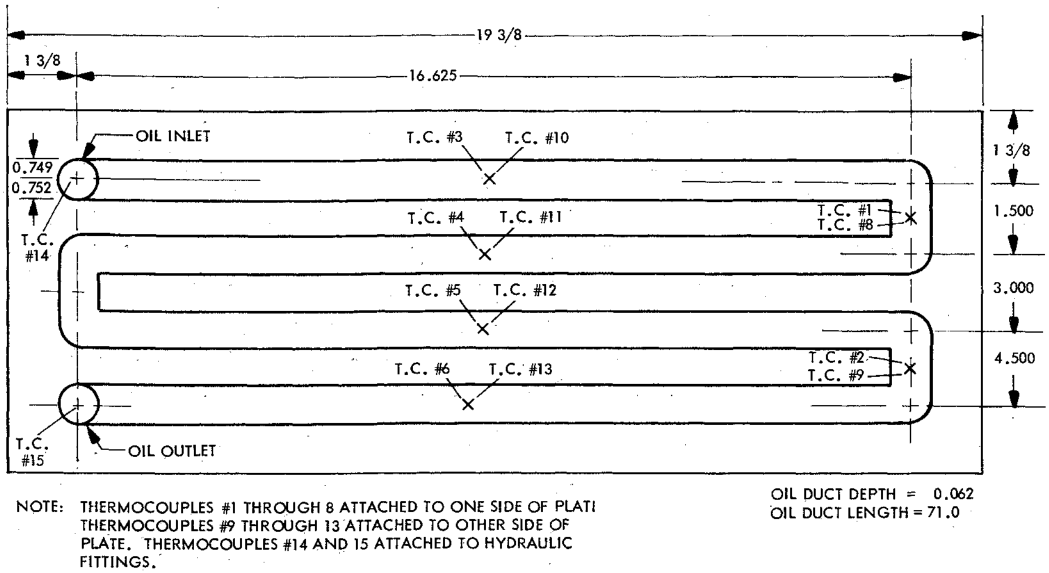

T.C. #	T (°C)	T.C. #	T (°C)
1	37	9	37
2	36.5	10	38
3	38	11	38
4	38	12	37.5
5	38	13	38
6	38	14	29
7	32	15	32
8	36		

TEST DATA

Fig. 1 Test cold-plate layout and test data.

Plotting of data for additional flow rates on Fig. 2 results in curve C representing a duct length of 16.625 in. Further, the data shows that at low fluid rates ($< \frac{1}{2}$ gal/min) the turbulence within the duct, due to not having fully developed laminar flow, is not considerable, and that the actual heat-transfer film coefficient approximates the average heat-transfer film coefficient as determined by the Hausen equation. With increased flow rate, however, Fig. 2, curve C, shows a divergence of both coefficients and indicates the effects of turbulence are coming into play. With this test data correlation it is now possible to predict with reasonable accuracy what the magnitude of the heat-transfer film coefficient will be for simple cold plates having the form factor described herein.

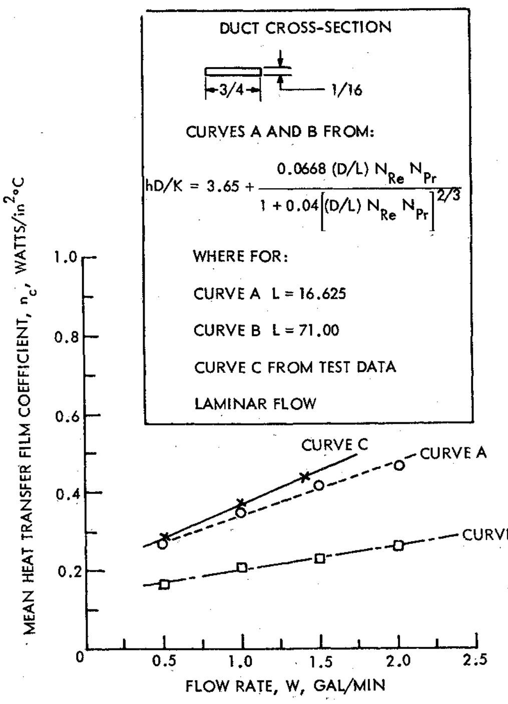

Fig. 2 Film coefficient vs flow rate of Coolanol 35 at 30°C.

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A Nomogram for High-Altitude Plume Structures

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Nomenclature

C_F = engine thrust coefficient for actual engine configuration
$C_{F\max}$ = maximum engine thrust coefficient, assuming an infinite area ratio

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D = plume drag
$Kn_{\bar{L}}$ = $\lambda_\infty/\bar{L}$ = plume Knudsen number
$\bar{L}$ = hypersonic plume scale
q_∞ = freestream dynamic pressure
T = missile thrust
λ_∞ = freestream mean freepath
x,y = axial and radial distance from rocket, respectively
$\bar{x},\bar{y}$ = $x/\bar{L}$ and $y/\bar{L}$, respectively

Introduction

THE structures of high-altitude hypersonic rocket plumes[1-8] can now be evaluated by using a variety of techniques; the most sophisticated are computer programs which include chemical and transport processes.[9,10] However, there are situations where such detail is not required, and the investigator is interested solely in the dimensions and location of a plume structure in a hypersonic flow. This Note presents a nomogram based on a simple model for hypersonic rocket-plume dimensions.

A Plume Model

In 1970, Jarvinen and Hill[11] proposed a simple calculation technique for estimating the dimensions of hypersonic rocket plumes, using tabulated values derived from calculations for inviscid plume flow. By their method, the plume's shape is normalized by two scaling parameters. The first scaling parameter is the plume hypersonic scale

$$\bar{L} = (T/q_\infty)^{1/2} \quad (1)$$

The other is the ratio of plume drag-to-thrust, defined by

$$D/T = (C_{F\max}/C_F) - 1 \quad (2)$$

The plume structures (with their coordinate system) of the Jarvinen-Hill "model" are shown in Fig. 1.

Recently, the applicability of the Jarvinen-Hill model was examined.[12] Comparisons with more detailed calculations[8] for high-altitude rocket inviscid-plume structures have shown that this model properly approximates the position of the contact surface separating the freestream and exhaust gases. Study of electron-beam data of simulated viscous plumes in a hypersonic freestream[13,14] has shown further that the inviscid Jarvinen-Hill calculation is useful in the viscous plume flow when properly qualified. In the viscous plume case, the inviscid contact surface of this model nearly coincides with a surface of equal freestream and exhaust species concentrations when these species have approximately the same molecular weights.[12]

The D/T dependence of the Jarvinen-Hill model is in qualitative agreement with the simulated plume behavior. This qualified applicability of the Jarvinen-Hill model appears to extend into the relatively low-density transitional flow regime for which the plume Knudsen number approaches 10^{-1}. For values of $D/T \sim 0.20$ the data show that the absolute location of the Jarvinen-Hill Mach disk is approximately correct.

The user of this plume model should be aware of its limitations, as the following examples show. Substantial errors in predicted plume shape occur when $\bar{L}$ is less than the rocket dimensions (characteristically a low-altitude limit to the model) and flow disturbances created by a relatively large missile body must be considered.[12] When the value of D/T is substantially smaller than 0.1, it can be shown that the plume flow is very slender with attached bow shocks at all altitudes,[15] in contradiction to the blunt nose-structure implicit in the Jarvinen-Hill model. Moreover, in the hypersonic limit for the nozzle exhaust flow (where $D/T \to 0$), it is shown[12] that the internal longitudinal scaling (i.e., the Mach disk location) of their model is incorrect.

Rockets with such low values of D/T are not the usual case, since most engines of interest have $0.15 < D/T < 0.25$ and display detached bow shocks at the high altitudes of interest for which this model was designed.

The Nomogram

Rapid calculation of plume sizes and shapes can be performed by using a nomogram (shown in Fig. 2) based on the Jarvinen-Hill model as applied to "typical" rockets ($D/T \sim 0.2$). This nomogram is a device for calculating the hypersonic scale length $\bar{L}$, given that, for the flight vehicle under study, its altitude, thrust, and speed are known. The $(D/T)^{1/4}$ dependence in the Jarvinen-Hill model has not been included since most existing missiles have values of D/T within a relatively restricted range ($0.15 < D/T < 0.25$) and, typically, the $\frac{1}{4}$-power variation will have a weak effect. Since the expression for $\bar{L}$, Eq. (1), requires ambient density rather than altitude as an input, the missile altitude must first be related

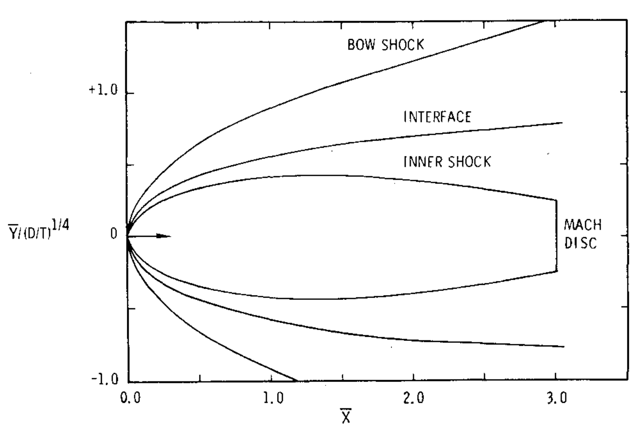

Fig. 1 "Universal plume" structure of Jarvinen and Hill.

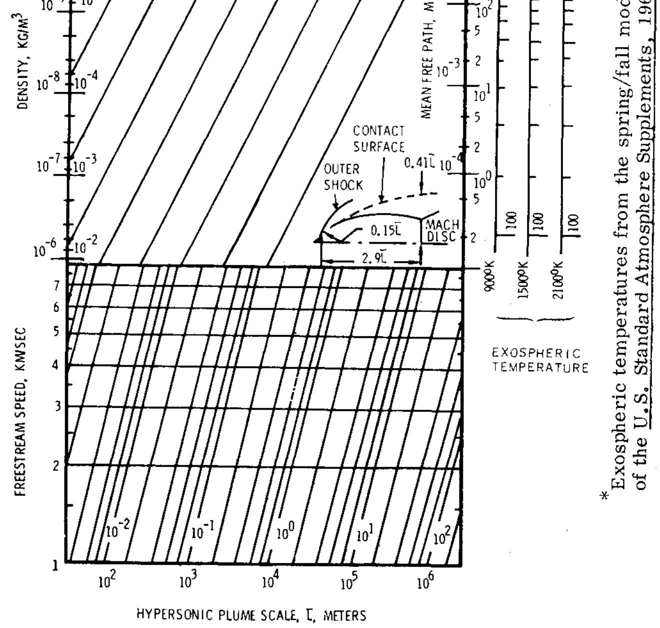

Fig. 2 Nomogram for plume structures.

to density and must take into account the state of the thermosphere (i.e., the atmosphere above 100-km altitude). The thermosphere is strongly affected by the solar radio and geomagnetic activity, and has strong diurnal and semiannual variations. Empirical models of the thermosphere and exosphere are given by L. G. Jacchia.[16] Beside place and time of flight, these models require daily and averaged values of 1) solar flux at 10.7 cm, and 2) the geomagnetic planetary index. These are given in the *Solar-Geophysical Data Prompt and Comprehensive Reports*, available through the National Geophysical and Solar-Terrestrial Data Center, National Oceanic and Atmospheric Administration, U.S. Dept. of Commerce, Boulder, Colo.

When the exospheric temperature has been estimated, the vertical altitude scales for three different exospheric temperatures, on the upper right side of Fig. 2, can be used to make a best estimate of the atmospheric density at the missile altitude by first interpolating an altitude for the calculated exospheric temperature. Note that the 1962 U.S. standard atmosphere[17] exospheric temperature is $\sim 1500°K$. This interpolated altitude is then read horizontally across to the exterior density scale markings on the left side of the figure. This line also gives the ambient mean freepath on the appropriately labeled exterior scale markings on the right side. Notice that the state of the thermosphere, as determined by solar activity, has a first-order effect on the ambient density and thus on the plume dimensions above 300-km altitude.

The missile thrust is entered from the scale outside the upper horizontal line of Fig. 2. This thrust is read diagonally down toward the left until it intersects the horizontal line just drawn. This is the first intersection. A vertical line is dropped from the first intersection into the lower box of the figure, where it intersects a horizontal line labeled on the left side with the given missile speed. This is the second intersection. The missile hypersonic plume scale is given by the scale exterior to the lower horizontal line of the figure. The magnitude of the missile plume scale is identified by the diagonal lines nearest the second intersection. The division of the ambient mean freepath by the hypersonic plume scale yields the plume Knudsen number.

To estimate the plume outline, the Jarvinen-Hill plume proportions for $D/T \sim 0.2$ are shown in Fig. 2 in the inset. They have been changed slightly to show better agreement with the electron-beam data when the "contact surface" is reinterpreted as described above for the viscous plume.

The procedure just described can be used to generate a series of points in the lower box, the loci of which show the history of the plume development. Notice that for full-scale missile calculations, the exterior scale markings are used as just described. For the wind-tunnel experiment design, different ranges of the variables are used, but the calculation procedure is the same, except that the interior scale markings are used.

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Laser Activated, Model Surface Recession Compensator System for Testing Ablative Materials

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Introduction

THE purpose of this Note was to develop an automatic surface recession compensator system to keep an ablating model in the uniform flow region of a high-pressure hyperthermal arc heater environment. Prior to the development of this system the front surface of an ablating model receded out of the region of constant pressure into the nonuniform

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