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Technical Report 32-1466

Ground Simulation of a Mars-Entry-Capsule Aeroshell Environmental History

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Prepared Under Contract No. NAS 7-100
National Aeronautics and Space Administration

Preface

The work described in this report was performed by the Engineering Mechanics Division of the Jet Propulsion Laboratory.

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Abstract

The present interest in the exploration of Mars provides a unique opportunity to simulate all of the critical environments in the flight history of an extraterrestrial entry vehicle on the ground in one facility. Not only is this simulation possible without interim re-exposure to earth ambient conditions, but the simulation is possible with existing technology on essentially full-sized vehicles (e.g., 20 ft in diameter). For a Mars mission, at least, the old question of the effect of early environments on later performance can be answered without significant qualification. This report describes the design of a single facility which is meant to provide reasonable simulation of chemical surface decontamination, dry heat sterilization, launch pumpdown, transit vacuum and temperatures, and the simultaneous entry heat and pressure pulses. Although most of the components are available, the facility has not been operated in the manner described.

Ground Simulation of a Mars-Entry-Capsule Aeroshell Environmental History

I. Introduction

The desire to land a scientific package on the surface of Mars provides a unique opportunity to simulate the entire mission profile for the entry capsule in an earth-located, ground-simulation facility. Because of the mildness of the Mars entry environment, the simulation can be carried out on samples which are either large compared to normal practice or even full scale in sizes up to 10 ft or more. Figure 1 provides an artist's conception of the ground, launch, transit, entry, descent, and impact phases in a Mars entry mission. The aeroshell, which includes both the aerodynamic structure and the entry heat shield, is affected, in some way, by each of the environments up to the descent phase of the mission (Refs. 1, 2). Of the environments in the earlier phases of the mission, only the interplanetary radiation is extremely difficult to simulate on large samples in ground facilities. The effects of an earlier environment on a material's performance during a later environment are not well understood.

Some failures in the space program have been attributed to a kind of coupled effect due to environments. Environments do change materials by adding or subtracting absorbed species, by changing chemical or physical structure, by irreversible reaction and removal, and by expansion or contraction of dimension. How much each of these effects changes later performance under mechanical or thermal load is controlled by a multitude of interrelated parameters. Until a considerably larger base of data on coupling effects becomes available, we must either establish a test facility which simulates a sufficient number of the environments to provide some form of verification, or overdesign with a fair-sized factor of

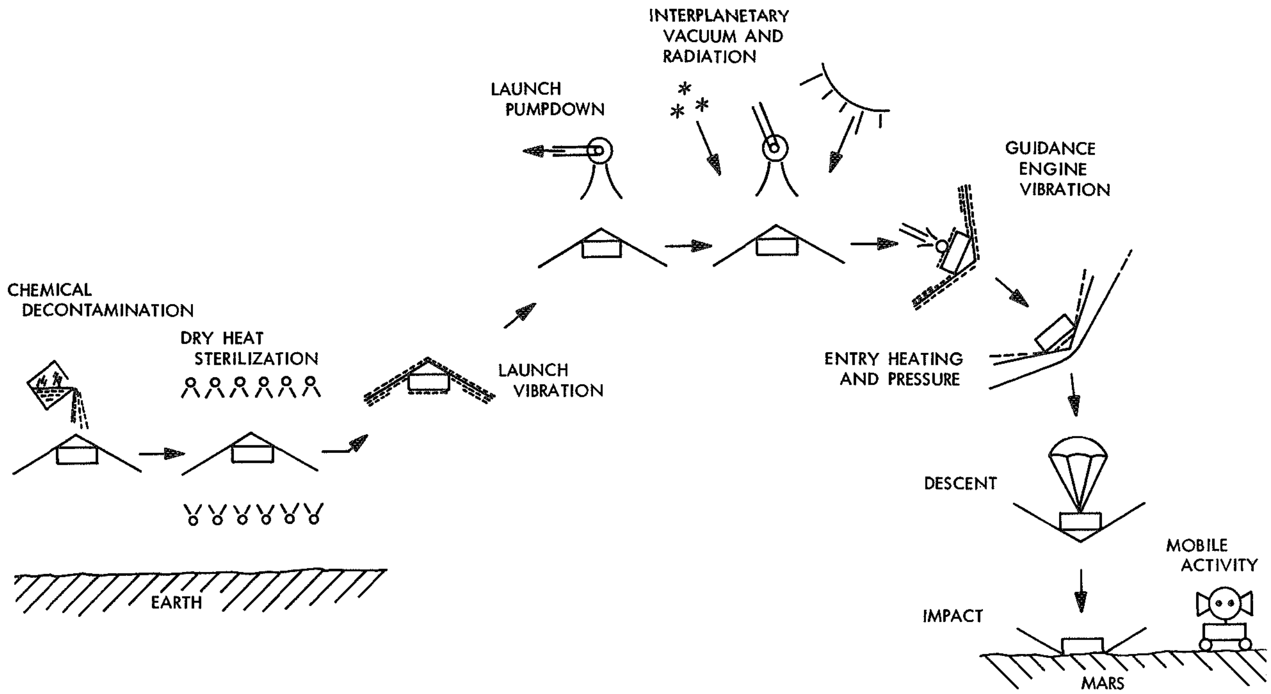

Fig. 1. Ground, launch, transit, and entry environments

safety. For earth entry, large factors of safety have allowed considerable success. For extraterrestrial planetary entry, this excess weight constrains payloads or necessitates larger, more expensive boosters for the same mission. In this report, the development of a facility to investigate the coupling effects of the Mars-entry mission environment is described.

II. Simulated Environments

A facility has been designed and assembled at JPL to investigate the effects of the environmental history of an aeroshell on its performance during entry into the Mars atmosphere. The environments simulated in the facility include chemical surface decontamination, dry heat sterilization, launch pumpdown, interplanetary vacuum, interplanetary temperatures, entry pressure pulse, and entry heating pulse. The mission-evolved specifications for these environments are outlined in detail in Ref. 1.

The chemical surface decontamination environment reduces the concentration of micro-organisms during component assembly so that less severe temperature-time histories can be used for dry heat sterilization. The chemical decontaminate is a mixture of 12% ethylene oxide (ETO) and 88% dichlorodifluorethane (Freon 12) with a concentration of 450 to 650 mg of ETO per liter of gaseous atmosphere and a relative humidity of 35 to 55%. The severest exposure presently contemplated is that for testing electrical piece parts and materials and uses six 28-h cycles at a 50°C dwell temperature.[1] Warm ETO is very reactive and could promote polymer degradation, stress corrosion, etc., which may influence later performance. Absorbed in porous heat shields or in a honeycomb sandwich, it may become even more reactive during later phases of the mission when temperatures are increased. There is some uncertainty, at present, that chemical surface decontamination will be used.

Dry heat sterilization acts as a terminal sterilization process. The severest time-temperature exposure contemplated is six 92-h cycles at 135°C in circulating, clean dry nitrogen with heat-up and cool-down rates of 56.5°C per hour at each end of the cycle.[1] Dry heat sterilization acts primarily as an additional cure or heat treatment for most materials under consideration for capsule aeroshells. In this case, the primary problems are due to distortion or to shear failure at interfaces due to differential expansions. Extra cure might also produce brittle-

[1]"Environmental Specification—Voyager Capsule Flight Equipment Type Approval and Flight Acceptance Test Procedures for the Heat Sterilization and Ethylene Oxide Decontamination Environments," JPL Spec. VOL-50503-ETS. Jet Propulsion Laboratory, Pasadena, Calif., January 12, 1966.

ness in resin systems used as adhesives or as part of various composite constructions for either the heat shield or structure.

During launch pumpdown, honeycomb sandwich structures experience sudden differentials in pressure from the inside out due to the inability of internal gases to diffuse out as rapidly as the drop of pressure during boost. Structures are not normally designed for this differential. During a typical boost, pressure drops a decade a minute for 8 minutes or less to approximately 10^{-5} or 10^{-6} torr. When the vehicle moves out of parking orbit, the vacuum gradually drops to the 10^{-12} to 10^{-16} torr common between earth and Mars. Again, high vacuum can remove absorbed species which might be critical to the nonbrittle performance of adhesives or other polymeric-resin utilizing composite systems. Temperatures during this transit exposure are estimated to range between +75°C and −125°C depending on the mission, sun angle, etc. At the higher temperatures, species loss or other forms of property degradation are accelerated. At the lower temperature, materials of construction are often brittle so that their performance may be degraded when exposed to flexure during entry.

Typical entry heat and pressure pulses for Mars are sketched in Fig. 2. No trajectory information is assigned to each set of curves because changes in entry velocity, entry angle, ballistic coefficient, diameter, nose radius, etc., could vary the peaks to nearly every position on the figure. Most of the Mars missions actually under consideration, fall somewhere between these extremes. The important point is that any facility should be able to simulate both the peaks and the ramps and should be able to provide a proper decrease in heating rate away from the stagnation point. Pressure and heating should also be accomplished simultaneously so that thermal and pressure stresses may be superimposed for actual verification of the aeroshell capability.

III. Environments Not Simulated

A number of the anticipated environments could not be simulated in a single test facility, or were left out, because they were assumed small in effect relative to the expense of incorporating them in a single facility. These environments include ground storage effects before launch, vibration during launch or during guidance corrections in space, and interplanetary radiation or particle impingement.

Ground storage effects due to wind, rain, sea water, etc., and spillage of rocket fuel during loading of the guidance engine fuel tanks are ignored in this facility. Each of these ground storage effects could potentially influence later performance but must be examined separately. Vibration during launch and during guidance corrections in space could be added to the facility by incorporating available, but expensive, shakers which operate within a vacuum while retaining all of the other facility functions. The shaped spectrum of Gaussian noise typical of launch can, literally, shake poorly-joined structures apart, or at least create planes of weakness which become critical during application of entry loads. Random noise, shocks, and low- and high-frequency vibration spectra vary depending on launch vehicle, but, for the most part, place severe constraint on construction. Guidance corrections in space provide lower level vibration in a potentially cold and thus brittle environment which may be, however, more limiting on the structure. In this facility, vibration is not accounted for and warm and cold vibration tests are required elsewhere for implied verification of structural concept integrity.

Interplanetary radiation and micrometeoroid puncture are also not simulated in this facility. Such simulation is not only difficult, but probably unnecessary. The radiation energy normally accommodated during transit from earth to Mars in nine months is not sufficient to degrade

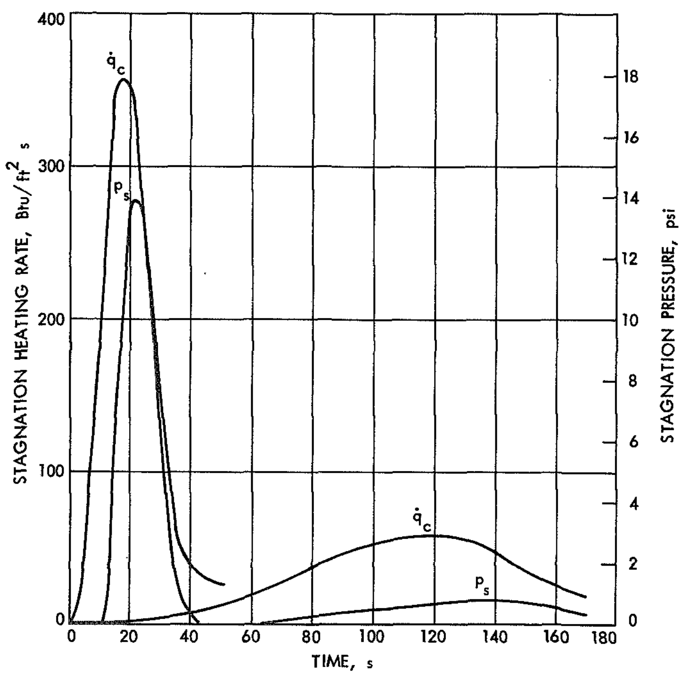

Fig. 2. Typical heating and pressure pulses for Mars-entry missions

the reasonably high temperature plastics and the metals normally used in spacecraft or capsule fabrication. Whether it is sufficient to cause failure when added to all the other environments is not answered, but some overtesting in the other environments should account for this. Micrometeoroid puncture is not a problem with most of the silicone elastomer resin-based composites contemplated for a Mars mission. Separate tests have shown puncture without failure (Ref. 3), and the probability of meeting a meteoroid large enough to affect thermal or mechanical performance is very small. These considerations and economics have prevented incorporating micrometeoroid puncture capability in this facility.

IV. Facility Design

A 4 ft by 8 ft facility has been designed to simulate each of the environments suggested earlier and is shown schematically in Figs. 3 and 4. Figure 3 is essentially a vacuum system layout showing the two separated evacuating capabilities and the sample holder and instrumentation feedthroughs. Figure 4 provides a layout of the water (H_2O), liquid nitrogen (LN_2), and gaseous nitrogen (GN_2) systems, showing the sample holder in relation to the LN_2 shroud and the lamp bank. The vacuum tank and the LN_2 shroud are shown in Fig. 5a, and the sample within the shroud in Fig. 5b. From the schematics it is obvious that some compromise was necessary to achieve a reasonable simulation of decontamination, sterilization, and the pressure and heating profiles of launch, transit, and entry. These compromises will be discussed in detail in the following paragraphs with the more detailed description of the individual components.

Accomplishment of chemical surface decontamination had been planned through the attaching of a slightly modified commercial ETO sterilizer control to the side of the major chamber and circulating the ETO through the chamber by drawing on one small mechanical pump adapted to handle ETO. The sample is held at 50°C by running hot water or hot gaseous nitrogen through the LN_2 shroud shown in Fig. 4. The major problem with this simplified approach is humidity control which will be somewhat erratic at best without expensive modifications. This was not considered important to the test as long as some humidity was provided without precipitation. Action to incorporate the ETO capability has not been initiated due to the uncertainty in whether ETO is required.

Dry heat sterilization is carried out by using the LN_2 shroud and the lampbank as coordinated heater elements (see Fig. 4 for position). Hot GN_2 can be run through the shroud with the lampbank unit at a low power setting and the two heat inputs balanced until the specimen thermocouple temperatures reach 135°C. Dry nitrogen at 135°C is also circulated through the test chamber. The major problems with this simplified technique are control of the required temperature ramps at each end of the six 92-h cycles at 135°C and temperature gradients within or along the samples due to view factor problems and oversimplified control of the heater elements. It is not expected that this will be a great enough deviation to affect the validity of the test.

Launch pumpdown is accomplished by the vacuum system shown in Fig. 3. One decade of pressure drop per minute is easily accommodated by the pumping system shown. Although the test chamber was adapted from an existing chamber which was not considered a particularly high vacuum system, it is capable of better than 10^{-5} torr on a short pumping time basis. A goal of 10^{-8} torr has been set but not yet achieved for long time pumping with cryogenic baffles and shroud. Most vacuum degradation will take place at 10^{-5} torr, but some materials contain absorbed species with vapor pressures in the 10^{-8} range. Any laboratory pressure below 10^{-8} torr does not provide any additional simulation benefit for most of the heat shield and structural concepts being considered for entry capsule aeroshells.

The entry pressure pulse is simulated by back filling the major chamber at a rate consistent with the pressure pulses shown in Fig. 2, while holding the back side of the sample aeroshell at a low vacuum (below 1 micron). The major chamber is then re-evacuated as rapidly as possible with the mechanical and diffusion pumps to further reproduce the flight pressure curve. The re-evacuation takes somewhat longer than the pressure drop in Fig. 2, but only provides a degree of conservatism as an overtest condition. The pressure simulated is also a constant over the entire surface rather than the distributed pressure of actual entry. This is accommodated by choosing a constant pressure differential which provides exactly the same maximum strains as those anticipated for the distributed entry pressure case.

The entry heat pulse is simulated by the radiant heater lamp bank shown in place in Fig. 3 and in detail in Fig. 6. The 600-W tungsten bulbs can produce up to 100 Btu/ft^{2}s at the stagnation point of a sphere cone configuration. Heating rates up to 160 Btu/ft^{2}s have been measured at the Jet Propulsion Laboratory (JPL)

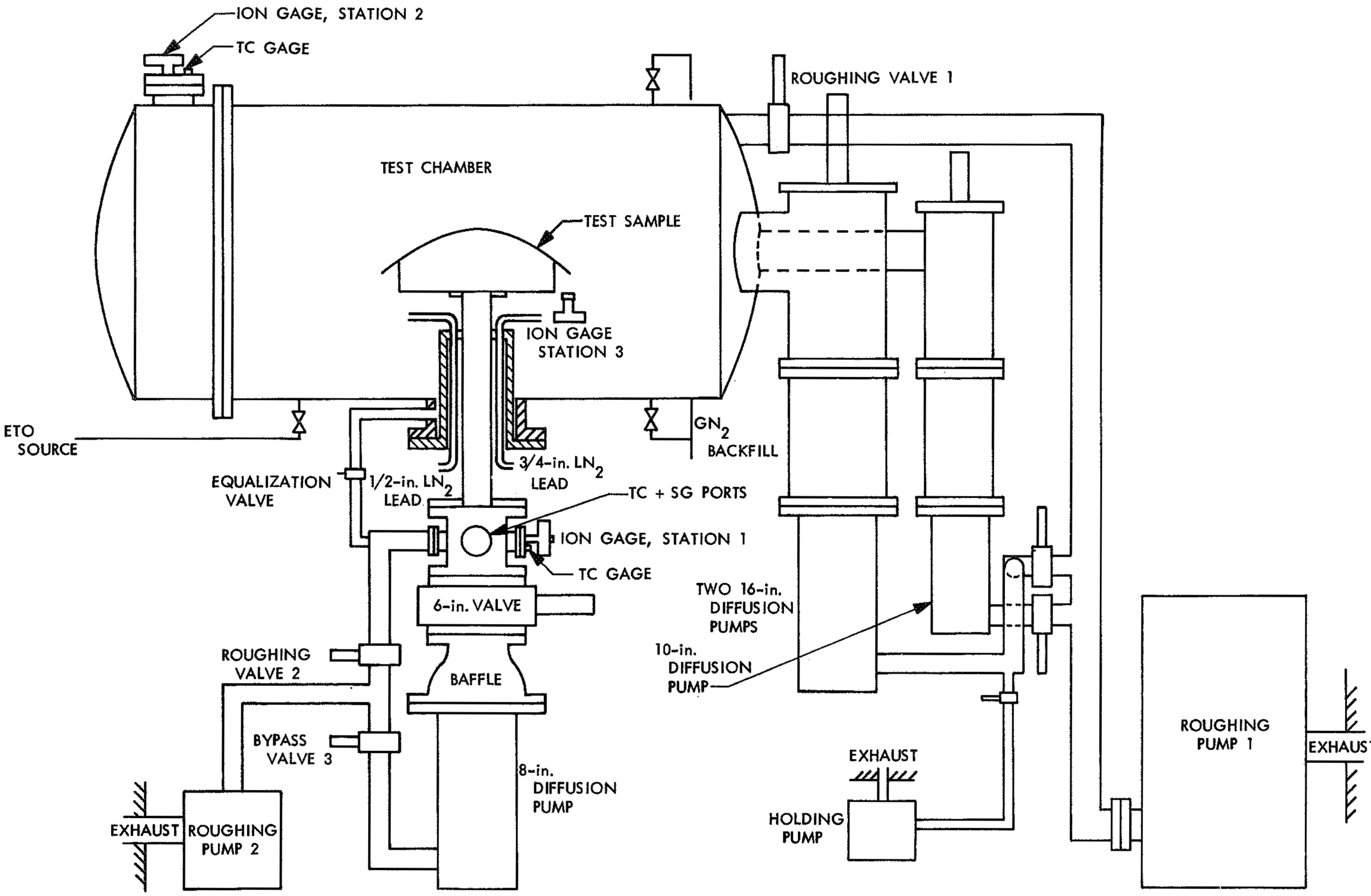

Fig. 3. Vacuum system layout for the integrated coupled environmental simulation test

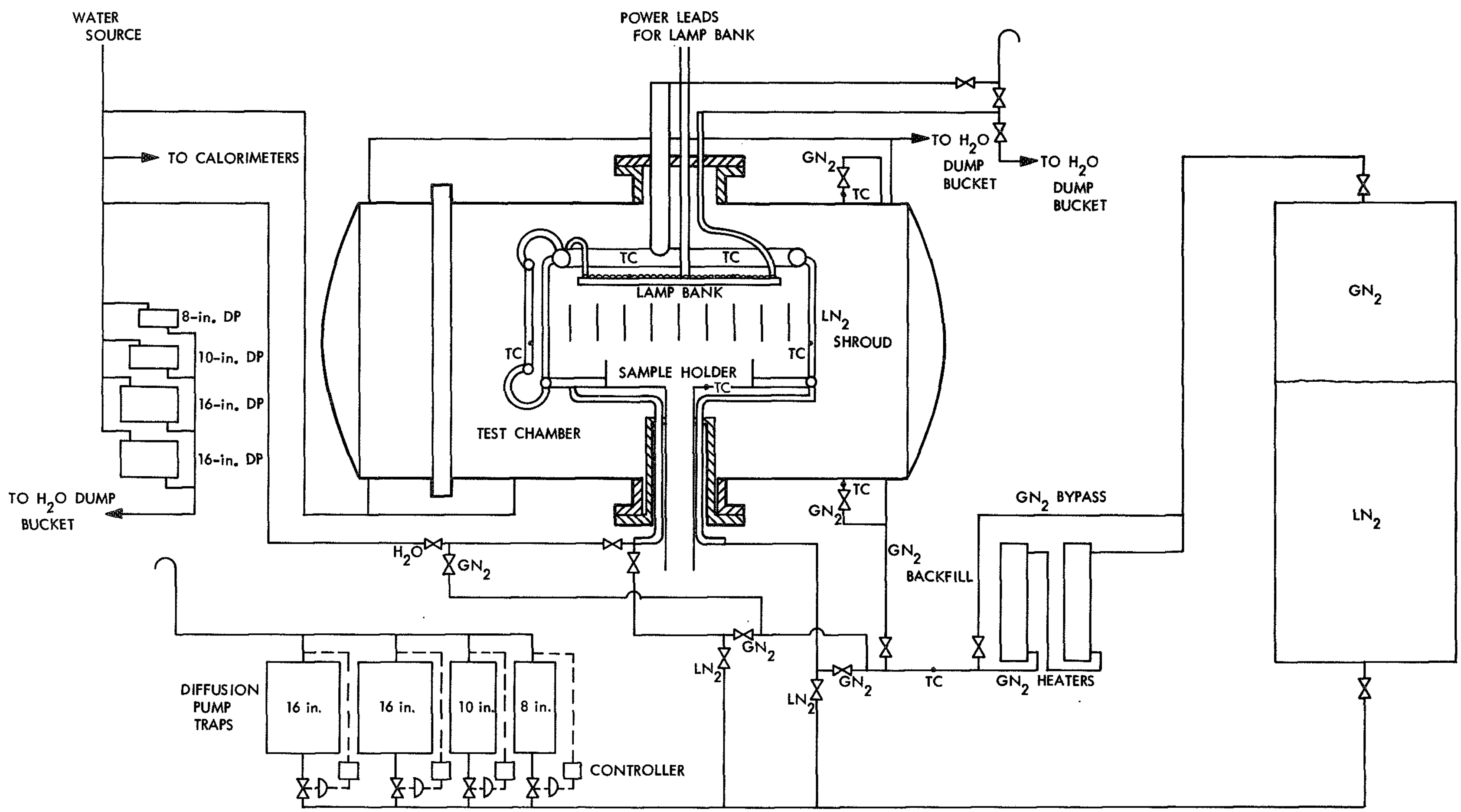

Fig. 4. Liquid and gaseous nitrogen layout and water layout for the integrated coupled environmental simulation test

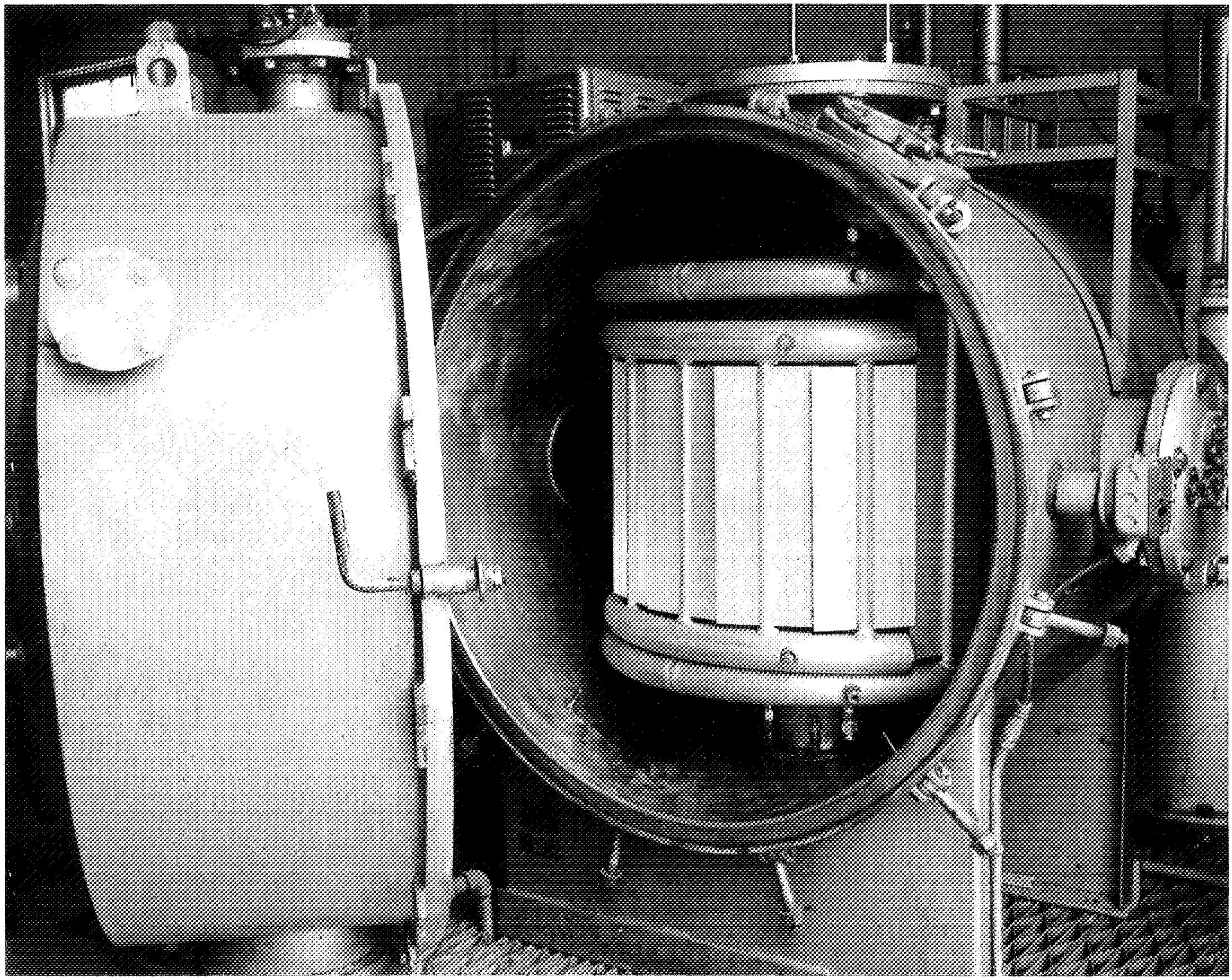

Fig. 5a. Simulation facility test chamber (tank and liquid nitrogen shroud)

on flat samples with the bulbs located somewhat closer. The heating rates shown in Fig. 2 are cold-wall convective rather than radiative heating rates. When the cold-wall heating rate is high enough, the gases evolved from the ablating heat shield block much of the heat, and some of the remaining heat is lost from hot-wall effects. Using a computer, these blocking effects can be measured from ablation response analysis, and the heat actually reaching the surface can be back calculated. This, then, becomes the heat which must be duplicated by the radiant lamp bank to simulate the actual convective heat pulse. For Mars entry, this can be as low as 15% of the cold-wall convective heating at the higher rates. For one direct entry condition of interest at JPL, stagnation cold-wall convective heating rates at the peak heating condition of 365 Btu/ft^{2}s are replaced by an equivalent unblocked radiative heating with a peak of 88 Btu/ft^{2}s. Shear is not a factor with most of the candidate heat shield materials for a Mars mission. Sweep of the evolved species away from the surface was also considered unimportant for this test, although some free convection takes place, induced by the lamps, and some of the backfilling gases for the pressure pulse simulation can be fed in along the centerline. The lamp bank can be controlled by a stepping function switching mechanism or by continuous dc control. One minor system problem is the need for insulating the cooling lines for the lamp bank from the shroud, since under some conditions the lamp bank may have water cooling while the shroud uses LN_2.

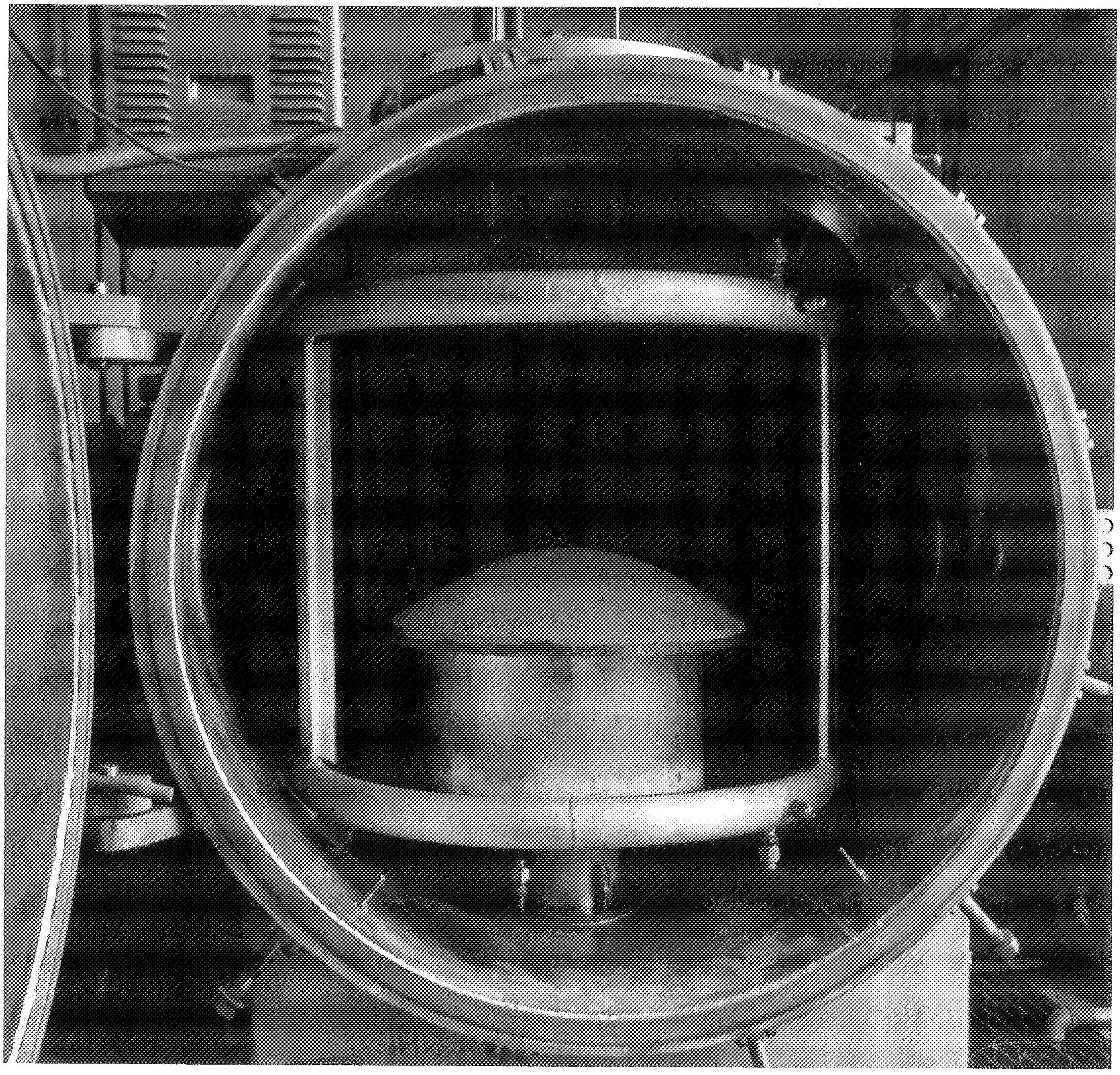

Fig. 5b. Simulation facility test chamber (sample in opened shroud)

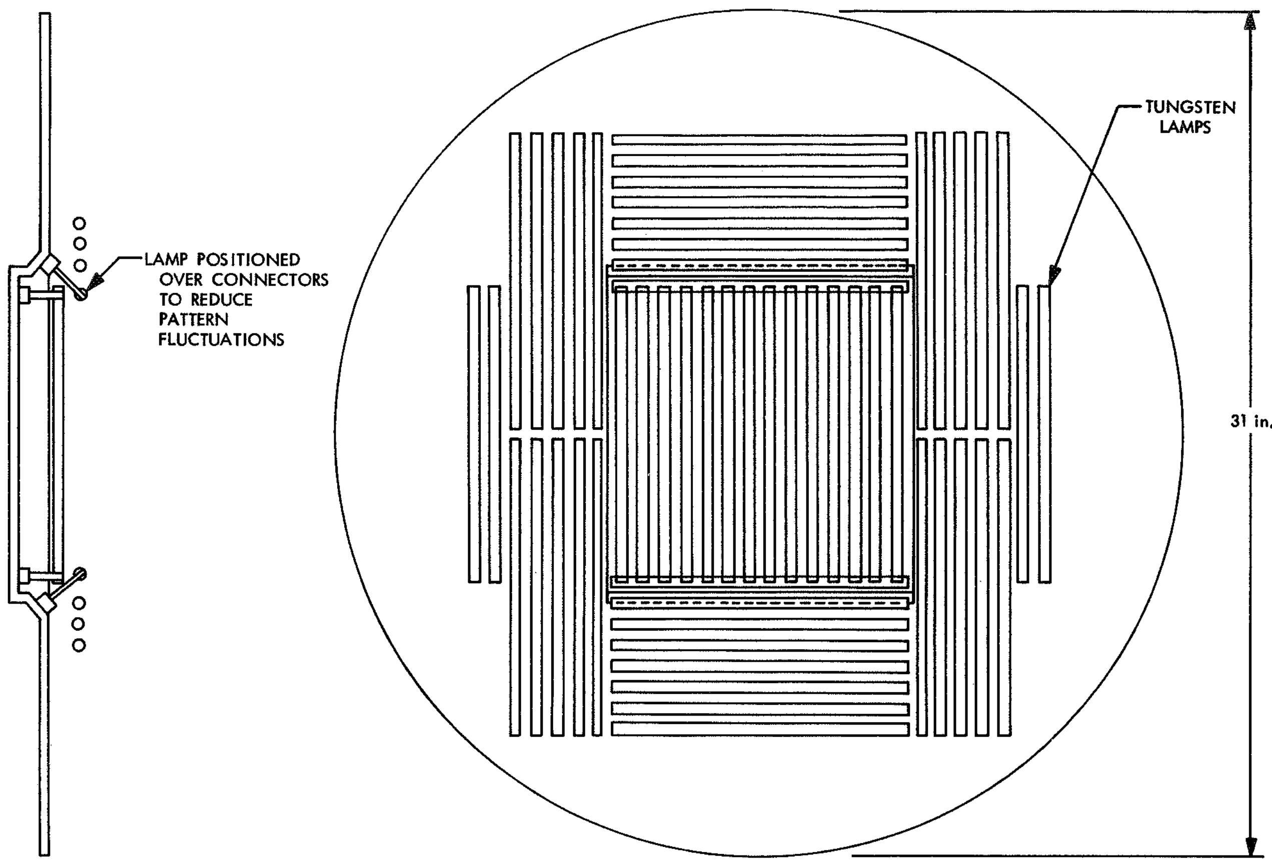

Fig. 6. Lamp bank schematic

V. Calibration Models, Chamber Instrumentation, and Test Samples

A photograph of the 1/4-in.-thick aluminum plate used as a heating rate calibration model is shown in Fig. 7 with the calorimeters attached in place. A schematic of the instrumentation set up for this heating rate calibration model is shown in Fig. 8. Calorimeters are positioned to provide a reasonable measure of the distribution of energy over the test curvature. Care is taken to provide the calibration model with the same absorptance as the test samples. Calorimeters outside the sample holder are brought within the cylinder through grommet seals, since a perfect seal between chambers is not necessary.

Chamber instrumentation includes pressure histories in the test area and temperature monitoring at critical locations in the heating and cooling systems. The pressure gage locations are shown in Fig. 3. Thermocouple and ion gages are used. Temperatures are monitored with chromel-alumel thermocouples at each of the positions identified by TC in Fig. 4.

The small developmental aeroshells used as test models are shown schematically in Fig. 9. The 2-ft aeroshell is a phenolic fiberglass honeycomb sandwich composite with a silicone elastomer-based heat shield as described in Ref. 4. A photograph of the partially instrumented aeroshell is shown in Figs. 10a and 10b. Each aeroshell is instrumented with strain gages on each face of the sandwich structure in the spherical nose and on each side of the reinforced support location. A schematic of the aeroshell instrumentation is shown in Fig. 11. Each strain gage is a 90-deg rosette with measurements along the hoop and radial direction. At most locations, 3 rosettes are positioned 120 deg apart on the aeroshell. Thermocouples are mounted near the strain gages to monitor temperature history and back feed information to the heater system to ensure proper temperature control. The small 2-ft aeroshells have the advantage of low cost, while providing adequate representation of fabrication techniques on larger specimens and a minimization of the importance of lateral effects during the ablation performance test.

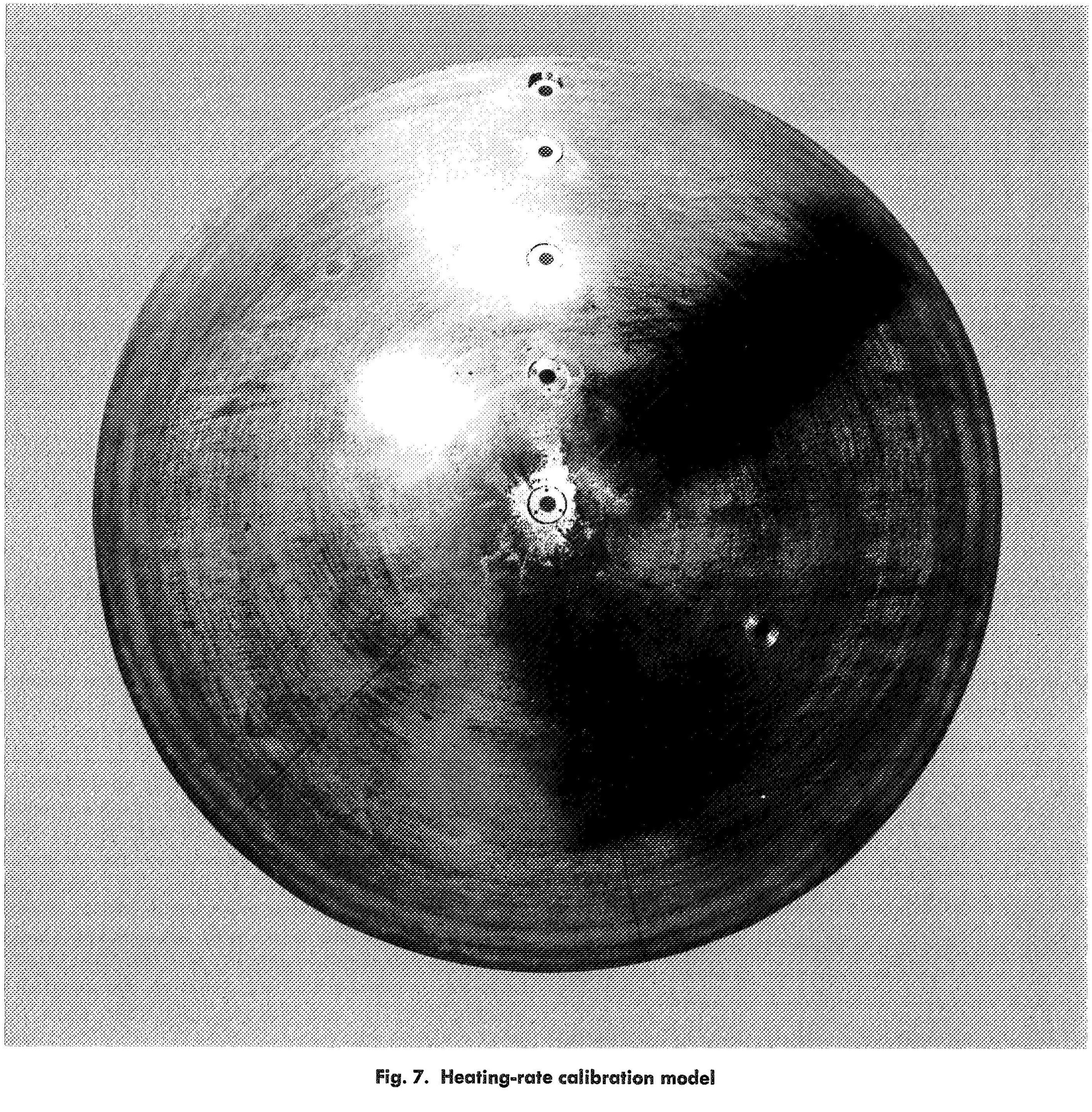

Fig. 7. Heating-rate calibration model

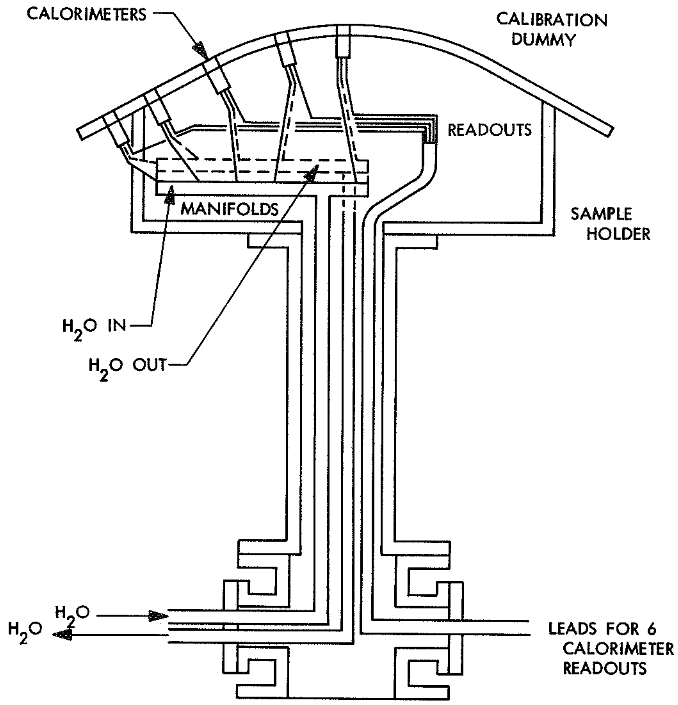

Fig. 8. Schematic of heating-rate calibration model instrumentation

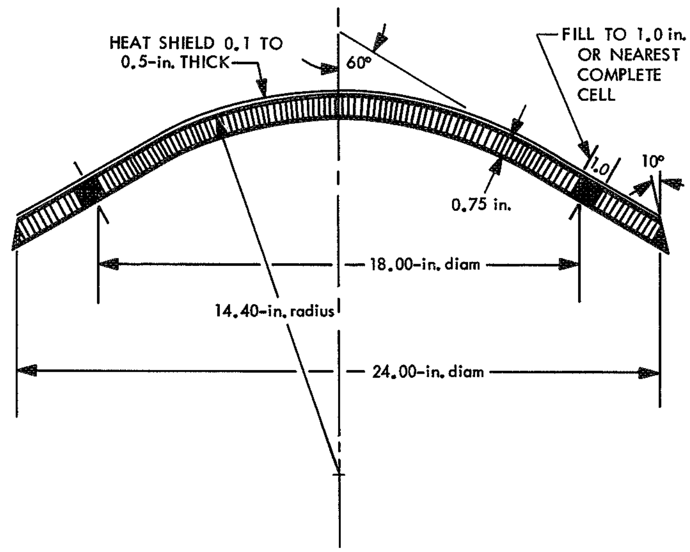

Fig. 9. Small developmental aeroshells

VI. Conclusions

A facility has been designed and partly assembled which is capable of simulating most of the critical environments seen by an extraterrestrial entry capsule on a Mars mission. The environments simulated include chemical surface decontamination, dry heat sterilization, launch pumpdown, transit vacuum, and entry heating and pressure pulses. This particular facility accommodates aeroshell models 2 ft in diameter, but, for Mars simulation, facilities are possible with sample sizes as large as our capability to build tanks and evacuate them. Reference 5 provides a description of a Mars entry simulation facility, related to this facility, but suitable for aeroshell samples up to 9 ft in diameter.

This facility was meant only to show feasibility and to provide comparative information on alternative structural concepts for inexpensive material screening. Some improvement in instrumentation and calibration is necessary if it is to be used in conjunction with a specific mission. For such a use, confirmation of the need for the ETO cycle is desirable as well as a re-evaluation of the cost and feasibility of adding a vibration shaker to the total system. Although the particular system described in this report has not been specifically demonstrated by operation at this time, it is considered feasible and desirable for any Mars capsule mission.

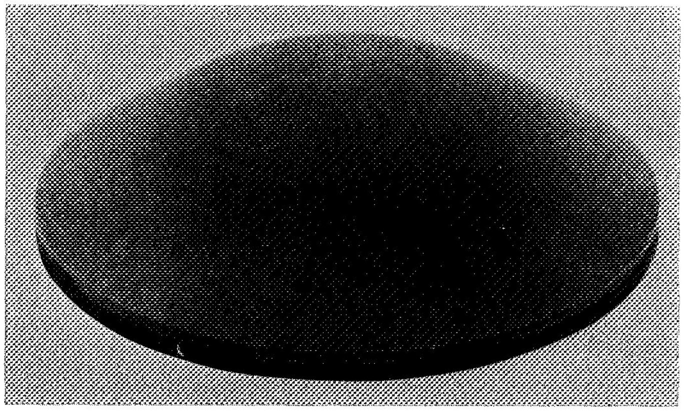

Fig. 10a. Partially instrumented aeroshell (top)

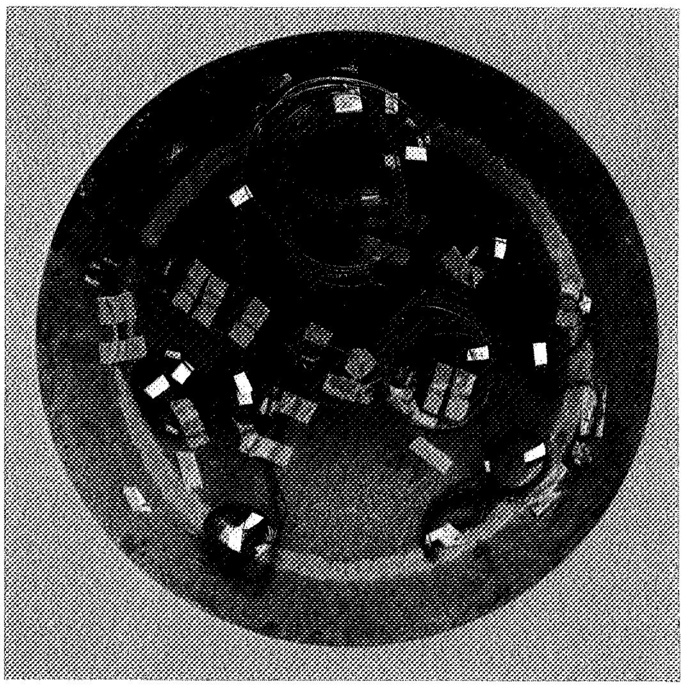

Fig. 10b. Partially instrumented aeroshell (bottom)

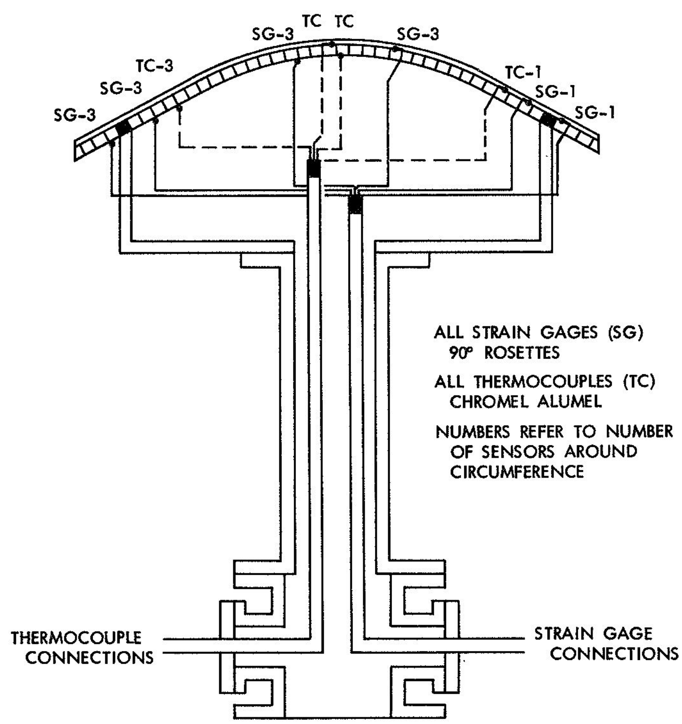

Fig. 11. Schematic of aeroshell instrumentation

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