AHEAD: A research project on advanced hybrid engines for aircraft development

An intermediate report

Ad de Graaff[1] and Arvind G. Rao[2],
AD Cuenta (ADC) and Technical University Delft

AHEAD is a research project sponsored by the European Commission. Partners are AD Cuenta, TU Berlin, Delft University of Technology. DLR German Aerospace Center, WSK PZL-Rzeszow, Israel Institute of technology-Technion

Abstract. This paper focuses on the intermediate results of the EC sponsored AHEAD project (Advanced Hybrid Engines for Aircraft development). The project investigates the possibilities to develop an aircraft and hybrid engines for the future with very low CO2 and NOx emissions to achieve the target for 50% less CO2 emissions in 2050 compared to 2005 as set by IATA. The project is focusing on a hybrid engine that will burn both LNG or LH2 and traditional bio fuels.

Keywords. Air transport, future aero engines, future aircraft configurations, environment, CO2

Introduction

Aviation will face some very exiting challenges in the future. One aspect will be the need to reduce emissions as air transport demand is growing. The other may be the shortage and pricing of aviation fuel. In order to satisfy the needs in the longer term future, radical new approaches are needed to cope with these challenges and to satisfy future needs. Current aero engines are well developed and incremental improvements will not be sufficient to respond to the challenges that lay ahead.

Based on initial ideas developed by Dr. Arvind Rao of Delft Technical University, the research project AHEAD was initiated and supported by the European Commission. The consortium started the project in October 2011 and the duration is 3 years. This report provides insight of preliminary results achieved midway the project.

[1] E-mail: adgraaff@hetnet.nl: 2 E-mail: A.GangoliRao@tudelft.nl

1. Setting the scene

Although the contribution by air transport to manmade CO2 emissions is a very modest 2%, it received a large amount of attention both in the political and the public domain. This is especially valid as aviation is predicted to grow at a rate of 5% per year in the coming decades, whilst other transport modes are converting to electrical energy and other non-oil based fuels. The European Commission has set stringent targets for future CO2 emissions in Europe. Besides the European Commission is very much concerned over the availability and accessibility of fossil fuels in future.

In a response IATA has set a target for CO2 reduction for 2050 at 50% of the CO2 emissions in 2005 despite a global growth of aviation of 5% annually. It is obvious that improved operations, novel traditional technology and the use of synthetic and bio-fuels will not enable the target to be reached. Improved and more efficient operations like the joint use of military airspace and improved Air traffic management can contribute a few percent for improvement. IATA's own analysis shows that technology improvements currently under investigation can contribute another few percent whilst bio-fuels are not substantially cleaner than kerosene and the production capacity of biofuels is rather limited as food production should not be endangered.

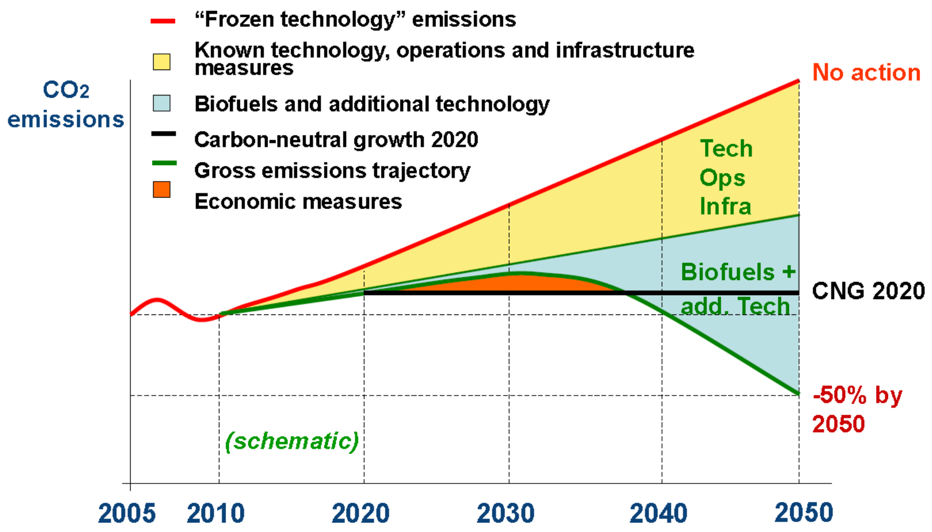


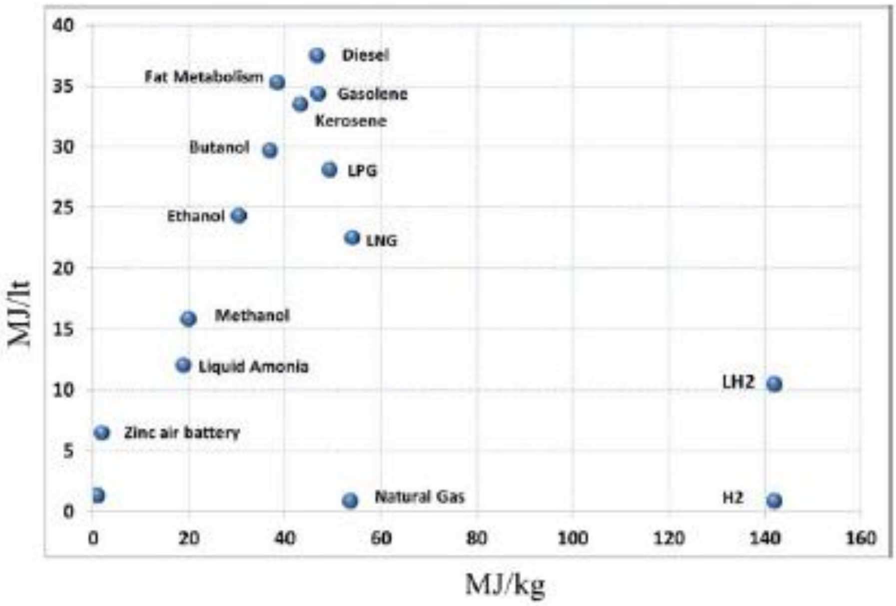
Figure 1. The IATA target (source IATA)

If the aviation sector wants to comply with the target set, something radical needs to be done. Existing fuels and technology improvements will be insufficient.
As a consequence the AHEAD project looked at alternative fuel for the long term future. Both Liquid Hydrogen and Liquid Natural Gas seem the most promising alternative fuels. Although LNG is still a fossil fuel, large reserves still exist enabling a decade of energy to the world.

The mass energy density of Hydrogen (LH2) is much higher than kerosene, so less fuel is needed. But the volume is much higher and the liquid has to be cooled.
The mass density of LNG is slightly better than kerosene but is also requires special low temperature storage tanks.

Figure 2. The mass energy density (Source TUD)

2. Future aircraft



Already some studies have been done on the integration of large storage tanks for LNG and LH2 on aircraft. These were based on the traditional lay out of aircraft and the proposed solutions would increase drag substantially.

Figure 3. Configuration with tanks above the cabin (Out of the Box project)

The AHEAD project proposed a Blended Wing Body aircraft configuration where the storage tanks can easily be integrated without creating extra drag. The tanks cannot be integrated in the wings. Therefore it was agreed that the wetted area of the wings would hold traditional (bio) fuel. This would create an opportunity to develop a hybrid engine that can use both traditional fuel and LNG or LH2.

TU Delft provided a design for a BWB aircraft with a slender wing that is in the same class as the Boeing B 777 and the Airbus A 340.

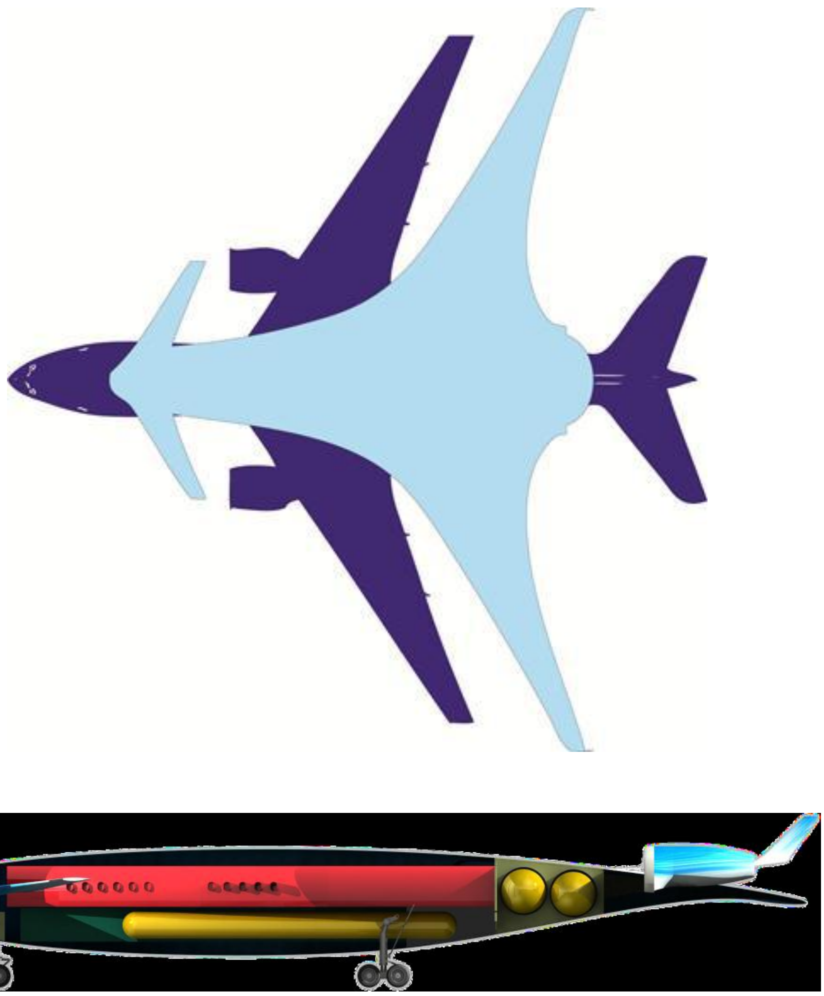


Figure 4 The basic configuration (source TUD)

The aircraft would be equipped with 3 storage tanks. A high percentage of the primary structure would be made of Carbon Fibre Reinforced Polymer. Stability would be assisted by canards and winglets. The control would be achieved by elevons, winglet rudders and variable chamber canard wings. Lift over drag is estimated as 24.2.

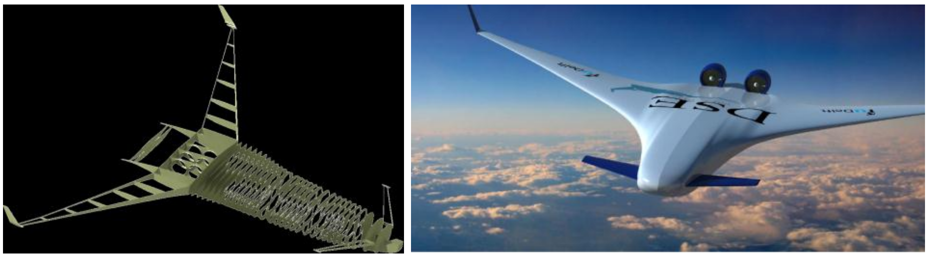
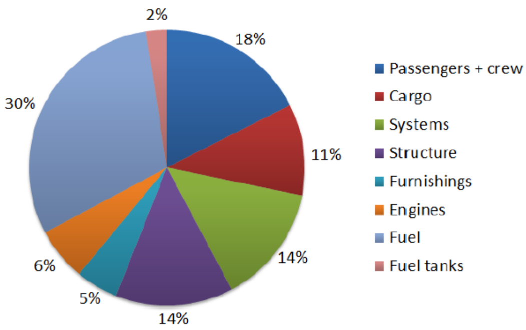


Figure 5 The aircraft layout (source TUD)

The initial weight breakdown is illustrated below (source TUD):

Preliminary design

Results – Weight breakdown



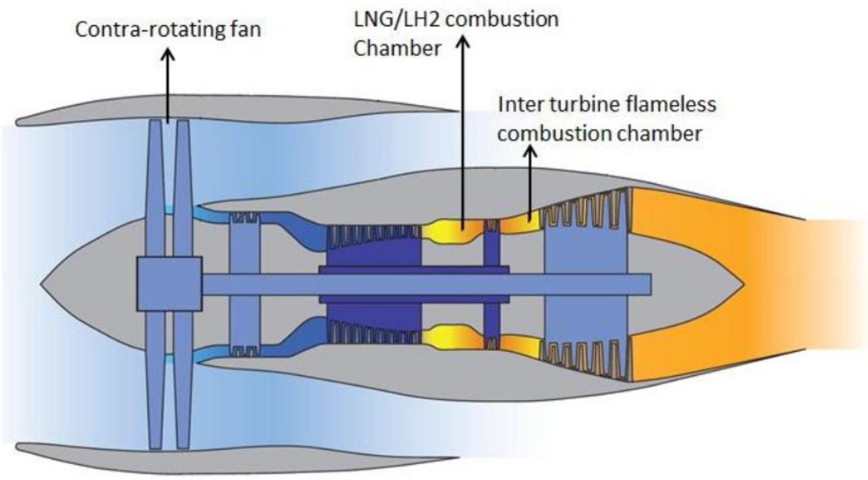
	New-BWB
Wo	242,800 kg
MTOW	237,970 kg
OEW	122,220 kg
W/S	265.04
$(T/W)_{TO}$	0.21
T_{TO}	527,810 N
T_{cruise}	98,195 N

3. The hybrid engine

One of the current trends in engine design is to increase the bypass ratio. The disadvantage is that the drag of shrouded engines is increasing accordingly. In case unducted fans are used, the noise generated by these so-called propfans may become a real problem. Ultra high bypass ratio engines may not be well suited for BWB aircraft as the turbulent boundary layer may damage the large fans of the engine.

Although no final decision has been made on the exact engine location of the proposed aircraft (buried, recessed or mounted on pylons), the idea was to create an engine that would have a relatively small diameter to reduce the installation penalty and to make the fans as strong as possible. It is proposed to have 2 counter rotating fans that are shrouded.
The engine would have 2 combustion chambers in tandem: one main combustor for LNG or LH2 and a second combustor to burn kerosene or biofuels. In order to reduce the CO2 and NOx emissions as much as possible the second combustor will use flameless combustion techniques.

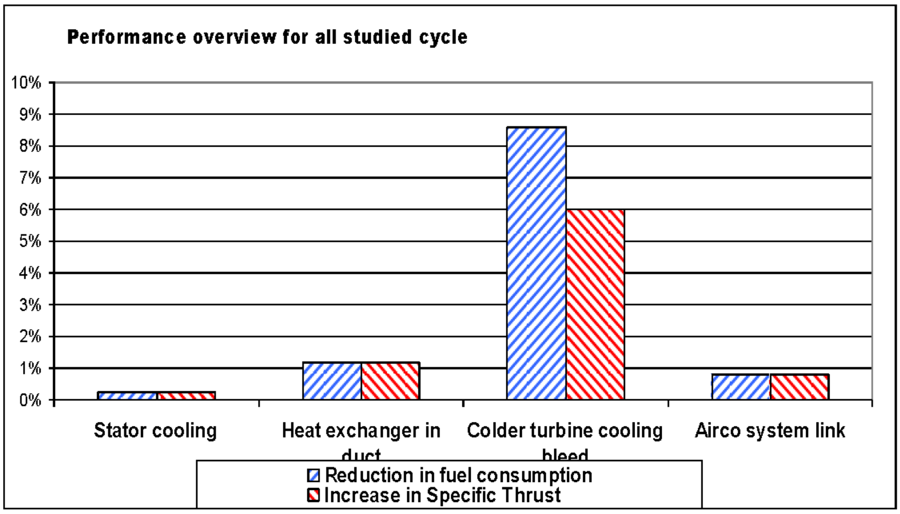
The schematic layout of the engine is shown below (Source AHEAD project):



4. The bleed cooling system

The objective of the engine design is to reduce fuel and to increase specific thrust. The best way to improve the thermal efficiency of the turbofan engine is to cool the bleed air using cryogenic fuel. The theoretical analysis shows the substantial benefits that can be achieved.

Figure 6 The effect of using Hydrogen as a heat sink mechanism (Source TUD)



Project partner WSK PZL Rzeszow provided the preliminary design of the envisaged heat exchanger. The design of the hybrid engine was defined based on existing engine geometry development. Designed heat exchanger assembly was proposed and placed on the engine housing within nacelle compartment. The solution seems to be very promising and a patent may even result from the project (ongoing patentability study).

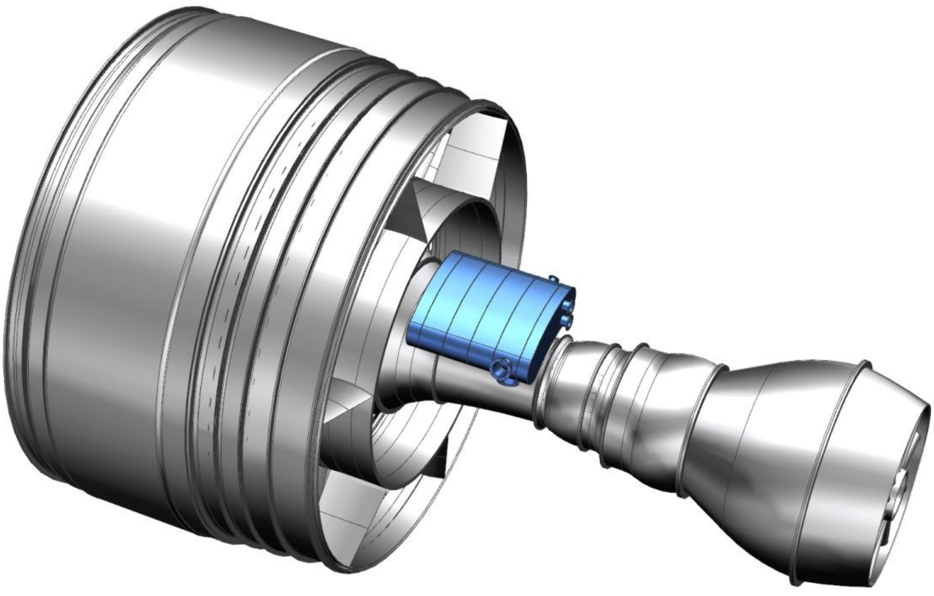


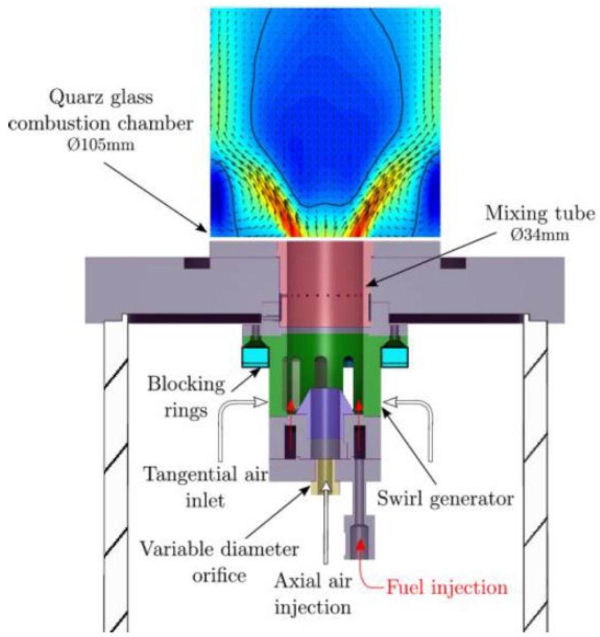
Figure 7 Hybrid engine 3D mock-up with basic model of the heat exchanger (Source WSK PZL Rzeszow).

5. The first combustion chamber

Lean premixed combustion allows for fuel-efficient, low emission combustion and is state of the art in stationary gas turbines. In the long term, it is also a promising approach for aero engines, when safety issues like flame flashback in the premixer can be overcome.

Premixed combustion is chosen as the preferred combustion mode since it exhibits much lower flame temperatures in comparison to diffusion flames and, hence, offers the potential for very low NOx emissions. Evaluating lean hydrogen combustion concepts for aero engines (Ziemann 1998) from preliminary tests indicated the low NOx potential of a premixed swirl-stabilized burner. Swirl is imposed on the flow to allow for sufficient mixing and to create a central recirculation zone which provides for recirculation of hot gases and hence flame stability (Gupta et al. 1984).

Figure 8: Schematic of burner configuration employing axial air injection (Source TU Berlin)



Applying aerodynamic, swirl-induced, vortex breakdown flame stabilization takes away the necessity of a bluff body or centre body which would potentially suffer from material degradation due to the high flame temperatures of hydrogen flames. Accordingly, in the current study, a cylindrical mixing tube without centre body is used in order to further enhance mixing. The swirling flow downstream of a mixing tube or nozzle exhibits a flow field with a recirculation zone, whose vortex breakdown under most conditions is situated just at or upstream of the nozzle exit (Burmberger et al. 2006 and Figure 4a).

Mayer et al. (Mayer et al. 2012) showed that without further effort such a flow field is prone to combustion induced flashback for high reactivity fuels.
TU Berlin applies axial air injection in a swirl-stabilized burner in order to achieve a flow field that allows for flashback-proof combustion of premixed hydrogen. This is realized by introducing a non-swirling jet on the central axis of the radial swirl generator which reduces the deficit in axial velocity and influences the location of vortex breakdown.

Excellent agreement is achieved according to the Particle Image Velocimetry (PIV) investigation of the isothermal flow field in a water tunnel and an atmospheric combustion test rig. Subsequent atmospheric re-acting tests reveal changes in the flow field due to the additional fuel momentum and the acceleration over the flame front. However, the positive effects of axial air injection are observed to be maintained in the presence of a flame. Moreover, the fuel momentum is indicated to positively influence flashback resistance. Accordingly, flashback-proof operation of the burner with axial injection at inlet temperatures up to 620K and up to stoichiometric conditions is verified by images, evidencing the flame to remain anchored in the combustion chamber.

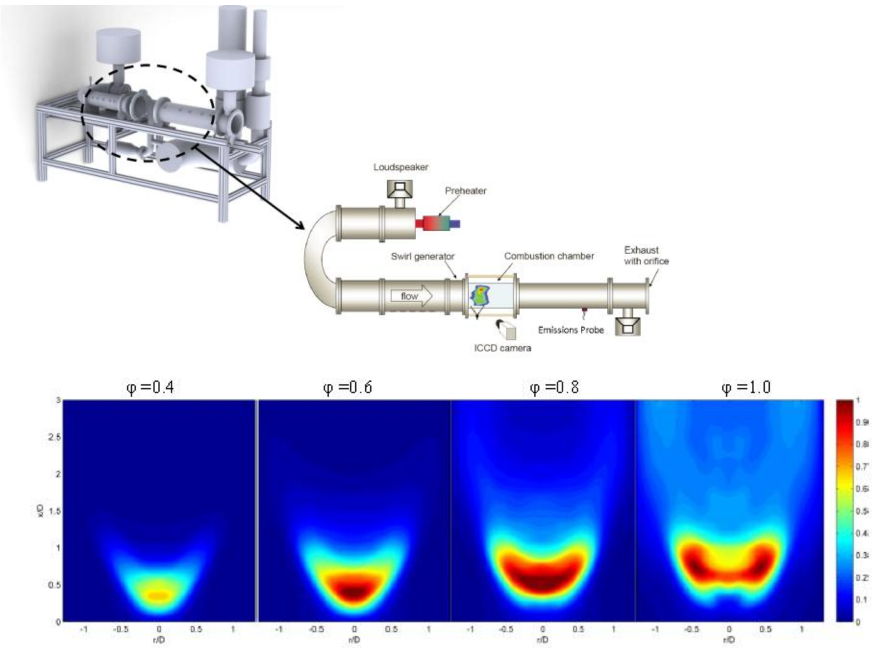


Figure 9: Abel-deconvoluted time-averaged OH* images normalized by maximum intensity of φ=1, indicating location of heat release. Images recorded at a mass flow of 180 kg/h and an inlet temperature of 620 K for configuration with long mixing tube and high swirl. (Source TU Berlin)

6. The second combustion chamber

The aim of this part of the AHEAD project is to design and validate a flameless combustor. The design is the responsibility of Technion whilst the validation will take place at IST in Spain.

The flameless combustion allows the recirculation of combustion products at high temperatures, with reduced oxygen concentrations in the reactants. The combustion allows for a highly transparent flame, a uniform temperature distribution and low NOx and CO2 emissions.

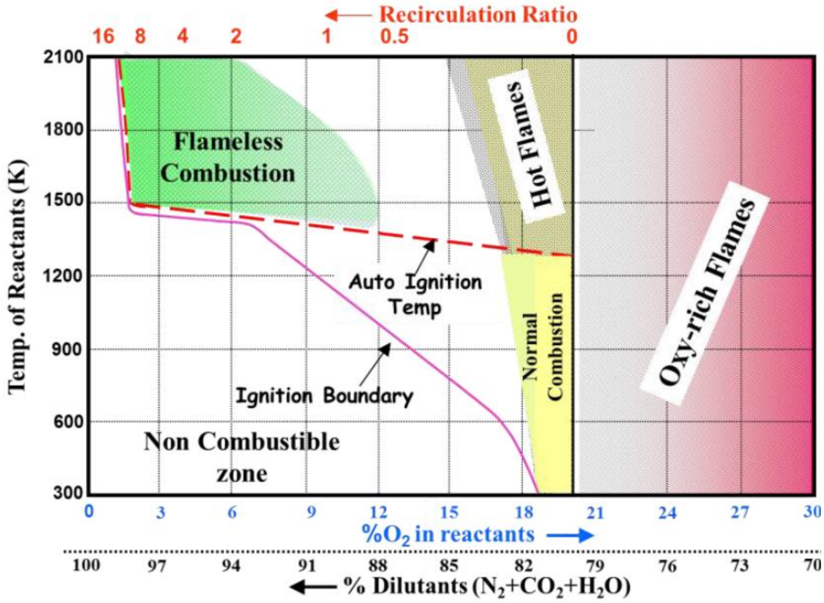
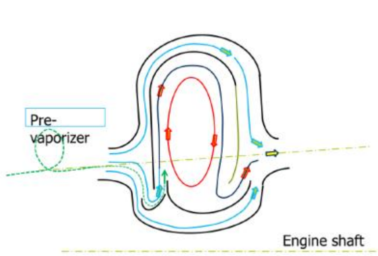
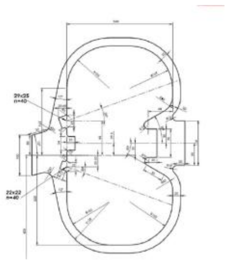


Figure 10 The principle of flameless combustion (Source Technion)

Several designs have been evaluated by Technion and two designs are being further investigated. Design examples:





This will result in tests to validate the designs. In the near future tests will be conducted in Spain.

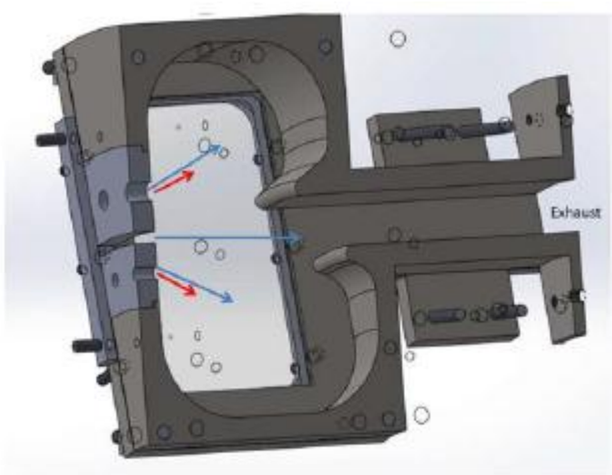


Figure 11: Side view of test article showing air (blue) and fuel(red) inlets, upper and lower cavities and the exhaust.

7. Engine integration

The project will investigate the actual incorporation of the second combustor in a current generation engine. If the volume is not sufficient, design recommendations will be prepared.

8. Expected performance

TUDelft will estimate the benefits of the alternative engine compared to existing engines. It was realized that these engines are representing the current generation and that further comparison is needed with engines that are currently under development, in order to understand the real benefits of the novel hybrid engine. It was also realized that the general performance estimates are very conservative in terms of Specific Fuel Consumption and that
Further improvements are likely.

TU Delft will estimate the performance of the envisaged engine using a model available in the Netherlands the so called GSP model..

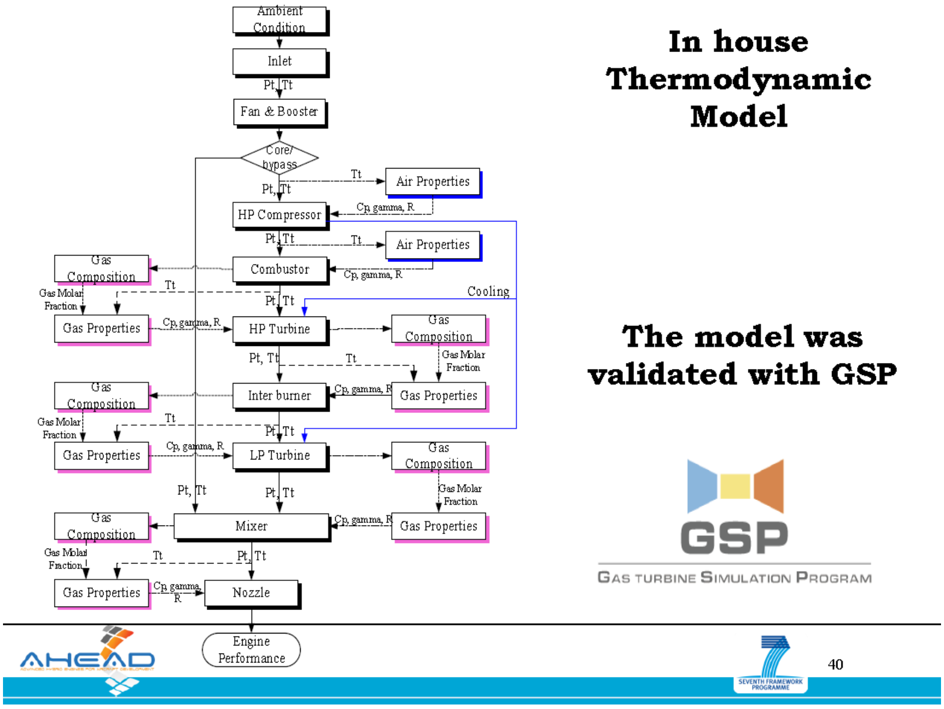
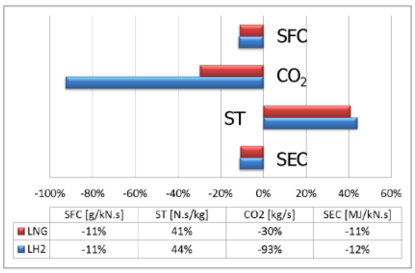


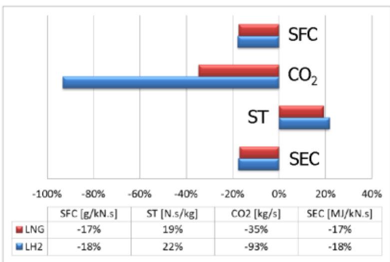
Figure 12: The engine evaluation model

It is expected that the new engine will show substantial improvements over the current generation of aero engines, as shown below:

Comparison of hybrid engine with GE90-94B



Comparison of hybrid engine with PW4056



9. Environmental impact

The use of alternative fuels and especially Hydrogen will have an effect on the water content in the engine exhaust. DLR Oberpfaffenhofen will assess the severity of the problem in terms of contrail formation and cloud formation which will have a greenhouse gas effect. Already it was established that the engine proposed will produce contrails at a lower altitude than conventional planes. In the tropics where the tropopause is higher the proposed aircraft will produce contrails very frequently. A further topic is the soot emission index of the proposed aircraft. The BWB aircraft might produce contrails with larger ice crystals in a smaller number that would imply a lower optical thickness and a shorter lifetime.

DLR is conducting several simulations to understand the effects of the new configuration on cloud formation and contrails. It will result in recommendations on preferred flying altitudes. This may result in an additional engine requirement.

10. Conclusion

The AHEAD project is half way at the moment. It already identified a possible aircraft configuration, demonstrated that burning Hydrogen in the first combustor of the aero engine is feasible and practical. It will demonstrate the feasibility of flame less combustion in the second chamber soon. The project will assess the total environmental benefits of the proposed engines as soon as experimental data are available and a good understanding of the water emissions is reached. At the end of the project the total benefits will be communicated.