

An Investigation of Bluff Body Blockage Corrections Using the NASA/ODU 6-inch MSBS

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ABSTRACT

Spheres of different diameters were tested in the NASA/ODU 6-inch MSBS. The objective is to develop an improved understanding of blockage corrections to be made to other bluff-body geometries. Drag coefficients are shown with classical corrections applied, along with wall pressure signatures and base pressure measurements. Anomalous behavior was observed with the largest diameter, thought to be some form of flow breakdown, hence uncorrectable interference.

1. Introduction

Corrections for blockage effects in wind tunnels have been studied for many decades but little attention has been paid to the case of re-entry vehicle shapes. In this case, a very large axisymmetric wake is developed by a body with significant internal volume. This differs from prior aeronautical applications, instead more closely resembling automotive geometries, without the complication of ground effect. As a first step towards validating a blockage correction method for subsonic testing in the NASA/ODU 6-inch MSBS, a series of spheres of varying diameters were tested in a test section equipped with wall pressure taps. Base pressure measurements were made using a sting-mounted probe.

2. Blockage Correction Methods

Simple blockage corrections are applicable to streamlined shapes with small wakes [1]. Here, any wake constraint does not substantially affect the model's flow field aside from a change in effective velocity. Where large regions of separation arise, wake constraint causes changes in base pressure, consequently additional drag. Maskell's method [2] was developed for corrections of bluff-bodies or stalled wings and has been widely used. The blockage correction can be as much as 5 times the value based on classical approaches. Some questions have been raised concerning the applicability to cases where the model has substantial internal volume, so alternative approaches have emerged for automotive testing [3]. Figure 1 illustrates the range of scenarios.

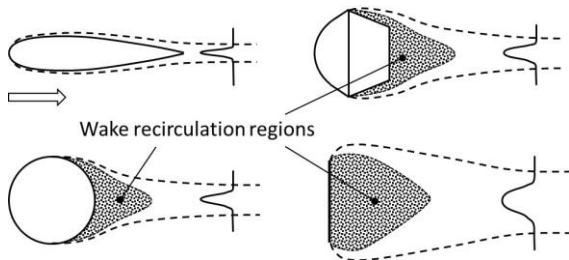


Fig. 1 Notional Wake Flow Structures (airfoil, capsule, sphere, plate (Maskell's model))

3. Method

The NASA/ODU 6-inch MSBS is described in several publications [4]. In the current configuration, the magnetization direction is vertical, with feedback control of translations, resulting in "free-to-yaw" behavior. The

low-speed wind tunnel features an octagonal test section, nominally 152.4mm across flats and 0.9m long. The squirrel cage fan can develop flows up to 150 m/s or so. Three sphere models were 3D printed with diameters of 44.45, 50.8, and 57.15mm, corresponding to blockage ratios of 8.1, 10.6, and 13.4% respectively. Surface finishes were considered acceptable to support laminar flow at lower Reynolds numbers. Each model contained with a 25.4mm diameter spherical Nd-Fe-B permanent magnet core. The overall facility is shown in Figure 2.

Wall pressures at 21 stations distributed along centerlines of 2 opposing flats were measured using a pair



Fig. 2 The NASA/ODU 6-inch MSBS

of Scanivalve™ DSA-3217 pressure scanners (10in H₂O range ≈ 2.5kPa). The tunnel reference static and the pitot pressure from a fine tube inserted into the model's wake from downstream were also measured. Drag calibration was carried out using deadweights connected via a pulley and fine thread. MSBS data for model position, electromagnet currents and other parameters was logged via the Speedgoat™ controller and downloaded posttest.

4. Application of Corrections

Maskell's method is applied by first defining a base pressure parameter, then iteratively solving for its value.

$$k^2 = 1 - C_{pb} \quad (1)$$

$$(k_c^2)_n = k^2 / \left[1 + \frac{1}{(k_c^2)_{n-1} - 1} \frac{C_{D1}S}{C} \right] \quad (2)$$

The dynamic pressure is then adjusted as follows:

$$\frac{q_c}{q} = \left[1 + C_{D0} \frac{S}{2C} - \frac{1}{(C_{pb})_c} \frac{S}{C} \right] \quad (3)$$

S is the model frontal area, C the tunnel cross sectional area, C_{D0} the drag due to skin friction and C_{D1} the drag due to base pressure. In this case, C_{D0} is taken to be very small. Further details are given in the literature [2,3,4].

5. Results

Uncorrected and corrected drag coefficients for the 3 spheres are presented in Figure 3. The values for the two smaller diameters collapse satisfactorily to reference values [6]. Values for the largest diameter are anomalous, especially at lower Reynolds numbers, and are discussed later. The empty tunnel pressure gradient was used as the baseline wall pressure signatures. At a flow dynamic pressure of 300Pa (22m/s), the gradient over the full length of the (unusually long) test section was of the order of 9% of this value, suggesting relatively thick wall boundary layers. Pressure signatures showed significant fluctuations, so were averaged over 50 samples. A theoretical signature was estimated by solving axisymmetric source and doublet flows. The measured signature around the model was biased downstream, representing the blockage of the near wake recirculation region, or “bubble” [3]. The far wake signature was weaker than expected, suggesting interaction with the wind tunnel wall boundary layers. Figure 4 shows one example.

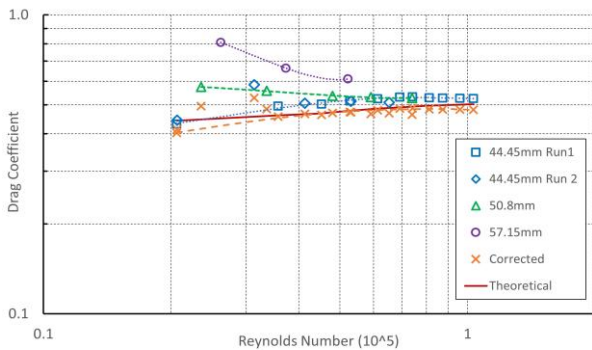


Fig 3. Drag Coefficients

Base pressure coefficients are shown in Figure 5, with values of the order of -0.6 seen for the two smaller spheres. The largest diameter is again anomalous.

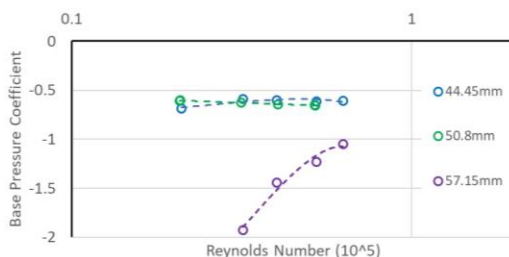


Fig. 4 Base Pressure Coefficients

6. Concluding Remarks

Results for the two smaller spheres collapse satisfactorily to each other and to reference data, but the largest diameter does not, with high uncorrected drag and low base pressure. This may indicate some form of flow breakdown, consistent with the fact that tunnel wall boundary layers at low speeds are relatively thick. A maximum usable model blockage ratio can perhaps be established, although further work is required to resolve some of the questions raised.

Pressure signature methods for blockage correction are now popular [3,4] but are difficult to apply here without further knowledge of the wake “bubble”.

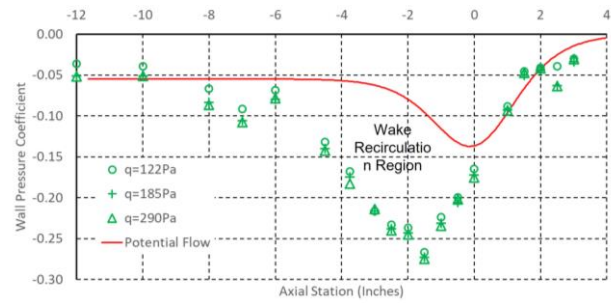


Fig.5 Wall Pressure Signatures (50.8mm case)

Acknowledgments

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