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Viking Mars Mission Support Investigations in the Langley Transonic Dynamics Tunnel

Jerome T. Foughner, Jr.

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Jerome T. Foughner, Jr.
Langley Research Center
Hampton, Virginia

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SUMMARY

Experiments in various laboratories and wind tunnels were used extensively in support of the Viking mission. One such facility was the Langley Transonic Dynamics Tunnel (TDT). Six different experimental investigations were conducted in the TDT over a 5-year period preceding launch of the spacecraft in 1975. These investigations, which supported elements of the entry and the landed phases of the Viking mission, are described in this paper. The objective of each investigation and selected experimental results are presented. How these wind-tunnel results contributed to spacecraft development and ultimately to the success of the Viking mission is indicated.

INTRODUCTION

The exploration of Mars is part of a general long-term scientific objective of understanding the formation and history of the solar system. The goal of the Viking program is to learn more about the planet Mars through direct measurements in its atmosphere and on its surface. The Viking program, which was initiated in 1969, culminated with the launching of two unmanned spacecraft in 1975, each consisting of an orbiter and a lander, and the touchdown of both landers on the Martian surface in 1976. An account of the Viking scientific investigations and objectives, along with descriptions of the launch vehicle and the spacecraft, is presented in reference 1. Summaries of the Viking lander engineering and science hardware performance during launch, interplanetary cruise, Mars orbit insertion, preseparation, separation through landing, and the primary landed mission are given in reference 2. Scientific results of the Viking program are summarized in reference 3.

Experimental investigations conducted in various laboratories and wind tunnels were used extensively to support Viking program spacecraft development. The purpose of this paper is to summarize six experimental investigations that were conducted in the Langley Transonic Dynamics Tunnel (TDT). The investigations conducted in this facility during the October 1970 to July 1975 time period supported elements of both the entry and landed phases of the Viking mission. Experimental investigations applicable to the entry phase of the mission included a determination of parachute environment and performance, aerodynamic characteristics exhibited by two separating bodies, and transonic pressure measurements to optimize the location and orientation on the lander of the entry stagnation pressure sensor. The experimental investigations applicable to the landed phase of the mission included a convective heat-transfer test to establish wind-shield requirements for radioisotope thermoelectric generators (RTG) and two investigations (1970 and 1975) which supported the development and calibration of the meteorological science experiment.

WIND TUNNEL

The Langley TDT was designed specifically (ref. 4) for the study of dynamic and aeroelastic problems of high-performance airplanes and space-launch vehicles. The TDT has a 4.9-m square test section with cropped corners and is a single-return, variable pressure, slotted-throat wind tunnel. The cross-sectional area of the test section is 23 m^2. The tunnel is capable of operation at stagnation pressures from 0.1 atm to atmospheric pressure and at Mach numbers up to 1.2 (1 atm = 101.3 kPa). The Mach number, density, or dynamic pressure can be varied independently with either air or freon as the test medium. Features of this facility which made it attractive for use in the Viking tests described herein are the large test section, low-density capability, transonic speed range, and a remotely operated turntable.

SUPPORT INVESTIGATIONS

The Viking flight plan consists of five major phases of operation: launch, cruise, orbital, entry, and landed. The experimental TDT studies summarized herein supported the entry and landed phases of operation.

The Viking mission sequence from separation to landing is shown schematically in figure 1. As described in reference 1, retrorocket engines on the entry capsule decelerate it out of orbit. As the capsule descends to the surface it is sequentially braked by aerodynamic drag, by a parachute, and finally by retrorocket engines on the lander. Experimental studies applicable to the entry phase of the mission included parachute environment and performance definition, aerodynamic characteristics exhibited by two separating bodies, and pressure measurements in the transonic range to optimize the location and orientation of a stagnation-pressure sensor on the lander.

The landed configuration is illustrated in figure 2. The experimental investigations which supported the landed phase of the mission included a convective heat-transfer test to establish the requirements for wind covers for the radioisotope thermoelectric generators (RTG) and two tests (1970 and 1975) which supported the development and calibration of the meteorological science experiment. These experimental investigations are identified in figure 3. A chronological listing of the experimental investigations is presented in table I.

Entry Phase

Parachute environment and performance (1971).- An aerodynamic decelerator subsystem is required during one phase of the Mars entry trajectory (fig. 1). The subsystem consists of a main parachute (disk-gap-band canopy) assembly trailing in the entry capsule wake. Initial wind-tunnel studies were conducted in the Arnold Engineering Development Center Propulsion Wind Tunnel (16T) facility (AEDC PWT 16T) to obtain drag performance of 10-percent-scale model parachute assemblies trailing in the entry capsule wake. Unexpected results were obtained at a Mach number of 0.6 and the tests were terminated due to severe parachute suspension-line vibration and canopy oscillation, drag-coefficient degradations, and several parachute suspension-line failures. After the suspension-line confluence end arrangement was modified to eliminate the failures, transonic tests were initiated in the Langley TDT.

A photograph of the disk-gap-band parachute model is shown in the lower right-hand portion of figure 3. The three objectives of the TDT tests were: first, to verify the AEDC PWT 16T test results; second, to validate parachute design changes; and third, to obtain additional transonic parachute performance data in the entry capsule wake environment. These goals were accomplished in that large drag reductions experienced by the original configuration were verified, the design changes produced considerable improvement in system performance, and the new configuration did not fail, although failure of some of the test-peculiar hardware (swivel and fabric riser) did occur. Typical results, presented in figure 4, show the effect on parachute drag of canopy trailing distance behind the entry capsule. The measured values of drag for the initial-design trailing distance ($x/d = 6.12$) are considerably less than the design or required value of drag (indicated by the dashed line in fig. 4) throughout the transonic Mach number range. Based on the experimental data obtained, the Viking parachute subsystem design was modified to provide longer suspension lines and thus a greater canopy trailing distance. Undesirable parachute dynamic motion was also reduced by this increase in canopy trailing distance. A chronological development of the Viking parachute configuration by wind-tunnel investigation over the range of Mach number from 0.2 to 2.6 is presented in reference 5.

Aerodynamic characteristics experienced by two separating bodies during aeroshell jettison (1972).- While decelerating from slightly supersonic speeds, the aeroshell is jettisoned from the lander/base-cover configuration (fig. 1). To determine that aeroshell staging could be successfully accomplished, and to establish spring-force requirements for the separation system, it was necessary to perform trajectory analysis to define the relative motion of the two separating bodies. Because the forces and moments experienced by the two separating bodies were needed for input to the analysis, wind-tunnel tests were conducted. Six component forces and moments were measured on the aeroshell and three components on the lander/base cover. The 10-percent-scale wind-tunnel models used are shown in the lower left portion of figure 3.

Results of the wind-tunnel tests are shown in figure 5 in the form of drag coefficient as a function of separation distance between the aeroshell and the lander/base cover. Data are presented for Mach numbers of 0.55 and 0.95. The effect of the lander/base cover on aeroshell drag extends to a separation distance of about 3 diameters at Mach = 0.55 and about 6 diameters at Mach = 0.95. In general, aeroshell drag increases initially, then as the distance between the two bodies is increased, the aeroshell drag gradually approaches the values measured under free-flow conditions. The shielding effect of the aeroshell on the lander/base cover extends to a separation distance of about 6.5 diameters at Mach = 0.55 and 9 diameters (extrapolated) at Mach = 0.95. In general, the lander/base-cover drag is essentially zero up to 1 diameter separation distance and has negative values at separation distances from 1 to 4 diameters depending on the Mach number. As the distance between the two bodies increases the lander/base-cover drag gradually approaches the values measured under free-flow conditions. The experimental aerodynamic characteristics of the lander capsule during aeroshell staging as measured in the Langley TDT were incorporated into the trajectory analyses and contributed significantly to the design of the successful separation of the aeroshell.

Transonic pressure measurements on the lander/base cover (1971).- One scientific objective of the Viking Program was to determine characteristics of the Martian atmosphere, including the variation of ambient pressure with altitude through the parachute phase of the entry (fig. 1).

Because the pressure field on and in the vicinity of the descending lander is affected by its passage through the atmospheric gases, wind-tunnel tests were conducted to determine the optimum location and orientation of a sensor to measure stagnation pressure. The ambient pressure is determined from the stagnation pressure after corrections are made for dynamic pressure and temperature effects as discussed in reference 6. The 19-percent-scale model, shown in the upper right portion of figure 3, was used in the wind-tunnel tests. This model was sting-supported and instrumented to measure static, stagnation, and fluctuating pressures at various locations. The model was tested at tunnel conditions simulating the median Reynolds number expected during parachute descent over the Mach number range from 0.2 to 1.1. Parameters which were varied included model roll angle and model angle of attack. Stagnation-pressure measurements were made using Kiel probes at various locations on the model. The advantage of Kiel probes compared with other total-pressure probes is insensitivity to direction of flow. Kiel probes are described in reference 7. Probes 1 to 6 were mounted on the bottom surface of the model lander, and probes 7 to 9 were mounted on the lander footpads as shown in figure 6. The location of probe 5 appeared to be the best because the results of the total-pressure ratio were nearly invariant as a function of angle of attack and combined pitch-roll attitude. Minor pressure-ratio variations were noted at a model roll angle of 135° and an angle-of-attack range of -7° to -15°. The variation was almost entirely eliminated by orienting the probe centerline at an inclination angle of 22.5° with respect to the bottom surface of the model lander. Accordingly, this location and skewed attitude were recommended for the Kiel probe.

As a result of lander geometric constraints and subsystem interferences, the originally recommended sensor location could not be used and alternate locations had to be evaluated. The final location of the Kiel probe was in the vicinity of footpad 2 or in the approximate location of model-test probe 6 (fig. 6). As shown in figure 1(b) of reference 6, the Kiel probe was oriented at an inclination angle of 22.5° with respect to the bottom surface of the lander. As reported in reference 6, the Viking Entry Science team successfully used this Kiel probe to measure pressures during parachute descent to the Martian surface. In addition, the instrument was used successfully by the meteorology science team to measure pressures after landing on Mars.

Landed Phase

Convective heat-transfer test to establish the requirements for RTG wind shields.- The primary purpose of the Viking radioisotope thermoelectric generators is to furnish electrical power when the lander is on the surface of Mars. A secondary purpose is to supply heat to the instrumentation housed inside the lander. Heat is needed for the lander because at night the atmospheric temperature on Mars (ref. 1) may drop as low as -120° C. When the lander is on Mars, heat is lost to the environment by radiation and convection. One concern was that high-velocity surface winds could make forced convection the dominant form of heat loss and could result in a depletion of the heat required for system survival. The purpose of the model scale tests was to measure the forced-convection heat transfer on the simulated RTG's with and without wind shields. Two different wind shields (partially enclosing the RTG's) were tested. The 45-percent-scale lander model and thermally simulated RTG's are shown in the center portion of figure 3.

Forced-convection heat-transfer coefficients measured in air are presented as a function of wind speed in figure 7 for an unshielded RTG and for the two different wind-shield configurations. Test results presented in figure 7 have been adjusted to Mars conditions. Also shown in figure 7 are the maximum allowable convective heat-transfer coefficients as defined by the Viking prime contractor, which will insure adequate heat for the lander system and instrumentation. Test results (fig. 7) indicate only slight reduction in RTG heat-transfer coefficients. Thus, an acceptable solution to the RTG convective cooling problem was not obtained for the simple wind shields used in this investigation. As seen in figure 2 and discussed in reference 1, the final solution to the RTG convective cooling problem was to totally enclose each RTG with a wind shield. This shield insured that excess heat from the RTG's would be available for the scientific instruments and would not be dissipated uselessly into the environment.

Flow-field measurements around a Mars lander (1970).- In an early concept of the Viking meteorology investigation, wind and temperature measurements were to be made by sensors located at the end of a boom deployed from the lander. The location and length of this boom were dictated by accuracy requirements. The optimum design of such a boom requires a knowledge of the flow field around the lander. Reynolds number is one of the key parameters for simulating the flow field around the lander. The low density capability and the large test section of the TDT made this facility well suited to simulate the Reynolds numbers expected on Mars with a large-scale geometrically accurate model. Test conditions were chosen that would give Reynolds numbers corresponding to both high and low Martian wind speeds. Two values of Reynolds number, 4400 and 97 600 (based on the length of the top surface of the full-scale lander, 1.59 m), were simulated for these tests. The lower Reynolds number represents essentially the minimum practical operating conditions for the TDT. A 45-percent-scale representation of a proposed lander is shown mounted on a turntable in figure 8. This installation permitted the rotation of the model to simulate changes in wind direction. Wind speed, wind direction, and ambient temperature in the flow field around the model were measured using the remotely operated survey device shown in figure 8. The arrangement of the wind sensors (hot-film anemometers) on the survey probe is shown in figure 9.

The wind-tunnel results (ref. 8) showed that the flow field around the lander was relatively insensitive to Reynolds number variation over the range anticipated on Mars and that the influence of the lander on the flow field decreased rapidly with distance from the lander. Operational characteristics of the hot-film anemometers were determined under simulated Mars surface conditions. The hot-film anemometers were shown to be a viable candidate for use on Mars. The meteorology system instruments on the Viking lander are described in reference 9. Two hot-film anemometers orthogonally oriented in the horizontal plane were used to determine wind speed and direction by measuring the power required to maintain constant overheating with respect to an identical unheated reference sensor.

Meteorology science experiments (1975).- The Viking meteorology experiment was one of nine scientific experiments carried out on the surface of Mars by each of two landers. The objectives of the meteorology experiment were to measure pressure, temperature, wind speed, and wind direction on the Martian surface. The measurement of atmospheric pressure for the meteorology experiment was accomplished by the Kiel probe used during the parachute phase of the mission. As reported by the meteorological science team in reference 9, the meteorology instrument system, including software, was subjected to an extensive test program in the Langley TDT. The test configuration shown in figure 10 included a flight sensor assembly and a meteorology boom assembly. The data from the TDT tests were reduced using the flight software, and the results were compared with facility parameters that were reduced independently. The results of these tests (ref. 9) indicated that the instrument system (including software, but not lander flow-field effects) has an accuracy of about ±10 percent in both wind speed and wind direction.

The meteorology boom was positioned on the lander (utilizing data from the 1970 flow-field survey) to minimize the effects of the lander-induced flow field. The boom is deployed 1.6 m above the surface and 0.61 m from the nearest part of the lander body. The influence of the lander configuration on local meteorological measurements was determined utilizing a 37.5-percent-scale model of the final lander configuration in association with the full-scale meteorology boom as shown in figure 11. Test results showed that the lander effect is about ±10 percent in both wind speed and direction. Meteorology results obtained on Mars for Viking 1 and 2 are summarized in reference 10.

CONCLUDING REMARKS

The experimental investigations summarized herein provided timely and significant technical information required in the development of various flight and scientific systems of the Viking spacecraft. The investigations were conducted in the Langley transonic dynamics wind tunnel over a 5-year period preceding launch of the spacecraft in 1975. The principal wind-tunnel contributions applicable to the entry and to the landed phases of the Viking mission are as follows:

1. Determination of parachute canopy trailing distance required to achieve acceptable performance and reduce dynamic motions which had resulted in test-system failures during earlier tests. Results were obtained by increasing suspension line length/canopy trailing distance.

2. Determination of the forces and moments exhibited by two separating bodies during aeroshell separations. These results were the primary inputs in the design of the aeroshell separation system and sequences.

3. Determination of the optimum location and orientation of a sensor on the lander, known as a Kiel probe, to accurately measure the variation of stagnation pressure with altitude during the parachute phase of entry. This sensor was also used successfully to measure pressures during the landed portion of the mission.

4. Confirmation of the need for radioisotope thermoelectric generator (RTG) wind shields. Forced-convection heat-transfer coefficients measured on the simulated RTG's without wind shields and with two different wind shields partially enclosing the RTG's were shown to be too high. Subsequent design activity produced an encapsulating shroud wind shield.

5. Determination of the flow field around an early lander model and its relative insensitivity to Reynolds number variation over the range anticipated on Mars. The study showed that the influence of the model on the flow field decreased rapidly with distance from the model. Hot-film anemometers used in the wind-tunnel investigation were shown to be suitable for use on Mars.

6. Verification of meteorology instrument-system performance including software.

Langley Research Center
National Aeronautics and Space Administration
Hampton, VA 23665
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TABLE I.- VIKING EXPERIMENTAL INVESTIGATIONS IN THE

LANGLEY TRANSONIC DYNAMICS TUNNEL

- Flow-field measurements around a Mars lander - meteorology system development (1970)
- Convective heat-transfer test to establish wind shield requirements for the radioisotope thermoelectric generators (1970)
- Parachute environment and performance (1971)
- Transonic pressure measurements on lander/base cover - stagnation pressure sensor optimization (1971)
- Aerodynamic characteristics exhibited by two separating bodies during aeroshell jettison (1972)
- Meteorology science experiments - system calibration (1975)

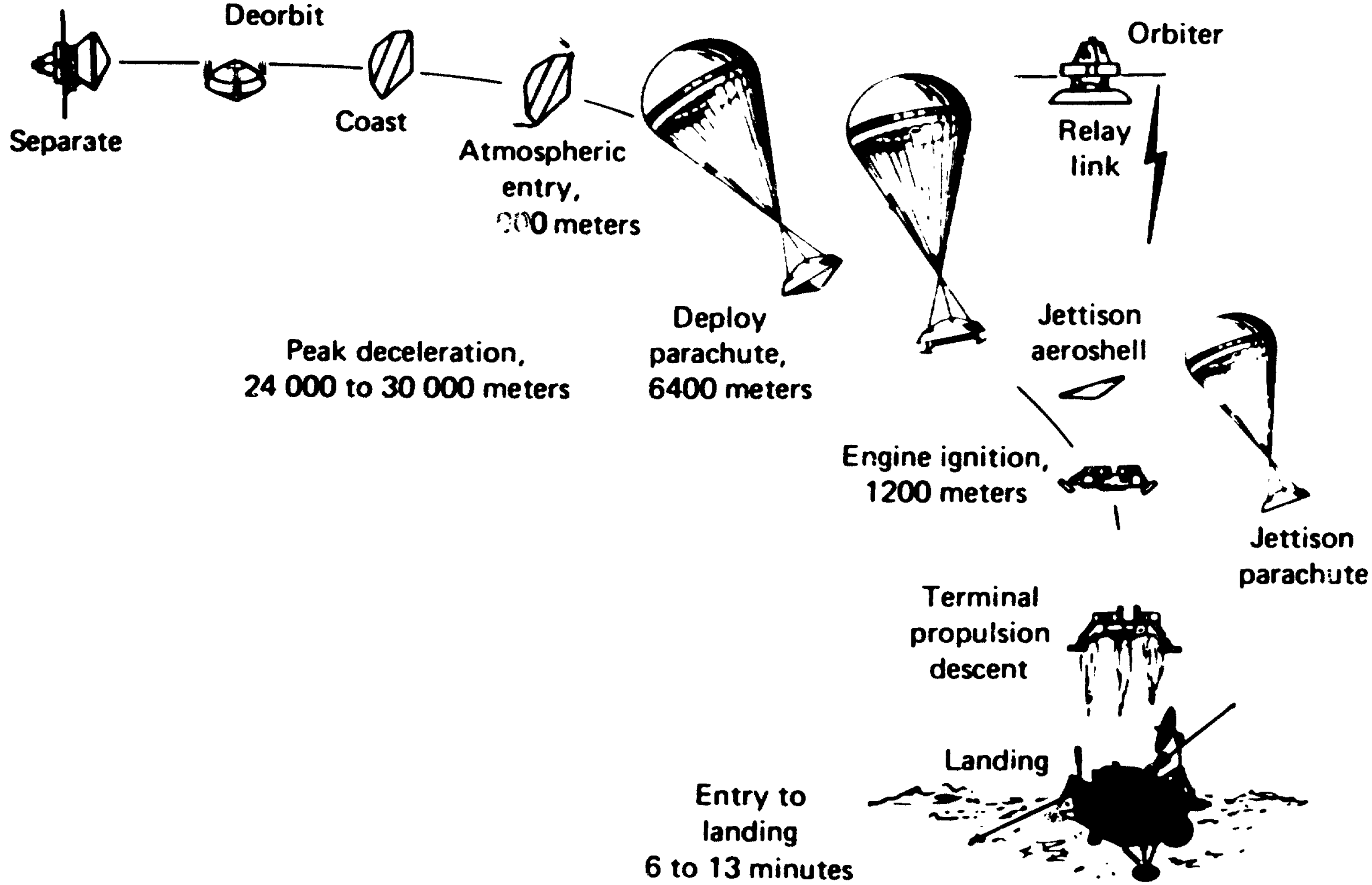

Figure 1.- Viking mission sequence from separation to landing.

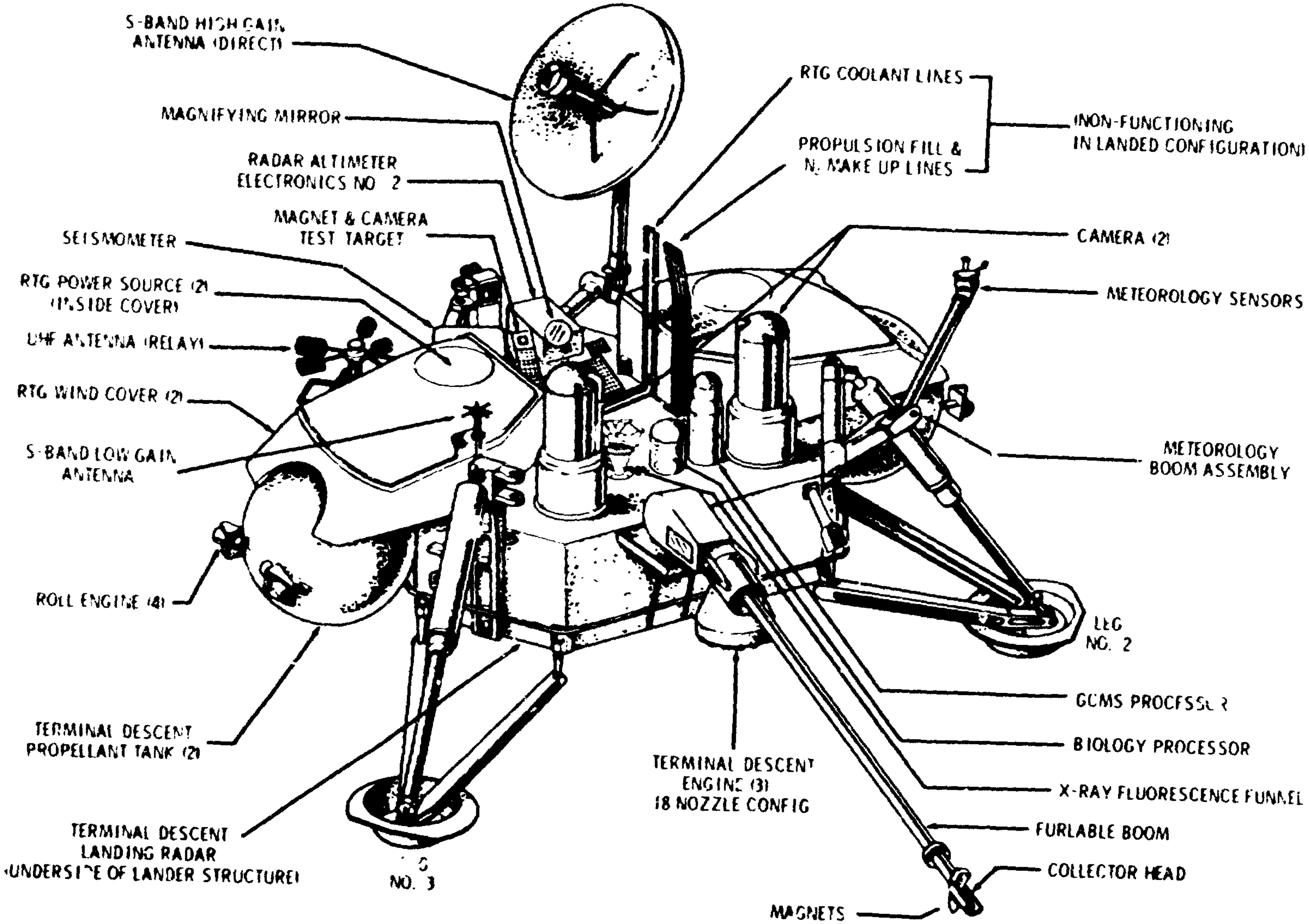

Figure 2.- Viking landed configuration.

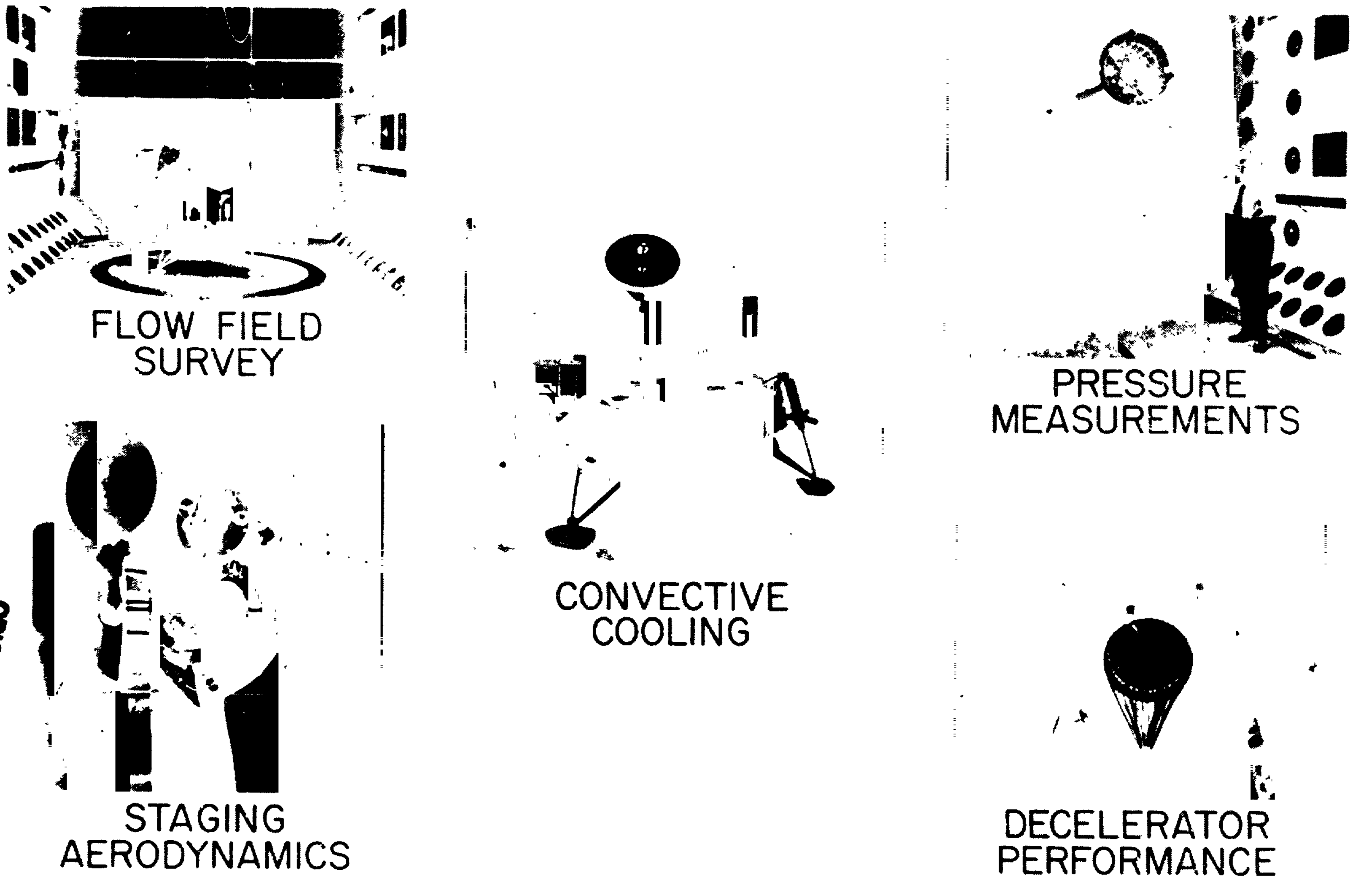

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Figure 3.- Viking experimental investigations in the Langley Transonic Dynamics Tunnel.

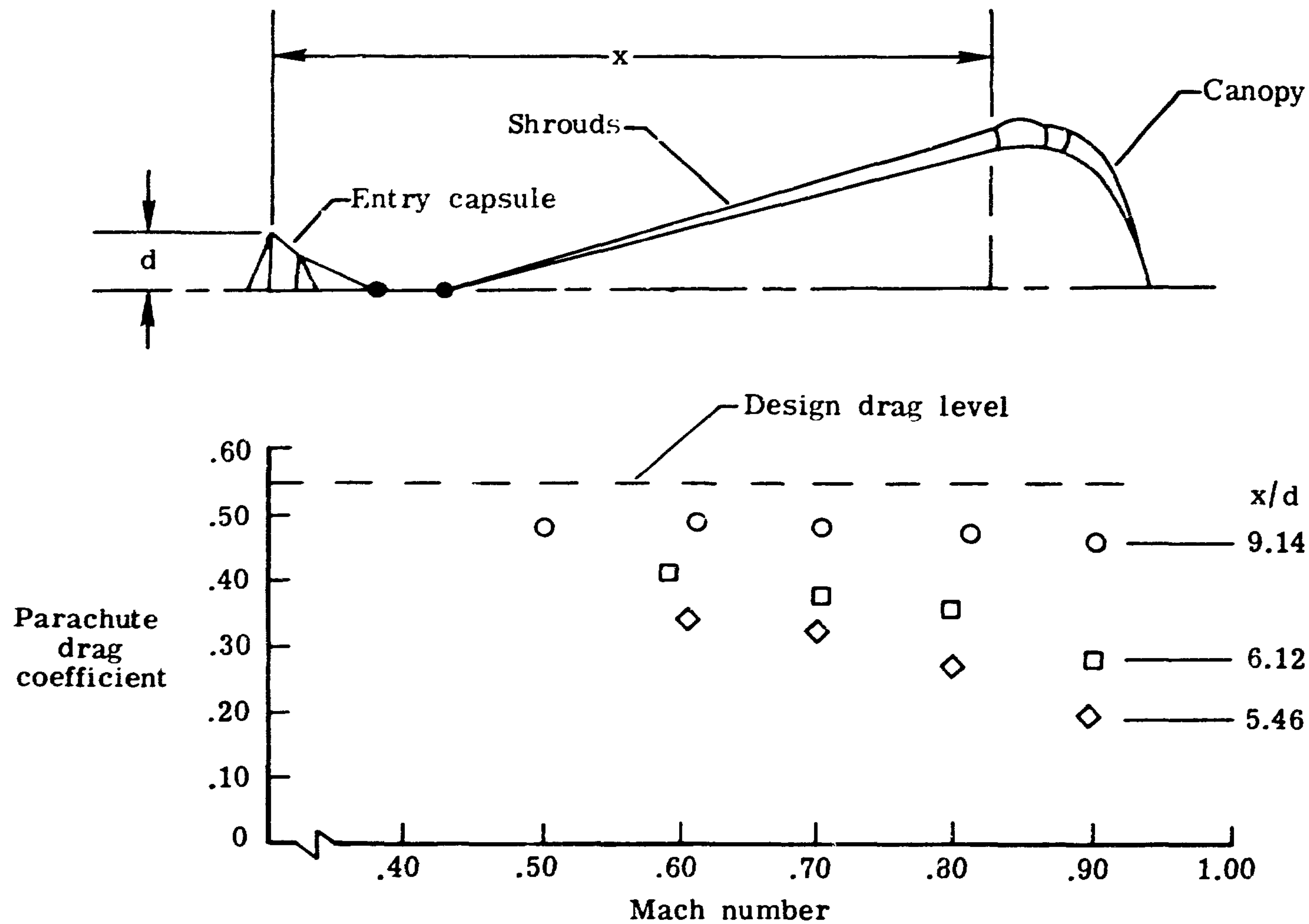
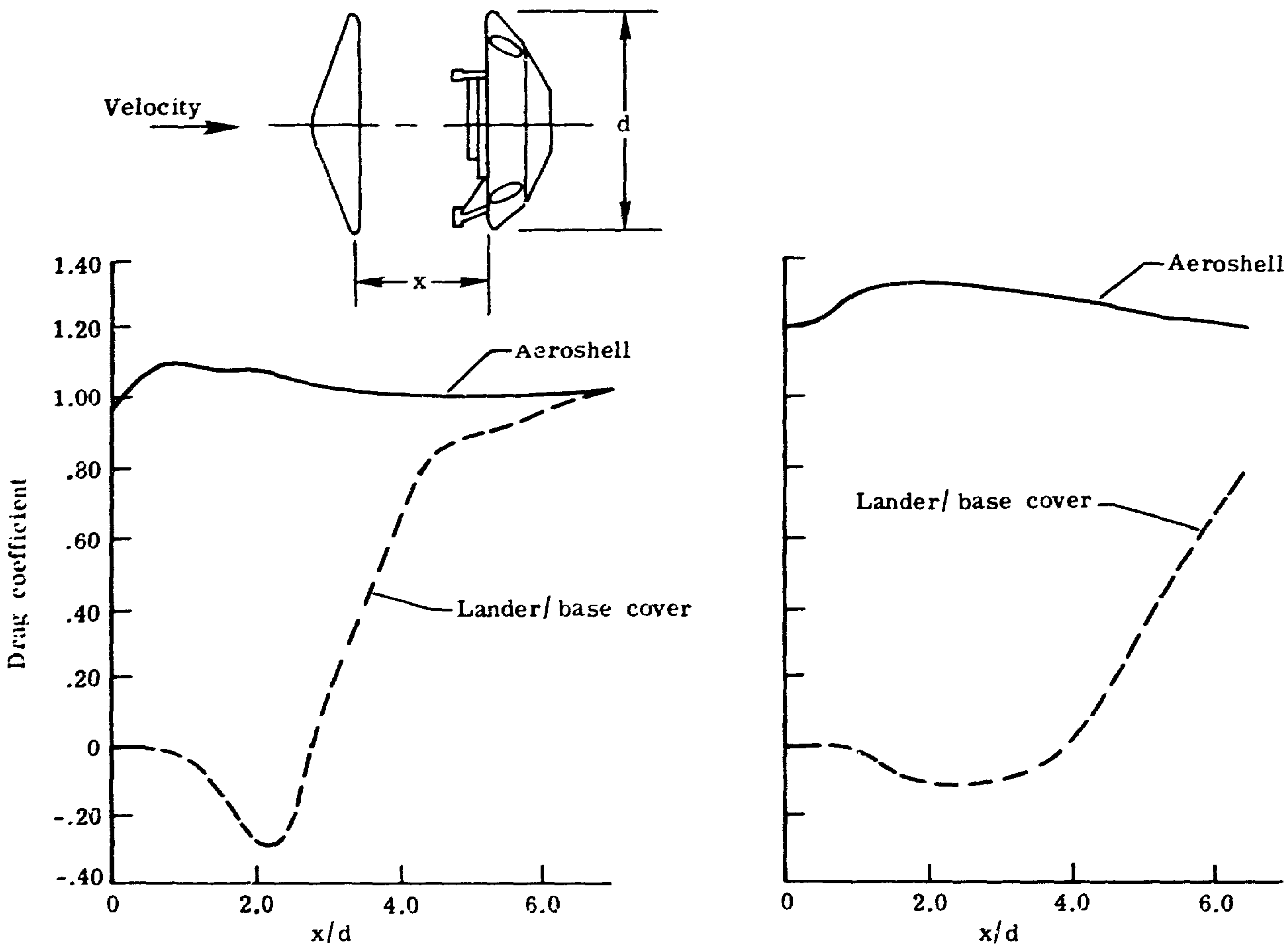


Figure 4.- Viking parachute drag-coefficient variation for several canopy trailing distances behind the entry capsule at a dynamic pressure of 2.87 kPa (x/d = 6.12 initial design value).



(a) Mach = 0.55.

(b) Mach = 0.95.

Figure 5.- Effect of separation distance on drag coefficients - Viking aeroshell and lander/base-cover assembly.

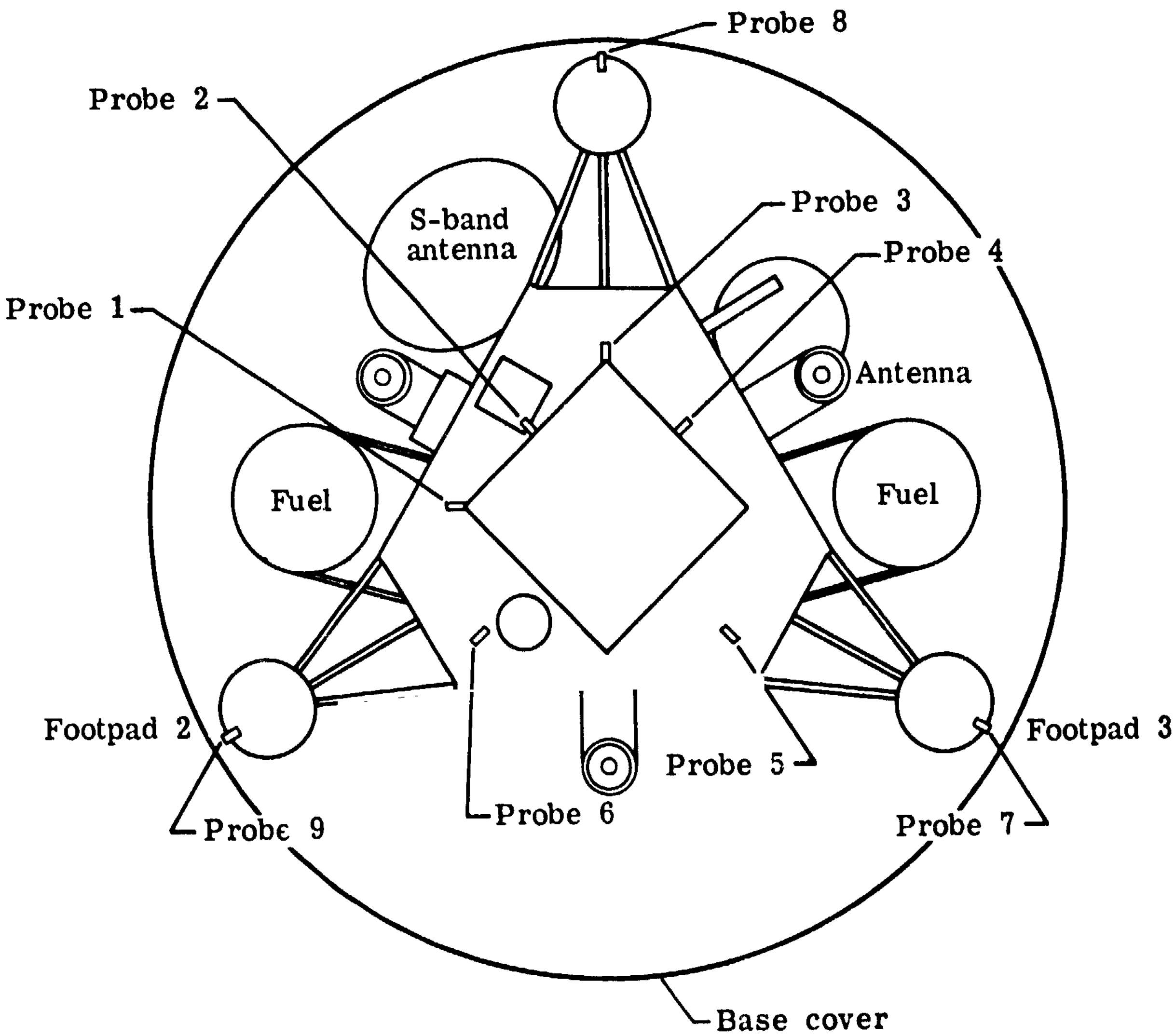


Figure 6.- Location of Kiel pressure probes 1 to 9 on lander/base cover.

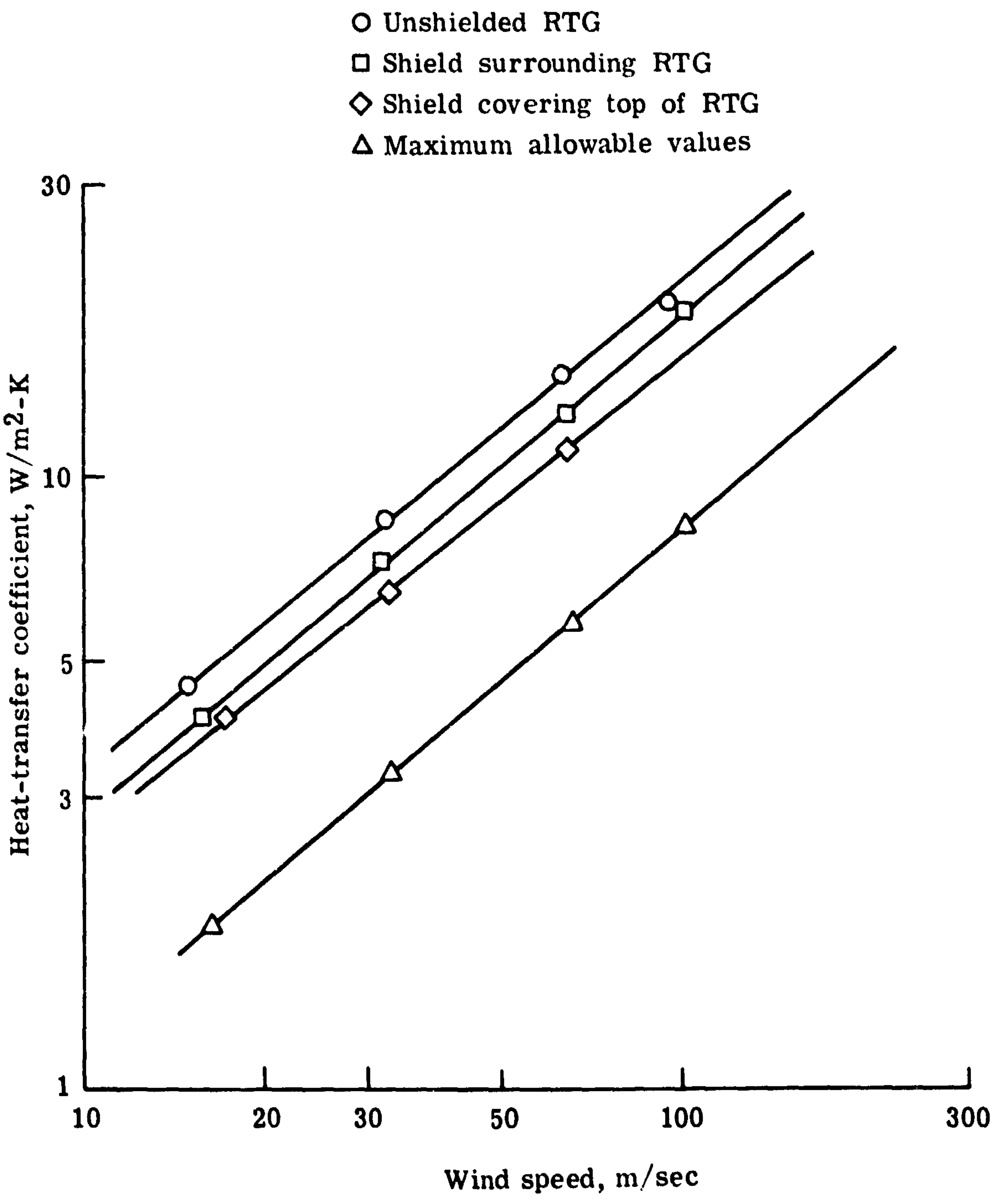


Figure 7.- RTG heat-transfer coefficient as a function of wind speed (adjusted to Mars conditions at 1860 N/m^2).

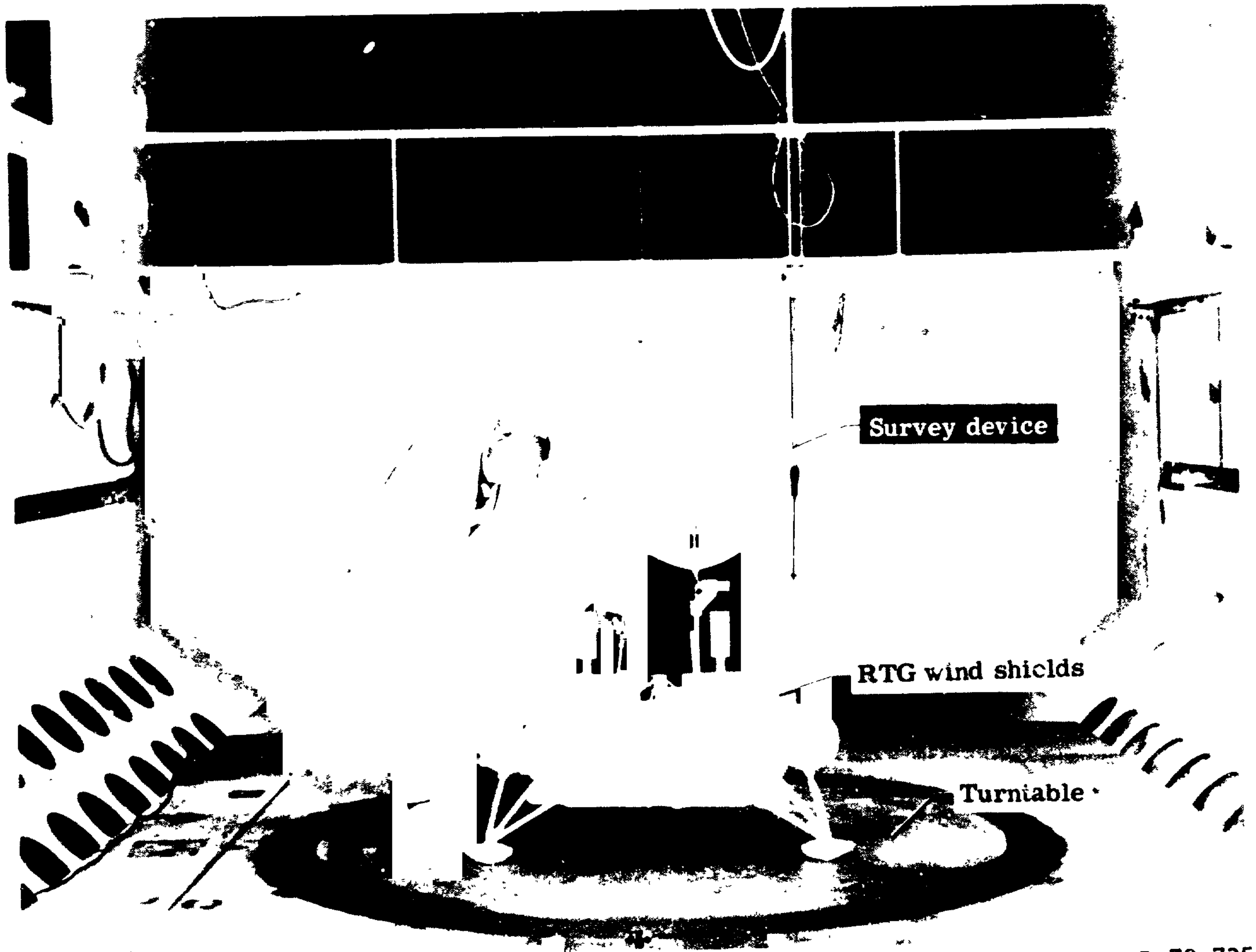


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Figure 8.- Viking 0.45-scale lander model installation - meteorology test.

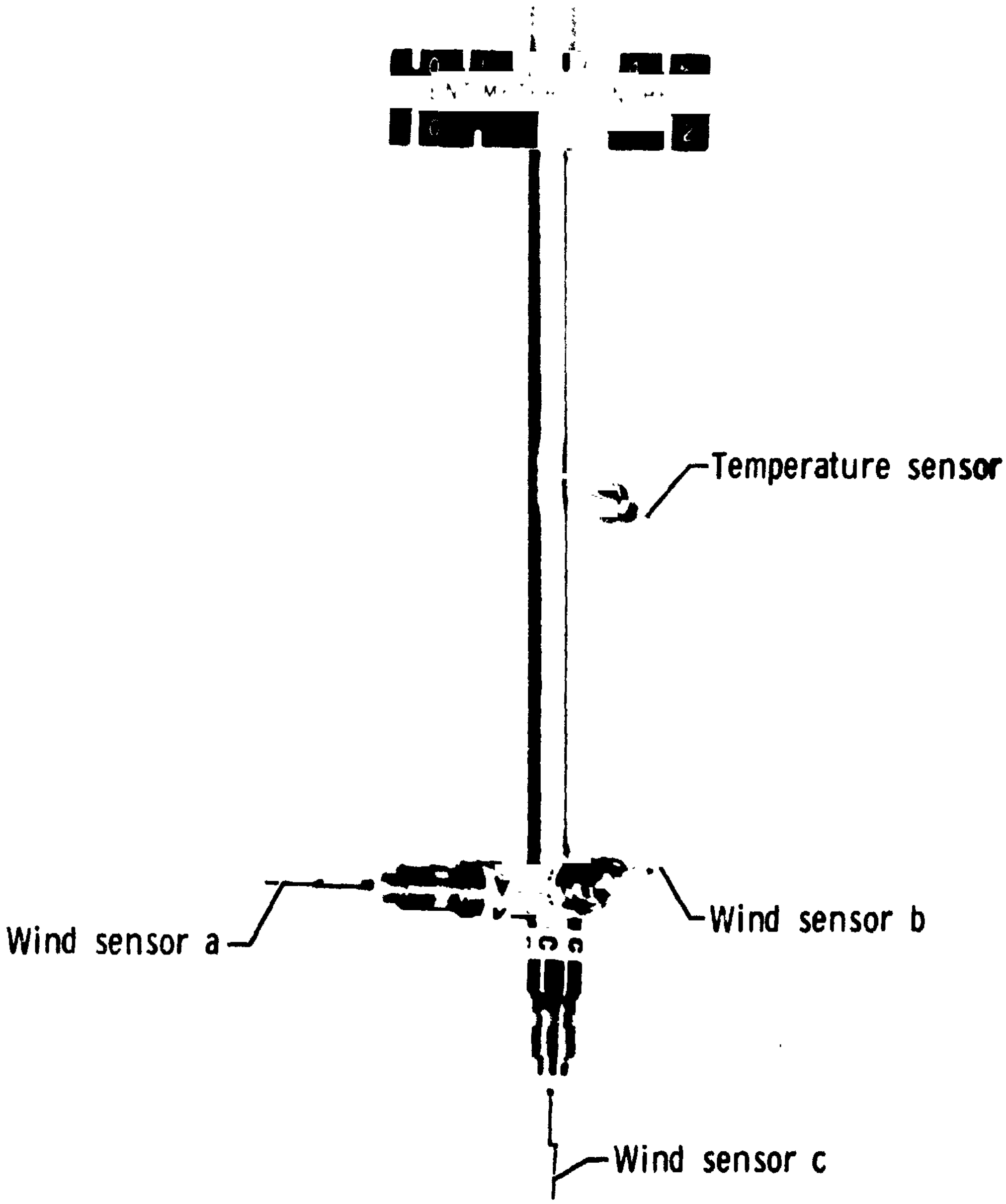

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Figure 9.- Viking meteorology test survey probe with hot-film sensors.

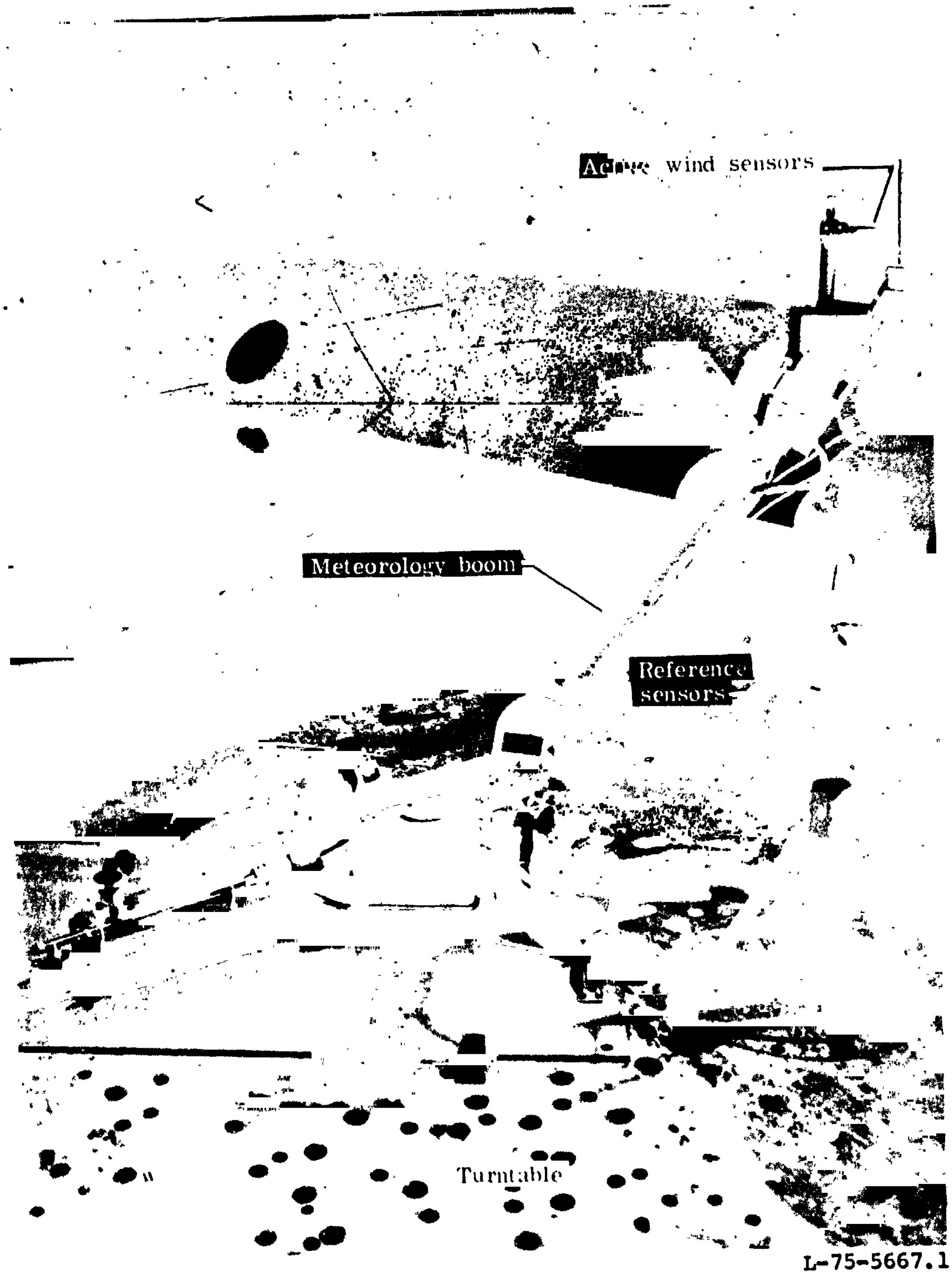

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Figure 10.- Wind-tunnel installation of full-scale Viking meteorology experiment.

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Figure 11.- Wind-tunnel installation of Viking lander model with full-scale meteorology boom.