



**POLITECNICO
MILANO 1863**



Pioneering Hydrogen Electric VTOL

42nd Annual VFS Student Design
Competition

Sponsored by Airbus

Executive Summary

Vehicle overview

Long Endurance

- Endurance of about 2 hours in the primary mission. It is obtained through a wing with high aspect ratio, reduced flight speed and optimized overall weight.
- Battery + fuel cell powerplant
- Required power is shared between battery and fuel cell.
- Battery covers peaks of power in vertical flight and guarantees high Specific Excess of Power in horizontal maneuvering flight.
- Fuel cell is used for cruise, loitering and other low power flight phases.

Hydrogen-electric eVTOL

- The use of hydrogen allows to obtain an eVTOL with no CO₂ emissions, making it suitable for operations in nature.
- No external electrical energy is required to recharge the battery, because it is recharged during flight and at the end of the flight through the fuel cell.
- The working principle is that of a full hybrid vehicle.



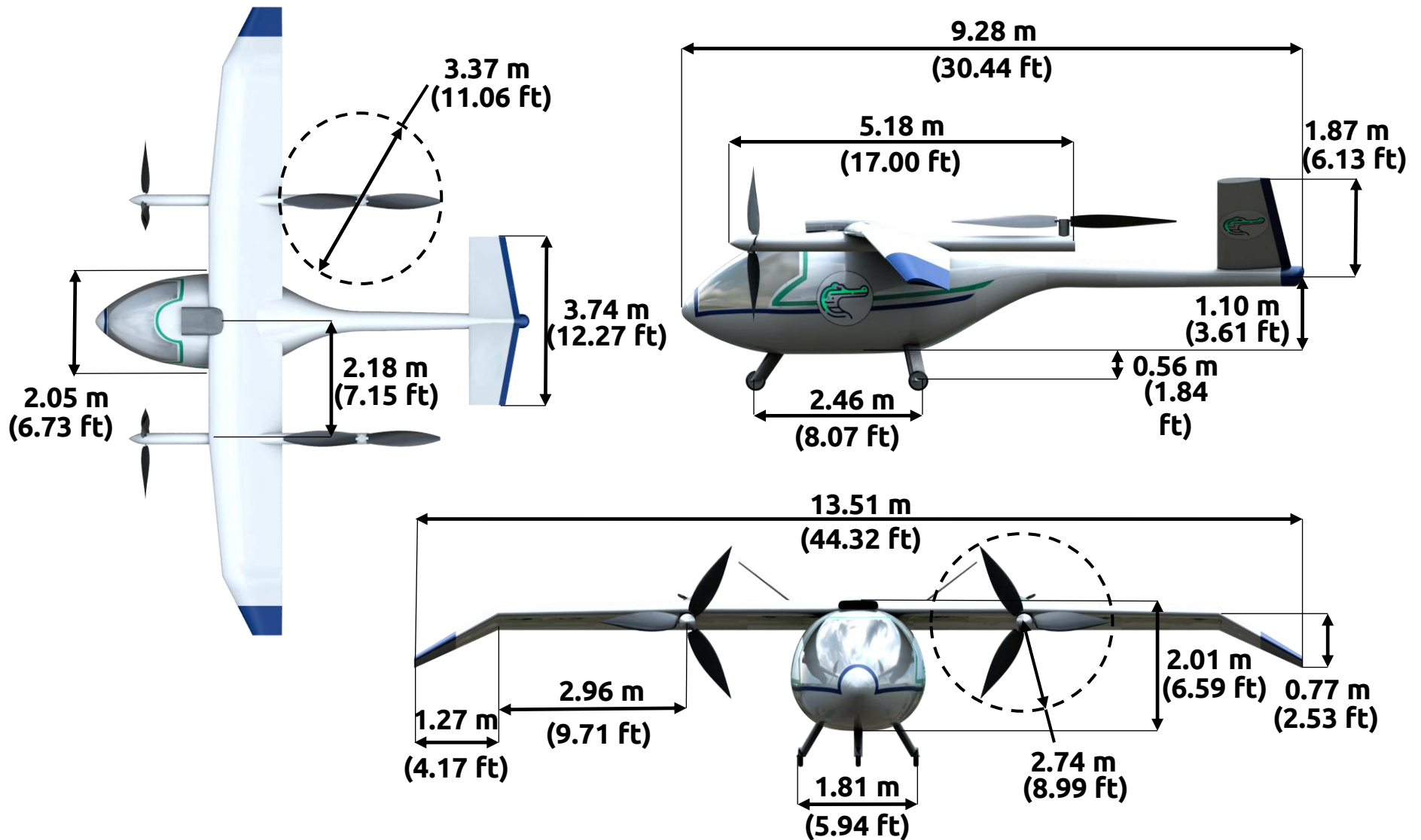
Modern 4-Propellers Vectored Thrust Configuration

- 2 tilting propellers in front of the wing.
- 2 vertical propellers behind the wing, that align with the airflow to reduce drag in horizontal flight.

Compactness

- The eVTOL is contained in a 10 x 10 x 4 m box in each phase of flight.
- Easy to store.
- Suitable for vertiport operations.
- Ease of ground movement.

Dimensions and characteristics



Introduction

Sobek is a four-engine vectored thrust eVTOL with the objective of reducing carbon and NOx emissions. Its name draws inspiration from the ancient Egyptian deity associated with Nile crocodiles, a parallelism that recalls the location assigned in the RFP for the sizing mission: the Alligator River National Wildlife Refuge. Flying over a National Park is always challenging, due to noise and pollution concerns. Those operations are strictly regulated by the FAA. Sobek does not pollute: it can help conduct such tasks. Only pressurized hydrogen is employed and converted into electrical energy through a Proton Exchange Membrane (PEMFC), also used to recharge a battery.

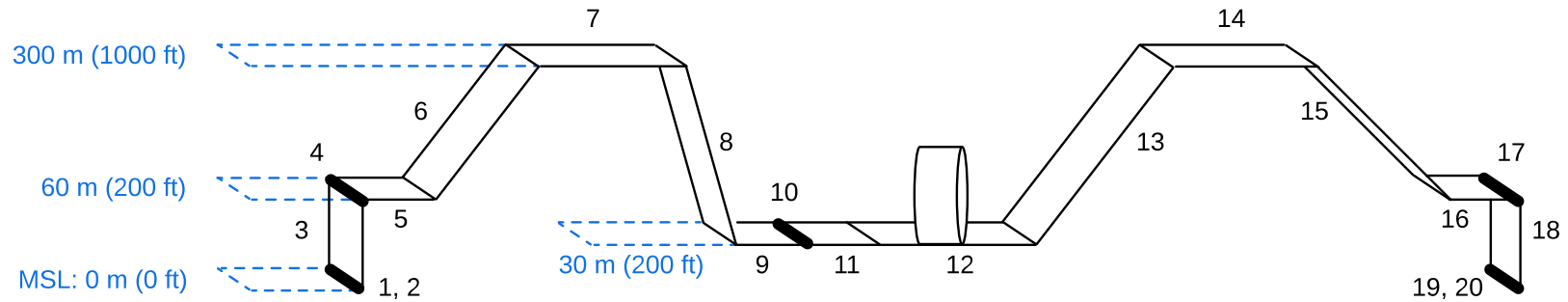
Vehicle overview

Sobek is designed to transport a payload of 185 kg (2 passengers and luggage), with the aim of spotting animals in the Alligator River National Wildlife Refuge for the highest (loitering) time possible. It is capable of 30 km range, 1.5 hours of loitering and then come back to the initial point of the mission. The overall endurance is about 2 hours.



Each Sobek unit has an estimated purchase price of \$4.45M, with maintenance costs at \$319/h, and direct operating costs of \$1.35M/yr.

The Pioneering Mission



- **Climb, descent, cruise:** flown at the best range speed of 35.4 m/s (68.8 kts)
- **Loiter:** flown for about 1.5 h at a speed of 34.3 m/s (66.8 kts), equal to 1.3 times the stall speed
- **Transitions:** they consist of four phases of the mission and occur each time the eVTOL goes from airplane mode to helicopter mode and viceversa



Configuration Choice

- 5 configuration families analyzed:



Helicopter



Compound



Fan-in-wing



Lift + cruise



Vectored thrust

- Results from the sizing code:

	t_{loit} [h]	MTOM [kg]	BM [kg]	FCM [kg]
Helicopter	0.25	1397	36	440
Compound	0.50	1439	178	245
Fan-in-wing	N/A	N/A	N/A	N/A
Lift + cruise	0.75	1327	152	165
Vectored thrust	1.50	1468	173	166



Major importance given to the configuration with the highest possible loiter time

- AHP criteria and results:

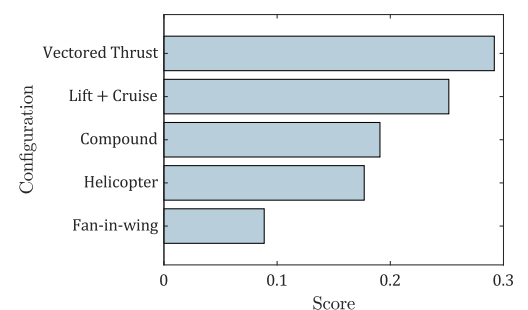
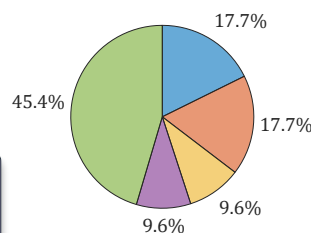
Endurance

Technology readiness

Complexity & affordability

Reliability & certification

Aeroacoustic emissions



Modern vectored thrust configuration

- Number of propellers and total disk area are selected through an optimization approach to **minimize disk loading** and staying within the assigned box.
- High wing aspect ratio to **minimize induced drag**.
- Innovative configuration with pylons on the wing to **reduce propellers download effect**.

Main project drivers

- Compactness
- Complexity/cost
- Aerodynamic efficiency
- Ground visibility

Design choices

- Two tilting propellers two fixed vertical propellers
- Fixed landing gear
- V-tail
- High mounted wing



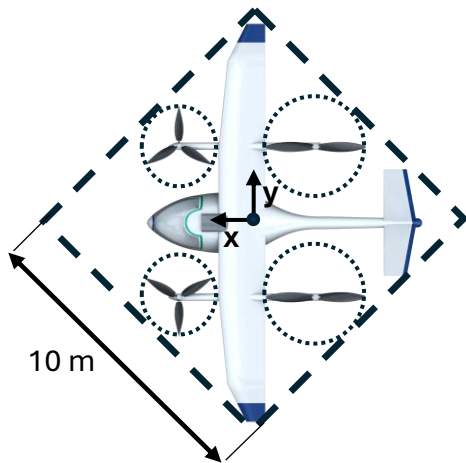
The optimization problem

Efficient **genetic algorithm** optimizer employed to find the final values of Sobek parameters, in order to maximize the loitering time.

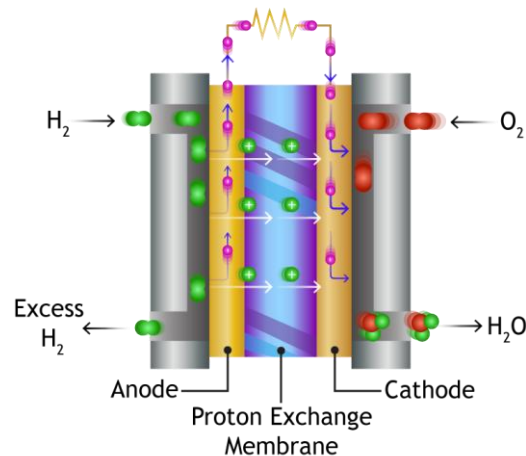
- **Cost function:**

$$T_{loiter} = \frac{(m_{H2_{tot}} - m_{H2_{used}})}{\dot{m}}$$

- **Main constraints:**



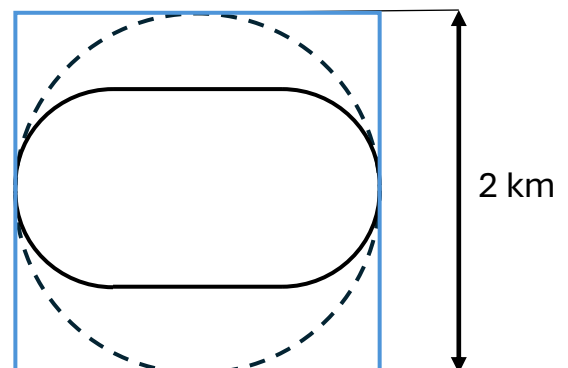
1. Geometrical box



2. Fuel cell parameters



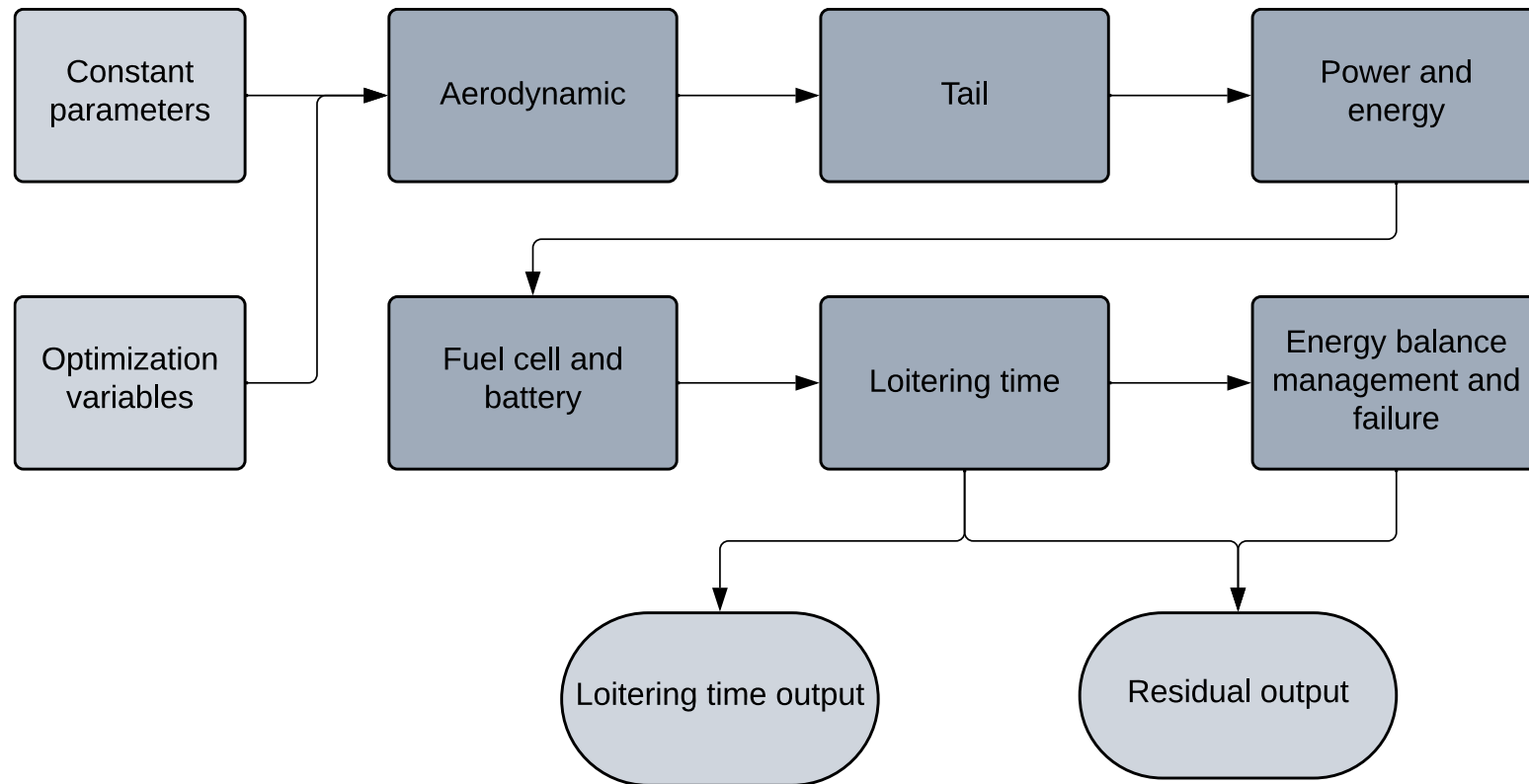
3. Battery failure conditions



4. Loiter limiting region of 2 km x 2 km.

The optimization problem: scheme

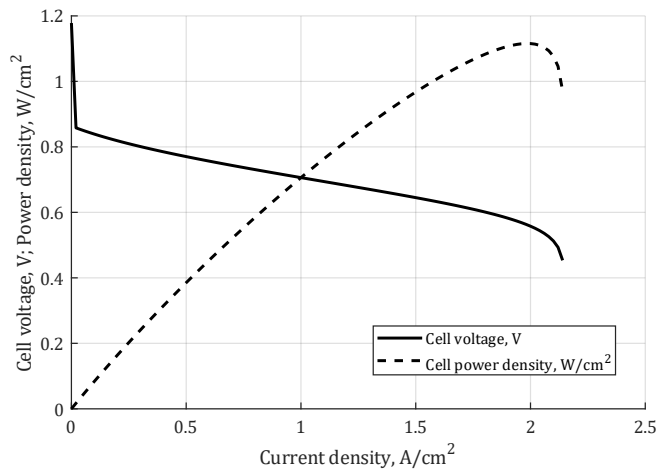
- **Main design parameters:** wing geometry, tail geometry, propellers radius, fuel cell voltage, battery discharge rate
- **Scheme:** optimization problem in divided into blocks that allow to obtain the cost function and to evaluate and maximize it



Powerplant and systems design

Fuel cell and tanks

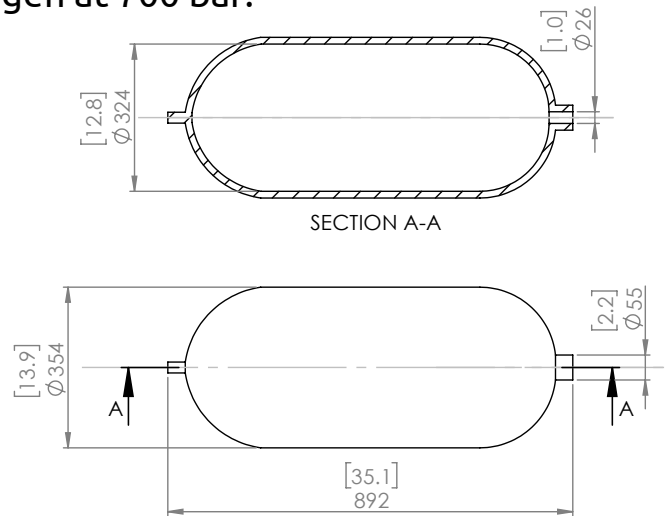
- Sobek uses a 79.8 kWe **Proton Exchange membrane fuel cell** as main source of energy.
- Use of **modern light composite tanks**: 7 type IV off-the-shelf pressure cylinders are used to store the hydrogen at 700 bar.



Fuel Cell cell polarization curve

Parameter	Value
Design Net Power	79.8 kW
Max Net Power	85.1 kW
Cell Voltage	0.62 V
Design Efficiency	0.37 [-]

Main Fuel Cell design parameters.



Hydrogen tanks

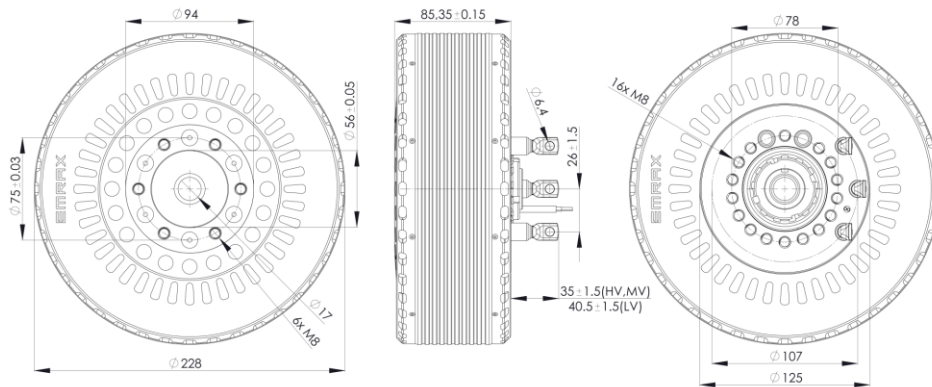
Parameter	Value
Weight of one Tank	34.4 kg (75.8 lb)
Number of Tanks	7
Total Hydrogen Mass	14.6 kg (32.2 lb)

Fuel system design parameters.

Powerplant and systems design

Emrax 228 electric motors

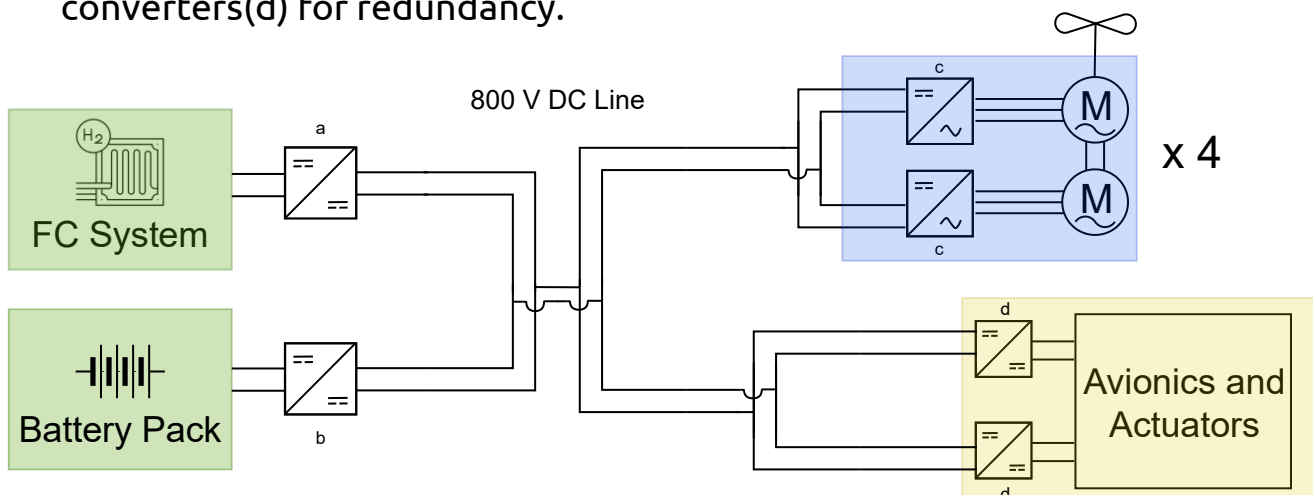
- 8 Emrax 228 electric motors stacked in couples are employed. Fail-safe design.
- Each motor has its own-independent electric motor drive connected in parallel to the bus line to increase redundancy.



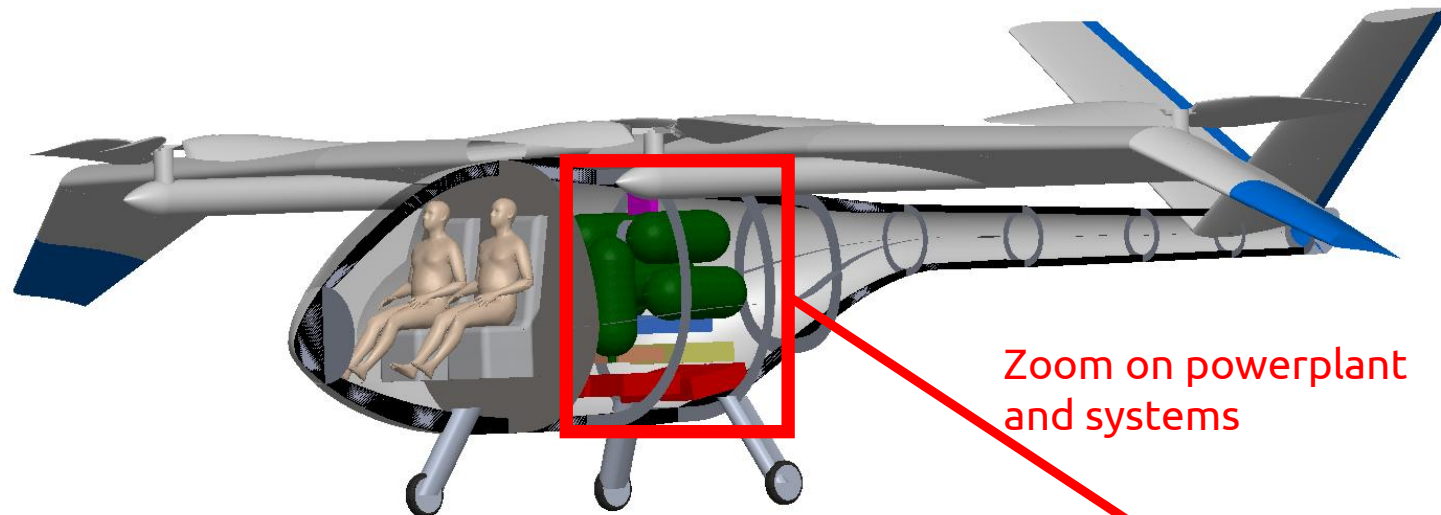
Parameter	Value
Number of motors	8
Rated continuous power	75.0 kW (100.6 hp)
Design rpm	6500 rpm
Weight of one motor	13.5 kg (29.8 lb)

Sobek electrical system

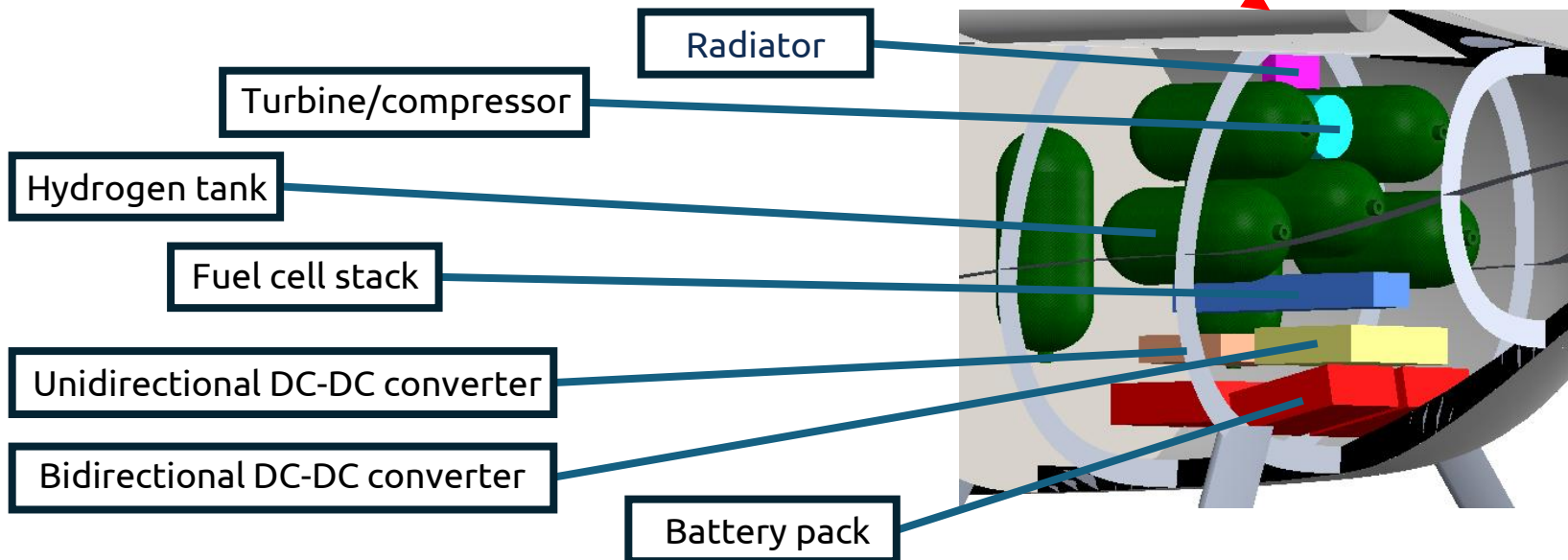
- The 250V fuel cell (FC) stack is connected to the 800 V DC line via an off-the-shelf unidirectional DC-DC converter (a).
- The battery is also connected to the 800 V line with a bidirectional off-the-shelf DC-DC converter (b), to allow recharging.
- Each motor has its own DC-AC drive (c).
- A parallel line is used for avionics and actuators, with separate DC-DC converters(d) for redundancy.



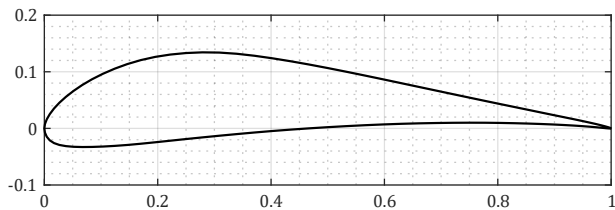
Internal layout



Zoom on powerplant and systems



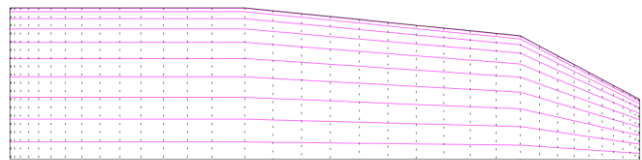
Wing design



FX 73-Cl1-152

High-lift low-Re airfoil suited to very low-speed flight throughout the mission. 15.2% thickness enhances structural stiffness.

- Cranked **Schuemann wing planform** as a viable alternative to the elliptical one in quest of high loiter efficiency.
- **Downturned wingtips** (24°) reduce induced drag and improve loitering time.
- Optimized through VLM analysis in AVL.



Sobek achieves a 26.4 m/s stall speed without the need for high-lift devices thanks to its tailored lifting surfaces, making slow low-altitude overflights of Alligator River possible without a further increase in drag.

S_{ref}	c_{MAC}	b	AR
19.40 m ² (208.8 ft ²)	1.436 m (4 ft 8.54 in)	13.51 m (44 ft 3.9 in)	9.41

Tail design

S_h	c_t	b_t	Γ_t
3.67 m ² (39.5 ft ²)	0.98 m (3 ft 2.58 in)	3.74 m (12 ft 3.2 in)	45°



- **V-tail configuration** to reduce the parasitic drag and stay out of propellers wake.
- **Combination of longitudinal and lateral control** actions to trim the aircraft.



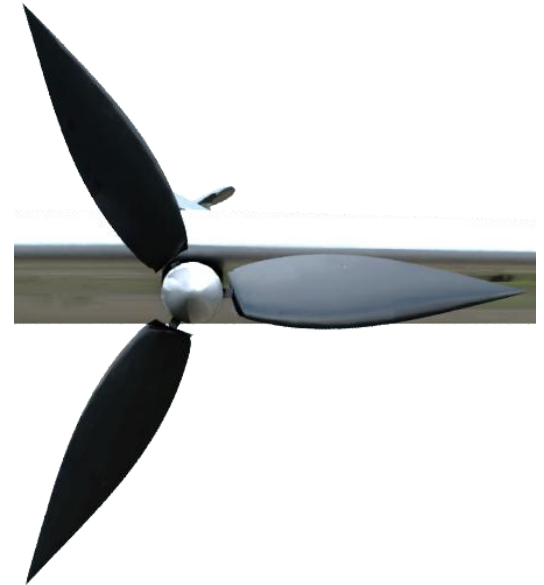
Propellers design

Vertical propellers

- 2-bladed propellers for reduced drag during horizontal flight.
- Designed for optimal hovering performance.
- Large diameter to reduce the required power.

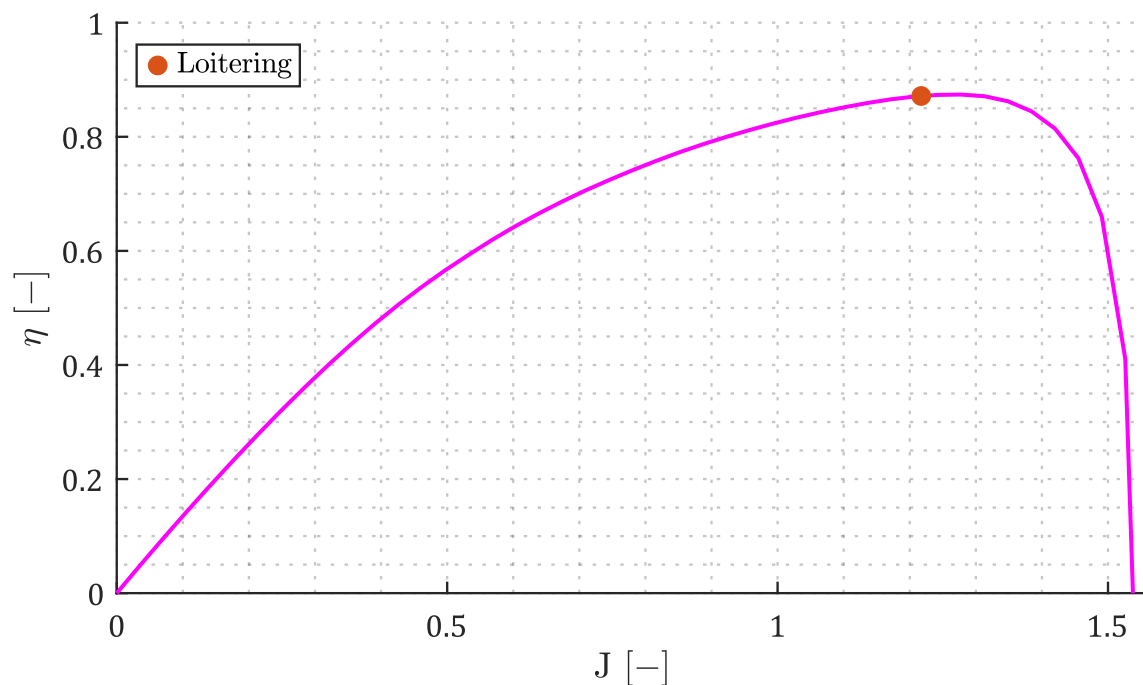
Tilting propellers

- High performance tilting propellers.
- Designed for both horizontal and vertical flight.
- Very low noise design in both horizontal and vertical phases.



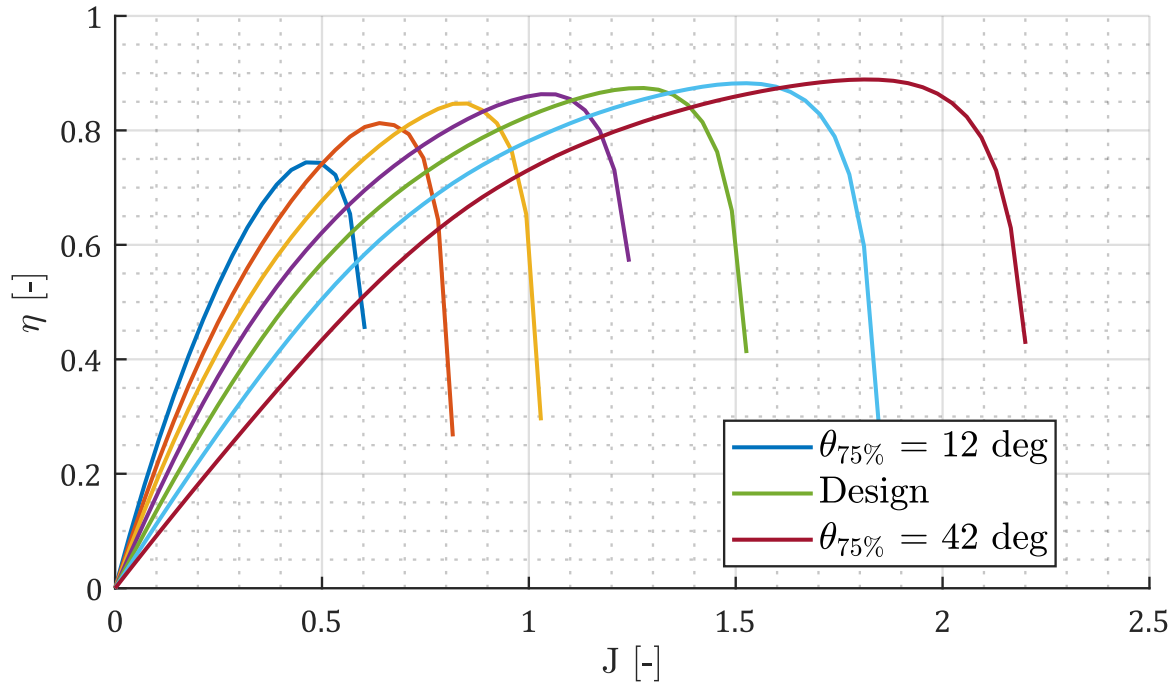
High efficiency blades

The well-designed blades allow to fly with high efficiency during loitering phases, a crucial aspect in terms of endurance maximization

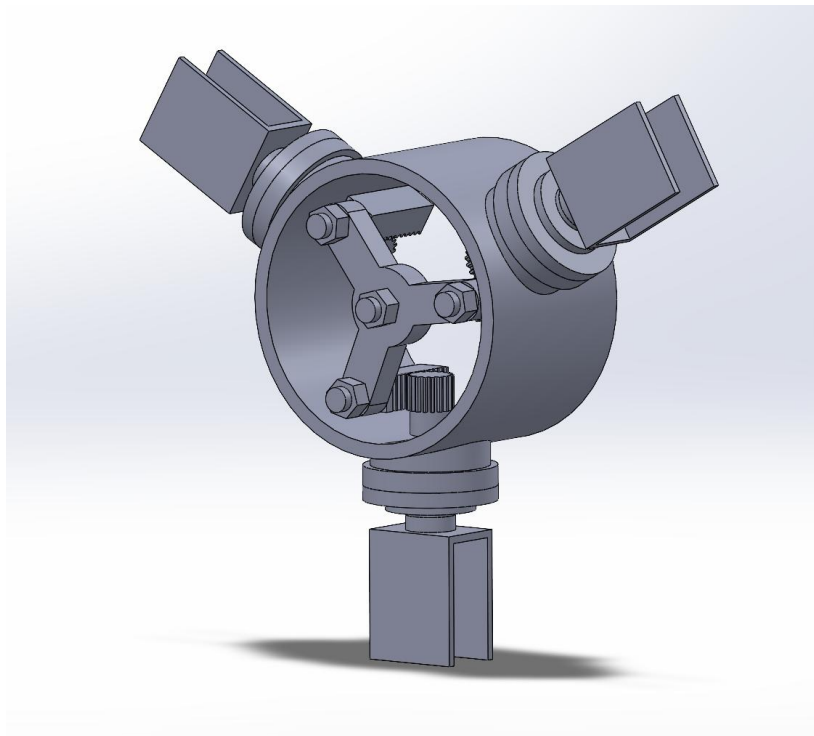


Propellers design

Variable pitch mechanism



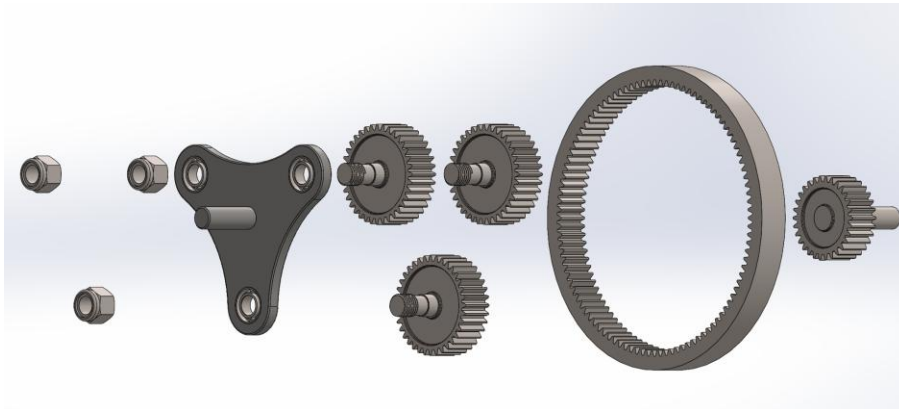
- Low complexity and weight.
- Improves cruise flight efficiency and at the same time provides excellent hover performance.



Transmission and tilting system design

Compact low weight gearbox

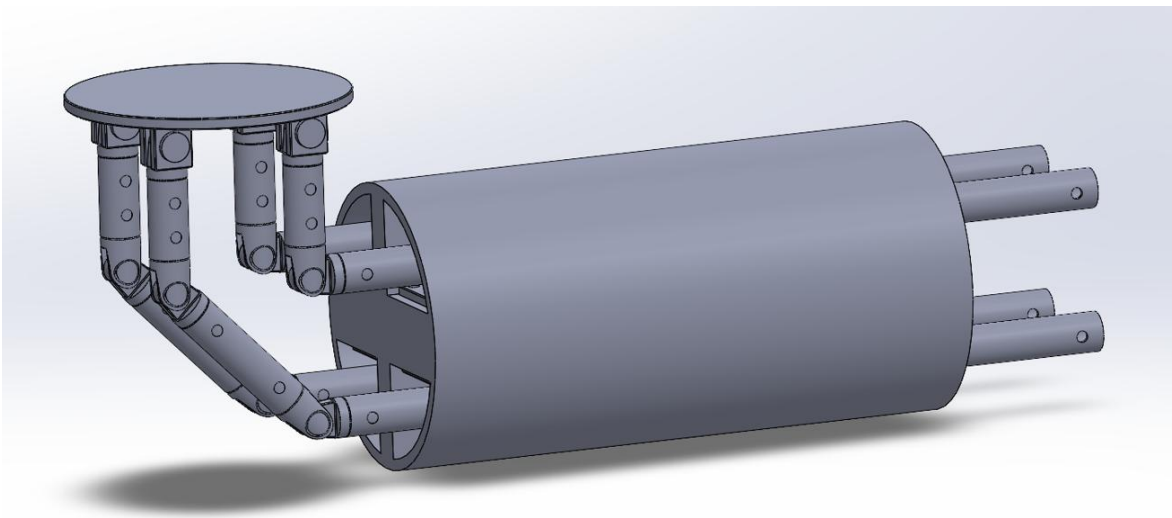
- 95% gearbox efficiency.
- Planetary gearbox to reduce weight and volume.



Parameter	Value
Fwd gear ratio	4.40
Aft gear ratio	2.50

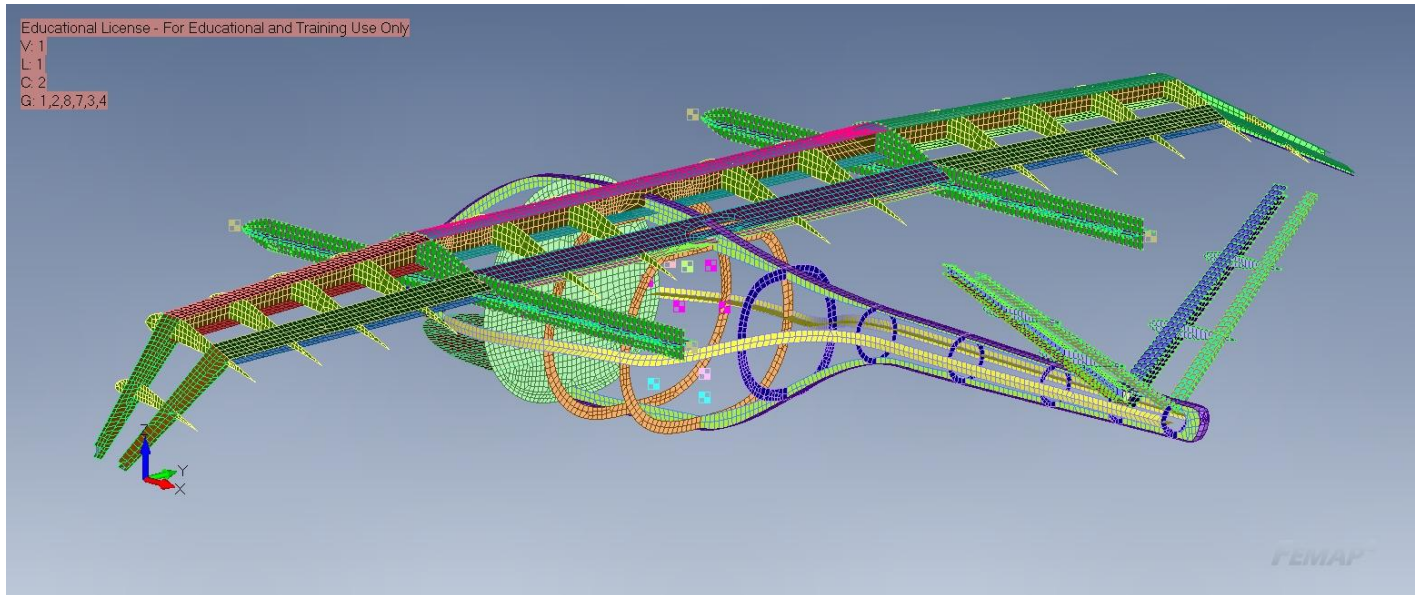
Revolutionary tilting mechanism

- Inspired by Joby Aviation patented technology.
- Moves propeller outwards to minimize download during hover.



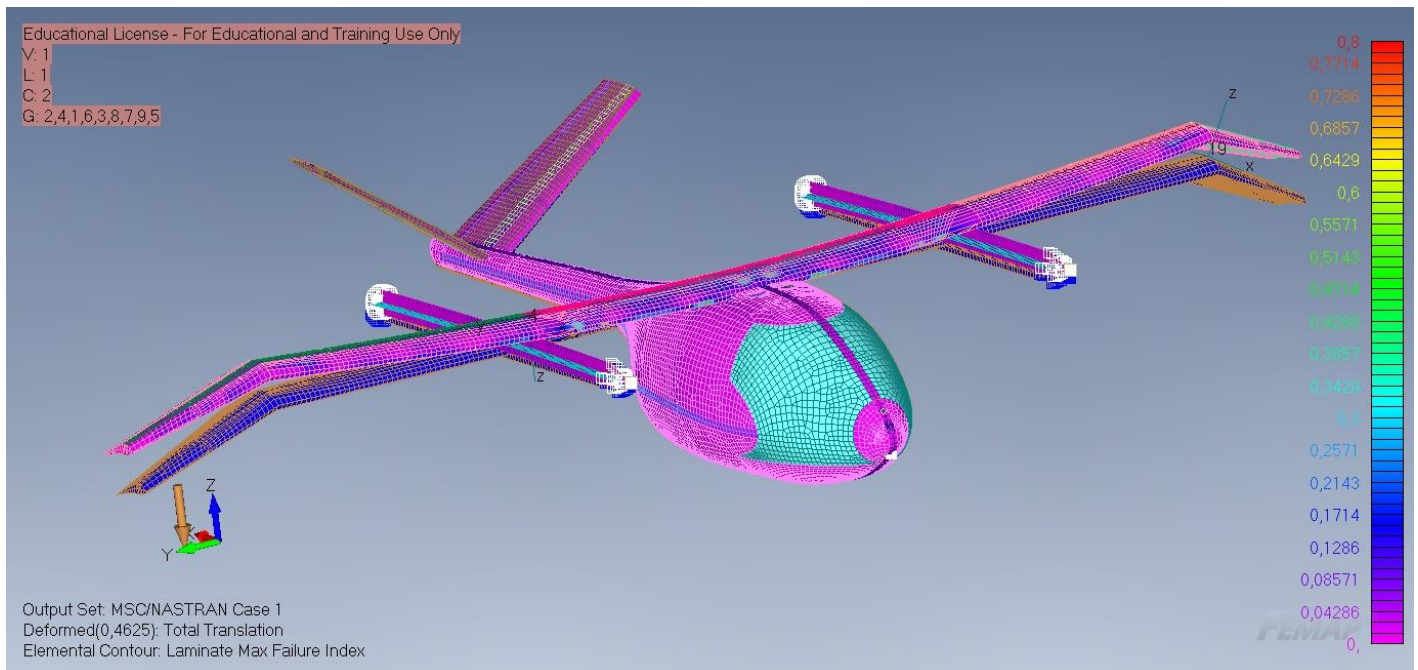
Airframe & Fuselage Design

Sobek internal structure made with plate elements



- Tadpole shape to minimize drag.
- Composite materials and honeycomb, to ensure the lowest weight.
- Titanium fireproof firewall.

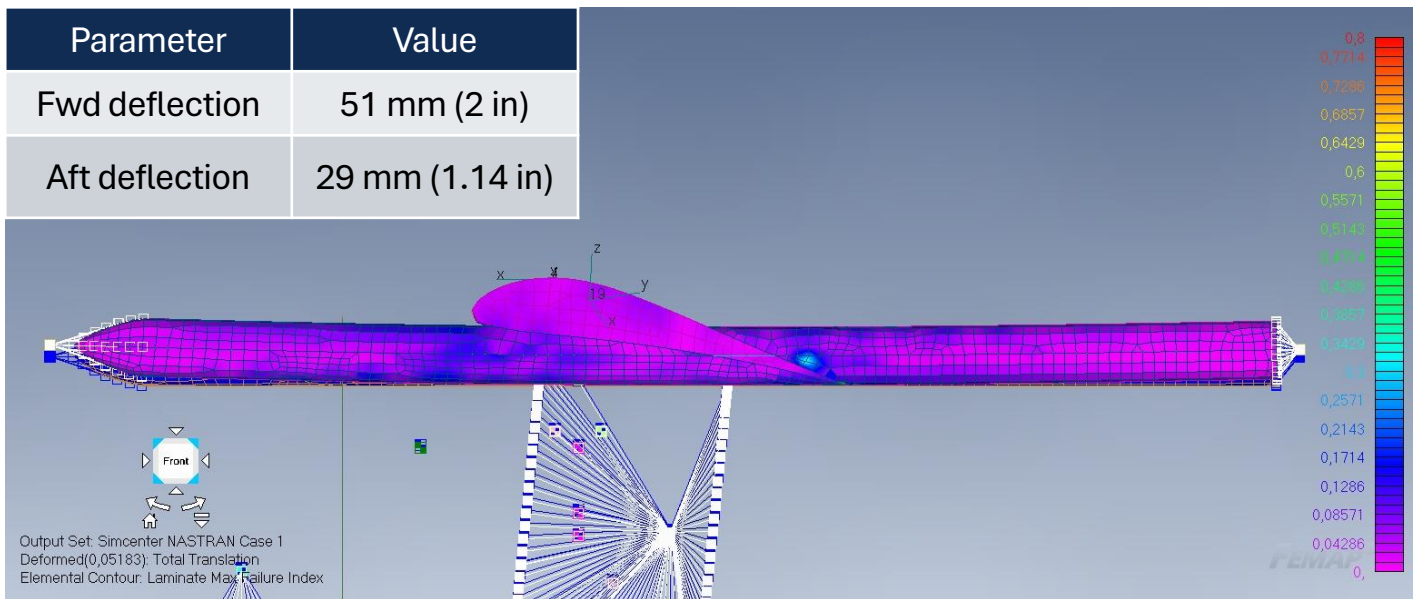
Sobek deformation under a static aerodynamic load



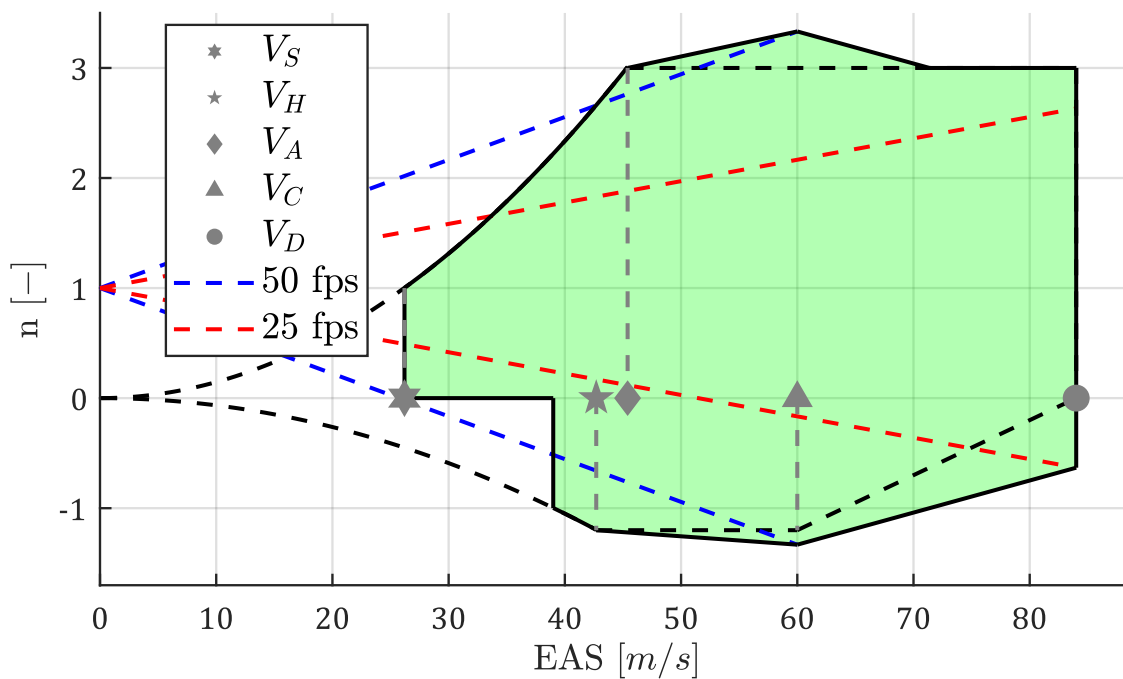
- The structural verification is made for a pull up maneuver at maximum load factor of 3, multiplied by a safety factor of 1.5

Airframe & Fuselage Design

Maximum pylon deflection in hover with 1.5 times the maximum takeoff weight



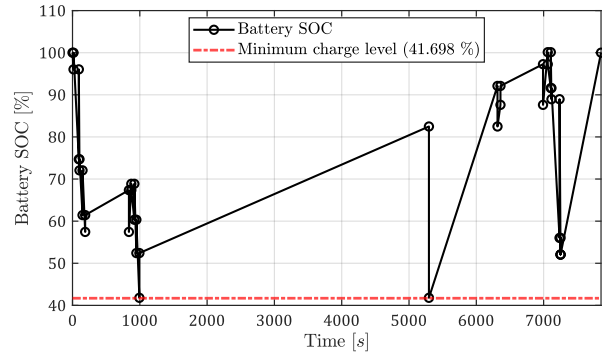
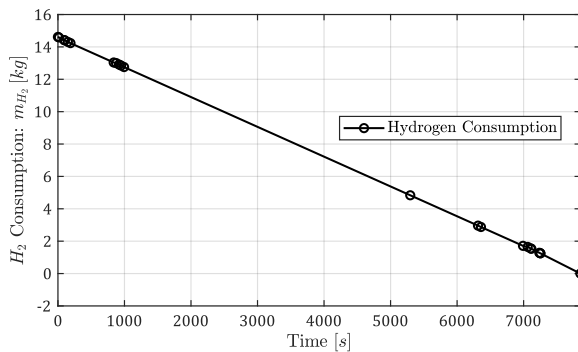
n-V diagram



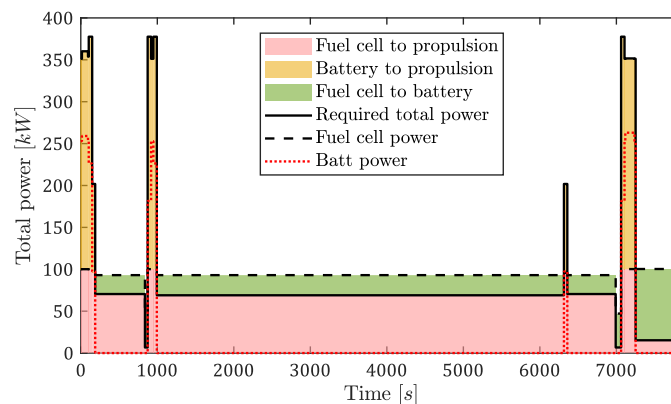
- Employed to determine the most requiring static loads to size the aircraft structures. Created in agreement with CS-23 regulations.

Performance

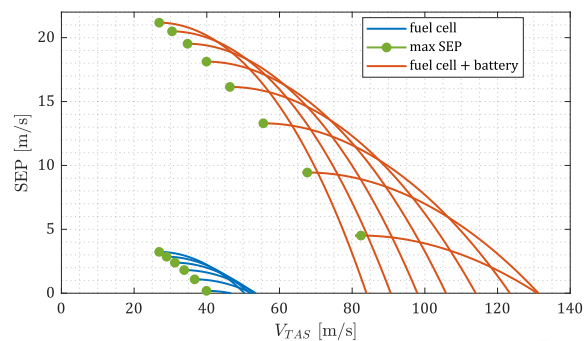
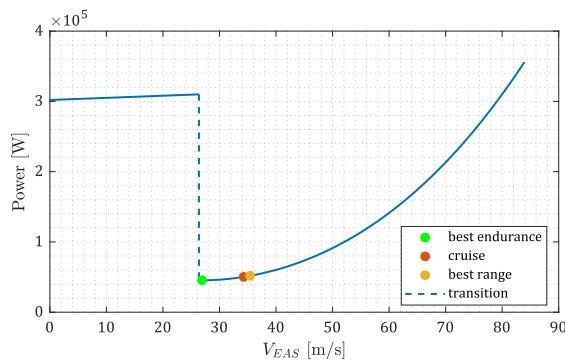
- Hydrogen consumption and battery state of charge evolution during the Pioneering Mission. First one is almost linear, while the second has rapid variations due to power peaks.



- Aerodynamic required power during the Pioneering mission, with sources of energy. Power peaks in vertical flight phases. Horizontal flight phases employed to recharge the battery through the fuel cell.



- Performance in airplane mode. Required shaft power at different flight speed on the left. Specific excess of power (SEP) parameterized at different altitudes on the right. Great SEP in horizontal power thanks to the high power given by the battery, with possibility to complete maneuvers with high load factors and rate of climbs.



Conclusions

Innovative prototype

- Use of hydrogen stored in gaseous form
- Hybrid powertrain system, with the only source of energy from hydrogen
- Developed with multidisciplinary optimization approach for integration of all subsystems

Safety first

- Designed considering failure conditions related to facilities
- Dual electric motors for each axis, with redundant control logic
- Parcelled battery, to reduce the effects of failure
- Tilt system with redundant actuators

Satisfied requirements

- Aircraft remains in the box of 10 x 10 x 4 m in all phases of flight, assuring operability from vertiports that accept that dimension
- Granting 1.5 h of loitering time
- Fuel cell and electrical system constraints, with a 800 V DC Voltage Line, and a stack temperature not exceeding the 90 °C limit.

High TRL

- Large use of Components Off-The-Shelf (COTS).
- Use of only current technologies.
- Tanks, DC-DC converters, and motors are taken from real-world applications.

