Boundary Layer Electron Profiles for High-Altitude Entry of a Blunt Slender Body

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Theme

A KEY factor in prediction of radio blackout during entry into a planetary atmosphere is determination of the magnitude and distribution of electron concentration (N_e) in the plasma layer. Several of the contributions made in the past ten years to improve this prediction capability can be credited to the RAM (Re-entry Attenuation Measurement) project—a carefully coordinated program[1] of laboratory tests, flight experiments, and theoretical analysis carried out at the Langley Research Center.

Because a complex chemistry system is necessary to calculate accurately trace species concentrations, computation of chemical changes along streamlines in a previously-calculated flowfield proved to be satisfactory and more economical than a complete flowfield calculation with nonequilibrium chemistry.[2] Except for minor displacement effects boundary layer has little influence on N_e profiles for blunt nosed bodies at the lower altitudes of interest, since the entropy layer is relatively thick and the N_e maxima fall in the inviscid portion. At higher altitudes, where boundary layers are no longer thin relative to the entropy layer and often include the peak of the N_e profile, a method was devised for following streamlines into the boundary layer.[3] The approach was useful, but, because ambipolar diffusion of charged particles could not be included, the results are invalid above a threshold altitude.[1]

In this paper the boundary-layer portions of previously published N_e profiles are calculated by means of a nonequilibrium, multicomponent diffusion, boundary-layer program,[4] and the results are compared with previously published profiles obtained by following streamlines into the boundary layer. Comparisons are made with experimentally measured profiles and also with profiles calculated for nonequilibrium fully viscous flow.[5]

Contents

The RAM C entry body was a spherically blunted 9° half-angle cone with a nose diameter of 30.5 cm (1 ft). Theoretical treatment of the inviscid flowfield for this body, and also of the method for following streamlines into the boundary layer, has been documented in the literature.[2,3] The technique is satisfactory at altitudes low enough that ambipolar diffusion is negligible. For higher altitudes, a program[4] for computing boundary-layer properties was used which allows for swallowing of inviscid streamlines by specification of the edge conditions. The wall boundary condition was equilibrium composition at specified wall temperature.

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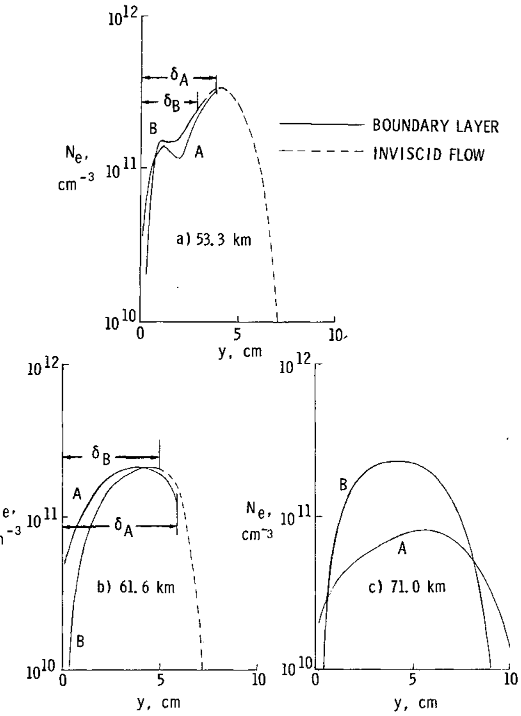

Fig. 1 Comparison of computed N_e profiles at $x/d_N = 4$ from nonequilibrium multicomponent diffusion program (curve A) with those from the streamline method (curve B).

Comparison profiles for the two kinds of boundary-layer calculations are displayed in Fig. 1. Ambipolar diffusion was not important for the altitudes of Figs. 1a and 1b, and profiles agree well. The profiles of Fig. 1c were computed for an altitude of 71.0 km (233,000 ft), the upper limit[1] for neglect of ambipolar diffusion of the charged species. Based on the present results, the upper limit for neglect of ambipolar diffusion is between about 60 and 70 km.

Figure 2 is a comparison between an electron concentration profile measured on the RAM C-III flight and the corresponding profile calculated using the boundary-layer theory described above. The agreement between boundary-layer theory and the data is good from the body surface out to about 9 cm; whereas beyond 10 cm the data points rise rather than fall as theory predicts. It is believed that the ionization currents collected by the outer probes at this altitude are masked by leakage currents in the insulators, which are increasingly degraded by aerodynamic heating as altitude decreases. Figure 3, on the other hand, compares RAM C-III data to profiles calculated for a fully viscous shock layer.[5]

Probe insulator leakage due to heating was recognized and discussed in a previous publication.[6] The effects are first noticed at the outermost probe and reach probes closer to the body surface as altitude decreases. A previously published criterion for

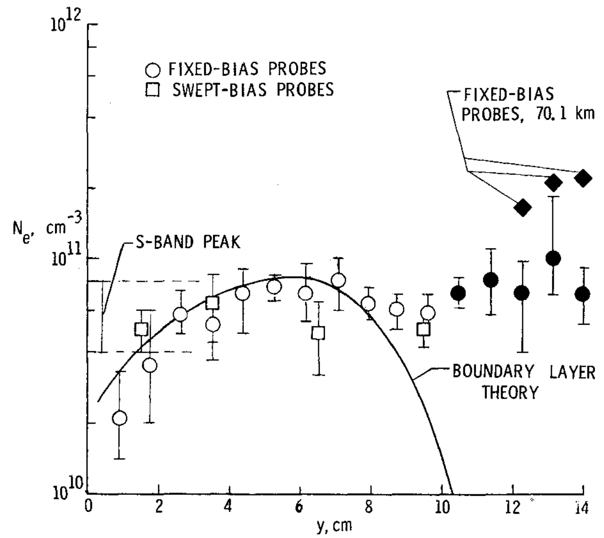

Fig. 2 Comparison of N_e profile for RAM C-III at $x/d_N = 4$ with profile calculated from boundary-layer theory; altitude = 71.0 km. (Filled symbols indicate data subject to heating effects.)

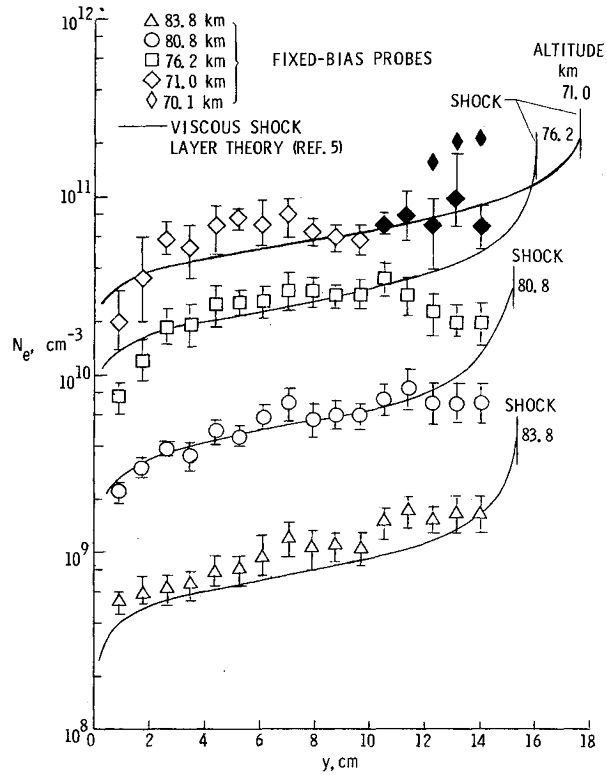

Fig. 3 Comparison of measured profile shapes for RAM C-III at $x/d_N = 4$ with profile shapes from fully viscous shock layer theory. (Filled symbols indicate probes affected by heating.)

discarding probe data for some of the outermost probes was based on temperatures measured in flight by thermocouples beneath the insulator surface.[6] A later investigation, based on surface heating effects and described in the backup paper, indicates that the heating effects may have had an earlier onset and may have involved more probe positions than was previously believed to be the case. The probe positions affected are indicated in Figs. 2 and 3 by filled symbols. Satisfactory agreement between measured and boundary-layer calculated N_e profiles is obtained when the probe results considered questionable by the new criteria are deleted.

For altitudes lower than 76 km, the results of the boundary-layer theory, rather than those of the fully viscous layer theory curves of Ref. 5, are believed to be appropriate for analysis of the RAM-C flowfield. Arguments in support of this hypothesis are a) shape changes in the experimental data profiles as altitude decreases, b) better agreement between calculated and observed attenuation of *S*-band transmission, and c) much better agreement between calculated and measured values of N_e at forward body stations ($x/d_N = 0.15$ and 0.76). The reader will find more detail in the backup paper.

References

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