Hydrogen aircraft of the future: Technology, potential and performance

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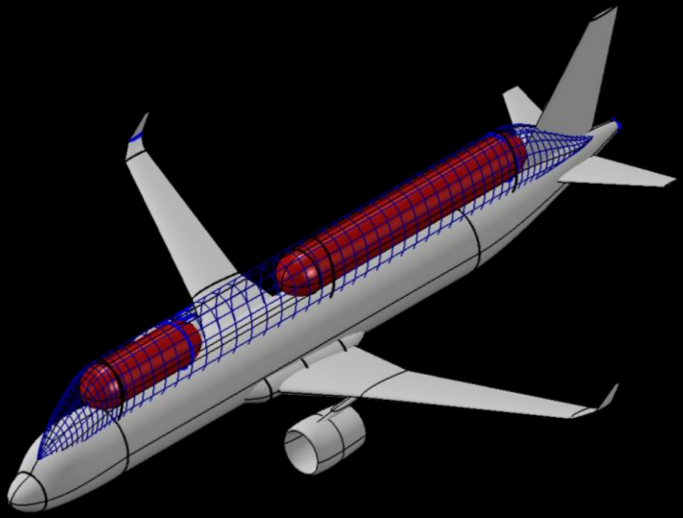

Major contributions also by: Carlos Xisto, Isak Jonsson and Christian Svensson

1. Can the flightpath 2050 targets be reached?

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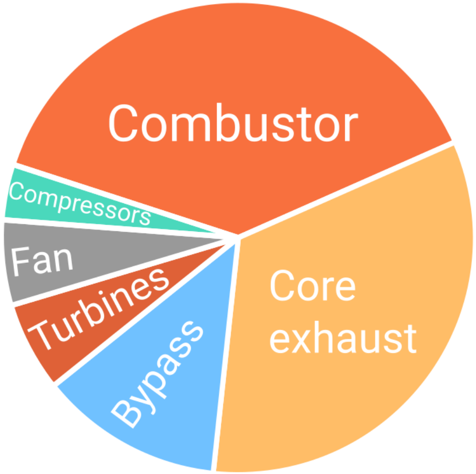
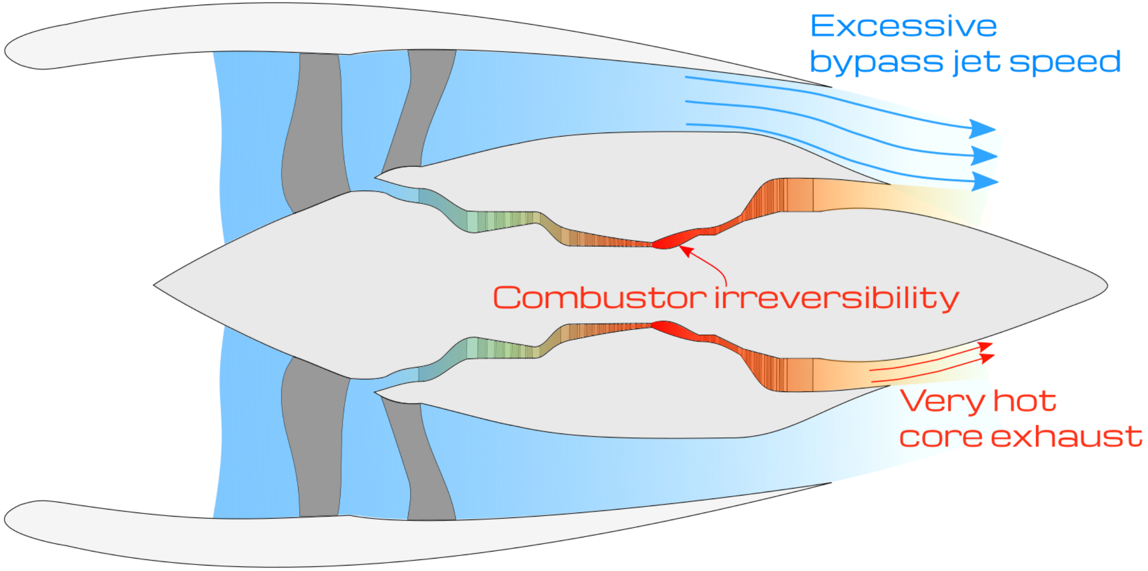
ULTIMATE (EU project - 2015 – 2018)

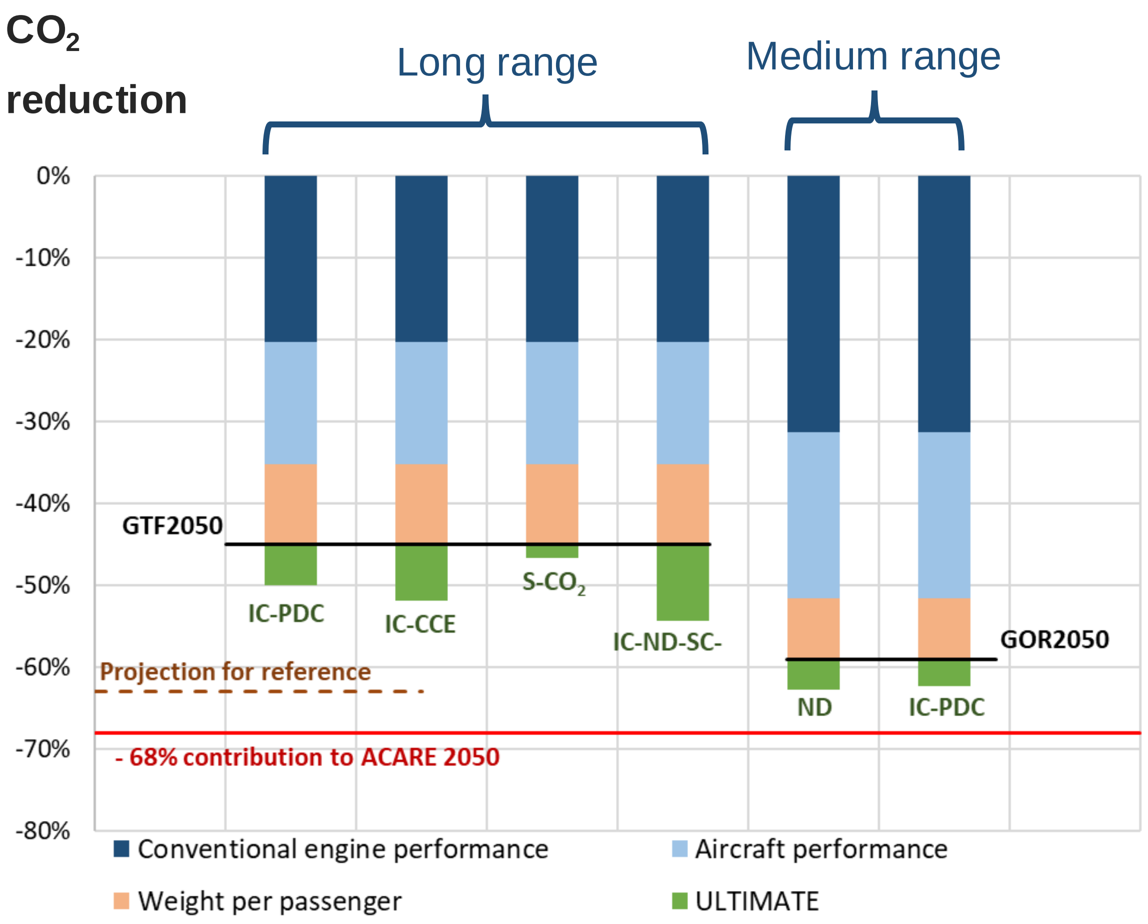
Ultra Low emission Technology Innovations for Mid-century Aircraft Turbine Engines





+ quite optimistic technology insertion for aircraft !

P. Heinemann, P. Panagiotou, Patrick Vratny, S. Kaiser, M. Hornung and K. Yakinthos, "Advanced Tube and Wing Aircraft for Year 2050 Timeframe," in 55th AIAA Aerospace Sciences Meeting , Grapevine, Texas, USA, 2017

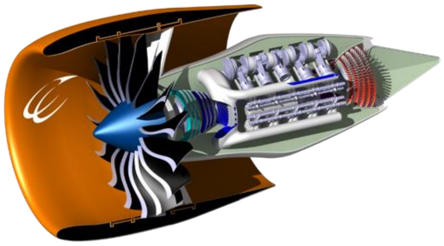


IC = Intercooled

PDC = Pulse detonation combustion

CCE = Composite Cycle Engine

ND = Nutating Disc



Can the targets be reached?

Probably not.

2. How far would the flightpath 2050 targets get us?

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Climate impact of targets

How far would they get us?
Quite far actually!

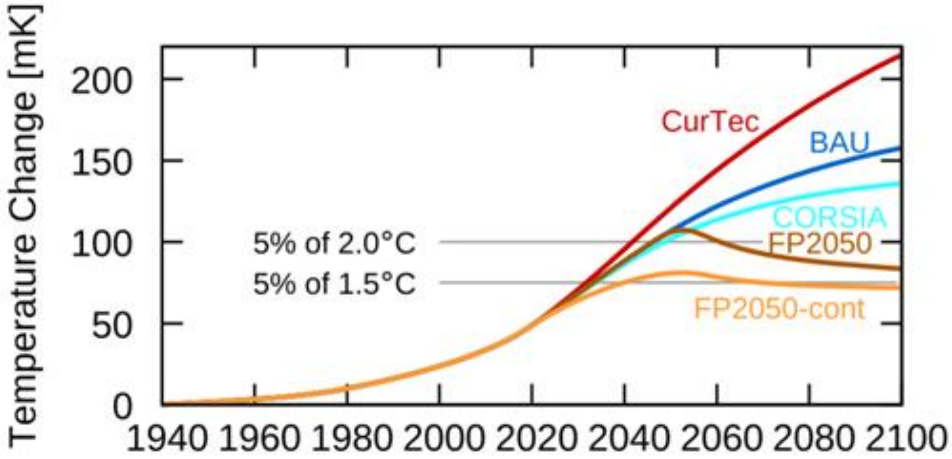

Fig. 2 Near-surface temperature change of five scenarios including CO_2 and non-CO_2-effects.

Grewe, V., Gangoli Rao, A., Grönstedt, T. *et al.* Evaluating the climate impact of aviation emission scenarios towards the Paris agreement including COVID-19 effects. *Nat Commun* **12,** 3841 (2021). https://doi.org/10.1038/s41467-021-24091-y

1. Reachable - hardly
2. Enough - almost

We need new fuels!

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Hydrogen can remove a large share of CO_2 emissions.

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Efficiency

Batteries

~ 5% (up to 500 km)[1]

Hydrogen

~ 52% (up to 3000 km)[1]

Synfuels

All ranges flown today

Range

Emissions split (percentages above) from:

[1]Graver, Brandon, Kevin Zhang, and Dan Rutherford. "emissions from commercial aviation, 2018." ICCT, 2019.

Rest of presentation will explore hydrogen aircraft:

1. Energy use vs range

2. Propulsion heat management

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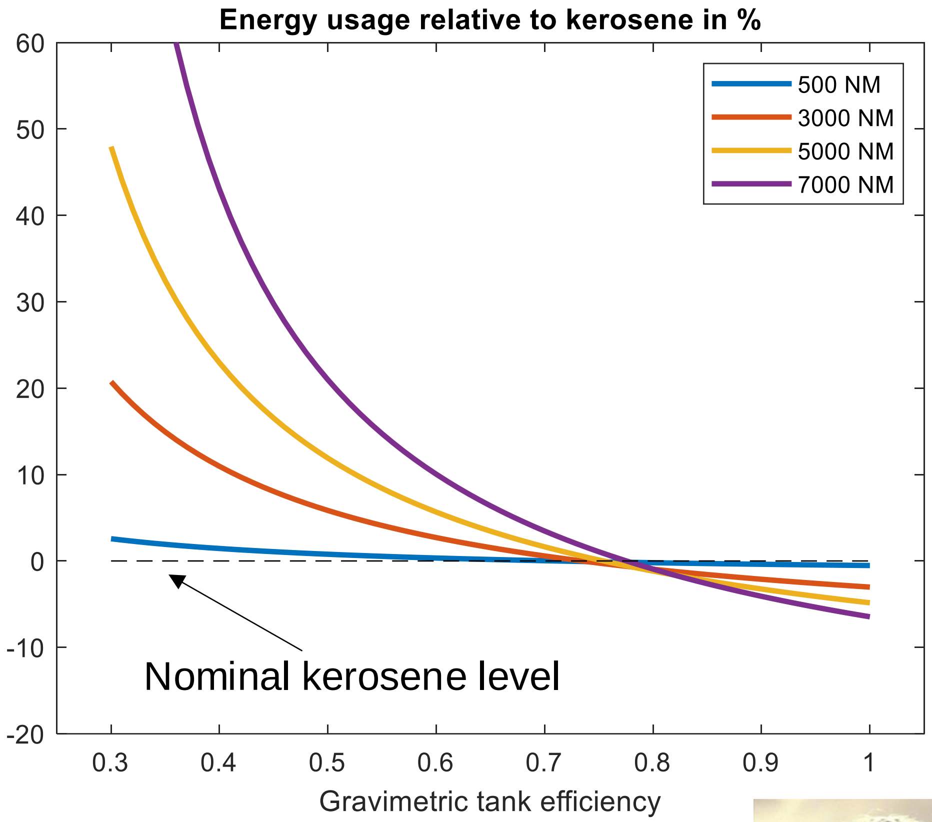
Range – back of the envelope

- Energy need:
  - Breguet range for 777-200ER/GE90
  - Including added drag
  - Including added mass

- Now let's take a closer look at these aircraft



Shorter ranges

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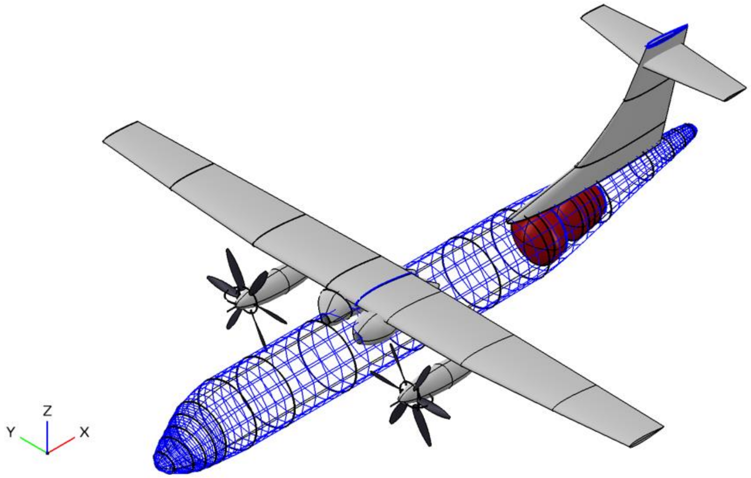
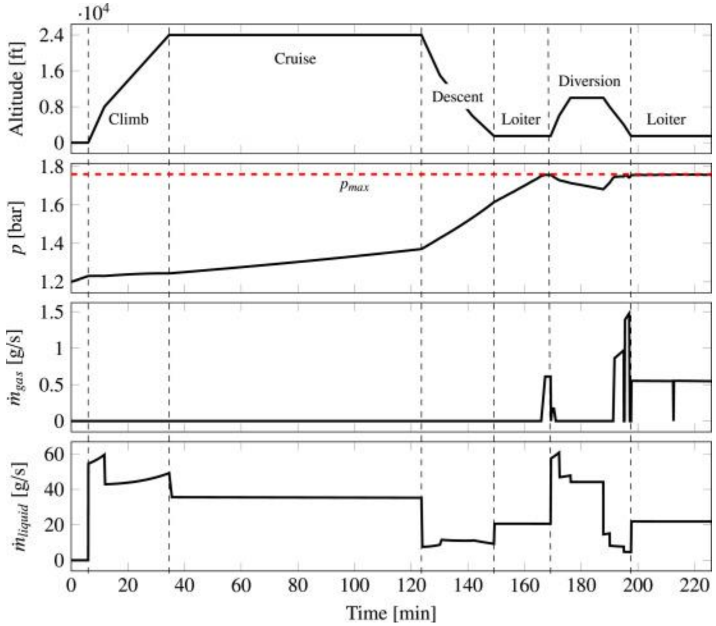
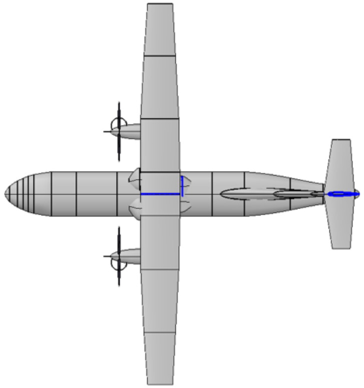
Air travel in the Nordic region

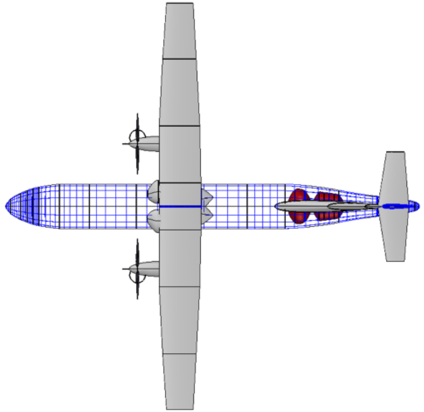
- State of the art fuel cell (PEM)
- Dynamic tank model
    - Optimization for design mission





Parameter	ATR 42-500	LH2 PEMFC
MTOW	18.600 kg	21.049 kg
MZFW	17.000 kg	20.573 kg
Wing loading	341 kg/m²	341 kg/m²
Fuselage length	22.7 m	26.5 m
Fuselage fineness ratio	7.68	8.98
Fuselage wetted area*	208.2 m²	243.6 m²
Wing reference area	54.5 m²	61.7 m²
Wing aspect ratio*	10.9	10.9
Wing-span	24.57 m	26.16 m
Wing taper ratio*	0.56	0.56
Flap configuration	Single-slotted	Single-slotted
Lift over drag	16.254	16.480
Energy use		Approx. -25% (FC benefit). +11% if FC efficiency benefit is not included

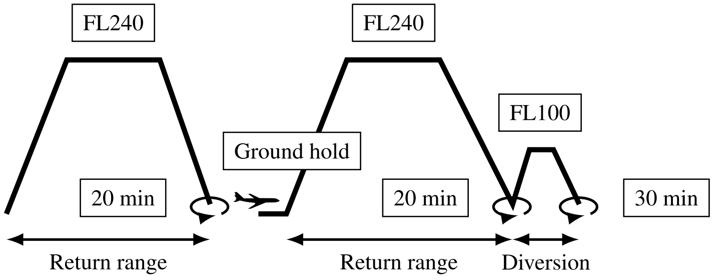




Svensson, C., Oliveira, A. A., & Grönstedt, T. (2024). Hydrogen fuel cell aircraft for the Nordic market. *International Journal of Hydrogen Energy*, *61*, 650-663.

Return-without-refuel

- Close to 80% of theoretical range for a 12 hour on-ground scenario
- Heavier, well insulated tanks gives the most operational flexibility with a small loss in range
- We could operate whole Sweden with initially only three hydrogen hubs



Medium range

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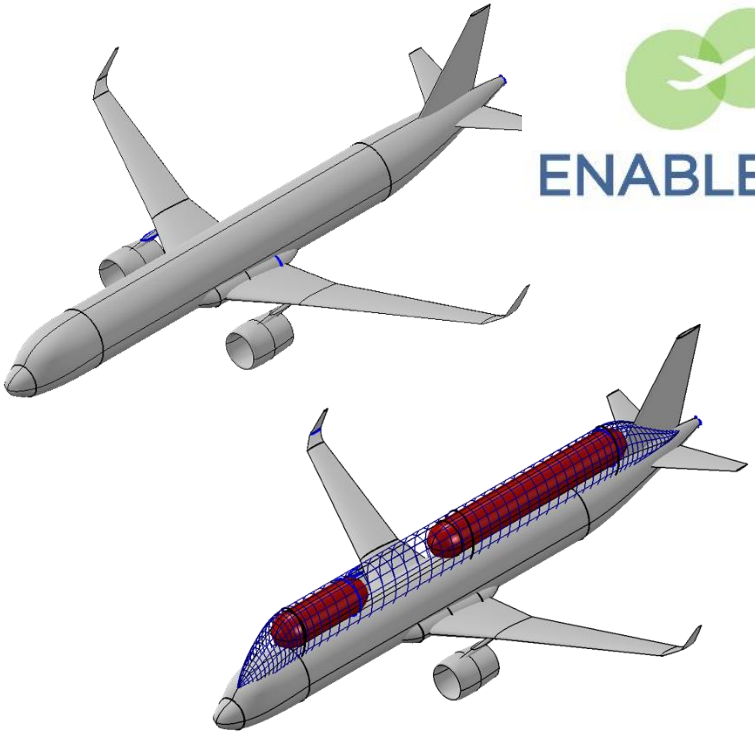
Parameter	Jet A-1 MR 2050	LH2 MR 2050
Mach	0.78	0.78
Maximum Takeoff Weight (MTOW) (kg)	77100	78600
Operational Empty Weight (OEW) (kg)	41400	51300 (+23.9%)
Design range (NM/km)	3000 NM / 5556 km	
Tank Volume (including insulation) (m^3)	-	35.4/80.2
Tank Weight (kg) (Incl. Structure/Fairing)	-	6505
Gravimetric efficiency	-	49.1% (67.6)⁺
Mission fuel mass including reserves (kg)	14746	6280
Wing Loading (kg/m^2)	670	596
Wing Area (m^2)	117	133
Block Energy Use (MJ/PAX/km)	0.490	0.579 (+18%)
FPR (cruise/toc)	1.41/1.49	1.43/1.52
OPR (cruise/toc)	43.8/52.5	42.6/50.4
BPR (cruise/toc)	16.64/15.03	18.5/17
SFC (mg/Ns) (cruise/toc)	12.6	4.41/4.42

⁺Excluding fairing mass



ENABLE·H2

- Increased wing loading not possible due to higher OEW for hydrogen aircraft

Long range

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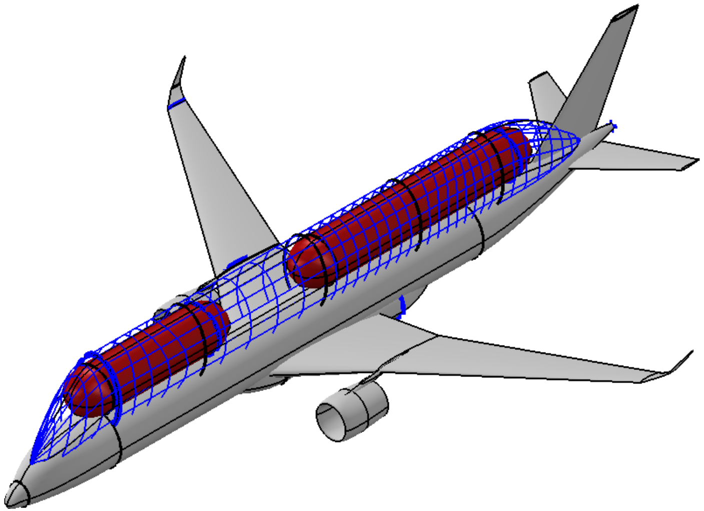
Parameter	Jet A-1 LR 2050	LH2 LR 2050
Mach	0.85	0.85
Maximum Takeoff Weight (MTOW) (kg)	293700	284000
Operational Empty Weight (OEW) (kg)	152300	194300 (+27.6%)
Range (NM/km)	7500/13890	
Tank Volume (including insulation) (m^3)	-	714
Tank Weight (kg) (Incl. Structure/Fairing)	-	26524
Gravimetric efficiency	-	61.4% (72.5%)+
Mission fuel mass including reserves (kg)		42100
Wing Loading (kg/m^2)	735	601.5
Wing Area (m^2)	410	477
Span (m)	69	70.5
Block Energy Use (MJ/PAX/km)	0.641 MJ/PAX	0.797 MJ/Pax (+24%)
FPR (cruise/toc)	1.42/1.47	1.39/1.45
OPR (cruise/toc)	68.2/75.3	67.4/76.5
BPR	19.6/19.2	23.1/21.7
SFC (mg/Ns) (cruise/toc)	12.24/12.51	4.34/4.35

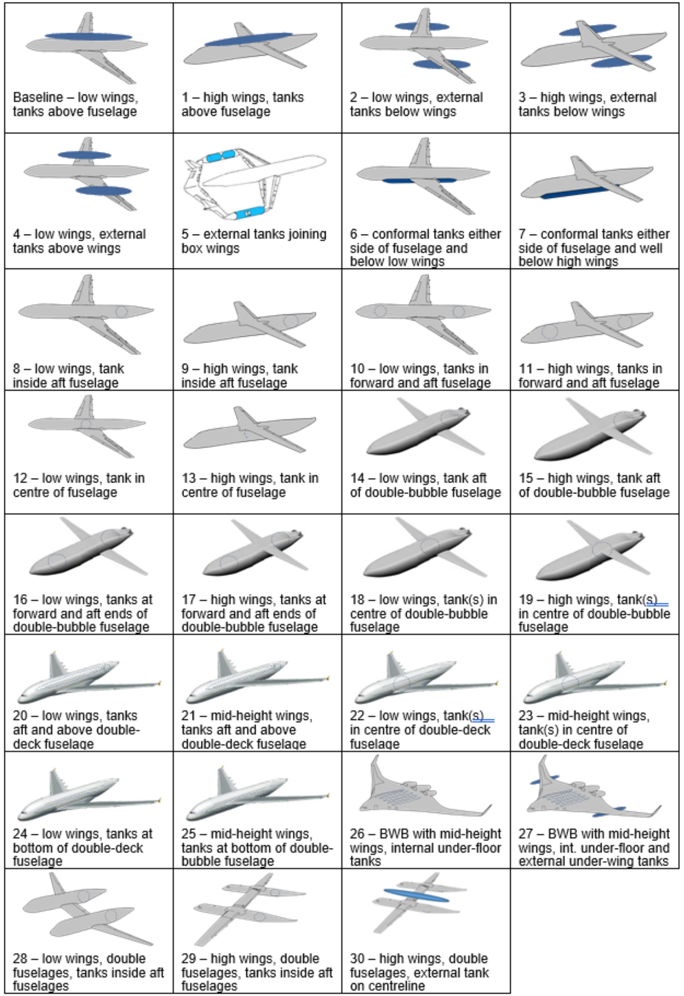
+Excluding fairing mass

ENABLE·H2



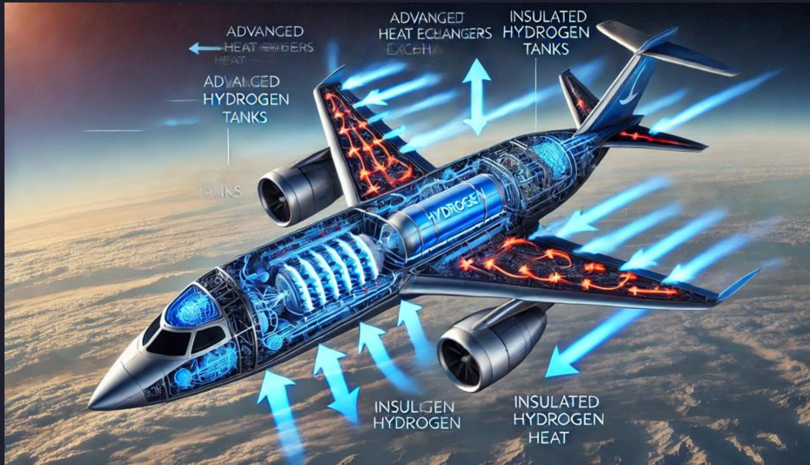
Xisto, Carlos, and Anders Lundbladh. "Design and performance of liquid hydrogen fueled aircraft for year 2050 EIS." *33rd Congress of the international council of the aeronautical sciences*. 2022.

- All hydrogen aircraft ranges seem feasible
- Potentially large advantages for fuel cell aircraft if integration is successful
- Tank technology critical for longer ranges
- Synergy between advanced airframe designs and storage improves performance but is not necessary



Rompokos, P., Rolt, A., Nalianda, D., Isikveren, A. T., Senné, C., Gronstedt, T., & Abedi, H. (2021). Synergistic technology combinations for future commercial aircraft using liquid hydrogen. *Journal of Engineering for Gas Turbines and Power*, *143*(7), 071017.

Heat management



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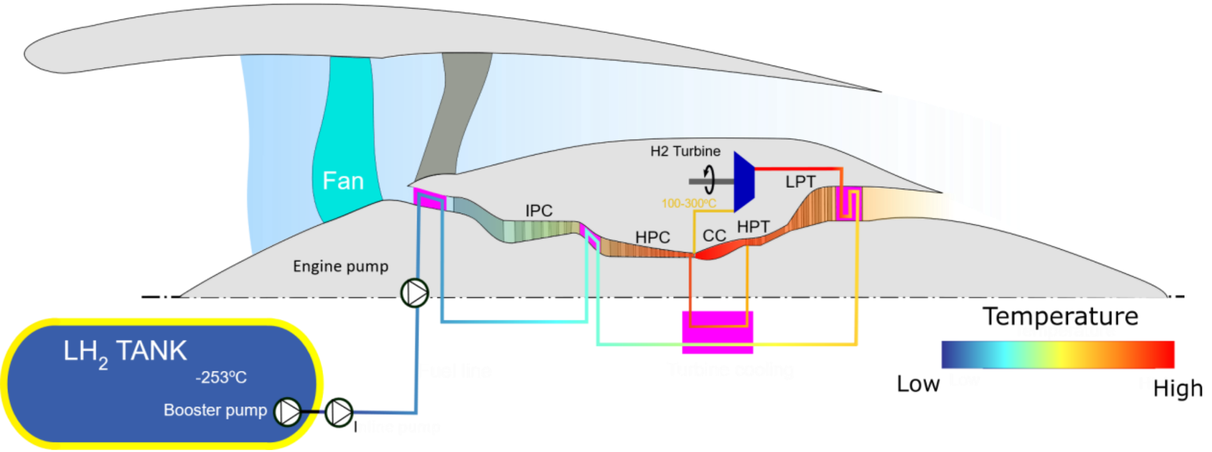
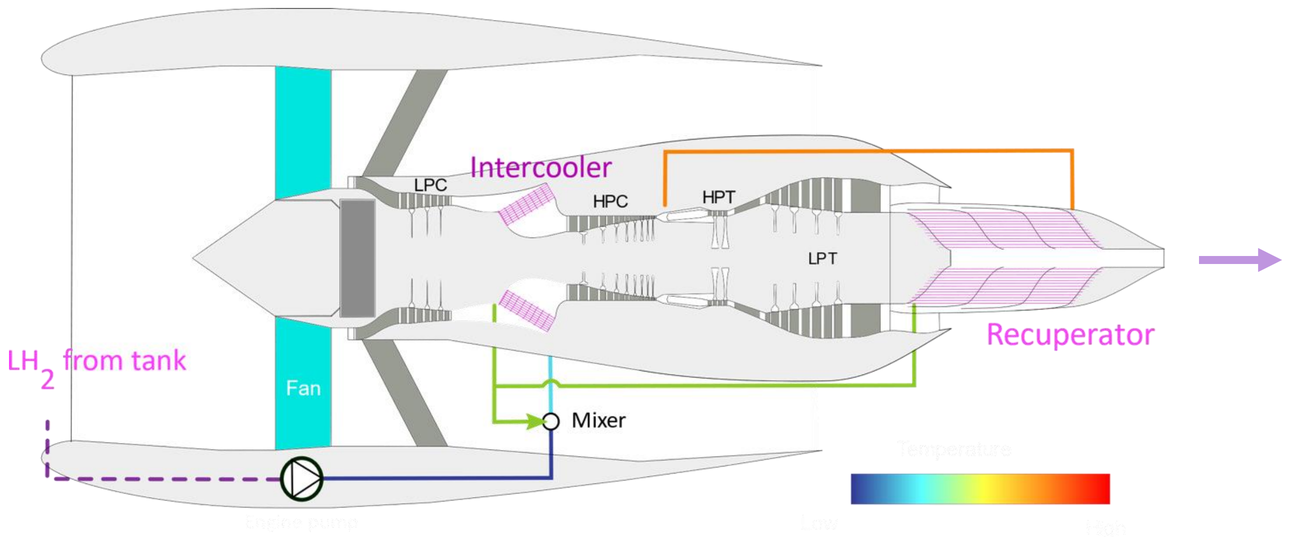
Heat-management potential LH2

- Cryogenic storage
  - -253 C
- Hydrogen is exceptional coolant
  - Using existing surfaces
  - High heat capacity
  - More compact HEX



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



GKN AEROSPACE

	Mass [kg]	Architecture	HEX mass* [kg]	Δ_{FB}
Baseline	3392	1+3+8+2+4	–	datum
Interc.	3402	1+3+6+2+4	129	−3.6%
Interc. – Recup.	3681	1+3+6+2+4	326	−5.5%

Patrao, Alexandre Capitao, et al. "Compact heat exchangers for hydrogen-fueled aero engine intercooling and recuperation." *Applied Thermal Engineering* 243 (2024): 122538.

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Short-Haul Flights May Be Fossil-Fuel-Free By 2045

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https://www.newsweek.com/fossil-fuel-free-flights-hydrogen-power-air-travel-1924613

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