66th International Astronautical Congress 2015

SPACE PROPULSION SYMPOSIUM (C4)
Hypersonic and Combined Cycle Propulsion (9)

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REAL TIME ESTIMATION OF AIR MASS FLOW RATE FOR SCRAMJET INLET BASED ON MULTI-SENSOR FUSION

Abstract

Accurate estimation of Air Mass Flow Rate($\dot{m}_a$) is desired for real time control of scramjet engine to avoid lean or rich blowout in its narrow operating range. Traditionally $\dot{m}_a$ is calculated from aerodynamic data such as angle of attack, freestream Mach number and static pressure, etc. Due to atmospheric variations, measurements of these aerodynamic data are inaccurate in hypersonic flight, even with the state-of-the-art Inertial Navigation and Flush Airdata Sensing System. In certain cases, the error of $\dot{m}_a$ can be more than 12% because of errors in aerodynamic data measurements. To reduce the error of $\dot{m}_a$, Unscented Kalman Filter(UKF), which is a multi-sensor fusion approach, was adopted to take advantage of priori knowledge and the pressure measurements of scramjet inlet. While it is difficult to measure $\dot{m}_a$ directly on an operational scramjet, it is a common practice to measure pressures along its inlet for unstart detection. Both $\dot{m}_a$ and inlet pressures could be depicted as functions of aerodynamic data. Computational Fluid Dynamics simulations were performed on a two-dimensional scramjet inlet to reveal the strong relevance between $\dot{m}_a$ and inlet pressures. A semi-empirical model for aerodynamic data, inlet pressures and $\dot{m}_a$ was developed based on oblique shock relations, and modified for the effect of viscosity according to numerical simulation results. From the differences between the model outputs and inlet pressure measurements, errors in aerodynamic data can be estimated and corrected by the UKF algorithm. UKF takes available measurements over time, suppresses the noises and produces a statistically optimal estimate of $\dot{m}_a$ recursively. Monte Carlo simulations were undertaken to verify the precision and robustness of the UKF algorithm under stochastic trajectories, random atmospheric variations and noisy inlet pressure measurements. Simulation results showed that the error of $\dot{m}_a$ was significantly reduced. The average error of $\dot{m}_a$ was less than 2.2%, and the worst case error was no more than 4%. It has been demonstrated that the multi-sensor fusion approach is promissing for real time air mass flow rate estimation in an operational scramjet engine.