Electrostatic Probe Data from Bell Sphere B09

RAYMOND W. HUGGINS*
Bell Telephone Laboratories Inc., Whippany, N.J.

Theme

ATMOSPHERIC re-entry data have been obtained from four electrostatic probes mounted on a beryllium sphere. These data together with the results of the analyses are presented, and comparisons are made with theoretical models.

Contents

General

Bell Sphere B09 was a 140-lb, 15-in.-diam beryllium sphere which was launched on a suborbital trajectory and re-entered the Earth's atmosphere with a velocity of approximately 6 km/sec. The probe geometries and locations were: a flush disk and a thin wire normal to the surface, each 6° off the front stagnation point, a flush disk 100° off the stagnation point, and a thin wire on a 2-in. support in the base recirculation region. The altitude ranges for which data were obtained are shown in Table 1. The motion of the sphere during re-entry was complicated and the probe currents were therefore strongly modulated and depended not only upon the ionization level, but also upon the instantaneous location of the probes in the flowfield. The sphere motion has been resolved and both data and results are presented a) at a fixed angle off the stagnation point as a function of altitude, and b) at a fixed altitude as a function of angle off the stagnation point. Only the results of the former will be presented in this synoptic. Other results obtained are the electron-to-ion current ratios and plasma potential measurements.

Results Summary

The reduced data from the four probes are shown in Fig. 1. The results for the two stagnation-point probes and the 100° probe were obtained from the ion current values at 10° and 100° off the stagnation point, respectively. In the case of the recirculation region probe, the envelope of the current modulation was analyzed. Also shown are: the altitude at which the telemetry link blacked out, plotted at the electron density for the critical frequency of the telemetry link; the equilibrium stagnation-point electron density calculated for a plane shock with the sphere velocity and altitude as input parameters; and ion densities at 90° off the stagnation point calculated at Bell Telephone Laboratories (BTL).†

Prior to and just after the shock formation, the data were reduced using quiescent (assumes no neutral gas flow) free-molecular and continuum models. After the shock formed, data from the stagnation point flush disk probe were reduced using a boundary-layer model based on the thin sheath limit of Chung's result.[1] For the 100° probe, Chung's stagnation point solution was extended to 100° using Newtonian flow theory in the manner in which Lees[2] extended his stagnation solutions around a blunt body. Data from the recirculation region probe were reduced using quiescent models only. The crosshatched region in Fig. 1 is thought to be data taken when the probe is in the high-velocity shear layer and the results are therefore inaccurate. For the stagnation region analysis, nonequilibrium "shock-temperature" densities were obtained from the work of Lin and Teare.[3] Flowfield parameters calculated at BTL were used for the 100° probe data analysis, and for the recirculation region probe, a pressure of $3p_\infty$ and a temperature of 1000°K were assumed.

Table 1 Altitude ranges for which data were obtained

Probe	Electron currents	Ion currents
Stagnation-point wire probe	95–80 km	90–40 km
Stagnation-point disk probe	95–70 km	90–40 km
100° probe	90–30 km	90–30 km
Recirculation region probe	90–80 km	90–20 km

Discussion of Results

Figure 1 suggests several significant results and correlations. The agreement between the ion densities given by the two stagnation region probes of different geometries down to an altitude of 65 km is gratifying. The results from the free molecular and continuum models merge for each probe at the altitude where the probe radii ≈ the ion mean free paths, and at 75 km, there is excellent agreement between the wire probe result obtained using a free molecular model and the disk probe result using a continuum model. Such agreement suggests that the values of density and temperature, and the scaling of the mobility with temperature are not seriously in error. The difference between the results from the quiescent models and those from the boundary-layer model at 65 km is explained by the fact that the boundary-layer model is formulated to give the ion density at the boundary-layer edge, whereas the quiescent models give the density close to the sphere wall. Also of significance is the close agreement at 55 km between the ion density given by the flush probe and that calculated for a plane shock in chemical equilibrium. At 55 km, the bow shock is

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Index category: Re-Entry Vehicle Testing.

* Member of Technical Staff.

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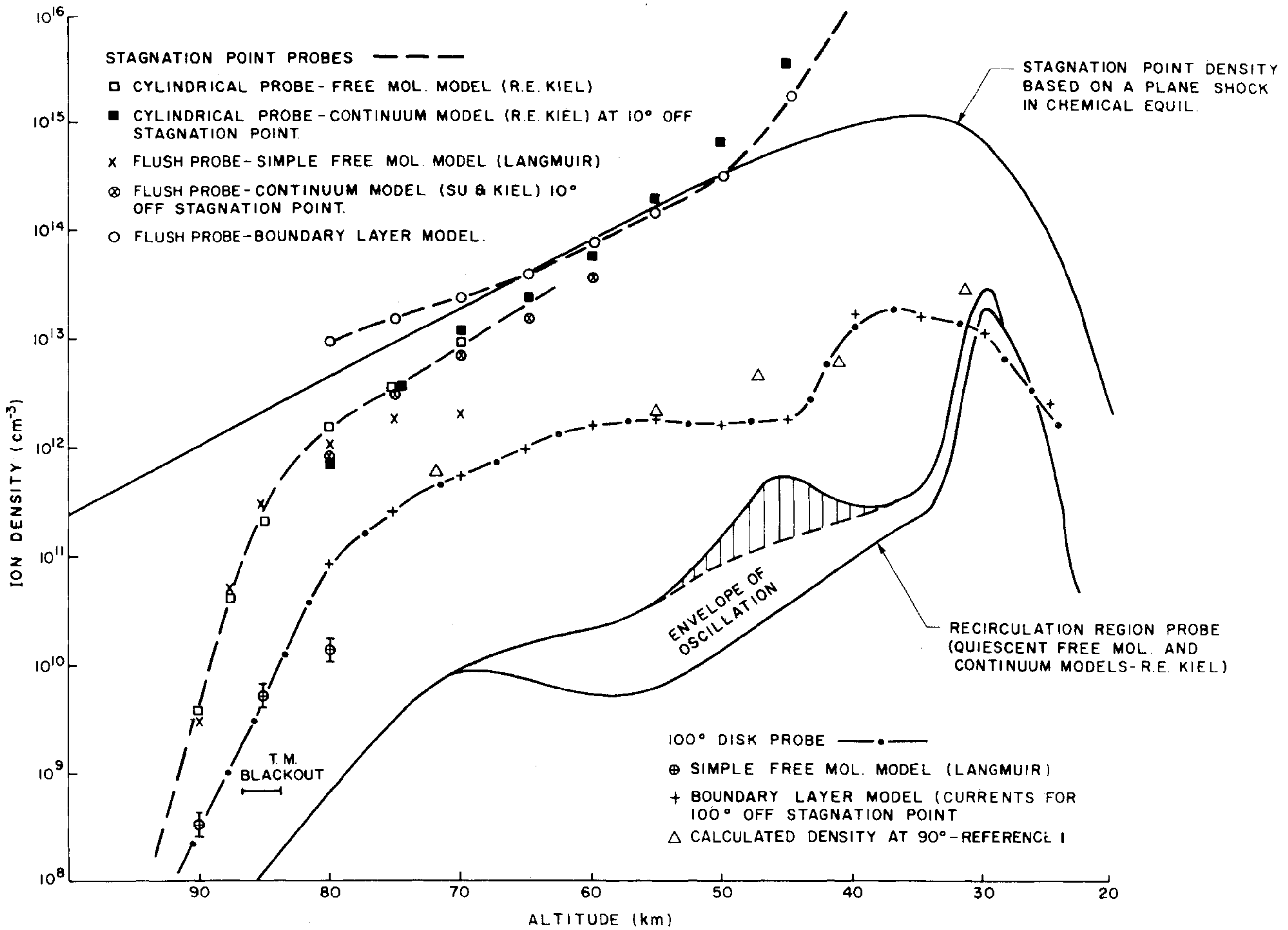

Fig. 1 Summary of analyzed data from all re-entry probes.

expected to be close to equilibrium. Not explained is the sudden rise in the ion density shown by both the stagnation point and 100° disk probes at ~47 km. The leveling off of the ion density at 100° between 60–45 km is believed to be due to recombination limiting. Other results presented in the full paper are the excellent prediction of the shock formation calculated by Bergeron† and agreement between calculations† of the ion density variation with angle off the stagnation point at 10°–20° and 100°–115° and the experimental results.

References

[1] Chung, P. M., "Electrical Characteristics of Couette and Stagnation Boundary-Layer Flows of Weakly Ionized Gases," *The Physics of Fluids*, Vol. 7, Jan. 1964, p. 110.

[2] Lees, L., "Laminar Heat Transfer Over Blunt-Nosed Bodies at Hypersonic Flight Speeds," *Jet Propulsion*, Vol. 26, April 1956, p. 259.

[3] Lin, S. C. and Teare, J. D., "Rate of Ionization Behind Shock Waves in Air. II. Theoretical Interpretations," *The Physics of Fluids*, Vol. 6, March 1963, p. 355.