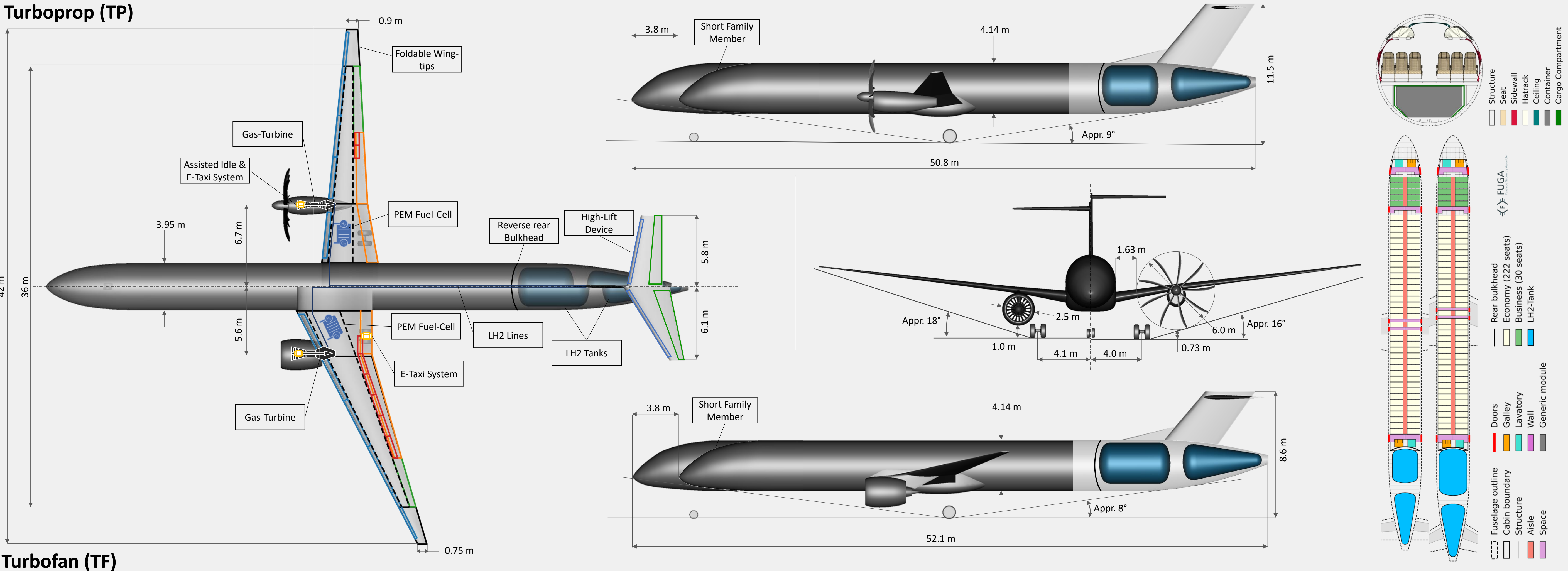


HYDROGEN POWERED SHORT-RANGE AIRCRAFT CONCEPTS WITH MILD-HYBRID-ELECTRIC-PROPULSION

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The MHEP Architecture

The energy carrier LH2 has the advantage to be efficiently processed either by combustion engines or PEM fuel-cells. While pure fuel-cell aircraft will encounter difficulties competing with gas turbines as a power provider in higher power classes and at higher cruise speeds. A hybrid application is more promising, which combines the two power providers in the most synergetic way.

The different behaviors of these two power providers are combined in the most synergetic way. The gas-turbine has the characteristic to operate at high efficiencies at high power classes. However, the efficiency of gas-turbines strongly reduces when operated on part load or idle condition. Additionally, the gas-turbine achieves very high mass specific power values. The efficiency of the fuel-cell instead is rather independent of the power class but has a strong dependency on the power setting. The lower the setting the higher the efficiency. Nevertheless, the fuel-cell is a rather mass intensive power provider.

These described characteristics result in the so-called Mild-Hybrid-Propulsion-Concept (MHEP). While the mass efficient gas-turbines are applied and operated as main power provider, hence at the maximum efficiencies, the much smaller fuel cell is operated during off-design phases (taxi-in and out, descent). Additionally, the fuel-cell provides power for the on-board systems since they are also operated during the off-design phases. The mission altitude and power profile of the fuel-cell is shown in Fig. 1. Since the share of the off-design energy consumption increases with decreasing range, the MHEP concept is especially promising for shorter ranges. Compared to kerosene powered aircraft, LH2 powered aircraft have a higher energy consumption the shorter the range they are operated at. This is due to the higher structure to fuel mass ratio leading to small take-off-mass savings for shorter ranges. However, this trend can be reversed by the MHEP concept, which is more efficient the shorter the distance, see Fig 2.

Turboprop	TP	Lower Heating Value	LHV
Turbofan	TF	Max. Take-Off Mass	MTOM
Liquid Hydrogen	LH2	Max. Zero Fuel Mass	MZFM
Gaseous Hydrogen	GH2	Max. Landing Mass	MLM
Mild-Hybrid Electric Propulsion	MHEP	Operating Empty Mass	OEM
Carbon Fiber Reinforced Polymer	CFRP	International Standard Atmosphere	ISA
Passenger	PAX	Sea Level	SL

Top-Level-Aircraft-Requirements

Design Range	NM	1500
Design Payload	t	23.75
Max. Payload	t	25.00
Design Passenger Capacity @95kg/PAX	-	250
Entry Into Service	-	2040
Design Cruise Mach Number	-	0.78 (TF) / 0.66 (TP)
Approach Speed (CAS)	kn	121 ≤ Vapp ≤140
ICAO Aerodrome Ref. Code	-	C
Take-Off Balanced Field Length (SL, ISA)	m	1900
Take-Off Balanced Field Length (4000 ft, ISA+15, 1000 NM)	m	2700
Max. Operating Altitude	ft	39100 (TF) / 35000
Alternate Distance	NM	200
Holding @1500 ft	min	30
Contingency Fuel	-	3%

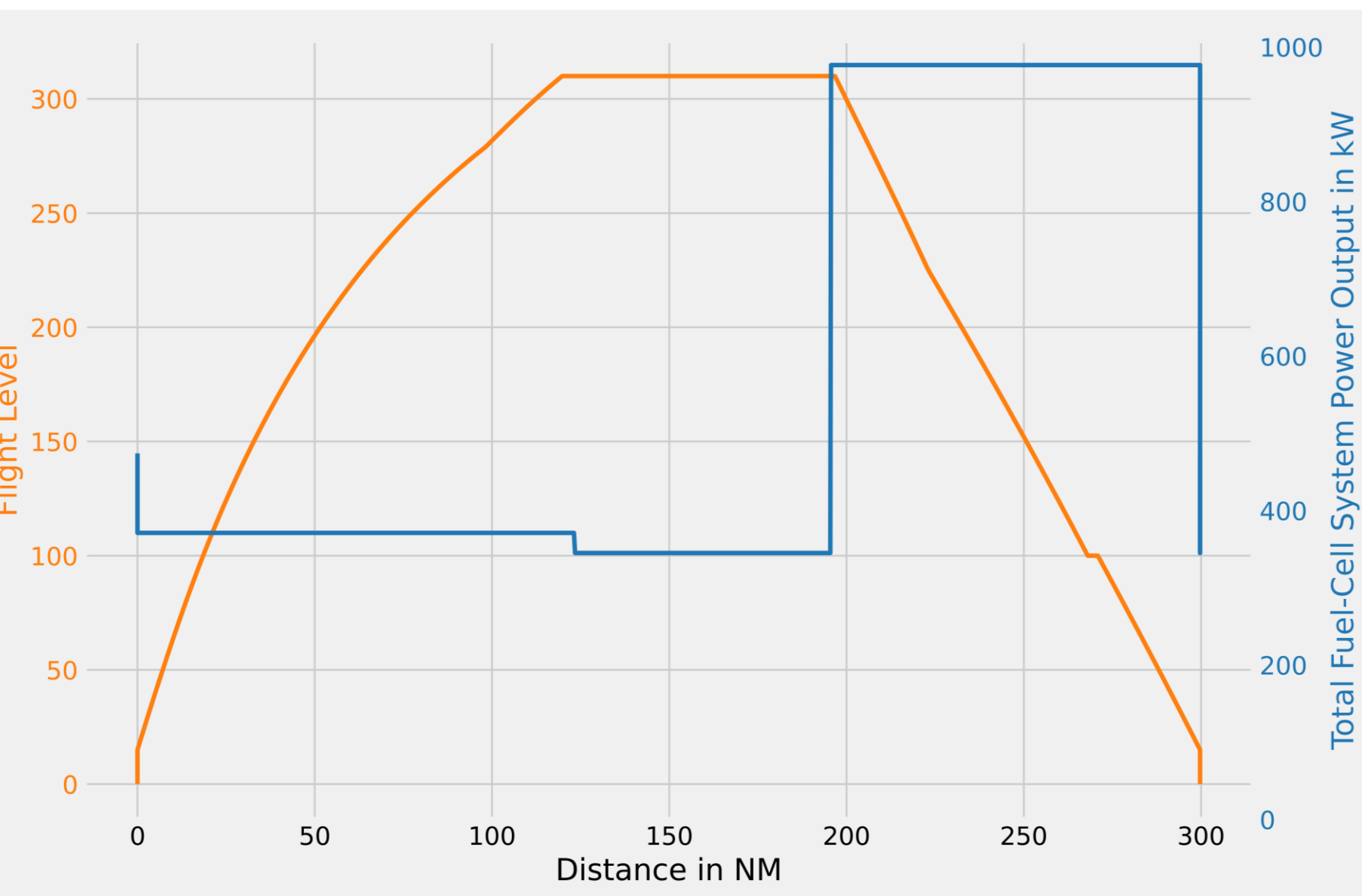


Fig. 1: Mission altitude profile and fuel-cell system output power profile for onboard-, assisted idle and e-taxi systems for 300 NM of the Mild-Hybrid Turboprop concept

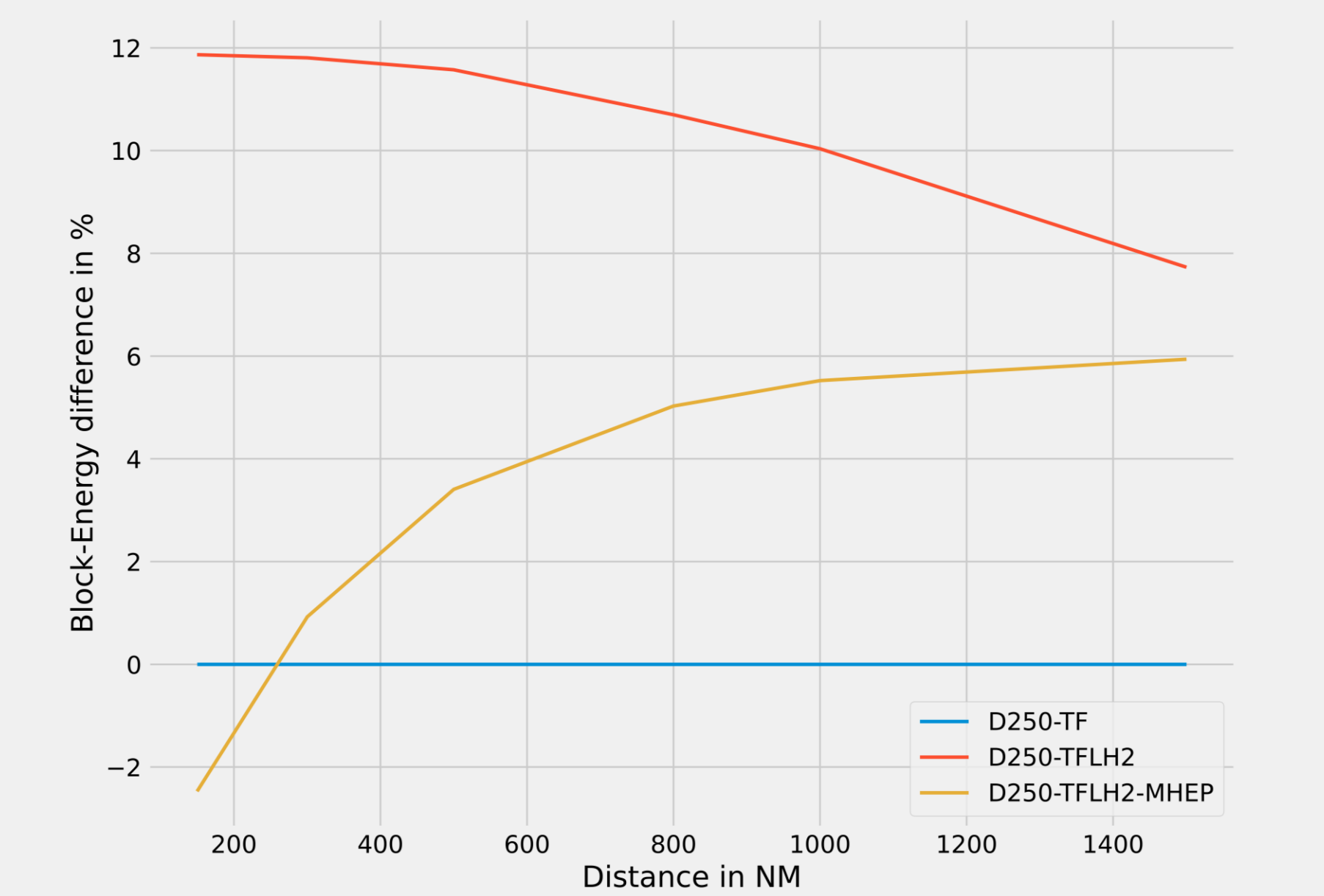


Fig. 2: Block-Energy difference between the kerosene baseline D250-TF, the LH2 short-range concept D250-TFLH2 and the Mild-Hybrid concept D250-TFLH2-MHEP

General Results

		Turbofan	Turboprop
MTOM	t	83.9	78.7
MZFM	t	80.7	77.1
MLM	t	81.7	77.9
OEM	t	55.6	52.1
Block-Fuel (@1500NM)	t	2.69	2.17
Block-Energy (@1500NM)	GJ	323	260
Block-Fuel (@800NM)	t	1.54	1.21
Block-Energy (@800NM)	GJ	185	145
Lift over Drag @ mid. cr.	-	19.1	20.5
Lift Coefficient @ mid. cr.	-	0.57	0.76
Drag Coefficient @ mid. cr.	-	0.0300	0.0372
Gas-Turbine Max. Thermal Power (per Engine)	MW	20.8	13.8
Max. Installed Thrust ISA (per Engine)	kN	136	125

MHEP System

		Turbofan	Turboprop
Installed Fuel-Cell System Power	MW	1.7	1.3
Max. Fuel-Cell Stack Power	MW	2.5	1.9
Fuel-Cell Stack Mass	kg	420	315
Fuel-Cell Subsystem Mass	kg	200	150
Overall MHEP System Mass	kg	1500	1200
Cooling Drag (@top of Descent)	N	510	330
Cooling Drag (@mid. Cruise)	N	75	70
Fuel-Cell System Efficiency (@top of Descent, LHV)	%	51	53
Fuel-Cell System Efficiency (@mid Cruise, LHV)	%	67	66

LH2 Storage

		Turbofan	Turboprop
Struct. Mass (CFRP)	kg	1220	795
System Mass	kg	580	575
Unusable LH2 mass	kg	145	65
Unusable GH2 mass	kg	10	4
Max. usable LH2	kg	2600	1020
GH2 vented	kg	0	0
Inner volume	m3	40.6	17.9
Max. oper. pressure	bar	2.0	2.0
Gravimetric Index *	%	59	42

* Considering structural, installation, crash structure and system masses

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