Preliminary evaluation of the benefits of converting the Grob Strato 2C into a H_2 powered passenger aircraft using fuel cells

Comparison with the Dornier 328 at iso-mission and iso-payload (30 pax)

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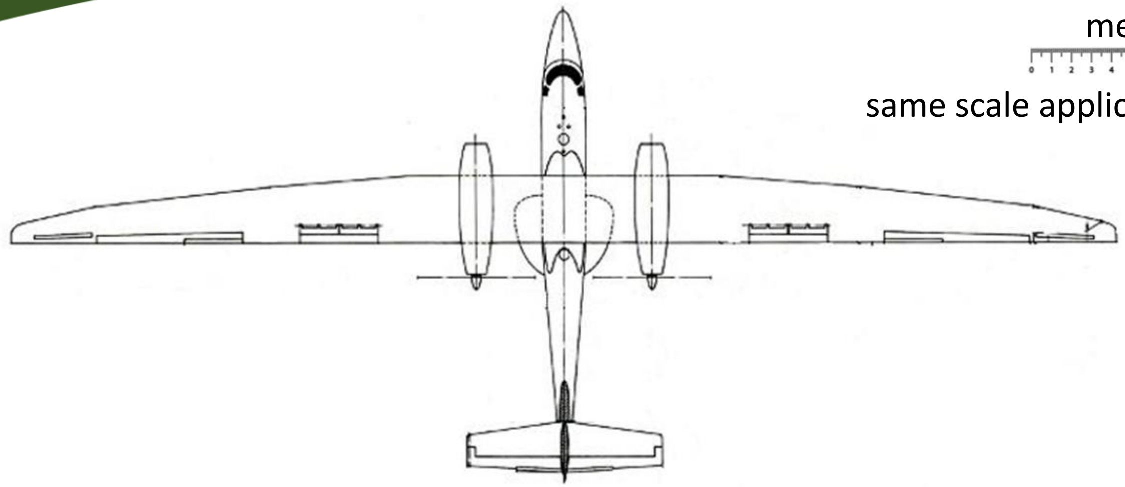
Aircraft characteristics

meters

same scale applicable for both aircraft

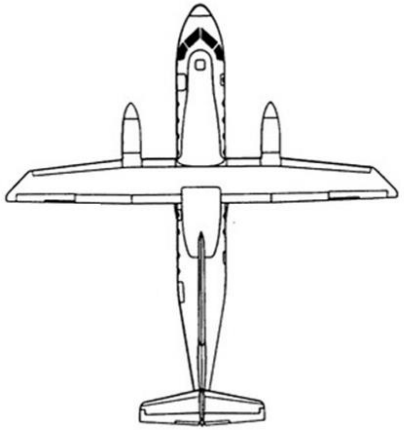
Strato 2C



Length:	23.98 m
Wingspan:	56.5 m
Cruise speed:	500 km/h
Empty weight:	6 650 kg
MTOW:	13 350 kg
Installed power:	2 x 300 kW
Power/MTOW:	**45 W/kg**

Δ mass = 6 700 kg

Dornier 328



Data available in the public domain

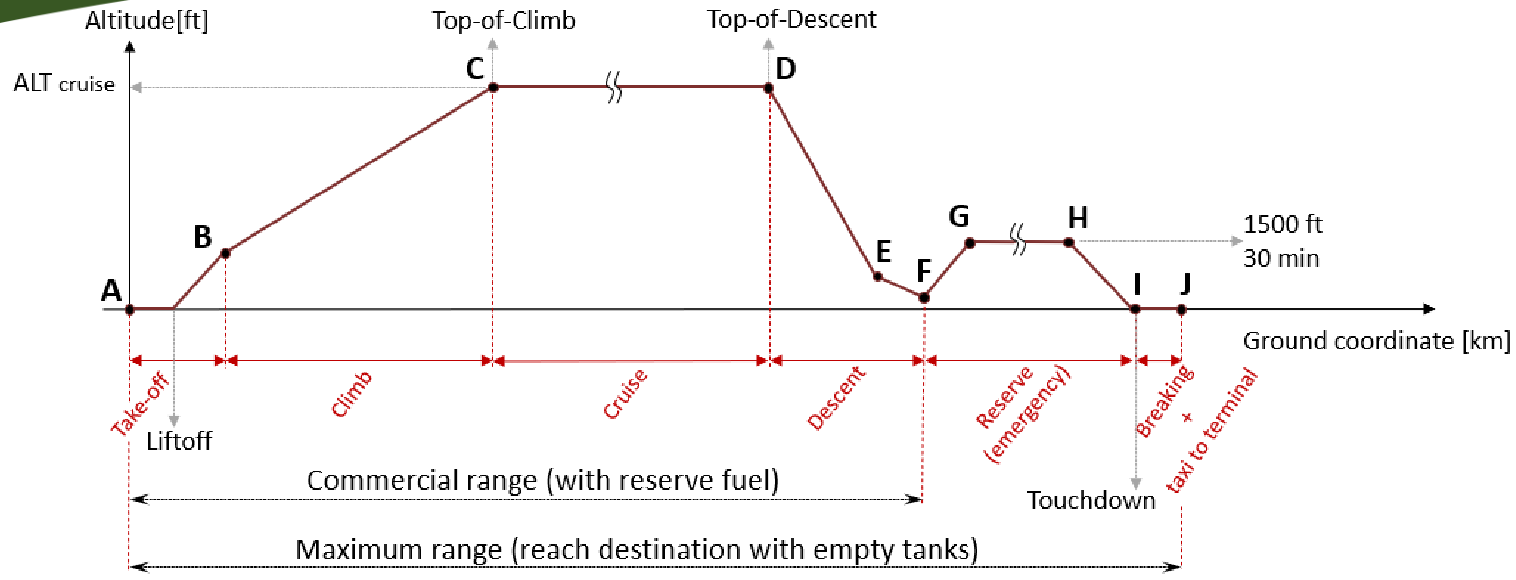
Length:	21.23 m
Wingspan:	20.98 m
Cruise speed:	620 km/h
Empty weight:	9 100 kg
MTOW:	13 990 kg
Installed power:	2 x 1 625 kW
Power/MTOW:	**232 W/kg**

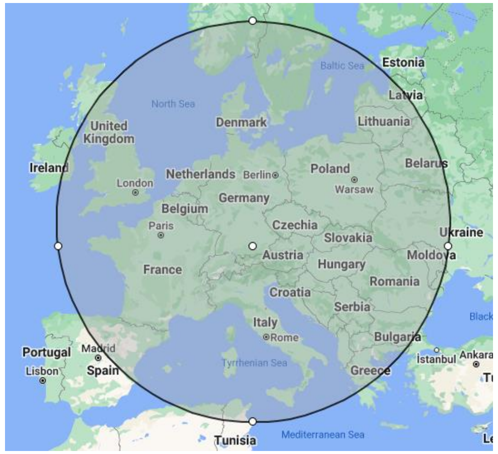
Δ mass = 4 890 kg

Design target: both aircraft to carry 30 passengers + 2 pilots + 1 flight attendant: 33 persons x 120 kg/person = 3960 kg of useful payload

Statement of work: the two aircraft are compared for the same mission (1400 km range, 30 passengers), in the assumption that the thermal powertrain is replaced by a hydrogen fuel cell electric powertrain (providing the same power as the thermal one), with H_2 stored as pressurized gas.

- **Mission definition**
- **Power/energy budget**





Range of 1400km starting from Wessling, Germany

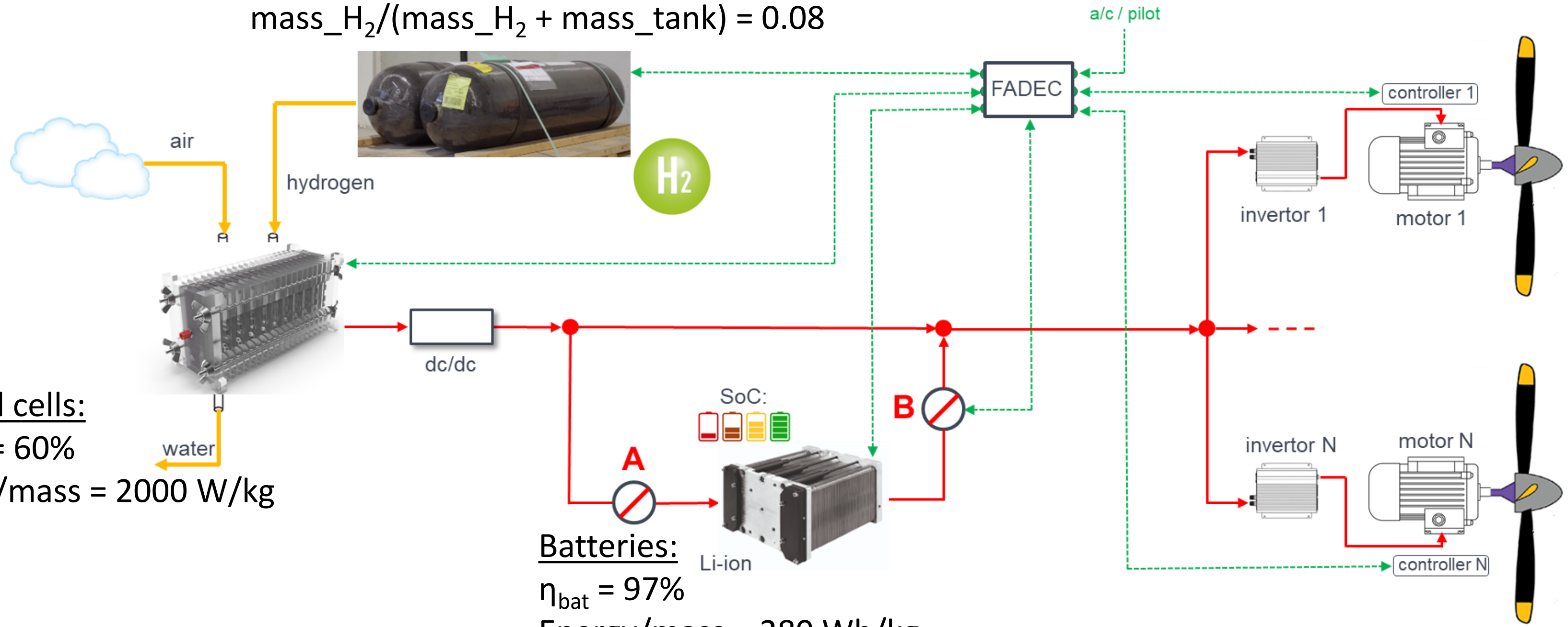
<u>Hypotheses</u>

- Mission range: 1400 km
- Mission reserve: 310 km
- Average speed:
  - Strato 2C: 500 km/h
  - Dornier 328: 620 km/h
- Mission time:
  - Strato 2C: 2h 48min
  - Dornier 328: 2h 16min
- Fuel cells ensuring all power at cruise
- The power deficit in other mission phases (e.g. take-off, climb) covered by batteries

Flight segment	Electric motor rating [%]	Power split between FC and batteries		Distance [km]	Case 1: Strato 2C					Case 2: Dornier 328				
		Fuel cells	Batteries		Time [h]	Power fuel cells [kW]	Power batteries [kW]	Energy fuel cells [kWh]	Energy batteries [kWh]	Time [h]	Power fuel cells [kW]	Power batteries [kW]	Energy fuel cells [kWh]	Energy batteries [kWh]
A-B	100%	60%	40%	20	0.040	360.0	240.0	14.4	9.6	0.032	1950.0	1300.0	62.9	41.9
B-C	80%	60%	20%	70	0.140	360.0	120.0	50.4	16.8	0.113	1950.0	650.0	220.2	73.4
C-D	60%	60%	0%	1235	2.470	360.0	0.0	889.2	0.0	1.992	1950.0	0.0	3884.3	0.0
D-E	20%	20%	0%	70	0.140	120.0	0.0	16.8	0.0	0.113	650.0	0.0	73.4	0.0
E-F	50%	50%	0%	5	0.010	300.0	0.0	3.0	0.0	0.008	1625.0	0.0	13.1	0.0
F-G	100%	60%	40%	5	0.010	360.0	240.0	3.6	2.4	0.008	1950.0	1300.0	15.7	10.5
G-H	70%	60%	10%	300	0.600	360.0	60.0	216.0	36.0	0.484	1950.0	325.0	943.5	157.3
H-I	20%	20%	0%	5	0.010	120.0	0.0	1.2	0.0	0.008	650.0	0.0	5.2	0.0
I-J	100%	60%	40%	0.5	0.001	360.0	240.0	0.4	0.2	0.001	1950.0	1300.0	1.6	1.0
Total energy required for the mission (including reserve):								**1195.0**	**65.0**				**5219.9**	**284.1**

- **Powertrain architecture**
- **Mass budget**

<u>H_2 gas tanks:</u>
mass_H_2/(mass_H_2 + mass_tank) = 0.08



<u>Fuel cells:</u>
η_{fc} = 60%
PW/mass = 2000 W/kg

<u>Batteries:</u>
η_{bat} = 97%
Energy/mass = 280 Wh/kg

<u>Motors:</u>
η_{mot} = 95%
PW/mass = 5000 W/kg

$\eta_{hydrogen \rightarrow power} = \eta_{fc} \times \eta_{mot} = 57\%$ → only 57% of the energy content of stored H_2 is used for propulsion

$\eta_{battery \rightarrow power} = \eta_{bat} \times \eta_{mot} = 92\%$ → only 92% of the energy content of batteries is used for propulsion

Mass budget:

	Mass H2 [kg]	Mass H2 tanks [kg]	Mass el. motors [kg]	Mass fuel cells [kg]	Mass batteries [kg]	Total mass powertrain [kg]
Strato 2C	53.2	595.8	120	180	252.3	**1201.4**
Dornier 328	232.4	2602.9	650	975	1102.9	**5563.2**

<u>Conclusions:</u>

- At iso-mission and iso powertrain architecture, the propulsion system of the Dornier 328 is 4.63 times heavier than the propulsion system of Strato 2C. The main reason: *the PW/weight at aircraft level*
- The powertrain is too heavy for the Dornier 328, while it can be easily accommodated by the Strato 2C

• Other aspects

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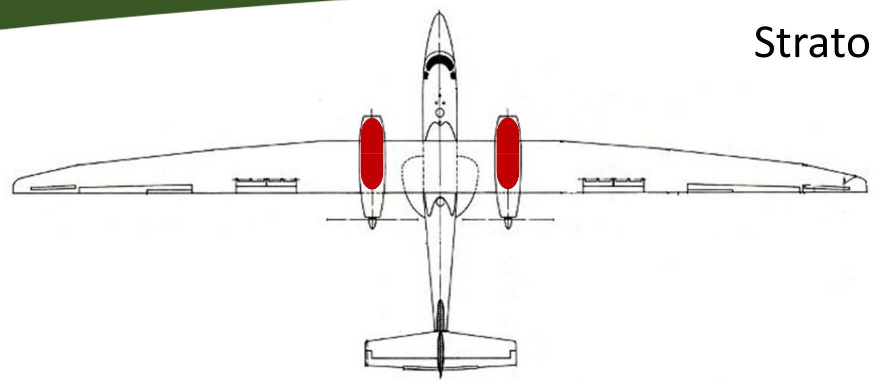
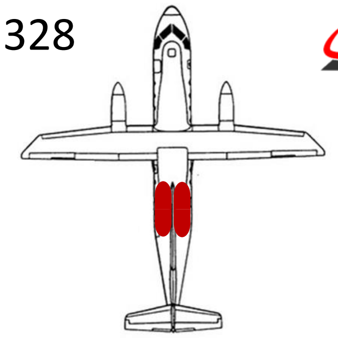
	Strato 2C	Dornier 328
		
Hydrogen tanks:	• Can be placed in engine nacelles • Zero impact on aerodynamics • Far from passengers – increased safety • Compressed gaseous H_2 can be used, storage technology already available	• Must be installed in the fuselage → reduce the number of passengers • Close to passengers, increased risks • Most likely, liquid H_2 is required → increased complexity

Thermal management:	• Relatively low levels of heat to dissipate:
	  • ~137 kW of heat to dissipate from the fuel cells (tbd)
	  • ~7 kW of heat to dissipate from the batteries
	  • ~30 kW of heat to dissipate from the electric motors
	174 kW in total
		• High amounts of heat to dissipate:
		  • ~741 kW of heat to dissipate from the fuel cells
		  • ~39 kW of heat to dissipate from the batteries
		  • ~162 kW of heat to dissipate from the el. motors
		942 kW in total

Cost of the system § (development): § the cost of each sub-system is orientative	• ~3000 €/kW fuel cell → 1080.0 k€ in total • ~70 €/kW battery → 16.8 k€ in total • ~60 €/kW motor → 36.0 k€ in total • H_2 tank: ~1000 €/kgH2 → 53.2 k€ in total ~1186.0 k€	• ~3000 €/kW fuel cell → 5850.0 k€ in total • ~70 €/kW battery → 91.0 k€ in total • ~60 €/kW motor → 195.0 k€ in total • H_2 tank: ~1000 €/kgH2 → 232.4 k€ in total ~ 6368.4 k€
Cost of operations/mission (energy cost only):	• 10 €/kg H_2 * 53.2 kg H_2 = 532 € (for tank refill) • 0.3 €/kWh electricity * 65 kWh = 19.5 € (for battery recharge) -- (+) Total: 551.5 € → 18.4 €/passenger	• 10 €/kg H_2 * 232.4 kg H_2 = 2324 € (for tank refill) • 0.3 €/kWh electricity * 284.1 kWh = 85.2 € (for battery recharge) -- (+) Total: 2409.2 € → 80.3 €/passenger

Conclusions

- The Strato 2C is an aircraft designed for long endurance at high altitude. The aerodynamic, mass and required thrust characteristics make it ideal for conversion into a H_2-powered aircraft for passenger transport;

- For passenger transport, the H_2-powered Strato 2C maximum altitude can be reduced to ~30 000ft, and a minimum cruise speed between ~300-350 km/h can be targeted (so that flying with this aircraft becomes competitive with travelling by train);

- The modified aircraft could accommodate up to 30 passengers with a small fuselage extension;

- The weight and cost of the H_2 powertrain are much lower for the Strato 2C, compared with other aircraft with similar performance;

- An iso-mission, iso-passenger comparison between the H_2-powered Strato 2C and the H_2-powered Dornier 328 reveals significant advantages in terms of mass and cost, and also in terms of the complexity of the H_2 storage system and thermal management.

- The modified Strato 2C can be transformed into an extremely competitive commuter / regional aircraft, in a much faster timeframe and with significant lower cost than a new, clean sheet aircraft design. Also, compared to retrofitting existing aircraft with H_2 powertrains, the performance (both technical and economical) of the modified Strato 2C is much better.

- The development of the H_2-powered Strato 2C for passenger transport is suggested to take place in two phases:
  - Phase 1 – the maturing of technologies in the context of an R&D project with public + small private investment (~3 years)
  - Phase 2 – the industrialization and commercial development of the aircraft with 100% private investment (~3 years). Thus, the aircraft can be available for commercialization in 2029.

Disclaimer: the numerical analysis and the data included in this document are only meant to offer an order of magnitude of the envisaged advantages. The analysis is not meant to be accurate, but informative.