ALFA-BIRD
Alternative Fuels and Biofuels for Aircraft development

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1 Summary

As planned originally in the ALFA-BIRD program, the fuel selection process is divided into two steps. The consortium has now completed the first step, which consisted in evaluating 12 blends in terms of their quality as jet fuel based on standard characterization only. These 12 blends were: FSJF[1], FT[2]-SPK[3], blends of FT-SPK with naphthenic cut or with hexanol or with furane or with FAE[4], in different amounts. These results were used for the selection of the 4 fuels that will be tested in detail in the second phase within ALFA-BIRD project, the assessment of the suitability of alternative fuels for aircraft. The 4 fuels selected are FSJF, FT-SPK, a blend of FT-SPK and 50% naphthenic cut, and a blend of FT-SPK and 20% hexanol. This fuel matrix offers the possibility to evaluate the potential of different chemical families which are paraffinic compounds, naphthenic compounds and oxygenated compounds. This is also representative of a short, middle, and long term view.

[1] FSJF for Fully Synthetic Jet Fuel
[2] FT for Fischer-Tropsch
[3] SPK for Synthetic Paraffinic Kerosene
[4] FAE for Fatty Acid Ester

2 Introduction

2.1 Purpose of the note

The European project ALFA-BIRD is dedicated to the evaluation of the most promising alternative fuels in aeronautics, at a middle, short and long term.

The purpose of this note is to explain the choice of the fuels that will be tested in the 2nd phase of the project. This 2nd phase is dedicated to combustion tests: ignition, heat release, combustion, evaporation...

The selection of the fuel is based on the report (D04) D1.2.1 Results of the analysis of the initial fuel matrix - selection of the most promising fuels and the outcomes of the meeting with the Advisory Group that took place on 26 November 2009 in Stuttgart.

2.2 ALFA-BIRD's mission and consortium

ALFA-BIRD (Alternative Fuels and Biofuels for Aircraft Development) is a project partially funded by the EU in the 7th Framework Programme for Research and Technological Development, under grant n° 213266. It started in July 2008 and will last four years. Its objective is to investigate and develop a variety of alternative fuels including biofuels that could gradually replace crude oil based Jet A-1/Jet A, which is currently in use in aeronautics. The main motivation is the need to ensure a sustainable growth of the civil aviation with regard to the impact of fossil fuels on climate change and air quality and also in the context of oil prices that are highly volatile and increasing in the long term.

One of the main challenges in the project is to propose fuels that meet the very strict safety and operational constrains in aviation (e.g. safe flight under very cold conditions), and are compatible with current civil aircraft, which is a must due to their long lifetime of almost 50 years. To address this challenge, ALFA-BIRD gathers a multi-disciplinary consortium composed of 23 members with key industrial partners from aeronautics (engine and aircraft OEM) and fuel industry, and from research organizations covering a large spectrum of expertise in such fields as biochemistry, refinery, combustion, aircraft systems or industrial safety, to name only a few. The ALFA-BIRD program is consequently dedicated to the selection and the evaluation of the most promising alternative fuels with short to long term perspective. In order to do so, the expertise of all partners will be gathered and the evaluation will be done on technical basis: physical properties, combustion behaviour, material compatibility, security aspects, but also on economical and environmental aspects (life cycle analysis).

3 Selection process of alternative fuels for aviation

As planned originally in the ALFA-BIRD program, the fuel selection process is divided into two steps. The consortium has now completed the first step, which consisted in evaluating 12 blends in terms of their quality as jet fuel based on standard characterization only (see Table 1). An exhaustive list of fuel options was proposed by IFP following their state-of-the-art study (Deliverable D01: "Overview of possible alternative fuels and selection of alternative fuels") and discussed amongst partners. The selection of 12 candidate fuels to be tested in this first step was then voted by ALFA-BIRD's Steering Committee on April 2009.

Fuel number	Description (volume % blends)
1	FSJF
2	FT-SPK
3	FT-SPK + 50% Naphthenic cut
4	FT-SPK + 20% Hexanol
5	FT-SPK + 10% Furane
6	FT-SPK + 20% Furane
7	FT-SPK + 30% Furane
8	FT-SPK + 10% FAE
9	FT-SPK + 20% FAE
10	FT-SPK + 30% FAE
11	FT-SPK + 50% HVO
12	FT-SPK + 75% HVO

Table 1: Description of the 12 blends used in SP1

This proposed fuel matrix of 12 Jet-fuel candidates is built around three axes, covering a wide range of alternative fuels. Regrouping these alternative fuels by chemical family, we have:

- paraffinic compounds
- naphthenic compounds
- oxygenated compounds.

The paraffinic compounds are stemming from FT synthesis (SPK), HVO[5] or sugar-to-alkane pathway. The naphthenic compounds represent products that come from direct liquefaction/pyrolysis of coal or biomass. Concerning the oxygenated compounds, the study of their potential use in aeronautics is very original and will be explored in ALFA-BIRD. Each selected chemical family is discussed in the following.

[5] HVO for Hydro treated Vegetable Oils

3.1 The reference fuel

The selection process adopted in ALFA-BIRD is a direct comparison of each fuel candidate with a well characterized and a certified reference fuel rather than a relative comparison between each candidate. The reference fuel is identical for all tests and all partners.

Jet A-1/Jet A is the conventional fuel for aeronautics. However, this product has a large variability according to the crude oil and the process (sweetening, hydroprocessing, among others). This implies for example a variation in the level of aromatics and sulphur.

ALFA-BIRD has chosen the FSJF from Sasol as the reference fuel for several reasons:

- To place the study in a long-term view
- To have coherence and to be complementary with respect to other EU and international initiatives (SWAFEA[6], CAAFI[7]).
- To have less variability on the reference.

The FSJF is a fully synthetic jet fuel and consists of 50% FT-SPK and 50% of severely hydrogenated coal tar kerosene. This product has a well-defined composition due to the fact that it comes from an identified refinery with a controlled process. Moreover, a synthetic fuel contains inherently less chemical families with a narrower distribution of components within each family. This in turn makes it an adequate reference as it is less prone to source/process-dependent variations.

3.2 The paraffinic compounds

A promising alternative fuel is FT-SPK. The Fischer-Tropsch synthesis is described in the following: Raw material (e.g. coal, natural gas, biomass) is broken down at high temperature to basic molecules (CO and H2 – this mixture is called synthetic gas or syngas), chemically cleaned, and rebuilt to different products (including jet fuel). This process makes mainly straight chain of hydrocarbons (paraffinic compounds). The advantage of this process is the large variability of the sources (coal, natural gas, waste, biomass) that could be used. The process is well known nowadays from coal and gas but the future development will be to use biomass or biogenic waste and side products as a feedstock.

FT-SPK[8] is used in ALFA-BIRD as a blending base; consequently, this product is also tested neat in order to have the possibility to clearly identify the fuel impact. FT-SPK used in the ALFA-BIRD project is within SPK specification limits (ASTM[9] D7655). It can be noticed that SPK has no aromatics (less than 0.5% mass), and the ASTM D7655 specifications indicate a minimum of around 8% of aromatics in the final blend (Jet + FT-SPK).

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[6] SWAFEA for Sustainable Way for Alternative Fuel and Energy in Aviation; see www.swafea.eu
[7] CAAFI for Commercial Aviation Alternative Fuels Initiative; see www.caafi.org

[8] There are currently no industrial plants for producing BtL, consequently the FT-SPK used in Alfa-Bird is a GtL from Shell. The GtL product is assumed to be similar to a BtL product because the same process is used.

[9] ASTM for American Society for Testing Materials. ASTM D7566 is a new specification for certifying a 50% blend of Jet A-1 and SPK produced from biomass using a Fischer Tropsch process.

HVO is also a paraffinic product. Its chemical composition and its physical properties are close to FT-SPK ones, provided they meet the same D7655 requirements. The potential of HVO has been explored in ALFA-BIRD by doing standard characterization.

It was decided to choose FT-SPK, representing paraffinic compounds, as the selected fuel for the second phase of ALFA-BIRD, mainly because of the availability of this product, and also, to be complementary with respect to other initiatives (SWAFEA, CAAFI).

3.3 The naphthenic compounds

The naphthenic or naphtheno-aromatic compounds can be produced from direct liquefaction of coal (nowadays) or biomass in the future (sustainable). This kind of molecule has some characteristics that seem to be suitable for jet fuel use: good cold flow properties as well as good energy content in volume, in particular. Some elements are still to be checked like the behaviour in combustion, the pollutant emissions, and the material compatibility, in agreement to ALFA-BIRD's mission: to revisit the fuel specifications and reconsider the whole aircraft system composed by the triplet: fuel, engine and ambience.

The main effect of adding naphthenic or naphtheno-aromatic to FT-SPK is to bring the FT-SPK blend into the Jet A-1 specification limits (ASTM D7655), mainly in terms of minimum aromatics contain (8% in volume by IP 156) and density (775 kg/m3 as a minimum by IP 365). This was observed during the first step dedicated to standard characterization with a blend of FT-SPK and 50% of naphtheno-aromatic cut.

Therefore, it seems important to explore the potential of this blend in more detailed tests.

3.4 The oxygenated compounds

The oxygen presence in the chemical structure is expected to affect key fuel properties including: energy densities, volatility, corrosion ability, material compatibility, and combustion properties. It is why the oxygen compounds can not be used as a blending component in a substantial volume. However, one of the interests to have oxygen in the molecule structure could be the reduction of the particulates emissions. Potential oxygenated fuels envisaged in the first step are listed below.

3.4.1 Alcohols

Alcohol - for fuel - is produced from the fermentation of sugars by enzymes. The feedstock might be sugarcane, sugar beet, wheat, barley, or corn. Presently, the process of fermentation cannot make use of the whole biomass, and significant research is underway to improve this. Moreover, the modification of the enzymes to allow the production of other alcohols such as hexanol is an area of research.

The interest – and the need - to use other alcohol in aeronautics instead of ethanol, is to fit with specified jet fuel properties such as energy density, flash point, water solubility... Some of these drawbacks can be overcome by the use of higher alcohols (means higher carbon number): as the increase of the carbon number will allow an increase of the energy density, the flash point...

In conclusion, ethanol is available worldwide, but it presents severe drawbacks. The use of higher alcohols could have a potential, provided that some production pathways are found. Moreover the CO_2 balance could be interesting. Consequently, alcohols can be an alternative fuel for aircraft but in a long term view.

However, alcohol can not be used as a blending component in a *substantial* volume to avoid an important decrease of the energy content. A blend of FT-SPK and 20% hexanol gives interesting results in standard characterization.

3.4.2 FAE (Fatty Acids Esters)

FAE (Fatty Acid Esters) is commonly referred to as "biodiesel" and is used as blending components for diesel fuel, in accordance with the EU legislation. The name biodiesel has been given to Fatty Acid Esters. The question remains whether FAE could also be considered as a possible alternative fuel to conventional jet fuel.

Esters have chemical and physical properties that are similar to conventional fossil fuel; but these properties depend on the starting material: esters can have different numbers of carbon atoms and varying degrees of unsaturation (number of carbon-carbon double bonds).

Due to their properties, FAE can not be directly used as a blending component for Jet fuels in *substantial* volume.

However, there exists a possibility to improve the properties of FAE for jet fuel use by the selection of the raw material (chain length / insaturation rate trade-off, use of another type of alcohol for trans-esterification process...). Additionally, FAE presents high availability due to a well known production process and to large production plant investments.

In the first step (standard characterization) of the ALFA-BIRD project, blends of FT-SPK and FAE (10, 20 and 30%) have been produced and analysed. It is observed that the addition of FAE implies an increase in acidity, in corrosion, and poor cold flow behaviour. The addition of FAE in a FT-SPK has a positive effect on the density.

Nevertheless, ALFA-BIRD will not explore any deeper the use of this type of compounds (FAE).

3.4.3 Furans

Furans are produced from carbohydrate components that can be found in lignocellulosic biomass, in sugar beet and in sugar beet pulp. The production method is still in the early stages of development and is therefore the subject of several research programmes. In spite of a high density, the cold flow properties as well as the boiling and the flash point of this kind of molecule are in the range of a Jet fuel.
Note that the oxygen content of this molecule that implies a low energy density in mass can be compensated with a high density, and consequently a correct energy density in volume. The material compatibility needs also to be checked.

The potential of furans, more precisely tetrahydrofurfuryl ethyl ether, was explored in ALFA-BIRD – within SP 1 tests - by doing blends of FT-SPK with 10, 20 and 30% of furans. Nevertheless, ALFA-BIRD will not explore any deeper the use of furans.

3.4.4 Conclusions

It is clear that oxygenated compounds are not "drop-in" fuels but it is important to study this alternative fuel in a long term view in order to evaluate their potential. From all the oxygenated compounds, it has been decided to select the blend of 20% of hexanol in FT-SPK in order to perform the second step in the selection process.

3. The fuel matrix for SP2 tests: Summary

For all of the reasons mentioned above, the Steering Committee has decided, after the consultation of the advisory board, that the following fuels will be tested for the second phase within ALFA-BIRD project, the assessment of the suitability of alternative fuels for aircraft. This selection is based on the standard characterization done on the initial fuel matrix (12 blends).

The 4 fuels proposed for the tests (ignition, combustion, evaporation...) in the second part of the project are:

- **FSJF**
- **FT-SPK**
- **FT-SPK + naphthenic cut (50%)**
- **FT-SPK + hexanol (20%)**

Remark: If there is an opportunity during the run of the project to test some new fuels, this will be done with standard characterization.

Description of detailed tests to be carried out within the 2nd phase of ALFA-BIRD

The fuel matrix for SP2 tests given above will be used to carry out more detailed tests within the 2nd phase of ALFA-BIRDS' program, the assessment of the suitability of given alternative fuels with respect to aircraft requirements.

These detailed tests will be performed in four different work packages focusing on:

(1) Injection and combustion

Experimental behaviour, up to real conditions; Model validation

(2) Engine systems integration

Experimental check of compatibility; Search for improved materials

(3) Aircraft systems integration

Experimental check of compatibility

(4) Safety, standards, regulations

Towards certification (regulations, standardisation)

Concerning injection and combustion, the selected alternative fuels must release the energy necessary to power aircrafts' engines. Therefore, the tests are directly related to the elementary physical phenomena occurring in the aircraft engines: atomization, single droplet and spray evaporation, vapour mixing, ignition, heat release, and combustion, with FSJF as reference. Results collected from these experiments are, for example, the evaporation rates of monodisperse streams of droplets evaporating in different pressure-temperature conditions; auto ignition delay time, laminar flame speed, and product pattern of the combustion, for a wide range of parameters. These data will enable to work also on chemical models to describe these kinds of characteristic combustion properties.

Concerning the engine systems integration, safety aspects of using the selected alternative fuels will be assessed. Any jet fuel will come into contact with a variety of materials both metallic and non-metallic. Hence, some tests are taken care of the fuel's property to act as a hydraulic fluid and as a heat sink in the engine control system. Therefore, static and dynamic tests will be undertaken on the non metallic materials found within the engine. Also, the effect of the fuels on wetted metals found in the engine will be studied. Further investigations are focusing on the hot end materials found in current engines. The main purpose of these hot-end tests is to ensure that no hazardous effect will occur to turbine blades, as a result of some – possible - reactions of combustion products of alternative fuels or from any traces of unknown compounds present. Also, the effect of the alternative fuels thermal stability will be evaluated, for example, on the performance of the control system as well as the propensity of the fuel to form gums and lacquers in the engine fuel injector (polymeric materials).

Concerning aircraft system integration, the selected alternative fuels will be tested on existing fuel systems. Issues are related to: sealing, corrosion, pumping, filtering, water compatibility, microbial contamination, gauging, and permeability, among others. Effects of temperature, altitude, water content/icing on general pumping performance, gravity feed and ice blockage of inlet strainers, will be studied. Further investigations are dealing with a more general material compatibility with fuel in the aircraft.

Concerning safety, standards, and regulations, all the data and experience gained in producing, handling, and testing the alternative fuels will be collected and analyzed with a main focus on safety issues. Then, the potential impact on the regulation and standardisation schemes will be established in an operational manner.

A much shorter version of tests to be done within SP2

The assessment procedure encompasses three main areas:

(i) the operational requirements (full flight envelope),
(ii) the material compatibility (fuel system within aircraft and engine),
(iii) the safety standards.

The first area of investigation is concerned with the fuel injection and combustion processes, which will be experimentally investigated and then modelled. Also, pollutant emissions will be analysed. Models will help perform further investigations based on computations. A second investigation level is related to suitability to engine and aircraft fuel systems. The components that will have been developed within SP1 will be tested with respect to the fuel ducts and seals.

At a third stage, investigation will be dedicated to safety concerns, and the capability to reach a certification level according to commercial aircraft regulations.

This analysis will provide a full insight into the qualification of a given fuel for aircraft application. A certification agreement should be the next step towards operational use.