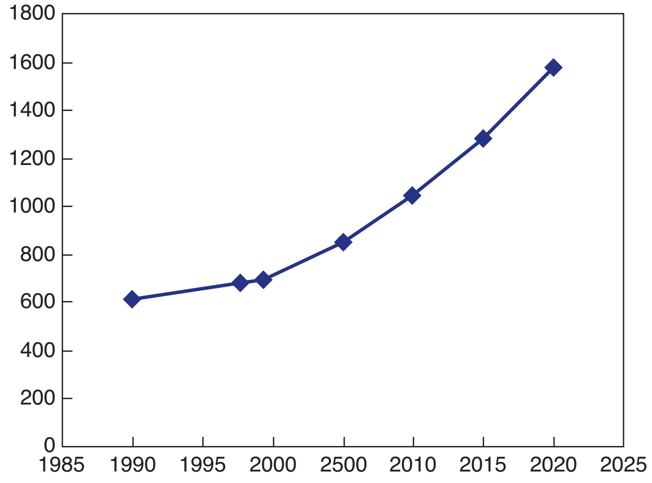
PANORAMA
2009
a look at ...

Aviation and alternative fuels

Several key priorities have been targeted for development in the aviation industry: diversifying energy resources, keeping consumption levels under control and reducing polluting emissions to improve air quality. Like the road transport sector, the air transport sector is mounting a determined effort to reduce the level of its greenhouse gas emissions. Among the various solutions under consideration, alternative fuels are attracting particular attention. However, not all alternative solutions can be exploited, because of the constraints specific to the use of aircraft. A precise assessment should be made of all possible solutions to determine which ones should take preference.

The reduction of greenhouse gas (GHG) emissions is a top objective in the fight against global warming. A major source of emissions, the transport sector and all of its segments, including aviation, must work towards this goal. For the time being, the impact of air transport is not very large: the oil used to produce jet fuel only represents 8% of total consumption. But this is expected to change in future, because air traffic is expected to grow. It has been forecast that world jet fuel consumption will increase by about 60% by 2020 (Figure 1).

Fig. 1 - World jet fuel consumption between now and 2020
(Million liters per day)



Source: US Department of Energy

Moreover, polluting emissions and nuisance levels (*e.g.* NOx, SO_2, soot particles, VOCs and noise) must be very strictly regulated to help preserve the quality of the local environment, including that of urban communities near airports. Today, the only fuels used by the aviation industry are oil-based. Since the oil price is likely to stay high over time and more effective regulation of total GHG emissions has become a global priority, it is imperative to identify, develop and offer alternative energies. Synthetic hydrocarbons and certain biofuels are looking like possible choices. In particular, the latter present a favorable "well to tank" GHG emissions balance. It is predictable that oil demand will eventually outstrip supply, which means that the aviation industry must tackle the technical challenge of adapting to alternative energies. Unlike the road transport sector, aviation still only uses replacement fuels to a very limited—not to say marginal—extent. These fuels are often used experimentally, sometimes in connection with applications for a distant future; in other words, they are still far from industrial application. The aviation sector is subject to major constraints: it must comply with a large number of very stringent safety criteria and may not consider any replacement solution to be satisfactory unless it is fully compliant.

Jet fuel: criteria and constraints

Jet fuel possesses specific characteristics and is subject to specific logistical constraints, among them:

- jet fuel is distributed worldwide to ensure intercontinental air traffic. This means enforcing international quality criteria and taking local production capacity into account. The most widely used quality standards

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are the ASTM D1655 (US) and DEFSTAN 91/91 (UK Ministry of Defence). A number of other specifications also exist, such as DCSEA (France) and GHOST (Russia). To ensure the quality of products distributed worldwide, a number of fuel suppliers developed international specifications in the form of a document entitled "Aviation Fuel Quality Requirements for Jointly Operated Systems" (AFQRJOS), also known as the Check List. It enumerates the most stringent requirements of the DEFSTAN specifications.

Since jet fuel is distributed globally, local production capacity is also a factor. Product quality requirements must be met in all countries, even in those where refinery installations are not best suited for the production of jet fuel. This criterion will be vital in the selection alternative fuels, because it must be possible to produce fuels of constant quality worldwide,

- aircraft have a long life expectancy (more than 30 years, on average). Alternative fuels must be compatible with existing fuels and not require any fundamental change to engine or aircraft architecture,
- criteria relative to the overall safety and reliability of key engines. To ensure flight safety and reduce the risk of incidents, each element of the aircraft should be subjected to a series of tests before being certified. This is also true of the jet fuel which must, by undergoing a complex certification procedure, show full compatibility with all engine parts and any materials that come into contact with the fuel (from supply and distribution to combustion),
- conditions of use vary widely, placing great constraints on the use of jet fuel. Temperatures range from about –60°C (at very high altitude) to nearly +50°C (when the aircraft is parked on the taxiway). The pressure level varies, too, from atmospheric pressure on the ground to about 0.3 bar at high altitude. Also, the low heating value must be managed with very great accuracy.

Jet fuels must meet a number of quality criteria, including the following (Table 1):

- flash point: This is the temperature above which the fuel is likely to ignite in the presence of a flame. It is a critical factor in aviation safety. Knowing the flash point, one can ensure that fuel vapors cannot ignite, for instance, in the presence of a charge of static electricity inside fuel tanks. For Jet A-1, the flash point should be greater than 38°C[1],
- cold resistance properties: Fuel pumpability should be preserved even at the extreme temperatures encountered at high altitude. A fuel's resistance to cold is strictly monitored. It is characterized by its freezing point (maximum for Jet A-1: –47°C[1])—and by its viscosity at –20°C (maximum: 8 mm^2/s[1]),
- thermal stability: Aircraft weight is key to fuel consumption. To avoid taking on extra weight in the form of additional fluids, aviation fuel usually serves as a heat transfer fluid and a coolant. Fuel is subject to particularly severe heating and cooling cycles with respect to thermal stability and oxidation. Fuel oxidation could cause deposits and varnish to form, which in turn could cause engine failure. The specification test method used to measure this parameter is known as the Jet Fuel Thermal Oxidation Tester (JFTOT). The jet fuel is sent through a tube at a given temperature 260°C[1] and the tube is assessed visually (color) and as a function of the head loss caused by deposits, if any (lower than 25 mmHg[1]),
- low heating value: This represents the amount of energy liberated per unit mass of jet fuel at combustion. It is a critical parameter with a direct impact on aircraft range. It should be higher than 42.8 MJ/kg[1],
- additives: The use of jet fuel additives is strictly regulated. They must first undergo tests to certify that they offer the desired efficiency and do not have any negative impact on the safety, durability or performance of the aero-engine or any aircraft components. The specifications clearly indicate the type of additive to use, the references of certified additives and the percentage concentration.

Tableau 1

The most common requirements for Jet A-1 as per DEFSTAN 91/91

	Jet A1
Flash point	38°C min
Crystallization (freeze) point	–47°C max
Viscosity at –20°C	8 mm^2/s max
Low calorific value	42.8 MJ/kg min

There are other constraints as well. Some are environmental, relative to GHG emissions and polluting emissions such as NOx or particulates, and others are economic in nature (*e.g.* the cost of alternative fuels and the competition with land-based modes of transport).

Methods of formulating alternative fuels

The object of many studies, already carried out or still underway, is to ascertain which alternative fuels have potential and characterize them. Until now, most

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(1) As per the DEFSTAN 91/91 specification, Issue 6.

research has borne on land-based modes of transport. The following alternative fuels have been identified:

- synthetic hydrocarbons of the GtL[2]or CtL[3] type obtained using the Fischer-Tropsch process,
- first-generation biofuels, including ethanol derived from sugar- or starch-producing plants and biodiesel derived from the transesterification of vegetable oils (fatty acid esters). The production processes for these products have reached maturity,
- biofuels yielded by the intensive hydrotreatment of vegetable oils, which can come from very different sources, or animal oils. These fuels are primarily composed of hydrocarbons whose properties close to those of GtL. Processes already exist or have reached an advanced stage of development, but researchers are also exploring various other resources that could be used to supply this pathway. Algae, which produce lipids, may be a possible new source of fatty acids suitable for conversion into biodiesel or hydrotreatment,
- second-generation biofuels produced from wood or vegetable waste, via two processes. One is a biochemical process that yields ethanol. The other is a thermochemical conversion process known as BtL ("biomass to liquids") used to obtain hydrocarbons comparable to GtL and CtL,
- molecules originating in biomass chemistry, including derivatives of succinic acid and levulinic acid as well as furan molecules,
- natural gas and hydrogen.

However, alternative fuels were originally developed for land-based transport and incorporating them directly into aviation fuels raises a number of problems:

- biodiesels show interesting potential as far as availability is concerned, but fail to meet several jet fuel specification requirements, especially regarding energy content, density and cold resistance (Table 2). Oxidative stability is also a problem, owing to the degree of unsaturation within the molecules in biodiesel. The product could be optimized by carefully selecting (oil-type) feedstocks with the most favorable characteristics in terms of chain length and degree of unsaturation. In addition, product purity must be guaranteed to avoid any risk of contamination, which could adversely affect the flash point of the product,
- both XtL[5] and hydrotreated vegetable oil (HVO) molecules offer high potential as far as energy content is concerned (Table 3), but research still needs to be done on density and cold resistance properties to optimize the chain length and branching rate. The choice of feedstock is also key to obtaining a favorable environmental balance (total GHG emissions over the entire life cycle of the product).

Tableau 2

Density, distillation and low calorific value: Jet A-1 versus VOMEs[4]

	Jet A-1	Rapeseed oil methyl ester	Soybean oil methyl ester
Density (kg/l)	0.775-0.840	0.885	0.883
Distillation (°C)	200-300	320-350	300-350
Low calorific value (MJ/kg)	42.8 min	37.3	37

Tableau 3

Density and low calorific value: Jet A-1 versus XtL

	Jet A-1	XtL
Density (kg/l)	0.775-0.840	0.775-0.785
Low calorific value (MJ/kg)	42.8 min	≈ 44

- the advantage of ethanol is that it can be produced in large quantities on a global scale by means of first - or second-generation processes. But its flash point and energy content make it unsuitable for use in aircraft ensuring medium- or long-distance flights (Table 4). However, avenues of research are opening up to explore the potential of longer-chain alcohols that can feature branching to optimize the trade-off between cold-flow properties, flash point and energy content.

Tableau 4

Flash point and low calorific value: Jet A-1 versus ethanol

	Jet A1	Ethanol
Flash point (°C)	38 min	9
Low calorific value (MJ/kg)	42.8 min	26.8

In the medium term, the biofuel pathways most likely to supply base oils for the formulation of jet fuels are BtLs and products obtained through the intensive hydrotreatment of vegetable oils (Table 5). These pathways yield paraffinic hydrocarbons containing no aromatics or sulfur

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[2] GtL: Gas to liquids, hydrocarbons obtained from natural gas through Fischer-Tropsch synthesis.

[3] CtL: Coal to liquids, hydrocarbons obtained from coal through Fischer-Tropsch synthesis.

[4] D. Ballerini, Les biocarburants – État des lieux, perspectives et enjeux du développement, Éditions Technip, 2006.

[5] The term XtL designates all synfuels obtained using the Fischer-Tropsch process, including CtL (coal to liquid), GtL (gas to liquid) and BtL (biomass to liquid).

which, after a hydroisomerization step, could be blended with conventional jet fuels or used pure, provided that their formulas are optimized with respect to key criteria such as lubricity, cold resistance and compatibility with materials.

Energies like natural gas and hydrogen will be candidates for use in a more distant future. This will entail a complete overhaul of basic aircraft design as well as the procurement, distribution, logistics and safety of jet fuels. A great deal of research will be called for. One project, the Cryoplane Project, has been undertaken to assess the technical feasibility, safety, environmental compatibility and economic viability of using liquid hydrogen as an aviation fuel. Coordinated by EADS Airbus and funded by the European Commission, it will probably take more than 20 years of research and development to bring the technology to maturity. Other solutions (*e.g.* heavy alcohols or fuels obtained by biomass chemistry) may also have long-term or specific applications.

Tableau 5

Alternative fuels and their potential for aviation applications.
Green: Similar to Jet A-1. Orange: Needs to be optimized.
Red: Does not comply with the parameters specified for Jet A-1)

	Biodiesel	XtL or HVO	Ethanol
Oxidative stability	🟥	🟩	🟩
Cold resistance	🟥	🟧	🟩
Low calorific value	🟥	🟩	🟥
Flash point	🟩	🟩	🟥
Density	🟥	🟧	🟩

Research and demonstration projects underway or planned

A number of research programs, along with a few demonstration projects, have been launched in different countries to study alternative aviation fuels. In France, industrial partners like Airbus and Snecma have teamed up with research laboratories (IFP, Onera, Cerfacs, LCSR-CNRS, Insa-LBB, LMGM and MMP) on the Calin Project, seeking to find ways to optimize operation of new low-NOx injection systems. At European level, the Alfa-Bird program, set up under the Seventh Framework Programme for research and technological development (FP7), will study the impact of new fuels on how aircraft turbines operate, including fuel properties, compatibility with materials, and combustion). Again, industrial firms (*e.g.* Airbus, Snecma, Shell and Rolls-Royce) have joined forces with research laboratories (*e.g.* IFP, Onera, DLR and CNRS). Another FP7 project, Dream, aims to design, integrate and validate new engine concepts based on open rotor contra-rotating architectures. Dream also calls for the demonstration of selected alternative fuels in aero-engines.

All over the world, initiatives are underway. In 2005, the Commercial Aviation Alternative Fuels Initiative started in the United States. In 2006, the IATA set up a task force on alternative fuels (AFTF). At home, the French Civil Aviation Authority (DGAC) is overseeing the *Futurs Carburants Aéronautiques* initiative. A number of ground and flight demonstrations have taken place: Snecma tested a 30% VOME fuel in a CFM58 engine; Airbus ran a test flight in which one engine of an Airbus A380 ran on a 40% GtL fuel; and Air New Zealand and Continental Airlines recently carried out further demonstrations. In addition, the South African company Sasol obtained certification for a semi-synthetic jet fuel containing 50% Jet A-1 and 50% CtL then, in April 2008, for a fully synthetic jet fuel.

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Final draft submitted in January 2008