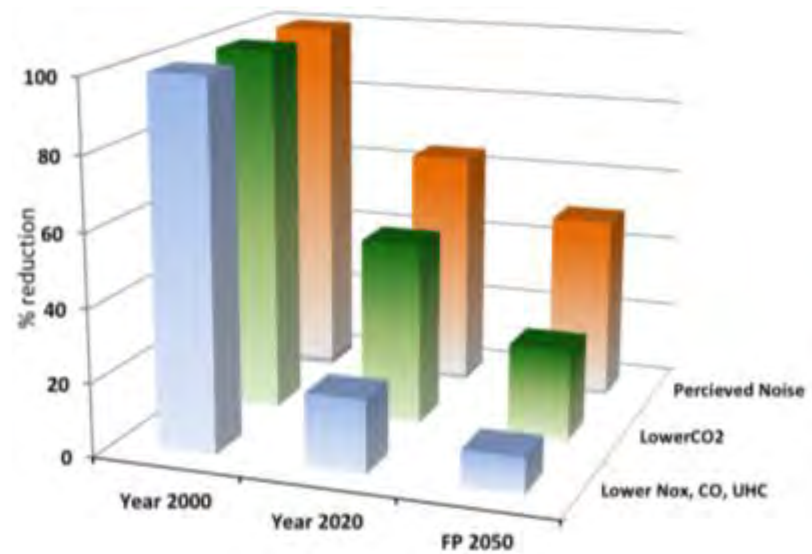
AHEAD : Advanced Hybrid Engines for Aircraft Development (ACP1-GA-2011-284636)

Level 1: Start 1/10/2011, duration 3 years

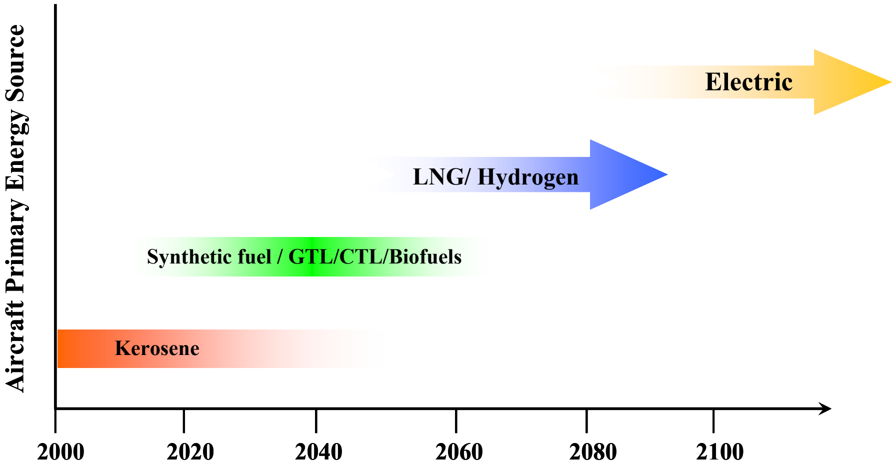
Scientific coordination: Dr. Arvind G. Rao

Main Challenges in Civil Aviation



Future Aviation Fuel

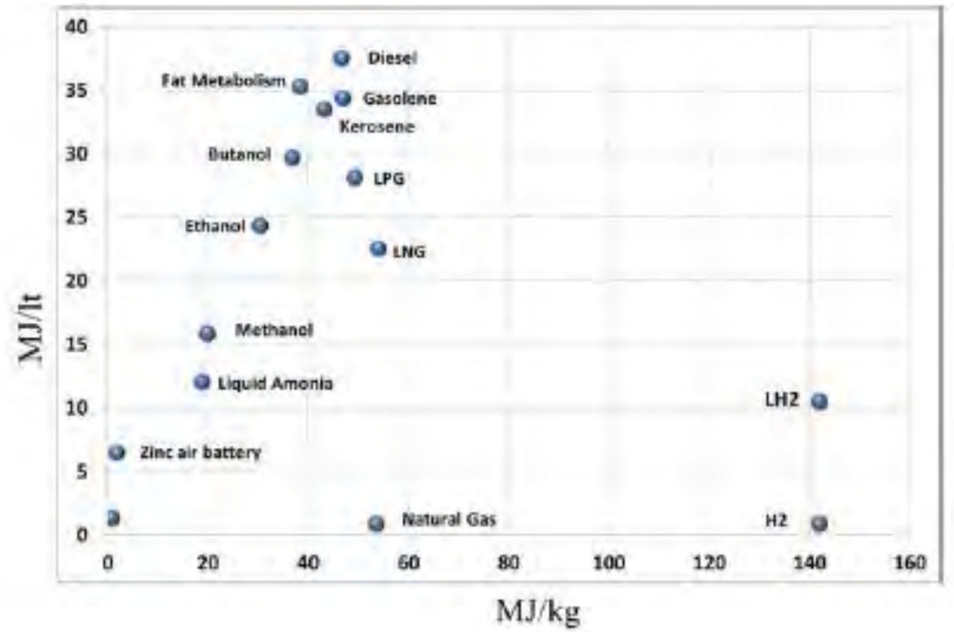
- The long term availability of fossil fuels cannot be guaranteed.
- As fossil fuel become scarce, the price will increase and alternative fuels may be used.
- In the medium term biofuels offer an attractive option.
- In the long term, Hydrogen or Liquid Natural Gas seems the most attractive option.



Cryogenic Fuels (LNG & LH2)

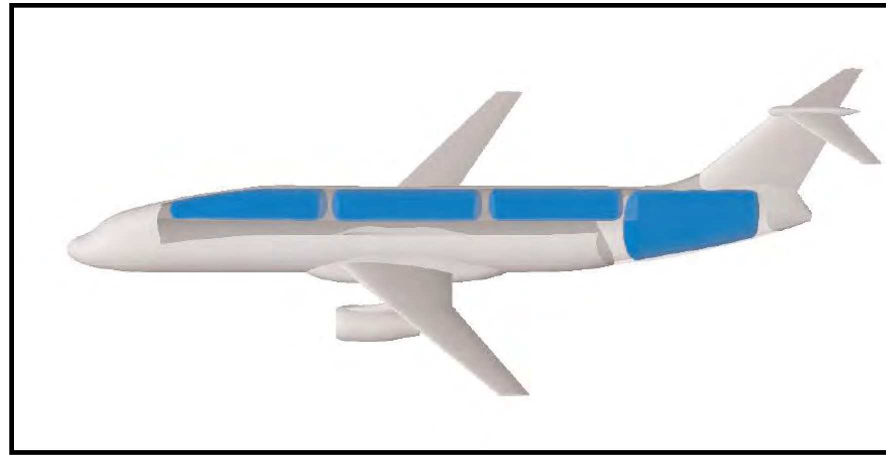
- The mass energy density of Hydrogen is much higher than of kerosene, so less fuel is needed. But the volume is much higher as well and the liquid has to be cooled.

- LNG mass density is slightly better than kerosene but it also requires special storage tanks.

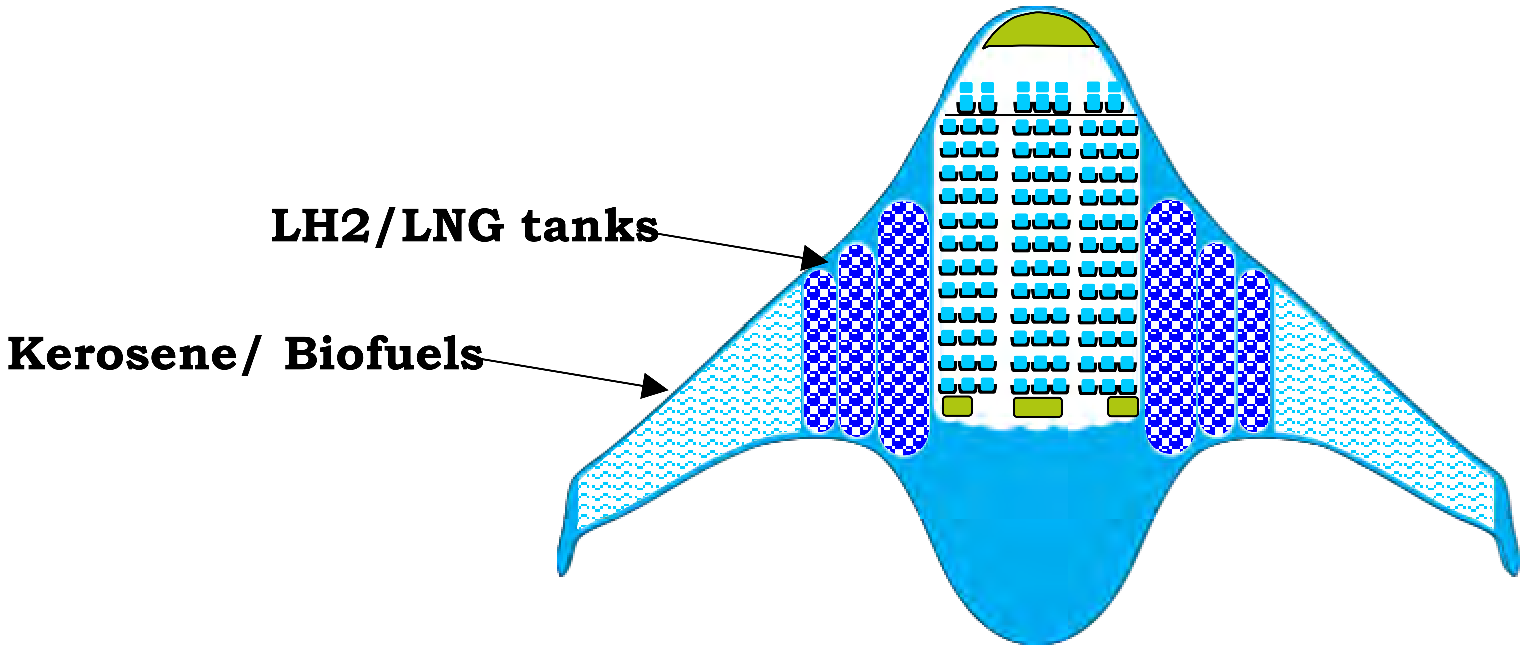


Storage of Cryogenic Fuels

- Storage of LNG and Hydrogen requires large low temperature tanks.
- Initial configuration studies proved to be unattractive as drag would be increased, thus increasing the fuel burn.
- New configurations are needed.

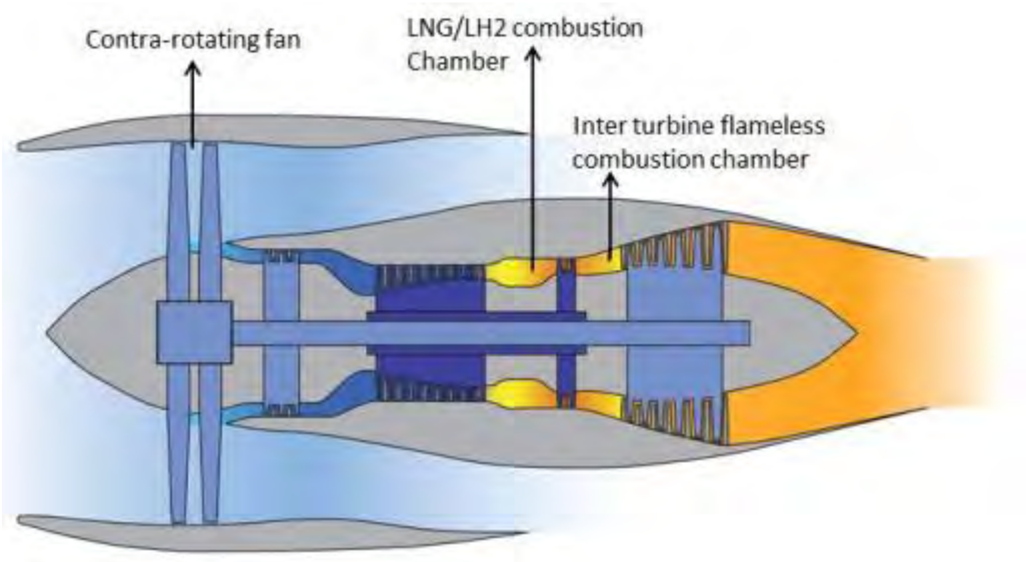


Storage of Cryogenic fuels in a Multi fuel BWB



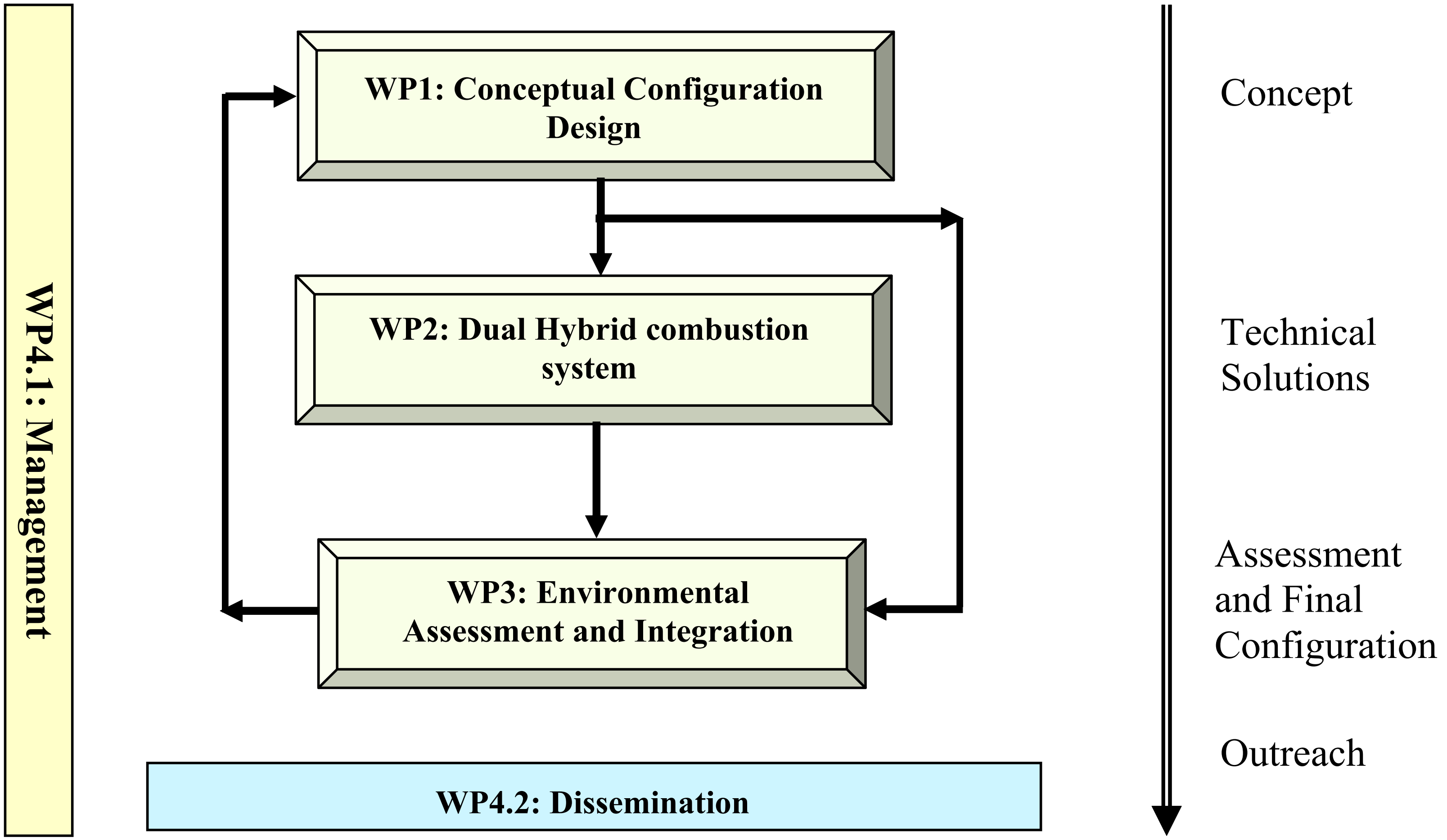
- BWB has inherently has extra volume which can be used to accommodate the cylindrical fuel tanks
- This novel idea of multi fuel BWB is unique which optimizes the usage of space in a BWB

Next generation hybrid engine



- LNG/ LH2 Main Combustor
- Kerosene/ Biofuel Secondary Flameless Combustor
- Bleed cooling by LH2
- Counter rotating shrouded fans
- Higher Specific Thrust
- Low Installation Penalty

Overview of the workpackage structure

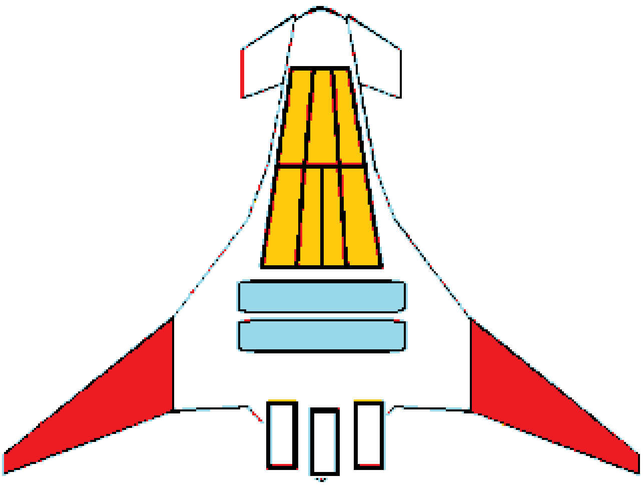


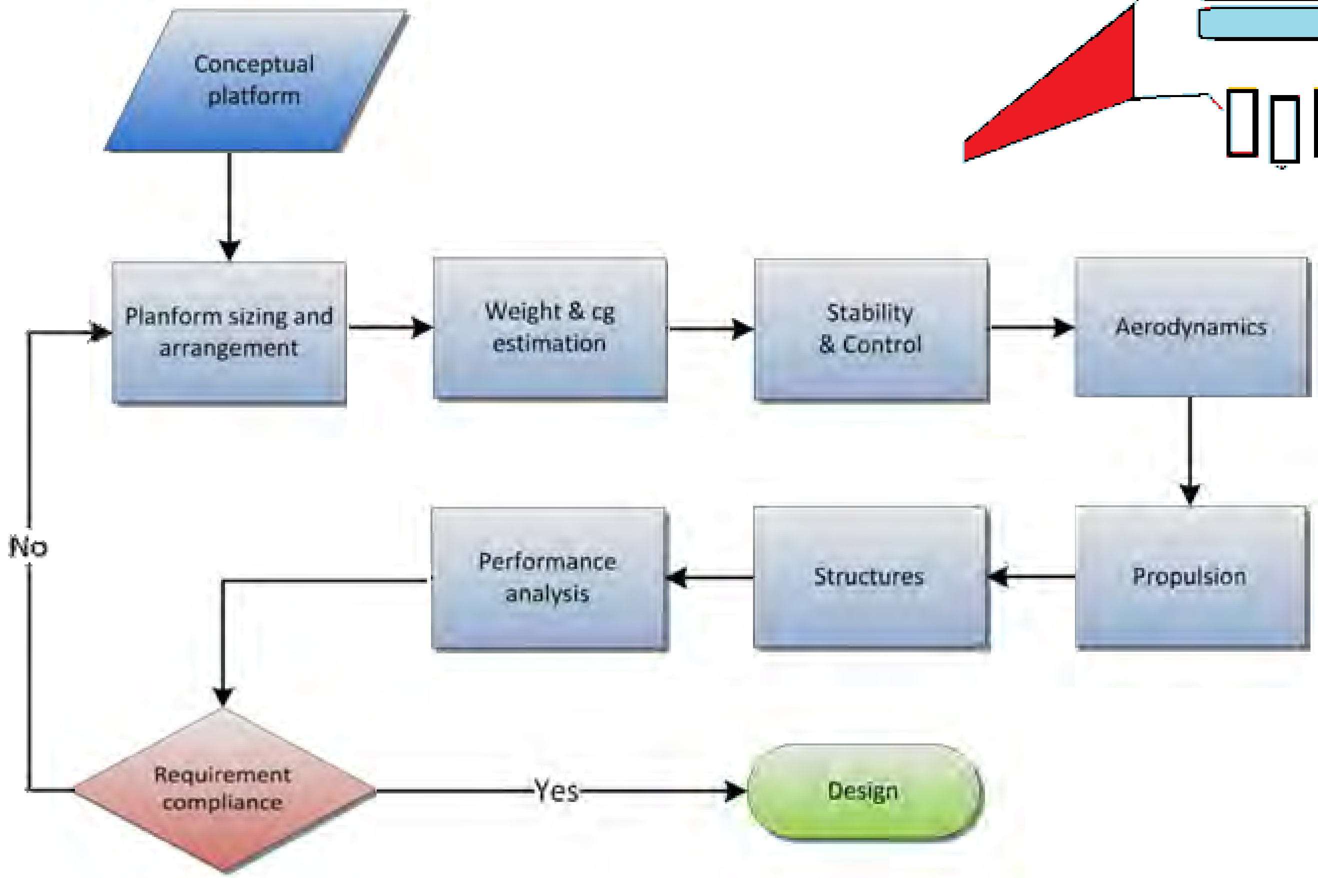
Multi Fuel Blended Wing Body Design

The main task in this WP is to do the conceptual design of the multi-fuel blended wing body aircraft

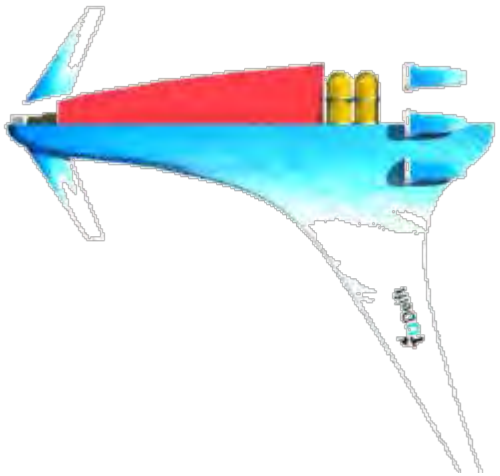
Preliminary design

Optimization procedure – Modules





Novel Configuration
Multi fuel Blended Wing Body



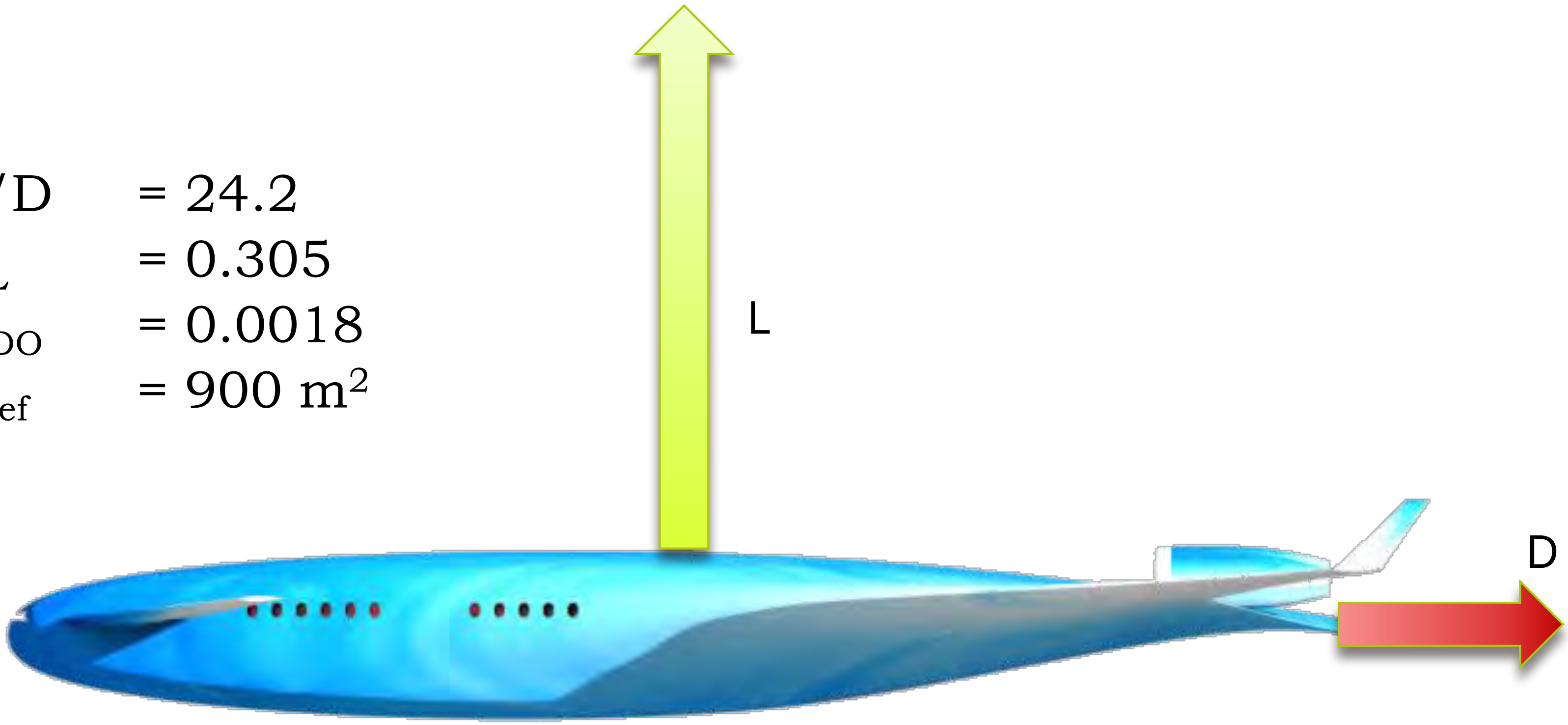
- TU Delft proposes a Blended Wing Body configuration combined with a slender wing for a very efficient new aircraft that would replace the Boeing 777 or Airbus 340.

- It incorporates 3 fuel tanks without substantial drag penalty.

Preliminary design

Results – Aerodynamics

$L/D = 24.2$
$C_L = 0.305$
$C_{DO} = 0.0018$
$S_{ref} = 900\ m^2$



Preliminary design

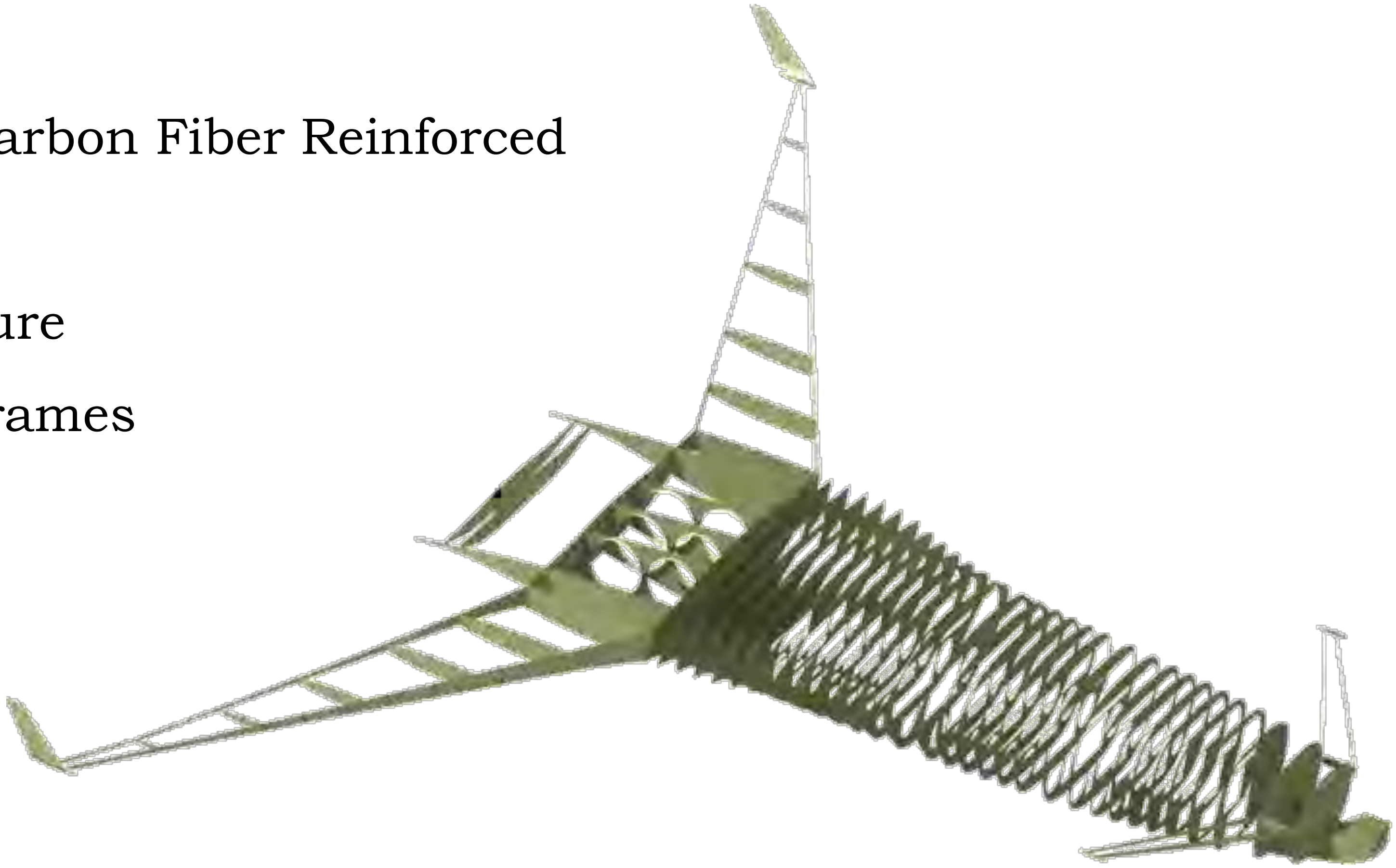
Results – Structures (1)

Materials: Carbon Fiber Reinforced

Polymer

Main structure

- Elliptical frames
- Ribs
- Bulkheads



Preliminary design

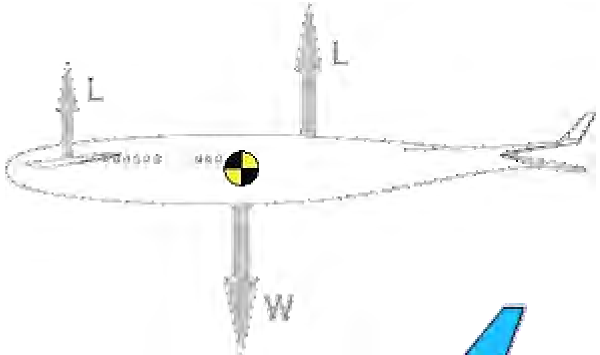
Results – Stability and Control

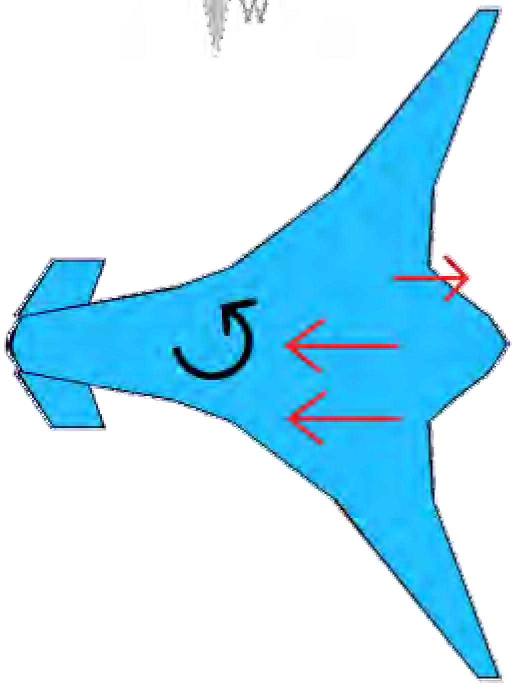
Stability:

- Canards
- Winglets

Control:

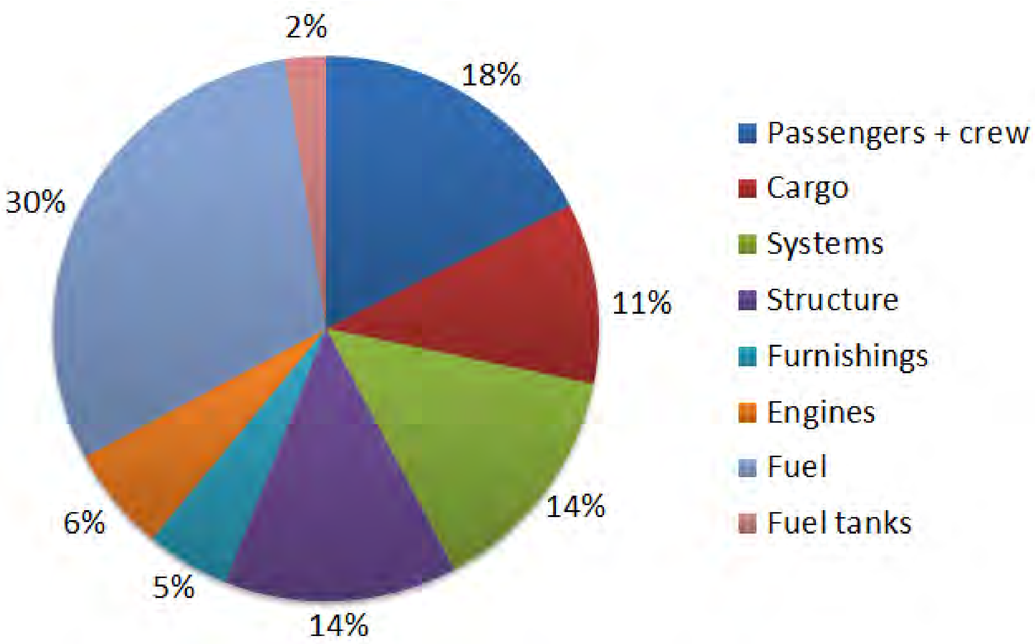
- Variable camber canard
- Elevons
- Winglet rudders





Preliminary design

Results – Weight breakdown

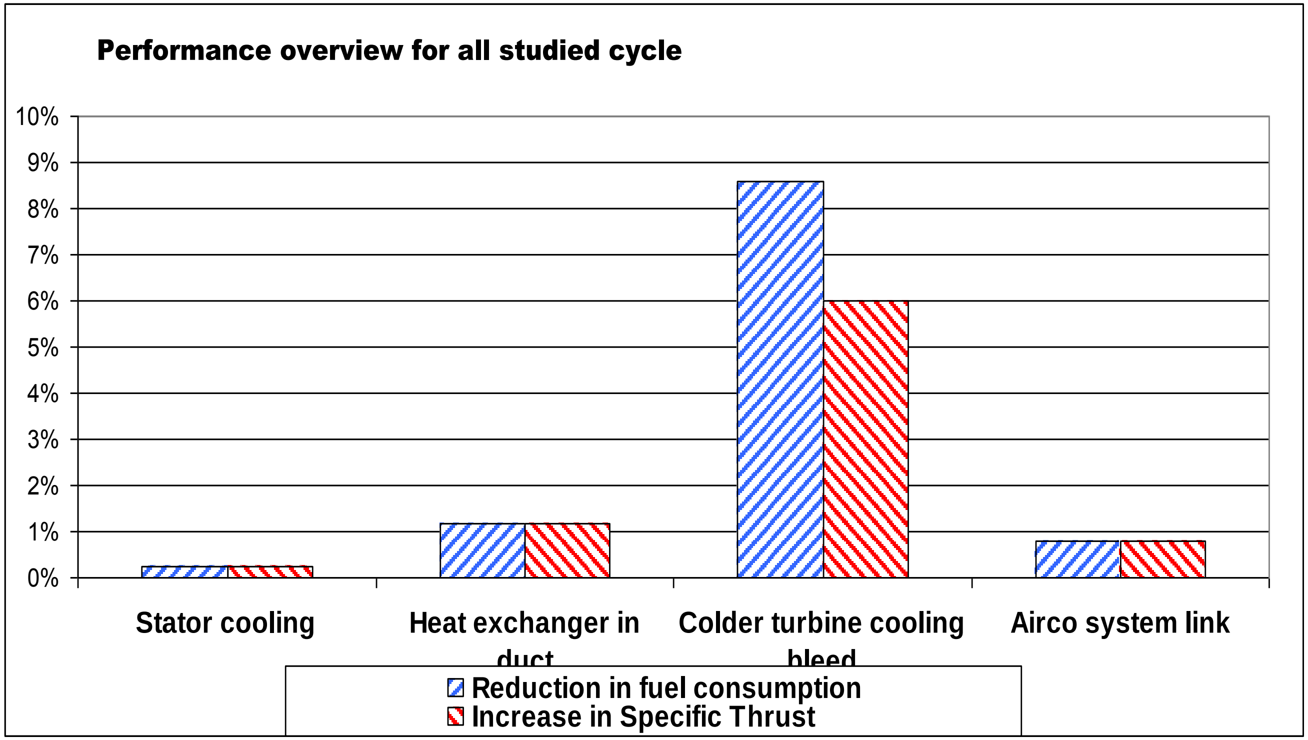


	New-BWB
Wo	242,800 kg
MTOW	237,970 kg
OEW	122,220 kg
W/S	265.04
$(T/W)_{TO}$	0.21
T_{TO}	527,810 N
T_{cruise}	98,195 N

The Bleed Cooling system

The main task of this task is to design a cooling system to cool the bleed air with the cryogenic fuel.

Use of Cryogenic fuel as a heat sink



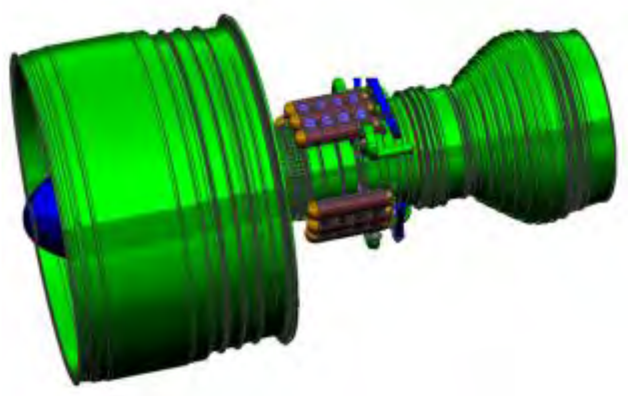
Using the cryogenic fuel to cool the bleed air is the best way of improving the thermal efficiency of a turbofan engine

Van Dijk, I.P.,Rao, G.A . and Buijtenen, J.P, "A Novel Technique of Using LH2 in Gas Turbine Engines", *ISABE 2009*, Sept 7-11, Montreal, ISABE 2009-1165

Aim and objectives

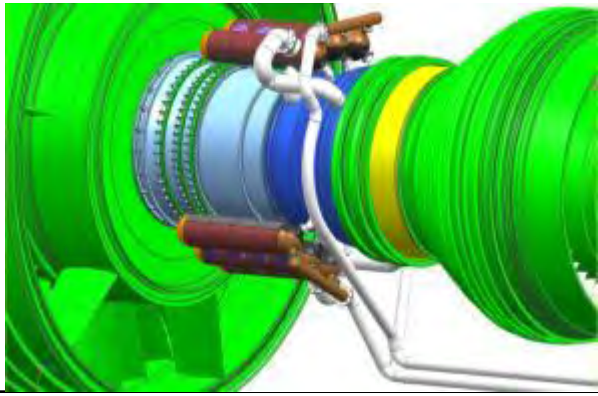
The specific objectives of this work package are to:

- To study and analyze suitable techniques / methodology that could be used for cooling the bleed air by using LH2



- Preliminary design of the heat exchange system between the bleed air and LH2

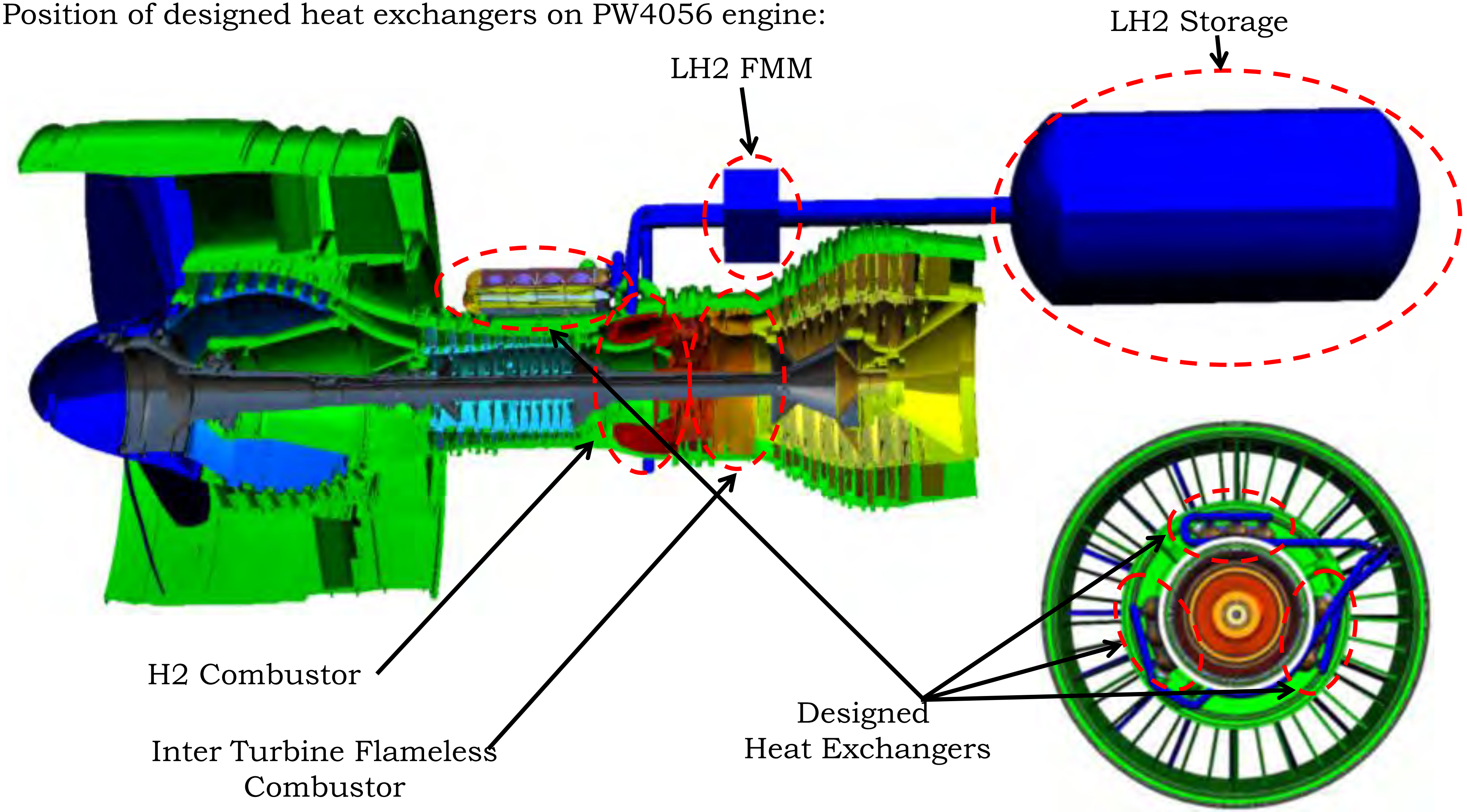
- To perform the sizing of the various components within the hybrid engine in order to obtain the approximate dimensions of the hybrid engine.



- To estimate the overall weight of the hybrid engine

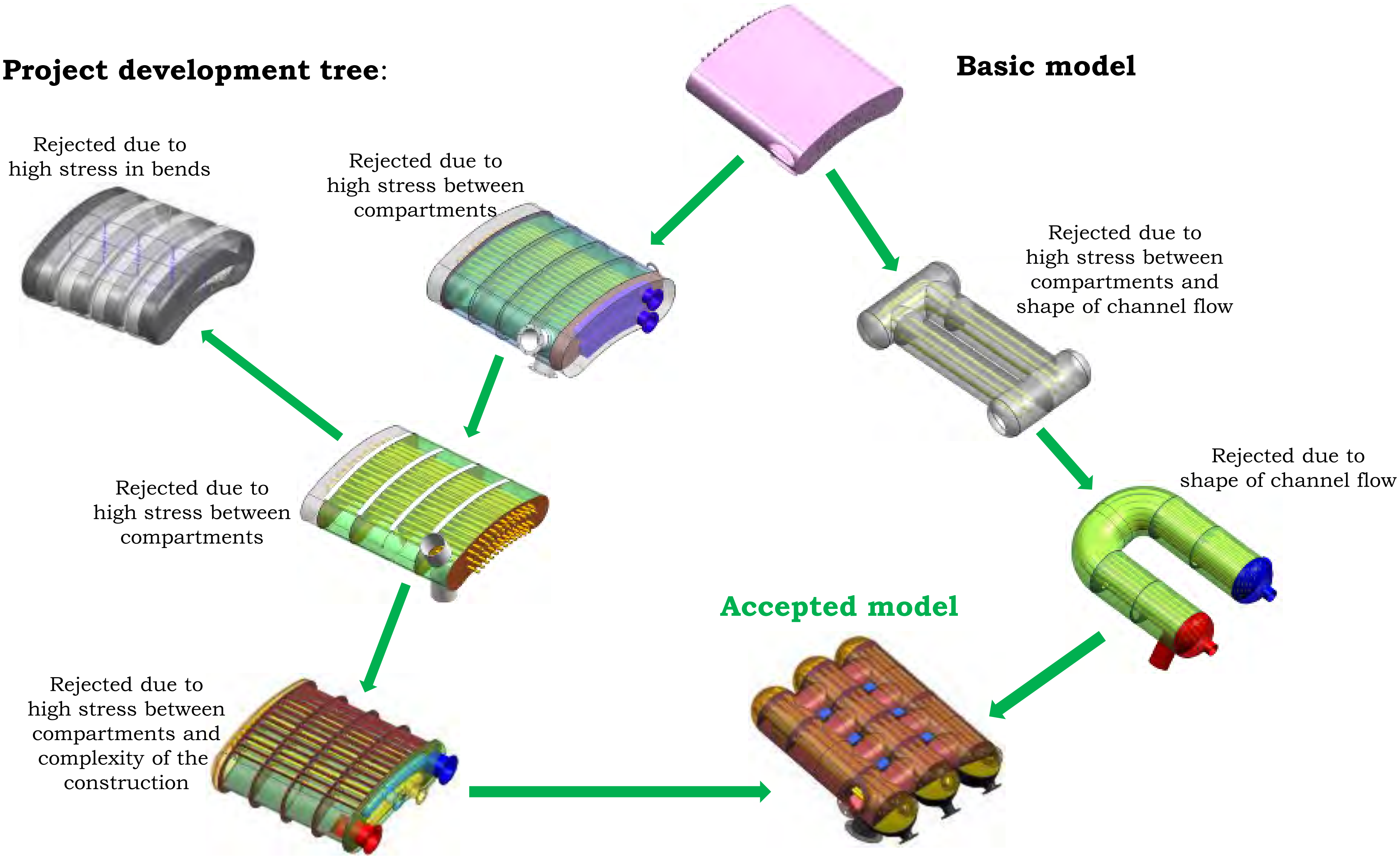
Design of the cryogenic fuel to air heat exchanger

AHEAD project based on baseline engine geometry:
Position of designed heat exchangers on PW4056 engine:



Design of the cryogenic fuel to air heat exchanger

Project development tree:



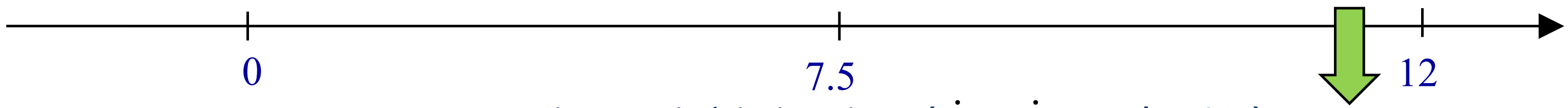
The hydrogen combustion chamber

The aim of this task is to design the primary combustor for the hybrid engine using hydrogen as fuel.

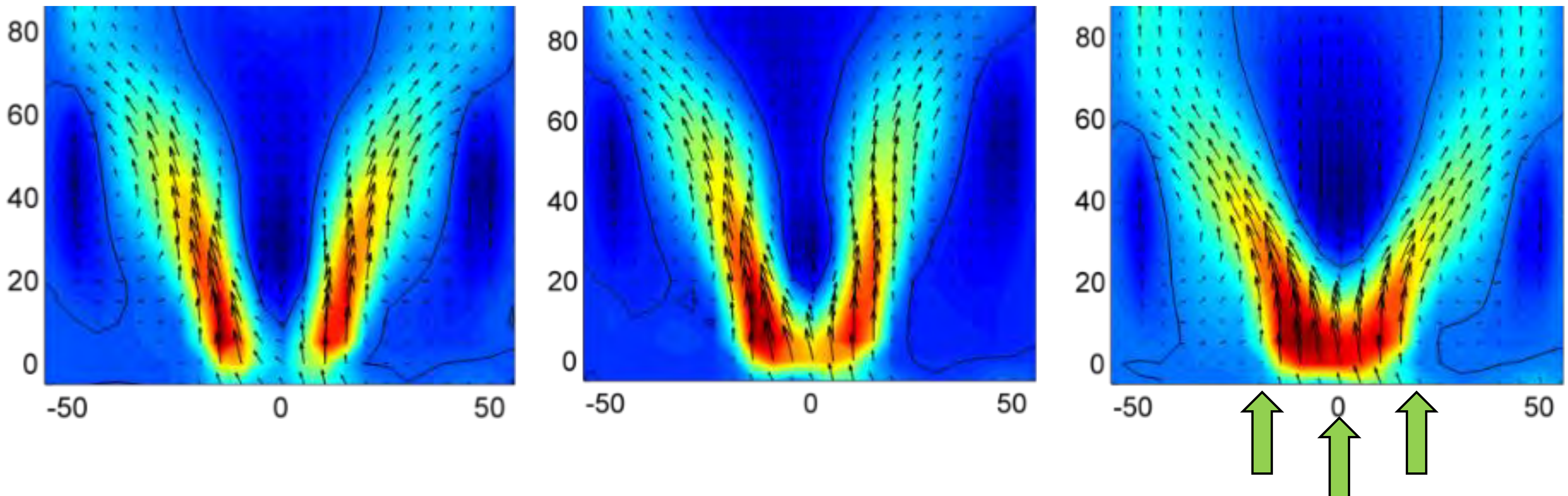
Axial Injection - PIV in Water Tunnel

- Axial injection controlled by mass flow meter
- Impact of axial injection:
  - Increases axial velocity at outlet
  - Downstream shift of central recirculation zone

→ desired flow field for $\dot{V}_{ax}/\dot{V}_{tot} = 12\%$

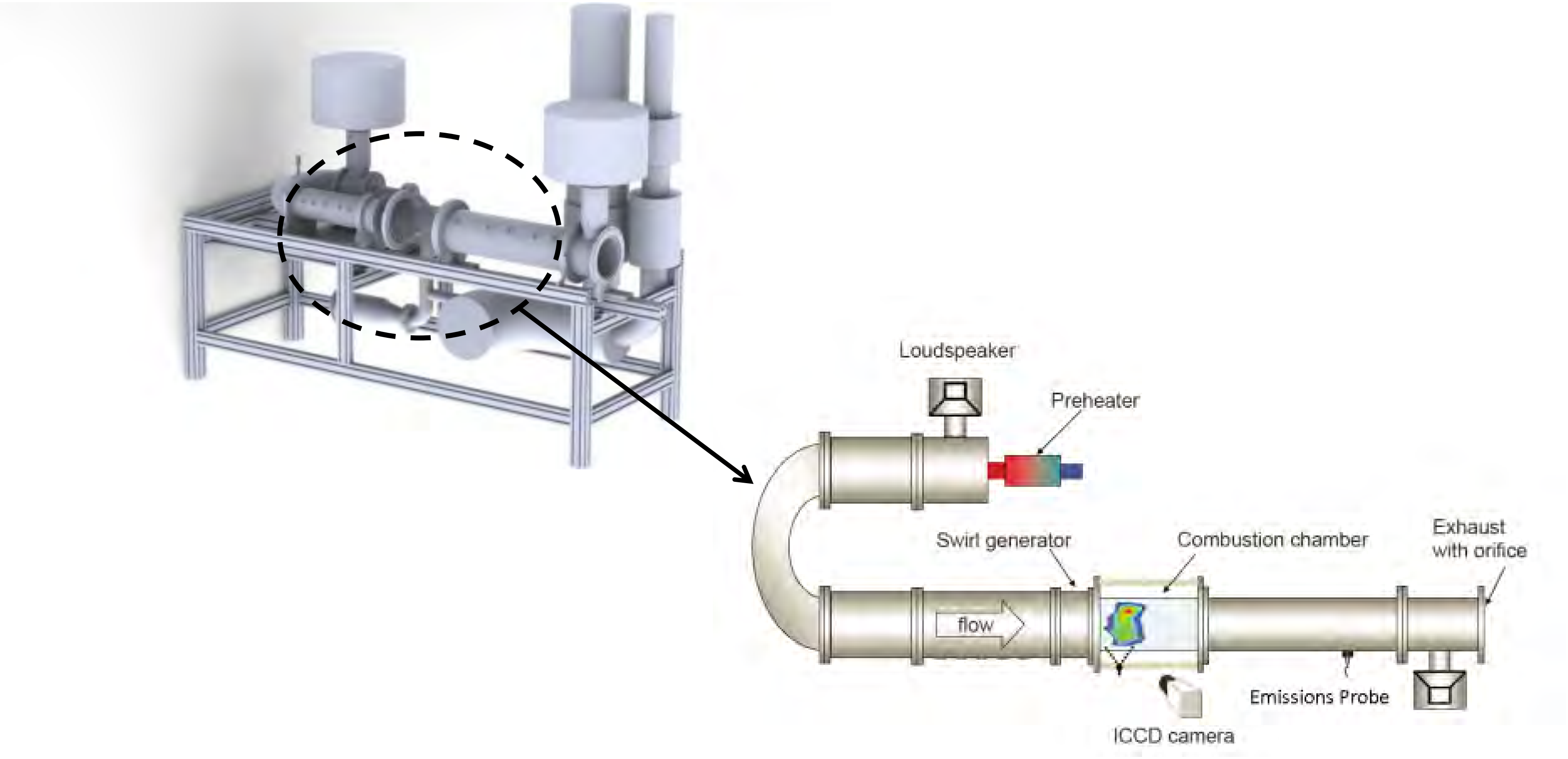


Increasing axial injection ($\dot{V}_{ax}/\dot{V}_{tot}$ in %)

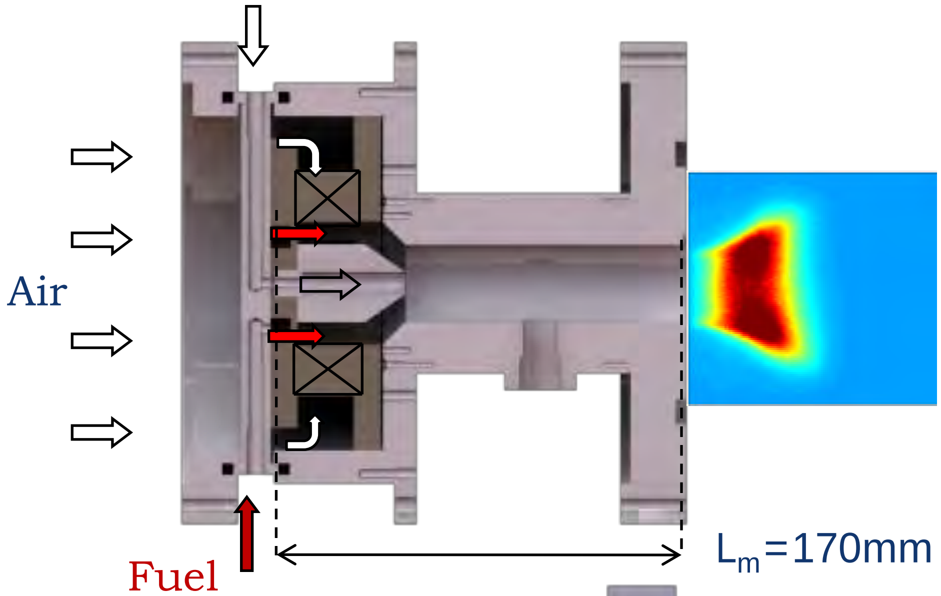


Combustion Test Rig

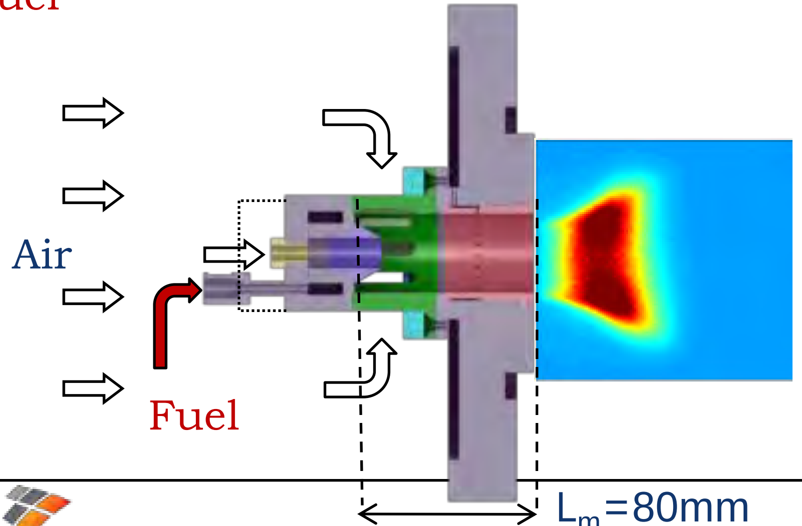
Gas-fired tests with 100% hydrogen with axial injection on the TUB combustion test trig



New Burner – Reduced Dimensions Approaching an Applicable Design

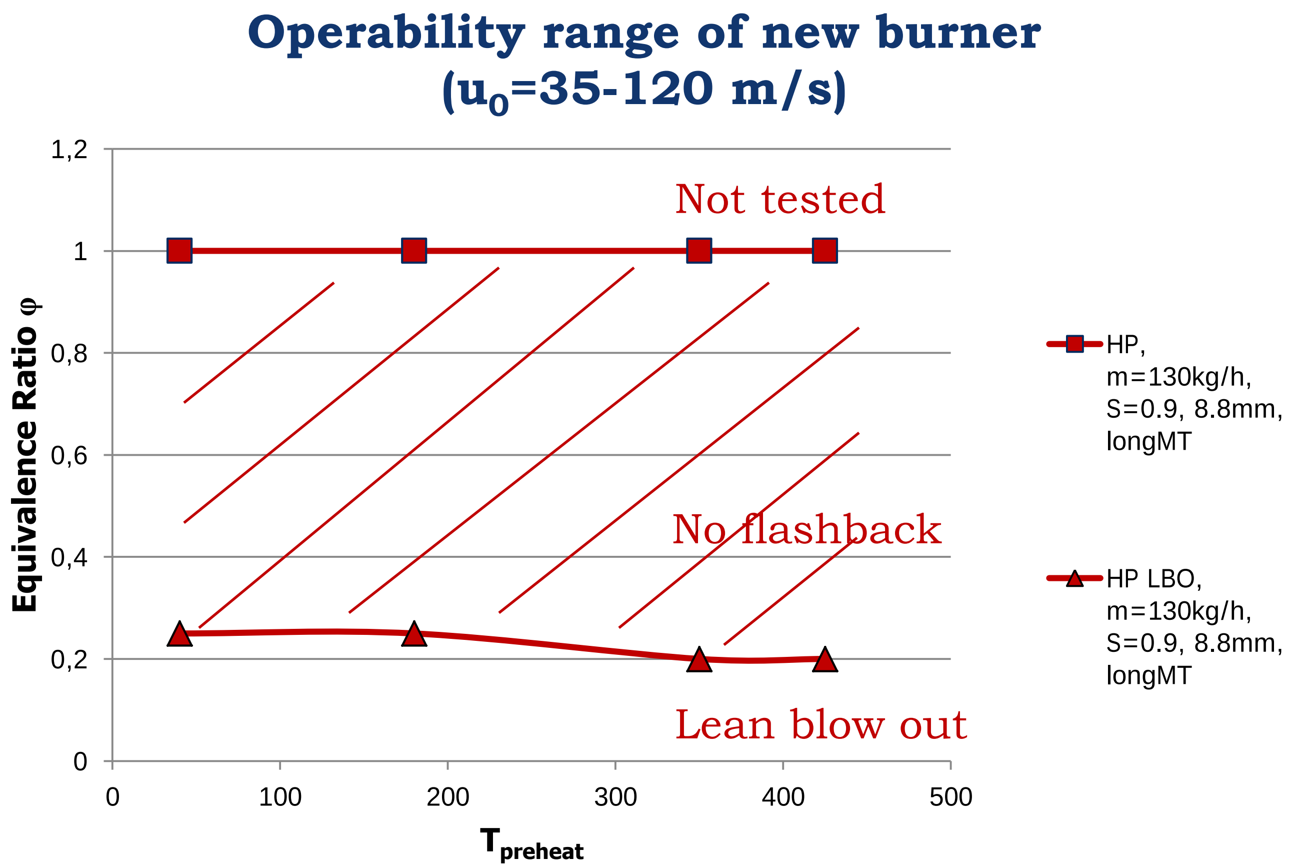


- Moveable Block (MB) burner:
- Large mixing length Lm=170mm
- Pressure loss > 10%



- New burner:
- Reduced mixing length
  - Long = 100mm
  - Short = 80mm
- Pressure loss 3-6%

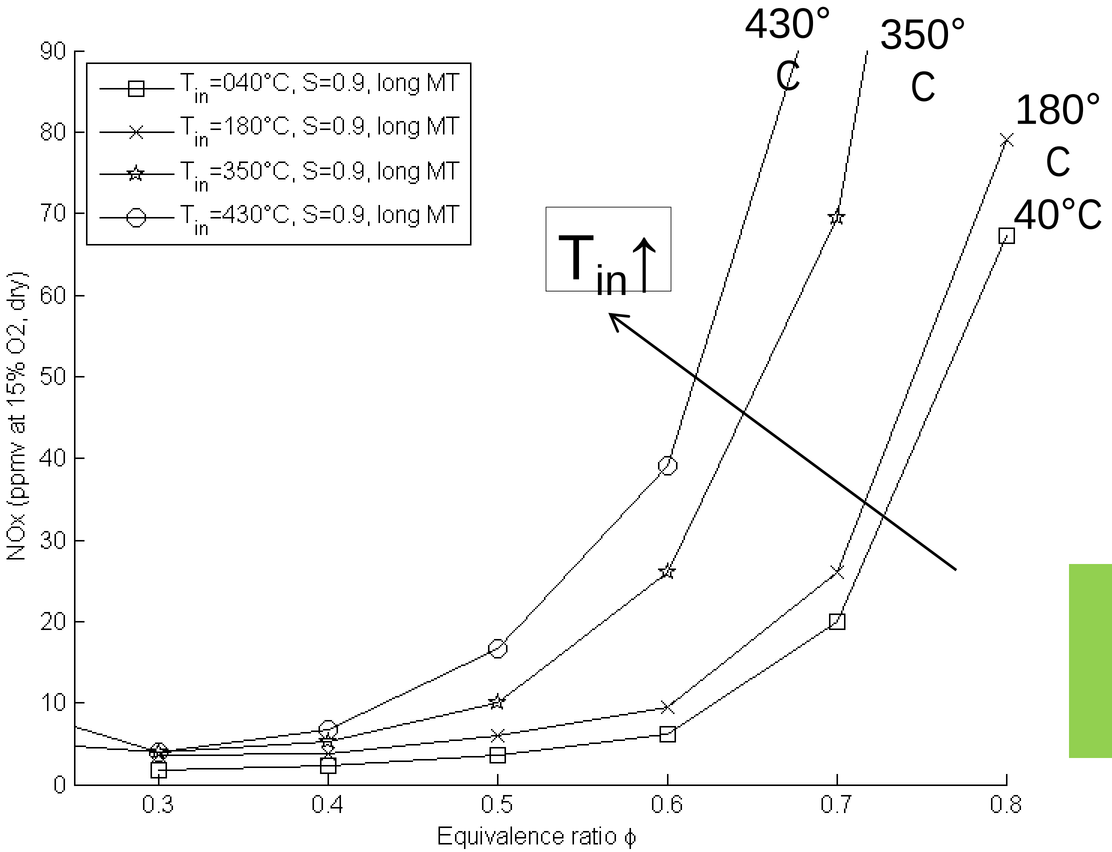
Gas Fired Tests: Stability Map



- Atmospheric conditions: new burner exhibits wide operational range without any flashback occurance

NOx emissions: Inlet Temperature (Tin)

- NOx emissions increase with inlet temperature Tin
- Below 20 ppm for all Tin at design equivalence ratio of φ≈0.4-0.55



S=0.9 and long mixing tube

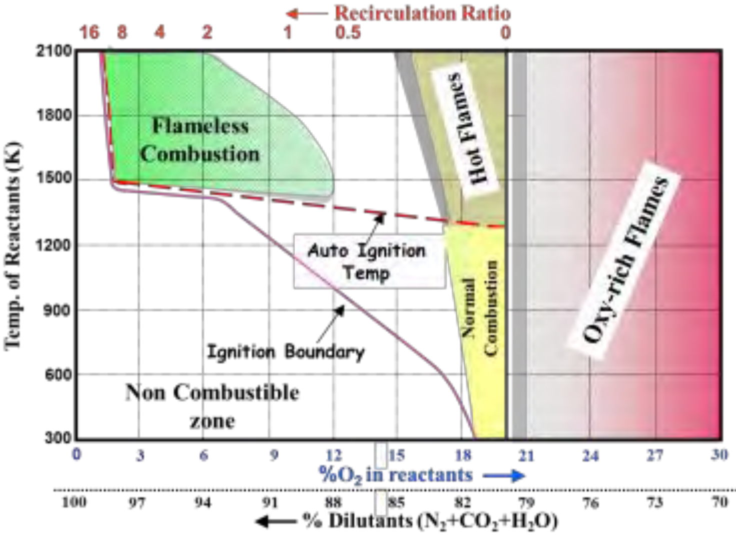
The Inter Turbine Flameless Combustion Chamber

The main aim of this task is to design and validate the secondary inter-turbine flameless combustion chamber for the AHEAD hybrid engine

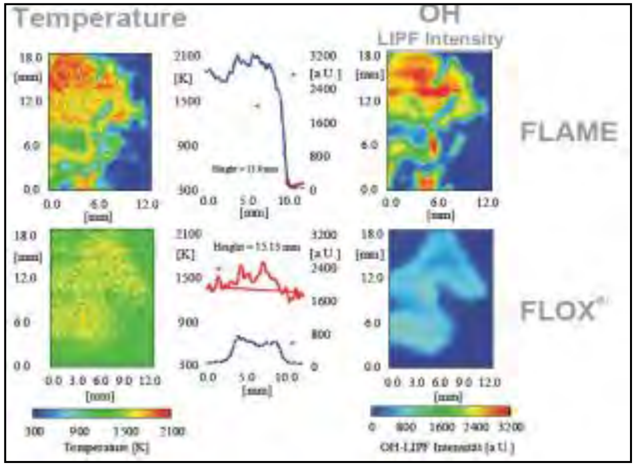
Flameless combustion

CHARACTERISTICS

- Recirculation of combustion products at high temperature (> 1000° C)
- Reduced oxygen concentration in the reactants
- Highly transparent flame with low acoustic oscillation
- Distributed combustion zone
- Uniform temperature distribution
- Reduced temperature peaks
- Low adiabatic flame temperature
- High concentration of CO2 & H2O
- Lower Damköhler number
- Low NOx and CO emission

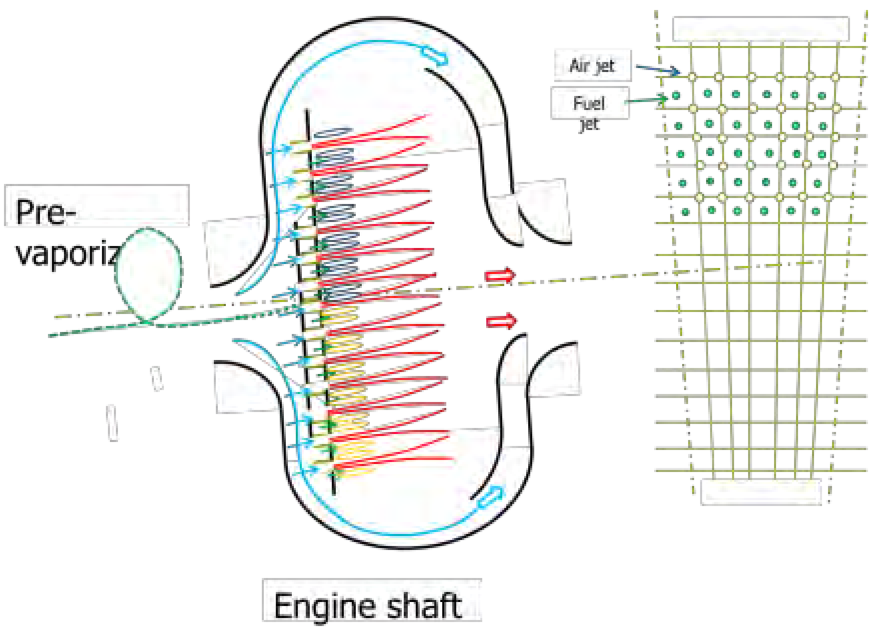


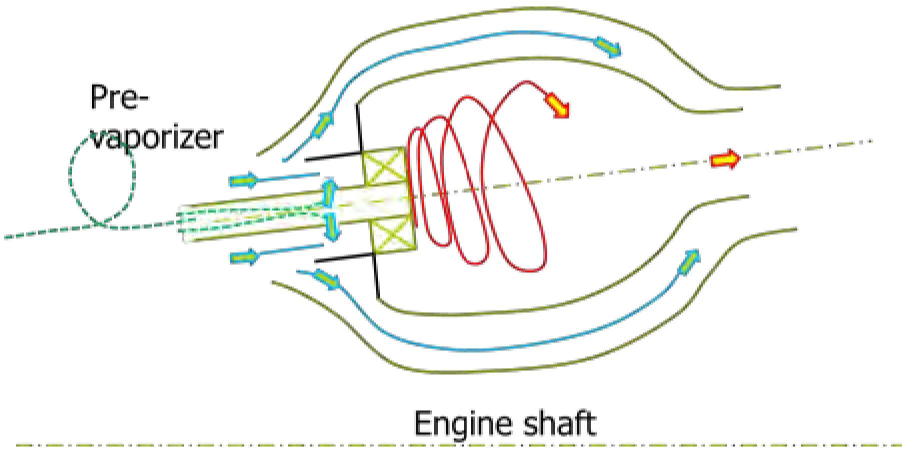
Different Combustion Regimes

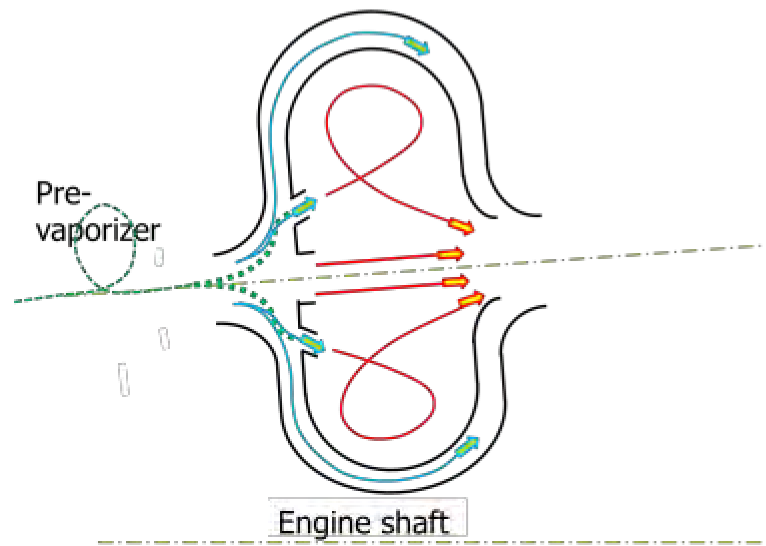


Comparison between a conventional combustion and Flameless Combustion (Wünning and Wünning, 2003)

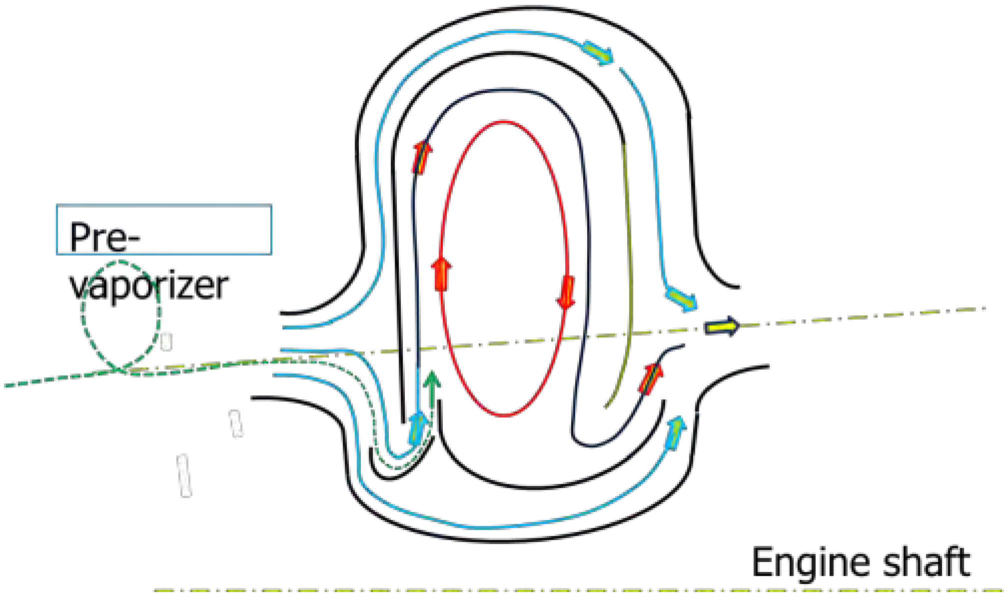
Evaluated combustor configurations for the Inter Turbine Flameless combustion Chamber

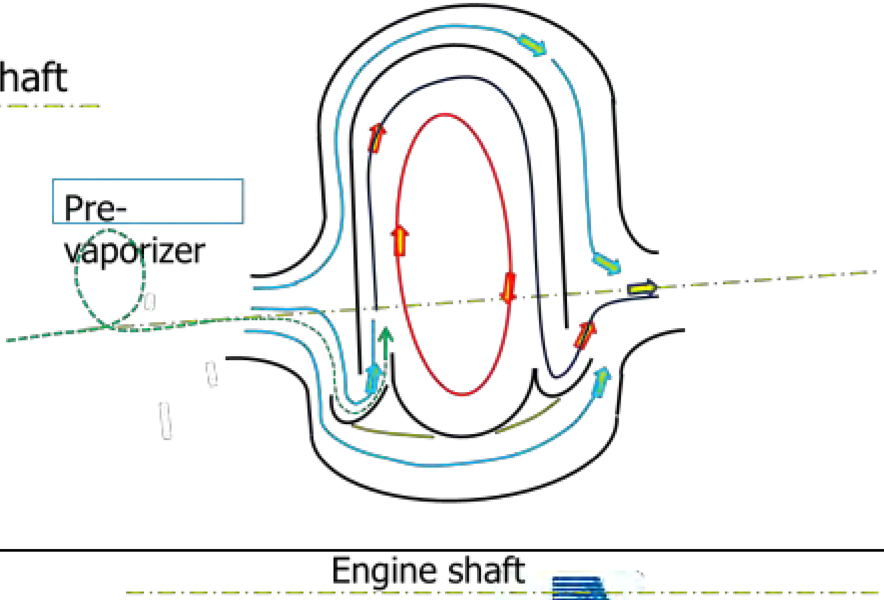




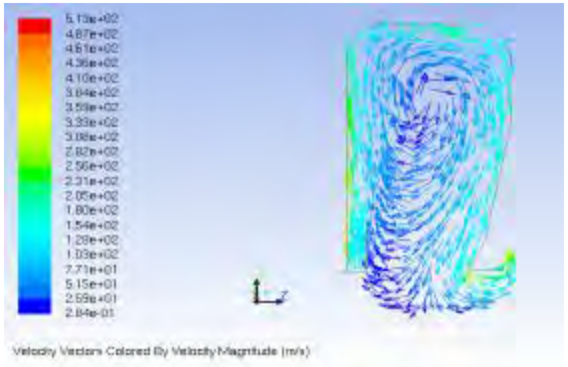


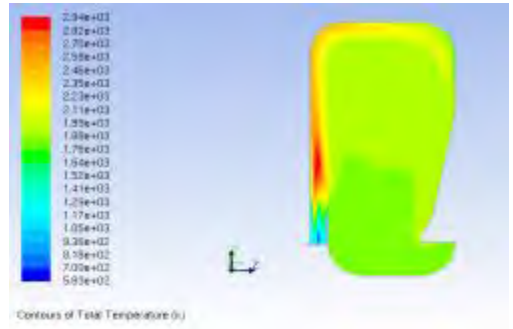
Slotted- recirculated ultra lean combustor version #2

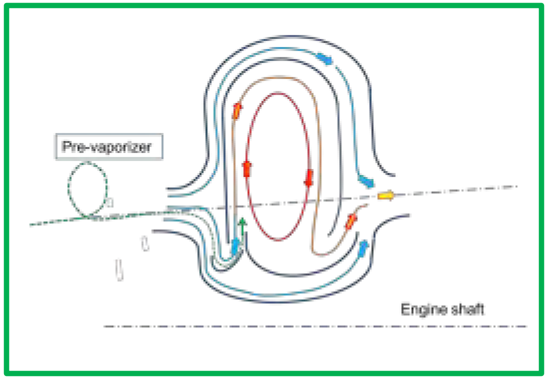


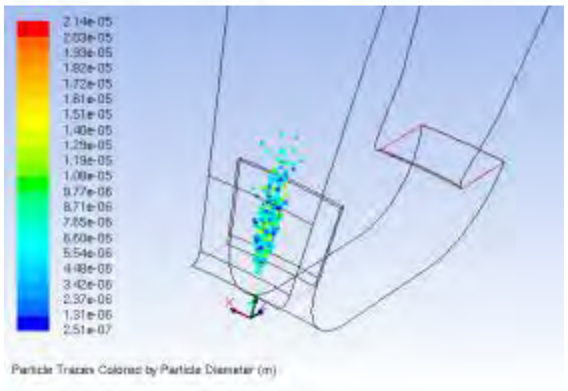


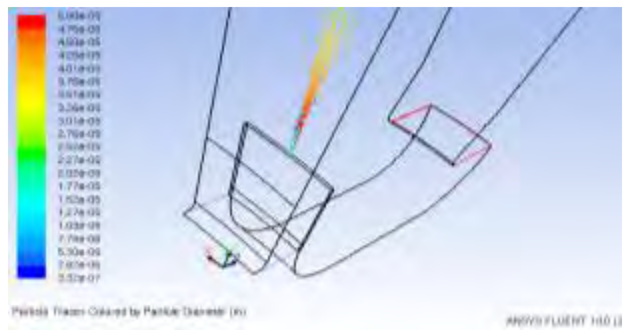
CFD for liquid fuel injection











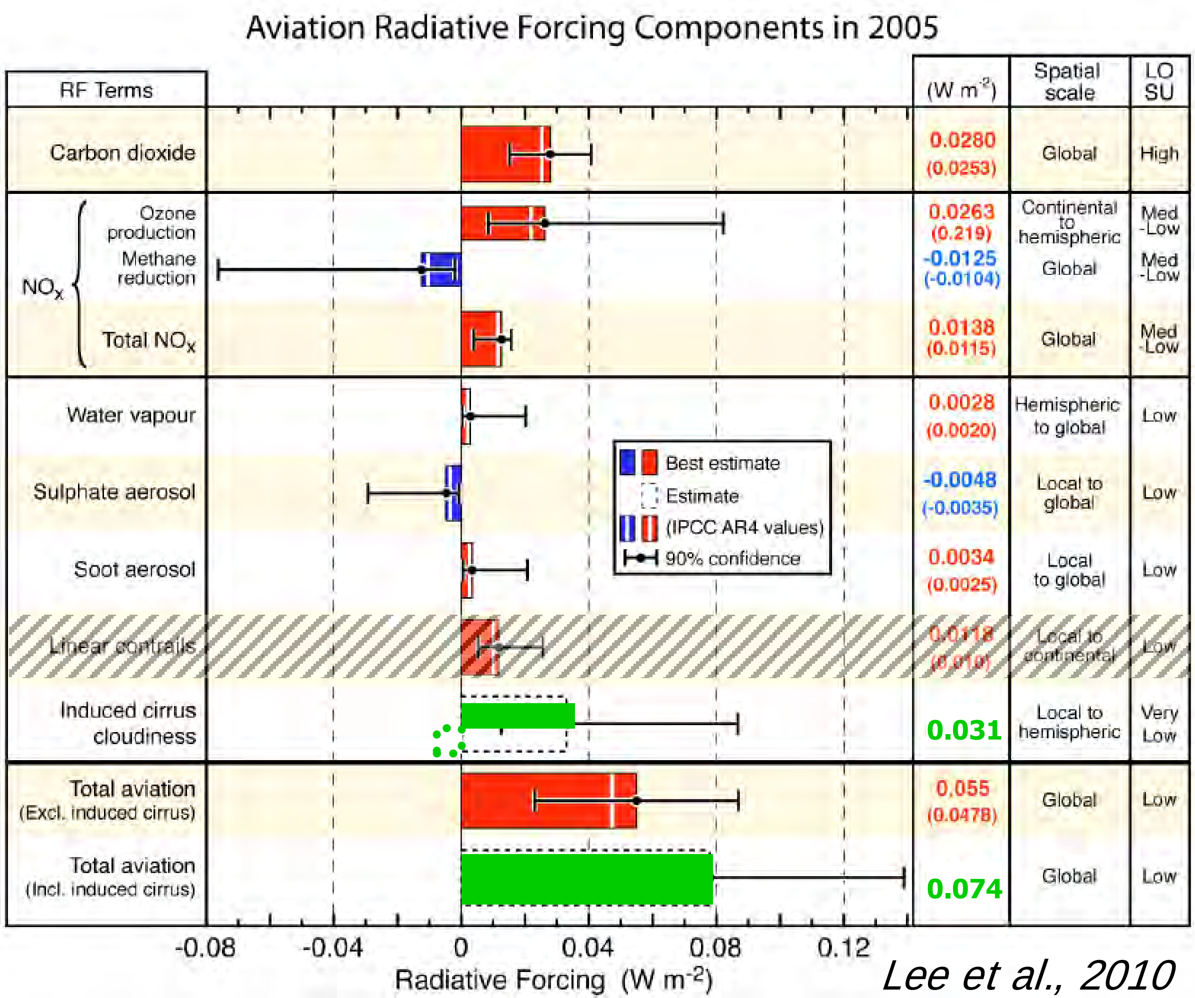
Left picture shows more significant evaporation process

Droplet evolution for two different injection points

Climate Impact Assessment of the Multi-Fuel BWB Aircraft

The primary aim of this task is to analyse the effect of changing aircraft emissions on the global climate due to the use of multi-fuel BWB with hybrid engine

Climate impact of current air traffic (2005)



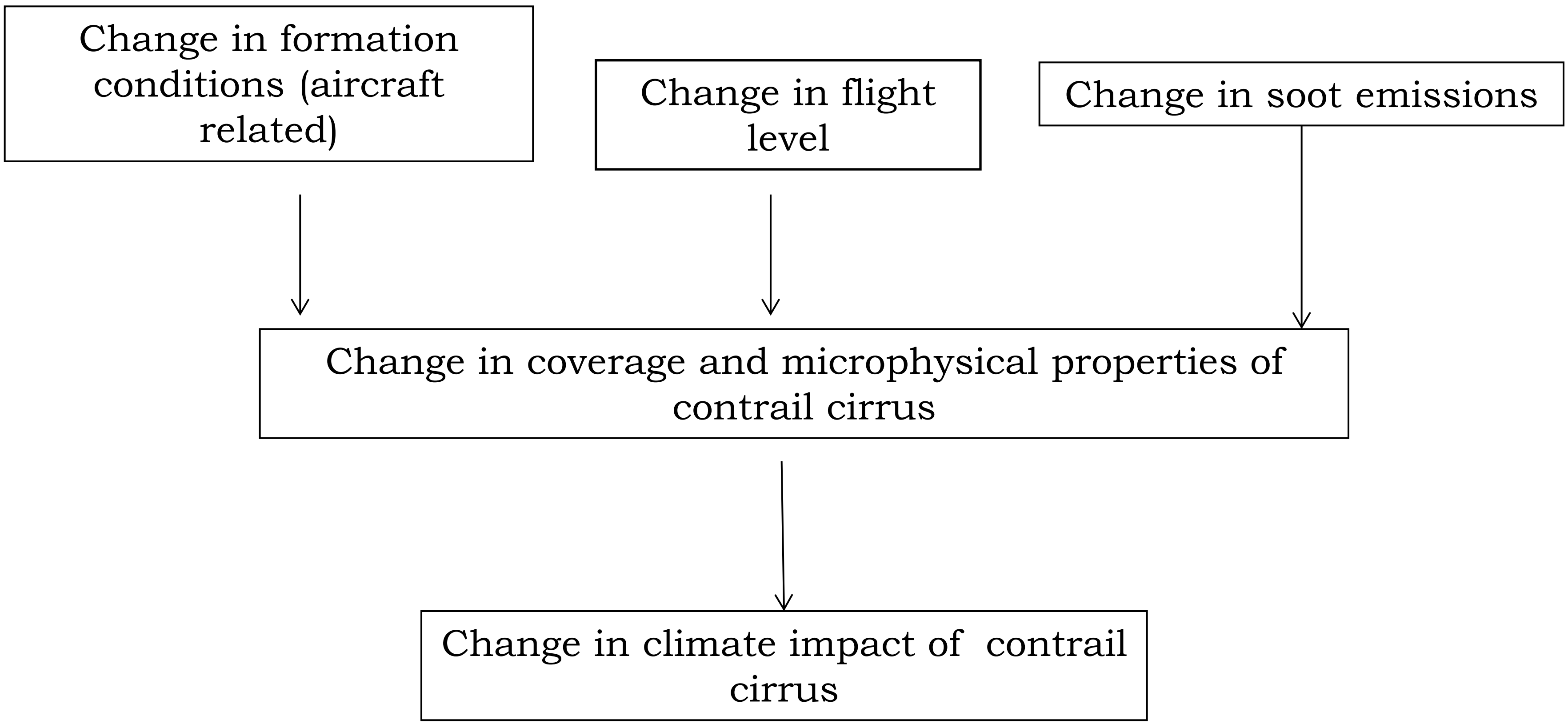
updated with Burkhardt&Kärcher, 2011 (for 2002 air traffic)

- Main contributors:
- Contrails
- CO2
- NOx

- 3.5-5.0% of warming
- attributed to air traffic

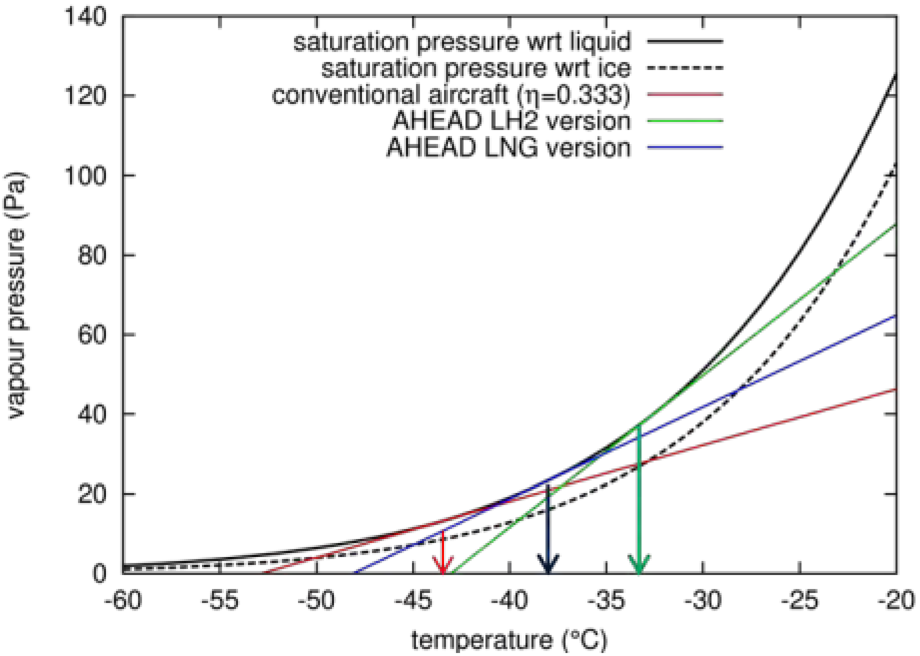
ACARE, 2008
The findings of the IPCC point very clearly to the need to do something but there are areas of detail where more understanding is needed.

Global climate impact of contrail cirrus

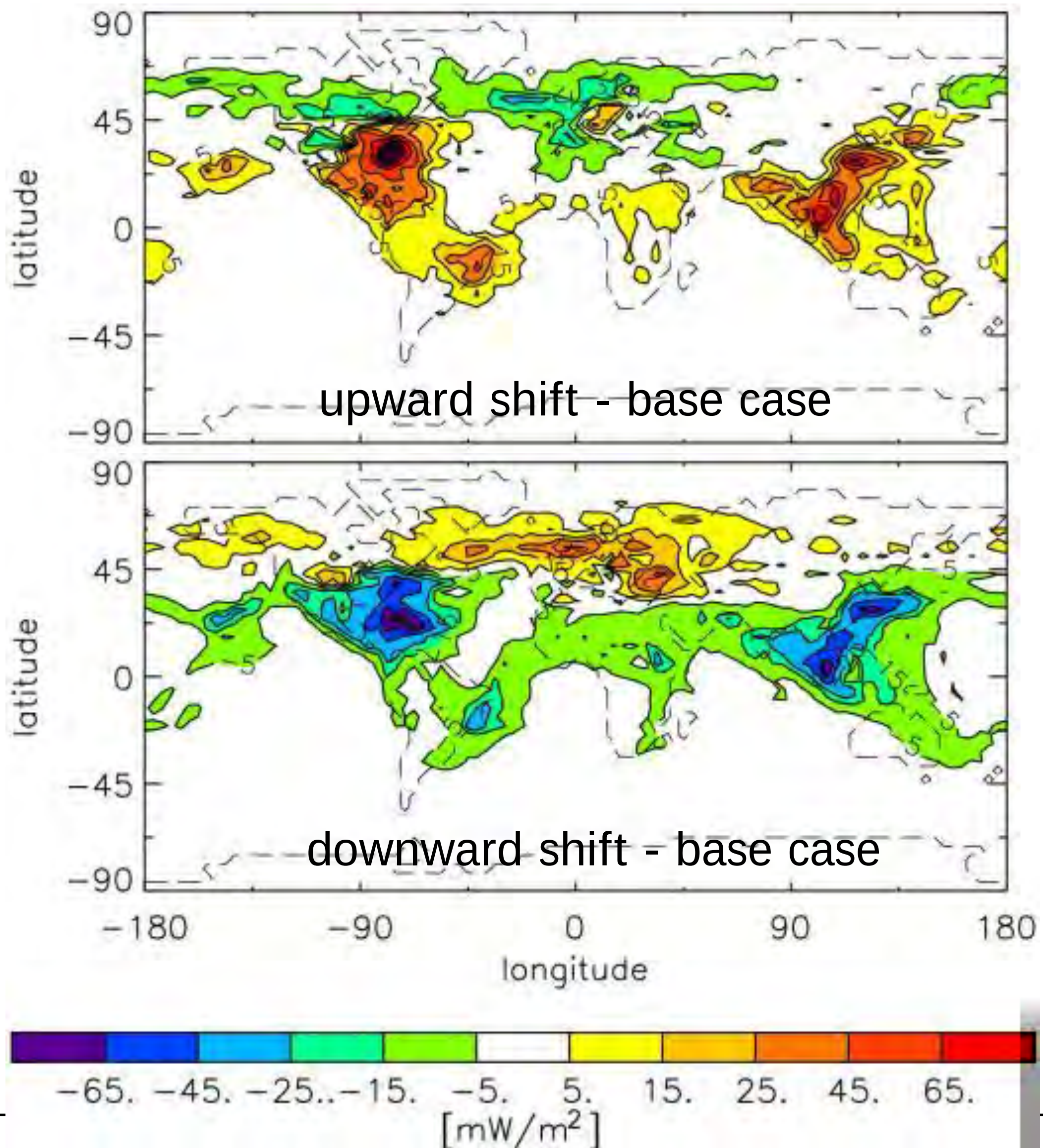


Change in formation conditions II
Implications for contrail formation (2)

AHEAD BWBs will produce contrails in a deeper atmospheric layer than conventional aircraft because the threshold temperatures are higher (i.e. formation starts at lower altitude).



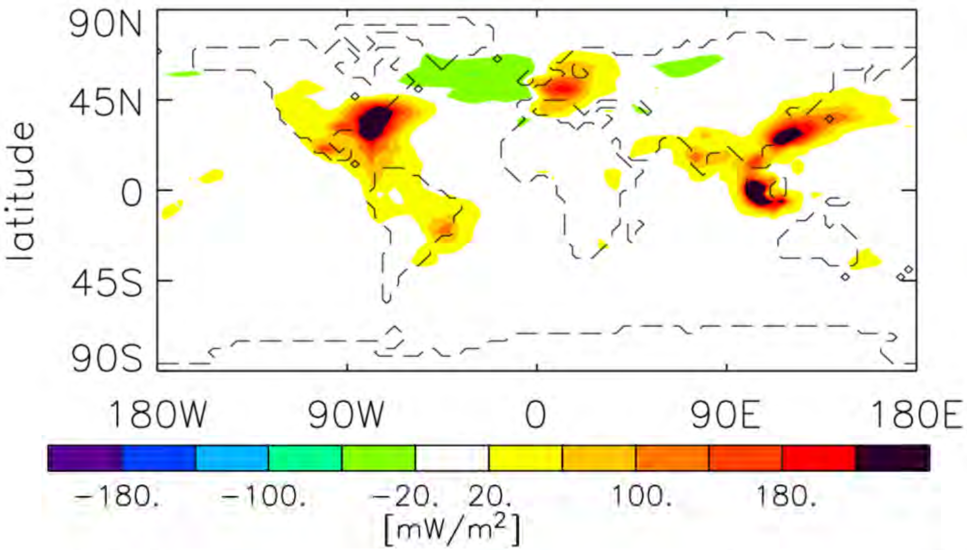
Changes in contrail cirrus RF due to changes in flight level



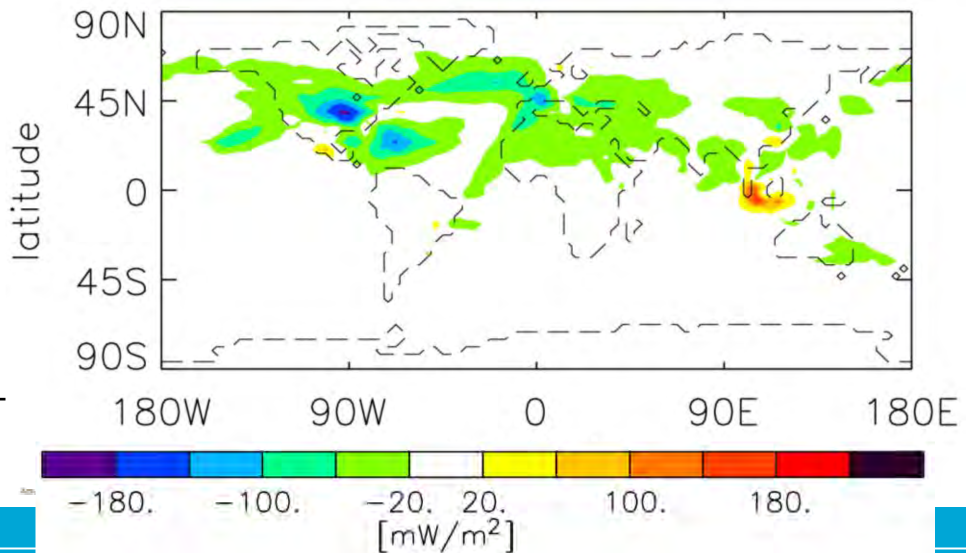
- decrease of RF in mid latitudes,
- increase in tropics/subtropics,
- globally +4 mW/m^2 (~9%)

- increase of RF in mid latitudes,
-decrease in tropics/subtropics,
- globally -6 mW/m2 (~13%)

LH2 version of AHEAD aircraft:
Contrail cirrus radiative forcing - change in formation conditions + shift of flight level by ~ 2000m

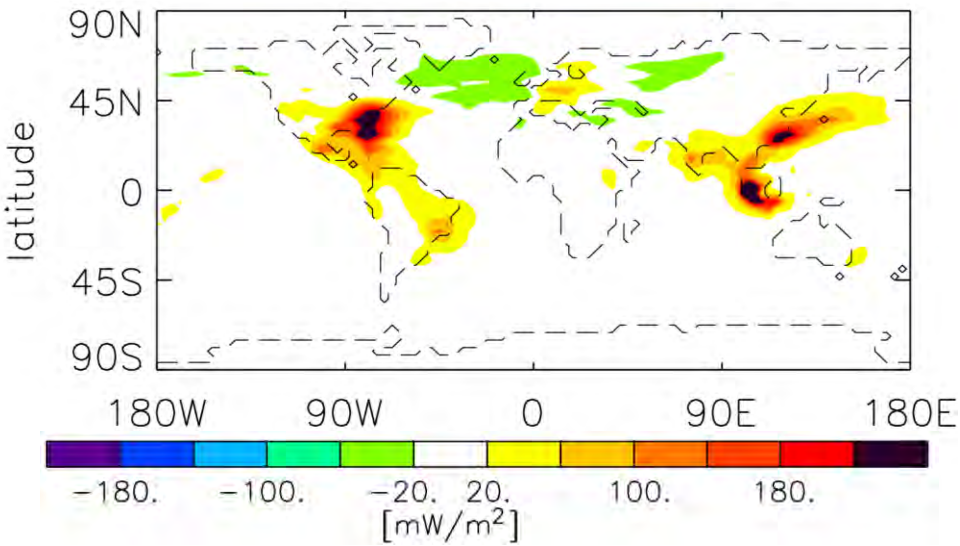


Change in contrail cirrus radiative forcing due to a replacement of conventional planes by LH2 planes and an increase in flight level by about 2000m (LH2up3 -- conventional). Contrail cirrus radiative forcing strongly increased (factor 1.5) particularly south of 45∘N.

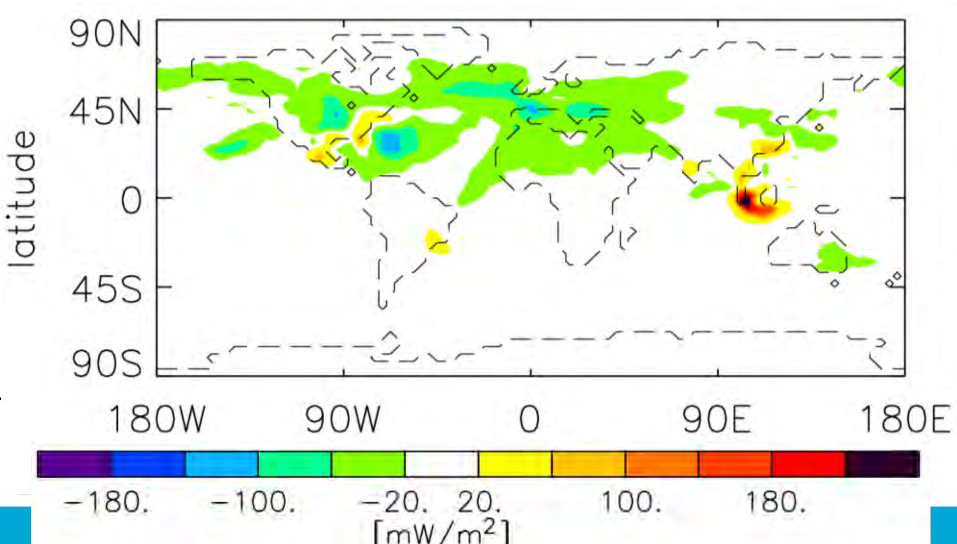


Change in contrail cirrus radiative forcing due to a shift in flight level of LH2 planes by ~2000m (LH2up3 – LH2). Contrail cirrus radiative forcing nearly everywhere decreased.

LNG version of AHEAD aircraft: Contrail cirrus radiative forcing - change in formation conditions + shift of flight level by ~ 2000m



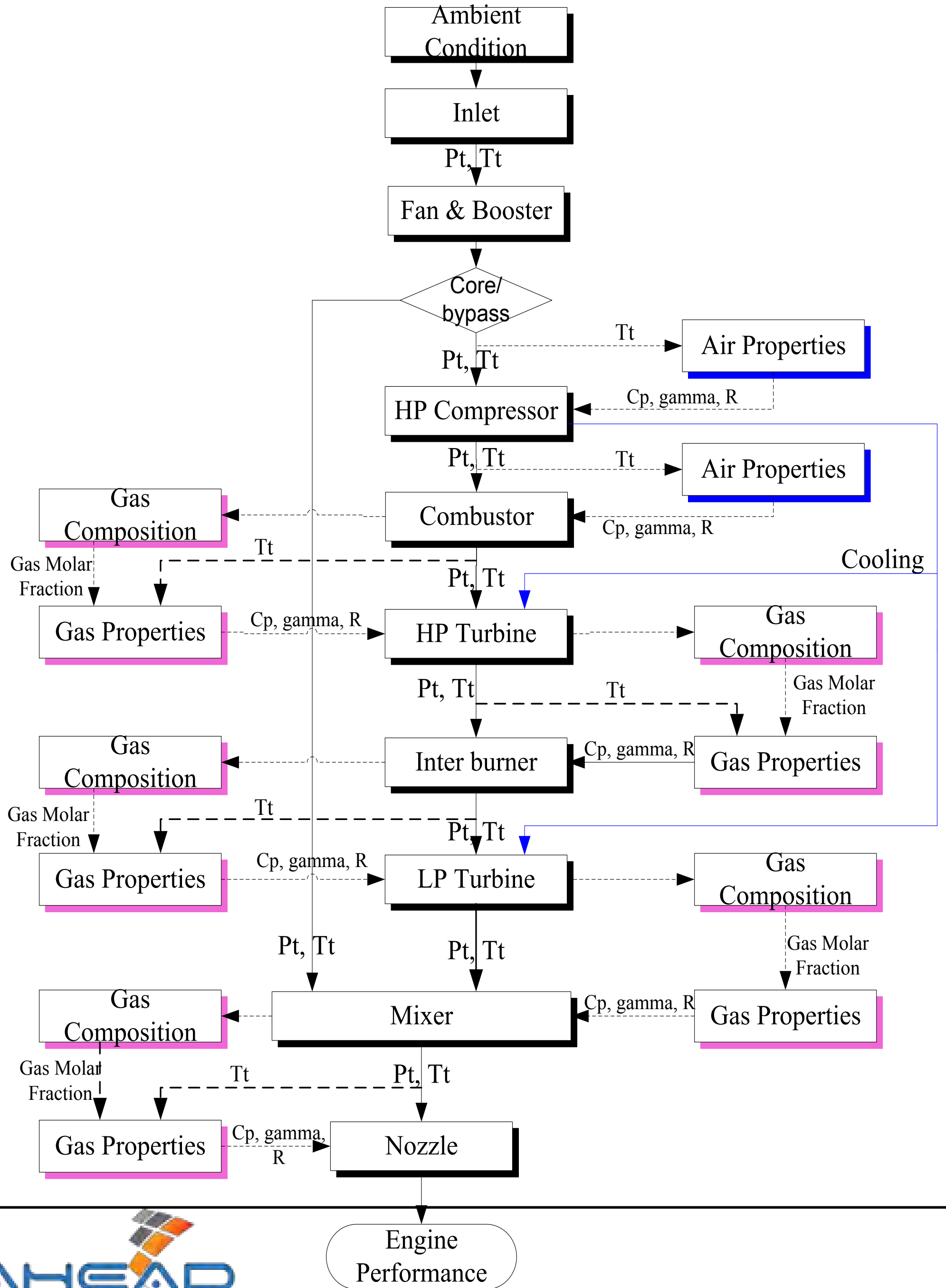
Change in contrail cirrus radiative forcing due to a replacement of conventional planes by LNG planes and an increase in flight level by about 2000m (LNGup3 -- conventional). Contrail cirrus radiative forcing increased (factor 1.4) particularly south of 45°N relative to conventional air traffic. Increases smaller than for LH2 planes.



Change in contrail cirrus radiative forcing due to a shift in flight level of LNG planes by ~2000m (LNGup3 – LNG). Contrail cirrus radiative forcing reduced in most places.

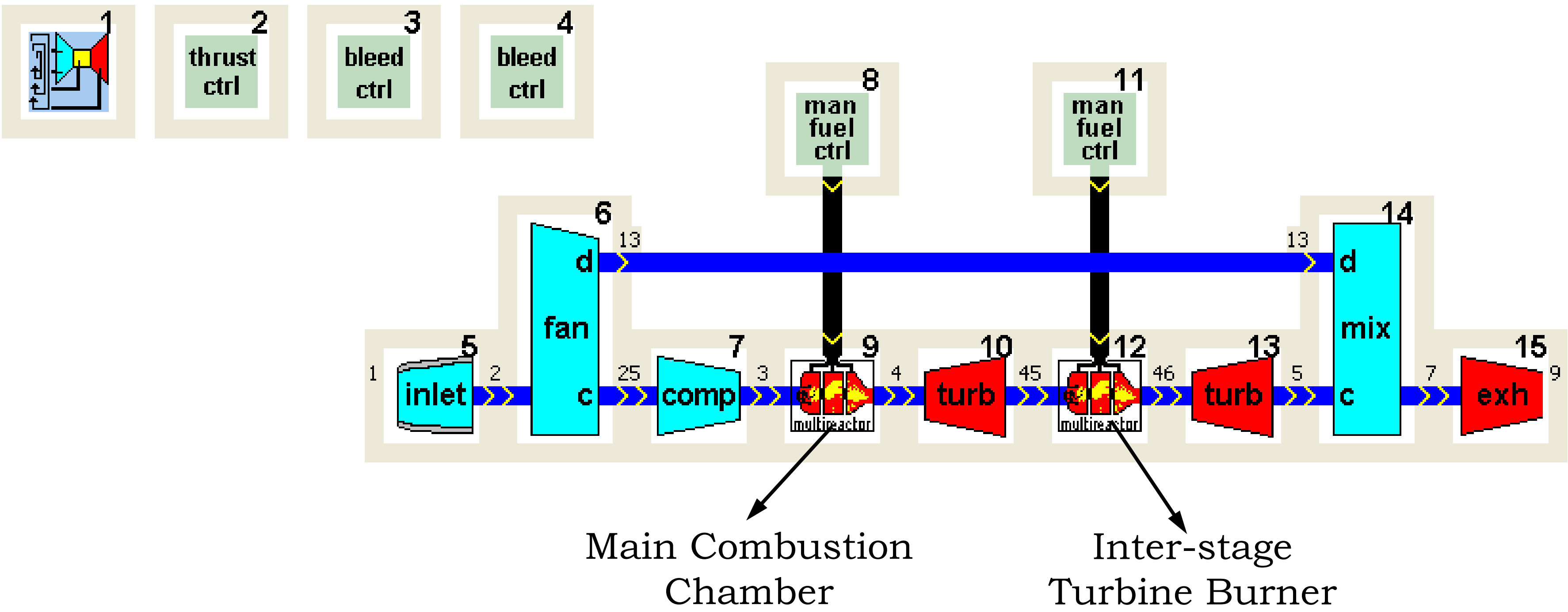
Hybrid Engine Performance

In house Thermodynamic Model

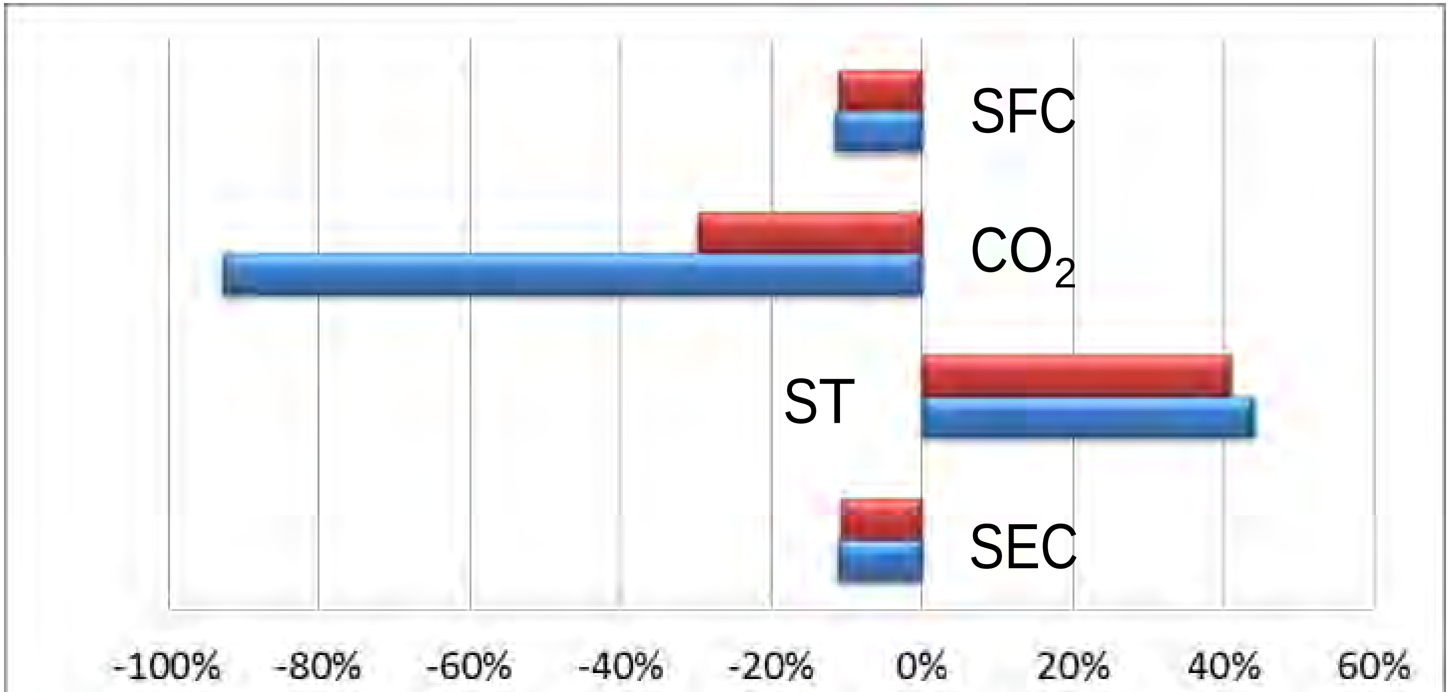


The model was validated with GSP

The Hybrid Engine Model in GSP

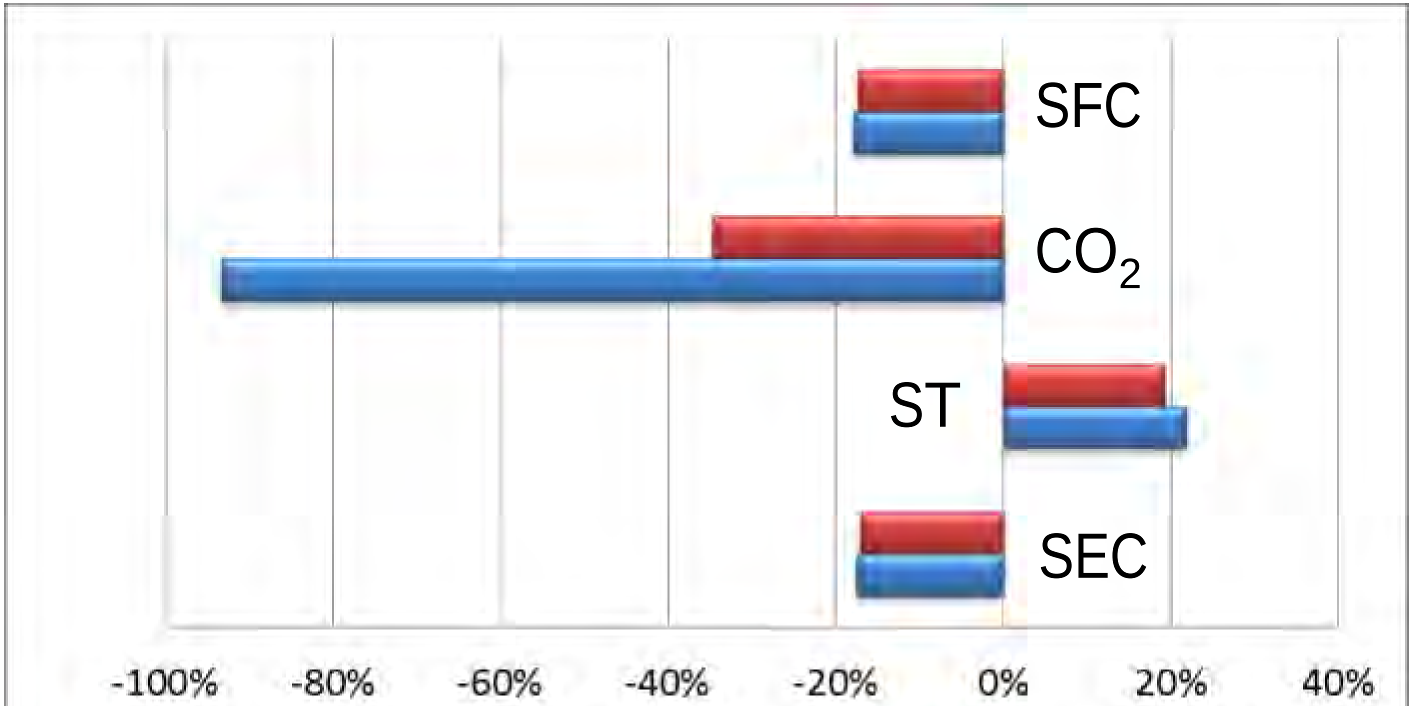


Comparison of hybrid engine with GE90-94B



	SFC [g/kN.s]	ST [N.s/kg]	CO2 [kg/s]	SEC [MJ/kN.s]
LNG	-11%	41%	-30%	-11%
LH2	-11%	44%	-93%	-12%

Comparison of hybrid engine with PW4056

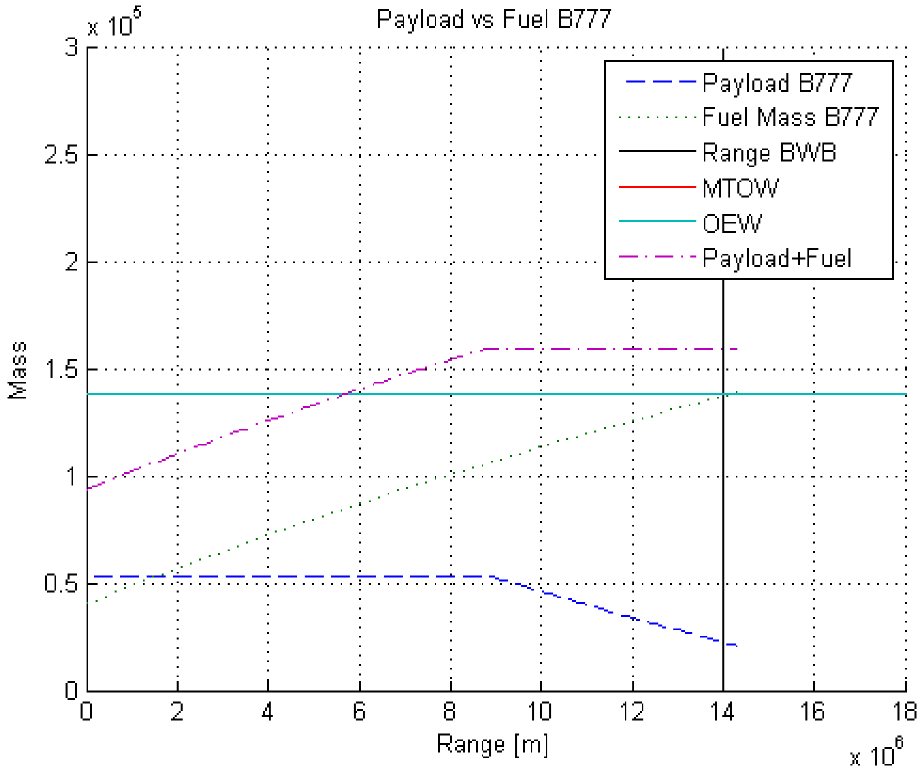


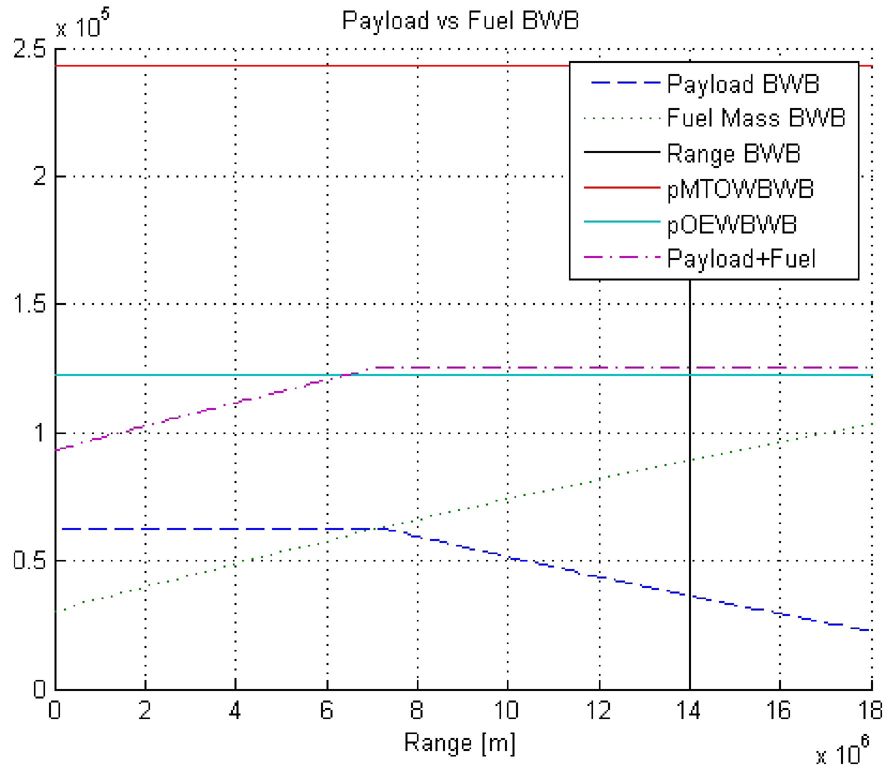
	SFC [g/kN.s]	ST [N.s/kg]	CO2 [kg/s]	SEC [MJ/kN.s]
LNG	-17%	19%	-35%	-17%
LH2	-18%	22%	-93%	-18%

Conclusion

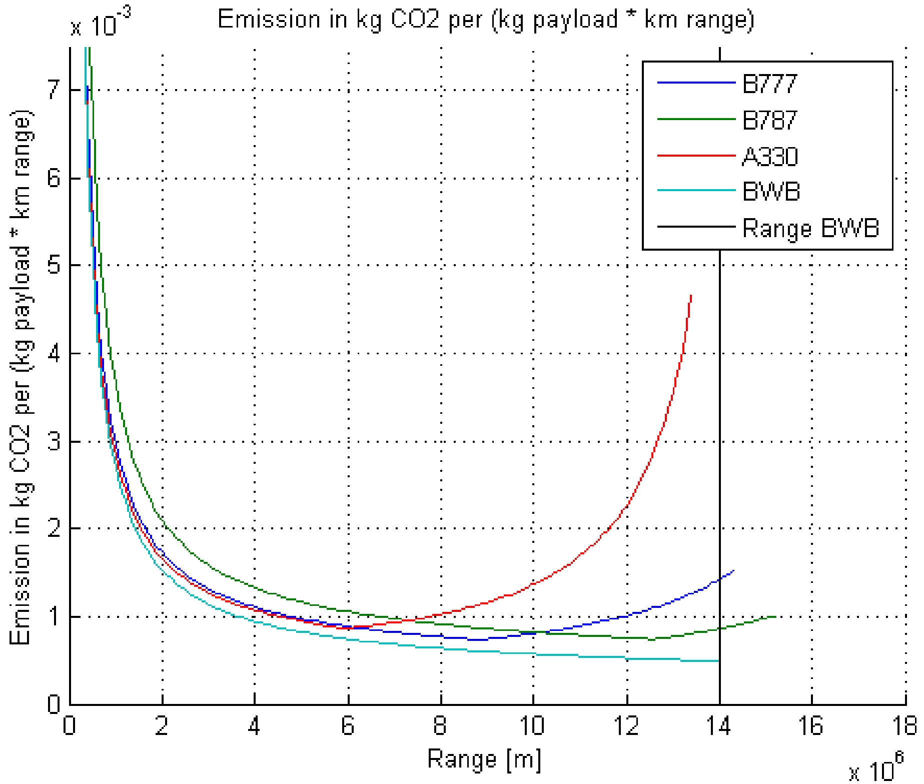
Comparison with B777-200ER (1)

Conclusion
Comparison with B777-200ER (2)





CO_2 Emission



range	**14000**	km			
Aircraft	Reduction (%)	KgCO2/(km*kg)	Payload (kg)	Passengers	kgCO2/(Passenger*km)
B777	**65.41**	0.0014189	22478	186	0.172
A330	89.267	0.0045728	5737.1	48	0.554
B787	42.913	0.00085974	28985	239	0.104
BWB	0	**0.0004908**	36400	**300**	**0.059**

The AHEAD Aircraft

Advanced Hybrid Engines for Aircraft Development AHEAD

- Delft University of Technology
- WSK PZL-Rzeszow S.A
- Technical University of Berlin
- DLR, IPA
- Israel Institute of Technology-Technion
- Ad Cuenta b.v.

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