ALFA-BIRD
Alternative Fuels and Biofuels for Aircraft development

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1 Summary

In July 2008, the ALFA-BIRD (Alternative fuels and biofuels in aviation) program was started. Its main purpose is to develop an ambitious programme on renewable alternative fuels for aviation. The main results obtained so far will be presented.

The fuel selection process – a two steps procedure - is completed, following the protocol agreed in the ALFA-BIRD proposal. The consortium has completed the second step, which consisted in selecting the 3-4 most promising blends of the fuel mixtures considered. This selection is based on the results of tests on the pre-selection of 12 blends (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).

The four fuels selected for the more detailed tests (e.g. focusing on ignition, combustion, evaporation...) are:

(i) FSJF,

(ii) FT-SPK,

(iii) a blend of FT-SPK and 50% naphthenic cut,

(iv) 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 with respect to a short, middle, and long term view of possible alternative fuels.

In the same time, the Alfa-Bird project started the subproject SP3 – Technical analysis and future alternative fuels strategy. The partners are currently defining the methodologies which will be used for the environmental and economical evaluations.

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[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

This note aims to explain the main messages which could be shared during the CAAFI conference and to provide a base of discussion to the advisory group.

First, this note will explain the selection of the fuels which are currently tested, within the timeframe in the 2nd phase of the project. These tests are mainly dedicated to combustion tests: ignition, heat release, combustion, evaporation…

Finally, this note will focus on the Subproject SP3 - Technical synthesis to set new standard requirements for these alternative components - and will explain what the objectives are and how we plan to proceed.

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 constraints in aviation (e.g. safe flight under very cold conditions), and that 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 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 and 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/phases. The consortium has completed the first step in March 2009, 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 Fischer-Tropsch 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.

3.1 The reference fuel: The FSJF from Sasol

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 (fully synthetic jet fuel) 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 an aromatics-containing stream derived from severely hydro-treated 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, compared to Jet A1/A. 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: the raw material (e.g. coal, natural gas, biomass and waste) is broken down at high temperature to basic molecules (CO and H_2 – 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

[5] HVO for Hydro treated Vegetable Oils
[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

and gas, in future it will be developed further 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 should be noticed that SPK has no aromatics (less than 0.5% mass), whereas the ASTM D7655 specifications indicate a minimum of around 8% of aromatics in the final blend (Jet + FT-SPK).

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 performing standard characterization.

Very high-quality diesel (and kerosene) can then be obtained by subsequent hydrocracking of the primary product. A large variety of vegetable oils-including domestic ones, animal fats and cheaper vegetable oils can be processed to yield the same final, high quality product.
Industrial hydrogenation plants are under construction. Neste Oil has developed the NExBTL® Process. In the hydrotreatment conditions, unsaturated fatty chains are hydrogenated. The resulting straight chains, mainly Cl2 to C18, are completely paraffinic. Such fully saturated compounds have excellent cetane index but generally poor cold flow properties compared to corresponding esters, which may require an additional hydroisomerization step.
UOP develops a process of HO made from Jatropha. This process consists of hydrocracking /isomerisation of vegetable oil (~ C9 paraffinic blend). The addition of aromatic compounds is possible in order to adjust the density.
Properties of this product are very similar to synthetic fuels coming from the Fischer-Tropsch process. HVO contains no sulfur, oxygen, nitrogen or aromatics. Heating value is similar to jet fuel, storage stability is good and water solubility is low. The high n-paraffin composition might lead to problems with cold flow properties. However, process is adjusted in order to obtain correct cold flow properties.
HO is a high quality product and presents similar properties compared to jet A1. But cold flow properties and lubricity have to be controlled. Regarding the process, there is a need to check the availability, the investment cost and the dependency of feedstock on oil composition.

It was decided to choose FT-SPK, representing paraffinic compounds, as the selected fuel 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).

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[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.

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). The last point, in particular, was observed within the first phase dedicated to standard characterization with a blend of FT-SPK and 50% of naphtheno-aromatic cut.

Therefore, it seems advisable to explore the potential of this blend (FT-SPK and 50% of naphtheno-aromatic cut) 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 density, 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, higher alcohols are considered to 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, mainly to avoid an important decrease of the energy content. A blend of FT-SPK and 20% hexanol gives promising 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 question arises 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 in different amount (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 studying blends of FT-SPK with 10, 20 and 30% of furans. Nevertheless, ALFA-BIRD will not explore any deeper the use of furans

The characteristics of some furanic were studied, in particular 2,5-dimethyl furan, often called 2,5-DMF and hydroxymethylfurfural, HMF or 5-(Hydroxymethyl)furfural. The molecule that seems to have a potential for aircraft application are 2-(methoxymethyl)tetrahydrofuran and 2,5-bis(methoxymethyl)tetrahydrofuran. In spite of a high density, the boiling point, the cold properties (viscosity at -20°C) and the flash point are in the range of jet fuel.

The main advantages and drawbacks of 5-HMF as a fuel are:

Advantages:

- a high flash point (around 80°C)

- the presence of oxygen can allow a decrease of particulates emissions

Drawbacks:

- The oxygen content of this molecule is higher than ethanol one (35%wt), inducing a very low heating value. Nevertheless, the very high specific gravity of the fuel (1.29) allows to compensate this oxygen content as far as volumic energy content is concerned.

- The presence of oxygen and of an aldehyde function can induce some issues concerning the material compatibility (especially elastomers)

- This molecule has a very high specific gravity (1.29), due to the presence of oxygen leading to the formation of H-bonds in the fuel.

- The melting point of the fuel is very high (around 35°C)

As a consequence, even if some production pathways exist, 5-HMF seems not to be usable as an alternative jet fuel.

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 more detailed investigation within the second step in the selection process.

4 The fuel matrix for SP2 tests

For all of the reasons mentioned above, the Steering Committee has decided, after the consultation of the advisory board, that the following fuels would be tested for the second phase within ALFA-BIRD project, the assessment of the suitability of alternative fuels for aircraft. This selection was 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%)**

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

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

These detailed tests are currently 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 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 are being assessed. Any Jet fuel will come into contact with a variety of materials both metallic and non-metallic. Hence, some tests analysed 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 are being undertaken on the non-metallic materials found within the engine. Also, the effect of the fuels on wetted metals found in the engine is being 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. Besides, the alternative fuels thermal stability is being 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 are being 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 are being 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 are being collected and analysed with a main focus on safety issues. Then, the potential impact on the regulation and standardisation schemes will be established in an operational manner.

5 Subproject 3: Objectives and work plan

This subproject is based on results within subprojects SP1 and SP2, and especially on the fuel market projection. This projection is available in the public deliverable D09 (D1.1.2 Projection of the Fuel Market to the Mid Term) which is available here.

5.1 Objectives of SP3

The main purpose of this sub-project is to provide a synthesis on the alternative fuels that have been developed within SP 1 and SP 2 for aircraft applications.

As the purpose is related to climate change, the main evaluation will be performed considering the environmental impact. The fuel candidates that will have succeeded into the whole selection process described within SP1 and SP2 will be evaluated with respect to environmental concerns. The improvement from standard fuel practices will be assessed, taking account of the whole production – distribution – combustion lifecycle.

Additionally, an economic evaluation will provide some insight into the related costs, and expected availability. As an industrial project should have been considered for this emerging industry, such evaluation will be quantitatively meaningful.

Finally, a technical synthesis, using Life Cycle Analysis, Life Cycle Costing, or Social-Economic Evaluation from ECHA, will also be performed, in order to set new standard requirements for these alternative components.

This global evaluation, combined with the chemical formulations and manufacturing processes developed within the remaining activities, will be the main result of Alfa-Bird: an innovative set of aircraft fuels implying reasonable ownership costs and guaranteeing sustainable aviation.

5.2 Work plan of SP3

5.2.1 WP 3.1: Environmental and energy balance

A complete emissions-related evaluation of the alternative fuels will be performed. The candidates that will have been selected within SP1 and SP2 will be assessed, in a global lifecycle analysis, and considering all the environmental concerns related to air transport (CO_2, NOx, particles, sulphurs, …).

This evaluation includes key parameters such as fuel production and distribution (well-to-tank), combustion within engines (which depends on the components to be burnt), and aircraft mission profile, which sets the weight of any emission on the atmosphere.

Finally, a scenario involving the whole aircraft fleet will be modelled in order to provide a global view of the environmental problem and the impact of alternative fuels.

5.2.2 WP 3.2: Economical evaluation (EU-VRi)

To perform the economical evaluation of the selected fuels, the partners decided to use the SEA method (Social Economical Analysis) provided by ECHA (European Chemicals Agency).

However, with the aim to have more comprehensive conclusions, we are working closely with SWAFEA study (Sustainable Way for Alternative Fuel and Energy in Aviation). The objective of this cooperation is to be able to compare the results from the two projects. To do, two ways are possible: use the same assumptions and the same methods on different fuels or use different methods and assumptions but which are comparable.

This issue will be discussed with SWAFEA partners after the conclusion of SWAFEA.

5.2.3 WP 3.3: Future alternative fuels strategy and implementation

A synthesis of the previous results (with respect to environment and economy), completed by the technical data from SP1 and SP2, will be performed. The risks and benefits will be assessed, and a hierarchy will be established among the set of candidates.

Complementarily, a scenario of implementation will be provided, which could combine some short-term and long-term solutions, with recommendations on the main actions/decisions to be performed, that will set the path to a real applicability of alternative fuels to air transport. This scenario will be elaborated and discussed during a workshop gathering all partners and a selection of experts who are not part of the consortium.

Complementarily, the potential to jointly improve combustion behaviour (low NOx) to greenhouse gases reduction by a combination of new technologies and alternative fuels will be addressed, and related recommendations will be provided that could help to reach the ACARE goals set for 2020.