OBJECTIVE: Develop, calibrate, and demonstrate a non-intrusive method to measure wall-shear-stress distributions in hypersonic ground test facilities.

DESCRIPTION: The ability to accurately predict the state of boundary layers and regions of separated flows is a key consideration for the design of hypersonic vehicles [Ref 1]. The state of the boundary layer affects the surface skin friction, which, when integrated, impacts predictions of flight performance through lift, drag, and moment coefficients [Ref 1]. In addition, flow separation influences the effectiveness of control surfaces and consequently the vehicle control authority. Therefore, accurate measurements of wall-shear-stress are paramount to predicting the characteristics of boundary layers and the performance of hypersonic vehicles. In addition, the availability of wall-shear-stress distribution measurements in hypersonic ground test facilities is highly valuable to improve and validate the computational tools needed to extrapolate ground test measurements to flight conditions.

Reliable sensors suitable for large-scale hypersonic ground test facilities have been developed and demonstrated over recent years for one-[Ref 2] and two-component wall-shear-stress measurements [Ref 3]. However, to obtain two-dimensional surface information using traditional sensors, one must use a large number of pointmeasurements that are individually attached/machined onto the surface. This process can be time-consuming and expensive. Ultimately, the number of sensors employed limits the spatial resolution of shear stress data, thereby limiting the usefulness of sensor data for complex flow fields. Oil flow visualization [Ref 4] is useful in obtaining near-wall streamlines, but cannot provide quantitative values of the skin-friction distribution. Quantitative methods such as shear-sensitive liquid crystals have been applied in high-speed flows [Ref 5], but its suitability for hypersonic wind tunnels remains uncertain because of spurious inputs due to variations in surface temperatures. This STTR topic is seeking a technique to quantitatively measure the skin friction distribution on the surface of hypersonic wind tunnel test articles.

KEY REQUIREMENTS
- Provides 2D measurements of the skin-friction distribution (magnitude and direction)
- Non-intrusive technique compatible with standard hypersonic wind tunnel test articles such as a sensing coating that can be applied on the surface
- Allows measurement on smooth curved surfaces (such as conical geometries)
- Spatial resolution better than or equal to 5 mm x 5 mm
- Temporal resolution greater than or equal to 1 kHz
- Wide dynamic range and high sensitivity to allow simultaneous measurements in regions of high shear (shear-stress magnitude ~ 250 Pa) and regions of separated flows (zero shear-stress or low magnitude with reversed direction)
- Intrinsic insensitivity to spurious inputs such as surface temperature and pressure or accurate correction of spurious inputs via calibration and/or input measurements

PHASE I: Develop a methodology for measuring the wall-shear-stress distribution at Mach 5 or above and surface temperatures up to 395K or above. Demonstrate the suitability of the measurement technique via benchtop experiments. Develop concepts for calibration and characterization of sensitivity to spurious inputs such as pressure and temperature. Develop a Phase II plan.

PHASE II: Further develop the methodology for measuring wall-shear-stress distribution globally and instantaneously at Mach 5-7 and surface temperatures up to 493K or above on canonical geometries such as flat plates and cones. Develop and validate a calibration methodology and characterize sensitivity due to extraneous inputs such as temperature and pressure. Validate measurements by comparing results with theory and previously published results. Validate the global measurements with several discrete shear stress sensors situated along the centerline or ray of a flat plate or cone. By the end of Phase II, the technology should be TRL 5.

PHASE III DUAL-USE APPLICATIONS: Further refine the measurement technology to increase the accuracy, range of conditions to higher Mach numbers, and dynamic pressures. Develop commercial system that can be marketed and deployed in large-scale ground test facilities operated by commercial space and aviation companies and the Federal Government.
REFERENCES:


KEYWORDS: Hypersonic Flow; Wall-shear-stress Distribution; Ground Testing; Non-intrusive; Diagnostics; High-speed