DLH25
LH2 RESEARCH BASELINE

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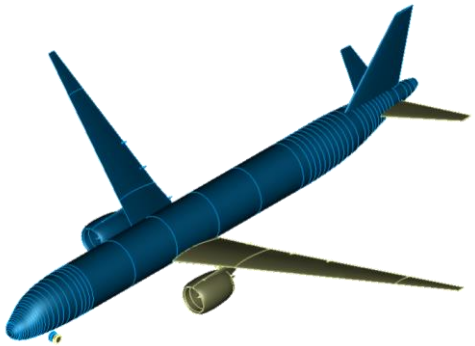
*Kotzem et. al:., CONCEPTUAL AIRCRAFT DESIGN OF A RESEARCH BASELINE WITH DIRECT LIQUID HYDROGEN COMBUSTION, *34th Congress of the International Council of the Aeronautical Sciences 2024*, Florence, Italy

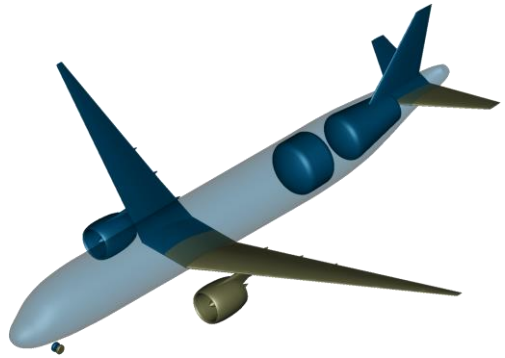
DLH25 – LH2 Research Baseline
Aircraft Design Process

- Selection of a suitable reference aircraft to represent the short medium range market
- Design and calibration of the D239 as a state of the art short medium range aircraft
- Design of the SAF Research Baseline DLR-F25 based on 2035 technology assumptions
- Design of the DLH25 LH2 Research Baseline derived from DLR-F25 and additional LH2 technology assumptions

D239
SMR representative aircraft
2020 technology



DLR-F25
LuFo VIRENFREI
SAF Research Baseline
2035 technology



DLH25
Clean Aviation ACAP
LH2 Research Baseline
2035 technology

DLH25 – LH2 Research Baseline
Top Level Aircraft Requirements

D239
SMR representative aircraft
2020 technology

Design Range	[nm]	2500
Design PAX (single class)	[-]	239
Mass per PAX	[kg]	95
Design Payload	[kg]	25000
Max. Payload	[kg]	25000
Cruise Mach number	[-]	0.78
Max. operating Mach number	[-]	0.82
Max. operating altitude	[ft]	40000
TOFL (ISA +0K SL)	[m]	2200
Rate of Climb @ TOC	[ft/min]	>300
Approach Speed (CAS)	[kt]	136
Wing span gate limit	[m]	<36
Alternate Distance	[nm]	200
Holding Time	[min]	30
Contingency	[-]	3%

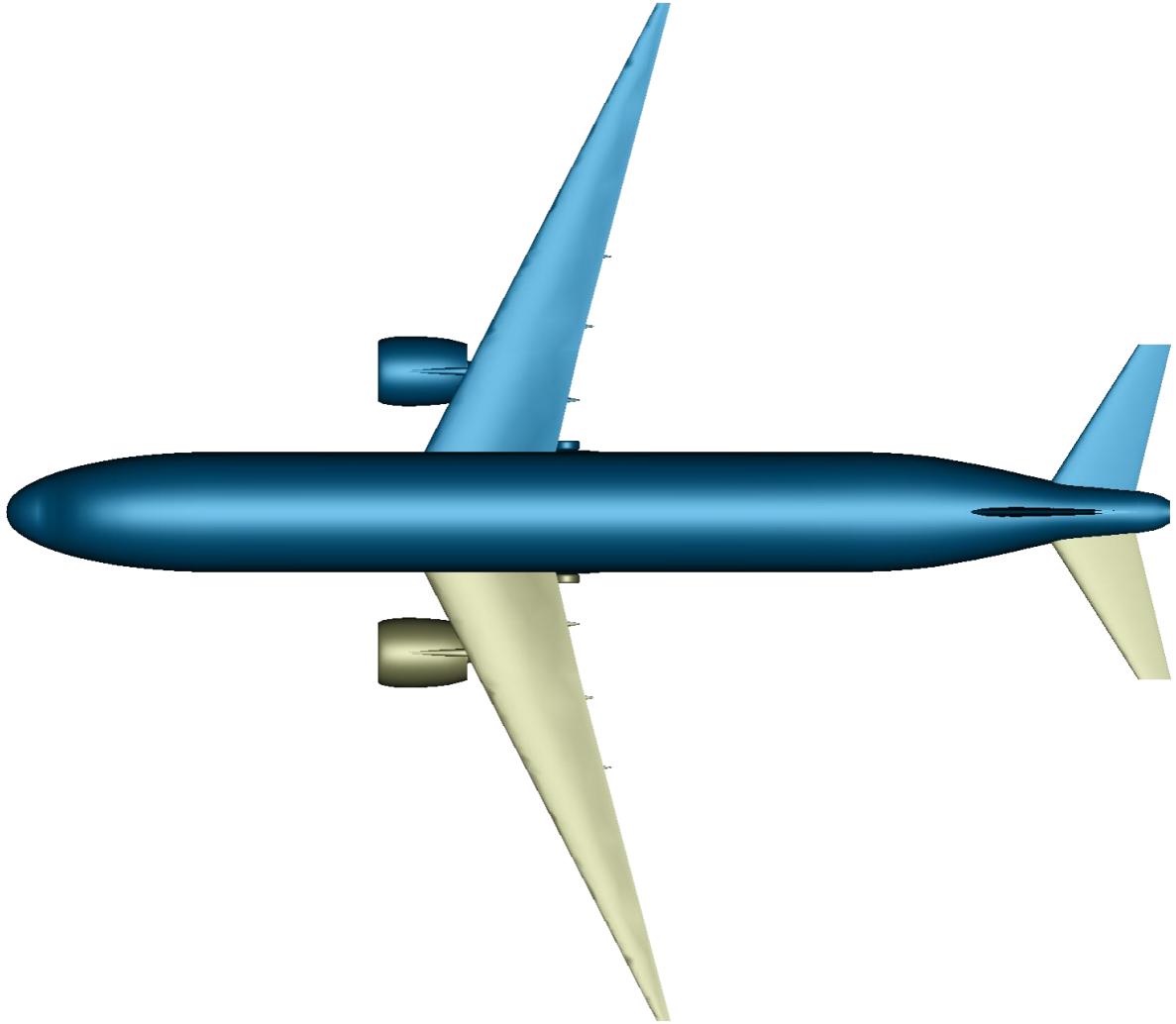
D239 Reference → DLH25 – LH2 Research Baseline
Technology Assumptions for EIS 2035

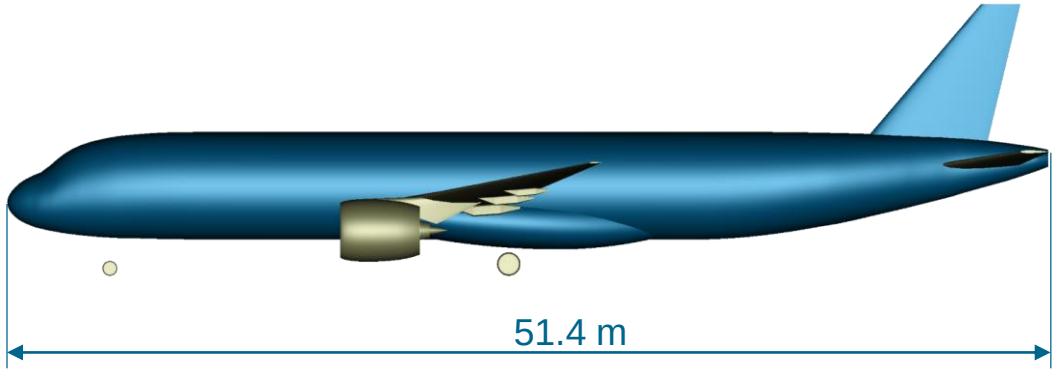
Technology	Assumption	Description
Gas Turbine Efficiency	+4%	Compared to a 2020 state-of-the-art geared turbofan, Bypass-ratio: 15, improved thermal efficiency.
Empennage Mass Factor	-3%	Compared to D239, New manufacturing and assembly methods.
Fuselage Mass Factor	-5%	Compared to D239, Advanced Al-alloys, manufacturing and assembly methods, revised production and certification requirements.
Wing Mass Factor	-30%	Compared to D239, Application of CFRP, advanced load alleviation, active flutter suppression, advanced drop hinge flaps and advanced winglets
System Mass Factor	-5%	Compared to D239, Onboard system architecture based on design by TUHH
Furnishing Mass Factor	ISO	Potential mass reductions are mitigated by new requirements and certification rules as well as additional modularity, manufacturability and increased complexity.
Operator Items Mass Factor	ISO	

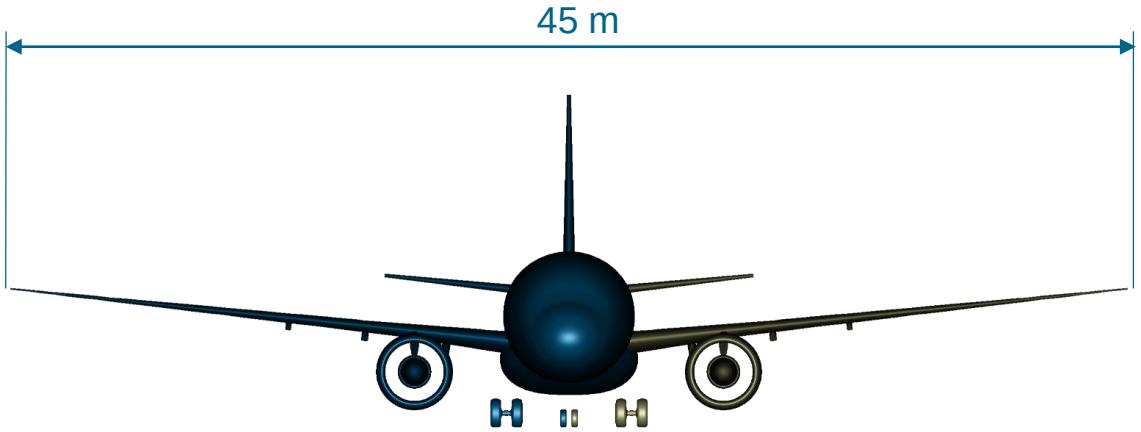
D239 Reference → DLH25 – LH2 Research Baseline
LH2 Technology Assumptions for EIS 2035

Technology	Assumption	Description
Engine Performance	+5%	Compared to a 2035 geared turbofan, Higher specific heat capacity in exhaust mass flow
Wing Mass Factor	+5%	Compared to DLR-F25, Based on analytical pre-calculations – No relief of wing structure due to dry wing
Fuselage Mass Factor	+7%	Additional mass for maintenance access panels, tank removal systems and crash structures

DLH25 – LH2 Research Baseline
General Arrangement

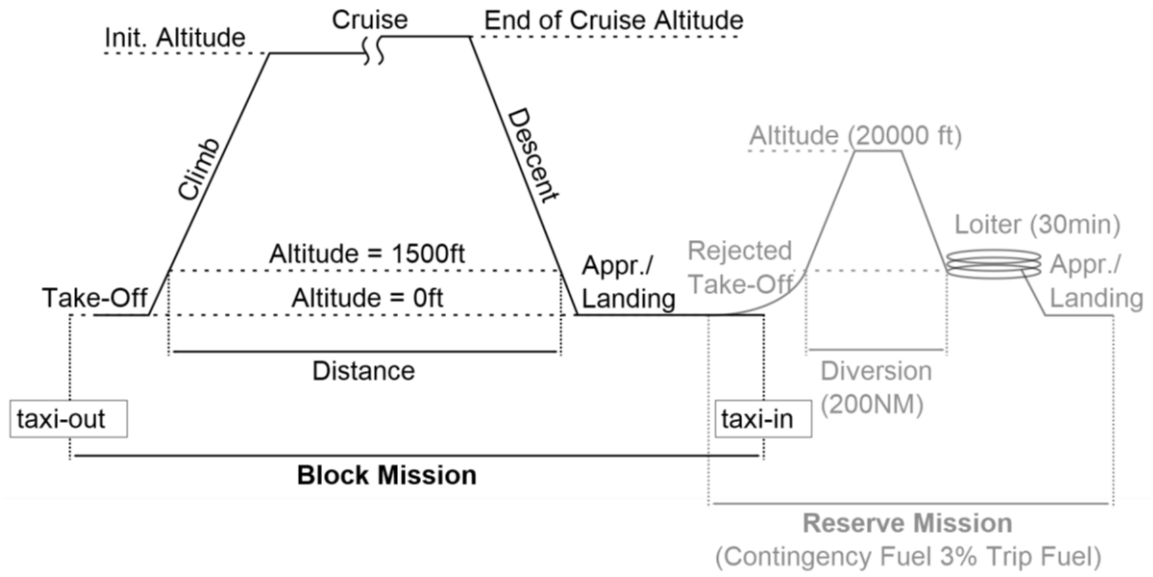






DLH25 – LH2 Research Baseline
Mission Definition and Key Aircraft Characteristics

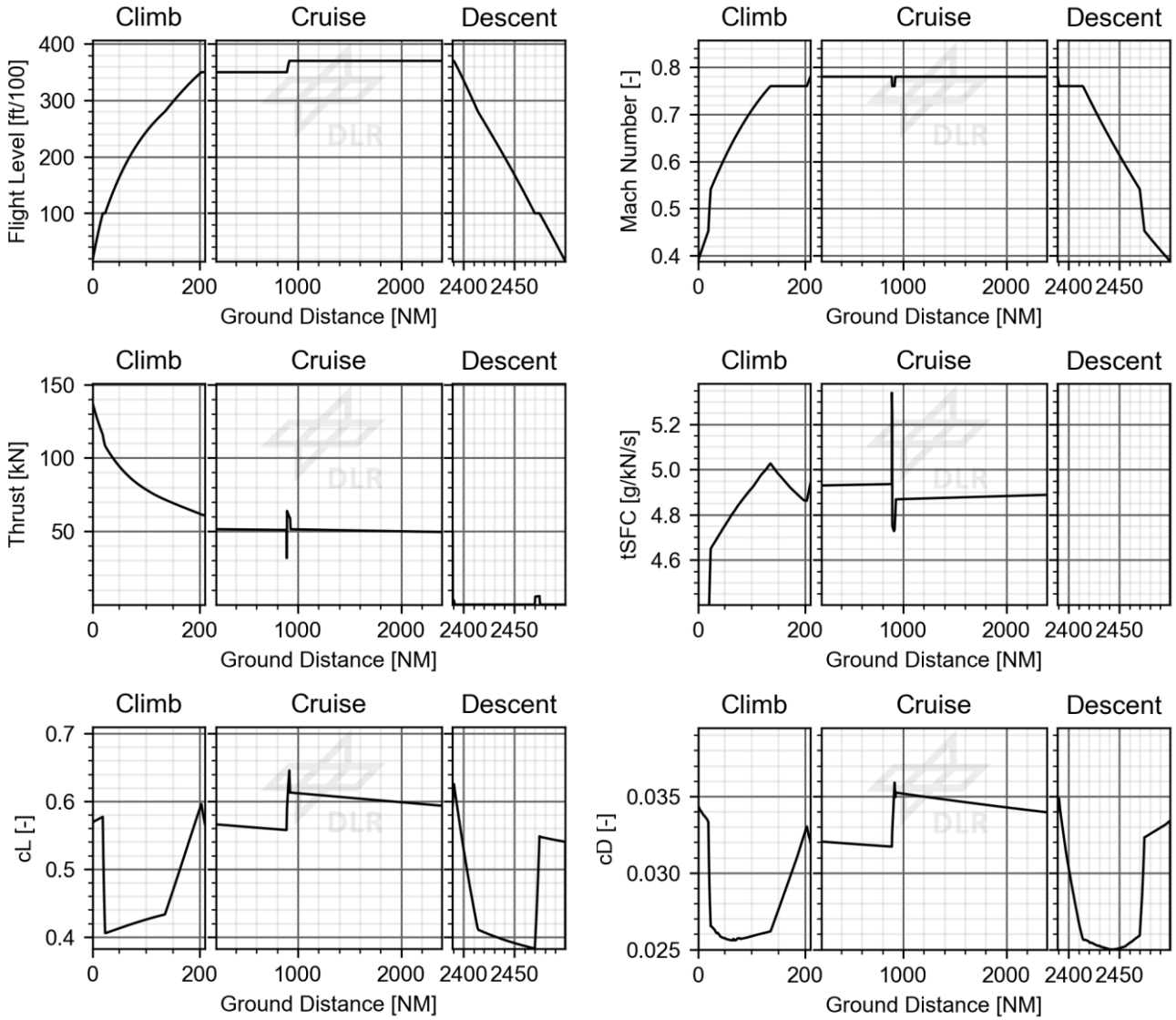
A design mission with a range of 2500NM and 25t of payload was defined according to the aforementioned TLARs. For this design mission, all performance data are calibrated i.e. engine and aerodynamic performances.



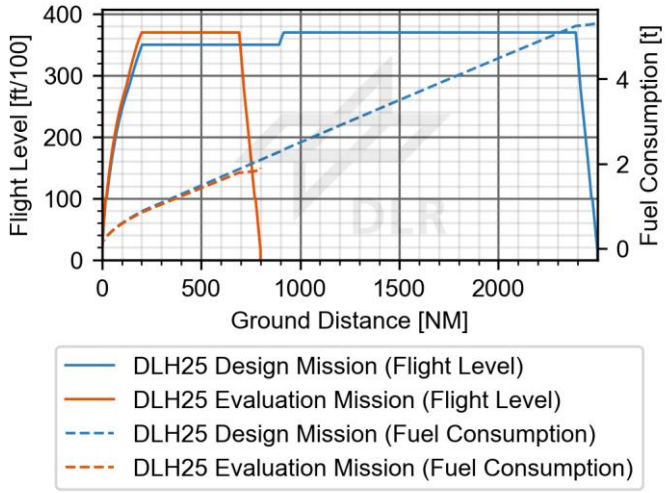
Parameter	Unit	Value
Design Range	NM	2500
Design Passenger Capacity	-	239
Design Cruise Mach Number	-	0.78
Max. Take-Off Mass	t	93.4
Max. Landing Mass	t	88.3
Max. Zero-Fuel Mass	t	87.0
Operating Empty Mass	t	62.0
Max. Fuel Mass	t	6.5
Max. Payload	t	25
Wing Area	m^2	158.0
Wing Span	m	45.0
Mean Aerodynamic Chord	m	4.3
Wing Loading (@MTOM)	kg/m^2	591.3
Thrust-to-Weight Ratio (@ISA)	-	0.331
Engine Type	-	Turbofan
Thrust (Sea Level Static, ISA)	kN	151.6

DLH25 – LH2 Research Baseline
Design Mission Performance

Mission Phase	Flight Time [min]	Fuel Mass [kg]	Distance [NM]
Block Mission	**362.0**	**5361.1**	**2499.8**
Taxi-Out	9.0	40.2	0.0
Take-Off	2.0	83.8	0.0
Climb	31.7	771.1	209.8
Cruise	291.9	4349.6	2179.3
Descent	18.4	67.8	110.8
Approach & Landing	4.0	30.3	0.0
(Taxi-In)	5.0	18.2	0.0
Reserve Mission	**70.2**	**1131.3**	**316.1**
Go-Around	1.6	33.9	0.0
Diversion Climb	14.5	359.1	83.3
Diversion Cruise	6.7	90.4	44.0
Diversion Descent	13.8	54.5	74.5
Holding	30.0	404.2	114.3
Diversion Approach & Landing	3.6	30.1	0.0
Contingency	0.0	159.1	0.0



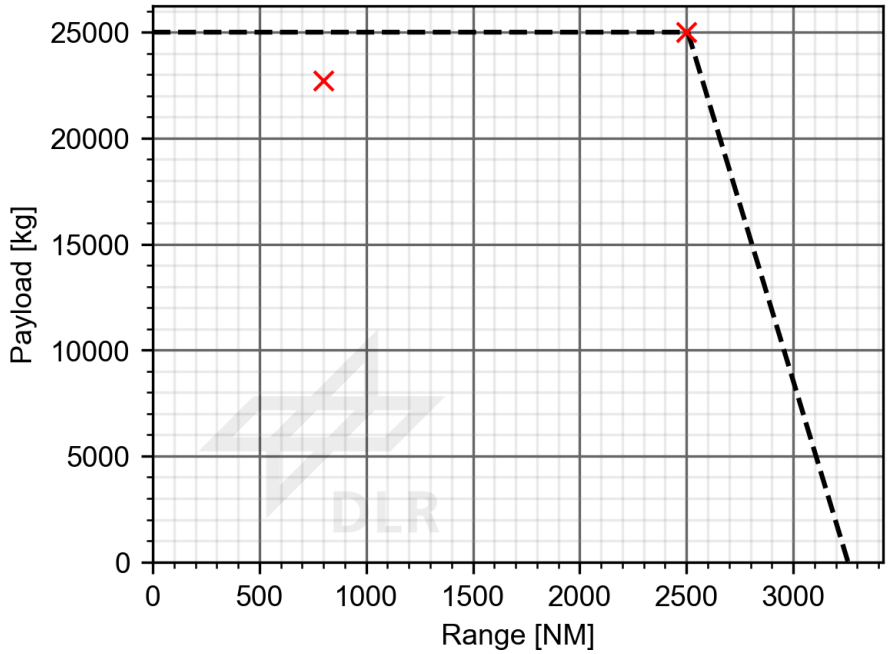
DLH25 – LH2 Research Baseline
Cruise Performance Comparison



Parameter	DLH25 Design Mission	DLH25 Evaluation Mission
Range [NM]	2500.0	800.0
Payload [t]	25.0	22.7
Mach Number (Cruise) [-]	0.78	0.78
Block Fuel [kg]	5361.13	1899.31
Init. Cruise Altitude [FL]	350.0	370.0
Mid Cruise Altitude [FL]	370.0	370.0
End of Cruise Altitude [FL]	370.0	370.0
No. of Cruise Steps [-]	1.0	0.0

Parameter	DLH25 Design Mission	DLH25 Evaluation Mission
Mid Cruise Performance		
Lift Coefficient [-]	0.611	0.583
Drag Coefficient [-]	0.035	0.033
L/D Ratio [-]	17.4	17.47
CAS [m/s]	129.9	129.9
TAS [m/s]	230.2	230.2
Angle of Attack [deg]	0.4	0.2
Thrust [kN]	51.1	48.6
Thrust max. [kN]	59.1	59.1
tsfc [g/kN/s]	4.87	4.9
Avg. Cruise Performance		
Lift Coefficient [-]	0.59	0.58
Drag Coefficient [-]	0.0337	0.0332
L/D Ratio [-]	17.51	17.47
CAS [m/s]	131.8	129.9
TAS [m/s]	230.4	230.2
Thrust [kN]	50.7	48.4
tsfc [g/kN/s]	4.89	4.9

DLH25 – LH2 Research Baseline
Payload-Range Characteristics



General Information:

- Max. Payload: 25000 kg
- Design No. PAX: 239 @ 95 per PAX
- Design Mission: 2500NM @ 25000 kg Payload

Mission Profile:

- Climb: 300kts
- Cruise: Mach 0.78
- Descent: 300kts

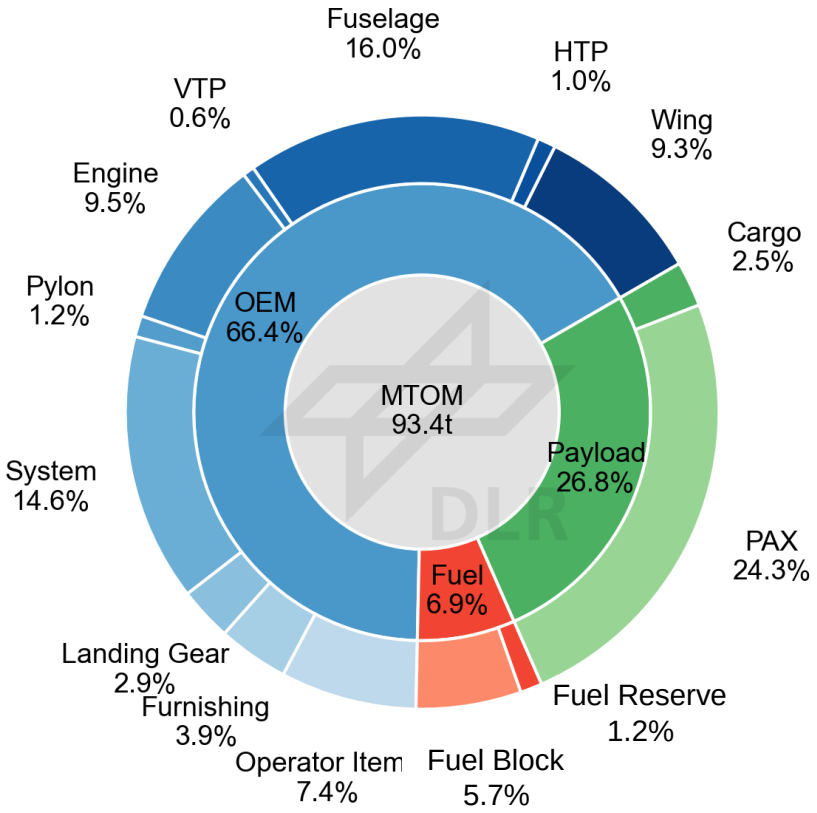
Reserve:

- No wind, ISA condition
- 200NM Alternate Airport
- 30min Holding @1500 ft
- Contingency Fuel: 3.0% Trip Fuel

Evaluation Mission:

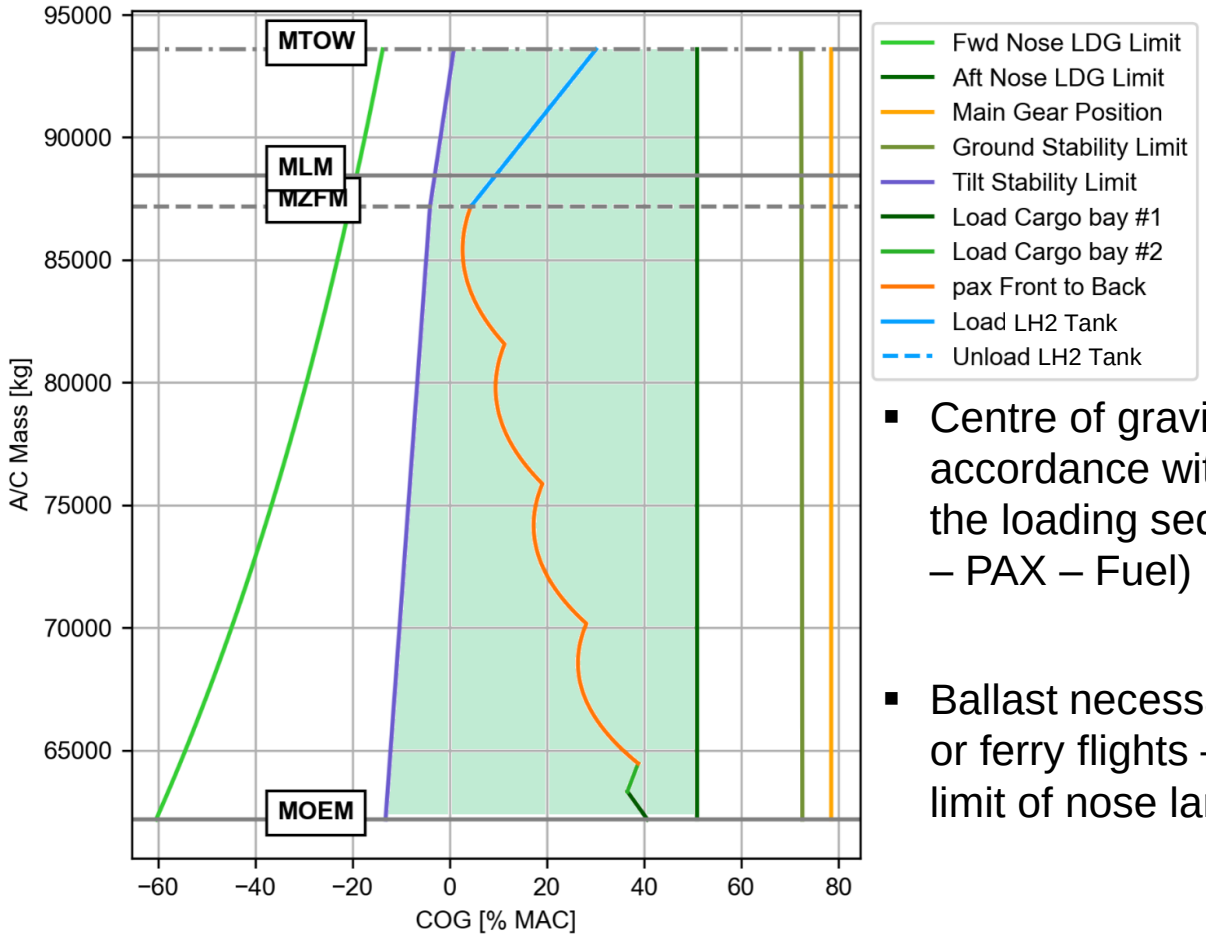
- Typical short-medium range mission of 800nm
- Payload without cargo as 239 Pax at 95kg

DLH25 – LH2 Research Baseline
Mass Properties



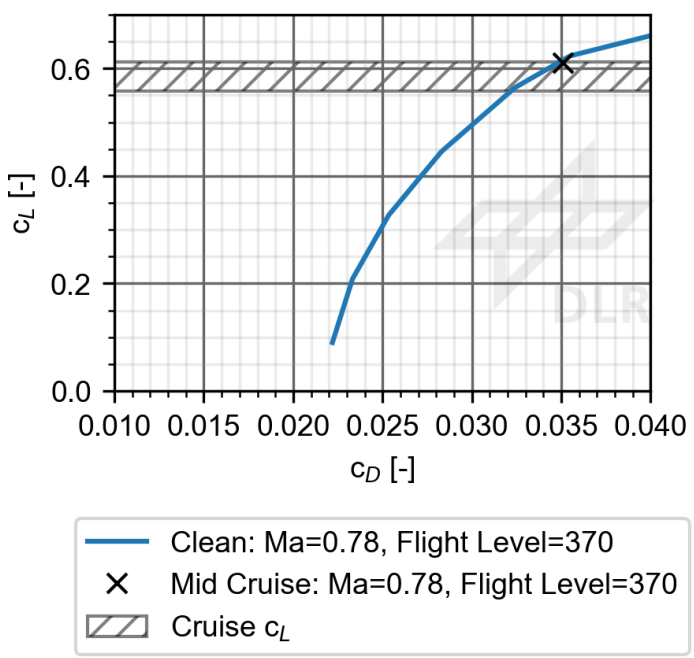
Component	Mass [kg]	x-Pos [m]
Wing	8683	23.44
Fuselage Structure	14989	21.66
HTP	921	48.46
VTP	585	47.08
Pylons	1077	20.71
Power Units	8867	18.96
Main Gear	2301	24.76
Nose Gear	425	5.07
Systems	13624	29.36
Furnishings	3600	17.69
Manufacturer Empty Mass (MEM)	55067	-
Operating Items	6934	-
Operating Empty Mass (OEM)	61997	23.16
Maximum Payload	25000	17.69
Maximum Fuel	6473	37.63
Maximum Zero-Fuel Mass (MZFM)	86993	-
Maximum Landing Mass (MLM)	88282	-
Maximum Take-Off Mass (MTOM)	93422	22.89

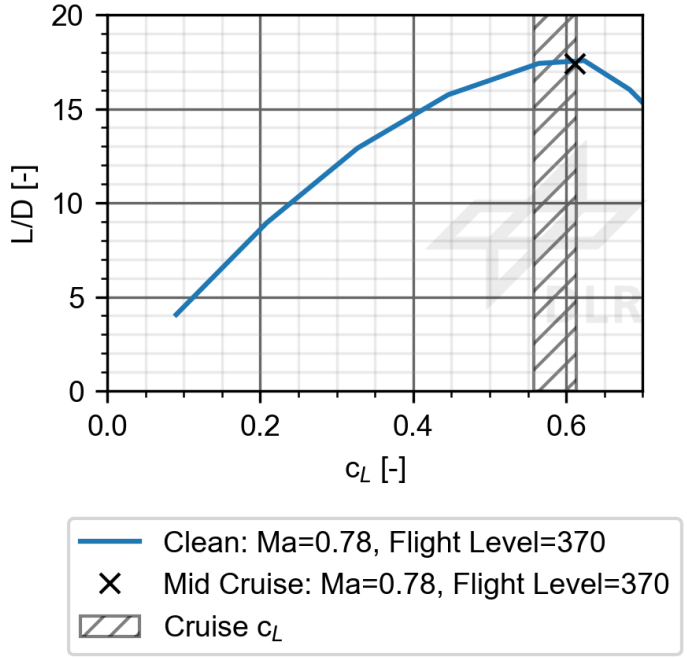
DLH25 – LH2 Research Baseline
CG Envelope



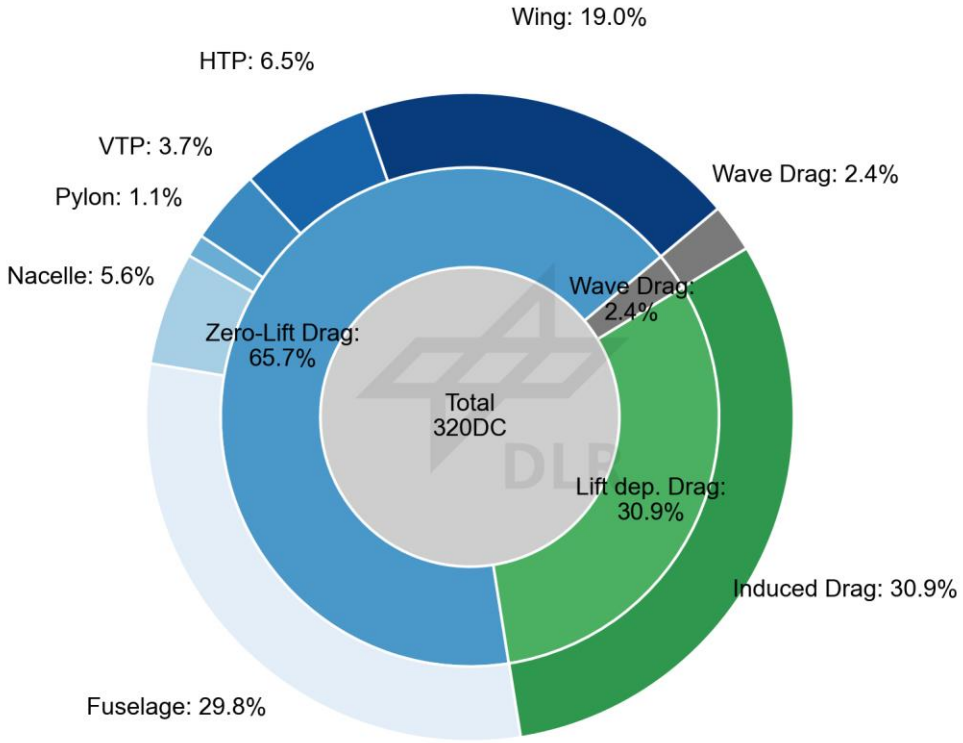
- Centre of gravity position is in accordance with all limitations during the loading sequence (2500 NM, Cargo – PAX – Fuel)
- Ballast necessary for low payload flights or ferry flights – Compliance with aft limit of nose landing gear

DLH25 – LH2 Research Baseline
Aerodynamic Performance



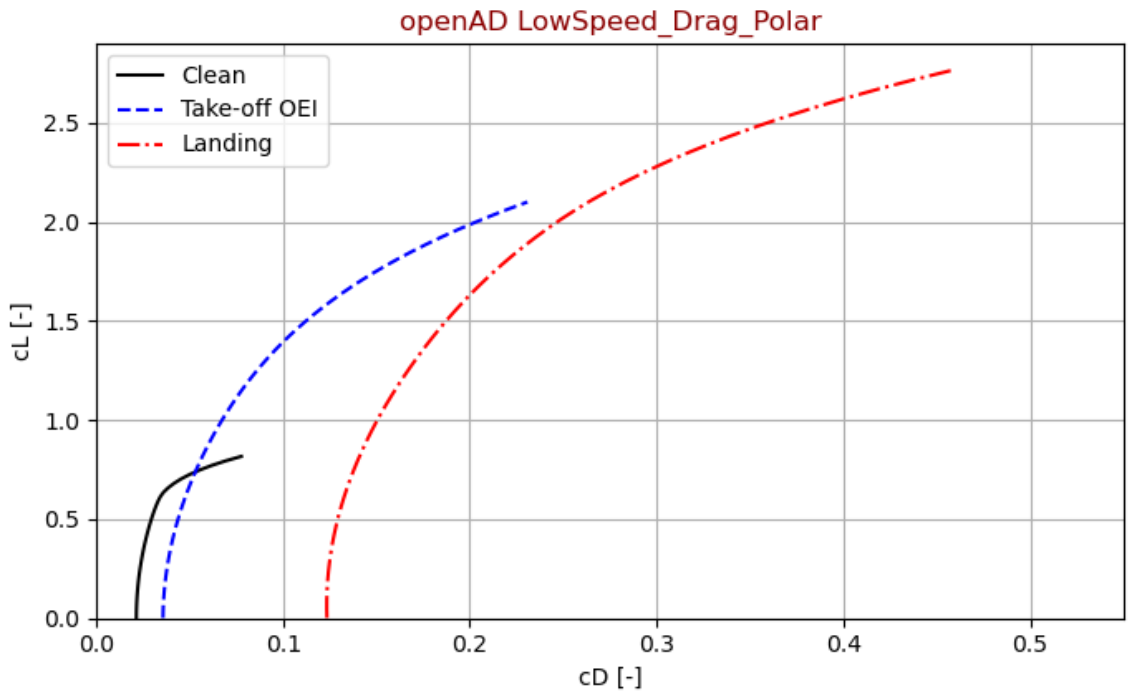


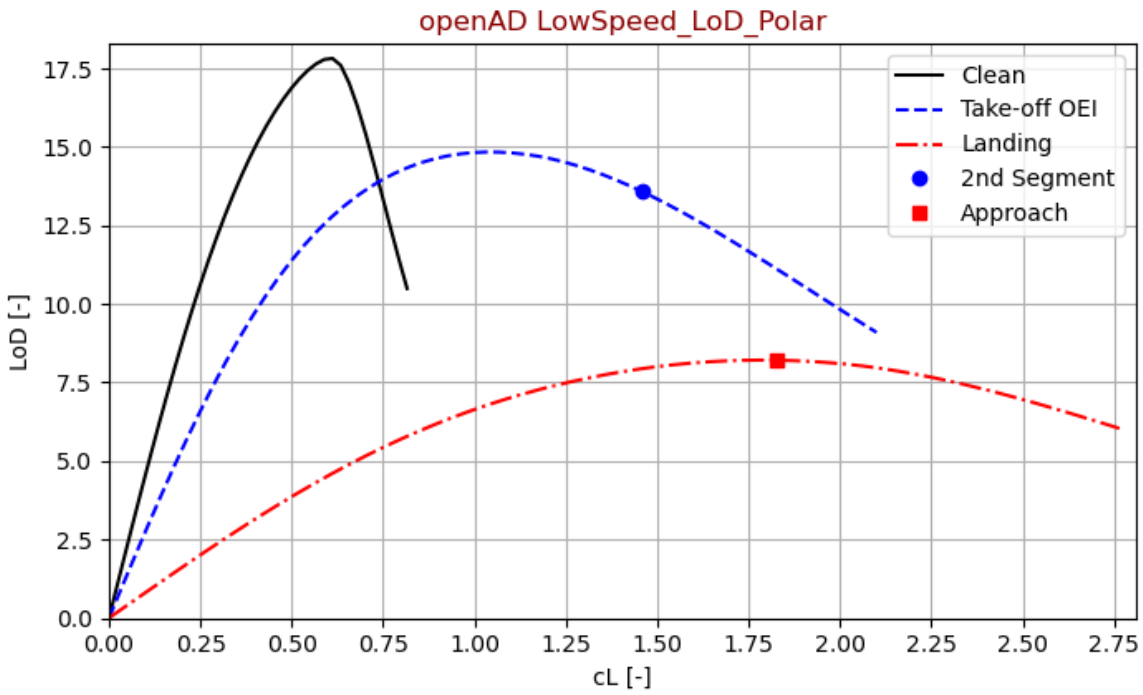
DLH25 – LH2 Research Baseline
Mid-Cruise Aerodynamic Drag Breakdown (Ma=0.78, Flight Level370)



Parameter	Drag Breakdown [DC]	Relative [%]
Zero-Lift Drag	**210.2**	**65.7**
Wing	60.9	19.0
HTP	20.7	6.5
VTP	11.7	3.7
Fuselage	95.5	29.8
Pylon	3.6	1.1
Nacelle	17.9	5.6
Lift dep. Drag	**98.8**	**30.9**
Induced Drag	98.8	30.9
Wave Drag	**7.6**	**2.4**
Total Drag	**320.0**	**100.0**

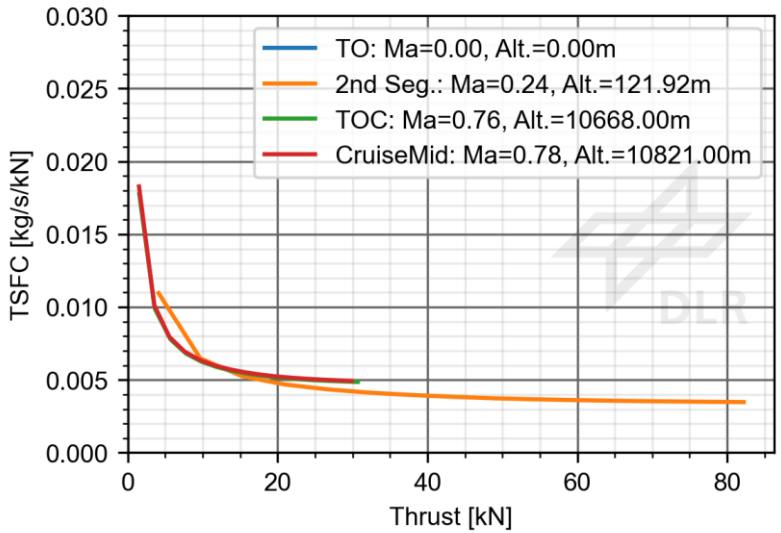
DLH25 – LH2 Research Baseline
Low Speed Aerodynamics





DLH25 – LH2 Research Baseline
Engine Performance Requirements

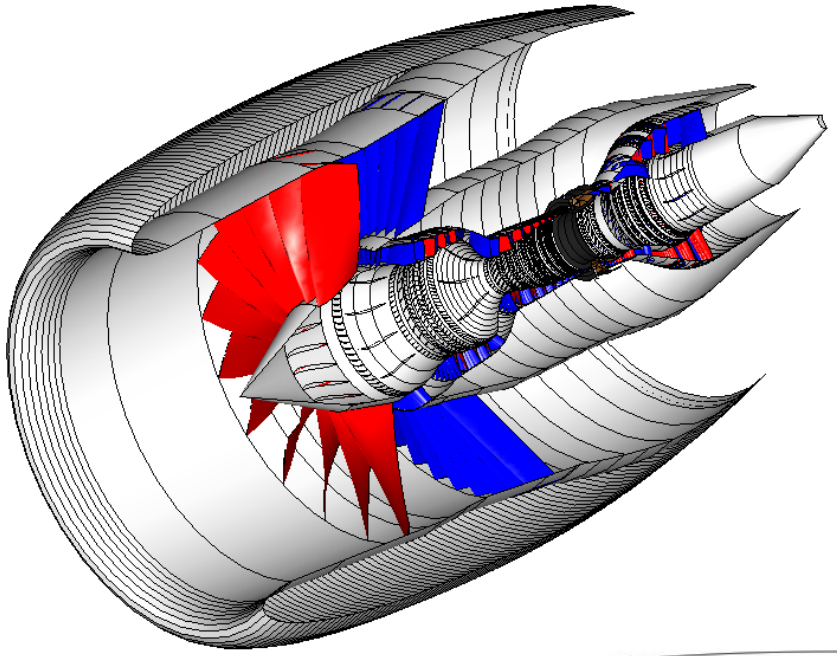
Parameter	Unit	Take-Off	EOF	2nd Seg.	TOC	Mid Cruise
Delta Temp. ISA	K	15.0	15.0	15.0	10.0	0.0
Mach-Number	-	0.0	0.23	0.23	0.76	0.78
Altitude	ft	0.0	35.0	400.0	35000	37000
Engine Rating	-	MTO	RTO	RTO	MCL	MCR
Thrust	N	151600.0	97800.0	89000.0	28300.0	25600.0
Shaft-Power Offtakes	kW	95.0	95.0	95.0	50.0	50.0
Bleed Air Offtakes	kg/s	0.0	0.0	0.0	0.425	0.425



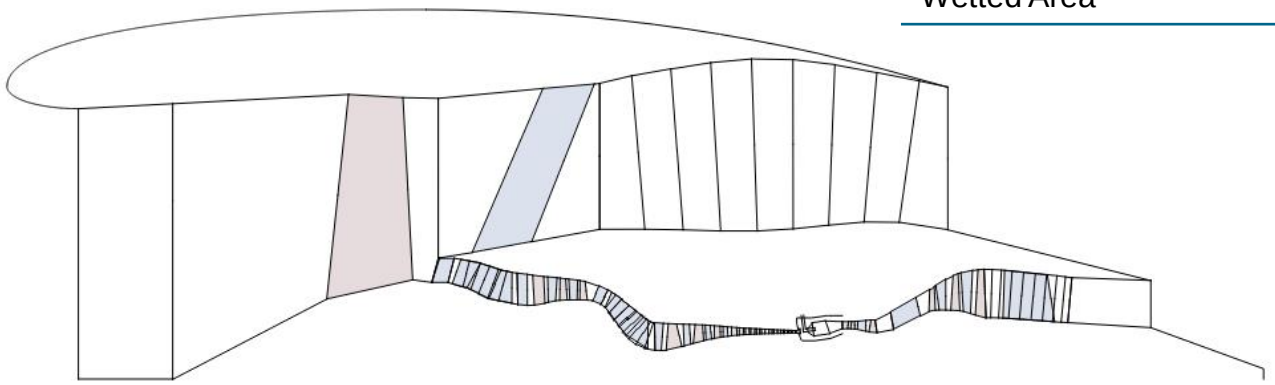
Description

- Take-Off:
  - at MTOM
- EoF (CS25.121a)
  - at approx. MTOM
  - Landing gear extended, Without ground effect
  - Critical engine inoperative
  - Gradient of Climb > 0%
- 2nd Segment (CS25.121b):
  - at approx. MTOM
  - Landing gear retracted , Without ground effect
  - Critical engine inoperative
  - at V2 Speed
  - Gradient of Climb > 2.4%
- TOC:
  - ROC ≥ 300 ft/min
- Cruise:
  - typically not a thrust sizing point but rather a efficiency related point

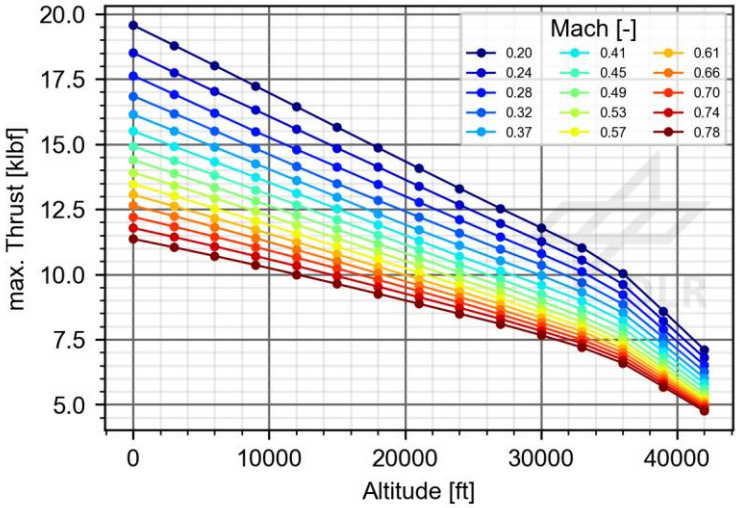
DLH25 – LH2 Research Baseline
Engine Characteristics

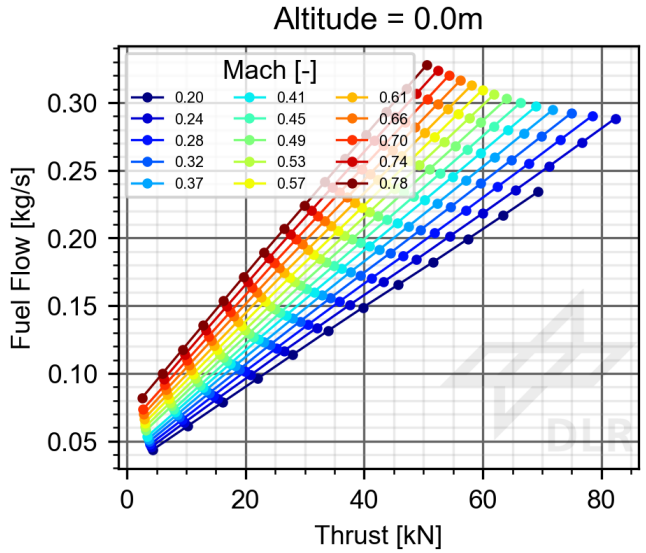


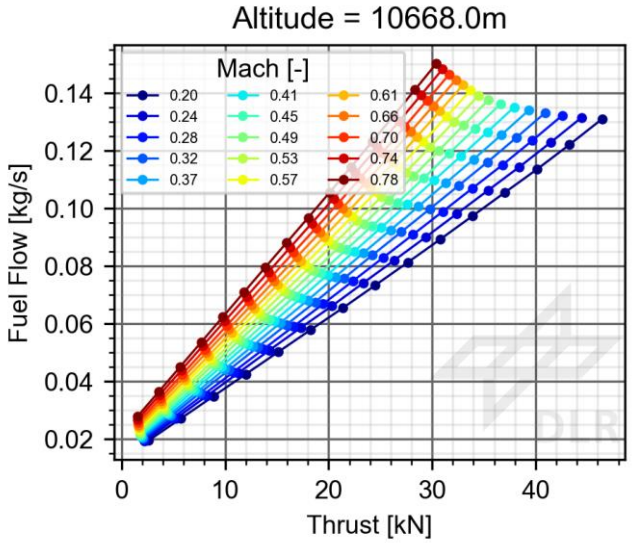
Parameter	Unit	Value
Engine GTF		
Fan radius	[m]	1.18
Mass Gasturbine	[kg]	3058
Bypass-Ratio	[-]	15
OPR	[-]	41.1
Equivalent static thrust (Sea-level/ISA)	[kN]	151.6
Nacelle		
Length	[m]	3.94
Diameter	[m]	3.10
Wetted Area	[m2]	34.53

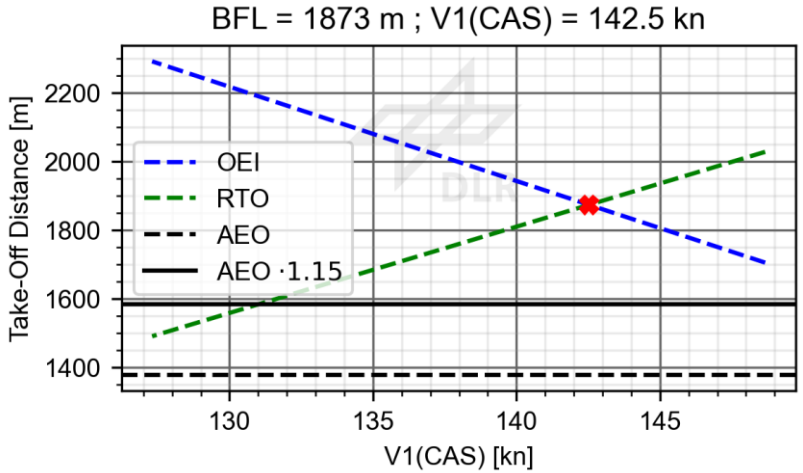


DLH25 – LH2 Research Baseline
Engine Performance

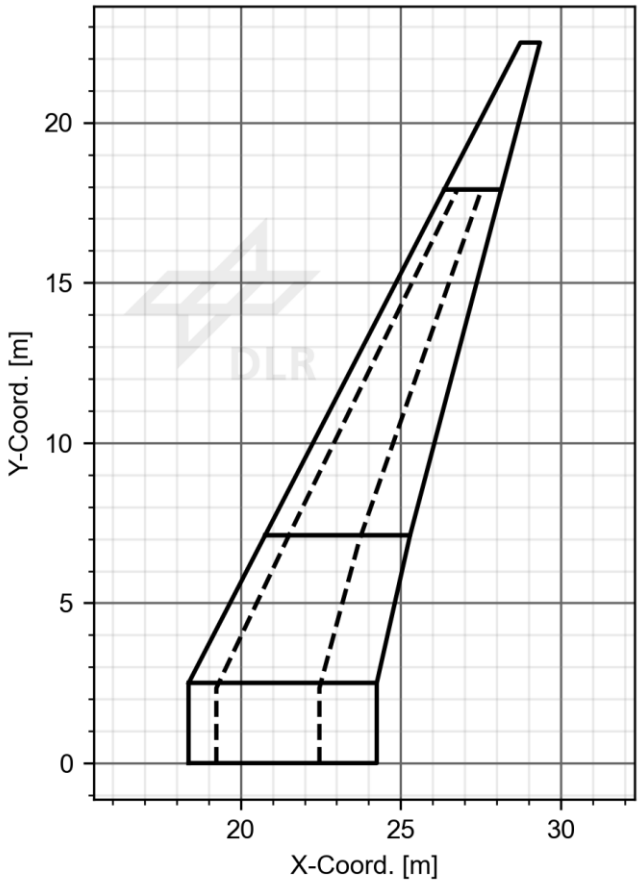






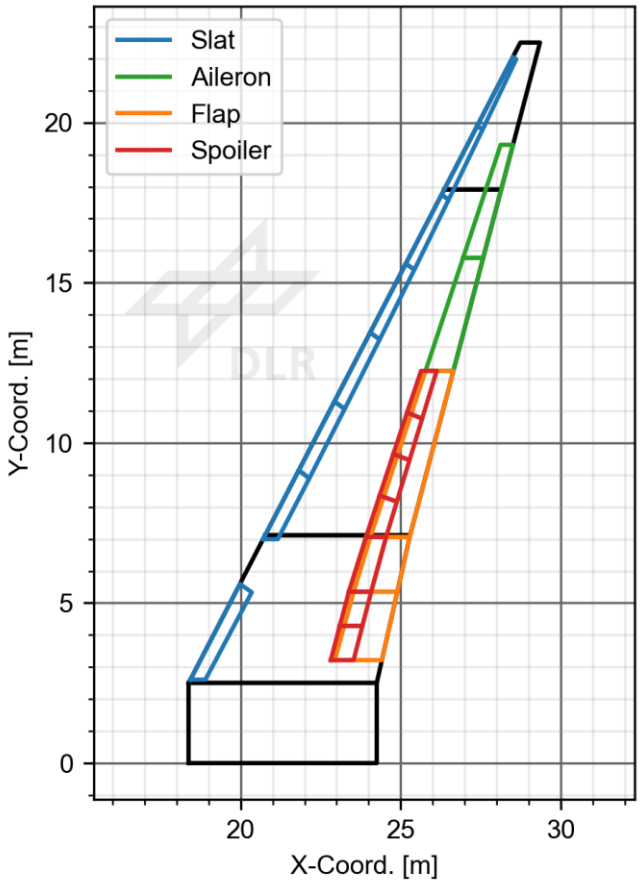


DLH25 – LH2 Research Baseline
Wing Box Geometry Overview



Wing Section	Unit	Center	Root	Kink	Mid	Tip
Position	m	0.00	2.51	7.12	17.91	22.50
Rel. Position	%	0.00	11.13	31.63	79.60	100.00
Chord	m	5.87	5.87	4.53	1.78	0.61
1/4 Chord Sweep	deg	0.00	0.00	24.00	24.45	24.46
LE Sweep	deg	0.00	0.00	27.40	27.40	27.40
TE Sweep	deg	0.00	0.00	12.80	14.78	14.78
Dihedral	deg	0.00	0.00	8.30	6.40	6.40
Twist Angle	deg	3.00	3.00	1.50	0.90	-1.00
Thickness Ratio	%	15.30	15.30	11.60	11.00	11.00
Rel. Spar Position						
Front Spar	%	14.70	14.70	16.40	23.10	27.10
Rear Spar	%	69.50	69.50	66.10	65.40	61.90

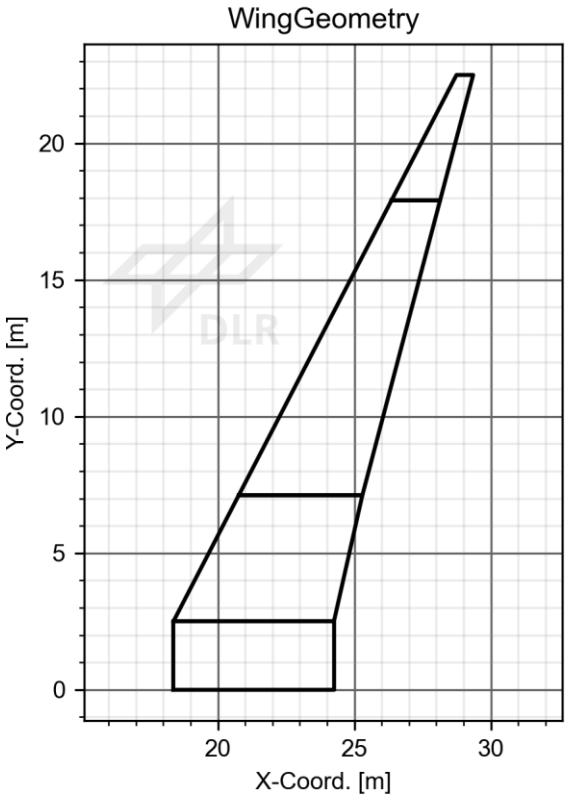
DLH25 – LH2 Research Baseline
Wing Movable Arrangement Overview

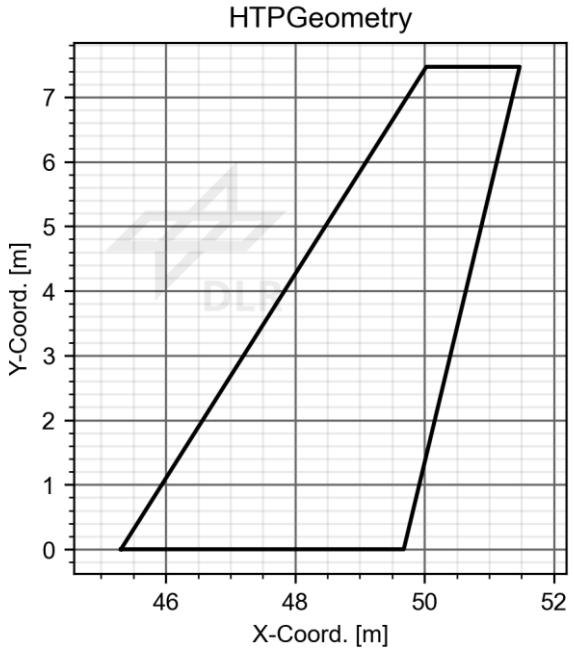


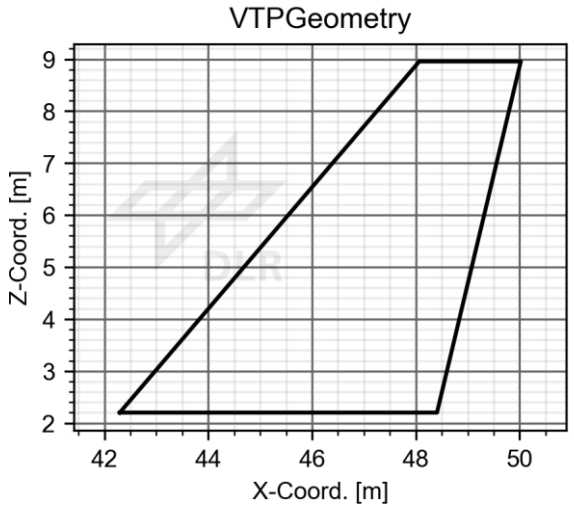
Control Surface	y Inboard	y Outboard	Chord Inboard	Chord Outboard
Slat1	2.606	5.594	0.47	0.5
Slat2	6.992	9.143	0.46	0.45
Slat3	9.143	11.294	0.45	0.43
Slat4	11.294	13.446	0.43	0.4
Slat5	13.446	15.597	0.4	0.36
DroopNose1	15.597	17.748	0.36	0.3
DroopNose2	17.748	19.899	0.3	0.22
DroopNose3	19.899	22.051	0.22	0.14
Flap1	3.216	5.355	1.44	1.32
Flaperon1	5.355	7.06	1.32	1.19
Flap2	7.06	12.246	1.19	0.84
Flaperon2	12.246	15.776	0.87	0.63
Flaperon3	15.776	19.307	0.63	0.38
Spoiler1	3.216	4.286	0.71	0.71
Spoiler2	4.286	5.355	0.71	0.7
FlaperonSpoiler	5.355	7.06	0.7	0.63
Spoiler3	7.06	8.356	0.63	0.6
Spoiler4	8.356	9.653	0.6	0.56
Spoiler5	9.653	10.949	0.56	0.53
Spoiler6	10.949	12.246	0.53	0.49

DLH25 – LH2 Research Baseline
Lifting Surface Geometry Overview

Parameter	Unit	Wing	HTP	VTP
Reference Area	m²	157.98	43.20	27.26
Span	m	45.00	14.86	6.76
Aspect Ratio	-	12.82	5.11	1.68
Taper Ratio	-	0.12	0.33	0.32
Mean Aerodynamic Chord	m	4.25	3.15	4.39
Avg. 1/4 Chord Sweep	deg	24.38	28.08	35.00
Avg. Dihedral	deg	7.18	6.00	-
Lever Arm	m	-	25.55	23.28
Volume Coefficient	-	-	1.6419	0.0893

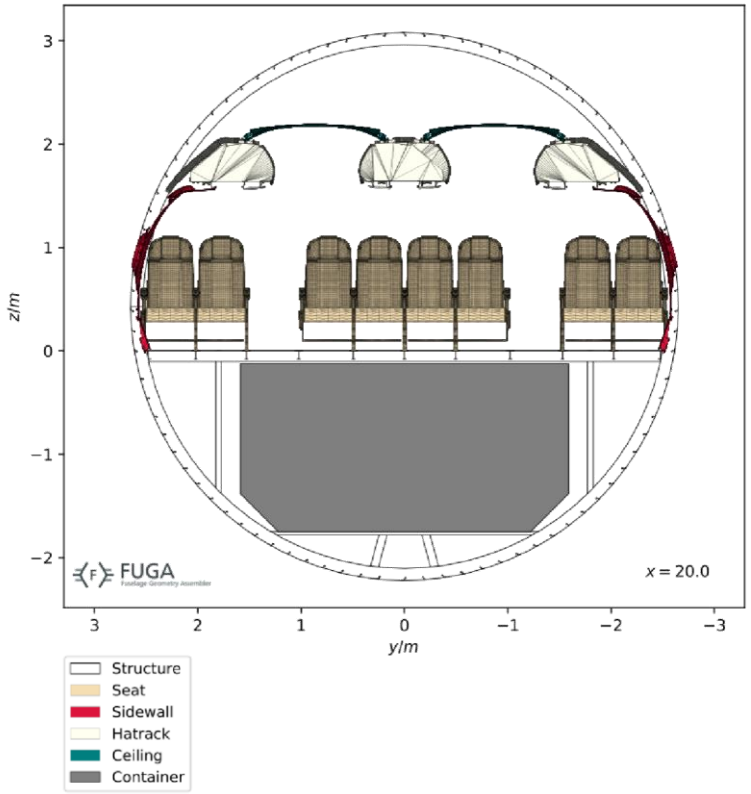




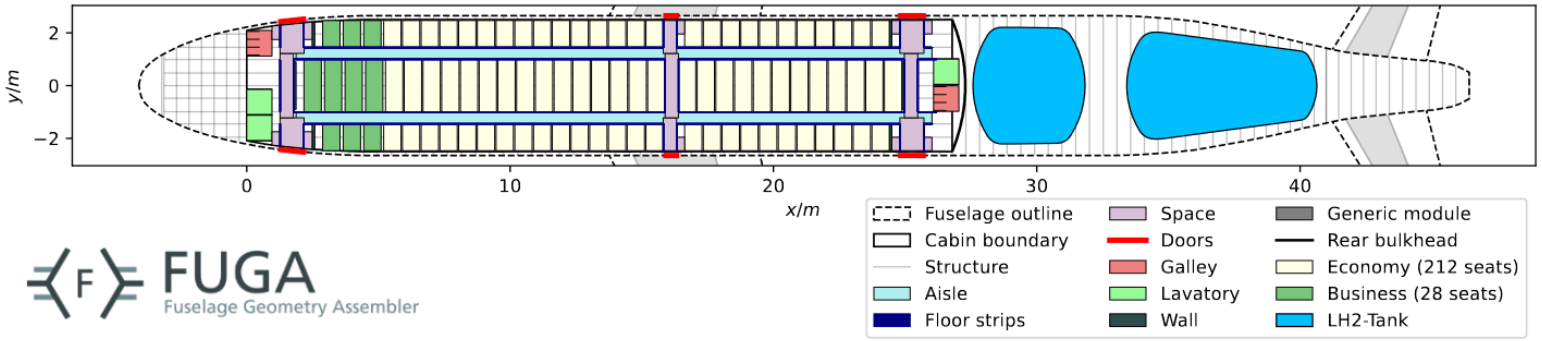


DLH25 – LH2 Research Baseline
Cabin and Cargo Layout

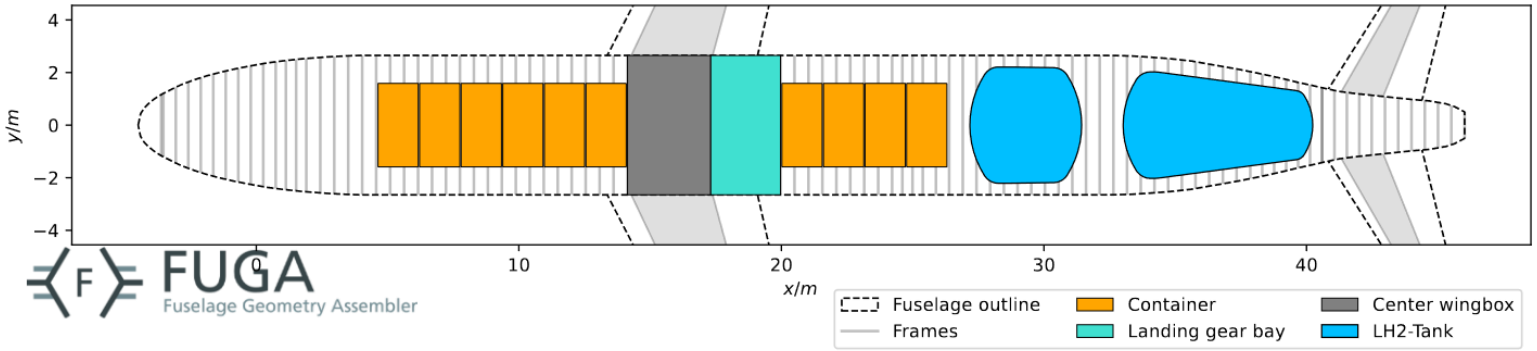
Cross Section



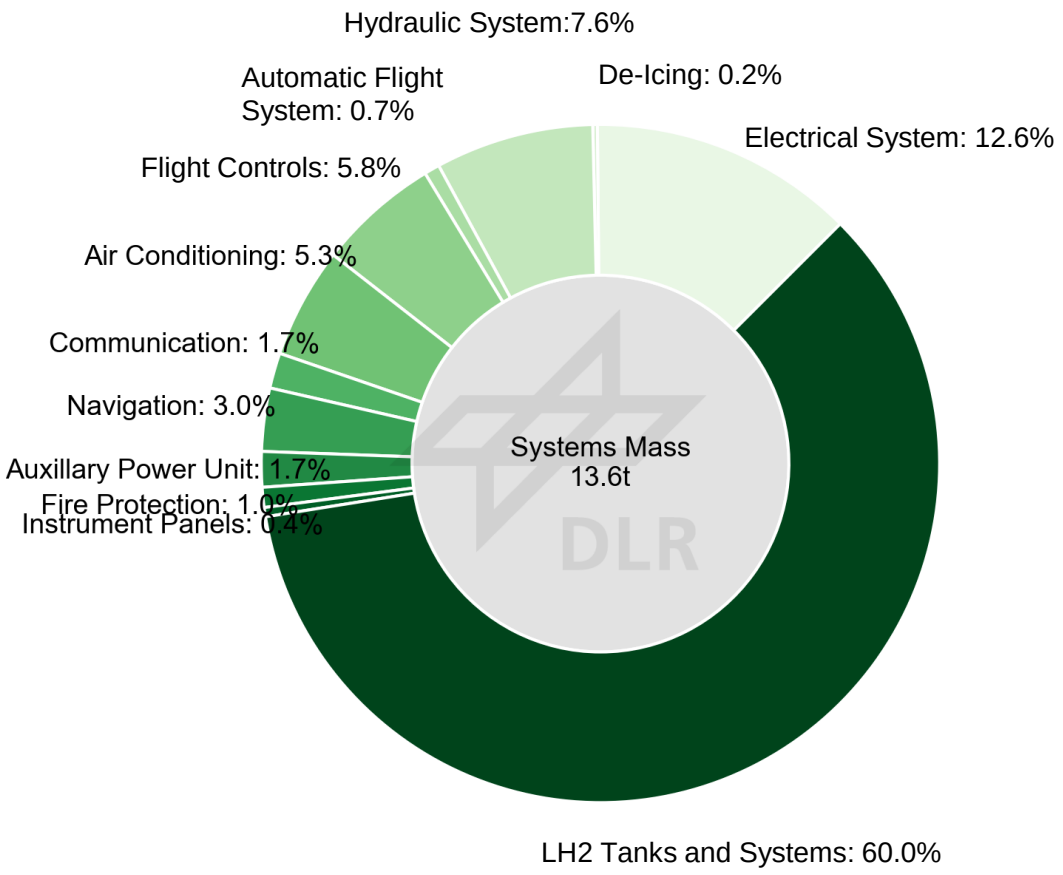
Cabin Layout



Cargo Compartment Layout



DLH25 – LH2 Research Baseline
System Mass Breakdown

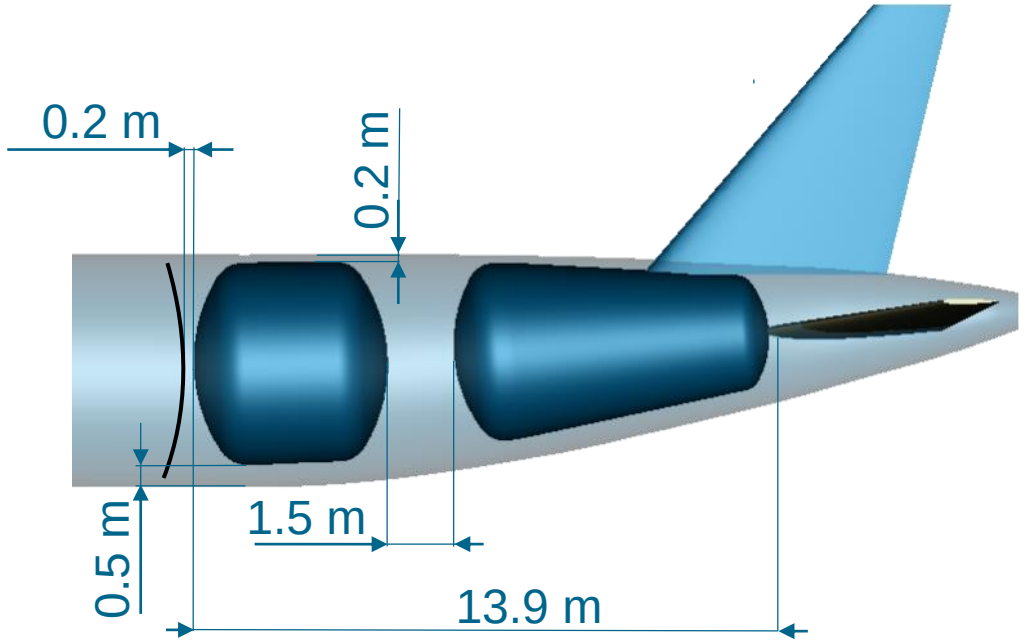


Component	Mass [kg]	Portion [%]
Air Conditioning	720	5.3
Auxiliary Power Unit (APU)	230	1.7
Automatic Flight System	100	0.7
Communication System	230	1.7
De-Icing	30	0.2
Electrical System	1723	12.6
Flight Controls	790	5.8
Fire Protection	130	1.0
Hydraulic System	1029	7.6
Instrument Panels	60	0.4
Navigation	410	3.0
LH2 Tanks and Systems	8175	60.0
Systems	13624	100.0

DLH25 – LH2 Research Baseline
LH2 Systems

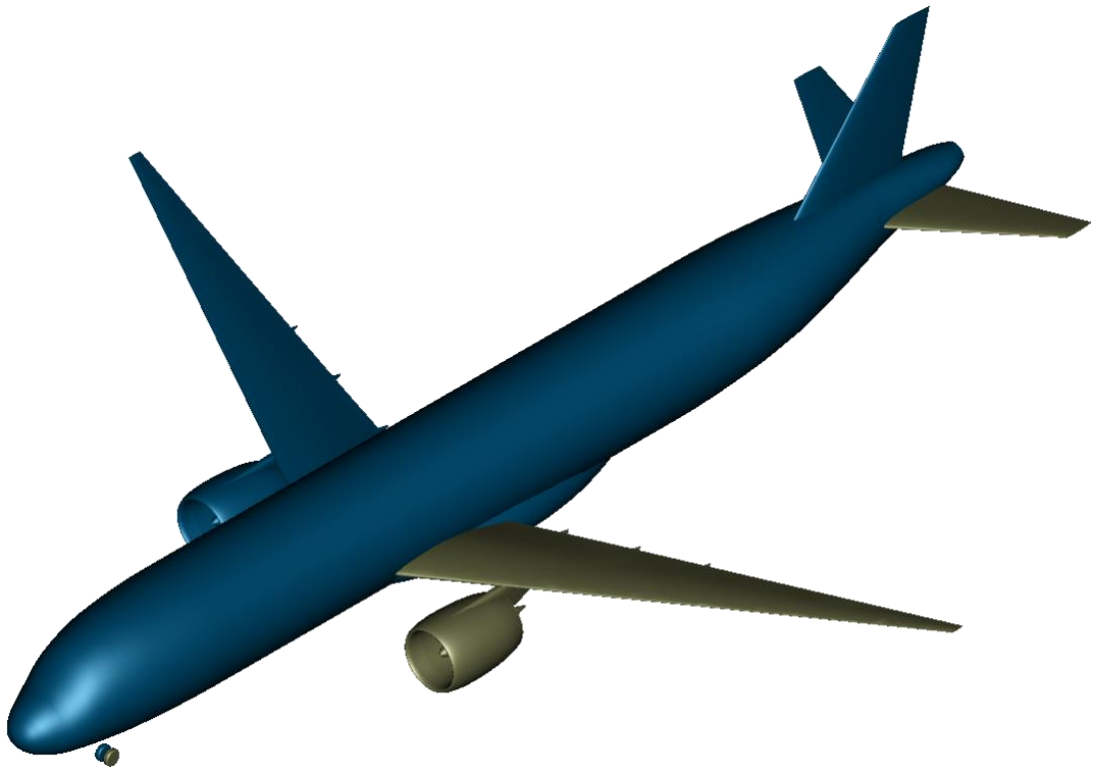
Additional Data of LH2 Tank Layout

PARAMETER	UNIT	TANK_01	TANK_02
Outer Bigger Radius	m	2.3	2.07
Outer Smaller Radius	m	2.28	1.38
Length	m	4.8	7.62
Inner Volume	m^3	55.8	55.8
Tank Mass	kg	2742	2887
Systems Mass	kg	356	370
GH2 Mass	kg	13	13
Usable Fuel Mass	kg	3237	3237
Total Fuel Mass	kg	3647	3647
Max Operating Pressure	bar	2.5	2.5
Portion of Unusable Fuel	%	10	10
Ullage Volume	%	4	4
Gravimetric Index	%	47.9	46.8



* Gravimetric Index total: $\mathrm{GI}_{\mathrm{total}} = \frac{\text{usable } fuel\ mass}{(total\ fuel\ mass + GH2 mass + structural\ mass + systems\ mass)}$

DLH25 – LH2 Research Baseline
Key Characteristics



DLH25 – LH2 Research Baseline		
Key Sizing Parameters		DLH25
W/S=MTOW/Sref	[kg/m2]	591
T/W=SLST/MTOW	[-]	0.33
Masses		
MTOM	[t]	93.4
MLM	[t]	88.3
MZFM	[t]	87.0
OEM	[t]	62.0
MFW	[t]	6.5
Block Energy (Design Range)	[GJ]	643
Block Energy (Evaluation Range)	[GJ]	228
Geometry		
Wing Span	[m]	45.0
Wing Aspect Ratio	[-]	12.8
Wing MAC	[m]	4.26
Wing Ref. Area	[m²]	158
Propulsion		
Equivalent static thrust (Sea-level/ISA)	[kN]	152
TSEC avg. cruise (800nm)	[MJ/s/kN]	0.588
Aerodynamic		
cL cruise (800nm)	[-]	0.58
L/D cruise average (800nm)	[-]	17.5
cL max TO	[-]	2.1
cL max LDG	[-]	2.76

Acronym Definition

Acronym	Definition
A/C	Aircraft
AEO	All Engine Operating
AMC	Aircraft Mission Calculation
App	Approach
APU	Auxiliary Power Unit
Avg.	Average
BPR	Bypass Ratio
CAS	Calibrated Airspeed
CS 25	Certification Specifications for Large Aeroplanes
CFRP	Carbon-Fiber-Reinforced Polymers
CG	Centre of Gravity
CPACS	Common Parametric Aircraft Configuration Schema
DC	Drag counts
EIS	Entry Into Service
EOF	End of Field
FL	Flight Level
hAP	Airport Altitude
HiFi	High Fidelity

Acronym	Definition
HTP	Horizontal Tail Plane
ICA	Initial Cruise Altitude
ISA	International Standard Atmosphere
IPT	Intermediate Pressure Turbine
ITD	Intermediate Turbine Duct
JAR	Joint Aviation Requirements
klbf	Kilo Pound-Force
kn	Knots
LE	Leading Edge
LFL	Landing field length
LoFi	Low Fidelity
MCL	Maximum Climb Thrust
MCR	Maximum Cruise Thrust
MEM	Manufacturer Empty Mass
MLM	Maximum Landing Mass
MTO	Maximum Take-off Thrust
MTOM	Maximum Take-Off Mass
MZFM	Maximum Zero-Fuel Mass

Acronym	Definition
NM	Nautical Mile
OAD	Overall Aircraft Design
OEI	One engine inoperative
OEM	Operating Empty Mass
OPR	Overall Pressure Ratio
PAX	Passenger
RCE	Remote Component Environment
ROC	Rate of Climb
RTO	Reserve Take-off Thrust
RWY	Runway
SFC	Specific Fuel Consumption
SL	Sea Level
TE	Trailing Edge
TLARs	Top-Level Aircraft Requirements
TOC	Top of Climb
TSFC	Thrust Specific Fuel Consumption
VTP	Vertical Tail Plane

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