure reaches a maximum and then rapidly decreases. This motion is shown in Fig. 2 for both the case where the re-entry vehicle initially tumbles before the angle-of-attack oscillation converges and the case where an initial tumble does not occur.

The analysis of the motion of the non-spinning vehicle was made from a point in its trajectory corresponding to atmospheric entry altitude. Nominal initial conditions on trajectory parameters were:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Altitude</td>
<td>400,000 ft</td>
</tr>
<tr>
<td>Inertial velocity</td>
<td>25,420 ft/sec</td>
</tr>
<tr>
<td>Flight path angle</td>
<td>-3 deg</td>
</tr>
</tbody>
</table>
Fig. 2. Typical Angle-of-Attack Histories for a Non-Spinning Re-entry Vehicle.
The vehicle was assumed to have a nominal initial angle of attack of 10 degrees and zero yaw and spin rates.

The resulting history of the nominal re-entry trajectory parameters are presented in Fig. 3.

The study of the effect of various parameters on the motion of the non-spinning vehicle encompassed the variation of the following quantities:

(a) Initial pitch rate  
(b) Initial altitude  
(c) Axial location of the center of gravity  
(d) Lateral offset of the center of gravity  
(e) Atmospheric density model  
(f) Damping in pitch parameter.

The convergence of the angle-of-attack envelope as the vehicle descends through the atmosphere is indicated by the amplitude of the angle-of-attack oscillation at altitudes of 200,000 and 85,000 feet. A discussion of the effect of the various parameters on the angle of attack at these two points follows.

(a) Initial Pitch Rate. The presence of a small angular velocity causes the re-entry vehicle to pitch to a high angle before the aerodynamic restoring moment begins to rotate the vehicle back toward a zero angle of attack in its first cycle of oscillation. If the initial pitch rate is sufficiently great, the vehicle will tumble before angle-of-attack convergence begins. Fig. 4 shows the effect of the initial pitch rate on the angle of attack at the 200,000- and 85,000-foot altitude points. Of note is the cusp which peaks at an initial pitch rate of 5.4 degrees per second. A physical explanation of this point follows: As the vehicle pitches up due to the initial rate, its pitch rate is continually being reduced by the aerodynamic restoring moment. At an angle of attack of 180° the pitch rate has been reduced to precisely zero and, since the aerodynamic moment is also zero at an angle of 180°, the vehicle theoretically proceeds to descend through the atmosphere tail first without oscillating. However, the vehicle is either aerodynamically unstable or has stability over only a few degrees of angle of attack in the vicinity of 180°. Therefore, any slight perturbation would cause the vehicle to move out of this unstable region. One perturbing factor is present due to the vehicle trajectory. This is the changing flight path angle which in the absence of a vehicle pitch rate becomes a changing angle of attack. The magnitude of this rate of change of angle of attack, while enough to perturb the vehicle off the tail-first attitude, is not large enough to substantially reduce the angle of attack.
Fig. 3. Re-entry Trajectory Parameters.
Fig. 4 Effect of Initial Pitch Rate
in the initial portion of the trajectory. As the vehicle is perturbed the aerodynamic restoring moment due to the increasing dynamic pressure and the changing attitude forces the angle of attack into the converging oscillatory motion. Thus the convergence is initiated from the full amplitude of angle of attack at a small rate and after a large portion of the trajectory has been traversed. Consequently the angle-of-attack envelope becomes very large.

The study indicates that for initial pitch rates less than 5.4 degrees per second the vehicle will not tumble before the angle-of-attack envelope begins to converge. For initial rates greater than 5.4 degrees per second, the vehicle tumbles a number of times equal to the number of cusps in that portion of the curve to the left of the initial pitch rate. The angle-of-attack convergence for a tumbling vehicle and a non-tumbling vehicle, shown in Fig. 2, corresponds to initial pitch rates of 6 degrees per second and 4 degrees per second respectively. The non-tumbling angle-of-attack envelope will be expanded for higher initial rates as indicated by that portion of the curve in Fig. 4 to the left of the first cusp.

(b) Initial Altitude. If for a given set of initial conditions the re-entry vehicle motion were initiated at a lower altitude, the higher initial aerodynamic restoring moment, which is due to the higher atmospheric density, would reduce the angle-of-attack growth caused by the initial pitch rate. As a result the amplitude of the first angle-of-attack oscillation as well as the envelope throughout the rest of the trajectory would be decreased. This is illustrated in Fig. 5 for initial pitch rates of 3 and 6 degrees per second. Also indicated is the dynamic pressure at various initial altitudes. Since the aerodynamic moment coefficient has only a small variation throughout the range of initial altitudes considered, the initial dynamic pressures are directly proportional to the initial aerodynamic restoring moments.

(c) Axial Center of Gravity. Fig. 6 shows the effect of the axial center-of-gravity position on the angle-of-attack convergence for initial pitch rates of 4 and 6 degrees per second at an initial altitude of 400,000 feet. The moments of inertia were assumed to be constant over this range of center-of-gravity locations. The curves for the pitch rate of 4 degrees per second are as expected; i.e., as the center of gravity is moved further aft of the nose, the aerodynamic stability decreases and the angle-of-attack convergence becomes worse. However, the curves for the initial pitch rate of 6 degrees per second indicate that as the center of gravity is moved aft the angle-of-attack convergence is improved. A physical explanation of this follows: For an initial pitch rate of 6 degrees per
Fig. 5. Effect of Initial Altitude.
Fig. 6. Effect of Gravity Position.
second, the vehicle tumbles once before its angle-of-attack convergence begins. If the vehicle has slightly less aerodynamic stability, the tumble will be completed sooner and hence convergence will begin at a higher altitude. The combination of the higher altitude and the pitch rate at the completion of the tumble results in improved angle-of-attack convergence in spite of the slight reduction in aerodynamic stability throughout the re-entry trajectory.

(d) Lateral Offset of the Center of Gravity. The effect of a lateral center-of-gravity offset in the plane of the trajectory is to displace the angle-of-attack envelope resulting in a trim angle of attack. The most serious effect of this trim angle of attack is the resultant dispersion of the impact point. The magnitude of the dispersion is approximately 65 nautical miles per inch of offset. A lateral offset out of the plane of the trajectory will result in an induced spin rate due to the unsymmetrical aerodynamic loading. In this event the vehicle will undergo a rotational motion around the velocity vector as will be discussed later.

(e) Atmospheric Density Model. The atmospheric density model used in any analysis has a significant effect on the angle-of-attack convergence of a non-spinning re-entry vehicle. A comparison was made using the 1956 and 1959 ARDC model atmospheres, pertinent portions of which are shown in Fig. 7. The two models do not differ below an altitude of 250,000 feet, but for the same initial pitch rate of 6 degrees per second the computation using the 1959 model showed that the vehicle tumbles once before convergence begins while that using the 1956 model shows that no tumble occurs. This difference in convergence is not surprising when one considers the fact that the densities given by the models differ by a factor of approximately 3 in the altitude range in which the first angle-of-attack oscillation occurs. Since the aerodynamic restoring moment is directly proportional to density, the aerodynamic restoring moment will also differ by a factor of 3. The computation using the 1959 atmospheric model would therefore be expected to show a much larger initial amplitude of angle of attack than that using the 1956 model before the aerodynamic restoring moment can cause the convergence to begin.

The exponential density variation defined by Eq. (1) and included on Fig. 7

\[ \rho = \rho_0 e^{-\beta y} \]  

is used in all of the referenced analyses except (5). In this analysis, Lichtenstein employed a density variation from
Fig. 7. Comparison of Atmospheric Density Models.
standard atmospheric tables contained in the Rocket Panel Proposal of April 1955. The density determined by the exponential variation is significantly affected by the values of the constants, \( \rho_0 \) and \( \beta \), used. In the altitude region where the first angle-of-attack oscillation occurs, the constants used by Sommer and Tobak, \( \rho_0 = 0.0027 \text{ slugs/ft}^3 \) and \( \beta^{-1} = 23,500 \) feet, give a density larger than the 1959 ARDC model atmosphere by a factor of 5. The constants quoted by the other authors, \( \rho_0 = 0.0034 \text{ slugs/ft}^3 \) and \( \beta^{-1} = 22,000 \) feet, result in a density larger by a factor of 2 over the 1959 ARDC model. Below an altitude of 300,000 feet, the latter exponential density variation is seen to fall below the ARDC density. The aerodynamic restoring moment due to the exponential density model, while greater than that for the ARDC model in the altitude region of the first angle-of-attack oscillation, thus becomes smaller below an altitude of 300,000 feet. The angle-of-attack envelope using this exponential density can thus be expected to start with a smaller amplitude and not converge as rapidly as when the 1959 ARDC model atmosphere is used.

It is emphasized that the differences in the atmospheric density models used are most critical for the case of re-entry with an initial pitch and zero spin rate. If there were no initial rates, the convergence of the angle-of-attack motion would be much less affected by these differences.

(f) Damping in Pitch. The determination of the damping in pitch coefficient of a blunt body as a function of angle of attack and Mach number is very difficult by theoretical means. It is equally difficult to obtain consistent experimental data. For the purpose of this study the damping in pitch coefficient was assumed to have a constant value independent of both angle of attack and Mach number. The effects of various constant damping coefficients on the angle-of-attack convergence is illustrated in Fig. 8. It can be seen that the effect of damping in pitch becomes important below an altitude of 200,000 feet when the pitch angular velocities become large.

Atmospheric Re-entry for a Spinning Vehicle

The motion of the re-entry body shown in Fig. 1 was studied for the case of spinning re-entry from orbital altitude. The initial conditions on trajectory parameters used in this study were:

- Altitude: 935,860 ft
- Inertial velocity: 24,766 ft/sec
- Flight path angle at 400,000-foot altitude: -3 deg
Fig. 8. Effect of Constant Values of Damping in Pitch Parameter.
A time history of the basic re-entry trajectory parameters is shown in Fig. 9. These parameters were essentially unaffected by the variation in motion due to changes in initial pitch and yaw rates.

The convergence of a typical angle-of-attack envelope for a spinning re-entry body is shown in Fig. 10. The motion of the spinning re-entry body, however, is more complex than that for the non-spinning planar re-entry previously discussed. Because of this a technique for graphing the details of the motion was devised. Fig. 11 is a pictorial representation of the motion trace of the vehicle spin axis and the velocity vector on an inertial sphere for a spinning vehicle having an initial yaw rate. Both the spin axis and velocity vector originate from the center of the sphere which constitutes the origin of the inertial coordinate system. The coordinates are the ordered Euler angles, \( \psi_i \) and \( \theta_i \), orienting the vehicle spin axis with an inertial axis and the ordered Euler angles, \( \tau_i \) and \( \lambda_i \), orienting the velocity vector with the same inertial axis. This representation shows the motion of the spin axis to be a precession cone outside the velocity vector from the initial altitude at orbit down to an altitude of approximately 320,000 feet, after which the aerodynamic moments become increasingly significant causing it to change to motion about the velocity vector. The latter is indicated when in some portion of the re-entry trajectory the spin axis traces a path circling the corresponding velocity vector such that the maximum included angle does not exceed 180 degrees. The total angle of attack, \( \eta \), is defined as the angle between the vehicle spin axis and the velocity vector.

A study was made to determine the effects of the following parameters on the re-entry motion:

(a) Magnitude and direction of initial angular rates
(b) Initial spin rate
(c) Initial vehicle attitude
(d) Moments and products of inertia
(e) Axial location of the center of gravity
(f) Radial location of the center of gravity
(g) Damping in pitch parameter.

The results of this study are discussed in the following paragraphs:

(a) Magnitude and Direction of Initial Angular Rates. The convergence of the angle-of-attack envelope of a spinning vehicle is highly dependent upon both the magnitude and direction of the initial angular rates. The magnitude of the precession cone angle, \( \delta \), for a spinning body with equal pitch and
Fig. 9. Re-entry Trajectory Parameters From Orbit Altitude.
Fig. 10. Typical Angle of Attack Convergence for a Spinning Re-entry Vehicle.
Fig. 11. Motion of the Vehicle Spin Axis and Velocity Vector in Inertial Space.

VELOCITY VECTOR

\[ \Delta h = 935,860 \]
\[ \Delta^2 = 600,000 \]
\[ \Delta^3 = 400,000 \]
\[ \Delta^4 = 250,000 \]

NOTES:

1. DASH LINE INDICATES POSITIONS ON THE BACK FACE OF THE INERTIAL SPHERE

2. 400K, ETC. INDICATE TRAJECTORY ALTITUDES
yaw inertias and zero products of inertia is given by Eq. (2) where \( I_p \) and \( I_R \) are the pitch and roll inertias, and \( p, q \) and \( r \) are
\[
\delta = 2 \tan^{-1} \frac{\sqrt{q^2 + r^2}}{I_p/I_R} \tag{2}
\]

the roll, pitch, and yaw rates, respectively. The position of the precession cone relative to the velocity vector is dependent on the direction of application of the initial angular rates. The momentum vector resulting from the application of various angular velocity vectors to the spinning vehicle causes the vehicle to sweep precession cones as shown in Fig. 12. Since the magnitude of the angle of attack is dependent on the position of the vehicle longitudinal axis in the precession cone relative to the velocity vector, it is apparent that the angle-of-attack envelope is highly affected by the direction of application of the initial angular rate. For a positive spin rate it can be determined that, for any given angular velocity, application in the negative yaw direction will result in the precession cone having the most severe limits on angle of attack. The effect of the magnitude of negative yaw rate was then studied. As shown in Fig. 13, this effect is primarily to change the magnitude of the precession cone angle in the high-altitude region. This is seen in the relation for precession cone angle, \( \delta \). When the pitch and yaw rates are both zero, the vehicle spin axis is stabilized, with no precession cone angle, at its initial pitch attitude. The convergence of the angle of attack in this case is indicated by the convergence of the \( \eta_{\text{min}} \) curve.

(b) Initial Spin Rate. The effect on the vehicle motion of varying the initial spin rate is primarily to change the magnitude of the precession cone angle in the high-altitude region. This can be seen from the precession cone relation stated previously and is illustrated in Fig. 14. At spin rates below 1.4 rpm, the precession cone angle and the maximum total angle-of-attack decrease from the limiting value of 180 degrees. For increased spin rates, the higher angle-of-attack envelope in the low-altitude region is due to the increased gyroscopic resistance to the aerodynamic stabilizing moments.

(c) Initial Vehicle Attitude. The angle-of-attack envelope at atmospheric entry altitude is a direct function of the vehicle attitude at the initiation of the motion study. This is shown in Fig. 15. Increasing the initial attitude is shown to result in a higher angle-of-attack envelope throughout the re-entry trajectory.
Fig. 12. Effect of Direction of Application of Initial Angular Rate to the Precessional Motion of a Spinning Vehicle.
Fig. 13. Effect of Initial Yaw Rate.
Fig. 14. Effect of Initial Spin Rate.
Fig. 15. Effect of Initial Attitude.
(d) Moments and Products of Inertia. The angle-of-attack envelope is shown in Fig. 16 to be virtually unaffected by a change in the level of equal pitch and yaw inertias over a range of approximately 20 percent. The effect on the maximum angles of attack of unequal pitch and yaw inertias is also found to be very slight. This is illustrated in Fig. 17.

The presence of mass asymmetries producing products of inertia, however, significantly affect the angle-of-attack history. The presence of these products of inertia causes the precessional motion of the vehicle to oscillate in magnitude and results in an expanded precession cone. Fig. 18 shows the magnitude of the maximum and minimum total angles of attack for the presence of singular or combined products of inertia amounting to 10 percent of the pitch inertia.

(e) Axial Location of the Center of Gravity. The axial location of the center of gravity is shown in Fig. 19 to have no effect on the angle-of-attack envelope until the region of the re-entry trajectory where the aerodynamic forces become significant. In the lower altitude regions, as indicated in the curves for 200,000 and 85,000 feet, the rearward movement of the center of gravity resulted in a gradually higher angle-of-attack envelope until the center of gravity was such that the vehicle became unstable. A further rearward movement of the center of gravity caused the angle of attack to rapidly diverge to the maximum 180-degree value. The angle-of-attack history is thus extremely sensitive to the center of pressure predictions for the vehicle throughout the flight regime.

(f) Radial Location of the Center of Gravity. For a spinning vehicle, the greatest effect of a radial center-of-gravity offset is to enlarge the angle-of-attack envelope in the lower altitude regions where the aerodynamic forces become significant. Since the radial center of gravity is fixed in the body, the spinning of the vehicle causes the aerodynamic forces to act in continually changing directions with respect to the fixed inertial space. This produces no net reaction continually in any one direction and therefore results in very little trajectory dispersion. However, because the vehicle is rotating about the velocity vector, these forces tend to enlarge the motion about the velocity vector and to cause the envelope of this motion to oscillate.

(g) Damping in Pitch Parameter. As stated previously, it is extremely difficult to define the variation of the damping in pitch parameter, $C_{mq} + C_{m\dot{q}}$, over the full Mach number and angle-of-attack regime by theoretical or experimental means. Therefore, stabilizing and destabilizing values of $C_{mq} + C_{m\dot{q}}$
Fig. 16. Effect of Moment-of-Inertia Ratio.
Fig. 17. Effect of Pitch Moment-of-Inertia Ratio.
Fig. 18. Effects of Products of Inertia Ratio.

- Altitude = 400,000 ft
- Altitude = 200,000 ft
- Altitude = 85,000 ft

Products of Inertia Ratio, $I_{ij}$ / $I_{pitch}$
Fig. 19. Effect of Axial Center of Gravity Position.

ENVELOPE OF TOTAL ANGLE OF ATTACK (DEG)

ηMAX
ηMIN

ALTITUDE = 400,000 FT
ALTITUDE = 200,000 FT
ALTITUDE = 85,000 FT

AXIAL CENTER OF GRAVITY (PERCENT OF VEHICLE LENGTH)
constant over the entire flight regime were used in studying the effect on the angle-of-attack convergence. The damping in pitch has little effect above an altitude of 300,000 feet due to the small magnitude of the aerodynamic forces. A constant positive or destabilizing value of damping coefficient is shown in Fig. 20 to cause the angle-of-attack envelope to diverge sharply below an altitude of 200,000 feet. The converse occurs for stabilizing values of damping. This is due to the very large values of pitch rate that occur in this portion of the trajectory as the frequency of oscillation increases rapidly.

Summary

A typical re-entry body has been studied for both spinning and non-spinning re-entry at high angles of attack. Since the design of a re-entry body is dependent on the most severe angle-of-attack history it is expected to encounter, it is important that the design angle-of-attack curve be predictable.

Planar re-entry is shown to pose many problems if an initial angular rate is present. The maximum rate must be less than that which would cause the vehicle to tumble initially. If this rate is approached, it becomes very difficult to predict the design angle-of-attack curve since the resulting maximum angle can be extremely large. While this is very unlikely, the realistic maximum angle of attack remains difficult to predict. In addition it becomes difficult to determine if moving the center of gravity forward or aft would be most advantageous to the system. The angle-of-attack convergence also becomes very sensitive to the atmospheric model used. In addition, a lateral center-of-gravity offset results in a huge dispersion of the impact point.

Spinning re-entry is more desirable for the design of a re-entry vehicle since the resulting gyroscopic stability from orbit to re-entry altitudes gives a controlled angle of attack at atmospheric re-entry. The convergence of the design angle-of-attack curve becomes less sensitive to initial angular rates, inertias, center-of-gravity locations, and the atmospheric density. The dispersion of the impact point also becomes negligible.

References

Fig. 20. Effect of Constant Damping in Pitch.


