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Mars Lander Vehicle/Parachute Dynamics

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SUMMARY

Parachute decelerators used exclusively or in combination with retro rockets have been considered prime candidates for the terminal descent and landing system of a scientifically instrumented Mars lander. The objective of this study is to understand basic relationships between parameters affecting dynamic response of the parachute and capsule and to define those aspects of the system which have a sensitive effect on the design of the lander capsule. Of particular interest is the response of the capsule to wind gusts and to establish the sensitivity to gust onset rates in the VM series of Martian atmospheres.

The model used in studying parachute/capsule relationships consists of two bodies, each with three degrees-of-freedom, connected by an elastic riser cable. The total elastic nature of the parachute and shroud lines is simulated by the equivalent elasticity of the riser cable. The parachute and its enclosed and apparent inertia effects are treated in a rigid body sense. Parachute opening phase dynamics are included in the analysis model.[1]

Motion of the system is examined in either the pitch or yaw plane with roll motion assumed to be controlled near zero by an attitude control system. Capsule attitude excursions and attitude rates are investigated in detail because of their impact on optical and radar sensors. The ability of a simple rate damping attitude control system to combat capsule oscillations is included in the study.

Usually a planetary entry vehicle utilizes a blunt body aeroshell coated with ablative material for the high dynamic pressure, high Mach number portion of the entry trajectory. Once this region has been traversed and Mach number is reduced to approximately 1.6, the parachute decelerator may be deployed. From this point on, the aeroshell serves little usefulness and may complicate the touchdown mechanics. It may be desirable, therefore to jettison the aeroshell as soon as possible after parachute deployment. The ease of accomplishing aeroshell separation while descending on a parachute is evaluated.

Parachute sizes studied vary from 64 to 84 feet sized to produce terminal velocities in the 300 fps range. Capsule weights of 2360 to 2640 lbs are considered. Parachute snatch force and opening shock forces in riser lines are reported for a final reference configuration.

DISCUSSION

The Voyager mission involves entry into the Martian atmosphere from an orbiting spacecraft of a scientifically instrumented payload for the purpose of atmospheric determination and surface experimentation. A high drag entry vehicle combined with a terminal deceleration system involving either parachutes or retro rockets or both will be used to achieve a soft landing on the planet surface. The parachute is used as an interim decelerator system between the high supersonic blunt body deceleration phase and the final touchdown and landing vernier retro phase. Parachute state-of-the-art and testing in the Planetary Entry Parachute Program (PEPP) have demonstrated parachute deployment up to Mach Number 2.6. Since M = 2.6 occurs higher than 100,000 feet in some estimates of the Martian atmosphere, a lower deployment altitude (approximately 24,000 feet above mean surface) is selected so that the orbiting bus vehicle does not disappear over the planet horizon as the entry vehicle is descending on the parachute. The parachute is cut loose shortly after vernier retro ignition which occurs at approximately 4000 feet over the local terrain.

One of the major problems of a Mars landing is the lack of definition of the Martian atmosphere. The best available scientific data has been used to postulate 10 atmospheres,[2] designated VM-1 through VM-10, varying in density, composition, temperature, pressure and scale height characteristics.

Density and speed of sound versus altitude are important properties for the parachute dynamics study and are reproduced in Figures 1 and 2. Notice that the outside limits of density are represented by atmospheres VM-8 and VM-9 above 17 kilometers and by VM-7 and VM-10 below 15 kilometers. The least dense atmosphere at parachute deployment altitudes is VM-7. For this reason it is used to size the parachute for a terminal velocity consistent with the capability of the vernier retro system. In all other atmospheres the terminal velocity will be lower and therefore within the decelerating capability of the vernier retro system.

The design criteria[2] specifies a continuous wind and wind shear criteria, both of which have been examined and found to be not critical from the dynamic standpoint. The criteria specifies that a step function wind gust of design magnitude shall be considered as well as removal of such gust at a critical point in the trajectory.

Gust response is therefore of primary concern in this study. Because a step gust may be unrealistic, gusts of varying onset rates are considered as well as the step gust.

For most of the gust response cases studied, the parachute is assumed to already have pulled the lander capsule out of the aeroshell with the capsule having no active attitude control. As will be noted, a special case is considered where gust response is made with an active attitude control system. Aeroshell separation is treated as a separate study in which parachute, lander capsule, and aeroshell are treated as three separate bodies before and after separation.

WIND GUST RESPONSE

This phase of the study determines parachute and capsule attitude excursions, attitude rates, and angle of attack perturbations resulting from a descent through the wind gust profiles shown in Figure 3. All of the cases studied in this section were in the VM-8 and VM-10 atmospheres. An attempt is made to generalize from the results in VM-8 to analytical predictions on performance in other atmospheres.

Planetary entry from orbit about Mars is made with an entry vehicle weighing 3078 pounds at an entry flight path angle of -14.5 degrees. The trajectory is picked up at 34000 feet altitude where parachute deployment is assumed to occur for this phase of the study. The following trajectory conditions exist in VM-8 and VM-10 at parachute deployment:

	VM-8	VM-10
Flight Path Angle, Deg	-27.5	-78
Velocity, fps	1010.	478
Mach Number	1.6	0.61

Systems Description

Parachute - A typical subsonic parachute is assumed with physical dimensions and orientation definitions shown in Figure 4. An arbitrary criteria of sizing the parachute for 290 fps terminal velocity in the VM-7 atmosphere at 10,000 feet is used in calculating the following reference diameter:

$$D_0 = \frac{2}{V_T}\sqrt{\frac{2(g_♂/g_⊕)W_L}{\zeta \pi C_{D_0}}}$$

where

V_T = Terminal velocity = 290 fps

$g_♂/g_⊕$ = Mars/Earth gravitational ratio = .383

W_L = Landed Payload including parachute = 2463 lbs

ζ = VM-7 Density at 10,000 ft = 1.18 x 10^{-5} slugs/ft^3

C_{D_0} = 0.6

$$D_0 = \frac{2}{290}\sqrt{\frac{2 \times .383 \times 2463}{1.18 \times 10^{-5} \times .6\pi}} = 64.2 \text{ ft}$$

In making the above calculations, a parachute weight had to be assumed. A better estimate of parachute weight is now possible using the following equation:[3]

$$W_P \cong .0243\, D_0^{\,2} = 100 \text{ lbs}$$

Additional parachute physical properties are as follows:

D_0 = 64.2 ft.

D_P = 40.8 ft.

Volume of enclosed atmosphere = $\frac{\pi D_P^{\,3}}{12}$

Mass of encl atmosphere = $\frac{\zeta \pi D_P^{\,3}}{12}$ = .28 slugs
(Values shown are for 20,000 ft in VM-8)

Apparent mass = .14 slugs

Enclosed + apparent = .42 slugs

Total chute mass = 100/32.2 + .42 = 3.53 slugs

Chute moment of inertia = 383 slug-ft^2 (includes apparent effect)

Capsule - The lander capsule at parachute deployment has the following physical properties:

$$W_C = W_{entry} - W_{Aeroshell} - W_{parachute} = 3078 - 615 - 100 = 2363 \text{ lbs.}$$

I_C = moment of inertia = 466 slug-ft^2.

Aerodynamic Data

Aerodynamic coefficients for the typical parachute used in this analysis are shown in Figure 5. The aerodynamic data for the legged lander configuration are based on an approximation of the actual porosity due to open frame construction and leg orientation. The following coefficients and slopes reflect conditions near zero angle of attack:

Parachute	Capsule
D_{ref} = 64.2 ft	D_{ref} = 10 ft.
C_A = 0.6	C_A = 0.6
C_{N_α} = .00643/degree	C_{N_α} = .012/degrees
C_{M_α} = .00424/degree about c.g.	C_{M_α} = .0045/degree
C_{M_Q} = -0.3	C_{M_Q} = 0

Gust Profiles

The constraints and requirements document[2] specifies that the design must be capable of accommodating a gust speed of the following magnitude:

Atmosphere	Design Gust Velocity - fps
VM-7 and VM-8	200
VM-9 and VM-10	100

The specification states further that removal of the gust at a critical stage of the induced motion shall also be evaluated. The specification is not clear as to the gust onset or removal rate. Since the onset rate is of major importance, several different rates are examined. The gust profiles shown in Figure 3 are generated by increasing the wind velocity from zero at 30,000 feet to 200 fps with a gradient ranging from 10 to 200 fps/1000' altitude. On the first series of runs, the wind velocity is held constant once 200 fps is attained. The second series simulates the removal of the gust with the same gradient $\frac{d\,VS}{dh}$ as was used for the onset. A third series simulates gust onset and removal with a cosine curve. A fourth series assumes a 40 fps/1000 ft gradient starting at three different altitudes.

Gust Onset Rate

Since the parachute lander will descend at different rates in the various VM atmospheres, the rate of change of wind velocity with time (d VW/dt) will not be the same even with identical wind versus altitude gradients (d VW/dh). The gust onset rate, (d VW/dt) appears to be the more significant variable and the one which will govern the attitude excursion, $\Delta\theta$. This study indicates that for a given configuration, the same trim attitude excursion will result in any atmosphere as long as the gust onset rate is the same.

Gust Onset Rate = wind gradient x terminal velocity

$$\frac{d\,VW}{dt} = \frac{d\,VW}{dh} \times \frac{dh}{dt}$$

Trim Attitude

For any given wind gradient $\left(\frac{d\,VW}{dh}\right)$ there should exist a trim attitude which will not be exceeded by increasing wind velocity. This will occur when the vehicle horizontal acceleration equals the rate at which the wind velocity is increasing.

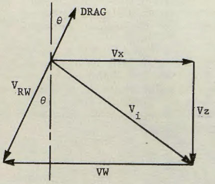
θ_T = trim when

$$\frac{dVx}{dt} = \frac{d\,VW}{dt}$$

$$\frac{d\,VW}{dt} = \frac{d\,VW}{dh} \cdot \frac{dh}{dt}$$

$$\frac{d\,Vx}{dt} = \ddot{X} = \frac{\text{Drag x } \sin\theta_T}{M}$$

$$\text{therefore, } \theta_T = \sin^{-1}\left(\frac{M}{C_A qS} \cdot \frac{d\,VW}{dh} \cdot \frac{dh}{dt}\right)$$



Step Function Gust

In addition to the gusts described in Figure 3, step function gusts of 200 fps in VM-8 and 100 fps in VM-10 are considered with onset at 10,000 feet and removal at 5000 feet. In order to soften the instantaneous nature of the step gust for digital simulation, the gust velocity was increased from 0 to 200 fps in 10 feet of altitude. This produces an onset rate of 4380 feet per second per per second in VM-8 and 2500 feet per second per second in VM-10.

Results

The results of this study indicate that angles of attack induced by gusts are relatively small compared with capsule attitude deviations from the no wind case. Considerably more interest has been shown in attitude excursions and attitude rates by those concerned about communications geometry and optical sensor performance. Consequently, these parameters are used almost exclusively in reporting the results of this study.

The basic capsule response to wind gusts is presented in Figure 6. In this series, the wind starts to increase from zero at 30,000 feet to 200 fps at various rates. Once 200 fps wind velocity is attained and held constant, the rapid change in attitude stops and gradually returns to zero. The attitude rate is the highest at initial gust onset with the following rates recorded for each of the wind gradients:

Wind Gradient FPS/1000 Ft.	$\Delta\theta$ Deg	Attitude Rate $-\dot{\theta}$ Deg/Sec
10	9.5	2.27
20	19.5	2.80
40	26.5	3.85
80	28.5	5.95
200	29.0	12.2

The difference in attitude ($\Delta\theta$) between a gust and the zero wind case is greatest when the gust represents a tailwind condition. The data presented, therefore, is for the tailwind condition. Note from the above data that the attitude change increases with increasing wind gradient but at a diminishing rate. An additional observation from Figure 6 is that the 10 fps/1000' gradient case attitude seems to be approaching an asymptote of 10 deg. If the gust magnitude were increased beyond 200 fps, it appears that the attitude would not increase beyond the trim condition already established.

The effect of removing the gust at the same rate as it was established is shown in Figure 7. The attitude excursion resulting from the gust removal is in no case greater than that established by gust onset. The following substantial attitude rates are produced at the inflection point of the gust profile.

Wind Gradient FPS/1000 Ft.	Attitude Rate $-\dot{\theta}$ Deg/Sec
10	2.21
20	4.1
40	7.72
80	14.82

A sharp or instantaneous reversal in slope of the gust profile is perhaps unreasonable. Consequently, a cosine shaped gust profile was examined. A comparison of the sharp edged and the cosine gust profiles is made in Figure 8. The resulting attitude excursions are nearly the same in the two cases. The major difference between the two profiles is apparent in the comparison of peak attitude rates and peak angles of attack induced at the gust profile inflection point in the table below:

Atmos	Wind Gradient FPS/1000'	Onset Rate Ft/Sec^2	H Ft	Sharp Edged Gust: $\dot{\theta}$ Peak Deg/Sec	Sharp Edged Gust: α Peak Deg	Cosine Gust: $\dot{\theta}$ Peak Deg/Sec	Cosine Gust: α Peak Deg
VM-8	20	4.38	20,000	4.1	1.91	1.74	.73
	40	8.76	25,000	7.72	3.86	3.2	1.39
	80	17.52	27,500	14.82	7.57	6.15	2.62
	80	17.52	10,000			7.73	3.76
	200	43.8	29,000			20.1	10.96
VM-10	34.9	4.38	29,800	3.6	2.05		
	80	100.	10,000			3.36	2.97

Note in the table and in Figure 8, that a different set of conditions are represented by an 80 fps/1000 ft gust at 10,000 feet in VM-8 and VM-10. In these two cases, the parachute was deployed at 15,000 feet to determine whether a lower deployment would sizeably affect the attitude excursion and attitude rates. The data shows only a minor increase in magnitude of these variables at the lower altitude.

As previously noted in the discussion of basic gust response in Figure 6, there appears to be a trim condition associated with each wind gradient in a given atmosphere. In order to verify this hypothesis, the wind gust profile for a gradient of 20 FPS/1000 ft is extended as shown by the dashed line in Figure 3 to a velocity of 400 FPS. A digital simulation of this condition produced the result shown in Figure 9. A trim condition is achieved at an attitude of 19 degrees. The analytical expression derived in the discussion predicts this trim attitude to be:

$$\theta_{Trim} = \sin^{-1}\left(\frac{M}{C_A qS} \cdot \frac{d\ V_W}{dh} \cdot \frac{dh}{dt}\right)$$

$$= \sin^{-1}\left(\frac{76.5}{1040} \times .020 \times 214\right)$$

$$= 18.3 \text{ degrees}$$

In a similar manner, the predicted trim attitude with a 40 FPS/1000 ft gradient is shown in Figure 9 to be 36 degrees. To arrive at this trim condition, however, would require a wind gust increasing to an unrealistically high value of 800 FPS.

The importance of gust onset rate $\left(d\ V_W/dt\right)$ in determining the attitude excursion in any atmosphere is demonstrated by duplicating the same onset rate used in VM-8 for a 20 FPS/1000' gradient in the VM-10 atmosphere:

$$\frac{d\ V_W}{dt} = \frac{d\ V_W}{dh} \times \frac{dh}{dt}$$

$$\frac{dV_W}{dt} \text{ (VM-8)} = .020 \times 219 = 4.38 \text{ FPS/Sec}$$

$$\frac{dV_W}{dt} \text{ (VM-10)} = .0349 \times 125.5 = 4.38 \text{ FPS/Sec.}$$

The result of the VM-10 simulation is shown dotted in Figure 9 along with the VM-8 data. Because of the different density, trim conditions are attained at a much different altitude. The important point, however, is that the trim attitude excursion (approx 20 degrees) agrees very closely with the trim attitude excursion experienced in the VM-8 atmosphere. In fact, if the difference in trim altitudes is normalized by dividing the delta altitude below 30,000 ft by the delta altitude to trim, the attitude response shows a very clear correlation in Figure 10. The attitude rate at gust onset, however, does not correlate with gust onset rate. An attitude rate of 3.56 deg/sec for the 34.9 fps/1000 ft gradient in VM-10 places it between 2.8 deg/sec and 3.85 deg/sec for the 20 and 40 fps/1000 ft gradients in VM-8. This leads to a preliminary conclusion that the attitude rate at gust onset is a function of the wind gradient $d\ V_W/dh$. This is verified analytically as follows:

assume

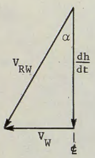
$$\dot{\theta} = f(\dot{\alpha})$$

$$\sin \alpha = V_W/dh/dt$$

but for small angles

$$\alpha = V_W/dh/dt$$

$$\dot{\alpha} = \frac{\frac{dh}{dt} \cdot \frac{d\ V_W}{dt} - V_W \cdot \frac{d^2h}{dt^2}}{\frac{dh^2}{dt}}$$



but if terminal velocity exists,

$$\frac{d^2h}{dt^2} \simeq 0$$

therefore

$$\dot{\alpha} = \frac{\frac{dh}{dt} \cdot \frac{d\ V_W}{dt}}{\left(\frac{dh}{dt}\right)^2} = \frac{d\ V_W}{dt} \cdot \frac{dt}{dh} = \frac{d\ V_W}{dh}$$

A comparison of attitude excursions resulting from a given gust shape at three different altitudes is presented in Figure 11. The excursion from the no-wind curve is roughly 26 degrees at all three altitudes.

A look at the effect of a step function gust of 200 fps in VM-8 and 100 fps in VM-10 in Figure 12 shows attitude excursions of 58 and 40 degrees respectively. In both cases shown, parachute deployment occurred at 15,000 feet with gust onset at 10,000 feet. The attitude rates resulting from step gusts in VM-8 and VM-10 are shown in Figure 13 to be roughly equal. The resulting capsule oscillation shows better damping in the VM-10 atmosphere because of the higher density.

Control System Capability

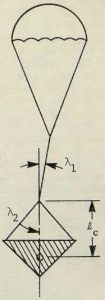
The effect of employing a rate damping attitude control system on the capsule as it encounters a 200 fps step function gust in VM-8 is examined. The control system involves simple on-off thrusters which come on when a threshold attitude rate is exceeded and stay on until the rate falls below the threshold. The system used has 50 ft-lbs of available control moment. In Figure 14, the capsule response with and without attitude control shows that this control system is capable of shortening the time required to reduce the attitude rate below a given level but is virtually powerless to modify the initial transient magnitude. Since there are no adverse effects noted from an active control system, the improved damping in pitch and yaw seem to warrant using the system during parachute descent.

Attachment Geometry

The riser line is normally connected to the capsule in a three or four point flexible cable yoke. The cable yoke will behave as a rigid truss as long as a tension load exists in the riser cable and the angle between the riser line and the capsule centerline does not exceed the angle between the cable yoke leg and the capsule centerline. This assumption is valid as long as roll is controlled to near zero.

Several cases are considered to determine the effectiveness of varying the capsule attachment geometry in controlling the perturbation resulting from a 200 fps step-function gust in the VM-8 atmosphere. Configuration and gust onset conditions are identical to those used in Figure 14 so that the control system capability may be compared to the effect of varying the length lc. Figure 15 shows the capsule attitude rate response to the step gust with lc equal to 8, 10 and 15 feet. A dramatic improvement in rate damping is noted as the riser attach point is moved aft. The damping when lc is equal to 15 feet is seen to be roughly comparable to the control system damping shown in Figure 14.

The assumption that the flexible cable yoke behaves as a rigid truss is not valid if the angle λ_1, (see sketch) ever exceeds the angle λ_2. In this study, the smallest value of λ_2 is equal to 32 degrees when lc = 15 feet. Since the largest value of λ_1, observed on any of the cases studied was 11 degrees, the rigid truss assumption is valid.



SEPARATION STUDIES

The object of this study is to prove that the aeroshell can be successfully separated from the lander capsule and parachute. This can be done by selecting a parachute with an effective ballistic coefficient that is smaller than the aeroshell ballistic coefficient. The parachute will then be decelerating the capsule faster than the aeroshell is decelerating to produce a net separation relative acceleration. It is noted that a completely different set of physical property data from that used in the gust response study is assumed in this section.

Capsule Properties

The capsule properties used in this phase are as follows:

Capsule weight = weight of Entry Vehicle
- Weight of Aeroshell
= 3031 - 391 = 2640 lbs

Capsule Moment of Inertia = 1668. slug-ft^2

Capsule diameter = 10 feet

Capsule Aerodynamics - same as coefficients assumed in gust response

Parachute Properties

A parachute is selected which has the potential of providing a satisfactory level of deceleration. This selection is an iterative process which had to be weighed against optimization studies of parachute and retro systems. The final selection is based on a terminal velocity of 265 fps in VM-7. The following parachute characteristics are used in the separation studies:

$$D_o = \frac{2}{V_T}\sqrt{\frac{2 \cdot g/g_o \cdot W_L}{\zeta \pi C_{D_o}}}$$

$$= \frac{2}{265}\sqrt{\frac{2 \times .383 \times 2640}{1.18 \times 10^{-5} \times \pi \times .55 \times .8}}$$

D_o = 84 feet reference diameter

D_p = 53.5 feet inflated diameter

Wt = $.0243 \times 84^2$ = 170 lbs (folded) = 5.28 slugs

Mass of encl atmosphere (VM-8) = .64 slugs

Apparent mass = .32 slugs

Enclosed plus apparent = .96 slugs

Moment of inertia = 1160 slug-ft^2

Parachute Aerodynamics - the coefficients used in separation studies are the same as shown in Figure 5 except the drag curve is shifted downward to produce a coefficient of 0.55 at zero angle of attack. This is done to add a degree of conservatism to the separation analysis.

Aeroshell Properties

The aeroshell is a reinforced fiberglas 70 degree half angle cone with a bluntness ratio of .5 (R_{Nose}/R_{Base}). The following additional properties are used:

Aeroshell weight = 390 lbs = 12.1 slugs

Aeroshell diameter = 19 feet

Aeroshell moment of inertia = 295 slug-ft^2 (pitch or yaw)

Aeroshell aerodynamic properties[4] apply to a 60 degree cone configuration. The drag coefficient variation with angle of attack and Mach number for a 70 degree aeroshell is of prime importance to the separation study and is presented in Figure 16. In order to minimize the aeroshell drag and to avoid re-collision problems that might occur if aeroshell separation were accomplished at parachute deployment, separation is delayed until a Mach number of .8 is reached.

Initial Conditions

The tentative plan for chute deployment involves an altitude trigger at 24,000-26,000 feet (18,000-20,000 above a 6000 ft terrain). Since aeroshell separation is dependent upon dynamic pressure in the following expression, it is conservative to demonstrate separation at the lowest dynamic pressure:

$$\text{Relative Acceleration} = q\left(\frac{1}{B_{EFF_{Chute}}} - \frac{1}{B_{A/S}}\right)$$

The higher end of the deployment altitude range is used because dynamic pressure goes down slightly with increased deployment altitude.

VM-8 atmosphere is used for the separation studies because it produces the highest Mach number at deployment altitude. With a ballistic coefficient of .2 slugs/ft^2 and a flight path angle of -20 degrees at atmospheric entry, the following conditions exist at chute deployment:

H_o = 26,000 feet

V = 1068 fps

γ = -27.1 degrees

M = 1.6

Separation Results

In order to lock up the radar as soon as possible and to preclude reflections from the aeroshell, it is desirable to move the aeroshell 100 feet away and outside a 15 degree half angle cone around the capsule centerline. The separation time-history for a system involving no separation aids is shown in Figure 17. Note that 100 feet of longitudinal separation is achieved in 3-4 seconds but the 15 degree desirability is not achieved for more than 10 seconds.

In spite of the fact that a separation can be achieved without special aids, there may be a desire to provide more positive separation with the aid of springs or other impulse device. In addition, one may balance the aeroshell with an offset c.g. to obtain a trim angle of attack other than zero in an effort to reduce drag and develop a side force. It is difficult to achieve a c.g. offset much greater than 6 inches without heavy ballasting. This would result in a trim angle of approximately 10 degrees. In Figure 16 it is seen that a 10 trim angle of attack reduces the aeroshell drag by only 2 percent. In Figure 18, the combined effect of 800 lbs of separation spring force plus a 6-inch offset c.g. is plotted. Not much additional separation distance is achieved but the aeroshell moves out beyond the 15 degree cone in less than 3 seconds.

OPENING PHASE

The opening phase parachute dynamics are simulated for the purpose of predicting riser loads. At chute deployment, the folded parachute in its deployment bag is given a delta velocity straight aft of the capsule to simulate mortar action. The deployment bag becomes a free body until it reaches the end of the riser line. At this point the deployment bag mouth tie is broken, allowing the shroud lines to pay out. When the riser and shroud lines are fully extended, the so-called snatch force is recorded, the deployment bag is shucked, and the parachute canopy begins unfolding to its inflated size. The opening shock peak in riser load occurs when the chute reaches full inflation.

This opening phase study is not intended to be a comprehensive survey of opening phase dynamics, but rather an exploration into those aspects of the problem which have a significant bearing upon the design of the lander capsule. Many of the characteristics of a large parachute as required in this application are poorly defined at this time. A riser spring constant is chosen to reflect a total riser and shroud line stretch of between 20 and 30 percent. A determination of the canopy filling time by strictly analytical means has not yet been developed. Empirical values have been compiled and analyzed[6] for chutes with inherent geometric porosity to generate the following filling time relationship:

$$t_f = \frac{0.65 \cdot \lambda_G \cdot D_o}{V_S}$$

where

λ_G = geometric porosity, %

D_o = parachute reference diameter

V_S = velocity at canopy inflation

Using the above formula, an estimated chute filling time is generated by assuming a geometric porosity of 20 percent. The manner in which the canopy projected area increases with time has a strong influence on the opening shock. For lack of better data, the canopy diameter is assumed to increase linearly during the filling time. A mortar velocity of 120 fps used in the PEPP program is assumed. The opening shock which results from using these assumptions is shown in Figure 19. It is apparent that opening shock is rather insensitive to small changes in mortar delta velocity and riser cable elasticity in this application.

Since a number of assumptions were employed in the above analysis, it is desirable to obtain a quantitative check on the validity of the digital model and the assumptions. Flight test data from PEPP rocket launch number 3 is compared to digital simulation results with identical conditions.

PEPP R/L 3 is a 30 foot diameter disk-gap-band chute with a 200 lb payload. Chute porosity is 15 percent with an actual filling time of 0.5 seconds at Mach number 1.56. From in-flight film, a time-history of chute projected area is obtained and plotted in Figure 20. A plot of area buildup with a linear diameter increase is seen to be only in fair agreement with actual test data.

A comparison of the digital simulation riser load with the tensiometer recorded on PEPP R/L3 is shown in Figure 21. The peak loads and general shape of the two curves are in good agreement. The high frequency hash on the flight data is no doubt a result of canopy flexing and shroud line vibration which in any case is almost impossible to simulate.

CONCLUSIONS

The parachute is basically a stabilizing influence on the capsule and generally will enhance or supplement the stability of the capsule. The attitude control system will provide additional stability to the extent that capsule control will not be a major problem.

The magnitude of attitude excursions from the nominal trajectory and maximum attitude rates will be dictated by the severity of the wind gust and onset criteria. Although an instantaneous gust of 200 fps is difficult to imagine, such a specification will produce attitude excursions approaching 60 degrees and attitude rates as high as 46 deg/sec. A step gust will not be catastrophic or cause an unrecoverable situation to occur but will degrade optical or radar system performance for a limited period of time. The attitude rate required to insure non-smear television coverage[5] decreases as the altitude at which quality coverage is desired increases. As an example, if attitude rates exceed 5 degrees/second, quality non-smear TV coverage cannot be assured above 6000 feet. The rate response to a step gust in Figure 14 shows that TV coverage will therefore be marginal for 15 seconds after gust onset. If the rate damping control were active, this time will be reduced to 8 seconds. Further improvement in rate damping can be achieved by proper design of the capsule attachment harness.

Aeroshell separation can be achieved successfully without special separation aids if separation is delayed until Mach number equals 0.8. Special separation aids, such as springs, to not offer much payoff in relative separation but may be

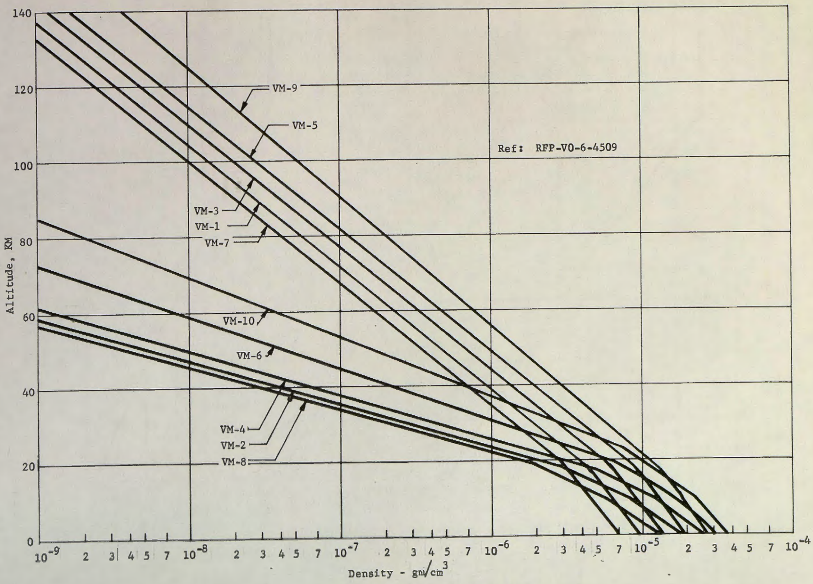


Figure 1 Martian Atmospheres

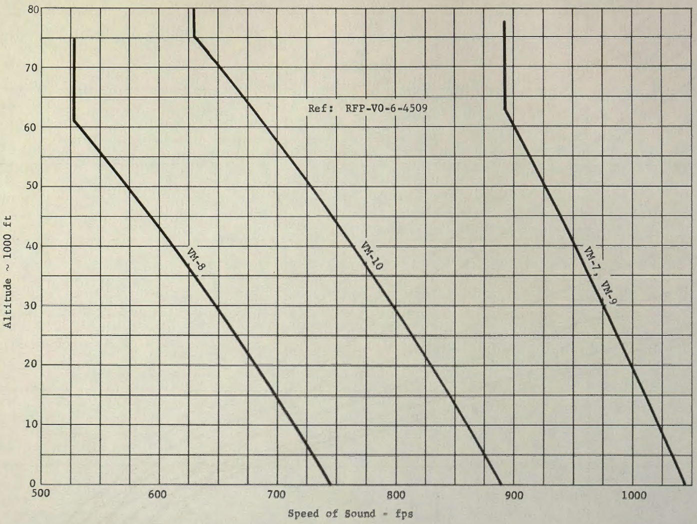


Figure 2 Speed of Sound, Selected Martian Atmospheres

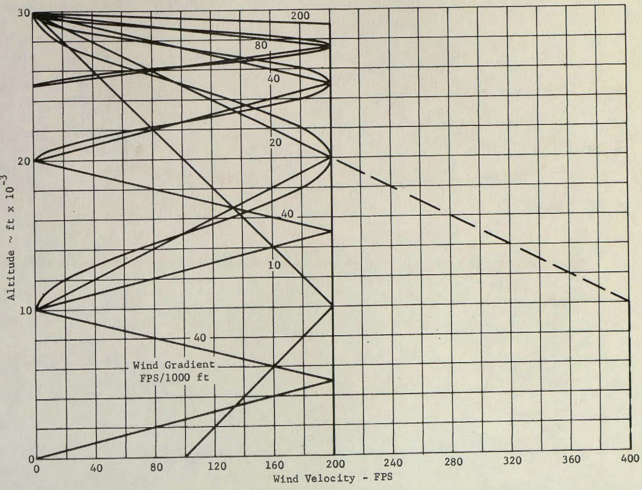


Figure 3 Wind Gust Profiles

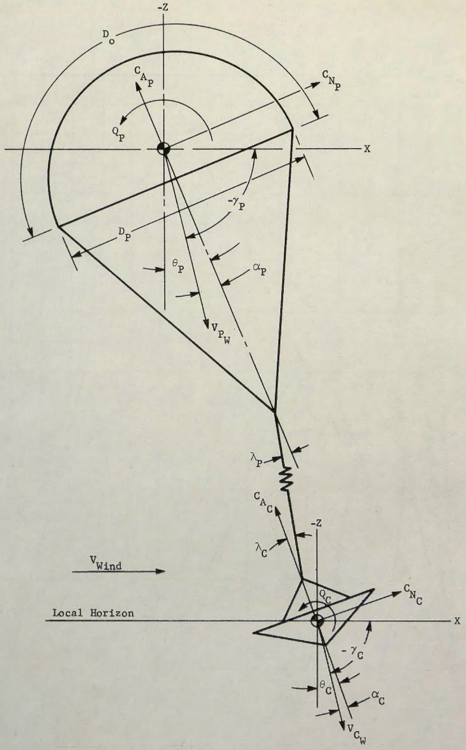


Figure 4 Parachute Coordinate System

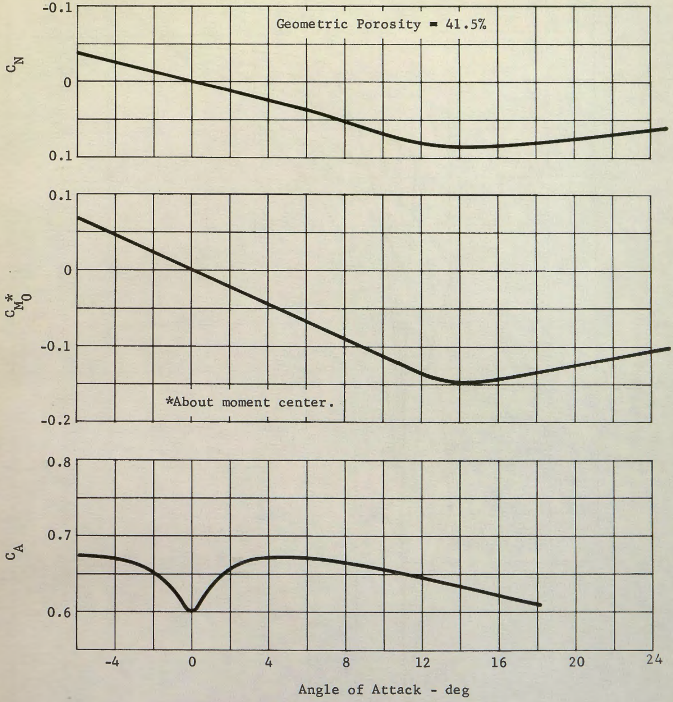


Figure 5 Parachute Aero Coefficients (Typical)

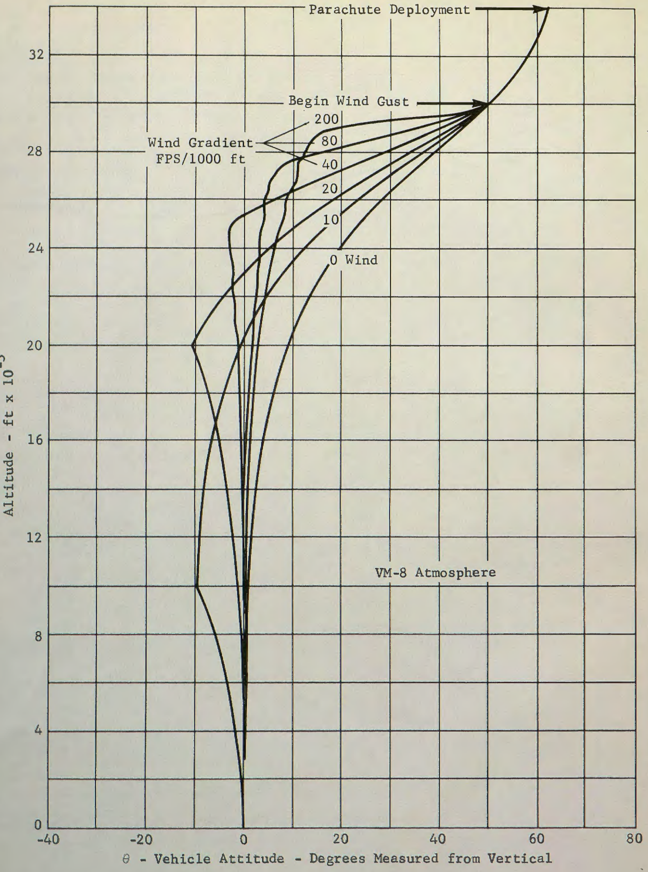


Figure 6 Basic Gust Response

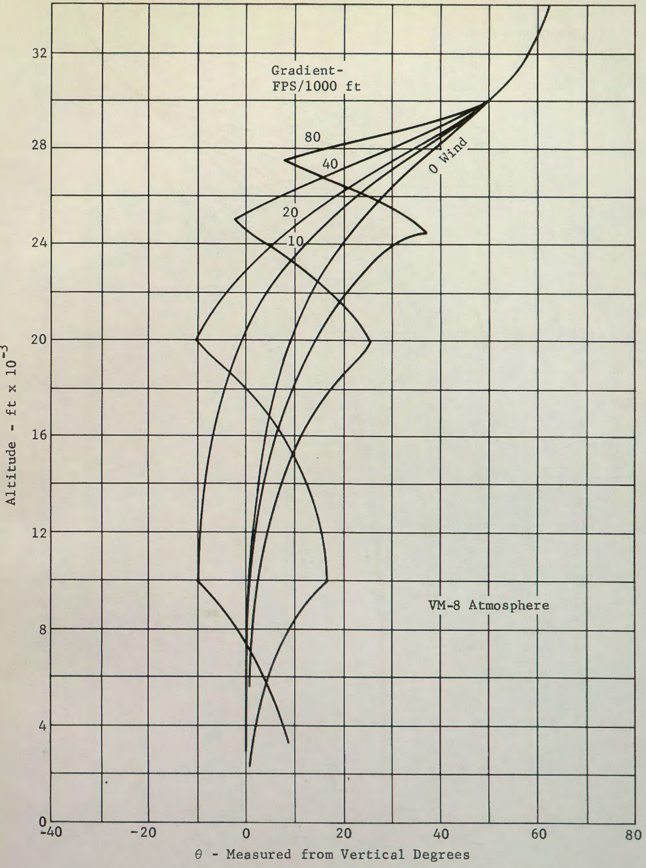


Figure 7 Gust Onset and Removal

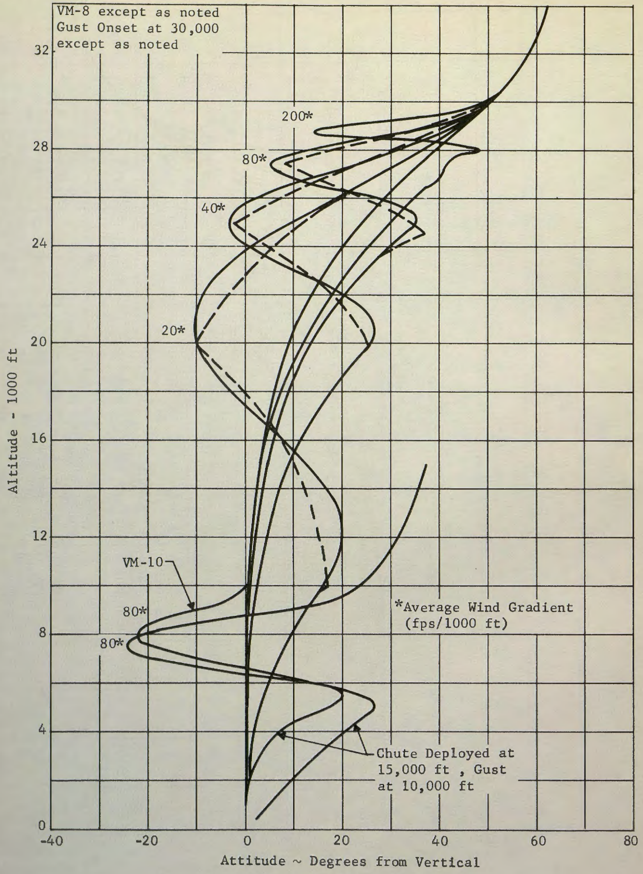


Figure 8 Wind Gust Onset and Removal

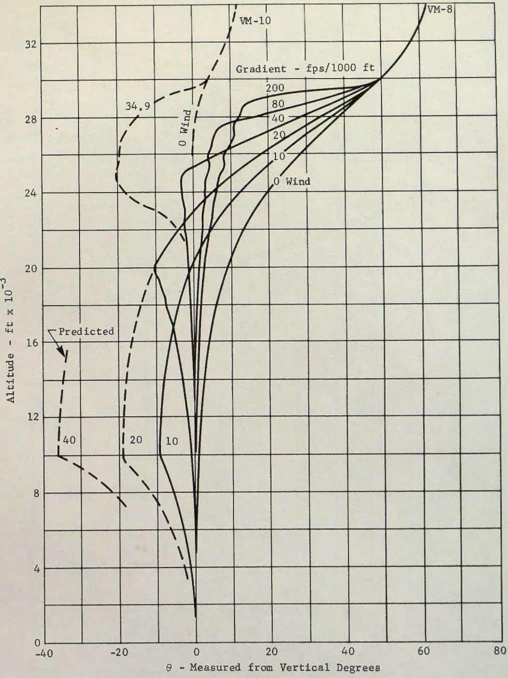


Figure 9 Gusts and Trim Conditions

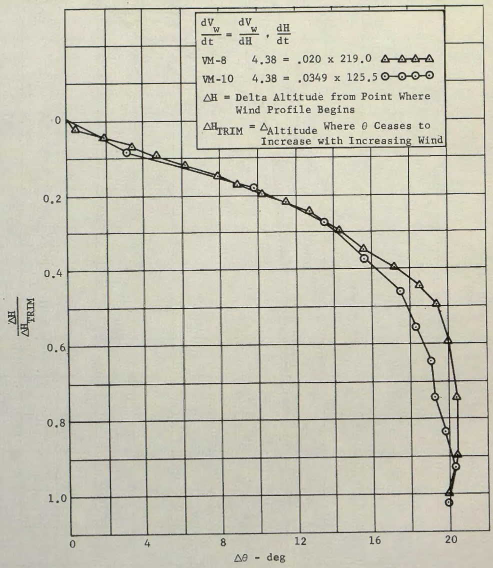


Figure 10 Wind Onset Rate Comparison

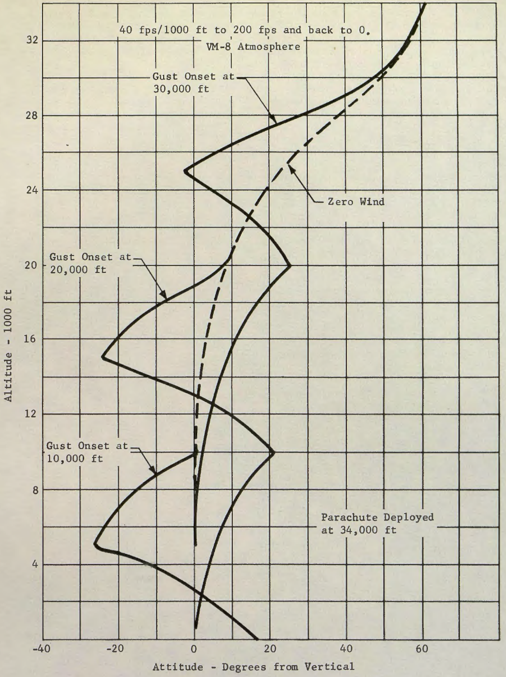


Figure 11 Wind Gust Altitude Effect

desirable in producing a cleaner, more positive initial separation. An offset aeroshell c.g. does not increase relative separation appreciably but is quite effective in moving the aeroshell off to the side of the capsule trajectory.

It is possible to obtain a good estimate of parachute opening loads in the Martian atmosphere by digital means. The accuracy of this estimate depends primarily upon a good foreknowledge of the parachute filling time and area build-up versus time.

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The information contained herein in no way constitutes a final decision by NASA or JPL or any other Government agency relative to its use in a Voyager-type program.

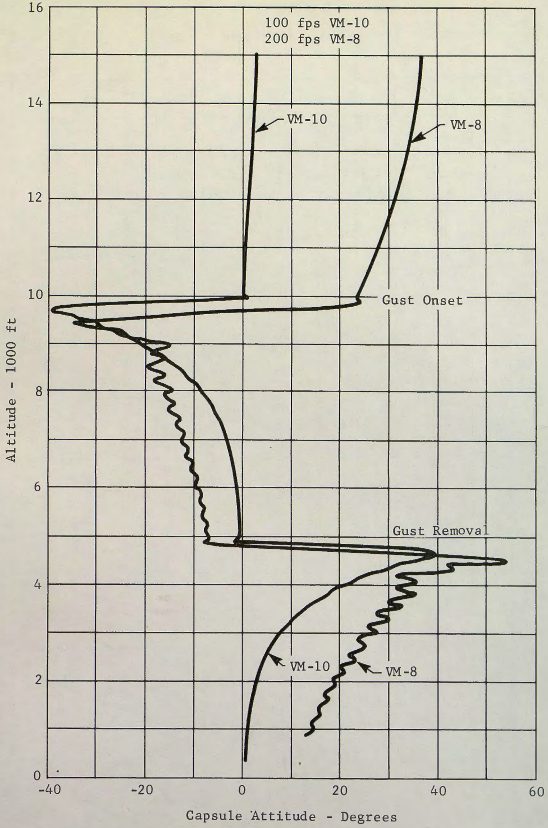

Figure 12 Response to Step Gust

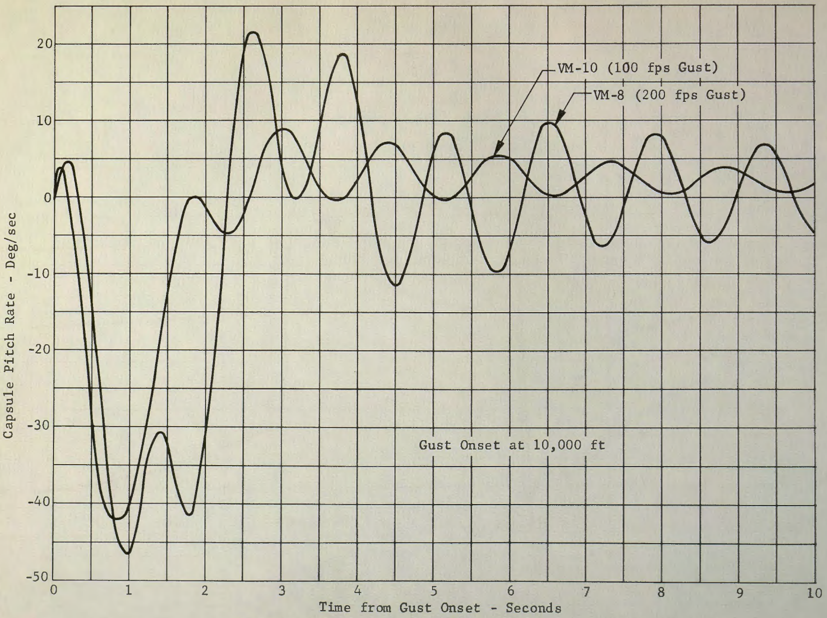

Figure 13 Attitude Rate Response to Step Gust

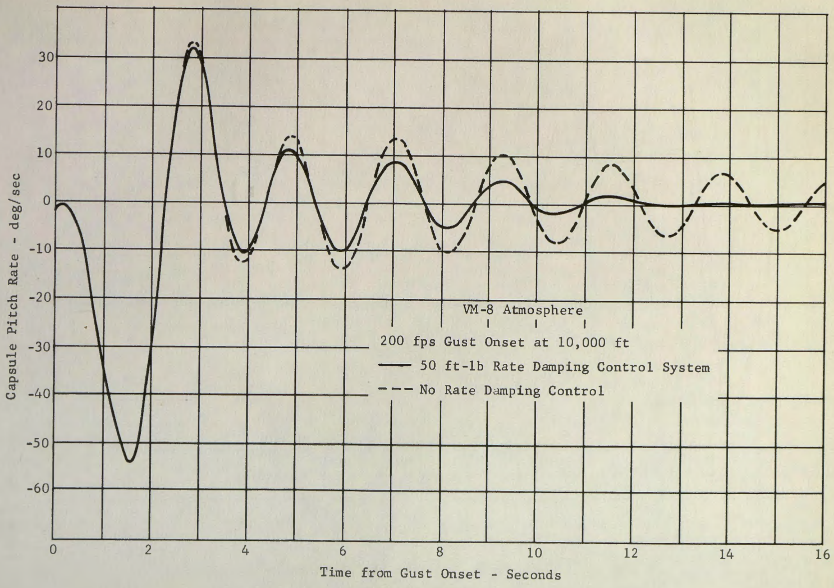

Figure 14 Attitude Rate Response to Step Gust

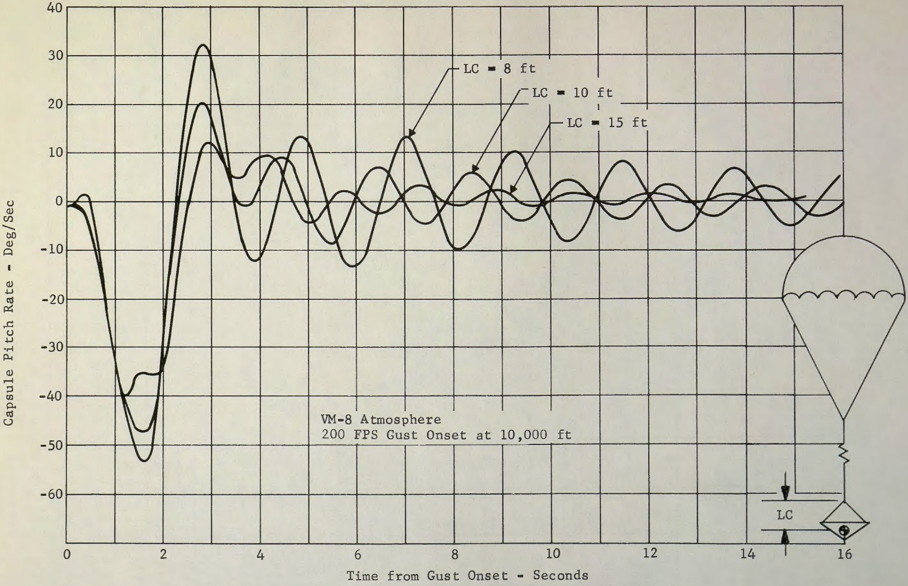

Figure 15 Attachment Geometry Effect on Step Gust Response

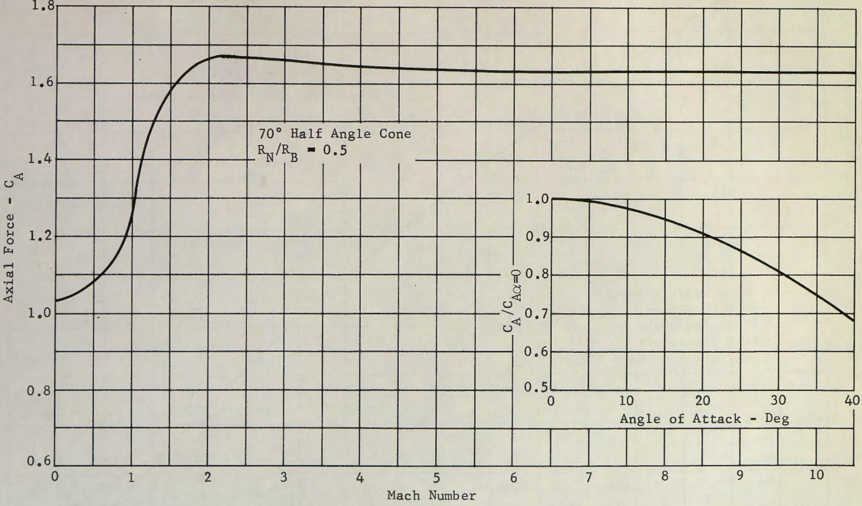

Figure 16 Aeroshell Axial Force Coefficient

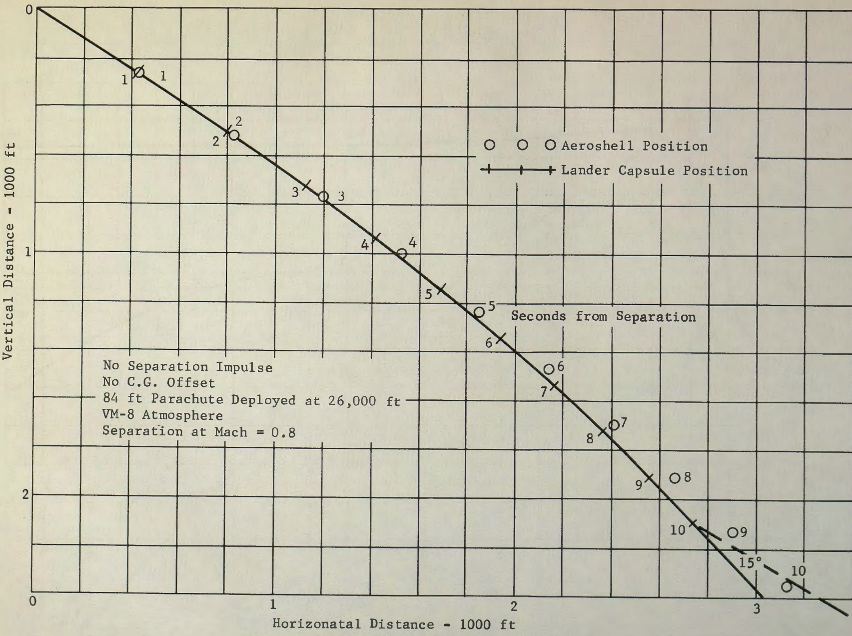

Figure 17 Aeroshell/Lander Separation

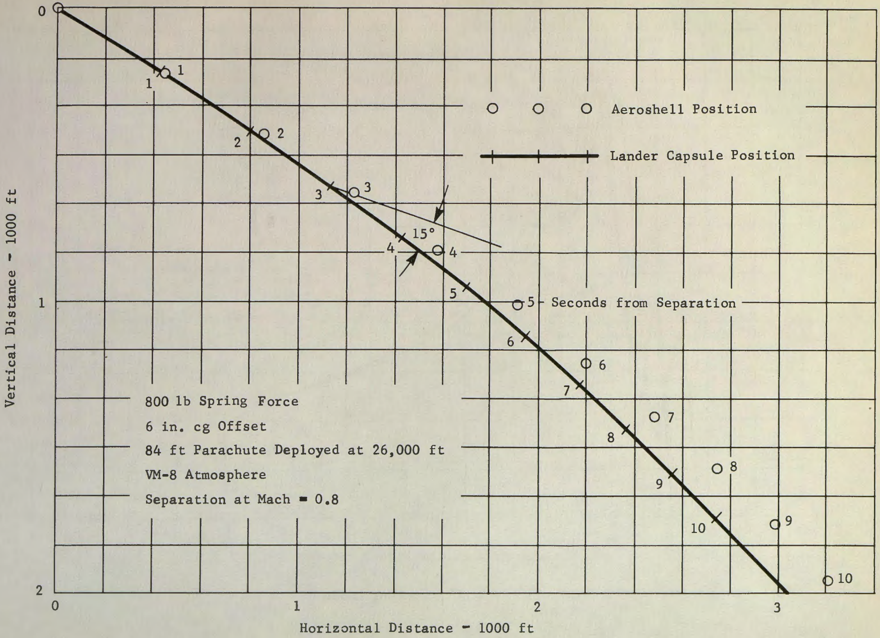

Figure 18 Aeroshell/Lander Separation

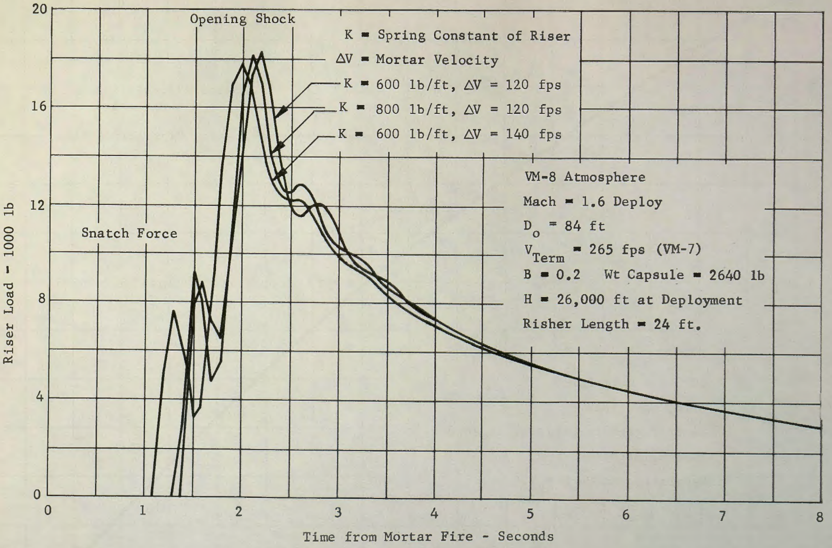

Figure 19 Parachute Opening Loads

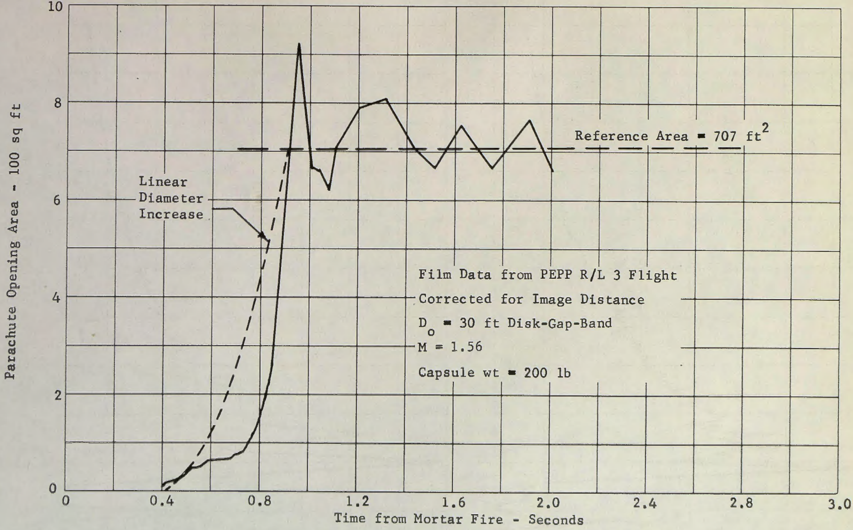

Figure 20 Parachute Opening Area

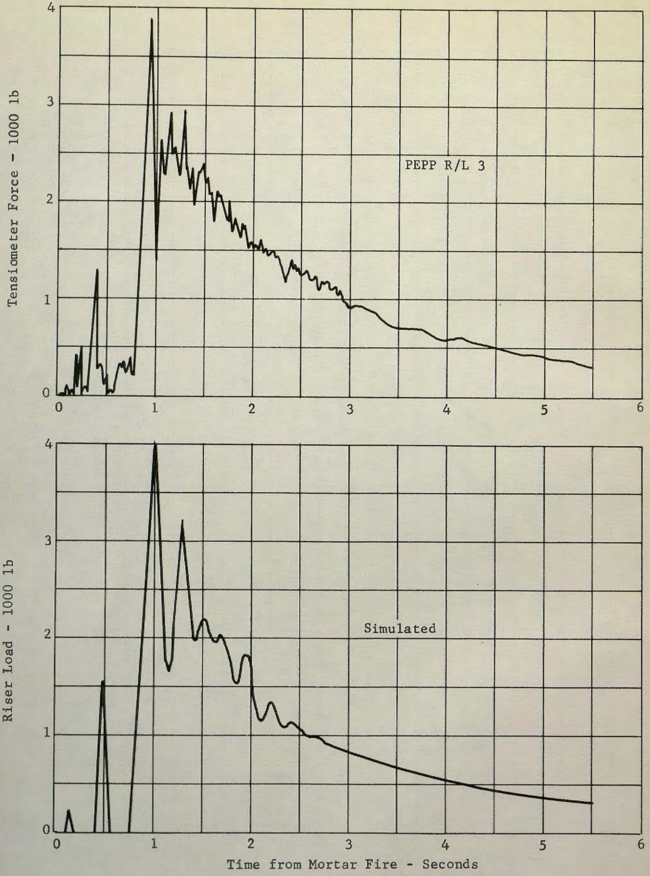

Figure 21 Parachute Opening Loads Actual vs Predicted