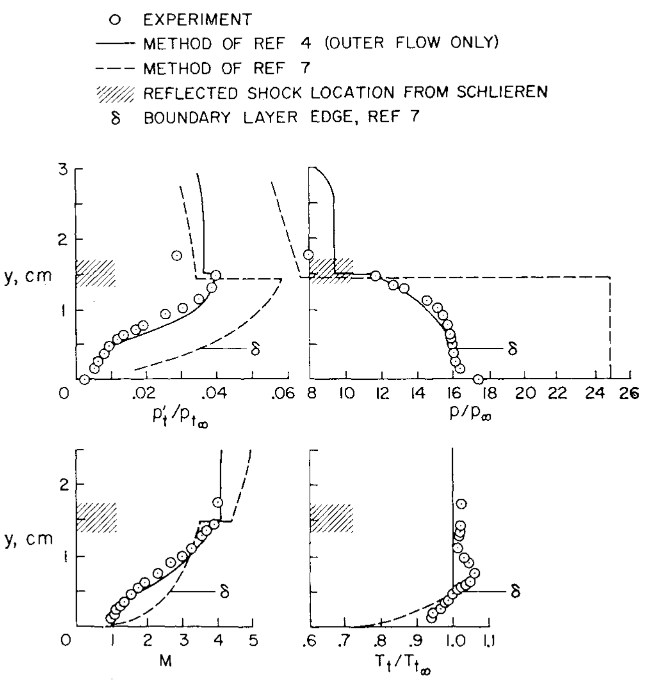


**Fig. 5 Comparison of experimental and predicted profiles of Pitot pressure, static pressure, Mach number, and temperature downstream of interaction (Station 94.5 cm).**

a turbulent boundary layer which contains an extensive region of separation.

Figure 5 shows profiles of experimental and predicted Pitot and static pressure, Mach number, and total temperature at station 3 (Fig. 1) just downstream of the interaction; at station 2 upstream the measured and predicted profiles agreed well. The predictions obtained by the methods of Ref. 4, which uses a control-volume type of analysis for interactions, and Ref. 7 are shown for comparison with each other as well as with the data. The outer layer results, shown for the method of Ref. 4, are in good quantitative agreement with the experimental data. It is worth noting that although the method of Ref. 7 greatly overpredicted the Pitot and static pressures below the reflected shock, the predicted Mach number near the shock was about the same as that obtained experimentally and by the method of Ref. 4. This result points out that Mach number profiles must be examined with caution because a seemingly correct Mach number may result from incorrect Pitot and static pressures.

In conclusion, it appears that the method of Ref. 4 affords a considerable improvement over previously used control-volume type models, and is applicable for interactions that occur between a shock wave and turbulent boundary layer developed over a compression surface having a blunt leading edge. This improvement applies primarily in the outer layer. Further improvement in the method will be required before better prediction can be made of the flow in the inner viscous layer. In particular, the method used for determining the inner layer must be capable of predicting the correct plateau pressure in the separated region. Some improvement might be expected with the use of more advanced boundary-layer techniques that permit the conditions on the dividing line (e.g., entropy, velocity gradient $(\partial u/\partial y)$, and pressure gradient $(\partial p/\partial y)$) to match those imposed by the flow in the outer layer.

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# A Venus Planetology Mission Based on the Planetary Explorer Spacecraft

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THE National Academy of Sciences has recommended,[1] that a series of low cost missions—including orbiters, atmospheric probes, and landers—be used for early exploration of the planet Venus. We have undertaken a preliminary study to identify a mission concept, investigate a range of Venus lander missions, and define the mission that appears most promising within the constraints imposed. In the execution of this study, the basic tasks were to determine if a worthwhile lander mission, in the 800 lb class, can be configured and what technology or state of the art advances may be required.

## Objectives

The science objectives presented in the NAS report are interpreted as follows: 1) Chemical composition of surface materials; identify the most abundant materials at widely separated sites. 2) Surface topography; identify surface features, elevation variations, microscopic imaging of surface materials, petrography. 3) Active seismology; determine the surface structure to 0.5 km depth. 4) Passive seismology; observe natural seismic activity at 3 sites. 5) Determine if an iron core is present. 6) Measure heat flux from the planet interior. 7) Measure atmospheric pressure and temperature at the surface.

In view of the current national goals and anticipated fiscal policies, it is necessary to provide the highest possible scientific return for the least cost. Measurements such as pressure-temperature profiles, atmospheric composition and wind velocity, which are capable of being made by probable earlier atmospheric probe or orbiter missions,[2,3] have been omitted. The science experiments and instruments considered are listed as follows: 1) Active seismology—3-axis seismometer,

Submitted July 14, 1971; presented as Paper 71-829 at the AIAA Space Systems Meeting, Denver, Colo., July 19–20, 1971; revision received November 16, 1971.
Index category: Entry Vehicles and Landers.

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microbarograph, explosive seismic source. 2) Passive seismology—seismometer, hot film anemometer. 3) Surface composition—gamma ray spectrometer plus neutron source. 4) Television—panoramic and microscopic. 5) Atmospheric pressure—at surface. 6) Atmospheric temperature—at surface.

### Discussion

Mission constraints are essentially those identified by the Academy. They include use of a Thor Delta 904 launch vehicle (≈825 lb payload to Venus), launch opportunities in the late 1970's and early 1980's, and two launches per opportunity. A Planetary Explorer (PE) spin-stabilized spacecraft will serve as the bus. Planet radius is assumed as 6050 km, with surface temperature and pressure of 765°K and 94 bars, respectively.

To identify a mission that will address all the planetology objectives, a series of missions was considered. Preliminary estimates of system weights indicated that all objectives could not be accomplished in full. Since the surface composition and seismic experiments have highest priority, they were retained, while television, which has a severe impact upon weight and power, was omitted.

A mission concept was developed using an entry vehicle that holds an instrumented lander and a separate vehicle containing an explosive charge for the active seismic experiment. From this concept, four representative missions were developed to bracket the allowable weight of 825 lb.

Mission A uses a single entry vehicle containing a lander and seismic source. The lander includes seismic and composition experiments, pressure and temperature instruments, and engineering subsystems. It has a capability for 1 hr of active surface lifetime and passive seismic monitoring of 30 hr. Separation between sensor and explosive capsule will be 1–2 km. This mission provides data for a single entry site.

Mission B uses the same components as mission A except that two landers and one explosive capsule are included in the entry vehicle. This improves the active seismic data by providing two refractive paths for shock velocity and two reflective readings to indicate the depth of harder layers and their elevation angle. The composition experiment is improved by sampling at two displaced sites. The penalty for the additional lander is reduced explosive weight that decreases the separation distance between the sensors and the explosive capsule, limiting the depth that will be explored; a distance of 0.6–1.0 km may still be achieved. Deterioration in the passive seismic experiment will also be experienced since the reduced volume and weight allocated for insulation will allow only a 1 hr surface survival time.

Mission C uses two of the mission A entry/lander systems, but with 1 hr active/passive surface lifetime and contains smaller explosive capsules; the distances between capsules and sensors are reduced to 0.5–0.9 km. Use of two entry vehicles allows for large separation in entry sites, significantly improving distribution of data on the planet.

**Table 1 Weight summary—mission C**

| | | | | | lb |
|---|---|---|---|---|---|
| Launch vehicle payload | | | | | 825 |
| Planetary Explorer bus | | | | 325 | |
| 2 entry vehicles + 10% | | | | 471 | |
| each entry vehicle | | | 214.2 | | |
| yo-yo despin system | | 1.5 | | | |
| extraction parachute | | 11.0 | | | |
| lander | | 116.7 | | | |
| explosive capsule | | 19.0 | | | |
| aeroshell | | 66.0 | | | |
| structure | 36.0 | | | | |
| heat shield (fwd) | 23.0 | | | | |
| heat shield (aft) | 7.0 | | | | |
| unallocated weight | | | | 29 | |

Mission D uses three entry/lander systems similar to those defined for mission C. It is anticipated that this configuration will exceed launch vehicle capabilities by 150–200 lb.

Mission C was selected for further definition, since it has the highest apparent science value of the three candidates which meet the weight limitations. Figure 1 shows the mode of operation for each entry vehicle, and a weight summary for the mission is shown in Table 1.

Operation of the system during launch and cruise is not unique and will not be discussed here. Activities of interest begin at planet approach when the PE bus is reoriented so that desired targeting of the entry vehicles may be affected. The vehicles will separate from the bus sufficiently in advance of atmospheric entry to provide the desired targeting. The proper cross range velocity and spin are imparted to the entry vehicle as a result of the angular velocity of the spinning bus. Timers (started at separation) will control all time-based events. Mounting of the vehicles on the spacecraft is shown in Fig. 2.

Each vehicle will enter the atmosphere in its aeroshell/heat shield and undergo the entry acceleration and heat pulse. A parachute will then be deployed to separate the aft cover and aeroshell. The parachute will stabilize the aft cover, and a small rocket motor will provide separation velocity to the explosive capsule. Timers in the explosive capsules provide a common time reference with the landers. Both the lander and explosive capsule descend with similar ballistic coefficients to about 0.5 km above the surface where a Beta glass parachute is deployed from the lander to slow and invert the vehicle for touchdown. The explosive capsule will descend to the surface and impact; no surface penetration is expected. Since the explosive capsule does not require a landing parachute, the capsule will arrive at the surface before the lander. Sufficient time will be allowed to assure lander impact, erection and calibration of the seismic experiment before the timer in the explosive capsule activates the charge. The seismic shockwaves will be recorded by the seismometer and

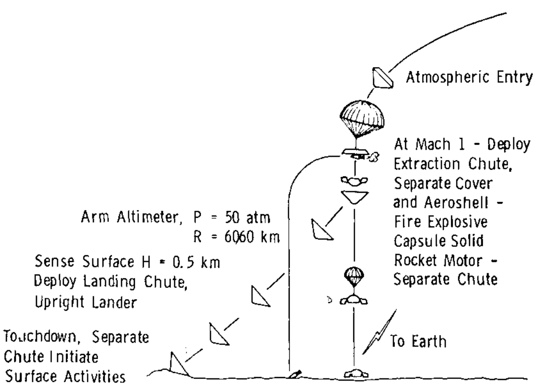


**Fig. 1 Atmospheric entry and descent.**

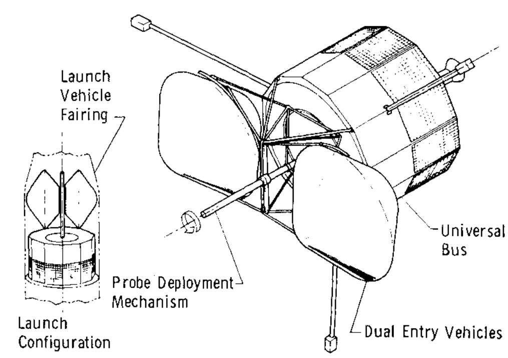


**Fig. 2 Cruise configuration.**

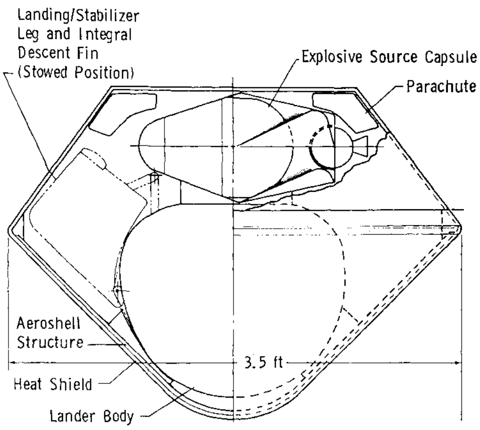


**Fig. 3 Entry vehicle.**

the distance from the detonation to the sensor will be determined by the transit time of the atmospheric shock. These activities will be complete within a few minutes after impact.

After the active seismic experiment, the neutron source for the composition experiment will be placed on the surface; composition, pressure, temperature, and passive seismic data will be recorded. Wind velocity data will be collected to isolate wind noise from natural seismic data. Stored data will be transmitted to Earth along with real time measurements. All subsystems not required for passive operation will be powered down to conserve power and minimize thermal loads.

The entry vehicle configuration is shown in Fig. 3. The aeroshell is a 3.5 ft-diam, aluminum honeycomb cone covered with a 0.3-in.-thick, lightweight elastomeric heat shield. The base cover is a sandwich shell structure, also covered with a thin heat shield.

The lander nests in the nose of the aeroshell with entry loads (450g) transmitted by uniform pressure from the spherical payload to the aeroshell. The explosive capsule is attached to the aft cover as shown in Fig. 3. Preliminary tests indicate that most components are compatible with these "g" levels, although development work will be required on many to assure a safe margin.

The lander configuration (Fig. 4) is designed to sustain a 50 min descent period plus a one hour lifetime after landing. An aluminum waffle pressure canister rigidly mounts the science instruments, a 5w transmitter, battery, data storage and related equipment. The canister is covered with a 1.7 in. layer of Min-K insulation and a vented titanium cover. In the area of the antenna, an RF-transparent polyimide cover is used. Phase change material is used inside the shell to control component temperatures.

Aerodynamic descent stabilization fins are structurally integral with the landing legs. The low body clearance is to ensure that the lander will imbed on crushable material on the base to provide good coupling with the surface for the seismic experiment.

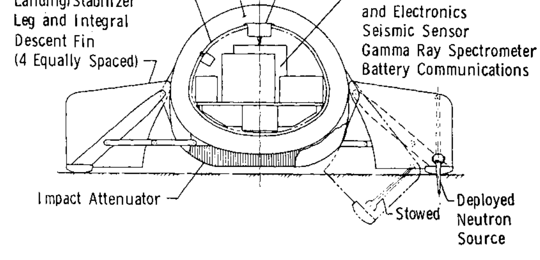


**Fig. 4 Seismic lander.**

The neutron source for the soil sampling experiment is carried outside the pressure canister on a spring-loaded arm and forced into the surface after the active seismic experiment. The sensor for the experiment is mounted inside the pressure vessel and requires no windows or penetrations for operation.

A timing reference common to both lander and the explosive capsule is provided by the use of crystal frequency standards, with counting circuits. These are synchronized as long as the lander and capsule are joined and are free-running after separation.

Each lander will have a direct noncoherent communications link to Earth. A crossed slot antenna with relatively low gain, about 5 db, was selected because its broad beam gives a high tolerance for pointing losses. A 5w transmitter is adequate for the 30 bps rate required by the science instruments. Link analyses account for losses due to atmosphere, pointing, multipath, and polarization. Fading losses due to atmospheric turbulence are minimized by the selection of noncoherent signalling.

The portion of the data system used for the seismic experiment is based on the Viking Mars Lander seismograph system. This system must be augmented to handle other inputs from pressure, temperature, microbarograph instruments and the gamma ray spectrometer. The system includes a variable bandwidth filter, switched as the sampling rate is switched, a logarithmic quantizer, a calibration circuit, and average and peak power measurement circuitry.

The configuration for the explosive capsule uses a design in which the explosive container is vented (since the explosive charge is capable of withstanding the ambient pressure). The inner shell contains the explosive charge while the outer shell protects the insulation from damage and maintains the aerodynamic shape. Thermal control of the explosive capsule is not difficult because its temperature limit is high, it has a large heat capacity, and its operating lifetime is short. A $\frac{3}{8}$-in. layer of insulation is sufficient. The detonator and timer electronics package requires protection from pressure and temperature, achieved by an insulated pressure resistant container. The explosive charge (TACOT) and the electronics compartment temperature limits are 600°F and 150°F, respectively. The explosive capsule requires a shape configured to match the ballistic coefficient of the lander, 3.8 slugs/ft$^2$, to reduce relative dispersions in landing sites due to winds. Small fins are required for stability.

## Conclusions

Based on the preliminary investigations discussed here, it is concluded that considerable scientific achievement is attainable within the payload constraints identified. The use of a Delta launch vehicle, a spin stabilized Planetary Explorer spacecraft, a modest weight assigned to science, and the use of existing qualified hardware will contribute to an economical mission approach. It is significant that this mission would be a natural successor to the Venus Multiple Probe and Orbiter Missions now being investigated by NASA.

Seismology objectives are met reasonably well for the active phase, but passive data will not be recorded as long as desired. The composition experiment should identify several of the surface elements. Some uncertainty still exists on shielding, system weight, and the packaging requirements of this experiment. No topography data is to be obtained on this mission due to the elimination of television. Presence of an iron core has not been pursued vigorously for this mission due to the difficulty in obtaining an unambiguous answer. Temperature and pressure measurements will be made at all four sites for the one hour lifetime and should contribute to the overall thermal mapping of the planet.

No significant departures from the anticipated 1975 state of the art have been identified; however, development of lightweight science instruments, pressure-resistant vessels, and heat shields are all worthy of attention. Additional launch vehicle payload capability appears available through use of later versions of the Delta series.

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# Electroadhesive Devices for Zero-*g* Intra/Extravehicular Activities

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## Introduction

FOR an astronaut to accomplish the wide range of tasks expected in future space missions, a rapid and versatile method of temporarily attaching him and his equipment to the spacecraft or worksite is needed. One method of effecting essentially unlimited maneuvering capability or worksite tiedown is being evaluated at the Langley Research Center (LRC). This method utilizes electroadhesive forces and offers a means of adhering to any conductive surface. LRC is evaluating electroadhesors to determine the attachment force levels obtainable, the range of useful application, and the practical configurations of electroadhesive devices.

## Electroadhesion Theory

Electroadhesion is an electrostatically induced attractive force between surfaces. Traditionally, electrostatic forces have been considered too weak to be of practical use. Recently, however, studies by the Chrysler Corporation under contracts to LRC, MSFC, and the Air Force have shown that electrostatic forces of useful magnitude can be produced and maintained.

The studies by Chrysler have demonstrated that when two oppositely charged conductors are separated by only a thin, but imperfect, insulating material, significant adhering forces between the conductors result. Figure 1 illustrates Paschen's Law, which partially explains this phenomenon. Note that the potential difference at which breakdown of the media separating the charged materials takes place is a function of the product $Pd$, where $P$ is the pressure of the prevailing medium and $d$ is the separation distance of the materials. The minimum breakdown potential is about 300 v which, at sea level pressure, corresponds to a separation distance of 0.01 mm. Increasing or decreasing the product $Pd$ from this point increases the breakdown voltage and therefore the sustainable electric field. The adhering force per unit is a function of the applied potential; therefore, it is desirable that the applied potential be high but less than the breakdown voltage. These conditions can best be met if $Pd$ is adjusted such that operation occurs on the part of the curve to the left

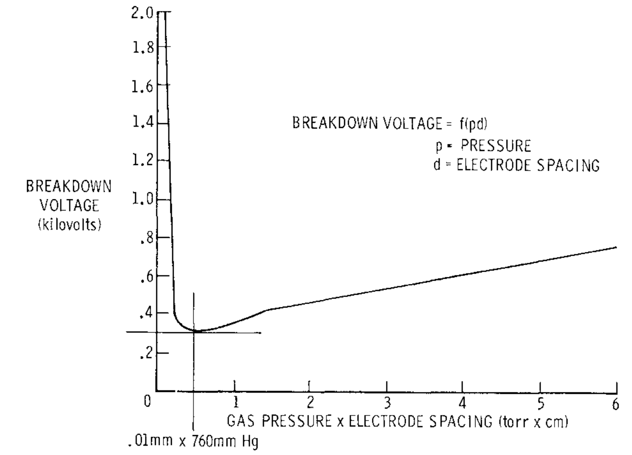


**Fig. 1 Breakdown voltage vs gas pressure-electrode spacing product in air, illustrating Paschen's Law.**

of the minimum breakdown potential. The low pressures inside spacecraft cabins and the vacuum conditions of space are particularly conducive to the use of this part of the curve.

An essential element of the electroadhesion phenomenon is the thin, imperfect insulating material between the charged conductors. Experiments have shown that the electroadhesive forces obtainable are highly sensitive to the resistivity and chemical composition of the insulating material. Apparently some migration of electric charge occurs through the imperfect insulator which reduces the separation of opposite charges without allowing significant discharge.

Figure 2 shows some typical characteristics of electroadhesion. Note that the adhesive force per unit area is a fairly linear function of applied voltage in a region above a certain minimum voltage. Beyond this region a plateau is reached, however. Decreasing the atmospheric pressure raises the level of this plateau. The curve also shows that the current required by the device is in the microampere range and that reducing the atmospheric pressure reduces this requirement. Extending these curves to vacuum conditions results in a force plateau of around 30–40 psi and a current requirement of 1 $\mu$A or less allowing high forces to be maintained with little energy consumption.

## Initial Development Studies

Because environmental pressures in space are favorable to electroadhesion, and because of the previously mentioned space applications of electroadhesion Langley awarded a proof-of-principle contract study of the phenomenon to the Chrysler Corporation. This study resulted in a preliminary

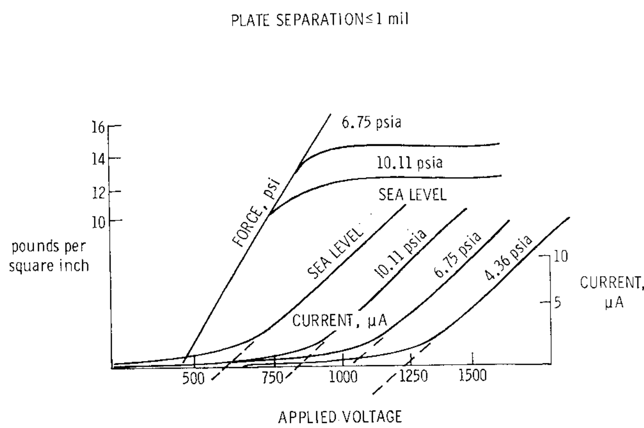


**Fig. 2 Typical electroadhesor characteristics.**

Received August 5, 1971; revision received November 10, 1971.

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