Blunt-Body Flow Field Visualization

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Figure 1. *Miniature blunt-body reentry capsule model interacting with food coloring dye in a laminar flow field.*

I. Introduction

Blunt-body fluid dynamics is a staple of modern aerodynamic theory for the application of space reentry vehicles. In 1951, H. Julian Allen at the NACA (National Advisory Committee for Aeronautics) Ames Aeronautical Laboratory introduced the concept of blunt body reentry vehicles as a way to reduce aerodynamic heating around the body. The rationale for this concept was that a blunt body, rather than a slender one, would create a stronger shock wave in front of the vehicle at high speeds and cause a larger heating of the airflow around the vehicle thereby decreasing the amount of energy available to be transferred into the body.[1] It was an amazing revelation that is still utilized throughout space industry almost 60 years later. It is this spirit that Figure 1 provides a simple low speed visualization of the flow field surrounding a blunt-body reentry capsule.

II. Experimental Setup and Analysis

Figure 1 consisted of a miniature blunt-body reentry capsule model attached to a brass sting assembly suspended in an open channel water flume located in the Integrated Teaching & Learning Laboratory (ITLL) at the University of Colorado Boulder campus. The water flume has a 2.5m x 76mm x 250mm water channel with a jacking arrangement that permits the slope of the bed to be adjusted between -1 to +3%. The water level in the working section of the flume is controlled by an overshot-weir arrangement at the exit of the channel.[3]

The blunt-body vehicle reentry model measures approximately 26mm in diameter at the base and 8mm at the top of the conic section. The model is attached to a brass tube that acts as a string assembly to hold the model in the water channel without significantly affecting the fluid dynamics around the model. The sting is 8mm in diameter and measures approximately 30cm in length, the base of the sting is attached to depth measurement device downstream of the reentry model.

The flow field seen in Figure 1 was generated from a 0% slope angle, a water depth of 20cm, and a flow rate of approximately 50 liters per minute (~8.333E-4 m^3/s). The Reynolds number for the water channel can be calculated using Equation 1.[4]

$$Re = \frac{QR_H}{\nu A}; R_H = \frac{bh}{(b+2h)} \qquad (1)$$

A	=	cross-sectional area (m^2)
b	=	water channel width (m)
h	=	water channel depth (m)
Re	=	Reynolds number
R_H	=	hydraulic radius (m)
Q	=	volumetric flow rate (m^3/s)
ν	=	kinematic viscosity of fluid (m^2/s)

For the flow conditions in Figure 1, the Reynolds number is estimated to be 1741.86 meaning that the water around the capsule is mostly laminar. The vortex structures outlined by the dye are generated by flow separation in the wake of the capsule.

III. Visualization Technique

Diluted food coloring dye was used for the flow field visualization in Figure 1. The dye was diluted sufficiently to provide neutral buoyancy when infused into the water flume at a depth of approximately 15 cm from the bottom of the channel. The dye was injected using a handheld plastic syringe and transparent vinyl tubing positioned within 1 cm of the reentry model's bottom surface.

Figure 1 was backlit by two halogen work lamps sitting behind a white piece of plastic attached to the backside of the water channel. The plastic acted as both a solid color background for the image and as a diffuser for the lighting. Backlighting the image also helped to reduce the appearance of shadows from the blunt-body model and sting assembly though some shadows are visible in the original image (Figure 2) from ambient light.

IV. Photographic Details

Figure 2. *Source image for Figure 1 prior to post-processing.*

Figure 1 is a cropped and post-processed version of Figure 2. Figure 2 was taken with a Samsung NX-10 interchangeable lens digital camera featuring a 14.6-megapixel 23.4mm x 15.6mm APS-C CMOS imaging sensor producing a 4592 × 3056 pixel resolution image.[2] The image was captured using the full resolution capabilities of the camera and stored in the camera's RAW unprocessed image format. Exposure was 1/160 of a second at a focal length of 55mm, aperture setting of f/5.6, and sensor sensitivity of ISO 200 at a lens distance of approximately 6 inches from the subject. The 55mm focal length gives the camera an effective field of view angle of approximately 24.0 degrees horizontally and 16.1 degrees vertically.

Post-processing of the image was conducted using Pixelmator (http://www.pixelmator.com/) image editing software available for the Mac OS operating system. The image was subsequently cropped, color inverted, and converted to a black-and-white color spectrum to produce the final image seen in Figure 1. Image brightness was also reduced to enhance the contrast between the blunt-body model and the food coloring dye.

V. Conclusion

The flow separation effect seen in Figure 1 provides some insight into the fluid dynamics of blunt-bodies. Foremost, it is easy to generalize that the majority of drag around a blunt-body is generated by flow separating from the body itself, commonly referred to as pressure or form drag. This stands in stark contrast to streamlined bodies that generate drag from the friction of the fluid moving along the surface of the body (skin friction drag). One point of interest to note is that pressure drag is reduced in turbulent flow, while skin friction drag is reduced in laminar flow leading one to conclude that blunt-bodies actually prefer turbulent flow when trying to minimize drag.[1]

References

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