47th AIAA Aerospace Sciences Meeting Including The New Horizons Forum and Aerospace Exposition
5 - 8 January 2009, Orlando, Florida
AIAA 2009-810

2009-0810

47th AIAA Aerospace Sciences Meeting, 5 - 8 Jan 2009, Orlando, Florida

Experimental Studies of Cavity Flame-Holding in a Mach 2.5 Cross Flow

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Flame stabilization in a supersonic cross flow is one of the major challenges in supersonic combustor design. Cavity induced flame stabilization is one potential approach since the low speed recirculation of hot products in the cavity can be used to provide efficient mixing and a re-ignition process that sustains the primary combustion process. A new test facility specifically designed to study cavity combustion and flame structure has been built and used to investigate ignition, flame structure and stability in a Mach 2.5 non-vitiated cross flow. The current study focuses on combustion stability of a mixture of methane and hydrogen injected at the bottom of the cavity. The effects of fuel mixture composition, cross flow heating, and their impact on the combustion process are reported in this paper.

I. Introduction

Non-premixed combustion into supersonic flow is challenging since the short residence time in the combustor limits overall mixing and competes with the chemical reaction times involved in the combustion process. Flame stabilization techniques using bluff bodies[1] have been shown to improve mixing and stability by creating a recirculation region in the wake, but can also result in drastic stagnation pressure losses. Cavity stabilization of the flame is an approach that has been explored in recent years[2] as a potential alternative. Since the cavity is submerged, stagnation pressure loss due to geometry generated shocks (as in the compression ramp geometry) is reduced. Since the residence time is longer, mixing is more efficient and combustion is potentially more stable. The recirculating hot zone also acts as an ignition or flame-holding source that stabilizes the combustion of a primary fuel injected in the supersonic cross stream.[3] Experimental studies of cavity stabilized flames in supersonic cross flow have been conducted in the past using ethylene as the primary fuel.[2,4,5] These studies have focused on determining blow out limits with a single fuel and relate it to the global Damkohler number.[4,5] Experimental results show that the fuel injection location has a great impact on the stability. These studies were conducted with floor injection and showed that higher stagnation pressure is required to maintain the combustion process.[6]

The main focus of this study is to determine if stable combustion can be sustained using methane as the primary fuel. This is a challenging objective due to its slower heat content and ignition characteristics. However, the potential of using methane as the cavity stabilizing fuel has some interesting practical implications for this type of combustor. As in the previous studies reported above, methane is also injected into a rectangular cavity, although its dimensions are different from past studies. Under the tested conditions and for the geometry investigated, it was not possible to sustain pure methane combustion without the presence of an additional energy source, such as a spark. This is because methane has a relatively slow chemistry. Therefore, to increase the stability domain without using spark (which is still used for initial ignition), a small amount of hydrogen is added.[7] Hence a CH_4-H_2 mixture is used for the entire experimental approach. A range of mixture compositions is studied for the purpose of understanding which compositions provide stable combustion and what mixtures result in blow out. The latter allows finding the minimal amount of hydrogen needed to ensure flame stability. Additionally, the effect of pre-heating the inflow air stream using

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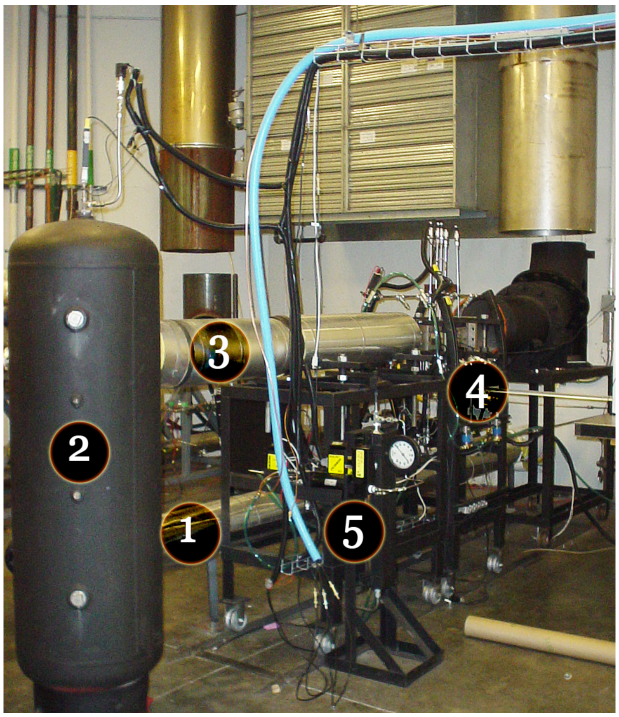
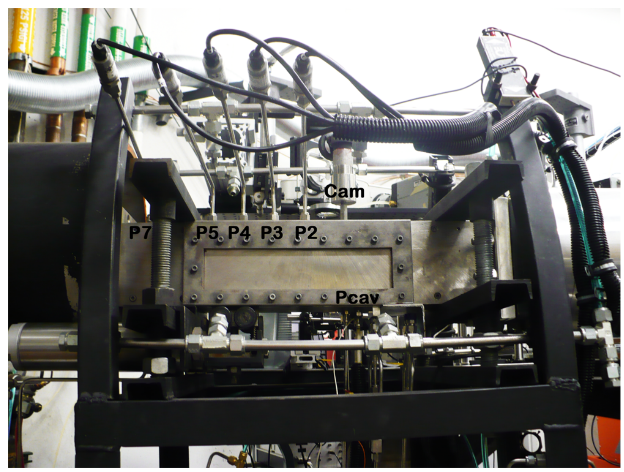
a non-vitiated process is investigated to determine the overall stability limits of the combustion mechanism in this combustor.

II. Experimental Facility

Figure 1 depicts the test facility. A blow down system and a heater provide a non-vitiated primary air flow. The stagnation pressure can be adjusted during the experiment within a 101-2169 kPa absolute range, whereas the stagnation temperature can reach up to 750 K depending on the mass flow rate. The maximum air mass flow rate does not exceed 3.02 kg/s, which gives a minimum runtime of 20 minutes depending on the stagnation temperature. The entire pipe is thermally insulated in order to minimize the enthalpy loss from the storage tank to the test section.



(a) 1. Delivery Pipe, 2. Settling Tank, 3. Flow Straightening Section, 4. Test Section, 5. Fuel System.



(b) Test section with blind side flanges and pressure tap hole configuration detailed in Table 1.

Figure 1. Georgia Tech supersonic combustor facility.

The test section is contained in a 635 mm × 114.5 mm × 133.5 mm stainless steel block (Fig. 2). The nozzle is designed with boundary layer compensation and provides a Mach 2.5 flow into a 31.75 mm × 63.5 mm rectangular cross-section test section. The nozzle and the test section is a single construction to achieve a smooth shock-free supersonic inflow by reducing the number of junctions and potential misalignments. The cavity is $D=$ 31.75 mm deep and $L=$ 97.5 mm long such that the subsonic flow region is about 80% of the supersonic core lying on top of the cavity. The facility has the capability to vary the cavity aspect ratio but for this study, it is held fixed at $L/D = 3.84$. A diverging ceiling starts 127 mm from the leading edge of the cavity with a angle of 2.5^o to allow for heat release and thermal expansion effect from the combustion. The pressure tap holes are located on the ceiling every 50.8 mm in order to capture the pressure rise due to heat release and track the shock pattern in the absence of windows. The cavity is instrumented with a pressure and a temperature ports located on the bottom wall 63.5 mm from the leading step.

Various fuel-injection strategies in the cavity are in place (floor, side-walls) but for this effort, only floor injection is studied. The fuel injection system ensures the delivery of a CH_4-H_2 blend through an array of six injectors equally spaced along the spanwise direction and located on the floor of the cavity, 6.35 mm downstream the leading step. Each injector is 2.3 mm in diameter. The fuel mixture composition is adjustable using two mass flow controllers. A 6000 V spark is also present at the bottom of the cavity and is used for ignition. Two side windows allow flow visualization techniques to be carried over a 292 mm long region starting 19.05 mm before the cavity leading edge. The windows are mounted on graphite and RTV gasket in order to compensate for the structure expansion under heating effect. The exit of the test section is at atmospheric pressure.

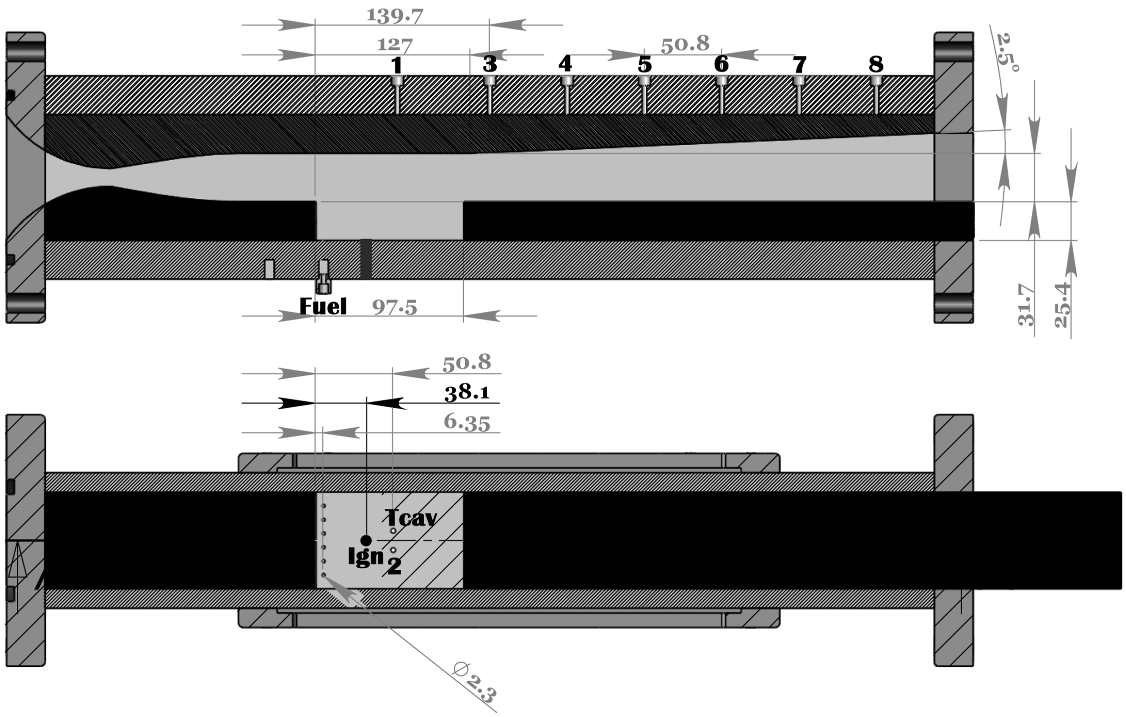


Figure 2. Test section (dimensions are in mm).

Pressure Port	1	2	3	4	5	6	7	8
With Side Windows	P2	Pcav	P3	P4	P5	x	x	P7
Without Side Windows	Camera	Pcav	P2	P3	P4	P5	x	P7

Table 1. Pressure instrumentation of the test section.

Figure 3 depicts the fuel system employed to reach the mixture composition targets. Both fuels are brought from their storage pressure to an identical fuel back pressure. By changing the fuel density, the back pressure regulates the range of mass flow rate covered by the system. Each mass flow rate controller operates accurately within a 140 kPa pressure drop; therefore it is inserted between two pressure reducers. The methane and hydrogen channels support up to 8 g/s and 0.74 g/s, respectively.

III. Data Acquisition Strategies

III.A. Mixture Space

Ignition depends on the size and the arc power of the ignitor, as well as the overall mixture present in the cavity. Ignition is achieved by ramping up the hydrogen channel, and once combustion occurs, the ignitor is switched off. From a stable combustion state, the fuel mixture composition is changed slowly to determine the lean blow out (LBO) limit with various mixture compositions. As shown below, there appears to be no uniqueness in the blow out mixture. Many combinations of air, methane and hydrogen may result in LBO. This may be a result of the interaction between chemical kinetics, molecular mixing (due to the presence of hydrogen) and the overall behavior of the mixing for the fixed L/D, Mach number and test section geometry. For a fixed geometry, the only parameters that can be experimentally varied are the fuel and air flow rates, and pre-heat temperature. Therefore, in order to characterize the stability limits, the overall mixture is

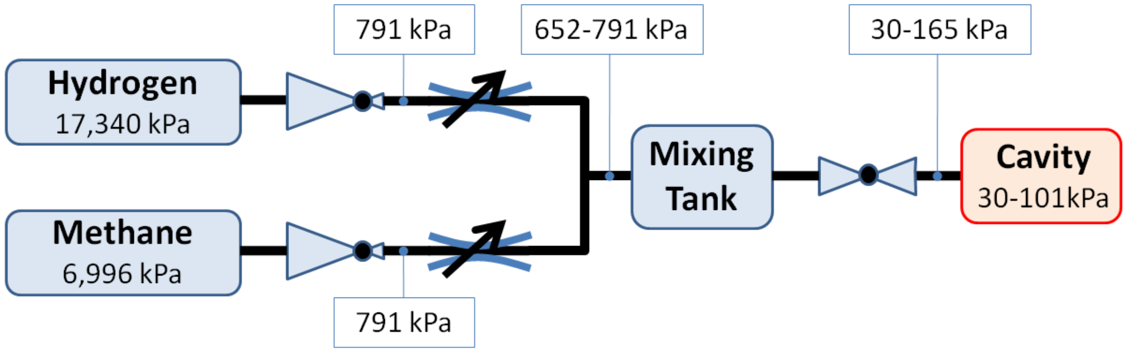


Figure 3. Block diagram of the fuel system network.

represented in a three dimensional space where a given regime is a point whose coordinates are the mass flow rates of air, methane and hydrogen. Under this representation the blow out limit draws a region which separates the stable combustion domain and the mixtures for which no combustion is sustainable. The stable combustion domain forms a volume in which lies all the mixture compositions that resulted in self sustained combustion in the cavity. This volume is expected to shift and stretch with the change of the preheat temperature, the fuel injection location and the cavity aspect ratio.

Figure 4(a) illustrates the stability domain and the blow out surface in the mixture space. The current study focuses on LBO only and therefore, does not cover the entire stable domain. Figure 4(b) shows a plot of the experimental data. Trajectories are plotted in the mixture space. These are the paths that satisfy ignition and burning so it is possible to estimate the size of the stable combustion domain. One can see that a series of blow out points terminates all the trajectories and draw a surface beyond which no flame is observed.

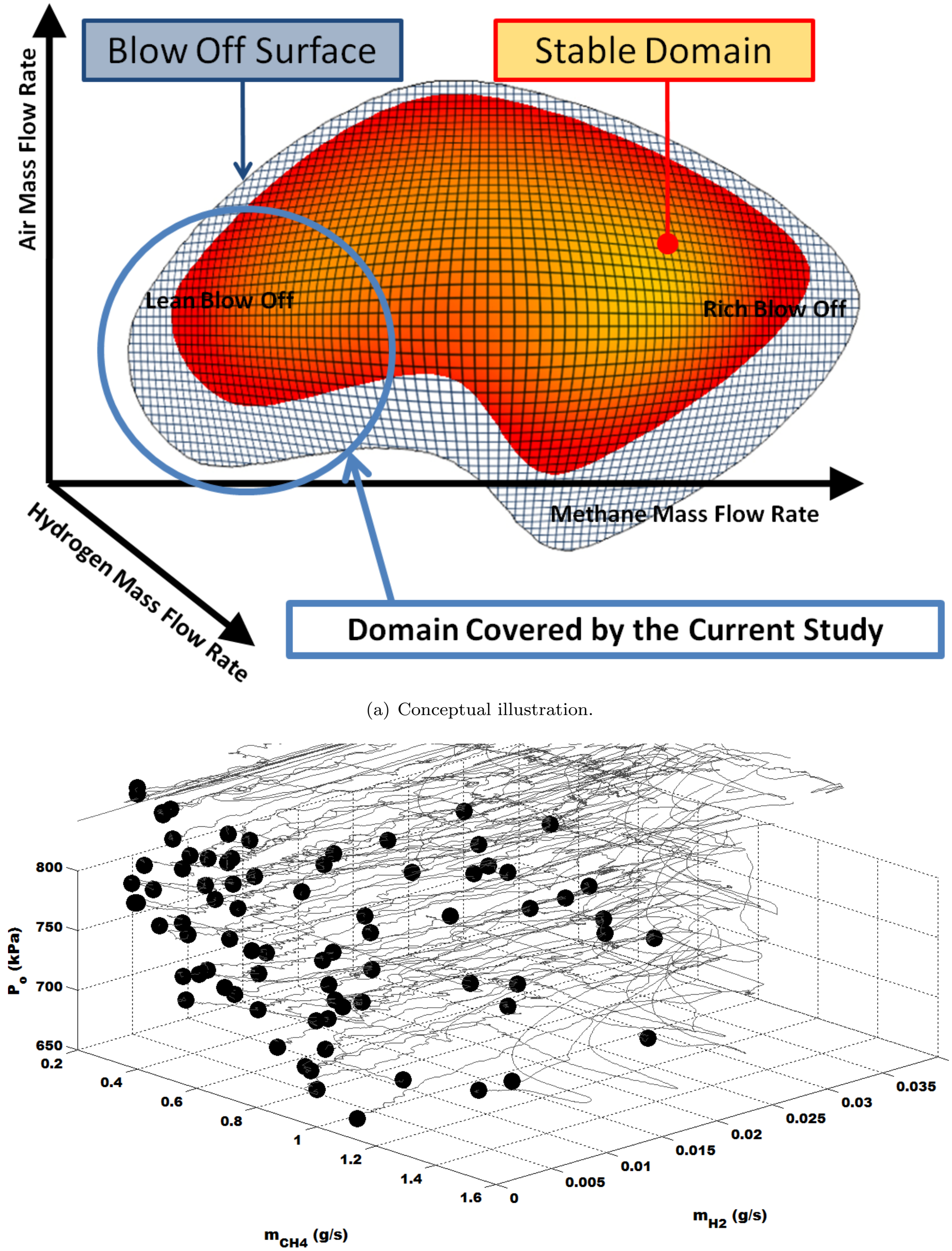
Since only the overall air mass flow rate is measured, the amount of air entering the cavity is not precisely known. Henceforth, the representation mentioned above does not refer to the precise reactant mixture present in the cavity, and only the term "overall mixture" is used instead. It is noted that there are many parameters that will control this overall mixture state, including the scale and the stability of the shear layer structures established at different air flow rates and combustion regimes. Sensitivity to some of these parameters will have to be addressed in future studies.

III.B. Flow Visualization

Flow visualizations have also been conducted to characterize the flow features in the combustor, although only limited results are reported here. Schlieren images of the flow revealed that a small gap in the window junctions is enough to cause an oblique shock formation that alters test section conditions. Quartz window blocks have a chamfer in order to prevent the edges from chipping; this chamfer causes a small triangular gap in the window junction. Two methods have been used to ensure smooth junctions. A window socket lip is made such that the block flushes with the combustor walls. In addition, RTV gasket is used to fill up the gap if the junction lies in a lower temperature region. However, even if the window junctions are carefully adjusted before testing, the high temperatures encountered during combustion over an extended period cause the metal parts to distort and in some cases, the trailing edge corners of the cavity expands into the Quartz blocks and eventually breaks the windows if the burning phase lasts more than a few minutes. Therefore, only limited flow visualization studies were conducted. Instead, plain side flanges were used to obtain a smooth test section and enclose the combustion region as shown in Fig. 1(b). No overheating has been encountered during testing using this approach.

III.C. Detection of Ignition and Blow Out Events

With side windows, ignition and blow out events are easily identified from the video data but as mentioned above, the majority of the tests are made without windows. Hence, there is a need to develop an accurate real time technique to detect ignition and blow out events. The simplest approach is to use a camera that



(a) Conceptual illustration.

(b) Experimental Data. Trajectories are in grey and blow out events are in black.

Figure 4. Stability domain and blow out surface in the mixture space.

films the inside of the combustor through the 1/8" tap hole located on the ceiling (Port 1 on Fig. 2). This video signal stands as a visual indicator during the test. Video data and temperature data are correlated to ensure a full reliability in determining ignition and blow out events. Figure 5 shows the temperature data in which the structure behaves as a thermal capacitor so that after ignition, it takes about 10 seconds for the combustor to stabilize at its burnt temperature. Ignition is tagged in the lower knee of the curve just before the sharp increase of temperature. At blow out, the temperature decrease with the same behavior as it also takes about 10 seconds for the combustor to reach the unburnt temperature.

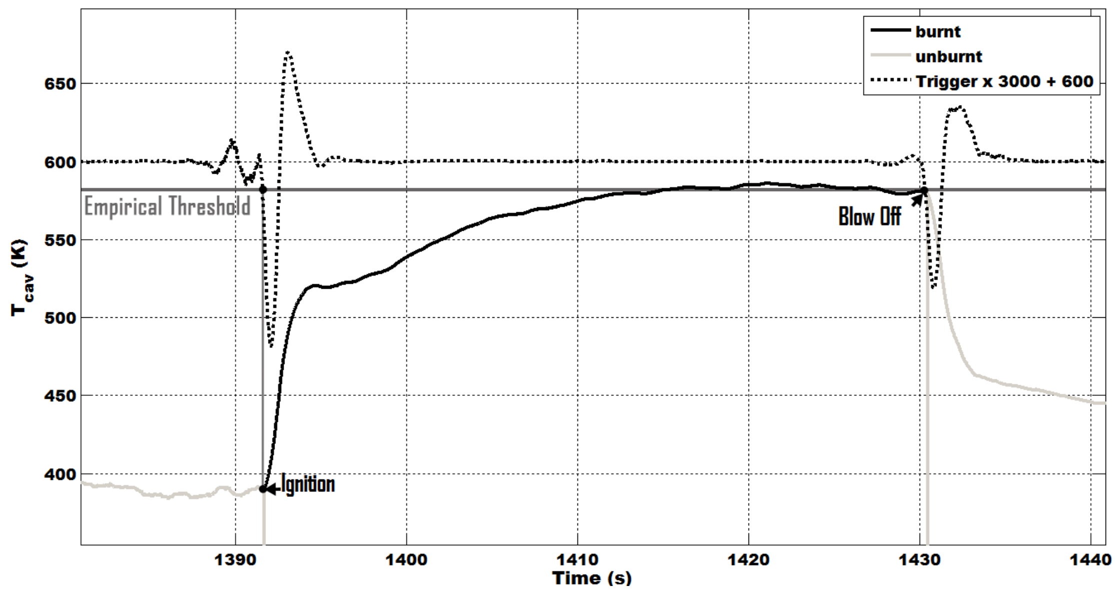


Figure 5. Ignition and blow out event tagging.

An efficient algorithm is used to post process the data in which the temperature measured in the cavity is used to detect the ignition and blow out phases. Two sliding averages $s_i(t)$ are obtained over different spans. The first average is carried over 1 second of signal, which is about the characteristic response time of the thermocouple, whereas, the second average is carried over 10 seconds of signal, which corresponds to the characteristic response time of the structure. Those are chosen values that may vary depending on the facility and the instrumentation.

$$s_i(t) = \frac{1}{\tau_i} \int_{t-\tau_i/2}^{t+\tau_i/2} T_{cav}(t')dt', \ \ \tau_{1,2} = 1, 10 \tag{1}$$

The relative difference is computed as in Equation 2. If the temperature is quite steady in time, the two averages tend to the same values and the difference is small. Note that s_1 has a faster time response than s_2 owing to a higher cut off frequency (1Hz) such that at ignition or blow out, the two signals phase out and the difference, respectively increases above or below 0. This variation is substantial if the temperature exhibits a coherent increase or decrease, which lasts about the time average span of s_2 ($\approx$ 8 seconds). The trigger signal is the relative difference multiplied by the time derivative of s_1.

$$Trigger = \frac{s_1 - s_2}{s_2} \frac{ds_1}{dt} \tag{2}$$

An empirical threshold is defined using the video data to indicate an event. If the trigger becomes less than the threshold value, a partition is created in the data as shown on Figure 5. The algorithm separates the burnt and unburnt data based on the average temperature in each partition. It is important to keep the algorithm simple to allow for real time applications. 180 blow out events were processed using this method within a couple of minutes with only two errors. The error induced by the time uncertainty on the fuel mixture composition does not exceed 0.1% of the full range of each fuel channel since the fuel mass flow rates slowly evolve when reaching blow out.

IV. Experimental Results

IV.A. Wind Tunnel Certification

The first pressure tap hole is located in front of all shocks described in Fig. 7. Therefore, the static to stagnation pressure ratio is computed in order to estimate the Mach number at the nozzle exit based on isentropic relations.

$$M = \sqrt{\frac{2}{\gamma - 1}\left(\left(\frac{P}{P_o}\right)^{\frac{1-\gamma}{\gamma}} - 1\right)}. \tag{3}$$

This estimate assumes that no heat is exchanged from the flow to its surroundings when the flow travels from the stagnation tank to the test section where the static pressure is measured. The presence of thermal insulation minimizes the heat transferred to the pipe wall so that the isentropic assumption holds reasonably. Experimental data from non-preheated and preheated case confirms a Mach number of 2.5 with a deviation of ±0.01 as shown in Fig. 6.

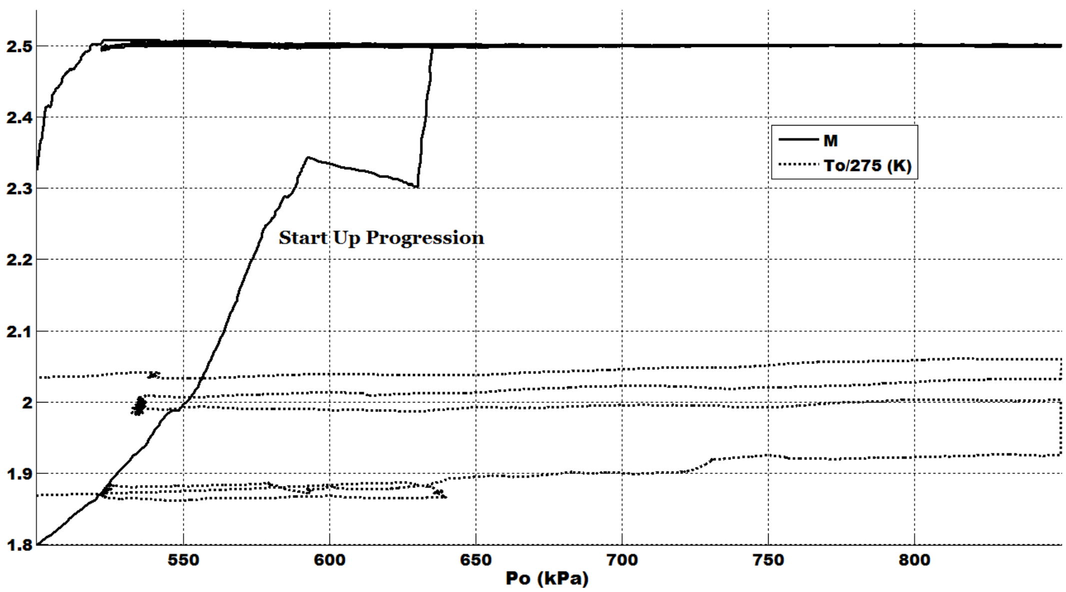


Figure 6. Mach number vs. stagnation pressure for a stagnation temperature ranging from 520 to 565 K.

IV.B. Flow Features and Flame Region

The tests have been carried over stagnation pressures that range from 500 to 850 kPa. Time average Schlieren flow visualization reveals the mean shock structure in the test section. Fig. 7 shows that the lifted shear layer deflects the flow toward the center line. This tendency of the mixing layer to reach over the leading edge has been mentioned by,[8] and is related to the effect of a high backpressure. Hence, an oblique shock anchors around the leading edge corner. The presence of this shock plays an important role in stabilizing the flame in the cavity since the post shock conditions are favorable to sustain combustion by both increasing the static pressure and temperature. Further downstream, the interaction between the shear layer and the supersonic main stream gives rise to a second shock at the trailing edge corner of the cavity. In addition, shocks emanate from the interaction between the primary shocks and the ceiling boundary.

Some of the initial studies all focused on the wind tunnel "starting problem" with combustion, which results in a mixed subsonic-supersonic process in the combustor. Progressive increase of the air mass flow rate is made from chocked nozzle conditions until fully supersonic test section regime is reached. Eventually, the flow in the isolator becomes supersonic and expands over the cavity under the form of a supersonic bubble that quickly damps if the primary air mass flow rate is still low since the back pressure is atmospheric (Fig.

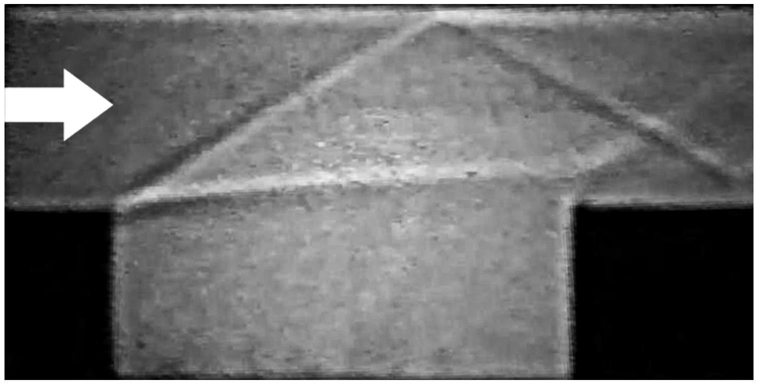


Figure 7. Shock features.

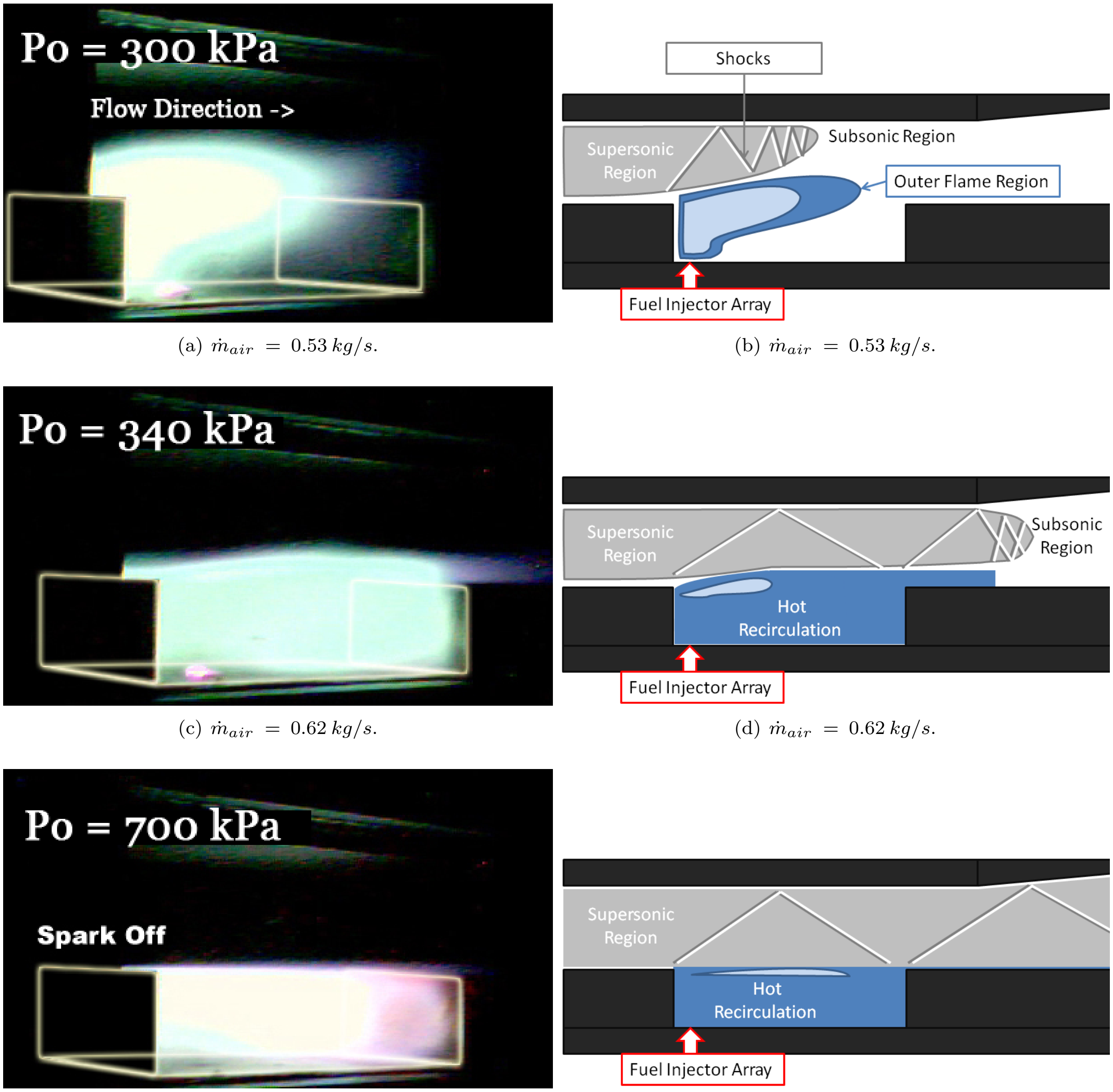
8(b)). In that case the flame region spans from the injector array up to the supersonic region, as seen in Fig. 8(a). Oscillations of the flame and overall poor stability with possible blow out are observed. Further increase of the mass flow rate leads to supersonic core expansion and decreases the subsonic region where the flame sits. Due to smaller flow time, the flame region stretches downstream and moves downward, into the cavity. Eventually, if the air mass flow rate is high enough, the main supersonic stream re-attaches at the trailing edge and encloses the reaction zone within the cavity (Fig. 8(d)). The flame re-attaches at the leading step and the recirculation of hot product forms. The flame then appears as a blue luminous zone due to CH-radicals, as seen in Fig. 8(c). Larger mass flow rates flatten the upper reaction zone boundary due to higher mean stream momentum (Fig. 8(e)) but the overall flame features remain relatively unaltered under stable conditions.

Additional video data at LBO reveals that the flame stays anchored in the injector region and its extent is progressively shifted from the downstream to the upstream side. This result is similar to the earlier observations[5,9] about the dynamics of cavity flames in the LBO limit.

IV.C. Factors of Influencing LBO

This section deals with series of tests without preheating the primary air stream. The distinct pressure and temperature trends observed in this study help to understand the influence of the supersonic core on the combustion process. Effect of preheating is discussed in a later subsection. Pressure, temperature and fuel mixture data has been collected on 98 blow out events. Figure 9 shows the typical behavior of the pressure measured in the cavity as a function of the stagnation pressure. The curve in blue is the pressure in the cavity in the absence of combustion; the proportional trend is related to the post shock conditions encountered past the leading edge. The data points in red is the cavity pressure measured under various combustion regimes. This pressure increases substantially as the combustion process intensifies. However, the blow out points lie close to the unburnt pressure such that the pressure drop at blow out is no more than 4 kPa. This suggests that as the combustor shifts toward the LBO limit, the pressure in the cavity tends to the pressure imposed by the supersonic core. Hence, the supersonic main stream mainly conditions the pressure in the cavity at LBO. This observation has an impact on the stability limits as a function of the air mass flow rate. At Mach 2.5, the static to stagnation pressure ratio (P/P_o) falls around 0.06 so that the pressures in the cavity at blow out ranges between 20 and 50 kPa.

Figure 10(a) is a representation of the blow out points as a function of the stagnation pressure and the hydrogen fuel mass fraction ($\frac{\dot{m}_{H_2}}{\dot{m}_{H_2}+\dot{m}_{CH_4}}$) over a larger number of tests with stagnation temperature of 300-320 K. The plot reveals that at lower stagnation pressure, the blow out events occur at higher hydrogen mass fractions. Since the hydrogen chemistry is more reactive than the primary fuel, more hydrogen is needed to stabilize the flame when cavity pressure reaches the lower values seen in Fig. 9. Moreover, the combustor exhibits a pronounced instability for stagnation pressure below 600. The blow out region spreads to higher hydrogen mass fraction, and the blow out events are not very repeatable (i.e., accidental blow out events occur). From the observation made in the previous subsections, the pressure at LBO can be estimated from the post shock conditions of the leading edge oblique shock, by neglecting the jump of pressure through the



(a) $\dot{m}_{air} = 0.53\,kg/s$.

(b) $\dot{m}_{air} = 0.53\,kg/s$.

(c) $\dot{m}_{air} = 0.62\,kg/s$.

(d) $\dot{m}_{air} = 0.62\,kg/s$.

(e) $\dot{m}_{air} = 1.3\,kg/s$.

(f) $\dot{m}_{air} = 1.3\,kg/s$.

Figure 8. Transient flame structure during stagnation pressure ramp up.

mixing layer. Indeed, the jump of pressure through the mixing layer is important in determining the amount of air that enters the cavity.

Recall that the temperature of the supersonic mean core is low relatively to the stagnation temperature since the flow has been accelerated through the nozzle. However, the temperature at blow out is close to the flame temperature since it is a necessary condition for the flame to exist. The reaction heat release is the main contributor in raising the cavity temperature even at blow out and it is not possible to infer that the supersonic core is the main factor in determining the cavity average temperature. Blow out occurs when the heat losses overcome the heat release by reaction until no stable combustion can be achieved. The majority of the heat losses occur at the wall and the shear layer. At the wall, heat is transferred to the structure and radicals are destroyed. In addition, the mixing layer represents an interface at which hot products and radicals are ejected downstream. Energy is also spent in heating the incoming mixture to bring it to its flammability limit, and this varies with the preheat condition.

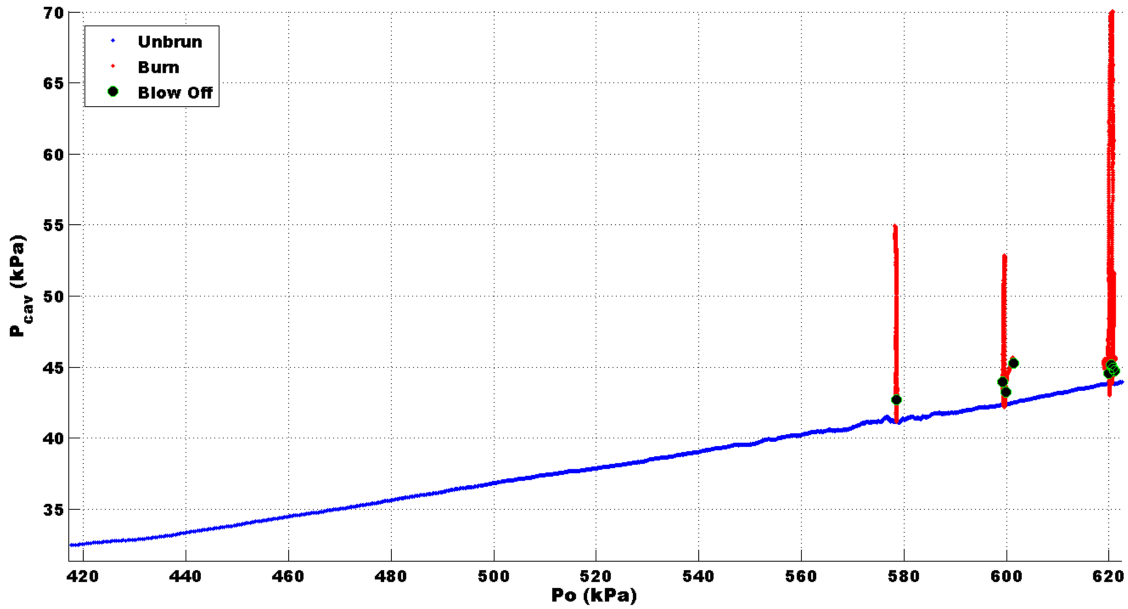


Figure 9. Cavity pressure Vs. stagnation pressure.

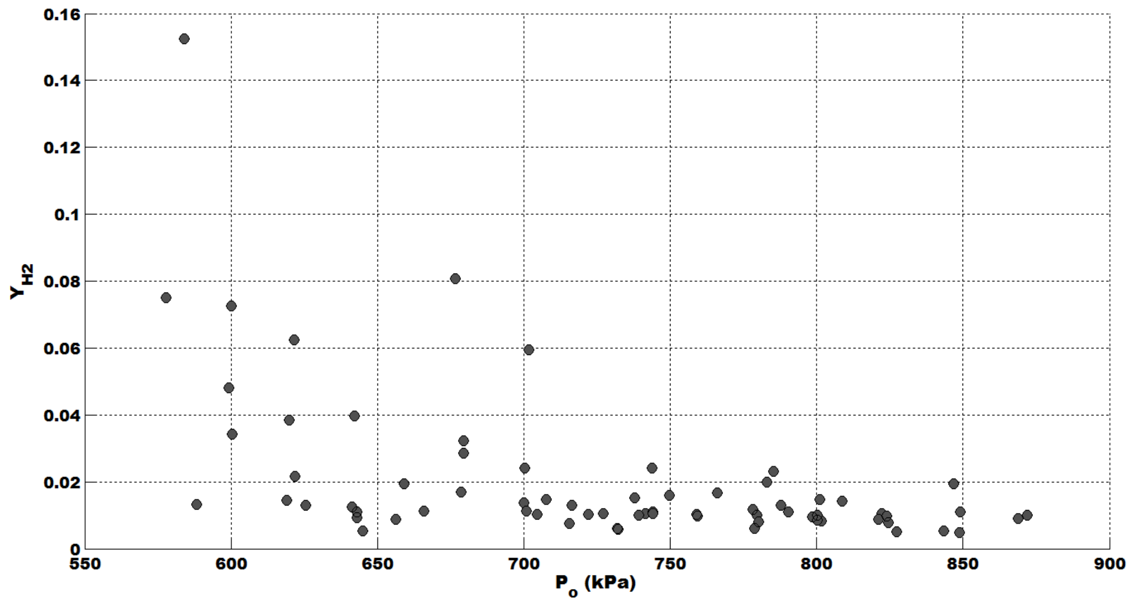
Figure 10(b) shows the blow out events as a function of the cavity wall temperature and the hydrogen mass fraction. The same trends are seen as in Fig. 10(a). The wall temperature is measured by the thermocouple located at the bottom side of the cavity, and this gives a rough estimate of the heat transfer to the wall assuming that the flame temperature is of the order of 2000 K. One can see that accidental blow out's occur with colder walls, whereas stability is regained with higher wall temperature. It turns out that lower wall temperatures are measured at lower stagnation pressure for which the supersonic core is colder. The high sensitivity of the combustion process to the temperature explains the lack of repeatability of the accidental blow out events.

IV.D. Blow Out Limits

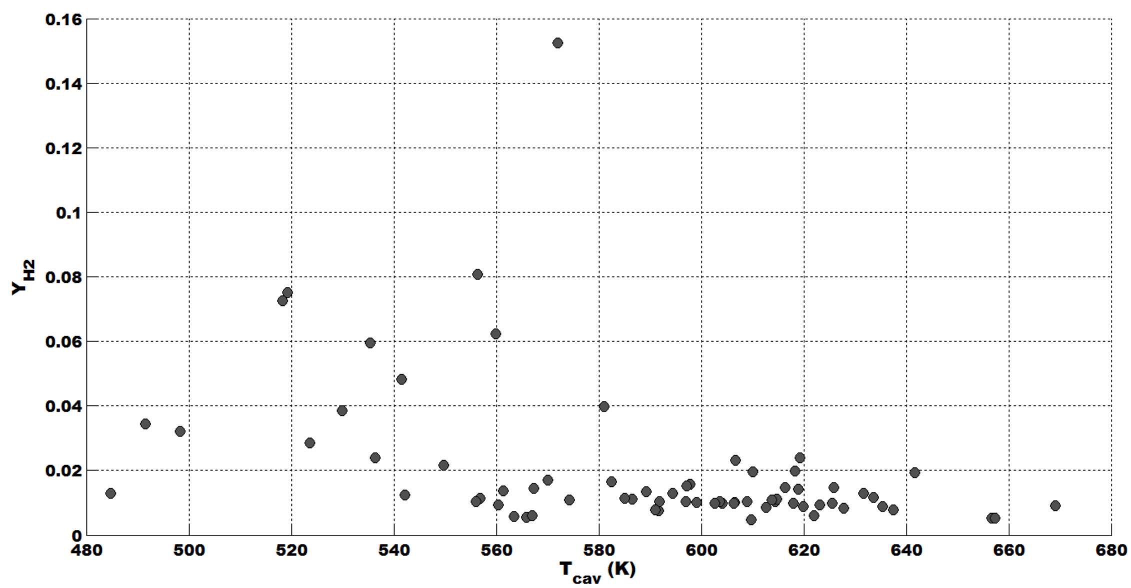
The mixture data is represented with respect to the stagnation pressure for the non preheated case in Fig. 11. At moderate and higher stagnation pressure, the blow out and ignition events shows a relatively good overall repeatability. The trends are consistent and in the mixture space, the blow out limit is not a line but rather a region where the probability of blow out reaches a significant value. As the pressure in the combustor increases, the hydrogen flow rates at which the flame blows off become nearly constant and are of the order of 0.01 g/s for most of the blow out data points collected. This behavior suggests the existence of a minimum overall energy release for the combustion to be sustained in the cavity.

As seen in Fig. 12(a), the blow out domain exhibits a stronger dependency on the mixture composition than on the overall air mass flow rate covered in those experiments. At low fuel rates (0.2-0.4 g/s of methane), the blow out limit progresses toward higher hydrogen flow rates due to the higher concentration of air and products. It is more challenging to sustain the combustion process when the fuel concentrations are low; the pressure plays an important role in this region. The higher pressures encountered when increasing the air mass flow rate imply higher collision rates that allow the combustion to be sustained when fuel is made rare. That is why the lowest hydrogen mass flow rate at blow out is generally reached for higher stagnation pressures.

The range that spans from 0.6 to 0.8 g/s of methane exhibits a very good stability, and it is difficult to find a blow out event. The most favorable conditions for holding a methane flame are found in this region and this tendency is due to favorable internal combustion features. Moreover, enough fuel mixture is found in this range to generate substantial heat but not too much methane that would increase the overall reaction time. At above 1 g/s of methane, the system exhibits a larger instability region with several accidental blow out's, and the dispersion of the blow out data points is substantially increased compared to the lower



(a) Hydrogen fuel mass Fraction Vs. stagnation pressure.

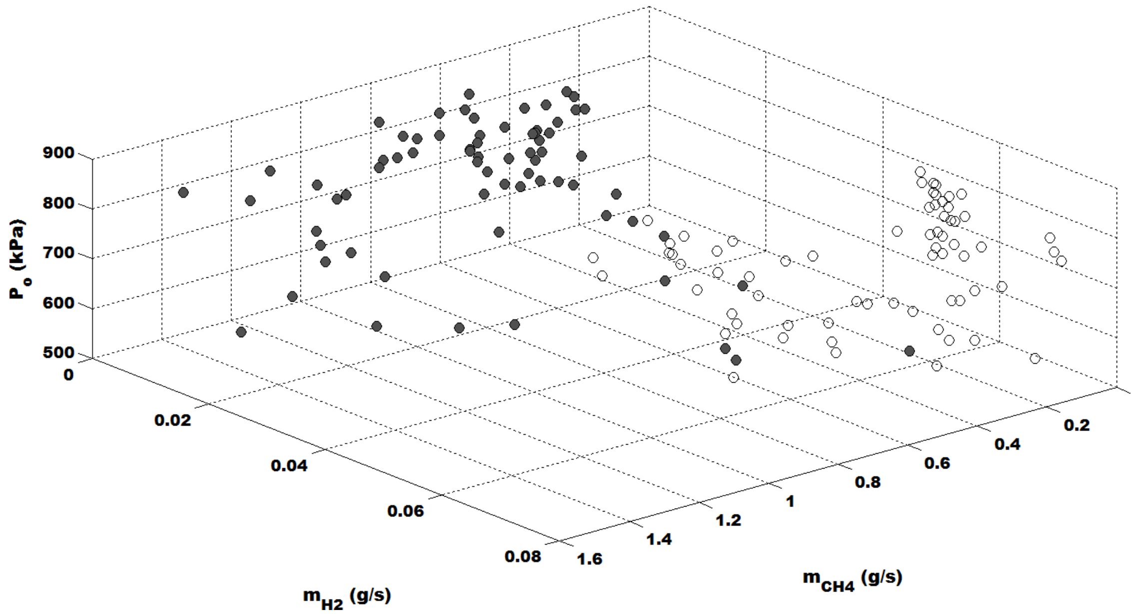


(b) Hydrogen fuel mass fraction Vs. bottom wall cavity temperature.

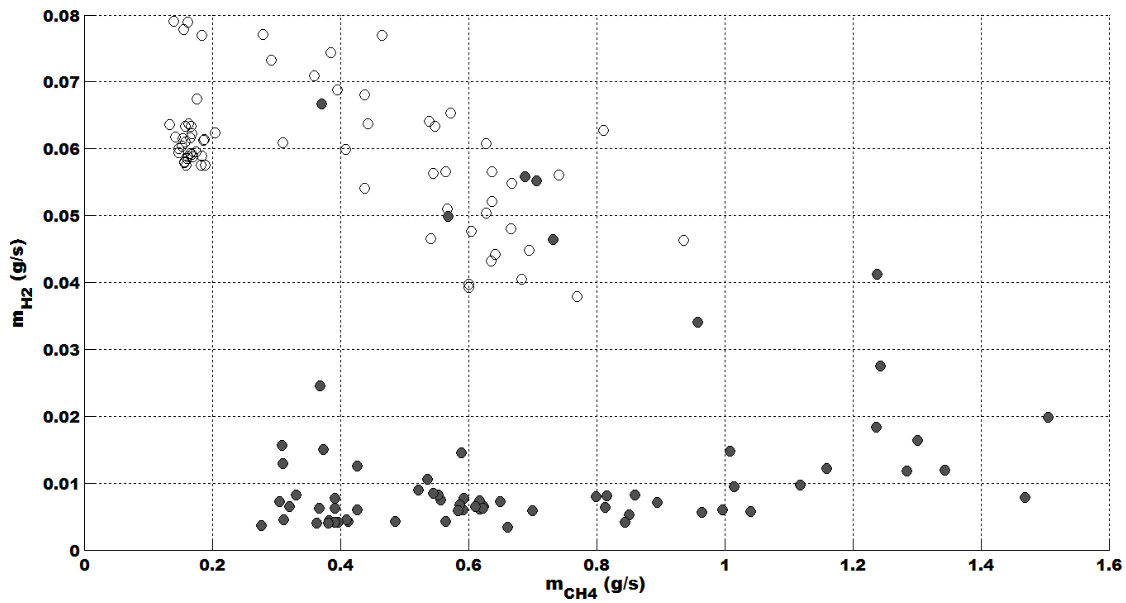
Figure 10. Influence of supersonic main stream on blow out events.

fuel flow rate regions. This happens when attempting to stabilize higher amount of methane with too little hydrogen present in the fuel mixture. Recall that pure methane combustion is not sustainable without any spark and hydrogen. Hence, there is a minimum fuel mass fraction of hydrogen that is needed to stabilize a given amount of methane. This should lie around 0.02 H_2 - 0.98 CH_4 for this region. Accidental blow out's are found in the lower stagnation pressures and mark the lower limit of the stable region. Such an effect is seen by the appearance of multiple accidental blow out's occurring in the top part of Fig. 11(b). These are direct effects of having low static pressure and temperature imposed by the supersonic cross stream. Note that some of those blow out events lie in the ignition domain, in that case, the presence of a spark during ignition prevents blow out to occur in these ranges.

Even in small quantities, addition of hydrogen in the fuel blend mixture is advantageous for increasing the stability of the combustor. The presence of hydrogen in the initial fuel mixture is believed to alter



(a) Without preheating.



(b) Without preheating: overall stability domain.

Figure 11. Ignition (circles) and blow out (dots) mixture data points without preheating (300 K).

the overall mechanism and create a reaction route that bypasses the slow methane pyrolisis, and therefore, leads to a faster build up of OH radicals. Such radicals are then immediately available for further reactions. Moreover, the results reveal that without preheating the main stream, methane flame combustion can be stabilized with smaller amounts of hydrogen for a particular fuel blend composition, e.g., less than 0.01 g/s of hydrogen with 0.6 g/s of methane.

IV.E. Effects of Preheating

The effect of having a hotter supersonic cross flow greatly impacts the stability. Compared to the case with no preheating, the blow out limit trend is shifted down to lower hydrogen flow rates leading in a greater stability domain. The dispersion of the data points is also considerably reduced. Some accidental blow out events are still found when operating at the worse conditions, i.e., at the lowest stagnation pressures and highest methane flow rates. The static temperature is of the order of 450 K without combustion, hence the amount of energy spent in raising the incoming mixture to its flammability limits is reduced. The wall temperature at blow out is systematically higher than 550 K and becomes nearly independent of the stagnation pressure, as seen previously in Fig. 10(b). The main effect of preheating is the decrease of the apparent heat losses. Heating of the incoming mixture is decreased, and the wall heat losses are smaller since the steel structure has a higher temperature with a preheat air stream. The supersonic air stream still plays a role but with a smaller impact.

The region of increased stability described in the non preheated case is still present in the 0.6 g/s of methane flow rate. The selectivity of this phenomenon on the fuel mixture composition suggests that the air-fuel stochiometry may become favorable for the combustion process to persist at lower hydrogen flow rates. Nevertheless, it has not been possible to relate this phenomenon to any substantial rise of the floor cavity temperature. In addition, the fuel jet exit velocity may also play an important role as it alters the mixing efficiency. The jet impinges the mixing layer with a different momentum depending on the fuel flow rate. Note that the fuel jet momentum is mainly carried by methane since methane gas has a much greater molar mass than the hydrogen so that the methane mass flow rate can be related to estimate the fuel jet momentum. For a fixed geometry and test conditions, pure methane combustion may be observed at a higher preheat temperature in the 0.6 g/s range of flow rate.

V. Conclusion

Stability of methane combustion diluted with small amount of hydrogen is studied in a Mach 2.5 supersonic cross stream. Addition of even a small amount of hydrogen greatly influences the reaction time as it alters the methane-air combustion mechanism in a more favorable manner. When the amount of fuel injected in the cavity is slowly decreased, the pressure drops and it is possible to have combustion without a substantial increase in pressure. The blow out conditions are partially governed by the supersonic cross flow regime. The study has also identified the existence of a particular fuel mixture composition, which results in an increased stability. Future studies will focus on the effect of higher preheat temperature, different L/D and fuel injection strategy. Effect of different fuel blends, e.g., ethylene-methane which as has been suggested as a surrogate for JP-7, will be also considered. Finally, a numerical study is currently underway to study this cavity stabilized combustion to obtain further insight into the combustion process and flame stabilization mechanism. These results will be reported in the near future.

Acknowledgments

This work was supported by Combustion, Science and Engineering, Inc. (Dr. Mike Klassen) under a Phase II STTR project funded by the OSD/DUSD(S&T) SBIR program (Dr. D. Risha). The authors acknowledge the help of David Scarborough, Combustion Lab Manager to set up the test facility.

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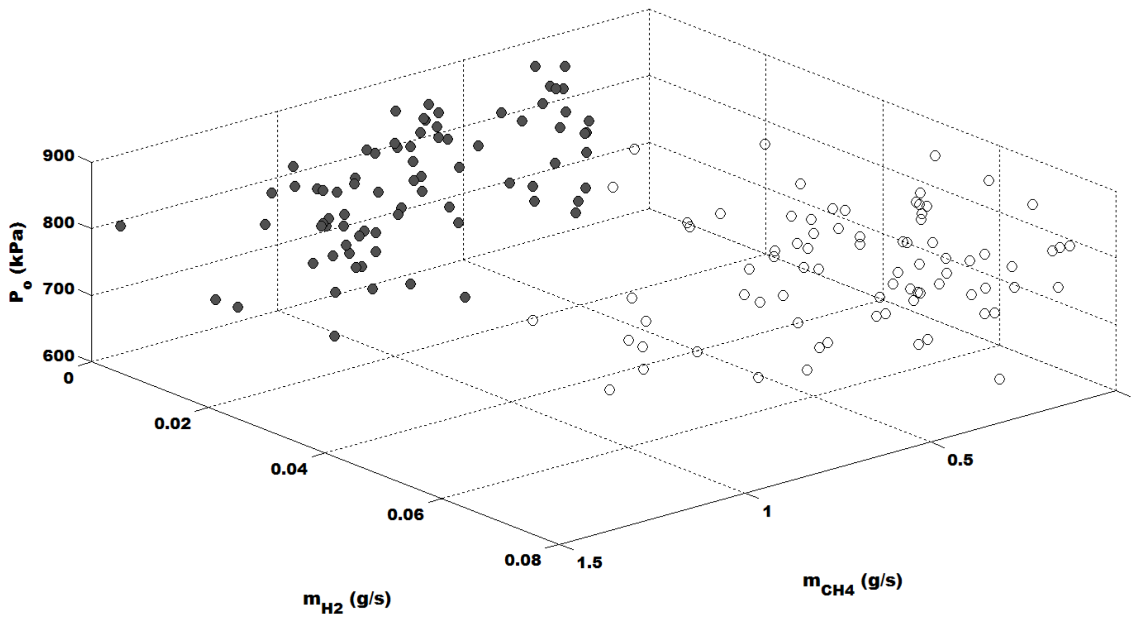
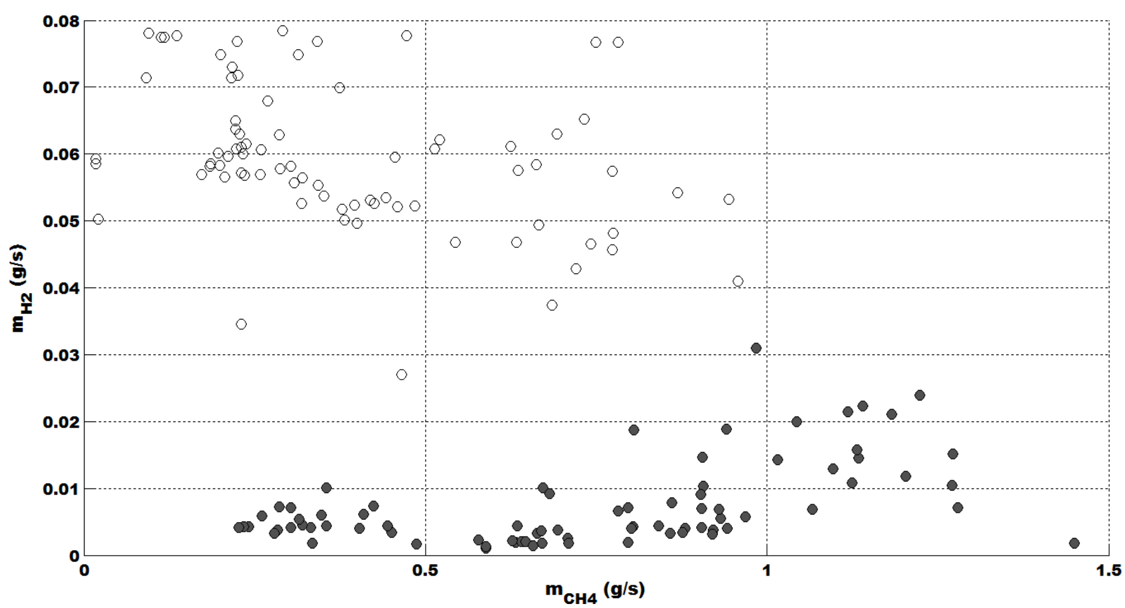


(a) Preheating at 550 K.



(b) Preheating at 550 K: overall stability domain.

Figure 12. Ignition (circles) and blow out (dots) mixture data points with 550 K preheating.