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Numerical studies of premixed hydrogen/air flames in a small-scale combustion chamber with varied area blockage ratio

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Abstract

The increasing use of hydrogen as a renewable source of energy underlines the need to be able to assess the safety risks involved in the event of an accidental explosion. This paper presents numerical studies for hydrogen/air propagating flames at an equivalence ratio of 0.7 in a laboratory-scale combustion chamber equipped with turbulence generating baffles and a solid square cross section obstruction. The large eddy simulation (LES) modelling technique is used with an in-house computational fluid dynamics (CFD) model for compressible flows to study the flow turbulence and the flame propagation characteristics. The study is carried out using four different baffle arrangements and two different solid obstructions with area blockage ratios of 0.24 and 0.5. Results for the generated peak overpressure and the timing at which it occurs following ignition are considered as the primary safety factors. The time histories of the flame speed and position relative to the ignition source are validated against published experimental data. Good agreement is obtained between numerical results and experimental data which enables further predictions where measurements are limited in the study of vented hydrogen explosions. It was concluded that adding successive baffles and increasing the area blockage ratio escalates the maximum rate at which pressure rises and raises the generated peak explosion overpressure.

Introduction

Hydrogen (H₂) has the potential to be used as a replacement fuel due to its renewability and relatively high energy density when compared to alternative hydrocarbons [1,2]. There is an opportunity in using hydrogen as a fuel for road vehicles and this has been proven with the development and subsequent release of hydrogen fuel cell electric vehicles to the public [3–5]. Attempts are also being made to develop a further understanding of hydrogen-fuelled internal combustion engines [6]. Hydrogen is also being considered as zero-carbon alternative to hydrocarbons for domestic or commercial heating [7]. With supporting hydrogen stations currently under construction, research is carried out to ensure sufficient engineering controls are in place for both normal and emergency operations [8,9]. As a result, it is necessary to consider the safety implications in the transport, storage and use of hydrogen as a fuel [3,4,10,11]. Hydrogen's relatively low density and wide range of flammability denotes that it mixes rapidly with surrounding air if released into the atmosphere, following which it is very prone to accidental explosions [12]. This is

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particularly dangerous in a partially-confined space as has been confirmed by several lab-scale studies of hydrogen deflagration [13–15]. Experimental studies published for several years have confirmed that hydrogen produces significantly higher explosion overpressure at much higher propagating flame speeds when compared to methane (CH_4) and propane (C_3H_8) [16,17]. These characteristics along with previous instances of accidents such as the Fukushima Daiichi nuclear disaster [18,19] highlight the importance of further understanding hydrogen combustion. The study presented in this paper uses the LES modelling technique to investigate the flame structure of lean hydrogen flames as they propagate through baffles and past a solid obstruction out of a vented chamber. The numerical results obtained are validated against experimental data obtained by Masri et al. [16]. The resultant peak explosion overpressure depends on various parameters such as the fuel/air equivalence ratio, the spacing between obstacles and their distance from the ignition source [20–23]. These obstacles act as turbulence generators ahead of the flame as it propagates through the baffles and past the solid obstruction [20,24]. As a result, a suitable numerical model would need to be able to predict how the obstacles and turbulence levels within the chamber influence the flame structure [20,21,25]. Large and small scale experiments have been previously carried out for hydrogen/air explosions and compared them to substitute hydrocarbons [16,17,26–29]. These experiments can be used to validate numerical models for further use.

Numerical modelling has proven to be an outstanding alternative in various industries including fluid dynamics, aeronautical and automotive, considering problems with complex non-reacting flows. As for turbulent reacting flows, there remain unresolved issues where further research is required. The accomplishments of numerical modelling in applications with non-reacting flows mean that there is an increasing use in the numerical modelling of turbulent combustion. Generally, the main computational modelling techniques are Direct Numerical Simulations (DNS), Reynolds Averaged Navier-Stokes (RANS) and Large Eddy Simulations (LES).

Previous research has successfully carried out numerical simulation for several applications of complex reacting flows [30–34]. Further, numerical results obtained through computational modelling convey how the flow reacts to various obstacles and obstructions in a semi-confined space [35–39]. The numerical approach still relies on an adequate turbulence and combustion model in order to accurately perform numerical analysis for a hydrogen explosion. A cost and time effective approach needs to be utilised depending on the application and computational resources available in order to produce adequate results within an acceptable amount of time [40]. The DNS technique is not typically applied due to relatively high computational expense when compared to suitable alternatives. The RANS technique has been accepted due to its satisfactory results for large scale applications [34,41–43]. On the other hand, the LES technique for turbulent flows has been used to numerically study vented explosions in lab-scale applications [11–15,27–29,34–42]. One of the key factors to consider for the LES technique is an appropriate sub-grid-scale (SGS) combustion model which is capable of providing results across a range of mixtures and flow conditions [53–55]. Flame surface density (FSD) based models have been applied for several test cases using turbulent premixed combustion. The FSD approach models the reaction rate as a

function of a defined filter width and a reaction progress variable. Previous studies have shown the importance of an appropriate FSD based SGS analysis using LES modelling [56–59]. In order to account for the unresolved part of the SGS reaction rate a dynamic flame surface density (DFSD) model obtains data from the resolved flame front as it propagates. This paper focuses on further validating the DFSD model for a lean hydrogen/air mixture at an equivalence ratio of 0.7 applied with two different area blockage ratios. Four different turbulence generating baffle configurations are used with smaller and larger area blockage ratios to validate the model and investigate numerical results where experimental data is available [16,17]. Further numerical predictions are made where experiments were limited.

Experimental setup

Experimental data is obtained using the laboratory scale combustion chamber developed at the University of Sydney, Australia [16,17,60]. The chamber measures 50 x 50 x 250 mm (5:1 aspect ratio) with a total volume of 0.625 litres. A schematic of the chamber is shown in Fig.1. The chamber is equipped with three removable baffles with five 4 mm wide and 3 mm thick strips separated by 5 mm gaps which provide an area blockage ratio (ABR) of 40%. Each baffle provides a volume blockage ratio (VBR) of 0.48% and is placed at 19 mm, 49 mm and 79 mm

Fig. 1 – Schematic of the combustion chamber (left) and removable baffle (right) (all dimensions in mm, not to scale).

downstream from the ignition source at the base of the chamber. The solid obstacle is placed at 96 mm from the base of the chamber. Two different central obstacles are used. The small solid obstacle has a square cross-section of 12 x 12 mm resulting in an ABR of 24% and a VBR of 1.152%. The large solid obstacle has a square cross-section of 25 x 25 mm resulting in an ABR of 50% and a VBR of 5%.

The lean hydrogen/air mixture enters the chamber through a non-return valve at atmospheric pressure and is allowed to settle before ignition is activated. One second before ignition, a hinged flap at the top of the chamber is opened and remains open which allows for venting of the explosion. The mixture is then ignited by an Nd: YAG laser which focuses an infrared output at 2 mm above the base of the chamber defining the start time for the experiment. Pressure readings are taken using two Keller type PR21-SR piezo-electric pressure transducers at a rate of 25 kHz. One of the transducers is placed in the base of the chamber and the other is placed at 64 mm from the top in the wall of the chamber. The evolution of the reaction zones is captured with high-speed laser-induced fluorescence from OH (LIF-OH) at a rate of 5 kHz. Four different baffle configurations combined with the small and large obstacle for a total of 8 configurations are investigated in this study and these configurations are shown in Fig. 2. The configurations are named based on the arrangement of baffles and the size of the obstacle used. For example, configuration BBBS uses baffle 1, baffle 2 and baffle 3 with a small central obstacle, whereas configuration OBOL uses only Baffle 2 and a large central obstacle. The experimental data shown for each configuration in this paper is an average acquired from approximately 50 experiments.

Fig. 2 – The 4 different baffle configurations shown which can be used with the Large (L) or Small (S) obstacles.

Experimental limitations

Experiments carried out using LPG (Liquified Petroleum Gas) and CNG (Compressed Natural Gas) successfully obtained overpressure and flame position data for various configurations with the large and small obstacle [16,17,60]. However, experiments carried out by AlHarbi [60] using lean hydrogen/air mixtures concluded that experimental equipment is limited and would need to be more advanced in order to obtain flame position data for hydrogen deflagration when using

the large obstacle. Experimental images could only be obtained for configuration 0B0L, which uses a single baffle in the middle of the chamber and the large solid obstacle, using a solid obstacle with an ABR of 50% as a result of the excessive propagating flame speed, even when using a lean hydrogen/air equivalence ratio. This means that although images were captured for experiments when using configuration 0B0L there is a visible lack of detail due to limitations in the experimental equipment which would need to be more advanced. This lack of detail when compared to the smaller ABR is reflected in the experimental data points for the flame position and speed data.

As a result, numerical results for the flame position and speed provide a prediction where experimental equipment was limited. As for the overpressure, data is available for multiple configurations using the larger ABR as it is within the limit of the piezo-electric pressure transducers. This is only achieved by using an equivalence ratio of $\Phi=0.7$ for the mixture to keep within the 100 kPa (1000 mbar) limit of the pressure transducers as explained by Masri et al. [16]. Combining a higher equivalence ratio with the larger ABR would result in excessive pressures beyond the limit of the transducers.

Numerical setup

Numerical simulations are governed by conservation equations for mass, momentum and energy. The reaction progress variable $\tilde{c}$ conveys the chemical state of a fuel/air mixture. Modelling the reaction rate for turbulent premixed flames can be difficult due to the complex interaction between the levels of turbulence as well as the thermodynamic, chemical states. Nevertheless, Neglecting Zeldovich instability, using a unity Lewis number and assuming a single step irreversible chemical reaction between reactants and products reduces the complexity of the system. More of the numerical model is detailed elsewhere [48].

The reaction progress variable $\tilde{c}$ is given by:

$$\tilde{c} = 1 - \frac{m_f}{m_f^0} \quad (1)$$

where, m_f is the local fuel mass fraction and m_f^0 is the fuel mass fraction unburned in the mixture. For the reaction progress variable, $\tilde{c} = 1$ is a fully burned mixture and $\tilde{c} = 0$ is an unburned mixture. The general form of the Favre-filtered transport equation for the reaction progress variable $\tilde{c}$ is given by:

$$\frac{\partial \bar{\rho} \tilde{c}}{\partial t} + \frac{\partial}{\partial x_i} (\bar{\rho} \tilde{u}_i \tilde{c}) = - \frac{\partial}{\partial x_i} (\bar{\rho} \tilde{u}_i \tilde{c} - \bar{\rho} \tilde{u}_i \tilde{c}) + \frac{\partial}{\partial x_i} \left(\bar{\rho} D \frac{\partial \tilde{c}}{\partial x_i} \right) + \bar{\omega}_c \quad (2)$$

Where $\bar{\omega}_c$ is the filtered source term and is given using the flame surface density (FSD) concept as:

$$\bar{\omega}_c = \rho_u S_L^0 \Sigma \quad (3)$$

where ρ_u is the unburned mixture density and S_L^0 is the un-strained laminar burning velocity. The sub-grid scale flame surface density Σ is given by:

$$\Sigma = 4 \sqrt{\frac{6}{\pi}} \Xi_\Delta \frac{\tilde{c}(1 - \tilde{c})}{\Delta} \quad (4)$$

where Δ is the combustion filter width and Ξ_{Δ} is the sub-grid scale wrinkling factor. Substituting equations (3) and (4) into the $\tilde{c}$ equation (2) gives [56,61]:

$$\frac{\partial \bar{\rho} \tilde{c}}{\partial t} + \frac{\partial}{\partial x_i} (\bar{\rho} \tilde{u}_i \tilde{c}) = \frac{\partial}{\partial x_i} \left(\frac{\rho_u \Xi_{\Delta} S_L^0 \Delta}{16 \sqrt{6/\pi}} \frac{\partial \tilde{c}}{\partial x_i} \right) + 4 \rho_u S_L^0 \sqrt{\frac{6}{\pi}} \Xi_{\Delta} \frac{\tilde{c}(1 - \tilde{c})}{\Delta} \quad (5)$$

Previous research suggests that the combustion filter width Δ should be greater than the mesh size Δ_x enabling the filtered progress variable gradients to be well resolved using an LES grid [59]. In this study the filter width used is 6 times the mesh size ($\Delta = 6\Delta_x$). The laminar burning velocity is set to 1.25 m/s and the thermal flame thickness is set a 0.12 mm for a hydrogen/air mixture at an equivalence ratio of 0.7 [62,63].

Computational setup

Fig. 3 – Computational domain showing grid resolution, combustion chamber, baffles and the small solid obstacle.

Numerical analysis using LES for hydrogen explosions is carried out using an in-house code known as PUFFIN [64]. The code uses the finite volume method on a

Cartesian grid to solve for equations of mass, momentum and scalar equations for compressible flow. The computational domain measures 50 x 50 x 250 mm for the chamber whereas the complete domain measures 325 x 325 x 500 mm with non-reflecting boundary conditions for the far field boundaries as shown in Figure 2. The solid walls of the chamber have adiabatic and no-slip boundary conditions. The shear stress at the wall is calculated using the $1/7^{\text{th}}$ power law wall function developed by Werner and Wengle [65]. More details on the boundary conditions, chemical model and reaction mechanism can be found elsewhere [64]. Following a grid sensitivity study a 2.7 million (90 x 90 x 336) cell grid was selected for configurations using both the small and large obstacles. Figure 3 shows the mesh refinement with the combustion chamber, baffles and solid obstacle. Ignition is provided by initialising a burned flame kernel which sets a defined number of cells to have a reaction progress variable of 0.5. The kernel is hemispherical in shape with a 4 mm radius and it is located at the base of the chamber.

Results and discussion

The results convey the nature of flame obstacle interaction as well as the resultant overpressure produced due to the explosion in the chamber. Maximum overpressures, rates which pressures rise and transient flame speeds are obtained from LES and compared with experimental data.

Results will be used to compare between H_2 and LPG, underlining the difference between the fuels and the difference in key combustion events and overpressure-time traces produced using an ABR of 25% when compared to an ABR of 50%. The main focus is on the area blockage ratio effects due to increased solid obstacle size and the effect of baffle configuration.

Effect of baffle configuration

Overpressure time traces shown in shown in Fig. 4 compare the results obtained using LES with the data attained from experiments. Fig. 4 conveys the trend of pressure rise for the hydrogen explosions using different configurations and an ABR of 50% for both the numerical results and experimental data. Fig. 5 shows a comparison between the overpressure-time traces for the configurations using the large solid obstacle (50% ABR) and the small solid obstacle (24% ABR). Observing the results in Figure 4 conveys that the additional baffles increase the peak magnitude of overpressure produced. The additional baffles also increase the rate at which pressure rises after ignition is provided and reduces the amount of time required in order to reach the peak overpressure magnitude. Configuration 0B0L in Fig. 4a uses only one central baffle and produces the lowest peak overpressure of 522 mbar at 5.7 ms. Utilising an additional baffle increases the turbulence intensity in the chamber and produces a higher peak overpressure in less time. This is shown in Fig. 4b where configuration 0BBL produces 669 mbar of overpressure at 4.79 ms. Peak overpressure for configuration BB0L shown in Fig. 4c was found to be 806 mbar at 4.65 ms. The maximum overpressure of 898 mbar is achieved using configuration BBBL, which has all three baffles equipped, in the least amount of time at 4.46 ms.

The maximum rate of pressure rise also increases when additional baffles are placed in the chamber. The experimental result for configuration BBBL is 337 MPa/s whereas LES produces max pressure gradient, dp/dt , of 302 MPa/s at 4.4 ms.

Configuration 0B0L produces a maximum value for dp/dt of 184 MPa/s experimentally, while numerical results found the maximum rate of pressure rise to be 176.79 MPa/s at 5.97 ms. This is also consistent when comparing configurations using the small obstacle where configuration BB0S in Fig. 5b produced 467 mbar at 4.32 ms while configuration 0B0S produced 324 mbar at 5.20 ms. The rate of pressure rise also increases with the number of baffles where configuration 0BBS reaches dp/dt max of 279 MPa/s whereas the maximum rate of pressure rise for

Fig. 4 – Overpressure-time traces for configurations using the large obstacle.

configuration BBBS is 300 MPa/s. The baffle configuration also affects the obstacle separation distance which when reduced, increases the combustion overpressure. It is also inferred that including successive baffles also decreases the obstacle separation distance. Figure 5 illustrates that configuration BB0S which has a distance of 47 mm between the second baffle and the obstacle produces a peak overpressure of 635.95 at 4.90 ms. On the other hand, configuration 0BBS which only has a gap of 17 mm between the final baffle and the small obstacle produced a lower peak overpressure of 466.72 at 4.32 ms. Similar observations have been made in other experimental studies [66].

The rate at which pressure rises is also affected by the reduced separation distance. Configuration BB0S produced a peak rate of pressure rise of 110.85 MPa/s numerically whereas the experiment found that the maximum rate of pressure rise is 71.07 MPa/s. The experiment using configuration 0BBS recorded a maximum rate of pressure rise of 274.22 where the LES-DFSD result found the maximum rate of pressure rise to be 300.32 MPa/s. These pressure history curve results are consistent with the experimental data as shown in Fig. 4 and 5, and is consistent with previously published numerical results [39].

(a) Comparison between overpressure-time traces for configurations 0B0S and 0B0L.

(b) Comparison between overpressure-time traces for configurations 0BBS and 0BBL.

(c) Comparison between overpressure-time traces for configurations BB0S and BB0L.

(d) Comparison between overpressure-time traces for configurations BBBS and BBBL.

Fig. 5 – A comparison between overpressure-time traces using the smaller and larger ABR.

Effect of increased area blockage ratio

Increasing the area blockage ratio impacts the flow path and subsequently impacts the flame structure. When comparing results for the same configuration using a different ABR, the flow initially follows an identical path as it propagates through the baffles. The most significant difference when using an increased ABR is that there is less area available for the flow to propagate past the obstruction meaning that there is a temporarily reduced flame speed as the spreading flame interacts with the solid obstacle. The flow then recirculates around the edges of the obstacle, allowing the consumption in the recirculating wake of unburned flow behind the obstacle. This wake is considerably larger when the ABR is approximately doubled resulting in an increased rate of pressure rise and a considerably higher peak combustion overpressure. Fig. 5 also helps identify that using the larger ABR increases the peak overpressure although it delays the time at which it occurs. This is particularly clear in Fig. 5a, where the peak overpressure is delayed by 0.6 ms and increases by 200 mbar. Using an additional baffle decreases the time delay due to more of the mixture being burnt in less time due to the increased levels of turbulence in the chamber. This is shown in Fig. 5c where the peak overpressure occurs 0.3 ms later and increases by 340 mbar using the larger ABR. Fig. 5d has the same delay of 0.3 ms with the overpressure increasing by approximately 100 mbar. The rate of pressure rise also increases when a larger ABR is utilised. Configuration 0B0S produces a peak rate of pressure rise at 4.4 ms of 78 MPa/s whereas configuration 0B0L produces peak dp/dt of 176.79 MPa/s at 5.97 ms. The rise in overpressure using the larger obstacle is likely to be attributed to the interaction of the flame front with the larger recirculating wake of flow which is created behind the solid obstacle. Fig. 6 and Fig. 7 show images of hydrogen/air flames propagating past one baffle and a solid obstruction. The lack of detail in Fig. 7a when compared to Fig. 6a is due to experimental limitations mentioned earlier. Images of the reaction zone are compared to results of the progress variable $\tilde{c}$ extracted from LES. The expanding flame forces the unburned mixture to go through the baffle which generates turbulent eddies. The initially laminar flame follows the path of the unburnt mixture through the baffle resulting in wrinkling of the flame front. As the flame passes through the baffle it separates into four different channels as a result of the baffle strips. These then reconnect due to the flame's lateral spread through the chamber, consuming the unburned mixture as shown at 4.8 ms in Fig. 7b. The flame then takes the path of least resistance to the side of the obstacle. As the flow propagates past the solid obstruction a wake of recirculating flow is generated behind it. The flow guides the flame to the unburned mixture in the wake. Comparing Fig. 6b and 7b shows the difference in the size of the wake due to the increased ABR and the increased distance that the flame covers before it reconnects behind the obstacle. Also, in Fig. 7b at 5.6 ms there is still an unburned portion of the flow behind the large obstacle. The symmetrical nature of the flame throughout combustion phases conveys the homogenous nature of the mixture. The burned mixture then propagates out of the open end (vent) at the top of the chamber. Both Fig. 6 and 7 show the ability of the numerical model to reproduce the flame structure and transient flame speeds to a relatively high degree of accuracy for the small and large ABR. The numerical

images show a well predicted flame structure and the interaction of the flame with the baffle and obstacles.

Fig. 6 – Flame structure comparison between (a) LIF – OH images and (b) numerical results for configuration 0B0S.

Fig. 7 – Flame structure comparison between (a) LIF – OH images and (b) numerical results for configuration 0B0L.

Comparison with LPG

A stoichiometric LPG/air mixture ($\Phi=1.0$) behaves significantly differently when compared to a lean hydrogen/air mixture ($\Phi=0.7$). A comparison is made between both fuels using three baffles with a small (BBBS) and large ABR (BBBL). The LPG used has a composition of 95% C_3H_8 , 4% C_4H_{10} and 1% of other hydrocarbons by volume. The flame thickness is set to 37 mm with a laminar burning velocity of 0.39 m/s [59]. Fig. 8 and Fig. 9 compare the overpressure time traces between LPG and hydrogen flames. Using the lean hydrogen mixture, configuration BBBL a peak

combustion overpressure of 898 mbar at 4.46 ms is seen whereas the stoichiometric LPG mixture only produced 107 mbar at 10.38 ms. Similarly, when using a smaller ABR, LPG using configuration BBBS produces a peak overpressure of 99 mbar at 10.52 ms, while H₂ produced a peak overpressure of 789 mbar at 4.15 ms. Increasing the ABR of the solid obstacle increased the peak overpressure by 14% for H₂ when compared to LPG which increased by 8%. The overpressure histories show that LPG with a higher equivalence ratio produces approximately 10% of the overpressure when compared to hydrogen. It also takes more than double the amount of time to do so. Further, the rate at which pressure rises for LPG is increased from 8.06 MPa/s to 13.85 MPa/s whereas the hydrogen mixture increases from 300.46 MPa/s to 349.56 MPa/s. This highlights the sensitivity of the lean hydrogen mixture to turbulence as well as the ABR when compared to propane. Note that the LES model can reproduce the overpressure-time traces for both fuels to a high degree of accuracy in a high turbulence environment.

Fig. 8 – Overpressure-time traces for H₂ (a) and LPG (b) using configuration BBBL.

Fig. 9 – Overpressure-time traces for H₂ (a) and LPG (b) using configuration BBBS.

Flame position and speed

Flame position-time traces are shown in Fig. 10a for the large ABR and Fig. 10b for the small ABR with a maximum flame position of 250 mm. Experimental data is limited for the large ABR as mentioned earlier. The flame transient speeds are shown in Fig.11. Comparing Fig. 10a and 10b shows that the flame generally requires more time in order to propagate past the large solid obstacle. Further, increasing the ABR also means that the flame requires additional time when in interacts with and subsequently propagates past the solid obstacle after which the increased turbulence intensity results in the jetting of the flame at higher speeds.

Fig. 10 – Flame position-time traces for (a) large and (b) small ABR.

Fig. 11 – Flame speed-time traces for (a) large and (b) small ABR.

Configurations 0B0L and 0B0S can be used as to demonstrate this as they are both validated against experimental data. At 4.8 ms, configuration 0B0S has a flame speed of 68.45 m/s whereas configuration 0B0L has a flame speed of 45 m/s. However, at 5.0 ms, configuration 0B0S reaches a maximum flame speed of 112.94 m/s while the increased ABR results in a flame speed of 124.23 m/s at 5.0 ms, which then increases to 143.06 m/s at 5.20 ms. Adding further baffles also promotes the generation of turbulence and subsequently increases combustion in the chamber

resulting in a faster propagating flame that departs the chamber in less time as shown in Fig. 10 and 11. This is conveyed when looking at figures for both the ABRs as increasing the number of baffles shifts the traces to occur in a reduced timeframe at higher flame speeds.

Conclusions

Research presented in this paper studied large eddy simulations using the dynamic flame surface density model to numerically investigate hydrogen combustion in a laboratory-scale combustion chamber. Four different baffle configurations were utilised to compare study the effects of a small ABR and a large ABR. A comparison with LPG/air ($\Phi=1.0$) confirms the sensitivity of a hydrogen/air ($\Phi=0.7$) mixture which produced a magnitude greater peak overpressure in under half the time duration following ignition. Based on the numerical results and analysis presented in this paper, the following conclusions are drawn:

- Hydrogen flames are quasi-laminar until they interact and propagate through baffles inducing turbulence. Including successive baffles will increase the turbulence intensity and create a complex wrinkled flame.
- Increasing the number of baffles and the ABR will raise the peak magnitude of overpressure and the peak rate at which pressure rises.
- The peak overpressure magnitude and timing are affected by the ABR and the relative distance of the baffles to the ignition source.
- The ABR of the obstacle impacts the flame structure as a result of the size of the flow generated wake behind the obstacle.
- The ABR has more of an effect on peak overpressure timing in configurations with less baffles and less of an effect on the magnitude with configurations employing more baffles.
- The LES – DFSD numerical approach is found to produce results with a high degree of accuracy when compared with experimental data.

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