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# Large Eddy Simulation of Triangular Bluff-Body Stabilized Flames in Partially Premixed Condition

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**Abstract:** In the present article the fractal model applicability is tested by simulating a bluff-body premixed flame anchored in a straight channel. The model assumes that chemical reactions take place only at the dissipative scales of turbulence, i.e., near the so-called "fine structures" (eddy dissipation concept). The model estimates the local spatial dissipative scale η, considering also the growth effect due to heat release. The premixed burner is simulated 3 dimensions, both for cold flow and for reacting cases. Results are compared with experimental data and show three-dimensional vortex structures periodically shortening the recirculation zone downstream of the bluff body and entraining fresh mixture into the hot recirculating region. This physical mechanism is involved in flame anchoring. The effect of assuming periodic boundary conditions in the span wise direction, instead of solid side walls, is also investigated. The analysis shows that periodic boundary conditions cannot capture various effects of side walls, such as the shortening of the recirculation zone and the flow acceleration downstream; furthermore, it also does not allow predictions of wall heat transfer. An LES numerical algorithm able to handle the entire range of combustion regimes and equivalence ratios is developed for this purpose.

**Key words:** LES · Turbulence · Partially premixed combustion · Bluff-body

## INTRODUCTION

A method widely used in combustors to anchor a turbulent flame consists in establishing a recirculation region of hot gases which continuously ignites the re-active stream. A backward-facing step or a bluff body is typically used for this purpose [1]. Developing future combustors and active or passive combustion control systems requires better understanding of flame holding, i.e., of turbulence–kinetics interaction, vortex dynamics, combustion instability, ignition and quenching. Analysis of combustion instabilities is particularly important in the design of reduced emissions. Combustors with bluff-body flame holders, like that analyzed in this paper, are characterized by a shear layer where vortices are shed due to Kelvin-Helmholtz instability.

Once a research tool, LES is now more widely used in studies of the dynamics of turbulent reacting flows [2]. The objective is to guide combustion chamber design and to simulate passive and/or active combustion control systems. Compared to DNS the description of small scales is lost, whilst, compared to RANS, the instantaneous large-scale fluctuations are resolved [3].

LES of reactive flows substantially differs from that of nonreactive flows. In the latter case, small scales are modeled considering their dissipative nature and assuming equilibrium. For reactive problems, successful LES is still a goal because chemistry occurs at non-resolved dissipative length scales, where reactants mix at the molecular level and the combustion process must be completely modeled. This is why so many turbulent combustion models can be assumed in both RANS and LES approaches [4].

**Premixed Flame Structure:** As stated earlier, the present work deals with premixed combustion. For a better under-standing of the results to be presented and of the limitations inherent to various combustion models, several brief considerations on the structure of a premixed Flame is discussed. As shown in Fig. 1, the structure of a

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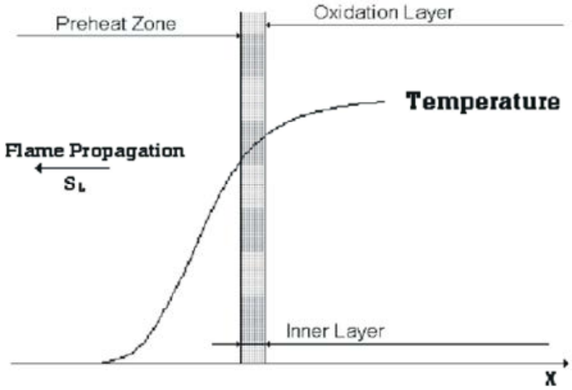


Fig. 1: Premixed Flame Structure

high activation energy, laminar premixed Flame contains three major regions 1.a preheat zone in the front of the Flame, where the temperature starts to raise by heat diffusion from the Flame front, 2.an inner layer where the fuel is consumed and the radicals are formed and destroyed and 3.an oxidation layer where the final combustion products are formed [5].

**Flame-Holder Blowout Limits:** From a physical point of view, the controlling stability parameter is the ratio of the chemical time versus the residence time (i.e. the Damkohler number). The residence time is in turn related to the geometry of the recirculation zone and to the rate of mass exchange through the shear layer. An increase in the incoming velocity tends to reduce the residence time through increased momentum transfer from the main flow into the recirculation region thus reducing the Damkohler number [6]. For equivalence ratios close to one, the residence time in the recirculation region approaches a maximum. For mixtures further away from the stoichiometric composition, the maximum temperatures are lower; hence the effect of heat release on the mass exchange rate reduction is less important. Also, the lower temperature implies lower reaction rates and hence, larger chemical times and larger Damkohler numbers. In conclusion, the incoming velocity for a stable flame is maximum for an equivalence ratio of (or close to) unity, while the limits of stability in terms of maximum and minimum equivalence ratio are wider as the approaching velocity of the main stream decreases [7].

**Test Case Description:** The burner simulated in this paper was designed to provide an experimental database for numerical code validation. It consists (Fig. 2) of a straight channel (length: 1 m, rectangular cross section: 0.12×0.24 m). The flame is anchored on a bluff-body, having an equilateral triangular cross section (side 0.04 m), located 0.55 m upstream of the exit [8]. A fresh mixture of air and propane is introduced at an equivalence ratio $\Phi$=0.65-1 and the air mass flow rate is 0.6 kg s. The inlet temperature is 288 K, in-let velocity, Uin, is 17m/s and turbulence intensity is 3–4%. The nominal pressure is 1 atm.

The finite-volume scheme is implicit, second order in time and second order upwind in space [9]. It is known that the leading term of the truncation error of the Taylor expansion of the discretized derivative indicates whether the error is diffusive or dispersive; the diffusive error is associated to even derivatives in the leading term, the dispersive error to odd derivatives. Due to the diffusive nature of the SGS eddy viscosity models, it is better to use numerical schemes with dispersive error than diffusive error, to reduce interference with the SGS model. Usually an even-order spatial scheme has a dispersive error; this is not the case for the second-order upwind scheme, that has both types of errors. However, when the eddy viscosity was turned off, the calculation diverged: a necessary (although not sufficient) condition to conclude that physical (subgrid) diffusion is larger than numerical diffusion [10].

**Non/Reactive Case: Results:** Results show that the flow is characterized by a recirculation zone downstream of the bluff body featuring periodically asymmetric vortex shedding, as also found numerically. The periodic or fully 3D BCs yield a vortex shedding at 107 Hz, in agreement with measurements (105 Hz). The Strouhal number, St=fh/Uin (f is the shedding frequency, this the bluff-body height, 0.04 m and Uin is the inlet velocity, 17 m/s.

For Reactive case both periodic and fully 3D BCs yield symmetric vortex shedding at 140 Hz. The estimated the recirculation zone is longer and broader in the “hot” case, meaning a more gradual dissipation of momentum in the wake region with respect to the “cold” case.

In the near field, where the combustion process occurs, the cross-correlation coefficient is negative for all three cases, except for a small region located. It is important to note that the flame surface is broken in the same region and it can be concluded that the vortical pattern tends to return to anti-symmetry whenever the reaction rate tends to 0, emphasizing the critical role of the heat release process in suppressing the anti-symmetric vortical pattern. Also interesting is the fact that the tendency towards symmetry increases as the heat release effect is stronger.

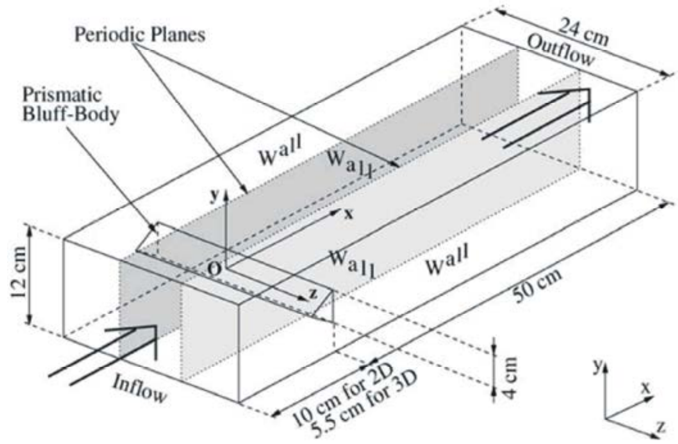


Fig. 2: Burner geometry in computational domain

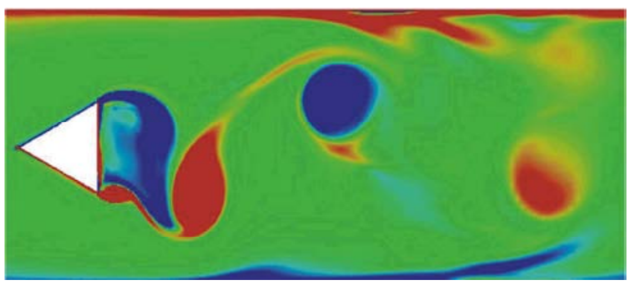

Fig. 3: velocity profile in non reactive flow field

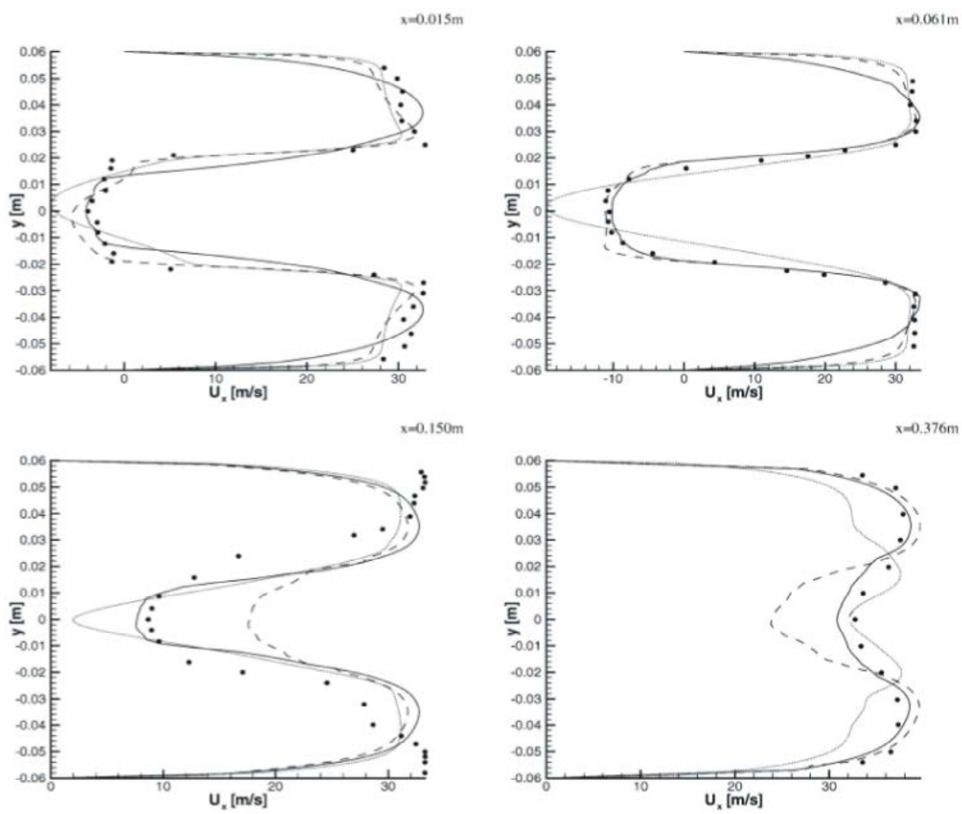


Fig. 4: Instaneous Temperature profile of a bluff body in reactive case

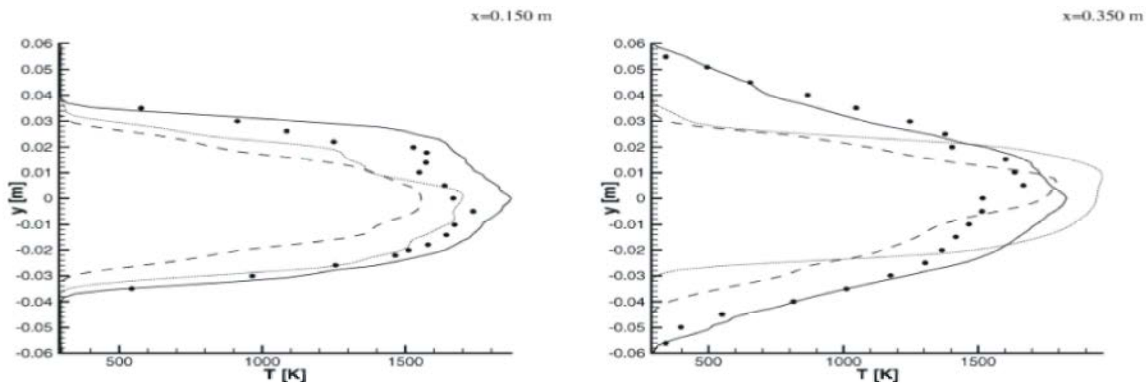


Fig. 5: Contour plot of instaneous Damhouler number

## CONCLUSION

Large eddy simulations of a model-scale combustor equipped with a bluff body to anchor the flame are carried out using a fractal model for the sub-grid scales. Numerical results obtained by simulating the whole 3D geometry are close to experimental data, implying that much of the turbulent kinetic energy spectrum is well resolved. This validates SGS model for LES. The flow is characterized by a recirculation zone downstream of the bluff body featuring periodic vortex shedding. As also confirmed be experiments, the shedding is asymmetric (107 Hz) in the nonreactive case and symmetric (140 Hz) in the reactive case. In the latter, hot combustion products are stored in-side the recirculation zone and then convected down-stream; ignition starts in the shear layers between the wake and the co-flowing fresh mixture. The three-dimensional turbulent structures shed from the bluff body drive macroscopic mixing between hot products and fresh reactants, thus anchoring the flame. During the roll-up and merging of vortices, turbulence is enhanced; multiple shear layer interaction wrinkles the flame, increasing its surface and the effective reaction rate. This anchoring mechanism is intrinsically un-steady, profoundly unlike that suggested by analysis of time averages.

## REFERENCES

1. Anand, M.S. and S.B. Pope, 1987. Calculations of premixed turbulent flames by pdf methods. Combustion and Flame, 67: 127-142.
2. Ballal, D.R. and A.H. Lefebvre, 1981. Some fundamental aspects of Flames stabilization. Fifth International Symposium on Air Breathing Engines, pp: 48.
3. Domingo, P., L. Vervisch and K. Bray, 2002. Partially premixed Flamelets in les of nonpremixed turbulent combustion. Combustion Theory and Modelling.
4. Dosing, M., A. Kempf, F. Flemming, A. Sadiki and J. Janick, 2005. A Combustion les for premixed and diffusion flames. Progress in Computational Fluid Dynamics.
5. Erikson, R.R., M.C. Soteriou and P.G. Mehta, 2006. The influence of temperature on the dynamics of bluff body stabilized flames, AIAA-2006-0753.
6. Tatyana Aleksandrovna Skalozubova and Valentina Olegovna Reshetova, 2013. Leaves of Common Nettle (*Urtica dioica* L.) As a Source of Ascorbic Acid, Vitamin C., World Applied Sciences Journal, 28(2): 250-253.
7. Rassoulinejad-Mousavi, S.M., M. Jamil and M. Layeghi, 2013. Experimental Study of a Combined Three Bucket H-Rotor with Savonius Wind Turbine, World Applied Sciences Journal, 28(2): 205-211.
8. Vladimir G. Andronov, 2013. Approximation of Physical Models of Space Scanner Systems World Applied Sciences Journal, 28(4): 528-531.
9. Naseer Ahmed, 2013. Ultrasonically Assisted Turning: Effects on Surface Roughness World Applied Sciences Journal, 27(2): 201-206.
10. Tatyana Nikolayevna Vitsenets, 2014. Concept and Forming Factors of Migration Processes Middle-East Journal of Scientific Research, 19(5): 620-624.