The Flame Structure of a Turbulent Supercritical Hydrogen/Oxygen Flow Behind a Splitter Plate

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The numerical simulation of fluid dynamics and combustion in cryogenic rocket engines is addressed in this paper, with the intent to elucidate the flame structure in the stabilization region. A model configuration is devised to allow a fully resolved simulation, both for the fluid dynamics and the chemical kinetics: a two-dimensional splitter plate represents the lip of an injector and the operating point is typical of a real engine. The flame structure is mostly lying on the diffusion counterflow flame manifold, although intermittent partially-premixed flames are also observable. These partially-premixed regions originate from diffusion flame folding and curvature which forms isolated pockets of reactants.

Nomenclature

\( T \)  
Temperature

\( P \)  
Pressure

\( V \)  
Molar volume

\( Y \)  
Mass fraction

\( \rho \)  
Density, kg/m\(^3\)

\( h \)  
Splitter plate height, m

\( \Delta \)  
Mesh cell size, m

\( x \)  
Axial position, m

\( y \)  
Transverse position, m

\( a \)  
Strain rate, s\(^{-1}\)

\( u \)  
Velocity, m/s

\( u_s \)  
Bulk velocity difference between the oxygen and hydrogen streams

\( N \)  
Avogadro number

\( \sigma_i \)  
Lennard-Jones potential-well depth

\( \epsilon_i \)  
Molecular diameter

\( k \)  
Boltzmann constant

\( \omega_{ac} \)  
Acentric factor

\( Z \)  
Mixture fraction

\( _i \)  
Species number

\( _c \)  
Critical point

\( _{in} \)  
Injection condition

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I. Introduction

The development of liquid-propellant rocket engines is a long and costly trial-and-error process. One of the major challenges in the design of the combustion chamber is to ensure a stable combustion. Indeed, the occurrence of combustion instabilities can cause structural damage but also raises critical issues for mission success. Another critical point is to ensure a steady combustion regime, avoiding flashback and blowoff events, for example. A key parameter controlling these phenomena is the stabilization of the flame downstream the injector, which is the subject of the present study. The literature on flame stabilization is extremely large, with detailed investigations using both experiments and numerical simulations. The main parameter describing flame stabilization is the distance from the injector to the flame front and a wide variety of phenomena have been reported with chemistry, transport and various sources of heat losses potentially playing an important role.

Cryogenic rocket engines operate at a very large pressure, at which reactants are usually under a supercritical state. In such conditions, the phase-change phenomena no longer occur and fluids evolve from a liquid-like state to a gas-like state in a continuous way. However, because the equation of state under such conditions is highly non-linear, very large density gradients due to temperature or composition variations are common. It has been shown that these gradients affect the overall dynamics of jets as well as the development of turbulence, mixing processes and eventually combustion.\textsuperscript{1,2} This particular behavior is a major issue for the development of accurate and quantitative numerical simulations. However, over the past 10 years, only a small number of research groups were able to conduct detailed simulations under fairly complex conditions, with developed turbulence\textsuperscript{3–5} and sometimes combustion.\textsuperscript{6,7}

The objective of this paper is to present a fully-resolved numerical simulation of a model injector to scrutinize turbulence, mixing and combustion processes downstream the injector. The numerics and models are first presented (Sec. II) followed by the description of the configuration (Sec. III). Then the validation of the chemistry is presented in Sec. IV, followed by the analysis of the reacting flow (Sec. V).

II. Numerics and Models

The compressible Navier-Stokes equations are solved using the AVBP code.\textsuperscript{8,9} In the present study, a two step Taylor-Galerkin scheme called TTG4A is used, which is third order in space and time.\textsuperscript{10} Real-gas thermodynamics are accounted for through the Peng-Robinson equation of state\textsuperscript{11} while transport coefficients are modeled based on the theory of corresponding states for the dynamic viscosity and the thermal conductivity\textsuperscript{12,13} and constant Schmidt numbers (c.f. Tab. 1). This overall numerical and modeling methodology has already been validated for non reacting flows.\textsuperscript{14} The critical-point coordinates of the intermediate species \( \text{OH}, \text{O}, \text{H}, \text{H}_2\text{O}, \text{HO}_2 \) (for which no experimental data are available) is estimated using the Lennard-Jones potential-well depth \( \sigma_i \) and the molecular diameter \( \epsilon_i \) of the \( i \)-th species from the CHEMKIN transport coefficients of the San Diego Mechanism, according to the following expression:\textsuperscript{15}

\[
V_{c,i} = 3.29N\sigma_i^3 \\
T_{c,i} = 1.316\epsilon_i/k
\]

where \( N \) is the Avogadro number and \( k \) is the Boltzmann constant. The acentric factor \( \omega_{ac} \) is set to zero for radical species. The numerical values for all species are summarized in Tab. 1.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>H2</th>
<th>O2</th>
<th>H2O</th>
<th>O</th>
<th>H</th>
<th>OH</th>
<th>H2O2</th>
<th>HO2</th>
</tr>
</thead>
<tbody>
<tr>
<td>( T_{c,i} ) (K)</td>
<td>33</td>
<td>154.581</td>
<td>647.096</td>
<td>105.28</td>
<td>190.82</td>
<td>105.28</td>
<td>141.34</td>
<td>141.34</td>
</tr>
<tr>
<td>( P_{c,i} ) (MPa)</td>
<td>1.2838</td>
<td>5.0430</td>
<td>22.064</td>
<td>7.0882</td>
<td>31.013</td>
<td>7.0883</td>
<td>4.7861</td>
<td>4.7861</td>
</tr>
<tr>
<td>( V_{c,i} ) (cm(^3)/mol)</td>
<td>64.284</td>
<td>73.368</td>
<td>55.948</td>
<td>41.205</td>
<td>17.069</td>
<td>41.205</td>
<td>81.926</td>
<td>81.926</td>
</tr>
<tr>
<td>( \omega_{ac} )</td>
<td>-0.216</td>
<td>0.0222</td>
<td>0.3443</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
</tbody>
</table>

Schmidt Number | 0.28 | 0.99 | 0.77 | 0.64 | 0.17 | 0.65 | 0.65 | 0.65 |

Table 1. Species critical-point properties (temperature \( T \), pressure \( P \), molar volume \( V \) and acentric factor \( \omega_{ac} \)) and Schmidt numbers.
III. Configuration

The configuration is a two-dimensional H$_2$/O$_2$ flame stabilized behind a splitter plate at a mean pressure of 100 bar. Although turbulence is a 3D phenomenon, the resolution required to perform a 3D resolved simulation is prohibitive. However, this study focuses on flame/flow interaction, which is mainly 2D in the stabilization region, and it is believed that the simplification to 2D is no a strong limitation for the present work. The computational domain, presented in Fig. 1, is 11h long in the x-direction and 10h in the y-direction, where $h = 500 \times 10^{-6}$ m is the splitter height. Hydrogen is injected above the splitter at a temperature $T_{H_2}^{in} = 150$ K and a bulk velocity $u_{H_2}^{in} = 125$ m/s. Below the splitter, oxygen is fed at $T_{O_2}^{in} = 100$ K and $u_{O_2}^{in} = 30$ m/s. These conditions were chosen to mimic a typical liquid rocket engine. The shape of the inlet velocity profiles follows a 1/7th power law. Although developed turbulence is generally present in the feeding lines of rocket engines, no velocity perturbation is added to the inflow boundary condition. Yet, strong turbulence levels caused by vortex shedding are observed downstream the splitter allowing for a developed turbulent mixing layer and strong flame / turbulence interactions (c.f. Sec. V). The outlet boundary condition is derived from the NSCBC theory$^{16,17}$ and accounts for both real-gas effects$^{18}$ and transverse terms.$^{19}$ With a procedure similar to that of Bogey et al.$^{20}$ a sponge layer of thickness $h$ is imposed at the exit of the computational domain to prevent spurious oscillations when the strong density gradients hit the boundary. The upper and lower boundaries are treated as symmetries while the splitter is an adiabatic no-slip wall. The mesh resolution is $\Delta = h/500$ in a layer containing the splitter, with a $3h$ vertical extent. Outside this zone, a transverse stretching factor of approximately 1.02 is employed. The mesh contains approximately 13.5 million nodes.

![Figure 1. Computational domain for the two-dimensional splitter-plate configuration.](image)

IV. Chemistry

The combustion of hydrogen and oxygen is modeled using a detailed scheme accounting for 8 species and 12 reactions,$^{21}$ derived from the San Diego mechanism.$^{22}$ The forward rate coefficients are given in Tab. 2. The backward reaction rates are classically computed using low-pressure entropy and enthalpy NIST/JANAF tables.$^{23}$ A more general treatment of the reaction rates in the real-gas framework, using chemical potentials directly computed from the equation of state has been investigated by Giovangigli $et$ $al.$$^{15}$ However, the impact on the flame structure appears to be rather small, showing that the perfect-gas treatment of the reaction rates is a good approximation: this is due to the high temperature (and hence perfect-gas behavior) at the flame location. Note that since high pressure is considered in the present study, only the high-pressure limit of the fall-off reactions have been used.

The validation of the implementation in AVBP is achieved by comparing the flame structure using CANTERA$^{24}$ and AVBP in a counterflow flame configuration. The numerical setup is that of an opposed-
<table>
<thead>
<tr>
<th>Reaction</th>
<th>(k)</th>
<th>(a)</th>
<th>(n)</th>
<th>(E^a)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (\text{H}+\text{O}_2 \rightleftharpoons \text{OH}+\text{O})</td>
<td>(3.52 \times 10^{16})</td>
<td>-0.7</td>
<td>71.42</td>
<td></td>
</tr>
<tr>
<td>2 (\text{H}_2+\text{O} \rightleftharpoons \text{OH}+\text{H})</td>
<td>(5.06 \times 10^4)</td>
<td>2.67</td>
<td>26.32</td>
<td></td>
</tr>
<tr>
<td>3 (\text{H}_2+\text{OH} \rightleftharpoons \text{H}_2\text{O}+\text{H})</td>
<td>(1.17 \times 10^9)</td>
<td>1.3</td>
<td>15.21</td>
<td></td>
</tr>
<tr>
<td>4 (\text{H}+\text{O}_2+\text{M} \rightarrow \text{HO}_2+\text{M})</td>
<td>(4.65 \times 10^{12})</td>
<td>0.44</td>
<td>0.0</td>
<td></td>
</tr>
<tr>
<td>5 (\text{HO}_2+\text{H} \rightarrow 2\text{OH})</td>
<td>(7.08 \times 10^{13})</td>
<td>0.0</td>
<td>1.23</td>
<td></td>
</tr>
<tr>
<td>6 (\text{HO}_2+\text{H} \rightleftharpoons \text{H}_2+\text{O}_2)</td>
<td>(1.66 \times 10^{13})</td>
<td>0.0</td>
<td>3.44</td>
<td></td>
</tr>
<tr>
<td>7 (\text{HO}_2+\text{OH} \rightarrow \text{H}_2\text{O}+\text{O}_2)</td>
<td>(2.89 \times 10^{13})</td>
<td>0.0</td>
<td>-2.08</td>
<td></td>
</tr>
<tr>
<td>8 (\text{H}+\text{OH}+\text{M} \rightleftharpoons \text{H}_2\text{O}+\text{M})</td>
<td>(4.00 \times 10^{22})</td>
<td>-2.0</td>
<td>0.0</td>
<td></td>
</tr>
<tr>
<td>9 (2\text{H}+\text{M} \rightleftharpoons \text{H}_2+\text{M})</td>
<td>(1.30 \times 10^{18})</td>
<td>-1.0</td>
<td>0.0</td>
<td></td>
</tr>
<tr>
<td>10 (2\text{HO}_2 \rightarrow \text{H}_2\text{O}_2+\text{O}_2)</td>
<td>(3.02 \times 10^{12})</td>
<td>0.0</td>
<td>5.8</td>
<td></td>
</tr>
<tr>
<td>11 (\text{HO}_2+\text{H}_2 \rightarrow \text{H}_2\text{O}_2+\text{H})</td>
<td>(1.62 \times 10^{11})</td>
<td>0.61</td>
<td>100.14</td>
<td></td>
</tr>
<tr>
<td>12 (\text{H}_2\text{O}_2+\text{M} \rightarrow 2\text{OH}+\text{M})</td>
<td>(2.62 \times 10^{19})</td>
<td>-1.39</td>
<td>214.74</td>
<td></td>
</tr>
</tbody>
</table>

Table 2. Forward rate coefficients in Arrhenius form \(k = AT^n \exp(-E/RT)\) for the skeletal mechanism.

\(^a\)Units are mol, s, cm\(^3\), kJ, and K.

\(^b\)Chaperon efficiencies are 2.5 for H\(_2\), 16.0 for H\(_2\)O and 1.0 for all other species.

\(^c\)Chaperon efficiencies are 2.5 for H\(_2\), 12.0 for H\(_2\)O and 1.0 for all other species.

\(^d\)Chaperon efficiencies are 2.0 for H\(_2\), 6.0 for H\(_2\)O and 1.0 for all other species.

Jet flame computed, in AVBP, on a simple square mesh (size \(h\)) with a constant grid size identical to that of the splitter case. The left boundary condition is a symmetry, the right side an outlet, while hydrogen comes from the top and oxygen from the bottom (Fig. 2). Injection velocities are determined to impose a constant strain rate, \(a\), on the flame:

\[
\begin{align*}
\text{u}_{\text{O}_2}(x) &= ax \quad (3) \\
\text{v}_{\text{O}_2}(y) &= -ay \quad (4) \\
\text{u}_{\text{H}_2}(x) &= ax \left( \frac{\rho_{\text{O}_2}}{\rho_{\text{H}_2}} \right)^{\frac{1}{2}} \quad (5) \\
\text{v}_{\text{H}_2}(y) &= -ay \left( \frac{\rho_{\text{O}_2}}{\rho_{\text{H}_2}} \right)^{\frac{1}{2}} \quad (6)
\end{align*}
\]

The hydrogen velocity is chosen so that the momentum flux \(\rho u^2\) is the same for both the oxygen and hydrogen streams, to place the stagnation point in the middle of the computational domain. The splitter height \(h\) and the mean velocity difference between the two streams at injection yield \(a = 3800 \text{ s}^{-1}\). A typical result for such a strained diffusion flame is presented in Fig. 2, showing streamlines superimposed to the temperature field.

The validation procedure compares three types of computation:

1. **CANT\_PG**: perfect-gas with CANTERA and detailed transport coefficients. The temperature of the fresh gases is raised to 300 K to limit real-gas effects.

2. **AVBP\_PG**: perfect-gas computation with AVBP and constant Schmidt numbers with mixture-averaged transport coefficients. The fresh gas temperature is also raised to 300 K. Comparison with CANT\_PG is both a validation of the implementation of the chemistry in AVBP as well as a validation of the simplified transport.

3. **AVBP\_RG**: real-gas computation with AVBP. The temperature of the fresh gases is back to those of the splitter case. In this case, real-gas effects on the flame structure are evaluated.

All three computations are compared, along a cut through the flame at \(x = h/2\) for the computational domain of AVBP (Fig. 2). Figure 3 shows the temperature and mass fraction of HO\(_2\) (the main initiator of combustion) versus the mixture fraction (defined as the mass fraction of the H element).

First, the agreement between CANT\_PG and AVBP\_PG is excellent: the maximum discrepancy for the temperature is of the order of 70 K, which gives a relative error of 2 %. The differences for the mass fraction...
Figure 2. Strained diffusion flame computed in AVBP: streamlines superimposed to the temperature field. Thermo-dynamic conditions correspond to the splitter case: hydrogen at 150K from the top, oxygen at 100K from the bottom and ambient pressure is 100 bar.

Figure 3. Comparison of (a) temperature and (b) $H_2O_2$ profiles versus mixture fraction between the three computations. The vertical line indicates the stoichiometric mixture fraction.

$Y_{H_2O_2}$ are even smaller. This agreement validates the implementation in AVBP as well as the assumptions on the simplified transport at this temperature. Second, the low injection temperature case (AVBP_RG) is very similar to the high temperature computation (AVBP_PG) in the flame region. This conclusion is similar to that of Ribert et al.\textsuperscript{26} which they justify by the fact that the combustion processes take place in hot regions where real-gas effects are negligible. This validates the chemistry model used in the splitter case computation.

V. Results and analysis

The spatial resolution in the present study is such that 500 grid points are used to discretize the splitter height $h$. As a comparison with previous efforts to compute such configurations,\textsuperscript{27} the resolution is ten times greater. The reactive simulations presented in this section use the kinetics validated in Sec. IV. Combustion is initiated in the computational domain with the following procedure: first the field of mixture fraction is computed from a non-reacting established flow, then, the flame structure from a laminar diffusion flame is applied onto this field with subsequent replacement of the composition and temperature. During this procedure, the cold-flow pressure and velocity fields are not altered. As expected, significant acoustic perturbations are generated when the flow adapts from this approximate solution but pressure waves eventually leave the computational domain and a stable combustion regime is reached.

First, general observations on the flame stabilization process are done in Sec. V.A. Then, the flame structure is analyzed in the mixture fraction space in Sec. V.B, to identify the combustion modes. Finally, the analysis in mixture fraction space is linked to flame features in the physical space introducing a new mixture index in Sec. V.C.
V.A. Flame stabilization

An instantaneous temperature field is presented in Fig. 4 with superimposed iso-contours of density gradient (green: $40 \times 10^6$ kg/m$^4$) and heat release (black: $10^{13}$ W/m$^3$, grey: $10^{12}$ W/m$^3$). The flame is not lifted and hot gases touch the splitter plate. This is certainly partially due to the adiabatic boundary condition imposed at the solid boundary. However, hydrogen / oxygen flames are known to be extremely reactive and experimental evidence under comparable thermodynamic conditions showed that the flame is stabilized very close to the plate.\(^{28}\) The flame is stabilized on the oxygen side, but in the light region (above the green iso-contour).

![Figure 4. Temperature field with superimposed density gradient (green: $40 \times 10^6$ kg/m$^4$) and heat-release (black: max heat release of case AVBP_RG; grey: 10% of case AVBP_RG).](image)

A close-up view of the vicinity of the splitter is presented in Fig. 5. Regions of strong heat release are visible at the edges of the high-temperature pocket, both on the hydrogen and oxygen sides. This is an indication that turbulent mixing is very intense in this region allowing each species to be transported across the splitter height. At this point of the analysis, this transport mechanism is not clear but animations of the splitter region show that large-scale vortices allow for fresh hydrogen to be transported towards the oxygen stream while at other times, burnt gases with excess oxygen are transported up to the hydrogen stream. It is therefore concluded that even though chemistry plays a key role in the stabilization of such flame, turbulent transport is also active and influences the combustion regime. It is also foreseen that for fuels with less chemical activity, turbulence could become a key stabilization process.

![Figure 5. Close-up view of the flame stabilization zone behind the splitter. Temperature field (yellow is 3800 K) with superimposed density gradient (green: $40 \times 10^6$ kg/m$^4$) and heat-release (black: max heat release of case AVBP_RG; grey: 10% of case AVBP_RG).](image)

The reacting flow field was averaged over a period of 0.3 millisecond. This corresponds to two flow-through times (using the oxygen bulk velocity), which is sufficient to observe the main characteristics of the mean field even though the average may not be fully converged. From the mean heat release field shown in Fig. 6, it is clear that the flame is composed of two regions: a stable diffusion flame located immediately
behind the splitter plate, within the recirculation zone, and a flame brush region, where the combustion mode is mainly diffusion, but where partially-premixed combustion also occurs, as will be shown in Sec. V.B and Sec. V.C.

The temperature field is very convoluted on both oxygen and hydrogen sides, especially in the second half of the computational domain which makes the combustion modes difficult to understand without additional information. This is the aim of the next sections.

V.B. Flame structure in the mixture fraction space

The flame structure (temperature vs. mixture fraction, for all points located before the exit sponge-layer) at three successive times is shown in Fig. 7, where the counterflow flame computed in Sec. IV is also shown as a dashed red line. The adiabatic flame temperature for a stoichiometric mixture is approximately 3800 K. This value is reached in the non-premixed flame at the stoichiometric mixture fraction. Most of the points are lying on the counterflow flame manifold, but intermittently, other combustion modes are observed. The blue arrow shown in the middle plot of Fig. 7, identifies a lean mixture ($Z < Z_{st}$) burning above the counterflow flame temperature, while a rich mixture ($Z > Z_{st}$) appears at a later instant, as shown by the red arrow in the right plot. The black arrow indicates a diffusion flame at a lower temperature than the one from Sec. IV, which regularly disappears. The combustion modes identified in the present global analysis will be further analyzed using normal cuts through the flame (local analysis) at the end of Sec. V.C.

V.C. Flame structure in the physical space

Several flame indices have already been proposed in the literature, based on fuel and oxygen mass fraction gradients,\textsuperscript{29–31} but they failed to provide a clear understanding of the combustion modes in the present

Figure 6. Average field of heat release. Black iso-contour: $\rho = 0.9 \rho_{\text{O}_2}^n$

Figure 7. Temperature vs. mixture fraction at three different times. Blue arrow: lean partially-premixed region. Red arrow: rich partially-premixed region. Black arrow: diffusion flame at a lower temperature.
configuration. A new index is thus proposed herein, inspired by the previous ones:

$$M_{ix} = \frac{Z - Z_{st}}{|Z - Z_{st}|} Y_{H_2} Y_{O_2}$$

(7)

This index enables the detection of regions where hydrogen and oxygen are mixed, while identifying if the mixture is rich ($M_{ix} > 0$) or lean ($M_{ix} < 0$). The amplitude of the $M_{ix}$ index shows the mixing intensity. If a flow region is identified as a rich mixture, the temperature of this mixture is needed to determine whether it is burning or not. This information is obtained from a hot temperature iso-contour (2000 K), circling hot gases.

For a counterflow flame configuration with the infinitely fast chemistry assumption (“mixed is burnt”), $M_{ix}$ is zero everywhere, whereas with finite-rate chemistry, $M_{ix}$ goes from small negative values to small positive values within a thin layer around the stoichiometry, as shown in Fig. 8.

Figure 8. Mixing index for the counterflow flame configuration of Sec. IV, ranging from $-10^{-3}$ in blue to $10^{-3}$ in red, the zero value being white.

Figure 9 shows the $M_{ix}$ index for an instantaneous solution over the whole computational domain, with the stoichiometric mixture fraction shown in green and a high heat release iso-contour (max heat release of case AVBP_RG) in black. Three different combustion modes are identified. Region 1 is a highly-strained non-premixed diffusion flame since the blue-to-red layer surrounding the stoichiometry is very thin, and intense heat release occurs. This is the major combustion mode in the computational domain. Region 2 is a lightly-strained partially-premixed flame, as will be shown later on. Region 3 is a rich premixed flame, since an isolated rich mixture (not surrounded by the stoichiometric line) is located in hot gases. This type of combustion mode occurs when convective motions extract and isolate the rich region of a partially-premixed flame (folding or curving the flame), or at the late stages of an oxygen pocket combustion, when almost no oxygen is left.


Figure 10 shows four successive instants of the $M_{ix}$ index with the stoichiometric and heat release iso-contours (identical to Fig. 9). It is a close-up view of the recirculation zone, showing the links between the combustion modes previously identified. At $t = t_1$, only a non-premixed diffusion flame is observable. However, on the right side, the stoichiometric iso-contour is highly curved and is being folded by vortical
motions shed at the hydrogen lip corner. At $t = t_2$, the latter flame portion is completely folded and partial-premixing starts. At $t = t_3$, a pocket of oxygen (containing some hydrogen) is burning in the hot gases, still in a partially-premixed flame mode (the stoichiometric iso-contour is separating an oxygen-rich mixture and a hydrogen-rich mixture). At $t = t_4$, most of the oxygen contained in the latter pocket has burnt and a rich premixed mixture is burning.

Finally, a cut through a partially-premixed flame (“region 2”) in the second half of the computational domain is shown in Fig. 11 (the time is different from Fig. 9). The cut location is also shown. It is clear that the points located above the counterflow flame profile (dashed red line) are due to partial-premixing, originating from the process described above.

Figure 10. Evolution of combustion modes with time. Blue-to-red color palette ranging from $-10^{-3}$ to $10^{-3}$: $M_{	ext{iso}}$. Orange: $T = 2000$ K. Black: Max heat release of case AVBP_RG. Green: stoichiometric mixture fraction.

Figure 11. Partially-premixed flame structure.
VI. Conclusion

Simulation of a splitter-plate stabilized H\textsubscript{2}/O\textsubscript{2} flame representative of a cryogenic rocket engine injector has been conducted. The dynamic and thermodynamic conditions are chosen to be representative of a real engine under steady operation: both fuel (hydrogen) and oxidizer (oxygen) are above their critical pressure. A reacting configuration was computed, on a two-dimensional domain with full resolution of vortical motions and realistic chemistry. The flame develops outside the dense oxygen stream and is anchored on the splitter, due to both the adiabatic boundary condition and the high reactivity of hydrogen. A complex stabilization process involving both chemistry and turbulent transport is observed, giving rise to intermittent partially-premixed regions that can have temperatures above the non-premixed counterflow flame configuration. However, these finite-rate chemistry effects are of minor importance and the reacting layer is mostly composed of variedly strained non-premixed flames. This work is to be continued, accounting for heat losses at the splitter in order to investigate stabilization mechanisms in a more accurate way.

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10 of 11

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