Transition in the Viscous Wakes of Blunt Bodies at Hypersonic Speeds†

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Summary

Transition from laminar to turbulent flow in the hypersonic wakes of spheres was detected in laboratory measurements of the radiation from the flow field. A hypervelocity gun facility was used to fire models, 0.22-in. in diameter, into a range at velocities from 10,000 to 17,000 ft/sec. Experiments were performed by changing: (a) the material of the projectile; (b) the ambient gas in the range; and (c) the pressure in the range. Three optical techniques were used to observe the wake radiation:

(1) Direct photographs of the projectile and flow field in air, which show a turbulent viscous wake as the pressure in the range is decreased from one atmosphere to about 20 cm Hg.

(2) Drum-camera photographs of the wake in air and argon, which show the luminous flow field at pressures between 30 and 0.5 cm Hg. At 30 cm Hg the trail is characterized by the presence of short luminous streaks, which disappear suddenly as the pressure is decreased below 3 cm Hg for air, and below 0.8 cm Hg for argon.

(3) Photomultiplier records taken through a thin slit with both air and argon, which show the main features of the flow field. Above the transition pressure, the intensity of radiation from the wake is always associated with fluctuations that appear to be the same phenomenon as the drum-camera streaks.

The appearance of the streaks in the drum camera and photomultiplier data is interpreted as transition from laminar to turbulent flow in the viscous wake, because experimental evidence shows that their appearance is not controlled by chemical, radiative, or ablative processes, but depends on aerodynamic effects. This conclusion is supported by other experiments based on optical and schlieren techniques. The transition in the wake at positions very close to the body is given by a local Reynolds number of 10^4 for air, and 3×10^3 for argon. The results indicate a possible local-Mach-number effect.

Symbols

c = heat capacity, Btu/lb-°R (0.4 for nylon; 0.3 for lexan)

D = diameter of sphere

I = relative radiation intensity

k = thermal conductivity, Btu/ft-sec-°R (3.9×10^{-5} for nylon; 3.1×10^{-1} for lexan)

L = distance downstream from shoulder of sphere

M = Mach number

P = pressure, cm Hg

R_n = radius of sphere, ft

R_e = Reynolds number based on local, inviscid-flow properties and dimension L or θ

S = space coordinate, unsteady frame of reference

t = time, μsec

T = temperature, °R unless otherwise specified

V_∞ = flight velocity, ft/sec

V_s = particle velocity in steady-state frame of reference

V_p = particle velocity in unsteady-state frame of reference, $V_p = V_\infty - V_s$

X = space coordinate, steady-state frame of reference

Z = distance from gun barrel to test window, ft

α = thermal diffusivity, ft²/sec ($\alpha = k/\rho c$)

ρ = density, lb/ft³ (70 for nylon and lexan)

θ = angle generated by rotation of nose radius away from stagnation point; also, laminar-boundary-layer momentum thickness

μ = viscosity, lb/ft-sec

Subscripts

e = external to viscous wake

n = nose radius

s = surface

st = stagnation point

o = sea level

∞ = ambient, flight velocity

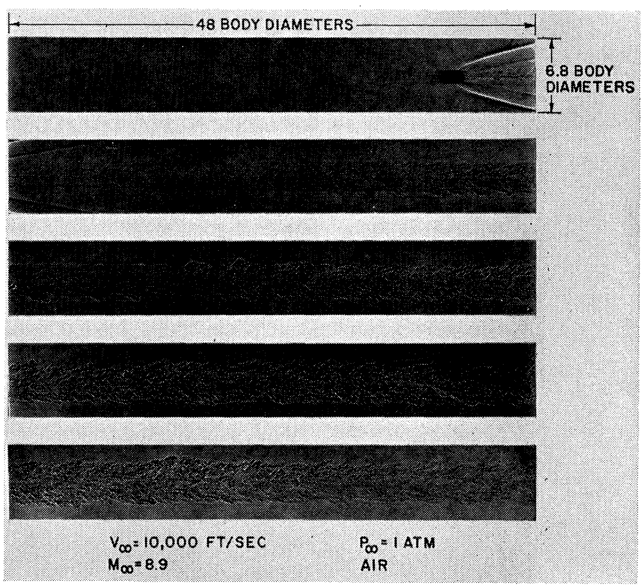

FIG. 1. Direct shadowgraph of projectile and wake. Exposure time, 1–2 μsec. Total length of shadowgraph is 5 ft or 240 projectile diameters.

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