FULL-SCALE SIMULATION OF PARACHUTE DEPLOYMENT ENVIRONMENT IN THE ATMOSPHERE OF MARS

By Clarence L. Gillis and Richard J. Bendura

NASA Langley Research Center
Langley Station, Hampton, Va.

Presented at the 14th Annual Technical Meeting of the
Institute of Environmental Sciences

St. Louis, Missouri
April 29 - May 1, 1968

FULL-SCALE SIMULATION OF PARACHUTE DEPLOYMENT ENVIRONMENT IN THE ATMOSPHERE OF MARS

By: Clarence L. Gillis and Richard J. Bendura, NASA Langley Research Center

Clarence L. Gillis

Richard J. Bendura

Clarence L. Gillis is head of the Aerospace Mechanics Branch of the Applied Materials and Physics Division at the National Aeronautics and Space Administration's Langley Research Center, Hampton, Virginia. He is also the manager of Langley's Planetary Entry Parachute Program. He earned the degree of B.S. in Aeronautical Engineering from the University of Pittsburg in 1939. During the time period from 1940 to 1946 he was engaged in wind-tunnel research at Langley on airplane performance, stability, and control. From 1946 to 1947 he worked on stability and control of pilotless aircraft at Glenn L. Martin Co. He returned to Langley in 1947 and contributed to the development of free flight rocket powered model research techniques for airplane and missile stability and control. Currently he supervises space related research including atmospheric entry, rocket control systems, and spacecraft mission research and development.

Richard Bendura joined the staff of the National Aeronautics and Space Administration's Langley Research Center, Hampton, Virginia in 1958. He has worked as payload engineer on a project dealing with the study of physical phenomena which occur during reentry of high speed objects into the atmosphere. His current work includes spacecraft attitude determination by photogrammetric means, free flight dynamic stability investigation of conical bodies, and investigation of large scale parachutes for space flight applications. He is a graduate of Virginia Polytechnic Institute and a member of the AIAA.

SUMMARY

A flight-test program was conducted to investigate the operating characteristics of large-size parachutes in an environment simulating that expected during a Mars landing mission. The choice of simulation parameters is discussed and the effects on the results of those quantities not simulated are considered. The environmental factors of major importance to the performance of the parachutes appear to have been adequately represented in the tests.

INTRODUCTION

Planetary entry missions will undoubtedly continue to be a part of national space flight goals although the time frame is uncertain. This includes entry of spacecraft into other planets such as Mars and Venus as well as into the atmosphere of Earth. The use of auxiliary aerodynamic decelerators offers economic and operational advantages on missions requiring the landing of a spacecraft on a planet surface in a relatively undamaged condition and has become an accepted practice for both manned and unmanned earth operations. Advanced flight operations, both interplanetary and earth bound, will impose new requirements on decelerator technology. It is thus necessary to continually update decelerator systems technology in order to permit their integration into advanced mission plans.

One of the new decelerator requirements for entry into planetary atmospheres is operation at high speeds in a low-density environment, such as is thought to exist on the planet Mars, and also exists on the Earth at altitudes above 100,000 feet. Studies have shown that aerodynamic decelerators offer advantages over propulsive deceleration systems even for these low-density environments. A Planetary Entry Parachute Program (PEPP) was conducted to investigate parachute deployment and performance characteristics under a combination of flight conditions where no previous experience existed. Descriptions of how the program was conducted are well covered elsewhere (refs. 1 and 2) and will be discussed only briefly here. The purpose of this paper is to evaluate and comment on the applicability of the simulated test environment to the conditions that might be expected on a typical entry into the atmosphere of Mars.

SYMBOLS

C_D	drag coefficient
D_o	nominal diameter, ft
F_p	opening force, lb
l	characteristic length
M	Mach number
m	mass, slugs
q	dynamic pressure $\left(\frac{1}{2}\rho V^2\right)$, lb/ft^2
S	nominal area, ft^2
t_f	inflation time, sec
V	velocity, ft/sec
ρ	atmospheric density, slugs/ft^2
μ	viscosity, lb-sec/ft^2
γ	ratio of specific heats

Subscripts:

E	Earth
M	Mars

L-5970

OBJECTIVES

The objectives of the flight program are listed in figure 1. A specific objective which established the required test environment to be simulated was to support a Mars lander mission by obtaining technology required for selection of a parachute system for further development. This constituted a limited screening process to determine whether parachutes would function at all under the expected conditions and then to select the most promising one or two configurations for more detailed development. A second and more general objective was to obtain a background of parachute technology and experience in low-density environments. Such information is needed from large-scale flight tests to permit correlation with data from smaller scale tests, and to assist in the development of methods for prediction of flight performance of aerodynamic decelerators.

ENVIRONMENT DESIRED

To define the environment in which parachutes will be required to operate in the atmosphere of Mars let us consider the flight conditions existing on typical entry trajectories as the spacecraft nears the surface. Figure 2 is a plot of dynamic pressure versus Mach number that would exist during the final portions of typical Mars entry trajectories. The enclosed area includes trajectories representing a range of entry angles and velocities, and entry body ballistic coefficient m/C_DS. The atmospheric properties used in the preparation of figure 2 are those for a postulated Mars atmosphere designated as VM-8, which results in a high Mach number at a given altitude. Mach number and dynamic pressure were chosen as the most significant parameters for design and operation of aerodynamic decelerators. The Mach number defines the aerodynamic flow patterns around the parachute and forebody. The loads existing on the parachute and thus the construction details such as material gage and suspension line sizes are a direct function of dynamic pressure. Numerous studies indicate that a parachute deployment capability up to $M = 1.6$ will provide useful Mars lander missions within current spacecraft and booster capabilities. Figure 2 indicates that for a Mach number of 1.6 a range of dynamic pressures from about 9.4 to 13.4 might be encountered, and this variation is primarily dependent upon the ballistic coefficient m/C_DS. Values of $q = 10 \text{ lb/ft}^2$ and $M = 1.6$ were chosen as the nominal parachute deployment conditions for most of the tests. The values actually obtained during the PEPP tests are indicated by the circled points in figure 2. For the initial test in the program (ref. 1), the nominal conditions were somewhat lower.

Figure 3 summarizes the environmental conditions required and the test quantities chosen to simulate them. Low atmospheric density and supersonic speeds were the two factors differentiating the aerodynamic regime from that of current experience. As mentioned previously, Mach number and dynamic pressure were chosen as the simulation parameters. Since a parachute is a towed device operating in the wake of a forebody, this wake can exercise an important influence on the operation of the parachute. This is particularly true for a blunt high drag body such as is utilized for most atmospheric entry missions. It was considered of fundamental importance that the correct forebody geometry and thus the body wake effects be represented in at least some of the tests. One of the two test techniques used for the test reproduced the entry body geometry, and this requirement established the unique test procedure to be described later.

Realistic parachute construction is considered important for several reasons. The low dynamic pressures existing for typical Mars entries result in parachutes of large size and very lightweight construction. The problem of cloth porosity (air permeability) becomes significant for the lightweight materials required for the parachute canopy. Total parachute porosity has been shown to be a critical factor in the performance of a parachute. Problems also exist with the scaling of parachute material properties, strength, and construction details such as seams and joints. The relatively unknown and unproved nature of parachute scaling relations in general also led to a desire to avoid the problem of scale effects. To achieve realistic parachute construction and to avoid scale effects as much as possible, large-size parachutes approximating the expected full-size mission articles were considered a necessary requirement of the tests.

It would be desirable to reproduce the trajectory history for a complete simulation. This would require a reentry trajectory for the earth-based tests, adjusted in entry angle to permit a close matching of trajectory parameters. Because of the impossibility of matching all parameters and because of the greatly simplified test procedure if this close matching is not required, the tests were designed to approximate only the conditions at parachute deployment and at the point where a steady rate of descent had been attained.

Another environmental factor of importance for this application is the requirement for sterilization of any spacecraft which will land on a foreign planet. The currently established sterilization procedure includes a heating requirement, and the effect of this heating on degradation of the material properties was considered to be an important factor in the current investigation. Based on some previous test results Dacron materials were chosen for parachute construction, and a 10-percent strength reduction was allowed for in the design to account for sterilization heating effects on the materials. Before flight each parachute, after being packed in its bag, was subjected to a heating cycle similar to that required for sterilization, in order that any material degradation would be properly represented in the flight tests.

Ideally two other factors should be simulated during the tests. One is the reduced gravity on the planet Mars and the other is the atmospheric composition. Although the reduced gravity cannot be simulated in an Earth environment, a technique involving a ballast release can be used to provide a partial simulation by a change in the steady-state descent rate to represent that which will occur on Mars. This technique was used in one of the tests and will be described later. In an Earth flight test it is, of course, impossible to represent any atmospheric composition which is different from that on Earth. Some evaluation of the probable effects of the different composition can be made from the gas properties of the assumed Martian atmosphere.

TEST PROCEDURE

Figure 4 is a schematic illustration of the test techniques employed to represent the decelerator operation for a typical planetary entry. An equivalent surface of Mars is represented by some Earth altitude (approximately 100,000 ft) dependent on the postulated Martian density. The final portion of a typical Mars entry trajectory is represented by the curve labeled "Mars entry trajectory." At an appropriate altitude indicated by the X a parachute deployment is initiated, the heat shield or aeroshell is separated from the instrumented payload, and the deployed parachute lowers the payload toward the surface. A rocket-launched series of tests was performed to gather basic data on parachutes 30 feet to 40 feet in diameter as indicated by the curve labeled "Rocket launch trajectory." The 2- and 3-stage vehicles were launched from the ground and when the proper simulation conditions had been attained (at point X) the parachutes were deployed. Each payload and parachute then continued over the top of the trajectory and then achieved a steady descent condition approximating the entry trajectory of interest.

It will be noted that the desired deployment conditions were obtained on an ascending flight path rather than on a descending path as for the Mars entry mission being simulated. This procedure greatly simplified the test operations. Further comments on the effects of this difference are included later. For the rocket-launched tests only the payload was represented during the tests. The absence of a blunt aeroshell thus eliminated the forebody wake effects during parachute deployment but provided a satisfactory representation of the conditions following aeroshell separation. A further description of this test technique can be found in reference 2.

A second test technique was developed to provide for investigation of forebody wake effects and to permit larger parachute sizes. A full-scale (15-ft-diameter) aeroshell containing the payload and parachute and a propulsion system was carried to an altitude of about 130,000 feet by a balloon, as indicated in figure 4. This balloon, with a volume of 26 million cubic feet, was the largest balloon ever launched, and its development is described in reference 3. The use of the balloon as a launch vehicle provided a low-cost solution to the problem of carrying the 15-foot-diameter aeroshell to the test altitude. This diameter exceeded the payload geometric capabilities of any rocket booster except the Saturn V. When the desired altitude had been attained the spacecraft was dropped, and the internal rockets ignited and propelled the vehicle to the desired test conditions at point X. The parachute was deployed and the instrumented payload extracted from the aeroshell. After traversing the apogee of the trajectory, the parachute and payload attained a steady descent. The parachutes used in this series of tests varied from 55 feet to 84 feet in diameter. The test technique is described more fully in reference 1. As with the rocket-launched tests, the simulated deployment conditions were attained on an ascending rather than a descending trajectory.

RESULTS AND DISCUSSION

Flight Summary

A total of nine rocket-launched flights and four balloon-launched flights were conducted during this program. Parachute deployments of two parachute configurations were successful both with and without the blunt forebody at a Mach number of 1.6. In the final two tests one of the two parachute configurations was successfully deployed without the blunt forebody at Mach numbers of 1.9 and 2.7. It is not the purpose of this paper to discuss the results of the parachute tests but to review and comment on the degree to which the test environment simulated that expected on a Mars entry mission and the possible effects on those factors which were not simulated.

Parachute Operating Regimes

The operation of a parachute begins with an initial transient stage during which the parachute inflates and produces a more or less rapid deceleration of the payload. Ultimately the parachute and payload reach a steady-state descent regime if sufficient time exists for this condition to occur. The transition from one regime to the other is a gradual process. As pointed out earlier, the ascending flight trajectories at parachute deployment did not reproduce the descending trajectories of a Martian entry but the actual conditions at the initiation of the transient regime (parachute deployment) were matched by the simulation parameters discussed. A steady rate of descent was also eventually reached during the tests, approximating a typical mission condition, although the transition between the two regimes was different for the Earth tests and typical Mars operations as was illustrated in figure 4. The two operating regimes may be conveniently studied separately since different parameters assume different degrees of importance in the two regimes.

Aerodynamics

Figure 5 lists several characteristics of the assumed atmosphere of Mars which define the atmospheric environment of an entering spacecraft. The corresponding values for Earth are shown for comparison. Most of the postulated atmospheres of Mars contain a preponderance of CO_2; for the present purposes an atmosphere with 100 percent CO_2 has been assumed. For comparison of properties dependent on altitude, altitudes of 15,000 feet on Mars and 130,000 feet on Earth were chosen. The value of 15,000 feet on Mars represents about the lowest altitude at which a parachute can be deployed to satisfy various mission constraints, and 130,000 feet on Earth represent about the level at which the Mach-number—dynamic-pressure simulation at parachute deployment is attained.

From figure 5 it is evident that the specific heat ratio γ is not significantly different for the two atmospheres. The free-stream Mach number and the specific heat ratio are sufficient to completely characterize a perfect gas in flow-field analyses. At the Mach numbers of the present tests, real gas effects are insignificant. Although the flow field around a forebody and parachute at supersonic speeds is very complex, the shock shapes are expected to remain virtually unchanged in the Martian atmosphere. For example, the shock displacement distance at the axis of symmetry can be expressed in terms of a density ratio across the shock (ref. 4) and at the Mach numbers of these tests the difference of about 3 percent in γ noted in figure 5 results in a much smaller change in the density ratio and thus the displacement distance. Thus, during the initial transient portion of the parachute operation the aerodynamic characteristics are not expected to be significantly different on Earth and Mars.

It is also seen in figure 5 that the speed of sound in the assumed atmosphere is less than in air. Since Mach number was a basic simulation parameter at parachute deployment for the present tests, the velocity in the Earth tests was greater than will be encountered in Mars by a factor of 1.48. Because the dynamic pressure (and thus the product ρV^2) was another simulation parameter, the density at the test altitude on Earth was less than that which would be experienced in the postulated Martian atmosphere by a factor of about 2.2 at the point of parachute deployment. These differences will have effects on several of the dynamic properties of the parachute operation, which will be discussed in the next section of this paper.

During the steady descent portion of the parachute operation the flight path is essentially vertical, and the vehicle is in equilibrium between the weight and the aerodynamic drag. The descent velocity is a low subsonic value and Mach number is no longer of major importance. From an aerodynamic viewpoint, Reynolds number $(\rho V l/\mu)$ is of more importance. Since, for the atmospheres of figure 5, $\mu_M/\mu_E = 0.565$ the product ρV must be the same ratio to provide identical Reynolds numbers. For a given payload mass the descent velocity on Mars will be smaller by a factor of 0.62 at corresponding densities because of the smaller gravitational attraction on Mars than on Earth. Velocity simulation is a desirable objective if a study of the response of the system to wind shears and gusts is of interest. The lower descent velocity on Mars may be simulated by reducing the weight of the test article for the Earth tests. This technique was used on one of the test flights of this series (ref. 1). The procedure consisted of dropping a ballast weight after the steady-state condition had been attained. The amount of the weight reduction and the altitudes at which corresponding Reynolds numbers and descent velocities are obtained must be established from the relations defining Reynolds number and descent velocity since both contain density. As an example, a weight reduction of 32 percent and an altitude of about 100,000 feet on Earth would provide the same descent velocity and Reynolds number as the original payload at an altitude of 15,000 feet on Mars. The use of a reduced weight for descent velocity simulation may be impractical, however, and not of sufficient importance to justify the added complication. If no weight reduction is utilized in the Earth tests, then the Reynolds number corresponding to that at 15,000 feet on Mars would be attained at an altitude of about 110,000 feet on Earth and at a descent rate about 47 percent higher than on Mars. The Reynolds numbers obtained in the present tests and those under the assumed conditions on Mars are of the order of 100,000 based on parachute nominal diameter. A review of data in reference 5 indicates that no major changes in drag of blunt bodies would be expected unless an increase in the Reynolds number by a factor of about 5 were encountered. Thus, the present tests gave fair representation of the parachute drag characteristics to be expected in the assumed Martian atmosphere.

As pointed out previously, porosity of the parachute is an important factor in parachute performance. The total porosity consists of the flow through the geometric openings in the parachute canopy plus the flow through the cloth. Reference 6 states that the flow through the cloth is proportional to the pressure differential across the cloth. The use of the full-size construction materials and methods for the parachutes of the present test series plus the selection of dynamic pressure as a simulation parameter provided assurance that the porosity effects were properly represented in the results.

Dynamic Effects

The problem of dynamic scaling is involved when a test simulation procedure contains any environmental elements not duplicating those of the system being simulated. During the transient portion of the parachute operation at and immediately following deployment, neither the velocities nor densities of a Mars mission were duplicated although the Mach number and dynamic pressure simulation should produce realistic forces and loads on the various components. The gravitational factor was also unavoidably different. Since the motion is transient in nature, however, the mass and inertias are the controlling factors rather than weight. Several analyses such as shown in references 6 and 7 have been made to establish scaling factors. The results of any such analysis are, of course, dependent on the quantities chosen for simulation. Neither of these references considered the effect of the dynamic pressure duplication chosen for the present tests.

Two quantities of major interest in the deployment dynamics of a parachute are the inflation time and the opening load. Some correlations of experimental and analytical results for these quantities at subsonic speeds have been made (refs. 8, 9, and 10). Figure 6 shows a curve (from ref. 8) of inflation time divided by parachute diameter versus velocity at beginning of deployment. Four points are shown from two types and two sizes of parachutes from the present tests. Although the basic correlation was made from subsonic data, the points obtained at supersonic speeds are in very good agreement with the curve. As noted previously, the velocity to be experienced in the assumed Martian environment will be less than for the present tests. If the variation of inflation time with velocity, shown in figure 6, is assumed to be valid at supersonic speeds, then it could be expected that an increase in inflation time of 40 to 50 percent would exist for the Mars mission.

Figure 7 (from ref. 9) shows a curve representing a correlation of experimental and analytical results on opening load versus a mass ratio. Physically the mass ratio is proportional to the ratio of the mass of the air acted upon by the parachute to the total vehicle mass being decelerated. Figure 7 also shows points from the four tests of the present series used for illustration. The values of the load parameter are lower than the curve of reference 9 and do not indicate a similar increase with decreasing mass ratio. The data from which the curve was derived were very sparse at the lower mass ratios and did not extend to the low values of mass ratio or to the supersonic Mach numbers characteristic of the present tests. More data will be required to establish firmly the type of variation under these conditions. Since the density for the simulated Mars mission will be greater than for the Earth tests, as pointed out previously, the mass ratio will be larger. Thus, from the data presented in figure 7 it can be concluded that the opening load will probably not be any larger than measured in the Earth tests and may be somewhat smaller.

In the present tests the payload and parachute decelerated more rapidly than is currently expected for a typical Mars mission resulting in less time at supersonic speeds. Part of this difference was caused by the gravitational effect resulting from the ascending flight path at parachute deployment for these tests as contrasted with the desired descending trajectory. Another reason is that the payloads were generally lighter in weight than were required for correct mass simulation. Although the payload masses approximated the desired values at the beginning of the flight program, the constantly increasing projected weights of the Mars mission conceptual designs during the course of this project resulted in smaller than desired values at the conclusion of the program. Whether the decelerations were realistic will, of course, depend on the value of (m/C_DS) finally chosen for the vehicle during parachute operation.

During the steady-rate-of-descent regime an item of major importance is the stability of the parachute-payload combination. Dynamic scaling parameters for motions of vehicles during equilibrium rates of descent have been derived in reference 7. If the flight vehicles utilized for the present tests are considered as full scale both in geometry and mass, then the velocity and the frequency of motions will be smaller by a factor of 0.62 on Mars than on Earth and the angular accelerations will be smaller by a factor of 0.38. These factors are a direct result of the reduced gravity.

Reference 7 also discusses a reduced weight and inertia simulation. It is shown that, if these quantities can be reduced in Earth tests to correspond to the reduced gravity on Mars, then the full-scale Earth test results, at the same atmospheric densities, will produce identical descent velocities, angular acceleration, oscillation frequencies, and oscillation amplitudes. The use of a ballast release from the payload to produce a weight reduction, as mentioned earlier, gives at best only an approximation to such a simulation since the weight and inertia of the parachute are not reduced correspondingly and the center of gravity of the system is altered. Or, looking at the scaling relation in another way, it can be stated that the motions obtained during the steady descent for the present tests are representative of those that would be obtained at the same density on Mars for a system similar in size and geometry whose component masses are larger by a factor of 1.61 than those existing in these tests.

The simulation conditions for the transient motion and for the steady-state motion are thus inconsistent. This is to be expected since the transient motion is an inertia effect while the steady-state motions are weight dependent. Both are also inconsistent with the requirements for Reynolds number simulation. The effects thus must be considered separately in planning test programs, and the test environment should be chosen on the basis of the factors considered to be the most important. In view of the uncertain nature of the Martian atmospheric properties, however, there seems to be little reason to strive for accurate simulation of any one set of characteristics at present.

Sterilization Heating

As described earlier, each parachute was subjected to a heating cycle representative of that required for terminal sterilization of spacecraft intended to land on other planets. The purpose was not to maintain sterility but to incorporate in the flight articles any material degradation or other effects that might occur as a result of the heating process. The packed parachute and deployment bag were subjected to a temperature of 125° C for 90 hours, and were then flown without being unpacked. Examination of the parachutes following flight did not disclose any damage or failures that could be attributed to the heating environment.

CONCLUDING REMARKS

A flight-test program has been conducted to investigate the operating characteristics of large-size parachutes in an environment simulating that expected during a Mars landing mission. The large number of factors affecting parachute performance and the different atmospheric composition and different gravitational value existing on Mars make an exact simulation of all pertinent parameters impossible in an Earth flight test. The factors of major importance to the performance of the parachute appear to have been adequately represented by the test procedures and test conditions selected. Consideration was given to the possible effects on the applicability of the results in those areas where exact simulation was not obtained. The aerodynamics of the system appear to have been well duplicated in the tests. The dynamic motions obtained approximated those of the intended application, the degree of approximation depending on the final values selected for the mass and inertia properties of Mars mission vehicles. The sterilization heating process appeared to have no significant effects on the Dacron materials chosen for parachute fabrication.

REFERENCES

1. Darnell, Wayne L., Henning, Allen B., and Lundstrom, Reginald R.: Flight Test of a 15-Foot Diameter (4.6 Meter) 120° Conical Spacecraft Simulating Parachute Deployment in a Mars Atmosphere. NASA TN D-4266, 1967.

2. Preisser, John S., Eckstrom, Clinton V., and Murrow, Harold N.: Flight Test of a 31.2-Foot-Diameter Modified Ringsail Parachute Deployed at a Mach Number of 1.39 and a Dynamic Pressure of 11.0 Pounds Per Square Foot. NASA TM X-1414, 1967.

3. Payne, James C.: Balloon Development for the Planetary Entry Parachute Program. AFCRL, Proceedings, Fourth AFCRL Scientific Balloon Symposium, James F. Dwyer, ed.: AFCRL - 67-0075, p. 11-18, January 1967.

4. Hayes, Wallace D., and Probstein, Ronald F.: Hypersonic Flow Theory, Vol. I, Inviscid Flows. Academic Press, New York, 1966.

5. Hoerner, Sighard F.: Fluid-Dynamic Drag. Published by the Author, 148 Busteed Drive, Midland Park, New Jersey, 1958.

6. Heinrich, H. G.: Model Laws Governing Parachute Performance in Martian Environment. Presented at WGLR-DGRR, Oct. 4-8, 1966, Bad Godesberg, West Germany.

7. Costigan, Peter J.: Dynamic-Model Study of Planetary-Entry Configurations in the Langley Spin Tunnel. NASA TN D-3499, 1966.

8. Performance of and Design Criteria for Deployable Aerodynamic Decelerators. USAF ASD TR-61-579, WPAFB, Dec. 1963.

9. French, Kenneth E.: Comment on "A Method for Calculating Parachute Opening Forces for General Deployment Conditions." Jour. of Spacecraft and Rockets. Vol. 4, Oct. 1967, pp. 1407-1408.

10. French, Kenneth E.: Model Law for Parachute Opening Shock. AIAA Jour. Vol. 2, Dec. 1964, pp. 2226-2228.

TO SUPPORT A MARS LANDER MISSION BY OBTAINING TECHNOLOGY REQUIRED FOR SELECTION OF A PARACHUTE SYSTEM FOR FURTHER DEVELOPMENT

TO OBTAIN A BACKGROUND OF PARACHUTE TECHNOLOGY AND EXPERIENCE IN LOW DENSITY ENVIRONMENTS, BY OBSERVING OR MEASURING:

(a) DEPLOYMENT DYNAMICS

(b) OPENING SHOCK LOADS

(c) DRAG

(d) PARACHUTE AND PAYLOAD MOTIONS

Figure 1.- Objectives.

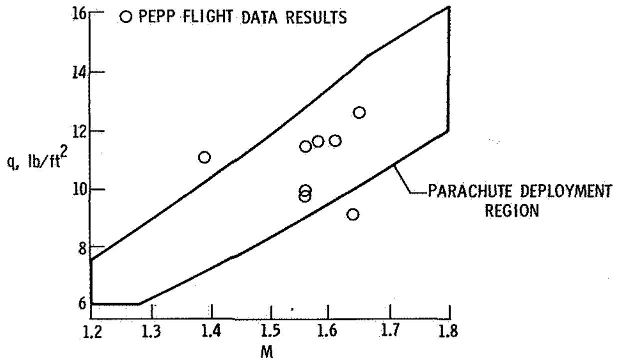

Figure 2.- Parachute deployment conditions for typical Martian entries.

ENVIRONMENT DESIRED	QUANTITIES CHOSEN FOR SIMULATION
LOW ATMOSPHERIC DENSITY SUPERSONIC AERODYNAMICS	MACH NUMBER DYNAMIC PRESSURE
FOREBODY WAKE	FOREBODY GEOMETRY
REALISTIC PARACHUTE CONSTRUCTION ABSENCE OF SCALE EFFECTS	FULL SIZE
TRAJECTORY HISTORY	DEPLOYMENT AND STEADY STATE CONDITIONS
STERILIZATION EFFECTS	STERILIZATION HEATING
REDUCED GRAVITY	
ATMOSPHERIC COMPOSITION	

Figure 3.- Simulation conditions.

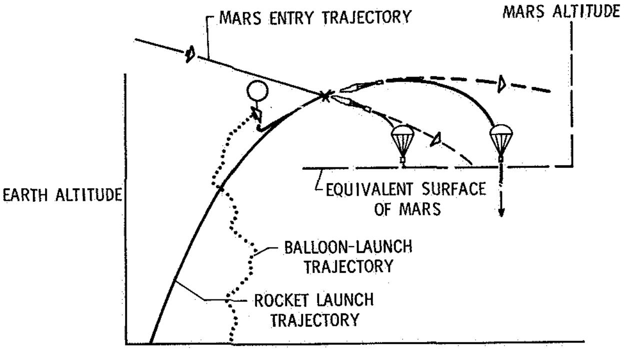

Figure 4.- Planetary entry simulation.

PROPERTY	EARTH	MARS
COMPOSITION	AIR	CO_2
DEPLOYMENT ALTITUDE (ft)	130 000	15 000
TEMPERATURE (^{0}R)	449	316
SPEED OF SOUND (ft/sec)	1038.5	699.0
RATIO OF SPECIFIC HEATS, μ	1.4	1.36
VISCOSITY, η (lb-sec/ft^2)	3.33×10^{-7}	1.88×10^{-7}
DENSITY, ρ (SLUGS/ft^3)	8.19×10^{-6}	18.0×10^{-6}

Figure 5.- Atmospheric properties at parachute deployment altitude.

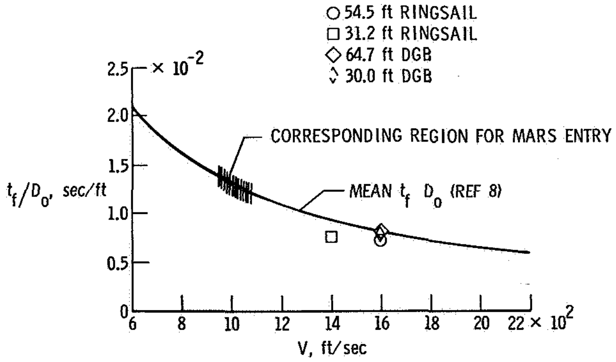

Figure 6.- Parachute inflation time.

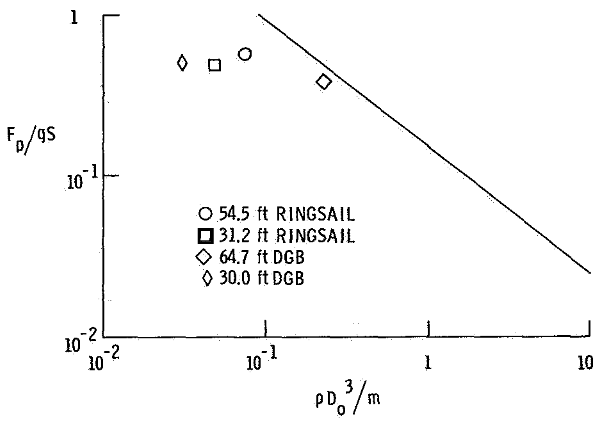

Figure 7.- Opening force versus mass ratio.

NASA-Langley, 1968