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Research Activity to Tackle the Challenges in Combustion for Aerospace Propulsion

The use of combustion for aerospace propulsion is inescapable for the long term. The improvement of the energetic efficiency, safety and reliability, and the compliance with increasingly stringent environmental rules require the enhancement of existing technologies and/or a breakthrough in propulsion devices. A vigorous research activity must be pursued in the field of combustion to meet these goals. This issue of AerospaceLab gives the reader an overview of this intense activity, ranging from experimental to theoretical and numerical work.

Combustion is a process that is used to supply more than 80 % of the world primary energy. Since this process still mainly relies nowadays on fossil fuels, it creates about 70 % of the Green House Gases (GHG). Technological solutions are today available for industry, housing and ground transportation, to cease using carbonated fuel combustion, i. e., to progressively shift to low GHG emission processes. The situation is different in aeronautics and aerospace, where combustion remains the only process able to supply the specific power and energy required to propel aircraft, rockets and missiles. This means that the optimization of this process is mandatory, not only to ensure ever better operational safety and to decrease the operation costs, but also to meet environmental requirements concerning emissions and noise. Only research work aimed at improving existing combustion technologies as well as introducing technological breakthroughs in propulsion devices can allow us to achieve these objectives. This research work must be based on an experimental activity involving accurate non-intrusive measurements to give us a deep insight into turbulent reactive flows, and an activity in numerical simulation and modeling making possible a comprehensive analysis of these reactive flows. Experimental and numerical activities are complementary of each other: numerical tools need to be validated by experiments and, on the other hand, the interpretation and understanding of the experimental results is greatly enhanced by numerical simulations.

In the short term, the use of hydrogen for transport aircraft is not a viable solution because of storage difficulty and operation safety, and the best way to lower the CO_2 emissions of air transport, aside from improving the specific fuel consumption, is the use of biofuels recycling the atmospheric CO_2. The question of biofuel use is wide and goes far beyond the sole problem of combustion. Therefore, it will not be addressed here.

The objective of this AerospaceLab issue is to give an overview of the vigorous research activity in the field of combustion. We focus here on research work with a TRL (Technology Readiness Level) lower than or equal to 6, in other words, on research concepts that have not yet been tested on flying vehicles.

Concerning aircraft propulsion, this issue starts with a description of the main features of the major combustion facilities used at ONERA and CORIA Rouen for experimental research on aerospace propulsion [AL11-01 and AL11-02]. The physical phenomena involved in turbulent combustion and the corresponding models to be introduced into the numerical tools are then discussed, and the validation of these tools using experimental results is exemplified [AL11-05]. The way in which these complex numerical tools are applied to industrial combustors is presented in AL11-06. Various solutions are used to improve engine efficiencies and, consequently, decrease the specific fuel consumption, one of which is an increase in the combustion pressure. However, this leads to a higher combustion temperature and, consequently, to higher NOx emissions. In order to offset this effect, lean premixed combustion is preferred, but this is at the expense of the combustion stability. The instability issue for this type of reactive flow is addressed in AL11-09. Other topics of interest regarding reactive flows are combustion noise [AL11-10] and pollutant emissions [AL11-07, AL11-08, AL11-11]. Concerning the last topic, [AL11-07] deals with strategies to simulate the formation of pollutants, such as soot and NOx, and presents some experiments designed to validate these strategies. [AL11-08] describes experimental studies to accurately characterize the soot emissions of turbojet engines and [AL11-11] focuses on the experimental study of a low-emission combustor designed for mid-power industrial turbines. Finally, technological breakthroughs are exemplified by presenting concepts allowing increased combustion pressures, using either the detonation mode or a constant volume chamber [AL11-12].

The use of combustion is also required for rocket and missile propulsion. For such vehicles, the main issues are improving operation safety (by limiting the combustion instabilities, for instance) and optimizing the specific impulse and the operating cost. Despite the low number of flights, the emission of pollutant species, such as chlorinated species, can also be addressed if solid propellant is used. A close look at air breathing combustion in ramjets and scramjets respectively [AL11-03, AL11-04] is taken. For ramjets, the objective is to improve the combustion efficiency and to prevent instabilities;

for scramjets, the difficulty lies in mixing fuel and air, and in anchoring the flame without thermal choking and/or an exceedingly great pressure drop. The physicochemical phenomena involved in solid-fuel rocket propulsion are described in AL11-13, with special emphasis on the unsteady behavior of reactive flows inside rocket combustion chambers. This is followed by a paper that concentrates on hybrid propulsion, combining solid and gaseous propellants to obtain a more flexible engine thrust [AL11-14].

The last topic developed in the issue is liquid propulsion, a complex technology that requires the injection of propellants into a high-pressure chamber, either by means of sophisticated pumping devices or high-pressure tank storage. In addition, it often requires the storage of cryogenic propellants. Despite its complexity, liquid propulsion is commonly used because it yields a high specific impulse. Two papers describe research work in the field of cryotechnical propulsion, the first being dedicated to the experimental activity carried out with the ONERA MASCOTTE facility [AL11-15], and the second to the numerical simulation of H2-O2 combustion with injection of cryogenic oxygen [AL11-16].

This issue of the AerospaceLab Journal is far from being exhaustive, but it is aimed at convincing the reader that top level research combining experiments, physical modeling and numerical simulations remains mandatory to tackle the wide range of issues linked to combustion in propulsion systems for aeronautics and aerospace, which are issues that extend from operation safety to performance optimization and environmental impacts