# A COST-EFFECTIVE NUMERICAL APPROACH FOR RISK-SEVERITY ASSESSMENT OF DEFLAGRATION EVENTS IN HYDROGEN-ENRICHED GAS TURBINE EXHAUSTS

**G. Lemmi*, P. C. Nassini**, M. Cerutti**, A. Andreini***
gianmarco.lemmi@unifi.it
*Department of Industrial Engineering, University of Florence, Italy
**Baker Hughes, Via F. Matteucci 2, 50127, Florence, Italy

**Abstract**
The integration of hydrogen into gas turbine systems offers a promising path toward decarbonization, yet it introduces new safety challenges due to hydrogen's high reactivity and wide flammability limits. In particular, the potential formation of flammable mixtures in the exhaust section under certain operating conditions raises concerns about deflagration events and the resulting overpressure, which can threaten structural integrity. This study presents a cost-effective numerical approach for assessing such risk scenarios and the related impact. A simplified, yet reliable CFD-based framework is proposed to predict the overpressure associated with air–hydrogen ignition events in gas turbine exhausts.

**Introduction**
The decarbonization of power generation has accelerated the integration of hydrogen ($H_2$) into gas turbine (GT) fuel blends [1]. While $H_2$ enrichment enables significant reductions in $CO_2$ emissions [2], it also introduces new safety challenges, particularly due to its high reactivity, low ignition energy, and wide flammability range [3–5]. In $H_2$-enriched GT exhaust systems, flammable fuel-air mixture can accidentally accumulate if some operating sequences are not handled in the appropriate manner, potentially triggering deflagration events that pose overpressure risks to surrounding structures [6]. As a result, this work proposes a tool for assessing the consequences of a potential ignition and deflagration event.
This study builds upon the authors' previous work on the characterization of deflagration phenomena in GT exhausts, where a tabulated chemistry approach was first calibrated and validated using literature test cases [7], and subsequently applied to a real-scale GT exhaust system developed by Baker Hughes [8]. In contrast to the initial effort, the present study incorporates more realistic, time-variant boundary conditions at exhaust plenum entry, capturing the dynamic evolution of mass flow rate, temperature, and residual $H_2$ concentration during an actual turbine emergency shutdown sequence. This enhancement aims to quantify the sensitivity of the numerical setup to the boundaries under representative transient operating conditions.

## Computational Domain and Numerical Setup

The computational domain corresponds to the full-scale exhaust plenum and stack of the Baker Hughes NovaLT™16 industrial gas turbine as installed in the test bench, with a total height of approximately 14 meters. It is discretized using a light hybrid mesh consisting of 1.8 million polyhedral cells (Fig. 1). Simulations are performed using the pressure-based solver in ANSYS Fluent 2023® R1, employing a Large Eddy Simulation (LES) framework with the RNG sub-grid scale model to handle unresolved turbulence. At the exhaust plenum entry, spanwise profiles of radial and tangential velocity components are imposed, coupled with time-varying unburnt mixture mass flow rate, temperature, and mixture fraction. The dynamic evolution of operating conditions during turbine shutdown sequence has been simplified by assuming the initial temperature equal to the exhausts one just before sequence start. For turbulent combustion modeling, a tabulated chemistry approach (FGM) is employed. The source term of the mean progress variable (PV) is computed using Zimont's Turbulent Flame Speed Closure (TFSC) model [9], opportunely calibrated in the authors' previous validation campaign. The laminar flame speed curve used for table generation was obtained by solving freely propagating premixed flames in Cantera [10], using the ELTE $H_2$ reaction mechanism [11].

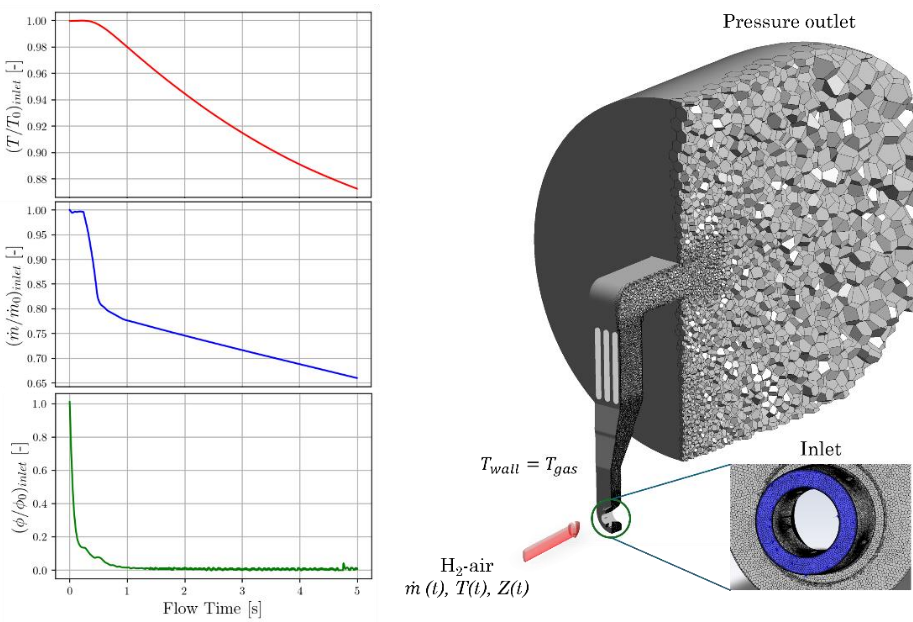


**Figure 1.** Computational domain and time-variant boundary conditions

## Deflagration and Overpressure studies

In the authors' previous work [8], the domain was filled with a perfectly premixed flammable $H_2$–air mixture at a given equivalence ratio ($\phi$), and forced ignition was applied at different locations to study the overpressure generated by the deflagration.

In the present study, two more realistic scenarios are investigated, both using time-variant BCs derived from actual shutdown transients.
In the first scenario, the domain is initially filled with expanded combustion products ($Z = Z_0$, $PV = 1$), into which a fresh $H_2$–air mixture ($Z = Z(t)$, $PV = 0$) is injected. In this configuration, the PV gradients at the interface between products and reactants act as an ignition trigger, as the TFSC model computes the source term of the mean PV based on its spatial gradient. Upon ignition, the flame anchors in the recirculation zone just above the diffuser, where the flow field resembles that of a bluff-body stabilized flame. The flame self-sustains for approximately 1 second before extinction due to fuel depletion. Locally richer mixtures compared to the previous study are noticed, as well as a peak overpressure nearly three times higher. Proper filtering highlights a different time-varying pressure signals between the two cases, however closely aligned in filtered peak magnitude.
In the second scenario, the domain is initially filled with hot air ($Z=0$, $PV = 0$), and the injection of the fresh mixture does not trigger the ignition. This simulation is used to identify regions where the combination of $\phi$ and residence time ($t_{res}$) could lead to auto-ignition. Selected locations in these regions are finally ignited, and results compared to the simplified case explored in the previous work.

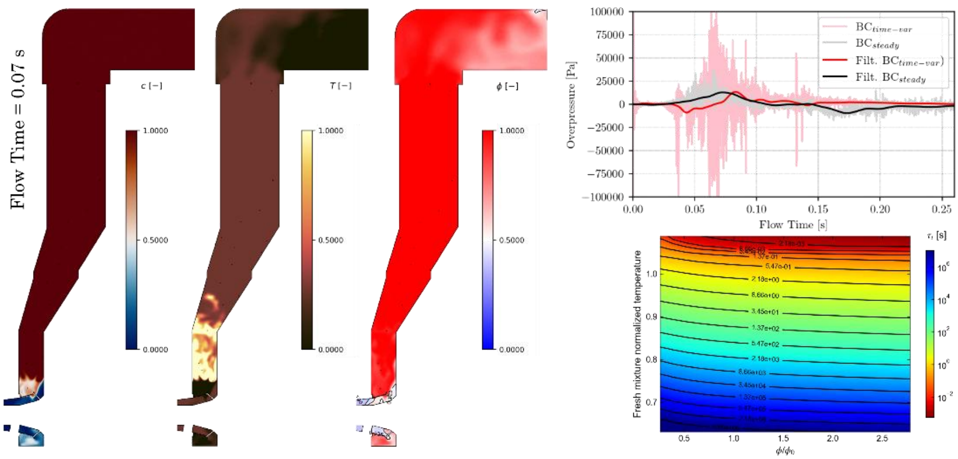


**Figure 2.** Normalized contours of progress variable, temperature, and $\phi$ at $t$ = 0.07s for the first scenario (left). Overpressure signal comparison (top right) and ignition delay time map (bottom right).

## Conclusions

This work presented a cost-effective numerical approach for the characterization of deflagration phenomena in GT exhausts. The study focused on the risk severity assessment of deflagration events during a hypothesized operational sequence, evaluating possible relationships between the $H_2$ concentration within the domain and the entity of overpressure upon ignition.

## References


[1] Cerutti, M, Pucci, E, Romano, C, & Dabiru, VR. "Development of an Hydrogen Fueled Gas Turbine Combustion System From Conceptual Through Full Scale Verification Test." *Proceedings of the ASME Turbo Expo 2023: Turbomachinery Technical Conference and Exposition*. *Volume 3A: Combustion, Fuels, and Emissions*. Boston, Massachusetts, USA (2023)

[2] Öberg, S., Odenberger, M., Johnsson, F., "Exploring the competitiveness of hydrogen-fueled gas turbines in future energy systems", *International Journal of Hydrogen Energy*, 47 (2021)

[3] Dryer, F., Chaos, M., Zhao, Z., & Stein, J., Alpert, J., Homer, C., 2007. "Spontaneous Ignition of Pressurized Releases of Hydrogen and Natural Gas into Air". *Combustion Science and Technology*. 179. 663-694.

[4] Proust, C., Daubech, J., "Hot Surface Ignition in Flowing Streams of Hydrogen-Air Mixtures." (2019)

[5] Skjold, T., et al. "Blind-prediction: Estimating the consequences of vented hydrogen deflagrations for inhomogeneous mixtures in 20-foot ISO containers", *Journal of Loss Prevention in the Process Industries, Volume 61, 2019, Pages 220-236,* ISSN 0950-4230

[6] Daubech, J., Proust, C., Jamois, D., Leprette, E.. "Dynamics of vented hydrogen-air deflagrations" 4. *International Conference on Hydrogen Safety (ICHS 2011),* Sep 2011, San Francisco, United States.

[7] I.C. Tolias, J.R. Stewart, A. Newton, J. Keenan, D. Makarov, J.R. Hoyes, V. Molkov, A.G. Venetsanos, Numerical simulations of vented hydrogen deflagration in a medium-scale enclosure, *Journal of Loss Prevention in the Process Industries*, Volume 52, 2018, Pages 125-139

[8] Lemmi, G, Nassini, PC, Cerutti, M, & Andreini, A. "Modeling and Predicting Deflagration Phenomena in Hydrogen-Enriched Gas Turbine Exhausts: A CFD Approach." *Proceedings of the ASME Turbo Expo 2024: Turbomachinery Technical Conference and Exposition. Volume 3B: Combustion, Fuels, and Emissions*. London, United Kingdom (2024)

[9] Zimont, V., Polifke, W., Bettelini, M., and Weisenstein, W. (July 1, 1998). "An Efficient Computational Model for Premixed Turbulent Combustion at High Reynolds Numbers Based on a Turbulent Flame Speed Closure." ASME. *J. Eng. Gas Turbines Power*. July 1998; 120(3): 526–532.

[10] David G. Goodwin, Harry K. Moffat, Ingmar Schoegl, Raymond L. Speth, and Bryan W. Weber. "Cantera: An object-oriented software toolkit for chemical kinetics, thermodynamics, and transport processes." https://www.cantera.org, 2023. Version 3.0.0. doi:10.5281/zenodo.8137090

[11] Varga, Tamás & Nagy, Tibor & Olm, Carsten & Zsély, István & Pálvölgyi, Róbert & Valkó, Éva & Vincze, Gergely & Cserháti, Mátyás & Curran, H.J. & Turányi, Tamás, "Optimization of a hydrogen combustion mechanism using both direct and indirect measurements", *Proc. Combust. Inst.* (2019)