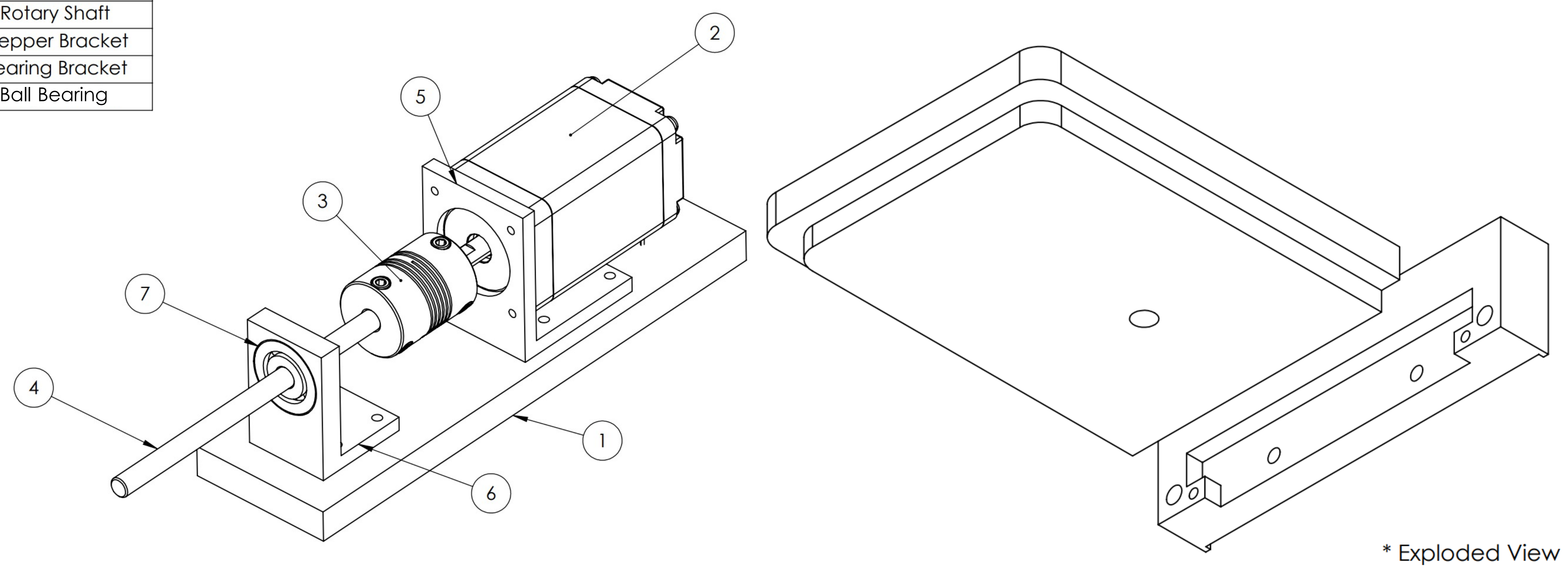
Design and Fabrication of Rotating Test Stand for Supersonic Wind Tunnel

CAL POLY
College of Engineering
Department of Aerospace Engineering

Suren Sanai*, Sam Groom, Peter Kim, Dr. Nandeesh Hiremath

1	Test Stand
2	Stepper Motor
3	Set Screw Coupler
4	Rotary Shaft
5	Stepper Bracket
6	Bearing Bracket
7	Ball Bearing



An assembly of the rotating test stand can be seen above (pictured left). The entire test stand consist of a stepper motor, alignment coupler, rotary shaft, ball bearing, and multiple supports. This rotating test stand interfaces with a newly designed test section lid for the Cal Poly Supersonic Wind Tunnel (SSWT). The lid is depicted in an exploded view above (right).

Why Rotate the Test Stand?

Whether it is the turning of an F-35 wing at Mach 1.6 or the tumbling of a reentering Dragon capsule, aerospace objects are often subject to rotation while traveling at supersonic speeds. While Cal Poly has already developed a detailed and novel system for testing the aerodynamics of rotating bodies at *subsonic* speeds [1], there is much to be desired in the development of *supersonic* testing systems. In developing a rotating test stand for the Supersonic Wind Tunnel (SSWT), the varying aerodynamics of bluff bodies across changing orientations can be systematically studied. This dynamic assessment is essential for understanding the real-world behavior of objects like atmospheric re-entry vehicles and small celestial objects. It also helps validate design limitations and provides valuable data for engineering applications [2].

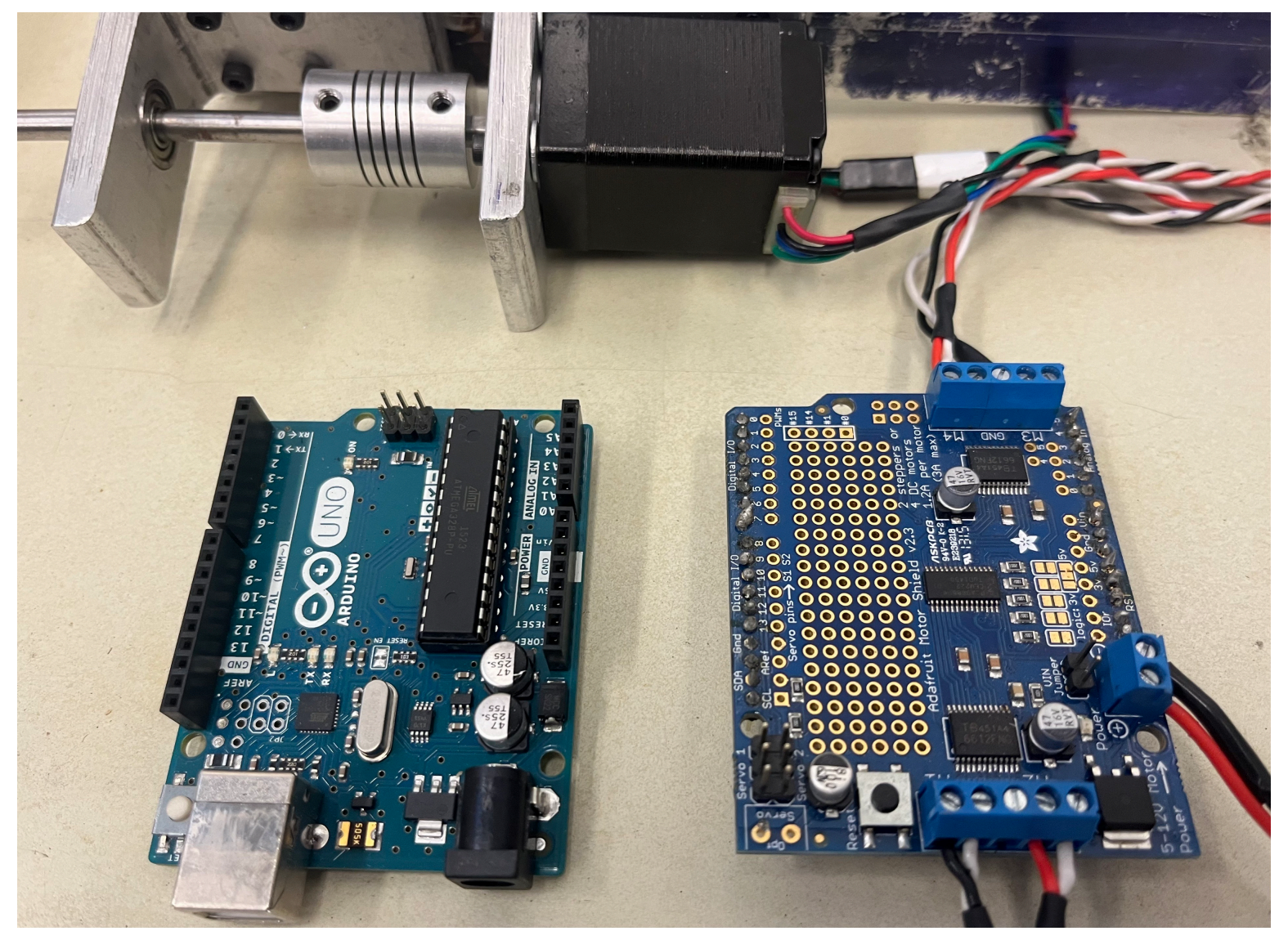


Figure 1. The Arduino UNO (bottom left) and the Adafruit Motor Shield V2 (bottom right) used to control the motor and drive current respectively. The motor shield is connected directly to the brushless stepper motor (top) which is used to rotate the test stand.

Controller Programming

HARDWARE

A **brushless stepper motor** was used to create rotational motion for the test stand by energizing coils in a specific sequence, causing the motor to move in precise, discrete steps, making it well-suited for applications requiring accuracy and control.
The **Arduino UNO**, a programmable open-source microcontroller board, was used as the input/output interface to upload programs to direct motor control.
An **Adafruit Motor Shield V2** was used in conjunction with the Arduino UNO to drive pulses towards the stepper motor coils, ensuring accurate control of its position and speed.

SOFTWARE

The rotational motion program was written using the **Arduino IDE** coding language which utilizes a simplified version of C/C++. The program employs a double forward stepping loop configuration. The step size and corresponding rotational period were selected through a system of trial and error to allow the model to rotate at one rotation per second. This rotation was further validated via video capturing.

Aerodynamic Load Estimates

To design and manufacture the rotating test stand, it is crucial that aerodynamic load estimates are made to establish critical design parameters.

The Mach number inside the test section can be found using the compressible flow isentropic relationships :

$$M = \sqrt{\frac{A^*}{A}\left[\frac{1}{\frac{2}{\gamma - 1}\left(\frac{1}{M^2} - 1\right) + 1}\right]}$$

Given that the test section to throat area ratio ($\frac{A^*}{A}$) is 4.8 and that the specific heat constant for air (γ) is 1.4, the above nonlinear equation can be solved to show that the test section Mach number is:

$$\boldsymbol{M_{TS} = 3.1318}$$

Using the above Mach number, as well as the known ambient pressure, standard isentropic flow equations can be used to calculate the static pressure in the test section [3].

$$\boldsymbol{P_{TS} = 15.438\ kPa\ (0.1524\ atm)}$$

A maximum value for the test section pressure can be calculated using normal shock relations, assuming a shock occurs as a result of the test stand's disruption of the flow field.

$$\boldsymbol{P_{MAX} = 174.082\ kPa\ (1.7180\ atm)}$$

Given that the coefficient of drag (C_d) for blunt bodies is 2.2 and that the maximum surface area of the rotating model is 1 in², the below equation can be used to calculate the aerodynamic load on the test stand model.

$$\boldsymbol{F = C_d\left(\frac{\gamma P_{MAX}}{2}\right)(M_{TS}^2)A_{model}}$$

$$\boldsymbol{= 1696.415\ N\ \ or\ 381.369\ lbf}$$

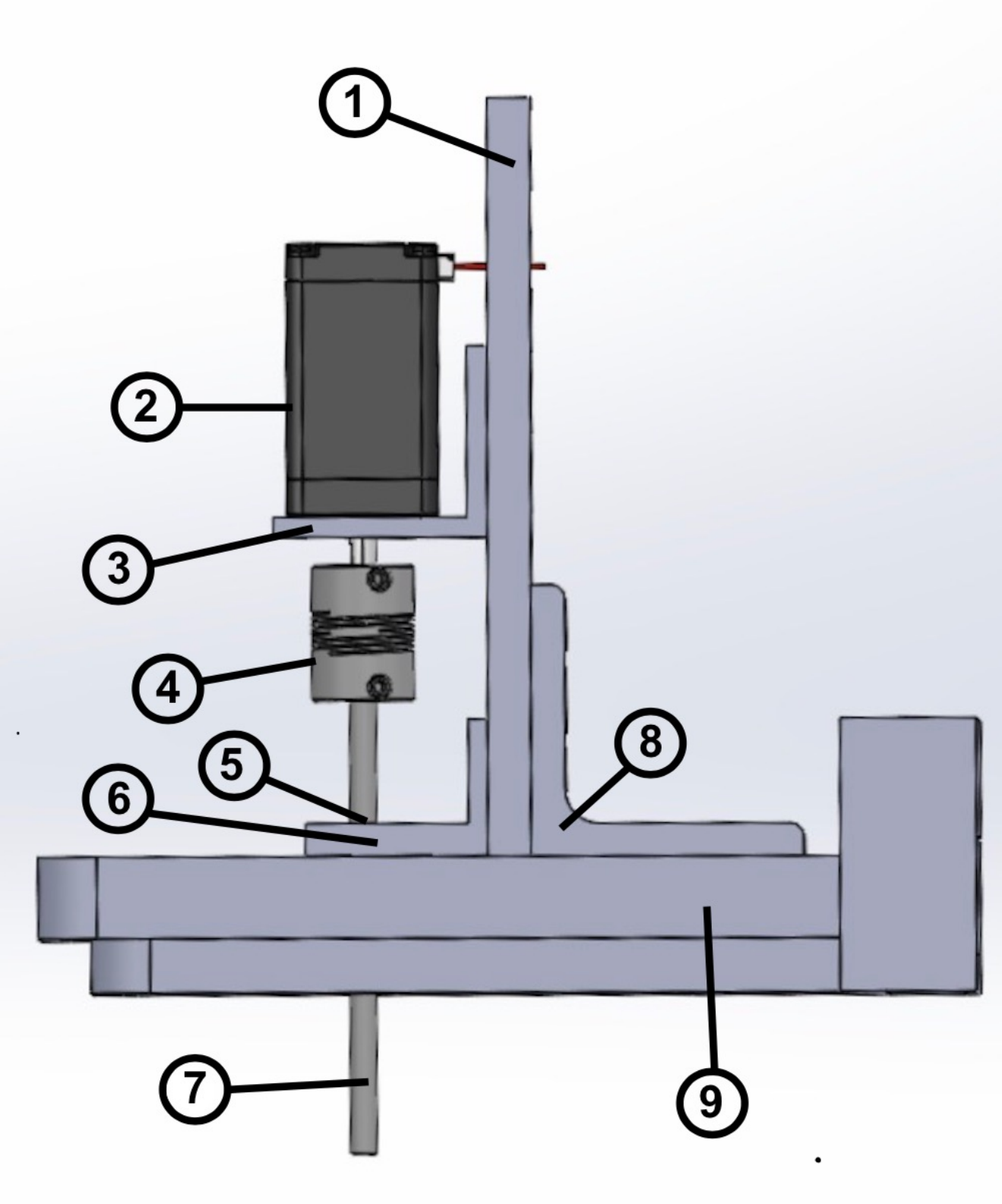
Design and Manufacturing

PRELIMINARY DESIGN

Initial designs for the SSWT test stand were drafted by referencing the existing rotating test stand in the Cal Poly Low Speed Wind Tunnel (LSWT). Additionally, dimensions of the Cal Poly SSWT were taken in conjunction with aerodynamic load estimates to both scale individual supports and conduct trade studies for mechanical components. An alternate lid for the SSWT test section was also designed to interface with the test stand. All designs were made using the CAD software SolidWorks.

MANUFACTURING

Engineering designs were made for all components to be manufactured using various machinery across the Cal Poly campus. 3D printers were also utilized to test the dimensioning of CAD models and for physical reference on the wind tunnel.



1	Rectangular Stand
2	Stepper Motor
3	Motor Mount Bracket
4	Shaft Coupler
5	Ball Bearing
6	Bearing Fit Bracket
7	Rotary Shaft
8	System Mount Bracket
9	Test Section Lid

Figure 2. The rotating test stand, fully integrated with the newly designed test section lid, is oriented above accordingly. During testing, a model will be mounted onto the rotary shaft for shadowgraph imaging.

Results and Testing

Rudimentary tests have been conducted verifying that the rotating test stand can withstand the predicted aerodynamic loads. The test stand, along with the newly manufactured test section lid, are currently being tested without models to ensure functionality under supersonic conditions. After multiple trials, the test stand will be re-evaluated for any new deformities due to airflow and drag forces.

Future Work

Once the system has been rigorously tested for structural stability, flow visualization techniques such as shadowgraph imaging will be used to both validate the design and gain a better understanding of the flow field [4]. Using this data, methods can be developed for controlling and manipulating the boundary layer flow around the model to optimize aerodynamic performance.

AKNOWLEDGEMENTS

The Authors extend profound gratitude to a distinguished cadre of advisors, erudite professors, esteemed colleagues, and venerable organizations, whose invaluable expertise, profound insights, and unwavering support have significantly enriched this research endeavor:

- Cody M. Thompson
- Cal Poly Mustang60 and Hangar Machine Shop Technicians
- Nevada National Security Site (NNSS) & SURP 2023 Program

REFERENCES

1 Cueto, Christian. "Design and Manufacturing of a Test Rig for Continuous Wind Tunnel Load Measurements." California Polytechnic State University, College of Engineering, San Luis Obispo, 2022.

2 Cardona, Vincente, and Viviana Lago. "Aerodynamic forces of interacting spheres representative of space debris re-entry: Experiments in a supersonic rarefied wind-tunnel." Acta Astronautica, vol. 191, 2022, pp. 148-159, https://doi.org/10.1016/j.actaastro.2021.10.036.

3 Hiremath, Nandeesh, and Justin Slavick. "Modification of Supersonic to Hypersonic Wind Tunnel by Sizing Heater for High Enthalpy Conditions." California Polytechnic State University, College of Engineering, San Luis Obispo, 2022.

4 Hargather, Michael, and Gary Settles. "Recent developments in Schlieren and Shadowgraphy." 27th AIAA Aerodynamic Measurement Technology and Ground Testing Conference, 2010, https://doi.org/10.2514/6.2010-4206.

* SURP AWARDEE