

# Design, Manufacture, and Calibration of a 5-Hole Pitot-Static Probe

## Team 130 Project Technical Presentation to the 2023 Spaceport America Cup

Joshua Bugel\* and Carl Anderson†  
*University of Minnesota Rocket Team, Minneapolis, MN, 55414*

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*University of Minnesota, Minneapolis, MN, 55414*

Team 130, University of Minnesota, has developed an innovative 5-hole Pitot-Static probe to showcase at the 2023 Spaceport America Cup. This design aims to advance flight evaluations and foster future system integrations by providing accurate measures of atmospheric pressure, angle of attack, sideslip, and Mach number throughout the flight. The team has previously designed multiple Pitot-static probes, however this is the first time angle of attack measurement capability has been incorporated, and was calibrated for the supersonic flight profile. The Pitot tube was designed with precision and manufacturability in mind, incorporating feedback from industry professionals. It was thoroughly simulated to ensure structural integrity and minimal aerodynamic impact on the vehicle during flight. Collins Aerospace supported this project by providing access to their transonic wind tunnel for calibration testing. The collected calibration data was used to train a deep learning model to accurately process the raw data into angle of attack & sideslip in the subsonic region and Mach number in the supersonic region.

At the front of the Pitot tube is a 6061-T6 aluminum cone, designed with a half angle of  $33^\circ$ , which houses five dynamic and eight static ports leading to six distinct pressure measurement ports. The diameter of the ports is a result of careful consideration of both expert advice from our mentors at Collins Aerospace and manufacturing limitations. This ensures optimal performance under real-flight conditions while remaining manufacturable in the University of Minnesota student machine shop. The probe's main body, also made from 6061-T6 aluminum, houses the dynamic pressure tubes. Additionally, our probe incorporates a clamping attachment mechanism, inspired by commercial nose cone tip compression designs. This guarantees a secure fit and robust performance throughout the flight profile.

To support the mechanical components of the probe, our team has designed an electrical system which aims to rapidly acquire high-quality data during flight. The system integrates six single-ended analog-output pressure transducers with a high-speed eight-channel 16-bit analog-to-digital converter (ADC), which then connects to the SRAD flight computer. This ensures reliable collection of high-quality data, which can be transmitted via live telemetry or saved on-board for post-flight processing

To validate the design, the team conducted rigorous testing at Collins Aerospace's transonic wind tunnel. Tests were conducted at various tunnel velocities, angles of attack, angles of sideslip, and roll angles, providing essential calibration data, particularly in the transonic and supersonic regions. At higher Mach numbers ( $> 0.95$ ), where the total angle is expected to be less than 2 degrees even under substantial wind shear, angle of attack and sideslip data was unable to be collected due to the physical limitations of the wind tunnel.

Further enhancing the system's reliability, deep learning techniques were employed for Pitot tube calibration, specifically targeting parameters that couldn't be resolved analytically like Mach number in the supersonic region and angles of attack & sideslip in the subsonic region. State of the art deep learning techniques were used to learn the transformations. Leave-one-out cross-validation, data augmentation using covariance matrix decomposition, weight regularization, and partial dependence were employed, resulting in a model that accurately translates raw sensor outputs into target parameters. Through the above techniques, rigorous model validation, and hyperparameter tuning, a testing root-mean-square deviation (RMSD) of 0.035 Mach number was achieved in the supersonic regime. For angles of attack and sideslip, the model was able to achieve a RMSD of  $1.11^\circ$  and  $0.957^\circ$ , respectively.

\* Simulations Lead, UMN Rocket Team, bugel003@umn.edu

† Avionics Lead, UMN Rocket Team, and08571@umn.edu

The aerodynamics of the pitot tube were also analyzed. Utilizing altitude and velocity data from RasAero II and atmospheric data from the University of Wyoming, a Mach number range was determined for the flight of the vehicle. From these, a number of axisymmetric fluid simulations were performed to evaluate the differences in the vehicle's performance with and without the Pitot tube. The results of this indicated minimal performance differences and allowed a qualitative resolution to static pressure measurement error in supersonic flight.

University of Minnesota's contribution to this year's Spaceport America Cup is the design, manufacturing, and calibration of a state-of-the-art 5-hole Pitot-Static probe for accurate Mach number, angle of attack & sideslip, and atmospheric pressure. As we prepare for our flight at the Spaceport America Cup, we stand ready to demonstrate the operational effectiveness of this cutting-edge solution, and its potential for future multisystem integration. A sensor that can accurately deliver real-time data on airspeed, altitude, and angle of attack and sideslip creates numerous opportunities for future development. This information can facilitate sophisticated post-flight analysis, supporting the creation of new simulation software. Real-time processing could empower future active control projects, such as apogee control using air brakes. Furthermore, it could assist in recovery by fostering the development of more precise state estimation algorithms.