Towards the Multifidelity Optimization of H2-Air Injector for Aircraft Propulsion

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TOWARDS THE MULTIFIDELITY OPTIMIZATION OF H2-AIR INJECTOR FOR AIRCRAFT PROPULSION

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ABSTRACT

The use of hydrogen as a fuel is one of the most promising way to reduce the climate impact of civil aviation but it requires the development of wholly new injectors in the engine's combustion chamber. Thanks to the increase in available computing power, new methodologies such as surrogate-based optimization, relying heavily on Computational Fluid Dynamics (CFD) along with automated optimization procedures, can be used to design these injectors. One important point is that 3D geometrical models and high-fidelity numerical approaches are often mandatory to capture key features of the multi-species, turbulent reactive flow through the combustion chamber. However, an optimization process only based on these approaches would be much too expensive. The multifidelity surrogate-based approach is a promising alternative and consists in using CFD simulations with various fidelities. However, its effectiveness depends on the correlation between the different levels of fidelity. The final, long run, goal of this work is the multifidelity optimization of H2-air injector for aircraft. In this paper, we focus on the very first steps of this work with the methodology presentation and a comparison of low (2D RANS) and intermediate (3D RANS) fidelities, which shows a fairly well agreement. Then, preliminary results of comparisons between intermediate and high (LES) fidelities, which highlight the need to improve modeling of RANS simulations, are discussed.

Keywords: Hydrogen combustion, CFD, Multifidelity optimization

NOMENCLATURE

S	Swirl number
CFD	Computational Fluid Dynamic
LES	Large-Eddy Simulation
RLE	Relaxation to Local Equilibrium
RANS	Reynolds-Averaged Navier-Stokes
MUSCL	Monotonic Upwind Scheme for Conservation Laws

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1. INTRODUCTION

Mitigating aircraft pollutants and green-house emissions constitutes a major and pressing challenge for manufacturers. For this purpose, H2 combustion is very promising but thermochemical properties of H2 and kerosene are so different that it seems unlikely to keep current combustion chamber injectors with hydrogen without any major modifications. Moreover, industrial announcements like Airbus who sets 2035 as a target impose short development times compared to previous generations of combustors.

Combustion chamber design improvement was based so far on successive experimental tests and numerical simulations. This approach, which was successful for legacy kerosene injectors, has already been applied as well for hydrogen injectors with the Micromix concept developed by the Aachen University of Applied Sciences [1] or the lean direct injection concept (LDI) developed by NASA [2]. However, the trial and error approach does not guarantee to get an optimal injector for a given design space. Nevertheless, thanks to the advances in computing science, new optimization techniques based on Computational Fluid Dynamics (CFD) have the potential to better explore the design space and lead to injectors with stable combustion and lower emissions.

The use of CFD simulations for optimization is already quite common in aerodynamics [3] with the use of gradient-based, gradient-free or surrogate-based methods, but the litterature is scarce for reactive flows because combustion simulations are generally more challenging and expensive than aerodynamic ones. However, the surrogate-based approach is really promising for CFD-based optimization and has already been used for combustion chamber design optimization. One key aspect of this kind of optimization study is the choice of the level of fidelity of the CFD simulation and several types of fidelity have been evaluated in the litterature. For example, Torkzadeh and al. [4] or Asgari and al. [5] used 2D axisymmetric RANS computations of a combus-

tor to build a surrogate model based on Support Vector Machine techniques and to perform a multi-objective optimization study directly on the surrogate. The cost of 3D RANS simulations is higher than the 2D simulations one but still affordable for an optimization study. This level of fidelity was used for example by Duchaine and al. [6] to optimize the combustor efficiency and the exit temperature profile. Duchaine and al. chose a Kriging-based metamodel combined with a lower confidence bound type criteria. RANS modeling allows some improvements in combustor performances but is intrinsically limited to take into account unsteady phenomena. Finally, it is worth noting that due to a much higher CPU cost, unsteady approaches such as LES have never been employed yet to the authors' knowledge for aircraft combustors design.

Optimization studies requiring a very large number of simulations, it is often compulsory to develop strategies to reduce the overall computational cost. Thus, one interesting idea would be to choose a multifidelity strategy for the surrogate based-optimization. However, this kind of strategy is efficient only if the different levels of fidelity are well-correlated [7]. In this context, two levels of fidelity are considered as correlated if the low-fidelity model, in spite of being less accurate, is able to predict the same trends than the high-fidelity one. The multifidelity approach was put into pratice for combustors for the first time by Wankhede and al. [8] who combined RANS and URANS 2D simulations with several mesh sizes and time steps to optimize a backward facing step using a Kriging-based surrogate, to perform Bayesian optimization studies. More recently, Toal and al. [9] used a multifidelity approach for a complex geometry really close to industrial combustors. In this work, they built a Co-Kriging surrogate and employed directly the predictor of the surrogate for a surrogate-based optimization study.

Independently of optimization questions, single combustion chambers or injectors simulations have shown for many years that LES approaches are much more predictive than RANS methods and lead to results that are often in very good agreement with experiment ([10] and [11] for example, among numerous works). Finally, it should be emphasized that all the studies in the litterature focus on conventional combustor and not on combustor working with hydrogen. Nevertheless, hydrogen have some specificities compared to kerosene. Indeed, contrary to kerosene which is injected as a liquid, hydrogen will be gaseous which is simpler to model (single phase, no atomization). Moreover, kinetic mechanisms for H2-air flames include less species and less reactions than kerosene ones. For a fixed modeling, the cost of a combustion computation is roughly proportional to the number of transported species (more species involving more equations to solve), so less species allows faster computations. For these reasons, optimization of H2 combustion chambers seems therefore more reachable than those operating on kerosene.

The final objective of our work is ambitious. It consists of developing a multifidelity Bayesian optimization for H2-powered combustor. The predictive but costly LES approach will be used as the highest level of fidelity while 3D and 2D RANS simulations will be used respectively as intermediate and low fidelity. The work presented in this paper constitutes only the very first steps of this work strategy and essentially aims to present the methodology, check the correlation between 2D/3D RANS simulations and finally quantify the discrepancies between RANS and LES results in order to anticipate the development of more accurate low-fidelity models. This paper starts by providing a brief description of the test injector, the chosen operating point and the numerical settings followed by the automated workflow for simulations. Then, 2D and 3D RANS simulations are compared in a parametric study. In the next part, a RANS simulation is compared with LES to quantify the differences between both modeling for this H2/air injector. It is worthwhile to note that LES simulation is not used to validate the RANS methodologies but to compare the behavior of the flame in RANS and LES. Finally, general conclusions and future prospects are presented.

2. TEST INJECTOR CONFIGURATION AND METHODOLOGY

2.1 The baseline injector

The injector geometry considered for this work is an axial swirl injector installed in the MICADO test rig [12] and illustrated in Fig.1. This bench allows the study of combustion with representative conditions of aeronautical combustion chambers. This injector is composed of 8 axial vanes through which the air is injected. Between each vanes, there are some holes (not represented in Fig.1) allowing to inject the fuel. The fuel can be injected through the tip of the injector to create a pilot flame to help the stabilization of the main flame too. The MICADO test rig was designed to work with methane but was chosen for this numerical study as it will be adapted in the future to burn hydrogen as well.

2.2 Parametrization of the injector and operating points

The injector was modeled with the CAD software Freecad [1] that allows to build a parametric version of the injector geometry as illustrated in Fig.2. The resulting model is a simplification of the real injector because the holes between the vanes are not taken into account. Hydrogen will be considered directly premixed with air. Moreover, a part of the air flow rate is used to cool the chamber during real experiments. The cooling system is not modeled neither but its impact will be taken into account on the effective air mass flow rate entering in the injector.

For this study, 4 parameters can be modified: the swirl number S, the pilot ratio PR (ratio between the hydrogen mass flow rate injected by the pilot and the global hydrogen mass flow rate), the pilot injector radius R_i and the opening radius R_o. S is defined as the ratio of the axial flux of tangential momentum over the characteristic radius times the axial momentum flux:

$$S = \frac{\int_{R_h}^{R_n} U_x U_\theta r^2 dr}{\int_{R_h}^{R_n} R_n U_x^2 r dr} \tag{1}$$

S can be linked to the deviation angle ϕ imposed by the vanes and to the inner (R_h) and outer radius of the injector (R_n) [13]:

$$S = \frac{2}{3}\left(\frac{1-(\frac{R_h}{R_n})^3}{1-(\frac{R_h}{R_n})^2}\right)\tan(\phi) \tag{2}$$

[1] https://www.freecadweb.org/

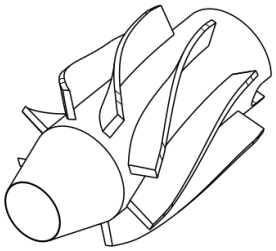

FIGURE 1: BASELINE VERSION OF THE H2-AIR INJECTOR

TABLE 1: RANGES OF VARIATIONS OF THE PARAMETERS

Parameter	S [-]	PR [%]	R_i [mm]	R_o [mm]
Lower bound	0.4	0	0.5	13
Upper bound	1.2	100	6.5	25

Eq.(2) gives an approximate result as some hypothesis are made in [13] but allows to choose the vanes angle of the parametric CAD model to match the desired swirl number. The two radius R_h and R_n are presented in Fig.3 (with diameters instead of radius).

The boundaries of the design space are presented in Table 1. These values allow a wide exploration of the design space to evaluate where the different CFD methodologies are well-correlated or where there are some significant differences. For the real injector installed in the test rig (called the baseline in the following sections), the geometrical parameters are: $S = 0.8$ corresponding to a vane angle of 45°, $R_i = 3.5$ mm and $R_o = 17$ mm.

The operating conditions of an injector (temperature, pressure, fuel and air mass flow rate,...) change greatly according to the flight phase (cruise, take-off, idle,...). The comparison of this study is made for cruise conditions described in Table 2. These conditions are not exactly the operating conditions of an aircraft engine but rather of an helicopter one. The presented flow mass rate are representative of a sector of the chamber (20 sectors per chamber). As explained before, the cooling system of the test rig is not simulated but we suppose that 20 % of the air mass flow rate is used to cool the walls of the chamber so only 80 % of the air mass flow rate given by Table 2 will be imposed at the inlet boundary condition.

2.3 Computational workflow

All computations of this work are made with the ONERA in-house CFD code CEDRE. This code is composed of several solvers including the finite-volume solver CHARME to solve the compressible Navier-Stokes equations for reactive flows on unstructured meshes. After the comparisons presented in this paper, the next step will be to perform optimization studies. Therefore, an automatic workflow has been developed to run CFD computations in a Python framework. Freecad allows to modify the geometry of the injector starting from a reference file. Then, the pre/post-processing Python package Cassiopée [14], developped by ONERA, is combined with CEDRE to generate the mesh for

TABLE 2: CRUISE CONDITIONS

P [bar]	T_{air} [K]	T_{H2} [K]	$\dot{m}_{air}$ [kg/s]	$\dot{m}_{H2}$ [kg/s]
8.2	624	250	1.325e-1	1.22e-3

3D RANS and LES computations. Cassiopée is able to separate the different surfaces of the CAD of the injector. This separation allows to identify automatically the boundaries conditions of the fluid domain. To generate the grid, Cassiopée begins by generating a 2D mesh on the surface of the injector, then, the 3D mesh is created in the volume based on the 2D one. Cassiopée has some functions to refine the mesh before computations. Once the mesh is generated, it is transferred to CEDRE for the CFD simulation. When the simulation is over, Cassiopée is used for the post-processing too. For 2D RANS simulations, Gmsh [15] is preferred to modify the geometry of the injector and to build the meshes. These meshes are unstructured and made of tetrahedras for 3D computations (triangles for 2D ones).

Meshes are made of approximately 2.7 M cells for 3D RANS simulations. This number of cells is sufficient to ensure the grid independence of the baseline case for 3D RANS simulations. As it was too costly to make a grid independence study for all other cases, the result for the baseline injector is generalized for other geometries.

2.4 RANS settings

For turbulence modeling, the k-ω SST [16] model is chosen. The chemistry-turbulence interaction is modeled with the relaxation to local equilibrium model (RLE) which makes the hypothesis of infinitely fast chemistry. There are other models with similar costs such as the EBU model [17] but most of them are based on the hypothesis of a single step global reaction whereas the RLE model can use as many species as needed to compute the equilibrium state. This model is similar to the time scale model presented in [18]. The main difference between both models is that the RLE model only uses a turbulent time scale whereas the model in [18] combined a turbulent time scale with a chemical one. In each cell, the local equilibrium is computed thanks to the local mean state $\tilde{U}$ (Temperature, pressure, mass fractions,...) and in this volume, the reaction rate $\overline{\dot{\omega}_k}$ for the RLE model is written as:

$$\overline{\dot{\omega}_k} = C\overline{\rho}\frac{Y_k^{eq}(\tilde{U}) - \tilde{Y}_k}{\tau_t} \tag{3}$$

with C a user-defined constant, $\overline{\rho}$ the mean density, $\tilde{Y}_k$ the mean mass fraction of the species k, $Y_k^{eq}(\tilde{U})$ its equilibrium value and τ_t the turbulent time scale accounting for turbulent mixing and turbulent diffusion. This time scale is computed thanks to the turbulence model. In this work, the chosen value for C is 1.

This model was first developed for rocket engines as the conditions in these engines make the combustion very fast. The conditions of this study (pressure and temperature) are far from those of a rocket engine but hydrogen burns really easily so it was assumed that the RLE model could be suitable for this type of configurations too. Moreover, this model introduces less numerical stiffness than a chemical mechanism, so it is possible to

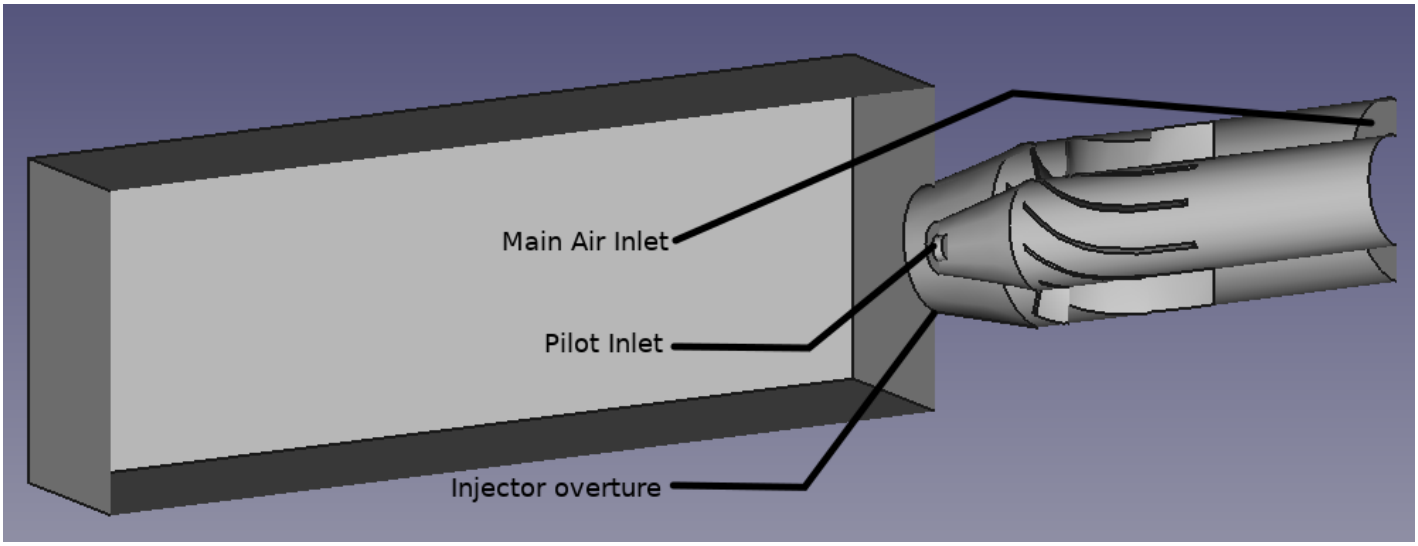

FIGURE 2: CAD MODEL OF THE INJECTOR

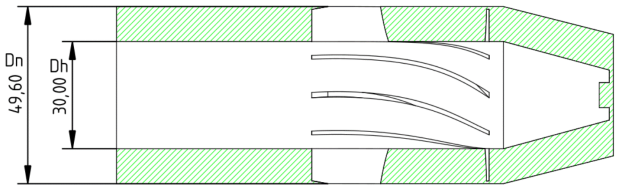

FIGURE 3: CUT VIEW OF THE INJECTOR

have a higher time step which is of great interest to reduce the computational time. This model is used to compute the reaction rates of all species (H2, O2, N2, OH, H2O, H, O) except NO and N. Indeed, reaction rates of these species are computed with a Zeldovich mechanism [19], which is adapted for modeling thermal NOx. No other pathways of NOx formations (N2O or NNH) is included. The quantity of NO produced in the injector depends mainly on the temperature in the flame and on the residence time of the burnt gases in the combustion chamber. Therefore, the NO estimation of a simulation is accurate with the Zeldovich mechanism if the temperature et velocities fields are precise.

In 2D axisymmetric simulations, it is not possible to represent geometrically the swirl vanes, but the swirl effect is taken into account through the inlet boundary condition where a rotation is imposed to the flow. This feature allows to represent swirling flows in 2D. The numerical methods consists in a second order MUSCL (Monotonic Upwind Scheme for Conservation Laws) type scheme for space discretisation, combined with a HLLC (Harten-Lax-van Leer-Contact) scheme for hyperbolic fluxes. In 2D, the HLLC scheme is used with a low-Mach correction. This correction is not used in 3D as it makes the simulation insufficiently robust. For time integration, a first order implicit scheme is chosen.

3. RESULTS

3.1 Parametric study of 2D and 3D RANS simulations

To evaluate the correlations between the different RANS approaches of this work, a parametric study is performed. The 4 parameters presented in 2.2 are modified one at a time. A total of 15 different cases are simulated in 2 different fidelities (2D and 3D) and the values of the parameters for each case are presented in Table 3.

TABLE 3: COMPUTATIONS OF THE PARAMETRIC STUDIES

Case	S [-]	PR [%]	R_i [mm]	R_o [mm]
G1 (Baseline)	0.8	0	3.5	17
G2	0.8	50	3.5	17
G3	0.8	100	3.5	17
G4	0.4	0	3.5	17
G5	0.6	0	3.5	17
G6	1.0	0	3.5	17
G7	1.2	0	3.5	17
G8	0.8	50	1.5	17
G9	0.8	50	2.5	17
G10	0.8	50	4.5	17
G11	0.8	50	5.5	17
G12	0.8	0	3.5	13
G13	0.8	0	3.5	15
G14	0.8	0	3.5	19
G15	0.8	0	3.5	21

The correlation is evaluated qualitatively by comparing the temperature and heat release fields and quantitatively by comparing the trend of the NO mass flow rate. As NO is a pollutant species and as the goal of a future optimization study will be to limit the emissions of NO, it is relevant to compare the NO mass flow rate between the differents methodologies.

Most computations give similar flow fields in 2D and 3D. The absolute values of the different variables can vary a lot between 2D and 3D methodologies but the flow fields exhibit the same structure (recirculation zones, position of the flame, ...). Therefore, the correlation between 2D and 3D fields is qualitatively good. However, whereas all 2D computations give steady solutions, some 3D simulations (G4, G7 and G15) tends to have

an unsteady behavior (like a URANS simulation) and it becomes necessary to average the results for these computations. These 3D simulations which do not have a steady solution are simulations at the limit of the design space, i.e simulations with "extreme" value of parameters. Some other 3D computations (G3,G8 and G9) give a steady solution but an non-physical result: the hydrogen jet from the pilot does not follow the axis of symmetry anymore but deviates from it.

For the sake of conciseness, only 4 computations are presented for a more detailed analysis: G1, G2, G3 and G7. These computations allows to show the different types of flame encountered with the chosen design space and to emphasize some of the difficulties that arise for 3D computations.

For G1 and G2, the 2D temperature and heat release fields (Fig.4-5) are in good agreement with the 3D fields. The aerodynamic fields (not shown here) are also very similar in terms of size and position of the recirculation zone. These two cases are examples of computations where the correlation is very good and show the various types of flames obtained for this parametric study.

G3 is representative of what happens when the velocity of the hydrogen jet from the pilot becomes important combined to a significant swirl effect. Whereas in 2D, the solution is totally symmetric (by construction), the hydrogen jet in 3D deviates significantly from the axis and the fields become asymmetric (Fig.6). The same phenomenon appears for G8 and G9. This phenomenon is not physical since there are no reasons for the jet to have a preferential side on average away from the axis. Therefore, the three cases with this asymmetric feature in 3D are not taken into account for the comparison of the NO mass flow rate. This asymmetric aspect is not due to the size of the mesh. Indeed, a computation with a finer grid was done (7M cells) and the jet tends to diverge too. Both meshes were unstructured, so it would be worth to try with a structured one.

G7 is representative of the case where 2D RANS gives a steady solution (Fig.7) but 3D RANS gives an unsteady solution that must be averaged. G4 and G15 have also an unsteady 3D solution. For G4, the averaged 3D solution is similar to the 2D one. For the two others geometries, this is not the case. More particularly, the two solutions have quite different behaviour. In both cases, the flame is quite compact and close to the injector but for the 3D case, it burns a little bit inside the injector. The aerodynamic fields (not shown here) show a more important recirculation zone (due to the high value of the swirl number S) for the 3D computation that creates a blocking effect. Therefore, for a high swirl number, the correlation between 2D and 3D computations is weaker. The correlation between 2D and 3D RANS simulations is rather good qualitatively for most of the computations of the parametric study. For a multifidelity optimization using a surrogate model, it is necessary to have a quantitative correlation too. To evaluate it, the evolution of the mass flow rate of NO is compared between each fidelity. Results are presented in Fig.8. The 3D computations with an unphysical result are not shown. When the swirl increases (with other parameters kept constant), the NO mass flow rate increases for both fidelity. Even if, the fields are different for a high swirl number, the NO mass flow rate correlation is preserved. This is rather a good thing to perform multifidelity optimizations because even if the fields are different, the optimization algorithm will be able to have informations about the trend of NO mass flow rate and its sensitivity to the differents parameters. For the pilot repartition, the 2D and 3D mass flow rates have also a similar trend. The mass flow rate is lower when PR values are close to 0 %, i.e when the combustion is premixed, whereas the mass flow rate increases quite importantly when PR tends to 100 % (the diffusion regime). This is physically coherent: the premixing regime is cleaner than the diffusion one. For an injector radius varying from 3.5 mm to 5.5, the NO mass flow rate increases for both fidelity. The slope of the curve is higher for 2D computations when the pilot injector radius is greater than 4.5 mm but the correlation remains acceptable between 2D and 3D RANS. When the opening radius increases, the NO mass flow rate decreases except in 3D when R_o is greater than 19 mm where the NO mass flow rate increases. This trend is not present in 2D but the 2 fidelities remain correlated for most values of R_o.

Overall, this parametric study show that the 2D and 3D RANS simulations are rather well-correlated on the studied design space. This is an interesting fact to perform a multifidelity optimization. However, for this study, each parameter was modified "one at a time" (with other parameters kept constant), so the correlation between both methodologies should be checked for interactions between parameters.

TABLE 4: GEOMETRY FOR RANS-LES COMPARISONS

Case	S [-]	PR [%]	R_i [mm]	R_o [mm]
G16	0.8	90.0	2.47	11.22

3.2 Comparison of RANS and LES methodologies

RANS modeling is known to poorly predict large scales mixing. Furthermore, an infinitely fast chemistry assumption has been made in this work. Consequently, we will now examine main discrepancies between the results obtained using this rather crude modeling and simulations using more accurate models. As no experimental data or DNS simulations are currently available for this injector, a LES simulation is used to provide information about the effects of the large scales of the turbulence on the flow. It is important to notice this LES simulation is not a reference for validation of RANS computations. Indeed, more detailled LES with finer grids will be performed in a future work for this specific purpose. However, LES simulations are intrinsically more advanced than RANS simulations, so this LES computation allows a better understanding of the flame in this injector. For this comparison, a new geometry, whose parameters are different from the geometries of the parametric study, is used and defined in Table 4.

This geometry is chosen because we expect it to be quite stable. As the different radius are reduced, the velocity of the flow will be more important and should be enough to avoid flashbacks. If the LES and RANS comparison is not in good agreement for this geometry, the differences between each methodology could be greater for other design points.

For the LES simulation, the mesh was also generated with

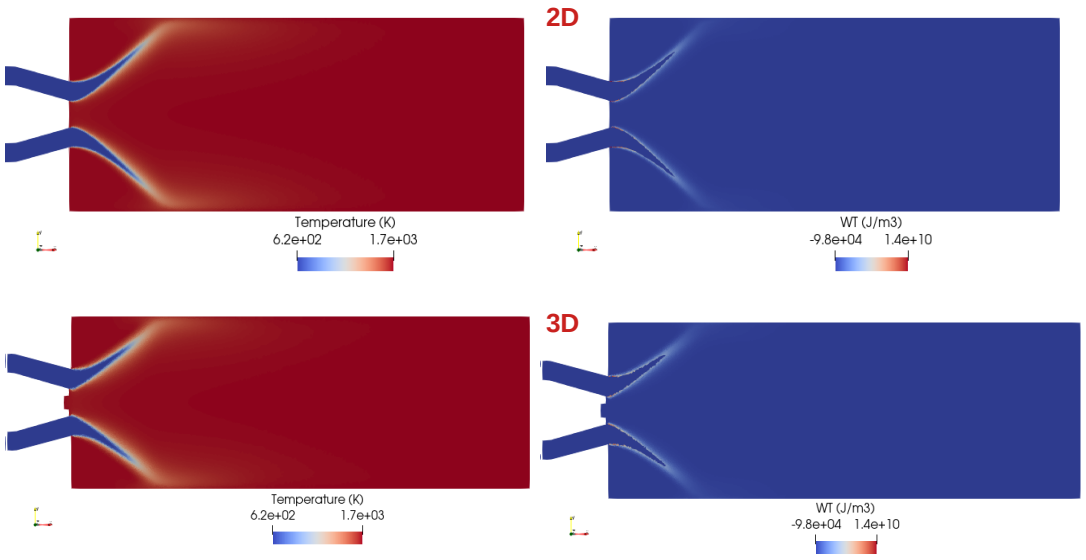

FIGURE 4: G1 HEAT RELEASE AND TEMPERATURE

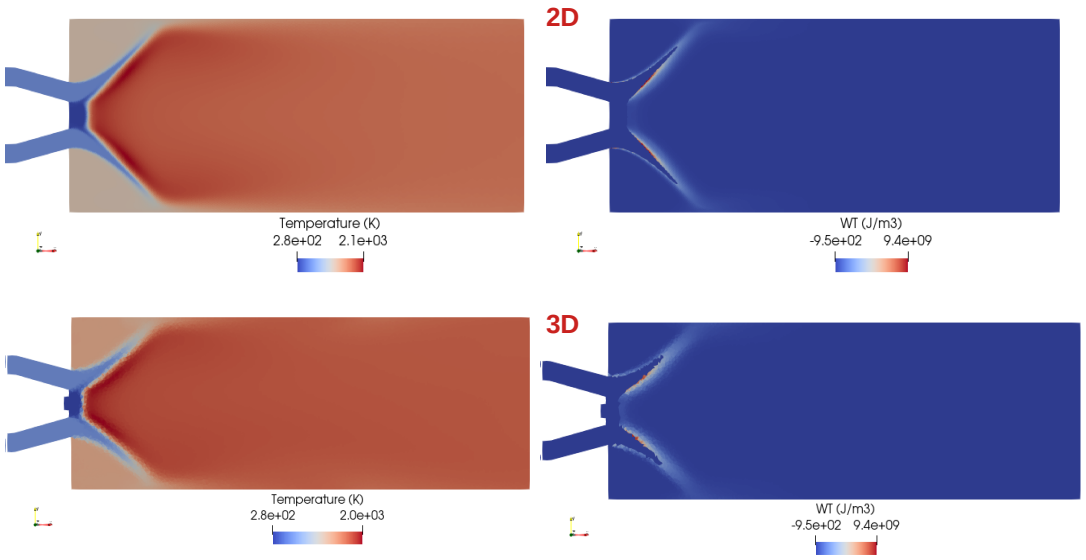

FIGURE 5: G2 HEAT RELEASE AND TEMPERATURE

Cassiopée and is made of around 10 M cells. The number of cells is quite limited. The goal of this simulation is not to be totally predictive as more resolved simulations will be done later, but to give more informations on the true behavior of the flame. For turbulence, the Smagorinsky model is used and the kinetics mechanism is the San Diego one [20] which is a detailled scheme made of 9 species and 21 reactions. The interaction between chemistry and turbulence is taken into account thanks to a Thickened Flame model using the Volpiani efficacity function [21].

As for the other geometries, the heat release and temperature fields are presented for the comparison. Fig.9 presents the LES instantaneous and mean fields and Fig.10 presents the 2D and 3D RANS fields.

For this geometry, the 2D and 3D RANS computations are not very well-correlated for the heat release fields because the 3D simulation does not give a steady solution and needs to be averaged whereas it is not the case for the 2D simulation. Consequently, for both simulations, the flame looks similar near the injector where it burns near the outer recirculation zone but far

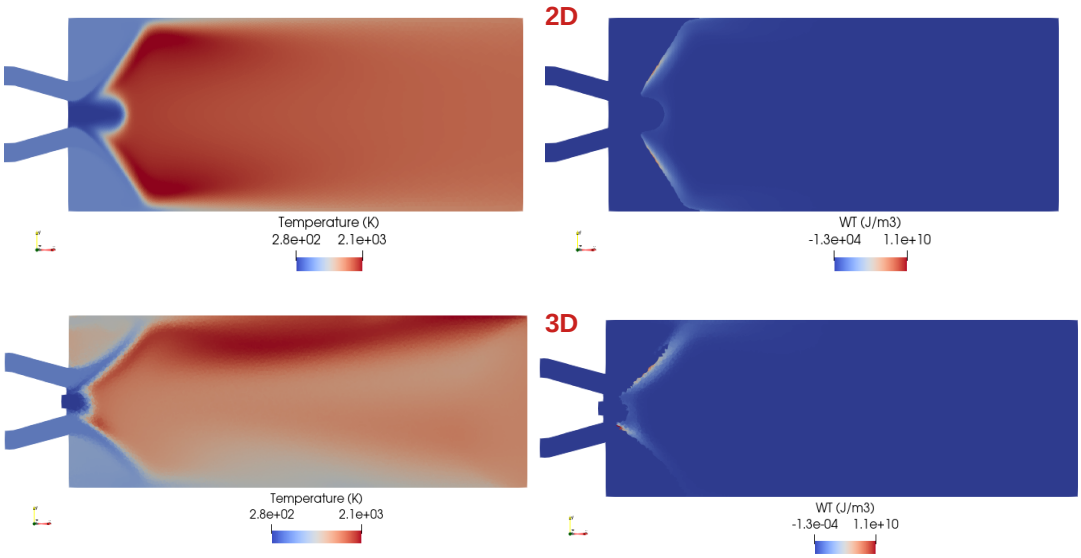

FIGURE 6: G3 HEAT RELEASE AND TEMPERATURE

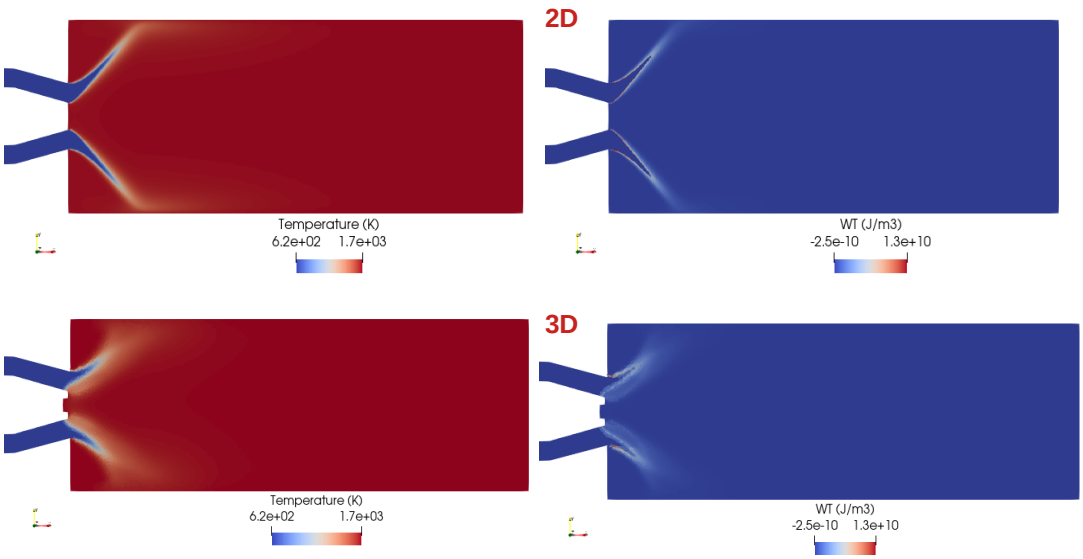

FIGURE 7: G7 HEAT RELEASE AND TEMPERATURE

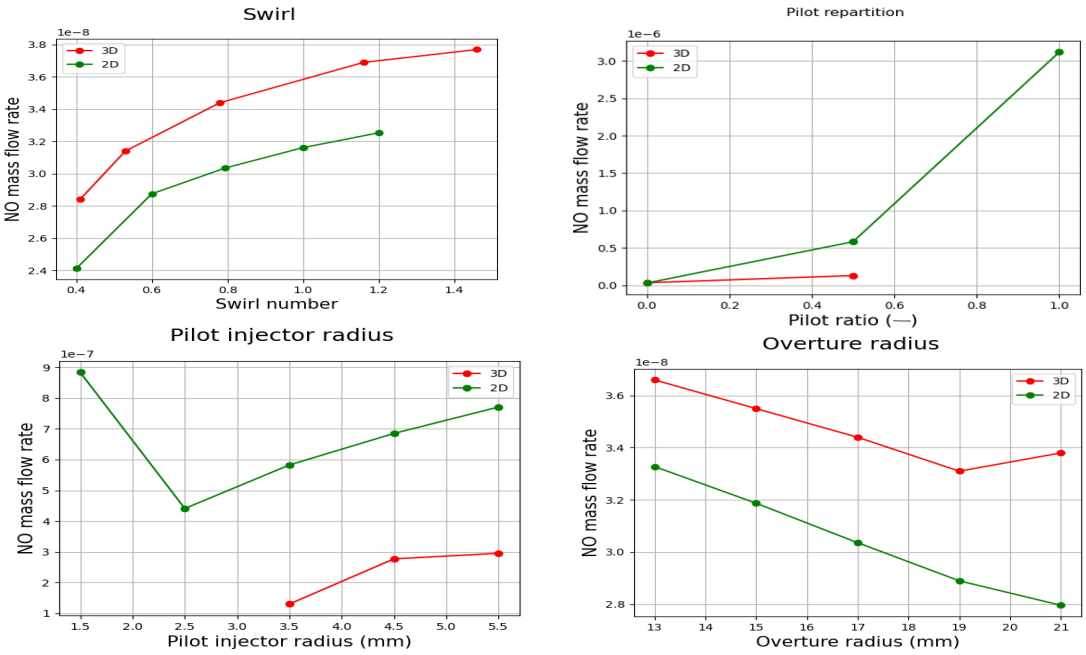

FIGURE 8: NO MASS FLOW RATE COMPARISONS

from the injector, the thickness of the 3D flame is higher due to the unsteady behavior while the 2D flame remains relatively thin.

The differences between the two RANS simulations remain acceptable but the comparison with LES underlines some major differences between both methodologies. In LES, the flame burns near the inner recirculation zone whereas it is not the case in RANS with the model RLE. Only 10% of the hydrogen mass flow rate is injected by the main inlet, so the equivalence ratio near the outer recirculation zone is very low. In LES, the combustion in this zone can occur only if some burnt gases with a temperature of more than 1400 K recirculate there. When the recirculating burnt gases are not hot enough (a temperature of 1000 K for example), as the local equivalence ratio is low, the fresh gases cannot burn. On the contrary, in RANS, this zone burns very well even if the local equivalence ratio is low too because the shear stress in this zone are important, so it produces a lot of turbulent kinetic energy and the value of τ_t in Eq.(3) becomes small. This analysis shows an important limitation of the RLE model where no limiters take into account the flammability limits of the mixture. Therefore, if the level of turbulence is high enough, it can burn where it does not in LES. More importantly, it does not burn at all in RANS with the RLE model between the pilot jet and the main jet while it is where the flame is in LES. One crucial difference too is the maximum temperature reached for both methodologies. In LES, there is a diffusion flame at the pilot jet that burns at stoechiometry, so it can reach a high temperature of flame whereas the RLE model does not burn near the pilot but in a very lean zone so the maximum temperature is much lower. This major difference of maximum temperature has a huge influence on the NO production since we have 5 orders of magnitude between the LES NO mass flow rate and the RANS NO mass flow rate at the exit of the injector.

By studying the unsteady dynamics of the flame, we see that the length and the shape of the flame are poorly reproduced. Assuming that LES results are closer to reality than the RANS ones (which seems to be a reasonable assumption), it is now necessary to develop model improvements for the RANS approaches to get close to the high-fidelity results. Of course, these improvement will surely be for part ad-hoc corrections (tuned to recover LES results), but not exclusively (used of more accurate Algebraic or Reynolds Stress Model, finite-rate chemistry,...). At last, the LES-RANS comparison was done for only one design point, so more geometries and operating points need to be tested to confirm (or not) this trend.

4. CONCLUSIONS AND PROSPECTS

The current paper presents the first step before employing a multifidelity optimization approach for aircraft combustors working with hydrogen. A simple geometry swirl injector operating near industrial targets is simulated and a parametric study based on 4 parameters is achieved to evaluate the correlation between 2D and 3D RANS simulations, using a turbulent combustion model based on local equilibrium and infinitely fast chemistry (RLE).

Results of this parametric study show that the 2D and 3D RANS methodologies are globally well correlated qualitatively and quantitatively except for very high swirl and low pilot radius. The RLE model allows fast computations compared to a detailled kinetics mechanisms and is therefore very interesting for an optimization purpose.

Discrepancies between LES and RANS simulations are observed and could be explained for two main reasons: the poor consideration of large-scale mixing or/and the infinitly fast chemistry assumption. To determine which reason is dominant, we will start by testing other turbulent combustion models (finite rate, including the use of the same kinetics as for the LES computation).

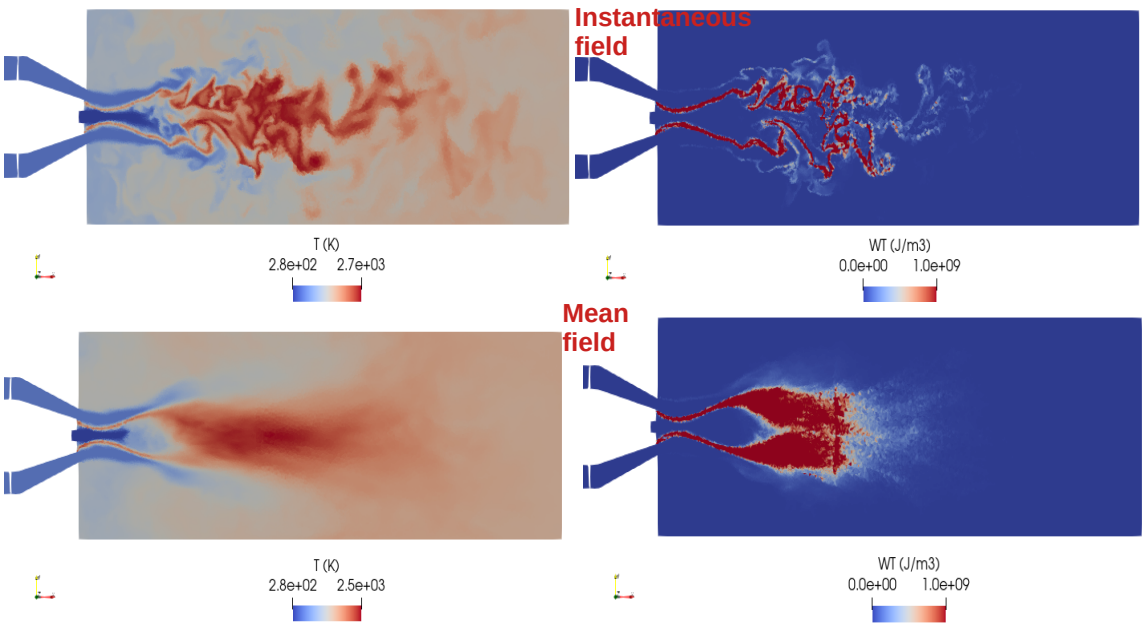

FIGURE 9: G16 HEAT RELEASE AND TEMPERATURE - LES

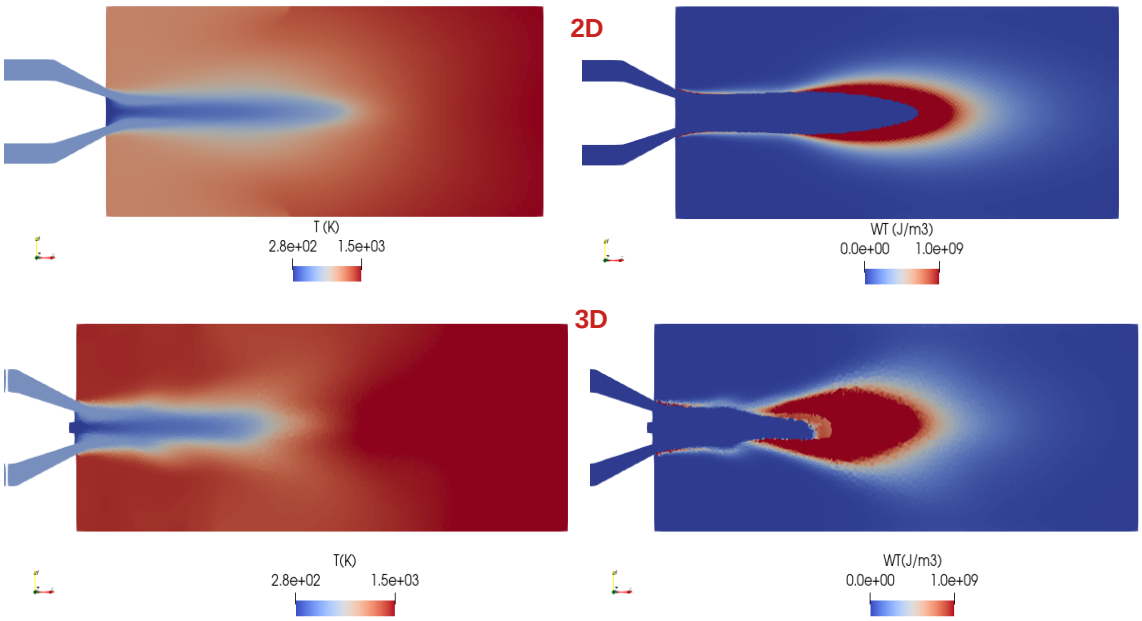

FIGURE 10: G16 HEAT RELEASE AND TEMPERATURE - RANS

Then, several approaches will be investigate in order to try to get RANS results closer to the LES ones (including the use of more complex and accurate models and an ad-hoc fitting approach).

Once a sufficient match between RANS and LES will be reached, it will be possible to combine these approaches (2D RANS, 3D RANS and LES) to perform a multifidelity Bayesian optimization of H2-air injector for aircraft propulsion with more accuracy. Finaly, a question of great importance still remaining open at this stage (but which will be a major topic of our research) is the proportion of high fidelity LES needed to carry out this optimization compared with RANS ones.

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