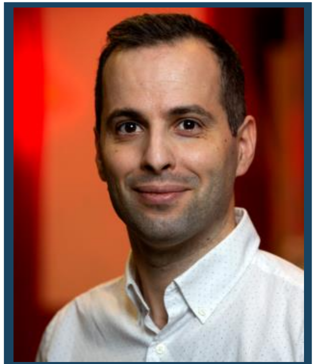
Opportunities for heat management in hydrogen fueled aircraft

UTIAS 7th International Workshop on Aviation and Climate Change (virtual),
Tomas Grönstedt, 2021-05-20

Isak Jonsson



Carlos Xisto

Tomas Grönstedt

- Preliminaries & targets
- Propulsion heat management general
- Propulsion heat management hydrogen
- Experimental activities
- Aircraft level modelling

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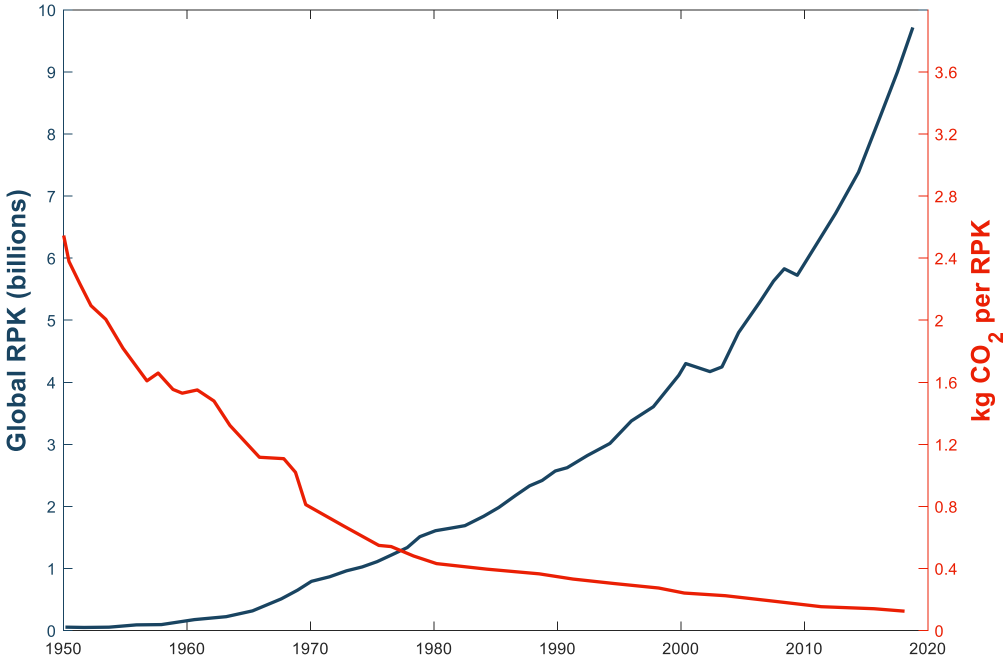
Aviation emissions

- CO_2 emissions in 2018 amounted to 918 million tons.
- Long term temperature increase depend mainly on CO_2
  - 1 kg emitted today gives 1.1 kg equivalent CO_2 in 100 years

Azar, C., Johansson, D.J.A. Valuing the non-CO_2 climate impacts of aviation. *Climatic Change* **111,** 559–579 (2012). https://doi.org/10.1007/s10584-011-0168-8

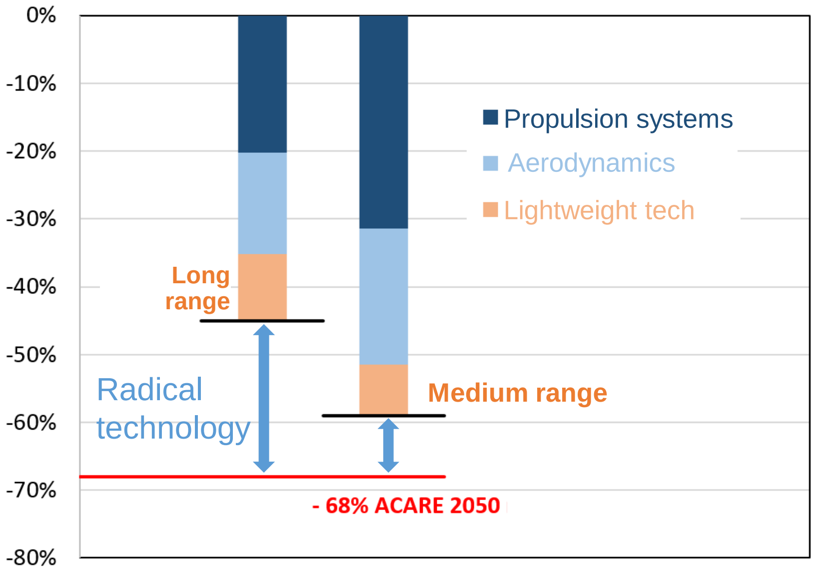


Lee et al, 2021

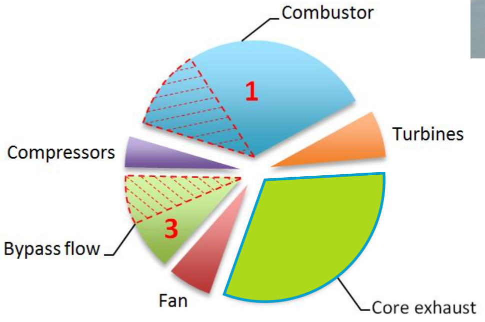
- Although emissions (kg CO_2 / RPK) have dropped by about an order of magnitude since since 1960 growth has outpaced efficiency improvement

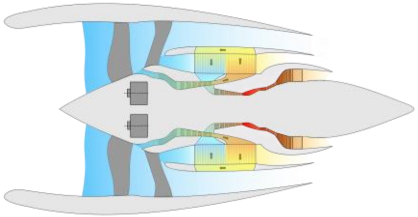
Environmental targets and their feasibility

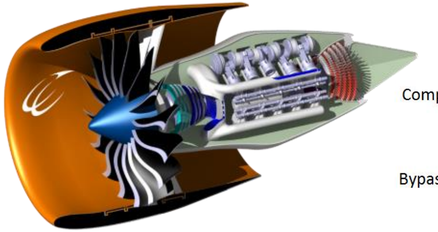
- Optimistic aircraft tech inclusion
- Very radical propulsion system
  - TRL 2 propulsion descriptions
- Perhaps possible to curb half of the growth rate

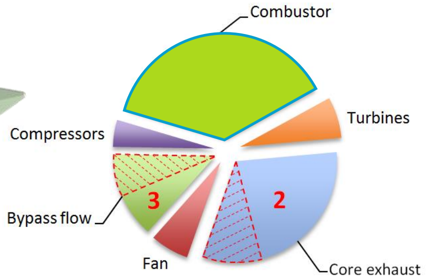


The Boxprop









Feasibility cont.

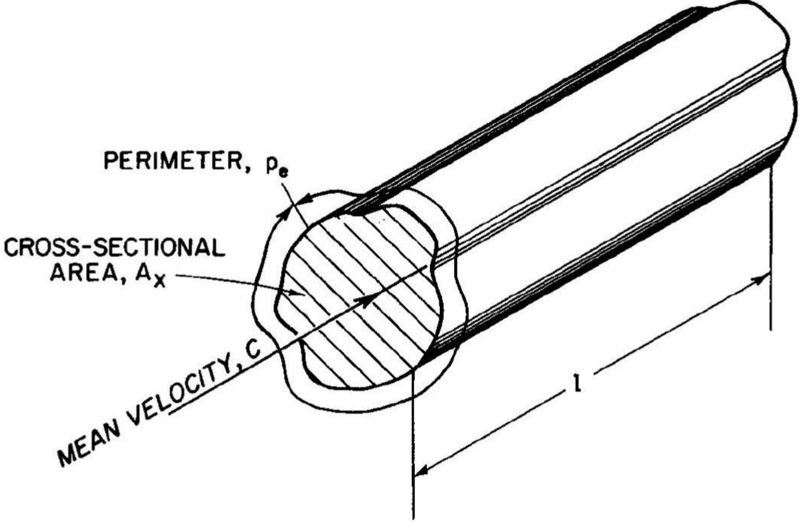
Time frame	Originator	Annual improvement
2017-2037	D. Zingg (ICAO)	1.25%
2000-2050	ACARE/EU	2.3% (68% tech. target)
2000-2050	ACARE/EU	2.7% (75% target)
2000-2050	ULTIMATE project – long range	1.2% (bl)[1], 1.5% (r)[2]
2000-2050	ULTIMATE project – short range	1.8% (bl)[1], 2.0% (r)[2]
1980-2015	L. Dray	3.2%
2015-2050	L. Dray	1.6%

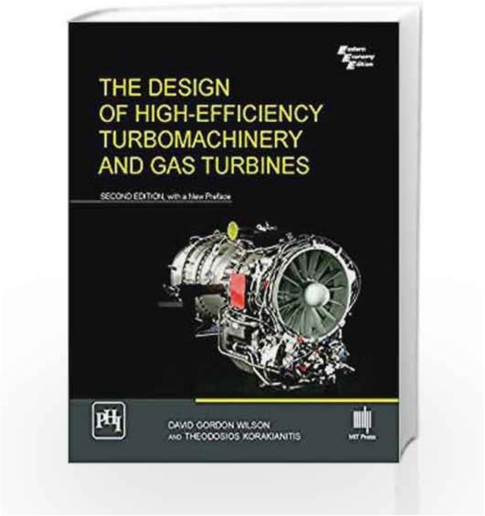
(bl)[1]= 2050 baseline

(r)[2]= 2050 radical tech

Opportunities for heat management

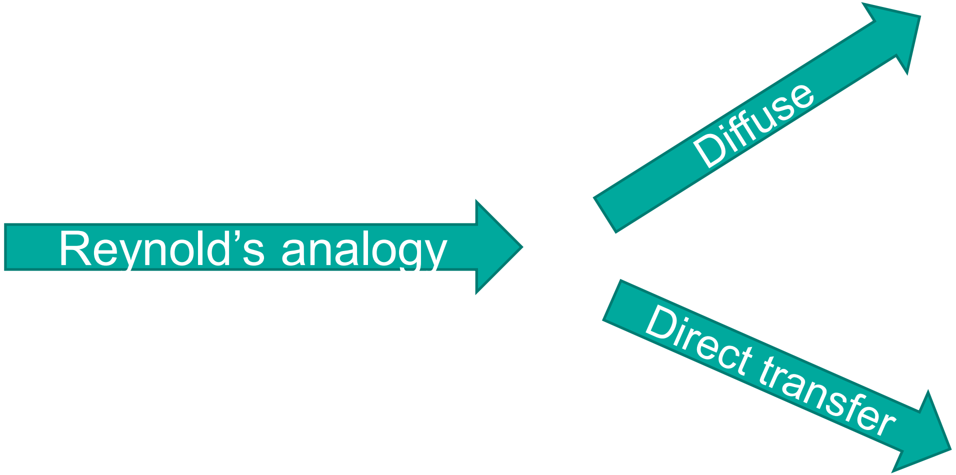
BACK TO BASICS





$$\frac{\dot{Q}}{\dot{W}} = \frac{Heat\ flow}{Pumping\ power} = \frac{\frac{\theta}{T}}{(\gamma - 1)M^2} \propto \frac{1}{M^2}$$

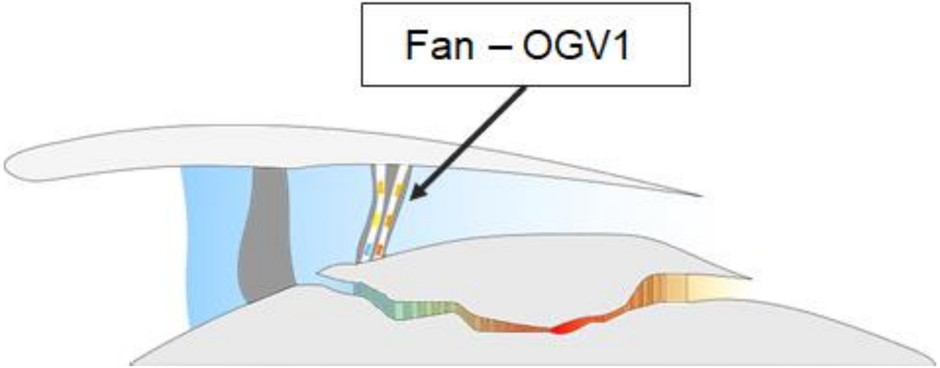
FEASIBLE PATHS FOR HEAT MANAGEMENT

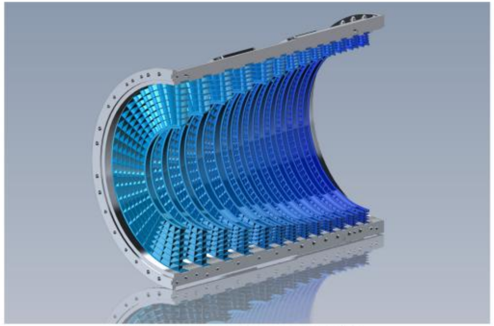


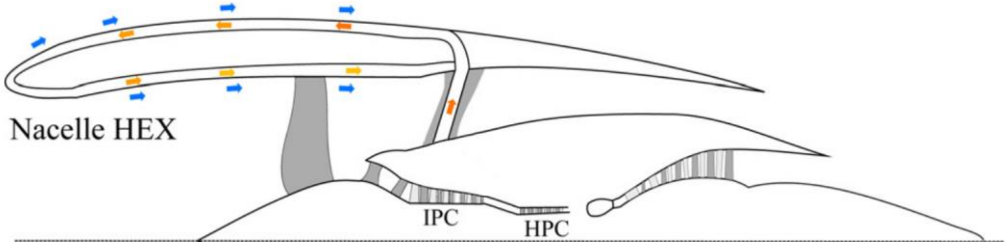
Necessary for larger heat transfers – when you have to add additional wetted surface

Feasible if existing surfaces can be used => synergistic use on smaller heat flows

Use of existing surfaces



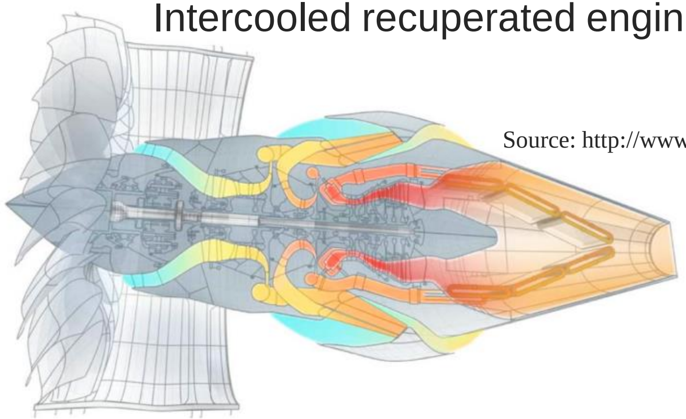

ROLLS-ROYCE MODEL 501-K COMPRESSOR HALF



Source: https://frontlineaerospace.com/technologies/isocool/

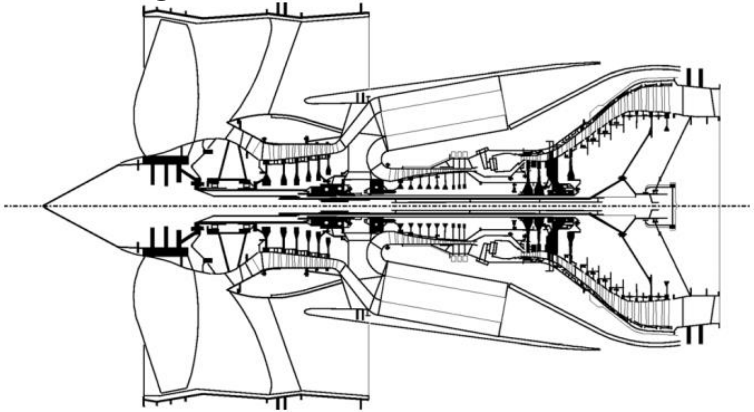
Large heat transfers

Intercooled recuperated engine

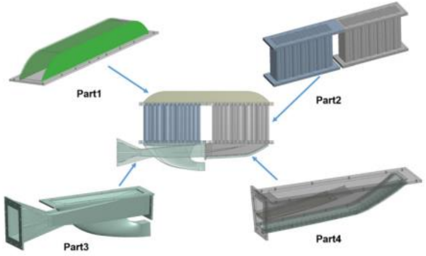


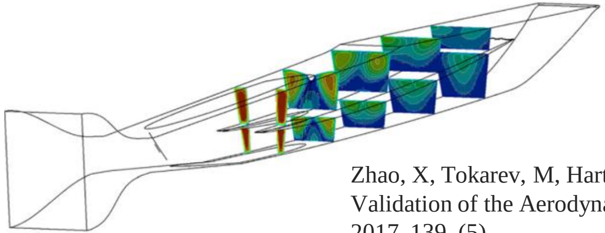
Source: http://www.newac.eu

Intercooled engine



Kyprianidis , K, G, Rolt A. M., Grönstedt T. Multidisciplinary Analysis of a Geared Fan Intercooled Core Aero-Engine, *J. Eng. Gas Turbines Power*. 136(1), Jan 2014



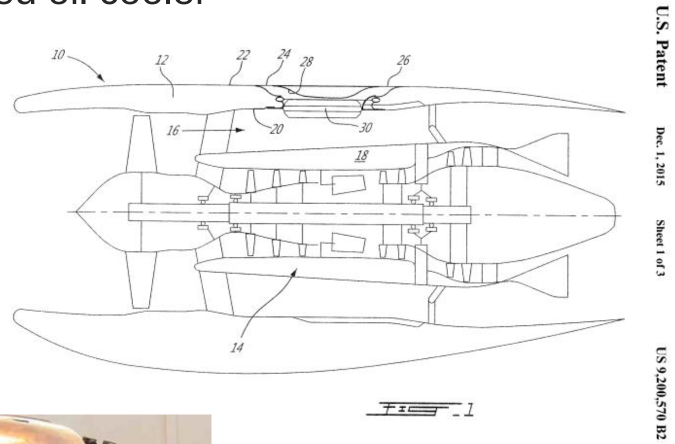


- If optimized intercooling could provide 3-5% fuel burn
  - OPR enabling
  - Use colder cooling air

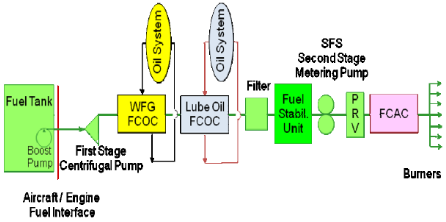
Zhao, X, Tokarev, M, Hartono, E. A., Chernoray, V. and Grönstedt T., Experimental Validation of the Aerodynamic Characteristics of an Aero-Engine Intercooler, 136(1), Jan 2017, 139, (5)

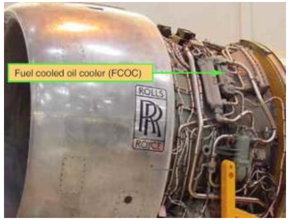
Conventional fuel heat management

Air-cooled oil cooler



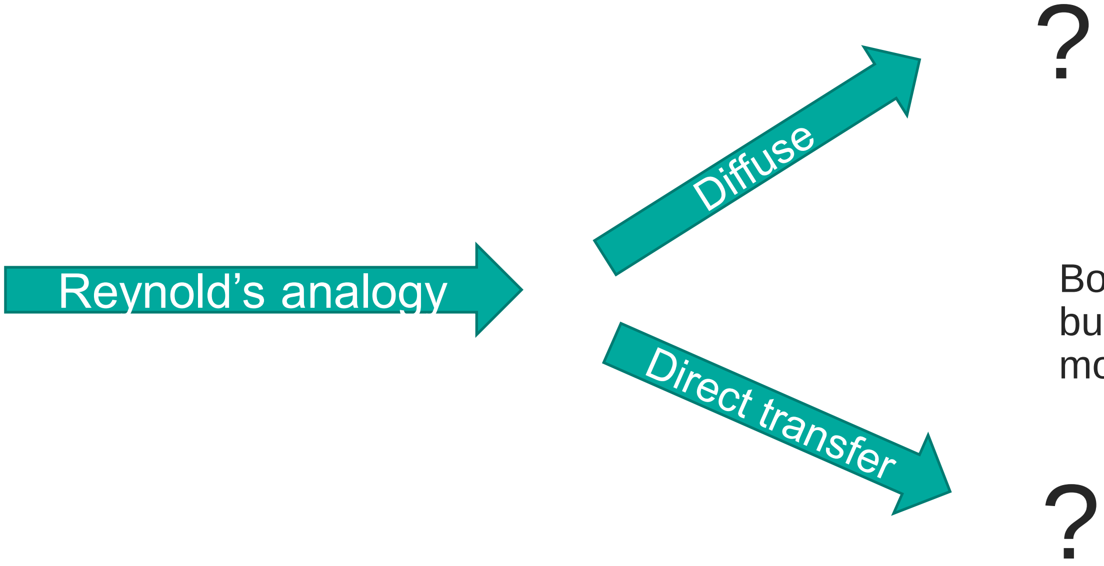
- Fuel additives to remove oxygen may increase max. temp by 200 K
- May remove air cooled oil coolers
- About 1% SFC benefit





Lundbladh, A., Donnerhack, S., Streifinger, H., Giuliani, F. and Grönstedt, T., "Future Innovative Cores for Commercial Engines", ISABE-2009-1277, Montreal, Canada

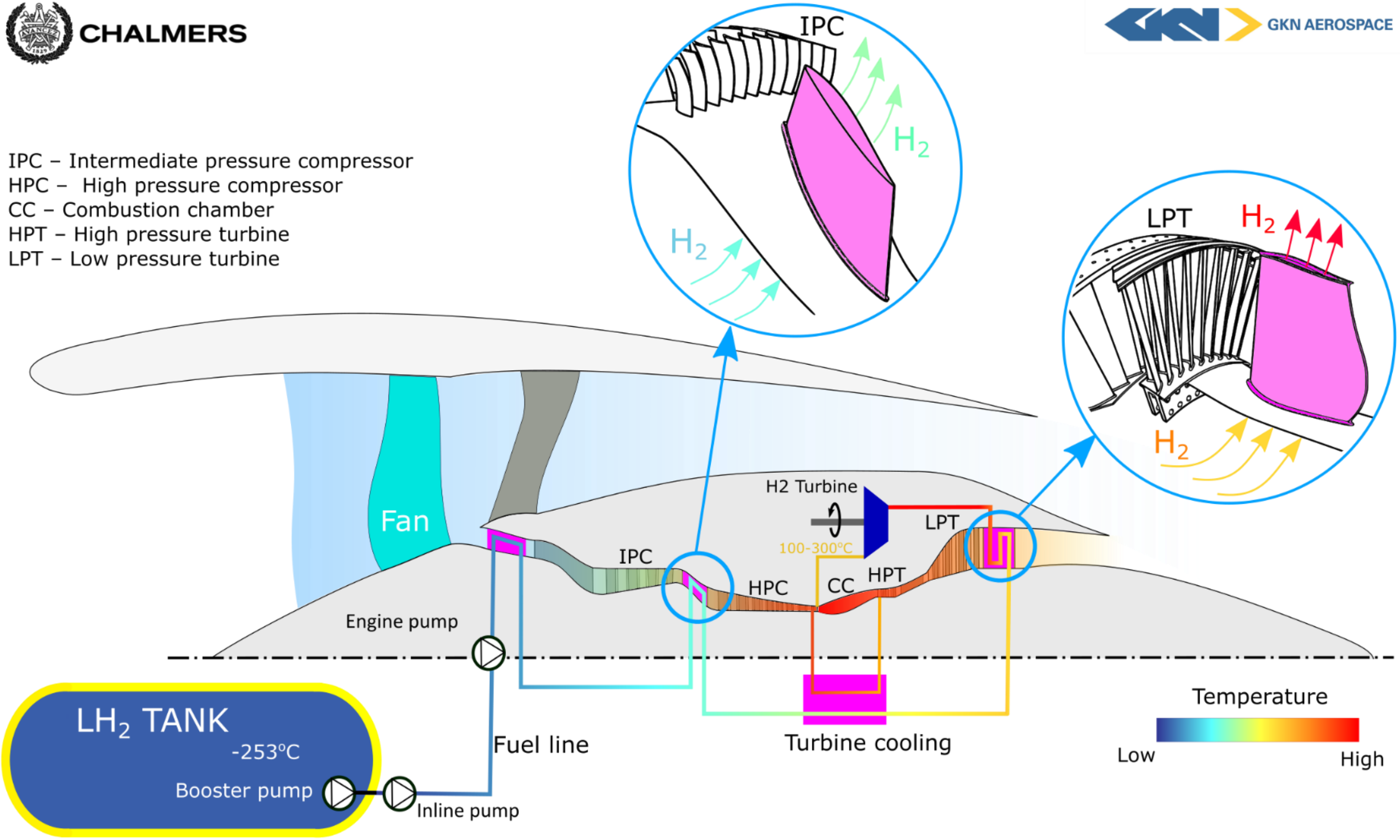
FEASIBLE PATHS FOR HYDROGEN HEAT MANAGEMENT

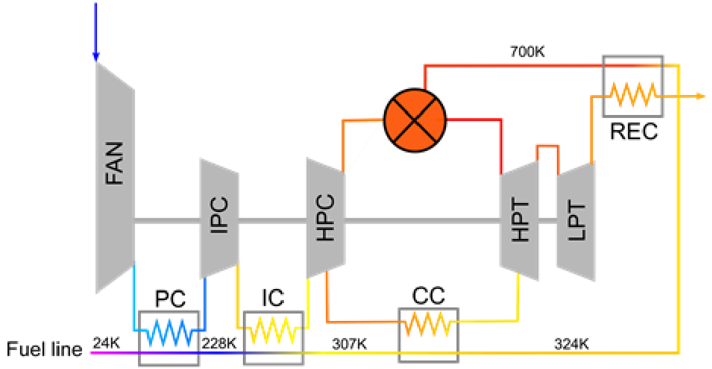


Both options feasible, but direct transfer more attractive

Hydrogen heat management

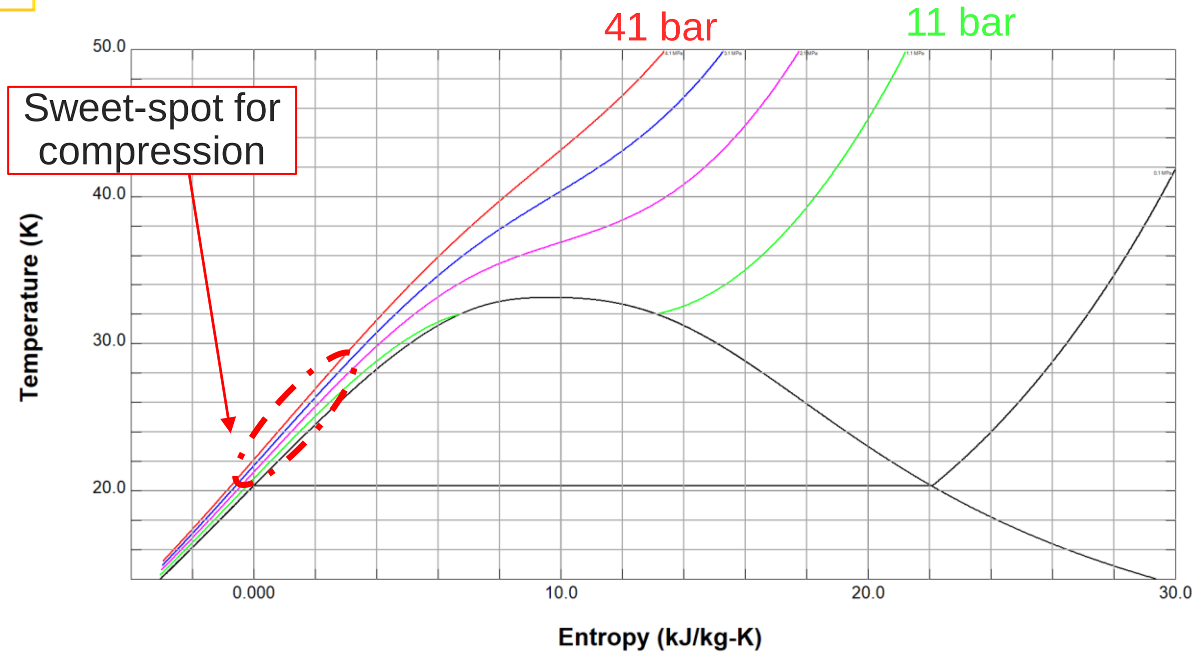
IPC – Intermediate pressure compressor
HPC – High pressure compressor
CC – Combustion chamber
HPT – High pressure turbine
LPT – Low pressure turbine



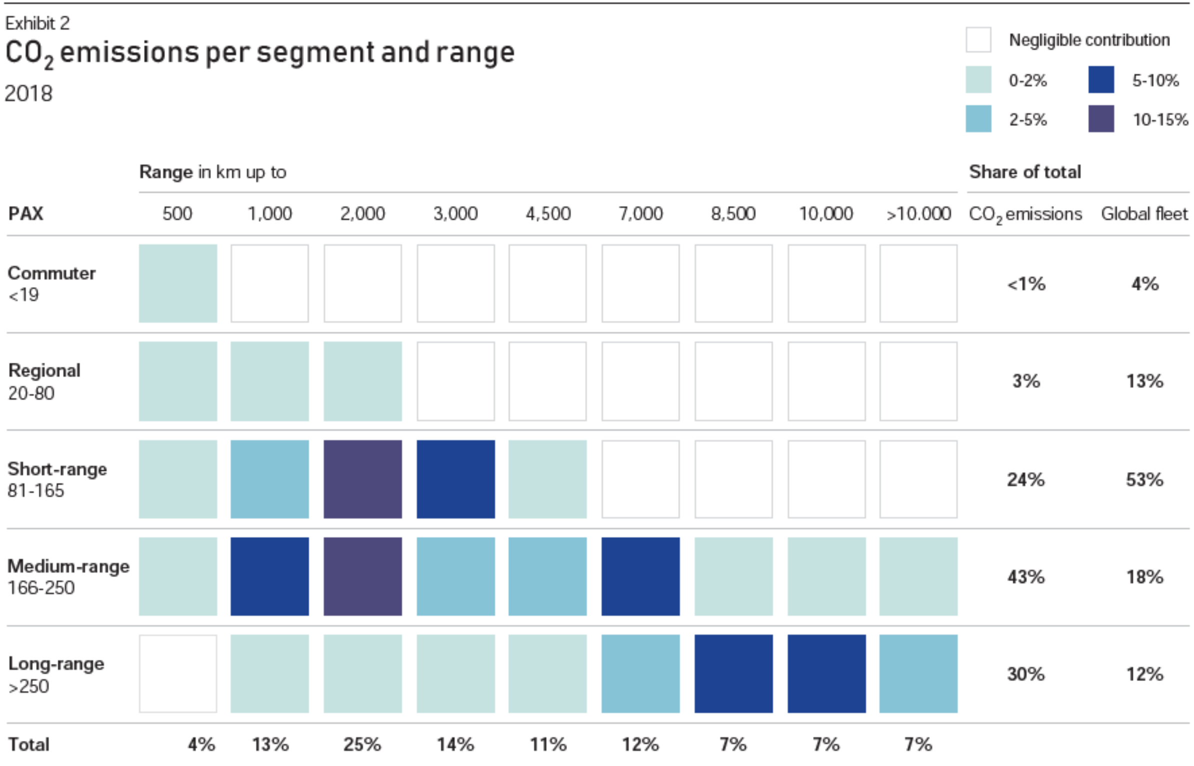


Temperature	Pressure	Enthalpy
22 K	2.3 bar	17.84 kj/kg
700 K	40 bar	9793.5 kj/kg
1000 K	40 bar	14229 kg/kg

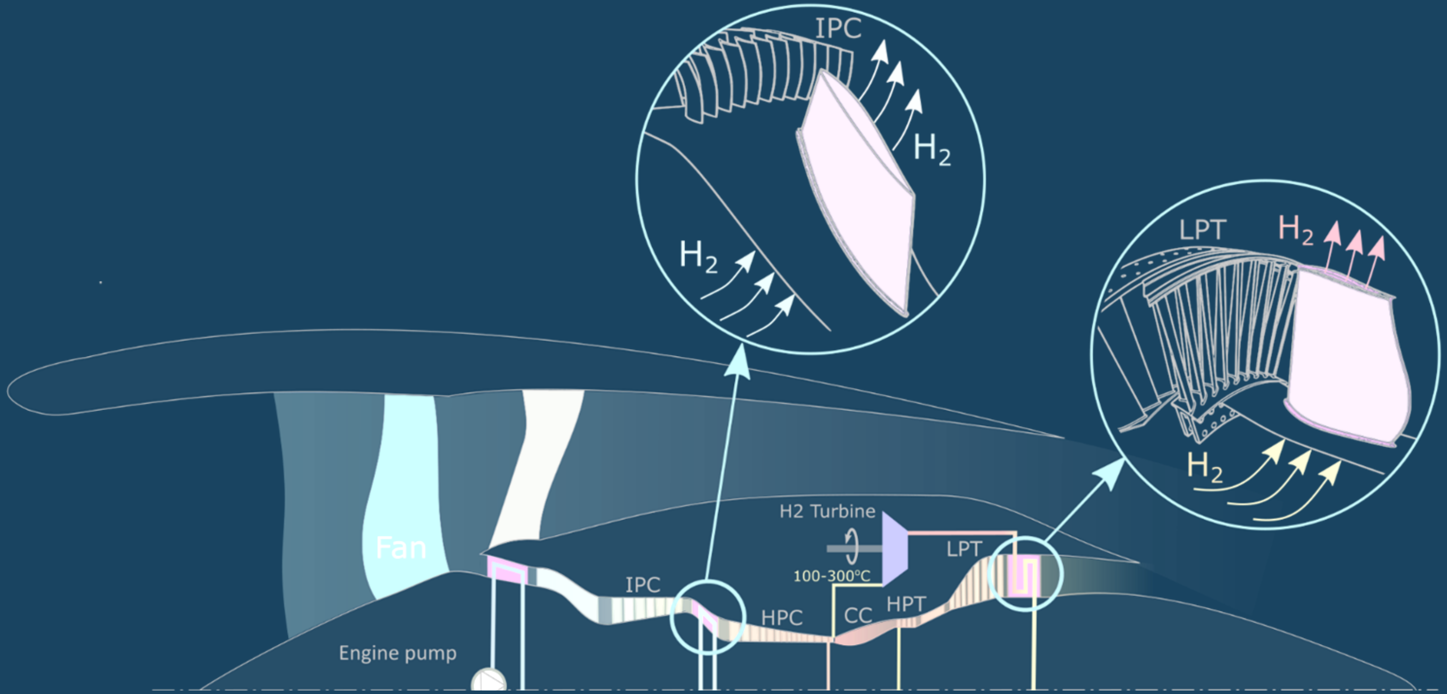
- Heat addition to fuel could easily be 10% of fuel heat value => 10% SFC!
  - Weight penalties
  - Pressure losses
- Can we gain further improvement from engine integration?



Climate relevance of range



Exploring integration experimentally



ENABLE·H2

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Heat management test facilities

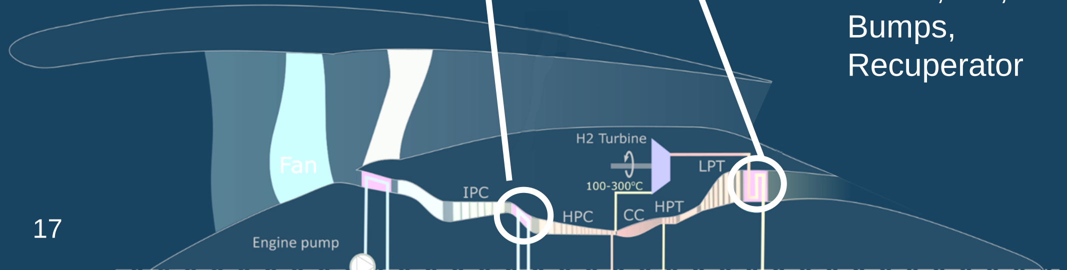
- Two annular test rigs now up and running
- Realistic-Re-number
- TRL 3-4
- Designed for detailed HEX studies

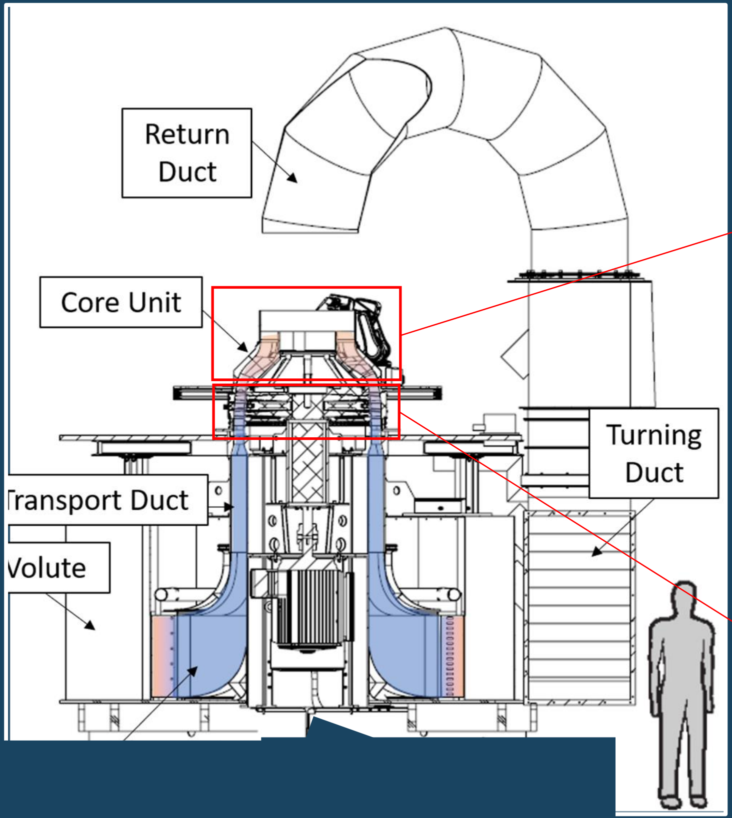
2 Stage LPC + ICD

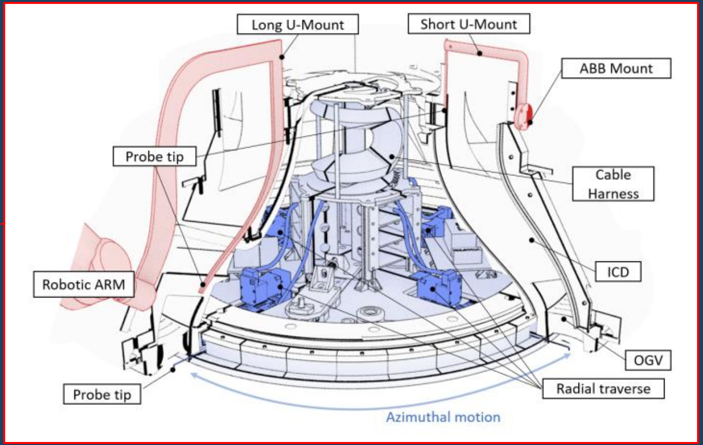
Finalizing stage
ENABLEH2
Synergies in ICD

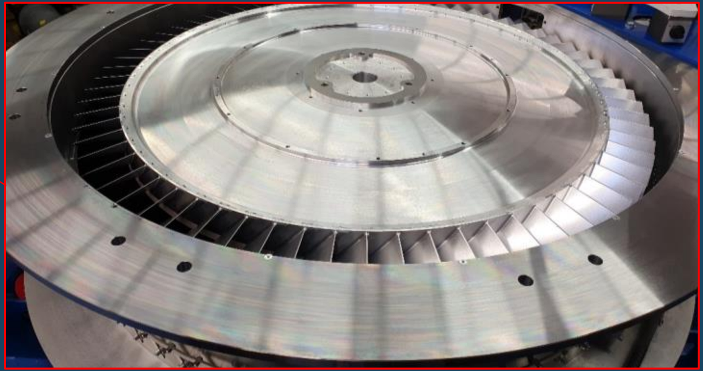
1 Stage LPT + TRS

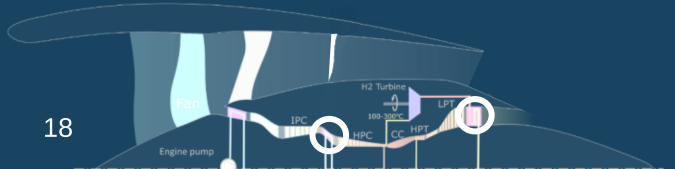
2017
Welds, NC,
Bumps,
Recuperator



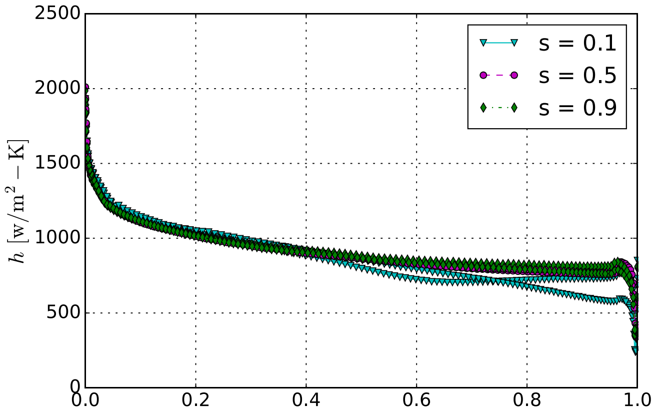

Return Duct
Core Unit
Turning Duct
Transport Duct
Volute

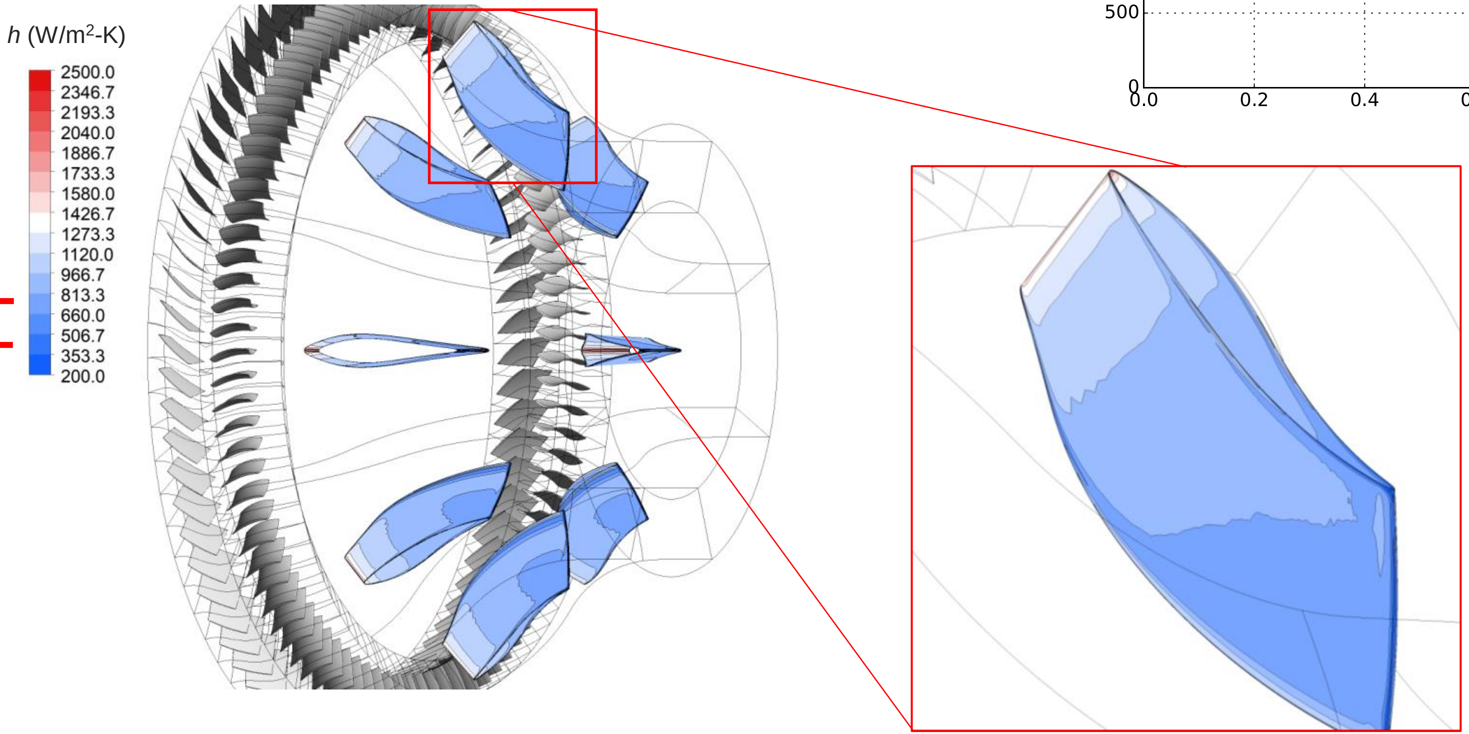

Long U-Mount
Short U-Mount
ABB Mount
Probe tip
Cable Harness
Robotic ARM
ICD
OGV
Probe tip
Radial traverse
Azimuthal motion

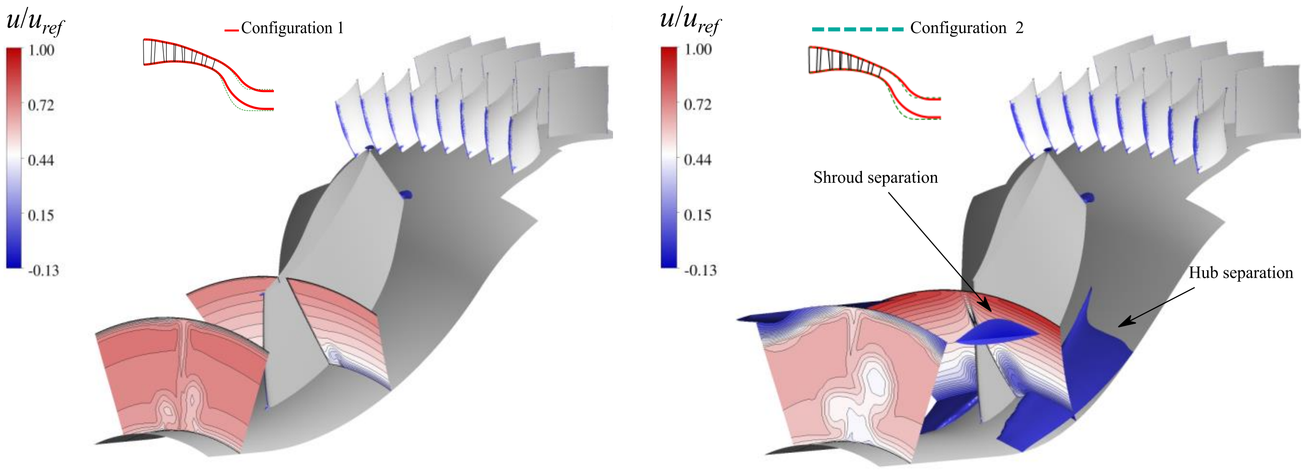



H2 Turbine
LPT
IPC
HPC
CC
HPT
Engine pump

- Usage of existing turbomachinery surfaces
- High heat-transfer rate per unit area at cruise condition
- Limited wetted area
    - Use shroud, hub and add splitter-vane







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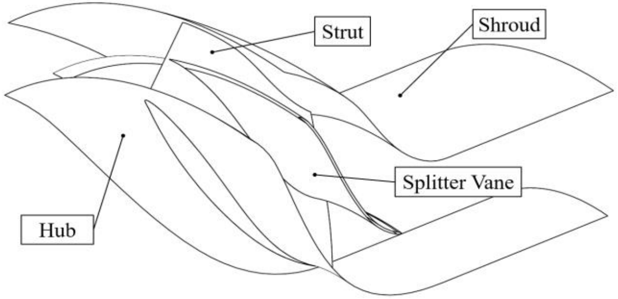
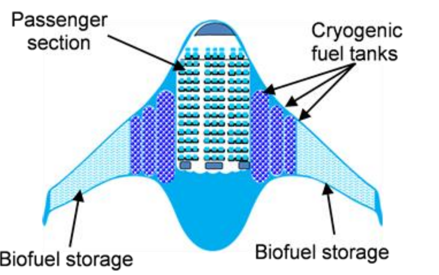
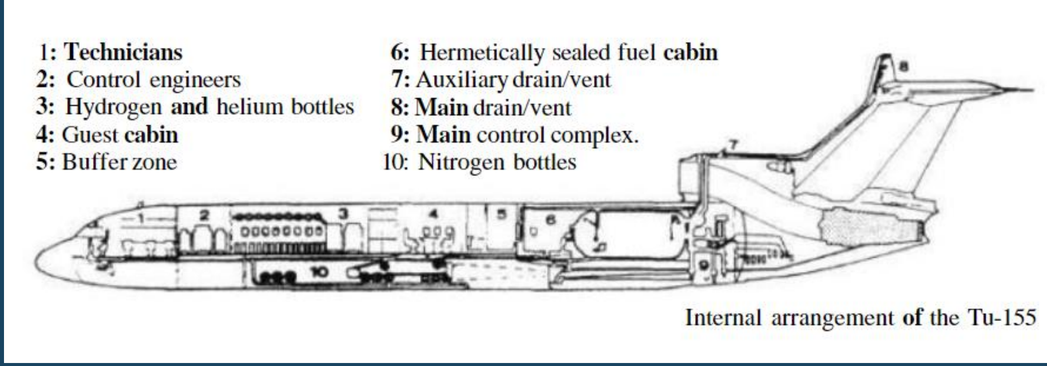
- Aggressive designs lead to flow separation
- Increased pressure loss in duct
- Penalties in compressor performance and surge margin
- Explore synergies with heat rejection



The aircraft level – ENABLEH2

AHEAD project





The more we get the longer we reach

Efficiency

Batteries

Hydrogen

Synfuels

Range

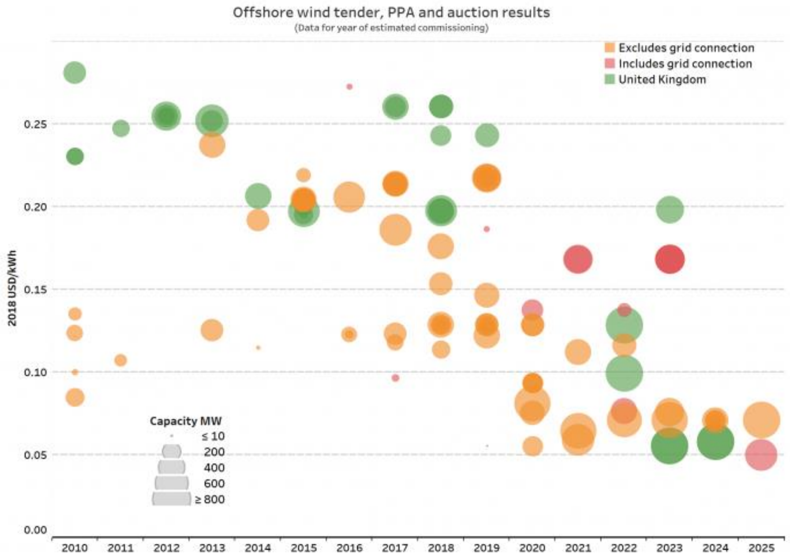
8 TWh ???
(with 6500 Wh/kg batteries)

22 TWh (Sweden)

50 TWh ???

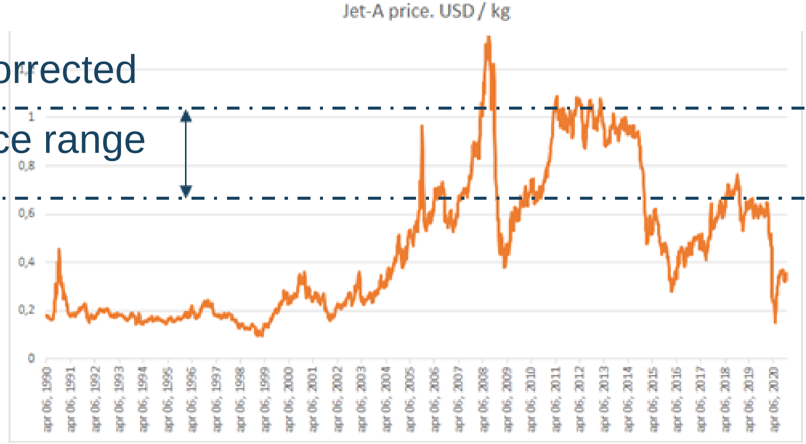
Fuel price prediction

- Predictions are difficult, especially about the future.
- Electrolysis about 50 kWh/kg
- Liquefaction 7 kWh/kg target.
- Green hydrogen from off-shore wind 2-3 USD / kg on long-term
- Solar is going through the floor



Heat value corrected

hydrogen price range



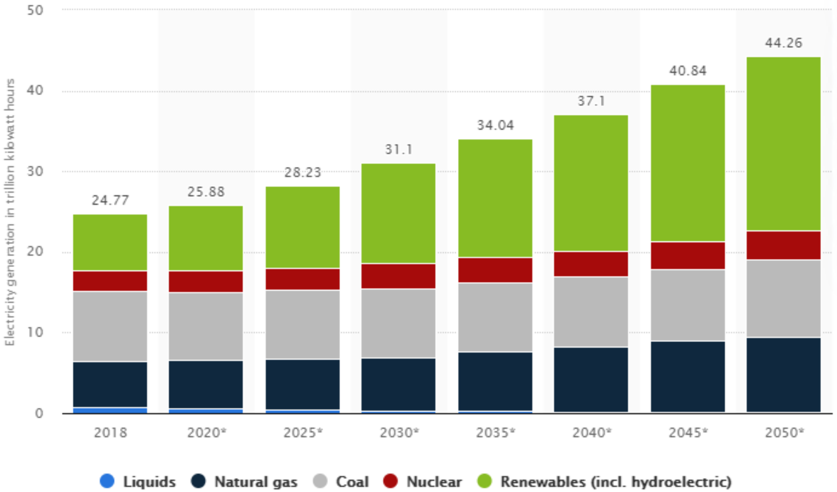
HOW MUCH ELECTRICITY CAN WE HAVE?!

Assuming

- 60 kWh / kg hydrogen
- 2018 fuel usage
- Same thermal efficiency
- 6.3 PWh
- ~25% of the projected green energy in 2050

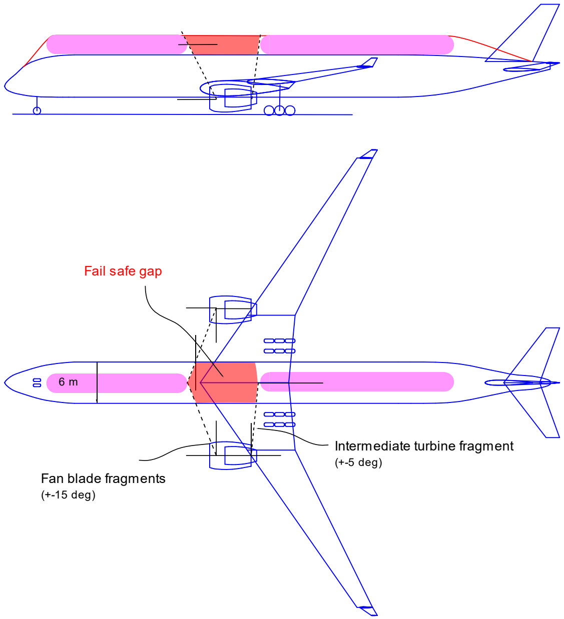
Even more for electrofuels

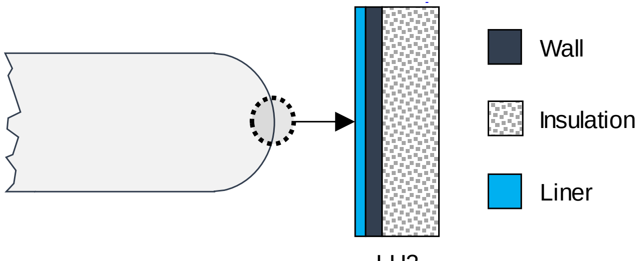
2050*	
• Liquids	0.17
• Natural gas	9.25
• Coal	9.6
• Nuclear	3.58
• Renewables (incl. hydroelectric)	21.66

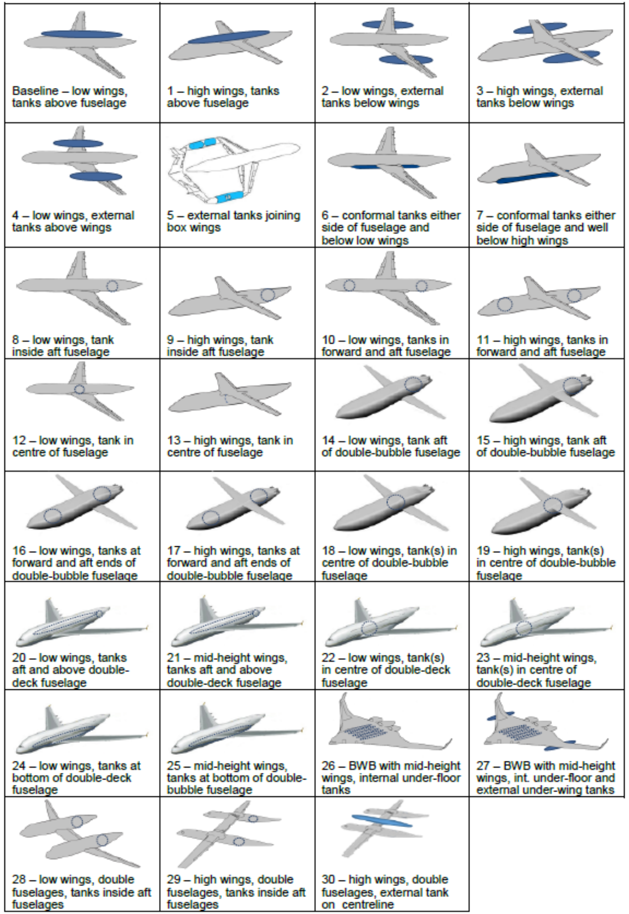


Cryogenic hydrogen tanks

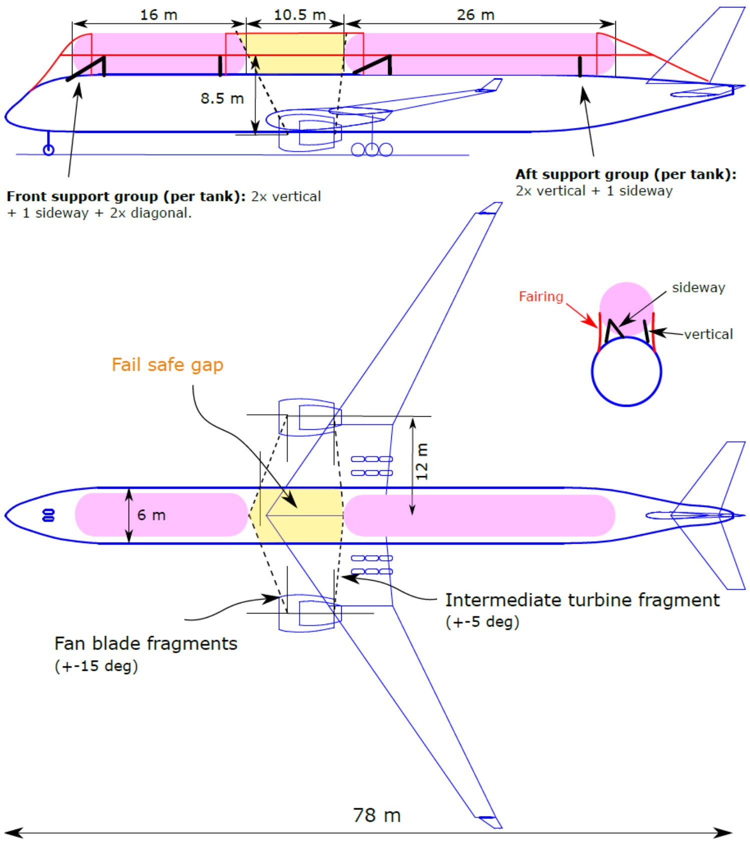
- ENABLEH2 study.
- Chalmers concept follows simple existing idea
- Focus innovation on propulsion system / fuel heat system
- Insulated foam tanks are low TRL
- Double walled vacuum tanks are heavy (difficult with longer ranges)
- Polyvinylchloride rigid closed cell





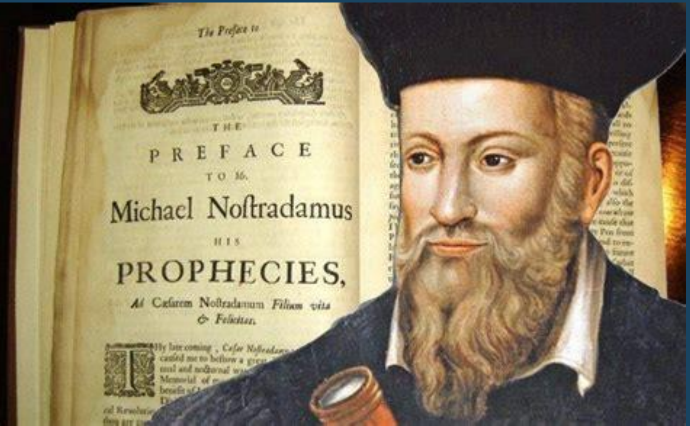


Rompokos, P, Rolt A, Nalianda D, Isekveren A T, Senné C, Grönstedt T., Hamidreza A., Synergistic technology combinations for future commercial aircraft using liquid hydrogen", Journal of Engineering for Gas Turbines and Power, Volume143, Issue, 7, 2021



	Jet-A (2020)	Jet-A (2050)	LH2 (2050)	LH2 versus Jet- A (rel.)
MTOW (kg)	338,500	294,500	284,800	0.97
OEW (kg)	167,700	152,300	194,300	1.28
L/D	19.1	20.6	17.9	0.87
Wetted area fuselage (m^2)	1300	1300	1970	1.52
LH_2 tank volume (m^3)	-	-	714	-
LH_2 tank weight (kg) + structures and Fairing	-	-	26,500	-
Cruise TSFC (mg/N/s)	14.1	12.5	4.5	0.36
Engine thrust SLS (lbf)	104,000	92,260	107,00	1.15
T/W	0.279	0.285	0.34	1.19
Mission Fuel (kg)	113,586	85,284	38,200	0.45
Energy use MJ/PAX/km	0.85	0.64	0.80	1.25
Energy use (rel. to 2020)	Datum	-28%	-11%	-

Hydrogen aircraft: when



NOW → 2028

Electrofuels

Hydrogen

Guessing the future

Generations	Hydrogen fuel	Electrofuel
2028 (N1)	Hydrogen demonstrator + new single aisle ?	
2035 (N2)	New hydrogen medium range aircraft + conventional twin aisle?	New single aisle + twin aisle?
2045 (N3)	Next generation hydrogen propulsion / aircraft	Back to radical tech.

AVANCEZ

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