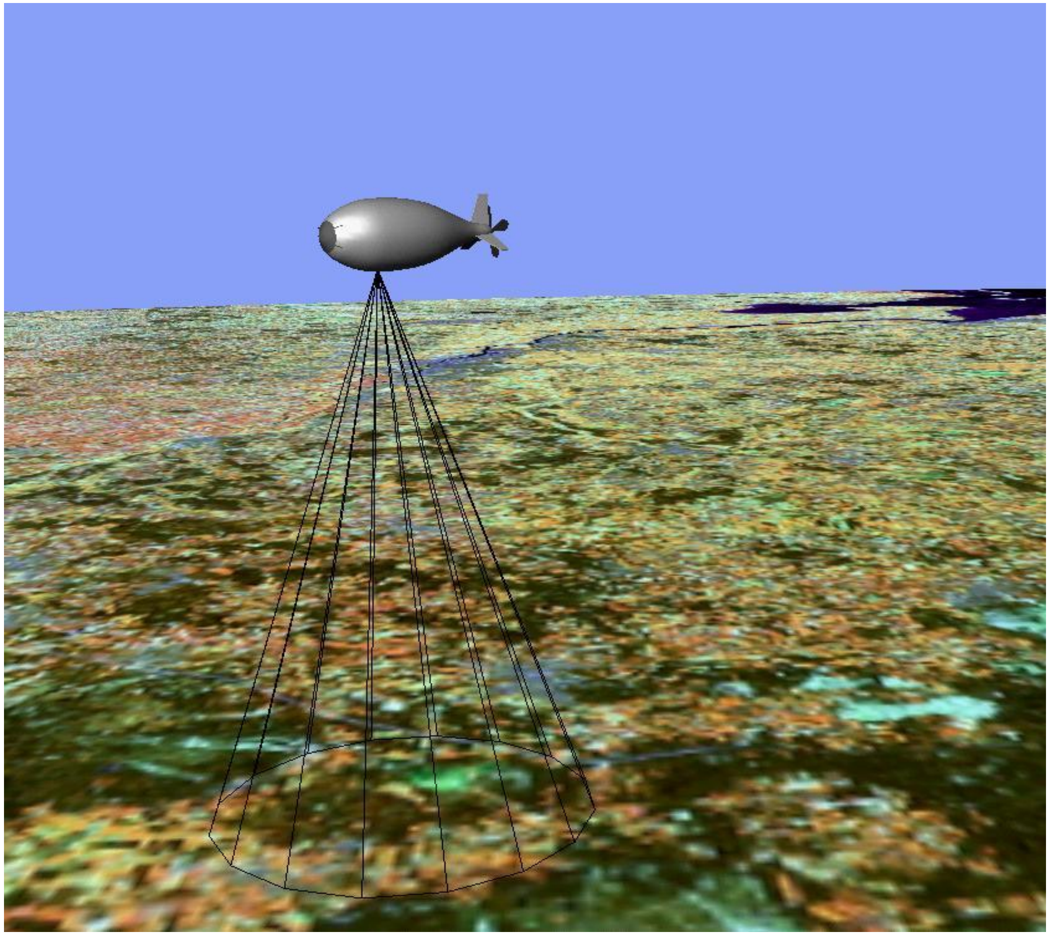
High Altitude Long Endurance Aerostatic Platforms:

The European Approach



Per Lindstrand – Lindstrand Technologies Ltd.
Peter Groepper - ESA
Dr. Ingolf Schäfer - CargoLifter

HALE History

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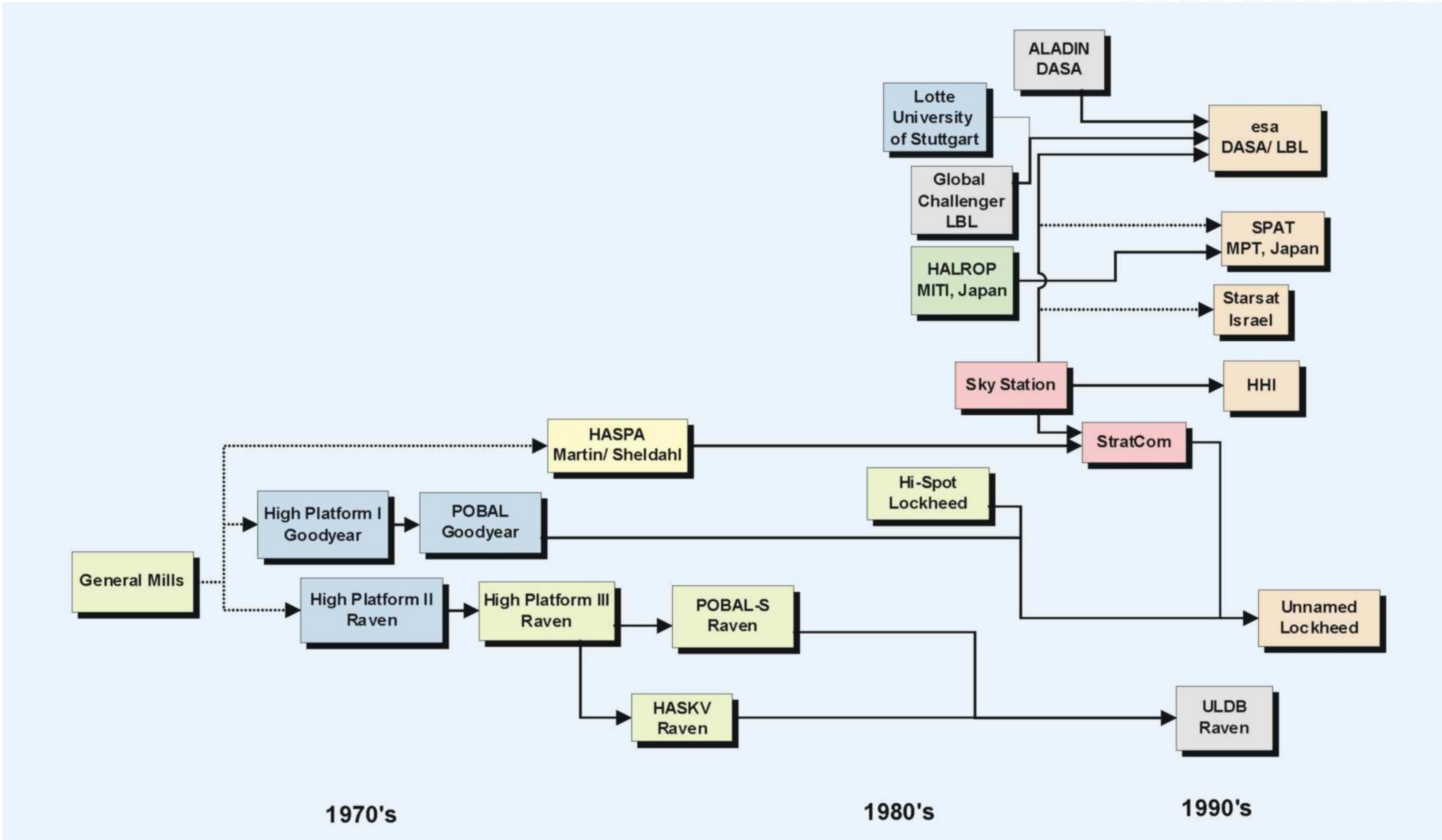
Year	Contractor	Payload	Altitude	Duration	Outcome	Additional Information
1958	General Mills	100 kg	18 – 20 km	8 hours	Study only	-
1970 High Platform 2	Raven	nil	20 km	2 hours	1 flight only	-
1976 HASPA	Martin / Sheldahl	100kg	Hangar testing only	-	-	-
1982 Hi-Spot	Lockheed Martin	Gross weight 11.7 tonnes	21 km	30 days	No flight	4 piston engines
1992 Japan Science Foundation	Halrop	nil	10,000 feet	-	4 short duration flights	
1995 Sky Station	LTL	600 kg telecom platform	21 km	5 years	No flight	
2004	JAXA/ NICT	100kg	13,000ft	5 years	1 flight	Severely underpowered
2011	Lockheed Martin	500kg	21 km	2 hours	'crashed & burned'	

History of platform development



Lindstrand Technologies Involvement

- **Sky Station 1996–1998**

  Bespoke cell phone station created by General Alexander Haig

- **European Space Agency 1998–2000**

  Development contract in partnership with Daimler-Chrysler Aerospace

- **Körber Prize 1999**

  Yearly award for science and engineering. Shared with University of Stuttgart

- **Kawasaki Heavy Industries 2001**

  Funded by Japanese Science Foundation

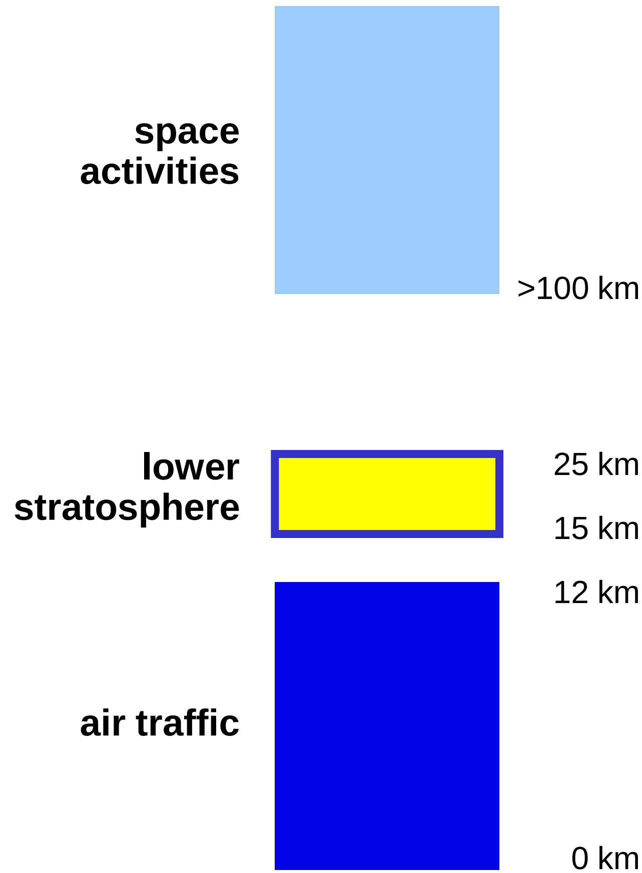
Stratospheric flight

Trends in Aeronautics:

- **Stratospheric flight offers opportunities nearly as broad as space flight.**
- **Today the potential of stratospheric flight is largely untapped, but in the future they will be complementary completion to spacecraft in a large variety of applications.**

Stratospheric long endurance platforms :

- **can be placed within the atmosphere in a geo-synchronous position.**
- **are under research since the late 1950s.**
- **could now be made simpler, lighter and more reliable because materials and key systems have been improved since the early days.**
- **are now within reach.**



Stratospheric Platform Categories

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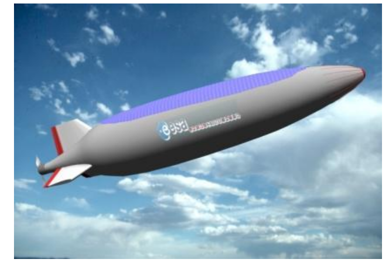
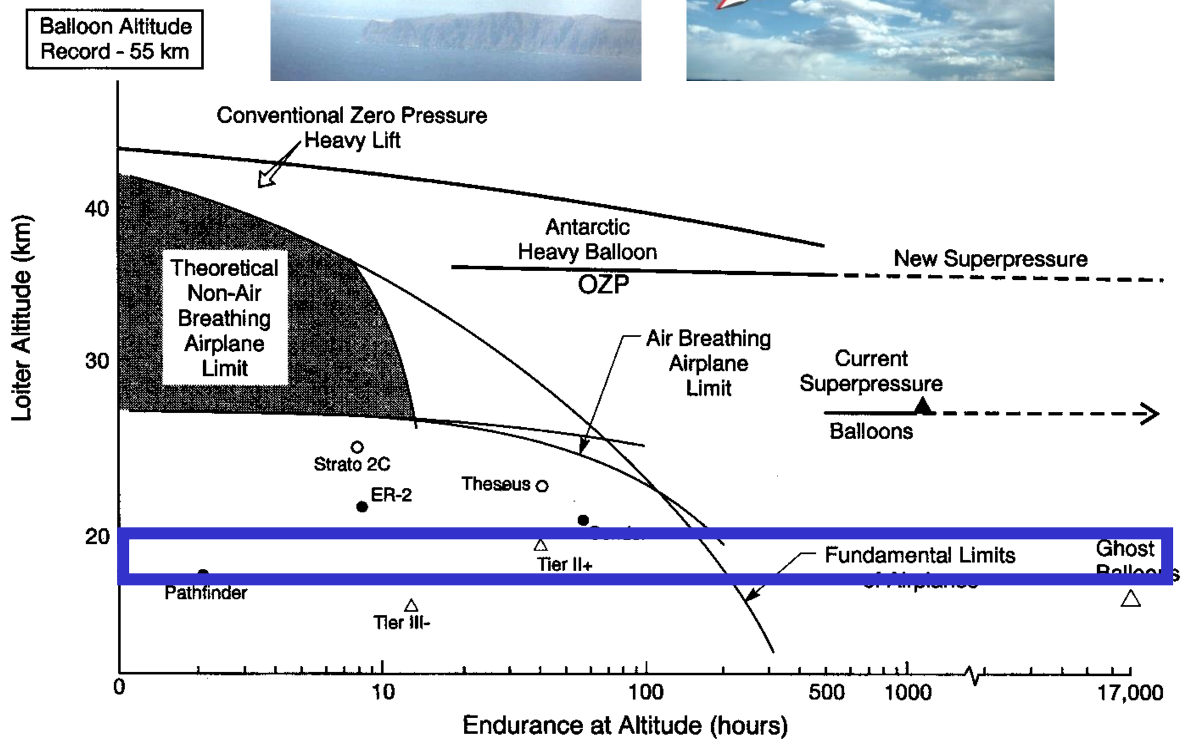
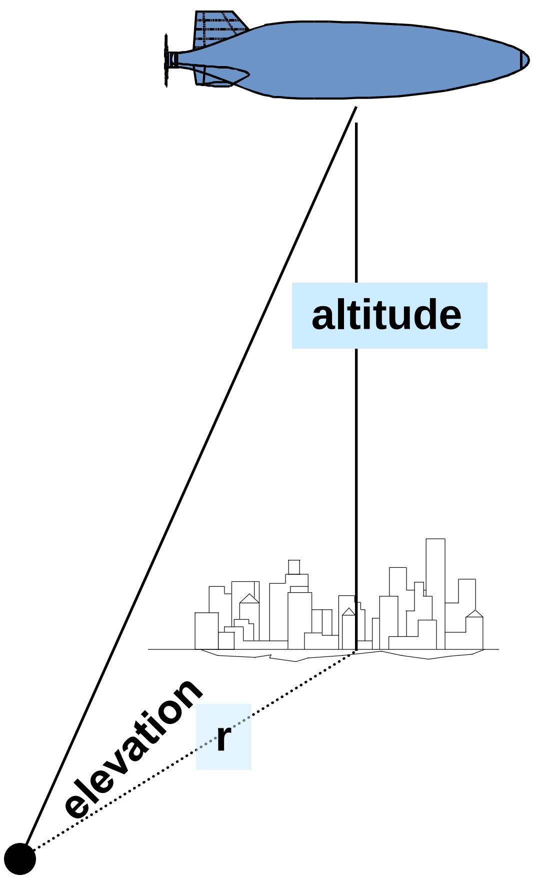
Aerostatic (vs aerodynamic) systems:

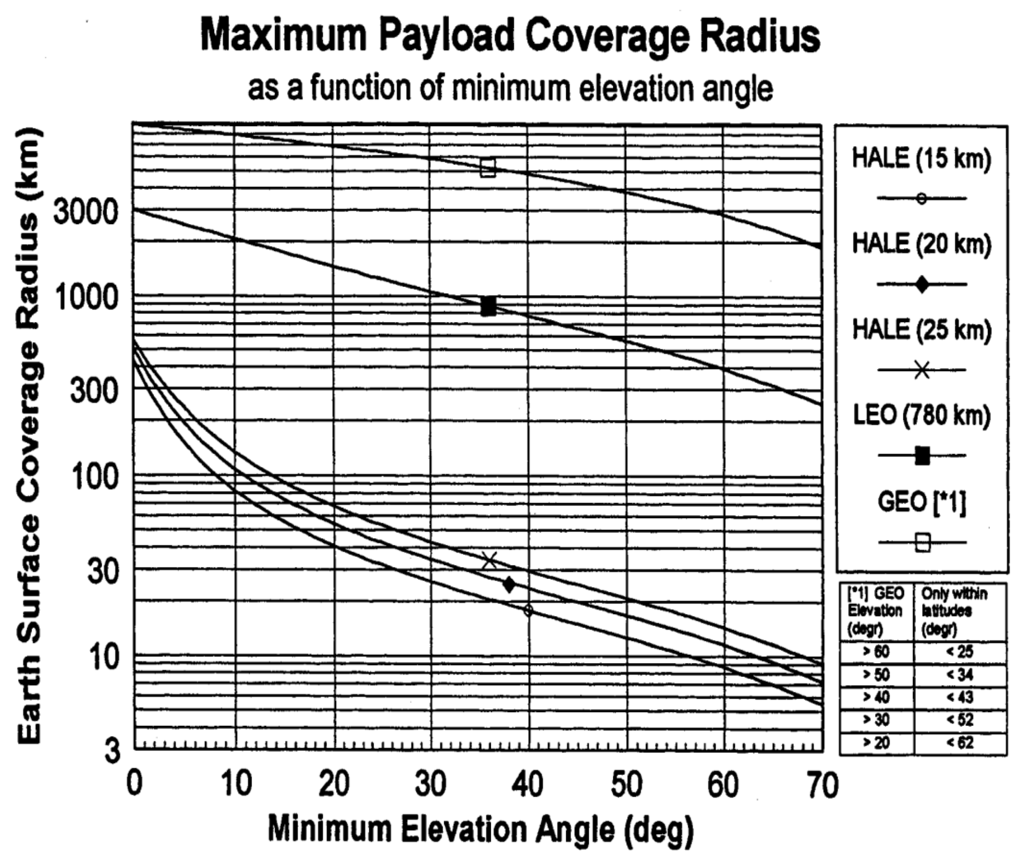
- long term missions (mission duration measured in months or years)
- payload capability
- safety
- geo-stationary positioning
- wind sensitivity
- new infrastructure





Stratospheric Platform Characteristics





Communications

Fraunhofer Gesellschaft, Erlangen, Germany

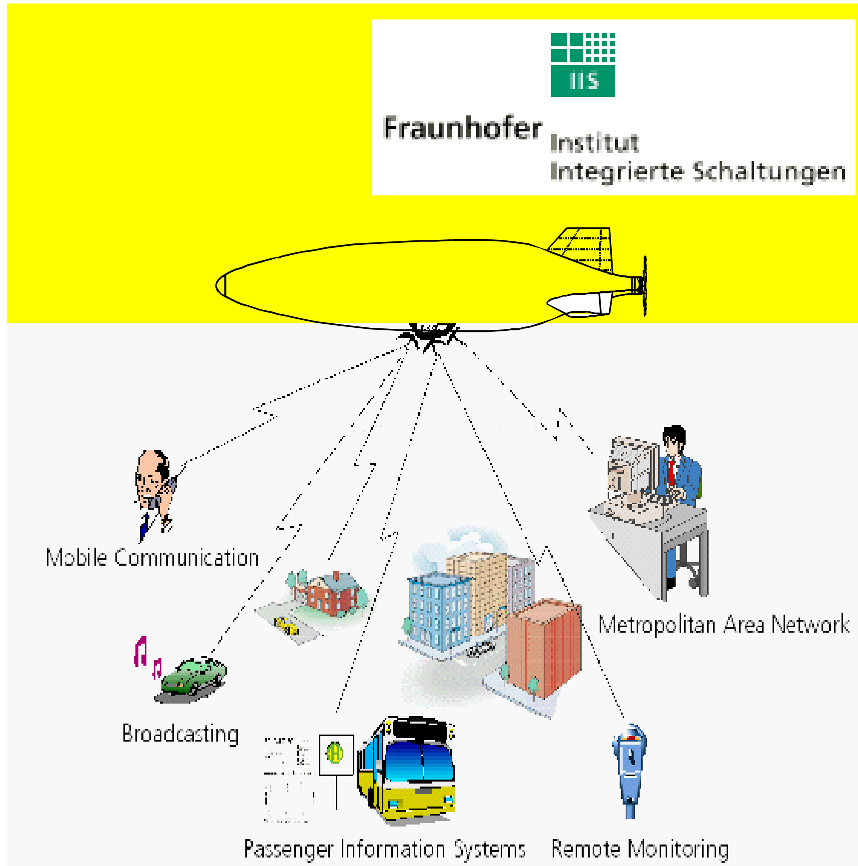
Services:

- **Cellular phone (S-UMTS)**
- **Metropolitan Area Network**
- **Remote Monitoring**
- **Passenger Information System**
- **Digital Broadcast**

Mission requirements:

- **High availability**
- **High reliability**
- **Station keeping**
- **Long term missions (5 years)**

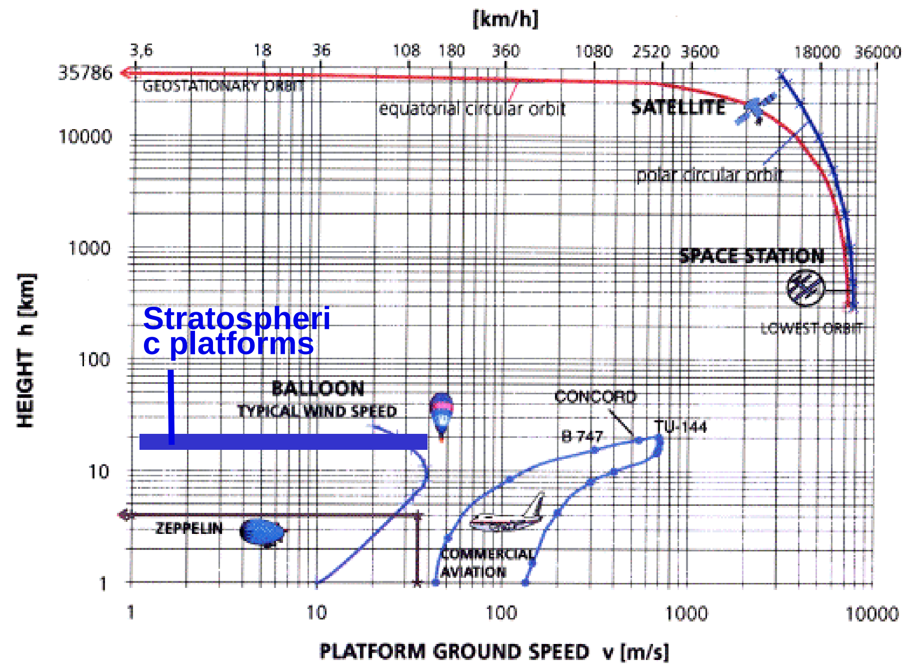
- **Very high commercial potential**



Remote Sensing

Remote Sensing Research Group,
DLR - Adlershof, Germany

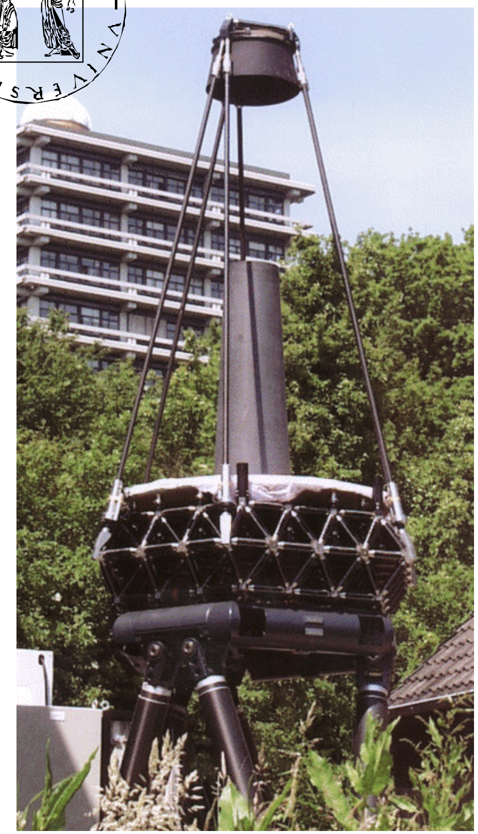
- **Services:**
  - **Coastal monitoring (multisensorial, spectroscopy, radar)**
  - **Disaster monitoring (forest fire, flood, volcanic activities)**
  - **Land use (Calibration of satellite data, detailed analysis)**
- **Mission requirements:**
  - **Patrol and station keeping**
  - **Different flight altitudes (10,000-25,000m)**
- **Very high scientific interest**
  Medium commercial potential



Science - Astronomy

Institute of Astronomy,
Ruhr-Universität, Bochum, Germany

- **Research areas:**
  - Infrared (IR)-observation
  - Far-Infrared (FIR)-observation
  - Pre-cursor mission for a stratospheric observatory
- **Mission requirements:**
  - Payload mass at least 1.000 kg for a 1.5 m telescope
  - Long term missions
  - More floating than geo-stationary positioning
- **Expected results:**
  - Comparable with a 2.5 m airborne telescope (SOFIA)
  - Comparable with HST



Environmental conditions - stratospheric winds

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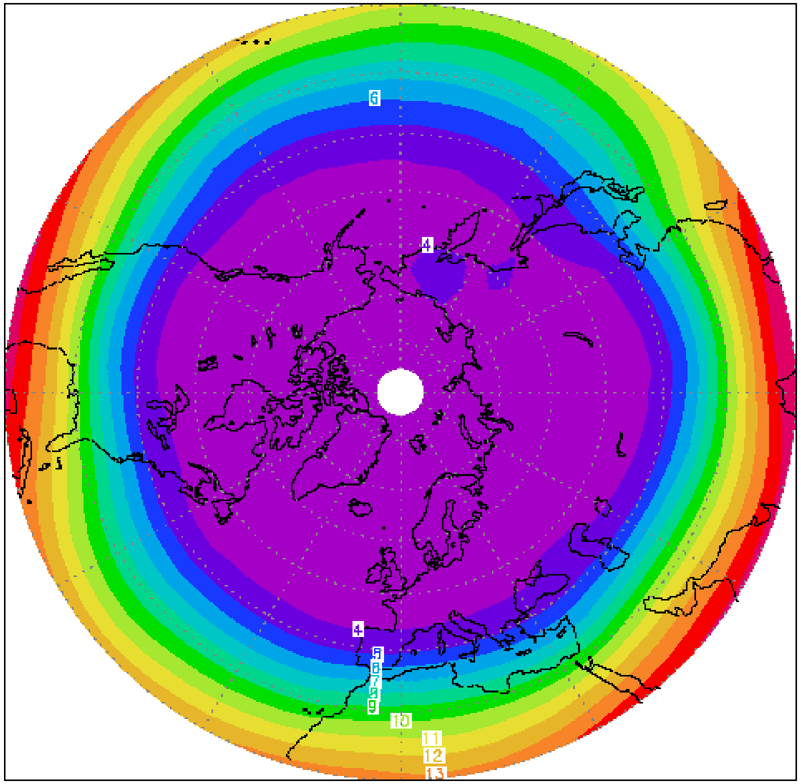
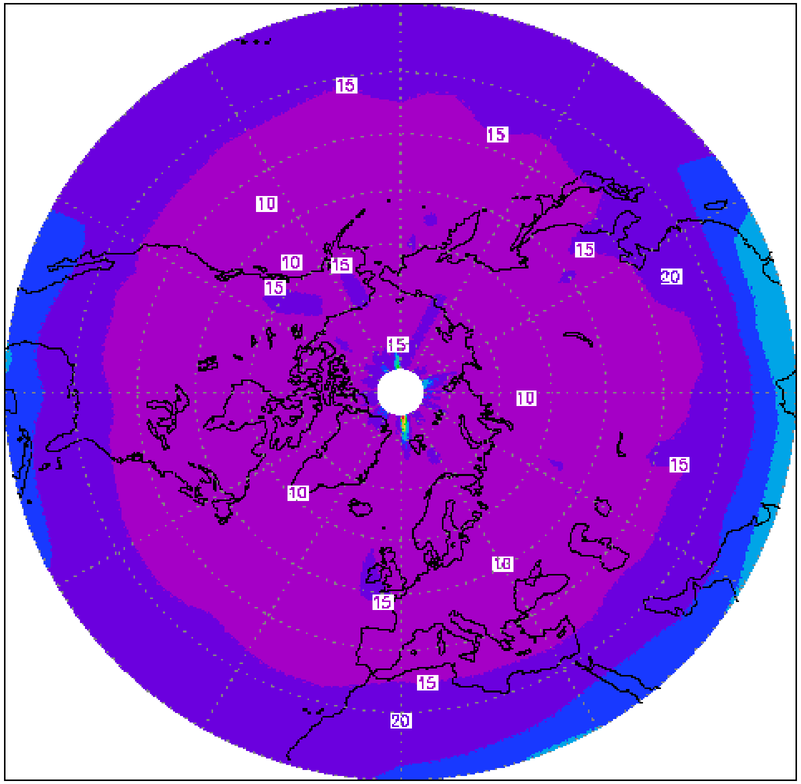
Wind conditions at 50 hPa pressure layer in summer (June, July, August) 1983-1995



average wind speed (m/s)



max. wind speed (m/s)

Environmental conditions - stratospheric winds

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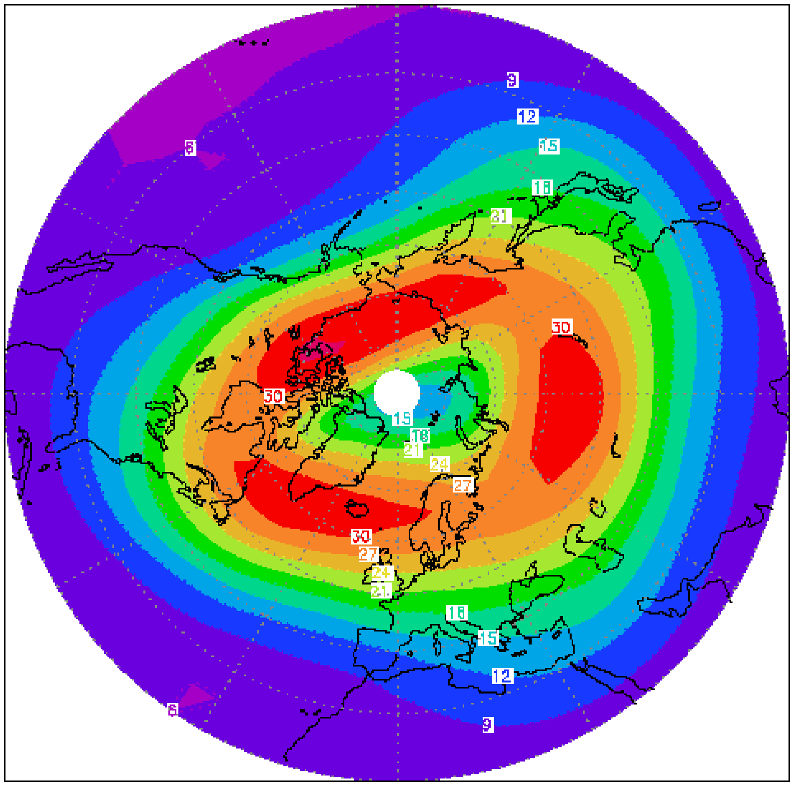
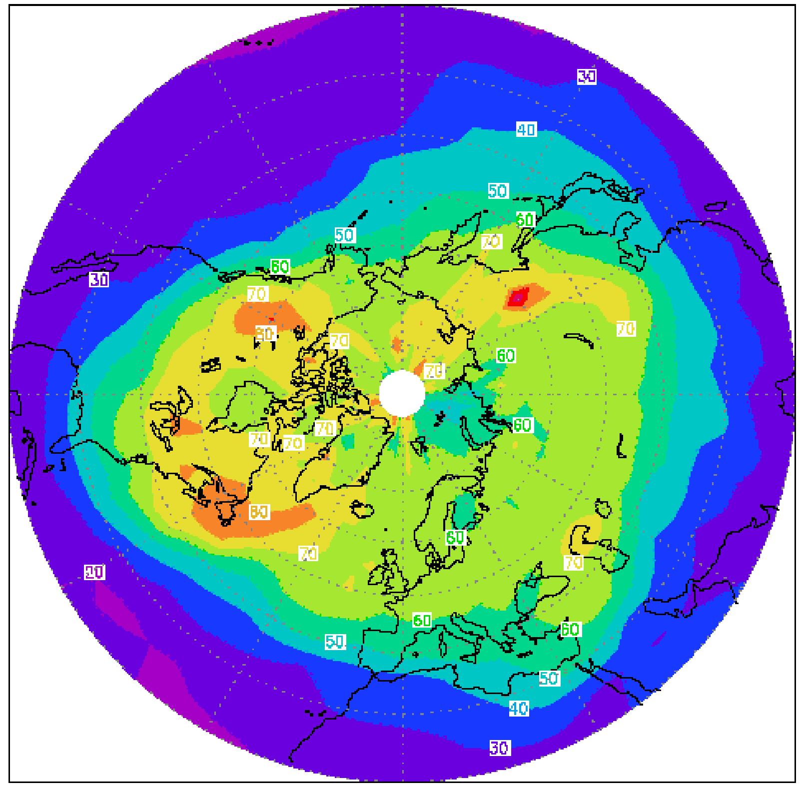
Wind conditions at 50 hPa pressure layer in winter (Dec, Jan, Feb) 1983-1995



average wind speed (m/s)

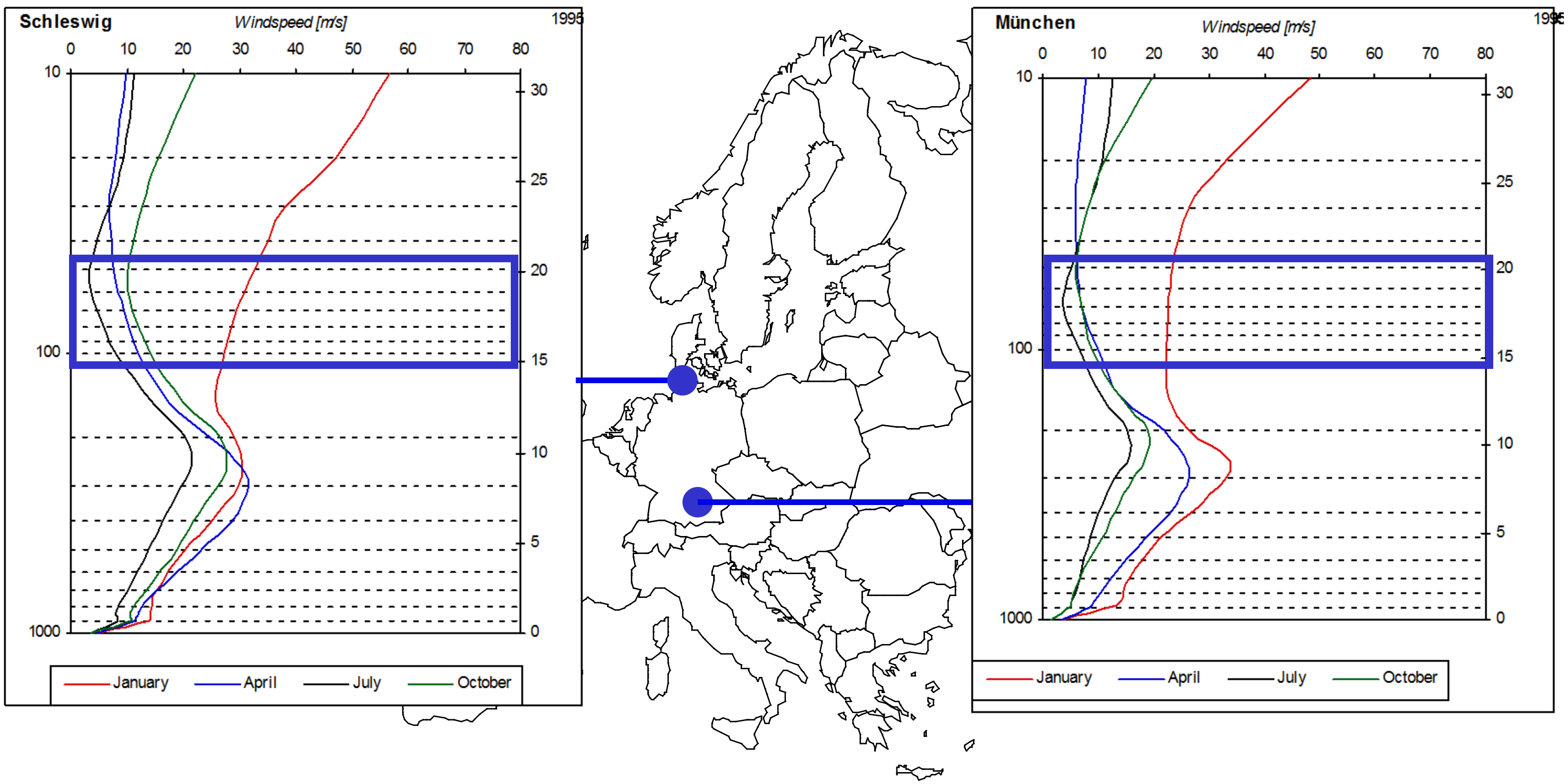


max. wind speed (m/s)

Environmental conditions - vertical wind profiles

Schleswig / Germany

Munich/ Germany



Current Platform Design - European ESA-HALE concept

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Design

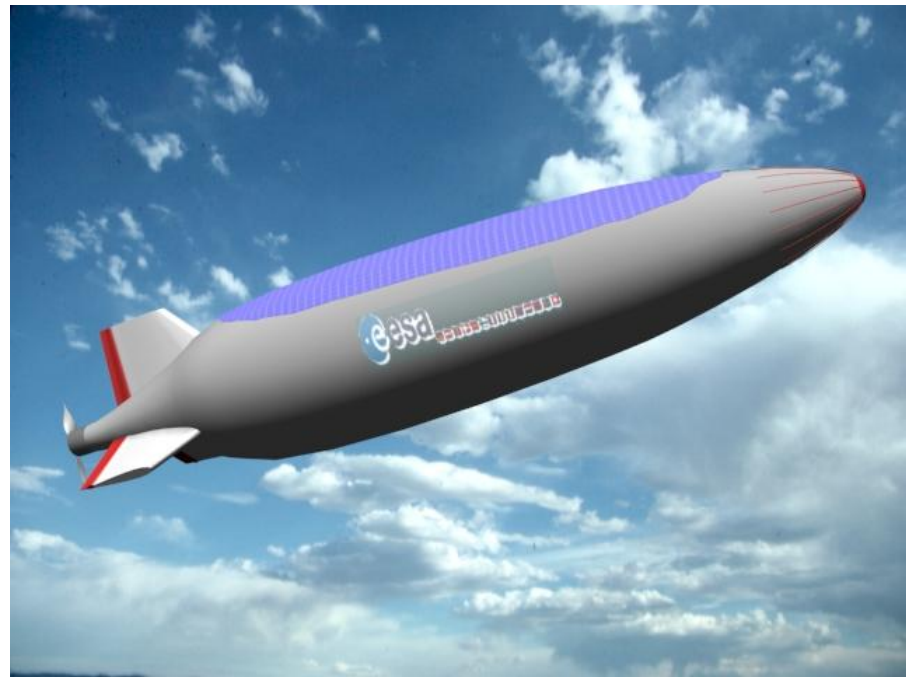
- Non-rigid structure
- stern propeller gimballed
- DC-Engine brushless
- Thin-film solar cells
- regenerative fuel cell

Performance

Altitude:	21,000 m
Speed:	25 m/s
Mass payload:	1,000 kg
Energy payload:	10 kW

System characteristics

Length:	220 m
Diameter:	55 m
Mass total:	20,800 kg
Volume:	320,000 m^3
Propulsion:	90 kW



Development concept

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Evolutionary approach

- First demonstrator (D15)
- Second demonstrator (D20)
- Pre-Series

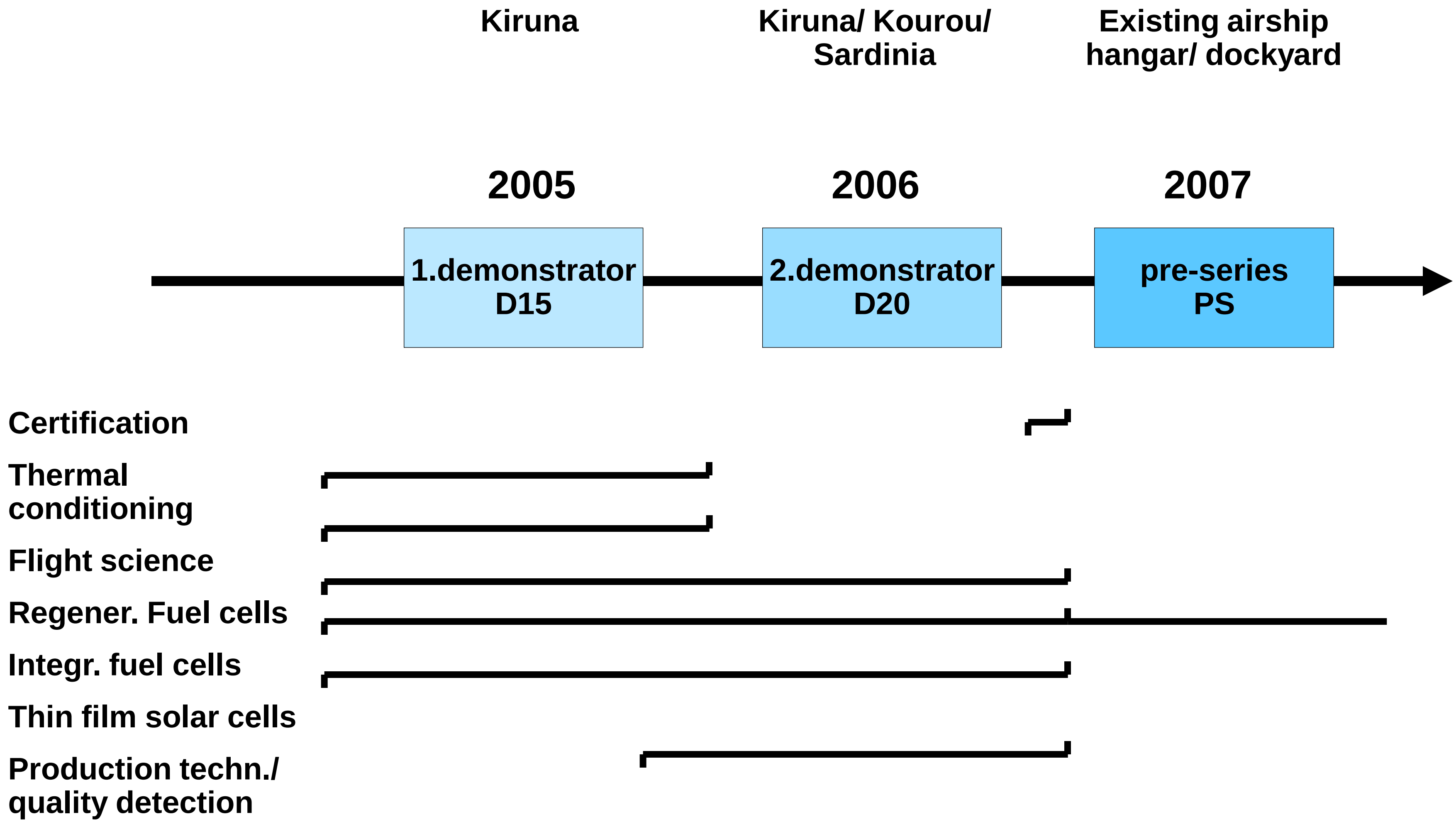
Risk reduction

- Staggered approach
- Clear defined functionality for demonstrators D15, D20 and Pre-Series
- Use of state-of-the-art technology

Development concept - HALE cornerstone missions

	1. Demonstrator D15 (principle)	2. Demonstrator D20 (capability)	Pre-series PS (functionality)
Objectives	- inflation - transit - demonstration station keeping - flight time 72h + - medium altitude - P/L recovery	- high-accurate station keeping - long term operations - high altitude - recovery of key system & P/L	- system operations - testing, production, machinery - ground infrastructure - service reliability - recovery procedure
What to learn?	- aerodynamic and flight mechanics data - environmental conditions (wind speed, - direction, forecast, accuracy - superpressure/ superheating - structural loads	- recovery strategies - payload flying parameters - reference applications	- manufacturing optimization - cost reduction
Focus	**platform**	**payload**	**services**

Development concept - schedule & technologies



Development concept - platform parameters

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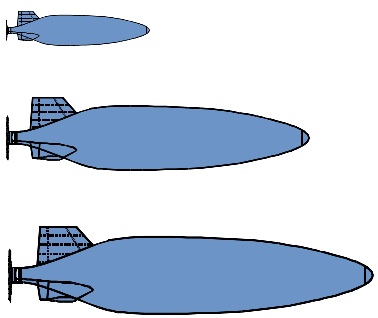


	volume	length	$mass_{sys}$	$mass_{pl}$
D15	16.000 m^3	80 m	2.700 kg	100 kg
D20	180.000 m^3	180 m	12.600 kg	500 kg
PS &series	320.000 m^3	220 m	20.800 kg	1.000 kg

+ technology research

Industrial Initiative

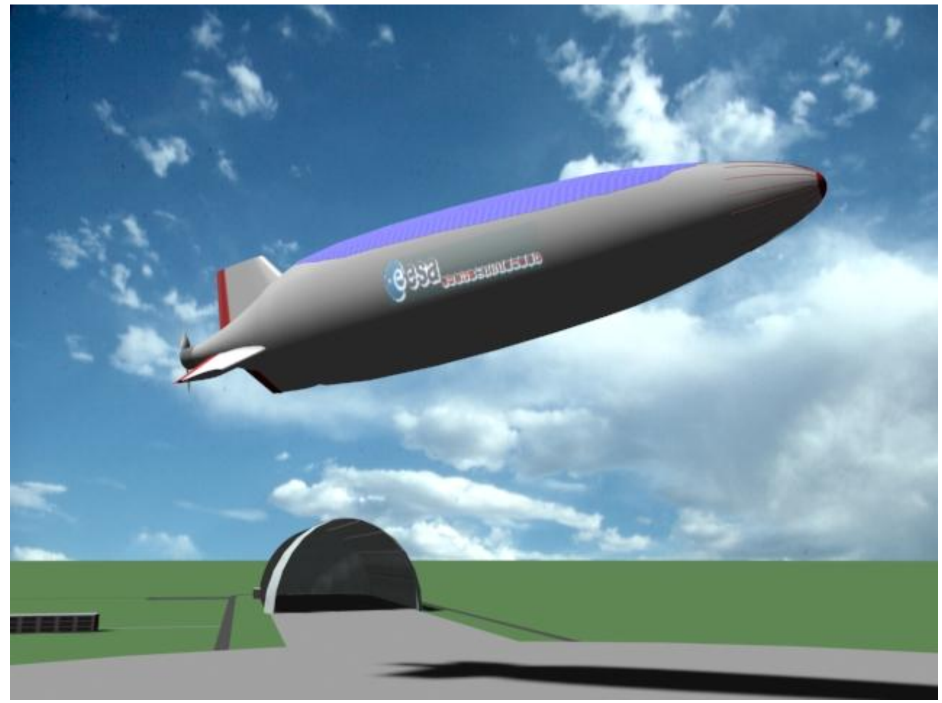
With Astrium GmbH (former DaimlerChrysler Aerospace) and Lindstrand Technologies Ltd.

a team has been established which:

covers all aspects of stratospheric aerostatic platforms from design and manufacturing up to operations.

accepts the global challenges and intends to become one of the world‘s leading providers of stratospheric aerostatic platforms

believes in the success of stratospheric platforms.



The vision

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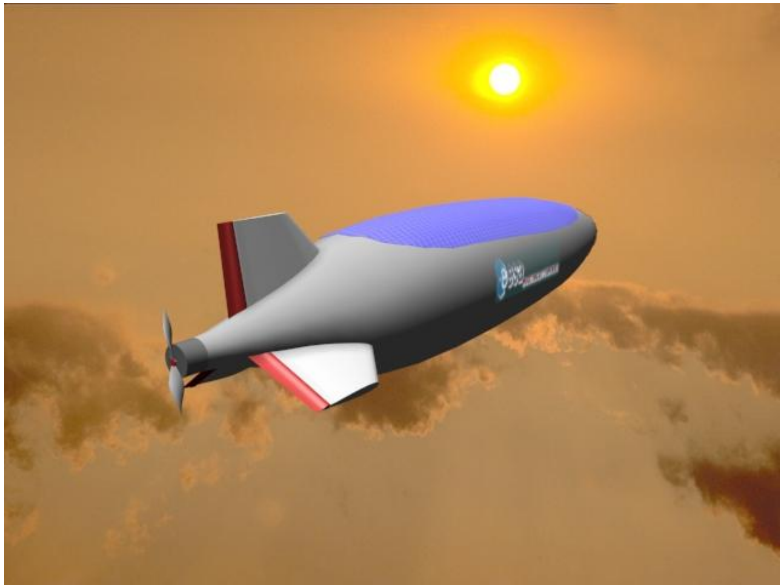
Source: Eriksson Microwave Systems, Stockholm

We assume the HALE payload being capable of handling 50,000 simultaneous phone calls.

Typically, in a larger city each subscriber during daytime 0.05 Erlang, I.e. will use the telephone for 20% of the time.

This translates into 50,000/0.05 = 100,000,000 which is the total number of subscribers the HALE airship can service.

If we assume each subscriber will phone for £1.20 (the average mobile user in Stockholm) per day one airship will generate 1,000,000 x £1.20 = £1.2M per day in traffic income and per year 365 x £1.2M = £438M.



HALE D-20 DESCRIPTION

– General Overview

– Aerodynamic Layout

– Lift Control

– Electrical Layout

– Power Management

– Operations

– Regulatory Issues

Atmospheric conditions at 20km altitude

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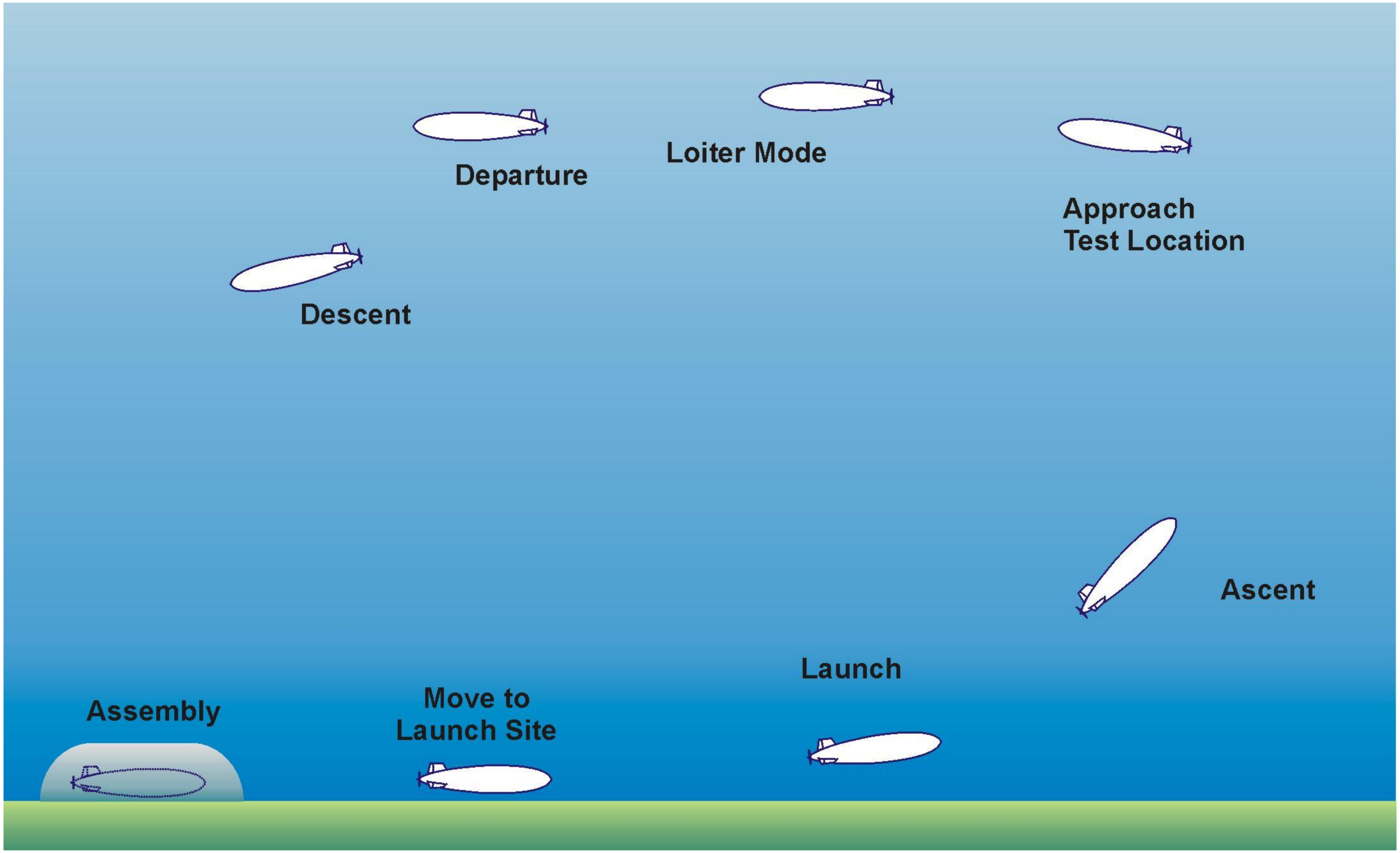
Pressure	**50mbar**
Temperature	**-56ºC**
Atmospheric density	**0.088 kg/m^3**
Gas expansion	**13.8**
Helium lift	**0.076 kg/m^3**

Operational States



Flight Controls

Control Surfaces for long-term flight control (dynamic lift, orientation towards sun)

Three-axis-control (roll for solar power optimisation)

Gimballed, feathered propeller for short-term flight control

Envelope pressurised during ascent

Controlled expansion of gas via special designed diaphragm

On lift off the envelope contains less than 10% of helium gas

Pressurisation during descent defined max. sink speed

Operational Phases

These data define the operational data for D-20. Design data including safety margins tend to have larger figures. **Operational Limits**	Sign convention, Remarks	Unit	Assembly	Move to Launch Site	Launch	Ascent	Approach to Demonstration Site	Demonstration & Test	Departure	Descent	Desintegration
max. horizontal speed (IAS)	positive: stream from front	m/s	NA	5	5	10	25	25	25	10	2
min. horizontal speed (IAS)	positive: stream from front	m/s	NA	0	0	5	5	0	5	5	0
vertical speed range	positive: ascent	m/s	NA	0	0 ... 2	2 ... 5	2 ... 5	0 ... 2	2 ... 5	2 ... 5	TBD
Altitude	(reference: CR (centre of reference))	m	NA	10 AGL	10 ... 100 AGL	100 AGL ... 20000 MSL	10000 MSL ... 20000 MSL	20000 MSL	10000 MSL ... 20000 MSL	1000 AGL ... 20000 MSL	0 AGL ... 1000 AGL
min. altitude accuracy	(goal)	m	NA	2	2	50	100	100	100	50	50
min/ max. attitude (Θ)	positive: nose up	°	-10/10	5	0/30	0/90	0/10	-10/10	-10/5	-90/90	-90/90
min/max pitch (AOA)	positive: nose up	°	0	-5/5	0/5	-10/10	-10/10	-10/10	-10/10	-10/10	-10/10
max. pitch rate		°/sec	10	10	5	5	5	5	5	5	5
max. yaw angle	(side slip angle)	°	10/10	5	5	5	5	5	5	5	5
max. yaw rate		°/sec	10	10	5	5	5	5	5	5	5
max. roll angle	(bank angle)	°	120	30	30	20	10	10	10	20	30
max. roll rate		°/sec	10	10	10	10	10	10	10	20	30
max. gas temperature difference	TBD	K	10	20	20	20	30	30	30	30	30
max. static heaviness		% of total mass	100	100	5	5	5	5	5	5	5
max.static lightness		% of total mass	100	10	10	5	5	5	5	5	5

Environmental Limits

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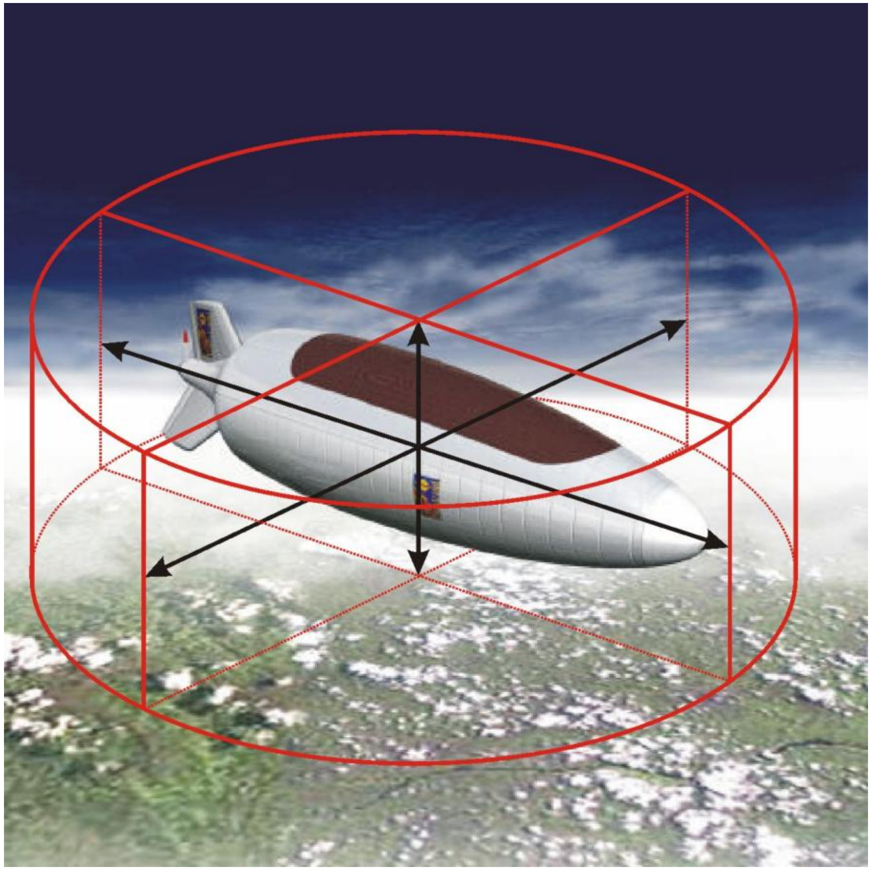
preliminary environmental conditions			Assembly	Move to Launch Site	Launch	Ascent	Approach to Demonstration Site	Demonstration & Test	Departure	Descent	Desintegration
max. ambient air temperature		°C	25	35	35	35	-40	-40	-40	35	35
min. ambient air temperature		°C	10	5	5	5	-65	-65	-65	5	5
max. steady wind speed horizontal		m/s	2	3	3	10	10	15	15	10	5
max. up & down draft 3sec		m/s	1	2	2	2	2	8	2	2	2
3 min		m/s	1	2	2	2	2	5	2	2	2
max. allowed thermal effects	(weak <1m/s vertical wind speed, moderate <2.5m/s, strong	CHAR	weak	weak	weak	weak	weak	weak	weak	weak	weak
humidity range		% rel.	0 ... 80	0 ... 80	0...80	0 ... 80	0 ... 20	0 ... 20	0 ... 20	0 ... 80	0 ... 80
dynamic stability of the atmosphere	(stable, unstable)	CHAR	NA	stable	stable	stable	stable	stable	stable	stable	stable
lightning conditions	TBD	CHAR	no	no	no	no	no	no	no	no	no
rain	(light, medium, heavy)	CHAR	no	no	no	no	no	no	no	no	no
hail	TBD	CHAR	no	no	no	no	no	no	no	no	no
extreme gusts		CHAR	no	no	no	no	no	no	no	no	no
microburst		CHAR	no	no	no	no	no	no	no	no	no
extreme up / down drafts		CHAR	no	no	no	no	no	no	no	no	no
extreme turbulences		CHAR	no	no	no	no	no	no	no	no	no
extreme wind shear	TBD	CHAR	no	no	no	no	no	no	no	no	no
wet snow		CHAR	no	no	no	no	no	no	no	no	no
hoar frost		CHAR	no	no	no	no	no	no	no	no	no
extreme pressure gradient		CHAR	no	no	no	no	no	no	no	no	no
extreme sudden temperature changes	10K/min	CHAR	no	no	no	no	no	no	no	no	no
sand		CHAR	no	no	no	no	no	no	no	no	no
corrosion		CHAR	no	no	no	no	no	no	no	no	no
EMC conditions		CHAR	no	no	no	no	no	no	no	no	no
icing conditions	(light, moderate, heavy)	CHAR	no	no	no	no	no	no	no	no	no
min. ambient air densitiy		ISA +°C	10	20	20	20	20	20	20	20	20
max. ambient air densitiy		ISA -°C	5	10	10	10	10	10	10	10	10
IMC		CHAR	NA	no	no	no	no	no	no	no	no

'Flight Box'



Vertical:	**+/- 500 ft**
Horizontal:	
Lateral:	**+/- 1500 m**
Longitudinal:	**+/- 1500 m**

Layout Airship

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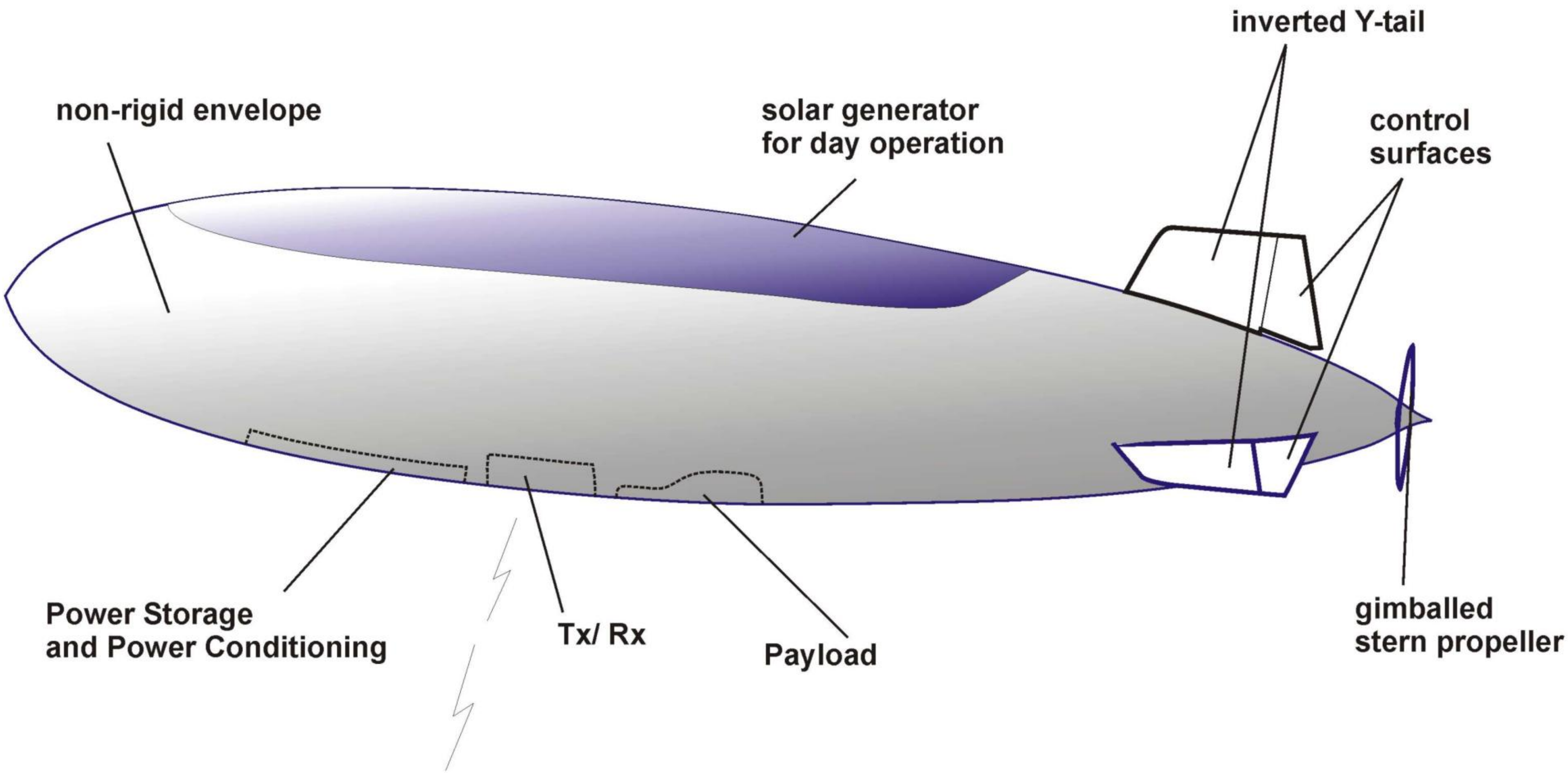


Technical Realization

Envelope: LTL design, based on 20 years of experience

Propeller: Efficiency-optimised design, two-bladed (University of Delft)

Motor: Efficiency and Reliability driven, direct drive for propeller

- EC-motor with rare-earth magnets, external rotor (University of Biel)

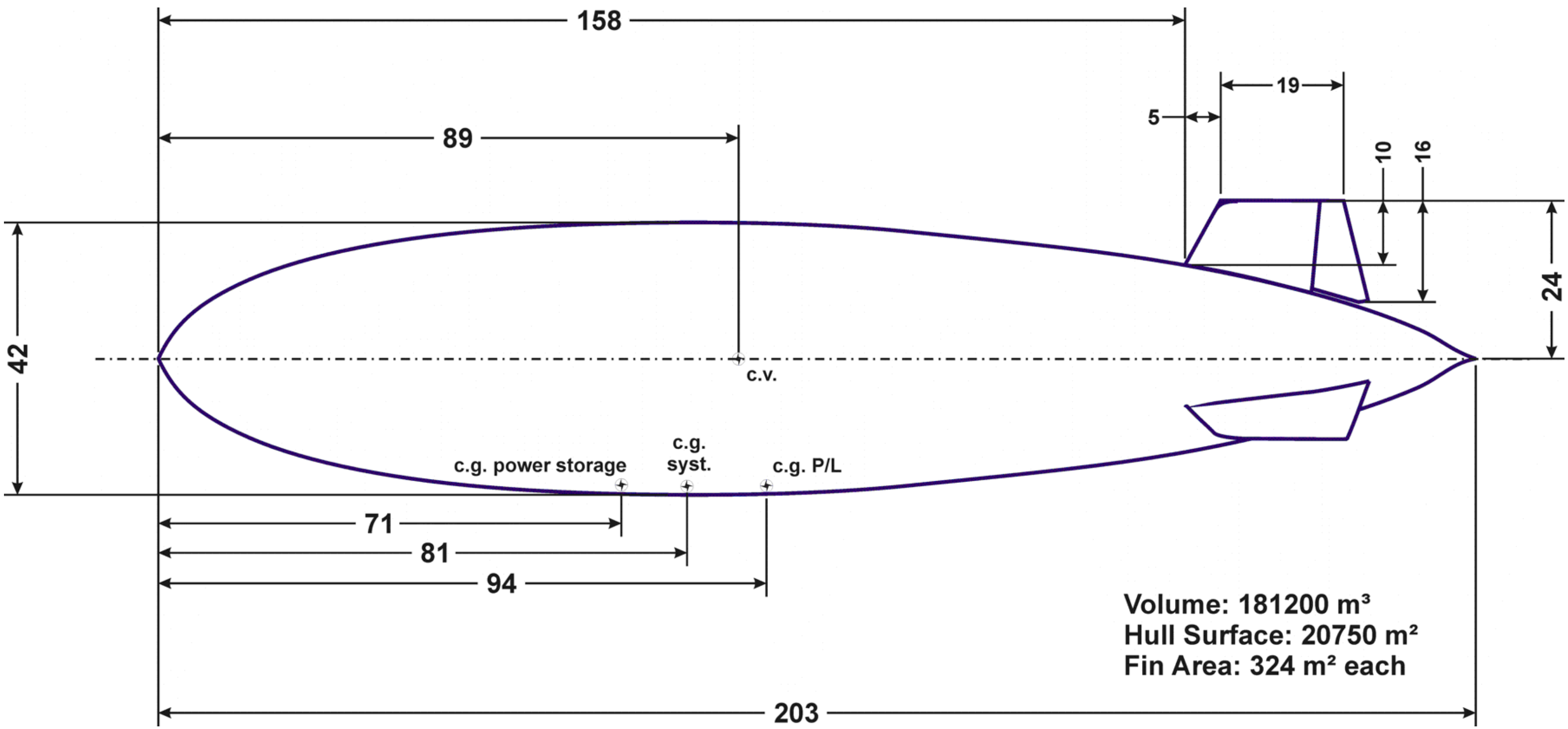
Rigid fins with control surfaces

Thin-film solar cells on polymer substrate

COTS electrolyser, weight-reduced and adapted for operational conditions

PEM fuel cell

Main Dimensions



Volume: 181200 m³
Hull Surface: 20750 m²
Fin Area: 324 m² each

Weight Status

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Status:					**13968**	**kg**
Component	*size*		*specific weight*		*Mass*	
envelope	20752	m^2	0,3	kg/m^2	6226	kg
diaphragm	10376	m^2	0,05	kg/m^2	519	kg
fins	971	m^2	2,00	kg/m^2	1941	kg
propulsor	80	KW	4	kg/KW	320	kg
solar array	3200	m^2	0,25	kg/m^2	800	kg
fuel cell	150	KW	5,5	kg/KWh	825	kg
electrolyser	180	KW	5,5	kg/KWh	990	kg
total gas storage	1,5	nights				
hydrogen storage					61	kg
oxygen storage					487	kg
power distribution					800	kg
systems and installations					500	kg
payload					500	kg

Aerodynamic Layout

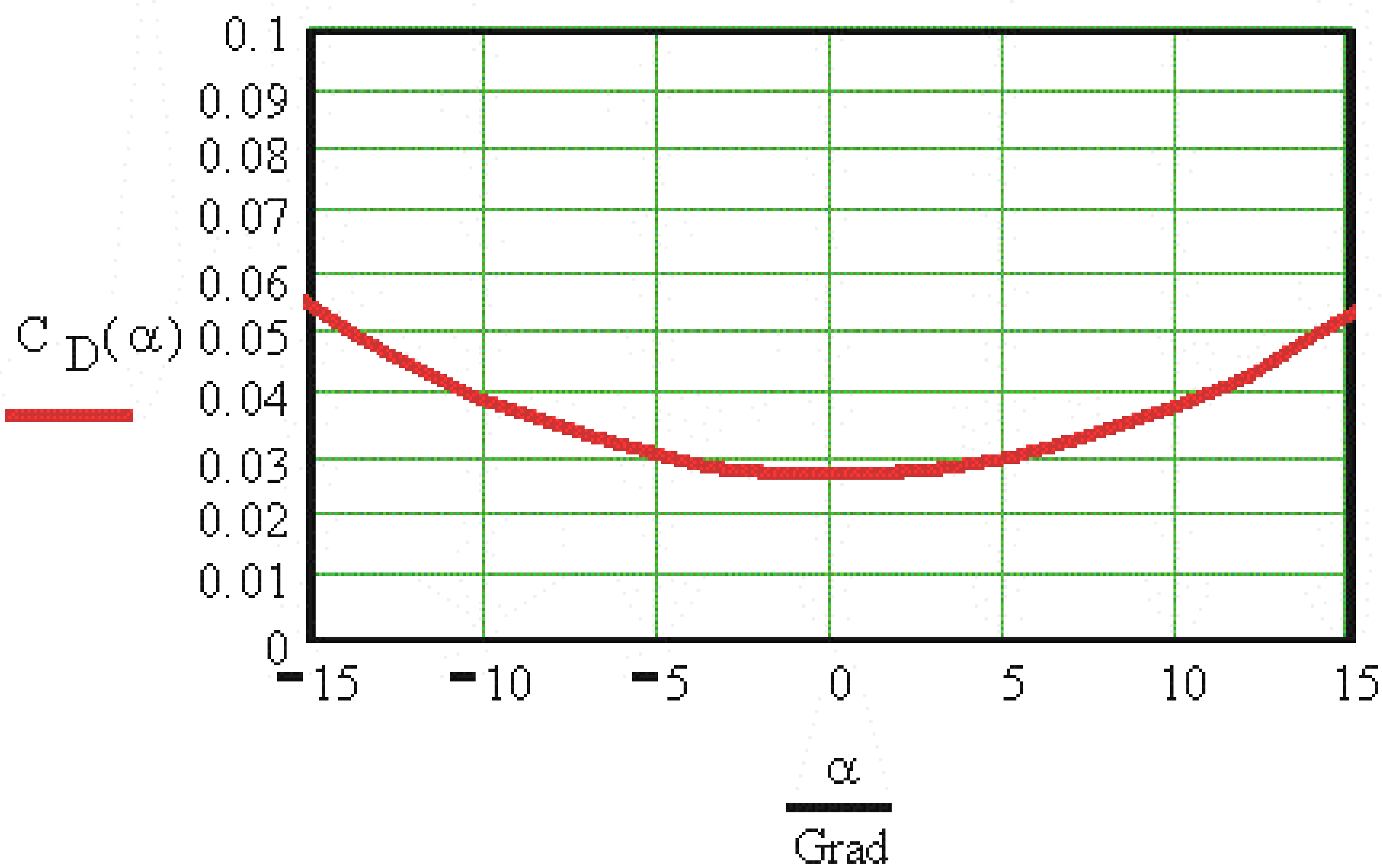
- Based on NASA I-YT design (Mc Lemore)

- Confirmed data for lift, drag and pitch

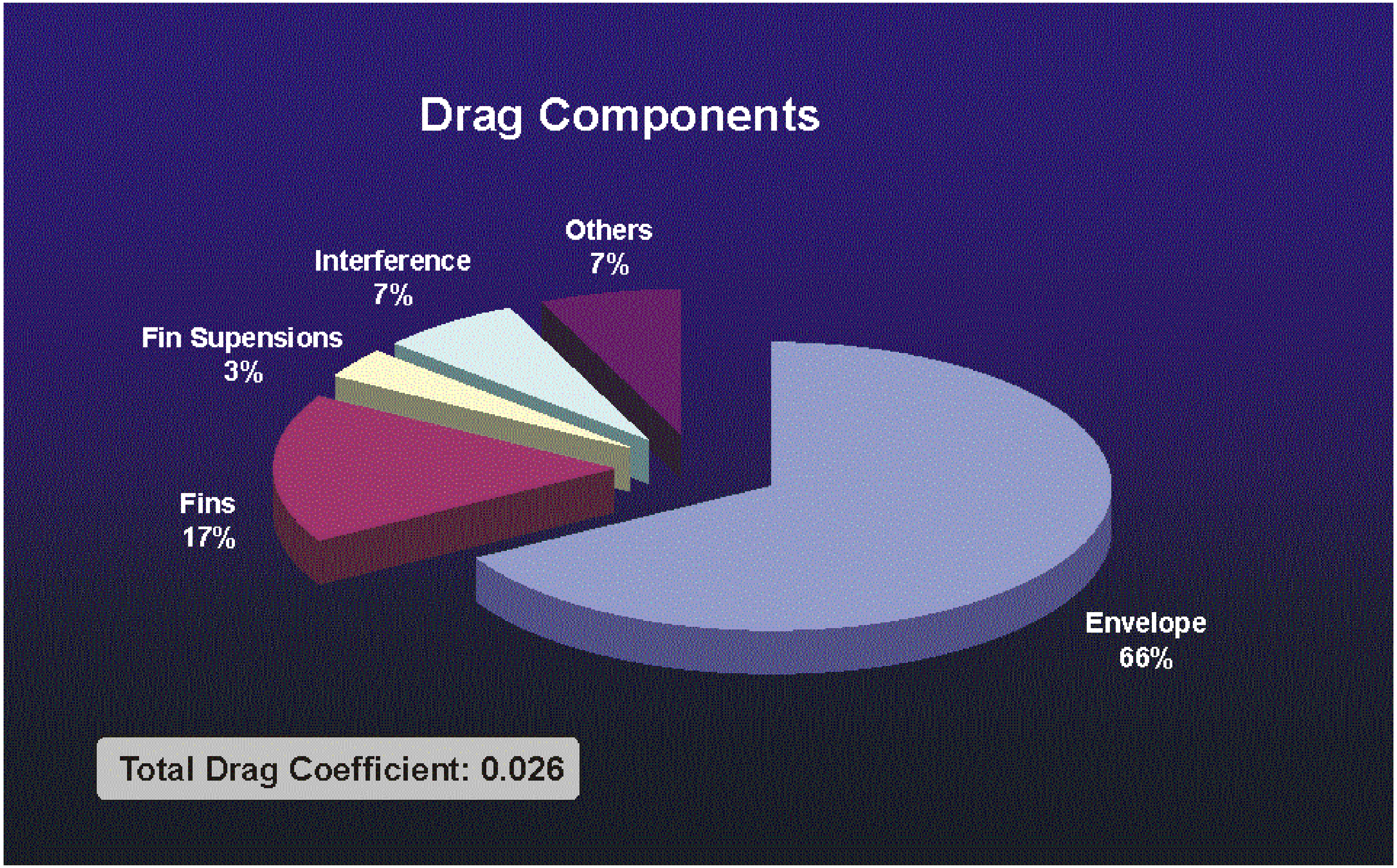
- Wind tunnel data for pusher propeller

- Propulsive efficiency data

Drag Coefficient



Drag Components



Aerostatic Layout

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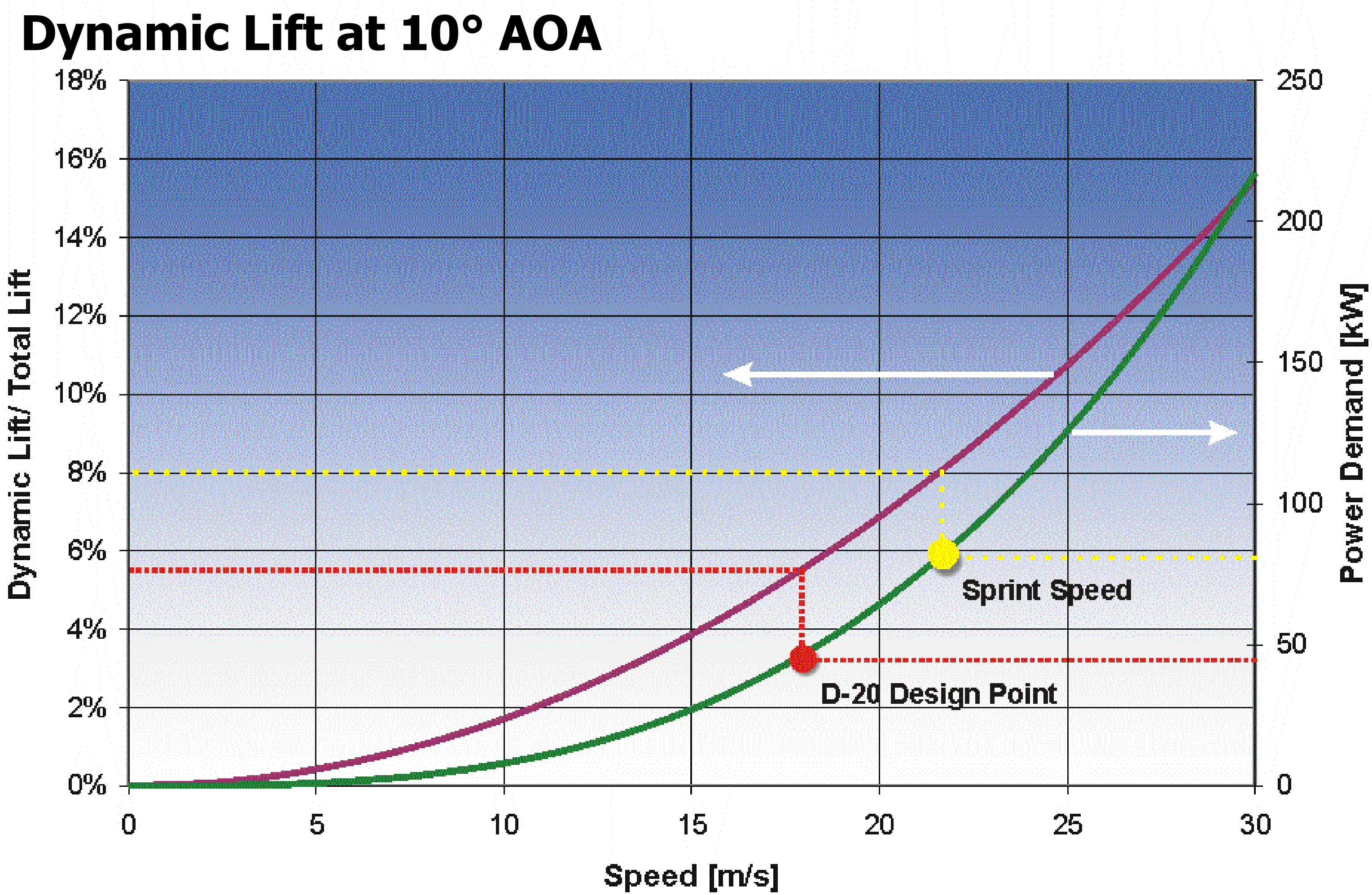
Lift Variation:

- **Regenerative fuel, gaseous storage: 13000 N (max. buoyancy + weight of burned fuel)**
- **Gas superheating without counteracting: 30K = 20000 N**
- **Night cold soak: 20K = 13000 N**
- **Total lift control demand: 40000 N max.**
- ***Note: max. lift demands (fuel, heat, cool) do not occur simultaneausly***

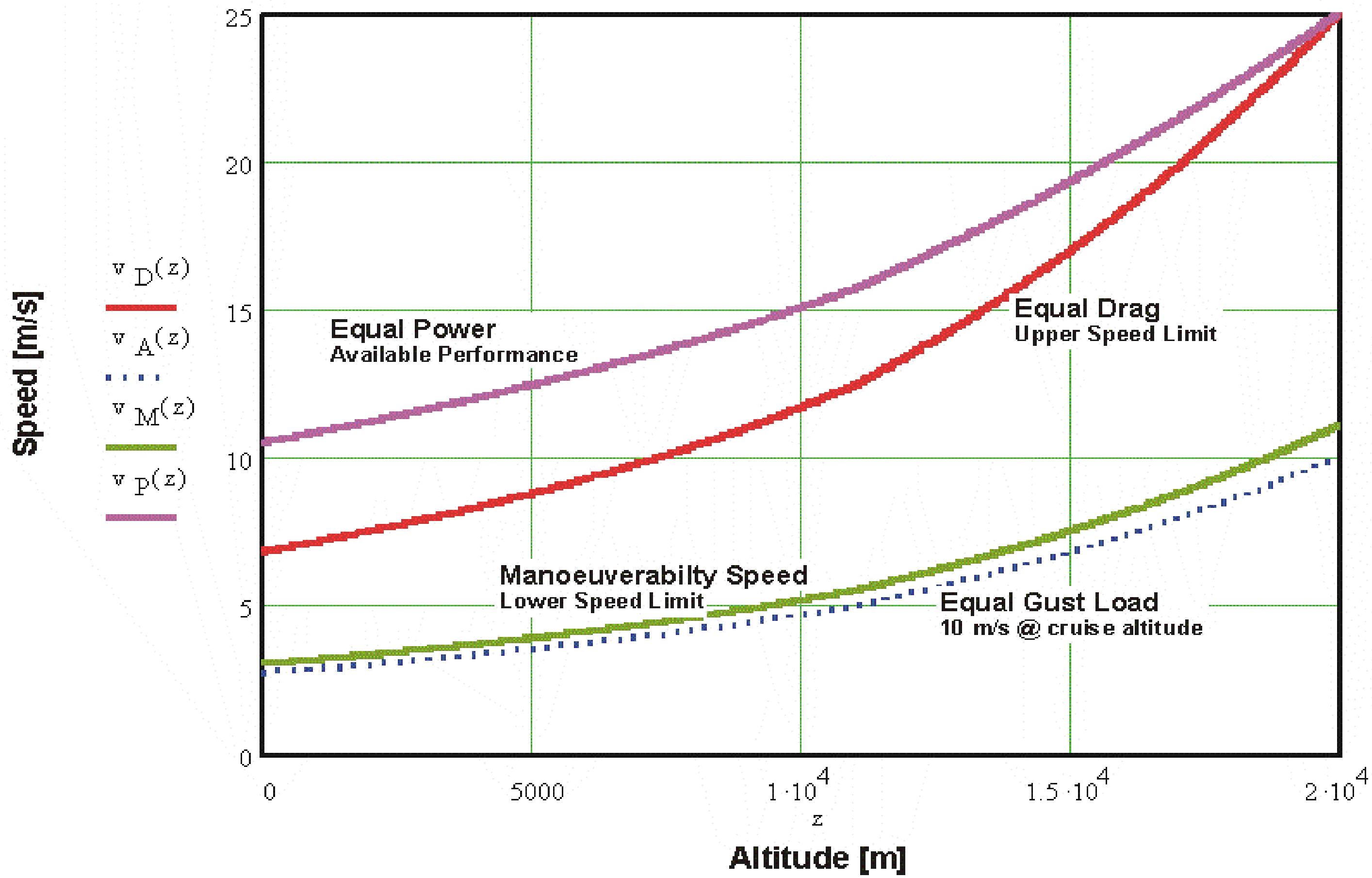
Compensation:

- **Convective heating/ cooling: fly faster than wind speed requires**
  - ⇨ **limits superheat to 15K max. = 10000 N**
  - ⇨ **limits cold soak to 10K max. = 6500 N**
- **Superpressure: Limit excess lift by increased gas pressure**
  - ⇨ **Lifting gas: compensates remaining superheat (Δp = 520 Pa)**
  - ⇨ **Regenerative fuel gas: limits excess lift at evening (Δp = 520 Pa)**
- **Dynamic lift: +/- 7000 N (=+/- 5% of total lift) for remaining lift variation**

Dynamic Lift Performance/ Power Demand



Speed Limits



Electrical Arrangement (1/2)

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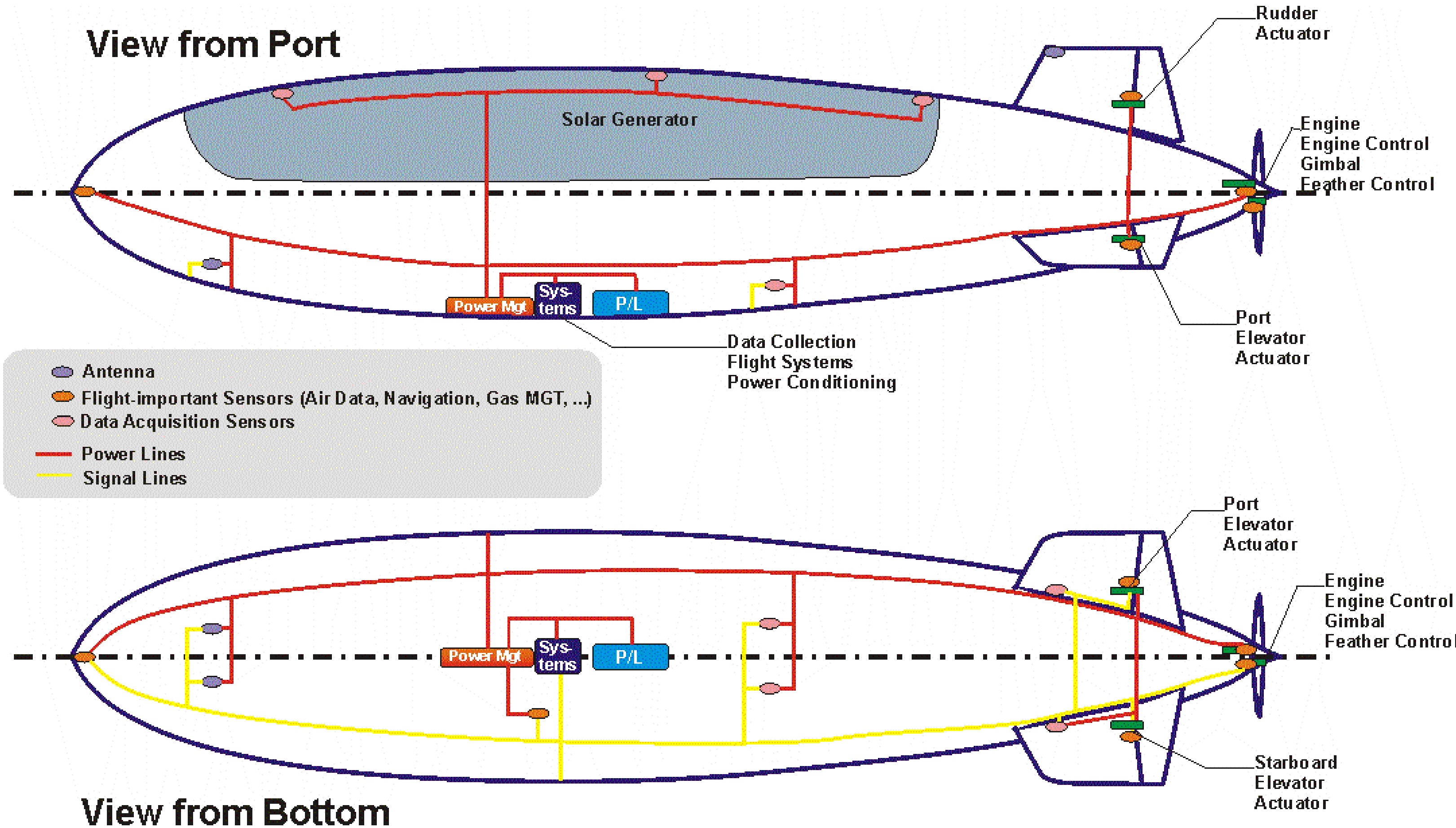
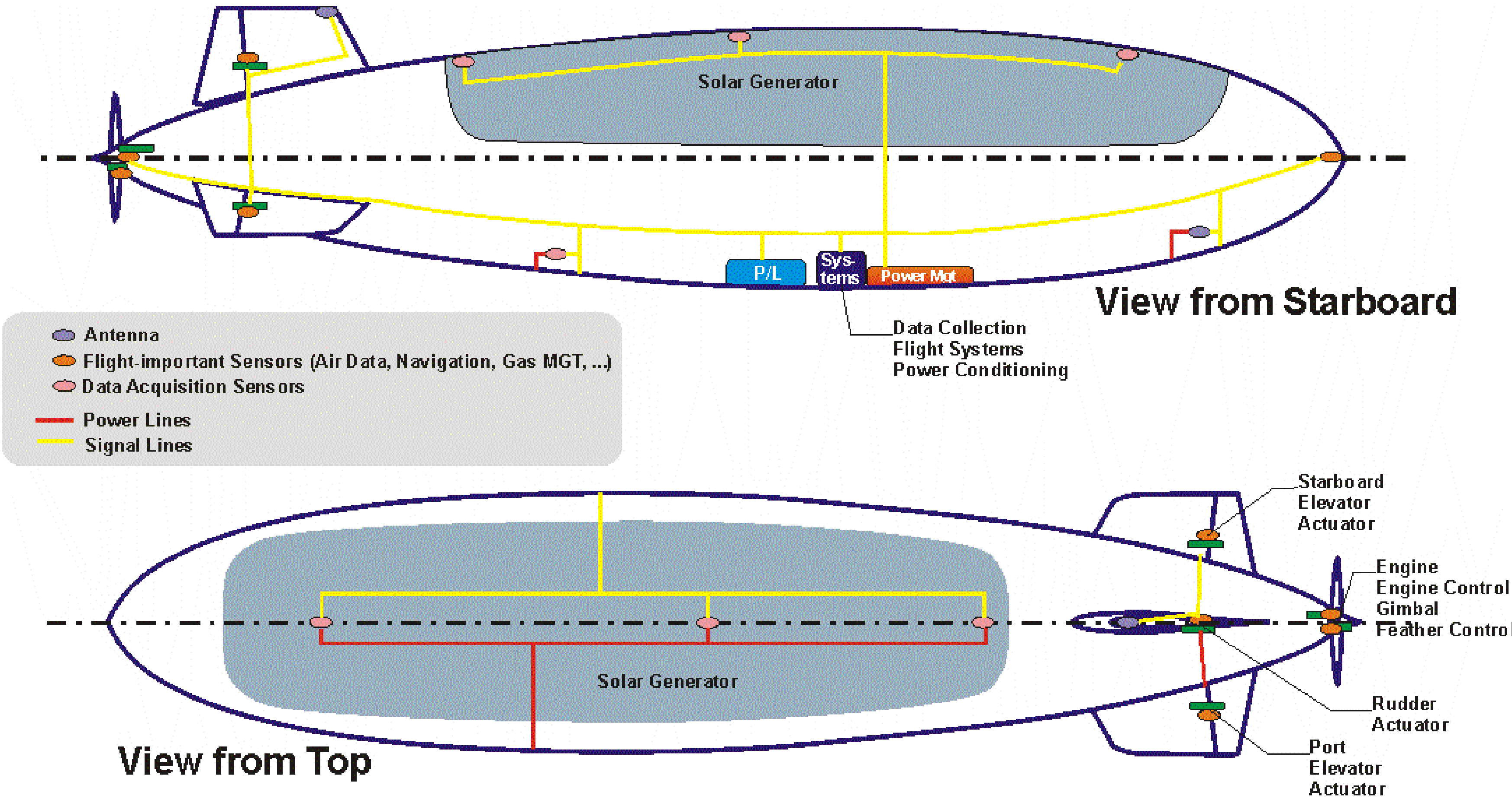
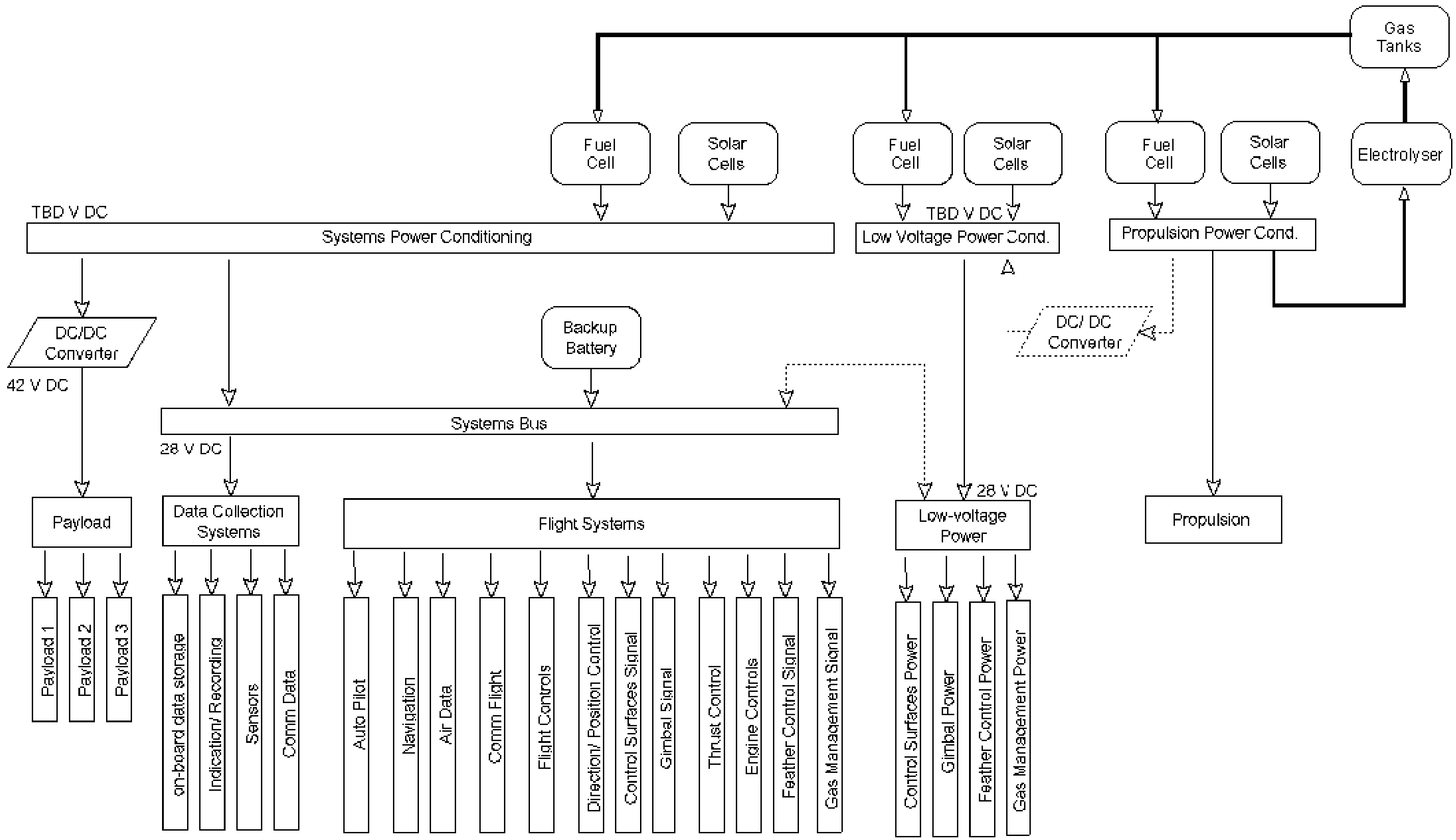


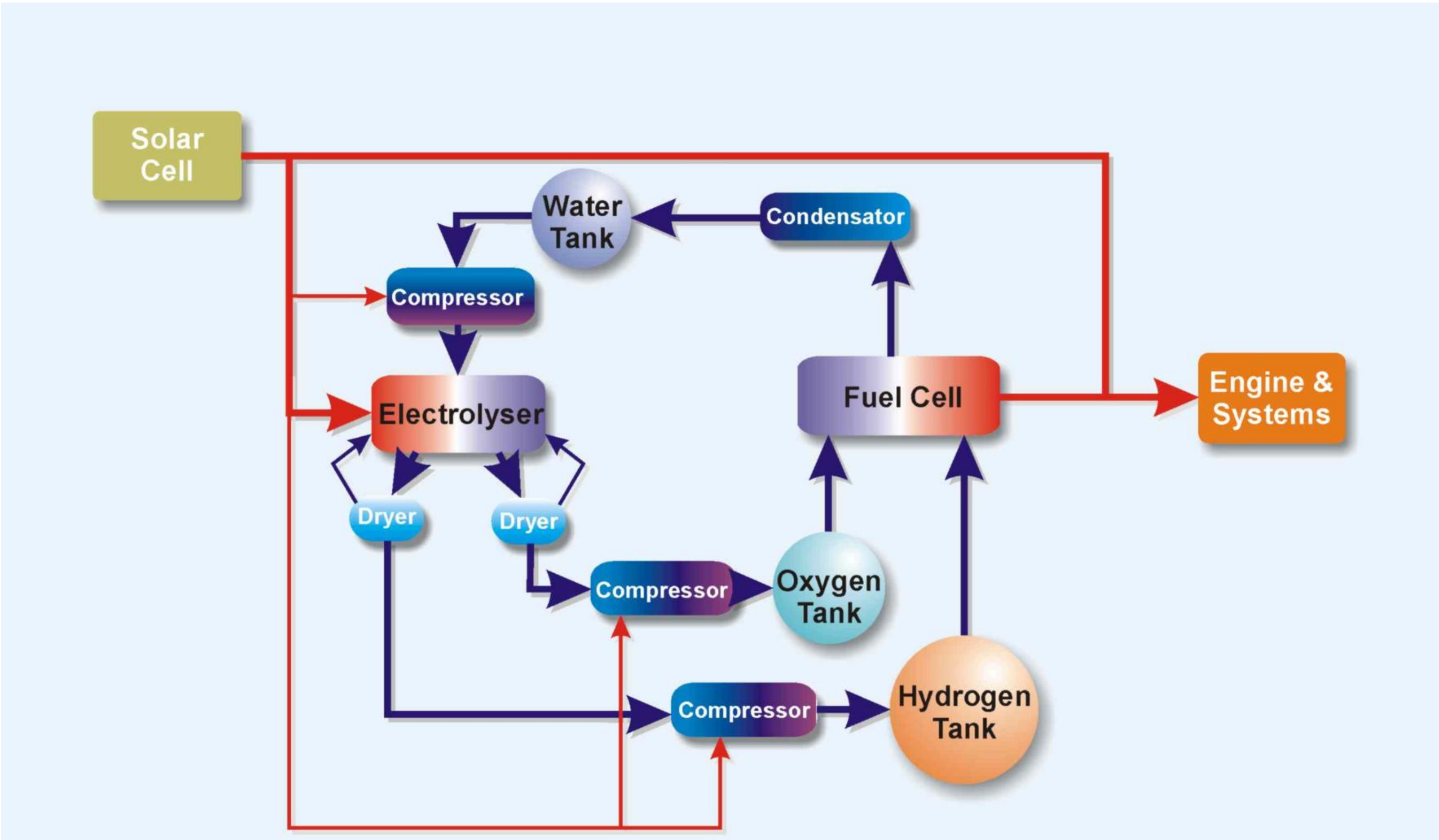
Electrical Arrangement (2/2)



Power Management System Architecture



Regenerative Fuel System Layout



Energy Balance

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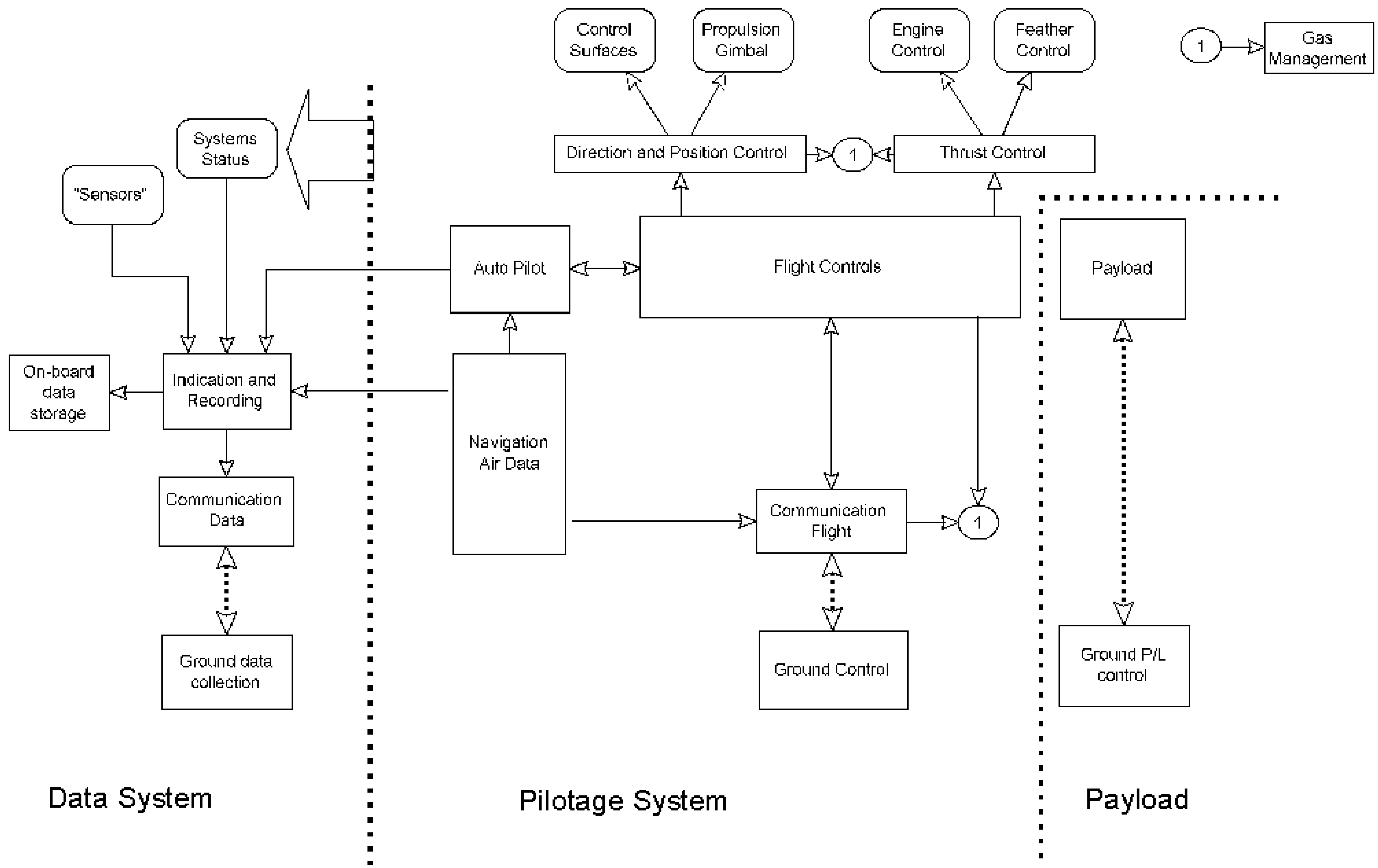
thrust power	31	KW
propeller eff.	76	%
propeller input	41	KW
engine eff. (incl. transmission losses)	90	%
engine input	46	KW
systems power	5	KW
payload power	5	KW
power input	56	KW
fuel cell efficiency	50	%
max. fuel cell input	112	KW

night duration	12	hrs
day duration	12	hrs
stored energy amount	1338	KWh
gas power density	33	KWh/kg
required hydrogen mass	41	kg
required oxygen mass	324	kg
electrolyser efficiency	75	%
max. electrolyser input	149	KW
transmission losses	10	%
solar cell output	184	KW
cell efficiency	8	%
incidence losses	20	%
solar radiation	1000	W/m^2
solar cell area	2875	m^2

Data Handling Systems Architecture

Lindstrand TECHNOLOGIES



Fabric Choices

Lindstrand TECHNOLOGIES

Vectran® is a high-performance multifilament yarn spun from liquid crystal polymer (LCP).

Vectran® is the only commercially available melt spun LCP fiber in the world.

Vectran® fibre exhibits exceptional strength and rigidity.

Pound for pound Vectran® fibre is five times stronger than steel and ten times stronger than aluminum.

These unique properties characterize Vectran®:

High strength and modulus
High abrasion resistance
Minimal moisture absorption
High dielectric strength
Low coefficient of thermal expansion (CTE)
Excellent property retention at high/low temperatures
Outstanding vibration damping characteristics
High impact resistance
Excellent creep resistance
Excellent flex/fold characteristics
Excellent chemical resistance
Outstanding cut resistance

Vectran’s major drawback is that it costs 3 times more than Kevlar.

Vectran Applications

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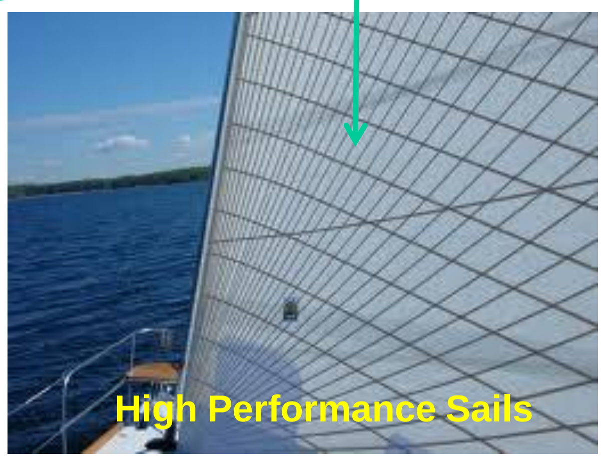
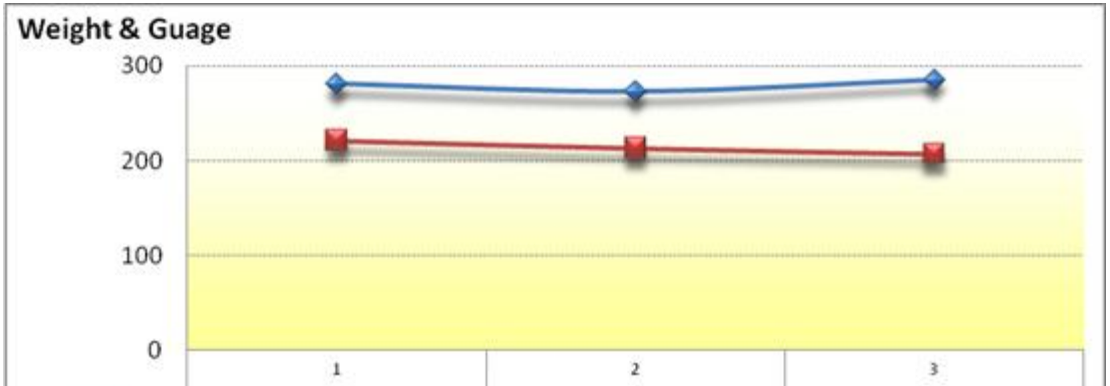
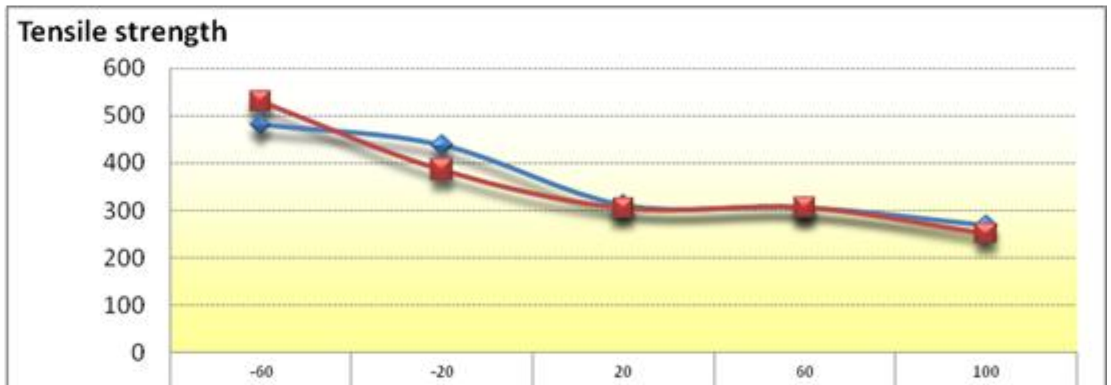


Properties of Vectran Fabric



	1	2	3
Weight	280.70	272.60	284.90
Guage	221	213	207



	-60	-20	20	60	100
Warp	481.05	437.33	310.72	305.96	267.98
Weft	530.59	385.65	305.17	306.53	251.49

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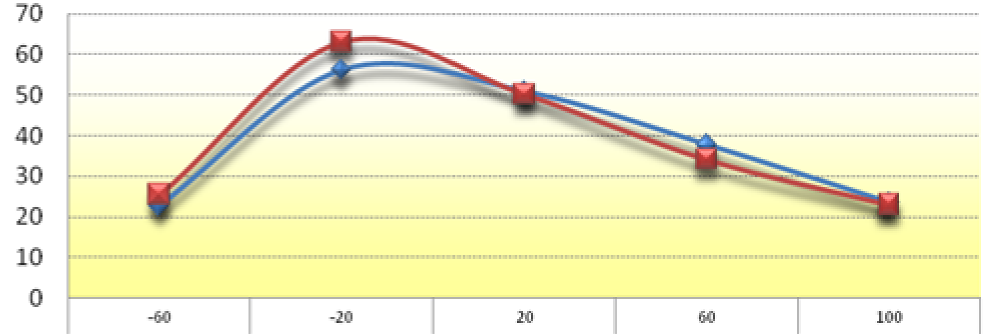
Double tongue tear strength (Max)

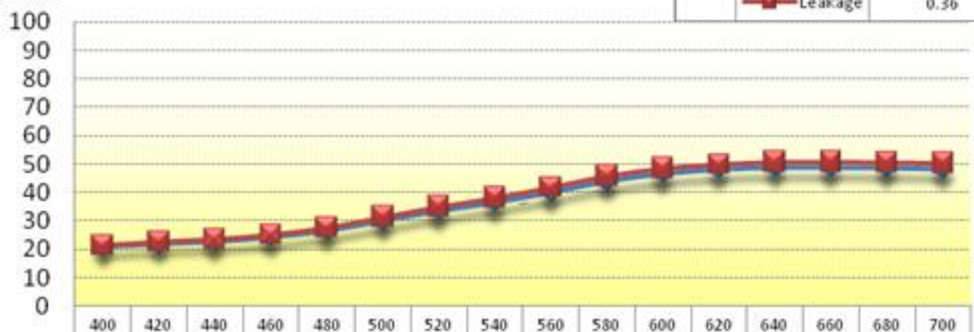


	-60	-20	20	60	100
Warp	22.90	56.15	50.84	37.70	23.44
Weft	25.43	63.18	50.20	34.11	22.95

Leakage after mechanical damage

	New	1 cycle	2 cycles	3 cycles	4 cycles	5 cycles
Leakage	0.36	0.72	0.57	0.41	0.39	0.36

Reflectance



	400	420	440	460	480	500	520	540	560	580	600	620	640	660	680	700
Inner	20.86	21.94	22.72	24.30	26.58	30.09	33.57	36.50	40.05	43.97	46.61	48.13	48.77	48.80	48.65	48.30
Outer	21.37	22.83	23.66	25.32	27.73	31.42	35.09	38.20	41.95	45.91	48.53	50.05	50.75	50.84	50.73	50.40

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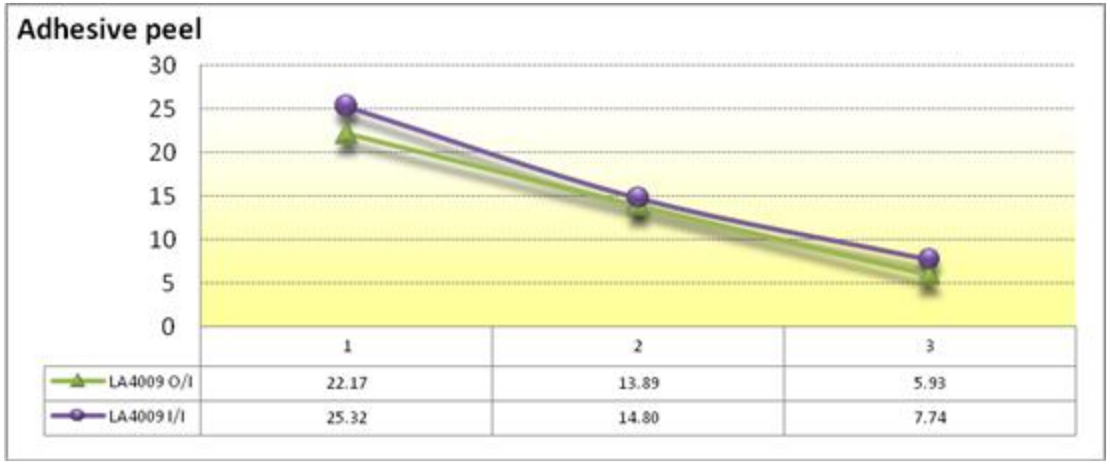
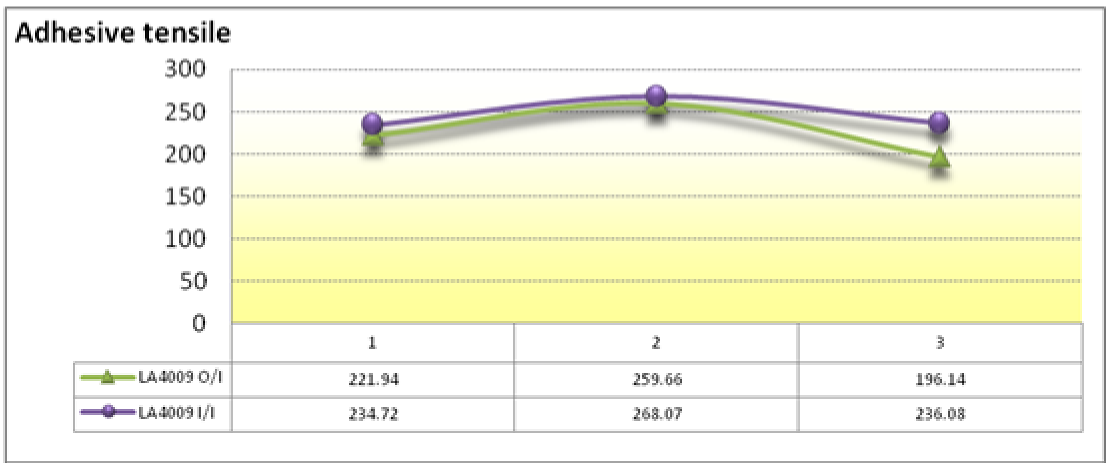
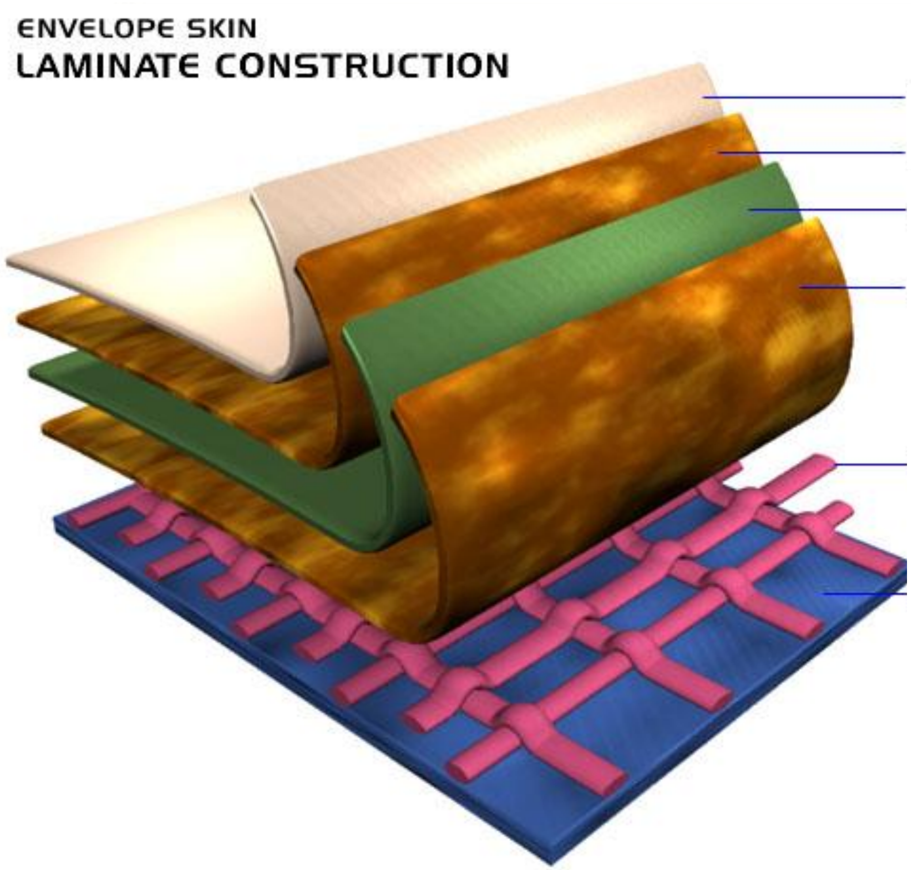




Airship Fabric



Regulatory Issues

Certification Standards for Airships:

- **Current standard – BCAR Section Q**
- **Soon to be replaced with EASA CS 30 N**

Flight Rules:

- **VFR - IFR**

Traffic Priority:

- **Airships have right of way against all other traffic**
- **No need for see and avoid capability**

Budget

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ITEM	VALUE	UNIT COST	TOTAL
Envelope	20,000m^2	\$250/ m^2	**\$5 million**
Fins	1,000kg	\$1000/ kg	**\$1 million**
Flight Controls	Unit	-	**\$1.5 million**
Propulsion	46kW	\$50,000/ kW	**\$2.3 million**
Solar Array	300kW	\$10,000/ kW	**\$3 million**
Fuel Cell	150kW	\$30,000/kW	**\$4.5 million**
Electrolyser	180kW	\$15,000/ kW	**\$2.7 million**
		SUB TOTAL	**\$20 million**
Flight Operations	Package		
System Integration	Package		**\$2 million**
Ground Support	Package		
Programme Management	Package		
		GRAND TOTAL	**\$22 million**

Conclusion

D-20 Design existent:

- Aerodynamic
- Aerostatic
- Propulsion & Power Management
- Structural Concept
- Operations
- System Requirements and Specs

Usage of mature technologies

Risk minimisation

PRODUCTION PROCESSES AND TECHNOLOGY

Fabric Inspection

Fabric Inspection is a key tool in determining the quality of the fabric supplied to Lindstrand Technologies.

Material is loaded onto a roller system that unwinds the fabric and passes it across the inspection table. The table has the facility to back light or top light the fabric. Fault diagnostics are recorded directly onto the integrally mounted computer. The inspection logs form critical data in subsequent project files as the material is consumed in the manufacture of company products. The final stage on the inspection table is to automatically re-roll the fabric for ease of handling.

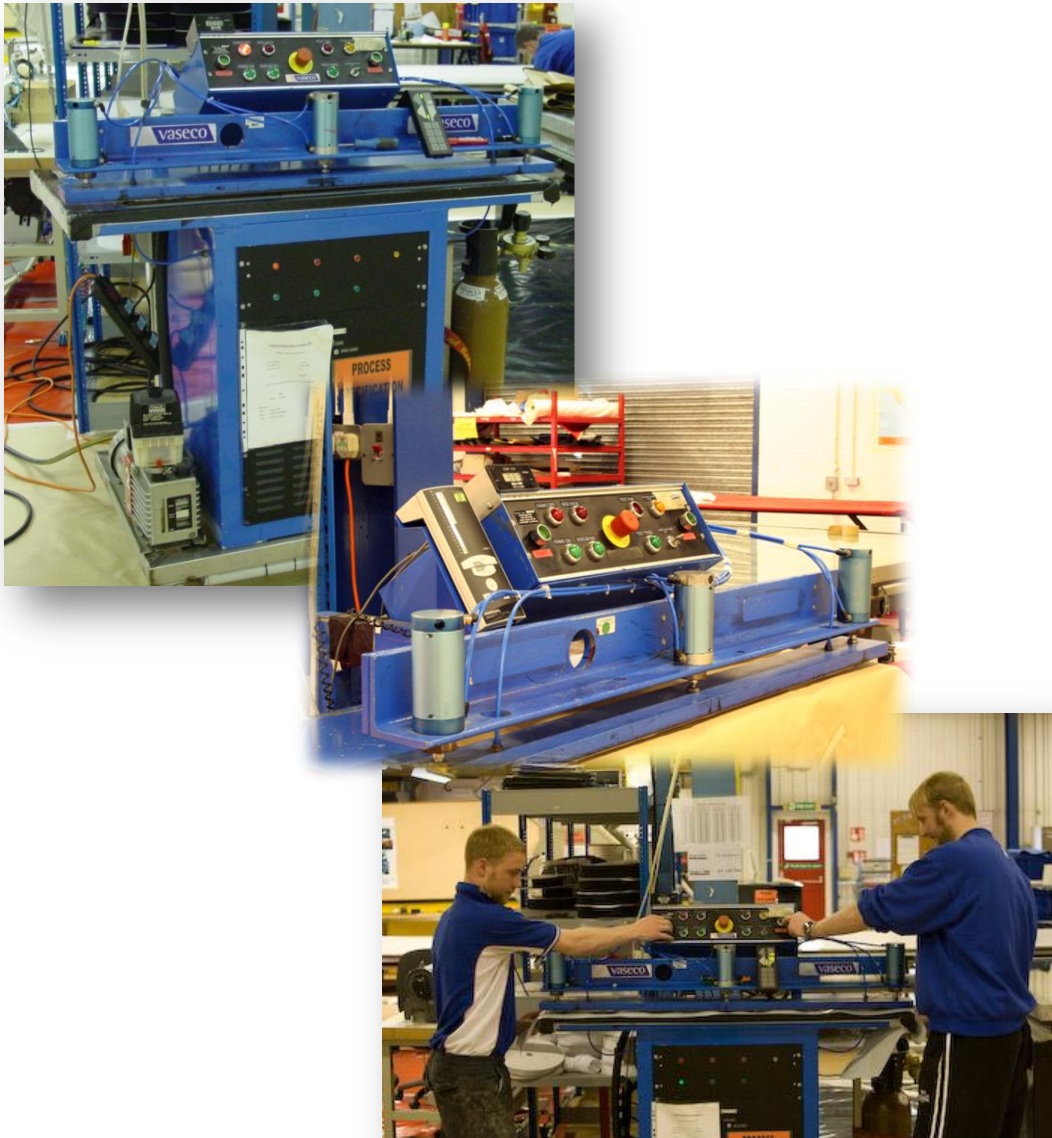
Fabric Cutting

There are 2 cutting tables at Lindstrand Factory.

Both have operating length of 21m, width of 1.8m and 3m. Machines can cut at approximately 60m/min and have a cutting accuracy of +/- 0.2mm.

They are both capable of working with a wide variety of fabrics including PU’s, PVC and the more exotic Kevlar and Vectran.

Helium Leakage Testing



This is a unique testing machine purpose built by Lindstrand.

It is based on a mass spectrometer. The underside of a fabric sample is pumped down to near vacuum. Helium is then injected on top of the sample, and any penetration is picked up by the mass spectrometer.

This machine can carry out a full helium leakage test in less than 14 seconds.

Fabric Welding

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High Frequency Welder:

High frequency welding is performed by 2 Fiab machines. The original machine has a moving table and the new gantry mounted machine allows for all manufacturing angles.

Hot Air Welder:

Hot air welding is currently the main method of joining materials in the production environment. Three purpose built welding machines are used on site. Each machines jets hot air onto the joining surfaces of the fabric with an operating temperature of between 200C°-650C° which are then pressed together at 7 bar.

Fabric Welding

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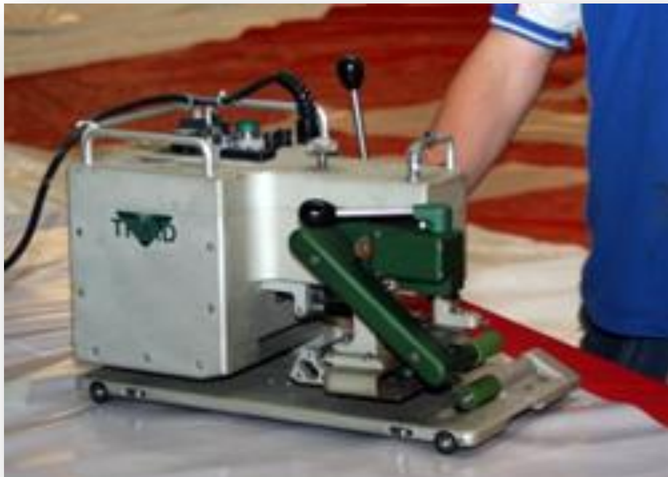

Hot Wedge Welder

A hot metal wedge radiate the heat into the fabric which is then pressed together by two rollers. This is a self propelled machine but can only be used for straight runs.

Ultrasonic Welder

This is a hand operated machine that is used primarily for repair work. It operates at 36kHz and is also used for reactivation of sheet adhesives.

Laser Welding

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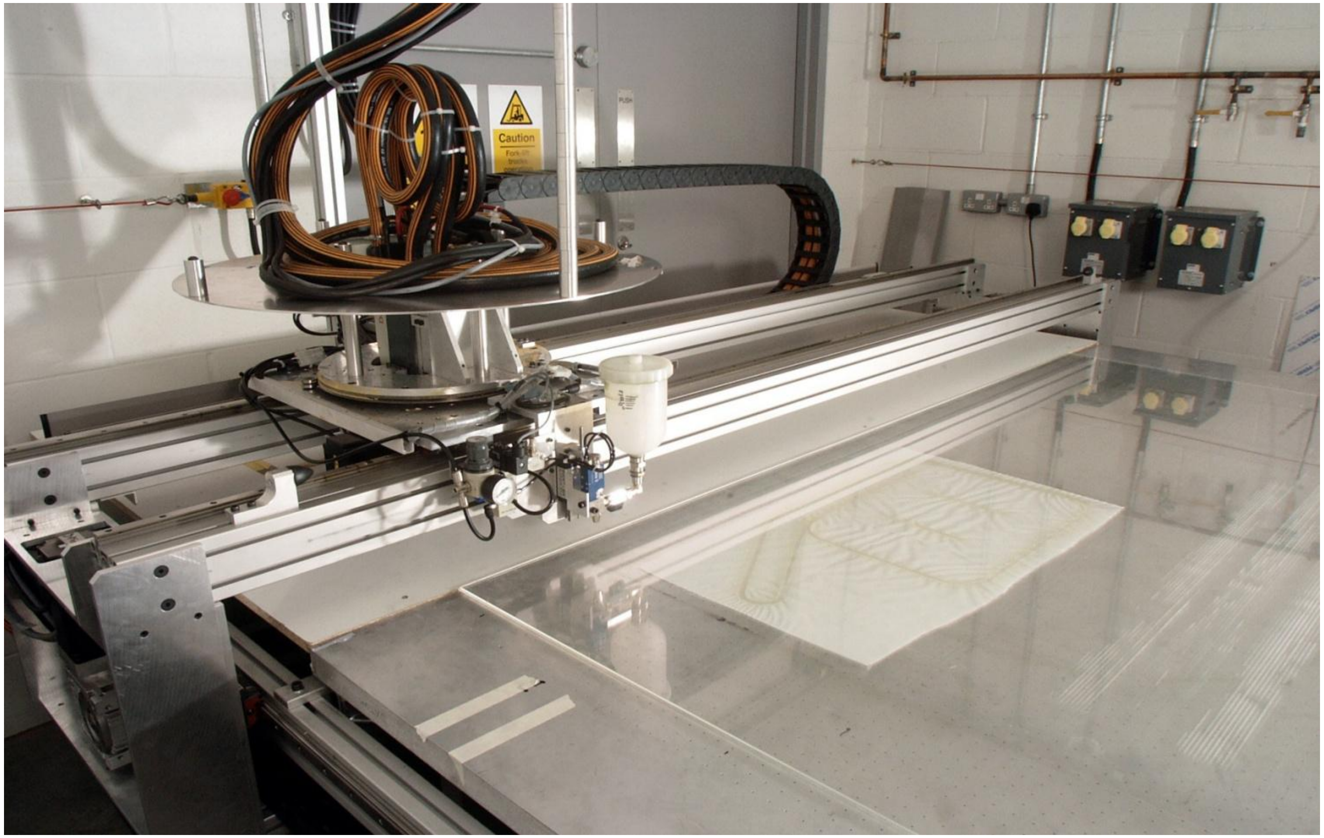
TECHNOLOGIES



900 nm wavelength