

# ***DLR Design Challenge 2023***



## **Prometheus**

### **Team Trier**

Milan Lieser  
Fabian Brust  
Michael Scheidt  
Elisa Kühn

#### **Academic Support and Advisor**

Prof. Dr. Sven König



**Hochschule Trier**

Fachbereich Maschinenbau

Schneidershof

54293 Trier

Submitted on July 11th, 2023



**Team Members**



Milan Lieser, M. Eng.  
Mechanical Engineering



Fabian Brust, B. Eng.  
Mechanical Engineering



Michael Scheidt, M. Eng.  
Mechanical Engineering



Elisa Kühr, B. Eng.  
Mechanical Engineering

Hochschule Trier  
Schneidershof, D-54293 Trier

### **Betreff: Bestätigungsschreiben**

Sehr geehrte Damen und Herren,

hiermit bestätige ich, dass die im Folgenden aufgeführten Mitglieder des studentischen Teams selbstständig den Flugzeugentwurf zur Teilnahme an der DLR-Design Challenge 2023 durchgeführt haben.

- Elisa Kühn
- Milan Lieser
- Fabian Brust
- Michael Scheidt

Mit freundlichen Grüßen,

Prof. Dr.-Ing. Sven König  
Betreuender wissenschaftlicher Professor

---

Unterschrift von Prof. König wird nachgereicht.

## Abstract

PROMETHEUS is a medium range unmanned aerial vehicle designed for internet recovery and coverage of a large area to maintain lines of communication over an extended period. In various scenarios, PROMETHEUS can carry out optical situational reconnaissance during time-critical disaster situations and provide comprehensive mobile network coverage as part of a fleet.

The aim was to develop a high-flying carrier platform with sufficient maximum speed to reach crisis areas quickly from the outside and to ensure comprehensive mobile network coverage from the air. Various proven concepts from aerospace engineering were used in the concept. PROMETHEUS has an all-electric propulsion system that, in addition to the on-board batteries, draws a significant part of the energy required from laminated solar modules during level flight. Particular attention was also paid to reducing overall drag throughout the fuselage, which was designed as a lifting body to work in conjunction with the wing configuration to generate the necessary lift.

Considering the prevailing pressure to innovate, key technologies with expected increases in efficiency were evaluated in preparation for a planned market entry in 2040.



## Zusammenfassung

PROMETHEUS ist ein unbemanntes Mittelstrecken- Luftfahrzeug zur Internet-wiederherstellung und -versorgung eines großflächigen Gebiets, um die Kommunikationswege für einen erweiterten Zeitraum aufrecht zu erhalten. In verschiedenen Szenarien kann PROMETHEUS sowohl in zeitkritischen Katastropheneinsätzen eine optische Lagebeobachtung durchführen als auch im Flottenverband eine großräumige Abdeckung mit Mobilfunkhardware aus der Luft zur Verfügung stellen.

Ziel war dabei die Entwicklung einer möglichst hochfliegenden Trägerplattform mit ausreichender Höchstgeschwindigkeit um Krisengebiete von außerhalb schnellstmöglich erreichen und weiträumig mit Mobilfunk abdecken zu können. Bei der Konzipierung kamen verschiedenste bereits erprobte Konzepte aus Luft- und Raumfahrt zum Einsatz. So verfügt PROMETHEUS über einen voll elektrischen Antriebsstrang, der neben mitgeführten Battery-Packs im Levelflight einen Großteil der benötigten Energie aus auflaminierten Solarfolien bezieht. Außerdem wurde ein Augenmerk auf die Verringerung des allgemeinen Luftwiderstands über den gesamten Flugzeugrumpf gelegt sowie dieser als Lifting-Body ausgelegt, um den benötigten Auftrieb nicht alleine aus der Flügelkonstruktion zu generieren.

Für einen geplanten Markteintritt im Jahre 2040 wurden Schlüsseltechnologien teilweise mit zu erwartbaren Effizienzsteigerungen berechnet, um den vorherrschenden Innovationsdruck miteinzubeziehen.

List of abbreviations

$m^2$	Squaremeter
$m^3$	Cubicmeter
$\frac{m^3}{s}$	flow rate
$km$	kilometer
$\frac{Mbit}{s}$	Data transmission speed
$NM$	Nautical Miles
$^{\circ}C$	Grad Celsius
$\frac{m}{s}$	Velocity
$m$	Meter
$s$	Second
$W$	Watt
$K$	Kelvin
$kg$	Kilogram
$\frac{kg}{m^3}$	Density
$kts$	Knots
$ft$	feet
$min$	minute
$\frac{feet}{min}$	climb rate
$\frac{Ns}{m^2} = \mu$	dynamic viscosity
$\frac{m^2}{s} = \nu$	cinematic viscosity
$Re$	Reynoldsnumber
$\frac{Wh}{kg}$	Energydensity
$GPa$	Gigapascal
$F_l$	Liftforce
$C_l$	Liftcoefficient
$AOA$	Angle of Attack
$C_d$	Dragcoefficient
$alpha$	Angle of Attack
$\rho$	Density
$N$	Newton
$l$	Lenth
$FL$	Flightlevel
$shp$	Shaft horsepower
$^{\circ}$	Angle
$L$	Liter
$\%$	Percent
$kWh$	Kilowatthour

€	Euro
$k_A$	Coefficient area
$s_{zones}$	number of flightzones
OBE	On board electronics
EIS	Entry into Service
GPS	Global Positioning System

## Contents

<b>1</b>	<b>Introduction .....</b>	<b>7</b>
1.1	Motivation.....	7
1.2	List of Requirements .....	8
1.3	Morphological Box .....	9
1.4	Knockout and Winner concept.....	10
<b>2</b>	<b>Aircraft Configuration .....</b>	<b>11</b>
2.1	Configuration and Placement.....	11
<b>3</b>	<b>Aircraft Requirements .....</b>	<b>12</b>
<b>4</b>	<b>Reference Aircraft .....</b>	<b>13</b>
4.1	Technology List .....	13
4.2	Mass Breakdown .....	14
<b>5</b>	<b>Aerodynamics .....</b>	<b>15</b>
5.1	Wing Design and Airfoil selection .....	15
<b>6</b>	<b>Concept.....</b>	<b>19</b>
6.1	Operational procedure system Level.....	19
6.1.1	Flightpath Algorithm .....	23
6.1.2	Flightpath Hamburg .....	24
6.1.3	Emergency Flightpath .....	25
<b>7</b>	<b>Cost Analysis .....</b>	<b>26</b>
<b>8</b>	<b>Usecases apart from emergency Operations .....</b>	<b>27</b>
<b>9</b>	<b>Refences.....</b>	<b>28</b>

## 1 Introduction

In July 2021, there was a flood event in the Ahr Valley that left a trail of devastation in its wake. Across the county, 62 bridges were destroyed and others badly damaged. In addition, seven bridges on the Ahr-Valley-Railway and 20km of railway tracks became impassable due to over- and underflow. In Rhineland-Palatinate alone 193 people died in the flood or are still missing, and 766 others were injured. At least 17,000 people lost their property directly in the disaster and of more than 3,000 damaged buildings, 467 were destroyed. In the early phase of the clean-up work, many volunteers offered their help, which caused local overload due to the destroyed access roads. It increased to such an extent that professional helpers, the Bundeswehr, and waste transport could no longer pass. Rapid initial clarification in the event of a disaster is the most important means of guiding the aid and rescue operations to the ground in a coordinated manner. In this way, the potential is carefully exploited, and the resources are distributed in a targeted manner to the individual crisis points. In addition to direct optical reconnaissance using visual and infrared camera systems from high and medium altitude, the provision of a mobile network is another passive approach to locating people in distress. [1] [2]

### 1.1 Motivation

During the event, flooding also occurred in Trier and surrounding areas. In the district of Ehrang, for example, the Kyll burst its banks with the tributary of the Moselle increasing its flow from 10.16 m<sup>3</sup>/s to 450 m<sup>3</sup>/s at the gauge in the town of Kordel. As a result, 690 houses were affected, and people were evacuated. The Ehrang hospital was also affected and due to the costs incurred of 30 million euros to structure and equipment, it was decided not to reopen it.[3]

While members of our team were not directly affected by the flood, the impact was felt by everyone. Hence our motivation, in view of the increasing number of climatic catastrophes, to provide useful systems to limit



the loss of life.

Figure 1

## 1.2 List of Requirements

1 Work process	1.1	Purpose	1.1.1	Internet supply	permanent supply	F
					0,1 Mbit/s per person	M
			1.1.2	Situation monitoring	Soil monitoring	F
	1.2	Target Group	1.2.1	German Center for Aerospace		F
			1.2.2	Government of the country of operation		
			1.2.3	Economy in the country of operation		
			1.2.4	Population of different countries		
			1.2.5	Supply of the federal states	Hamburg 755 km <sup>2</sup>	M
		Schleswig-Holstein 15.804 km <sup>2</sup>	M			
	1.3	Use	1.3.1	Lifetime	>10 years	W
			1.3.2	Operational readiness	Less than one hour	M
			1.3.3	Weather independent	Weather independent	F
					Day-independent	F
					Seasonless	F
			1.3.4	Weatherproof	Operation up to 55 latitude	F
max. 100 NM from ground station (NM=Nautical miles)					F	
2 Energy	2.1	Mechanical energy	2.1.1	Drive	Freely selectable	
			2.1.2	Source	Converter	
	2.2	Electrical energy	2.2.1	Generation	Freely selectable	
			2.2.2	Source	Storage	
	2.3	Power	2.3.1	Efficiency	High as possible	W
			2.3.2	Supply of all modules and of the flying object		F
3 Safety	3.1	Occupational safety	3.1.1	Unmanned flights	Collision Prevention	F
			3.1.2	Fail-safe	acceptable level	F
	3.2	Approval	3.2.1	TÜV, VDE		F
			3.2.2	Compliance with CE directives		
4 Movement	4.1	Forces	4.1.1	Landing forces		
			4.1.2	Aerodynamic forces	Lifting forces	
					Turbulence forces	
			4.1.3	Aerolastic forces		
			4.1.4	Weight forces		
			4.1.5	Deformation	resistance to permanent deformation	
	4.1.6	Thermal stresses	Temperature resistant -55°C to 45°C	M		
	4.2	Kinematics	4.2.1	Speed	v>45 m/s	M
				Movement	straight	F
			4.2.2	Aircraft movements	Rise, sink	F
					Left, Right	F
	4.3	Geometry and Weight	4.3.1	Geometry	Aerodynamic	M
4.3.2			Weight	as light as possible	W	

5 Production and service	5.1	Quantity / Execution	5.1.1	Number of flying objects	$n \geq 1$	F
			5.1.2	Number of Internet modules	$n \geq 1$	F
			5.1.3	Number of radar modules	1	F
			5.1.4	Number of antenna internal modules	$n \geq 1$	F
			5.1.5	Antenna for communication with the ground control	1	F
			5.1.6	Control	Manned	W
	Unmanned	W				
	5.2	Control	5.2.1	Quality inspection according to DIN		
	5.3	Mounting	5.3.1	Ready mounted		
			5.3.2	Modular	Interchangeable modules	
	5.4	Transportation	5.4.1	By car trailer or truck		
	5.5	Manufacturing	5.5.1	Expandable		
			5.5.2	cheap and automatable production		
			5.5.3	Clean processing		
6 Other	6.1	Costs	6.1.1	Costs are to be kept as low as possible	Maintenance	F
					Acquisition	F
					Operation	F
	6.2	Emissions	6.2.1	Minnimal emissions		M
			6.2.2	Geräuschpegel	As low as possible	W
	6.3	Disposal	6.3.1	Environmentally friendly		
			6.3.2	Recyclable		
	6.4	Dates	6.4.1	Entry of Service (EIS)	2040	F
6.4.2			submission	08.08.2023	F	

Table 1 List of Requirements

### 1.3 Morphological Box

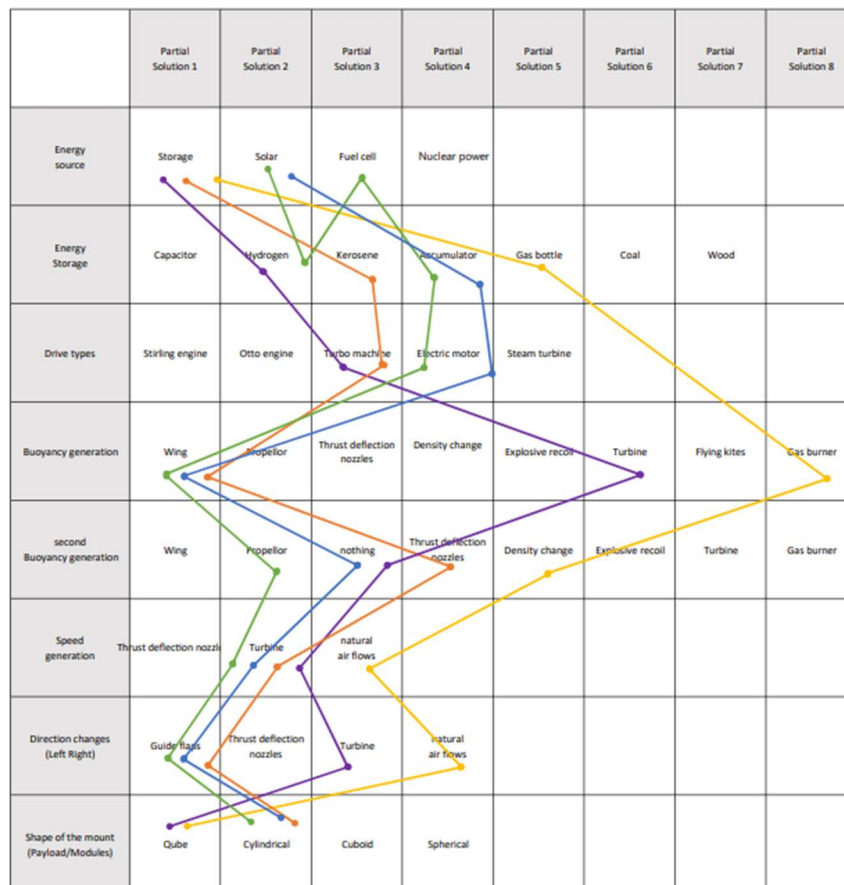


Table 2 Morphological Box

## 1.4 Knockout and Winner concept

Fixed receivables	Concept 1	Concept 2	Concept 3	Concept 4	Concept 5
Soil monitoring	✓	✓	✓	✓	✓
Weather independent	✓	✓	✓	✓	✗
Day-independent	✓	✓	✓	✓	
Seasonless	✓	✓	✓	✓	
Operation up to 55 Latitude	✓	✓	✓	✓	
max. 100 NM from ground station (NM=Nautical Miles)	✓	✓	✓	✗	
Supply of all modules and the flying object	✓	✓	✓		
Collision Prevention	✓	✓	✓		
Fail-safe acceptable level	✓	✓	✗		
TÜV, VDE	✓	✓			
straight	✓	✓			
Rise, fall	✓	✓			
Left, Right	✓	✓			
Number of flying objects	✓	✓			
Number of Internet modules	✓	✓			
Number of radar modules	✓	✓			
Number of antenna Internal modules	✓	✓			
Antenna for communication with the ground control	✓	✓			
Maintenance	✓	✓			
Acquisition	✓	✓			
Operation	✓	✓			
Entry of Service 2040	✓	✓			
delivery 08.08.2023	✓	✓			

Table 3 Knockout and Winner concept

## 2 Aircraft Configuration

### 2.1 Configuration and Placement

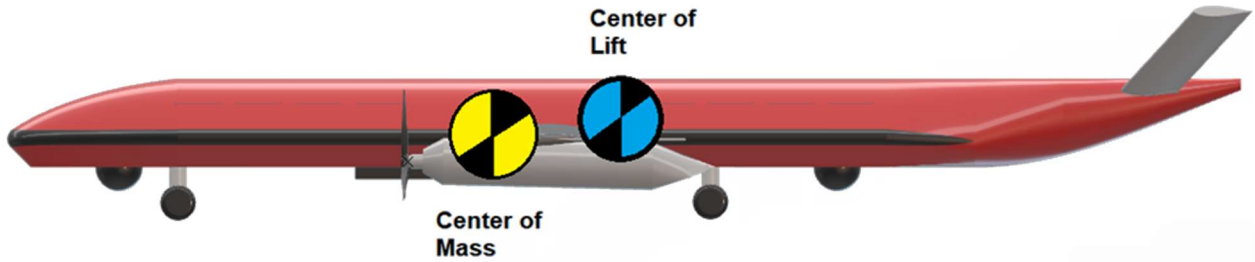


Figure 2: Center of Lift and Center of Mass and Center of Lift of Prometheus

Prometheus will be able to cover both Emergency Scenarios in a very similar configuration. It was assessed that for lifting a gross weight of 3,5 tons into an operational height of up to 13 km, a Wing Area of about 20m<sup>2</sup> would be needed. To produce the subsequent Airspeed, 2 electric Engines with Propellers would be placed on the lifting Wings, each with a Net-Power output of about 750kW. These engines would draw their power from up to 8 powerbanks, where both are cooled by a liquid-cooled thermal management system, radiating the heat overboard inside the engine nacelles. The telecommunication-antennas are placed on each wingtip, while the radar-dome sits on the bottom of the fuselage in the aft of the aircraft and the visual camera dome sits in the front of the aircraft.

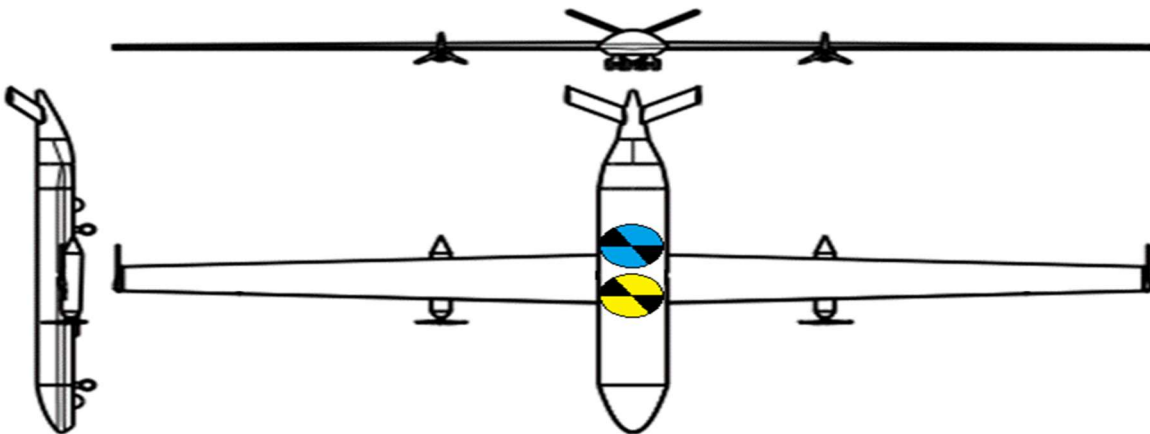


Figure 3 Three side view

In addition, cameras are installed in both wing tips, which point in the direction of flight while another camera is installed in the nose of the aircraft and can be controlled by a drone pilot. The mission equipment is behind the camera in the front of the aircraft alongside is the relay for the broadband internet. Immediately behind the relay is also a launcher for mini drones for local reconnaissance support. After use, these can be collected by the ground staff and thus returned to base and reused. The mini drones are initially controlled via the aircraft or via the base station and then, if necessary, transferred to a mobile user. Some mini drones are equipped with an emergency first aid kit in addition to their reconnaissance module and can also be requested by ground personnel.

PROMETHEUS is designed to make each module highly interchangeable. Each wing, battery-pack or engine-nacelle is dismountable from the plane to allow rapid serviceability in the case of detected wear and tear.

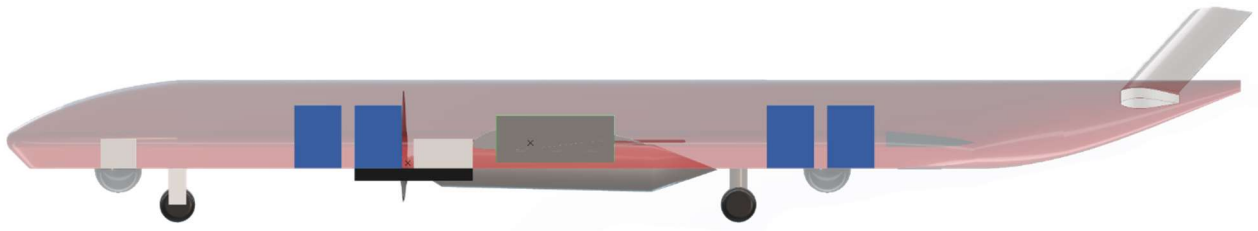


Figure 4: Placement of parts

This also allows for an even distribution of the center of mass slightly in front of the center of Lift where the 500kg battery-packs can be mounted and locked in the preferable positions.

### 3 Aircraft Requirements

Table 2 shows the individual requirements that the concept must meet, with an outlook on the fulfillment of the application scenarios defined in the assignment.

<b>PROMETHEUS</b>	
Range	1400NM / 2600km
Design Payload	25 kg
Max Payload	50 kg
Cruise Speed	250 kts
Max. operating altitude	42.500 ft
TOFL	< 1.000 m
Landing Distance	< 1.200 m
Approach Speed	120 kts
Wingspan	21,5 m
Number of Aircraft for full coverage	440

Table 4 Prometheus physical key data

PROMETHEUS aims to fulfill the following Certification at the time of market entry:

DIN EN 9132: This standard deals with the airworthiness of unmanned aircraft systems (UAS) and can be relevant for the certification and operation of drones of this size and speed. It sets requirements for design, construction, operation, and maintenance.

Luftverkehrs-Zulassungs-Ordnung (LuftVZO): The LuftVZO contains provisions and procedures for the approval of aircraft in Germany. For drones with such characteristics, specific approval requirements and procedures may apply.

Approval Directive LBA-ECAR 21: The approval directives of the Luftfahrt-Bundesamt (LBA) according to the European Civil Aviation Regulations (ECAR) 21 can be relevant for drones of this size and performance. These directives specify detailed requirements for the certification of aircraft.

Aeronautical Information Publication Germany (AIP Germany): The AIP Germany provides information on aviation infrastructure, airspace classifications, and specific operational restrictions in Germany.

For the best possible coverage of the area of service with telecommunications, the highest possible flight altitude is beneficial. Therefore, our concept aims to place several flying objects simultaneously in the range from FL300 to FL425, which can communicate with each other and with participants on the ground as relays.

#### 4 Reference Aircraft

In the concept phase, the aim was to have an aircraft that could fulfill both scenarios (Internet failure / disaster) without major modifications. It was already evident in the first research that measures to reduce weight will play a key role in the development of the concept. Therefore, carbon fiber composites are mainly used in the construction of the fuselage and wing structure.

PROMETHEUS	
Dry Weight	2500 kg
Max Take off Weight	3500 kg
Max TOFL	1200 m
Climb Rate	350 ft/min
Cruise Speed	180 kts
Engines	2 x 750kW Electric Engines
Battery Capacity	6000 kWh in up to 16 Powerbanks

Table 5 Prometheus operational key data

With a targeted market entry in 2040, an increase in capacity was taken into account, especially in the area of propulsion battery development, due to the increasing pressure to innovate in propulsion concepts. In addition to take-off mass and fuselage space requirements, an improvement in the power density of the propulsion battery also has other influences on the concept aircraft, such as adjustments for a more powerful thermal management system.

#### 4.1 Technology List

##### Key technologies

Propulsion

##### Explanation

One engine delivers 750 kW of shaft power at a weight of 75 kg. Today's engines, from Magnix e.g., deliver 650 kW at a weight of 200 kg. A reduction in weight with an increase in power has already been seen in similar dimensions in combustion engines.[4][5][6]

Battery power density

Prometheus assumes a tenfold increase in the power density of batteries in the next 17 years. Battery technologies such as lithium crystal batteries and lithium air batteries currently have the best chance of achieving this goal. The theoretical energy density of the lithium-air battery is already 3,450 W/Kg, which is in the order of magnitude needed for Prometheus. Prometheus expects that the periphery will be improved in the next 17 years and thus the

optimal utilization of the lithium air battery will become even better.

**Material**

Prometheus assumes progress in the materials industry, which manages to combine lightweight construction methods with the optimum properties of the material. This is then further supported by design optimization, which helps reduce the mass of the aircraft while maintaining the same.

For the inner Wing structure carbonfibre-composites will be used for Spars and Ribs where the outer skin will be reinforced if necessary with an underlying layer of Aluminium sandwiched below the carbonfibre-material. This would allow to avoid buckling of the carbonfibre as a failure-mode when applied with compressive stress. While carbonfibres possess high tensile strength of up to 7 GPa, its axial-compressive strength is only half of that, with the traverse compressive strength being even lower. [19]

The fuselage will also be constructed mainly from carbonfibre-composites to bring the overall weight down, with minimal use of Aluminium-beams to distribute the load of the battery-banks.

**Insulation layer**

The insulation limits are within the operating range of the fuel cell, but the Prometheus team expects that the insulation will achieve weight savings. As a concrete value, the team sees 75 % of the mass needed today for insulation. Prometheus also believes that the cooling of battery systems will continue to improve.

**Modularity**

The flexibility that the aircraft brings with it is of enormous importance, both in economic and research terms. Disaster management benefits from the versatility of the aircraft.

There is nothing to be said against its use for EIS, but the modular principle should be emphasized once again.

**Mini drones**

By carrying small drones, Prometheus can perform additional tasks. Thus, it is possible to ensure the supply of the area and at the same time support the rescue forces through targeted use of small drones

**4.2 Mass Breakdown**

Component	Weight [kg]	Gross-weight [kg]
Fuselage		600
Wing	150	300
Tailplane		50
Undercarriage		120

Avionic / Electronics		69
Engines	75	150
Fuel/Batteries	2000	2000
Thermomanagement-system		180
Minidrone Carrier		5
Minidrone	1	6
Payload		20
Dry-Weight		3.300
MTOW		3.500

Table 6 Masses Proportion of Prometheus

One wing has a weight of 150 kg which makes 300 kg in total. It must be mentioned that the electricity of the wing is part of the wing weight and not of the Avionic/Electronics.

## 5 Aerodynamics

### 5.1 Wing Design and Airfoil selection

The first approach for designing the wing geometry was to select an already tried and tested airfoil. The influence of the lift coefficient on the lift force can be derived approximately from the lift equation:

$$F_L = C_L * \frac{1}{2} * \rho * v^2 * A$$

The air density  $\rho$  can be read from the standard atmosphere. The square of the flight speed  $v$  and the wing area  $A$  remain as individual variables. The lift coefficient  $C_L$  includes all complex dependencies and is usually determined experimentally or by CFD simulations.

The WORTMANN FX 63-137 airfoil was therefore used as a reference, as it generates a positive lift force for angles of attack from  $-7.5^\circ$  to  $12.5^\circ$  with a lift coefficient of up to 1.75. [7]

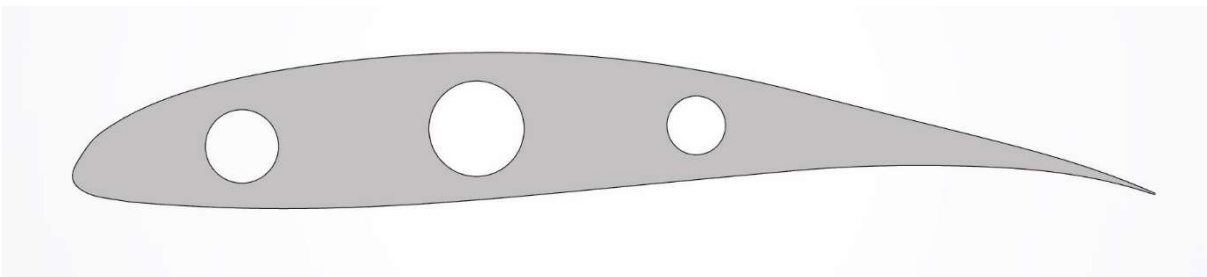


Figure 5 Airfoil

The drag coefficient  $C_d$  reaches its minimum at an angle of attack of  $0^\circ$  and is always below 0.3 between  $-10^\circ$  and  $+10^\circ$ .

With a comparable Reynolds-Number of  $1,5$  to  $2,0 * 10^6$  only the upper limits of pre-calculated  $C_l$  and  $C_d/\alpha$  graphs are applicable. Although moderate changes in viscosity have to be expected when the air pressure and temperature drop. But above FL290 PROMETHEUS is also picking up flightspeed to reduce its angle-of-attack. [10]

$$Re = \frac{\rho \cdot v \cdot l}{\mu} = \frac{v \cdot l}{\nu}$$

With

- $v$  = Velocity of the fluid
- $l$  = The characteristic length, the cord width of an airfoil
- $\rho$  = The density of the fluid
- $\mu$  = The dynamic viscosity
- $\nu$  = The kinematic viscosity

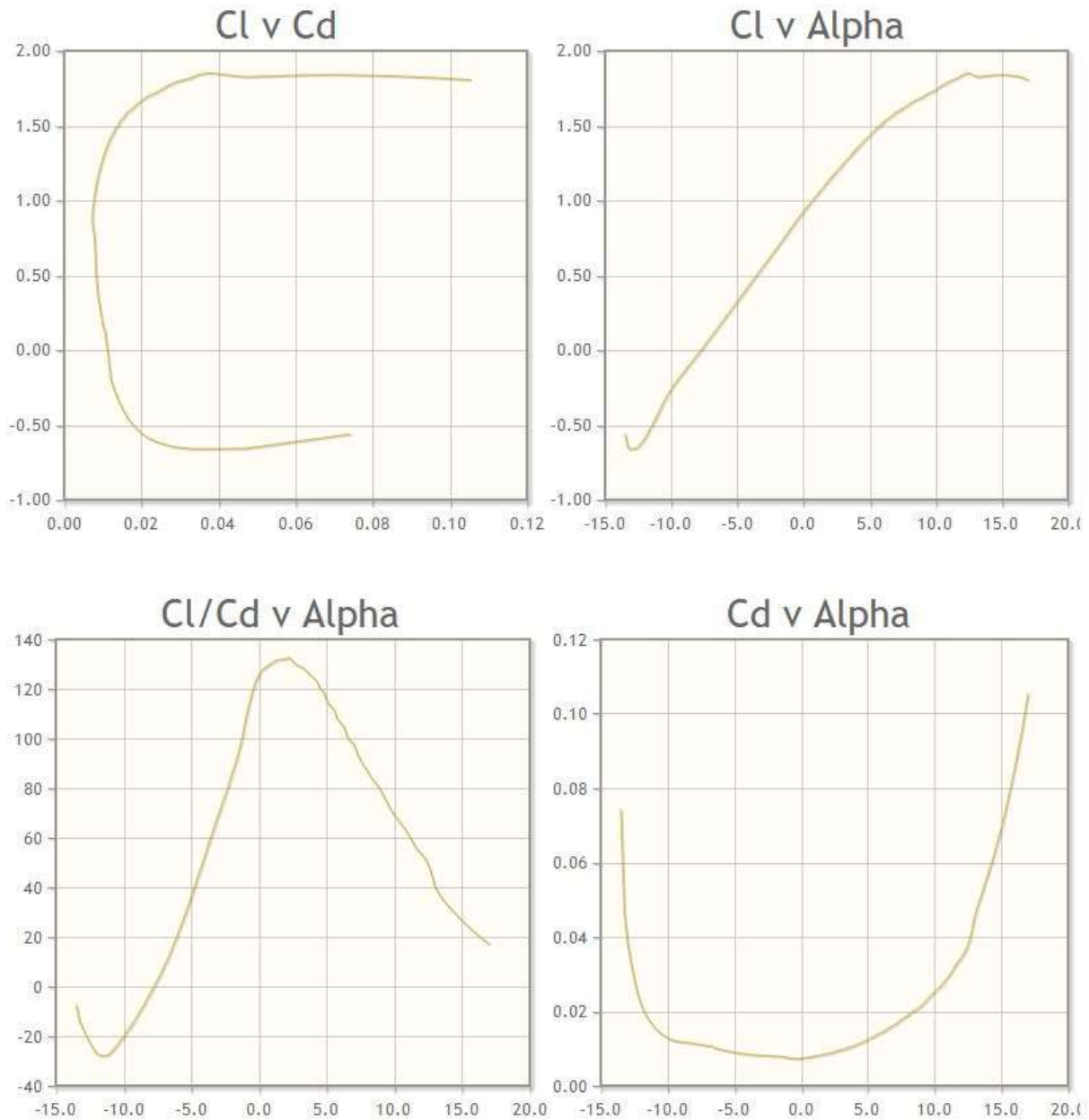


Figure 6 Lift and Drag coefficient graph

To calculate the wing area, the wing was assumed to be a trapezoid. Its length from leading to trailing edge is 1.5 meters at the wing root and 0.75 meters at the wing tip. With a wingspan of 10 meters, this results in a wing area of 11.25 m<sup>2</sup> for one wing and 22.5 m<sup>2</sup> for the entire aircraft without the tail unit.



Figure 7 Main Lift Wing

Substituting these design values into the lift formula leaves only operational variables such as speed and air density that can be exhausted by adjustments to the flight path.

For example, about 35,000 N of lift can be generated for FL300 and 136kts at 7° AoA.

For a given flight path with an average climb rate of 360 ft/min at 146 knots, FL300 can be reached within 90 minutes, purely mathematically.

Reference Points were taken from two already existing Aircraft:

Eviation Alice: High-Class Twin-Engine Electric Aircraft for Passenger Transport [8]

Wingspan: 19,2 m

MTOW: 7.491 kg

Cruise Speed: 220 kts

Powerplant: 2x 700 kW Electric

Beechcraft KingAir 360ER: Twin-Engine Turboprop Aircraft for Passenger Transport [9]

Wingspan: 17,65m

MTOW: 7.484kg

Cruise Speed: 303 kts

Powerplant: 2x 1050 shp Turboprop

Height ft	Height m	AirDensity (ISA) kg/m <sup>3</sup>	Speed m/s	Speed Kn	Wing-Area overall m <sup>2</sup>	Cd	1,75 max Cl	Mass N	Excess Lift	Lift N	Rate of climb m/s	Rate of climb ft/min	Time to next (sec) sec	Time to next (min) min	Flighttime min min
0	0,00	1,23	75	146	20	0,01	1,00	34335	2	68670	1,98	390	504	8	8
3281	1000,00	1,11	75	146	20	0,014	1,10	34335	2	68670	1,98	389	506	8	17
6562	2000,00	1,01	75	146	20	0,017	1,21	34335	2	68670	1,97	388	507	8	25
9843	3000,00	0,91	75	146	20	0,0095	1,34	34335	2	68670	1,98	391	504	8	34
13123	4000,00		75	146	20			34335	2	68670	2,00	394	500	8	42
16404	5000,00	0,74	75	146	20	0,0095	1,66	34335	2	68670	1,98	391	504	8	50
19685	6000,00		75	146	20			34335	2	68670	2,00	394	500	8	59
22966	7000,00	0,59	75	146	20	0,01	1,55	34335	1,5	51503	1,48	292	674	11	70
26247	8000,00		75	146	20			34335	1,4	48069	1,40	276	714	12	82
29528	9000,00	0,47	90	175	20	0,01	1,27	34335	1,4	48069	1,38	271	727	12	94
32808	10000,00		90	175	20			34335	1,4	48069	1,40	276	714	12	106
36089	11000,00	0,37	90	175	20	0,018	1,61	34335	1,4	48069	1,36	267	737	12	118
39370	12000,00		90	175	20			34335	1,2	41202	1,20	236	833	14	132
42651	13000,00	0,27	90	175	20	0,0185	1,59	34335	1	34335	0,00	0			
42651	13000,00	0,27	144	250	20	0,004	0,62	34335	1	34335	0,00	0			

avg. Rate of climb 350 ft/min (to 10km)

Table 7 Flightpath breakdown for Mission-Operation

Other factors influencing the wing geometry are the need for ailerons and landing flaps. In addition, it must be examined whether, in addition to the two transverse spars, which connect the individual wing ribs, further stringers must be used to further stiffen the structure. The remaining space between the ribs can be used

to transport additional battery packs and coolants. Consideration is given to reducing frame components such as stringers if the wing load can be absorbed by subsystems.

In addition, a transmitting/receiving antenna for data transmission and the position lights are housed on both wing tips.

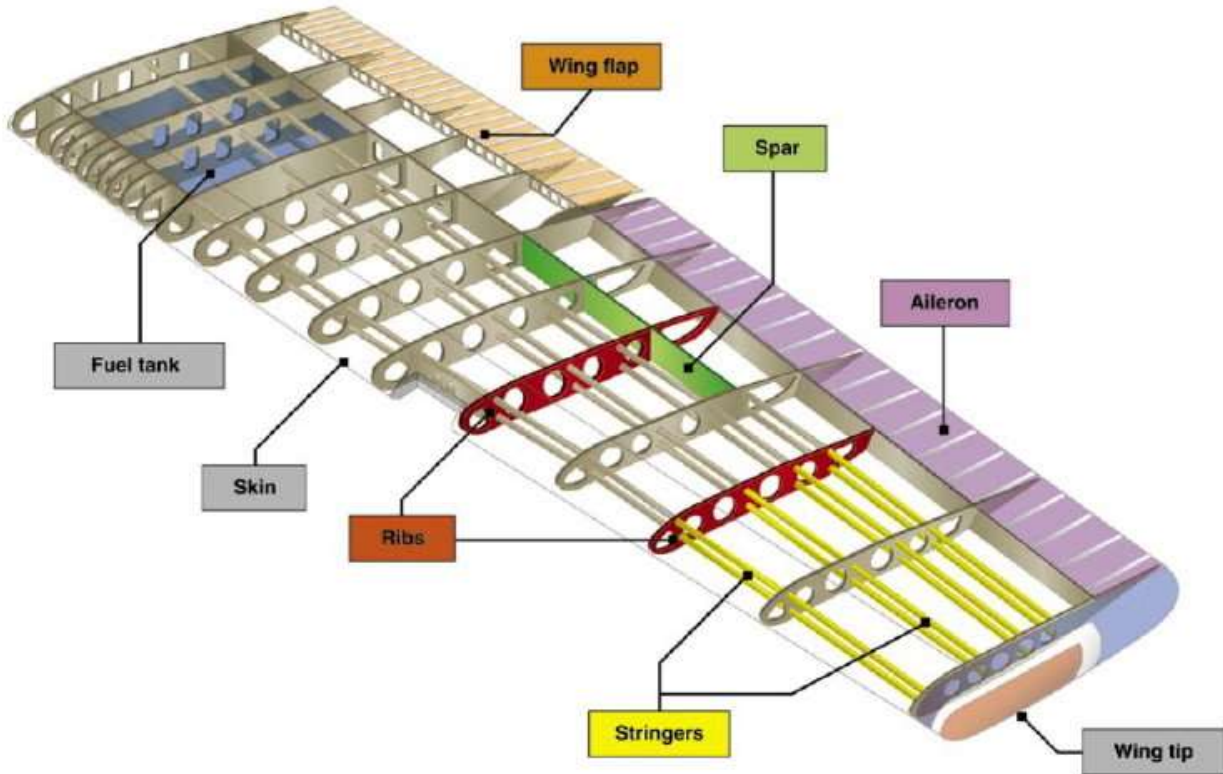


Figure 8 General Lifting wing structure

Source: Designing of an aircraft based on preliminary mission requirement Siddharth Raj Gupta [11]

Wing area overall	22,5 m <sup>2</sup>
Dihedral-angle	0°
Aspect-ratio	8,9
Area single wing	10 m
Grossweight (empty) overall	227,3 kg
Length wingroot	1,5 m
Length wingtip	0,75 m

Table 8 Liftwing Stats

If it is necessary to add Winglets to the Wingstructure to improve the aerodynamic properties will be decided after detailed CFD simulation

#### Thermomanagement

As a thermal management system, a coolant reservoir of approx. 25 liters per drive motor unit is required. The cooler is located directly behind the propeller hub and is cooled by the propulsion airflow. Adjustable Inlet-flaps regulate the incoming air mass flow in order to keep air resistance as low as possible. However, it

is predictable that during the take-off process, the 2 x 750 kW electric motors are briefly operated in the overload range, accompanied by excessive thermal loading of the cooling system. However, the ducting-system and the coolant volume are dimensioned from the outset in such a way that overload peaks can be easily absorbed without exceeding local critical temperatures.

In addition, the coolant supply can be used to cool the drive batteries and to condition the on-board electronics during the flight. The outer skin is clad on the inside with thermal insulation materials to keep temperature fluctuations as low as possible; A controlled heat supply or dissipation is nevertheless necessary in the event of strong solar radiation and/or on hot days at low altitudes.

The thermal management system estimates the following masses as the estimated weight:

100kg coolant in total

50kg fluidlines and control valves

10kg for 4 electric pumps 20kg for 2 water coolers

## **6 Concept**

### **6.1 Operational procedure system Level**

PROMETHEUS is a drone that can cover a vast area as a swarm of several aircraft. The basis of the swarm is the flight algorithm, which maximizes coverage by computing maps of the optimal flight path. Its great strength is the versatility it can be used for, thanks to the application-specific adjustments. With its modular wing system, PROMETHEUS can be transported in trucks and can take off and land on almost any runway. PROMETHEUS is controlled by mobile base stations that can be transported with drones. The base station consists of a control unit the size of a freight container and a transmitter that is carried in an additional trailer. A base station is designed to automatically control up to 25 drones. The positioning has theoretically no limit. In an absolute emergency, the control container and the transmitter can follow the fleet and be available on the road. The base is therefore also independent of the runway, but it is also recommended that both are spatially close to each other to ensure a smooth connection.

For a Fleet of 440 aircraft, where only 321 are on approach or in mission flight, 13 base-stations are needed to cover the complete fleet. Each ground station would be manned by 2 technicians, leading up to 26 workers in total.

Scenario 1: Area coverage of Hamburg and Schleswig-Holstein with telecommunications. Reaching the deployment site from outside (100NM), loiter phase, return to base when all clear is given or handoff to the following aircraft

Scenario 2: Area coverage of local incidents with telecommunications and radar reconnaissance, start in flight from outside (170NM) with 75% energy reserve, loiter phase, return to base when all clear or handoff to following aircraft.

With a total weight of 3 tons, PROMETHEUS is able to climb to an altitude of 10km (32,808ft) within 100 minutes (1h 40min) and stay there. A peak altitude of up to 13km (42,651ft) is possible for better areal coverage.

Height ft	Height m	Speed m/s	Speed Kn	Rate of climb ft/min	Flighttime to next min	Powerdraw kW	Work to next KWh	Battery-Charge %
0	0	75	146	390	8	1500	210	99,3
3281	1000	75	146	388	8	1500	211	95,7
6562	2000	75	146	387	8	1500	212	92,2
9843	3000	75	146	390	8	1500	210	88,7
13123	4000	75	146	394	8	1500	208	85,2
16404	5000	75	146	390	8	1500	210	81,7
19685	6000	75	146	394	8	1500	208	78,2
22966	7000	75	146	292	11	1500	281	74,7
26247	8000	75	146	276	12	1500	298	70,1
29528	9000	90	175	271	12	1500	300	65,1
32808	10000	90	175	276	12	1500	300	60,1
36089	11000	90	175	266	12	1500	309	55,1
39370	12000	90	175	236	14	1500	347	50,0
42651	13000	144	250	0	180	750	2250	44,2
Return to Base			160		120	200	400	6,7

Table 9 Operational flightpath with power consumption

For Mission **Scenario 1**, area coverage is provided by multiple aircraft following a predetermined flight path that extends from base, across the entire mission area, and back to base. The airfield "Holtenau" **EDHK** near the city of Kiel is assumed to be the Base of Operation. Centrally placed, from here all mission areas can be reached in a timely manner. With a paved runway of 1260 x 30m, there is enough space for take-offs and landings.

However, the parking space and hangar capacity of the airfield must be massively expanded in order to be able to accommodate the planned fleet of around 440 aircrafts in the event of the all-clear. Alternatively, a distribution of the individual aircraft to neighboring airports is also conceivable, with the operative base remaining at Holtenau Airport, where aircraft are serviced and reloaded.

The fleets are divided into three groups:



Figure 9 Operational Areas

**Group Hamburg:** Deployment over the city of Hamburg due to the local accumulation of telecommunication partners.

Number of areal coverage aircraft: 13

Number of aircraft in standby and ascending/descending: 6 + 4

Duration of the Loiter phase: 3 hours.

**Group Schleswig-Holstein North:** Coverage of the northern operational area due to long flight routes that must be covered. Framing of the operational area Sylt - Flensburg - Kiel - Itzehoe - Sylt

Number of areal coverage aircraft: 136

Number of aircraft in standby and ascending/descending: 68 + 16

Duration of the Loiter phase: 3 hours.

**Group Schleswig Holstein-Ost:** Division of the operational area between Itzehoe and Kiel due to long flight routes. Framing of the operational area: Kiel - Itzehoe - Lauenburg - Fehmarn - Kiel

Number of areal coverage aircraft: 136

Number of aircraft in standby and ascending/descending: 68 + 16

Duration of the Loiter phase: 3 hours.

**Scenario 2** calls for the deployment of a single aircraft:

With 75% remaining energy reserves, the flight time at an altitude of 13,000m is still sufficient for 6 hours of pure flight time. However, it must be noted that 25% battery capacity is already required for the ascent to an altitude of 7,000m. Therefore, the sprint to the target area for this scenario must be assumed from the ascent phase. A flight speed of up to 146 knots can be assumed for the sprint to the operational area, which would mean that the operational area would be reached at a distance of 170NM after 1 hour and 9 minutes. A maximum expected headwind of 50 knots compared to the cruising speed would be the reducing means here, which would extend reaching the operational area to 1 hour 46 minutes. Once there, PROMETHEUS reenters the Loiter phase and begins area reconnaissance and telecommunications deployment. After about 3 hours in the Loiter phase, PROMETHEUS has to return to the base, if necessary, however, there would be enough preparation time to send another aircraft to the target area.

#### **Limitations:**

For both scenarios, the basic limitation is the type of energy supply. Even with massive innovation in the field of battery technology and the associated increase in storage capacity, a three-fold increase in the capacity expected by 2030 from 400-500Wh/kg to 1500Wh/kg would still be borderline for purely battery-electric flight in connection with fulfilling the deployment scenarios.

It is therefore being considered to increase the energy density of the onboard battery with a fuel cell, which converts the onboard hydrogen to generate electricity during the entire flight operation. As a result, the fuel cell is designed for 25% of the installed engine power so that it only contributes to the power supply during flight operations. Increasing the overall energy density would thus contribute to lengthening the loiter phases over the deployment area.[12]

However, the use of a fuel cell as a range-extender would only be seen as a bridging technology, since the production and compression of green hydrogen is less efficient than storing the electrical energy from renewable energy sources directly in the drive battery. The aim is therefore to exploit the constantly increasing pressure to innovate in the field of battery technology due to the requirements of vehicle manufacturers and power producers and to promote purely electric flight.

A tenfold increase in the current energy density of traction batteries from 250 Wh/kg upto 2500 to 3500 Wh/kg by market entry in 2040 would be desirable.

This prognosis is supported by the steady advance of development in the field of vehicle drive batteries. The US Geological Survey predicted in 2017, that the gravimetric energy density of traction batteries could increase to 400-500 Wh/kg by 2030 and that the course of innovation suggests exponential growth. [13]



Figure 10 Li-Ion batterie Innovation

### 6.1.1 Flightpath Algorithm

The flight algorithm is designed to save the weather data and traffic situation via a constant download and store it as a backup. At the beginning of the mission, the user loads the geodata of the flight zone into the algorithm and defines the emergency flight path. Via an input, the user determines how many aircraft are available to him. An optimization function forms the optimal flight path in order to maximize the area covered with minimum aircraft deployment. The area covered by an aircraft is not represented by a circle, but by a square that lies inside the circle (see figure). The assumption is to ensure a continuous connection. For a first estimation of the required aircraft, the aircraft are calculated in a way that the coverage statically overlaps the whole area.

Although this condition is static, an addition of a factor  $k_A$  of the aircraft is determined in order to cover the area dynamically. In addition, twice the number of flight zones is multiplied by the factor  $k_A$  in order to include the aircraft in the take-off and landing phase. This results in the formula:

$$n_{plane} = k_A \cdot n_{stat} + (6 \cdot s_{zones} \cdot k_A)$$

The factor  $k_A$  is a factor that depends on the area and takes into account the geometric shape of the area to be covered. The flight algorithm is then used for the final aircraft route. For an estimated route, one can connect the centers of the static coverage. Which can be seen in figure \_\_.

In general, however, an operator can always intervene via the base station and take control of the drone and return it to the algorithm when finished. It should be noted that the user always has the final decision.

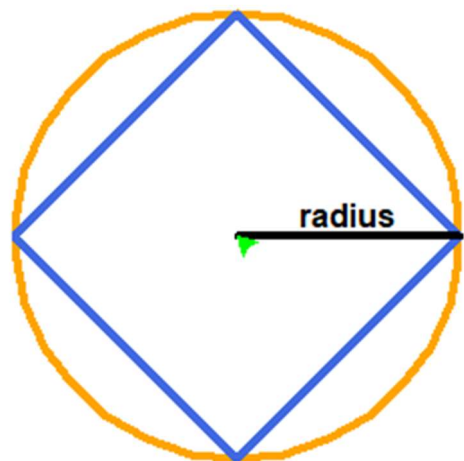


Figure 11 single areal coverage

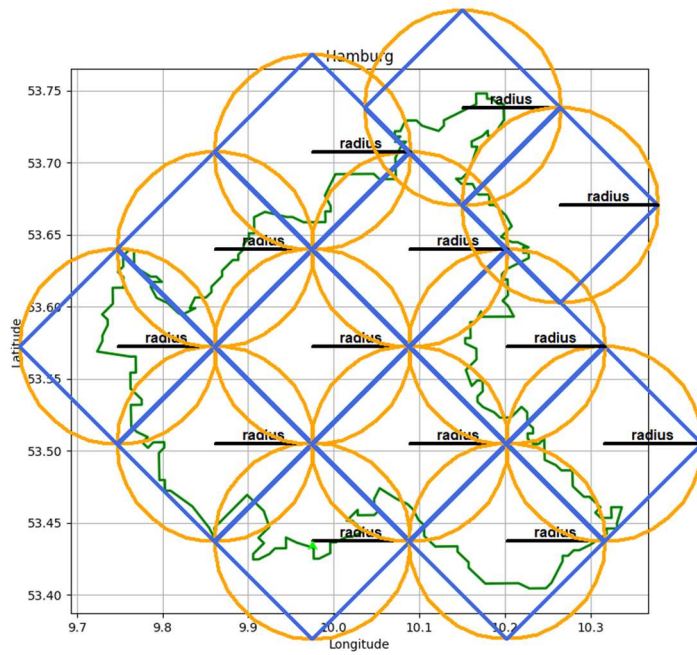


Figure 12 areal coverage for Hamburg

### 6.1.2 Flightpath Hamburg

The principle is exemplarily transferred to the city of Hamburg and visualized in the adjacent figure. For the area of Hamburg, 21 aircraft must be provided with  $k_A=1$ . If this model structure is transferred to Schleswig-Holstein, this corresponds to 440 aircraft.

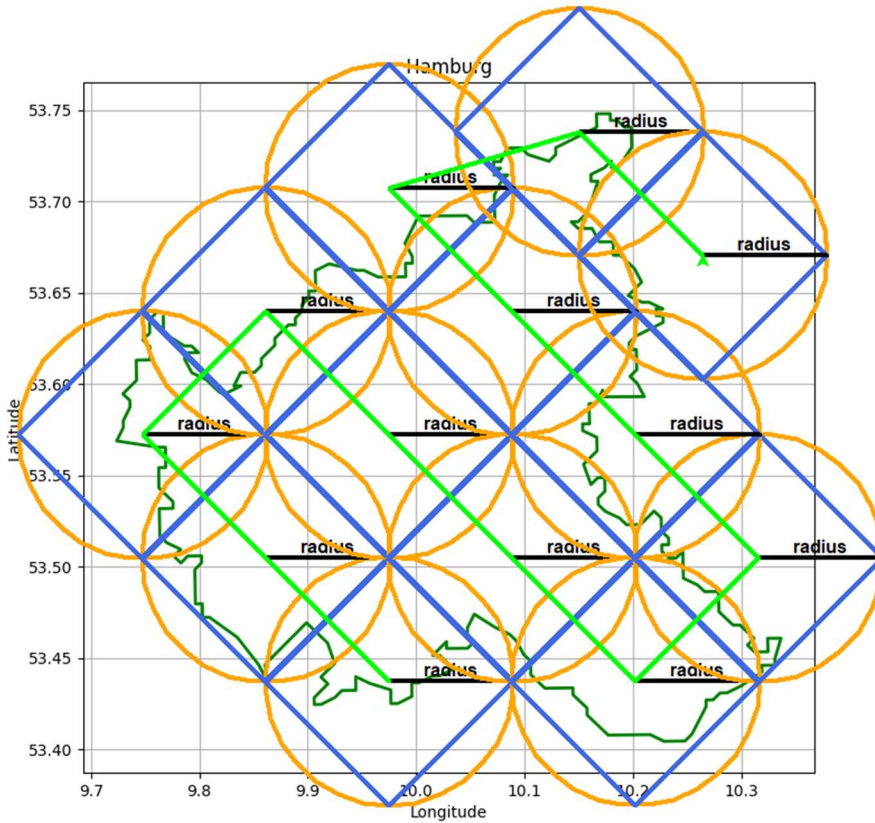


Figure 13 areal coverage for Hamburg with flightpath

### 6.1.3 Emergency Flightpath

If an aircraft loses contact with the ground station, its task in the system is to descend to a safe altitude. This is approx. 3500 m above sea level. At the same time, the base station receives feedback about the loss of signal so that a new drone can be prepared. If the signal cannot be re-established, the drone will continue to fly for 5 min after reaching the flight altitude of 3500 m and then fly back to the base station and make all landing preparations. In case the connection to the drone cannot be re-established, the drone will circle at safe altitude next to the base station outside the drone flight zone. In the event of a permanent loss of connectivity, the drone has the mission to crash over a secured area after the previous procedure has expired. The crash is accomplished via a slow descent of the drone until it makes contact with the ground. For the failure of the board electronics, another board electronics is installed to take over the control. If the first electronics fails, the second takes over and sends a signal to the base station. The base station then decides on the further course of action. However, it is recommended to order the drone back. If one drive unit fails, the other drive unit should still generate enough thrust to bring the drone into a safe zone.

## 7 Cost Analysis

Predicting prices over a 17-year span is not realistic. However, the cost estimate can be done from today and estimate the EIS with minor changes. Batteries are projected to cost €120 per kWh in 2023. The price here is assumed for lithium-ion batteries if it is assumed that the state of the art will continue to determine the price. In this case, it can be assumed that the price will not change. The motor is assumed to cost one million euros in order not to keep the budget too small. CFRP was used as the material, which is currently traded at 82€ per kg in the automotive industry. A reduction of the price to 60€ per kg seems realistic from the point of view of mass ordering in 2040. The drones used will become better and better through improved technology, while costing less. The launcher for the rudimentary system is assumed to be about €100. This amount is assumed to be constant. The same applies to the OBE, as it must meet the minimum standard. The cooling of the battery is assumed to be 0.96 € cheaper per kWh. The landing gear and the payload are assumed to have a fixed amount, since minimum standards must be met here as well.

The development of the base, the algorithm and the full design of the drone are assessed at just under €60 million and split between the drone for funding. The annual cost of mission command is estimated at 16 million euros. But at this point it must be said that no repair costs are included in these 16 million euros. A final summation of the costs results in approximately 935.7 million Euros, which is roughly equivalent to the EIS 929.1 million. This difference is due to wage inflation and improved technology.

Cost calculation				
One Time Price	m= 950		kWh= 3000	
Part	Noitz (Today)	Price Today	Notiz(Eis)	Price EIS
Batteries	120€/kWh	360.000,00 €		360.000,00 €
Engine	no price available	1.000.000,00 €		1.000.000,00 €
Material	82€/kg	77.900,00 €	60€/kg	57.000,00 €
Mini drones	1000€/Drone	6.000,00 €	800€/Drone	4.800,00 €
Mini drones Carrier	approx. 100 €	100,00 €		100,00 €
OBE	approx. 5.000 €	10.000,00 €		8.000,00 €
Cooling	3,46€/kWh	10.380,00 €	2,50€/kWh	7.500,00 €
Undercarriage	approx. 50.000€	50.000,00 €		50.000,00 €
Payload (DLR)	approx. 200.000 €	200.000,00 €		200.000,00 €
<b>Development</b>				
Basis	7.000.000 €	7.000.000,00 €		7.000.000,00 €
Basis price	200000 per 25 planes	4.000.000,00 €		4.000.000,00 €
Coding (Algorithm)	5*5 Software à 60.000	1.500.000,00 €	5*5 Software a 70.000	1.750.000,00 €
Full Development	50.000.000 €	50.000.000,00 €		50.000.000,00 €
Average/plane	500 planes	117.000,00 €		125.500,00 €
<b>Repeating costs</b>				
Crew(Ground)	75 Mechanics 60.000€	4.500.000,00 €	75 Mechanics a 65.000	4.875.000,00 €
Crew(Air)	25 pilots 60.000€	1.500.000,00 €	25 pilots a 70.000	1.750.000,00 €
Rent (Mission)	1 year	10.000.000,00 €		12.000.000,00 €
Summation		16.000.000,00 €		18.625.000,00 €
Average(Year/plane)	500 planes	32.000,00 €		37.250,00 €
Summe per plane		1.863.380,00 €		1.850.150,00 €
Summ Fleet		935.690.000,00 €		929.075.000,00 €

Table 10: Cost calculation

---

## 8 Usecases apart from emergency Operations

The almost unrestricted ability to communicate is a privilege that is of great importance to the public, even outside of crises and disasters, and it is no longer possible to imagine our society without it. Nevertheless, German mobile networks, especially in rural regions or those surrounded by many mountains, have inadequate network coverage. To address this issue, it is first necessary to determine where the current network has concrete gaps and what causes them. This is where our payback plan will come in.

To cover the investment costs as well as to avoid downtime and the associated potential damage caused by standing, the drones will be earmarked for civilian operations in the telecommunications sector. For this purpose, mobile network providers are supported by our services to improve their service in terms of network coverage. In cooperation with us, there is the possibility of commissioning network tests that can be carried out by the drone fleet. With the technology already integrated, supplemented by a modular measurement kit, the drones are to fly over certain areas in pre-programmed flight patterns and map the network coverage. This is done using a synchronization of GPS data with the amplitudes of the measurement signals and, if necessary, ground scans. This enables the providers to take targeted and resource-saving improvement measures. Compared to other mobile measurement systems, this method offers the advantage that the system can be used in an almost  $CO_2$ -neutral manner. In addition, regions can be surveyed independently of the existing infrastructure on the ground.

Furthermore, the drones can be rented as temporary repeaters, for example to maintain communication lines during maintenance work on transmission towers or similar. This would significantly increase the flexibility of providers and, consequently, customer satisfaction.

This deployment plan provides for a 90-percent utilization of the fleet, so that the ability to act in the event of a disaster is always guaranteed. The permanent use for telecommunication providers ensures the quickest possible amortization and offers additional added value for the population. An additional field of application could be research at universities. They could use the drones to research intelligent swarm systems and thus improve the algorithm or for parts tests at low altitude.

## 9 Refences

[1]	Aufsichts- und Dienstleistungsdirektion (ADD) Aktuelle Situation - Zahlen und Fakten Ahrflut <a href="https://web.archive.org/web/20210731110520/https://hochwasser-ahr.rlp.de/de/aktuelle-lage/zahlen-und-fakten/">https://web.archive.org/web/20210731110520/https://hochwasser-ahr.rlp.de/de/aktuelle-lage/zahlen-und-fakten/</a> Access: 07-2023
[2]	Verkehrssituation Ahrtal Süddeutsche Zeitung <a href="https://www.sueddeutsche.de/panorama/hochwasser-unrat-aus-katastrophengebiet-wird-weiter-abtransportiert-dpa.urn-newsml-dpa-com-20090101-210724-99-511152">https://www.sueddeutsche.de/panorama/hochwasser-unrat-aus-katastrophengebiet-wird-weiter-abtransportiert-dpa.urn-newsml-dpa-com-20090101-210724-99-511152</a> Access: 05-2023
[3]	Flutkatastrophe 2021: Ehrang (Stadt Trier) <a href="https://www.swr.de/swraktuell/rheinland-pfalz/trier/trier-ehrang-nach-dem-hochwasser-100.html">https://www.swr.de/swraktuell/rheinland-pfalz/trier/trier-ehrang-nach-dem-hochwasser-100.html</a> Access: 05-2023
[4]	Battery Electric, Hybrid Electric and Hydrogen Electric Systems <a href="https://www.magnix.aero/services#motorTab">https://www.magnix.aero/services#motorTab</a> Access: 07-2023
[5]	magnix unveils two electric propulsion units optimized for flight <a href="https://www.militaryaerospace.com/commercial-aerospace/article/14232274/magnix-unveils-two-electric-propulsion-units-optimized-for-flight">https://www.militaryaerospace.com/commercial-aerospace/article/14232274/magnix-unveils-two-electric-propulsion-units-optimized-for-flight</a> Access: 07-2023
[6]	magnix stellt zwei flugoptimierte elektrische Antriebseinheiten vor <a href="https://www.prnewswire.com/news-releases/magnix-stellt-zwei-flugoptimierte-elektrische-antriebseinheiten-vor-885656911.html">https://www.prnewswire.com/news-releases/magnix-stellt-zwei-flugoptimierte-elektrische-antriebseinheiten-vor-885656911.html</a> Access: 07-2023
[7]	Airfoil Tools Wortman fx 63-137-il <a href="http://airfoiltools.com/airfoil/details?airfoil=fx63137-il">http://airfoiltools.com/airfoil/details?airfoil=fx63137-il</a> Access: 07-2023
[8]	Reference Aircraft Eviation Alice <a href="https://www.eviation.com/aircraft/">https://www.eviation.com/aircraft/</a> Access: 07-2023
[9]	Reference Aircraft King Air 360ER <a href="https://beechcraft.txtav.com/en/king-air-360er#specs">https://beechcraft.txtav.com/en/king-air-360er#specs</a> Access: 07-2023
[10]	Airfoil Tools Reynolds Number Calculator <a href="http://airfoiltools.com/calculator/reynoldsnumber">http://airfoiltools.com/calculator/reynoldsnumber</a> Access: 07-2023
[11]	Designing of an aircraft based on preliminary mission requirement <a href="https://www.researchgate.net/publication/324835087_Designing_of_an_aircraft_based_on_preliminary_mission_requirement_-_2">https://www.researchgate.net/publication/324835087_Designing_of_an_aircraft_based_on_preliminary_mission_requirement_-_2</a> Access: 07-2023
[12]	NATIONAL BLUEPRINT FOR LITHIUM BATTERIES <a href="https://www.energy.gov/sites/default/files/2021-06/FCAB%20National%20Blueprint%20Lithium%20Batteries%200621_0.pdf">https://www.energy.gov/sites/default/files/2021-06/FCAB%20National%20Blueprint%20Lithium%20Batteries%200621_0.pdf</a> Access: 07-2023
[13]	U.S. Geological Surver Mineral commodity summaries 2017 <a href="https://pubs.er.usgs.gov/publication/70180197">https://pubs.er.usgs.gov/publication/70180197</a> Access: 07-2023

[14 ]	Munro <a href="https://leandesign.com/2020/02/14/tearing-down-tesla-segment-4-battery-cooling-system-comparison-on-tesla-model-3-vs-bmw-i3/">https://leandesign.com/2020/02/14/tearing-down-tesla-segment-4-battery-cooling-system-comparison-on-tesla-model-3-vs-bmw-i3/</a> Access 07.2023
[15 ]	Magnix <a href="https://www.magnix.aero/services">https://www.magnix.aero/services</a> Access 07.2023
[16 ]	Ainoline <a href="https://www.ainonline.com/aviation-news/aerospace/2022-12-05/magnix-makes-leap-electric-motors-hydrogen-fuel-cells">https://www.ainonline.com/aviation-news/aerospace/2022-12-05/magnix-makes-leap-electric-motors-hydrogen-fuel-cells</a> Access 07.2023
[17 ]	Fraunhofer ISI <a href="https://batterie-2020.de/wp-content/uploads/2018/01/batterie-2020.de-energiespeicher-roadmap-2017-energiespeicher-roadmap-dezember-2017.pdf">https://batterie-2020.de/wp-content/uploads/2018/01/batterie-2020.de-energiespeicher-roadmap-2017-energiespeicher-roadmap-dezember-2017.pdf</a> Access: 07.2023
[18 ]	Jobtensor <a href="https://jobtensor.com/Gehalt/Softwareentwickler">https://jobtensor.com/Gehalt/Softwareentwickler</a> Access 07.2023
[1 9]	Carbon Fiber Propertie <a href="https://www.sciencedirect.com/topics/materials-science/carbon-fiber-properties">https://www.sciencedirect.com/topics/materials-science/carbon-fiber-properties</a> <b>Access 07.2023</b>