Transition Correlations for Hypersonic Wakes

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Introduction

THE purpose of the present note is to indicate some general correlations of the available wake-transition data for spheres, cones, wedges, cylinders, and sphere-cones[1–5, 8]; the parameters used are the freestream Reynolds number (based on the transition length measured from the base of the body) and the freestream Mach number Additionally, it is found that, by multiplying the Reynolds number by a suitable Mach number function, the effects of body shape are scaled out (within the inherent scatter), and the data for all body shapes correlate This Mach number function is the square of the ratio of freestream Mach number to local inviscid Mach number in the wake region

Data Correlations

Figure 1 presents the data of Refs 1–5 and 8 reduced in terms of freestream Reynolds and Mach numbers, the former being based upon the transition distance measured from the base of the body The correlation of the transition data in terms of these parameters is suggested by similar correlations for separated shear layers [9, 10] The cone and sphere data are inconclusive with regard to the effect of cone angle, cone base diameter, or sphere diameter; the wedge data do indicate an effect of wedge angle, as reported by Demetriades [5]

A single point that represents an average for the cylinder data gathered at the Graduate Aeronautical Laboratory, California Institute of Technology (summarized in Ref 8) is shown on Fig 1; the agreement with the sphere data is seen to be good

Instead of employing the freestream properties in the Reynolds and Mach numbers, it is possible to recast the data

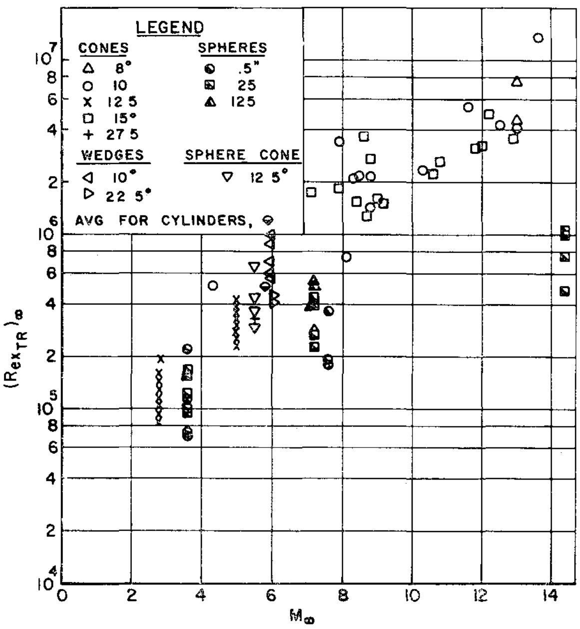

Fig 1 Wake-transition correlation in terms of freestream Reynolds and Mach numbers

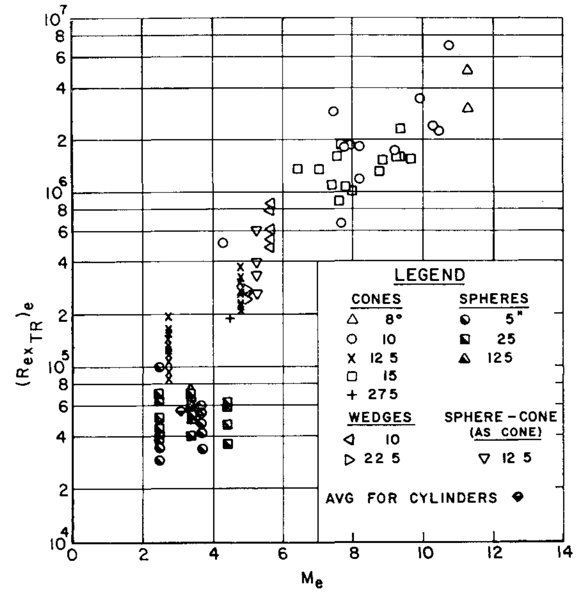

Fig 2 Wake-transition correlation in terms of local Reynolds and Mach numbers

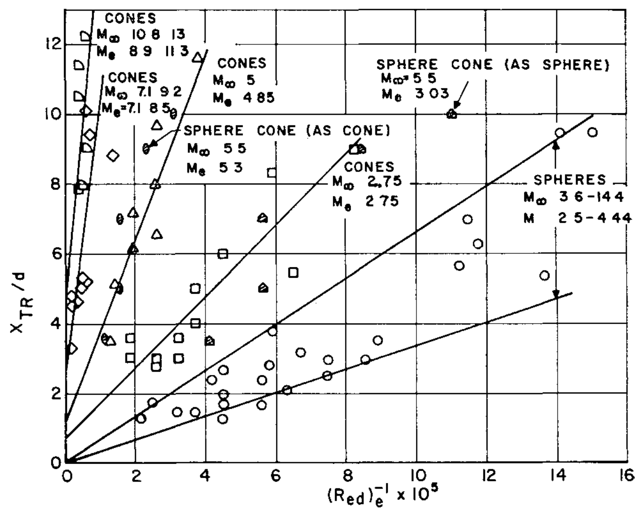

Fig 3 Effect of Mach number on wake-transition distance

in terms of estimated local inviscid properties in the downstream wake region For the present purpose, these inviscid properties were estimated by assuming the flow history to consist of an appropriate "body shock" and a subsequent isentropic expansion to freestream pressure The "body shock" was considered to be a normal shock for the spheres and cylinders and the appropriate conical and oblique shocks for the various cone and wedge angles, respectively Perfect-gas relations ($\gamma = 1\ 4$) were employed in these calculations

The reduction of the data in terms of local Reynolds and Mach numbers is shown in Fig 2 The sphere-cone (ratio of nose radius to base radius equal to 0 5) was considered as a cone for this presentation (see below) The scatter in the cone, wedge, and sphere-cone data is essentially the same as that of Fig 1: the sphere data groups at $(R_{ex_{TR}})_e \sim 5(10)^4$ (also see Fig 3) as noted by Lees[7] and by Webb et al [6] Figure 2 also indicates the average for the cylinder data[7, 8] $(R_{ex_{TR}})_e \sim 5\ 6(10^4)$; as noted by Lees,[7] there appears to be no difference between sphere and cylinder data

The marked difference between the cone and wedge data compared to the sphere data and the trend of Demetriades' wedge data clearly points to an effect of bluntness or body shape Therefore, in order to correlate all body shapes, an additional parameter defining the "body bluntness" should enter into the correlation The ratio of freestream Mach number to the local inviscid wake Mach number (as defined

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in the foregoing) appears to be a reasonable choice for a bluntness parameter, since it is completely specified by the bow shock, which, in turn, is governed by the body shape For the data under consideration, it appears that the square of this Mach number ratio may be used to collapse all the data into one grouping, as shown in Fig 4 The correlation is of the form $(R_{x_{TR}})_\infty(M_\infty/M)^2$ as a function of M_∞, where the local Mach number M is obtained as just described It is seen that this correlation represents all the data, at least to first order

Figure 3 shows X_{TR}/d as a function of the inverse local Reynolds number based on body diameter, $(R_{e_d})^{-1}$ Here, the effect of Mach number and body bluntness (cones vs spheres) is re-emphasized The fact that the sphere data do not group with the cone data on the basis of local Mach number supports the concept of a constant $(R_{e_{x_{TR}}})_e$ for spheres

The sphere-cone data are shown in Fig 3 according to data reduction both as a cone and as a sphere The "sphere-cone as a cone" correlates much better with the cone data than does the "sphere-cone as a sphere" with the sphere data This may be partially explained by the fact that, for the experimental conditions, boundary-layer calculations indicate that the boundary layer on this blunt sphere-cone "swallows" a substantial portion of the fluid that passes through the strongest region of the bow shock Consequently, the inviscid wake fluid has not passed through a normal shock but rather through a weaker shock; therefore, it is representative of the inviscid flow associated with a slender vehicle

Additional information relating to the "sticking distance"[7] may be deduced from Fig 3 However, lack of space precludes an extensive discussion here; it is only noted that the correlation used by Demetriades[8] which employs the difference between transition and "sticking" distances in the Reynolds number does not improve any of the correlations shown here (In some cases, scatter is actually increased) Further details on this point and on other aspects of the material presented here may be found in Ref 11

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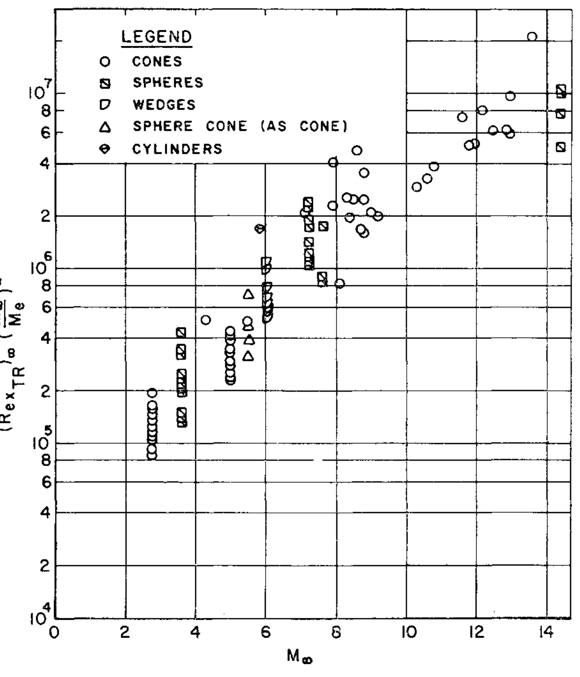

Fig 4 Unified wake-transition correlation

Approximate Nonequilibrium Air Ionization in Hypersonic Flows over Sharp Cones

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SEVERAL highly accurate methods have recently been developed for obtaining the nonequilibrium electron density distribution about a sharp re entering body Thus, Wood et al [1] have obtained inviscid flow-field solutions for cones and ogives by coupling the method of characteristics with a chemically reacting streamtube analysis between grid points

For the multicomponent air laminar boundary layer, numerical solutions of the coupled boundary layer and chemical kinetic equations have been obtained by Lenard and Blottner[2] by a finite difference method and by Pallone et al [3] using a multistrip integral approach These procedures, in general, are quite accurate but require extensive use of high-speed digital computers

More approximate boundary-layer theories that have been used are the "streamtube" method, which neglects diffusion, e g , DeRienzo et al [4] and Pallone et al ,[3] and the method of "local similarity," e g , Lenard and Blottner [2] The streamtube procedure, although highly flexible and useful for assessing effects of different chemical reactions, overpredicts the ionization rates The locally similar method[2] involves the solution of a nonlinear two-point boundary-value problem and requires more computer time than the more accurate finite-difference method, especially at the larger distances from the nose Thus, Blottner[5] concludes that, even for the two-component case (dissociating oxygen), the finite-difference method is more efficient

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