

# THE AHEAD PROJECT

## Advanced Hybrid Engines for Aircraft Development



**Aviation is an ever-increasing market and more passengers and cargo are carried each year. The world is becoming ever more connected. However, this does come at a price: aviation has a marked influence on the environment. If aviation is to thrive in the future, breakthroughs in aircraft design and propulsion systems are needed. The AHEAD project is an attempt at achieving such a breakthrough.**

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### CHALLENGES FACED BY AVIATION

Commercial aviation has made substantial progress since its inception and is now the backbone of a modern society. In the past ten years, passenger numbers have grown by 45% and freight traffic has increased by more than 80% on a tonne-kilometre basis [1]. Moreover, aircraft emissions have reduced significantly over the last forty years, for example, noise has reduced by 20 decibels, fuel consumption by 70%, carbon monoxide emissions by 50% and unburned hydrocarbon and smoke by 90% [1]. Despite all these positive developments, some serious challenges toward the environment, the community and the availability of fuel resources are encountered by aviation. The total emissions from the aviation sector are still increasing rapidly and now the sector is an active contributor to global warming. Therefore, the Advisory Committee for

Research in Aeronautics (ACARE) has targeted the reduction on various fronts of noise, air pollution and fuel consumption. The ACARE goal is shown in Figure 1. It aims to reduce CO<sub>2</sub> emissions by 75%, NO<sub>x</sub> emissions by 90% and the perceived noise levels by half in the year 2050, compared to the baseline year 2000 [2]. To achieve this objective, a combined improvement in the aircraft, power plant and the air traffic management system is required.

As is known, the reduction of NO<sub>x</sub> emission mostly depends on the evolution of combustion technology. However, CO<sub>2</sub> emission is the product of chemical reactions between the carbon content of the fuel and air: as long as conventional fuel is in use, the ACARE goal to reduce CO<sub>2</sub> emission remains difficult. To achieve this target, alternative fuels have been put forward. A scenario of future aviation fuels are indicated in Figure 2. It is anticipated

that aviation will see a significant use of alternative fuels, starting with synthetic fuels such as Gas To Liquid (GTL), Coal To Liquid (CTL) and biofuels. In a few decades, hydrogen or hydrogen-rich fuels, such as Liquid Natural Gas (LNG) can probably be used to reduce the carbon footprint of aviation for long range aircraft. By the end of this century, we might have the technologies in place for powering an aircraft electrically.

Due to its much higher energy density than kerosene, hydrogen can reduce the amount of fuel which needs to be carried onboard. Moreover, as a type of non-carbon fuel, burning hydrogen will be able to reduce the CO<sub>2</sub> emission significantly, which makes it very attractive. Some efforts have been made to prove the feasibility of implementing the hydrogen in aviation. The "Cryoplane" concept under the 5<sup>th</sup> Framework Program of the Euro-

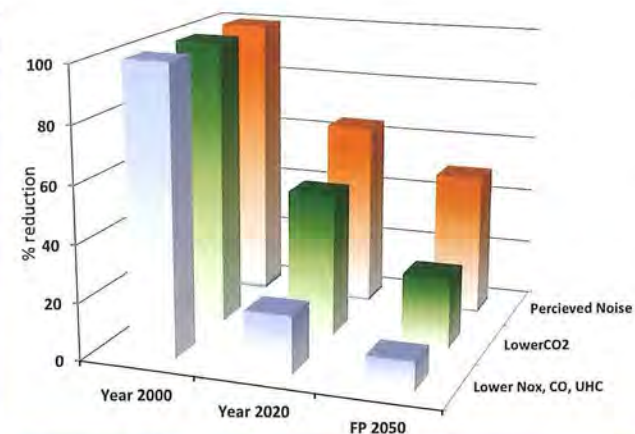


Figure 1. ACARE vision for Europe

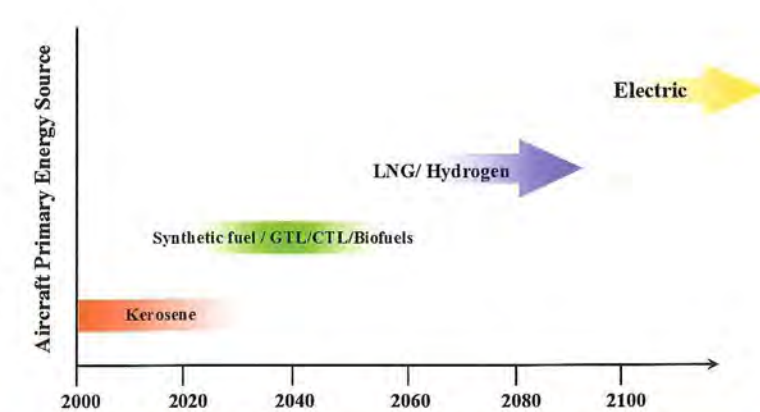


Figure 2. Primary energy source for long range aircraft

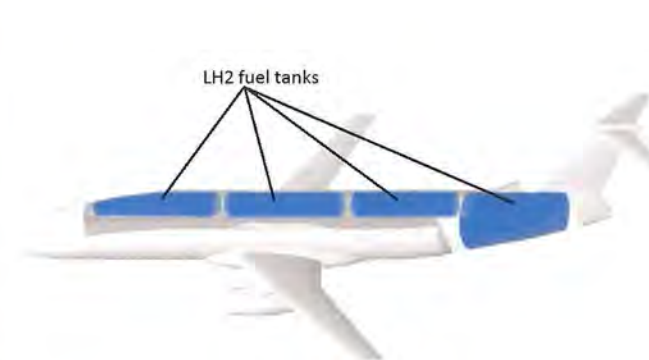


Figure 3. LH2 tank storage scheme of "Cryoplane" project

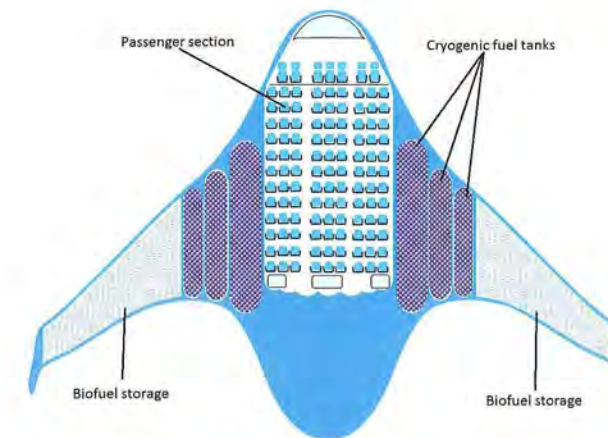


Figure 4. A futuristic BWB aircraft layout with LH2 and biofuel tanks

pean Commission is one of the examples. Conventionally, fuel is stored in the wings of an aircraft. However, the liquid hydrogen (LH<sub>2</sub>) has to be stored in pressurized cryogenic cylindrical tanks, which do not fit in the wings. Therefore, the fuselage was considered to accommodate the fuel tanks in the "Cryoplane", as indicated in Figure 3 [3]. Although the fuel tanks are accommodated, this configuration is not so suitable from a passenger comfort, safety and aerodynamics point of view.

### THE MULTI-FUEL BLENDED WING BODY AIRCRAFT

To summarize, according to the current research efforts based on current technologies, there seems to be a very little chance to meet the ACARE goals and therefore breakthrough technology is needed. During the past years, an innovative Blended Wing Body (BWB) configuration has been studied by many researchers around the world, including the "CleanEra" group from TU Delft, and it seems to be a promising candidate to replace the existing aircrafts. Instead of a separate fuselage with wings, an integration of body and wing is used for the BWB [4]. This results in a larger amount of space available within the aircraft, thus making it possible to carry cylindrical fuel tanks to store the

cryogenic fuel.

A novel way to overcome the storage problems of hydrogen is a multi-fuel BWB aircraft presented in Figure 4. The wings of a BWB have sufficient room for storing LH<sub>2</sub> tanks, without interfering with the passenger section. Further away from the central line, where wing thickness is reduced, liquid biofuel can be stored. Thus, a multi-fuel BWB concept with a combination of biofuel and cryogenic fuel is proposed and investigated by the "AHEAD" project sponsored under the 7<sup>th</sup> Framework of EU.

### THE HYBRID ENGINE

To power the multi-fuel BWB aircraft, a new type of propulsion system—called the hybrid engine—has been conceived, which is able to meet the requirements of the multi-fuel BWB aircraft. The novel features of this engine and its schematic are shown in Figure 5.

The novel engine proposed is quite different than a conventional turbofan and includes many breakthrough technologies. The various novel technologies involved in the proposed engine configuration are described as follows.

**Boundary Layer Ingestion (BLI):** this is

a method of increasing the propulsive efficiency of the engine by embedding the engine within the airframe such that the engine can ingest the low velocity boundary layer flow of the aircraft, reducing the engine ram drag. Also, the jet of the engine contributes to aircraft "wake filling", thus reducing the overall dissipation.

**Counter-Rotating Fans (CRF):** The aircraft-engine integration of future BWB aircraft presents unique challenges due to BLI. Such configurations also require that engines be smaller in diameter to reduce the nacelle-wetted area. Thus, it can be seen that the current trend of increasing bypass ratio and diameter of engines will not be able to meet the requirements of future BWB class of aircraft. The proposed hybrid engine with counter-rotating fans has a smaller diameter and higher propulsive efficiency for the same bypass ratio. Furthermore, since each stage of the fan is less loaded than a single stage fan, a CRF engine can sustain more non-uniformities in the flow generated due to BLI compared to a conventional architecture.

**Bleed Cooling:** With increasing pressure ratio, the temperature of bleed air (the air that is used for cooling the hot section components like the turbine blades and



vanes) increases, leading to the increase of the amount of bleed air required for the hot components cooling. This increase has an adverse effect on the thermodynamics of the gas turbine engine, reducing the efficiency of the cycle. The cryogenic fuel used in the proposed hybrid engine is an excellent heat sink, which can be used for cooling the bleed air, thus reducing the amount of bleed air required. Meanwhile, the temperature of the cryogenic fuels is increased, which reduces the use of combustion heat to increase its temperature, resulting in less fuel consumption for a given temperature within the combustion chamber.

### The Hybrid Dual Combustion System:

The proposed innovative hybrid engine uses two combustion chambers as shown in Figure 5. The main combustor operates on LH<sub>2</sub>/LNG while the second combustor (between the high pressure turbine and the low pressure turbine) uses biofuel in the *flameless combustion* mode. Such a novel combustion system has never been used before for aero-engines. There are several advantages of this unique layout. Firstly, since the flammability limits of hydrogen/methane are wider than kerosene, the combustion can take place at lean conditions, thus reducing NO<sub>x</sub> emissions significantly compared to a conventional kerosene combustor. Secondly, the LH<sub>2</sub> used for the first combustor can be used for cooling the bleed air, as mentioned in the previous section. Moreover, using LH<sub>2</sub> in the first combustion chamber will increase the concentration of water vapor and reduce the concentration of O<sub>2</sub> in the second combustion chamber, thus creating a vitiated environment in which flameless combustion can be sustained. The implementation of the flameless combustion can minimize the emission of CO, NO<sub>x</sub>, UHC and soot. Additionally, the reduced emission of soot and unburned hydrocarbon also reduces the amount of nucleation centers available for condensation of water vapor in the plume, thus reducing contrail formation.

### RESULTS AND CONCLUSIONS

The "AHEAD" BWB aircraft is an environmentally friendly aircraft burning cryogenic fuels (like LNG/LH<sub>2</sub>) and biofuels. It is preliminarily designed for carrying around 300 passengers over a 14,000km range. The comparison of the layout of the BWB to the Boeing 777-200ER is provided in Figure 6. The shorter and wider body of the aircraft makes it more aerodynamical-

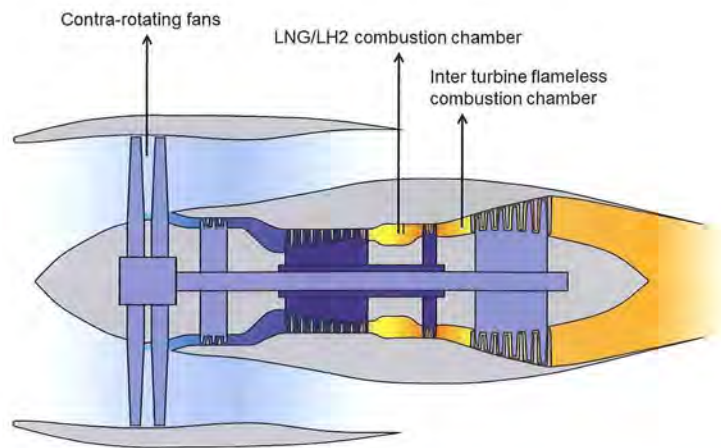


Figure 5. Schematic of the Hybrid Engine



Figure 6. Comparison of the BWB with a Boeing 777-200ER

ly efficient than a conventional cylindrical body aircraft. Combined with the advanced hybrid engine, the multi-fuel BWB is able to reduce CO<sub>2</sub> emission by around 65% compared to a conventional Boeing 777-200ER aircraft.

To conclude, if civil aviation is to maintain its growth, radical changes in the aircraft and propulsion systems are required. The proposed multi-fuel BWB aircraft utilizing a hybrid turbofan engine has the potential to reduce CO<sub>2</sub>, NO<sub>x</sub> and noise emissions substantially. ✕

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