# About Me

## Anthony Hovenburg

**PhD Candidate at Maritime Robotics and NTNU**

Supervisors: Rune Storvold

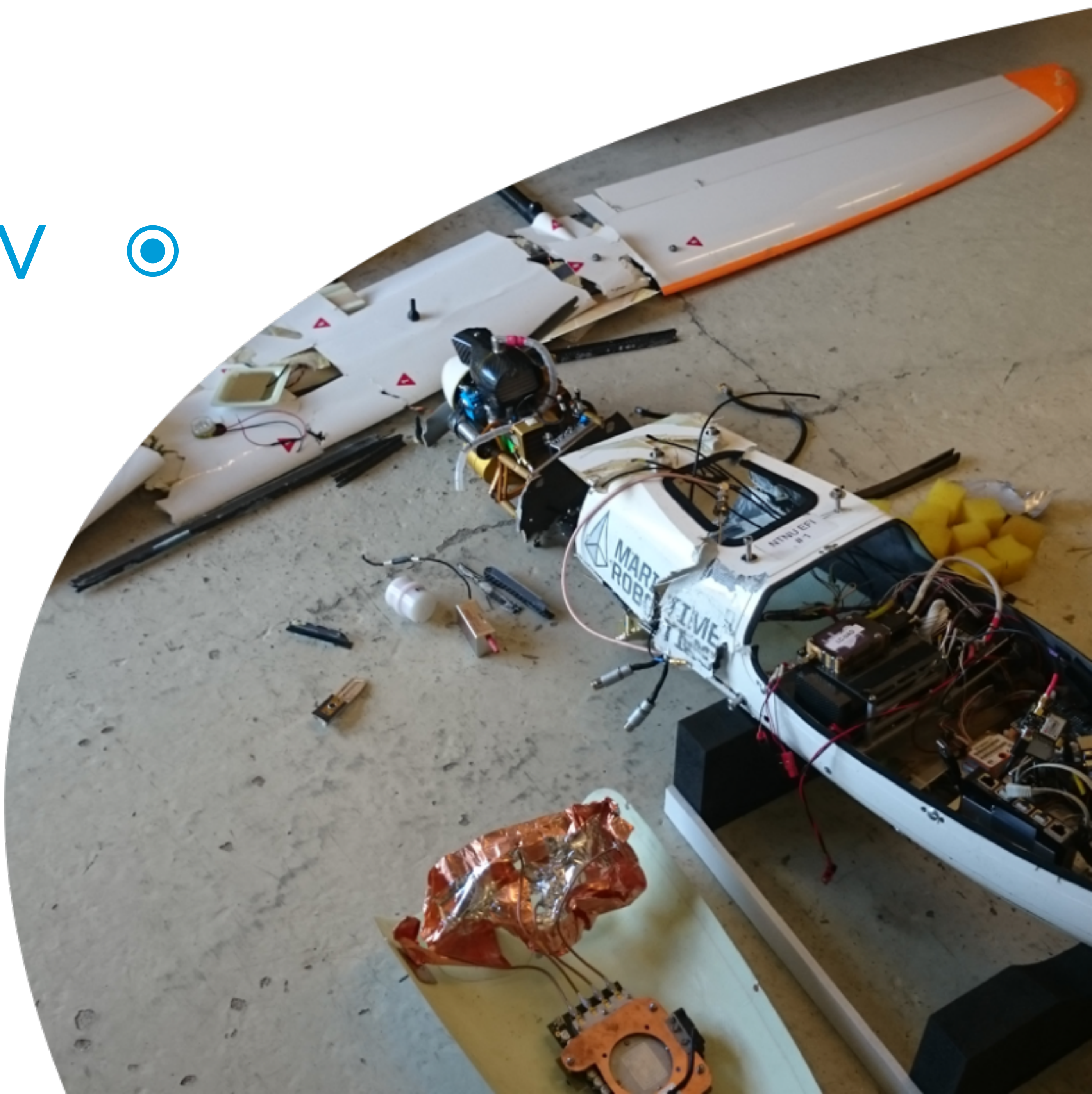
Tor Arne Johansen

# Penguin UAV

Performance issues

Reliability issues

Simply not very usable...



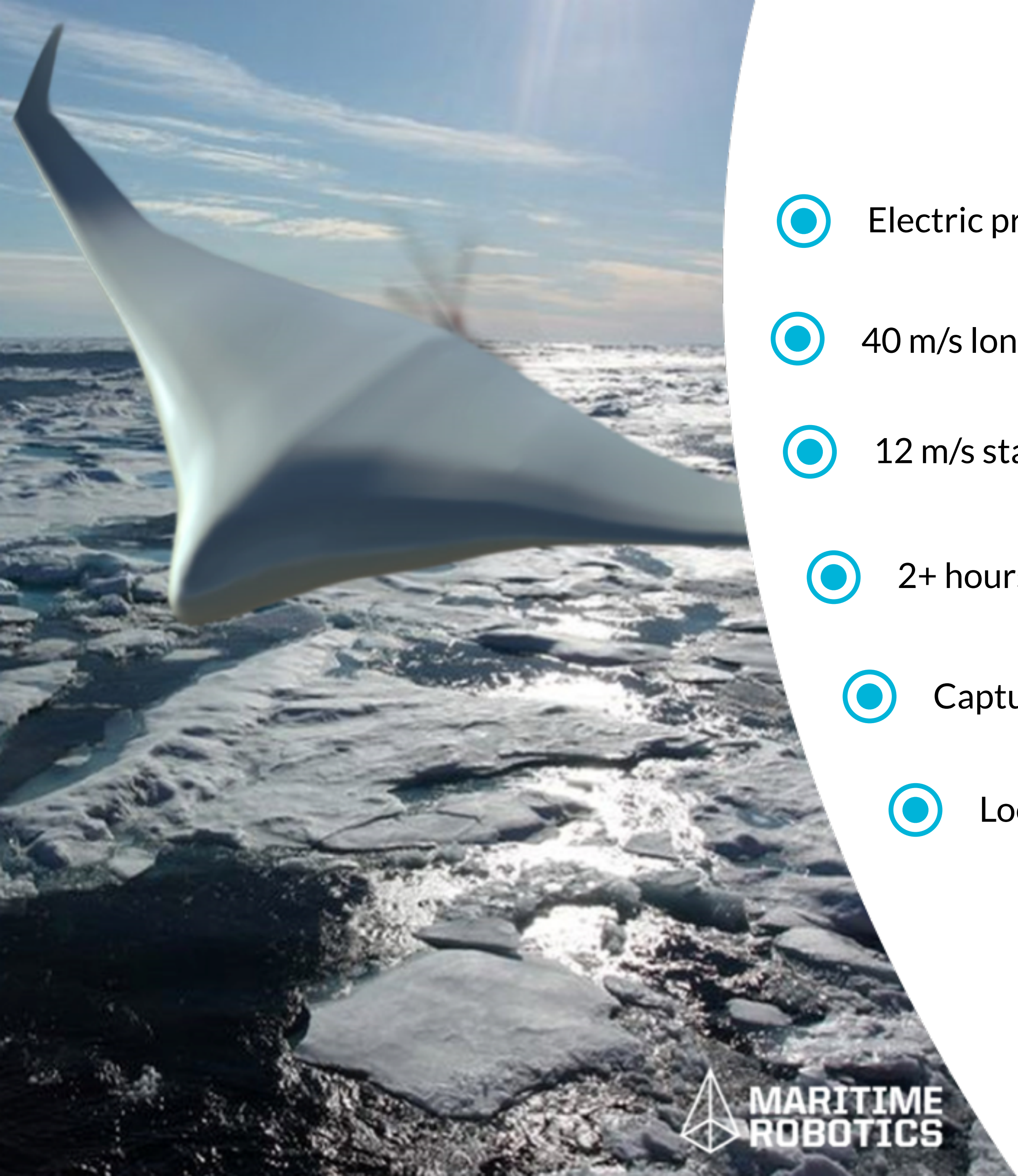
# Project New UAV

Norway's NextGen UAV

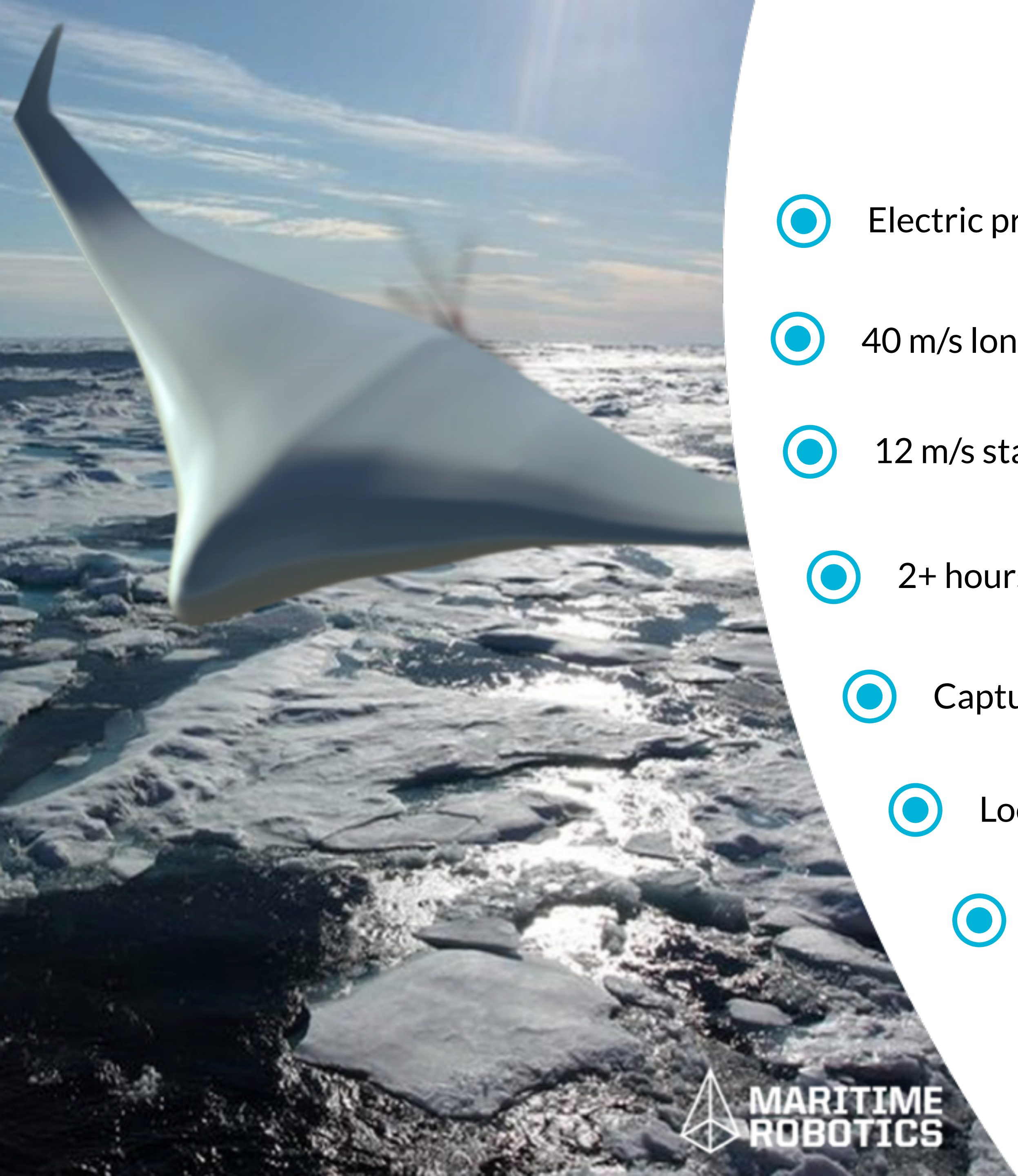
Feb 16

Discussing the requirements


MARITIME
ROBOTICS




- Electric propulsion
- 40 m/s long-range cruise speed
- 12 m/s stall speed
- 2+ hours flight endurance
- Captured on a ship by net
- Looks pretty




- Electric propulsion
- 40 m/s long-range cruise speed
- 12 m/s stall speed
- 2+ hours flight endurance
- Captured on a ship by net
- Looks pretty
- **Maximum total weight 12 kilograms**

# Breaking
# the news

**Explaining what are the trade-offs in:**

Airspeed

Flight endurance

Flight range

Total weight

Etc.

# Project New UAV

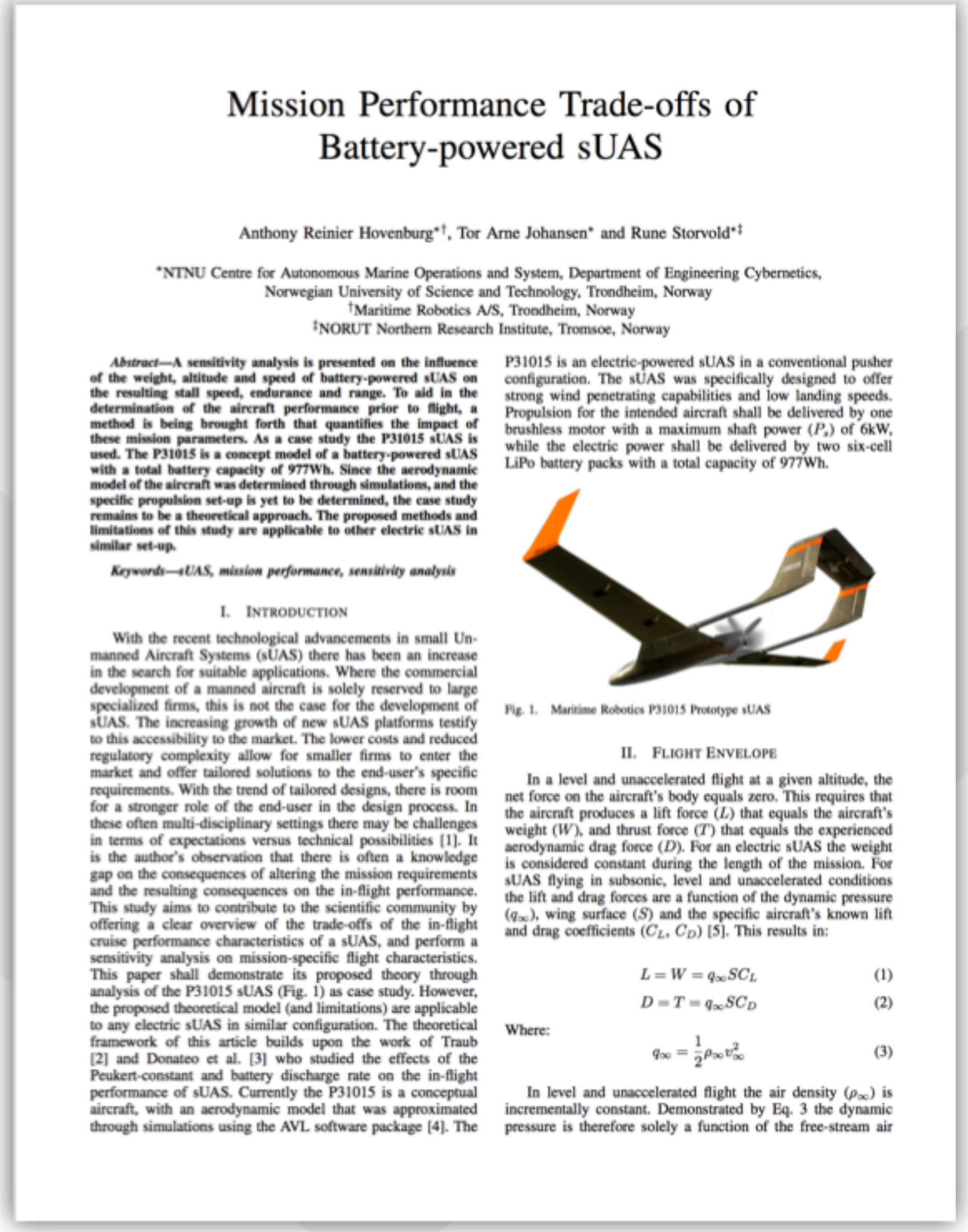
Norway's NextGen UAV

Feb '16

Discussing the requirements

Jun '16

Requirements set


# Mission Performance Trade-offs of Battery-powered sUAS

Anthony Reinier Hovenburg*†, Tor Arne Johansen* and Rune Storvold*‡

*NTNU Centre for Autonomous Marine Operations and System, Department of Engineering Cybernetics, Norwegian University of Science and Technology, Trondheim, Norway
†Maritime Robotics A/S, Trondheim, Norway
‡NORUT Northern Research Institute, Tromsoe, Norway

***Abstract*—A sensitivity analysis is presented on the influence of the weight, altitude and speed of battery-powered sUAS on the resulting stall speed, endurance and range. To aid in the determination of the aircraft performance prior to flight, a method is being brought forth that quantifies the impact of these mission parameters. As a case study the P31015 sUAS is used. The P31015 is a concept model of a battery-powered sUAS with a total battery capacity of 977Wh. Since the aerodynamic model of the aircraft was determined through simulations, and the specific propulsion set-up is yet to be determined, the case study remains to be a theoretical approach. The proposed methods and limitations of this study are applicable to other electric sUAS in similar set-up.**

***Keywords*—sUAS, mission performance, sensitivity analysis**

## I. Introduction

With the recent technological advancements in small Unmanned Aircraft Systems (sUAS) there has been an increase in the search for suitable applications. Where the commercial development of a manned aircraft is solely reserved to large specialized firms, this is not the case for the development of sUAS. The increasing growth of new sUAS platforms testify to this accessibility to the market. The lower costs and reduced regulatory complexity allow for smaller firms to enter the market and offer tailored solutions to the end-user's specific requirements. With the trend of tailored designs, there is room for a stronger role of the end-user in the design process. In these often multi-disciplinary settings there may be challenges in terms of expectations versus technical possibilities [1]. It is the author's observation that there is often a knowledge gap on the consequences of altering the mission requirements and the resulting consequences on the in-flight performance. This study aims to contribute to the scientific community by offering a clear overview of the trade-offs of the in-flight cruise performance characteristics of a sUAS, and perform a sensitivity analysis on mission-specific flight characteristics. This paper shall demonstrate its proposed theory through analysis of the P31015 sUAS (Fig. 1) as case study. However, the proposed theoretical model (and limitations) are applicable to any electric sUAS in similar configuration. The theoretical framework of this article builds upon the work of Traub [2] and Donateo et al. [3] who studied the effects of the Peukert-constant and battery discharge rate on the in-flight performance of sUAS. Currently the P31015 is a conceptual aircraft, with an aerodynamic model that was approximated through simulations using the AVL software package [4]. The P31015 is an electric-powered sUAS in a conventional pusher configuration. The sUAS was specifically designed to offer strong wind penetrating capabilities and low landing speeds. Propulsion for the intended aircraft shall be delivered by one brushless motor with a maximum shaft power ($P_s$) of 6kW, while the electric power shall be delivered by two six-cell LiPo battery packs with a total capacity of 977Wh.

Fig. 1. Maritime Robotics P31015 Prototype sUAS

## II. Flight Envelope

In a level and unaccelerated flight at a given altitude, the net force on the aircraft's body equals zero. This requires that the aircraft produces a lift force ($L$) that equals the aircraft's weight ($W$), and thrust force ($T$) that equals the experienced aerodynamic drag force ($D$). For an electric sUAS the weight is considered constant during the length of the mission. For sUAS flying in subsonic, level and unaccelerated conditions the lift and drag forces are a function of the dynamic pressure ($q_\infty$), wing surface ($S$) and the specific aircraft's known lift and drag coefficients ($C_L$, $C_D$) [5]. This results in:

$$L = W = q_\infty S C_L \quad (1)$$

$$D = T = q_\infty S C_D \quad (2)$$

Where:

$$q_\infty = \frac{1}{2}\rho_\infty v_\infty^2 \quad (3)$$

In level and unaccelerated flight the air density ($\rho_\infty$) is incrementally constant. Demonstrated by Eq. 3 the dynamic pressure is therefore solely a function of the free-stream air

# Mission Performance Trade-offs of Battery-powered sUAS

2017 International Conference on Unmanned Aircraft Systems (ICUAS)

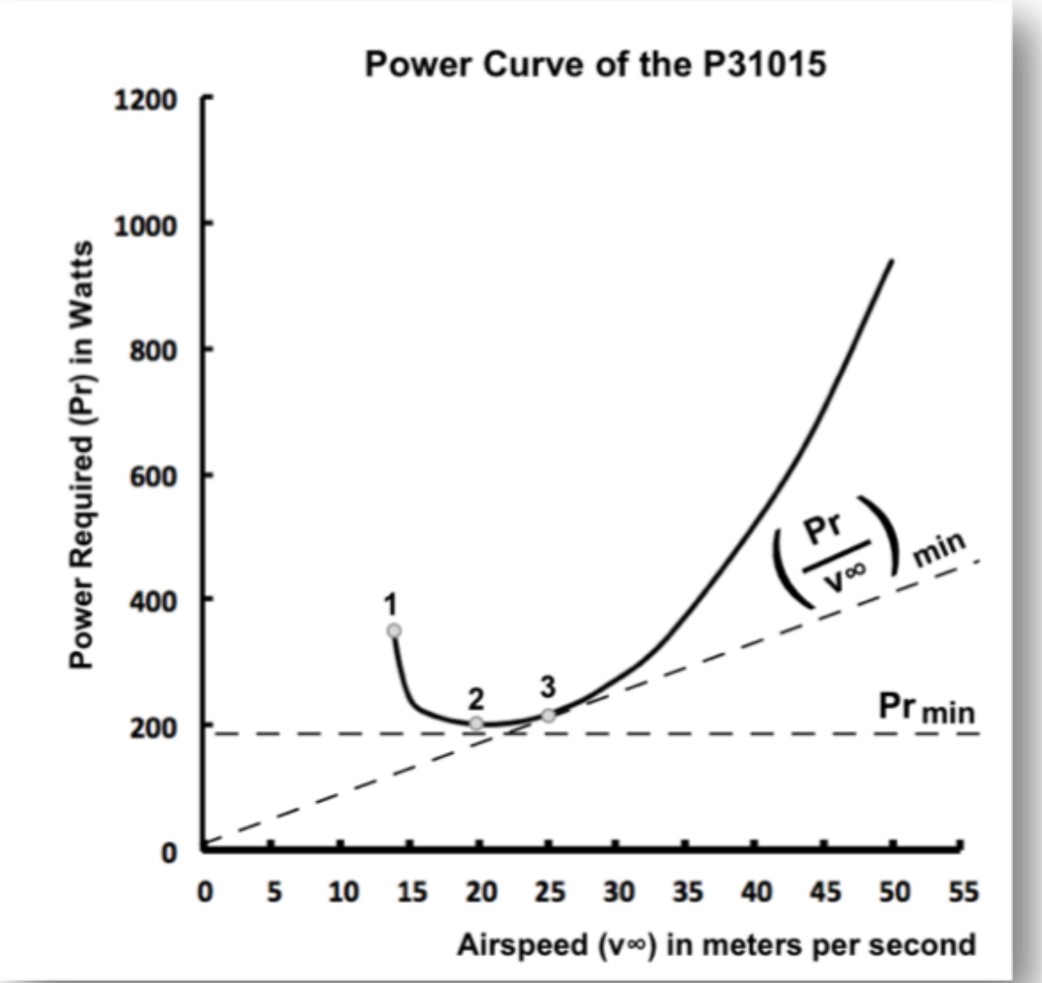
- Anthony Hovenburg
- Tor Arne Johansen
- Rune Storvold

# Question: how does a change in …

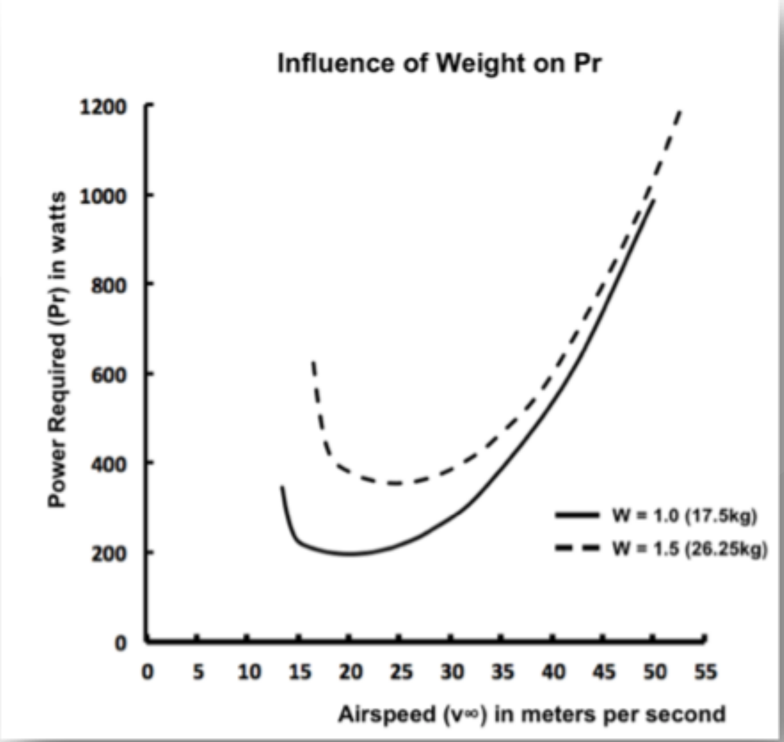
- Weight
- Altitude
- Airspeed

# affect the aircraft's …

- Maximum range
- Maximum endurance
- Stall speed



# Influence of **weight** on the performance of battery-powered aircraft



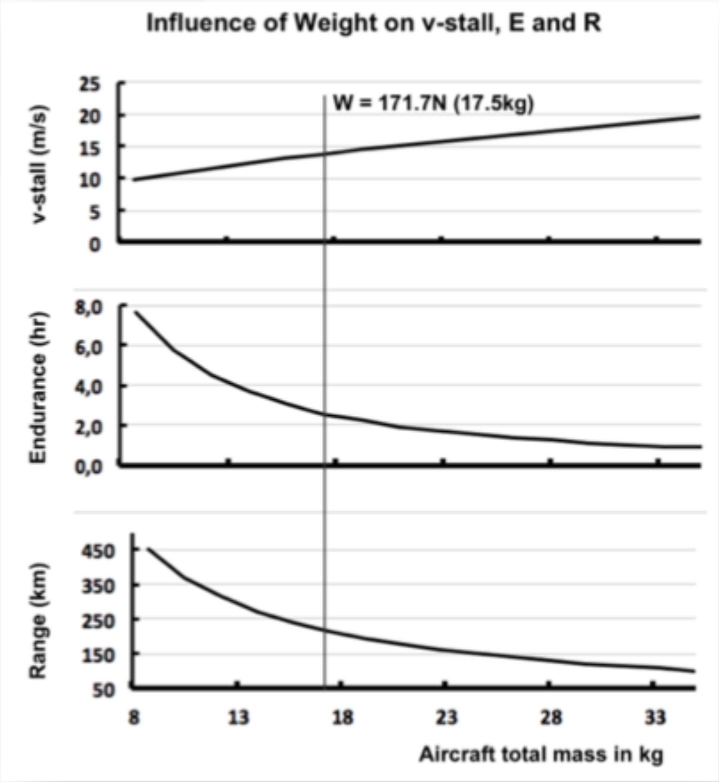

-Maximum Endurance (**Emax**) is influenced by: $W^{\frac{-3n}{2}}$

-Maximum Range (**Rmax**) is influenced by: $W^{\frac{1-3n}{2}}$

-Stall speed (**Vstall**) is influenced* by: $\sqrt{W}$

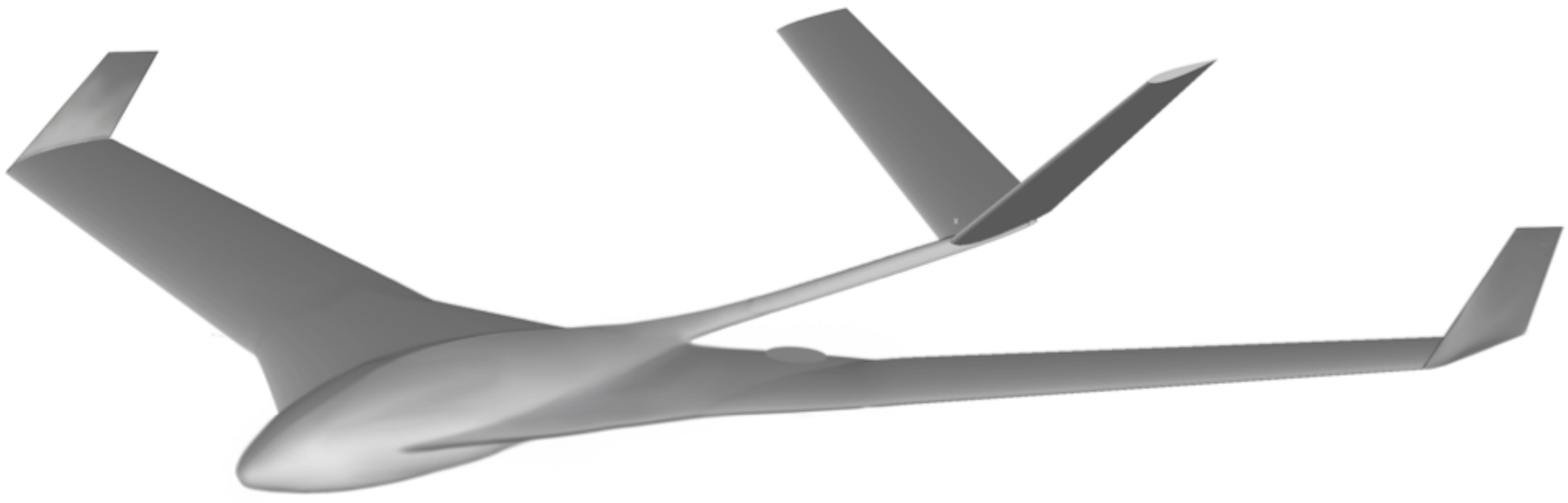
TABLE I. RESULTING PERFORMANCE AT VARYING WEIGHT

| $W_f$ as fraction of 17.5kg | $v_{stall}$ $(ms^{-1})$ | $E_{max}$ (hr) | $R_{max}$ (km) |
|---|---|---|---|
| 80% | 12.3 | 3.7 | 272.0 |
| 100% | 13.8 | 2.57 | 214.0 |
| 120% | 15.1 | 1.9 | 175.9 |
| 140% | 16.3 | 1.51 | 149.1 |



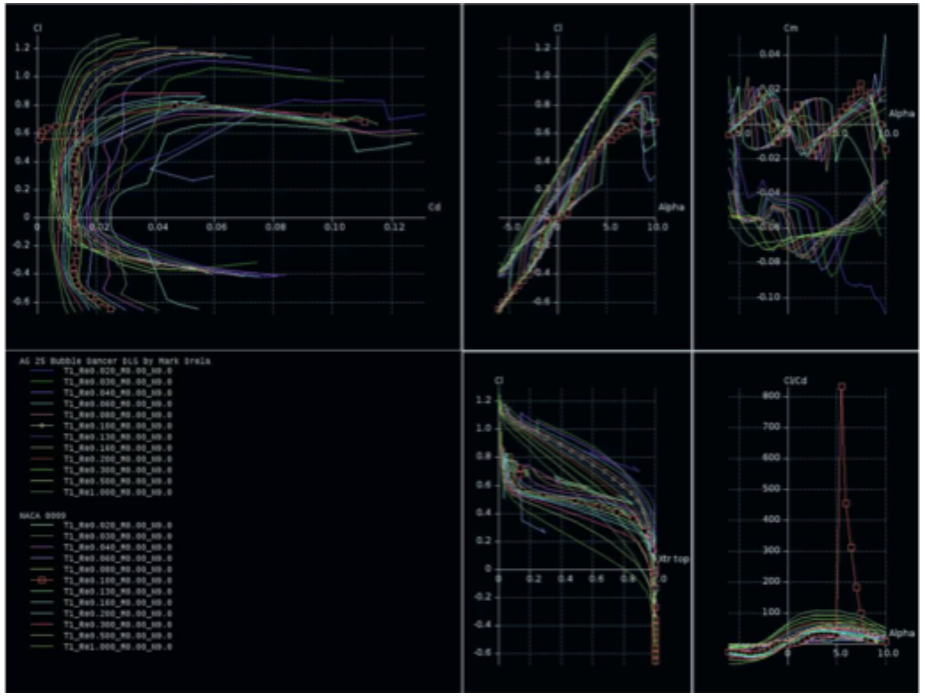
# Early proposal

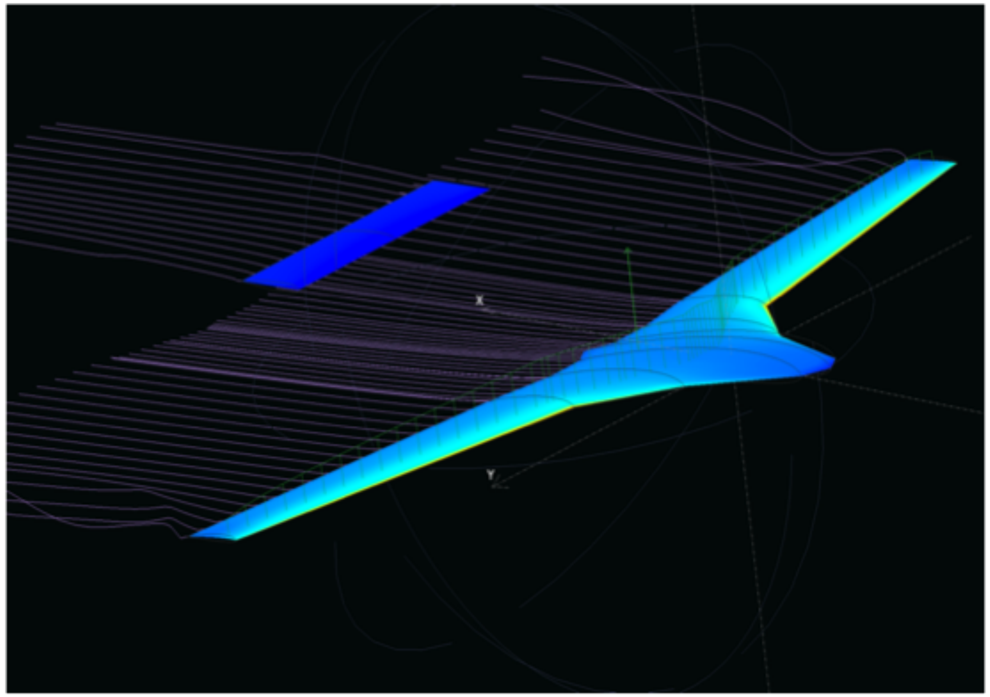
Aerodynamic design



# Further estimating in-flight performance

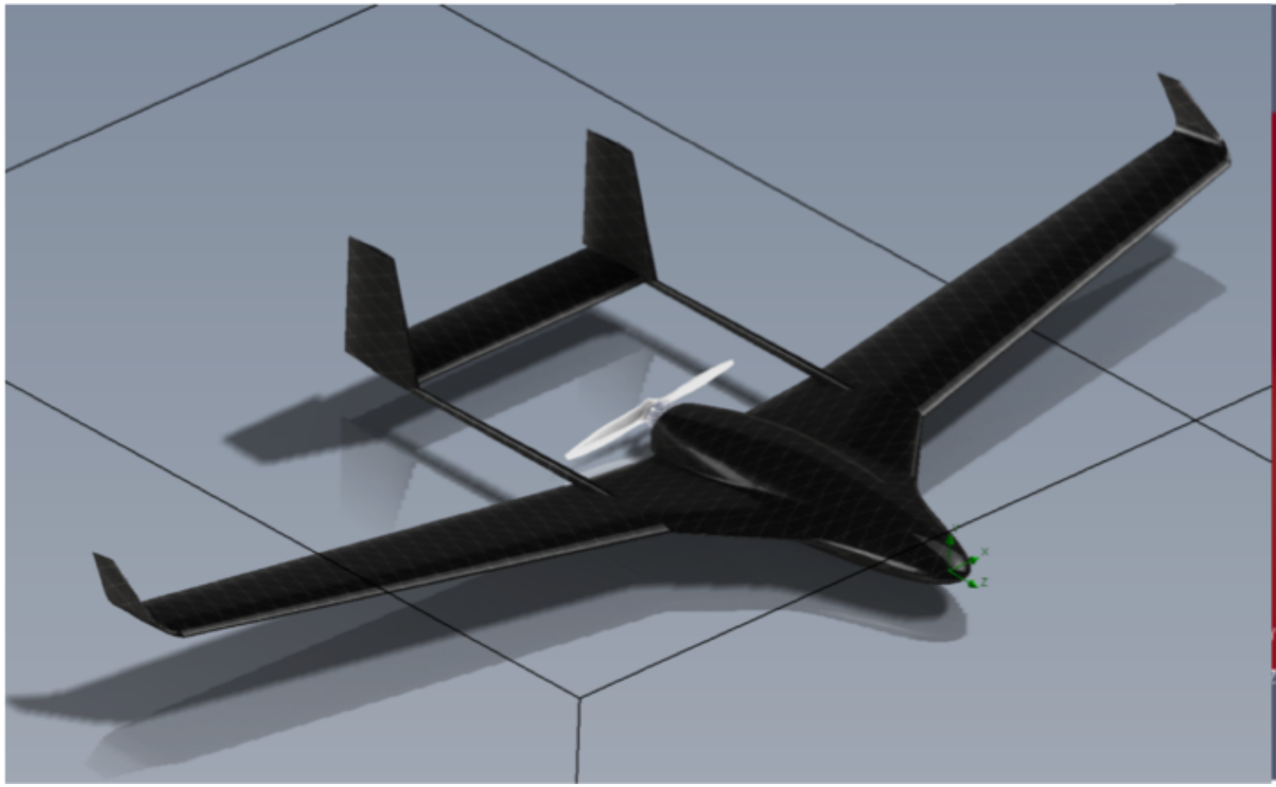
- Estimating the in-flight cruise, take-off and landing performance
- Validating the static stability model estimations

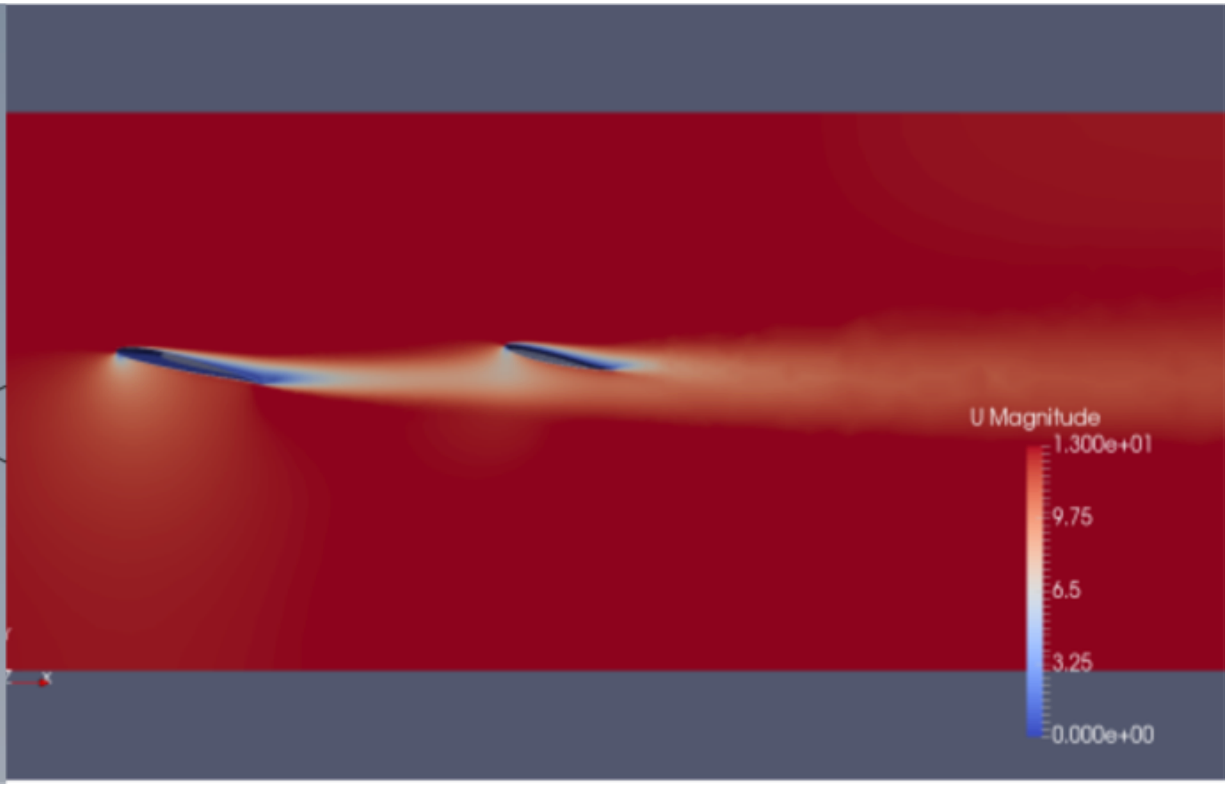


# Further estimating in-flight performance

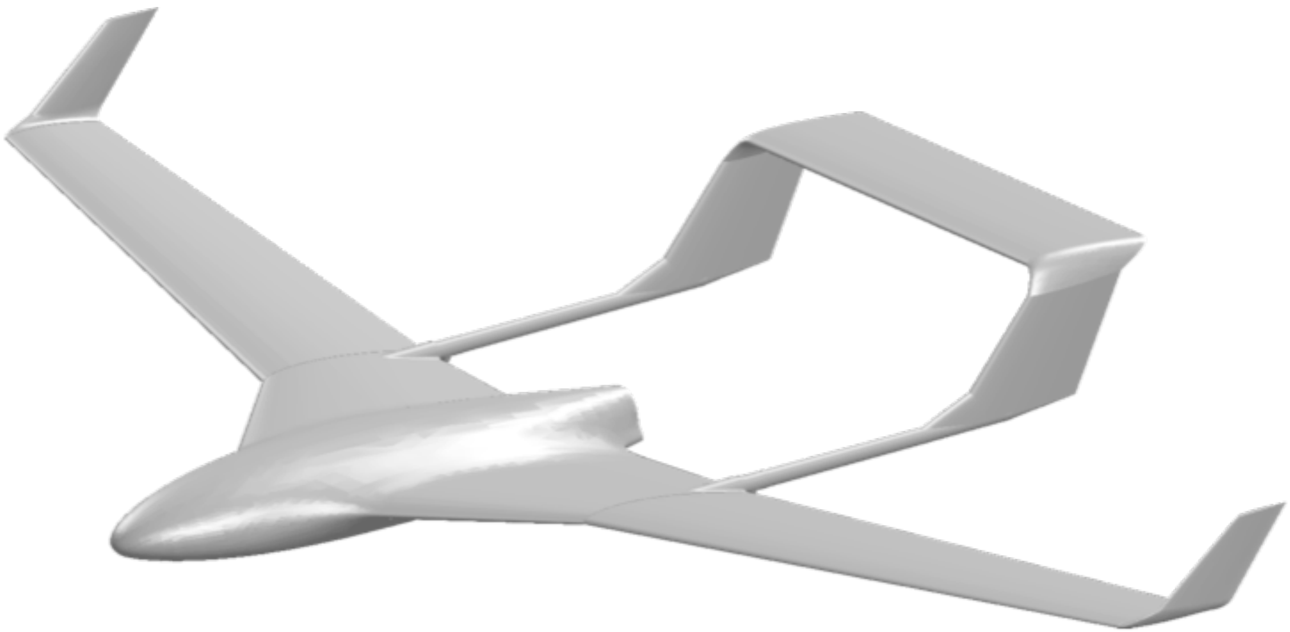
- Estimating the in-flight cruise, take-off and landing performance
- Validating the static stability model estimations





# Final proposal

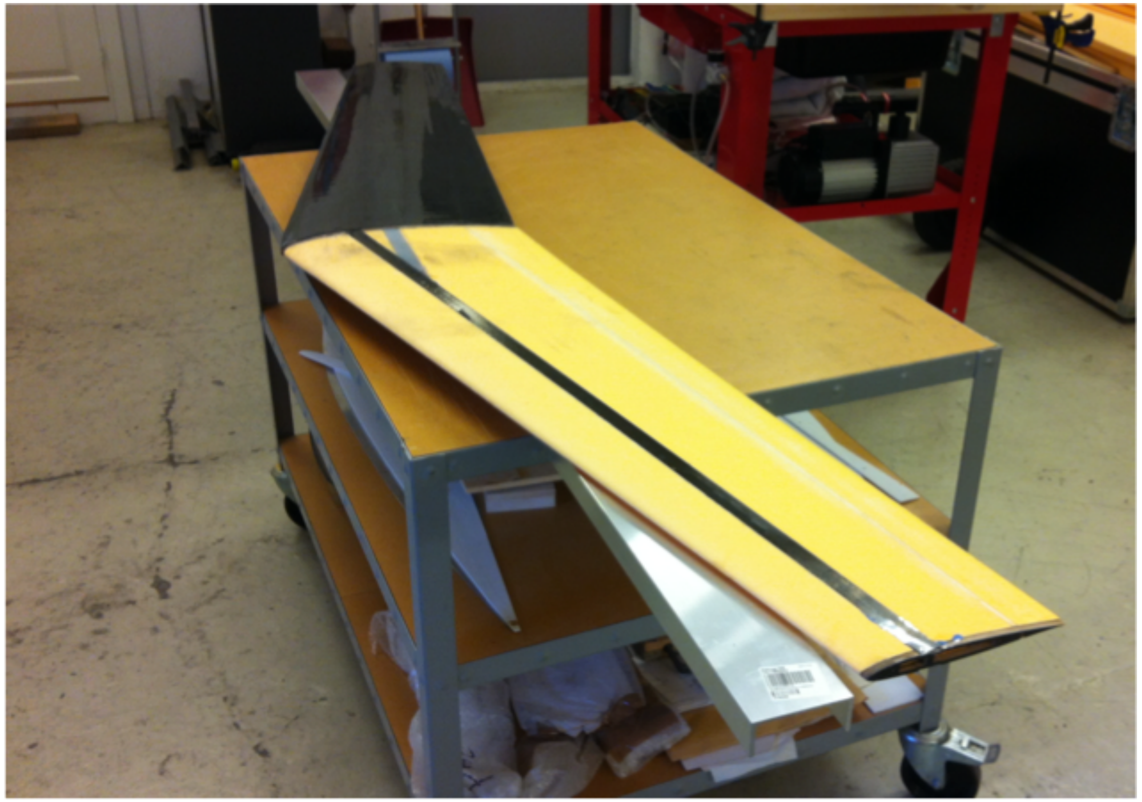
Aerodynamic design



# Final proposal

Aerodynamic design

# Construction …



# Prototype delivery

# Project New UAV

Norway's NextGen UAV

Feb '17

Finished building prototype

# Project New UAV

Norway's NextGen UAV

Feb '17

Apr '17

Finished building prototype

Test flight #1

☹

# Project New UAV

Norway's NextGen UAV

**Feb '17**

Finished building prototype

**Apr '17**

Test flight #1

☹

**Jul '17**

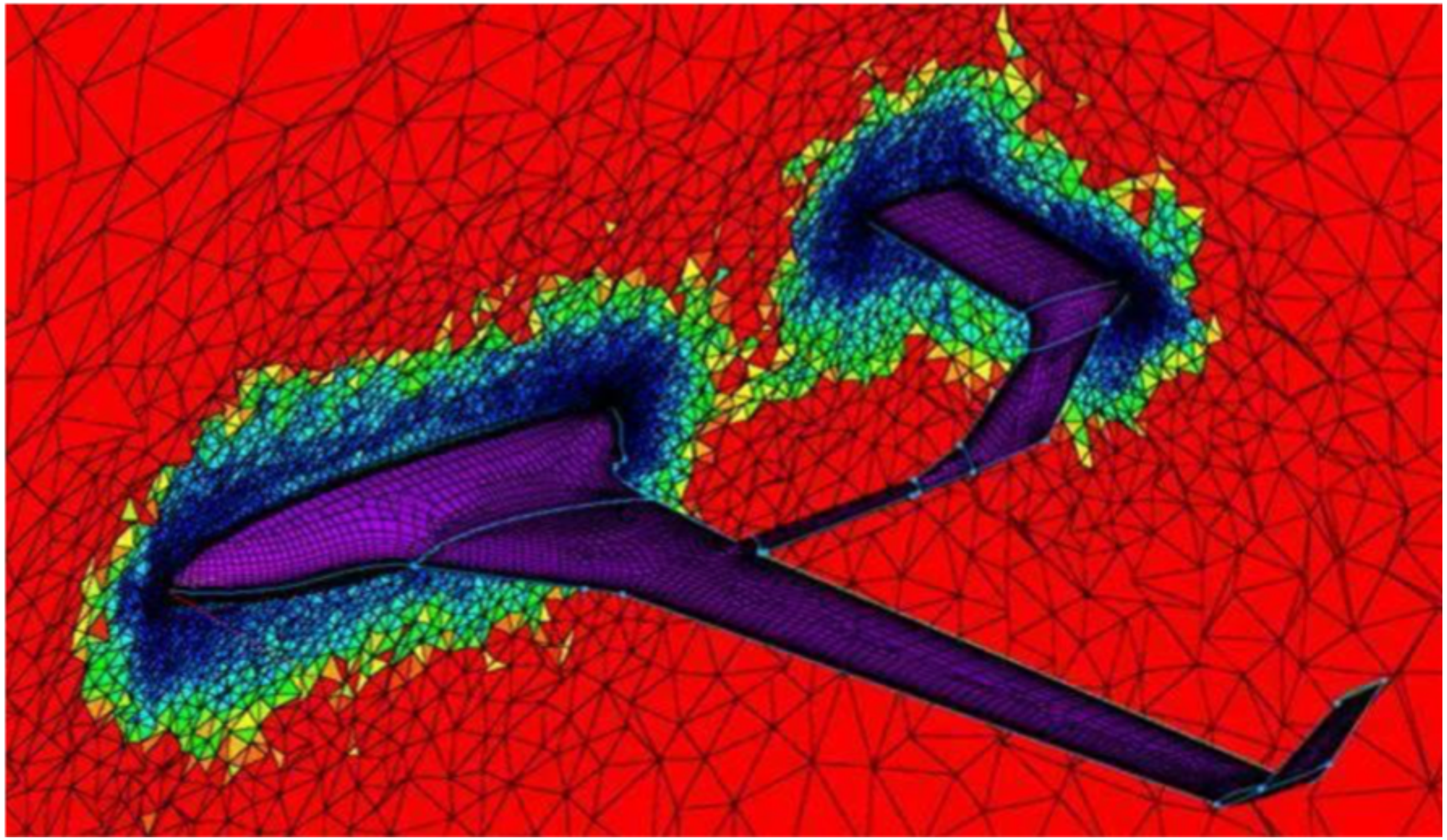
Test flight #2

☺

# Success!

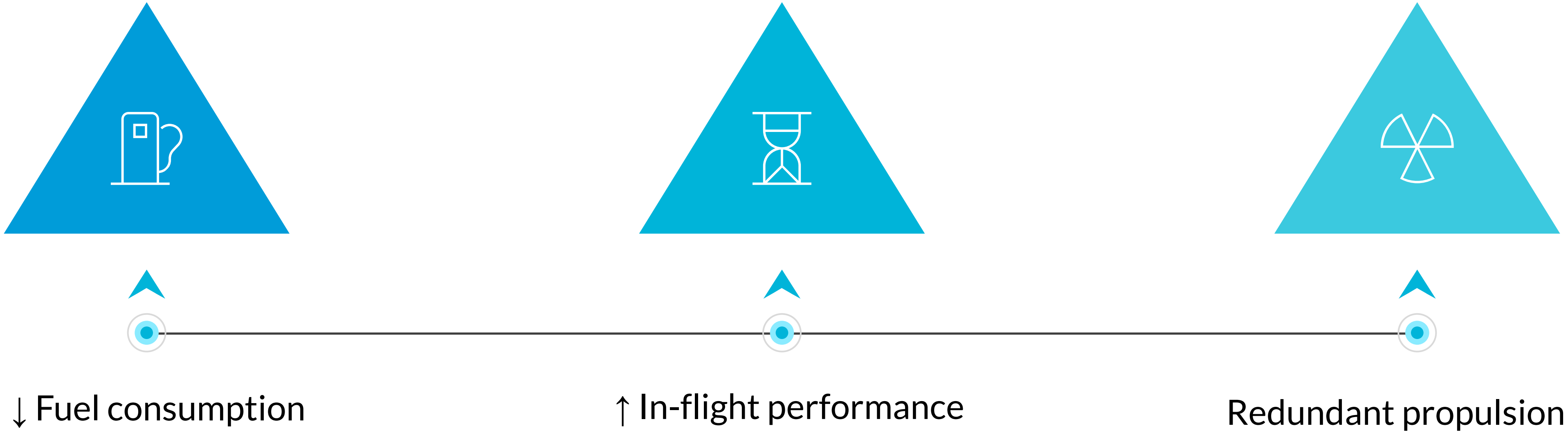
(after one practice round....)

# Further analysis CFD (or windtunnel?)



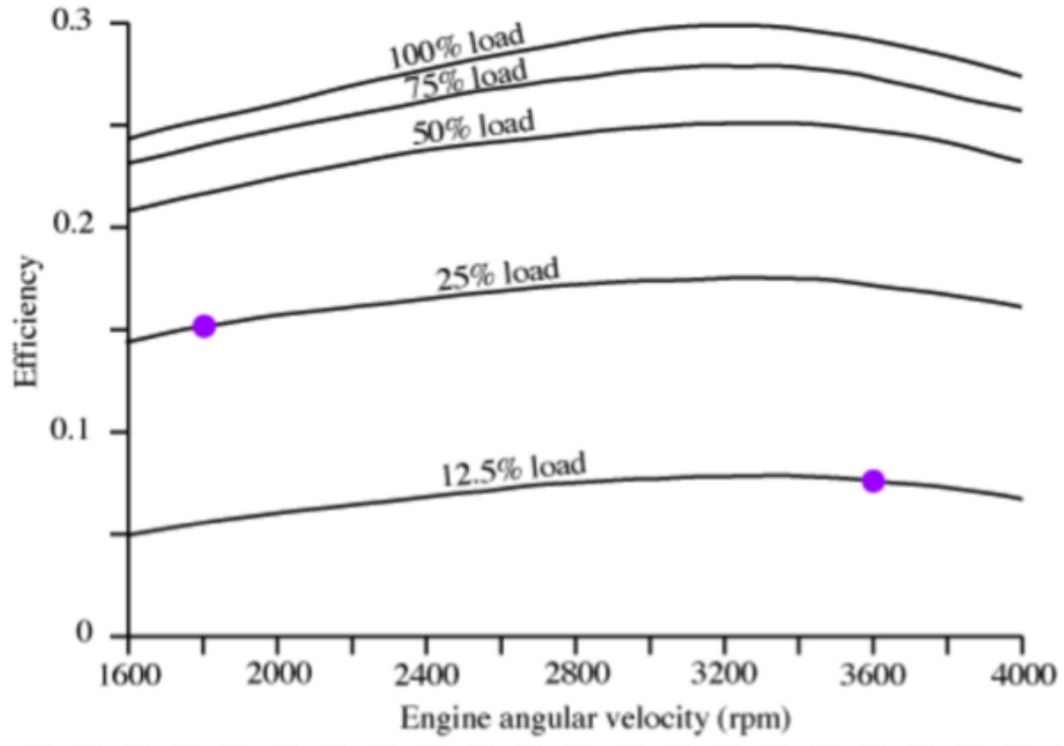
# Hybrid-Electric Propulsion

For Unmanned Aerial Vehicles



# Hybrid-Electric Propulsion

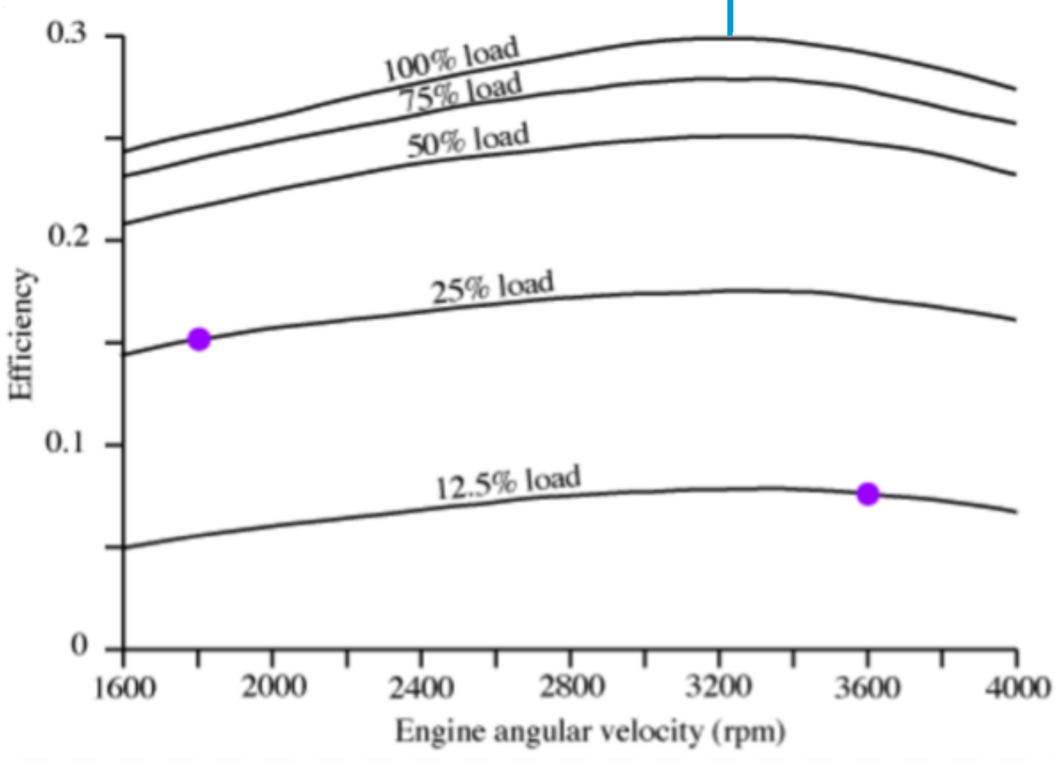
For Unmanned Vehicles




# Hybrid-Electric Propulsion

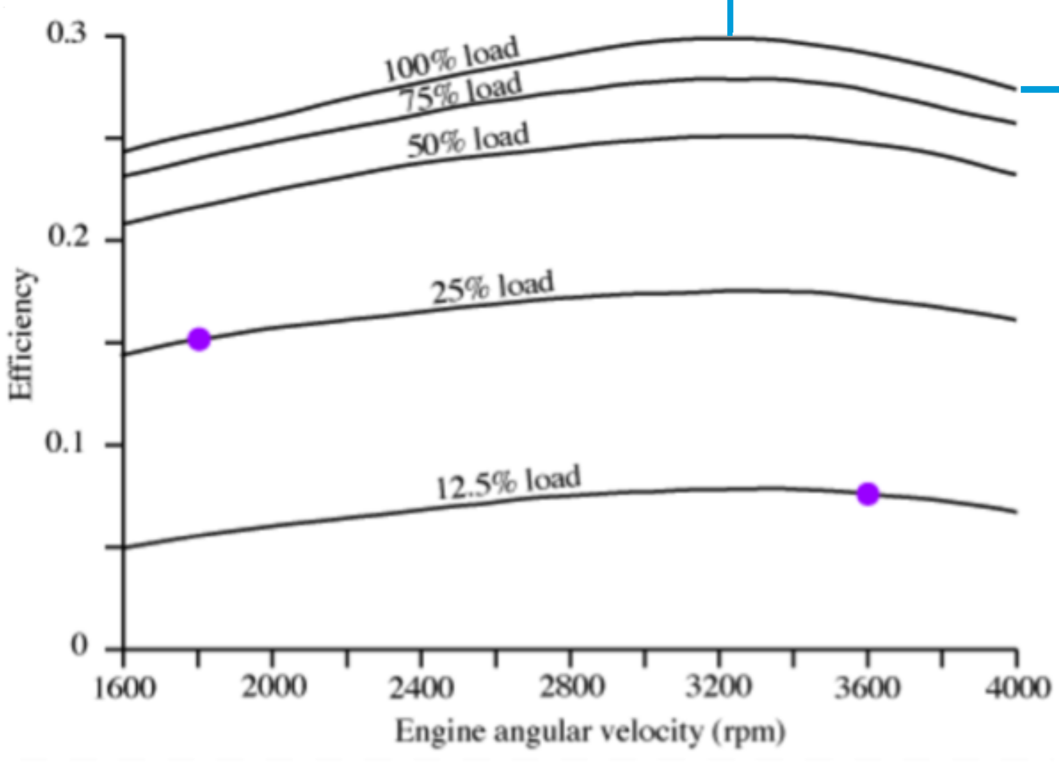
For Unmanned Vehicles

Desired engine load during cruise



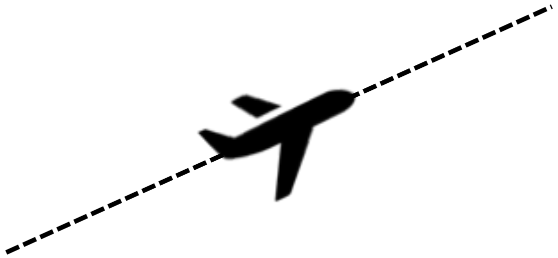

# Hybrid-Electric Propulsion

For Unmanned Vehicles



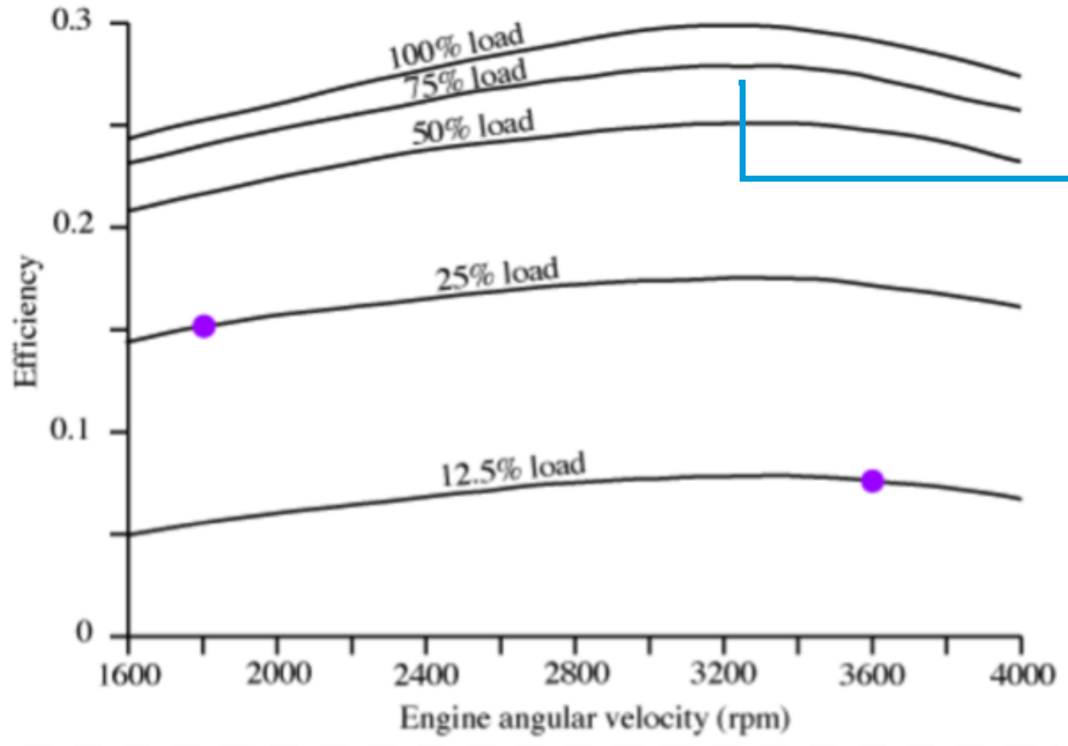

Desired engine load during cruise

Take-off power (not sufficient)



# Hybrid-Electric Propulsion

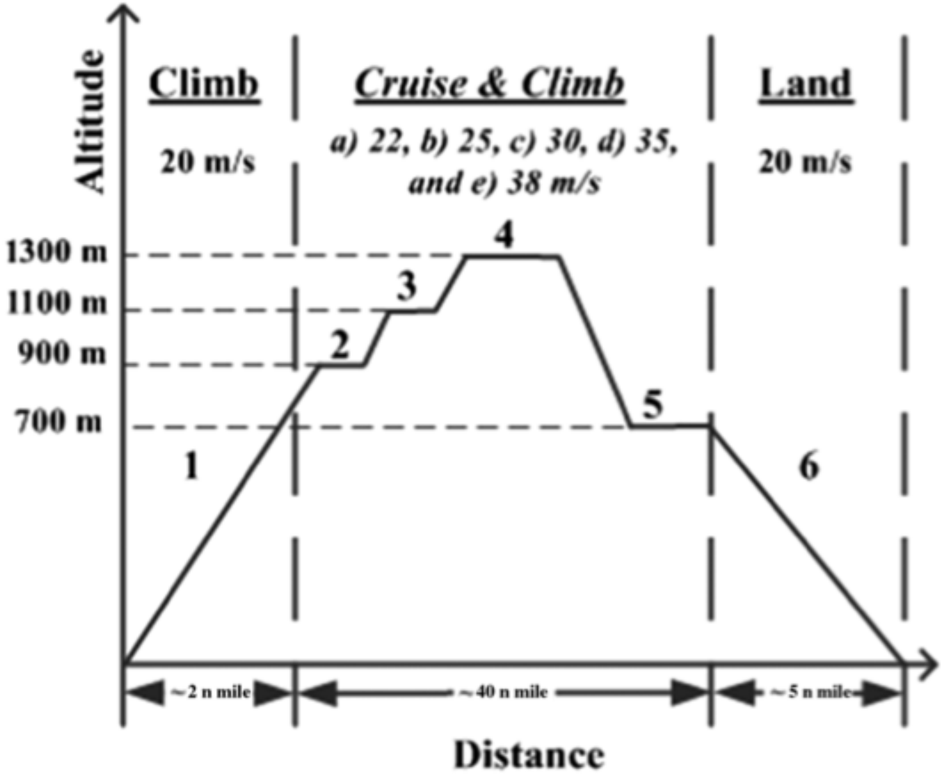
For Unmanned Vehicles




Bigger engine: sub-optimal cruise performance

# Hybrid-Electric Propulsion

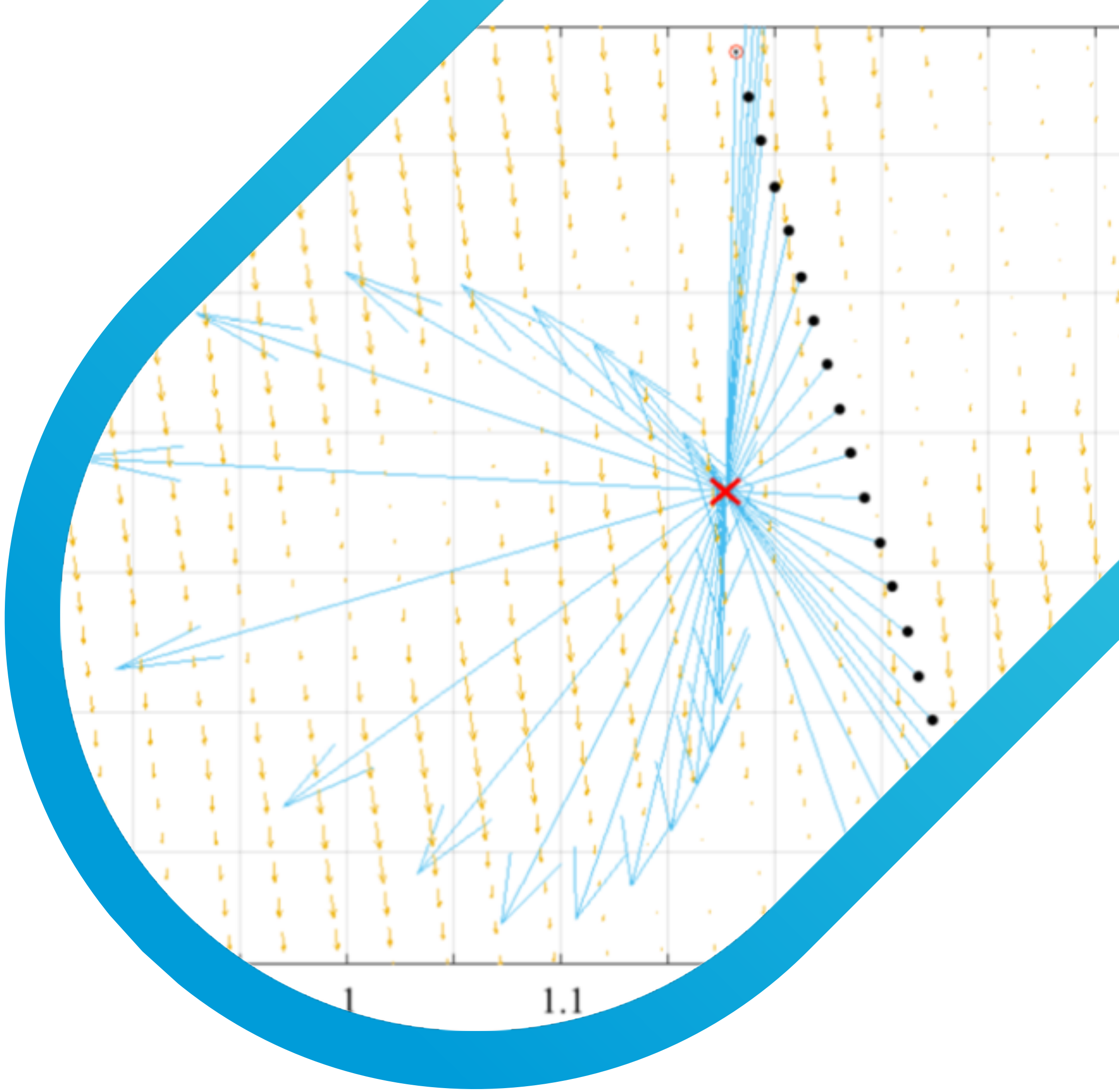
For Unmanned Vehicles

# Contingency Path Planning for Hybrid-electric UAS

A.R. Hovenburg, C. R. Dahlin, F. A. A. Andrade

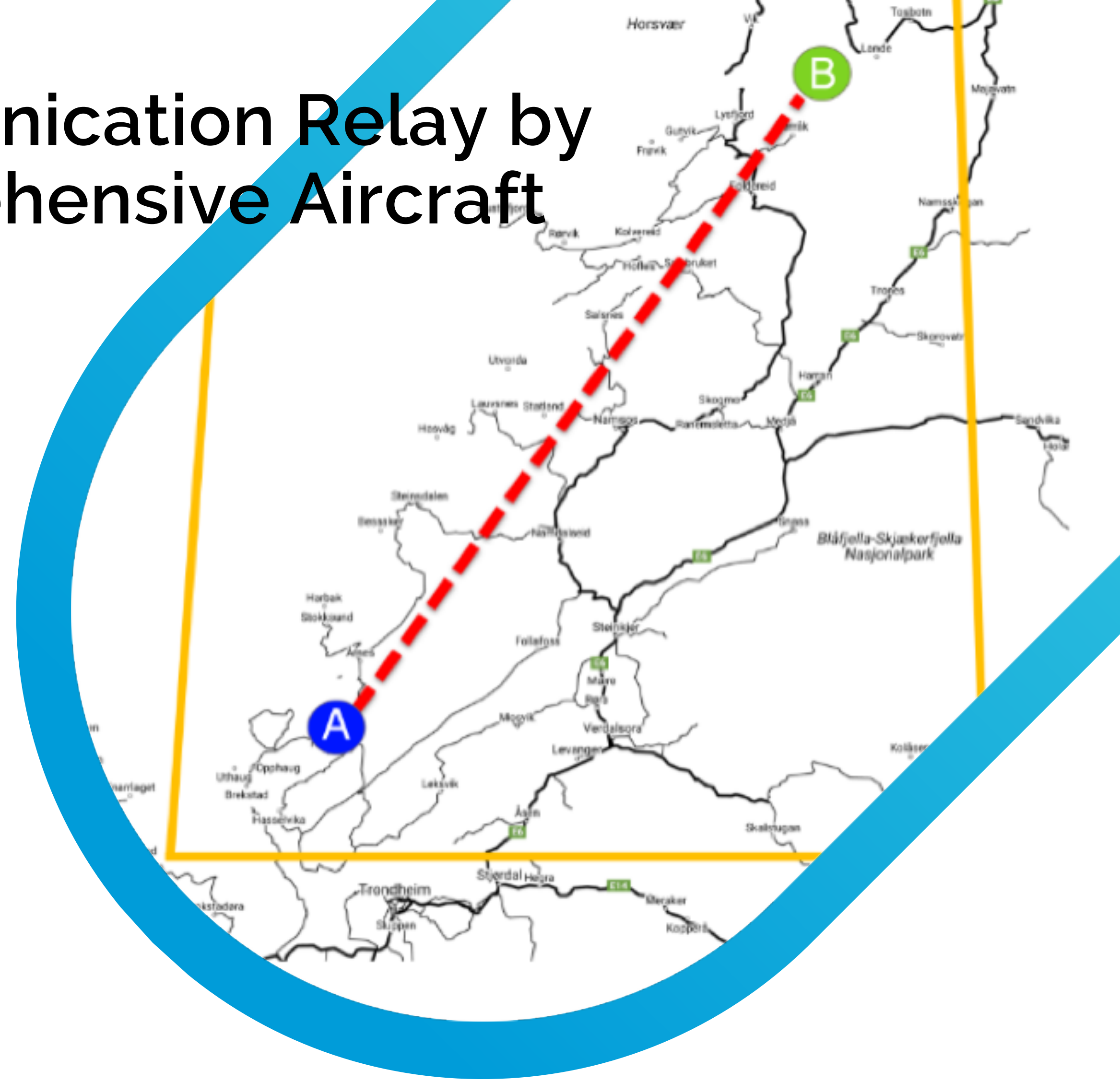
- Utilizing redundant propulsion
- Pre-determined safe-zones
- Particle swarm optimisation
- Inclusion of detailed wind maps



# Path Planning of Multi-UAS Communication Relay by Decentralized MPC Using a Comprehensive Aircraft Performance Model

A.R. Hovenburg, F. A. A. Andrade, C. R. Dahlin

- Communication relay using UAVs
- Aircraft performance model
- Inclusion wind maps
- MPC versus PSO
- Hopefully flight tests



# Performance optimization for hybrid-electric sUAS equipped with de-icing systems

A.R. Hovenburg, , R. Hann, K.L. Sørensen, T.A. Johansen

- Performance study
- Variation in de-icing strategy
- Penalty on flight range/endurance
- Pre-mission analysis (block fuel, etc)
- Path planning optimization (trajectory)

# Mission-based optimization of HEPS in sUAS

A.R. Hovenburg, T.A. Johansen, R. Storvold

- Mission analysis (adopt)
- Generator sizing (adopt)
- Block fuel
- Battery capacity
- Generic performance algorithm

# Why I believe in HEPS in sUAS

1

**Cleaner**

Reduced emissions
and noise pollution

2

**More efficient**

Reduced fuel consumption
and/or increased performance

3

**Bridging technology**

Transitioning towards
battery-only propulsion

4

**Scalable**

Reduced fuel consumption
and/or increased performance


Thank you!
Questions?