Aero-Performance Considerations for the Design of eVTOLs

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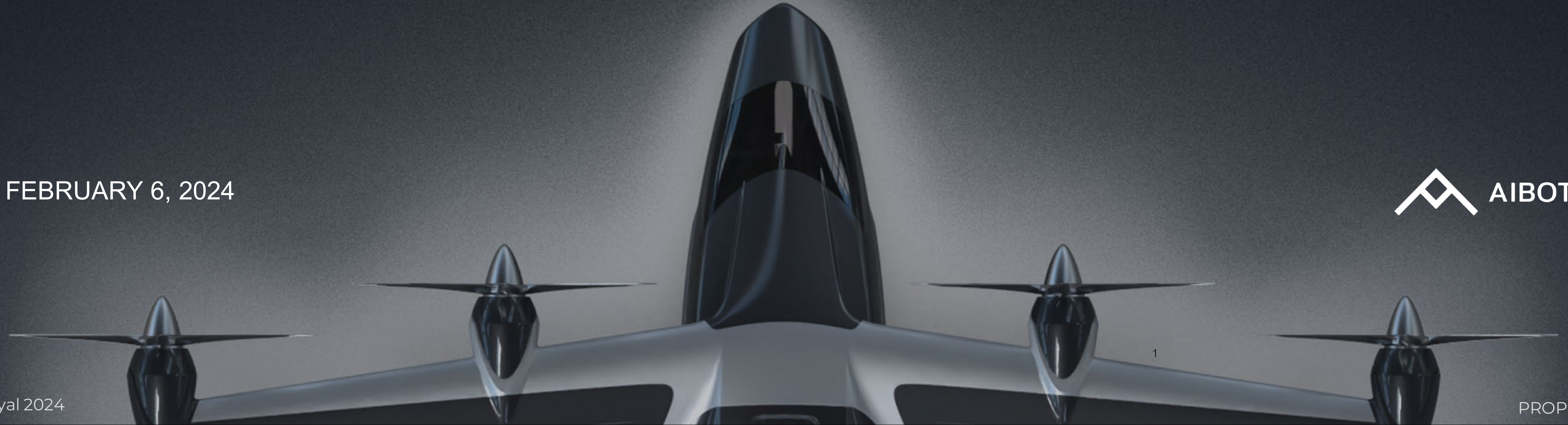
AIBOT



eVTOL: Their Different Configurations


Airbus: Vahana


Vertical : VX4


Joby: S4


Volocopter: Volocity


Archer: Midnight


AutoFlight: Prosperity

- Safety
- Low noise

- Range
- Cruise speed

- Cost per passenger mile
- Reduced footprint

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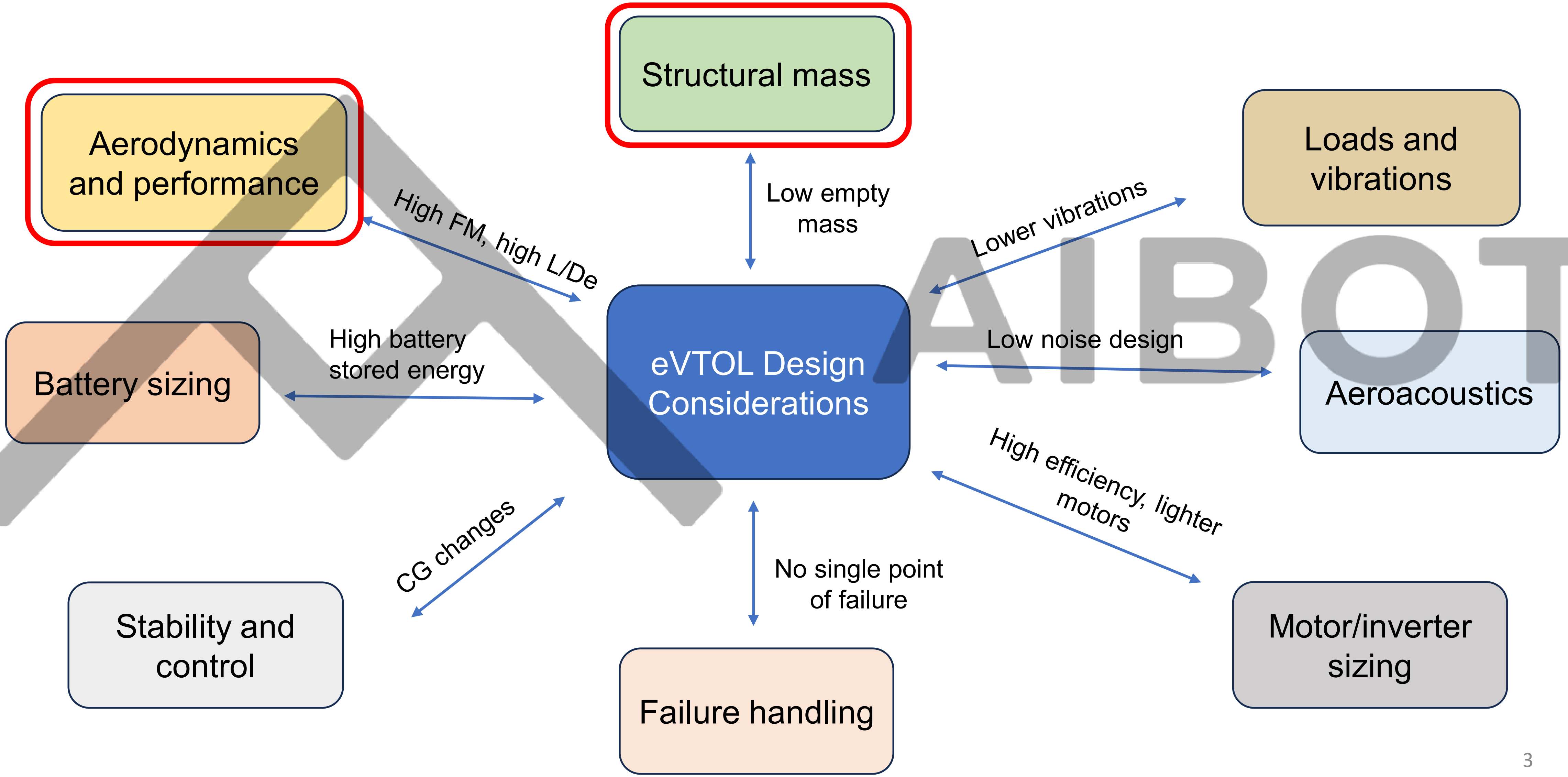
Multidisciplinary Design of eVTOLs



eVTOL Design Considerations

Structural mass

Low empty mass

Aerodynamics and performance

High FM, high L/De

Loads and vibrations

Lower vibrations

Battery sizing

High battery stored energy

Aeroacoustics

Low noise design

Stability and control

CG changes

Failure handling

No single point of failure

Motor/inverter sizing

High efficiency, lighter motors

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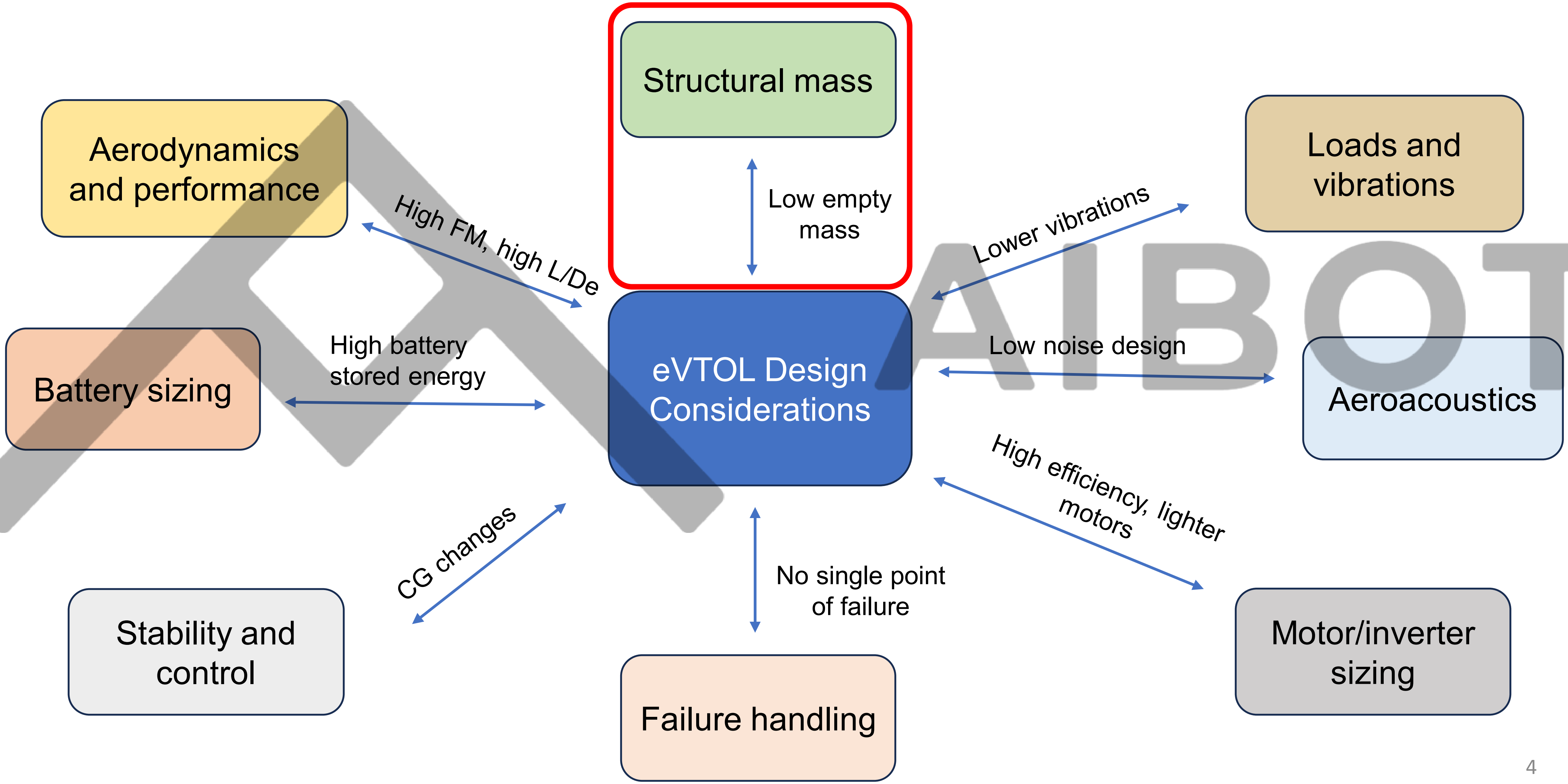

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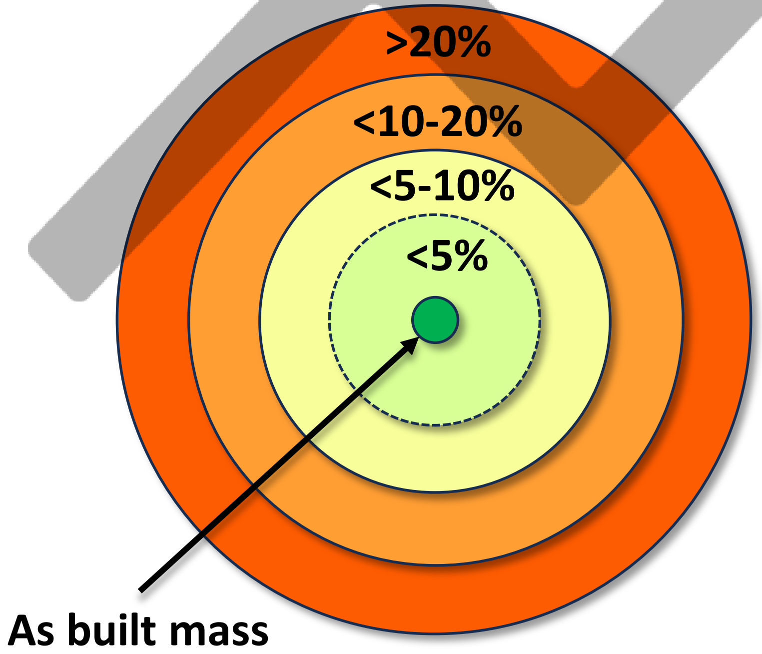
Estimating Empty Mass of an eVTOL

- Empty mass = Takeoff mass – battery mass – payload mass
- Trendlines/empirical relations exist for predicting empty mass of helicopters and airplanes
- No database available for eVTOLs!
- How much “growth” from the initial empty mass and “as built” empty mass is acceptable?



Vahana: Image taken from public domain

Sensitivity of eVTOL Takeoff Mass with Empty Mass

Size an eVTOL to get a payload of 1000 lb and a range of 100 miles with L/De = 11

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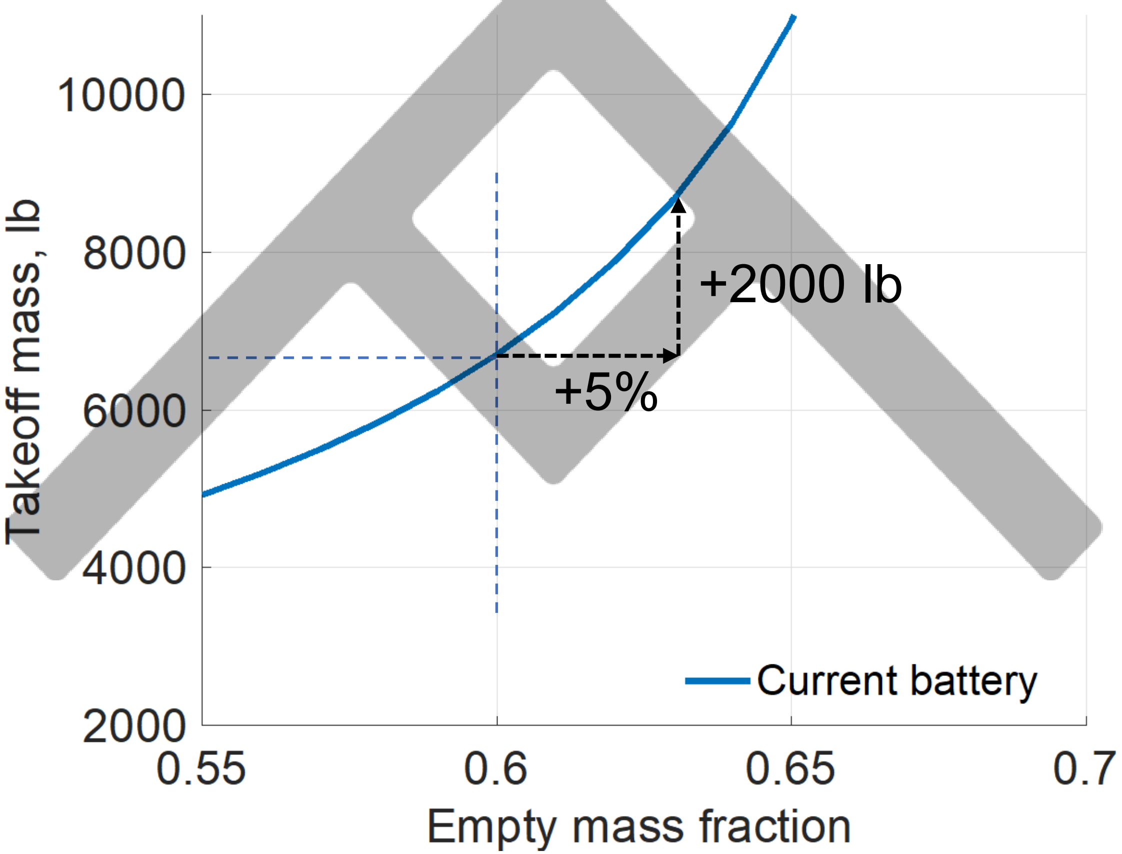

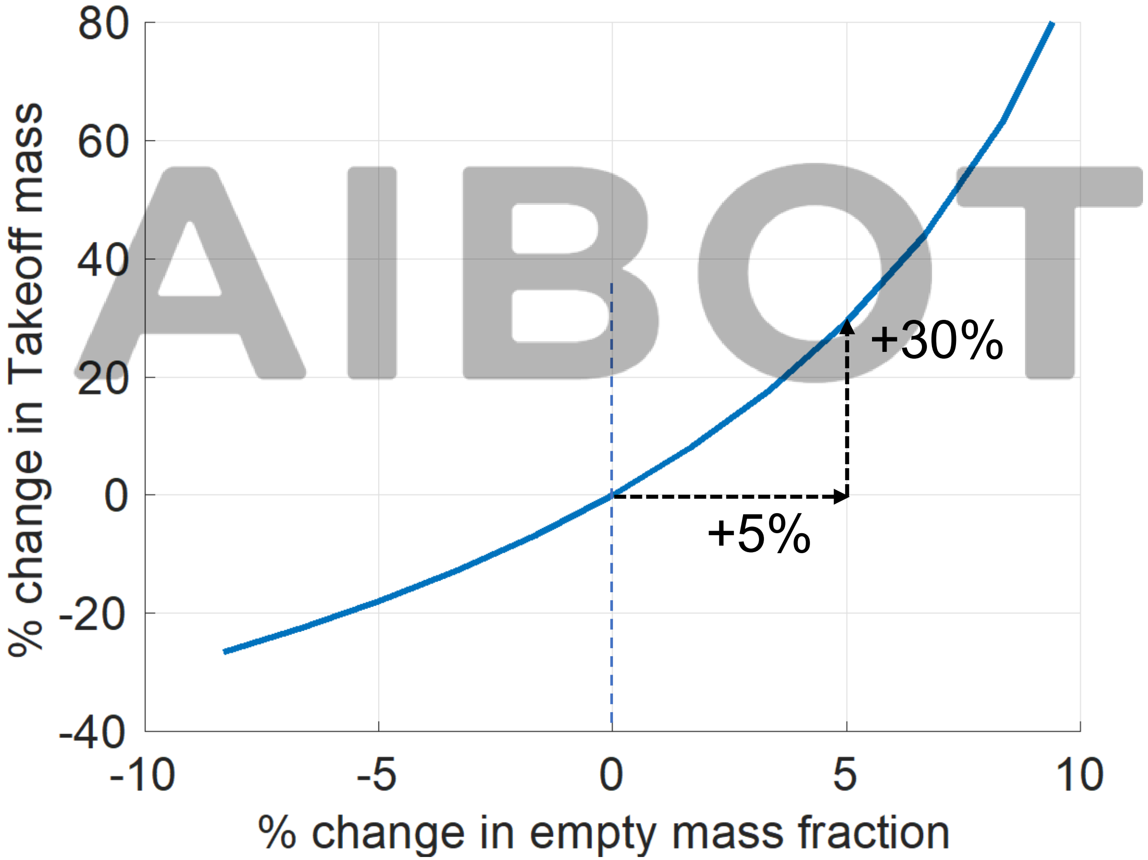

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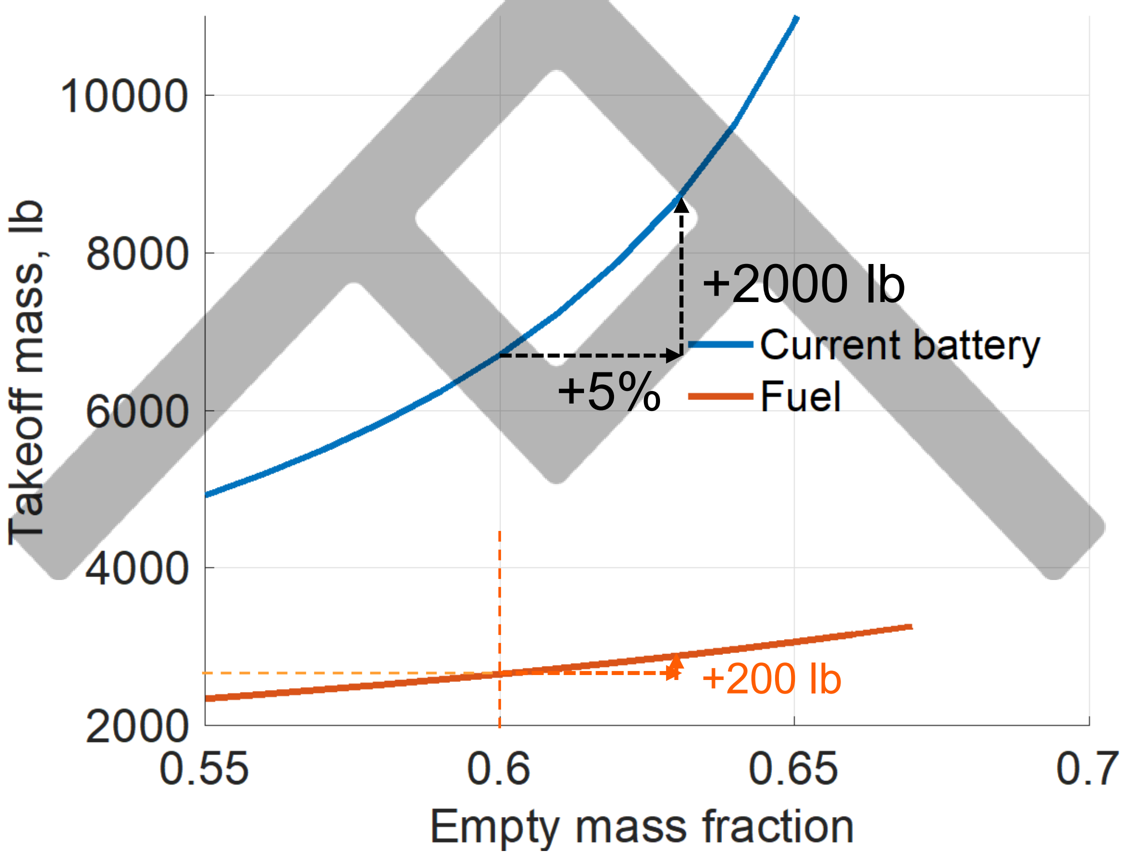
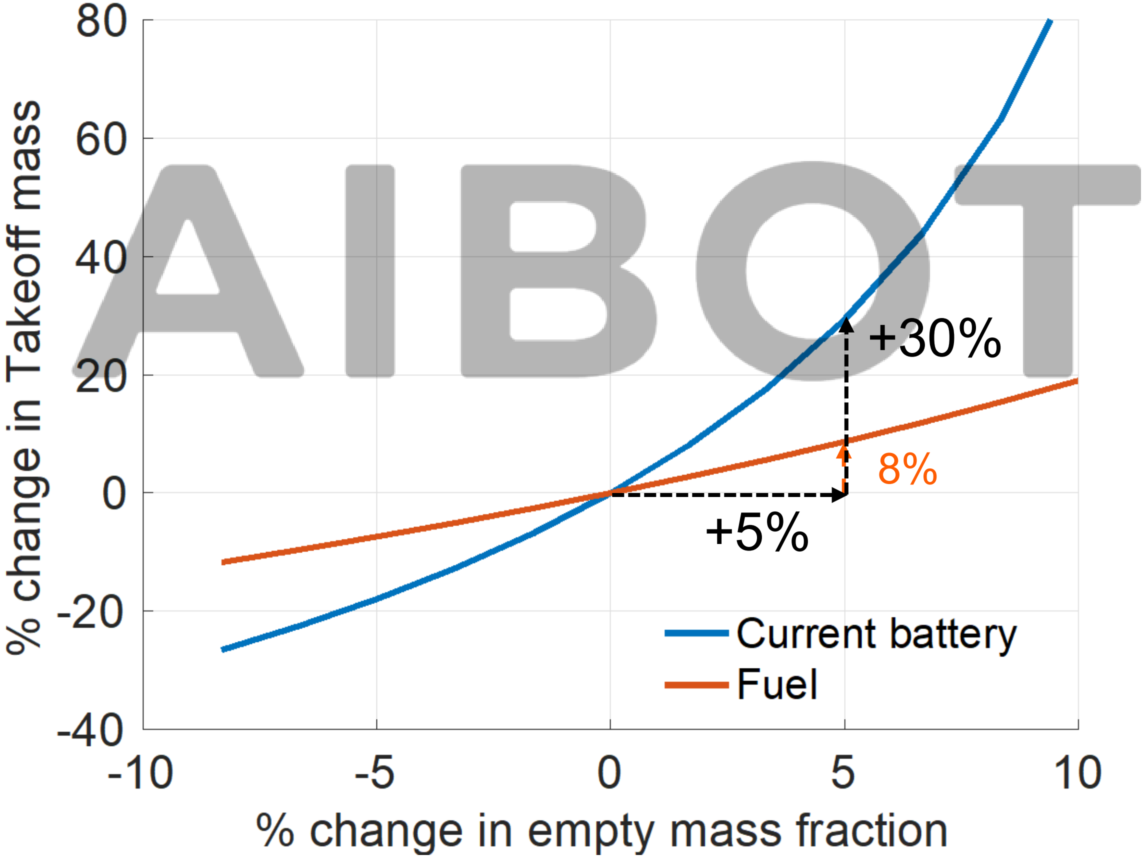
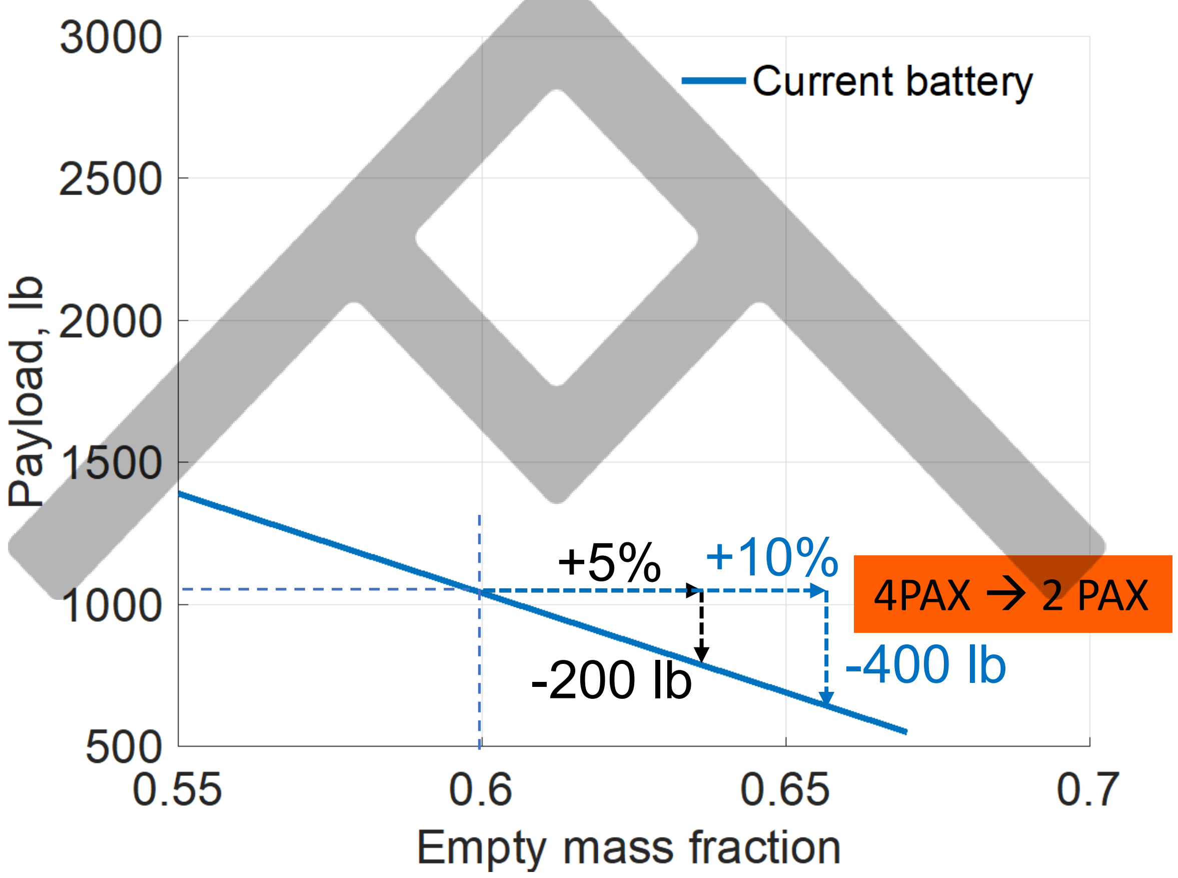
Size an eVTOL to get a payload of 1000 lb and a range of 100 miles with L/De = 11

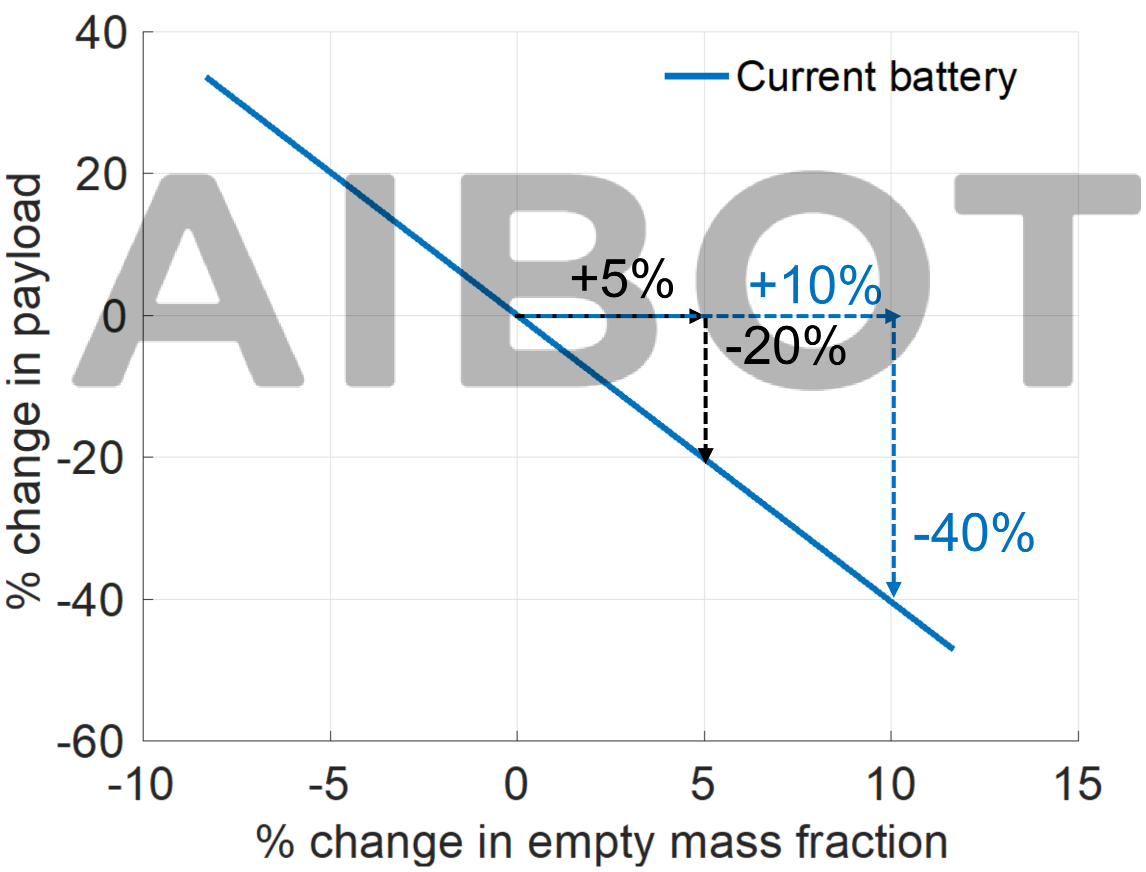




Sensitivity of eVTOL Payload with Empty Mass

Payload versus empty mass for a 7000 lb eVTOL for range of 100 miles with L/De = 11



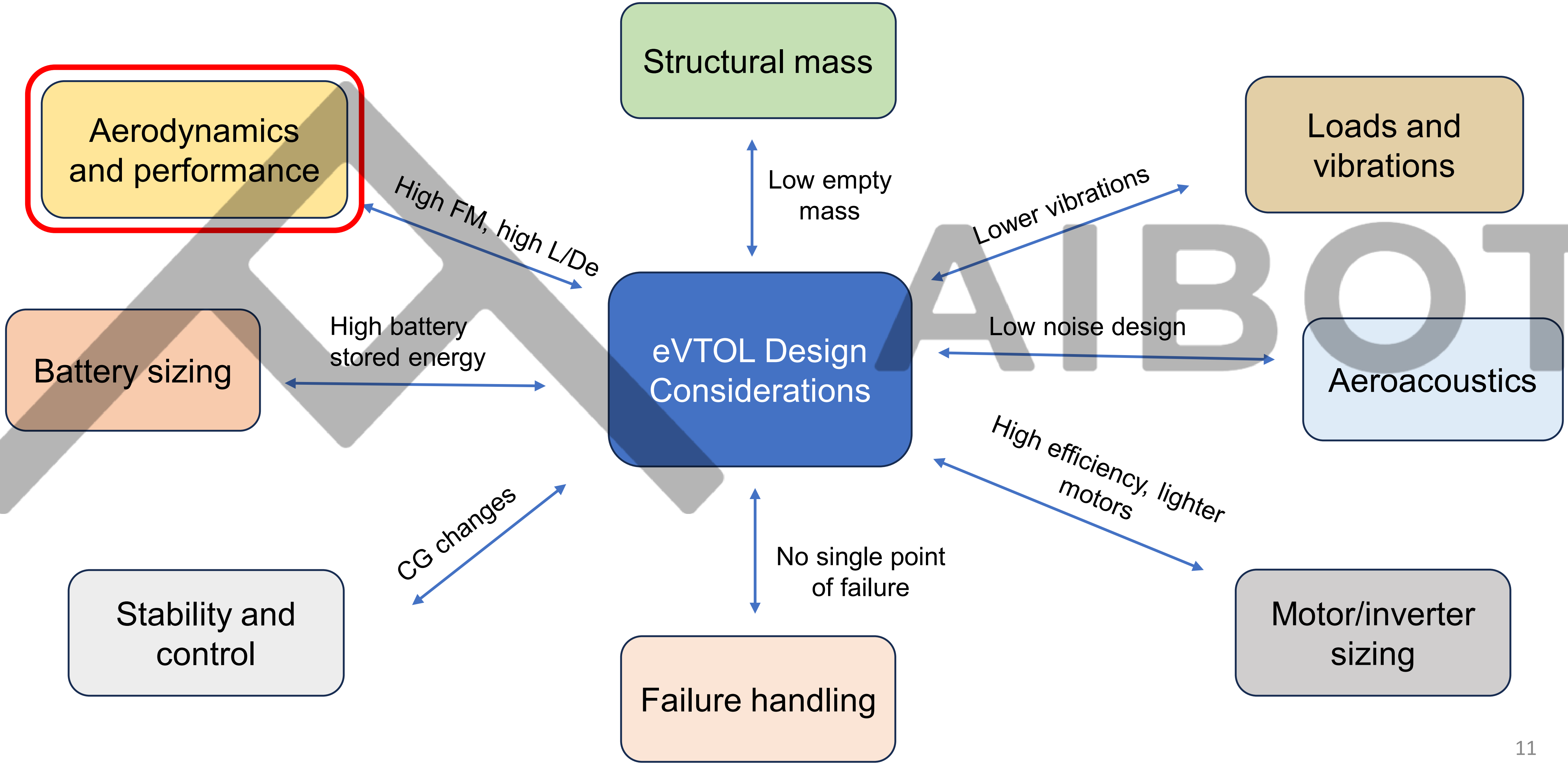


eVTOL Empty Mass Management

- Start with a “realistic” empty mass based on configuration
- Detailed mass buildup at conceptual design phase
- Careful consideration of **empty mass and performance** tradeoffs early in the design phase
- Bottom-up structural mass analysis using FEA early in the design phase
- Keeping realistic margins for mass “growth”
- Keeping a close track of every sub-system mass at every stage of development

Vahana: Image taken from public domain

Multidisciplinary Design of eVTOLs



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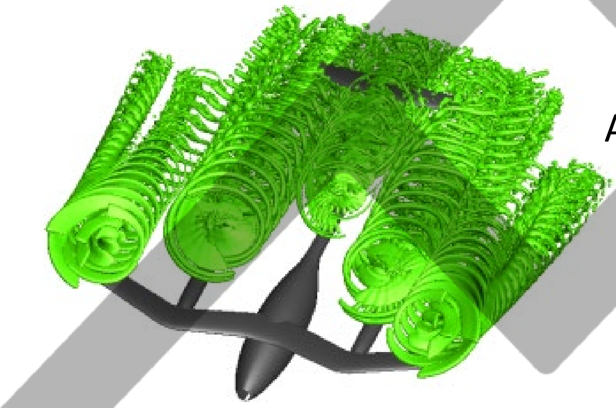
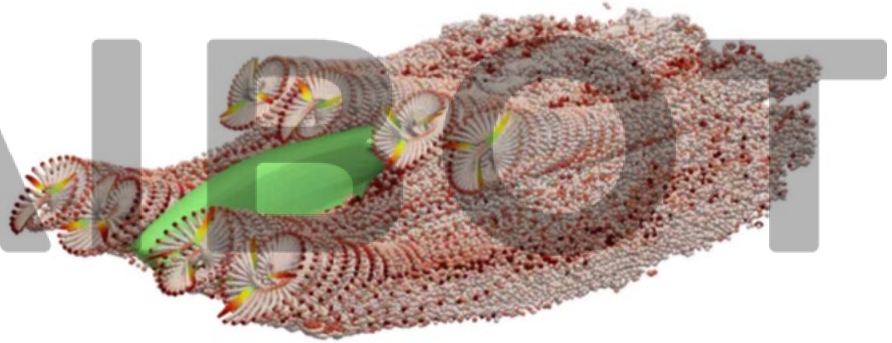
eVTOL Interactional Aerodynamics

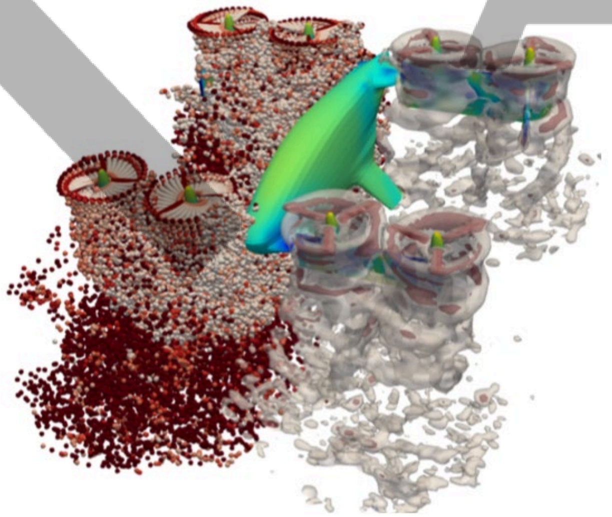
- Modeling eVTOL interactional aerodynamics is challenging
- Accurate interference modeling important to design an efficient, low noise, low vibration, and high performance eVTOL



ART-VVPM



DUST



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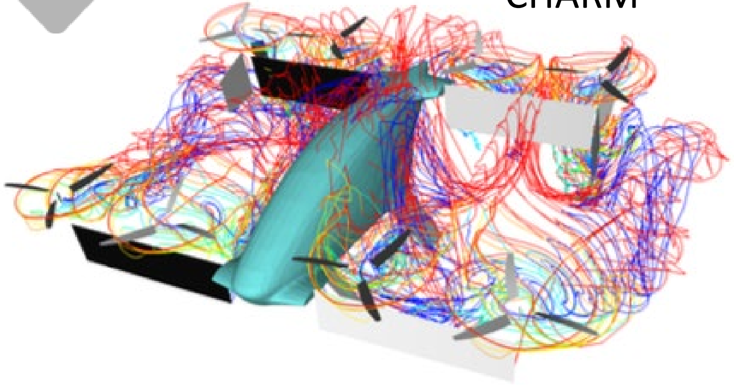
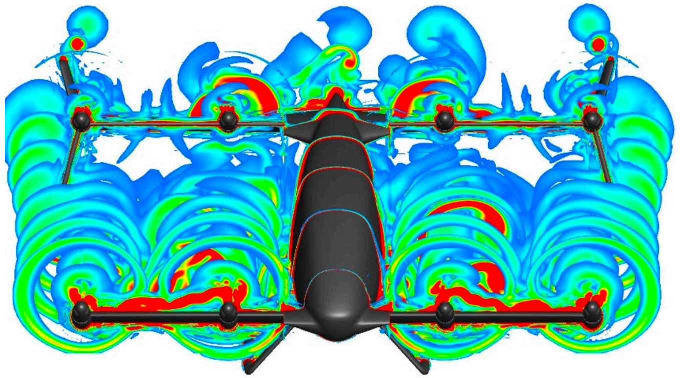


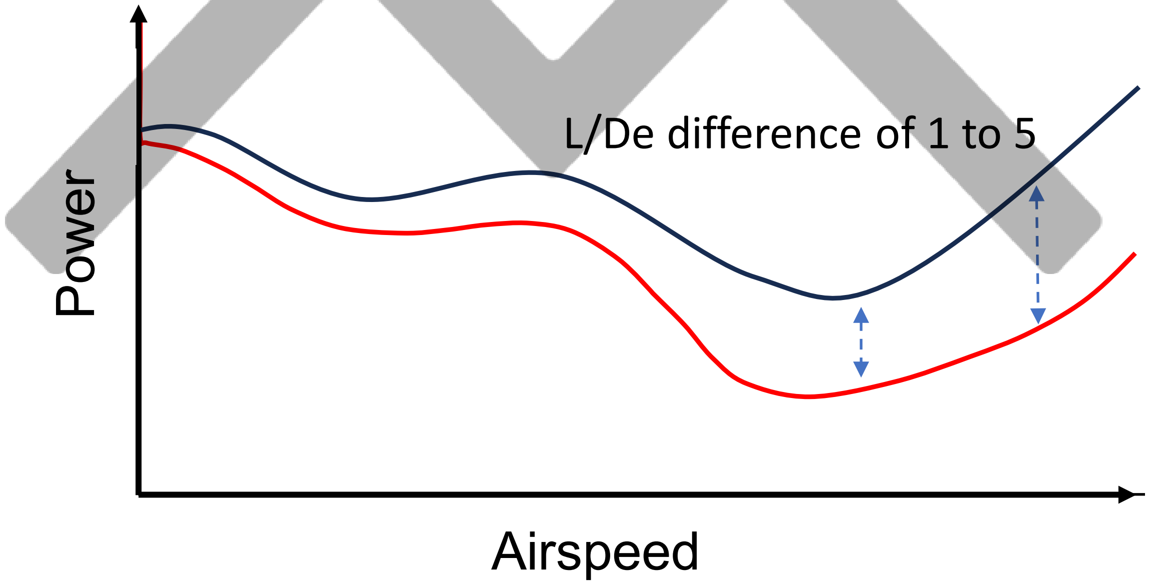
CHARM

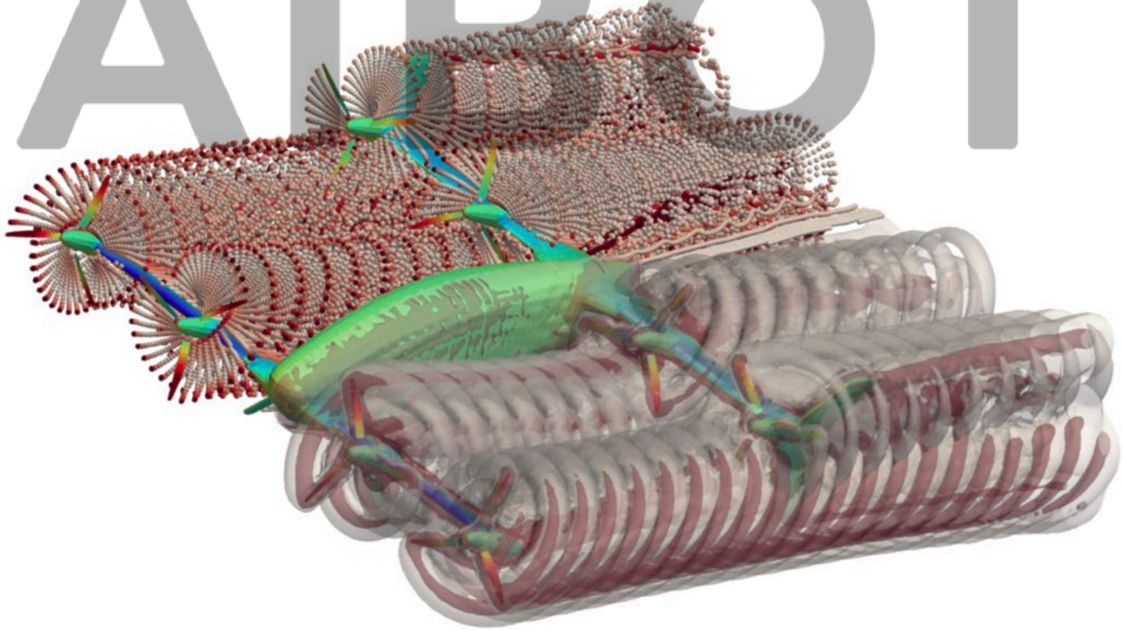


CFD: Rosita

Modeling Aero Interference Early in eVTOL Design

- L/De is an important metric for eVTOL performance in cruise flight mode
- Aerodynamic interference can significantly impact L/De predictions
- Need to study design drivers early in conceptual design: Placement of wing(s), props for improved efficiency and lower vibrations





Sensitivity of eVTOL Takeoff Mass with L/De

Size an eVTOL for a 1000 lb payload and a range of 100 miles with empty mass fraction 0.6

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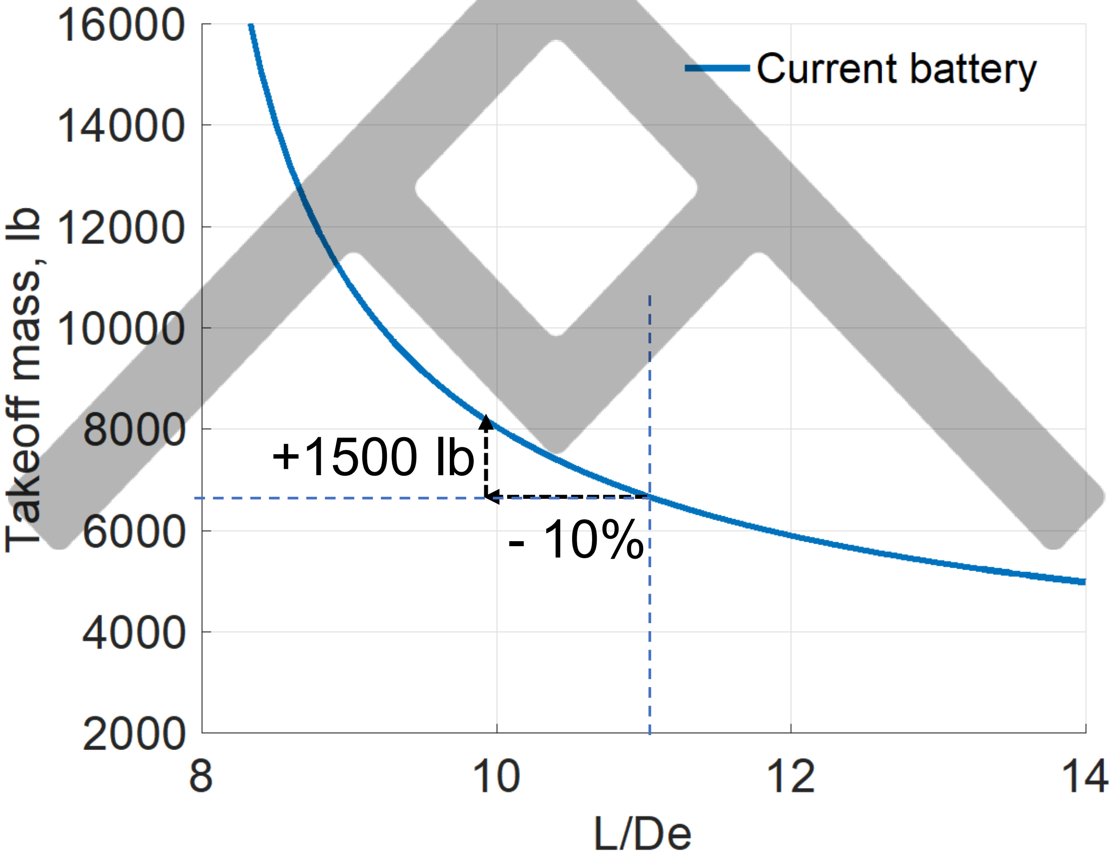
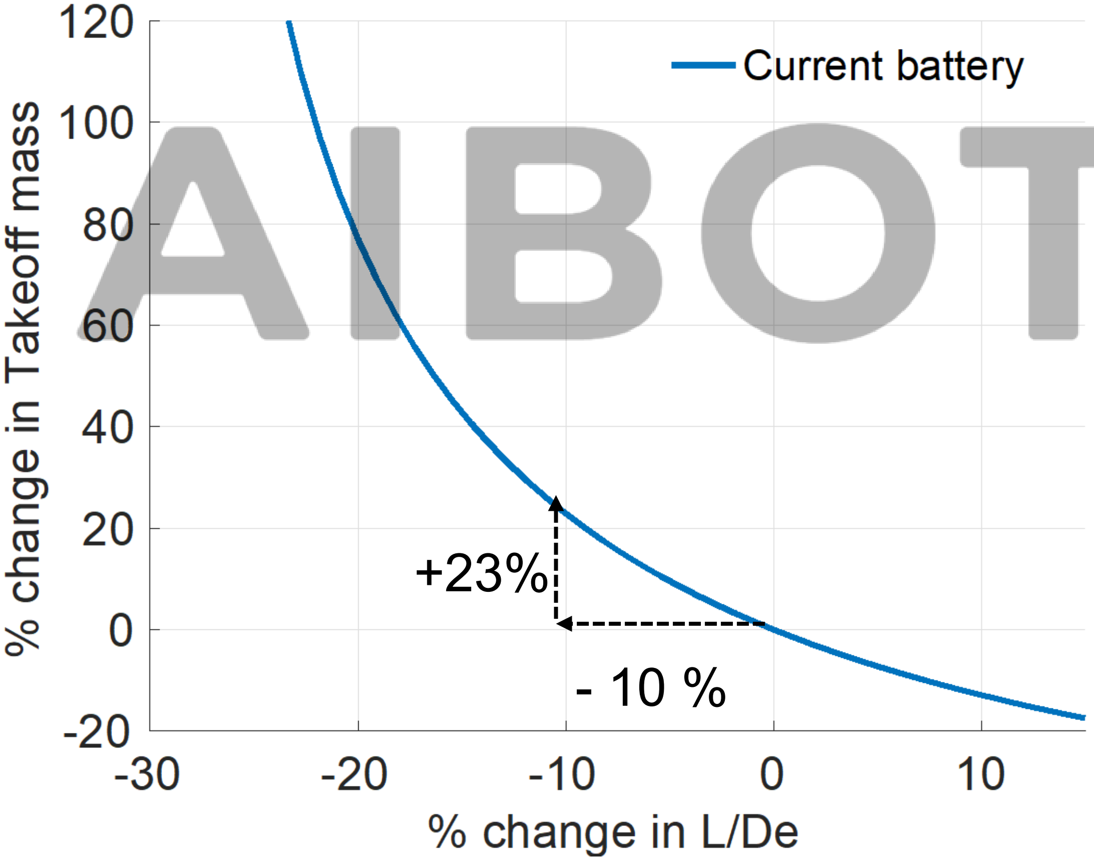
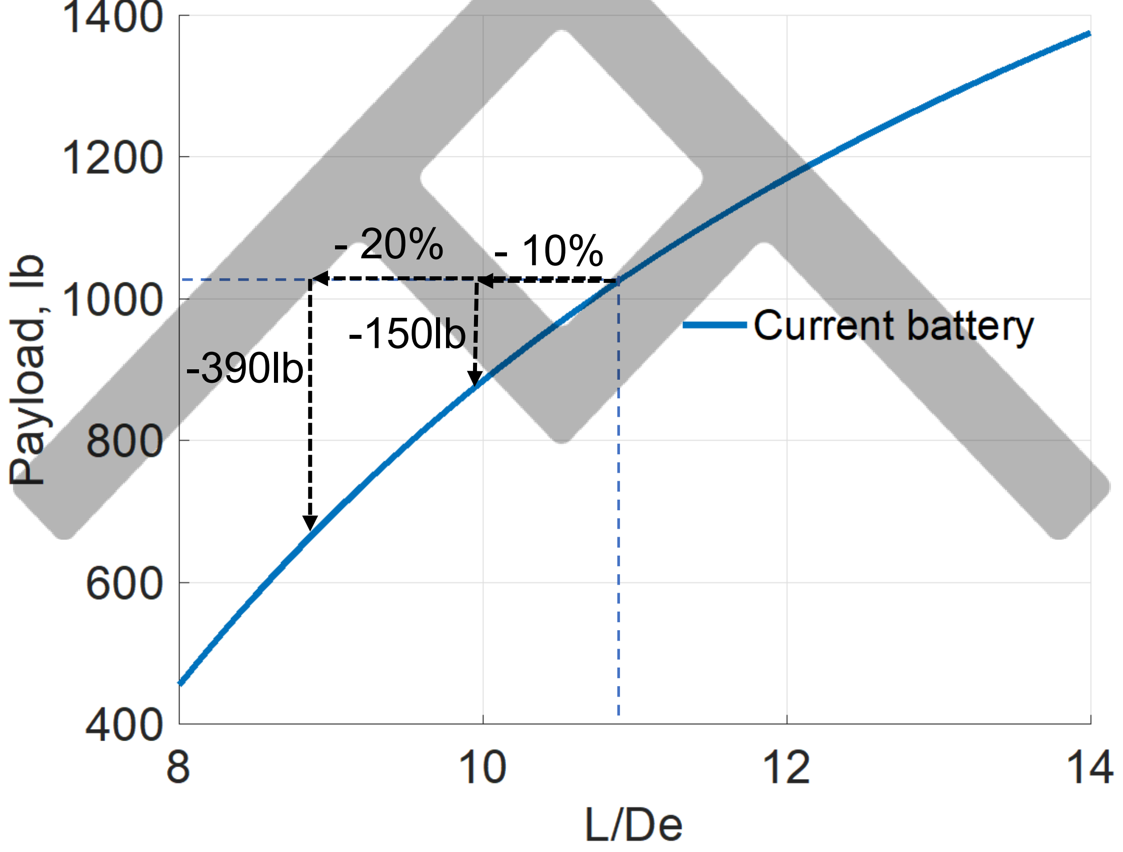
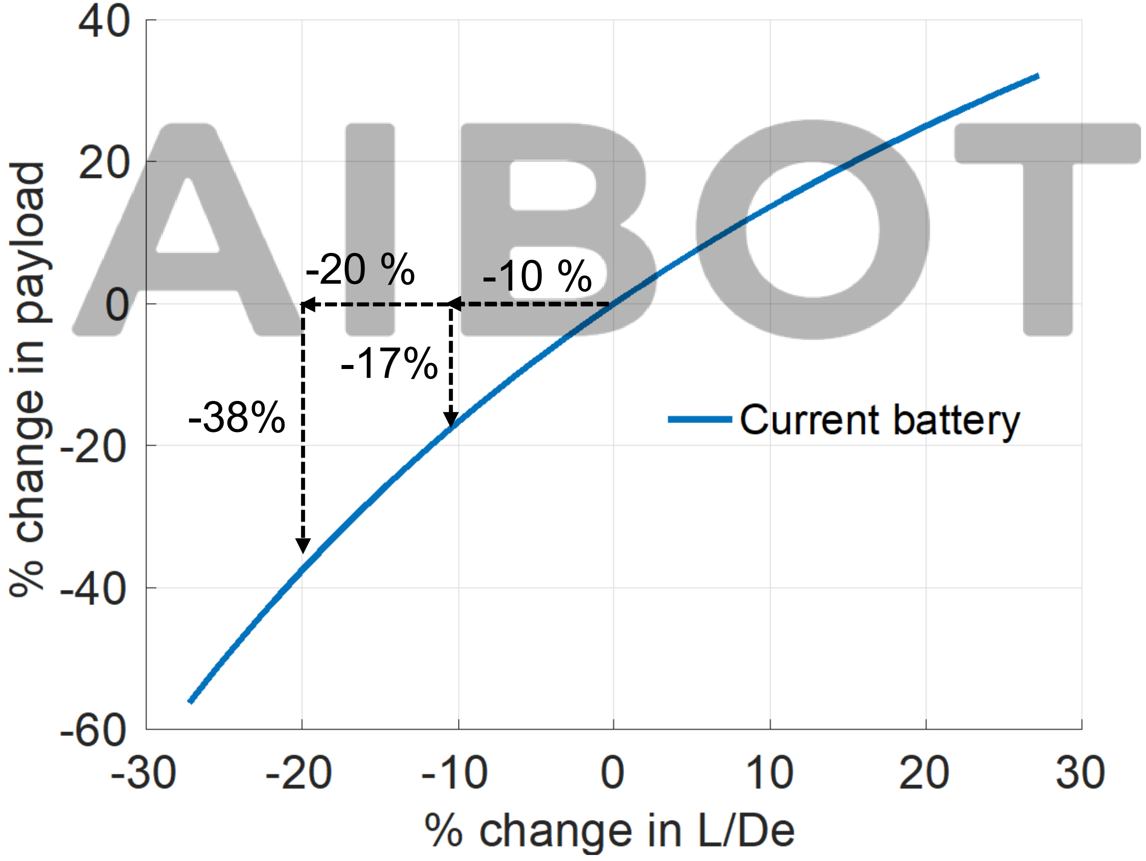




Sensitivity of eVTOL Payload Mass with L/De

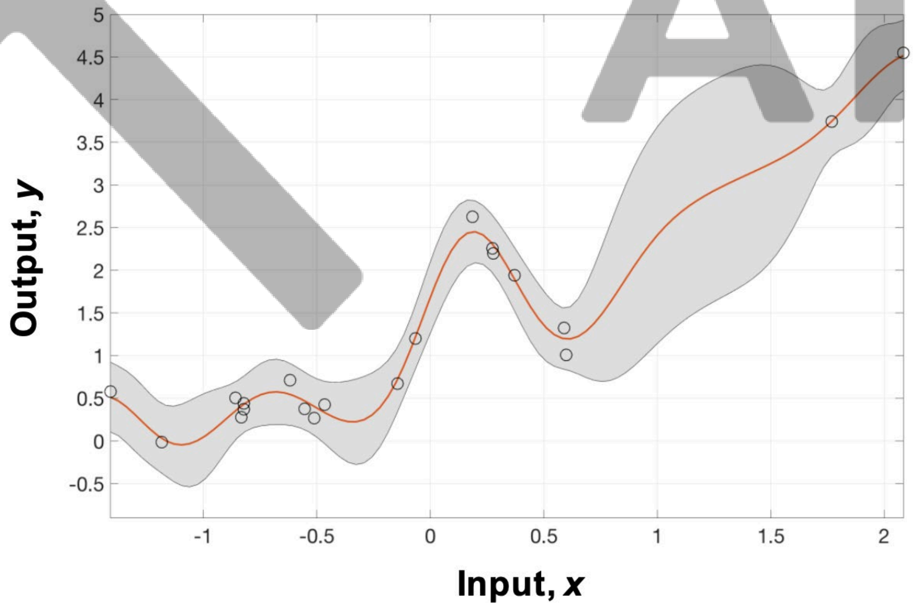
Payload versus L/De for a 7000 lb eVTOL for range of 100 miles with empty mass fraction of 0.6





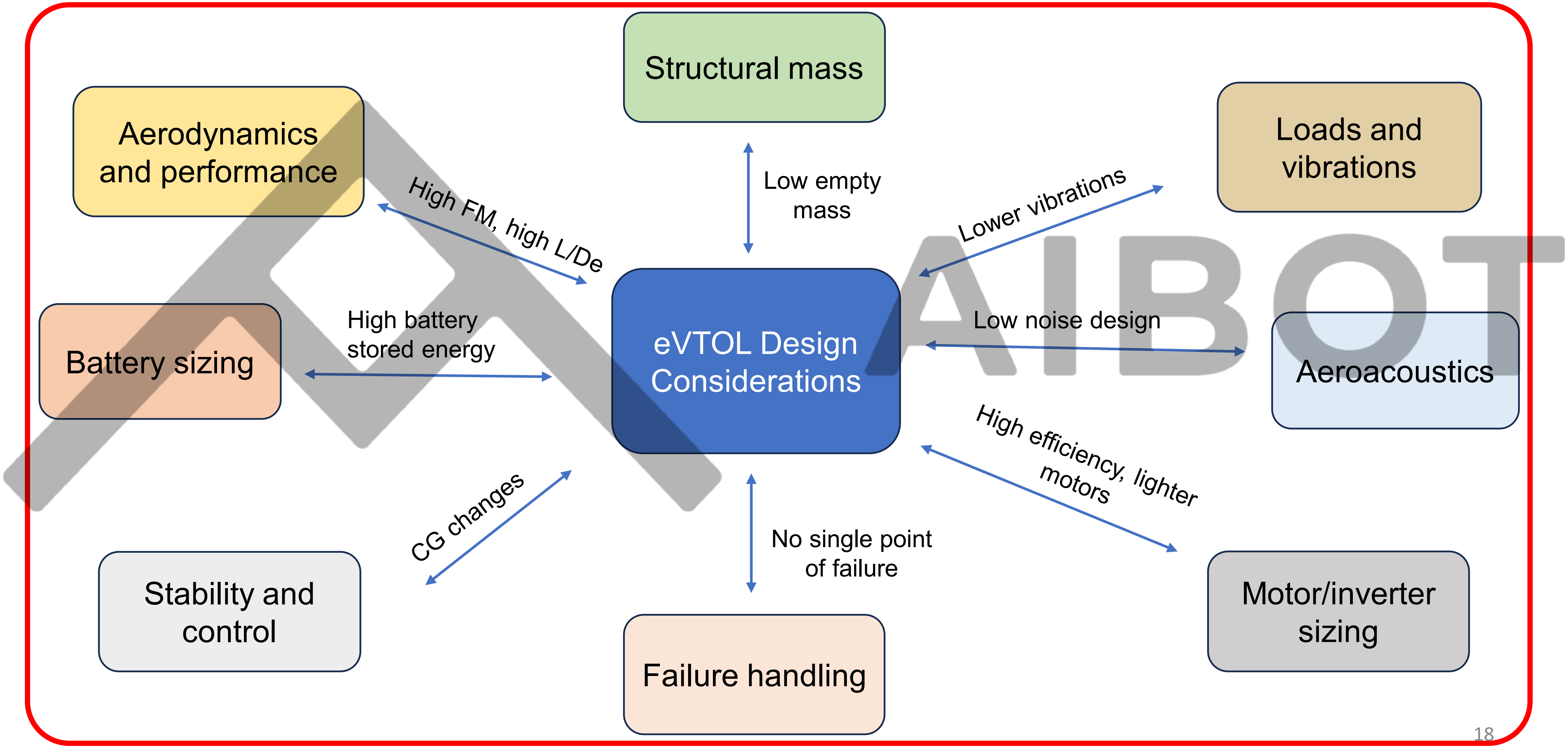
How to Model Aero Interference for eVTOL Design?

- Lower order aerodynamic models not suitable
- Higher fidelity CFD solutions can be accurate but computationally expensive
- Medium fidelity modeling (free wake, vortex particle method) can be a good compromise
- Surrogate models for interactional aerodynamics in the design phase



Source: “Tiltwing Multi-Rotor Aerodynamic Modeling in Hover, Transition and Cruise Flight conditions”, AHS 2018

Multidisciplinary Design of eVTOLs



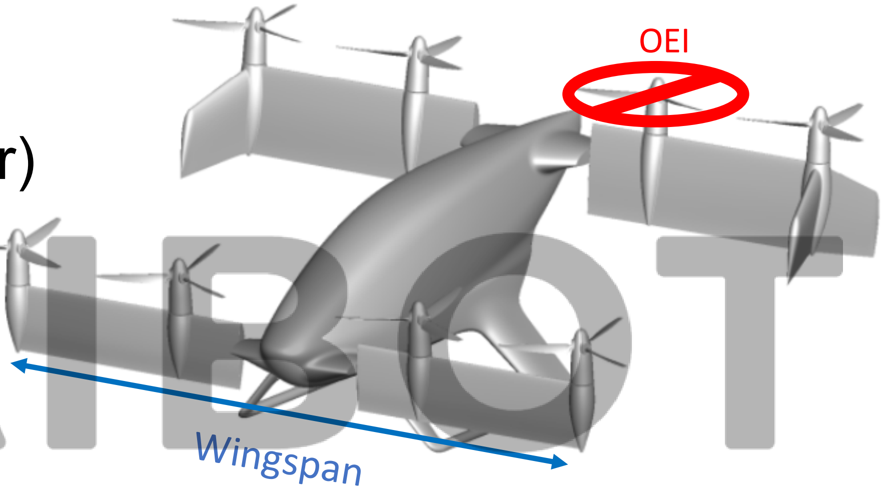
eVTOL Design and Prop Diameter

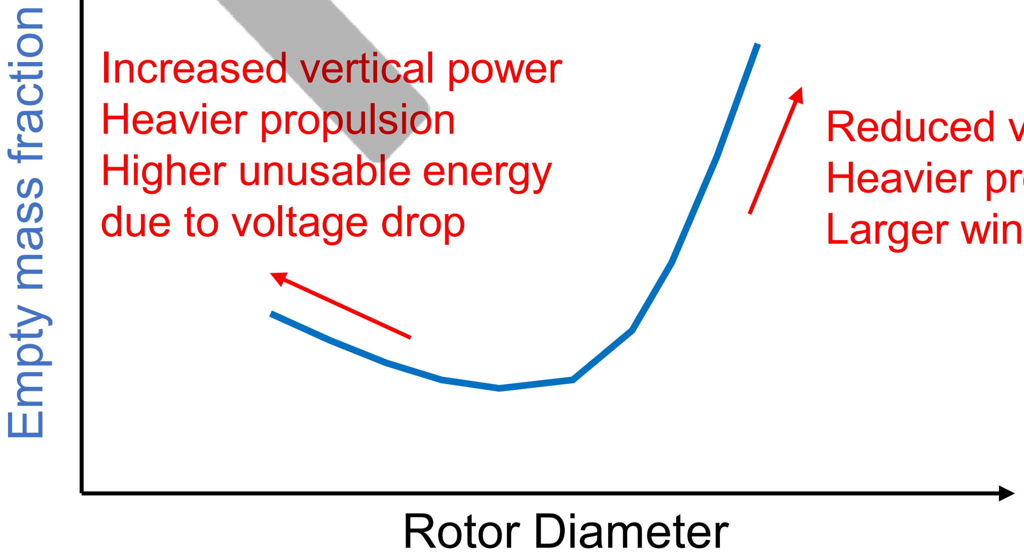
- Hover + OEI at the end of a mission is an important sizing condition
- For fixed takeoff mass:

$$\text{Vertical Power} \propto \sqrt{\text{Disk Loading}} \propto 1/(\text{Rotor Diameter})$$

$$\text{Wingspan} \propto \text{Rotor Diameter}$$

$$\text{Wing profile power} \propto \text{Wing area}$$





Increased vertical power
Heavier propulsion
Higher unusable energy
due to voltage drop

Reduced vertical power
Heavier props
Larger wing(s), actuation

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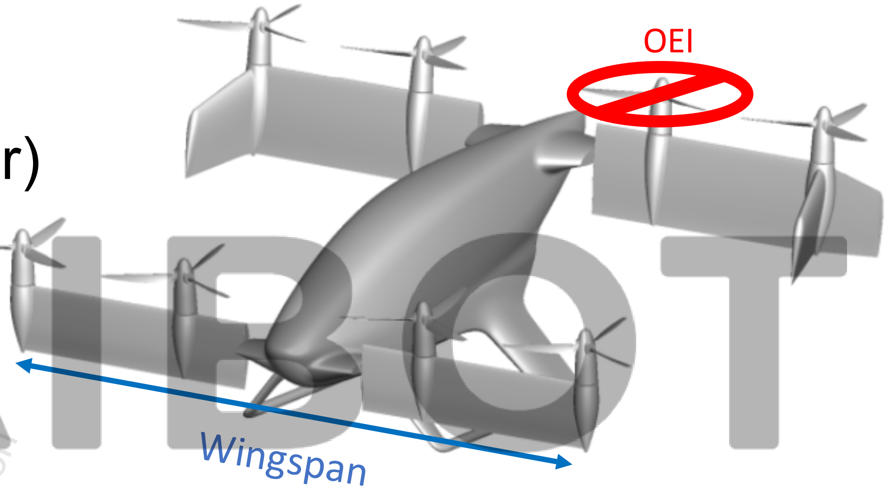

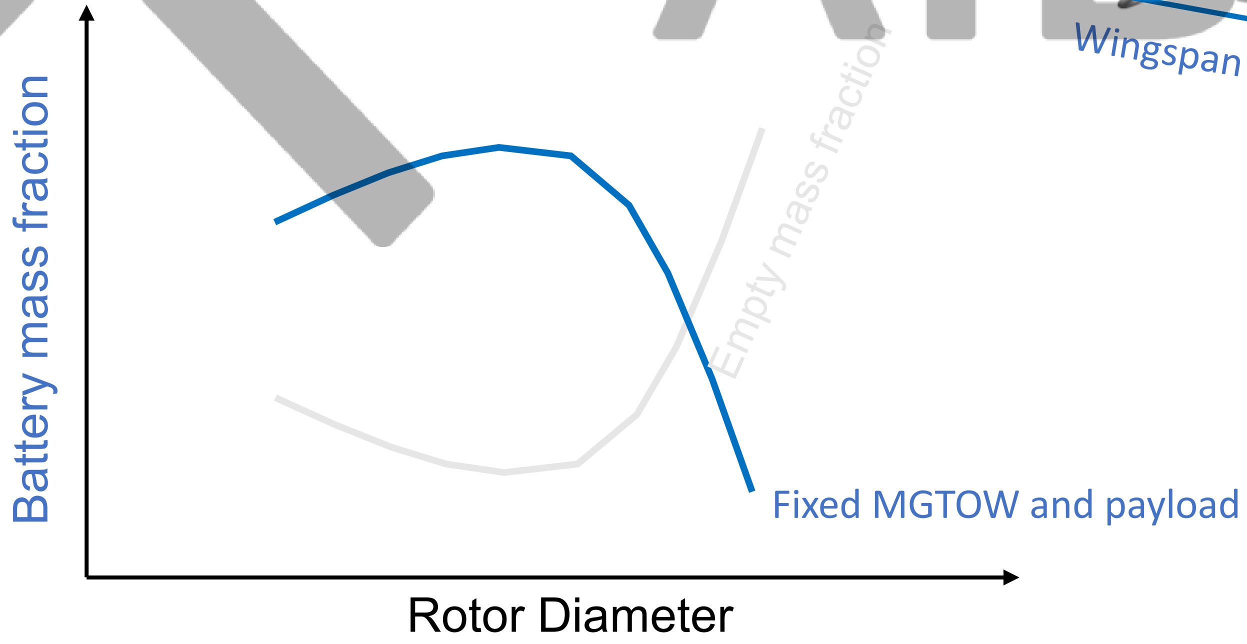

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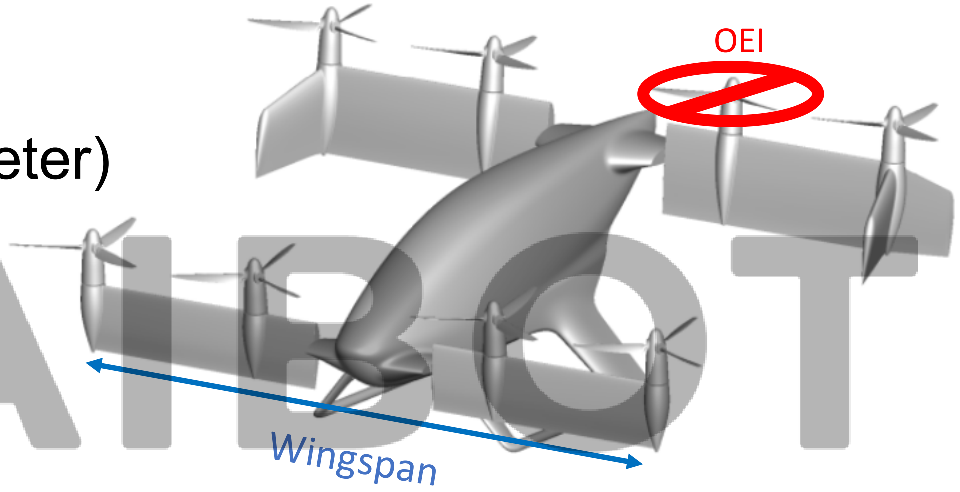

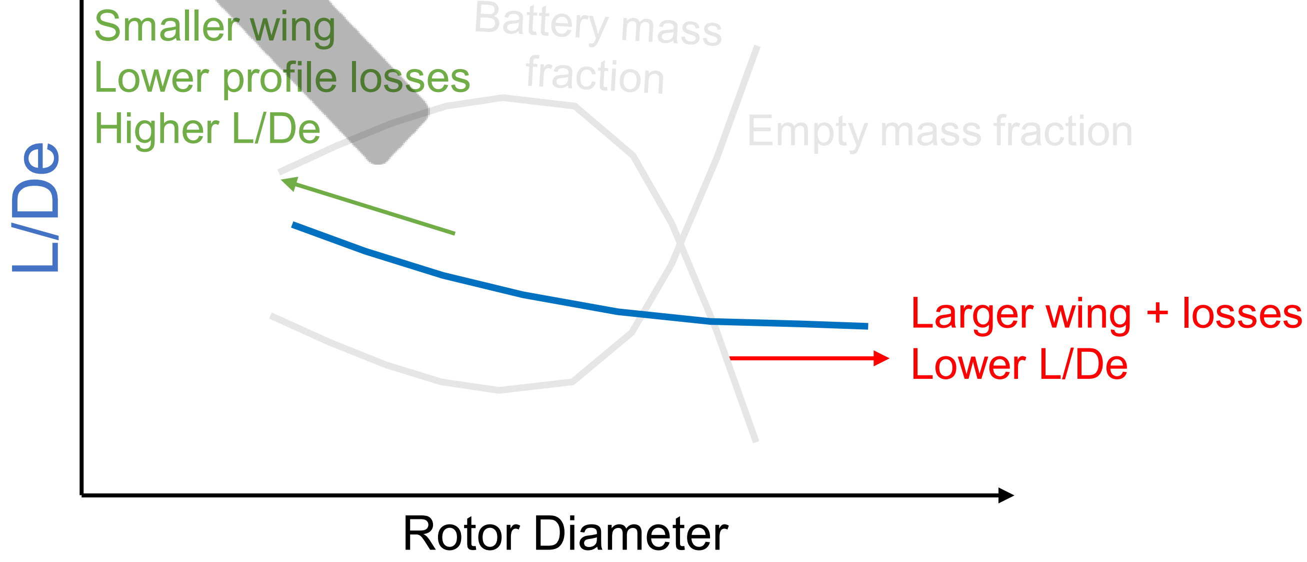

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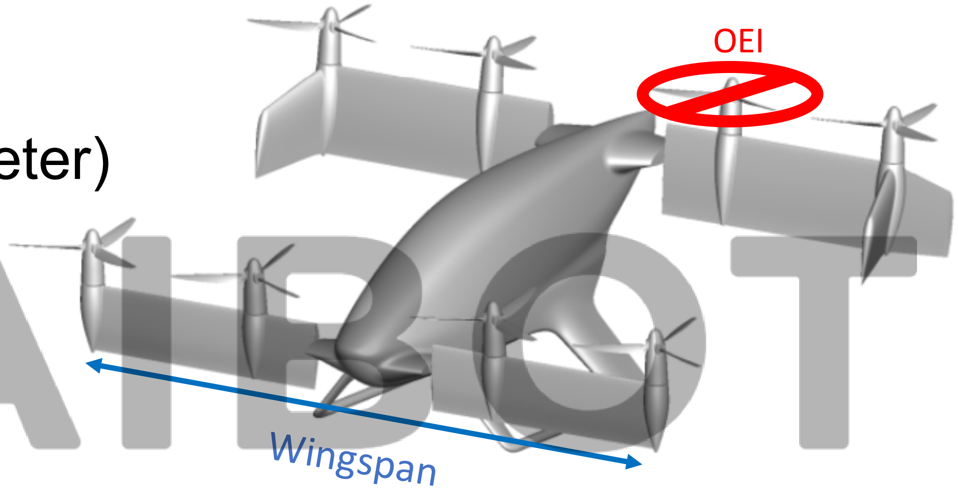

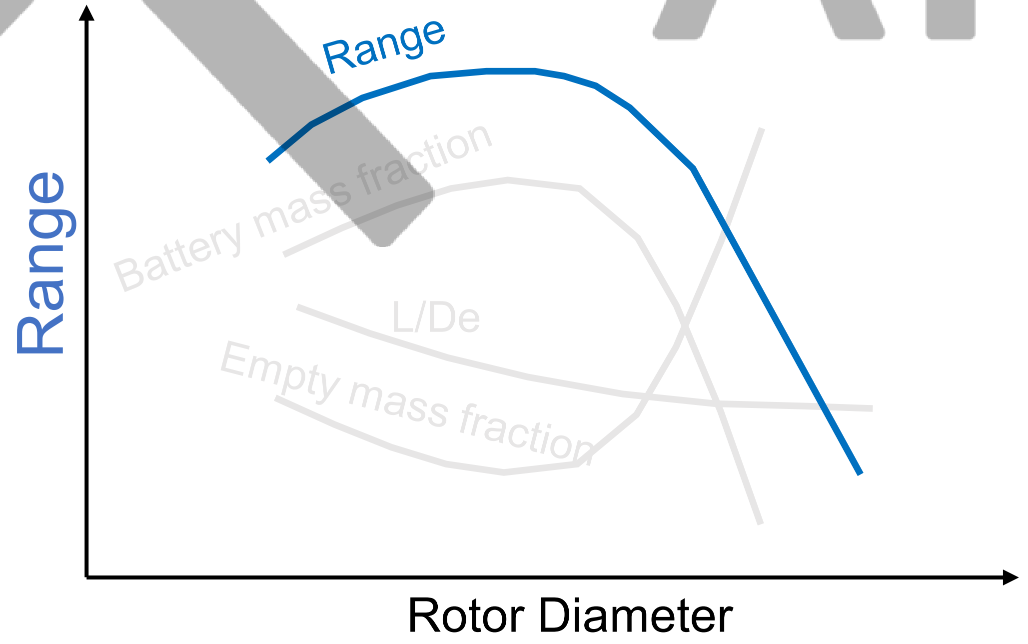

Concluding Remarks

- Reliable empty mass predictions very important early in the design phase
- Empty mass management critical to building a “successful” eVTOL
- Reliable aerodynamic interference predictions important to predict L/De
- Surrogate aerodynamic models can be used for performance predictions
- Higher range design is a trade-off between empty mass, efficiency, and low noise design
- eVTOL design is a multidisciplinary “optimization” problem

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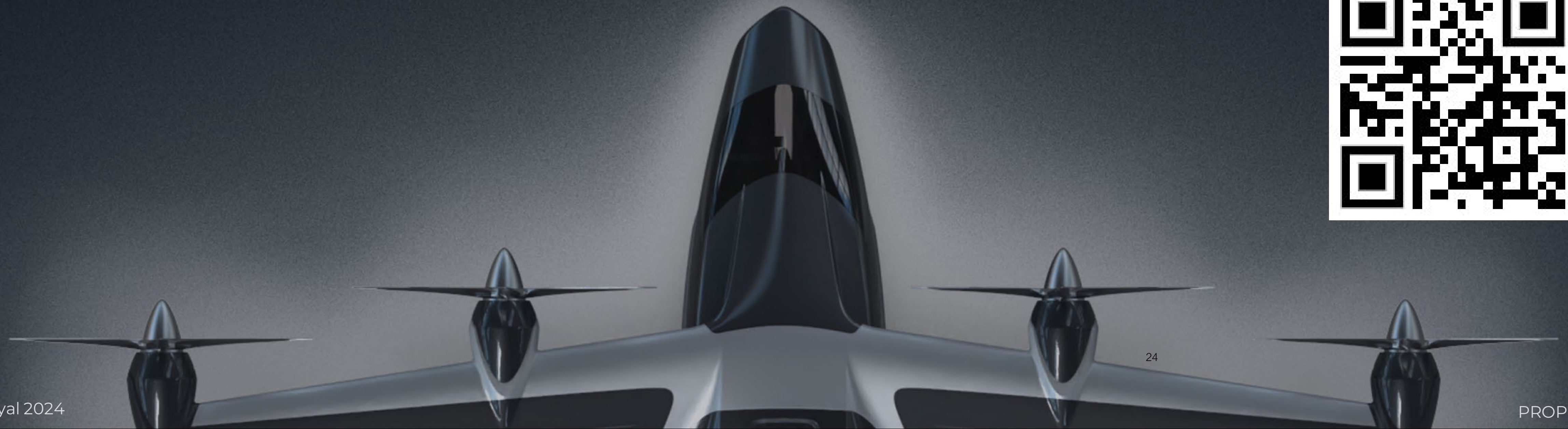
Thank You



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