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

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PERFORMANCE OF HIGH MACH NUMBER SCRAMJETS - TUNNEL VS FLIGHT

Abstract

When analysing scramjet engines, financial constraints limit many researchers to ground-based impulse facilities and numerical studies. Impulse facilities are further limited by structural constraints and driver contamination, which often restricts supply conditions to mid-range (Mach 5-8) scramjet tests. This is reflected in the corresponding flight experiments and numerical studies available in the literature. However, access-to-space, hybrid rocket-scramjet-rocket systems demand scramjet operation to higher Mach numbers, invariably experiencing significant heating loads throughout the operation window. Management of these thermal loads may depend on fuel-based regenerative cooling, maintaining engine internal wall temperatures at near material thermal limits. Hence, the scramjet will encounter operating conditions which vary distinctly between short-duration impulse flows and steady operation. As such, a numerical study is performed in the present work, which compares the Mach 12 Rectangular-to-Elliptical Shape-Transitioning flow path's performance in a ground-based impulse facility, to steady Mach 12 operation in flight. Chemically reacting solutions to the Reynolds-Averaged Navier-Stokes equations were developed, with equations closed through the Spalart-Allmaras turbulence model. Room temperature (300K) isothermal wall boundaries and fuel plenums are maintained for shock tunnel conditions. Flight operation is modelled through 800K inlet walls, with the wall temperature increased proportionally to internal contraction ratio to reach 1800K by the combustor entrance. Fuel-based regenerative cooling is assumed to require the full available cooling capacity, heating liquid hydrogen fuel to 1000K prior to injection. Hydrogen fuel is injected through both inlet and combustor-based flush-wall injectors, achieving an equivalence ratio of 1.26 for both ground-based and flight conditions. Initial results indicate boundary layer growth in the flight condition exceeds the tunnel condition by 7% by the inlet fuelling location. Mixing and combustion performance indicates that while flight conditions promote more rapid mixing, combustor temperatures may inhibit reactions proceeding to completion, reducing the efficiency achieved. While viscous drag is increased within the flight case, the reduction in heat transfer through the walls permits greater inviscid thrust to be obtained, providing a net increase in performance. Initial results suggest that while the net impact on thrust is modest, the fact that the counteracting forces undergo more substantial changes may imply that the optimal engine design for flight may differ considerably from that which gives the best performance in the tunnel.