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VELOCITY DECAY IN THE INTERMEDIATE WAKE REGION BEHIND HYPERSONIC SPHERES

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by

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ABSTRACT

Axial velocity decay data for hypersonic sphere wakes obtained with the sequential spark and probe array techniques have been fitted with an equation of the form $V_W/V_\infty = C_1 (X/D)^{C_2}$. This power law is found to fit the data very well for axial distances between 300 and 1000 body diameters behind the body. Values of C_1 and C_2 obtained from sequential spark measurements are given as a function of radial distance from the wake axis. Near the axis, the absolute value of C_2 is slightly greater than unity, decreasing to about one-third at radial distances of about two body diameters.

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It has been shown by Townsend (1) that in the case of the incompressible "self-preserving" axisymmetric turbulent wake, the growth of the viscous core varies as the 1/3 power of the distance behind the body, while the decay of the wake velocity varies as the minus 2/3 power of the distance. For the hypersonic turbulent wake, there is a large amount of wake growth data (2,3) existent to show that the 1/3 power law is obeyed over a range of axial distance from 100 to 10,000 body diameters behind a body. Until recently, velocity data has not been available on which to test the minus 2/3 power law in the hypersonic case, where the effect of large density variations might be expected to cause departures from such a law.

Experiments using CARDE hypersonic range facilities are now in progress to measure both velocity and mean density profiles across the turbulent wake (4,5). Consideration here will be restricted to velocity data. Most of this data has been obtained using the sequential spark experiment which measures the velocity profile across the wake at given axial distances behind the projectile.

The sequential spark technique, which is based on stereo measurement of the displacement history of an illuminated ionized path across the wake, has been described in recent publications (4,6). Considerable data has been generated for spheres over a range of pressures at hypersonic velocities. In addition measurements of wake velocity have been obtained at CARDE using arrays of electrostatic probes (7) and this data is in good agreement with the sequential spark data (8). The purpose of this note is to present preliminary results regarding the decay of the hypersonic turbulent wake velocity behind spheres as a function of axial distance downstream and of radial distance from the wake axis.

The velocity data obtained from measurements in a large number of firings at various axial distances (X/D in body diameters) has been separated according to various values of radial distance (R/D in body diameters) from the wake axis. For each value of R/D, the pertinent data has been fitted by the least mean squares method on an equation of the form

$$V_w/V_\infty = C_1 \, (X/D)^{C_2}$$

where V_w/V_∞ is the normalized wake velocity and C_1 and C_2 are constants for a given R/D.

Figure 1 gives an example of such a power law fit of sequential spark data at a radial distance of 0.7 B.D. (body diameter). The spark data (open points) pertains to 1.0 inch diameter sphere firings at 40 torr ($P_\infty D$ = 100 torr cm) at velocities of 12,000 to 15,000 ft/sec and is concentrated at axial distances of 300, 600 and 1,000 B.D. behind the projectile. Also shown for comparison are velocity results obtained with arrays of probes (solid points) using 2.7 inch diameter sphere firings at 20 torr (P_∞ D = 135 torr cm) over a range of velocity from 14,000 to 15,000 ft/sec. The agreement between the two sets of results is very good. Figures 2 and 3 show similar comparisons at values of R/D of 0.9 and 1.2 B.D. respectively.

In Figures 4 and 5, the values of C_1 and C_2 obtained from least mean square fits of sequential spark data are plotted as functions of R/D. Because of the large scatter in the data, which masks a weak dependence on pressure and a weaker dependence on Mach number, it was desirable to lump as much of the available data as possible to increase statistical accuracy. The crosses on the figures indicate data obtained from rounds at 20, 27, 40 and 76 torr, with velocities from 12,000 to 15,000 ft/sec. (Assuming a linear dependence of wake velocity on ambient pressure, the distributions of points are reasonably balanced, giving an average pressure of 40 torr.) These results may be compared with the open circle points, in which only data obtained at 40 torr is used. In the case of the "lumped" data, the number of data points is roughly 20 at 300 B.D., 10 at 600 B.D. and 40 at 1000 B.D. In the 40 torr case there are about 14 points at 300 B.D., 8 at 600 B.D. and only 4 at 1000 B.D. It is possible that these differences in the distribution of data points between the two cases may affect the slopes obtained from the power law fits, since the sequential spark data indicates a curvature departing somewhat from the power law fit at small R/D (Figures 1 and 2). However, despite the differences, both cases show the same trend.

Considering the exponent C_2, it may be seen that the velocity at small R/D decays approximately as the power of minus unity, while weaker values of the exponent occur at larger radial distances. Plotting the velocity decay at constant values of radial distance normalized to the wake width would result in higher absolute values of C_2. The values of C_1 in the two cases show comparable trends, except for the apparent deviation at small values of radial distance. The solid black circles on Figures 4 and 5 are values of C_1 and C_2 obtained from the electrostatic probe array velocity data shown on Figures 1 - 3.

The most important result of this work is that the wake velocity at intermediate values of axial distance (300 - 1000 B.D.) behind spherical projectiles appears to decay with a power law dependence on axial distance. The value of the exponent varies smoothly between values of the order of minus unity near the wake axis and about minus 1/3 at radial distances of about 2.4 body diameters.

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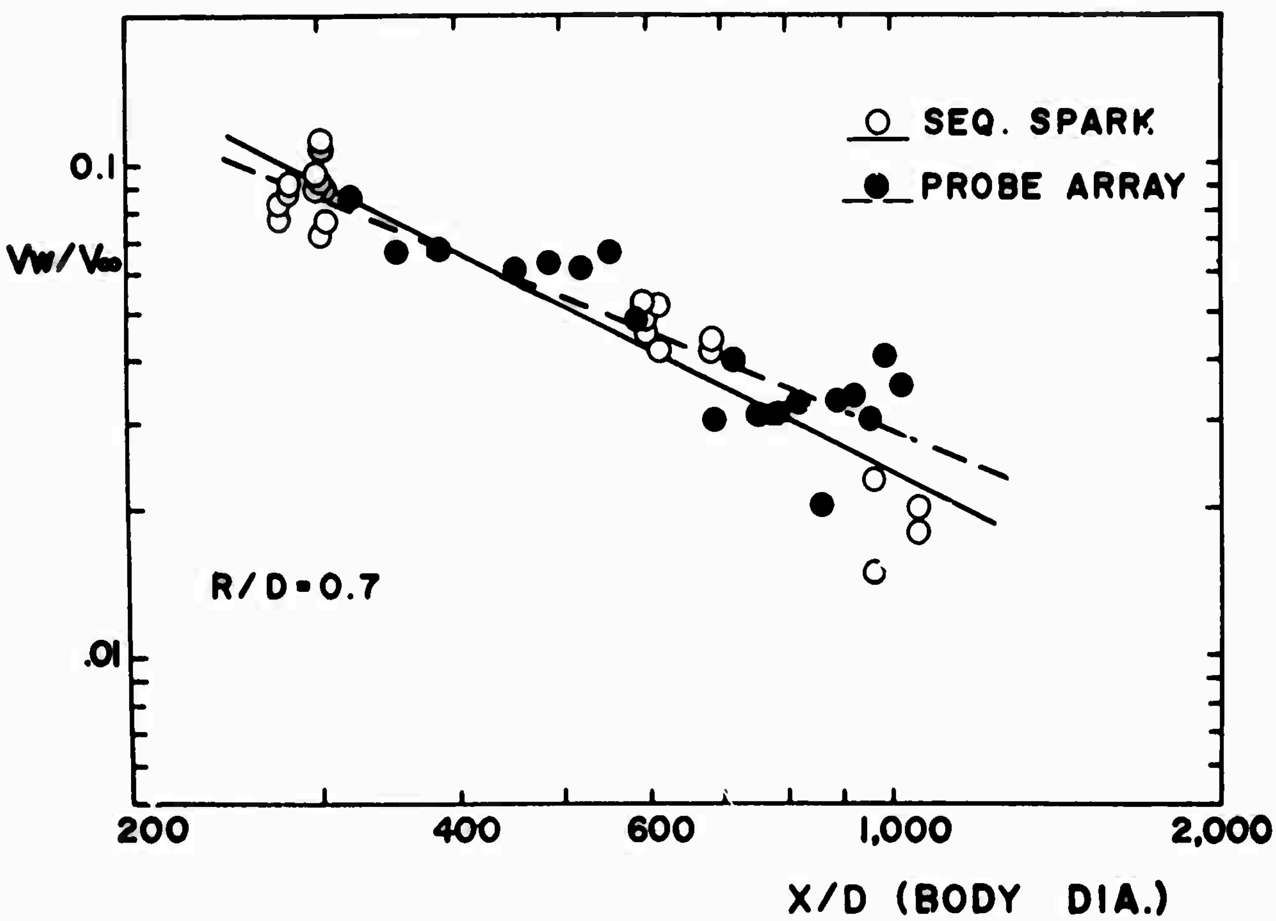

FIGURE 1 - Power law fits of sequential spark and electrostatic probe array wake velocity data at R/D = 0.7. The spark data is from 1 inch diameter sphere firings at 40 torr and velocities from 12000 to 15000 feet/sec while the probe data is from 2.7 inch sphere firings at 20 torr and velocities from 14000 to 15000 feet/sec.

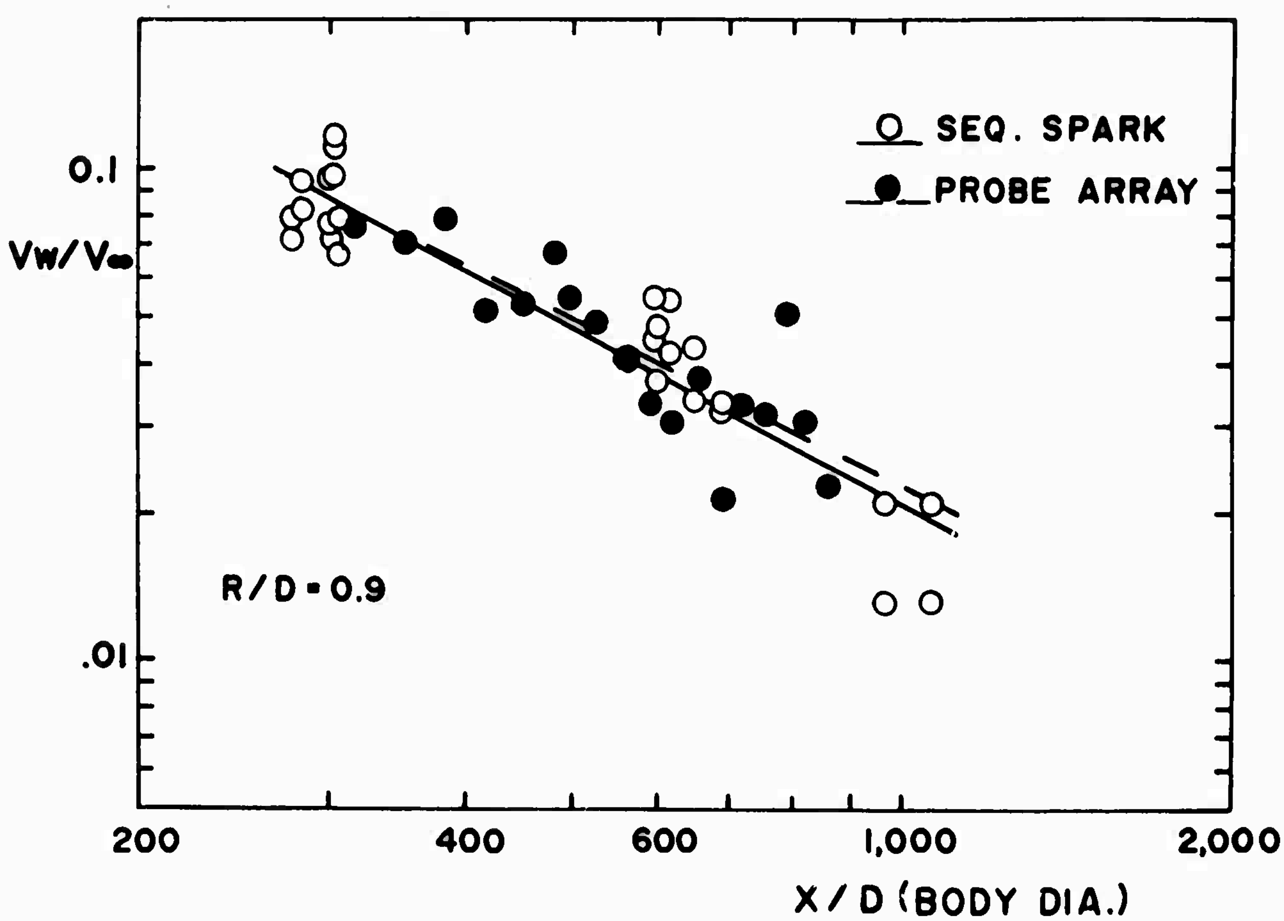

FIGURE 2 - Power law fits of sequential sparks and electrostatic probe array wake velocity data at R/D = 0.9. The spark data is from]. inch diameter sphere firings at 40 torr and velocities from 12?00 to 15000 feet/sec while the probe data is from 2.7 inch sphere firings at 20 torr and velocities from 14000 to 15000 feet/sec.

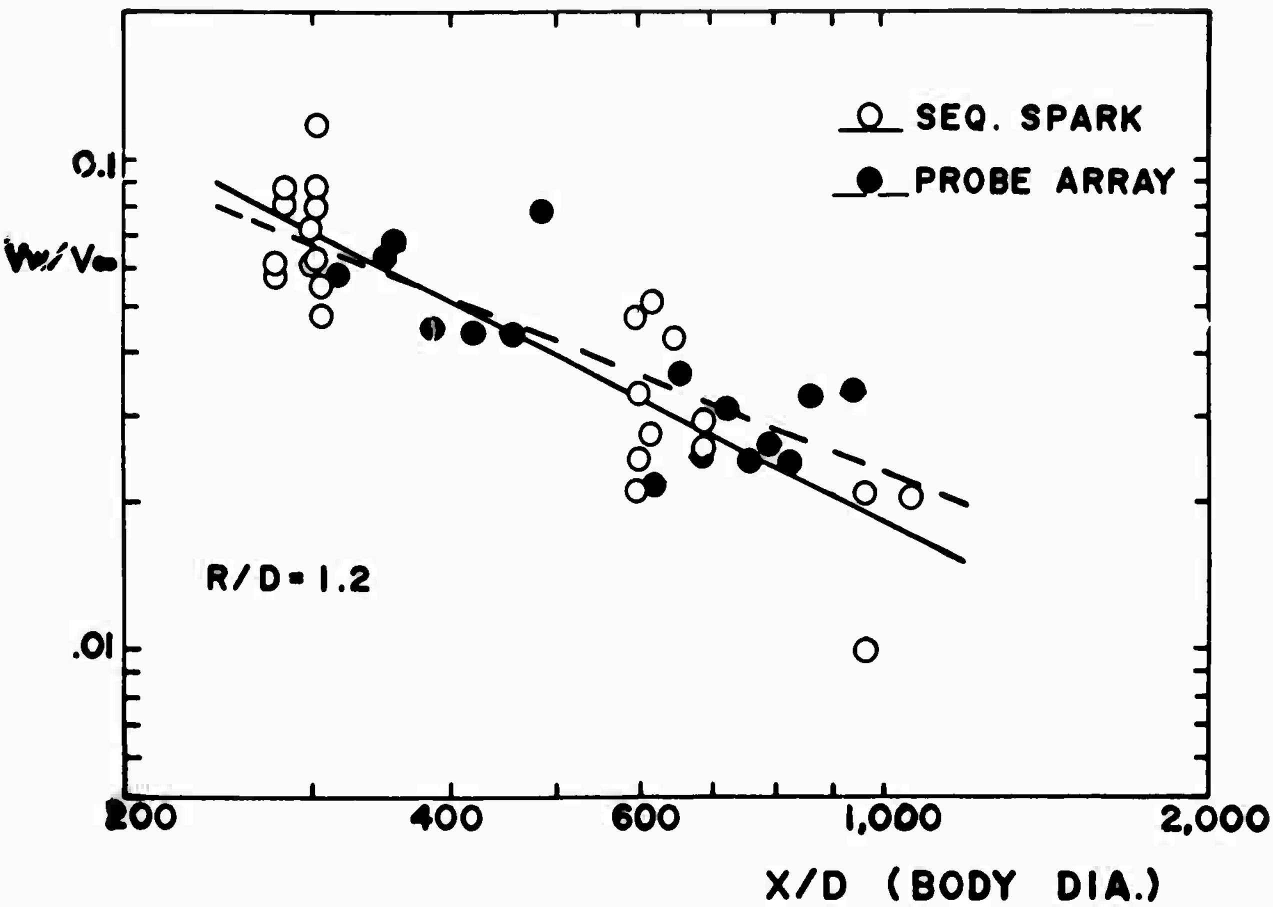

FIGURE 3 - Power law fits of sequential sparks and electrostatic probe array wake velocity data at R/D = 1.2. The spark data is from 1 inch diameter sphere firings at 40 torr and velocities from 12000 to 15000 feet/sec while the probe data is from 2.7 inch sphere firings at 20 torr and velocities from 14000 to 15000 feet/sec.

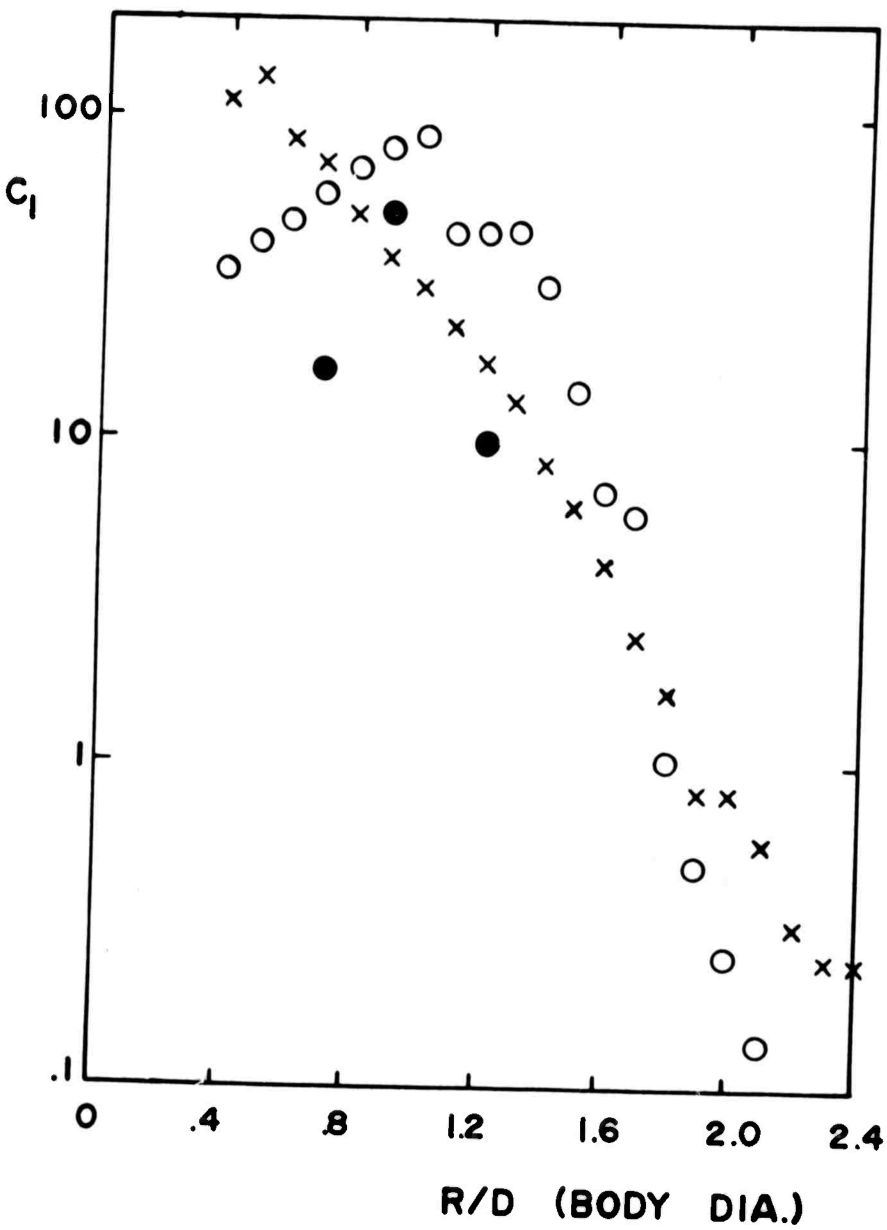

FIGURE 4 - Constant C_1 as a Function of R/D

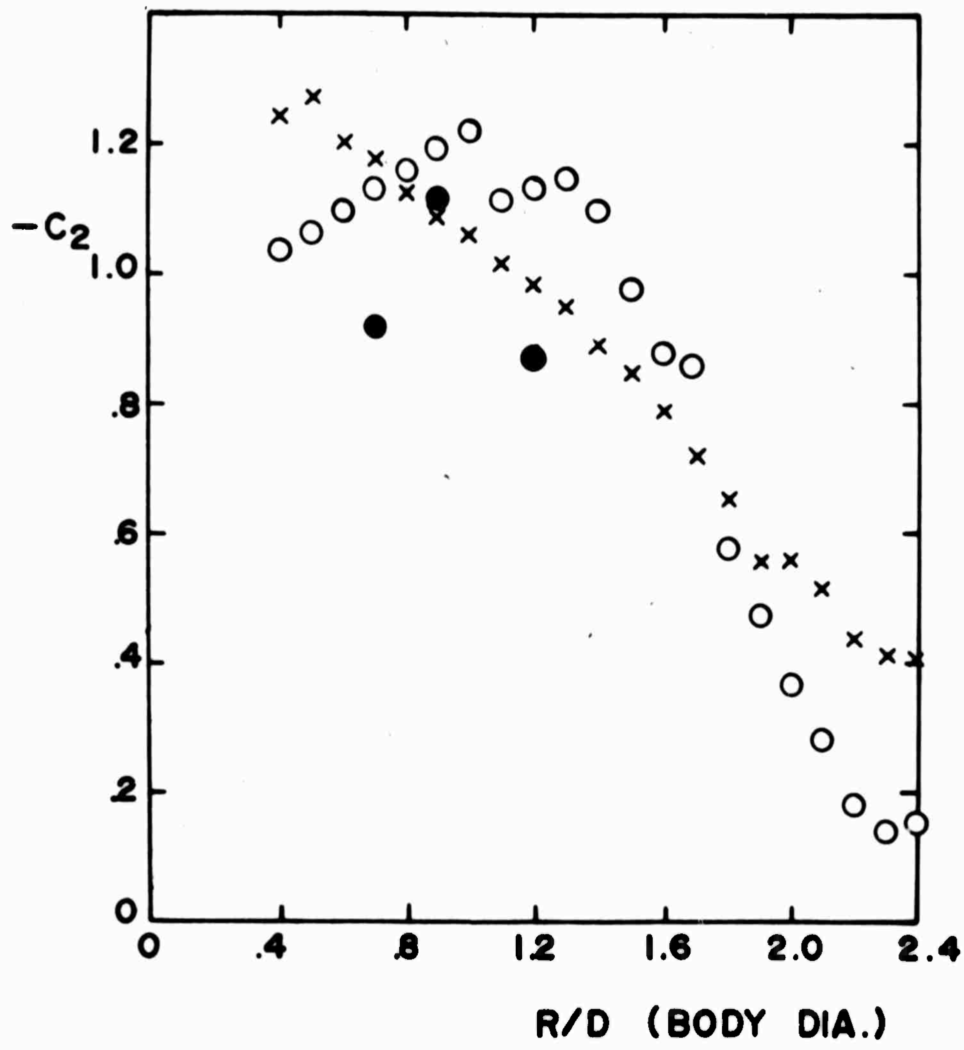

FIGURE 5 - Value of Exponent C_2 as a Function of R/D

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