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Strategies toward experimental assessments of new aviation renewable fuels and blends: the BIOREFLY project

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Abstract

The reduction of greenhouse gases emissions from the aviation sector is focused on better engine efficiency or optimized flight pathways. However, the most relevant is probably the use of sustainable biofuels. In order to meet the strict jet fuel specifications for commercial flights, these biofuels (drop-in fuels) must contain only paraffinic hydrocarbons, without heteroatoms. Several renewable aviation fuels have already been certified by ASTM, others are under examination. A new promising route consists in the thermochemical conversion of lignin, the main co-product from 2nd generation ethanol. The EU FP7 BIOREFLY project will develop a first industrial pre-commercial lignin-to-jet fuel 2000 t y^{-1} demonstration plant. The present work describes strategies, equipment and R&D lines of BIOREFLY, which aims at evaluating the properties of this bio-jet fuel and its blends in view of future ASTM certification. Injection features and the combustion properties of aviation engines will be investigated in an optical combustor rig. Combustion parameters, emissions and chemiluminescence provide fundamental data to understand the combustion behavior for different hydrocarbons species. Tests in micro-gas-turbines (i.e. power generation and APU-derivative units) will assess the effect of fuels in terms of emissions and evaluating their performances.

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Keywords: biofuels; aviation; renewable jet fuel; hydrotreating; combustion; emissions.

1. Introduction

1.1. The context

Renewable fuels plays a key role into aviation sector to reduce greenhouse gases emissions and to introduce a sustainable fuel that can substitute the traditional jet fuel. In order to mitigate the CO_2

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emissions to face the global challenge of climate change, IATA set three main target: (1) a 1.5% average annual improvement in fuel efficiency from 2009 to 2020; (2) carbon-neutral growth from 2020 [1] and (3) a 50% reduction in carbon emissions by 2050 [2]. A four-pillar strategy designed to reach these goals focused on improving technologies (among these, the use of renewable fuels), logistics optimization, more efficient infrastructures and a single global market-based measure, to fill the remaining emissions gap. The introduction of biofuels into aviation sector must not alter the aircraft engine performance and the fuel must conserve its properties during the wide range of atmospheric conditions during flights. Challenging requirements are set through the severe specification of ASTM D1655 [3] for jet fuel: thus a biofuel suitable for aviation has to be fully composed by hydrocarbons in the range of kerosene, to be blended as drop-in fuel. Various production process and blend for alternative aviation fuels were approved by ASTM [4,5] and can be used in commercial flights, such as Fischer Tropsch-derived fuels and Hydrotreated Renewable Jet fuel (HRJ), both blendable up to 50% in volume fraction with Jet A-1, or Synthetic Iso-Paraffinic (SIP) kerosene, which can be blended up to 10%. Several new processes are currently under development [6], and over 15 new pathways to produce renewable jet fuel blending components are currently in the ASTM approval process [7], in addition to the first three pathways. Despite the production of renewable fuels is convenient in terms of energy return [8], several barriers related to economy [9,10], regulatory framework [11] and feedstock supply [12], make the commercial production of biojet still a challenge.

1.2. The EU FP7 BIOREFLY project

Bioenergy plays a key role in the EU's long term energy strategy, and diversification of feedstock and pathways is crucial. A major route is HRJ, which can be adopted using traditional vegetable oils as well as other non-food lipid-sources: HRJ from camelina and used cooking oil was produced in the framework of ITAKA [13]. Feedstock costs are the single largest contributor to the overall price of lipid-derived hydrotreated fuel (65-76%) [14]. As the development of new pathways to renewable jet fuel is crucial, the EU FP7 BIOREFLY project [15] will develop a very innovative lignin-based route at industrial pre-commercial scale. As a preparatory work towards future ASTM D4054 [4] certification (not part of Biorefly project), some actions are being carried out, such as the analysis of chemical properties, atomization and combustion features and preliminary micro-gas-turbines (APU-GPU) tests.

1.3. The fuel

Hydrocarbons species contained in the jet fuel obviously determines major effect on fuel properties. Straight paraffinic components are characterized by high hydrogen-to-carbon ratio, and therefore generate a to high production of heat per unit mass compared to the other hydrocarbons. Cyclic paraffins instead increase the density and reduce the freezing point of the final blend. In contrast, low concentration of aromatics and olefins are requested due to their fast smoke production and reactivity during combustion. Conventional fossil jet fuel mixture includes different classes of hydrocarbons (70 – 85% n-, iso- and cyclo-paraffins, < 25% aromatics and < 5% olefins, in volume fractions) so to meet ASTM D1655 [3]. The approved HRJ fuel does not contain aromatics, thus a major concern in the use of these renewable biojet is to ensure a minimum content of aromatics (8.4% volume) so to guarantee seal tightness over time [16]. As a consequence, the ASTM approved aviation blend range between 16.8%, to allow 50% blend of HRJ and FT-derived fuel, and 25% content. Zhang et al. [17] studied the characteristics of several commercial fossil and alternative aviation fuels to define their combustion behaviour versus hydrocarbon composition. Since alternative jet fuels can vary significantly in composition as compared to conventional jet fuels, understanding the effect of fuel properties (both physical and chemical) on combustion is essential.

2. Experimental

During operation, aviation gas turbines must ensure high quality atomization and stable combustion. Several fuel properties, such as density, viscosity and tension surface have a significant influence on spraying process [18] together with spray characteristics, such as injection pressure, geometry and nozzle type, combustion chamber pressure, environment temperature and atomizing/combustion air. All this determines different atomization, vaporization and subsequent combustion performances of the air-fuel mixture. In the framework of BIOREFLY, RE-CORD developed a preliminary series of tests on HRJ blends to evaluate and assess the performance of new renewable aviation fuels. Testing campaign was divided into three main experimental step: atomization, combustion and gas turbine performance.

2.1. Atomization and pumping rig

A test rig for pump and nozzle testing for aviation engines was developed. The rig is designed to work with pressure-swirl nozzles, selected as representative atomizers for the nozzles adopted in aviation. Spray characteristics will be evaluated by using optical measurement systems: PIV, at selected sections of interests, to evaluated cone and spray penetration; P/DPA, if deemed necessary for more detailed studies on droplets size and velocity. Conventional and renewable jet fuels are injected in an atmospheric insulated chamber, maintaining same injection conditions as aviation engines. Preliminary results during test bench commissioning showed similar spray features in terms of spray cone angle and global SMD.

2.2. Combustor rig

The experimental characterization of the combustion behavior of renewable aviation fuels and their blends is carried out using a gas turbine swirl burner in a cylindrically confined, optical combustor. A High Pressure Optical Chamber (HPOC) to study the liquid and gaseous fuels is present at Gas Turbine Research Centre (GTRC), an experimental facility at Cardiff University. A scaled tangential swirl burner was designed on the basis of experience and numerical models of previous aerospace research [19–22]. The rig can operate at various equivalence ratios and operating pressures (up to 20 bar). The rig is able to evaluate emissions, flame behavior and chemiluminescence profiles to evaluate OH* radicals formed during combustion. The results of the experimental campaign focused on HRJ investigation [23] showed superior response by the presence of biojet, showing more stable flame patterns, lower emissions and homogeneous OH* production profiles. The reduction of aromatics generated a reduction in soot formation and showed a more stable overall behavior as the HRJ content increased. Chemiluminescence results demonstrated how HRJ OH* production takes place close to the nozzle in the shear layer, whilst the increase of aromatic fuels have a retardant effect on the production of the radical, thus leading to production of species such as CH*, herein soot formation. This study focused on the interaction between the relative quantities of aromatics and paraffinic hydrocarbons into fuel, which have a profound and measurable effect on the soot generation in the primary zone of the combustion chambers. Future work will investigate the pollutant species in the exhaust gases as a verification mean of the above.

2.3. Micro-gas-turbines

Two selected micro-gas-turbines were selected to evaluate the performance of BIOREFLY lignin-to-jet fuel: (1) Garrett GTP 30-67 is a 25 kW APU-derived power unit, with a single reverse flow silo combustion chamber and a pressure swirl nozzle (Fig.2); (2) Capstone C30 LF is a 30 kW stationary power unit, with a three air-assisted injection lines in separated combustion chambers. The units were already previously tested with road biofuels to evaluate emission index and performance [24,25]. Literature generally indicates that aromatic HCs in or above the kerosene boiling range tend to burn less efficiently that paraffinic hydrocarbons [26,27]. As observed by Lobo et al. [28], combustion of full-paraffinic reduces particulate matter emissions in aviation turbines and auxiliary power units (APUs). Preliminary measures from Garrett GTP 30-67 were reported in Fig. 1 using diesel and denatured ethanol as fuels.

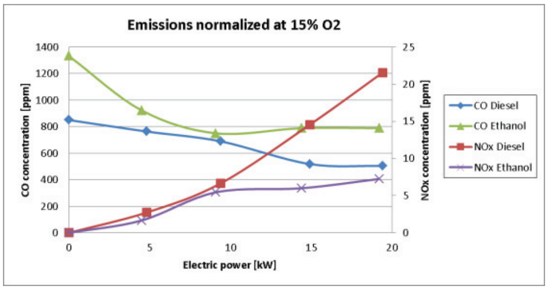

Fig. 1. Emissions index of Garrett GTP 30-67 during commissioning.

Fig. 2. Garrett GTP 30-67 at RE-CORD facility (Scarperia, Florence, Italy).

3. Discussion and future development

Literature on HRJ and FT-derived biojet fuels, free of aromatic HCs, would suggest a similar combustion for the BIOREFLY jet fuel, as they are all composed by paraffins. However, the presence of n-, iso- and cyclo-paraffins at different share will modify the fuel properties. The experimental campaign investigating the BIOREFLY fuel in micro gas turbines (GPU) will be fundamental to characterize its combustion behavior, as a preparatory work towards possible and future ASTM certification. Currently the use of surrogate fuels is taking interest: some author [29] replicated the physical (evaporation) and chemical (combustion) characteristics of real Jet A and JP-8 adopting a surrogate based on a single compound per class of hydrocarbons (e.g., n-dodecane as paraffin, toluene as aromatic, etc.). Surrogate fuels can replace mixtures of real HCs and oxygenated fuels [30], and they are often used in place of real fuels in computational combustion studies [31]. The combination between these recent achievements and the found results from atomization and chemiluminescence can improve the knowledges about the combustion behavior of renewable fuel blends. Moreover, MGTs tests will be focused on validating the best renewable blends for aviation.

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