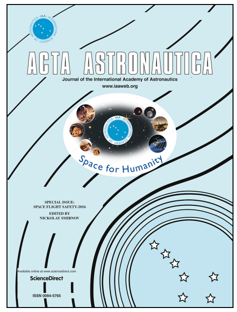

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PERFORMANCE OF HIGH MACH NUMBER SCRAMJETS - TUNNEL VS FLIGHT

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While typically analysed through ground-based impulse facilities, scramjets experience significant heating loads in flight, raising engine wall temperatures and the fuel used to cool them beyond standard laboratory conditions. Hence, the present work numerically compares an access-to-space scramjet's performance at both these conditions. The Mach 12 Rectangular-to-Elliptical Shape-Transitioning scramjet flow path is examined via three-dimensional and chemically reacting Reynolds-averaged Navier-Stokes solutions. Flight operation is modelled through 800 K and 1800 K inlet and combustor walls respectively, while fuel is injected at both inlet- and combustor-based stations at 1000 K stagnation temperature. Room temperature walls and fuel plena model shock tunnel conditions. Mixing and combustion performance indicates that while flight conditions promote rapid mixing, high combustor temperatures inhibit the completion of reaction pathways, with reactant dissociation reducing chemical heat release by 16%. However, the heated walls in flight ensured 28% less energy was absorbed by the walls. While inlet fuel injection promotes robust burning of combustor-injected fuel, premature ignition upon the inlet in flight suggests these injectors should be moved further downstream. Coupled with counteracting differences in heat release and loss to the walls, the optimal engine design for flight may differ considerably from that which gives the best performance in the tunnel.
Keywords: Scramjet; Mach 12; Access-to-Space; Shock Tunnel; Flight Experiment

I 1. Introduction

While scramjets display improving technological readiness, financial constraints limit many researchers to ground-based impulse facilities [1] or numerical studies [2]. As Mach number increases, however, increased working pressures drive up the operational costs of reflected shock tunnels, while turbulent mixing between the driver and test gas interface reduces available test time [3]. These limitations have restricted the Mach number regime of flight tests, with the corresponding computational studies typically analysing mid-range Mach number ($5 \leq M < 10$) scramjets. These have included the Mach 5 X-51A [4], the Mach 7 X-43A [5] and the Mach 8 HyShot II [6] and HIFiRE 2 [7] experiments. While a small subset of ground-based studies examined high Mach number ($M \geq 10$) scramjets [8, 9], limited flight data exists for these engines. Restricted to the Mach 10 X-43A flight experiment [10], the significant expense and difficulty of high Mach number flight tests have driven the development of alternative tools to analyse steady scramjet operation. Computational fluid dynamics (CFD) is increasingly capable of fulfilling this role.

Simulations of mid-range Mach number flight experiments were subjected to extensive validation against shock tunnel data prior to the flight tests [11, 12]. Post-flight computational analysis displayed good agreement between the numerical studies and the steady flight data [13]. Further studies validated pre-flight predictions against flight data [10], supporting CFD's use as a scramjet design tool. As such, the opportunity exists to extend CFD's use to examine steady flight operation of high Mach number scramjets in the absence of experimental flight data.

Under flight conditions, wall surfaces encounter substantial thermal loads, with temperatures by necessity maintained near material thermal limits. Compared to cold-walled shock tunnel models, higher wall temperatures reduce energy loss through boundaries, while increasing the boundary layer thickness [14]. Active cooling measures are likely required to withstand these temperatures, with regenerative cooling using the fuel a likely candidate. This technology is in a mature state in rocket systems [15], and recently employed in the X-51 scramjet flight experiment [16]. It follows that injection of heated fuel will likely positively affect engine performance by reducing ignition delay, while mitigating system energy loss [17].

This paper compares flow-field differences and performance data of a scramjet operating within a shock tunnel environment, to one operating under steady flight. The Mach 12, Rectangular-to-Elliptical Shape-Transitioning (M12REST)

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