Static and Dynamic Testing of Blunt Bodies in a Subsonic Magnetic Suspension Wind Tunnel

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ABSTRACT

The MIT 6-inch magnetic suspension wind tunnel is used in two configurations to measure lift forces of two blunt bodies and produce free-to-pitch oscillations driven by capsule static stability and dynamic instabilities. Lift tests show that static aerodynamic data can be measured on a magnetically levitated model without moment control. Free-to-oscillate results show that magnetic suspension balance system (MSBS) can produce capsule dynamics suitable for extracting static and dynamic stability data.

1. Introduction

The MIT 6-inch magnetic suspension wind tunnel [1] has been refurbished through a partnership between NASA and Old Dominion University. The tunnel is being used to develop test methods to measure pitch damping characteristics of blunt entry vehicles. Wind-on levitation was achieved in the fall of 2017. This was followed by calibration of the MSBS and characterization of different core materials as well as the first static drag measurements [2]. Test procedures are being developed to measure lift forces with models suspended at angles of attack and dynamic testing where the model is free to pitch, while constrained in the other degrees of freedom. Work has focused on demonstrating the f easibility of static and dynamic testing without moment control of the test articles.

2. MSBS Operation

Levitated models are controlled using a state estimator and Linear Quadratic Regulator (LQR) feedback design, with integral feedback to reject steady disturbances. Rotational states of the model are not sensed or commanded, and so were not part of the regulator design. The control system was implemented in Simulink, and autocoded to create software compatible with a real-time computer operating at 1000 Hz. Position feedback comes from an Electromagnetic Position Sensor (EPS) system. The intended use for this tunnel is to measure the dynamic stability of blunt bodies by measuring free oscillation histories. Separating dynamic aerodynamic moments from static aerodynamic moments and magnetic moments with a full 6-DoF controller was deemed impractical.

3. Model Test Configurations

To achieve free oscillation a number of model materials (permanent magnets and iron alloys) were assessed to see if a spherical core would rotate freely when levitated. The coercive forces of all materials tested were too high to achieve free oscillations. However, each levitated core would freely rotate about the magnetizing field. In normal operation this results in models rolling freely in the flow. Neodymium-iron-boron (NdFeBo) permanent magnet cores were shown to stiffly align with the magnetizing field, while remaining free to rotate about the N-S axis. This feature was employed to create a set of models held at fixed angles of attack to measure lift. The MSBS was then rotated 90 degrees to demonstrate that models can pitch freely about the magnetizing axis. Figure 1 shows the two test configurations. A new smaller test section (2.375-in. H x 2.664-in. W) was fabricated that could pass through the side viewing ports of the MSBS. The rotation meant that the duties of the side and drag force coils are swapped.

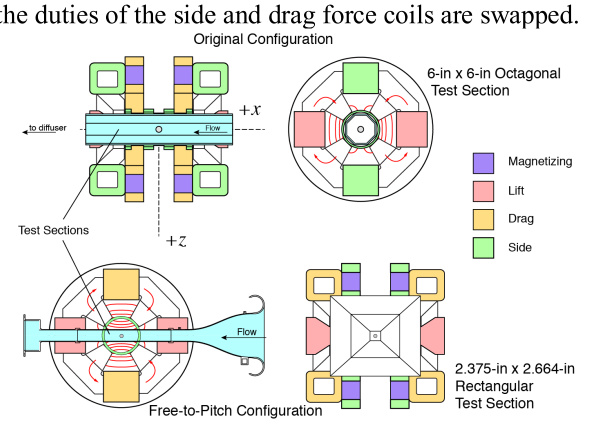

Figure 1 MSBS orientations for force and oscillation testing

4. Wind Tunnel Models for Lift and Pitching

Models of the Stardust capsule [3] and an approximation of the Orion entry vehicle were 3D printed with PLA plastic. 0.75-inch diameter x 0.75-inch length cylindrical NdFeBo magnets were located inside the models, canted at 8 and 16-degree angles relative to the model axes of symmetry. When levitated in the baseline MSBS configuration, the magnets would align with the magnetizing field, parallel to the tunnel freestream, holding the models at 8 and 16 degrees angle of attack. Dynamic pressure sweeps were run to measure the lift coefficient at these angles.

Another Stardust model was 3D printed to accommodate a 0.75-inch diameter NdFeBo sphere, which allowed for a smaller model to fit around the magnetic core so as to reduce blockage in the smaller free-to-pitch test section. The poles of the magnet were oriented to be orthogonal to the spin axis of the model, though a small sideslip was observed when levitated. In

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the transverse tunnel, the model was free to pitch and oscillated in tunnel flow due to its static pitch stability.

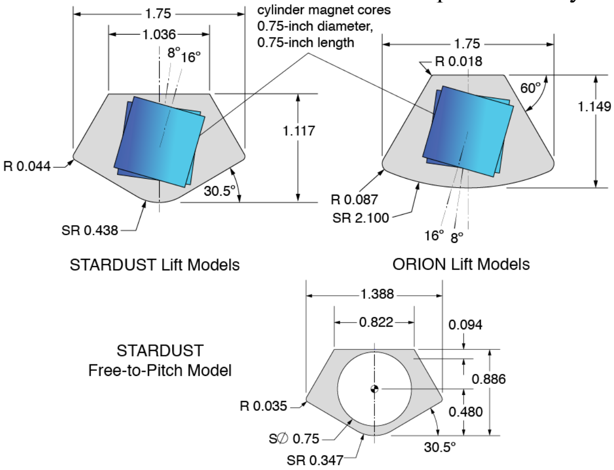

Figure 2 Lift and Free-to-Oscillate Wind Tunnel Models (dimensions in inches)

5. Lift Tests

Lift coefficient data from the Stardust and Orion canted-core models are plotted against reference wind tunnel data in Fig 3. Agreement is good for this preliminary assessment. The wind-off levitation current was subtracted from the lift current history and root-sum-squared with the side force current to determine the total lift force. The variation due to dynamic pressure needs to be investigated further. Signal-to-noise improved as dynamic pressure was increased. During testing the models rolled about the tunnel centerline. The 16-degree models showed more roll and lateral translation due to their increased lift, limiting the maximum dynamic pressure.

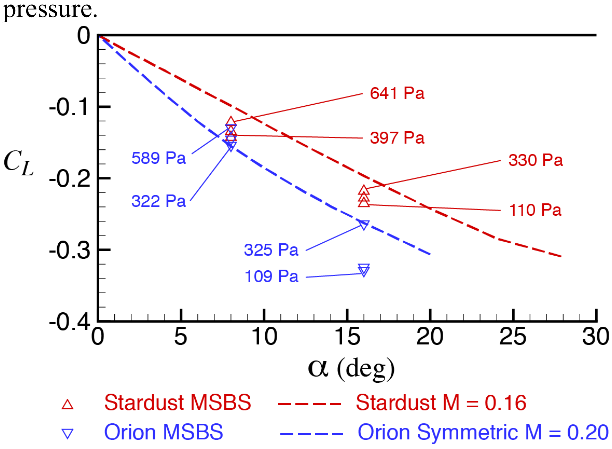

Figure 3 MSBS lift compared to historical wind tunnel data

5. Free to Oscillate Tests

The small Stardust free-to-pitch model is shown levitating in the transverse tunnel in Fig. 4. Video data at a small dynamic pressure (estimated to be approximately 50 Pa) was recorded and digitized to determine the attitude history. The planar attitude history can be approximated by the equation shown in Fig. 5 [4]. This model was fit to the measured attitude history to identify the oscillation frequency and nose-down trim angle (the model cg was slightly forward of the magnet centroid). Future work will use this model to extract static and dynamic moment coefficients.

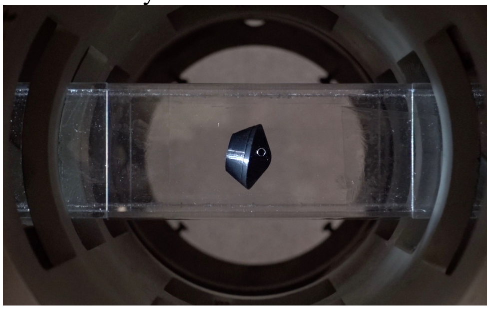

Figure 4 Free-to-pitch Stardust capsule in transverse tunnel

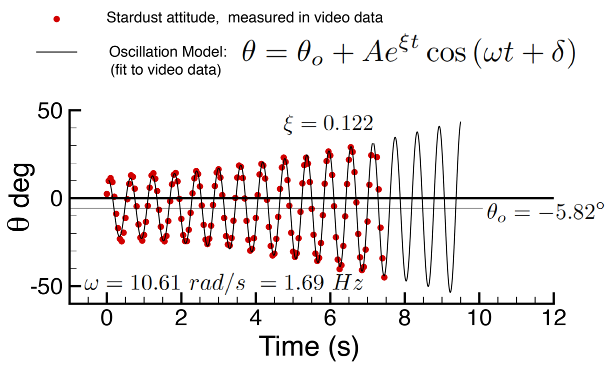

Figure 5 Planar oscillation model fit to Stardust video data

This free-to-oscillate configuration was intended as a proof of concept test to demonstrate that models would oscillate freely and capsule oscillations would grow or decay due to dynamic damping properties of the capsule. This demonstration was successful, although several sources of error must be addressed before the accuracy of aerodynamic coefficients can be determined. Model blockage affected dynamic pressure measurements during this test. The active control of the MSBS acting at a (small) distance from the model cg can introduce non-aerodynamic oscillation growth or decay. The MSBS control inputs can produce plunging motions that affect the angle of attack history, complicating pitch damping measurements as well.

Conclusion

Static lift forces were measured and free pitch oscillations recorded to extract damping information of blunt bodies. Future work will assess error sources and measure capsule pitch damping with uncertainties. Lessons learned from the transverse configuration can be applied to future MSBS designs for dynamic testing.

References

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