DESIGN OF A NOVEL PROBE FOR OPTICAL DIAGNOSTICS IN HIGH-ENTHALPY SUPERSONIC FLOWS

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ABSTRACT

This manuscript details the development of a novel probe that allows the placement of sensitive diagnostic hardware in high-speed flows (M>5) with static temperatures exceeding 500K. The optical hardware is enclosed in a large interior volume (980cc) that is maintained at or below 40ºC using an open cycle gaseous cooling scheme, and an aerodynamic probe body is designed to minimize flow disturbances and enable the use of short focal length laser diagnostics. A 1D non-isentropic conjugate heat transfer model was used to size the cooling channels by estimating convective heat transfer coefficients along the probe in subsonic conditions up to Mach 0.85, where an average value of ~550 W/m2/K was obtained for 600K flow. Well-known correlations for turbulent flat plates and circular tips were used for the calculations. 3D RANS simulations were conducted to validate the results predicted by the 1D model and estimate the heat transfer coefficient at a set of supersonic Mach numbers (M=1.5, M=2.3, M=3), closer to design conditions. The maximum discrepancy found for the average heat transfer coefficient between the 1D and 3D models is below 8%. Preliminary tests have been conducted with an additively manufactured probe body at the Purdue Experimental Turbine Aerothermal Laboratory (PETAL), where pressure losses inside the cooling jacket, temperature distribution in the external walls, and vibrational responses have been experimentally measured for different coolant pressures.

INTRODUCTION

High enthalpy supersonic flows provide a challenging environment for laboratory diagnostics. Intrusive sensors can generate shock-induced flow structures, and recovery temperatures can easily exceed the thermal limit of even most robust sensors [1]. Non-intrusive diagnostics avoid these problems, but their application to high supersonic conditions is still being perfected. The required structural integrity of supersonic facilities generally limits optical access, and signal levels and spatial resolution are typically low due to the large standoff distances and focal lengths used [2]. Thus, the designed probe is meant to close the gap between intrusive and non-intrusive techniques, allowing the introduction of optical elements for laser diagnostics inside a test section, reducing the focal length in low optical access supersonic facilities, while minimizing flow disturbance and thermal loads to the optical hardware.

RESULTS AND DISCUSSION

The main geometric and thermal features of the designed probe are shown in Figure 1. The general dimensions are close to the minimum ones that leave enough clearance for the integration of the optical hardware and cooling jacket, and the shape of the leading edge was selected to minimize flow disturbance over the top wall, where the optical window is located. Figure 1 also shows a schematic of the aerodynamic and thermal behavior of the probe. Coolant is injected from a plenum and conducted around the optical hardware through a set of cooling channels that dissipate heat from the probe walls. Coolant is finally ejected through an array of backward facing holes that create a film of cold flow around the nacelle, effectively reducing the recovery temperature and increasing cooling effectiveness. With this architecture, an average cooling effectiveness of ~60% has been obtained numerically even for low ejection blowing ratios (BR=1.5).

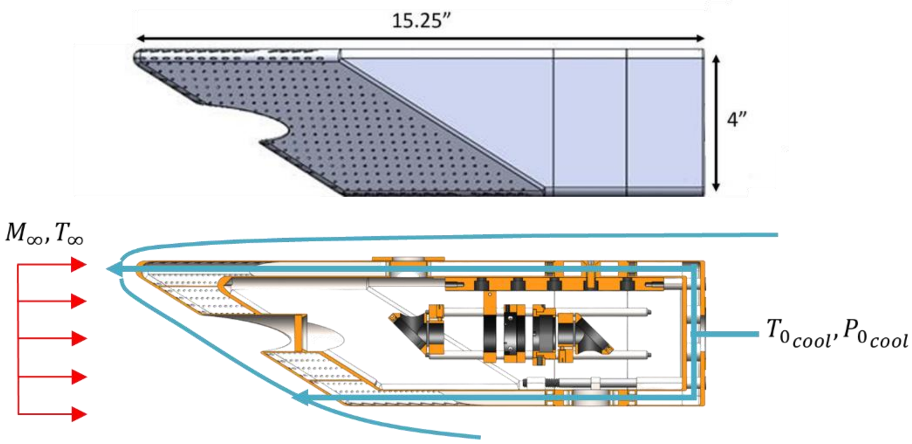

Figure 1. Geometry of the optical probe and section view of the cooling jacket with a scheme of the flow pattern inside and around the nacelle.

REFERENCES

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