Systems Engineering Challenges of a Solar Powered High Altitude Aircraft

INCOSE 32nd Annual International Symposium 2022

Andreas Bierig, Florian Nikodem, Daniel Rothe, Christoph Hagen, Malte Rahm

Institute of Flight Systems / Department for Safety Critical Systems & Systems Engineering

DLR

Background and Motivation

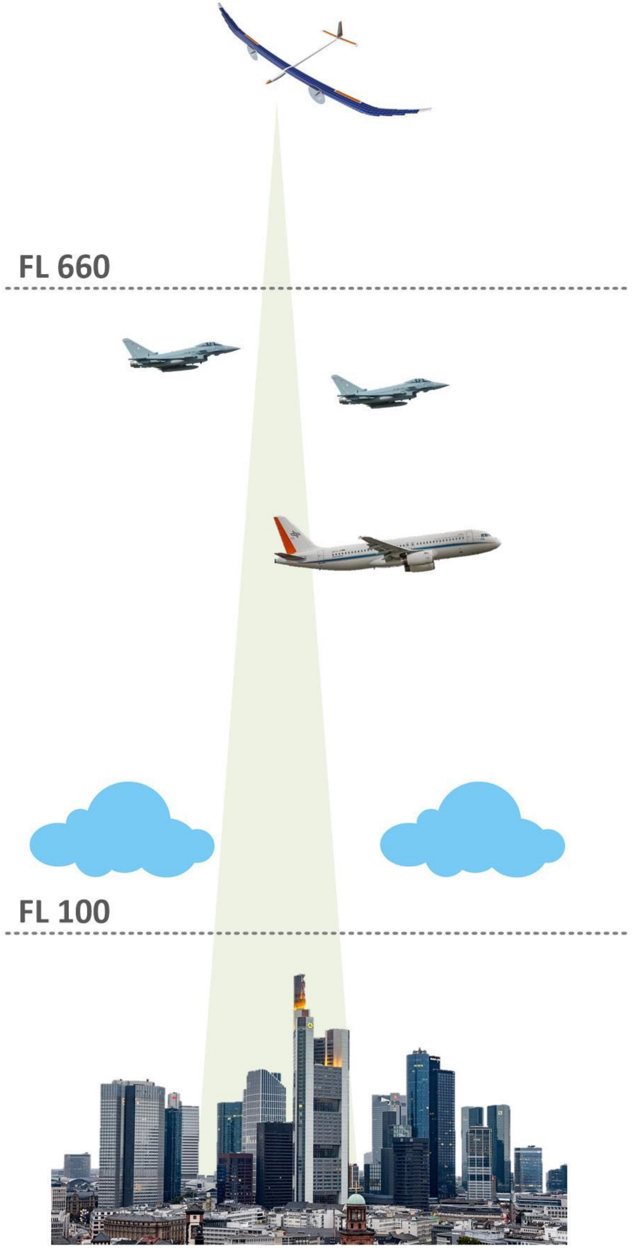
- Aircraft flying at high altitude with long endurance are an interesting alternative to convectional satellite systems

- These so-called High Altitude Platforms are especially attractive because:

  - *They can be manufactured, launched and operated for reasonable low cost*

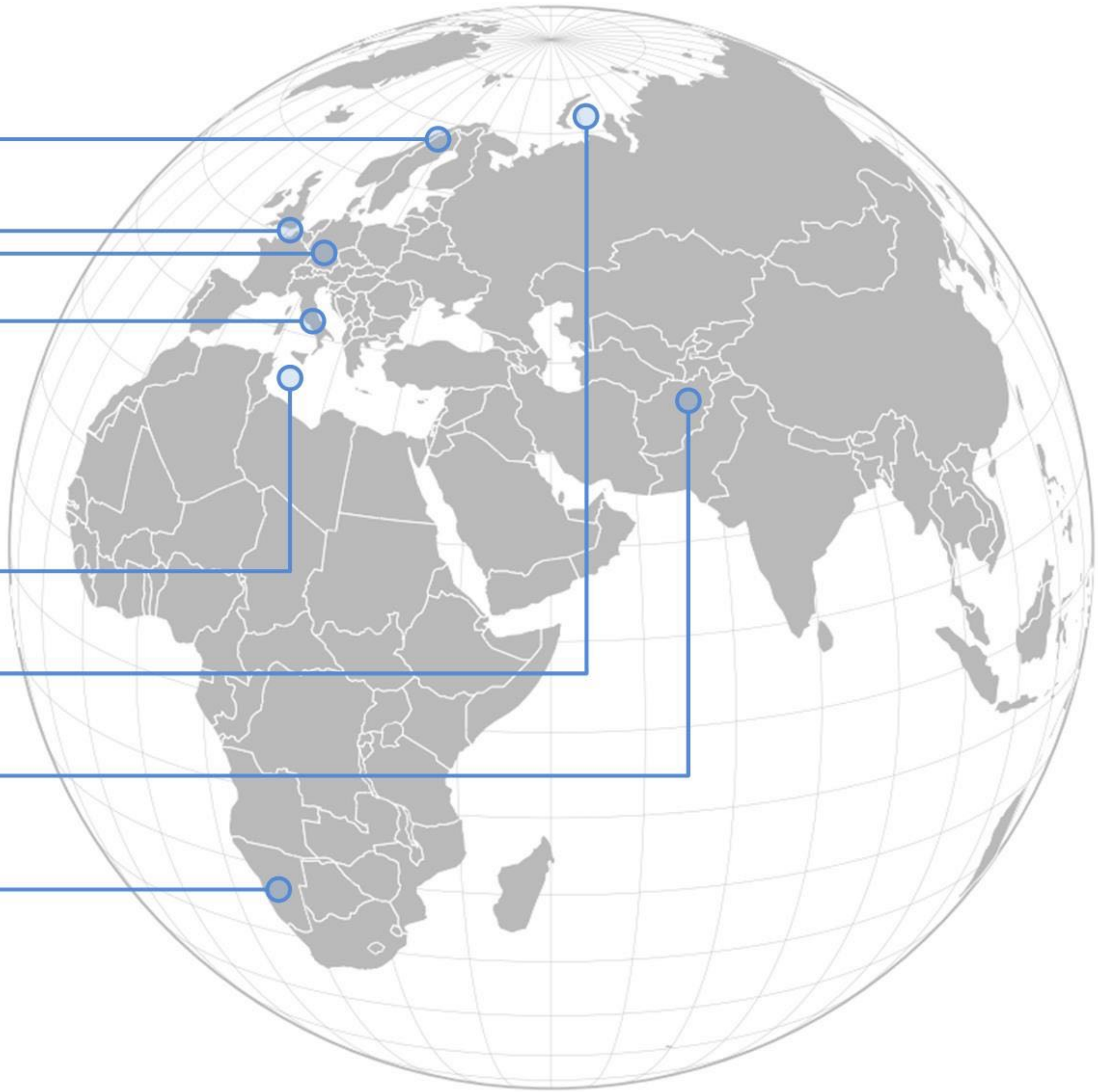
  - *They can serve for many different applications, such as earth observation and communication hubs*

- DLR researches in the areas of technologies as well as applications of very long endurance high altitude platforms. Recently a research demonstrator is being built to conduct scientific experiments



Example Missions

- *Glacier monitoring*
- *Vessel emissions*
- *Floods*
- *Earthquakes*
- *Mediterranean Sea monitoring*
- *Bering Strait*
- *Surveillance for peace keeping missions*
- *Animal tracking*



DLR‘s High Altitude Research Platform HAP

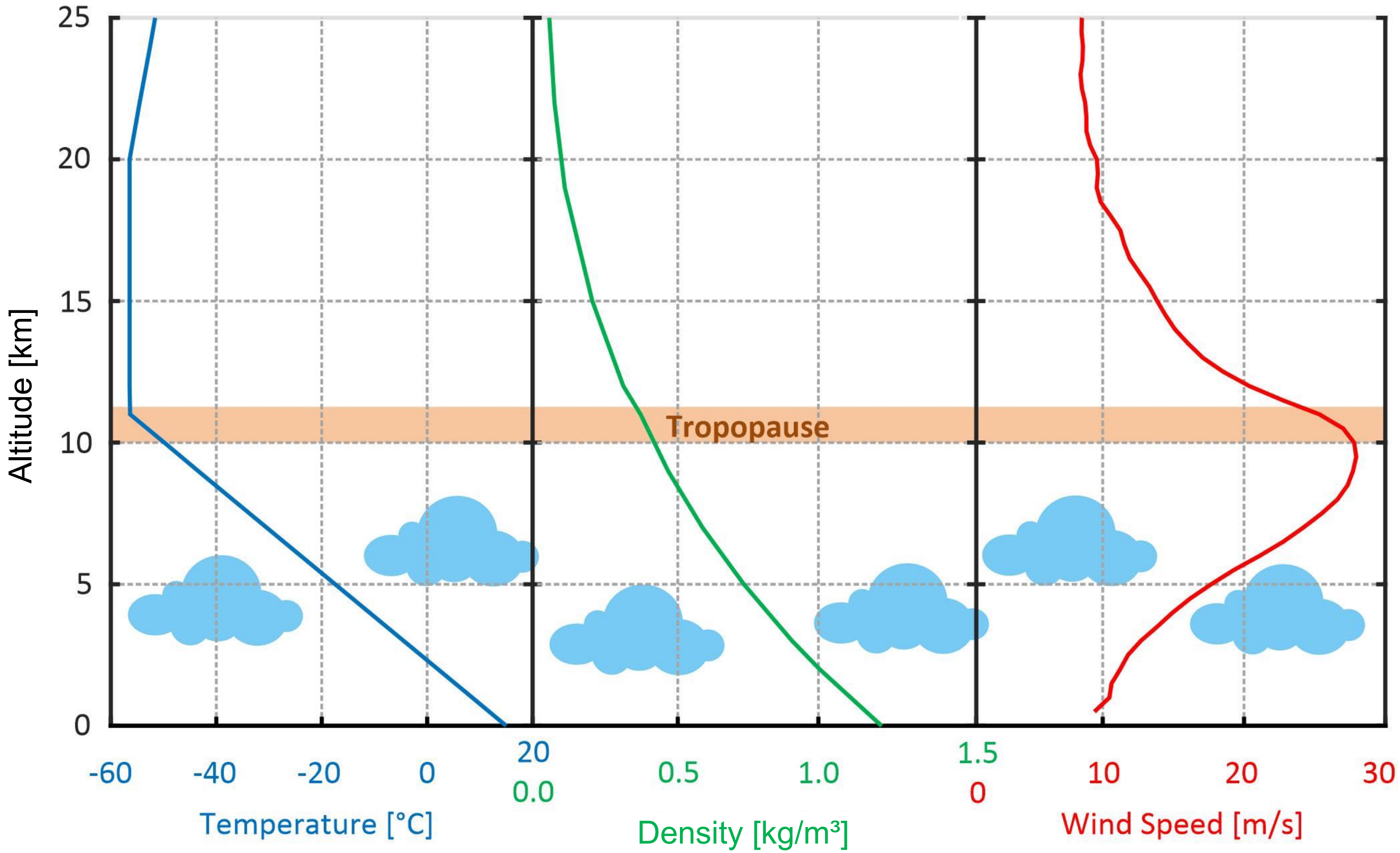
- DLR is on the way to establish a full scale research platform for high altitude aircraft

- The aim is to gain knowledge about the operation conditions and the design of such aircraft

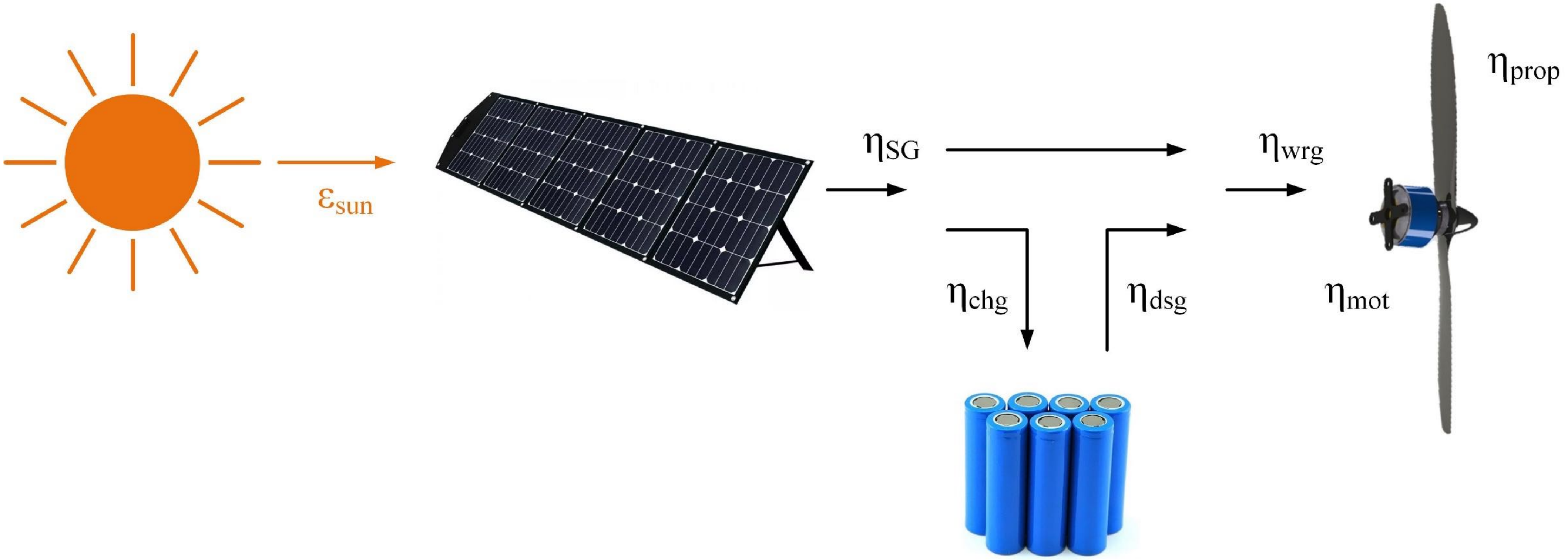
- The platform shall also be used to demonstrate innovative payload systems and missions

Considering the Environment

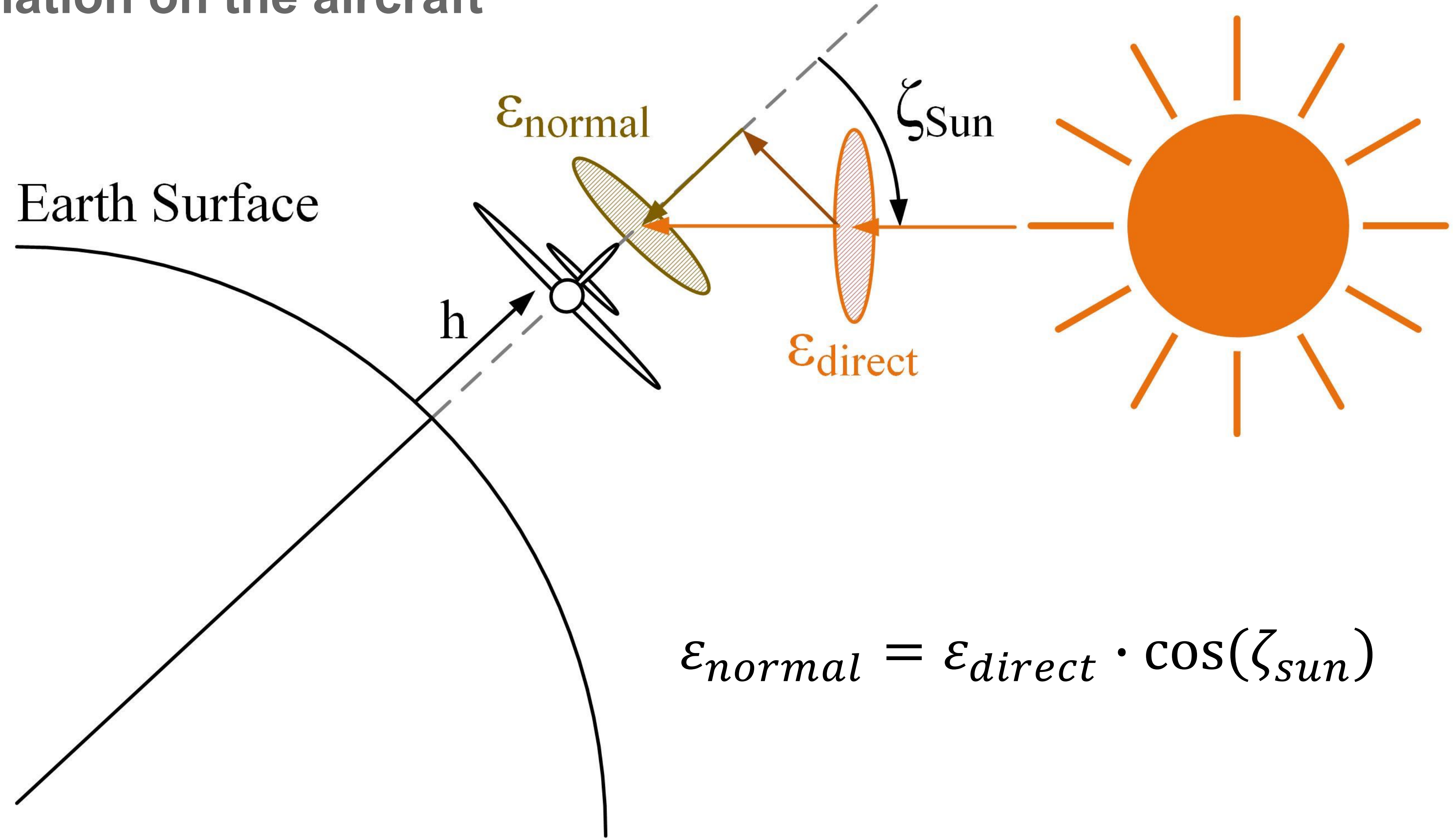
- Sweet spot above controlled airspace is above 18 km
- Very low temperatures during night
- High temperatures during day due to sun radiation
- Very low air density
- Jet stream and turbulences on the way up and down



Basic Operating Principle

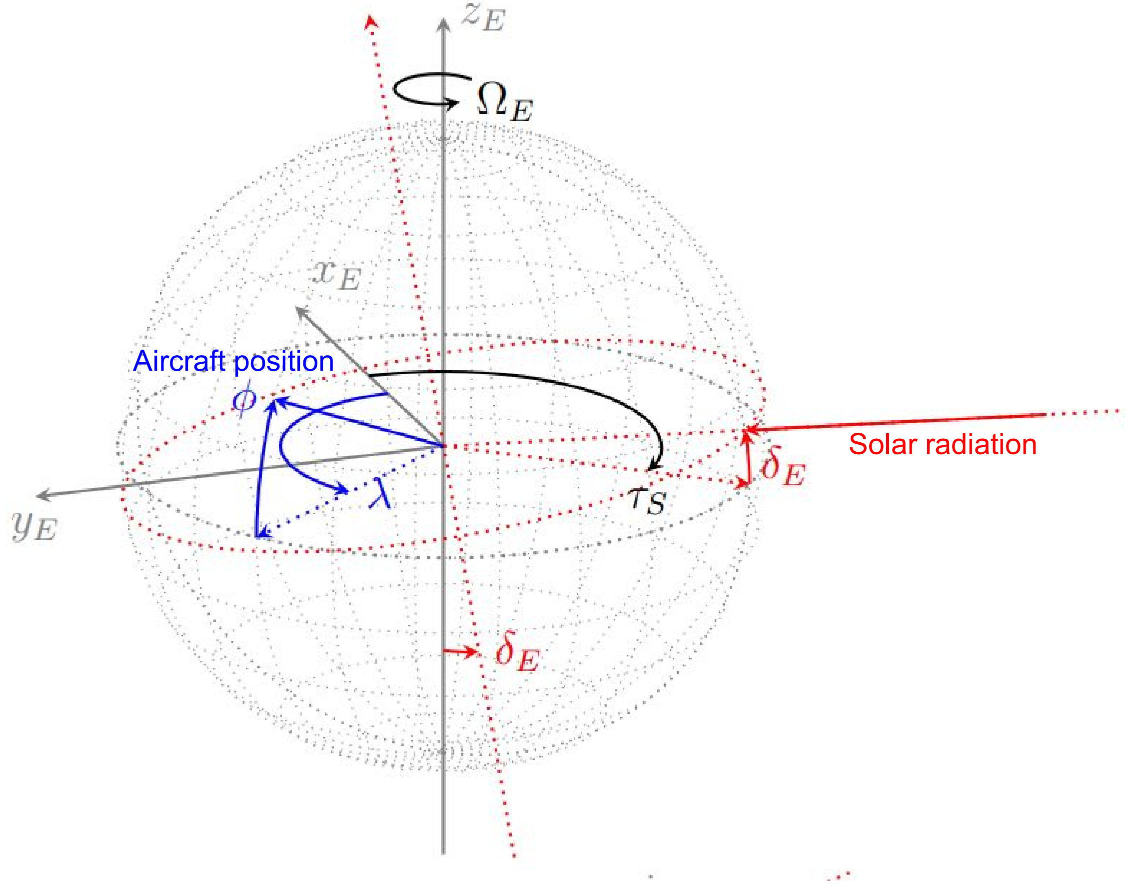


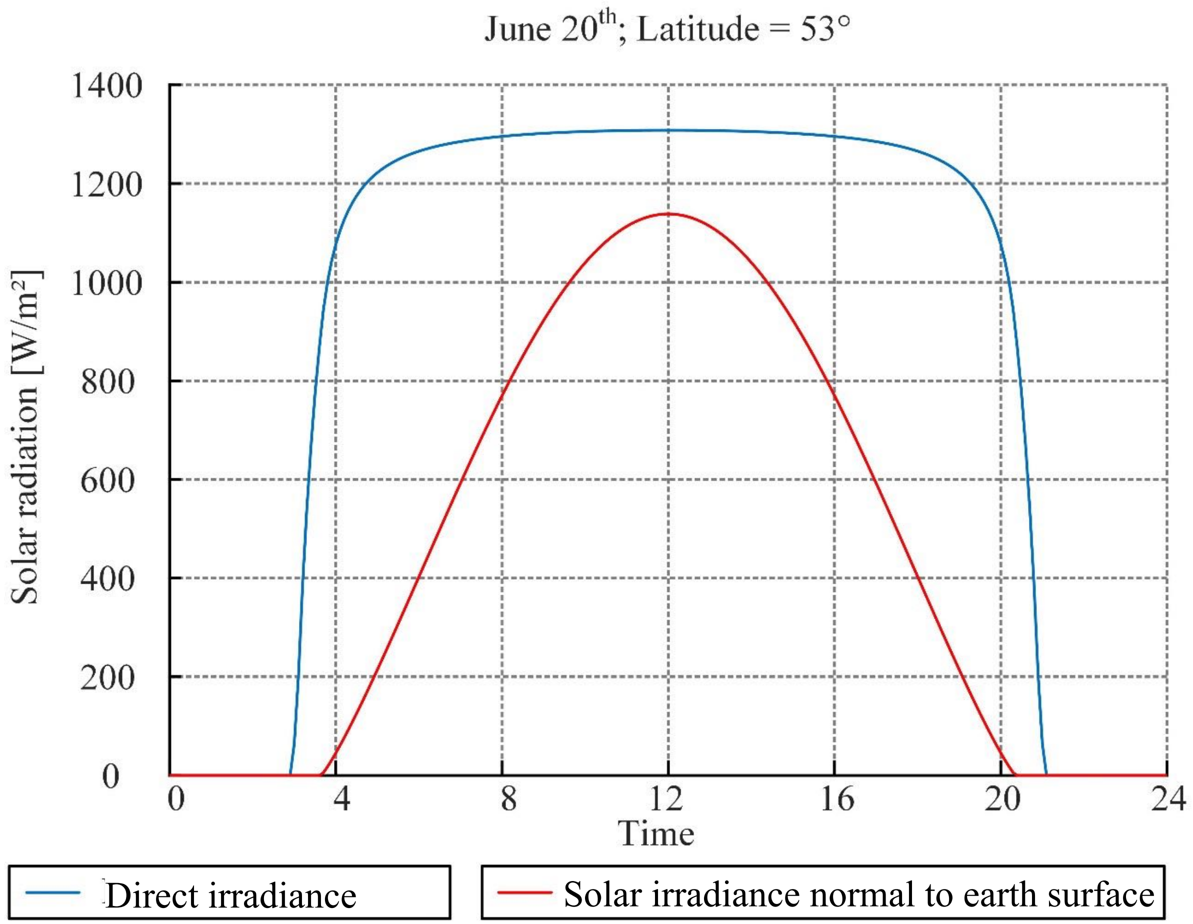
Solar radiation on the aircraft



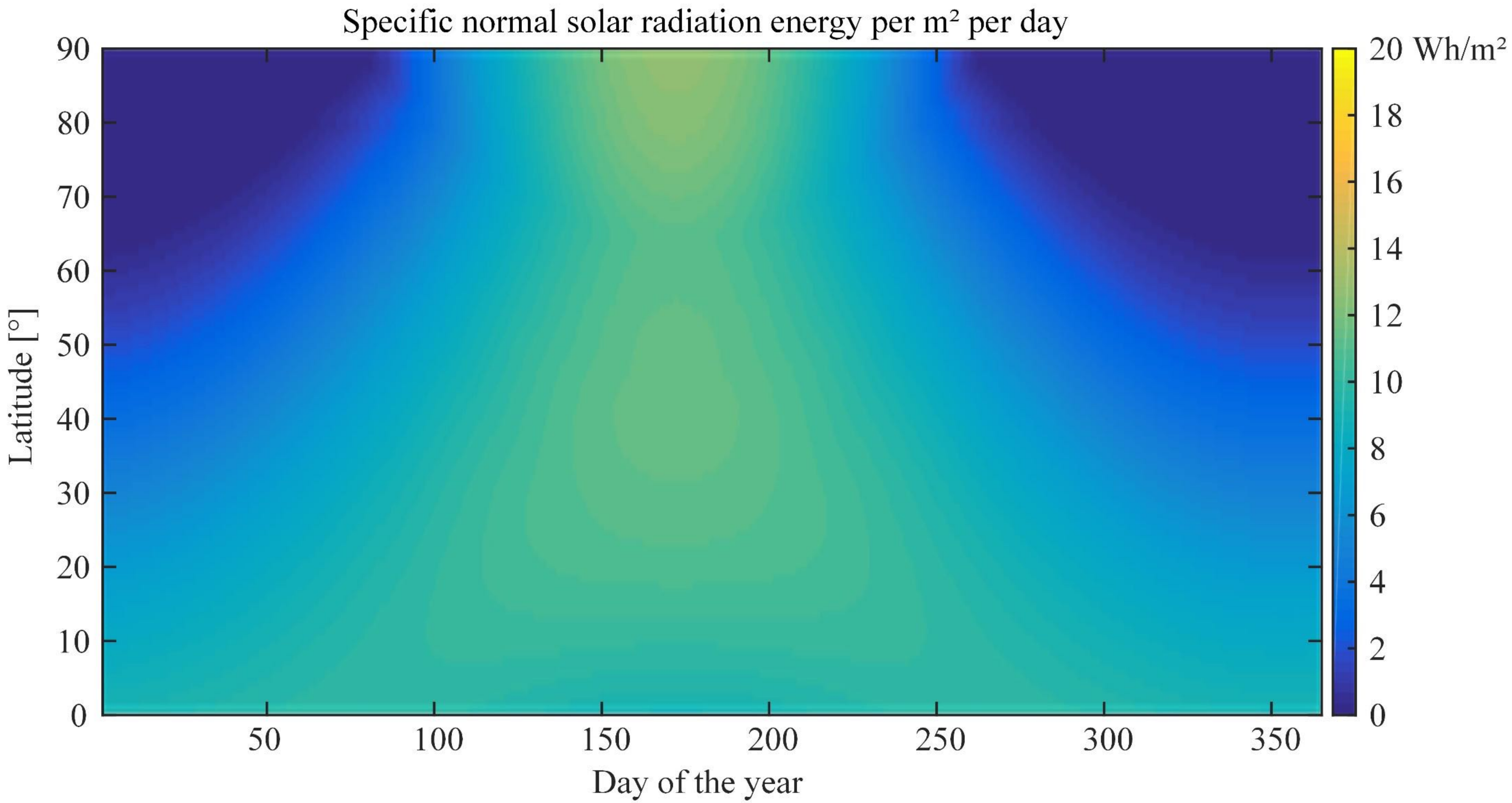
$$\varepsilon_{normal} = \varepsilon_{direct} \cdot \cos(\zeta_{sun})$$

Solar Radiation on the Aircraft



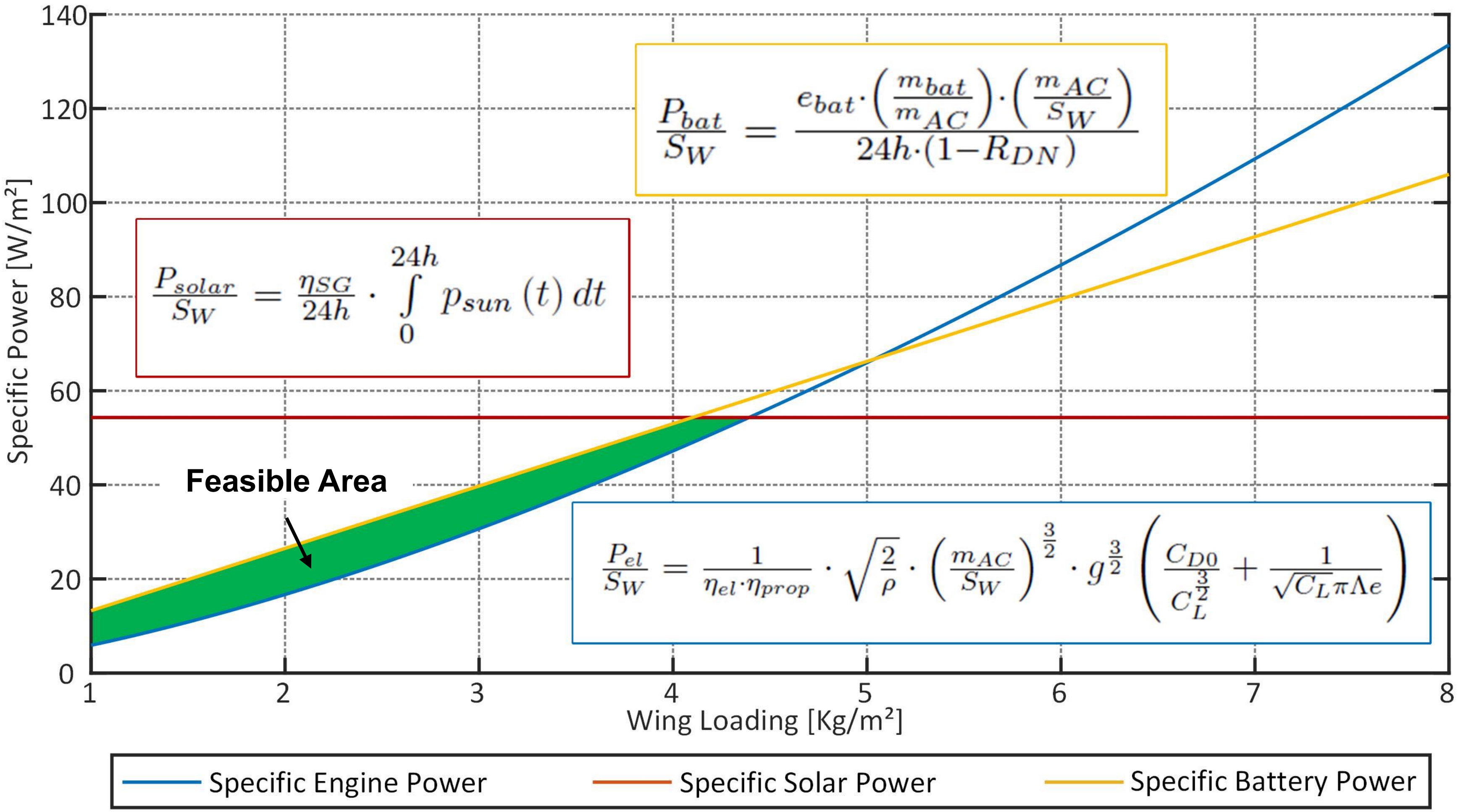


Available solar energy per day



Example of a Constraint Diagram for a High Altitude Platform

- $\Phi = 60°$
- Day: June 20th
- H = 18.000 m
- e_{bat} = 280 Wh/kg
- $\eta_{SG} = 0.15$
- $m_{bat}/m_{AC} = 0.45$
- $\eta_{el} = 0.8$
- $\eta_{prop} = 0.8$



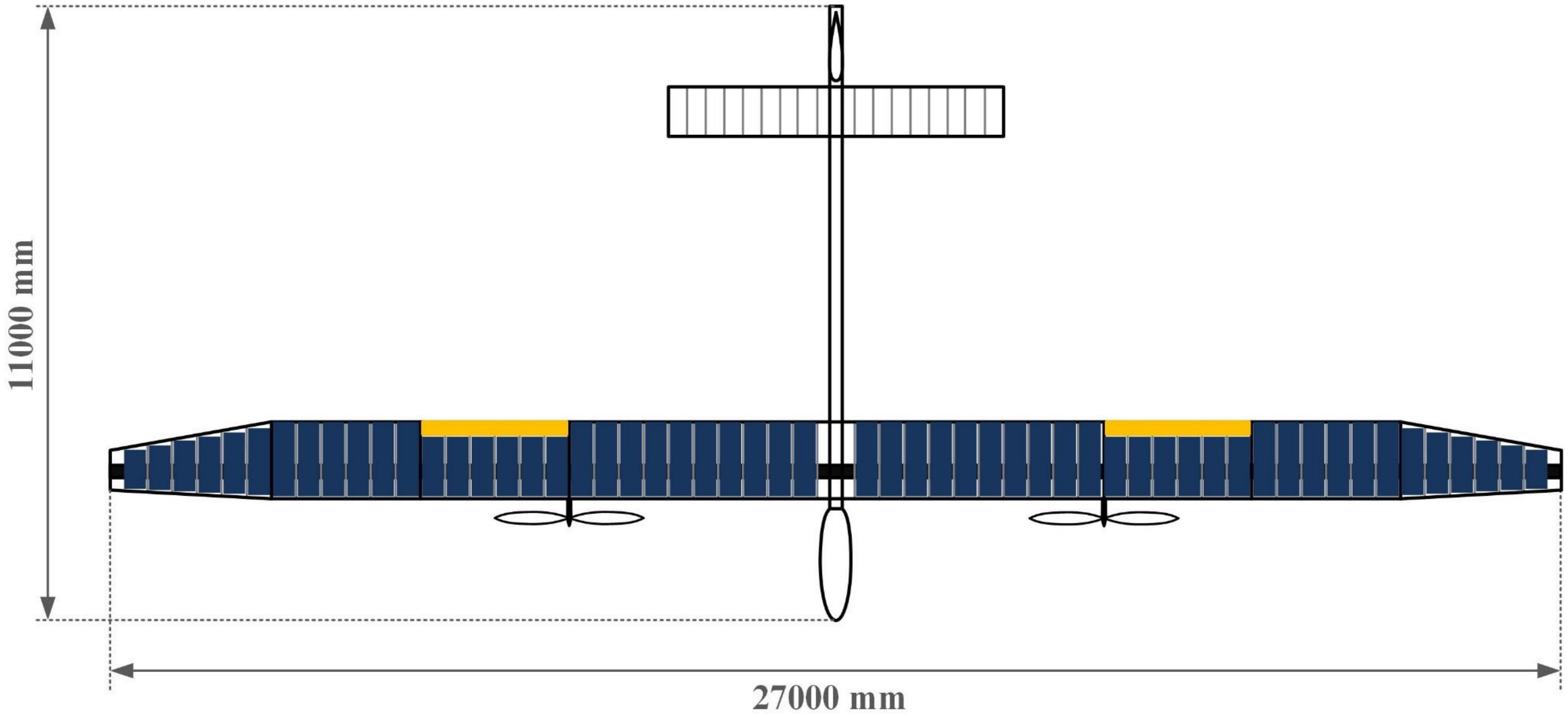
HAP basic design parameters

$$\Lambda = 21$$
$$S = 27m$$
$$c = 1.4m$$

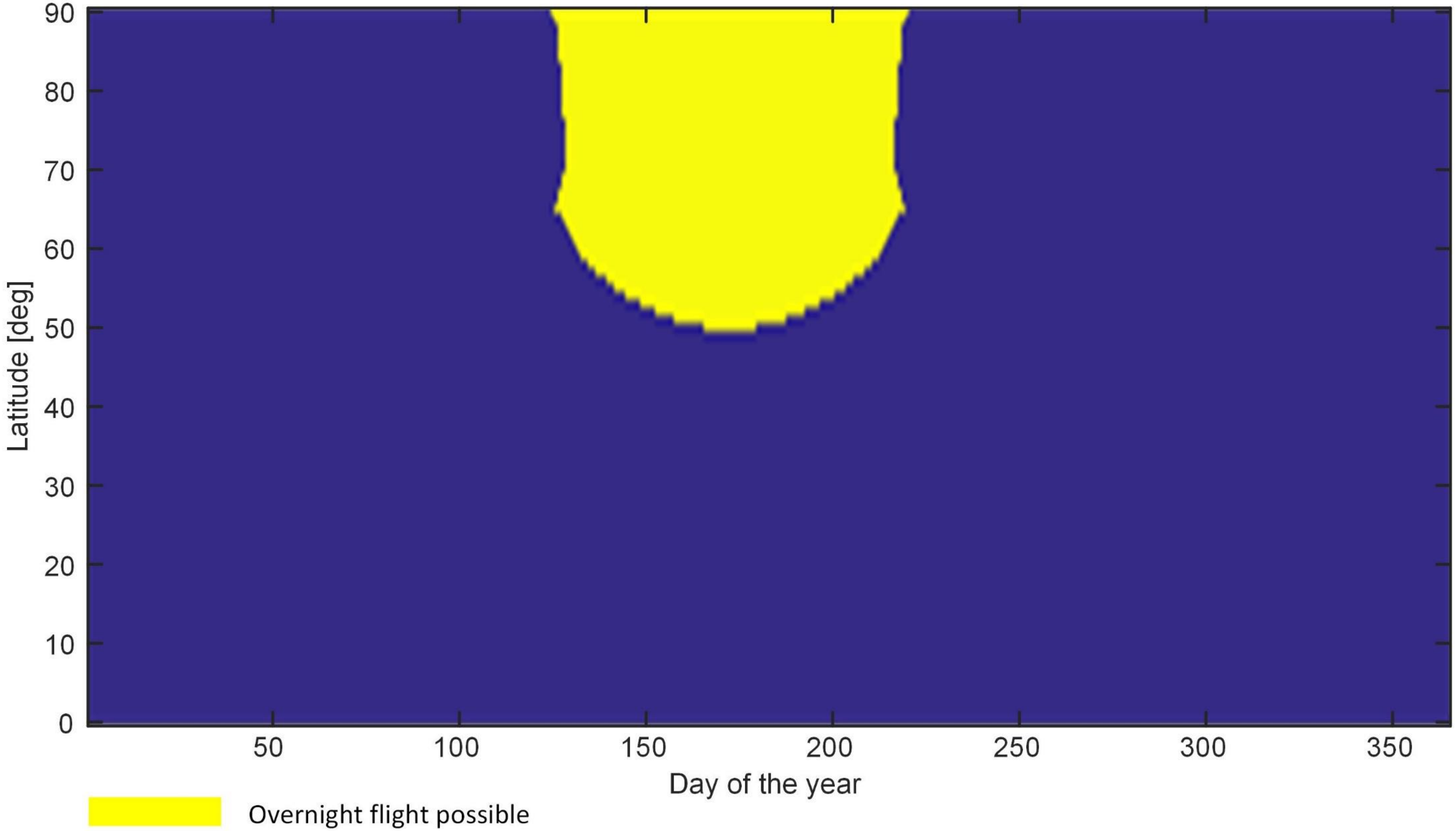
$$m_{ac} = 138kg$$
$$S_{ref} = 38m^2$$

$$W_L = \frac{3.7kg}{m^2}$$

$$S_{SG,max} = 30m^2$$



Capability for Persistent Flight at 18000 m (59055 ft)

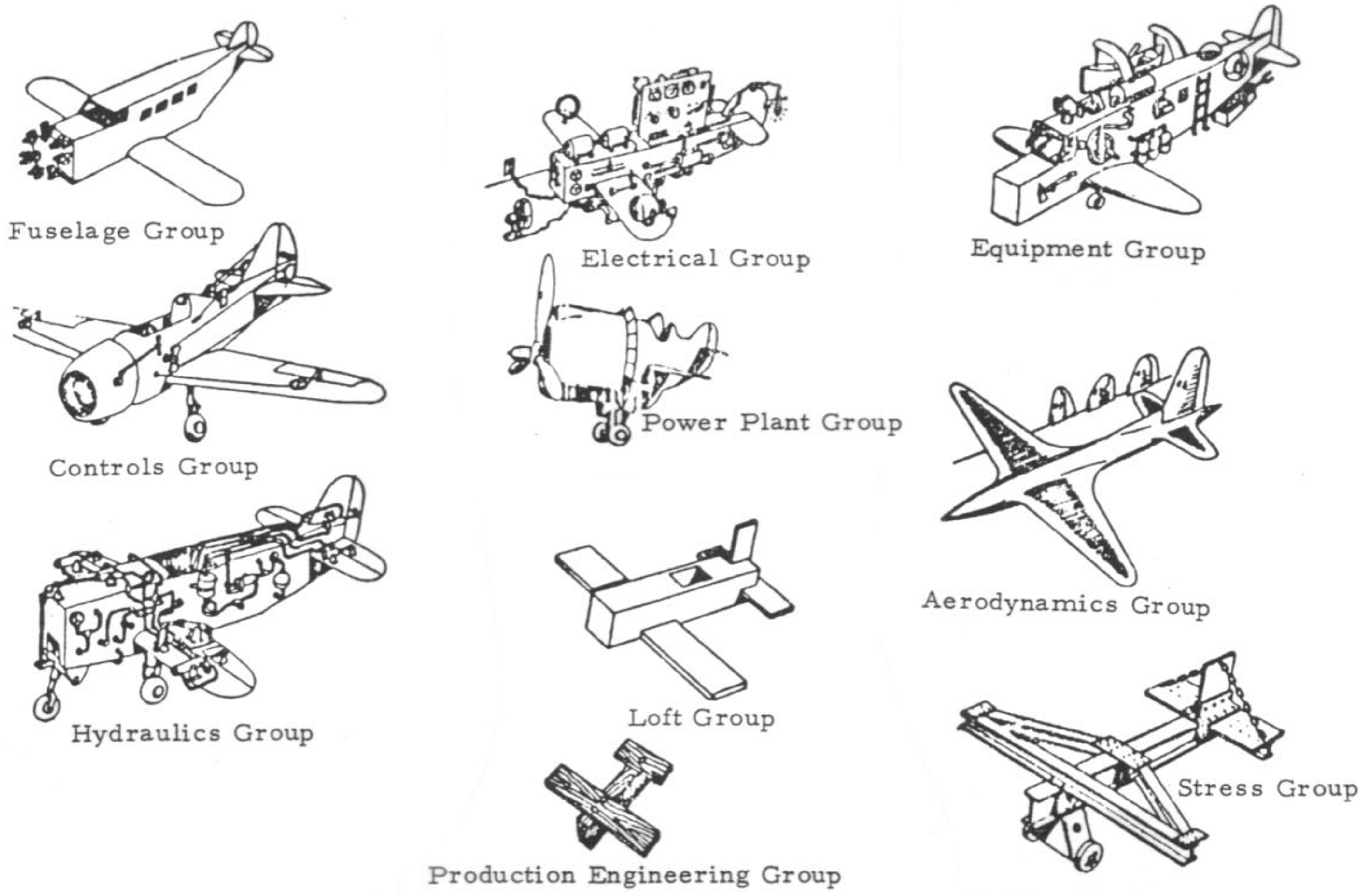


Systems Engineering Challenges

- Developing an aircraft capable of sustained flight in the stratosphere poses some significant challenges
  - *An aircraft with large dimensions and extremely low weight needs to be realized*
  - *In order to achieve an extremely low weight, a high degree of integration must be achieved*
  - *Traditional load requirements from aircraft construction cannot be used, as this leads to impermissibly high weights. Furthermore, operational limits must be specified to not exceed the load capabilities*
  - *Interdisciplinary thinking is essential in all design decisions*
  - *The different experiences of the members of the young team in the field of aircraft construction and integration must be taken into account*

Complexity of the Design Process

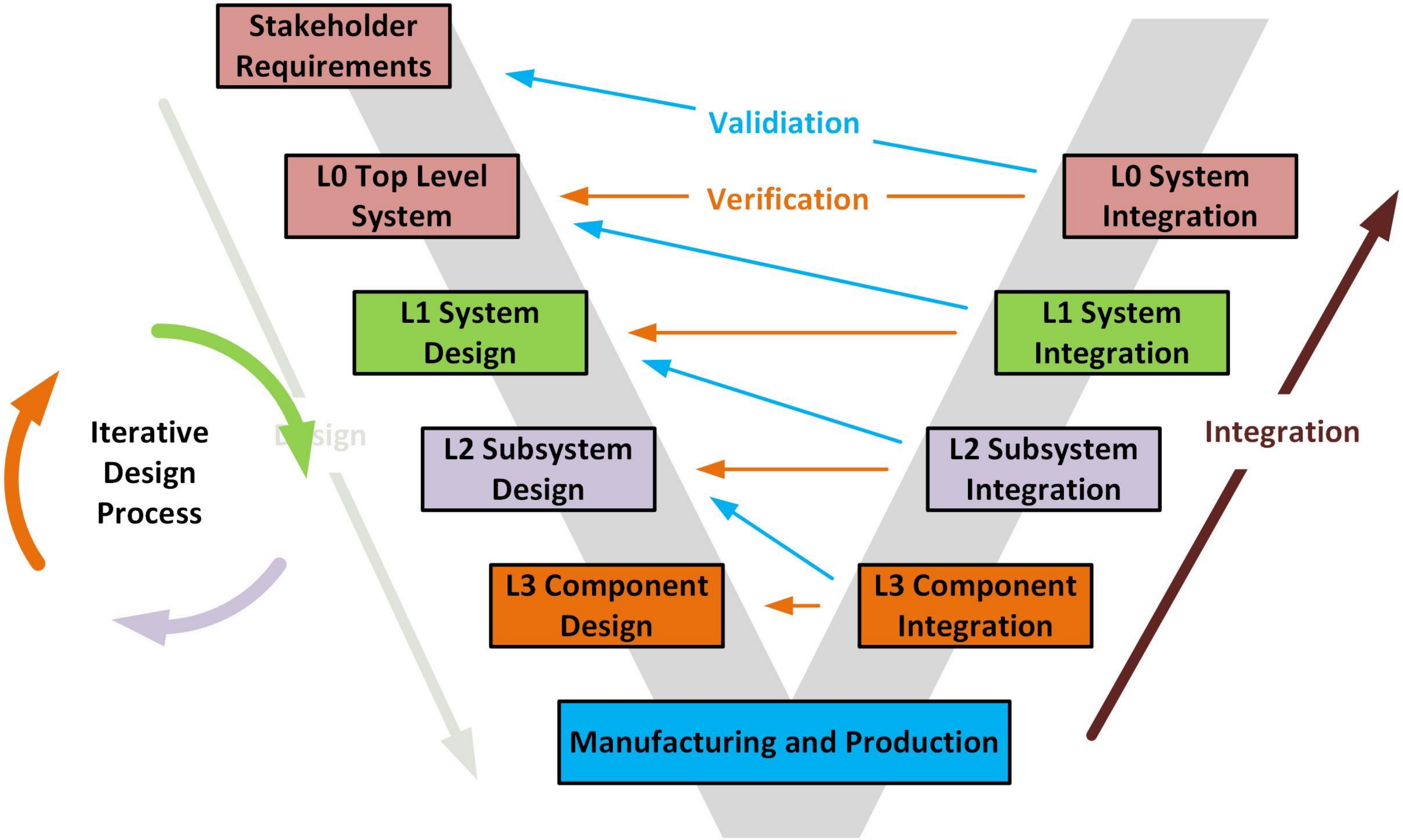
- Special engineering disciplines tend to see the overall design through the lens of their discipline
- This problem even increases, when a highly integrated design is necessary
- To cope with this problem, a holistic understanding of the effects of design decisions must be fostered in the team



Involved Organizations

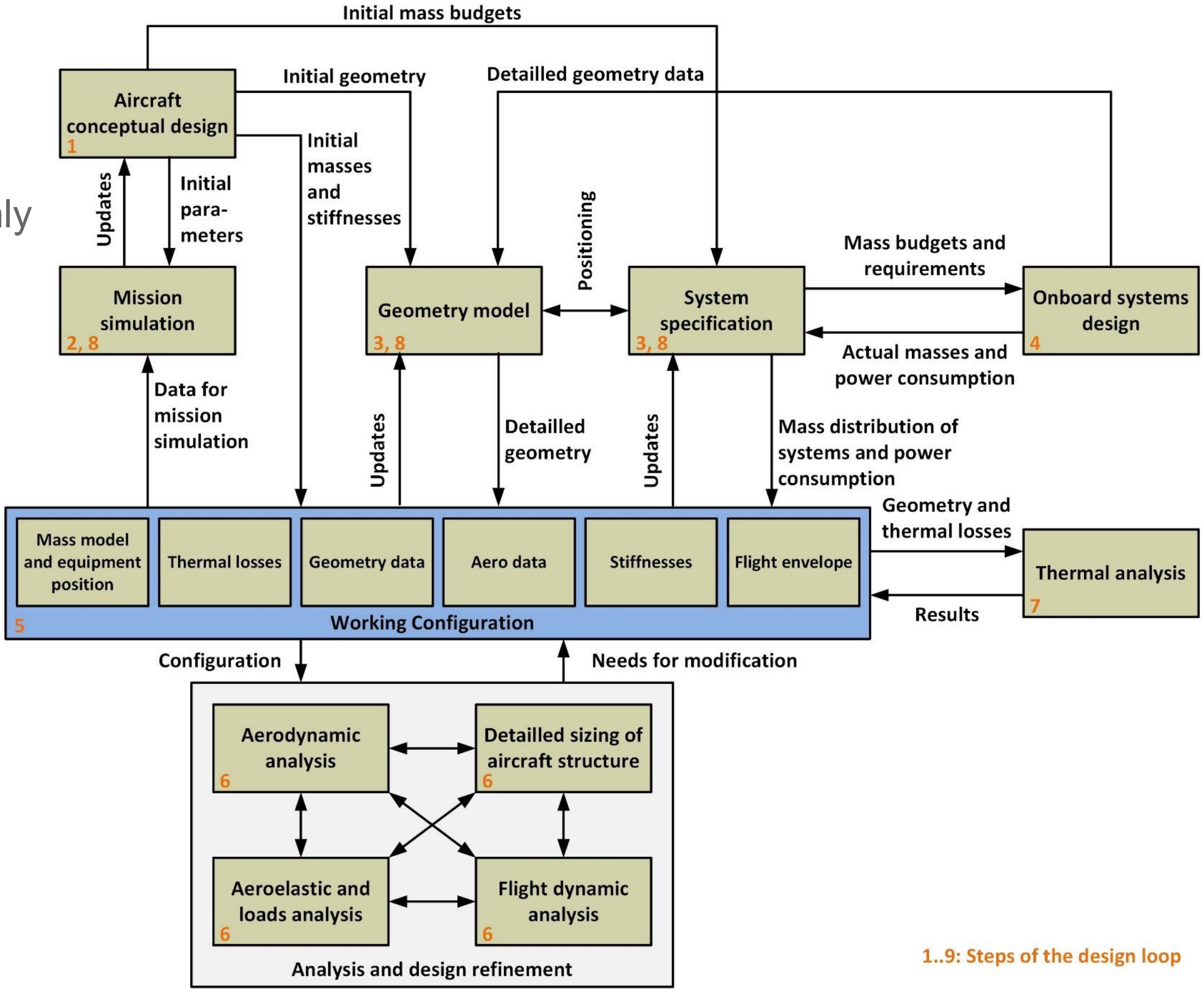
- DLR is organized into different scientific institutes
- To get all necessary expertise involved in the project, scientists from 14 institutes make up the project team
  - *6 institutes from Braunschweig*
  - *4 institutes from Oberpfaffenhofen (Munich)*
  - *1 institute each from Berlin, Cottbus and Oldenburg*

Systems Engineering Model

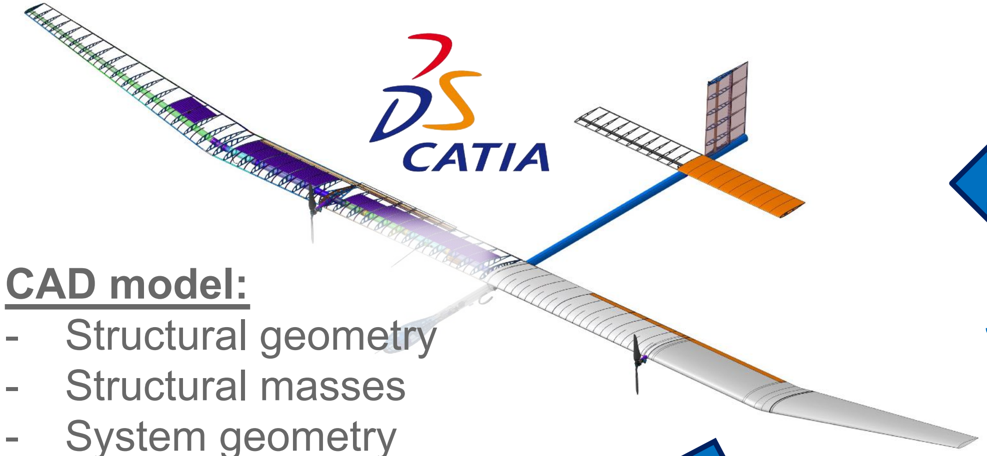


Aircraft Design Process

- The design process of the aircraft is highly iterative
- The feasibility of the design is frequently assessed by means of a mission simulation
- Each iteration results in a consistent working configuration
- The design process is the same for the preliminary design and detailed design; Only the design depth in the steps changes

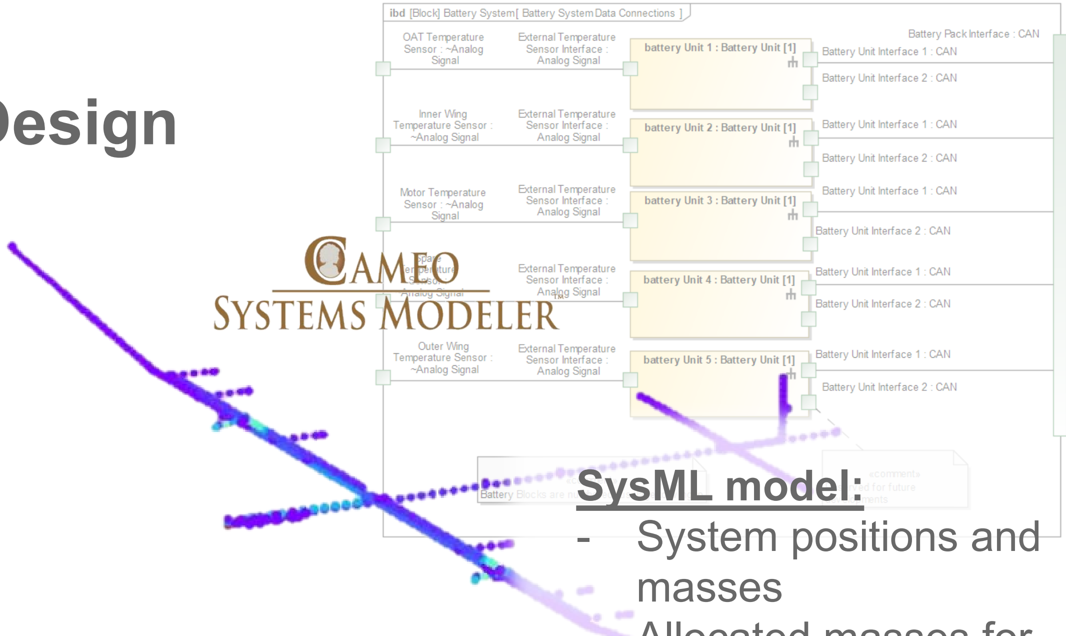


Stiffness and Mass Models for Aeroelastic Design



CAD model:
- Structural geometry
- Structural masses
- System geometry

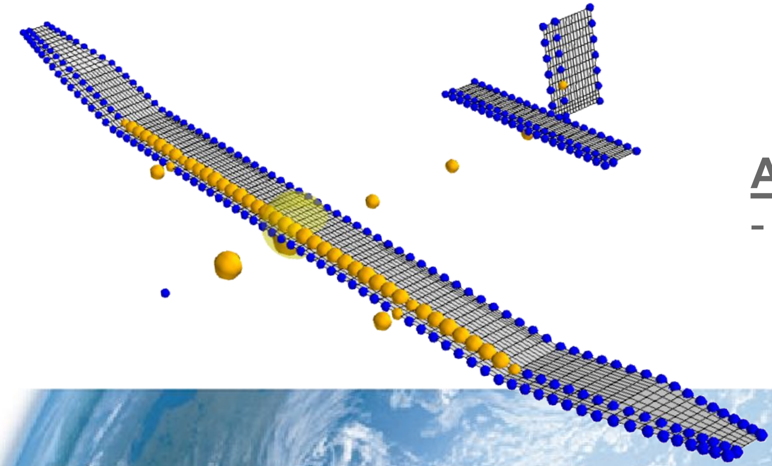
Script based synchronization of system positions



SysML model:
- System positions and masses
- Allocated masses for mass budget and estimated masses for calculations

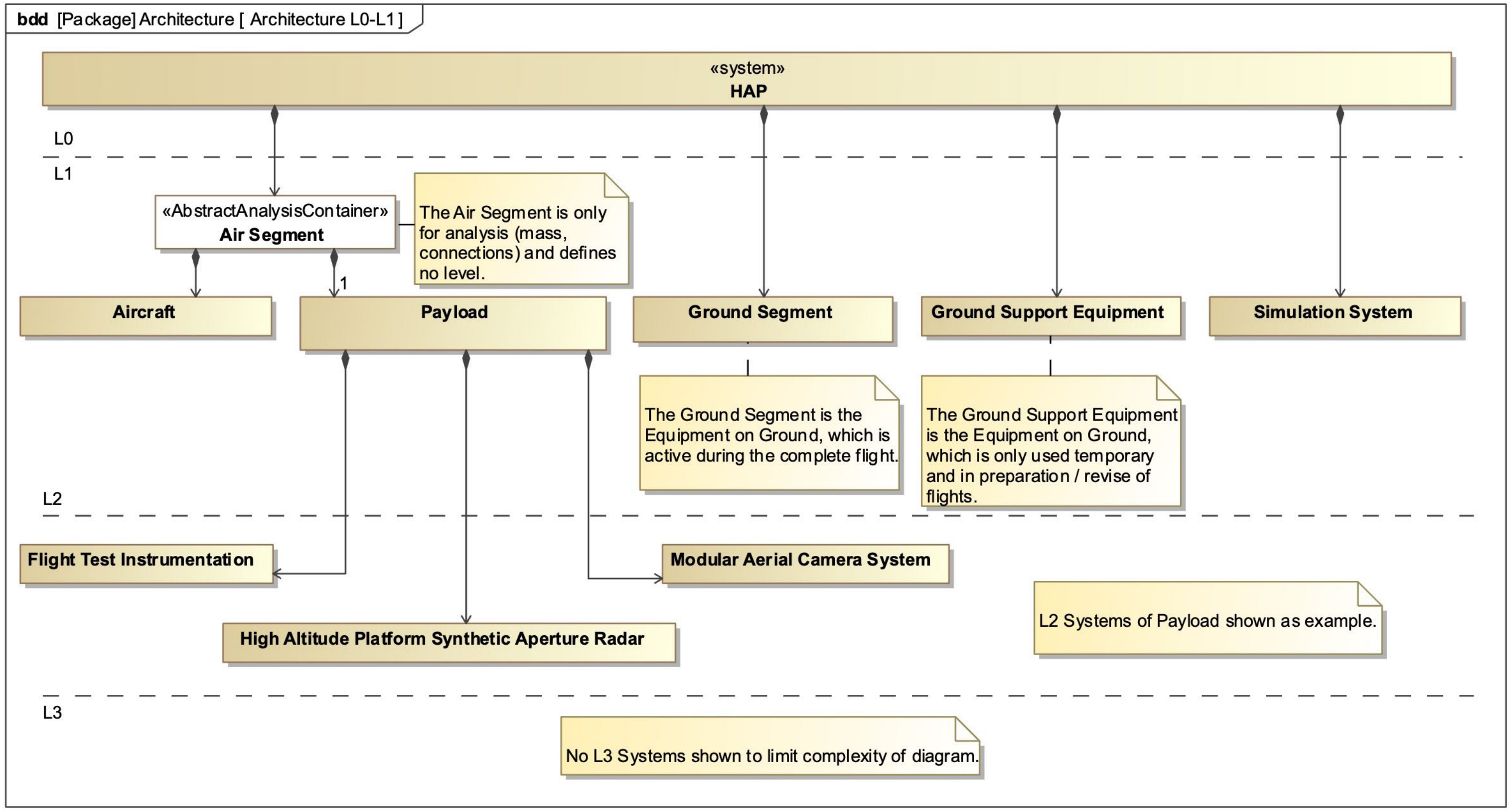
Structural geometry is transformed into a FE model for structural stiffnesses and masses

System mass model



Aeroelastic model:
- Detailed load analysis including elastic deformation, gusts and maneuvers

Central SysML Model



Modelled contents:

- *System Breakdown*
- *Requirements and Verification Planning*
- *Device Positions and Masses*
- *Connections and Interfaces*
- *Bus Data Management*

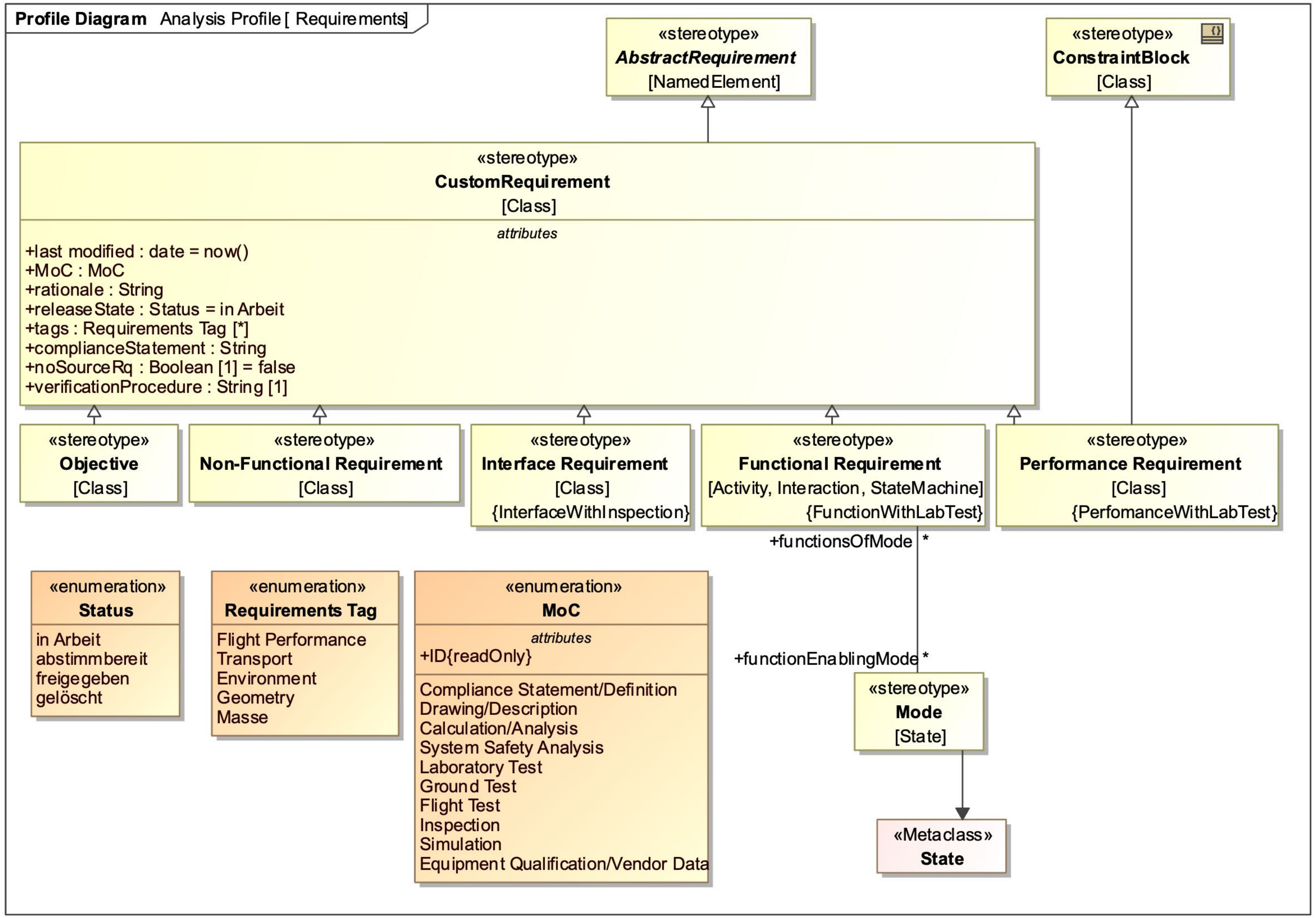
Reasons for using a model instead of documents:

- *Single source of truth for better design consistence*
- *Significant workload reduction by automated reports and model exchanges*
- *Partly automated design iterations allow low design margin policy*

Requirements Modelling

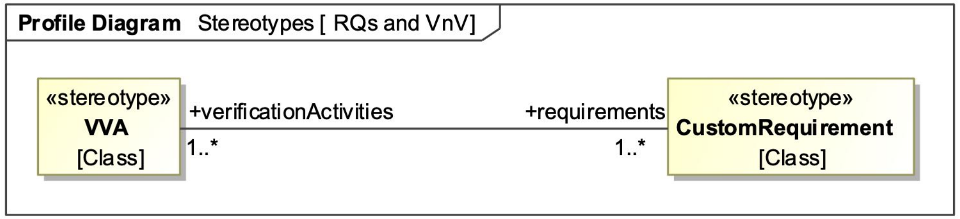
- Model based requirements engineering offers:
    - *Direct connection to its matching system element*
    - *Improved consistency for changing system architectures*
    - *Requirement traces for improved dependency modelling*

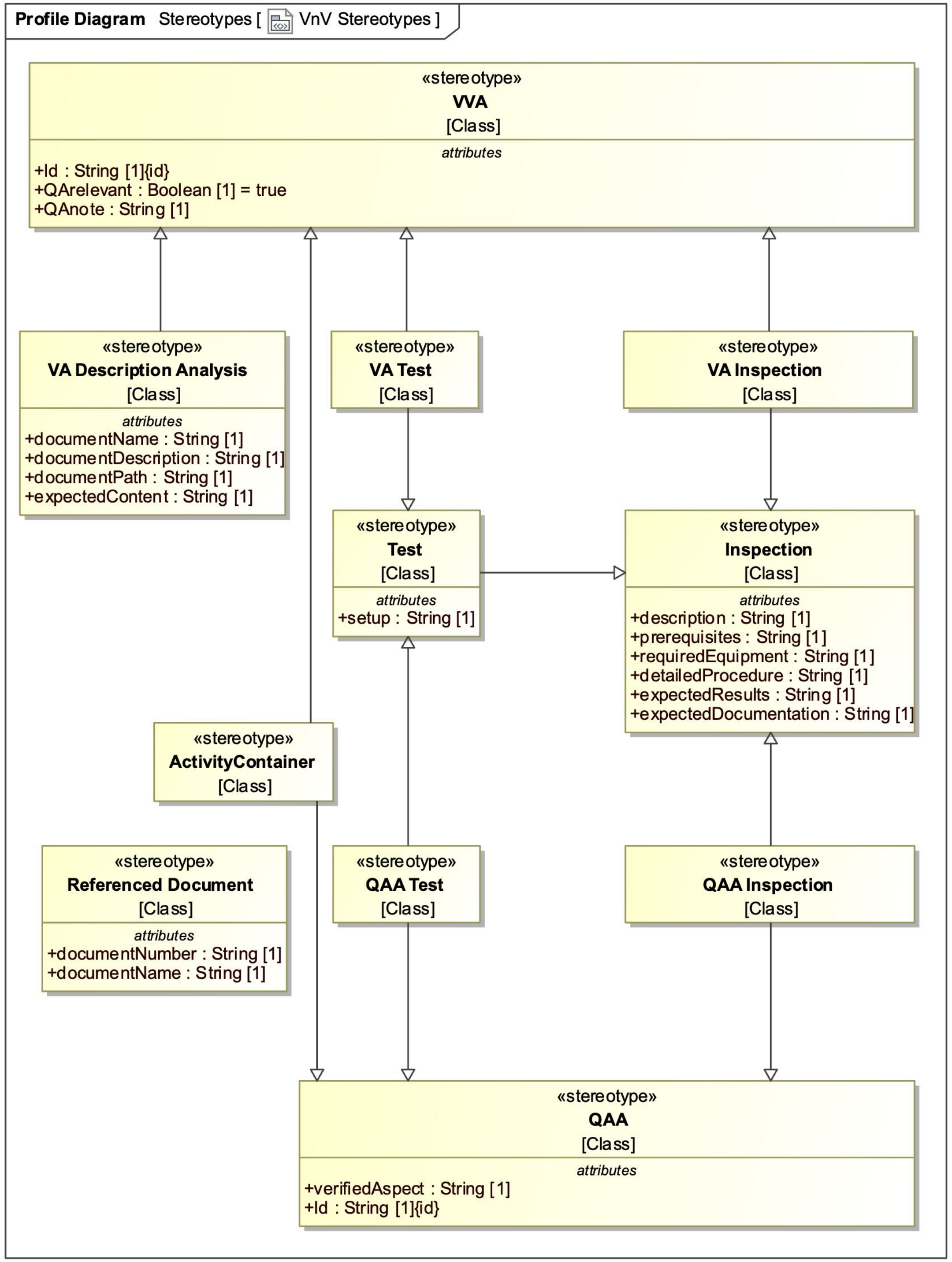
- MBSE tool enables validation of Requirements:
    - *Completeness of definition*
    - *Traceability*



Verification Planning

- Motivation for model based verification planning:
  - *Related requirements are already modelled*
  - *Main effort for document based verification planning is document structuring and change management which can be conducted by software*
- MBSE tool offers:
  - *Export this planning in reviewable documents*
  - *Validate completeness of descriptions and completeness of activities*



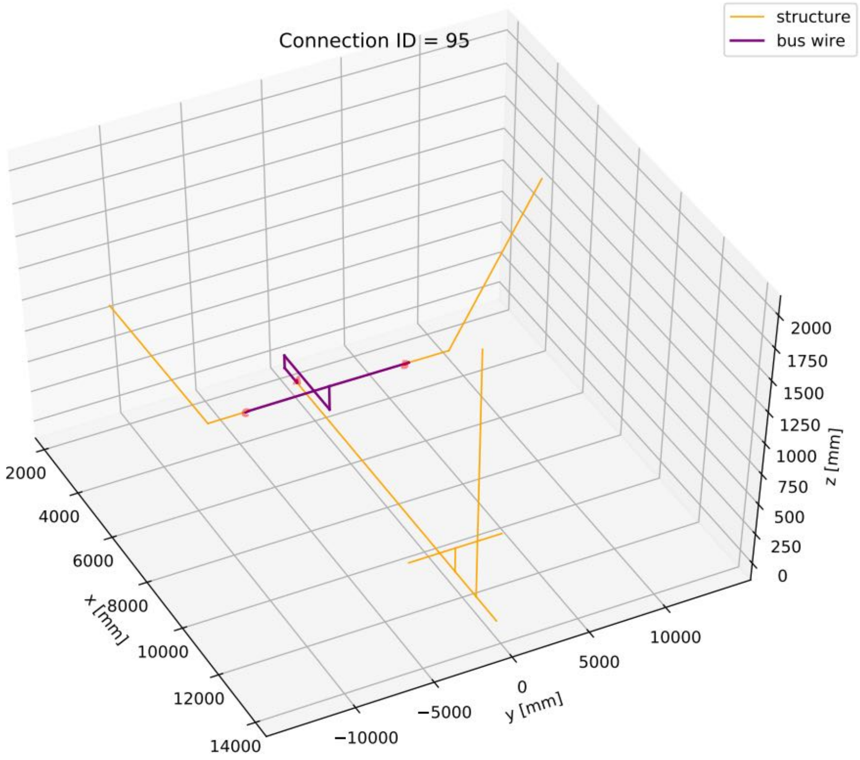


In collaboration with oose. Innovative Informatik

Cabling model

- Motivation:
  - *Cables are close to 10% of the aircrafts mass*
  - *Ultra-light structure is very sensitive to mass distribution*

  → detailed cable model necessary
- Positions and connections already in SysML
- Developed Python tools allows to model cabling automatically
- Important result: precise and automatically generated cable mass distribution



Name: Strobe : Avionic Power 14; : Strobe Lights Power

Devices:
aircraft.drive train rh.power distribution unit [A]
at Pos(2998.0/ 0.0/ 20.0)
aircraft.platform communication system.position lights.rh light [B]
at Pos(4630.0/ 5240.0/ 245.0)
aircraft.platform communication system.position lights.lh light [C]
at Pos(4630.0/ -5240.0/ 245.0)

Line List:
Pos(2998.0/ 0.0/ 20.0) - Pos(2998.0/ 0.0/ 0.0)
Pos(2998.0/ 0.0/ 0.0) - Pos(2300.0/ 0.0/ 0.0)
Pos(2300.0/ 0.0/ 0.0) - Pos(2300.0/ 0.0/ 105.0)
Pos(2300.0/ 0.0/ 105.0) - Pos(4841.0/ 0.0/ 105.0)
Pos(4841.0/ 0.0/ 105.0) - Pos(4841.0/ 0.0/ 301.0)
Pos(4841.0/ 0.0/ 301.0) - Pos(4841.0/ 5240.027/ 298.35)
Pos(4841.0/ 5240.027/ 298.35) - Pos(4630.0/ 5240.0/ 245.0)
Pos(4841.0/ 0.0/ 301.0) - Pos(4841.0/ -5240.027/ 298.35)
Pos(4841.0/ -5240.027/ 298.35) - Pos(4630.0/ -5240.0/ 245.0)

Length: 14.475335629868406 [m]
Total Length: 14.776 [m]

Cable Type: power cable 83
With mass per length: 0.00313 [kg/m]

Weight: 0.04530780052148811 [kg]
Total Weight: 0.047 [kg]

Valid: True

Remarks on the Model Based Approach

- The model based approach has proven very effective in the project
  - *Single source for design information*
  - *Ensuring information consistency*
  - *Generation of documents from the model*
- Modelling experts are needed to set up and maintain the model
  - *There should be one person or a little team with a strong modelling background, who is responsible for the model structure and performs main modelling activities*
  - *Each member of the design team must have access to model, to get valid design relevant information*
- A central model repository, e.g. Cameo Team Work Cloud, helps to manage the evolution of the model and enables concurrent modelling activities

Outlook & Final Remarks

- The project is heading to the Critical Design Review, which is scheduled for spring 2023
- The first version of the aircraft will have only 10 m² (app. 30% of the wing area) of solar cells due to high cost
- We aim to perform the first flight at low altitude in summer 2024
- Short endurance high altitude flights will be conducted, starting in 2025
- Based on the experience from the high altitude flights, the aircraft will be modified for long endurance flights and further flight testing

Thank you for your attention!

Andreas Bierig, CSEP, PMP
Andreas.Bierig@dlr.de
+49 531 295 2304