# A Base Pressure Experiment for Determining the Atmospheric Pressure Profile of Planets

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**An experiment is described which consists of monitoring the base pressure of an entry probe and deriving the freestream pressure profile of a planet through correlation curves which directly relate base pressure to freestream pressure for the varying trajectory conditions. The experiment/technique is applicable for Mars, Venus, and Jupiter entry probes. The base pressure experiment offers distinct advantages to an entry probe mission such as a positive indication of where $M_\infty = 1$ occurs in the entry trajectory, a positive indication of boundary-layer transition onset, and a freestream pressure boundary condition at the $M_\infty = 1.2$ trajectory point independent of any other onboard or offboard measurements. The results of a recent slender cone $R/V$ flight test have demonstrated the feasibility of the experiment by deriving the atmospheric pressure profile of Earth from base pressure measurements. Available flight and ground test base pressure data have been reviewed and an assessment made of which parameters are important to the base flow phenomena, which are well known and which require more investigaton to calibrate the experiment by obtaining additional data.**

## Nomenclature

$A$ = base area
$D_B$ = base diameter
$M_L$ = local Mach number preceding the base
$M_\infty$ = freestream Mach number
$\dot{m}$ = mass addition rate
$\dot{m}/\rho AV$ = mass addition parameter
$P_b$ = base pressure
$P_b/P_\infty$ = base pressure ratio
$P_L$ = local cone pressure preceding the base
$P_\infty$ = freestream pressure
$R_{e_D}$ = freestream Reynolds number based on diameter
$R/V$ = re-entry vehicle
$r_o/R$ = radius ratio on base
$r/R$ = nose to base radius bluntness ratio
$V$ = velocity
$X/L$ = axial station
$\alpha$ = angle of attack
$\phi$ = offset angle on base
$\theta_c$ = cone angle
$\gamma$ = ratio of specific heats
$\rho$ = freestream density

## I. Introduction

IT is of paramount interest to the scientific community to determine the atmospheric structure of the planets of our solar system in keeping with the planetary exploration goals of NASA. One of the more important properties of a planetary atmosphere to be determined is the static pressure profile. Present concepts[1–5] to make atmospheric measurements with entry probes include the use of an onboard accelerometer during the high speed (hypersonic) portion of the flight to derive the freestream density from which the freestream pressure is computed. The accelerometer technique, however, introduces unacceptable errors in the low speed (transonic/subsonic) portion of the flight, consequently stagnation pressure and temperature measurements are utilized to derive the freestream properties in this regime.

The prime purpose of the present paper is to describe a new simple experiment[6,7] to directly derive the atmospheric pressure profile of a planet from the hypersonic to subsonic flight regimes which could be used as an alternate to, or could complement and provide boundary conditions for the accelerometer technique. The experiment consists of monitoring the base pressure of an entry probe and deriving the static freestream pressure profile of the planet through empirical correlation curves (calibration and correction factor curves) which directly relate base pressure to freestream pressure for the varying trajectory conditions. The base pressure experiment is applicable for either a Mars, Venus, or Jupiter entry probe mission.

The base pressure measurement/technique to determine the atmospheric pressure profile offers distinct advantages for a planetary entry probe mission which would complement other entry science measurements. These are: 1) Base pressure measurements exhibit a sharp slope change at a Mach number of unity. This slope change can be used as a Mach meter for the entry probe and is therefore useful to determine when $M_\infty = 1$ occurs for trajectory reconstruction analysis. 2) Base pressure measurements can be used to define the boundary-layer state and provide a definite indication of transition onset. 3) Base pressure ratio is relatively independent ($P_b/P_\infty \approx 0.55$) of trajectory conditions ($R_{e_D} \approx 10^5$ to $10^7$) in the low supersonic velocity regime ($M_\infty \approx 1.2$). This trajectory point can provide a boundary condition on the $P_\infty$ experiment independent of any other onboard or offboard measurements. 4) The base pressure levels are the same order of magnitude as the freestream pressure. 5) No holes are required through the forebody heat shield. 6) Base pressure measurements are less sensitive to Mach number trajectory errors than stagnation pressure measurements. 7) Base pressure characteristics are relatively insensitive to angle-of-attack/vehicle motion for planetary entry configurations. 8) The base pressure measurement requires instrumentation presently available that has been successfully flight tested on current re-entry vehicles.

The base pressure technique also has disadvantages, the primary one being that base pressure is a function of several variables, and no theoretical techniques are available which adequately define the functional relationship of base pressure to freestream pressure. Accordingly, the aerodynamicist must rely on flight and ground test data correlations to define the base pressure characteristics of the probe. Once the base pressure characteristics are known, the only variables left are the trajectory conditions. Trajectory reconstruction analysis will provide these variables ($M$, $R_e$, $\alpha$, $\gamma$), and then the freestream pressure profile of the planet can be derived using the present experiment technique.

The feasibility of the base pressure experiment has been demonstrated on a recent[6] slender cone $R/V$ flight test in which the static freestream pressure profile of Earth was derived solely from the $R/V$ base pressure measurements and a knowledge of the

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base pressure characteristics of slender cones. Base pressure data[3,4,8–15] for blunt planetary entry configurations is very limited, consequently, the base flow characteristics for planetary entry probes are not known with a high degree of confidence. The problem then is to calibrate the base pressure experiment for planetary entry configurations by obtaining additional ground test base pressure data on these bodies. These ground test data can then be correlated to provide a semiempirical technique to define the base pressure characteristics of entry probe configurations at any trajectory condition. The required ground tests are within the current state-of-the-art of existing ground test facilities using free-flight telemetry techniques.

## II. Base Pressure Parameters

Base flow is a complex phenomena, and is a function of many variables. Table 1 defines the variables and illustrates those which must be considered for various planetary missions.

It should be noted that the ground test data of Ref. 16 have shown a dependency of base pressure to temperature. However, the author has never observed a temperature effect in *R/V* flight data, and in addition Refs. 17 and 18 indicate that varying temperature by a factor of two does not affect base pressure. Accordingly, temperature effects have not been considered in the present paper.

The following section will briefly illustrate the effect of the above variables on base pressure. It is generally recognized that the best way to obtain valid interference free base pressure data is with a free-flight model. Accordingly, even though several sets of data may be available to illustrate a trend using sting, strut, or wire supports, free-flight data (full scale *R/V* or free-flight ground data) will be shown, if available, to illustrate the point.

### Configuration Effects

Base pressure is a strong function of forebody configuration in both laminar and turbulent flow.[19–23] Low drag bodies tend to produce low base pressure ratio levels while high drag bodies (typical of planetary entry configurations) tend to produce base pressure ratio levels factors of ≈2 to 5 higher. Afterbody configuration also affects base pressure and can alter the base pressure ratio levels by ≈25%.[24,25] These configuration variables do not enter into the present experiment since once the specific entry probe configuration is chosen, the base pressure characteristics would be obtained for that configuration during the normal ground tests required to define the aerodynamics of the probe.

### Reynolds Number Effects

Base pressure ratio is a strong functon of Reynolds number in laminar flow[26–34] and decreases with increasing Reynolds number. Figure 1 presents typical laminar flow free-flight telemetry base pressure data[10] obtained in the GE LTTF shock tunnel ($M_\infty = 12.6$) on planetary entry configurations which illustrates this trend. However, this Reynolds number trend does not hold in turbulent flow, and it has been shown[21,22,27,28,30,35,36] that base pressure ratio is relatively constant with Reynolds number once a turbulent boundary layer has been established. This is illustrated quite clearly in Fig. 2 which presents base pressure data for a sharp cone ($M_\infty = 4$) in laminar and turbulent flow. Also shown is the classic minimum in the base pressure ratio curve which is a prime indicator of onset of boundary-layer transition. Basically the rate of change of base pressure (in absolute pressure psia) *dp/dt* takes a sharp increase during transition from a laminar to turbulent boundary layer. This manifests itself in a minimum

**Table 1 Base pressure variables**

| | | |
|---|---|---|
| Configuration/heat shield dependent | | |
| Forebody configuration<br>Afterbody configuration<br>Radial location<br>Heat shield material | Constant for any one mission | |
| Trajectory/planet dependent | Mars | Venus/Jupiter |
| Reynolds number | Yes | No |
| Mach number | Yes | Yes |
| Angle of attack | Yes[a] | Yes[a] |
| Mass addition | No | Yes[a] |
| Gas composition ($\gamma$) | Yes | Yes |

[a] Effects may be small or neglected dependent upon experiment initiation altitude.

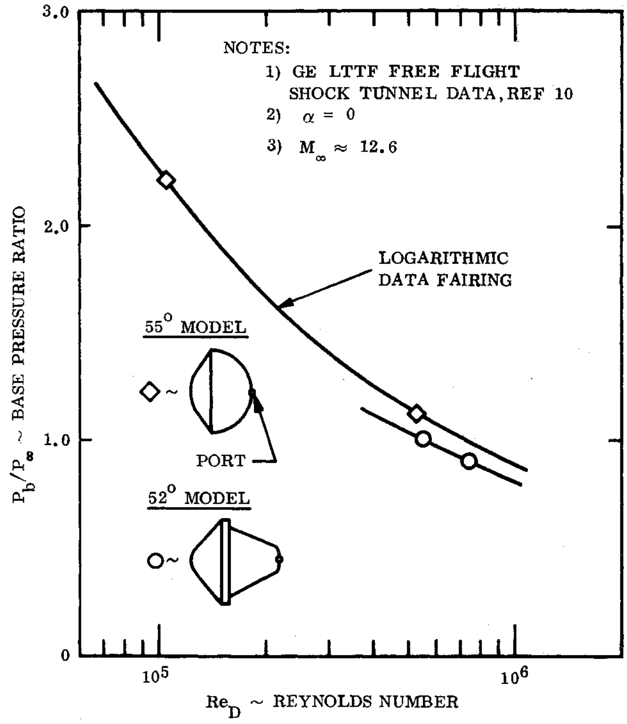
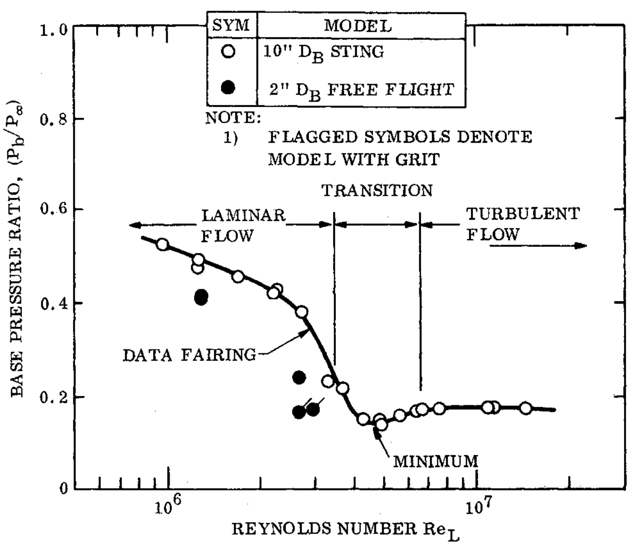



**Fig. 1 Effect of Reynolds number on base pressure ratio in laminar flow.**




NOTES:
1) GE/AEDC TUN A DATA, REF 21
2) $\alpha = 0$
3) MACH NO. = 4
4) 10° SHARP CONE

**Fig. 2 Effect of Reynolds number on base pressure ratio in laminar and turbulent flow showing minimum at transition for sharp cone.**

in the base pressure ratio vs altitude or Reynolds number curve as shown in Fig. 2. This classic minimum shows up on all slender cone *R/V* flight test data, and is one of the prime indicators of transition onset.[37] It is the opinion of the author that this indicator would also be present on blunt planetary entry bodies.

### Radial Gradient Effects

Large radial base pressure gradients are present in laminar flow.[26] The pressure is highest at the center of the base and decreases as the outer edge of the base is approached as shown by the free-flight telemetry data[10] on a typical planetary entry body in Fig. 3. This radial gradient trend is consistent with base flow models which hypothesize that the base centerline represents a rear stagnation point with the flow expanding from this point causing a decreasing pressure away from the center. The magnitude of the gradient is most severe at low Reynolds numbers, and decreases with increasing Reynolds numbers.

The turbulent flow regime is characterized by the absence of radial gradients and a relatively constant pressure over the base, as shown by the full scale flight data[14] of Fig. 4 on a typical planetary entry configuration.

### Mach Number Effects

Base pressure is a strong function of Mach number in both laminar and turbulent flow. Accordingly, the Mach number characteristics are one of the more important parameters to define for a planetary entry probe. The typical variation of base pressure ratio with Mach number in turbulent flow for a planetary entry configuration is presented in Fig. 5. This variation is based on full scale *R/V* flight test data[14] for a blunt 52° sphere cone with a reverse frustum afterbody. It is significant to note that the base pressure varies from a low of 30% to a high of 130% of freestream pressure for the Mach number regime form $M_\infty \approx 0.4$ to 10.5. In addition, the base pressure ratio curve has a minimum at $M_\infty \approx 3$ $(P_b/P_\infty \approx 0.3)$ and then increases with increasing Mach number approaching unity at $M_\infty \approx 10$. Additional flight data (not shown) for the blunt 52° planetary entry configuration suggests that the base pressure ratio approaches $P_b/P_\infty \approx 2.0$ at $M_\infty \approx 20$. The turbulent flow base pressure ratio variation shown in Fig. 5 would be similar for laminar flow, however, the absolute level would be higher. This is illustrated by the sharp cone flight and ground test data[21,22,32] of Fig. 6.

The transonic base pressure flow phenomena is characterized by a sharp slope change at a Mach number of unity $(M_\infty \approx 1)$ as shown by the data[3,4,11,14] of Fig. 7. This slope change can be used as a Mach meter for an entry probe to determine where $M_\infty = 1$ occurs to provide a bench mark for the probe trajectory reconstruction analysis. This discontinuity is a repeatable phenomena that can be utilized as a boundary condition on the entry science measurements and the probe trajectory. For very low subsonic velocities $M_\infty < 0.5$ the base pressure is approximately 90% of $P_\infty$ and approaches 99% of $P_\infty$ for $M_\infty < 0.2$.

The low supersonic velocity regime, $M_\infty \approx 1.2$ (see Fig. 7) has a unique base pressure characteristic in that base pressure ratio appears to be independent of trajectory conditions $(Re_D)$; this trajectory point can be used to provide a boundary condition on the experiment. It has been found that base pressure ratio varies

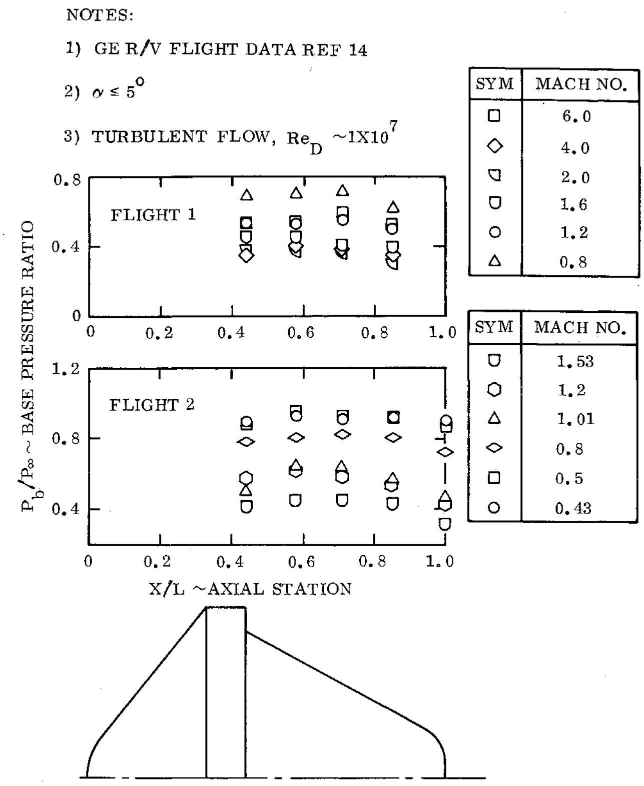



Fig. 4 **Afterbody base pressure ratio distribution in turbulent flow.**

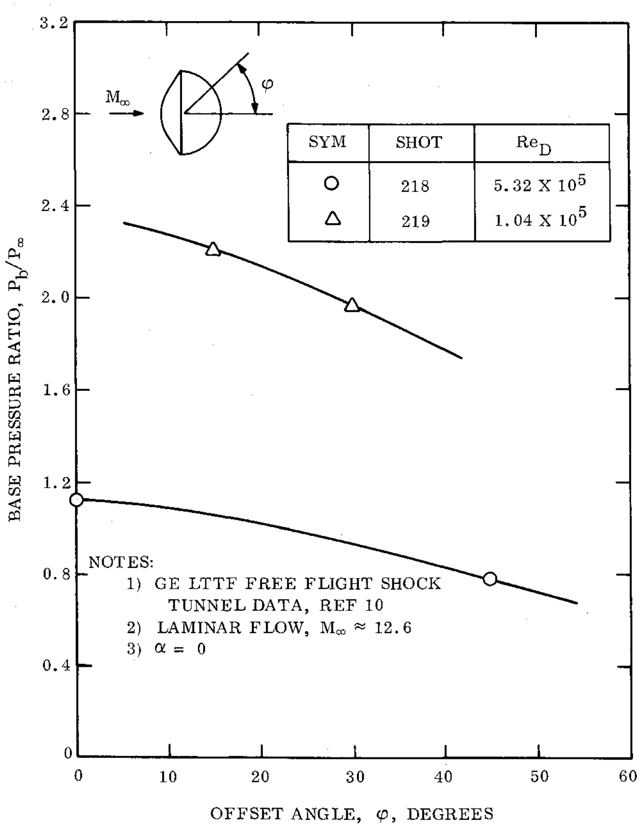



Fig. 3 **Afterbody base pressure ratio distribution in laminar flow.**

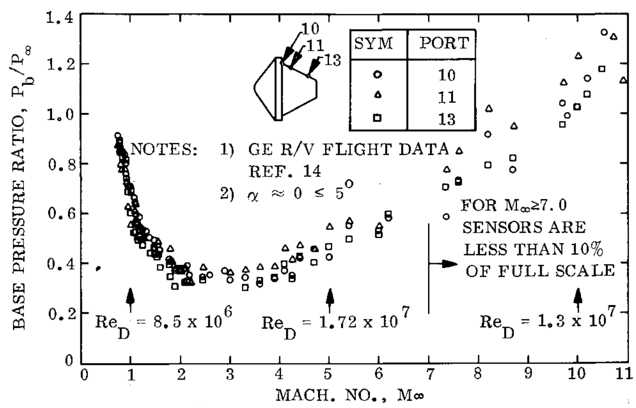



Fig. 5 **Effect of Mach number on base pressure ratio in turbulent flow.**

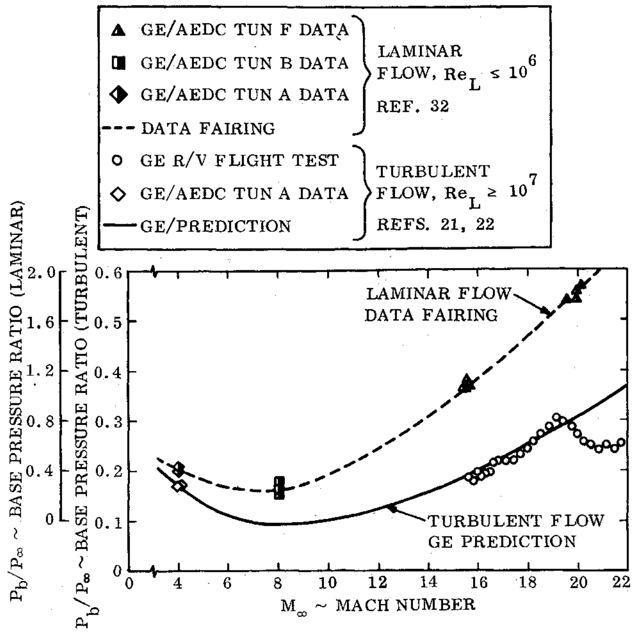



**Fig. 6 Effect of Mach number on base pressure ratio in laminar and turbulent flow for sharp cone.**

between $P_b/P_\infty \approx 0.5$ to 0.6 for order of magnitude changes in Reynolds number. Other Mach number points ($M_\infty \approx 1$) were found to be very sensitive to Reynolds number and Mach number changes. It is therefore, proposed that the $M_\infty \approx 1.2$ velocity regime be utilized to establish a boundary condition for the $P_\infty$ base pressure experiment and other entry science experiments. The $P_\infty$ at this point is easily obtained by knowing the measured base pressure for the probe and the fact that the ratio of base to freestream pressure is approximately 0.55 just prior to $M_\infty = 1$. The $M_\infty = 1$ base pressure slope change would be obvious from the planetary entry probe data. Therefore, the freestream pressure of the planet could be ascertained at this point independent of any other onboard measurement, or offboard tracking or trajectory calculations using only the entry probe base pressure data.

| SYM | DATA SOURCE | REF. |
|---|---|---|
| (hatched) | GE COMPILATION | 11 |
| ○ | GE DROP TEST DATA | 11 |
| ▲ | GE DROP TEST DATA | 11 |
| ▲ | GE R/V FLIGHT TEST | 14 |
| ○ | NASA AMES FLIGHT DATA | 4 |
| △ | NASA AMES FLIGHT DATA | 3 |

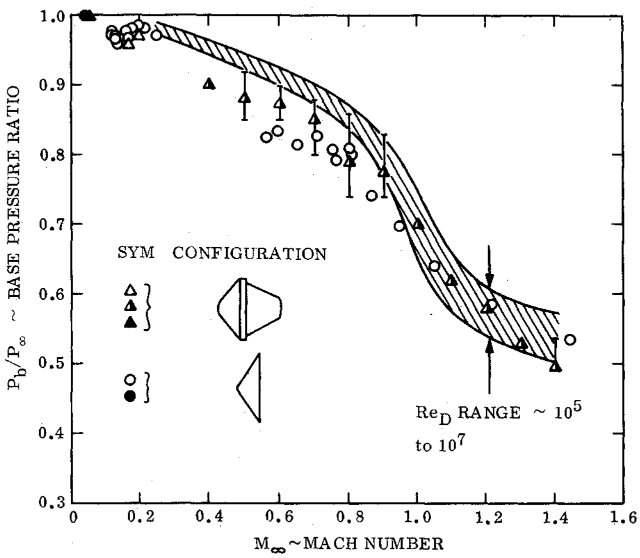



**Figure. 7 Subsonic transonic base pressure ratio data showing slope change at $M_\infty = 1$.**

### Angle of Attack

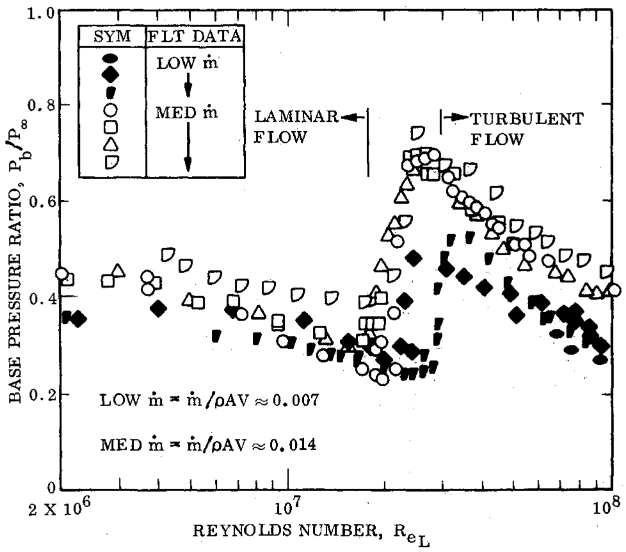
Angle of attack effects on base pressure are not well understood in the author's opinion, and require additional investigation. However limited ground test data do exist[8,38] which indicate that base pressure ratio is relatively invarient to an angle of attack of $\approx 10°$. Since the presently proposed base pressure experiment would be initiated in the re-entry trajectory where the angle of attack would be damped to less than 10°, or would trim at a constant angle of attack, $\alpha$ effects can probably be neglected.

### Mass Addition Effects

Mass addition due to the products of ablation from the heat shield predominately occur in turbulent flow and tends to raise the base pressure[39] as shown by the flight data of Fig. 8. Mass addition effects will not have to be considered for a Mars probe due to the low heating environment, and resultant negligible mass addition rate. However, a Venus or Jupiter probe will experience a high heating environment, resulting in high mass addition rates for $M_\infty > 20$. Mass addition effects of Venus and Jupiter need not be considered if the base pressure experiment is initiated below ~200,000 ft at which time the velocity is low ($M_\infty < 4$) and the $\dot{m}/\rho AV$ rates will be low enough to neglect.

### Gas Composition ($\gamma$) Effects

It has been shown[40] that freestream gas composition ($\gamma$), significantly alters the drag and stability of planetary entry configurations. Ballistic range data from *NOL* have graphically demonstrated through excellent shadowgraphs that both the bow shock wave geometry and the base flowfield and wake region geometry drastically change when tests are conducted in a gas composition of Freon ($CF_4$, $\gamma = 1.17$) compared with conventional air ($\gamma = 1.4$). Typical *NOL* shadowgraphs for two different tests conducted in air ($\gamma = 1.4$) and $CF_4$ ($\gamma = 1.17$) are presented in Fig. 9. Two points are significant: First, the bow shock wave can be seen to be closer to the body, and more nearly approximates a normal shock for the $\gamma = 1.17$ test




NOTES:
1) GE R/V FLIGHT DATA, REF 39
2) SLENDER CONE R/V AT $\alpha \approx 0$
3) OFF CENTER PORT
4) $M_\infty \approx 21$

**Fig. 8 Effect of mass addition on base pressure ratio for slender cone.**

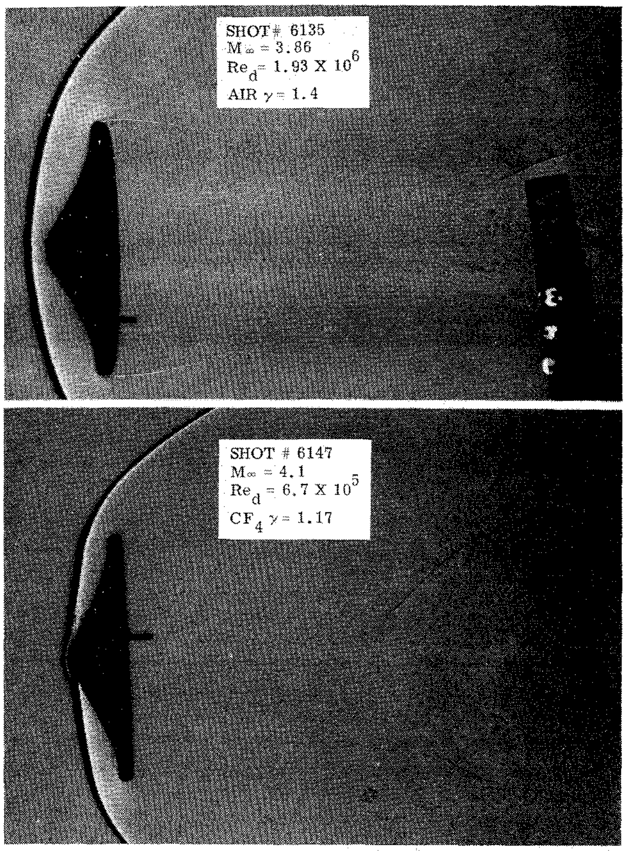



Fig. 9 Effect of gas composition ($\gamma$) on flowfield (NOL data by M. Krumins, Ref. 40).

compared with the $\gamma = 1.4$ test. The closer bow shock wave would tend to produce higher local pressures and lower local Mach numbers on the cone surface for $CF_4$ than air. Both these trends would tend to produce higher base pressure for the $\gamma = 1.17$ case compared with the $\gamma = 1.4$ case. Second, the flow in the base region is different for $CF_4$ ($\gamma = 1.17$) than air ($\gamma = 1.4$). The lip shock[25] and hence the wake expansion angle for the $\gamma = 1.4$ case can be seen to be nearly parallel to the freestream flow. However, for the $\gamma = 1.17$ test, the lip shock and expansion angle are not parallel with the freestream flow and can be seen to expand to higher angles. In addition, the neck of the wake and the trailing shock is closer to the model for the $\gamma = 1.17$ test compared with $\gamma = 1.4$ test. Both of these phenomenon, the higher expansion angle and the shorter wake length for the $\gamma = 1.17$ case would tend to produce a lower base pressure for the $\gamma = 1.17$ case compared to $\gamma = 1.4$ case.

Sufficient information is not available at the present time to say with any degree of certainty, which direction (an increase or decrease) the base pressure ratio would go for a gas composition which approximates the expected $CO_2$ atmospheres of Mars or Venus ($\gamma \approx 1.2$). Accordingly, state-of-the-art ground tests are required to assess the affect of $\gamma$ on base pressure ratio prior to use of the base pressure experiment on a planetary entry probe mission.

## III. Ground Test Requirements and Data Correlations

The previous section has illustrated that the main base pressure variable to be evaluated to calibrate the base pressure experiment is the effect of $\gamma$ (gas composition) on base pressure. The effect of other variables ($M$, $Re$, $\alpha$, $\dot{m}/\rho AV$) are known with sufficient confidence to either neglect the term, or obtain check data points which could be obtained during the $\gamma$ tests or as a part of the normal testing required to define the aerodynamics of the entry probe configuration. The base pressure ground tests

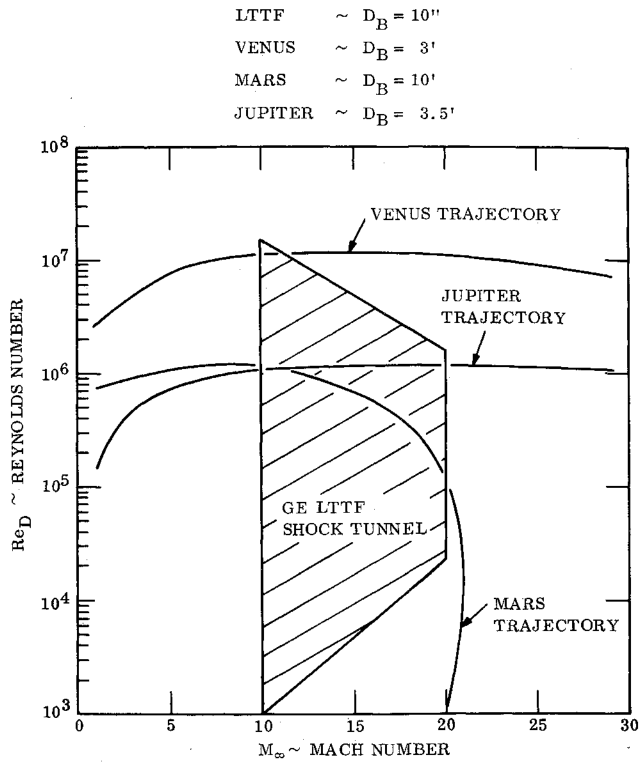



**Fig. 10 Mach-Reynolds number simulation map of shock tunnel.**

should employ the free-flight telemetry technique[10,11,32,41–47] to insure interference free valid data. In addition, ground test facilities should be chosen that have the capability to simulate entry trajectories for Mars, Venus and Jupiter probes. Figure 10 presents the $M_\infty - Re_D$ map of one such typical facility, the GE LTTF shock tunnel, which can simulate planetary entry probe trajectories from $M_\infty \approx 20$ to $M_\infty \approx 10$. Figure 11

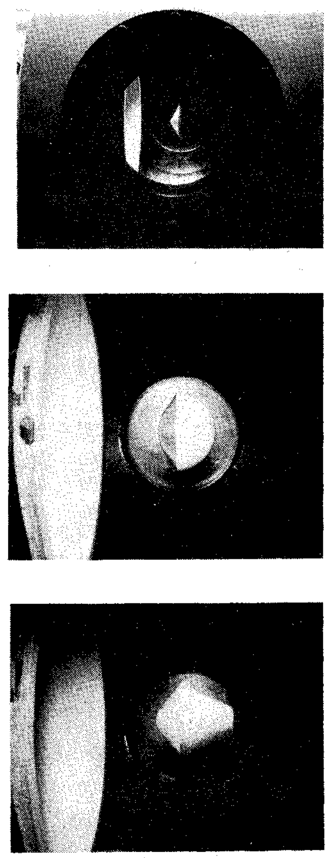


**Fig. 11 Typical planetary entry free-flight models suspended in shock tunnel prior to base pressure tests.**

presents photographs of typical planetary entry models prior to free-flight base pressure tests in the shock tunnel. Obviously, other ground test facilities[48–52] must also be considered to obtain data for lower Mach numbers for basic aerodynamic as well as base pressure tests.

### Data Correlations

Data correlations are valuable tools which can be utilized to assess the validity and trends of measured data, be it flight or ground test data, and to aid in calibrating the base pressure experiment. It would be highly desirable to gather and correlate ground test data, so that data that does not simulate flight conditions can be extrapolated to full scale flight conditions. In addition, it would be desirable to correlate both flight and ground test data to validate ground test simulation techniques.

### Turbulent Flow Correlations

The author has had some degree of success correlating turbulent flow flight and ground test data based on local flow conditions. The original correlation[19] was performed in 1965 using both slender and blunt $R/V$ flight data. The data were found to correlate when the ratio of base to local cone pressure were plotted vs the local Mach number preceding the base. The original correlation is shown in Fig. 12 along with flight and ground test data and the present revised correlation. It is expected that this type of correlation could be accomplished for blunt planetary entry bodies.

### Laminar Flow

Laminar flow correlations are more complex because unlike turbulent flow, radial base pressure gradients exist, and the base pressure level is a strong function of Reynolds number. Several experimenters have proposed various correlation parameters which appear to work in limited areas. However, the author knows of no single correlation parameter which encompass the bulk of the free-flight ground test and full scale $R/V$ flight test data. Indications are that further work is required to derive a correlation parameter which would force the available laminar flight and ground data to collapse to a single curve similar to the turbulent flow correlation of Fig. 12. It is felt very strongly that the ordinate for such a laminar flow correlation would consist solely of $P_b/P_L$, the ratio of base to local cone pressure. It is considered that the abscissa, however, would be a function of the local Mach number, local and/or freestream Reynolds number, base diameter, and boundary-layer thickness to some power (not necessarily the same for each term). The precise form of such a correlation is not known at this time, but requires further work.

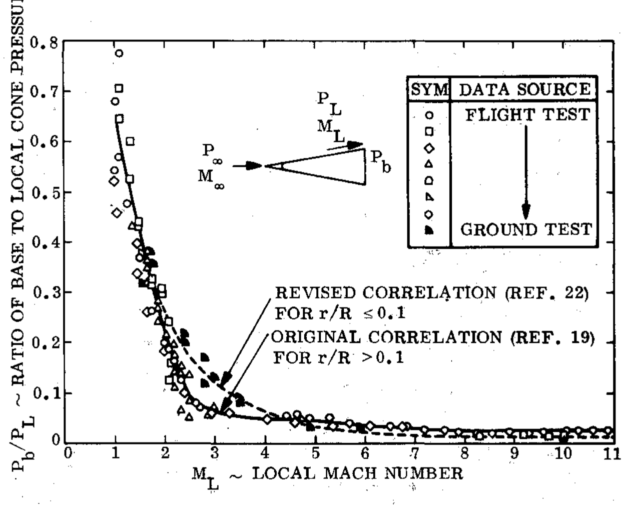



Fig. 12 Turbulent flow base pressure correlation.

## IV. Base Pressure Experiment for Mars, Venus, and Jupiter

It is proposed to initiate the base pressure experiment at an approximate altitude of ≈200,000 ft for all planets. Figure 13 presents typical entry trajectories[53] for Mars, Venus and Jupiter. For the ≈200,000 ft experiment initiation altitude, a Mars entry probe mission will encompass the Mach regime from hypersonic ($M_\infty \approx 20$) to transonic flow, while Venus and Jupiter missions will vary from low supersonic ($M_\infty \approx 4$) to subsonic flow with the probe experiencing $M_\infty < 0.5$ for the major portion of the trajectory (<160,000 ft).

### Mars Mission

Mars has a tenuous atmosphere[54] consequently, the entry probe, in all probability, will have a laminar boundary layer.[55] Accordingly, the base pressure will be a strong function of Reynolds number in addition to Mach number, gas composition, and angle-of-attack effects. Mass addition effects can be neglected for a Mars probe due to the low heating rates. Of the four parameters to be considered for Mars: Reynolds number, Mach number, gas composition ($\gamma$) and angle of attack, the only major unknown is the gas composition ($\gamma$) effect. Sting support ground tests† are presently planned on the Mars Viking program to assess the effect of $\gamma$ on forebody and base pressures. With these test results and the presently available data trends, sufficient information will be available to conduct the base pressure experiment qualitatively. The accuracy of the experiment could be improved quantitatively, however, with free-flight telemetry ground tests.

A block diagram illustrating the experiment for Mars is presented in Fig. 14. The Mach number, Reynolds number, gas composition ($\gamma$) and angle of attack will be known from the trajectory reconstruction analysis and the entry science measurements. With these time dependent parameters known, the calibration curves and correction factors can be entered/applied and the freestream pressure profile derived. The calibration curves and correction factors, of course, are the input required from ground tests and data correlations to relate base pressure to freestream pressure. Note that a feedback loop

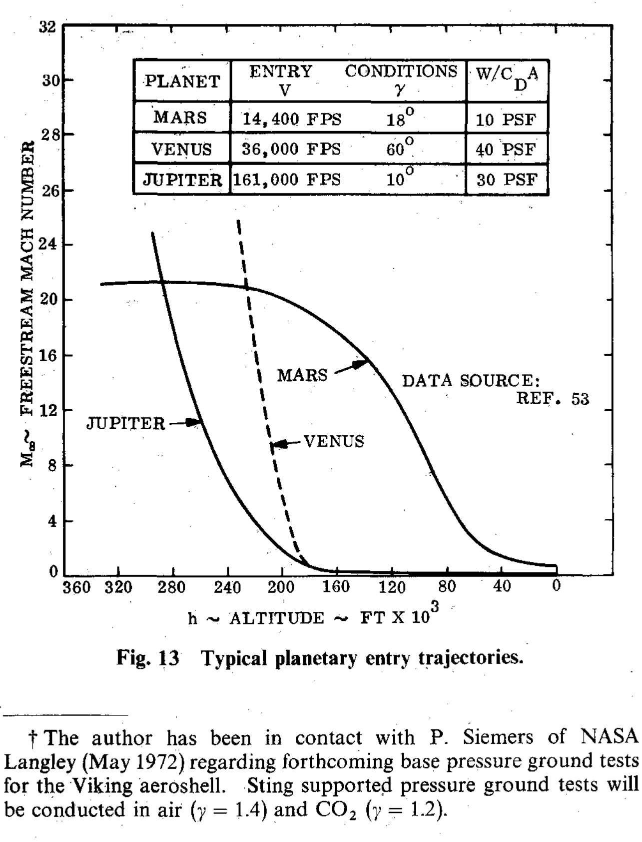
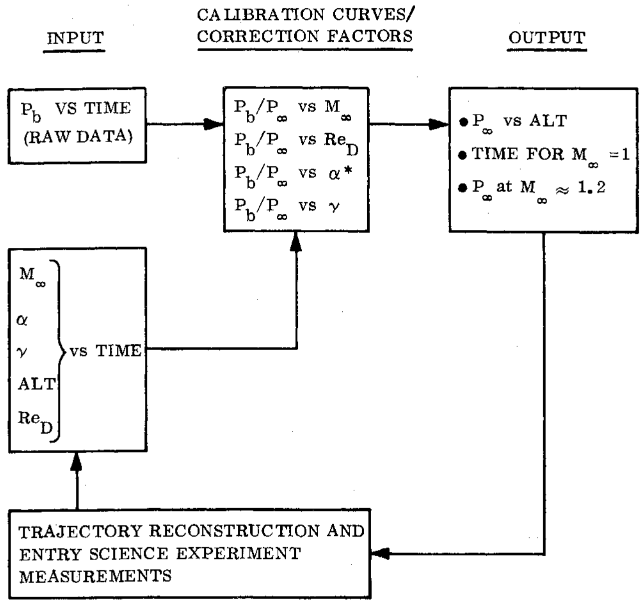



Fig. 13 Typical planetary entry trajectories.

† The author has been in contact with P. Siemers of NASA Langley (May 1972) regarding forthcoming base pressure ground tests for the Viking aeroshell. Sting supported pressure ground tests will be conducted in air ($\gamma = 1.4$) and $CO_2$ ($\gamma = 1.2$).




*CORRECTION FACTOR MAY BE SMALL

**Fig. 14 Base pressure experiment for Mars (laminar flow).**

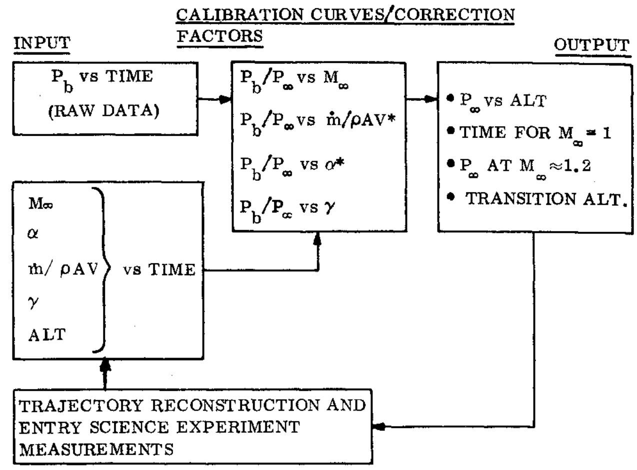
exists so that the entry science measurements and trajectory reconstruction analysis can take advantage of the boundary conditions imposed by the base pressure experiment. The presently described experiment for Mars could be readily implemented on the Viking program since the Viking entry probe will be making a base pressure measurement‡ during entry to monitor the base environment for engineering purposes. A low range pressure transducer ($\approx$0.0005 to 0.1 psia) is required for a Mars mission. Flight pressure sensors of this range are available and have been successfully flight tested on $R/V$'s.[6]

### Venus/Jupiter Mission

Venus and Jupiter both have dense atmospheres;[56–59] accordingly, probes into these planets will probably experience a turbulent boundary layer[60] during the major portion of the entry trajectory. The base pressure experiment for both Venus and Jupiter is relatively simple to conduct using an initiation altitude of $\approx$200,000 ft since the majority of the turbulent flow base pressure variables drop out or can be neglected. A block diagram illustrating the experiment is presented in Fig. 15. Note that the only variable that need be considered (below $\approx$200,000 ft) is the Mach number. The probe angle of attack will be damped out to small angles, the major heating pulse will be over thus eliminating mass addition effects, and the gas composition ($\gamma$) effect is believed to be small at lower Mach numbers. (Both Venus and Jupiter probes are subsonic by $\approx$180,000 ft.) This $\gamma$ postulate must be verified however by ground tests. The base pressure experiment is particularly attractive for mini probe missions to Venus and Jupiter that contain a minimum entry science instrument package. The base pressure experiment provides a maximum data return of: a) the freestream pressure profile, b) the time at which $M_\infty = 1$ occurs, c) the time at which onset of boundary-layer transition occurs, and d) the $M_\infty = 1.2$ $P_\infty$ boundary condition independent of other measurements.

A high range pressure transducer ($\approx$1.0 to 1500 psia) is needed for a Venus or Jupiter mission. High range sensors of this range are available as off the shelf flight hardware.

‡ The author has been in contact with B. Polutchko of the Martin Co., Denver, Colo. (Dec. 1971) regarding possible base pressure measurements for the Viking Mars entry probe. Polutchko indicated that a base pressure measurement (single port) would be made as an engineering measurement on the Viking probe.




*CORRECTION FACTORS CAN BE NEGLECTED FOR EXPERIMENT INITIATION ALTITUDE OF ≈200,000 FT.

**Fig. 15 Base pressure experiment for Venus and Jupiter (turbulent flow).**

It should be noted that the base pressure experiment can be conducted at higher altitudes for Mars, Venus, or Jupiter. The higher altitude experiment for Mars is no more complex than the presently proposed 200,000 ft experiment. However, the higher altitude experiment for Venus or Jupiter is more complex because mass addition effects would have to be considered. Gas composition ($\gamma$) effects would also be larger at the higher Mach number associated with the higher altitude experiments on Venus and Jupiter. In addition, lower range flight pressure transducers would be required. Specific details regarding flight pressure transducers applicable for planetary entry missions are discussed in Ref. 6.

## V. Slender Cone $R/V$ Earth Flight Experiment

A simple slender cone experiment has been conducted to validate the base pressure technique of deriving $P_\infty$. In the course of the many GE flight programs over the years, the base pressure characteristics of slender cones have been well established. The experiment was conducted under the assumed ground rule that the base flow characteristics $P_b/P_\infty$ were a functon only of Mach number. This is the case for turbulent flow on Venus and Jupiter, and it simplified the present problem since the purpose of the experiment was to demonstrate feasibility only. It was proposed to derive the freestream static

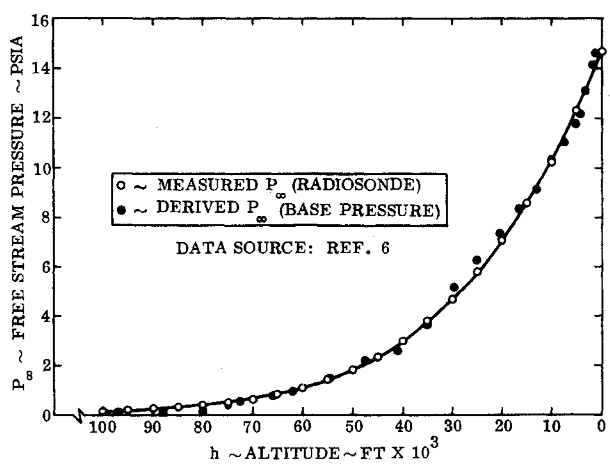



**Fig. 16 Freestream pressure ($P_\infty$) derived from base pressure measurements of slender cone flight test experiment.**

pressure profile ($P_\infty$ vs alt) of the Earth using the base pressure measurements from the next GE slender cone $R/V$ flight. The flight vehicle was equipped with a single base pressure port $T$ tapped to a low range 0–0.5 psia and a high range 0–5.0 psia pressure transducer. Both transducers were utilized in the experiment and provided data from ~100,000 ft to impact. The $P_\infty$ was derived by knowing the Mach number history of the $R/V$, the measured base pressure, and the relationship between base pressure ratio ($P_b/P_\infty$) and Mach number. Angle-of-attack effects were considered negligible.

A comparison of the freestream pressure profile derived from base pressure measurements with the freestream pressure profile measured by radiosonde data in the impact area is shown in Fig. 16. Agreement is relatively good with the largest discrepancy being ~10%. The agreement shown is not an isolated case as the author has obtained similar results for several flight vehicles. This curve (Fig. 16) clearly demonstrates the feasibility of using base pressure measurements as a technique for deriving the static freestream pressure profile of a planet.

## VI. Concluding Remarks

This paper has described a simple experiment to derive the atmospheric pressure profile of a planet using base pressure measurements. The experiment is applicable for a Mars, Venus, or Jupiter entry probe. The base pressure experiment offers advantages such as the measured pressures are the same order of magnitude as the freestream pressure, base pressure measurements are less sensitive to Mach number trajectory errors than stagnation pressure measurements, no holes are required through the forebody heat shield, base pressure measurements provide a positive indication of $M_\infty = 1$ in the re-entry trajectory, a positive indication of boundary-layer transition onset, and the $M_\infty = 1.2\ P_\infty$ boundary condition independent of onboard or offboard measurements. The results of an Earth flight test experiment using a GE slender cone $R/V$ to derive the atmospheric pressure profile of Earth from base pressure measurements have been presented. These results clearly demonstrate the feasibility of using base pressure measurements to derive the static freestream pressure profile of a planet. Flight test pressure sensor range requirements for Mars, Venus and Jupiter entry probes have been assessed and recommendations made.

The forthcoming Viking entry probe to Mars presents a unique opportunity to perform the base pressure experiment since a base pressure measurement is presently planned for engineering purposes. This paper has defined, in general, the technical effort required to utilize base pressure measurements for the future exploration of the planets by atmospheric probes. It is evident from the review of available flight and ground test data that additional limited ground tests and data correlations must be performed to firmly establish the base pressure characteristics of planetary entry probe configurations. The basic unknown to be determined is the effect of gas composition ($\gamma$) on base pressure. However, the author believes that the potential information that can be obtained from base pressure measurements of a planetary entry probe more than offsets the ground test effort required to define the base flow characteristics.

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