N91-10901

DIRECT SIMULATION OF RAREFIED HYPERSONIC FLOWS

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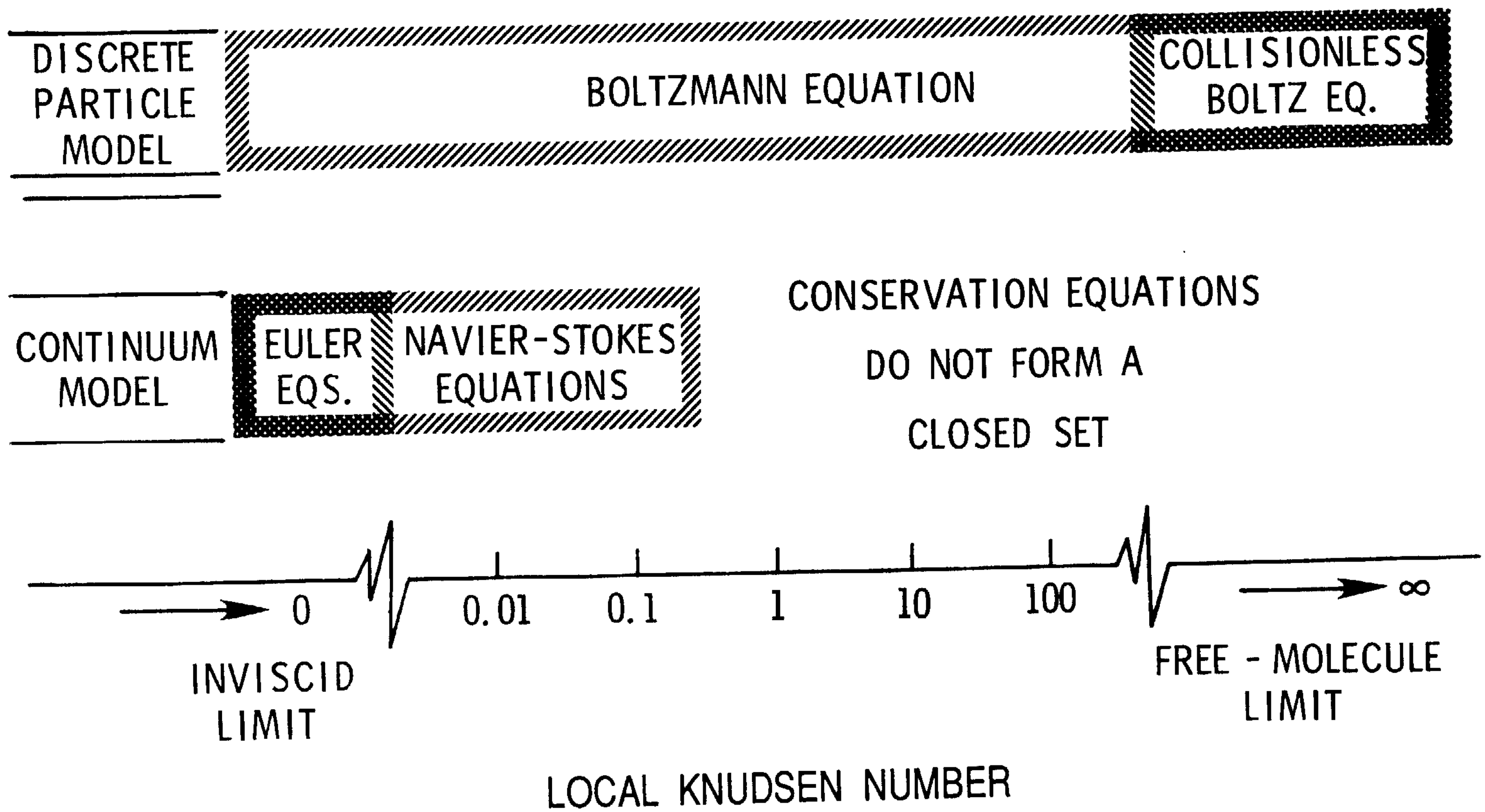
As the capability of the space transportation vehicles (STV's) expand to meet the requirements for future space exploration and utilization, the effects of rarefied hypersonic flows will play a more significant role in defining the aerodynamic and aerothermodynamic performance of STV's. This is particularly true of the low lift/drag aeroassisted STV's where aerobraking occurs at relatively high altitudes and high velocity. Because of the limitations of the continuum description as expressed by the Navier-Stokes equations and the difficulties of solving the Boltzmann equation, the particle or molecular approach has been developed over the last three decades for modeling rarefied gas effects. The direct simulation Monte Carlo (DSMC) method of Bird is the most used method today for simulating rarefied flows. The DSMC method provides a direct physical simulation as opposed to a numerical solution of a set of model equations. This is accomplished by developing phenomenological models of the relevant physical events. The DSMC method accounts for translational, thermal, chemical, and radiative nonequilibrium effects. The present discussion will review the general features of the DSMC method, the numerical requirements for obtaining meaningful results, the modeling used to simulate high temperature gas effects, and applications of the method to calculate the flow about an aeroassist flight experiment vehicle (AFE). The AFE simulates a geosynchronous return while entering the Earth's upper atmosphere at approximately 10 km/s. Results obtained using a general 3-D code are presented for the more rarefied portion of the atmospheric encounter (altitudes of 200 to 100 km) emphasizing surface, flowfield, and aerodynamic characteristics of the AFE. Finally, results obtained using axisymmetric and 1-D versions of the code are presented for lower altitude conditions.

KNUDSEN - NUMBER LIMITS ON GAS FLOW MODELS



DIRECT SIMULATION MONTE CARLO METHOD

- o The Real Gas Flow Is Modeled By Some Thousands Of Simulated Molecules

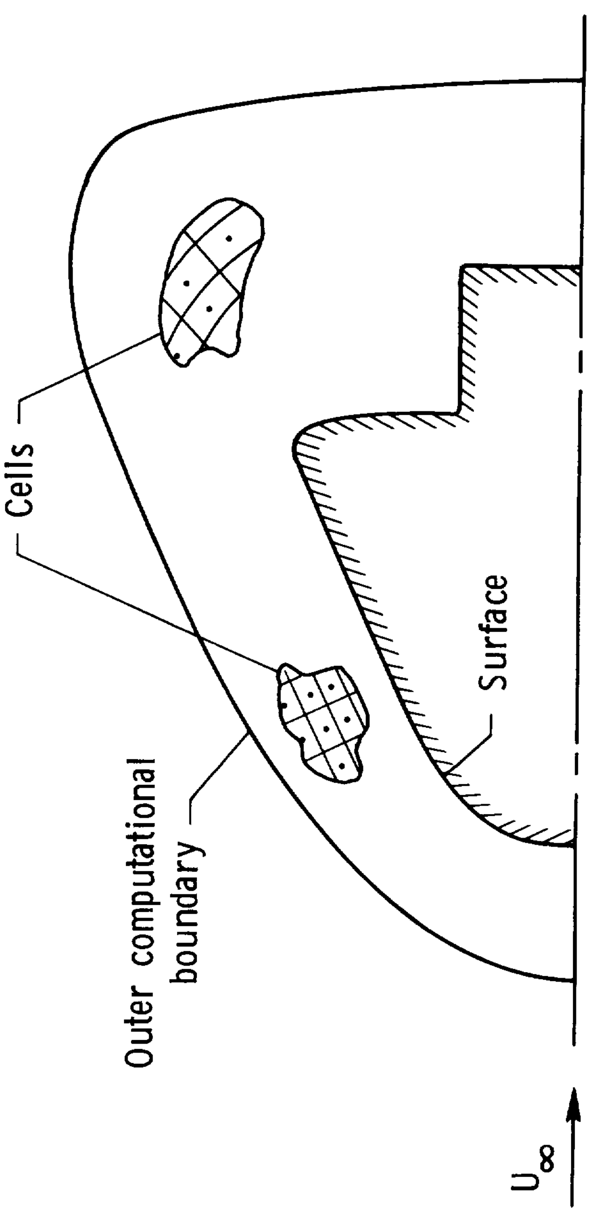
- o The Position Coordinates And Velocity Components Are Stored In The Computer

- o The Molecules Are Simultaneously Followed Through Representative Intermolecular Collisions And Boundary Interactions In Simulated Physical Space

DSMC METHOD

- Each simulated molecule represents a large number of real molecules.
- The molecular motion and collisions are uncoupled over a small time step.
- The relative locations of molecules in physical space cells are disregarded in the selection of collision pairs.
- The computational time can be directly proportional to the number of simulated molecules.

COMPUTATIONAL DOMAIN



REAL AIR MODEL

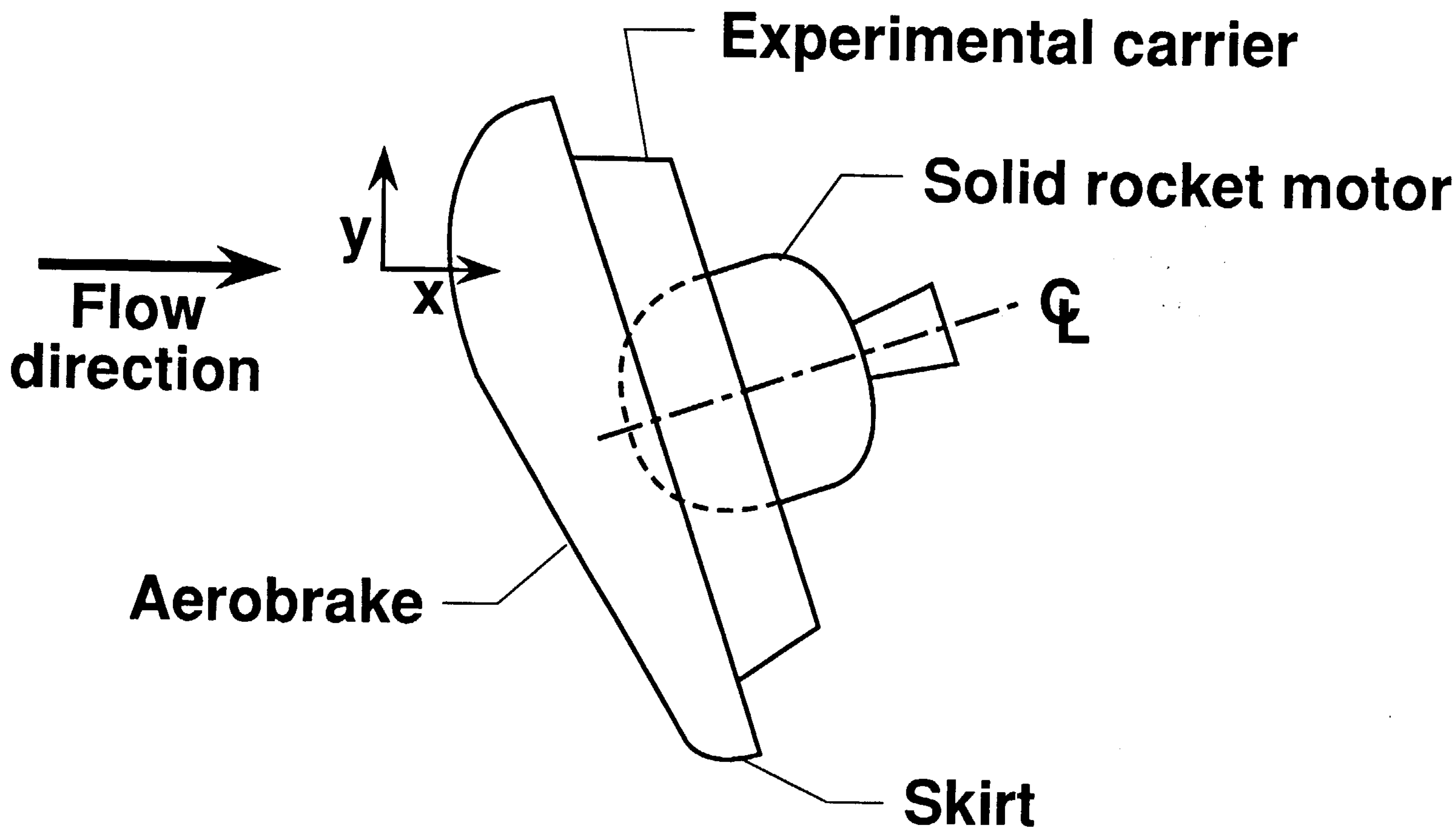
- Elastic collisions
  Variable diameter Hard Sphere (VHS)

- Rotation and vibration
  Larsen-Borgnakke model

- Chemical reactions
  Collision theory with reactive cross sections from continuum rate constants

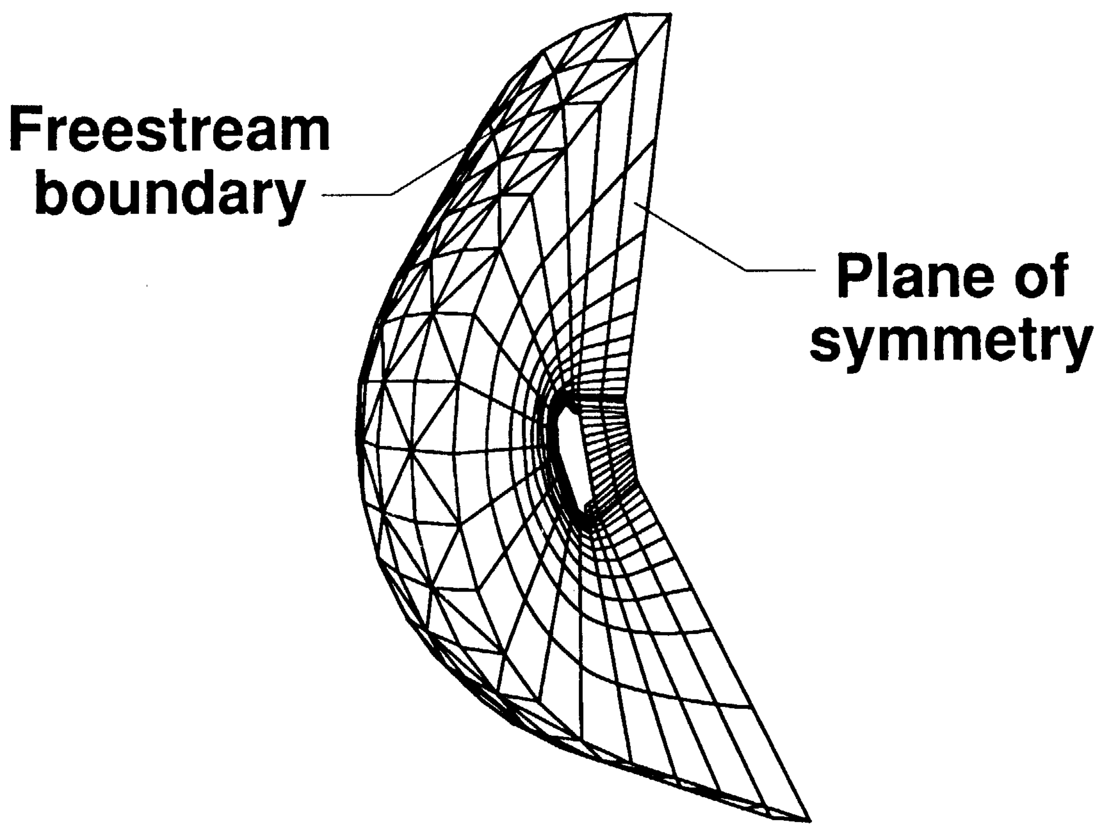
- Thermal radiation (bound-bound)
  Electronic state distribution from analog of Larsen-Borgnakke method. Mean radiative lifetime from data. Finite absorption cross-section

AFE FLIGHT CONFIGURATION

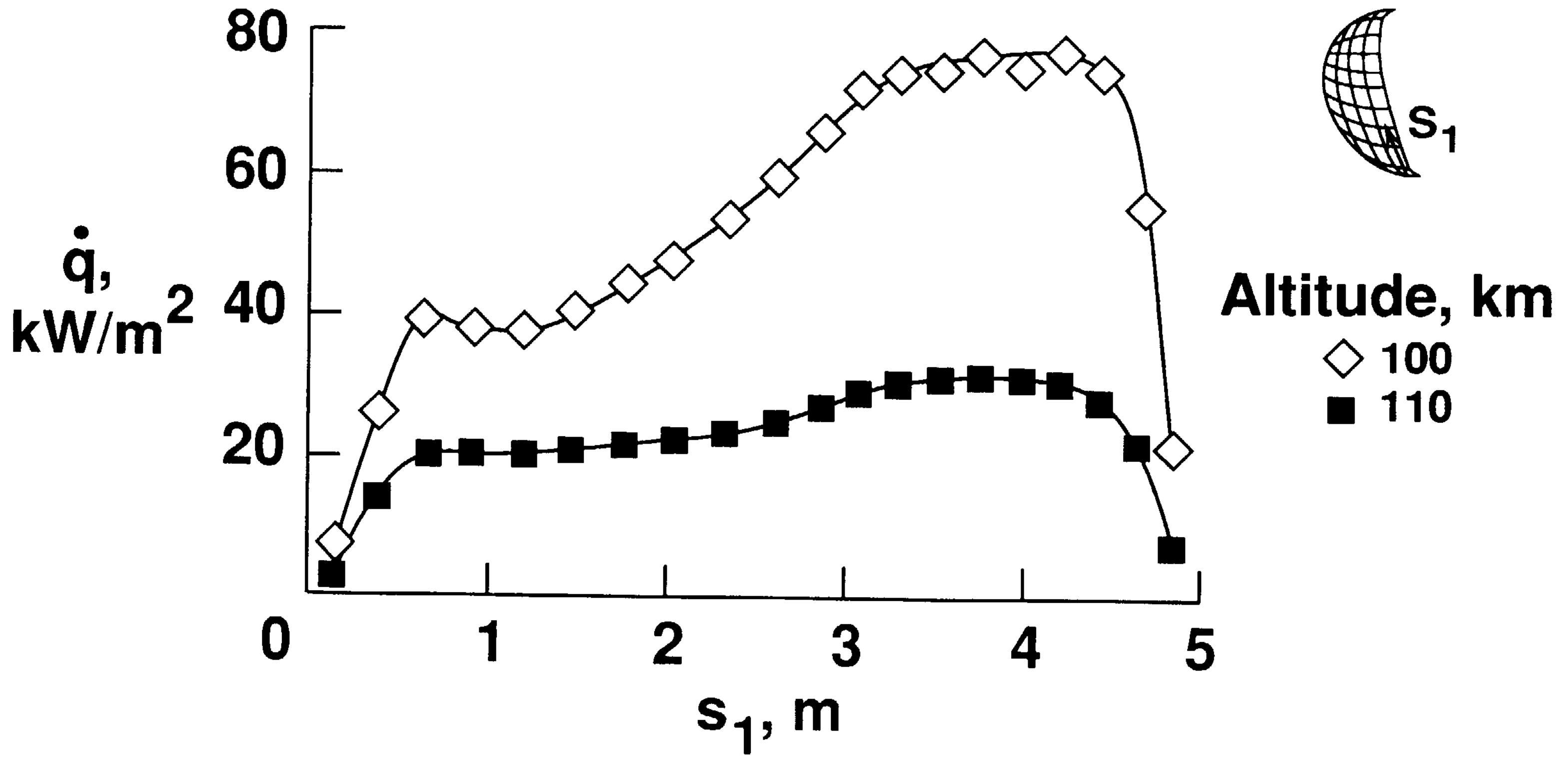


COMPUTATIONAL GRID

Alt = 120 km

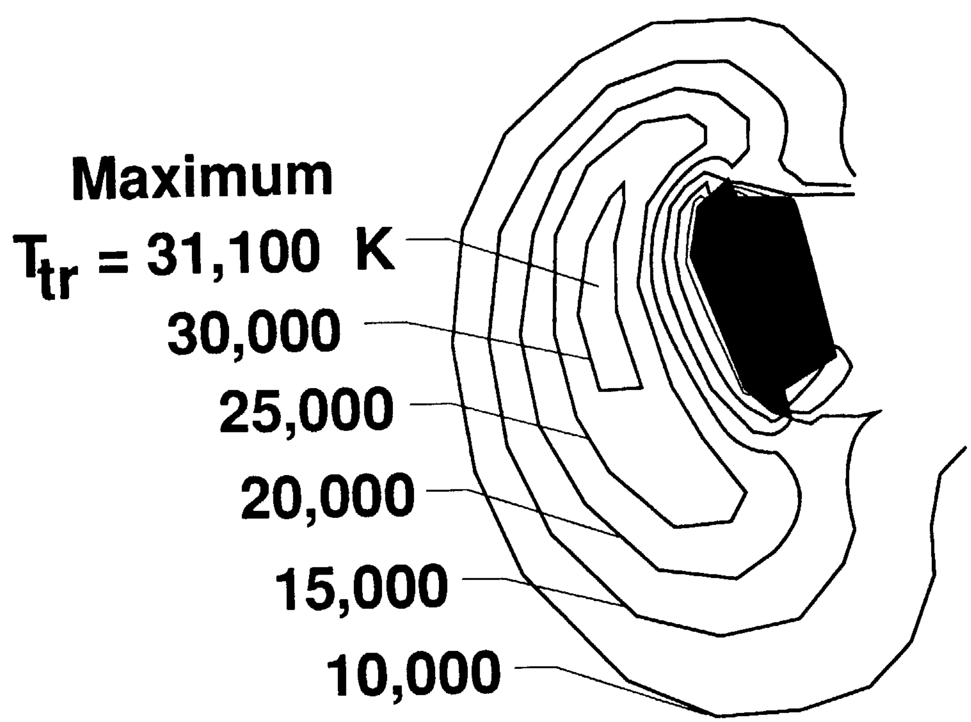


SURFACE HEAT TRANSFER RATE DISTRIBUTIONS



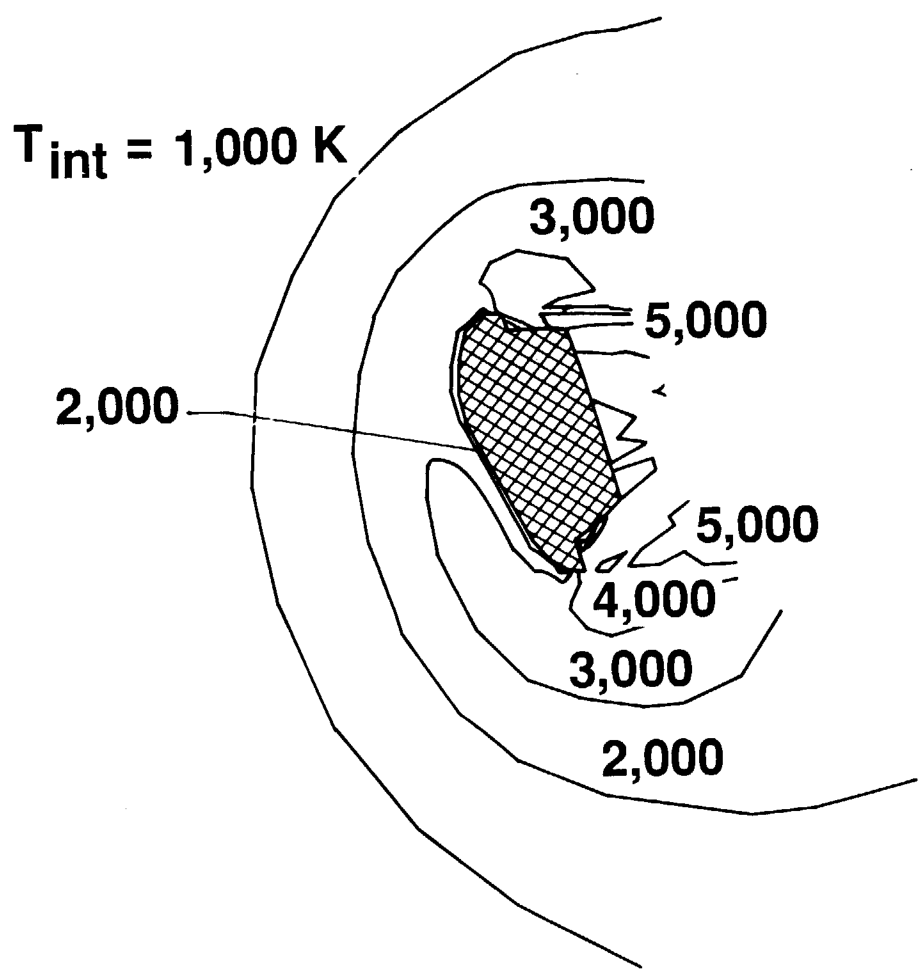
TRANSLATIONAL TEMPERATURE CONTOURS FOR AFE FLOWFIELD

Alt = 120 km

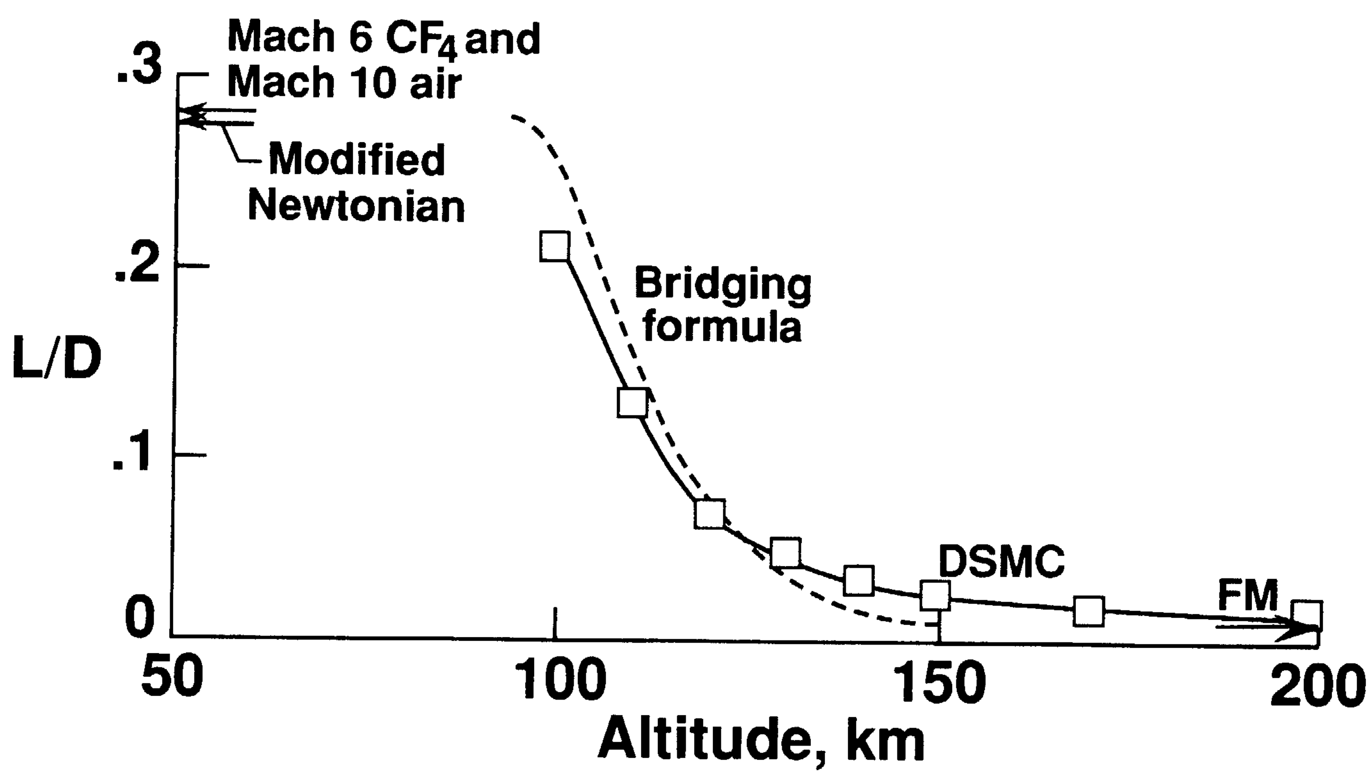


INTERNAL TEMPERATURE CONTOURS FOR AFE FLOWFIELD

Alt = 120 km

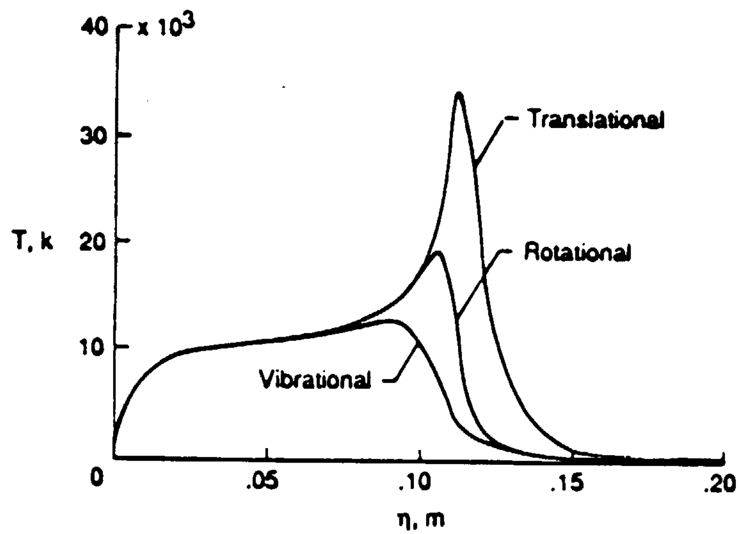


L/D VARIATION

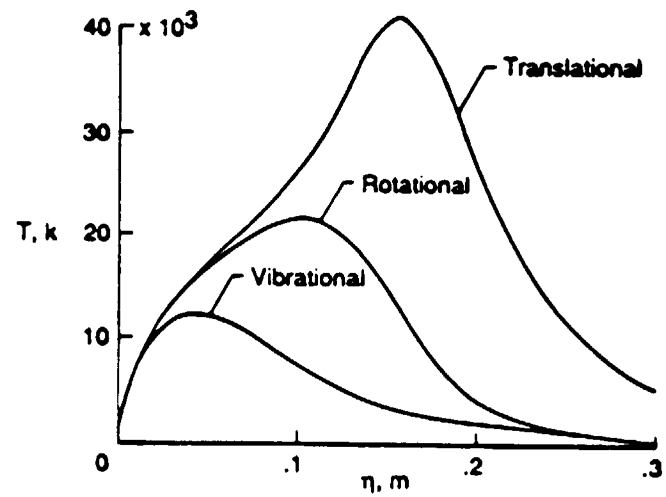


TEMPERATURE PROFILES

Alt = 78 km, U_∞ = 9.1 km/s



Alt = 90 km, U_∞ = 9.9 km/s



MOLE FRACTION DISTRIBUTIONS

Alt = 78 km, U_∞ = 9.1 km/s