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Editorial

Special Issue "Advances in Hybrid Rocket Technology and Related Analysis Methodologies"

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Hybrid rockets are chemical propulsion systems that, in the most common configuration, employ a liquid oxidizer (or gaseous in much rarer cases) and a solid fuel; the oxidizer, stored in tanks, is properly injected in the combustion chamber where the solid fuel grain is bonded. In the classical arrangement, one or more ports are present in the fuel grain whereby the oxidizer flows and burns with the fuel vapors. When speaking about hybrid rockets, one cannot avoid stating that, although they may seem to lie somewhere between a liquid and a solid propellant system, this propulsion technology, thanks to the phase separation of the two propellants and the vast choice of available inert fuels, features unique advantages, well known in the propulsion community [1,2], which are not enjoyed by either liquids or solids. In fact, because they essentially preserve performance comparable to the high level of the most complicated liquid rocket engines, their several benefits, spanning lower development cost, higher safety and less environmental impact, can lead to extensive employment as game changing technology in the current space arena characterized by a dramatic upsurge of worldwide activities and the parallel emergence of different types of space actors [3,4].

The hybrid rocket concept dates back to the early twentieth century [5], but till about a decade ago, hybrids have been perceived as a niche technology; nowadays, however, they are attracting renewed interest from both the propulsion technical community and industry. The number of researchers involved in this subject has increased more and more all over the globe along with the launch of student sounding rockets [6,7].

Hybrid propellant engines can be used in practically all applications where a rocket is needed, but there are certain cases where they present a superior fit, such as the above-mentioned sounding rockets, tactical missile systems, launch boosters and the emerging field of commercial space transportation. The novel space tourism business will definitely benefit from their safety and lower recurrent development costs. The famous Virgin Galactic SpaceShipTwo is, indeed, a spacecraft propelled by a hybrid rocket engine that aims to take tourists on brief trips to suborbital space at an unusually large flight frequency [8]. Manufactured by The Spaceship Company, the vehicle is currently in an advanced testing stage. Furthermore, it was last October 8 that Boeing announced a strategic investment in Virgin Galactic, which could eventually support high-speed future passenger transportation systems [9]. Those are all clear signs of growing, genuine attention toward the hybrid rockets alternative, and probably the real challenge facing researchers is inseminating the hybrid culture to enable the widespread adoption of this technology, which is still hindered not for technical reasons, but due to societal factors like the stereotype represented by the mature solid and liquid propellant rockets. Within this framework and with the latter purpose, the Special Issue of Aerospace "Advances in Hybrid Rocket Technology and Related Analysis Methodologies" was born.

The current key research areas include systems to improve the slow fuel regression rate, such as the selection of paraffin-wax-based fuel casting; the enhancement of wall heat transfer with nonstandard oxidizer injection methods and/or fuel grain configurations; the effects of the addition of energetic ingredients into the fuel, the suppression of combustion instability; and the optimization of engine components.

Scientists from Japan, USA, China, France, Australia, South Korea and Italy have contributed to make this Special Issue an amazing collection of papers drawing a picture of the state of the art. I am honored to present twelve excellent articles from some of the most accredited scholars active in the sector as well as from emerging research organizations covering a wide range of topics, which encompass nearly all the subjects just listed above, from fundamental research to real-world applications.

Three review papers appear in the Special Issue; Marquardt and Majdalani [10] revise the Marxman's classical diffusion-limited regression rate model with the purpose of complementing the existing literature, providing a unique combination of detail and brevity that will be appreciated by newcomers entering the field. The development of accurate simulations of reacting flows incorporating the capability of modeling the fuel surface regression poses significant challenges for computational methods, and the article from Di Martino et al. [11] is concerned with the application of computational thermo-fluid-dynamics to the simulation of the internal ballistics of rockets burning either standard polymeric or liquefying fuels; finally, Chen et al. [12] conducted an excellent survey of several innovative methods under testing to improve the solid fuels' combustion properties, presenting a number of experimental results.

Three research papers address particularly innovative themes in the hybrid rocket literature: the article from Messineo and Shimada [13] is centered around a non-conventional engine configuration where the oxidizer injection in the fuel port is split in two separated streams: one of which is axial and the other is tangential with the idea of controlling, independently, both the injected flow rates to optimize the mixture ratio with a given thrust profile. A theoretical investigation into the feedback control of hybrid rocket engines is, thus, addressed; Casalino et al. [14] examined the viability of an electrically driven pump-fed hybrid rocket for small launcher upper stages of the Vega class, demonstrating that it can be a suitable option for the replacement of the conventional pressurized gas feed system. The third paper from Moon et al. [15] reports on an assessment of a hybrid rocket for underwater propulsion, suggesting that the throttleable hybrid engine could be an effective candidate for a short-duration, high-speed marine boosting device as an alternative to the solid propulsion system.

The remaining research articles deal with more standard topics, yet are well deserving of attention. They focus on the scaling up problem, the CFD modeling of the regression rate, the application of ballistic reconstruction methods to the engine performance evaluation and the effect of energetic ingredients to improve the regression rate. Experimental results from a number of firings of a paraffin-based, 1 kN thrust rocket are discussed by Battista et al. [16]; the results of numerical simulations carried out with an ad-hoc CFD code are reported by Bianchi et al. [17] for the high-density polyethylene regression rate calculation, highlighting the influence of the gas-phase radiation contribution to the total heat flux to the surface; some preliminary data from small-scale static firings of 3D printed fuel grains made by several materials are shown in [18], by Mc Farland and Antunes; the experimental performance data acquired from a hybrid rocket fed by nitrous oxide and high density polyethylene for the application to an apogee kick motor were treated by Kamps et al. [19]. Regression rate and mass burning rate obtained with the addition of nano- or micron-sized aluminum powders and oxidizer-containing fuel-rich composites to HTPB (Hydroxyl-terminated Polybutadiene) are investigated in comparison to the baseline pure fuel in the paper of Paravan [20].

Finally, the subject analyzed by Whitmore [21] in the twelfth paper, which at the moment of this foreword is still on the publication path, is the investigation into a fluid blend of nitrous oxide and gaseous oxygen as a significantly safer and higher volumetrically-efficient alternative for the current generation of environmentally-unsustainable spacecraft propellants.

The first article appearing in this issue was published on 6 March 2019, whereas the last was just a few days ago; since then, from the MDPI articles' access metrics service, one can see a continuous increase of interest in the papers, with peak numbers of about 1300 downloads and 2000 views per article. The latter data are extremely encouraging and, considering the relatively small competent community compared to the solid and liquid propulsion groups, make us hope one day soon we will see large-scale development of hybrid rocket engines.

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