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Rear Stagnation Point Location in a Subsonic Near-Wake

R.A. Merz*
Air Force Institute of Technology, Wright-Patterson Air Force Base, Ohio
and
R.H. Page† and C.E.G. Przirembel‡
Rutgers University, New Brunswick N.J.

Nomenclature

x = axial distance from base (positive: downstream)
$x_{s.p.}$ = location of rear stagnation point
D = model diameter
d = probe diameter
M_l = approach Mach number
C_p = pressure coefficient

Introduction

NUMEROUS experimental investigations of axisymmetric near-wakes have shown that the low-pressure recirculation region associated with blunt based vehicles contributes to the total drag of the body. This contribution may be significant depending on the geometry of the vehicle and its speed. A knowledge of near-wake phenomena is essential for reentry vehicle design, since it is this region that provides the initial deceleration of the body. In addition, the near-wake structure determines the configuration of the far-wake. Information concerning both of these regions of flow is necessary for the successful deployment of any parachute and for determining its inflation-drag and -stability, drag efficiency and structural loading. All these data must be known to accomplish a soft landing.

Over the past thirty years, there have been many experimental investigations of the wakes of various axisymmetric bodies and a number of theoretical analyses. Rather complete literature reviews of the available data may be found in Refs. 1-3. From these reviews, it can be seen that there is a paucity of consistent, reliable experimental data in the subsonic speed range. It is in light of this fact that the results contained in this Note are presented.

The extent of the near-wake region is very important to the design of decelerator systems and theoretical wake analyses. One wake characteristic which is dependent on the freestream Mach number and describes the size of the near-wake is the location of the time averaged, rear stagnation point. Attempts in the past to locate this point as a function of Mach number in subsonic flows have been hampered by the presence of a sting or other model support devices and by probe interference effects. This Note presents some recent data where these effects have been eliminated.

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Index categories: Jets, Wakes, and Viscid-Inviscid Flow Interactions; Entry Vehicle Testing; Subsonic and Transonic Flow.

*Instructor, Aero-Mechanical Engineering Department. Member AIAA.

†Professor and Chairman, Mechanical, Industrial and Aerospace Engineering Department. Associate Fellow AIAA.

‡Associate Professor, Mechanical, Industrial and Aerospace Engineering Department. Member AIAA.

Apparatus and Procedure

A series of tests were conducted in a second-generation Rutgers Axisymmetric Near-Wake Tunnel (RANT II).[1] This tunnel was designed and constructed for interference-free studies of turbulent axisymmetric near-wakes at subsonic speeds. As shown in Fig. 1, the unique feature of RANT II is an upstream sting which was designed as an integral part of the nozzle to produce uniform flow over a 1.9-cm diam cylindrical model. RANT II is an open jet, blowdown type tunnel capable of producing speeds over the entire subsonic Mach number range. The nozzle has an overall contraction ratio of 8:1 and an exit diameter of 10.16 cm. Reynolds numbers for the tests varied from 0.1×10^7 per meter to 3.1×10^7 per meter. Stagnation pressures varied from just above atmospheric pressure to 206 kPa absolute, while the stagnation temperature was 283 K ± 11 K. Velocity profiles of the boundary layer approaching the blunt base showed that it was turbulent and fully developed for all approach Mach numbers.

A stagnation point may be characterized as a point in a flowfield where the static and total pressures are equal (that is the dynamic pressure equals zero). For an axisymmetric body, one such point occurs on the centerline at the downstream limit of the near-wake. Figure 2 shows a schematic of the flow model. To locate this point, total and static pressures on the near-wake centerline were measured by extending either a pitot probe or a static probe from the blunt base through a hole in the center of the base. Both probes consisted of a straight piece of stainless steel tubing with an o.d. of 0.89 mm and an i.d. of 0.61 mm. The tip of the pitot probe was open and rounded while the static tube had a tip which was plugged and rounded. The static probe had an orifice 0.56 mm in diameter located on the side wall of the probe 0.60 cm from the tip. The location of both probes was changed by manually sliding them in or out of the base. The position of each was measured with a precision scale readable to 0.25 mm. The pressure sensed by the probes was measured with a water manometer readable to 0.13 cm of water.

In addition to the probe pressure, the base pressure was measured to monitor the basic flow. No change in base pressure was observed during the centerline surveys. This was

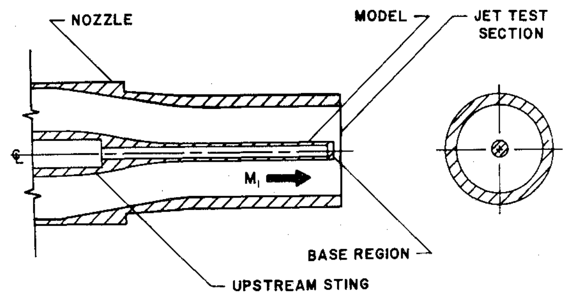

Fig. 1 Schematic of RANT II nozzle.

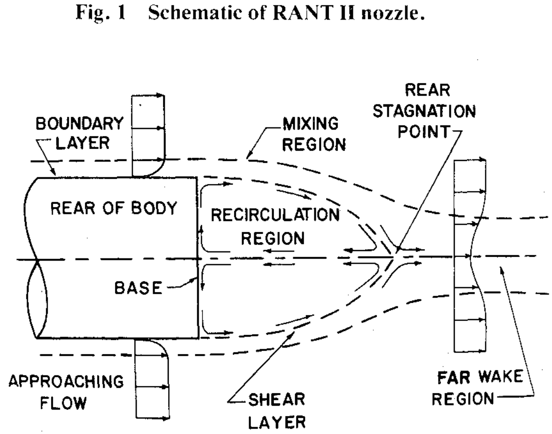

Fig. 2 Flowfield schematic.

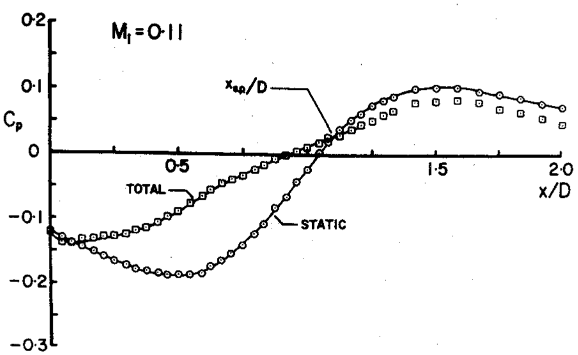

Fig. 3 Centerline pressure distributions – $M_l = 0.11$.

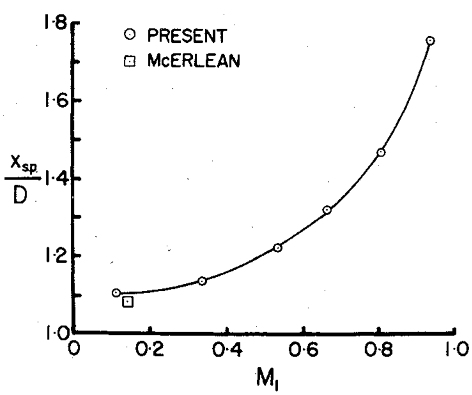

Fig. 4 Rear stagnation point location vs Mach number.

expected,[4] since the ratio of probe diameter to base diameter was small ($d/D = 0.0467$).

Throughout all the experiments, the test section static pressure was measured with a 0.762-mm diam pressure tap located three base diameters upstream of the blunt base. Also, the tunnel total pressure was measured with a Kiel probe in the tunnel plenum chamber. These pressures were read on a water and a mercury manometer, respectively. Each was readable to 0.13 cm of manometer fluid.

Results and Discussion

Tests were conducted for Mach numbers of 0.11, 0.33, 0.52, 0.66, 0.80, and 0.94. The measured total and static pressures were plotted in pressure coefficient form against the distance from the base. The tunnel test section conditions were used in the pressure coefficient calculations, while the model diameter was used to normalize the distance from the base. A typical plot is shown in Fig. 3 for the incompressible case.

The point on the graph where the static pressure is equal to the total pressure is the time-averaged, rear stagnation point. At this point the average centerline velocity is zero. It should be noted that in Fig. 3 data points from the total pressure probe are shown beyond the rear stagnation point, but since the flow did not impinge on the probe orifice, the data points do not represent the centerline total pressure.

From the plots of centerline total and static pressures, the average rear stagnation points were located. Figure 4 shows the variation of the location of the average rear stagnation point with approach Mach number. It can be readily seen that as the Mach number increased, the rear stagnation point moved downstream. For all subsonic Mach numbers, the rear stagnation point was found to be between one and two model diameters downstream of the base. These results can be compared with those of Campbell and Brown[5] for a Viking '75 entry vehicle. They report rear stagnation points from two to four model diameters downstream for Mach numbers between 0.4 and 1.2. However, it must be remembered that the initial angle of separation for their model was considerably different than in the present study. The present results for the incompressible case are in agreement with those of McErlean.[2]

Conclusion

An interference-free study of the location of the average rear stagnation point in the near-wake of an axisymmetric cylindrical blunt based body has been completed. Over the entire subsonic Mach number range, the location of the average rear stagnation point was found to be between one and two model diameters downstream of the base. This point moved downstream with increasing Mach number.

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