Reference aircraft and sizing process

Public Workshop: Novel Tools for Novel Aircraft

Bristol, 06 February 2025

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eVTOL mUlti-fideliTy hybrid desIgn and Optimization for low Noise and high aerodynamic performance - Grant Agreement 101138209

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Introduction and Context

- In order to fulfil eVTOLUTION objectives, with particular focus on evaluation of aerodynamic performance and noise emissions, also looking at regulatory compliance, **a relevant case study shall be considered** to enable detailed studies. Notably:

  - A set of **reference missions** shall be defined to assess «realistic» operational scenarios;

  - A **baseline aircraft layout** and category shall be identified as main platform for the related studies;

  - A set of «**design exercises**», to be considered for the analyses concerning aerodynamic characterization and noise, shall be defined

Objectives

To characterize the eVTOL concept at system level and provide a bounding box, in terms of what is technologically possible and permitted by the current regulations.

- **Activities addressed:**

- Mission profiles definition (VAERO)
- Reference vehicle definition (VAERO)
- Energy management and cooling system design (POLITO)
- Analysis of current noise regulation (TuDelft)
- Safety and risk analyses related to UAM operations and aircraft design (GKN)
- Definition of an up-to-date regulatory framework of the main certification aspects of UAM aircraft and determining how it will affect the design process (GKN)

Mission profiles

Use cases:

1. Airport transit (60%), 10-50 miles (16-80 km)

2. Inter-city and point-to-point routes (30%), 50-100 miles (80-160 km)

3. Tourist or island connectivity (10%), up to 100 miles.

Flight-profiles:

1. Constrained intracity scenario

2. Unconstrained intercity

3. Partially-constrained intercity

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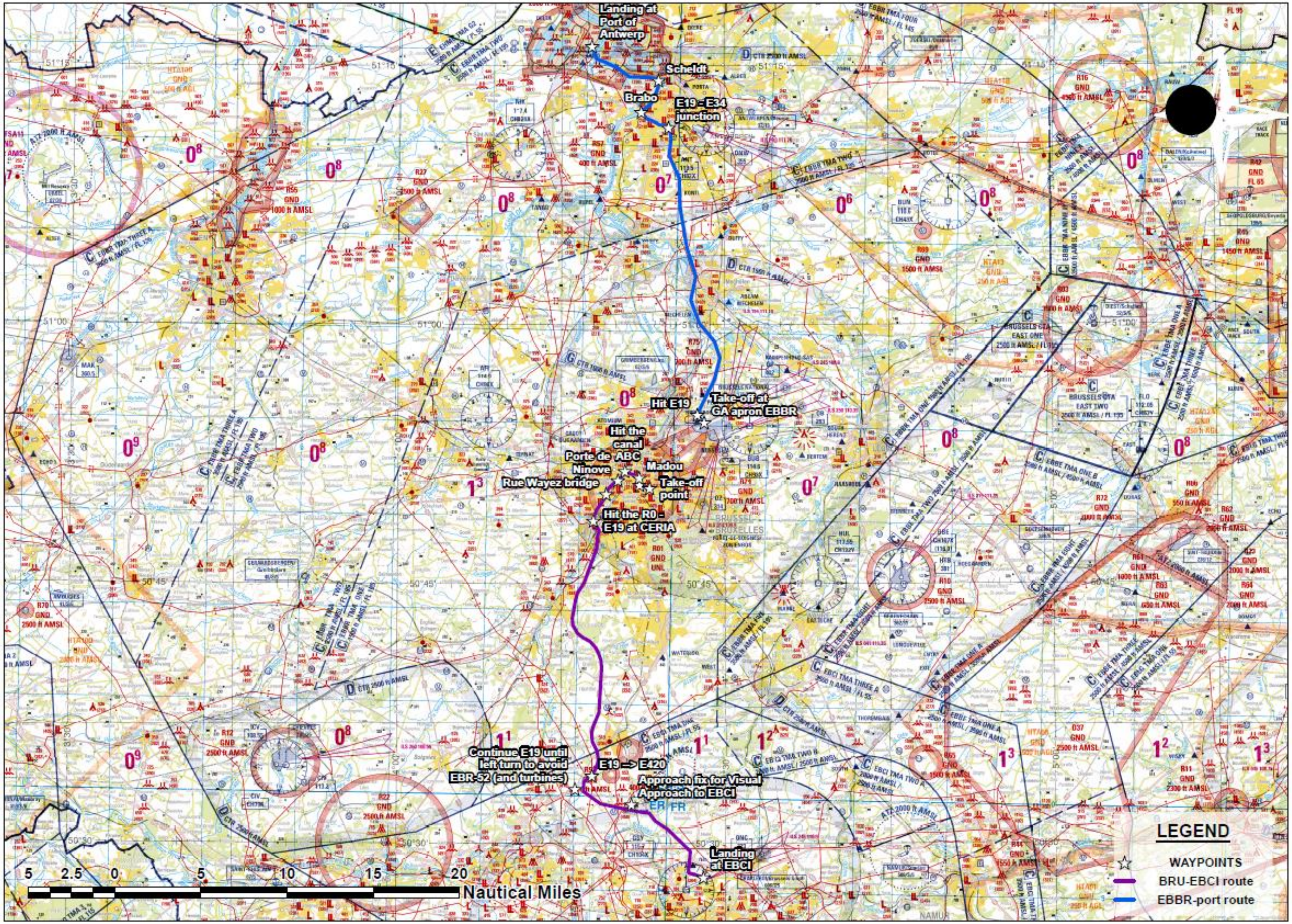
Mission profiles

Phase	Constrained intracity mission	Unconstrained intercity mission	Partially-constrained intercity mission
Take-off	Lift off and vertical climb to 100 ft AGL, remain over FATO with wind gusts/turbulence Hover turn 180°	Lift off and vertical climb to 15 ft AGL, still air (No hover turn)	Lift off and vertical climb to 100 ft AGL, remain over FATO with (moderate) wind gusts/turbulence Hover turn 180°
Initial climb	Low speed manoeuvres at 40 KEAS for 30 seconds Transition to wing-borne, climb gradient 12.5 % Wing-borne climb to 1000 ft AGL	(No low speed manoeuvres) Transition to wing-borne, climb gradient 4.5 % Wing-borne climb to 1000 ft AGL	Low speed manoeuvres at 40 KEAS for 30 seconds Transition to wing-borne, climb gradient 12.5 % Wing-borne climb to 1000 ft AGL
En-route	Wing-borne climb to 2000 ft AGL Cruise at 150 KEAS, 2000 ft AGL Wing-borne descent to 1000 ft AGL Hold at speed for best range for 5 mins	Wing-borne climb to 2000 ft AGL Cruise at speed for best range, 2000 ft AGL Wing-borne descent to 1000 ft AGL (No hold)	Wing-borne climb to 2000 ft AGL Cruise at 150 KEAS, 2000 ft AGL Wing-borne descent to 1000 ft AGL Hold at speed for best range for 3 mins
Approach	Wing-borne descent to conversion height Conversion to thrust-borne, descent gradient 12.5 % Low speed manoeuvres at 40 KEAS for 30 seconds	Wing-borne descent to conversion height Conversion to thrust-borne, descent gradient 4.5 % (No low speed manoeuvres)	Wing-borne descent to conversion height Conversion to thrust-borne, descent gradient 4.5 % (No low speed manoeuvres)
Landing	Hover turn 180° Vertical descent from 100 ft to touchdown, remain over FATO with wind gusts/turbulence	(No hover turn) Vertical descent from 15 ft to touchdown	(No hover turn) Vertical descent from 15 ft to touchdown

Specific missions



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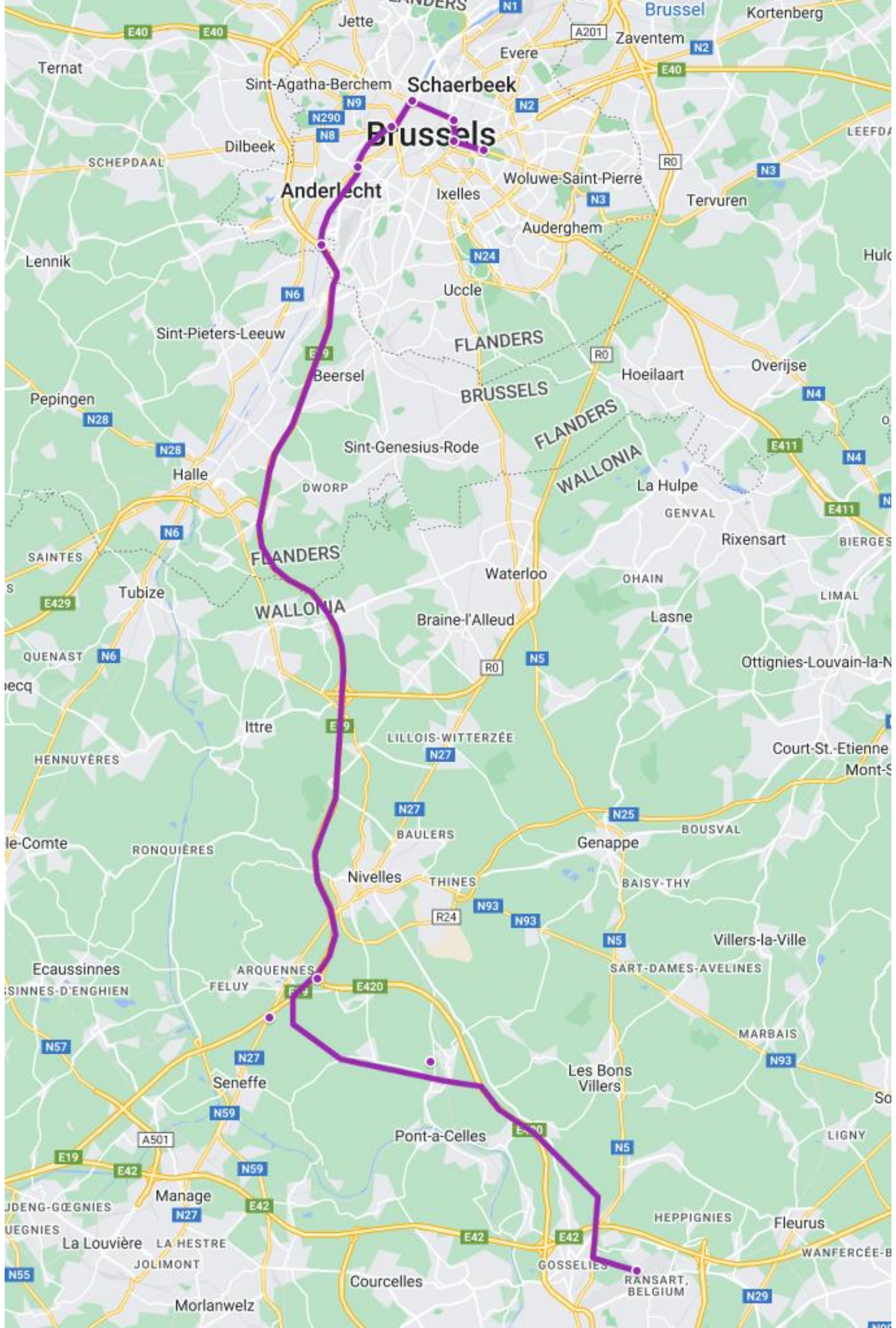
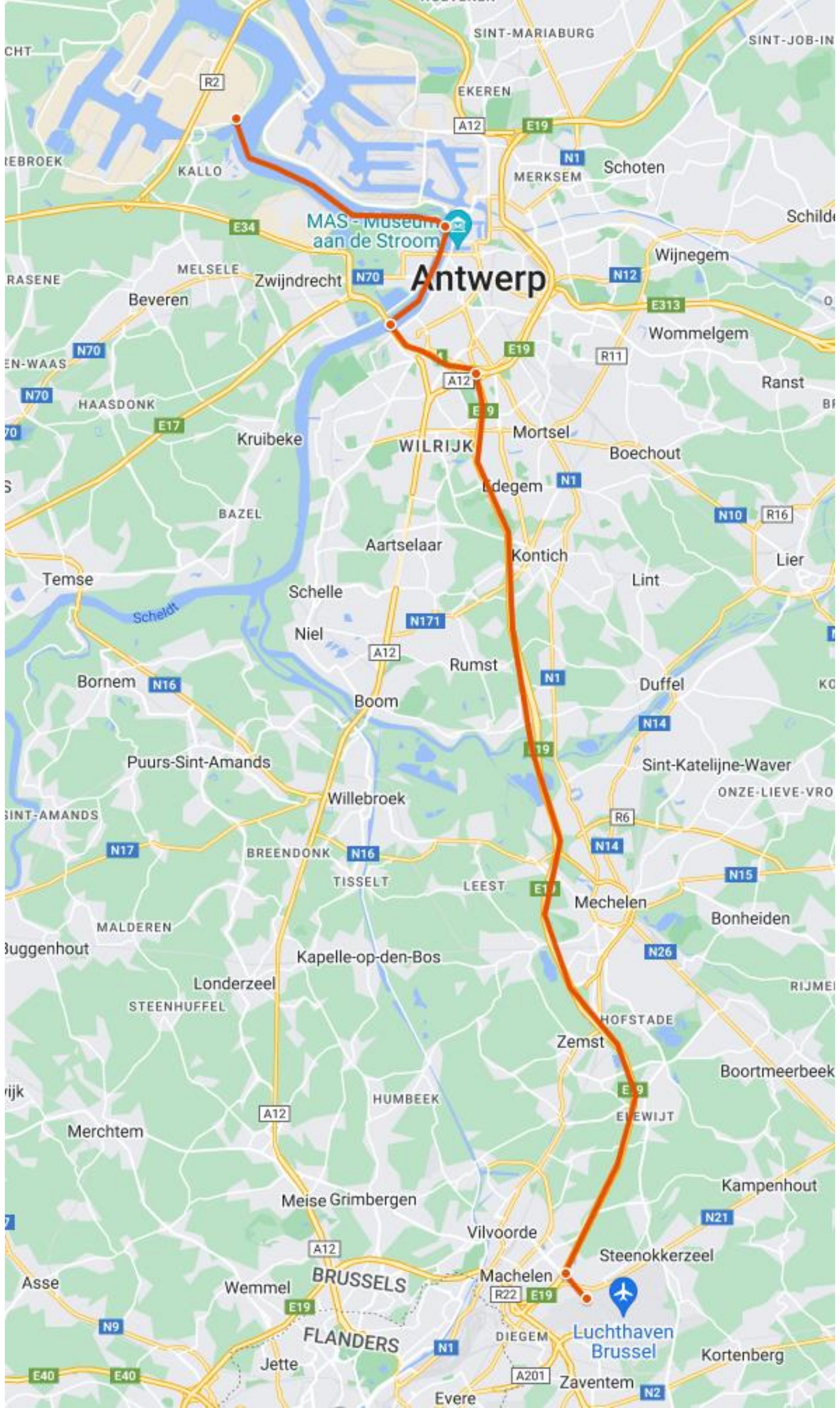
Specific missions





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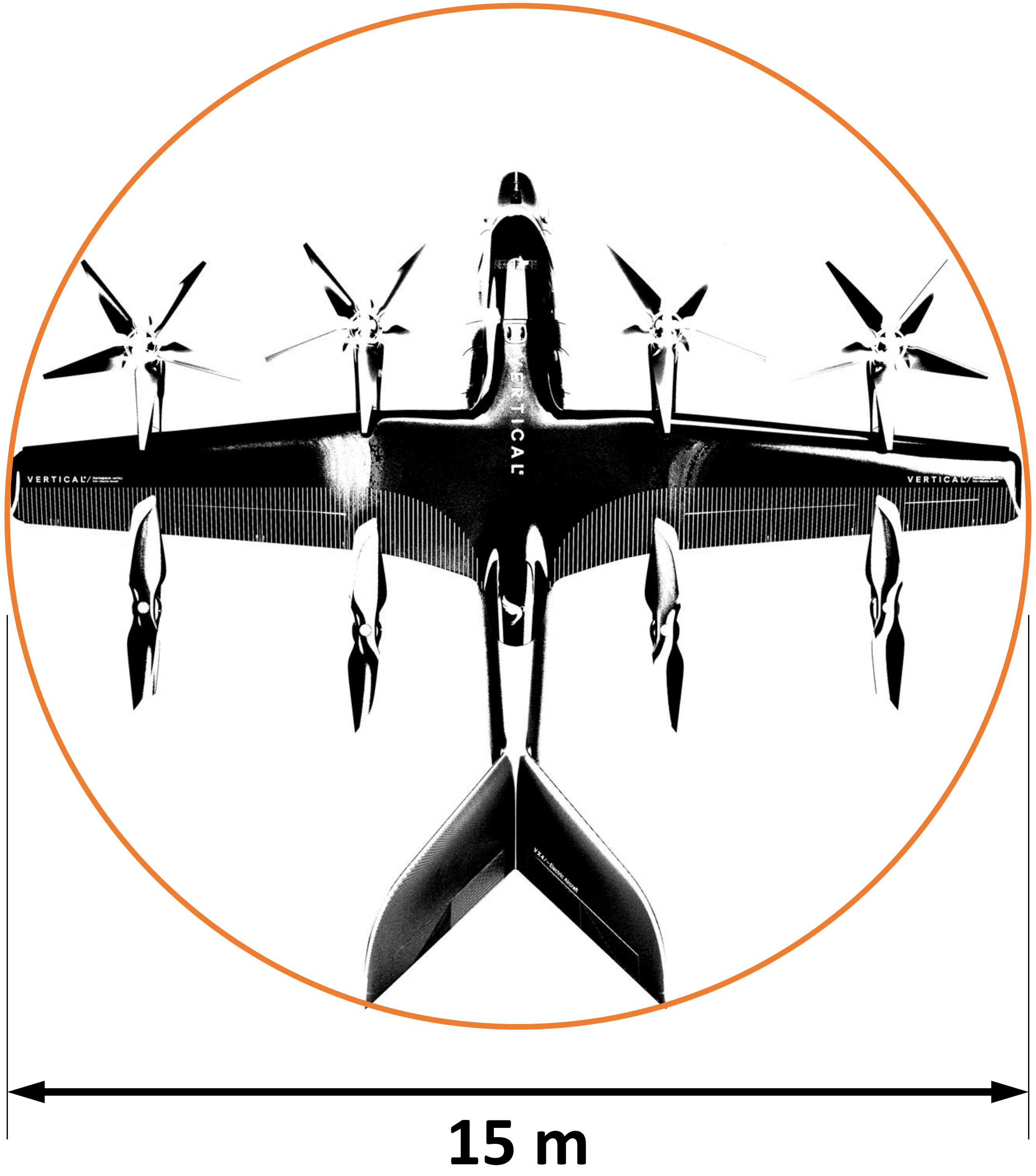
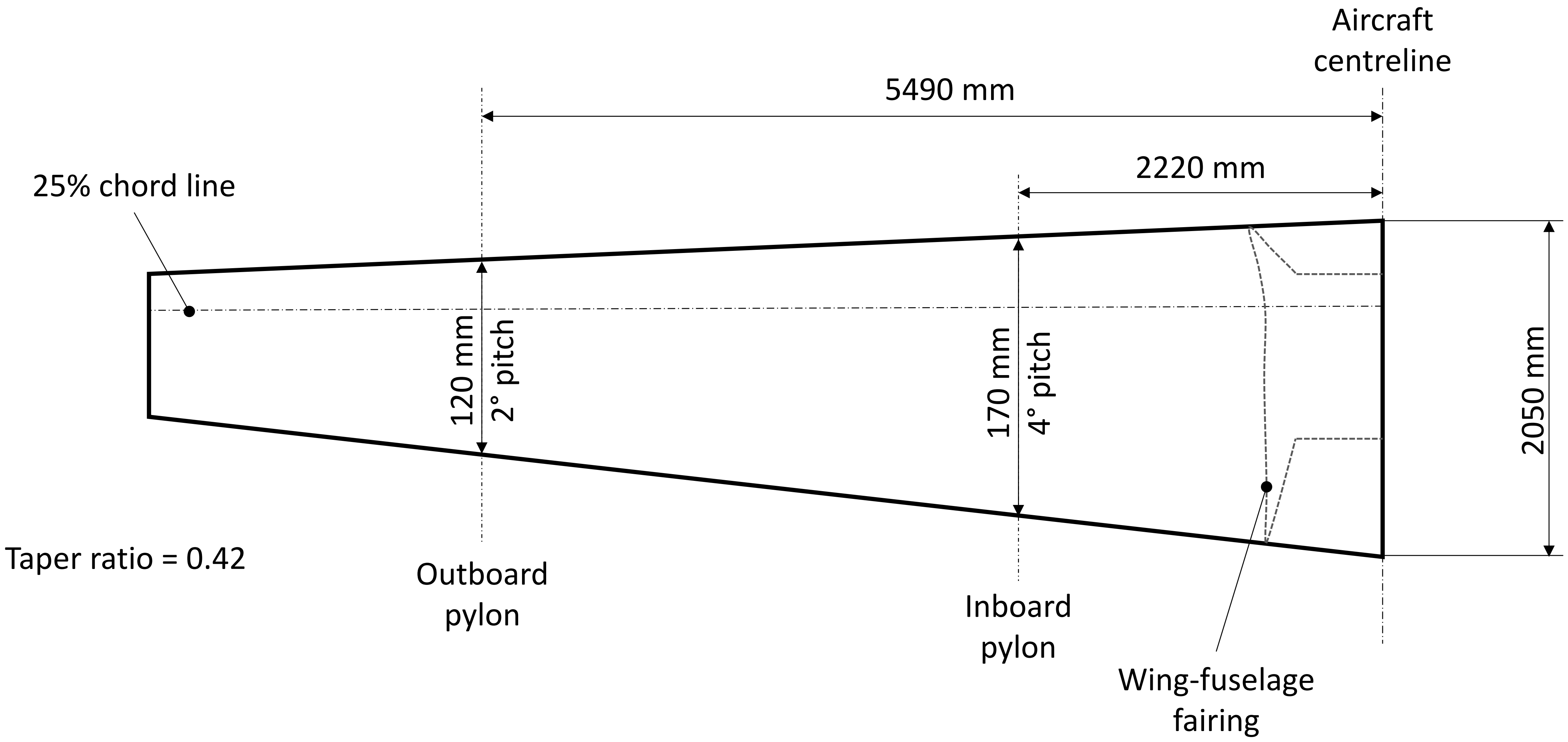
Baseline vehicle parameters

- MTOW 3150 kg
- V_{cruise} 120 knots / 220 km/h
- Pilot + 4 pax + luggage
- Eight propellers
  - Four tilting forward of wing
  - Four lift-only aft of wing
- Projected EIS 2031
  - Technology maturity date 2028

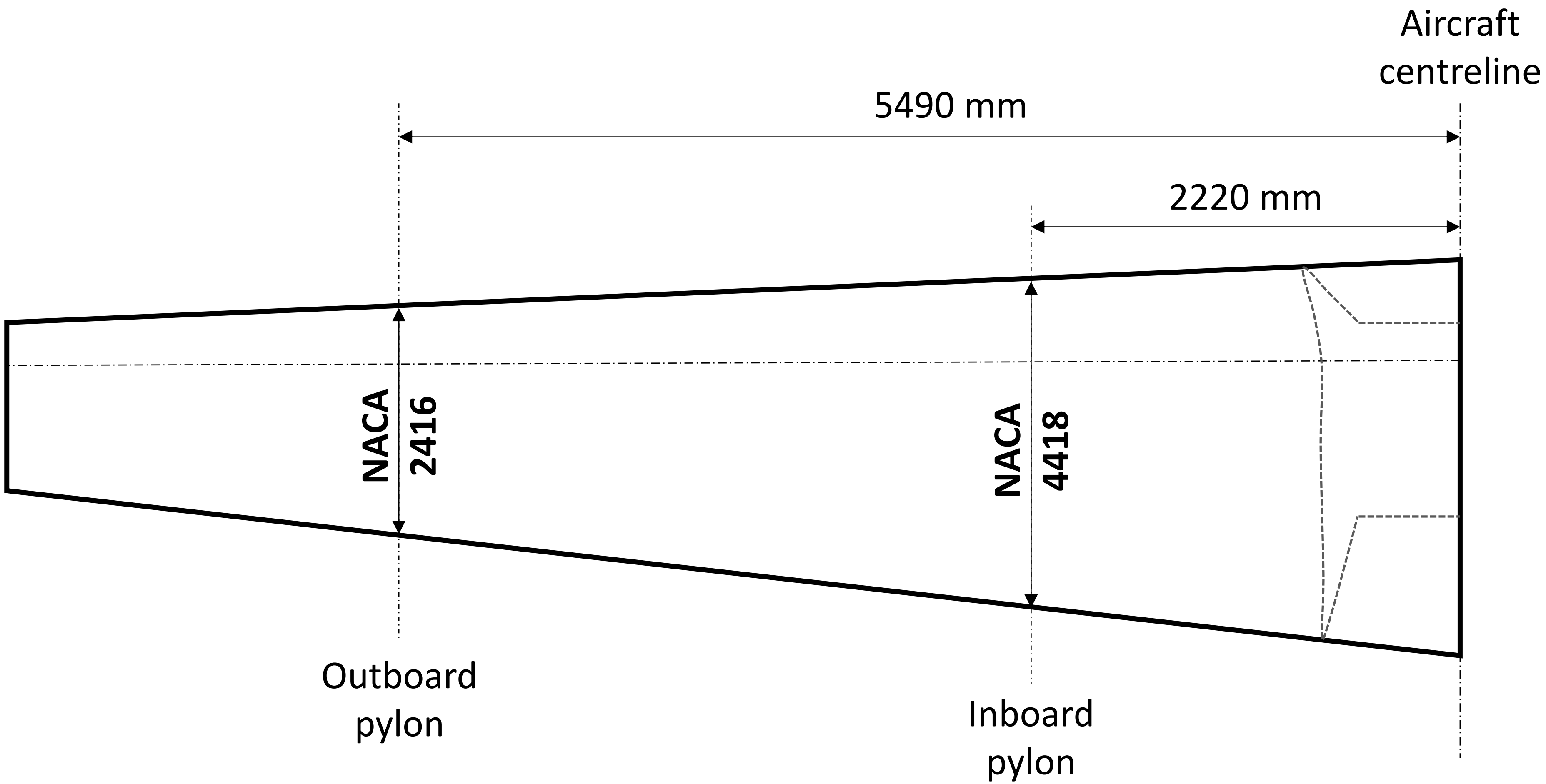
Baseline vehicle parameters



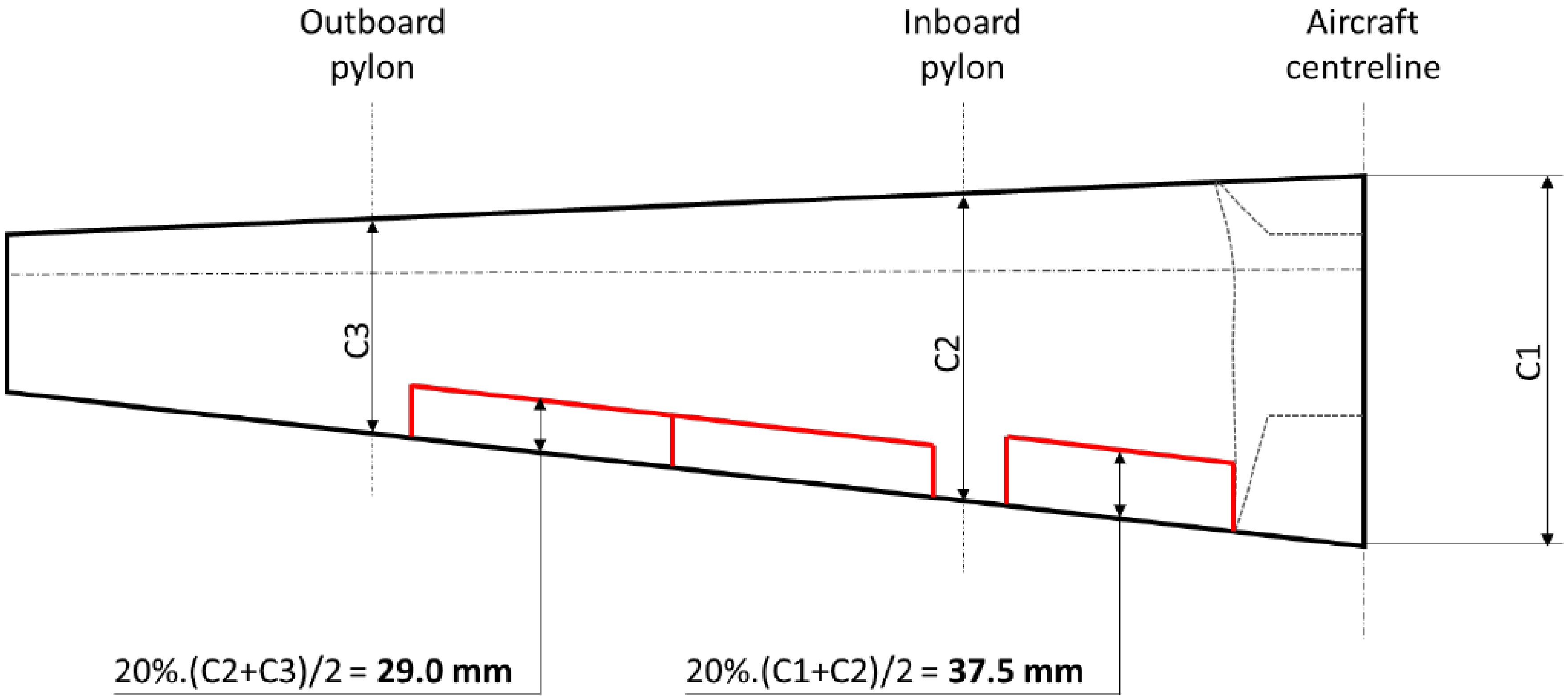
Wing planform

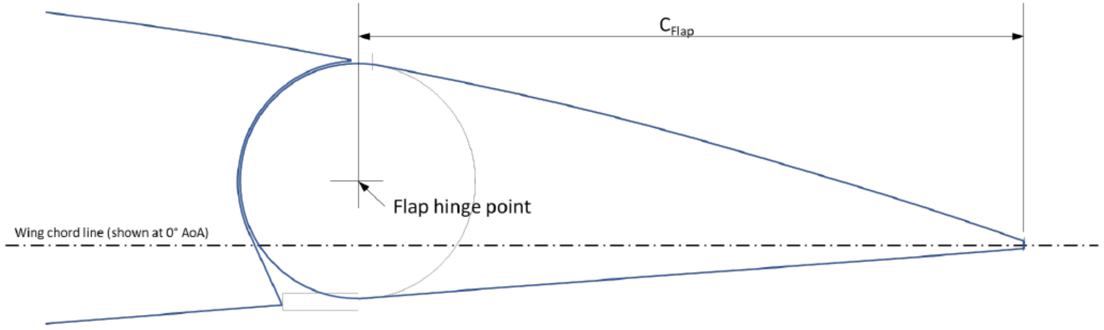


Wing airfoils



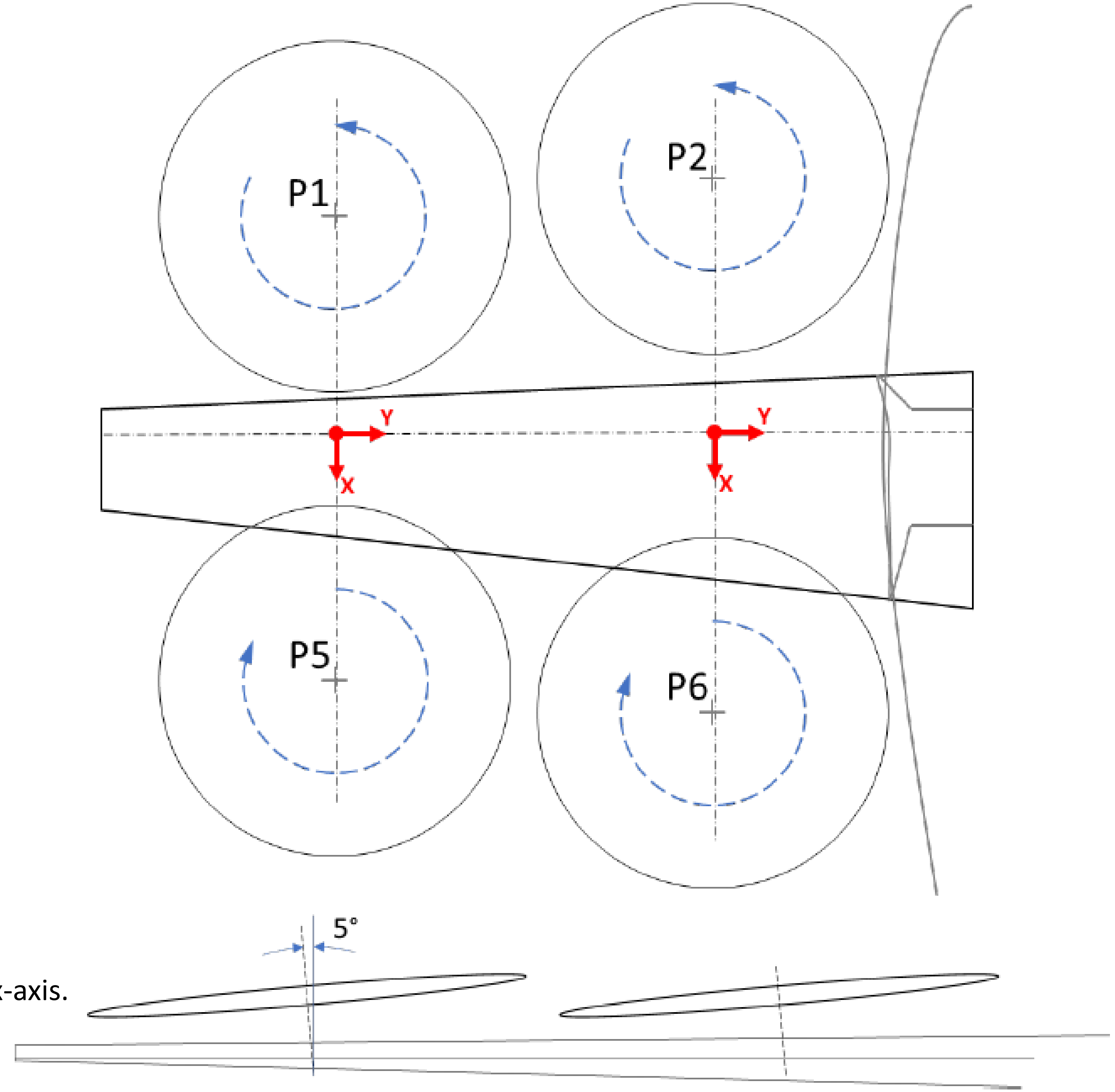
Flaps


Outboard pylon
Inboard pylon
Aircraft centreline
C3
C2
C1
20%.(C2+C3)/2 = **29.0 mm**
20%.(C1+C2)/2 = **37.5 mm**


C Flap
Flap hinge point
Wing chord line (shown at 0° AoA)

Propeller locations

Propeller	X, mm	Z, mm
P1, hover	-1870	370
P1, cruise	-2080	-140
P2, hover	-2200	320
P2, cruise	-2420	-190
P5	2130	370
P6	2400	320

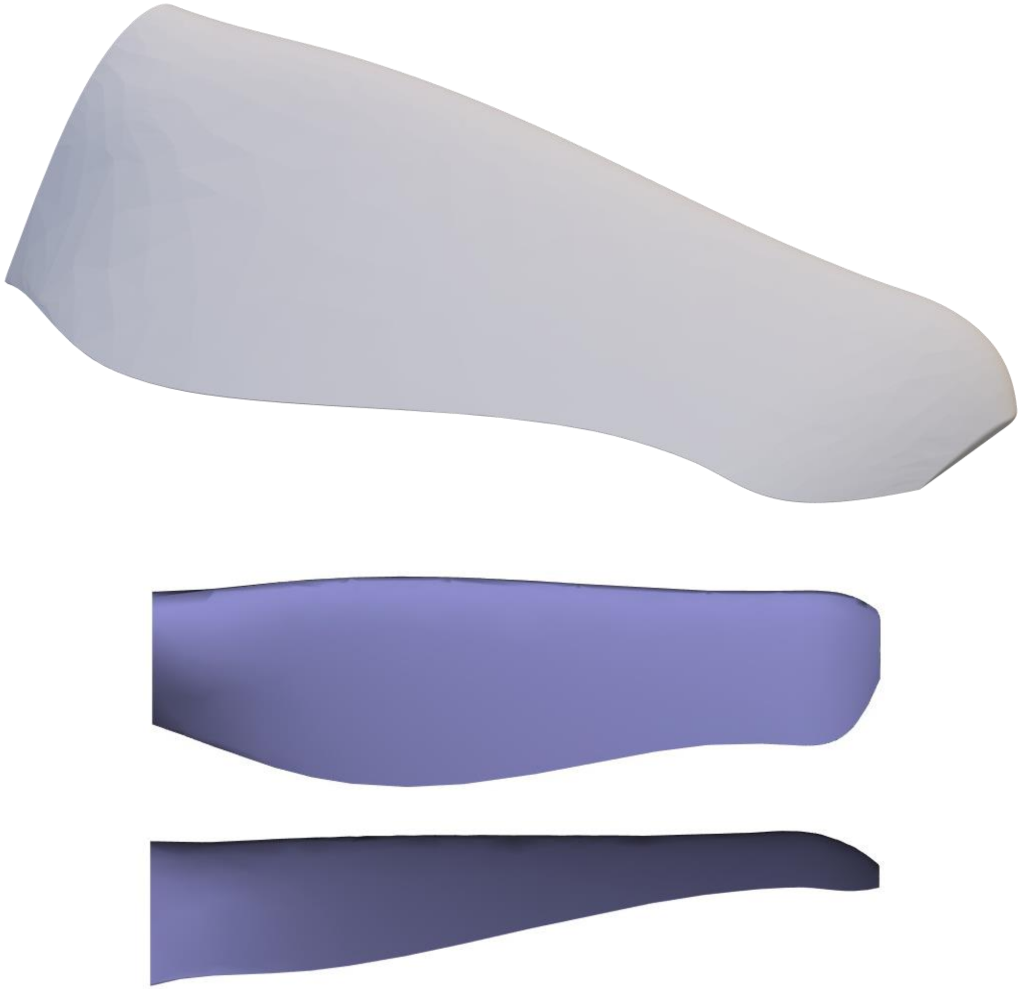


Locations are relative to wing 25%-chord line.
Hub reference point is where blade 25%-chord lines intersect.

To prevent cascade failure the propellers are rotated 5° around the aircraft x-axis.

Forward propeller geometry

- Five-bladed forward propeller
- Blade geometry has been adjusted to account for Reynold’s number effects

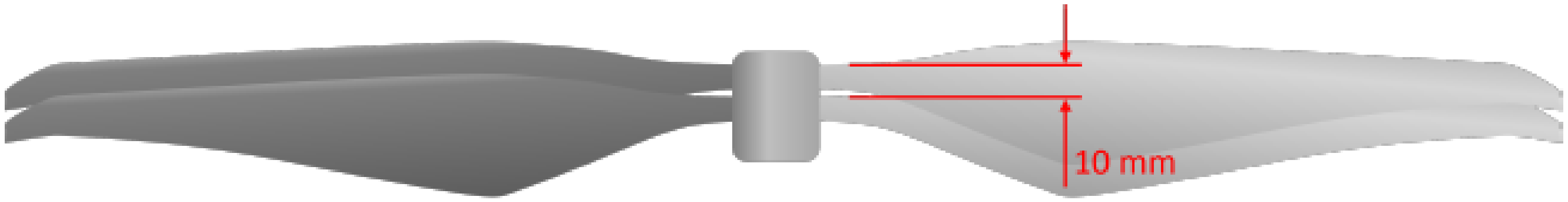


Aft propeller geometry

- Four-bladed aft propeller
- Blade geometry has been adjusted to account for Reynold’s number effects

Aft propeller geometry

- (Optional) vertical offset to allow stowing
  - Easier to study 'in-plane' props



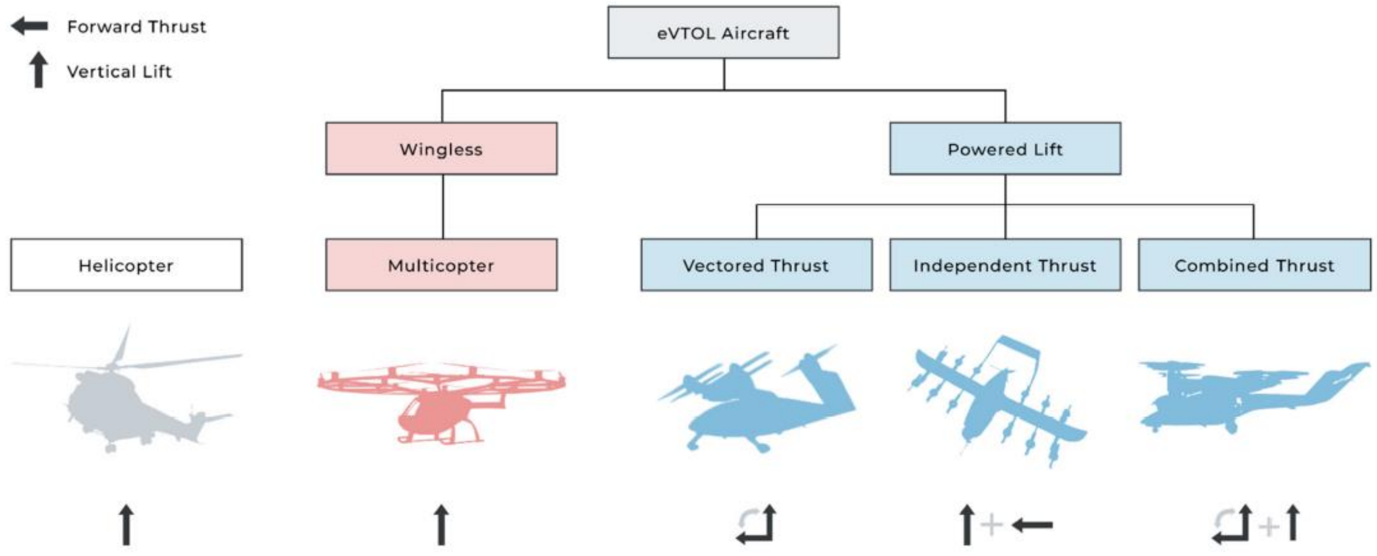
Vertical offset of aft propeller (shown parked)

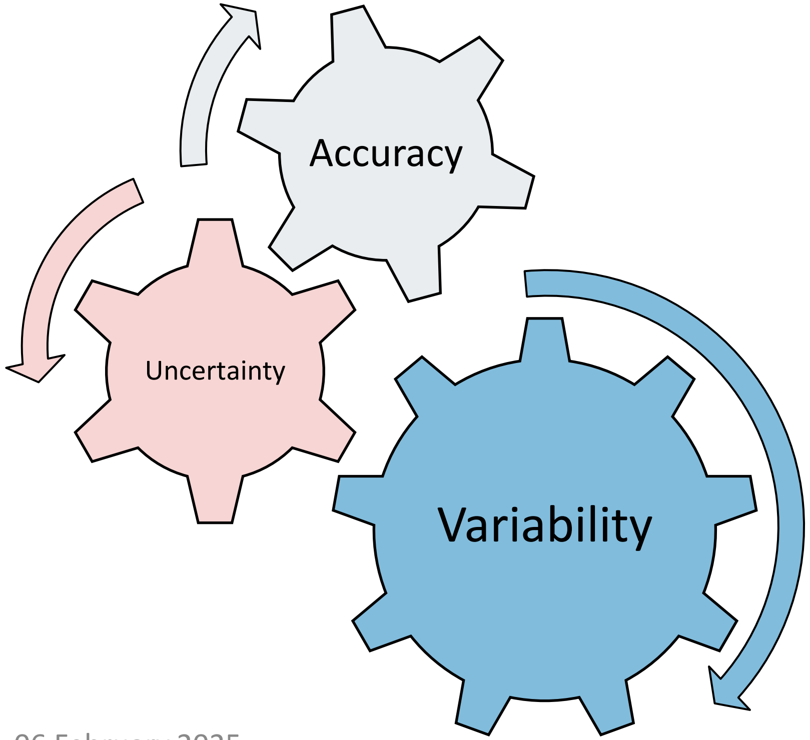

G-EVTA

Shaping a tool for eVTOL design

- Establishing a methodology enabling a **rapid aircraft sizing and modelling** is essential in early design phases of an aerospace product, especially if characterized by a high-degree of innovation and uncertainties.

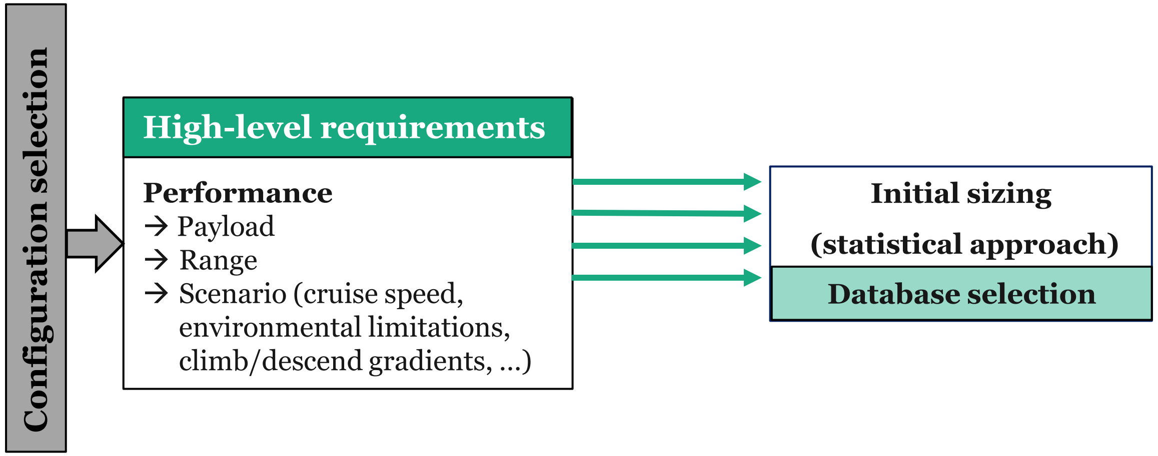
- Conceptual design routines shall aim at proposing **simple, stable and replicable design methods** in order to derive the main design variables of the aircraft, ultimately to predict the effectiveness during operations.





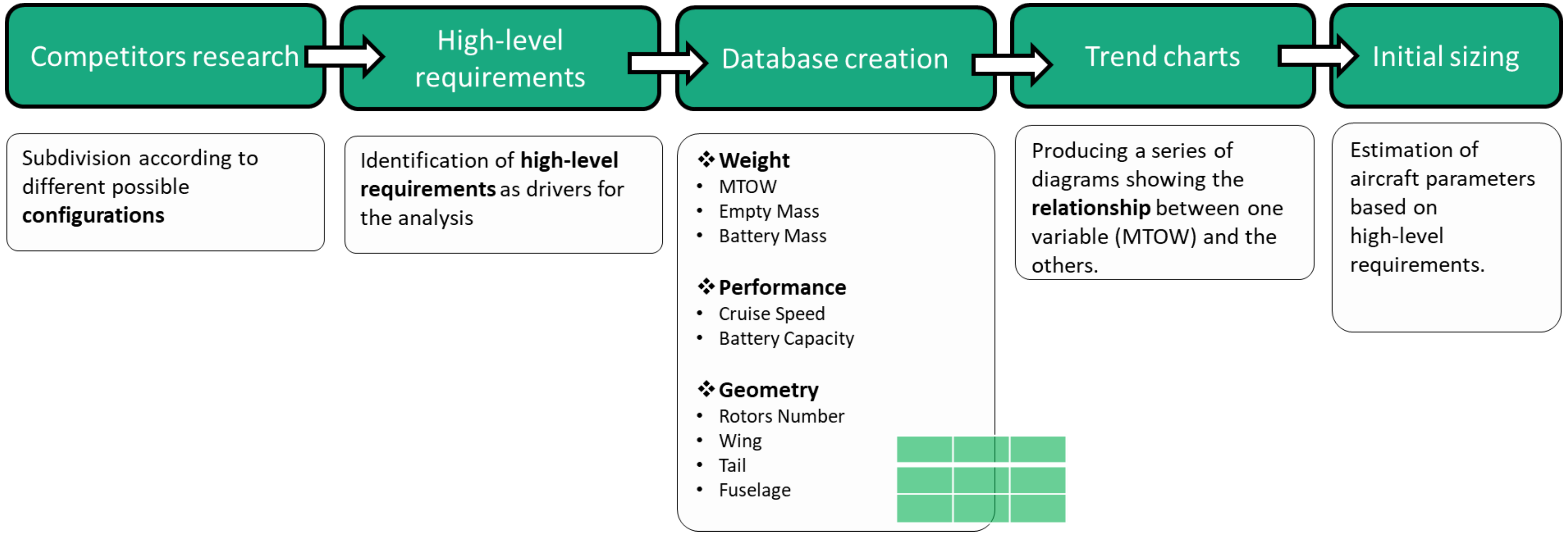
[Ref.] O. Ugwueze, T. Statheros, N. Horri, M. A. Bromfield, J. Simo. An efficient and robust sizing method for evtol aircraft configurations in conceptual design. Aerospace, 10 (3), 2023. https://doi.org/10.3390/aerospace10030311

Conceptual design methodology (1/4)

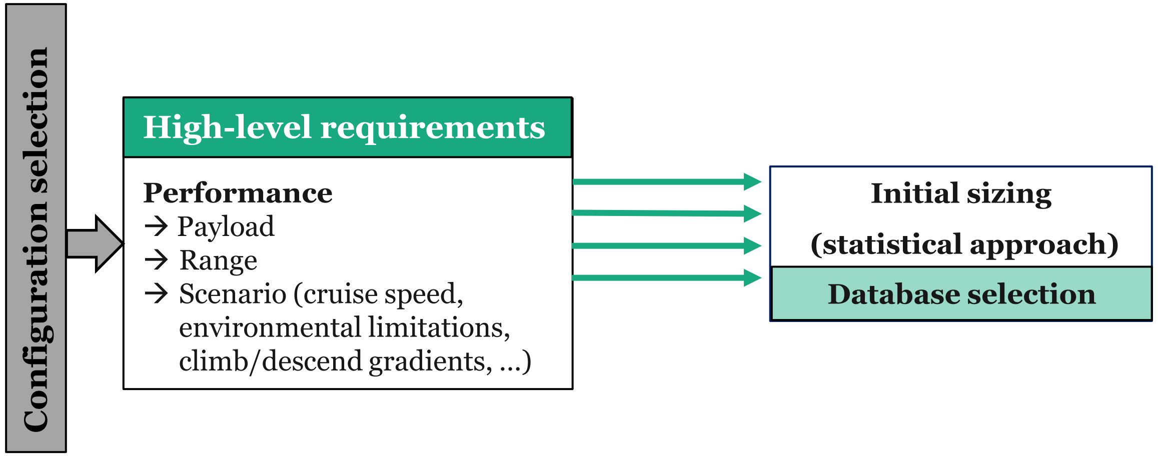


- Statistics is always a good source of data to start a design process, but this is applicable only if similar products exist in a certain quantity.

- This is even more **challenging if the user deals with innovative concepts**, which are still under development (no stable examples also from competitors).



Conceptual design methodology (2/4)



- Statistics is always a good source of data to start a design process, but this is **applicable only if similar products exist in a certain quantity**.
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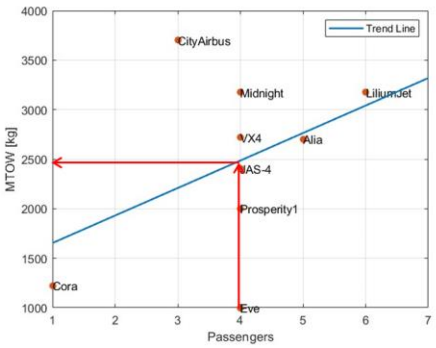
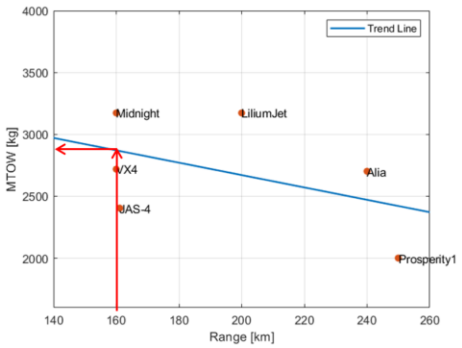
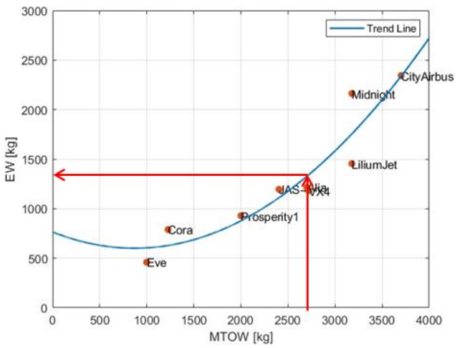
MTOW = f(payload)



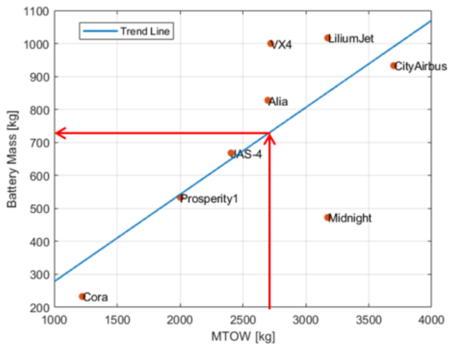
MTOW = f(range)



OEW = f(MTOW)



Battery mass = f(MTOW)



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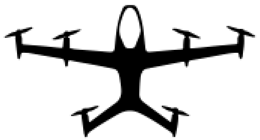
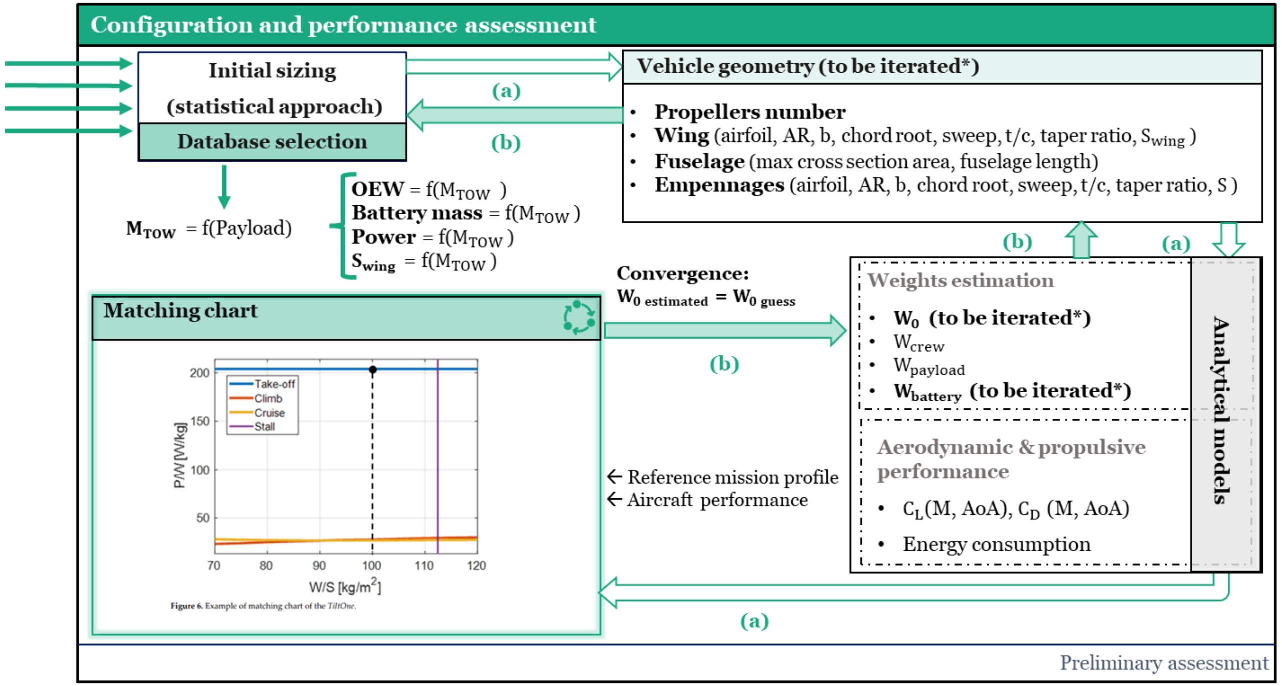


- Still, a good starting point for the next step!

Conceptual design methodology (3/4)



- Iterative conceptual design process based on convergence loop (e.g. gross mass)
- Main results: mass breakdown, basic performance, vehicle size and dimensions
- Reference to selected mission profile (high-level reqs.)

Complete loop (Roskam / NASA FLOPS methods):

Performance Requirements

$$\left(\frac{P}{M_{TO}}\right)_{TO} = \sqrt{\frac{T}{A}\frac{g}{2\rho}} \cdot \frac{k_T}{FoM\ \eta_{prop}} g \qquad \left(\frac{P}{M_{TO}}\right)_{CL} = \frac{1}{E_{CL}\eta_{prop}} \sqrt{\frac{2g}{\rho C_{L_{CL}}}\left(\frac{W}{S}\right)} + \frac{ROC}{\eta_{prop}}$$

$$E_{bat} = \sum_{i=1}^{n} \left(\frac{P}{M_{TO}}\right)_i t_i M_{TO}$$

$$\left(\frac{M_{TO}}{S}\right)_{Max} = \frac{\frac{1}{2}\rho V_{stall}^2 C_{L_{Max}}}{g} \qquad \left(\frac{P}{M_{TO}}\right)_{CR} = \frac{1}{E_{CL}\eta_{prop}} V_{CR}$$

Mass evaluation

$$M_{bat} = \frac{E_{bat}}{SED}\frac{(1 + SOC_{Min})}{\eta_{bat} \cdot EOL} \qquad M_{fus} = 14.86 \cdot (M_{TO})^{0.144} \cdot \frac{L_f^{1.161} \cdot (N_{pax} + N_{crew})^{0.455}}{P_{Max}}$$

$$M_i = \cdots \qquad M_{TO} = \sum_{j=1}^{m} M_i$$

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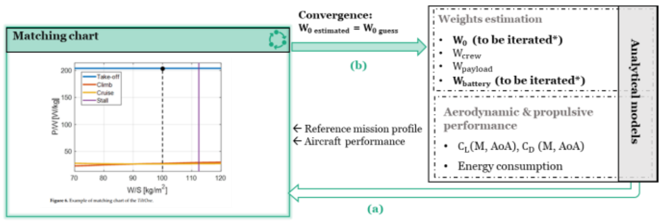
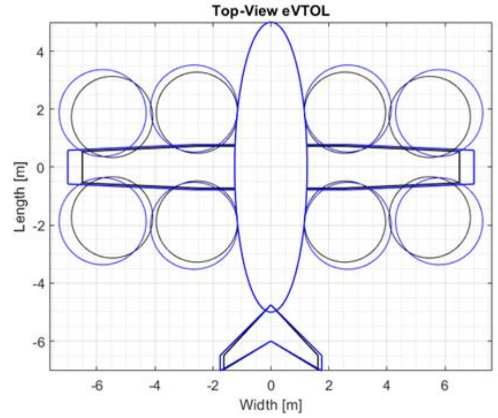
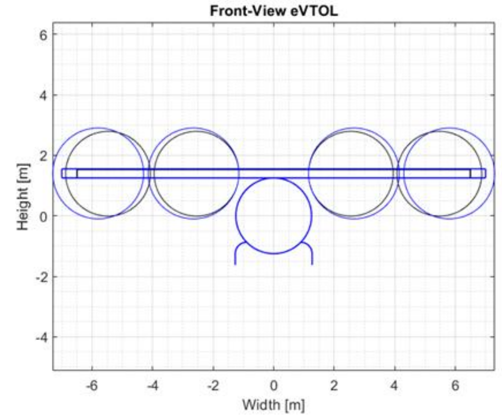
Conceptual design methodology (4/4)



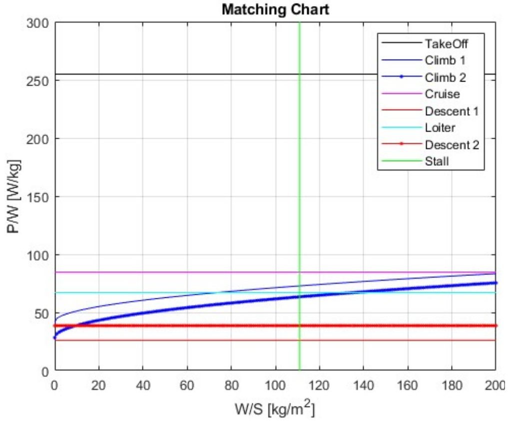
__ Statistics
__ Complete loop

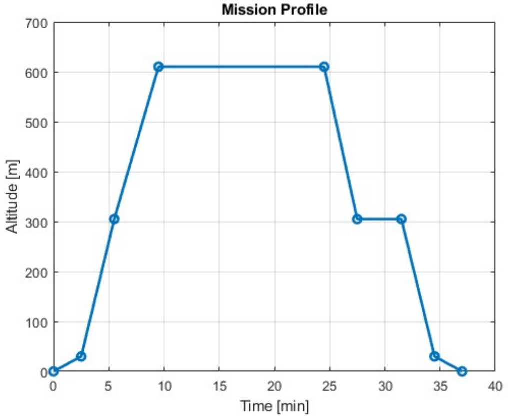


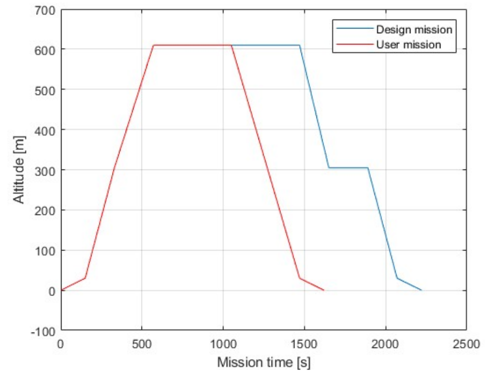


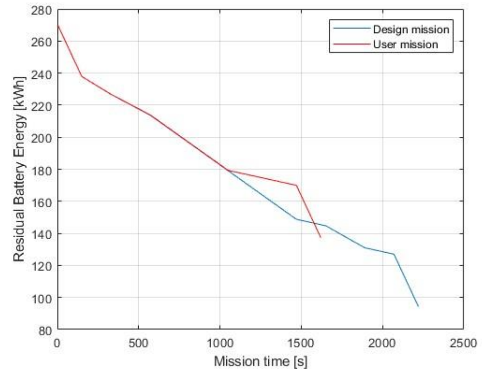
Parameter	Value
Gross mass	3253 kg
Empty mass	1827 kg
Battery mass	887 kg
Power-to-weight	250 W/kg
Wing loading	110 kg/m2
Disk loading	550 N/m2
Wingspan	14 m
Fuselage length	10 m
Rotors	8
Rotor diameter	3 m

From sizing (**design mission**) to «operations» (**user mission**)









- Design
- Prediction of aircraft usage and related operational cycles

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Conclusions and next steps

- A set of **reference missions and a baseline aircraft** have been identified to support the different activities within eVTOLUTION Project;

- A **conceptual design tool was developed** to enable eVTOL sizing within the Project, also looking at the data coming from the baseline aircraft for validation purposes;

- Analysis of the **impact of aircraft architecture** and related power requirements onto on-board subsystems is ongoing, with particular focus **on energy management and cooling**;

- **Safety and certification aspects** will be assessed with reference to this architecture;

- «**Design exercises**» will drive domain-specific studies on aerodynamics and noise.

Thank you for your kind attention!

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