

Reduction of Auto Ignition Temperatures in Scramjet Combustors using catalytic Fuel Pre-Treatment of Hydrogen

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Currently the main focus in supersonic combustion research lies on steady state conditions at flight Mach numbers of 8. Since the final goal of most scramjet related projects is to create a supersonic civil aircraft capable of traveling at these speeds during cruise, systems with a low number of different propulsion devices are preferred to save weight and complexity. Therefore, it is suitable to transition to ram/scramjet mode as soon as the thermodynamic cycle efficiencies allow more efficient operation than the propulsion systems used during the start and initial acceleration stages. This extension towards lower transitional flight Mach numbers creates new challenges in terms of combustor efficiency, flame stability and auto ignition limits within the scramjet combustor.

Figure 1 shows the operational range of a generic scramjet. The boundary towards lower flight Mach numbers is limited by auto ignition, ignition delay and flame stabilization. The boundary towards higher flight Mach numbers is given by the dissociation temperature of combustion reactants and products. By increasing the reactivity of the fuel, the ignition boundary can be shifted to lower flight Mach numbers while keeping the combustor Mach number constant.

To counter the effects of low combustor inlet temperatures resulting from low flight Mach numbers, several options have been investigated in the past. For example micro-ramjets within strut injectors [1] and internal combustion of pilot flames [2;3] were suggested. All of these concepts result in very high thermal loads within the injectors, adding to the immense heat flux introduced by the free stream towards all combustor surfaces.

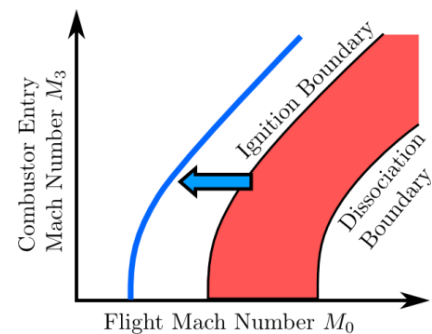


Figure 1: Operational boundaries of a generic scramjet

Therefore, an option with low heat release inside the injector was selected for the current work, resulting in the use of catalysts. To keep temperatures inside the injector low, a heterogeneous reaction within a catalyst bed inside the injector burns a small percentage of the hydrogen fuel with previously added air. The fuel rich reaction keeps temperatures low and is expected to provide intermediate reaction products for the injection. These radicals then reduce the ignition delay times as well as the auto ignition temperatures within the main combustion chamber. The low temperatures within the injector additionally contribute to increased catalyst lifetime.

To quantify the resulting effect as well as to determine suitable mixtures for this process, a preliminary reactor, (Figure 2) has been designed, which allows to investigate the reduction of the required ignition energy. The reactor with an internal cross section of 12x12 mm comprises two separate hydrogen and oxidiser inlets, which lead to a mixing zone of 30 mm length, followed by the monolithic catalyst. The catalyst is an Al_2O_3 monolith of 20 mm length with 40 g/ft³ platinum coverage and 1x1 mm quadratic channels. The processed mixture is ejected through a circular orifice of 0.5 mm diameter and ignited by an electrically heated coiled filament (not shown). The electrical power supply driving the coiled filament is controlled using pulse width modulation (PWM). Thermocouples in the reactor setup measure the heat release along the reactor, while pressure measurements provide both pressure

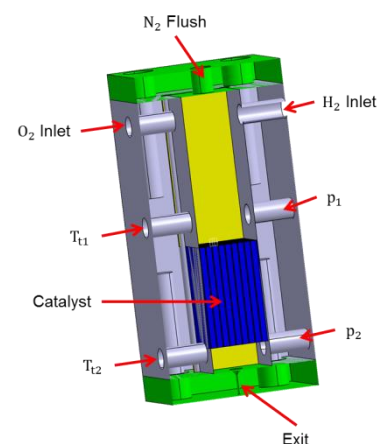


Figure 2: Reactor Setup

losses along the catalyst as well as partial pressure measurements during fuel mixture calibrations. An additional thermocouple is used to detect ignition at the coiled filament. In case of catalyst light off, flame propagation into the reactor or successful ignition of the mix outside the reactor, fuel and oxidizer are turned off immediately and the whole reactor is flushed with nitrogen.

During preliminary test runs, which were performed to test the safety systems, an interesting effect was observed. Several tests with identical settings were conducted immediately following each other. To eliminate the risk of catalyst light off, no oxidiser was injected. After activating the hydrogen injection, the PWM duty cycle of the power supply and thus the thermal energy released by the coiled filament was increased using a ramp function until ignition was detected. In each test batch conducted, the respective first run achieved ignition at a lower PWM duty cycle, while all consecutive runs achieved ignition at a reproducible higher level. The effect can be seen in Figure 3, where the time difference of approximately 2 s between the ignition points and therefore a distinctively different coil heat release is observable. Ignition is achieved at the point where temperature starts to rise rapidly. The effect occurs despite initial N_2 flushes of the reactor, but is not observed when the catalyst is removed from the reactor. These findings suggest the effect is caused by residual adsorbed oxygen on the catalyst, which diffused inside the reactor through the exit port hole during pauses between the test batches. The adsorbed oxygen subsequently reacts with injected hydrogen and significantly decreases the ignition energy of the ejected gas. During the tests, no temperature rise inside the reactor is detected, which suggests only small amounts of oxygen atoms are reacting.

To validate this theory of residual adsorbed oxygen and to further increase the effect of the catalytic precombustion, test series with fuel-rich hydrogen-air-mixtures are currently under investigation and the full paper will investigate these results, too.

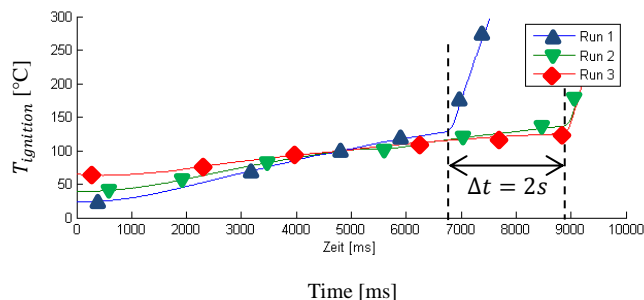


Figure 3: ignition detection temperature over time

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