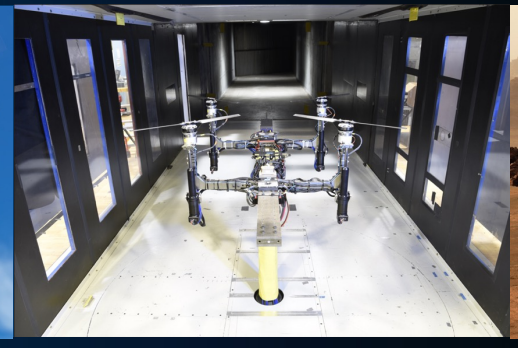
# Urban Air Mobility
# Vehicle Architecture Trends

## ICAS
## EMERGING TECHNOLOGY FORUM 2023
## FUTURE AIR MOBILITY
## – BARRIERS AND ENABLERS –

## NASA Revolutionary Vertical Lift Technology Project

**Presented by: Chris Silva**

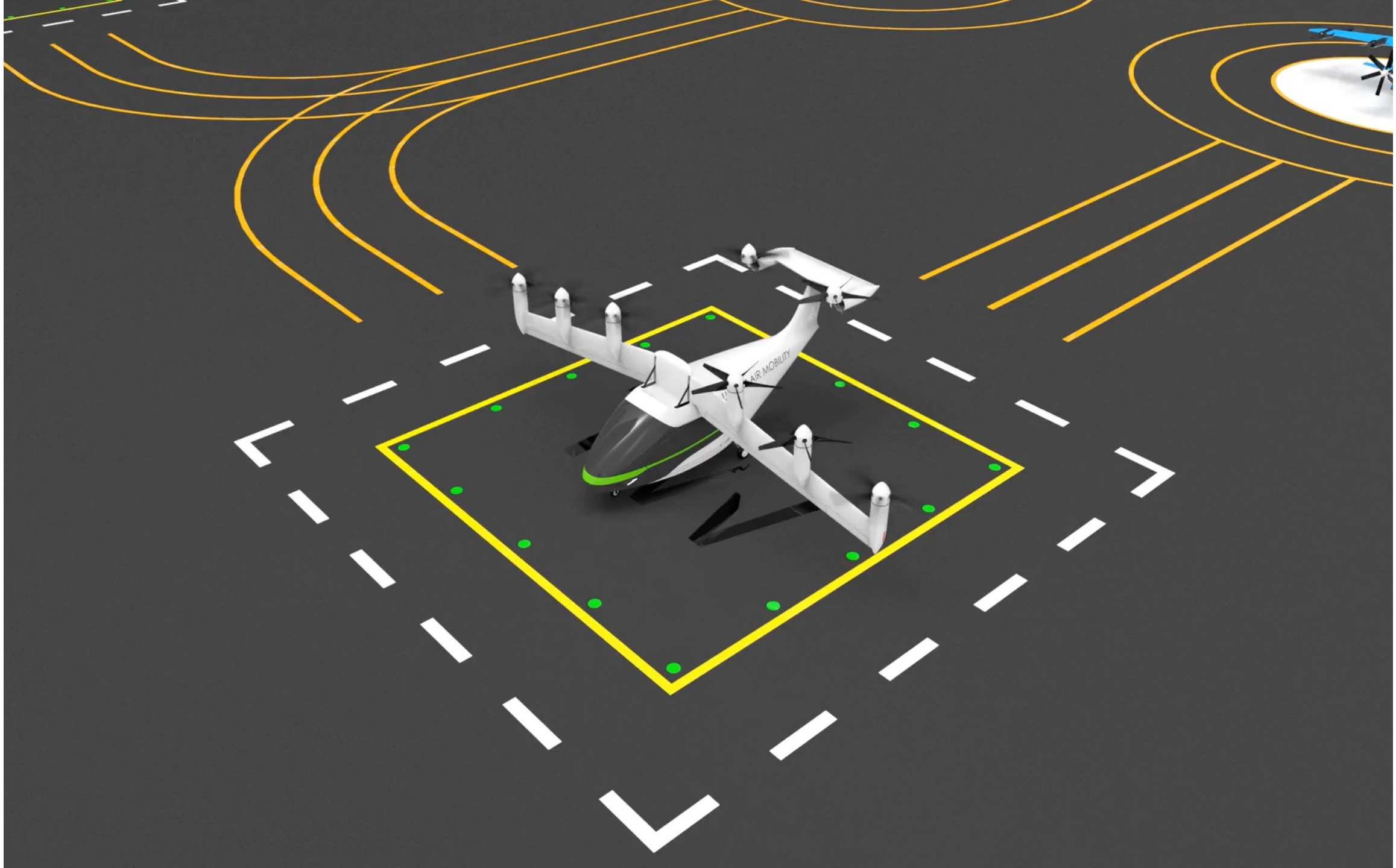


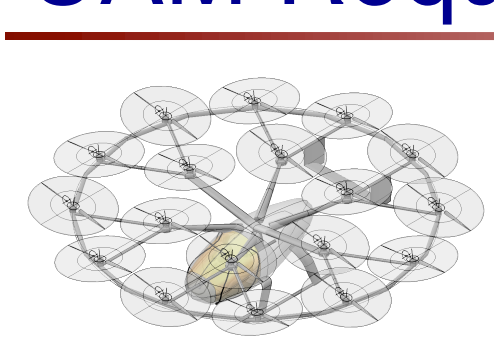

What is different? Why haven’t we been doing this with helicopters?

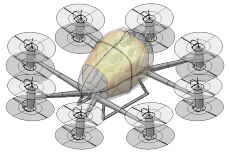
# What is different? Why haven't we been doing this with helicopters?

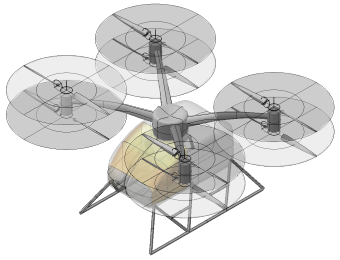
- U.S.A. had large-scale commuter helicopter service 40-60 years ago, and Canada has it today
- Helicopters have been **too loud**, **too expensive**, and **too dangerous** for everyday travel
- Alternative (electric) propulsion may drastically cut energy cost and reduce emissions
- Ridesharing taxi service may solve the first/last mile travel inconvenience
- Autonomy may drastically reduce flight crew cost
- Quiet rotorcraft technology now exists
- We have better predictive tools

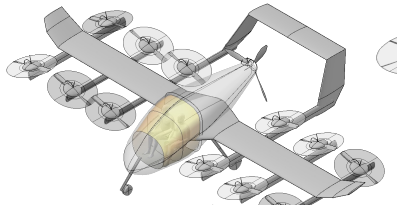

AIR MOBILITY

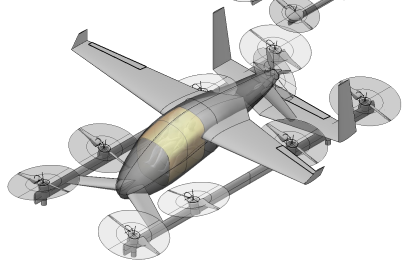
# UAM Requirement: Convenience

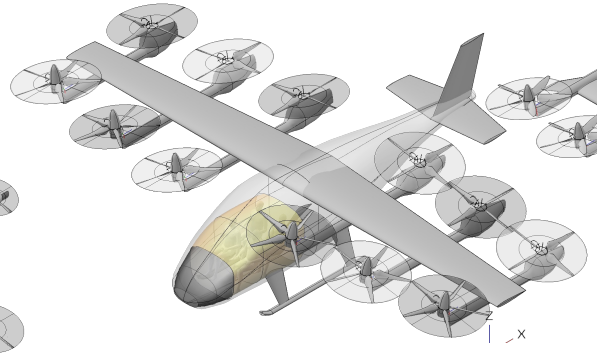


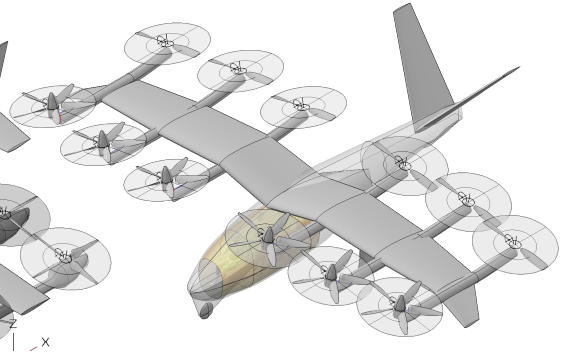


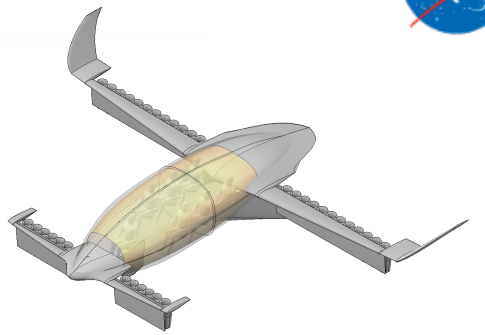


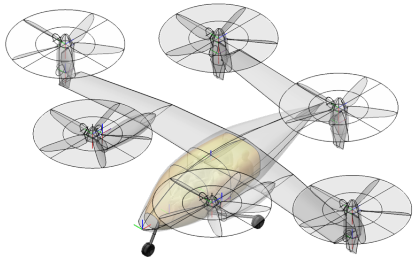


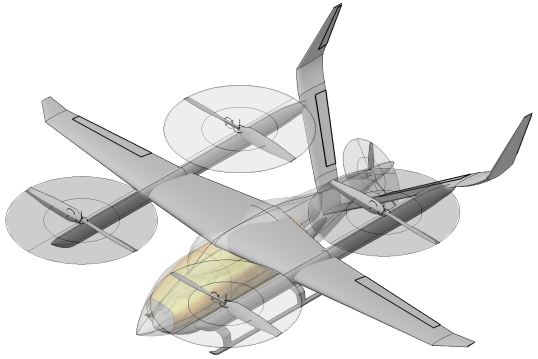


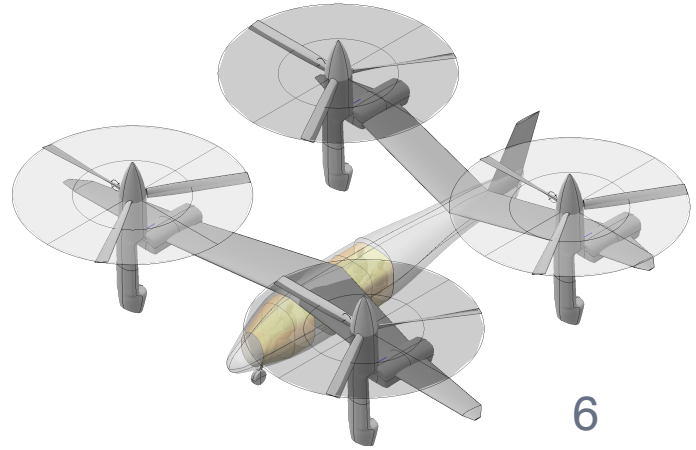












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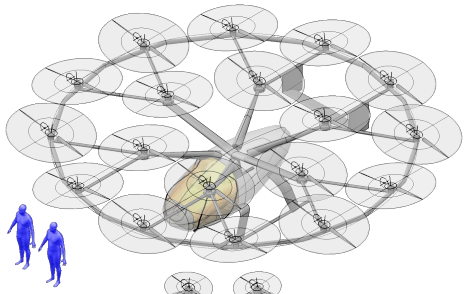
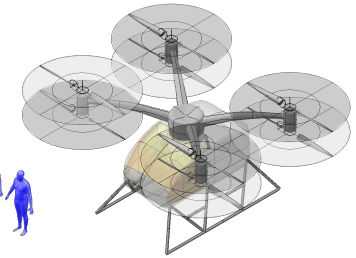
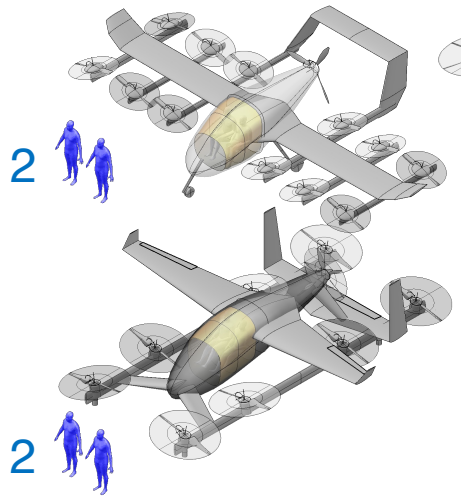
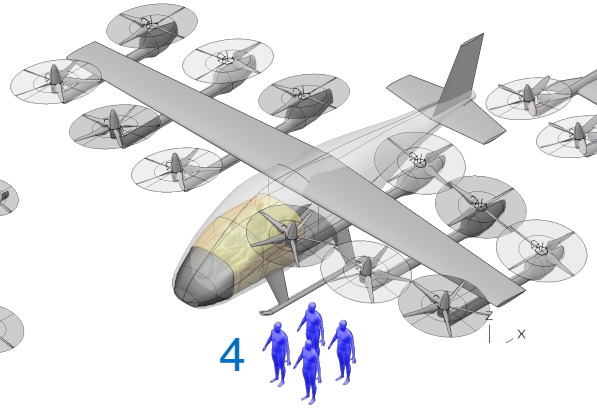
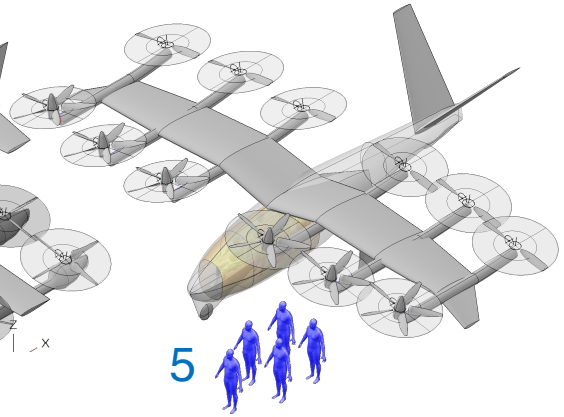
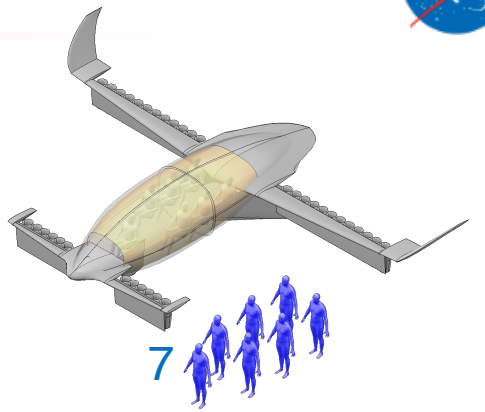


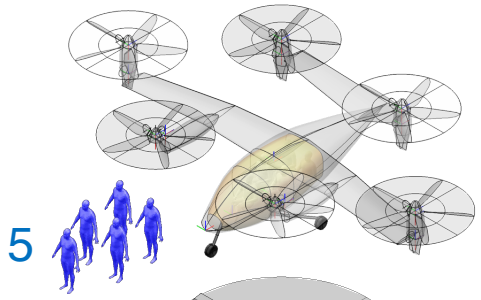



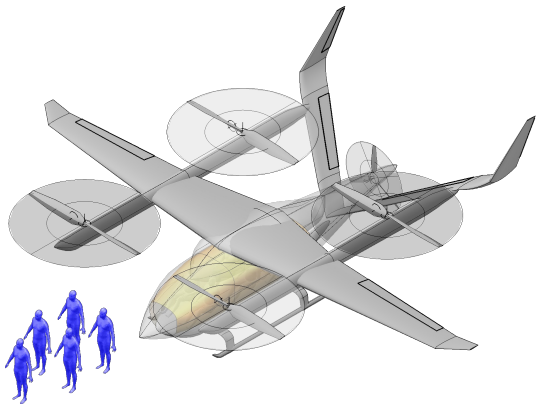



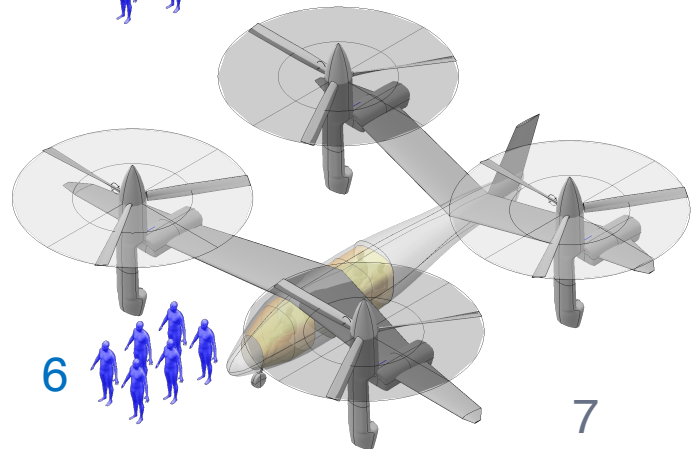




Between 2 and 7 occupants



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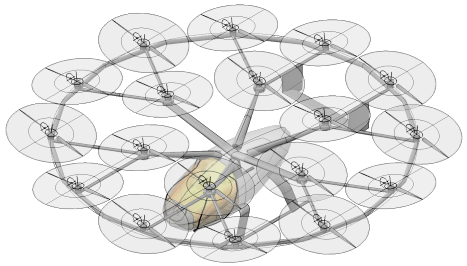
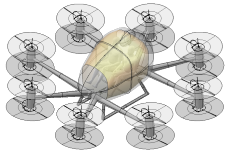
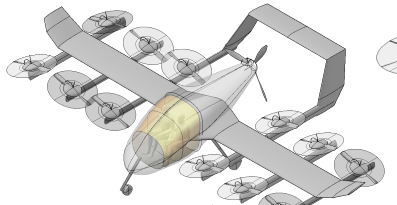
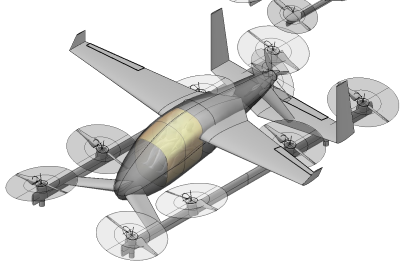
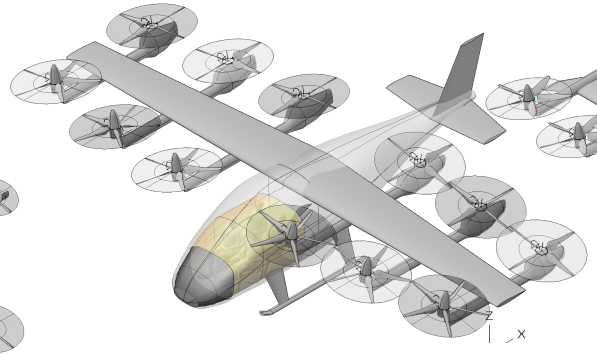
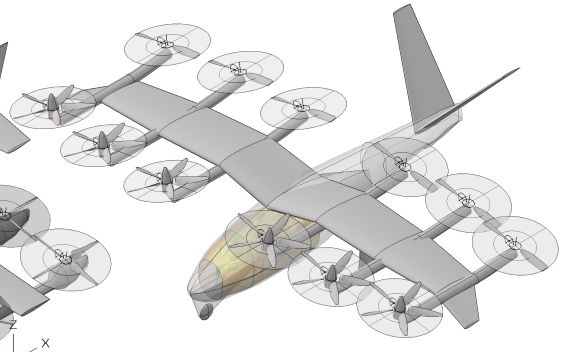
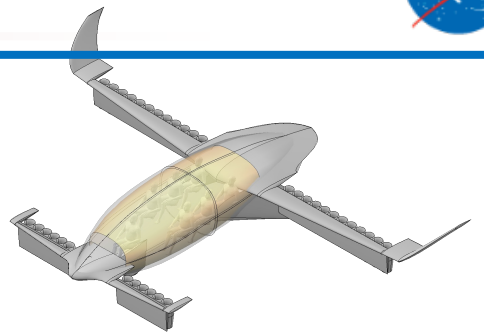
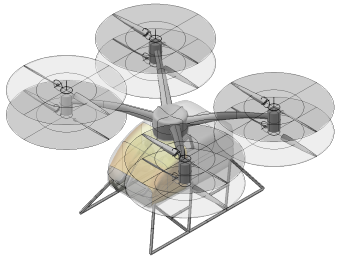
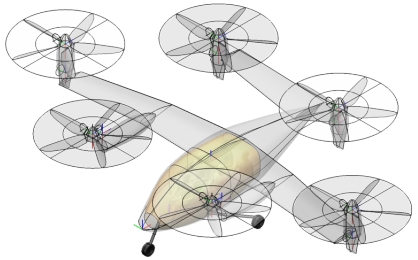
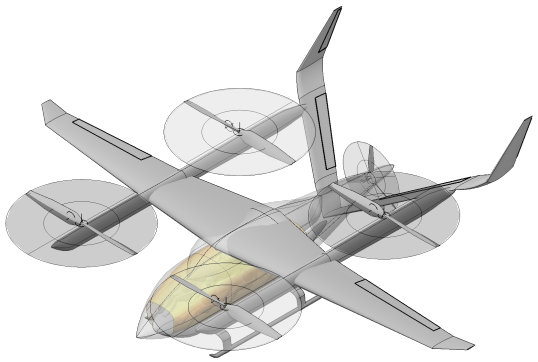
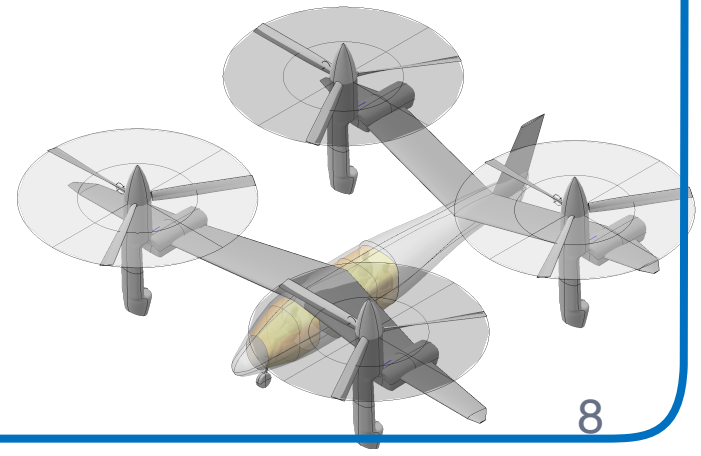
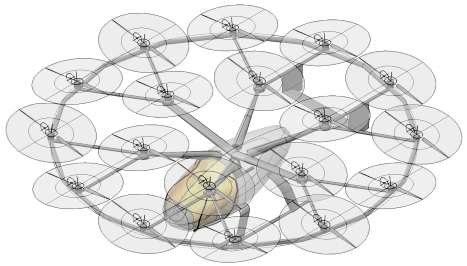











Vertical Takeoff and Landing

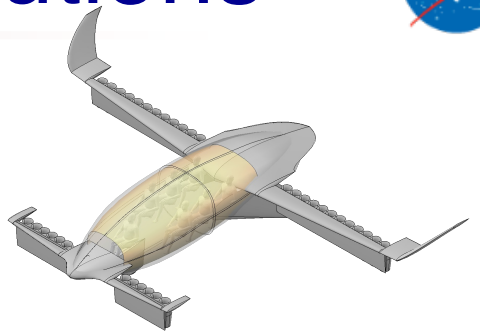



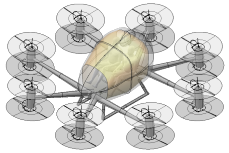
# We observe very diverse VTOL vehicle solutions

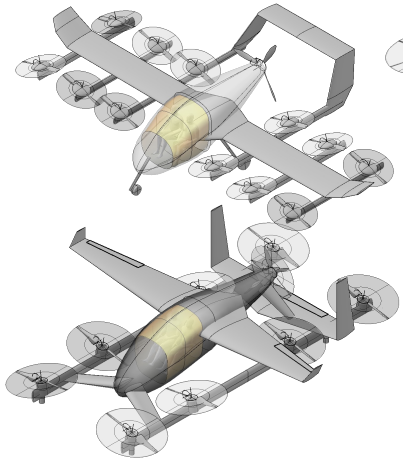


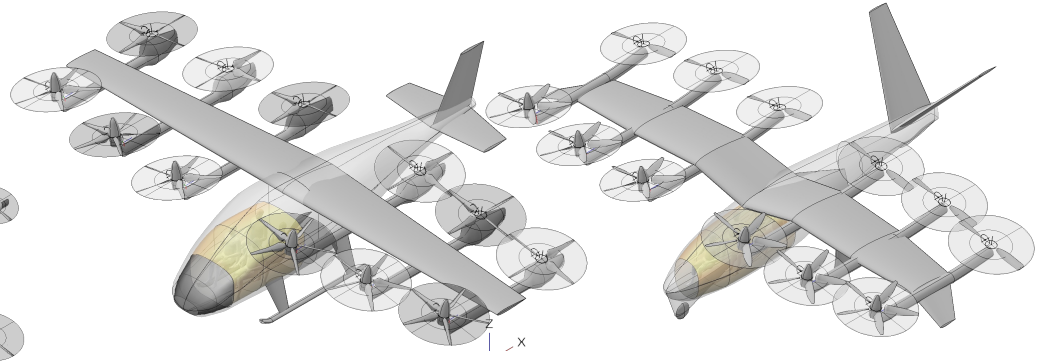
Stopping rotor
Lift+cruise

Stop some rotors,
tilt some rotors



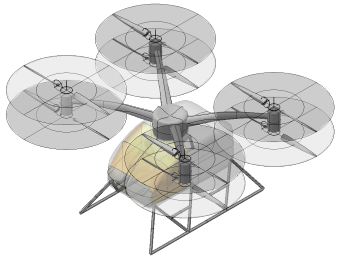


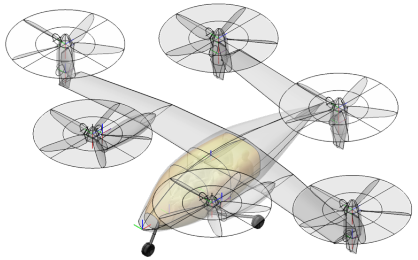


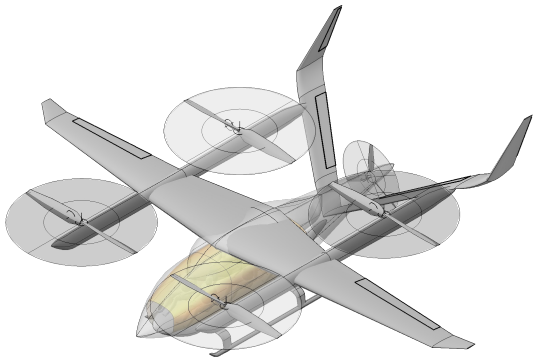


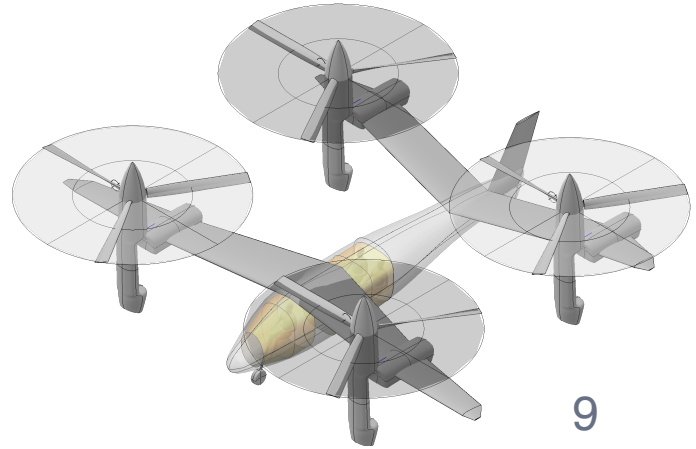
Tiltrotors and tiltwings

Multicopters









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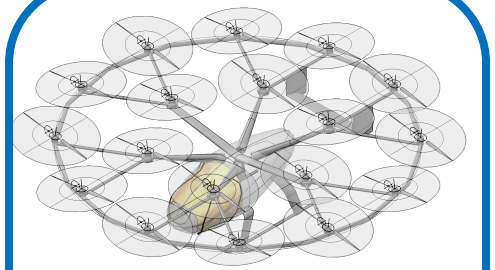
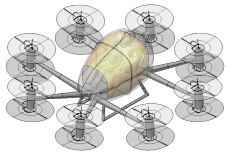
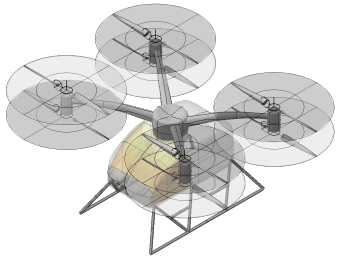
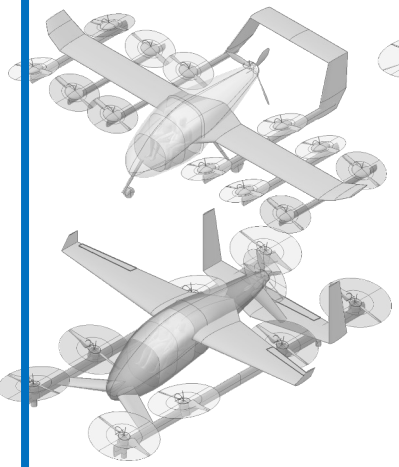




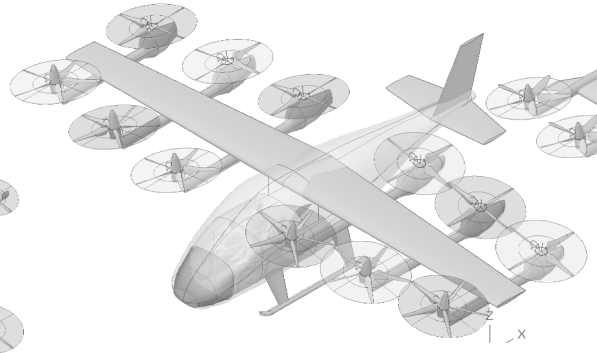
Multicopters

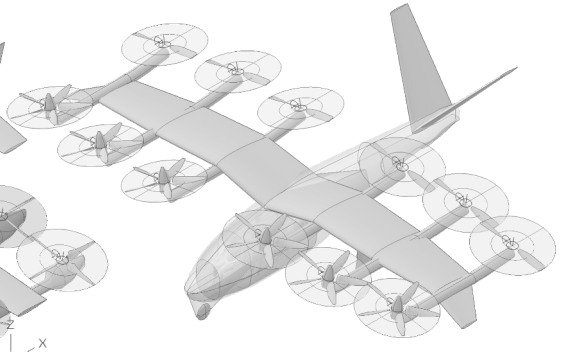


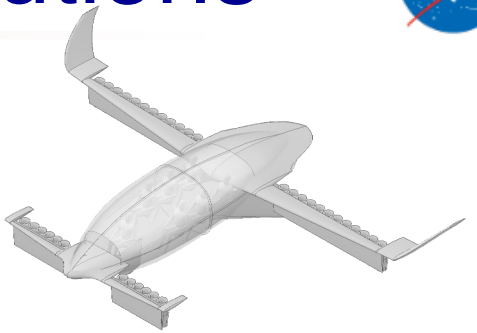
Stopping rotor
Lift+cruise



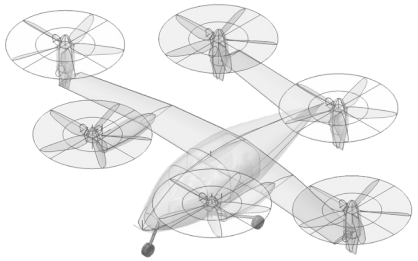
Stop some rotors,
tilt some rotors

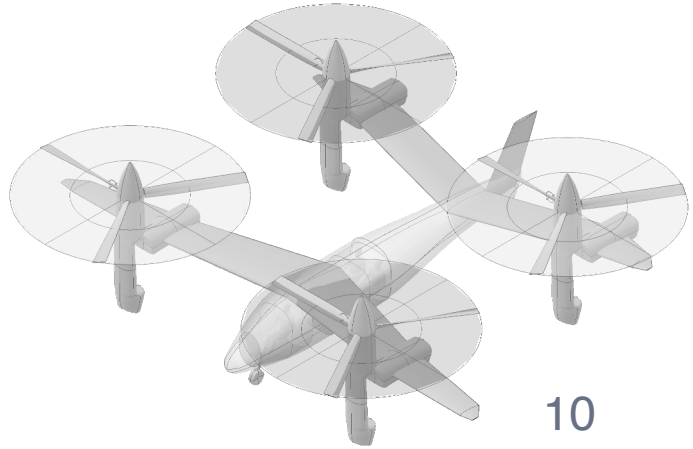






Tiltrotors and tiltwings





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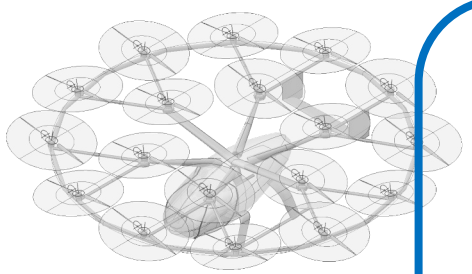
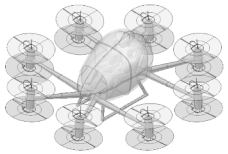
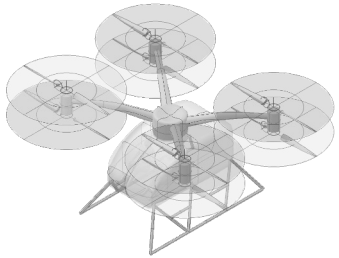




Multicopters



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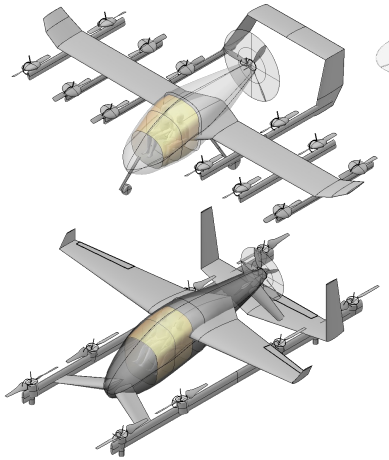

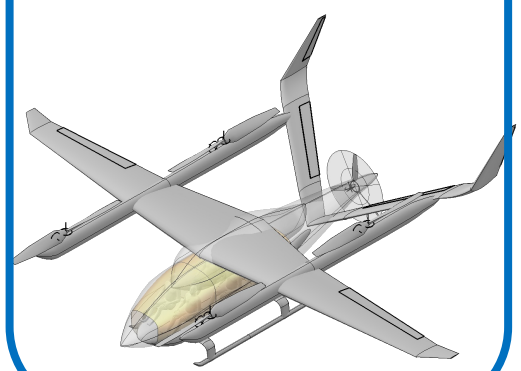

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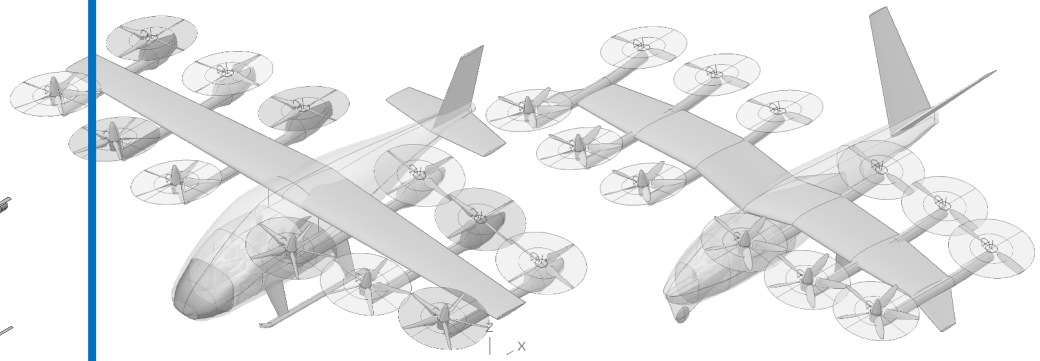

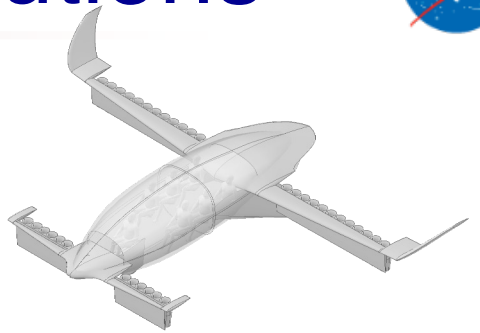

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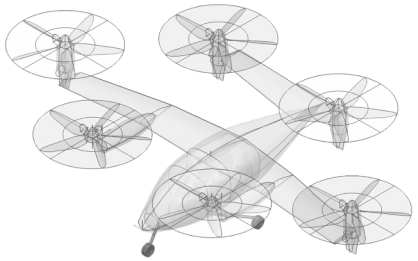
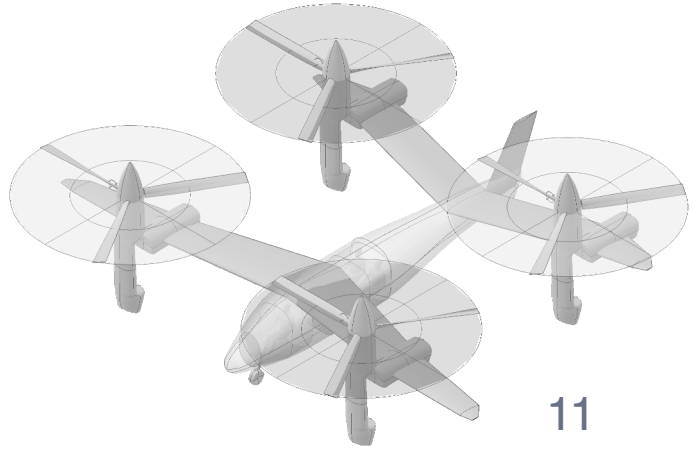
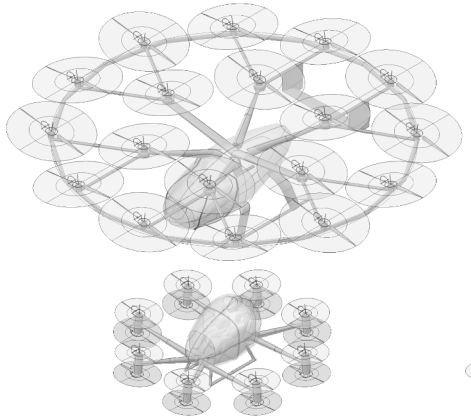
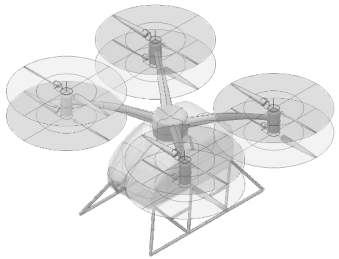




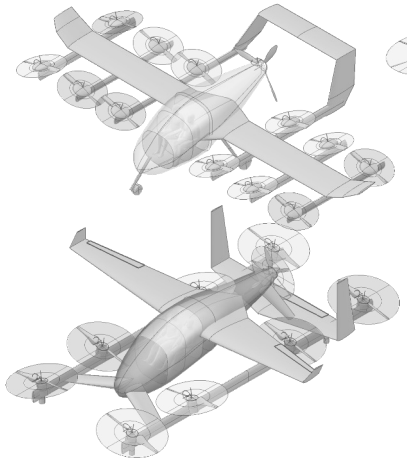
# We observe very diverse VTOL vehicle solutions

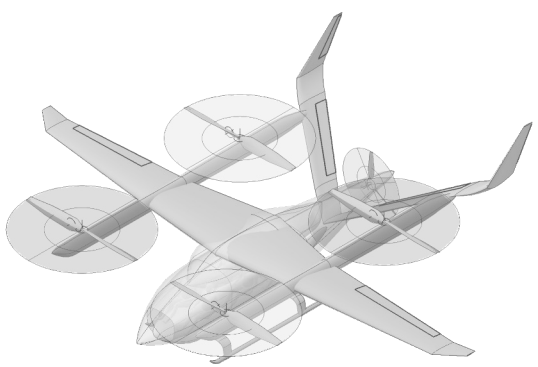


Multicopters

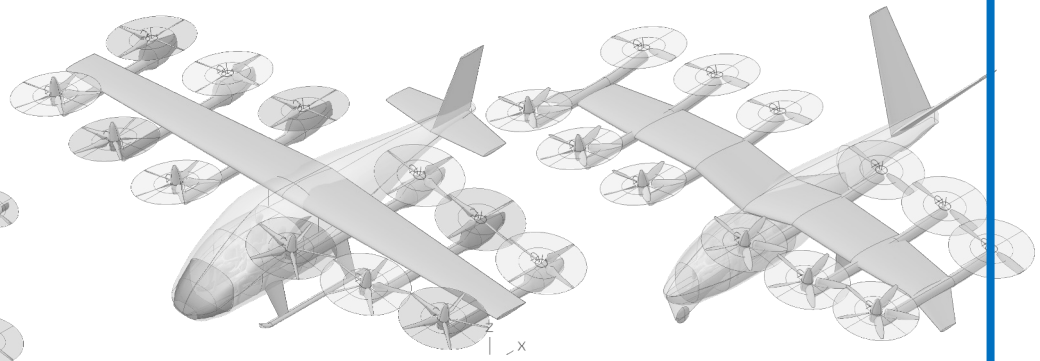


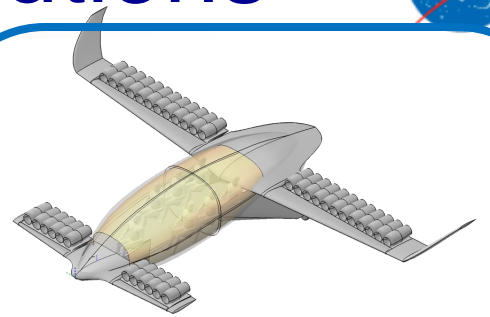
Stopping rotor
Lift+cruise



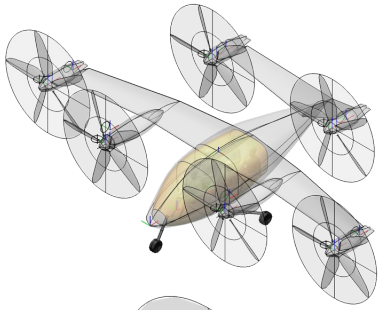


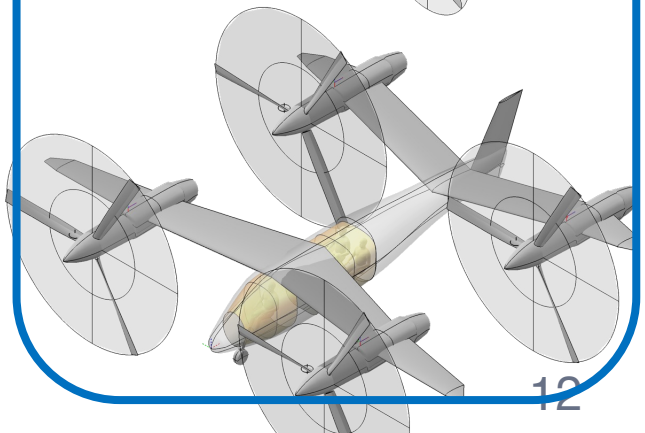
Stop some rotors,
tilt some rotors



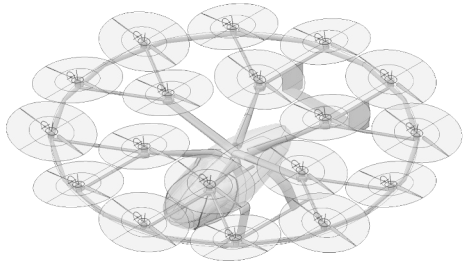


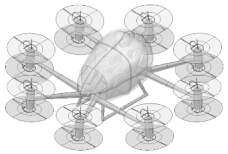
Tiltrotors and tiltwings



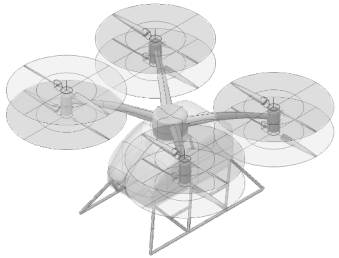


# We observe very diverse VTOL vehicle solutions

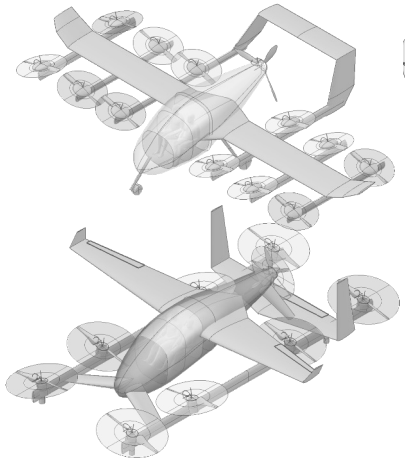


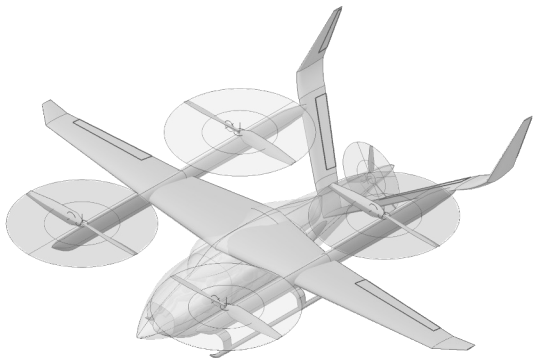


Multicopters

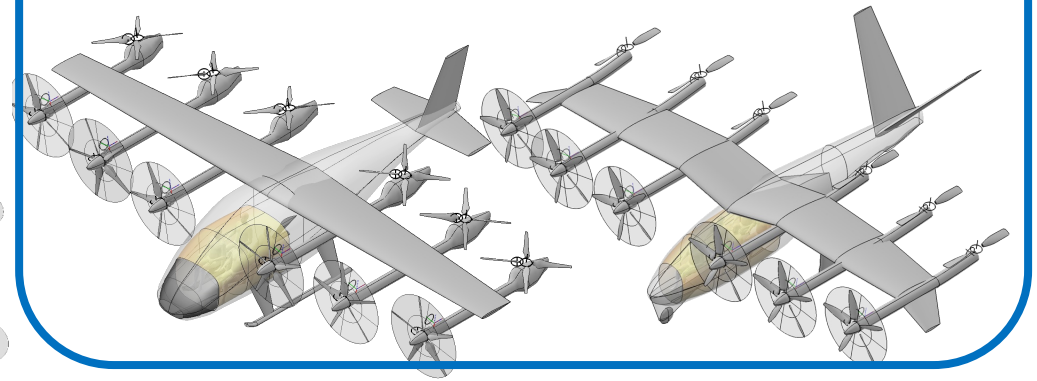


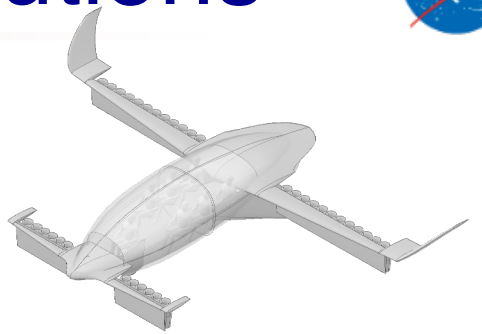
Stopping rotor
Lift+cruise



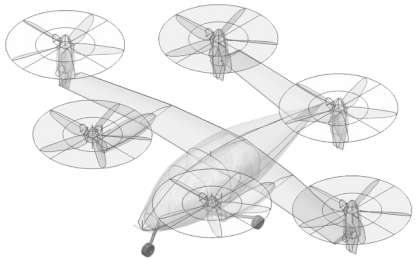


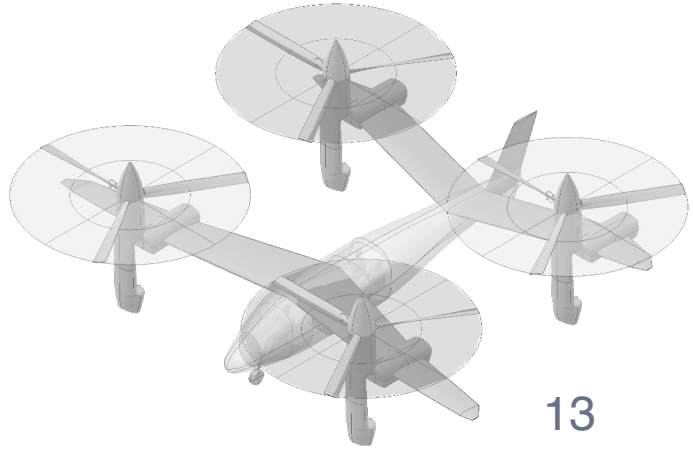
Stop some rotors,
tilt some rotors



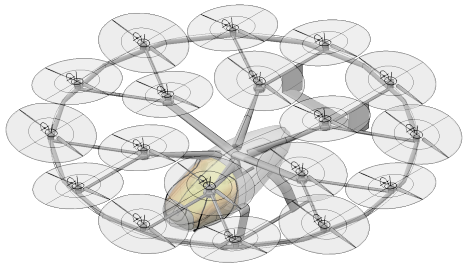


Tiltrotors and tiltwings



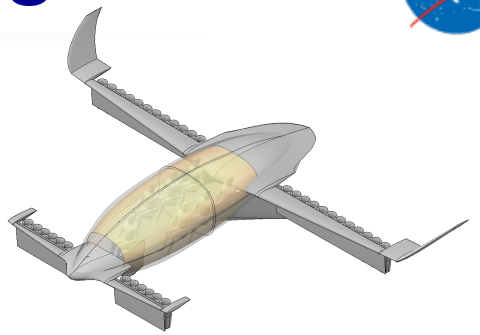


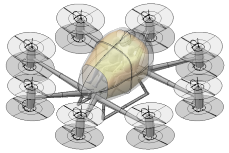
# The arrangement of rotors indicate priorities

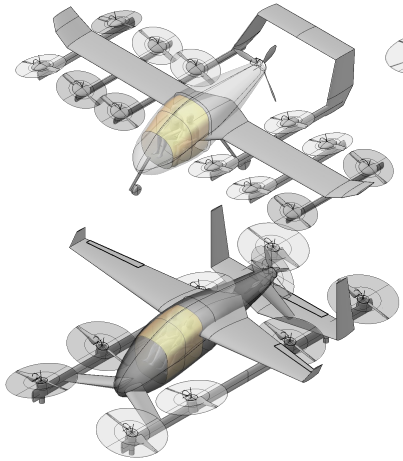


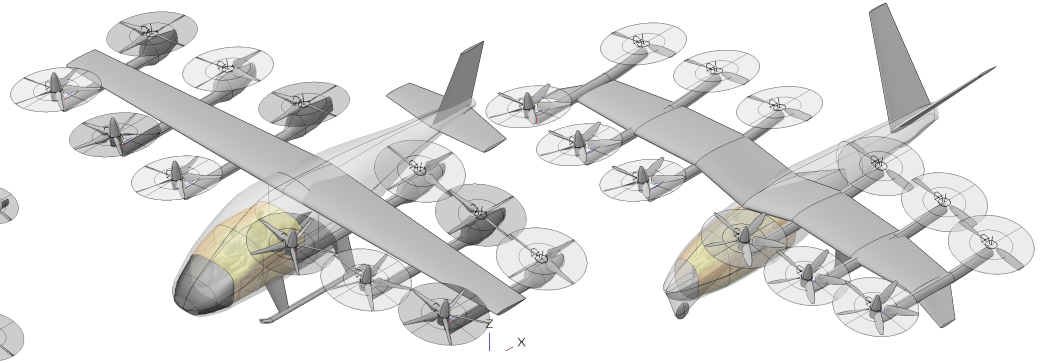
Stopping rotor
Lift+cruise

Stop some rotors,
tilt some rotors



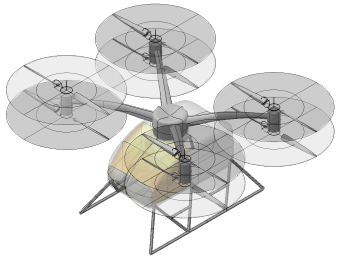


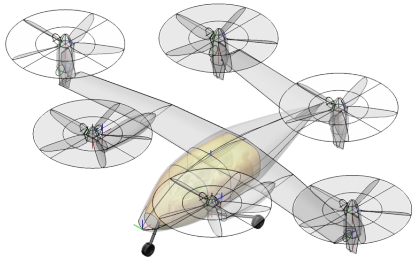


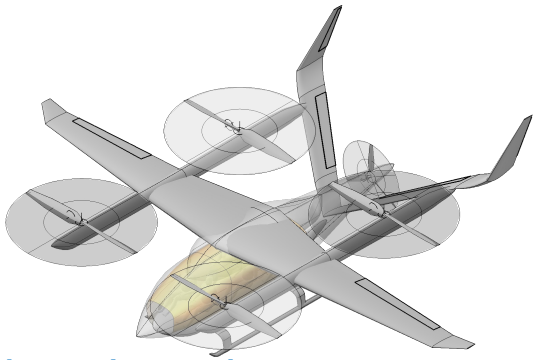


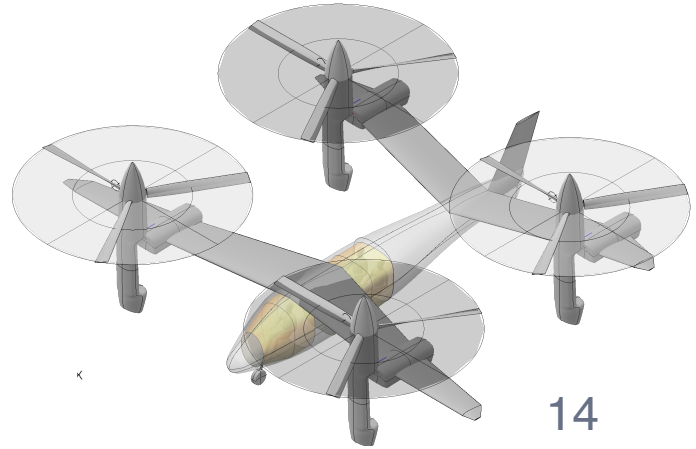
Tiltrotors and tiltwings

Multicopters



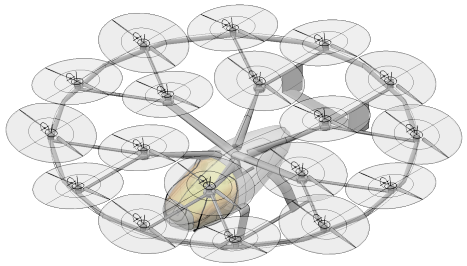




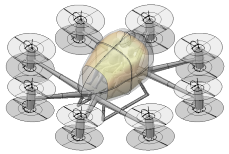


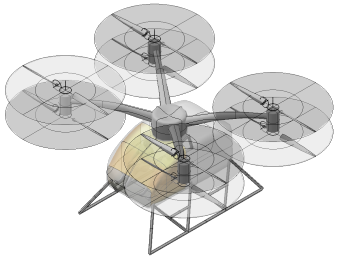
More like an airplane in cruise →

# The arrangement of rotors indicate priorities

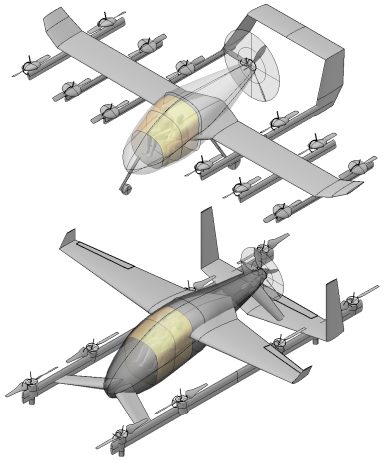


Multicopters

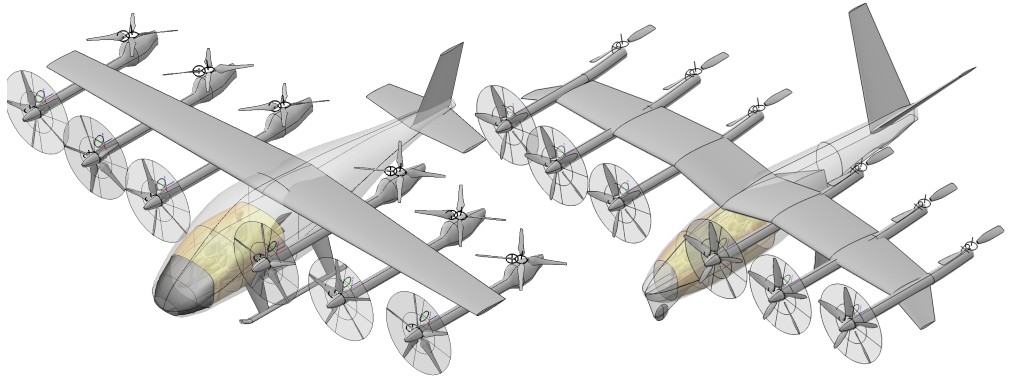


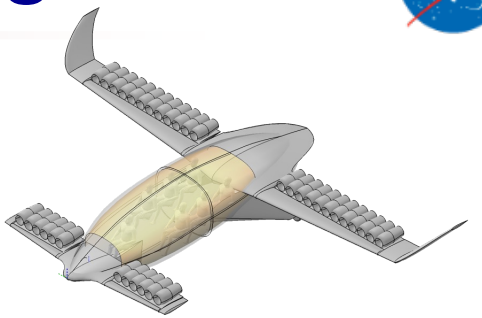


Stopping rotor
Lift+cruise

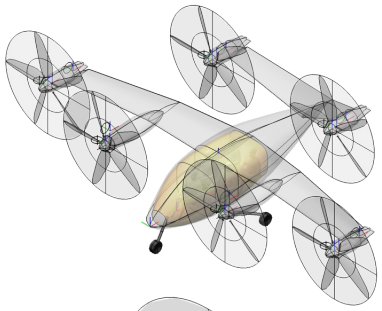


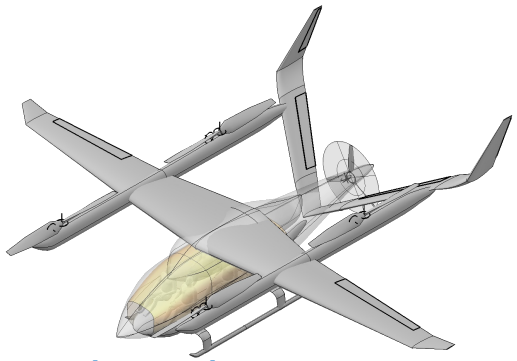
Stop some rotors,
tilt some rotors

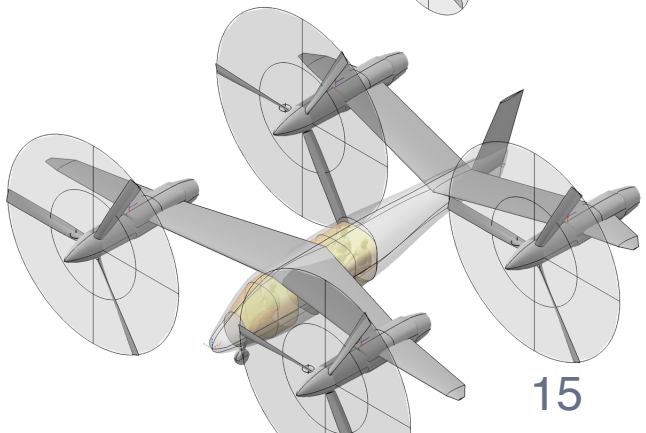




Tiltrotors and tiltwings

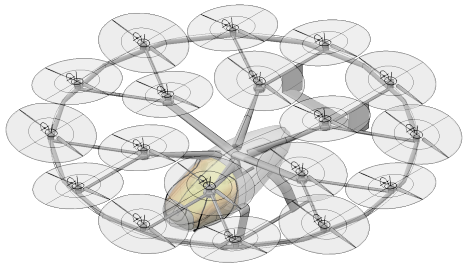


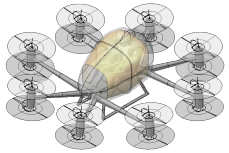


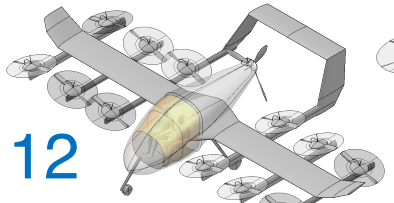


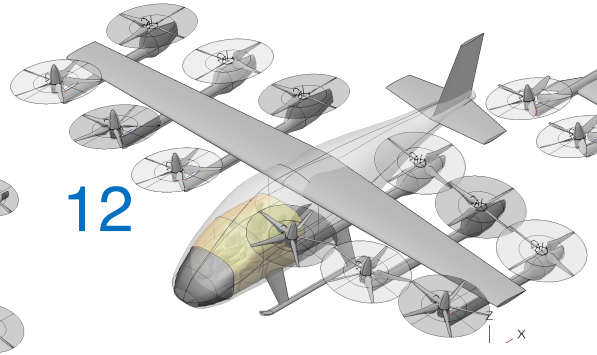
More like an airplane in cruise →

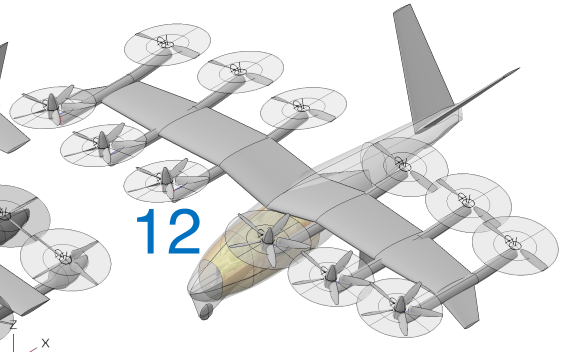
# The arrangement of rotors indicate priorities

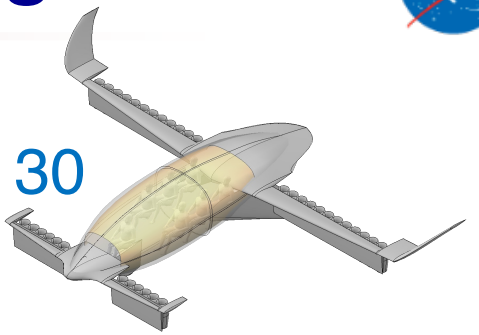


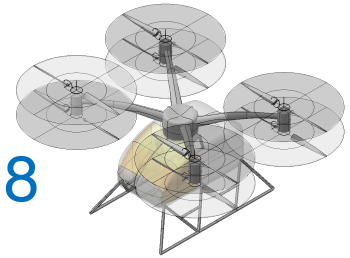



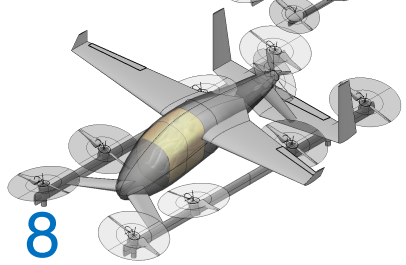



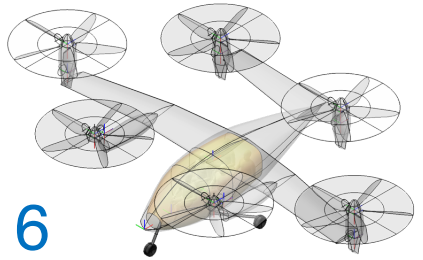



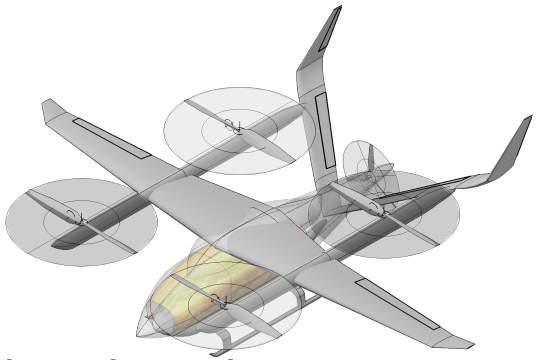



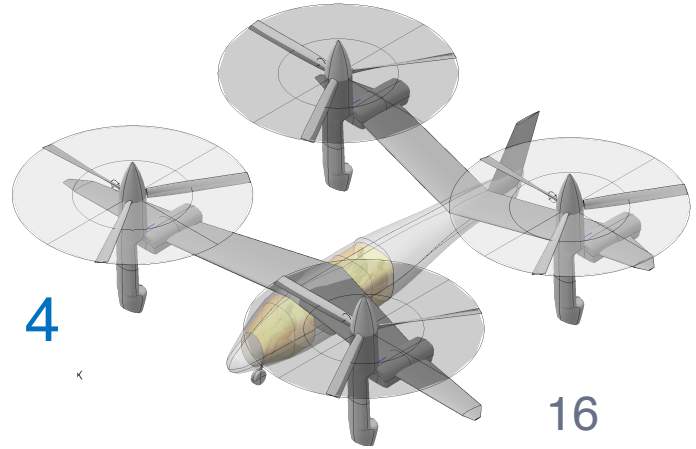



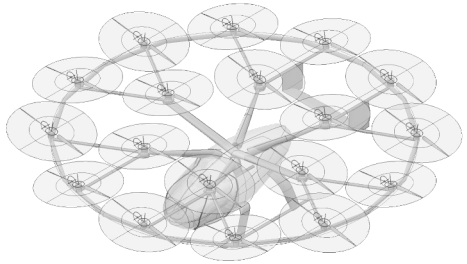



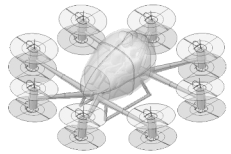



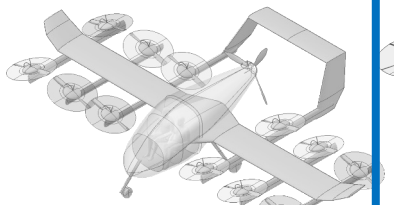

More lifting rotors for redundancy

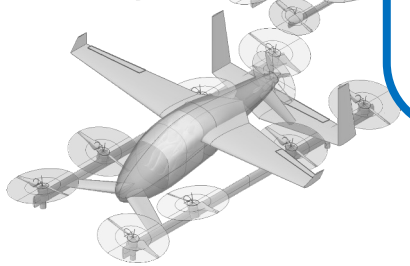
More like an airplane in cruise

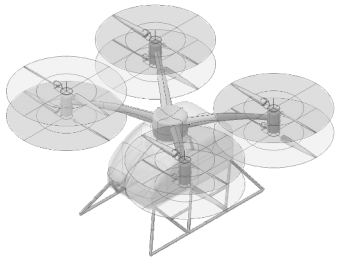
# The arrangement of rotors indicate priorities

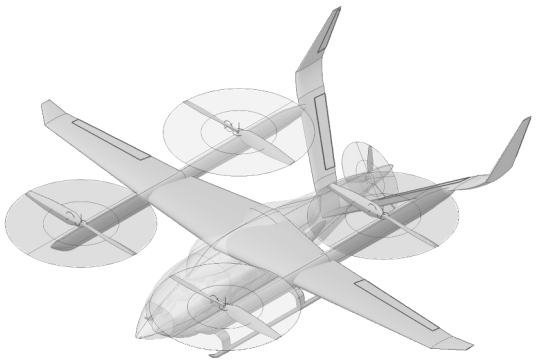




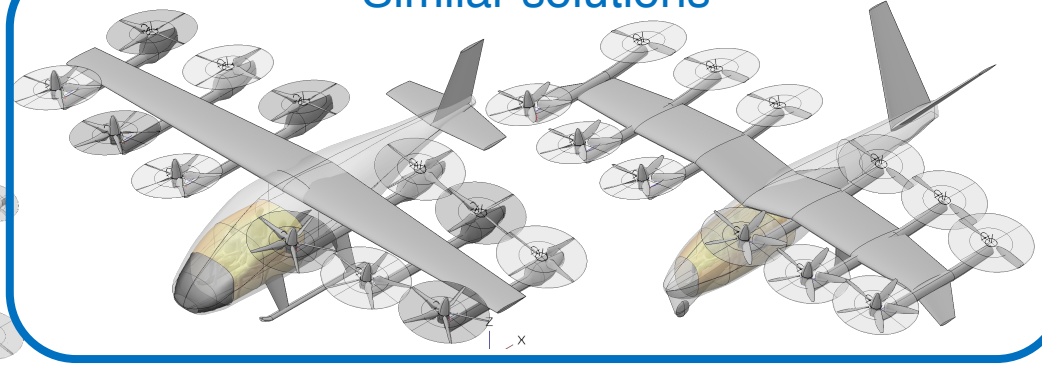


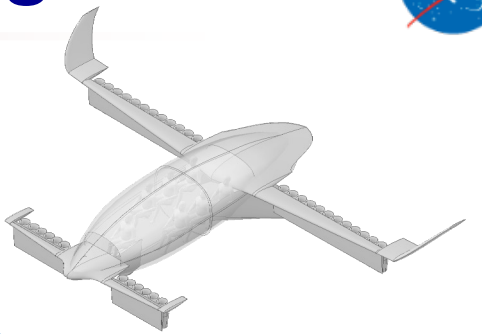


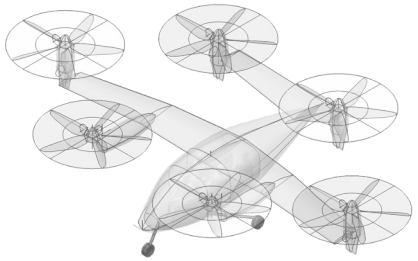


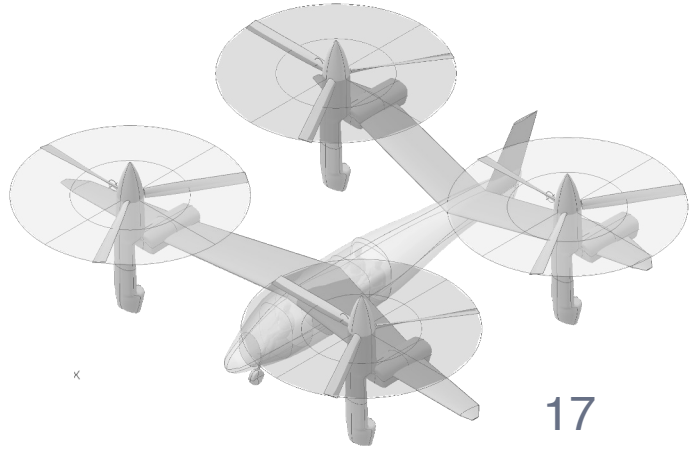


Similar solutions

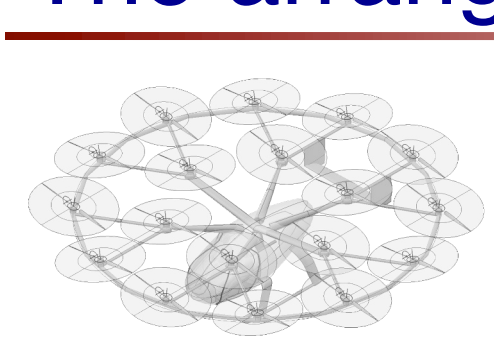


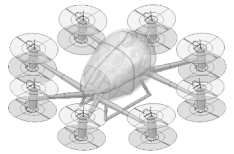


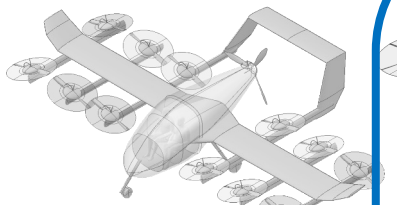


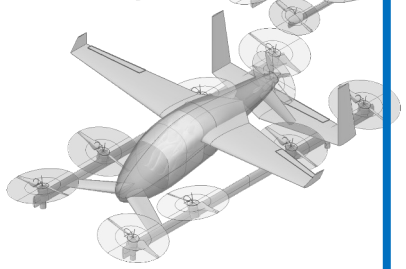


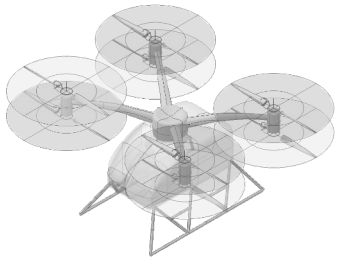
# The arrangement of rotors indicate priorities

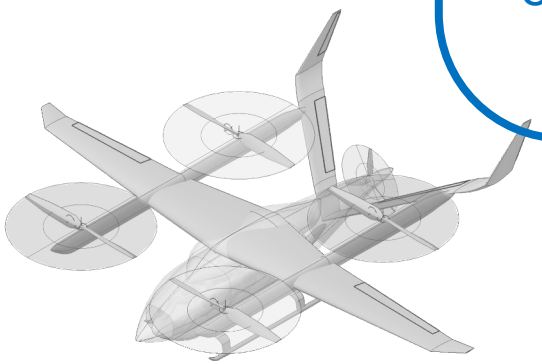




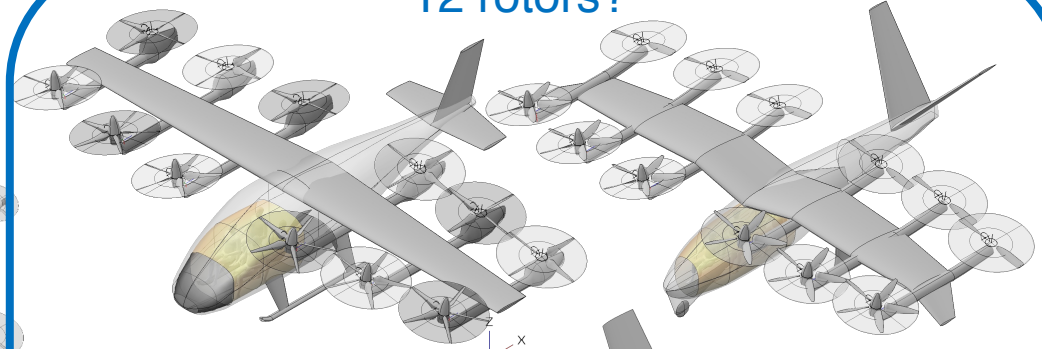




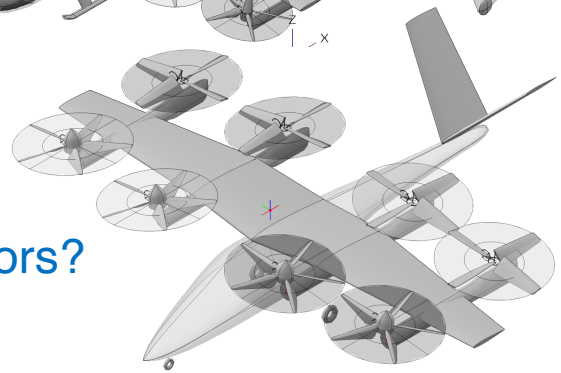


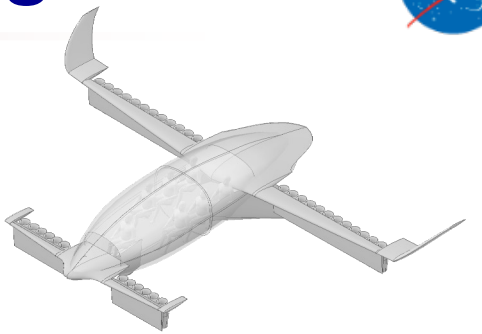


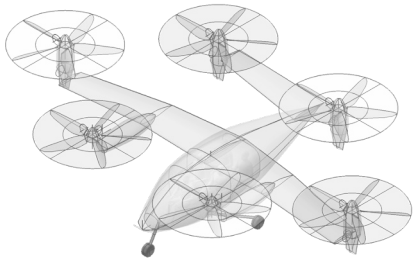
12 rotors?

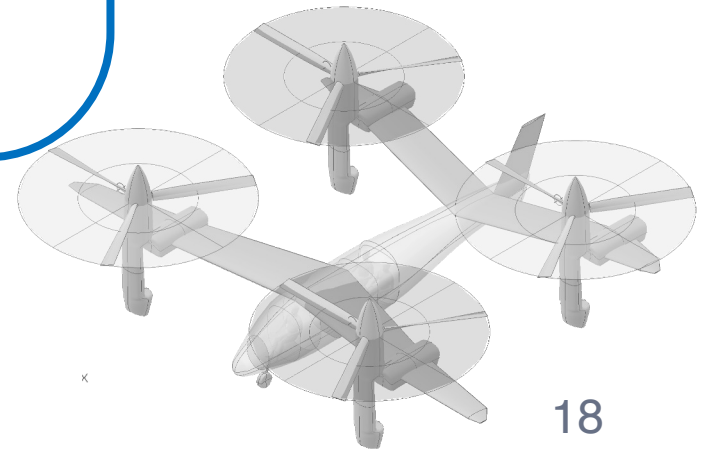


8 rotors?

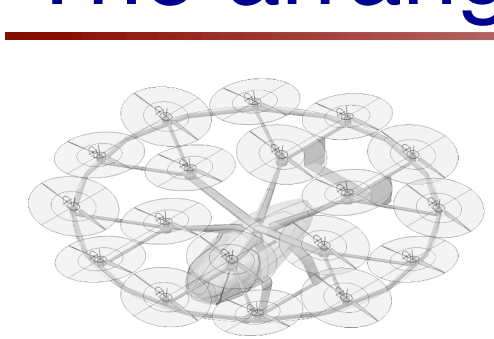


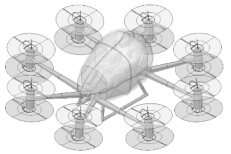


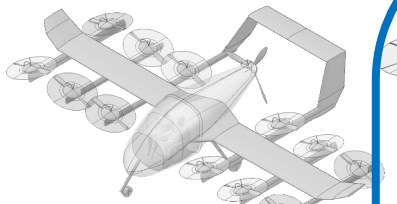


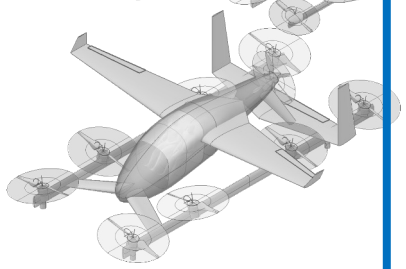


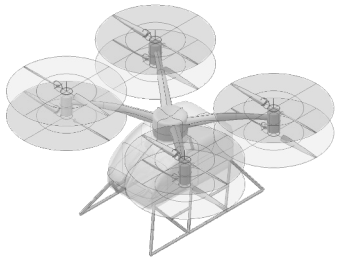
# The arrangement of rotors indicate priorities

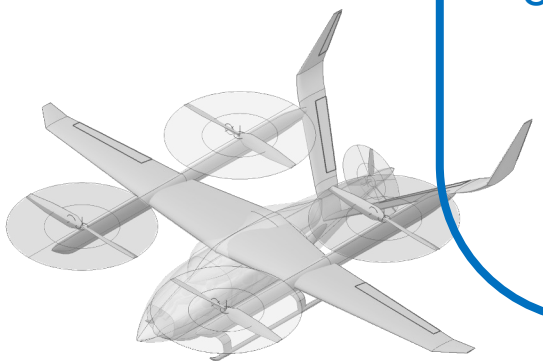




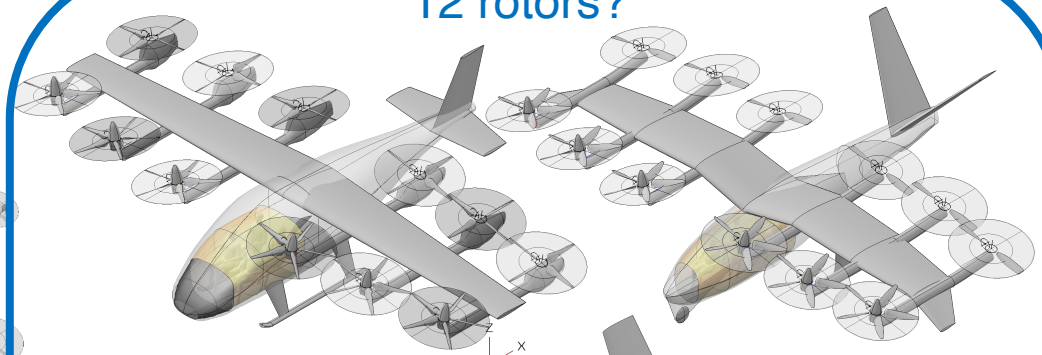


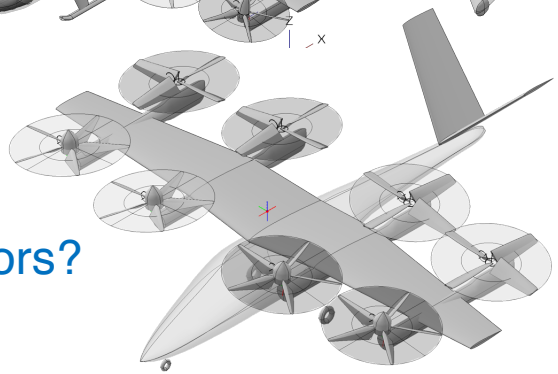




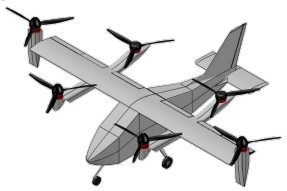


12 rotors?

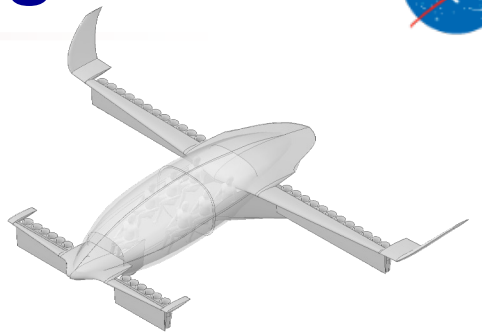


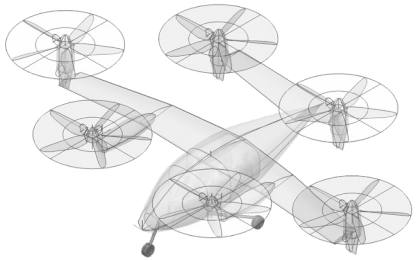


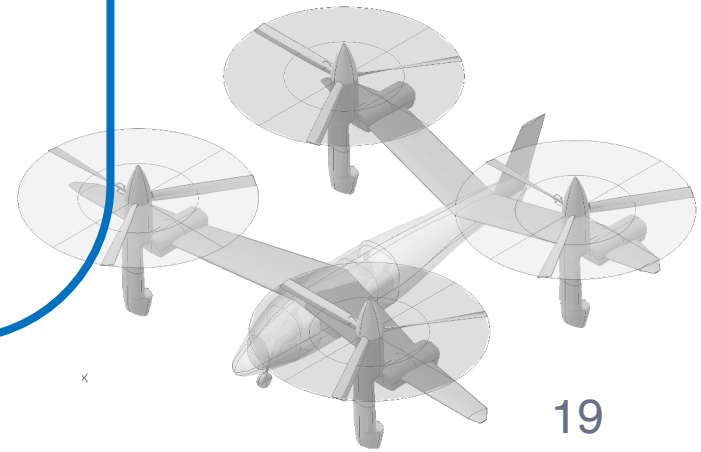
8 rotors?



6 rotors?







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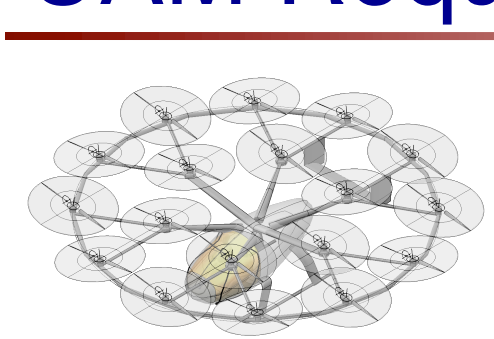
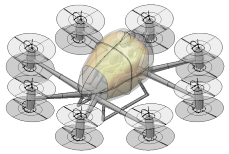
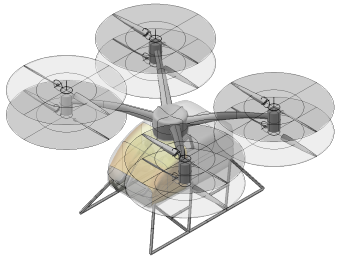
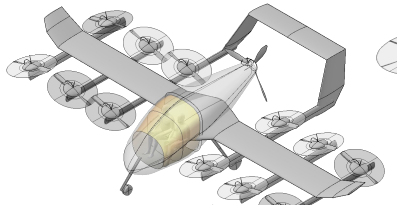
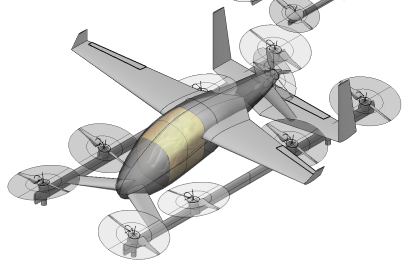
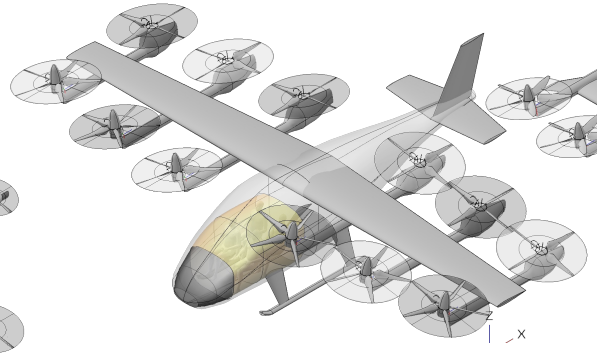
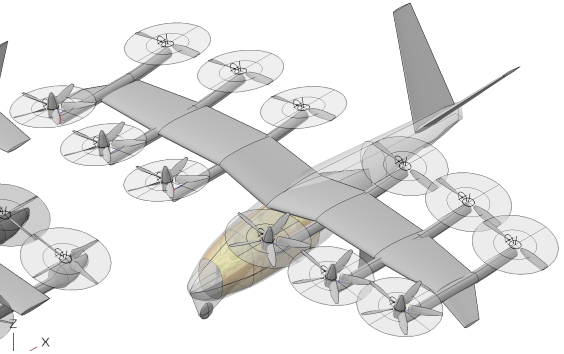
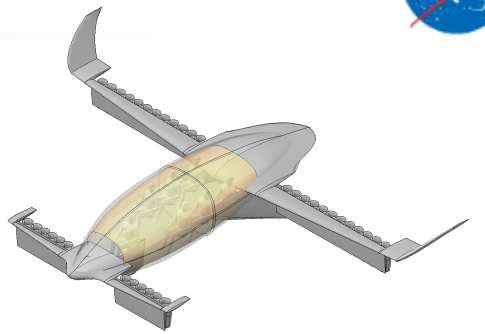
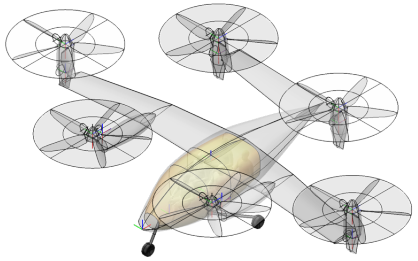
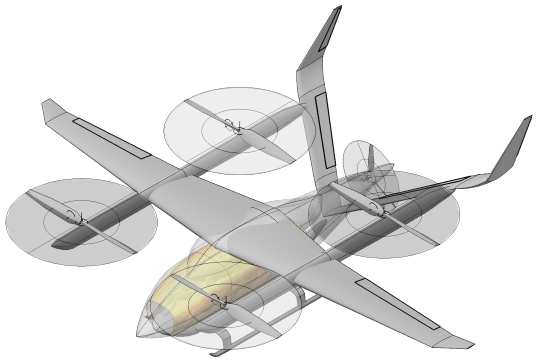
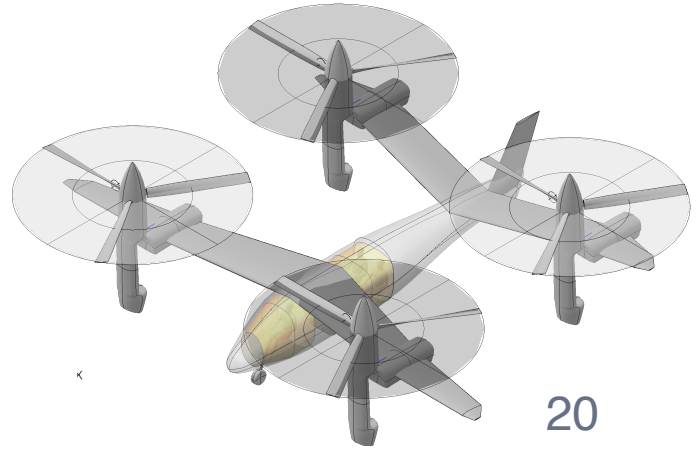

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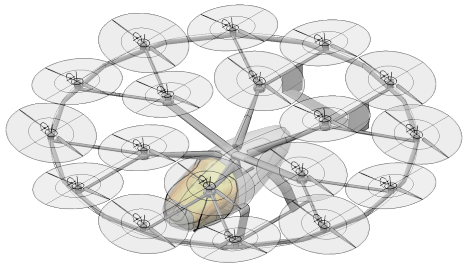
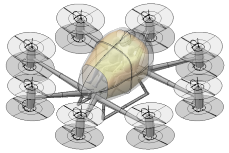
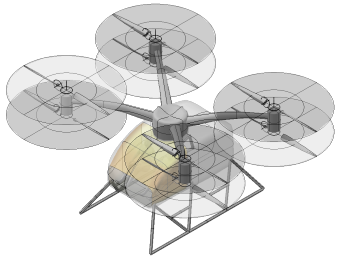
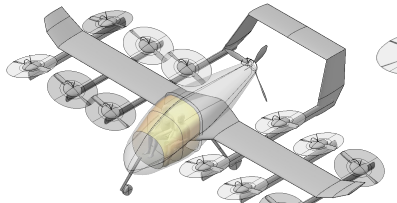
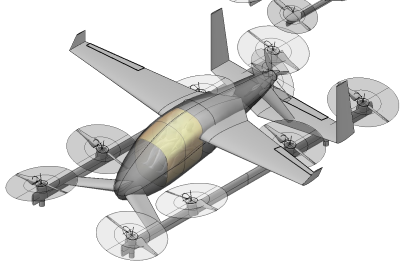
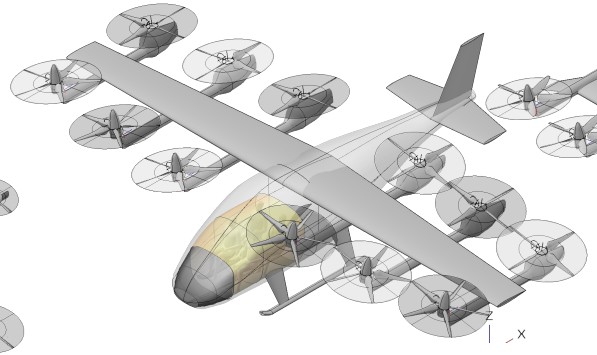
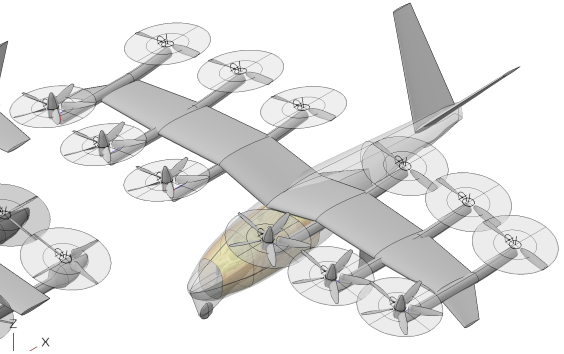
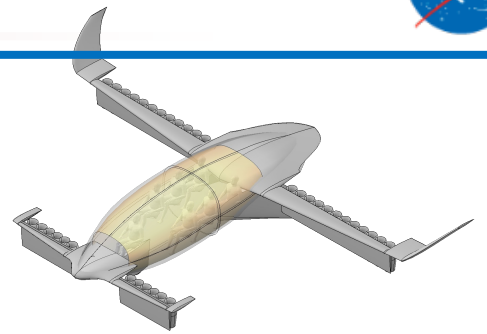
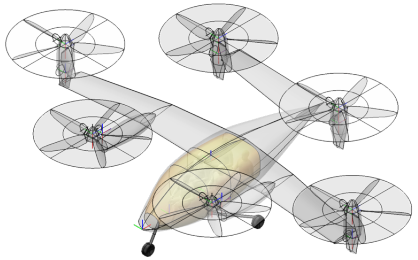
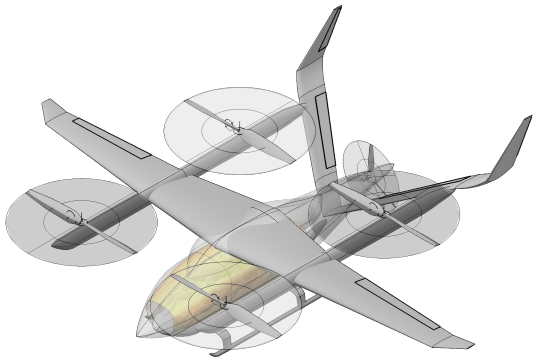
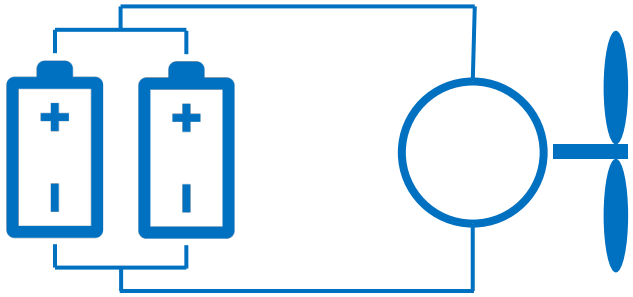
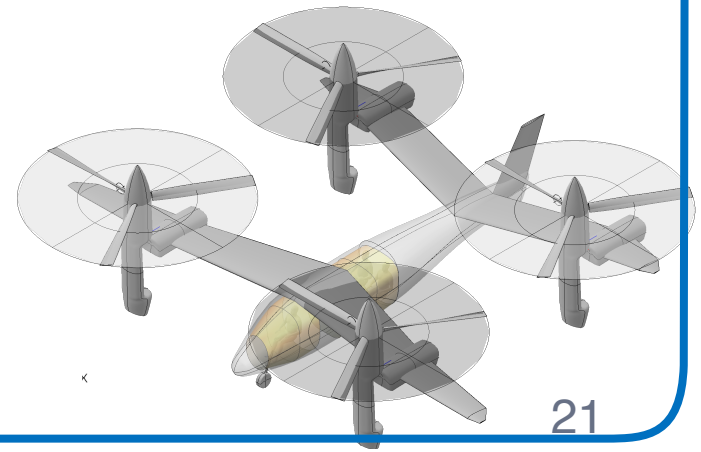

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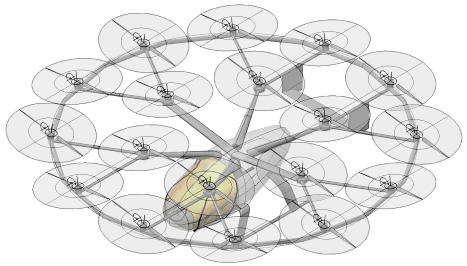
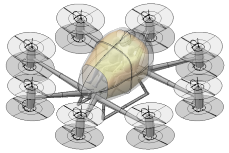
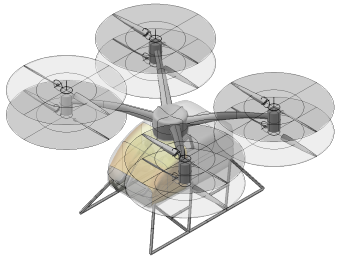
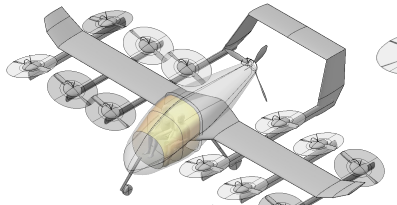
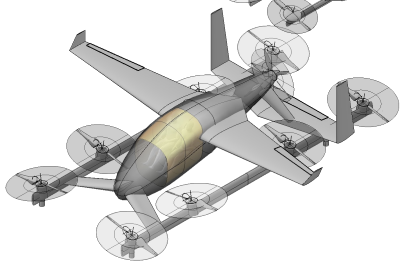
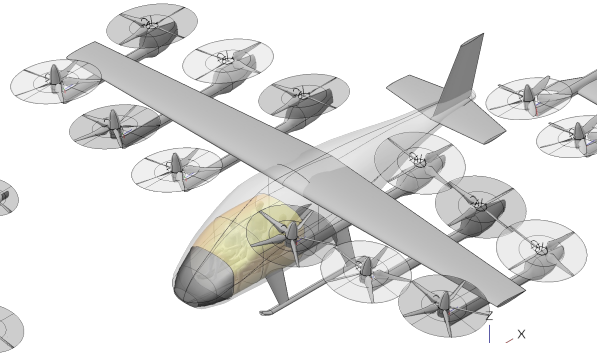
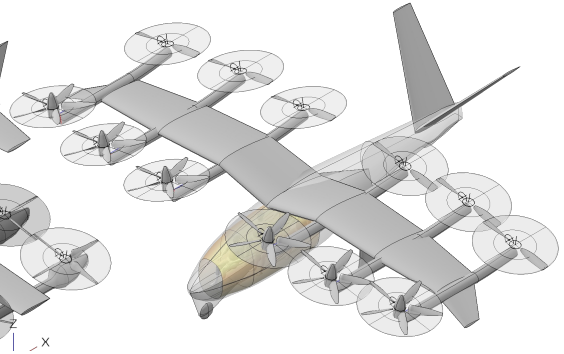
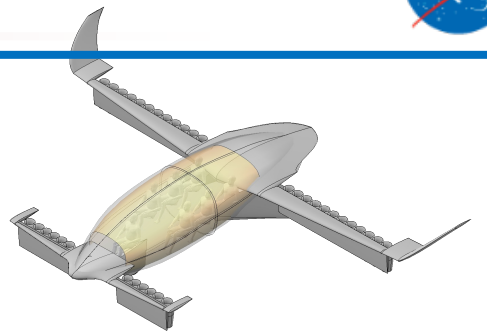
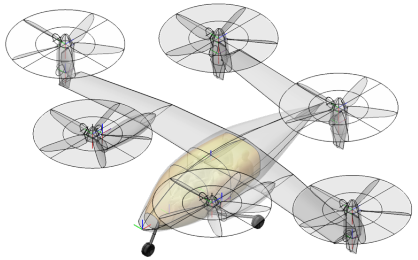
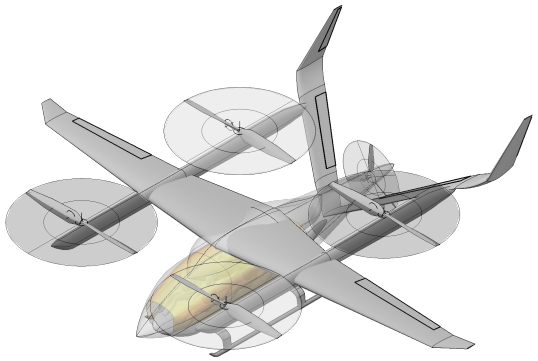
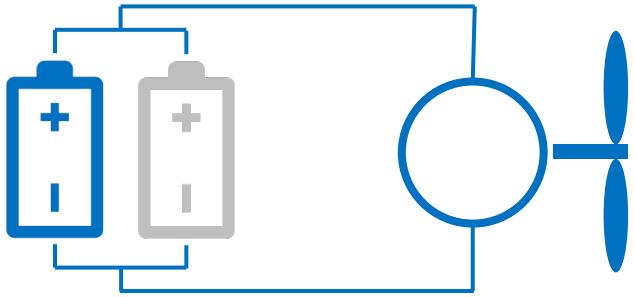
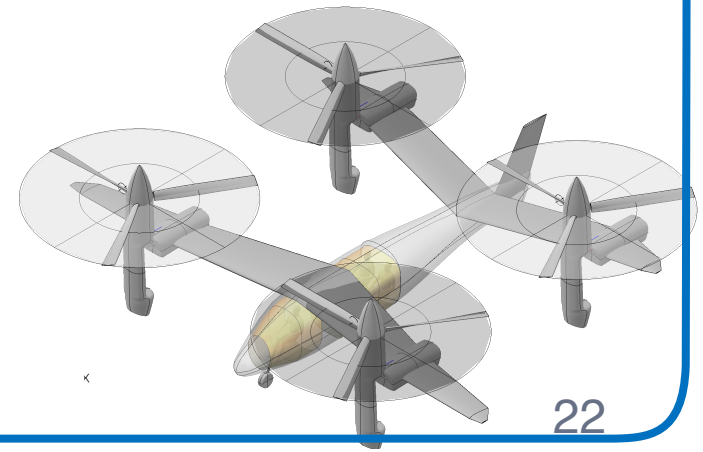

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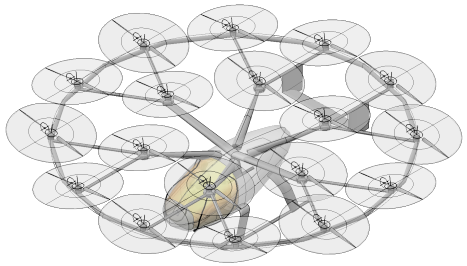
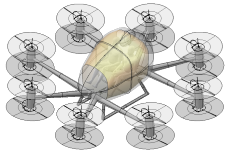
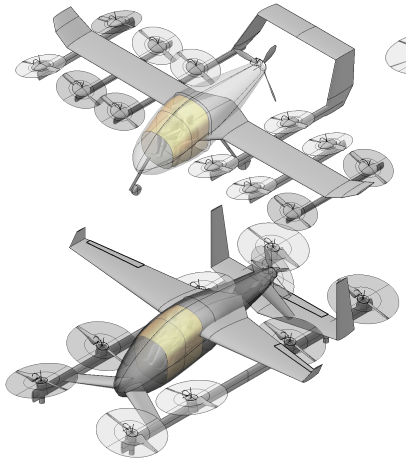
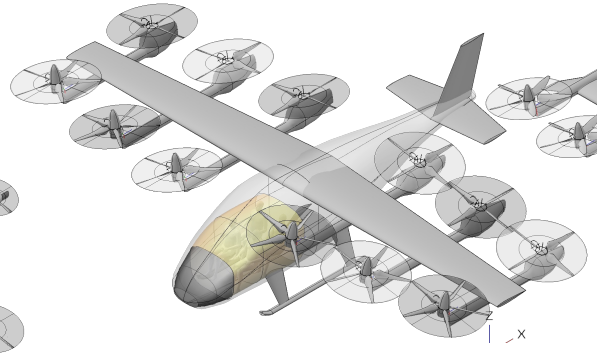
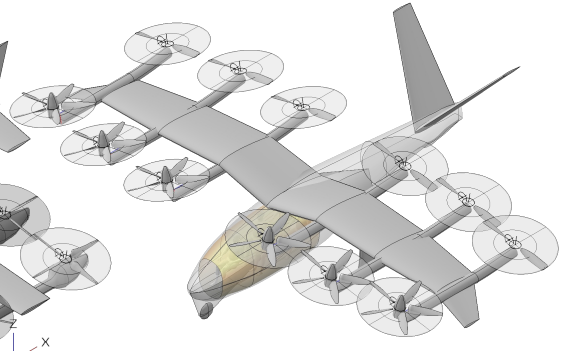
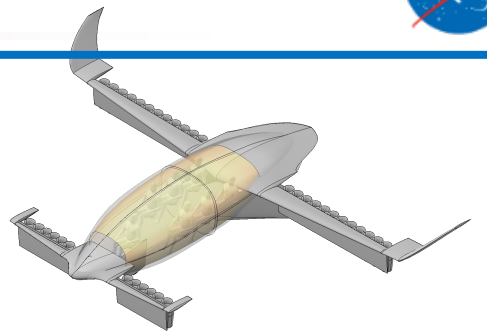
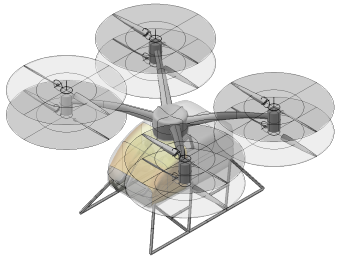
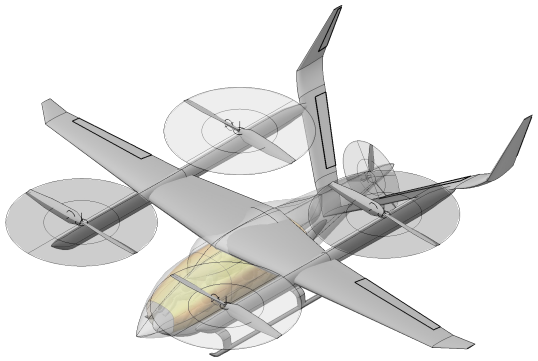
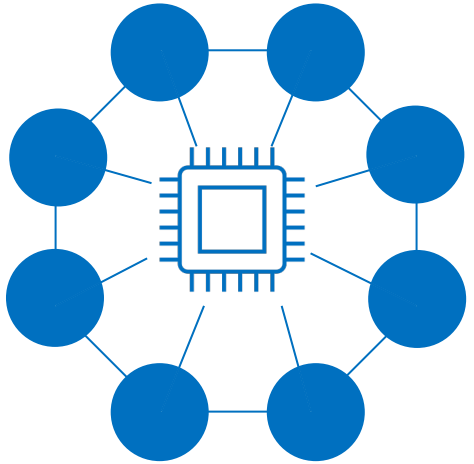
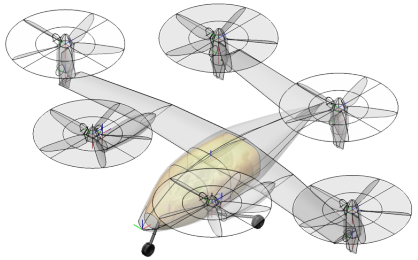
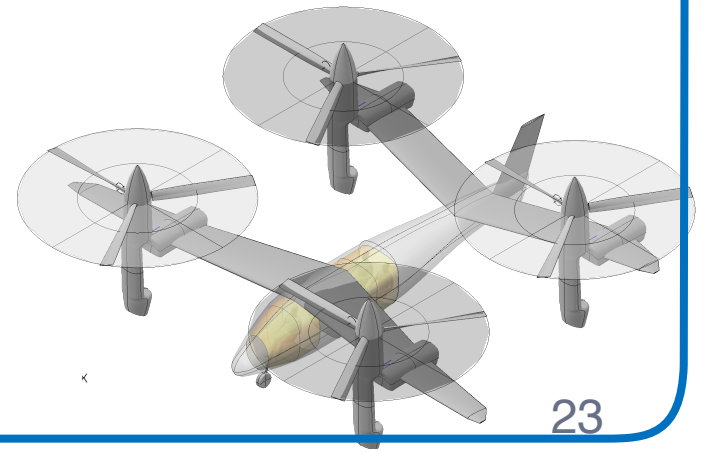

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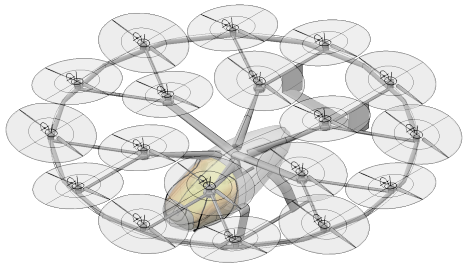

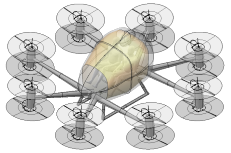

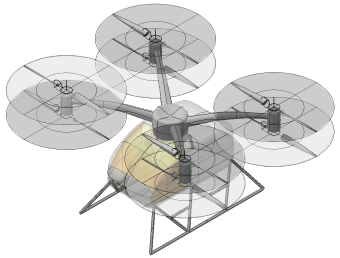

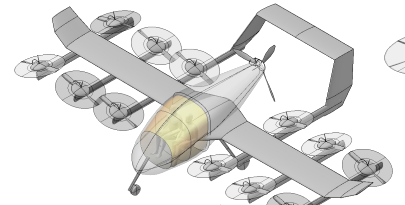

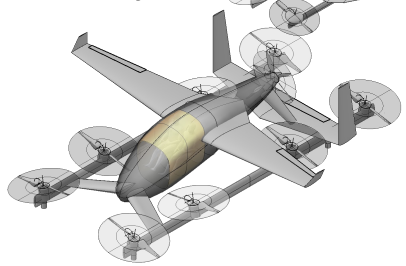

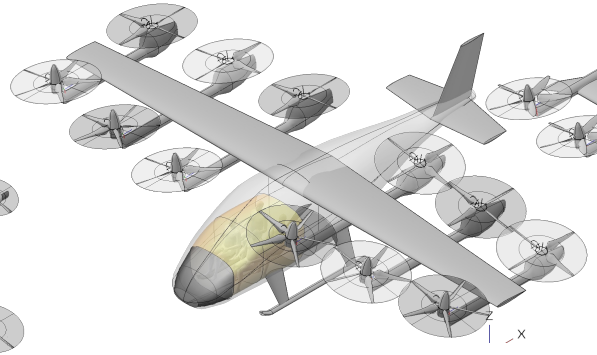

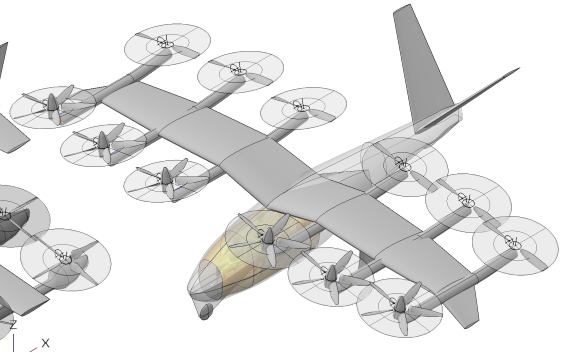

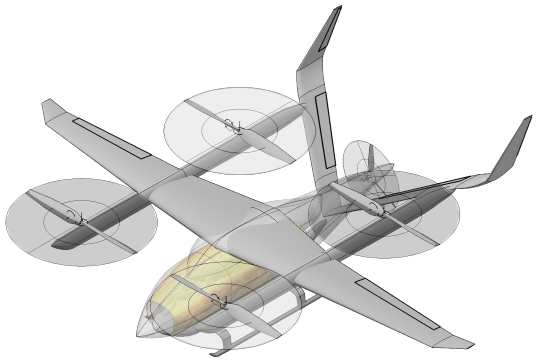

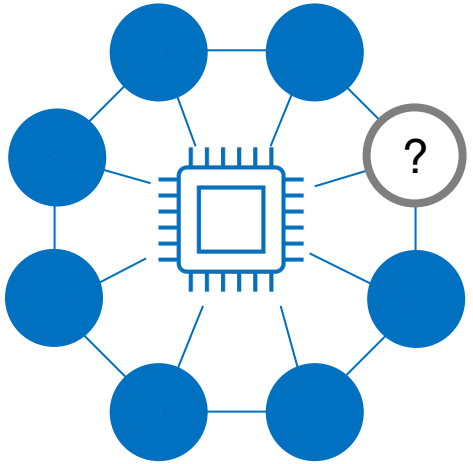


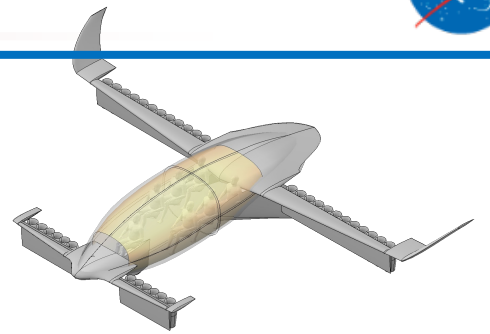

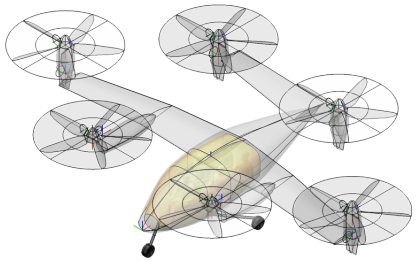

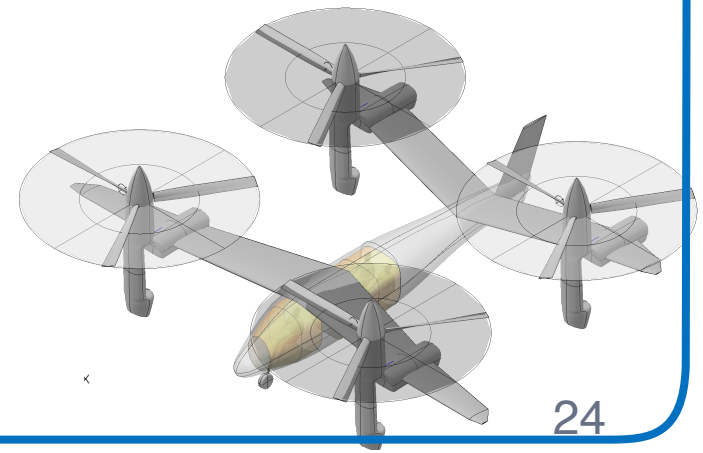

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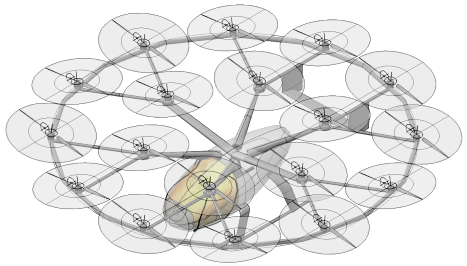
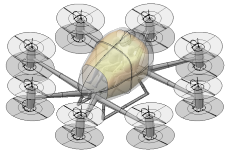
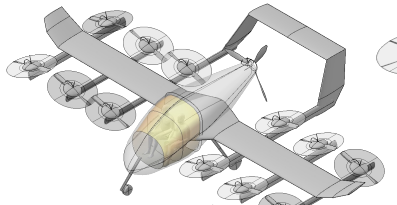
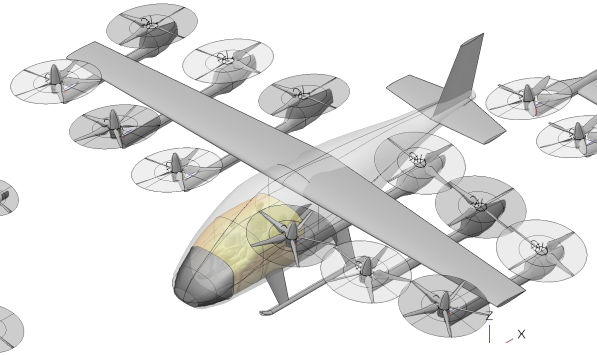
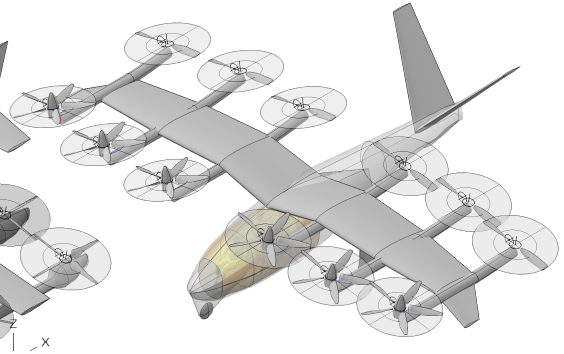
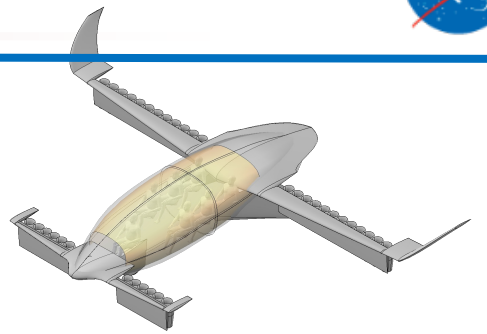


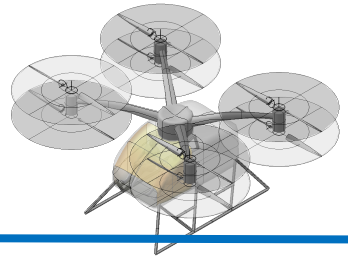


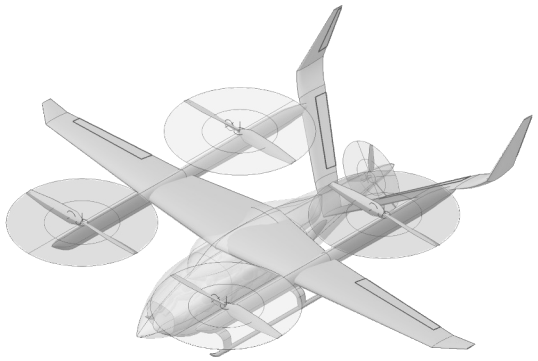




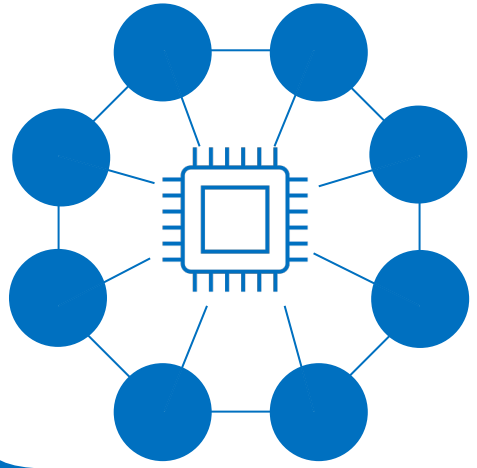


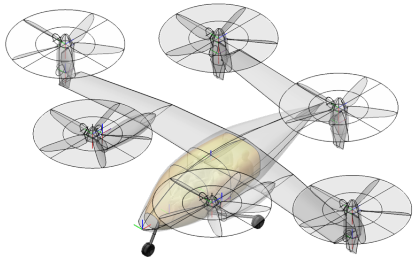


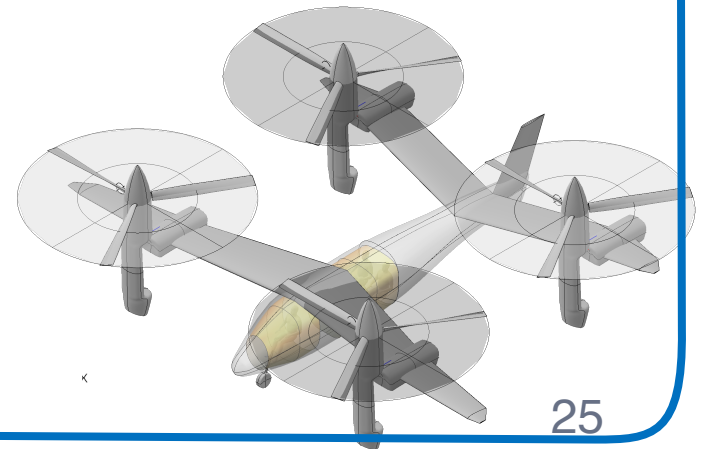




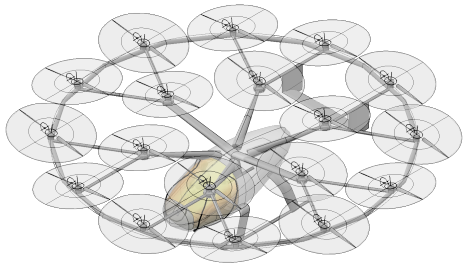
Tolerant to loss of power
in a single lifting rotor

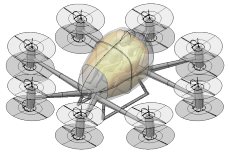


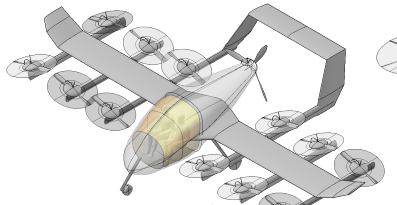


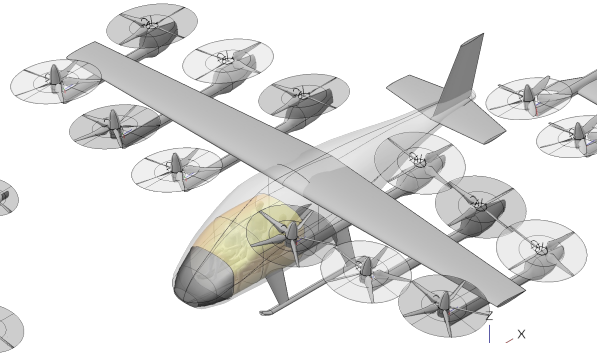


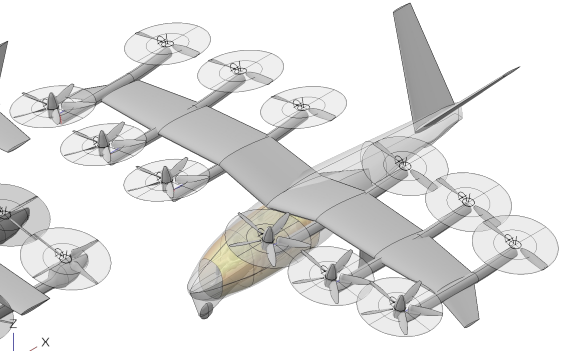
# UAM Requirement: More safe

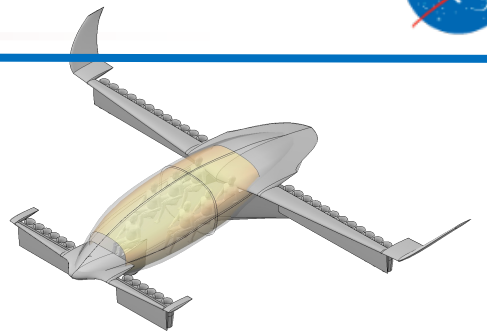


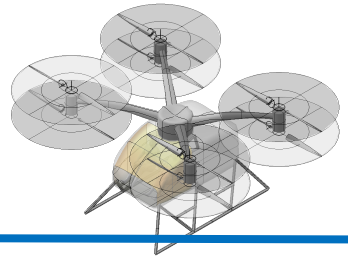


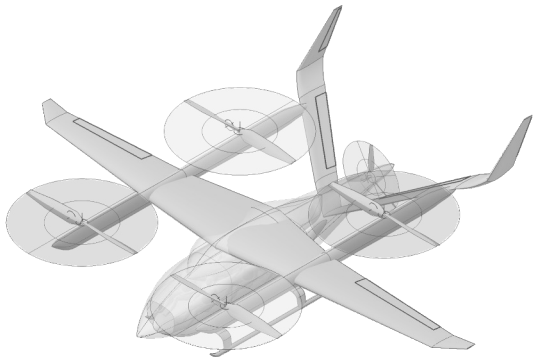




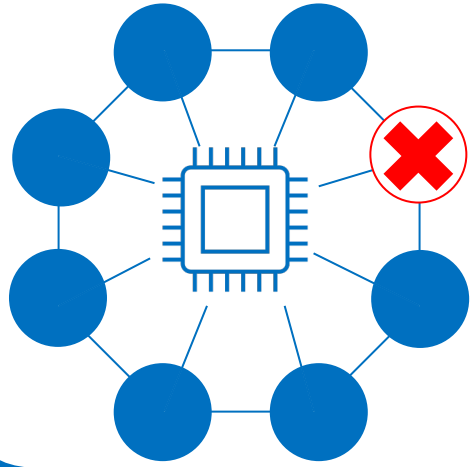


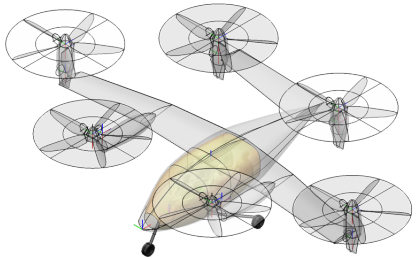


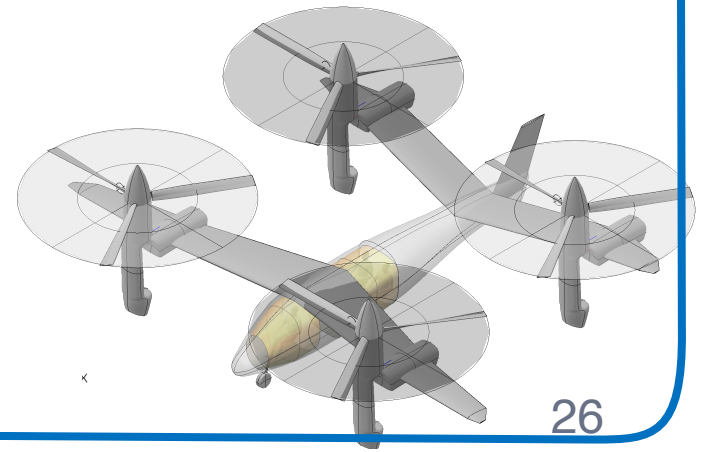




Tolerant to loss of power
in a single lifting rotor







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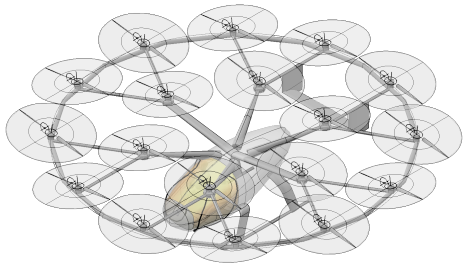

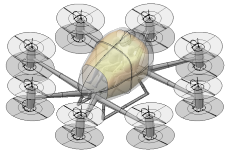

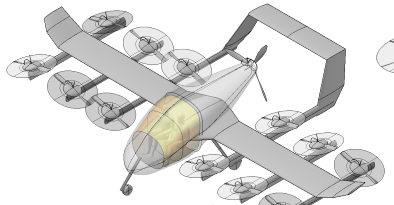

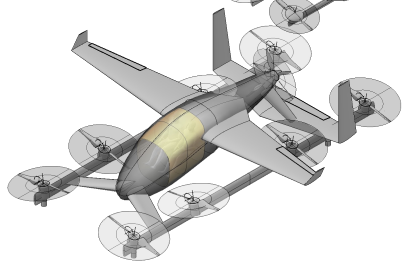

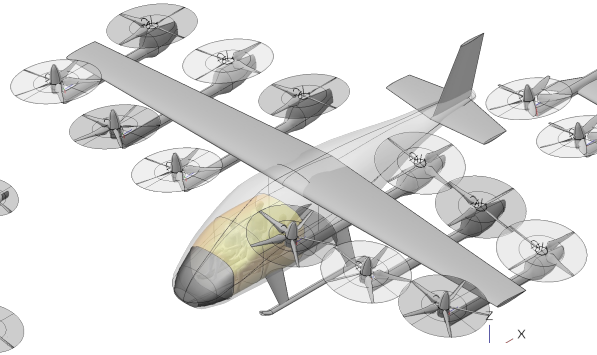

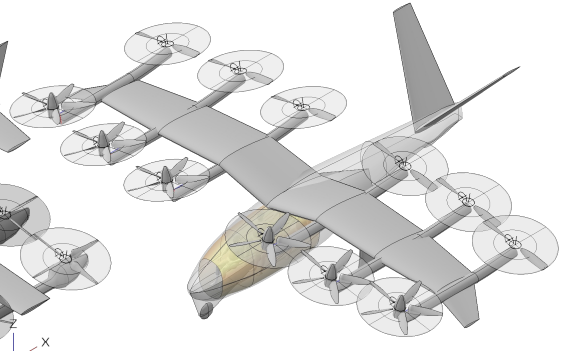

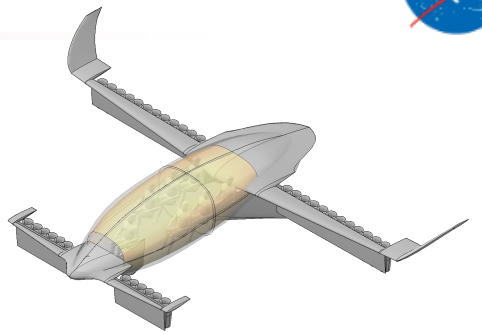

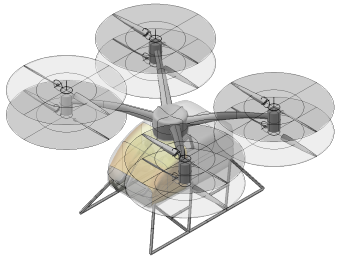

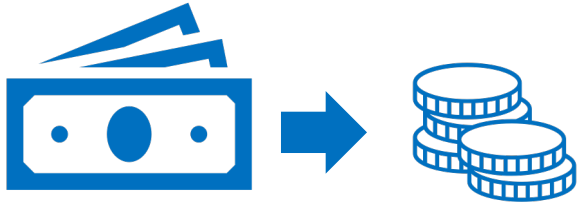

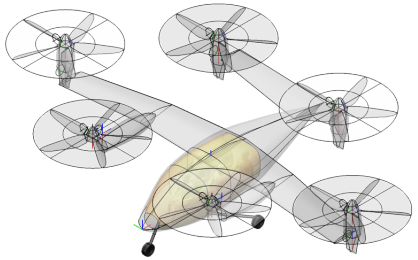

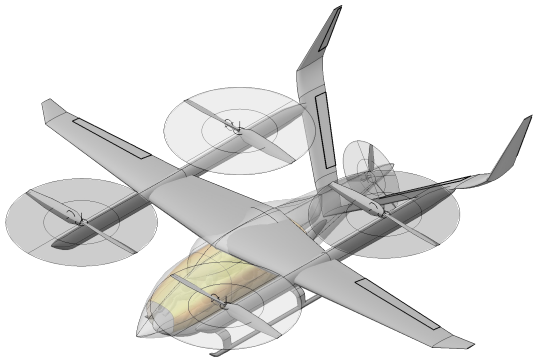

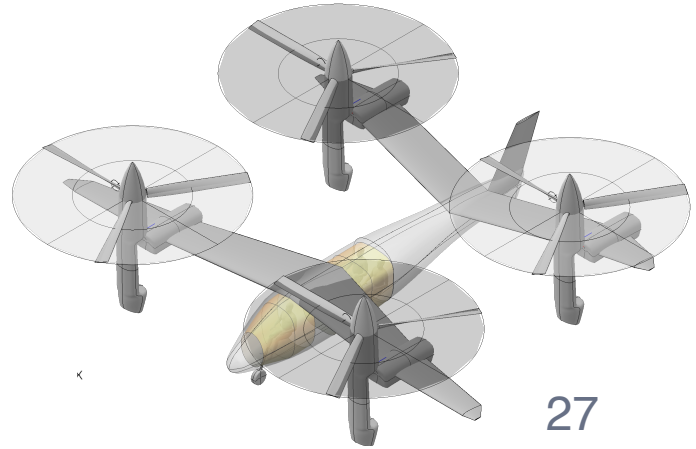

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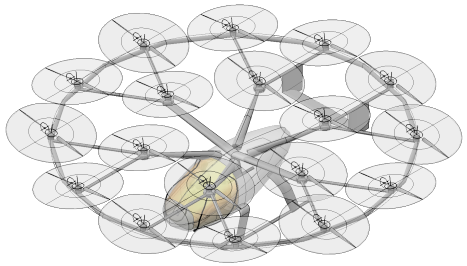
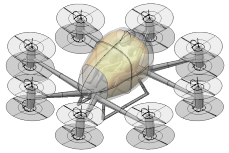
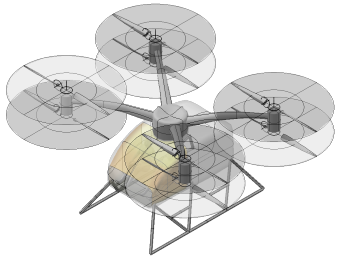
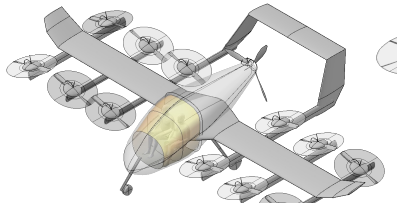
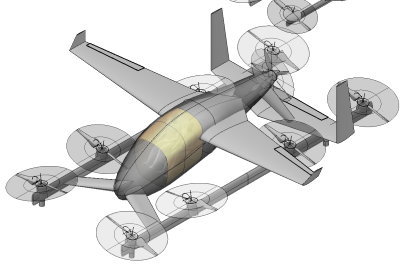
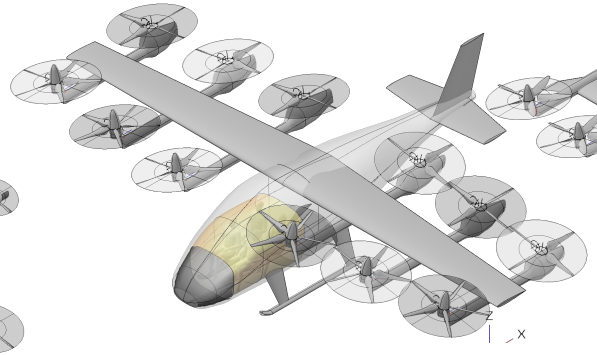
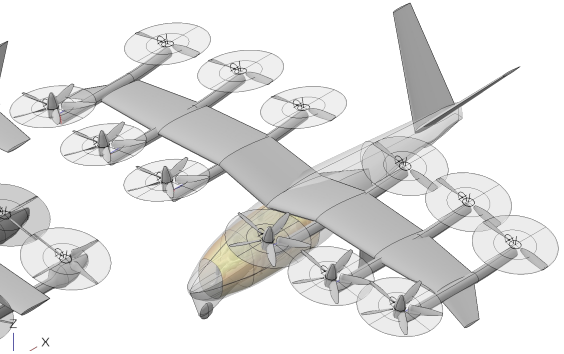
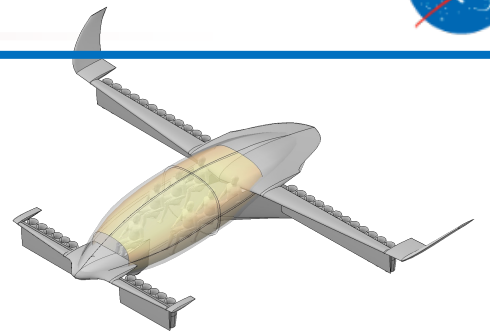
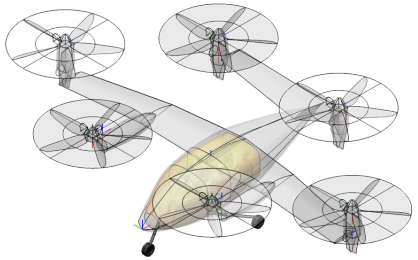
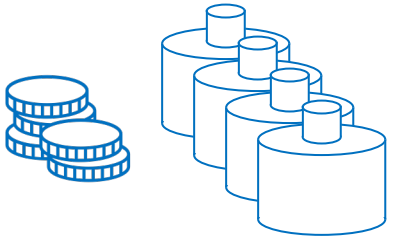
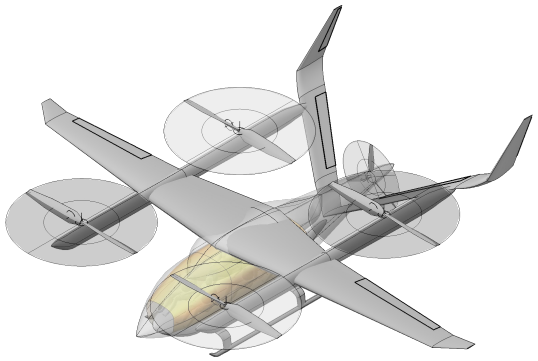
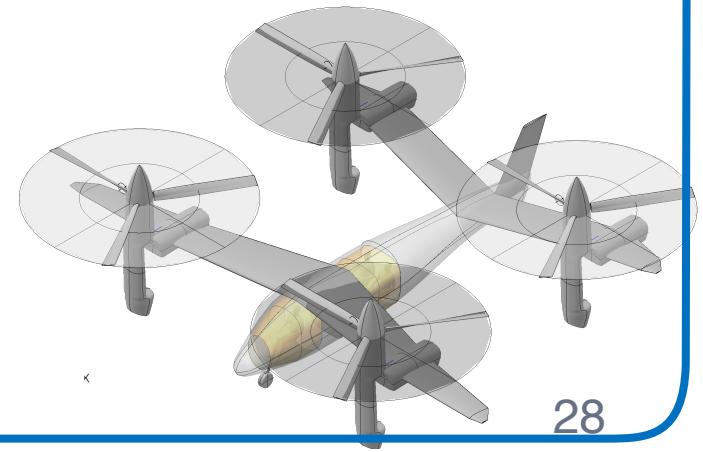

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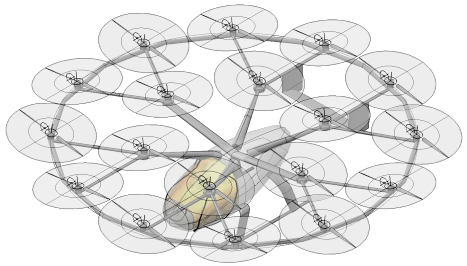
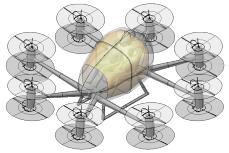
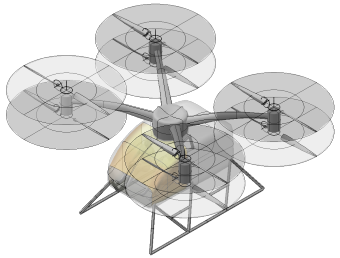
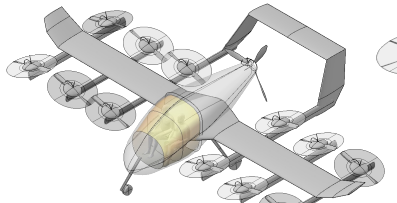
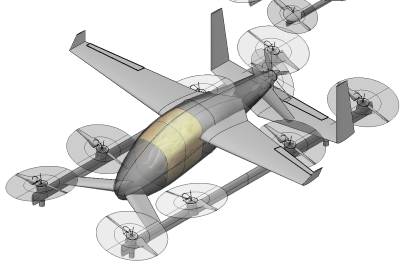
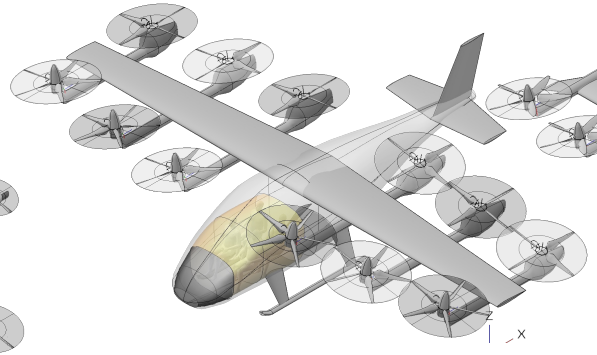
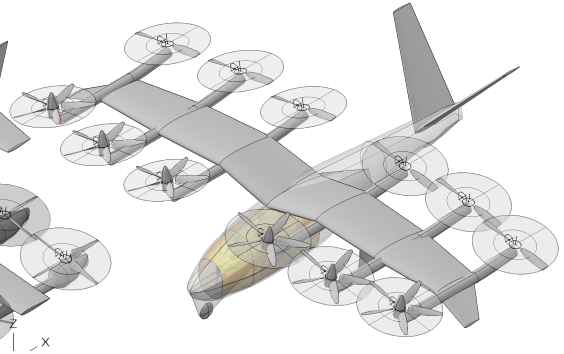
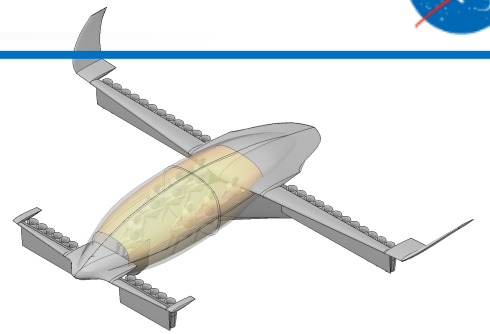
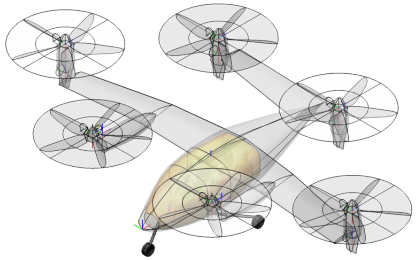
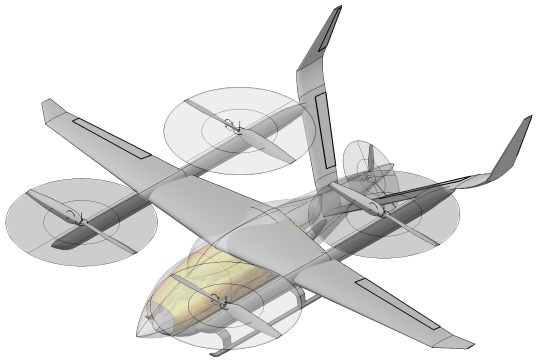
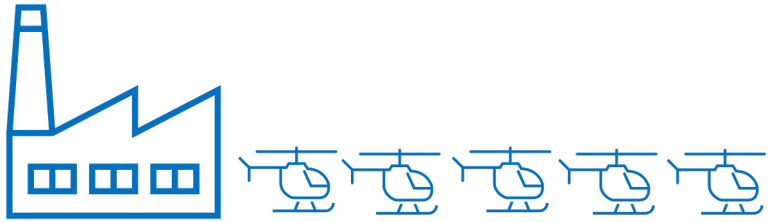
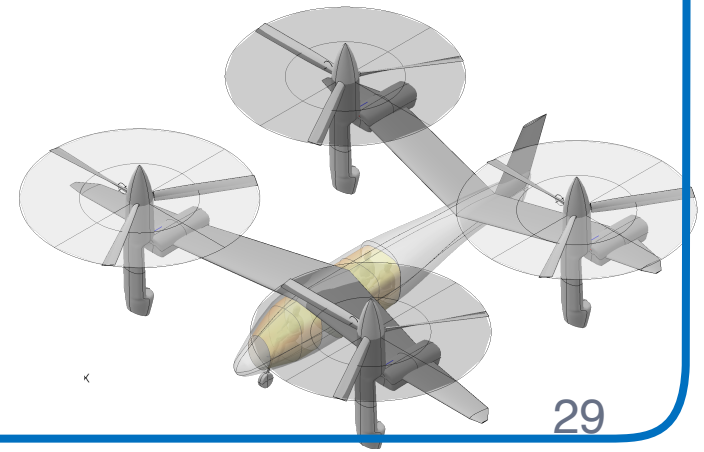
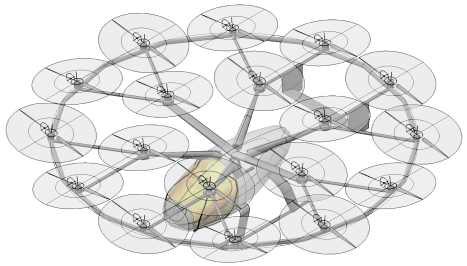
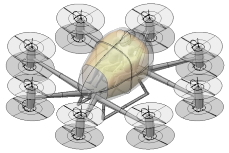
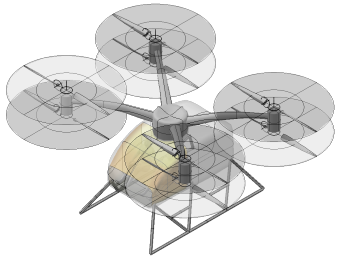
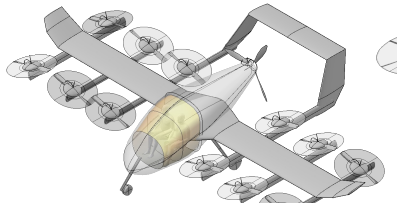
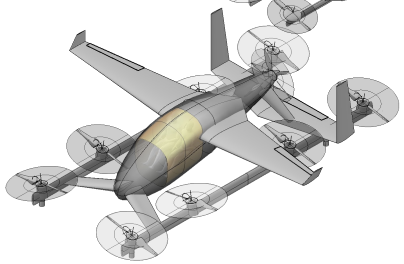
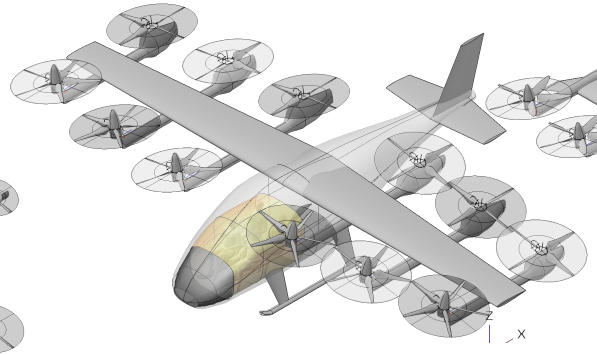
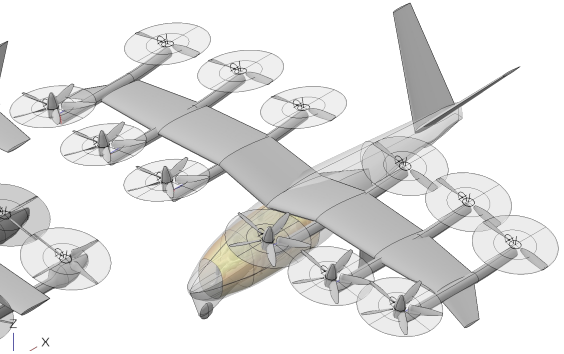
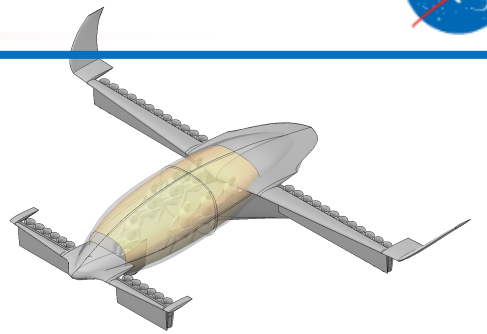
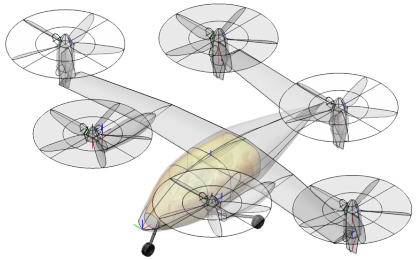
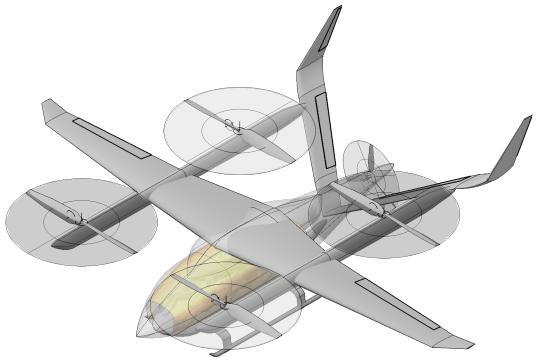
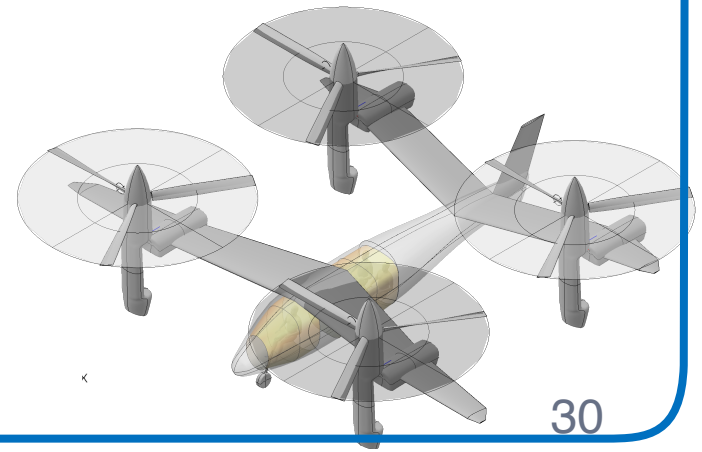
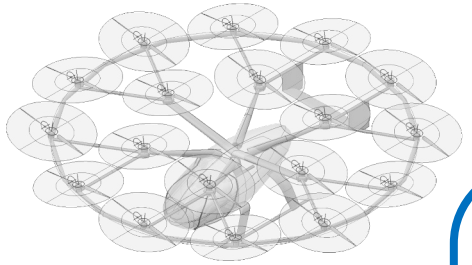













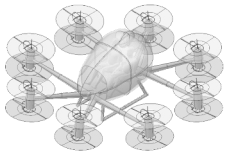
# UAM Requirement: Less cost

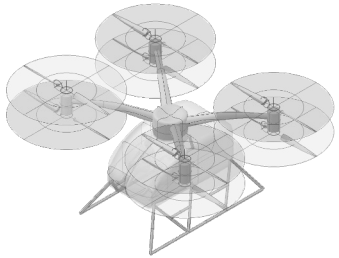











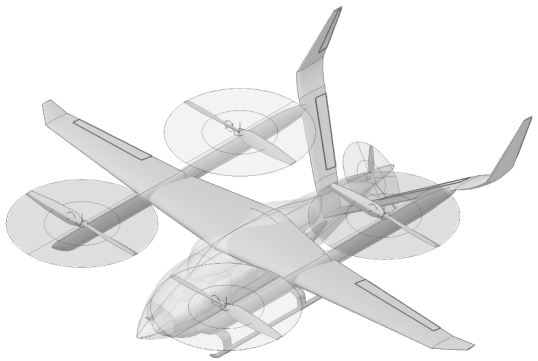



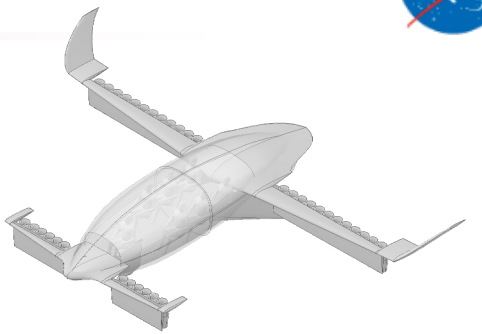
# UAM Requirement: Less cost

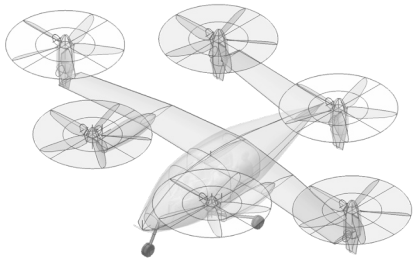


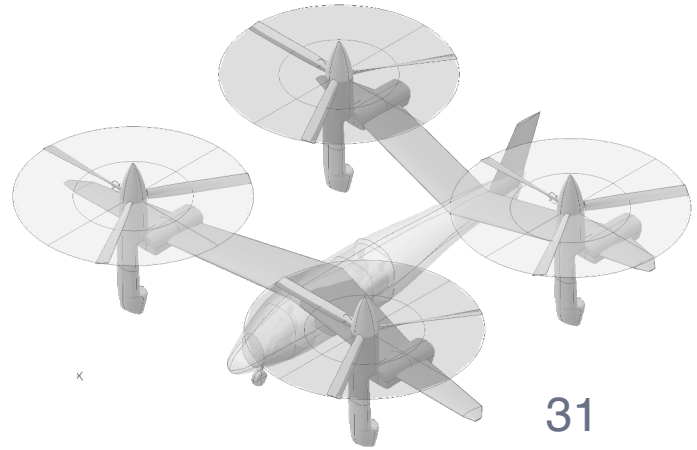




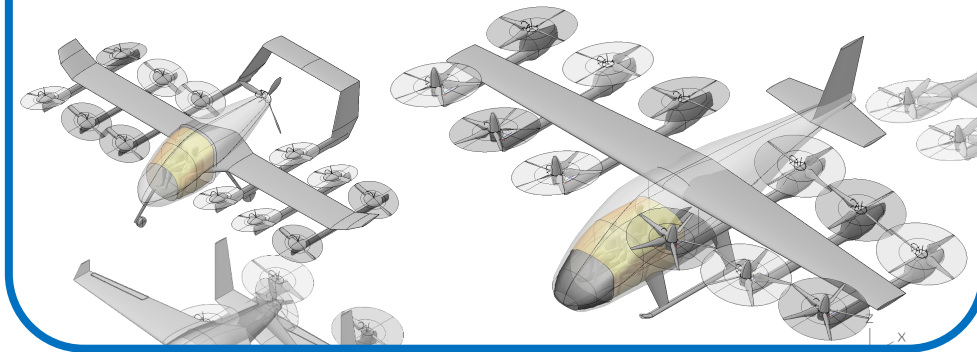




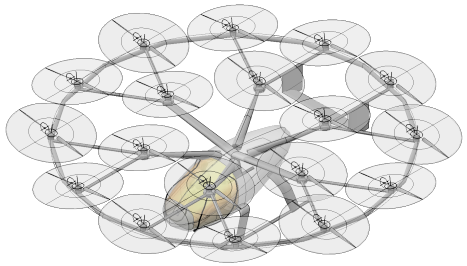


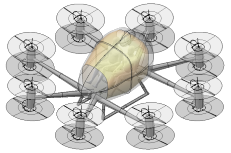


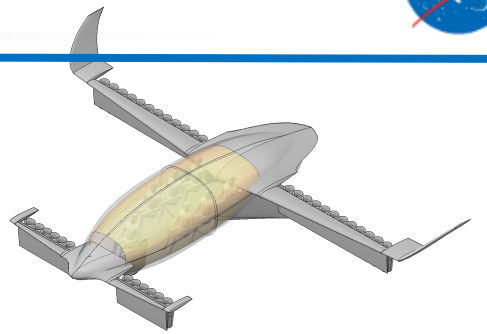
No pilots onboard

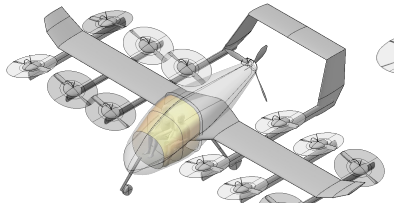


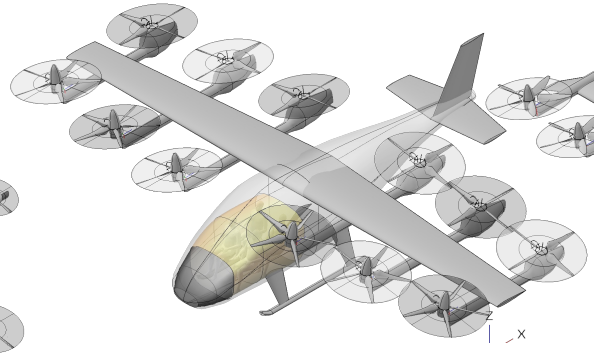
# UAM Requirement: Less cost

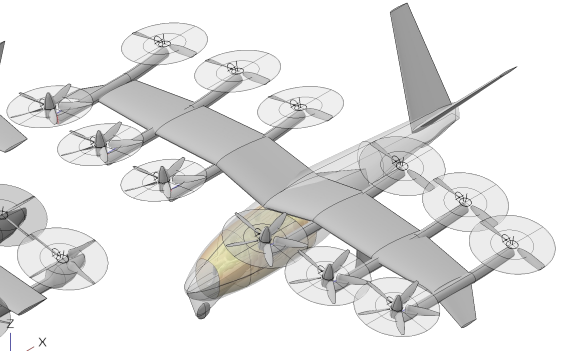


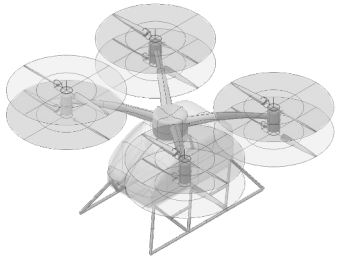


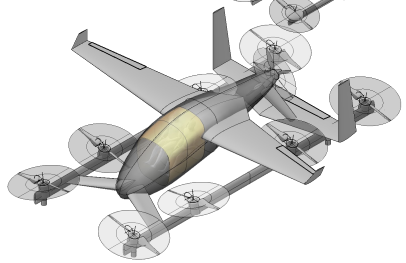




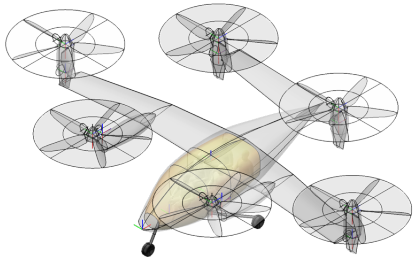


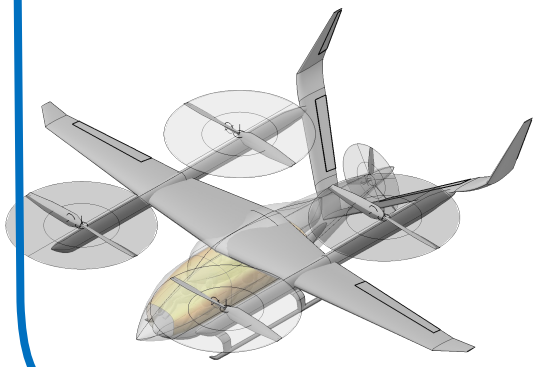


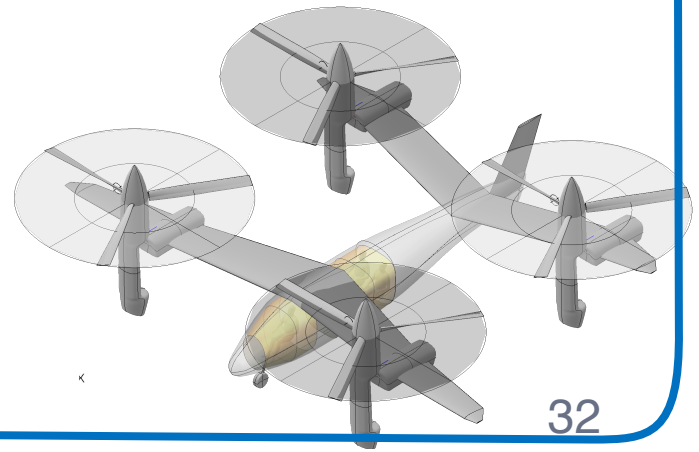




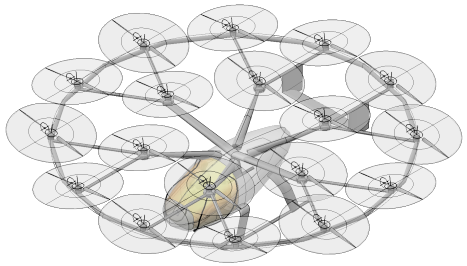
Battery electric propulsion
from cheap electricity

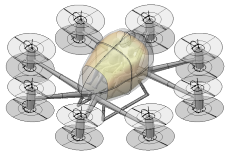


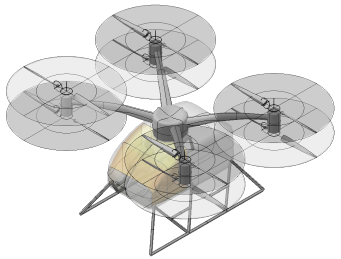


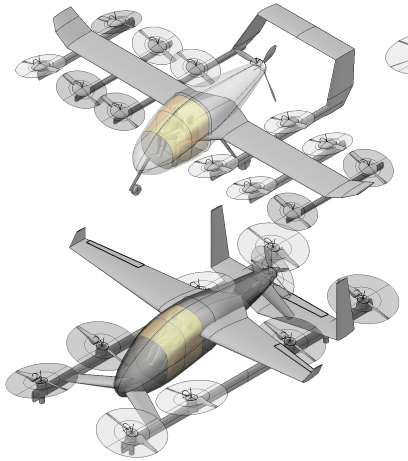


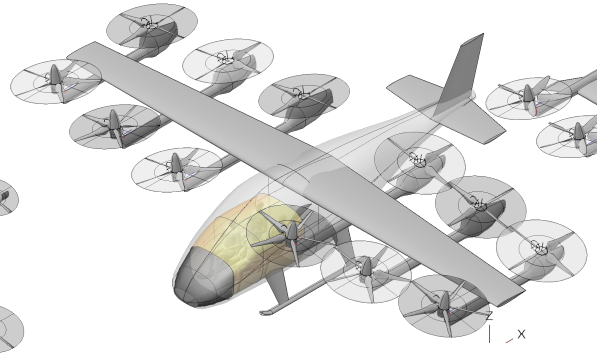
# UAM Requirement: Less cost

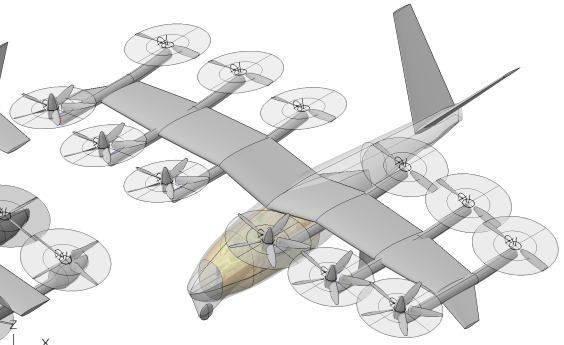




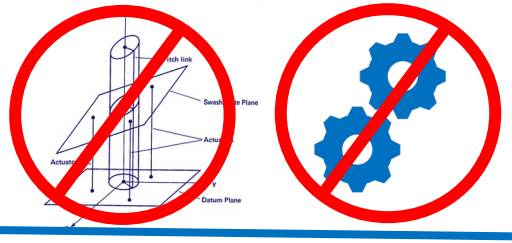


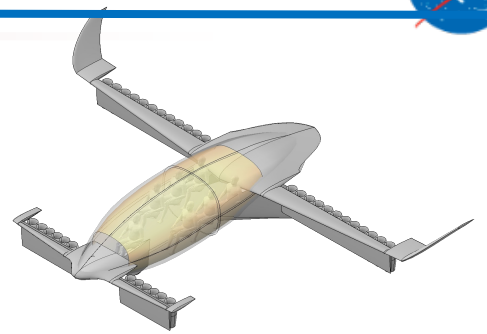


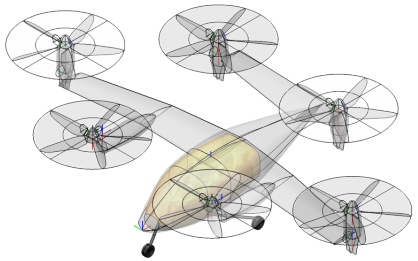


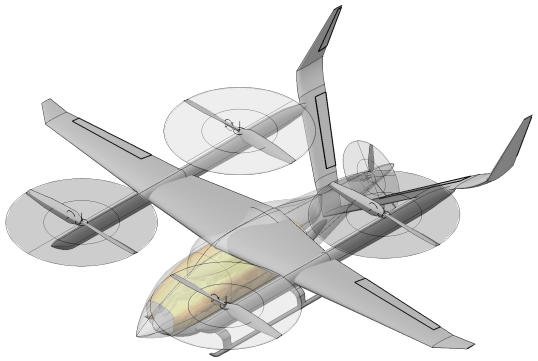


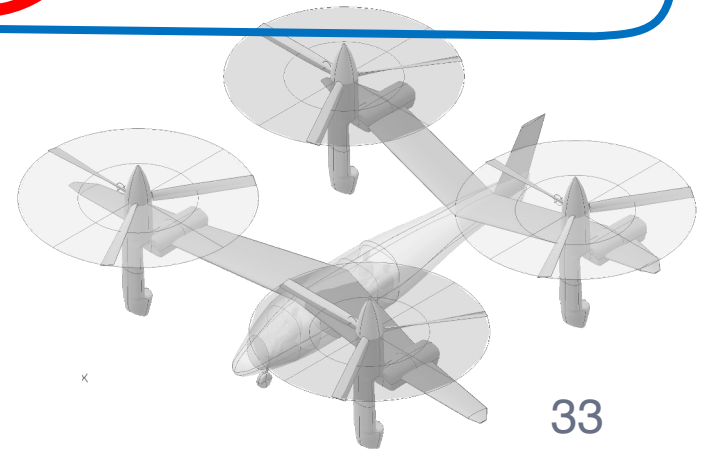
No cyclic rotor control
No gearbox





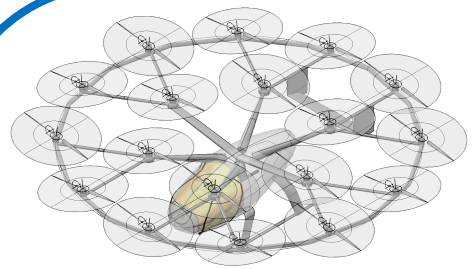


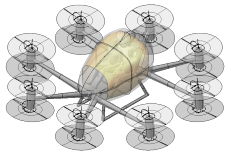


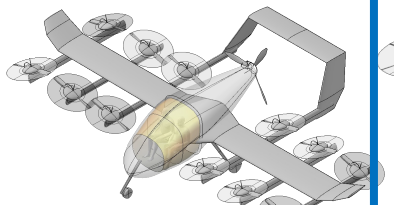


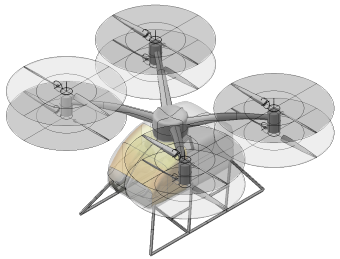
# UAM Requirement: Less cost

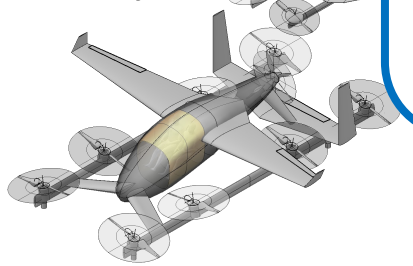
Fixed pitch, no-articulation, no-tilt rotors

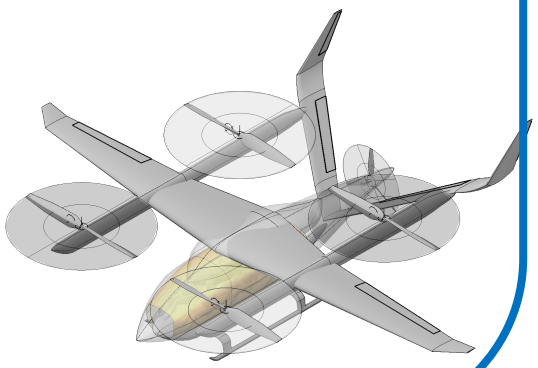




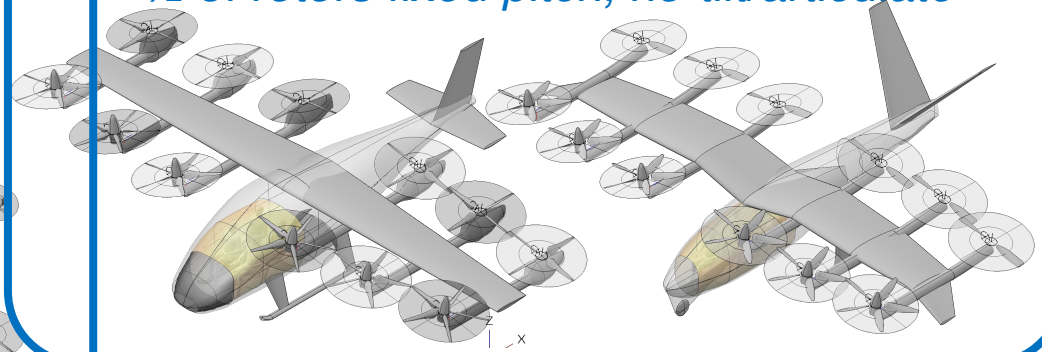


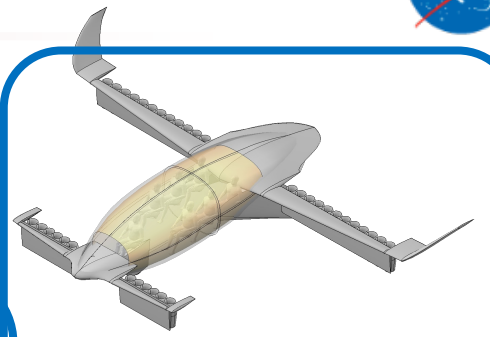




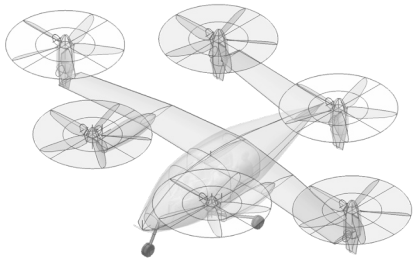


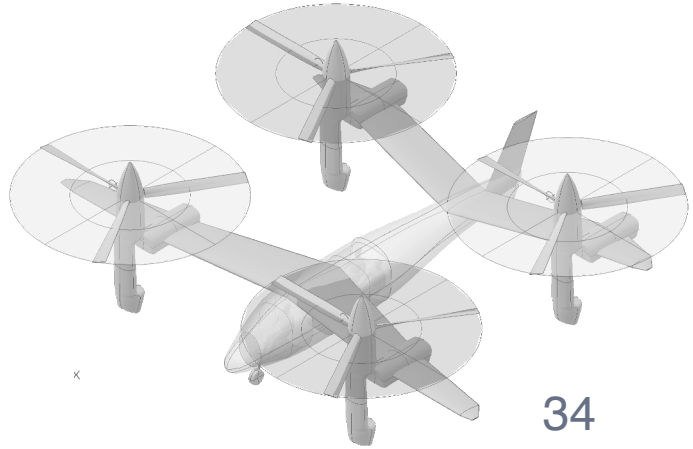
*½ of rotors fixed pitch, no-tilt/articulate*



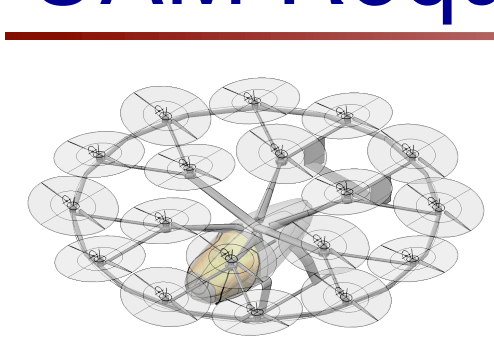


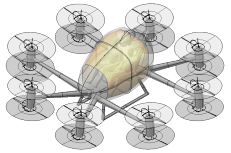
*Fixed pitch rotors*

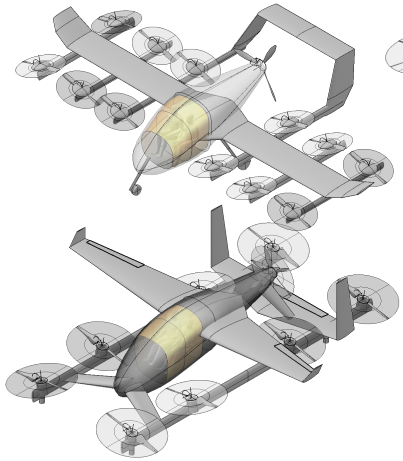


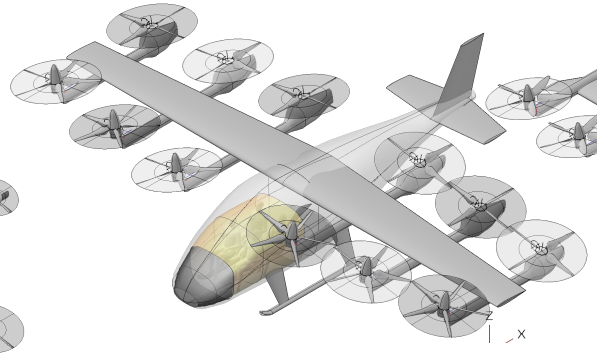


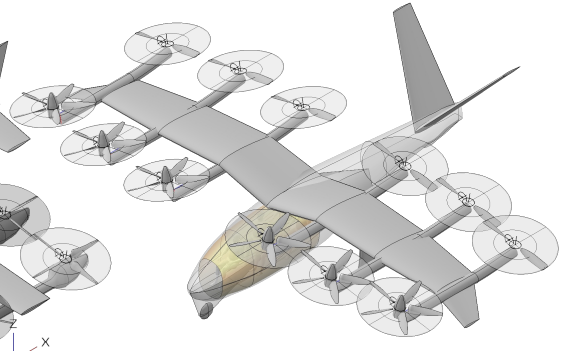
# UAM Requirement: Less noise

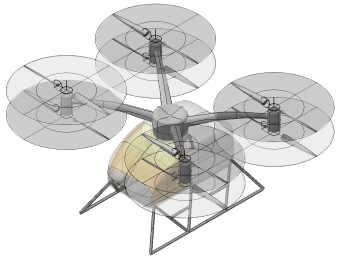


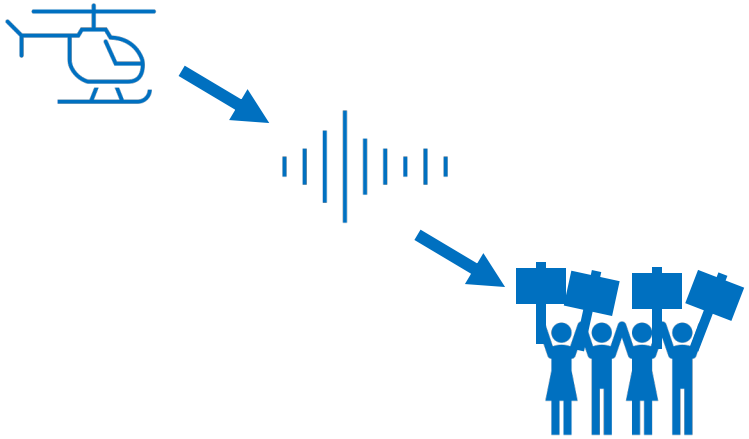


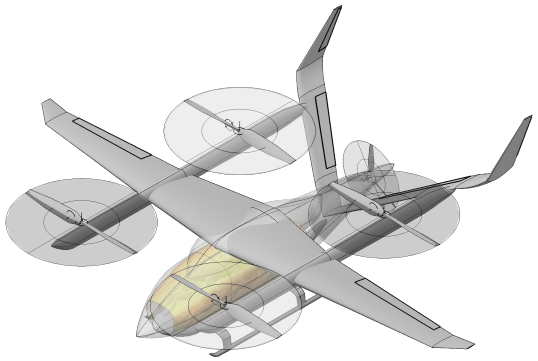


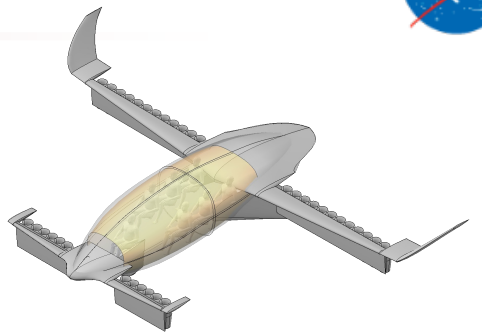


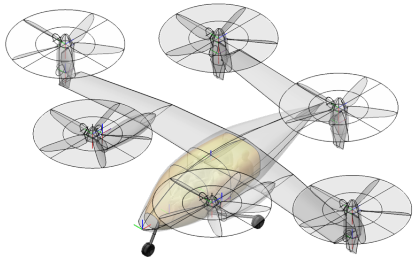


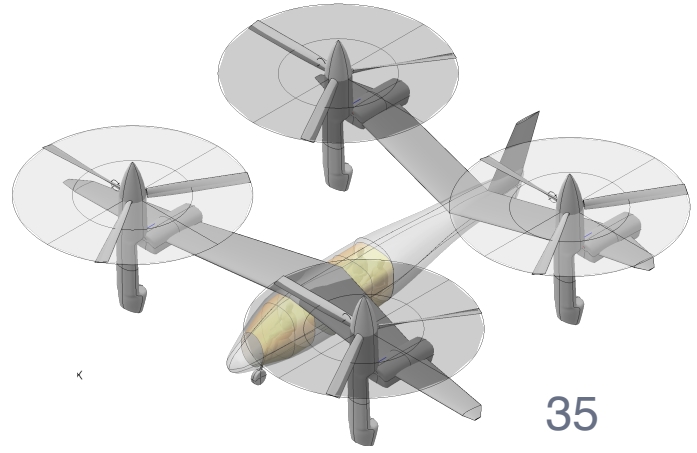




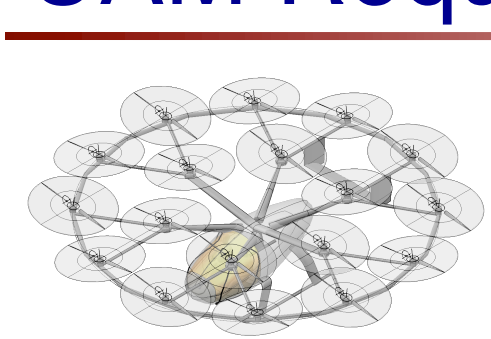


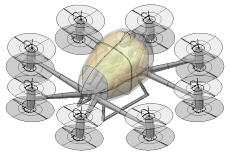


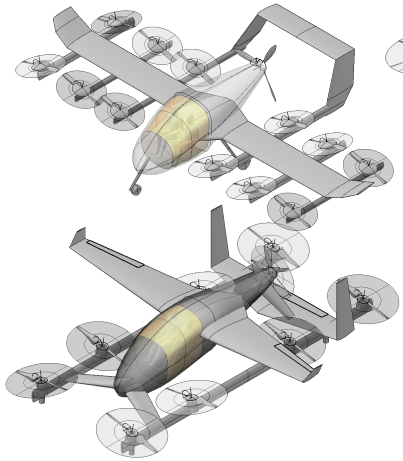


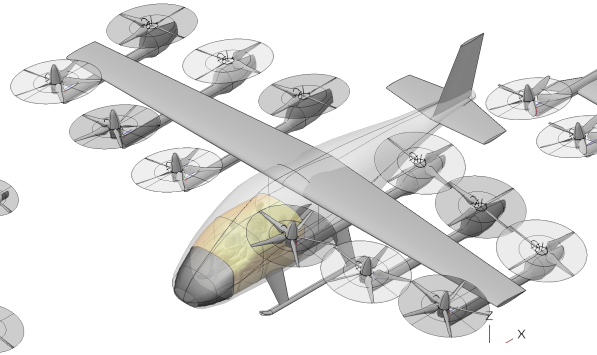


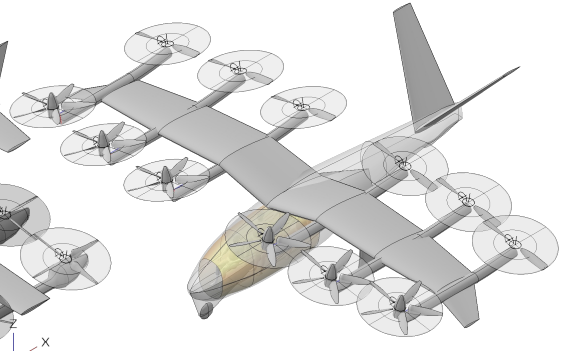
# UAM Requirement: Less noise

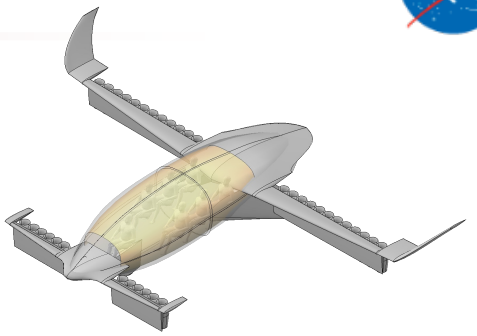


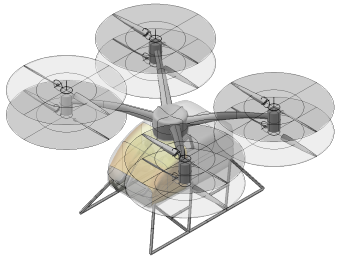


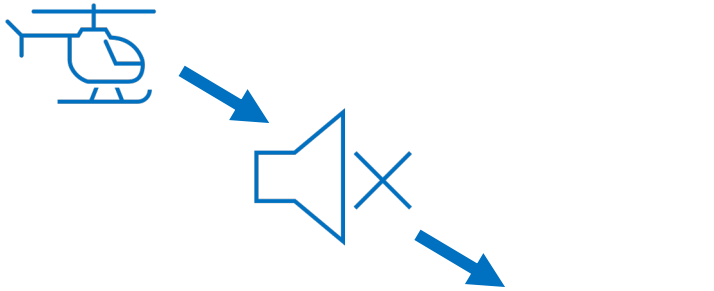


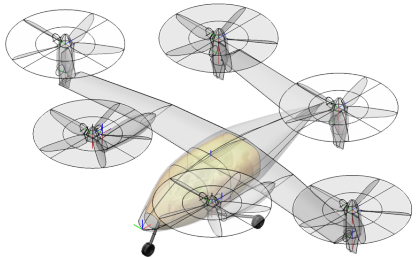


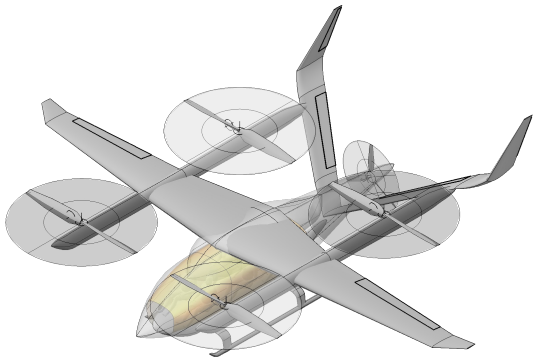


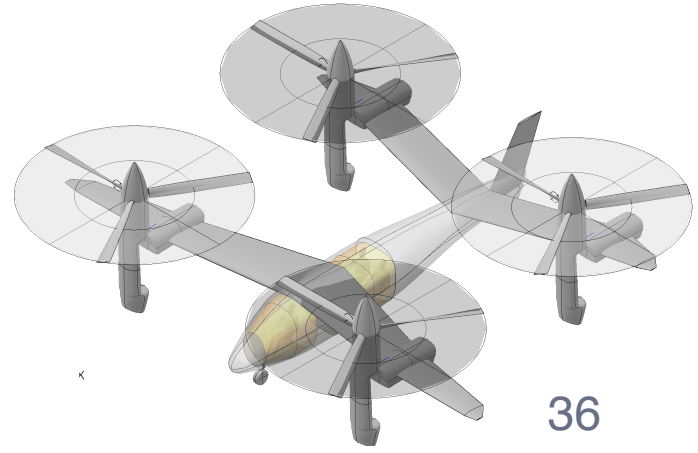




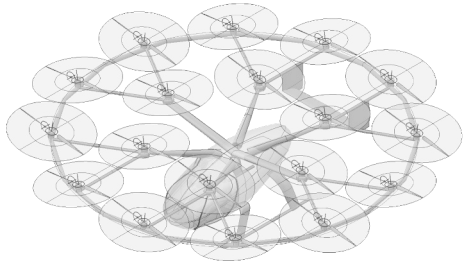


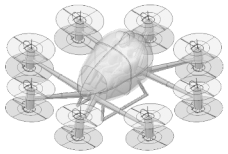


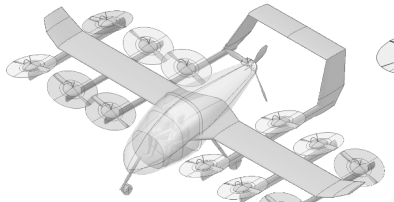


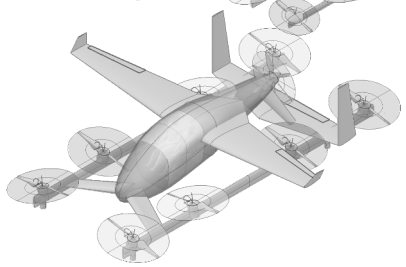


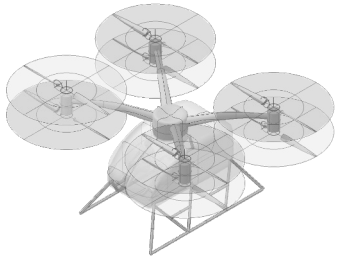
# UAM Requirement: Less noise

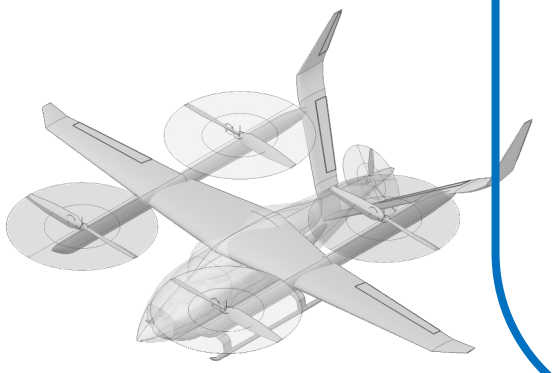


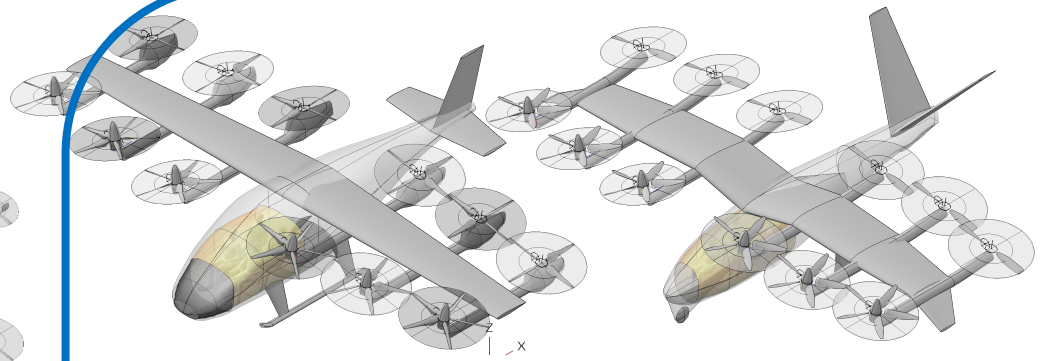




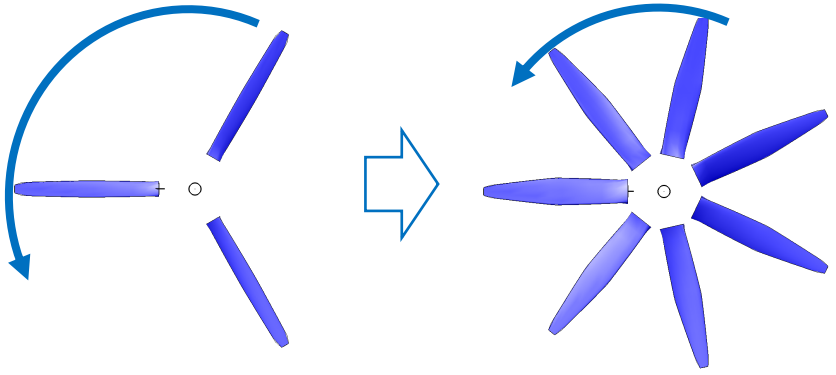


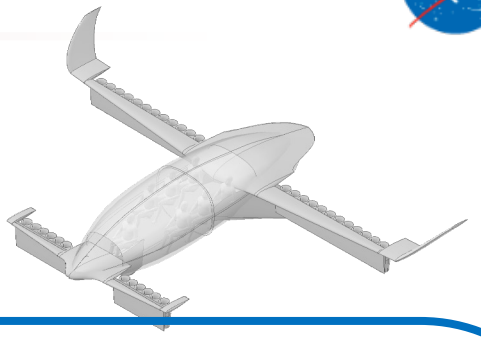


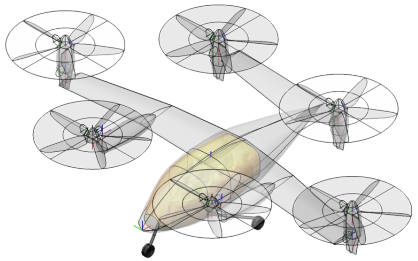


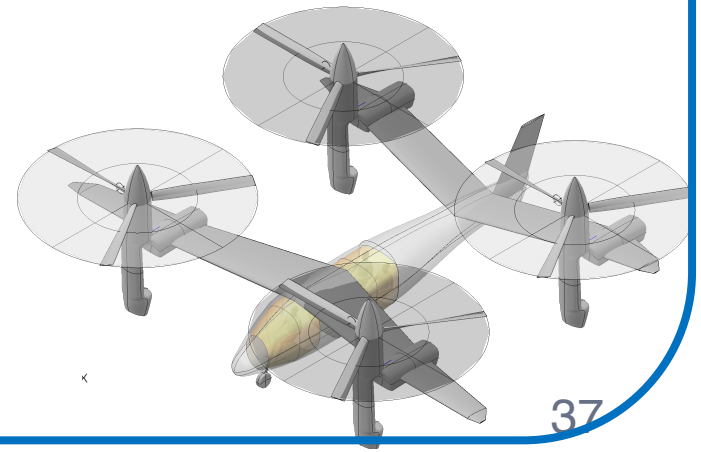


Lower rotor tip speed and
more blades in open rotors

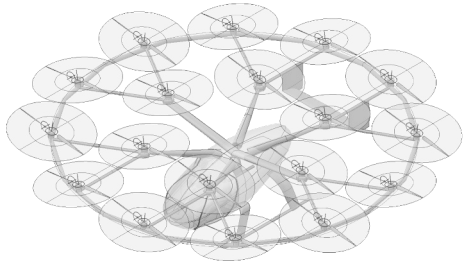


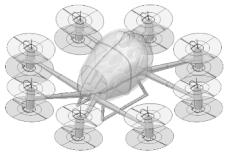


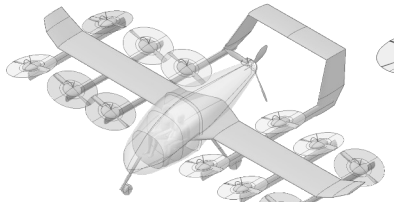


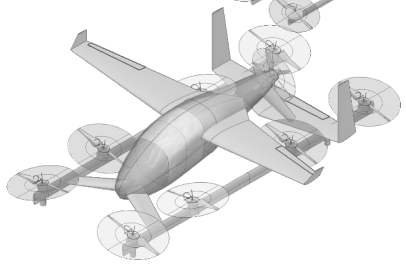


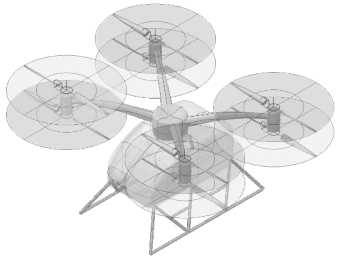
# UAM Requirement: Less noise

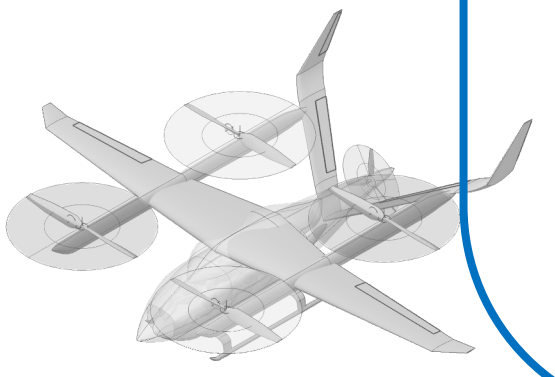


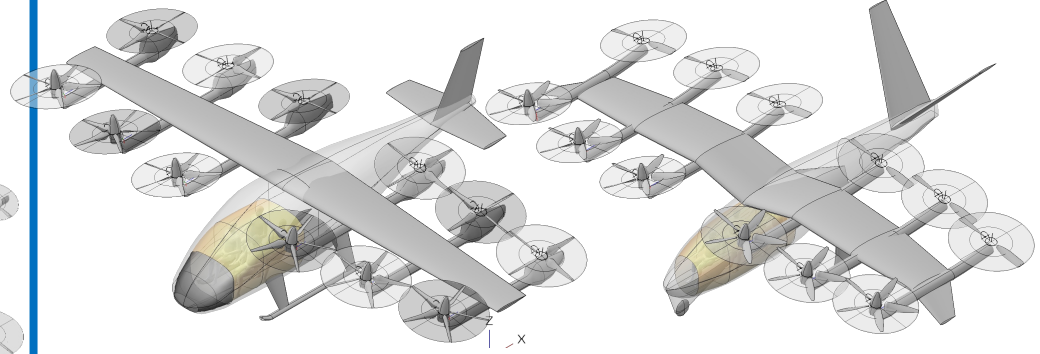




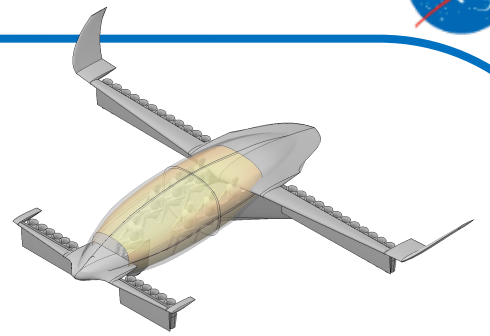


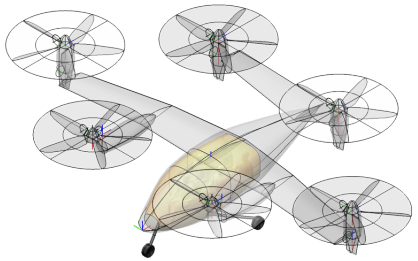


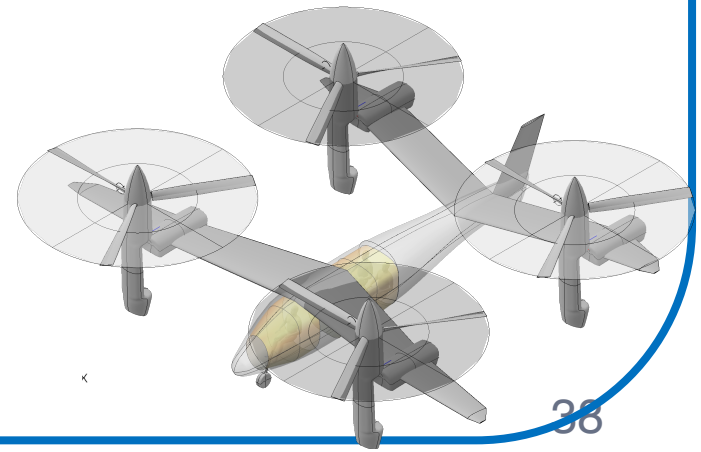




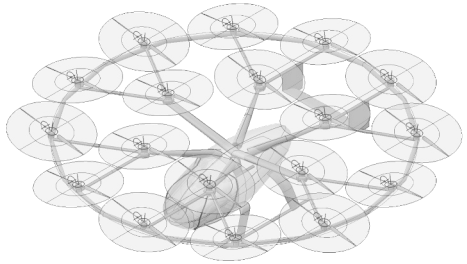
Tilting for cruise

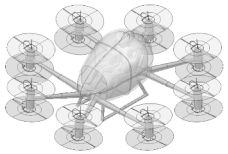


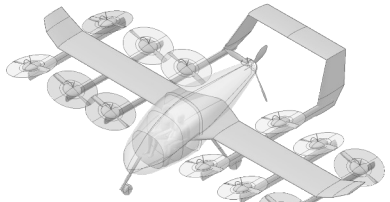


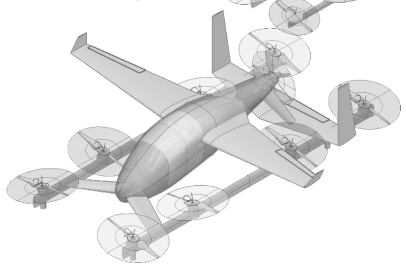


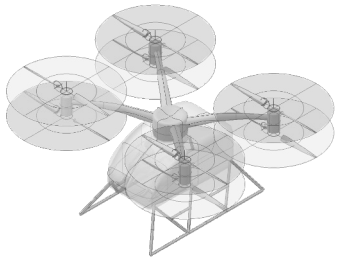
# UAM Requirement: Less noise

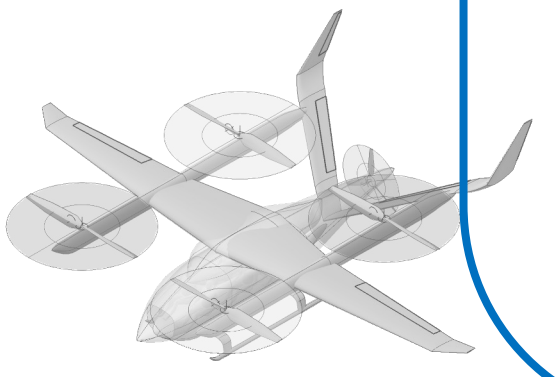


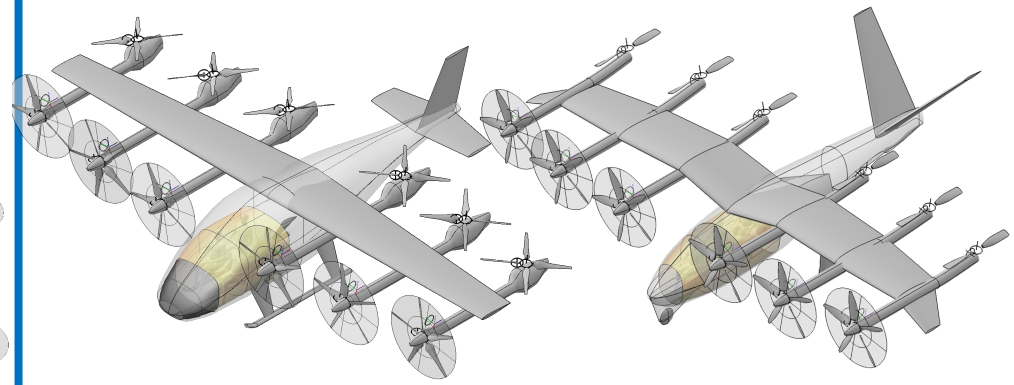




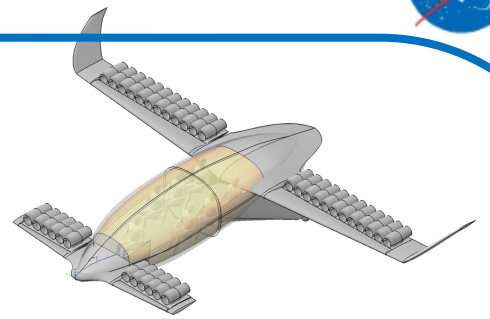


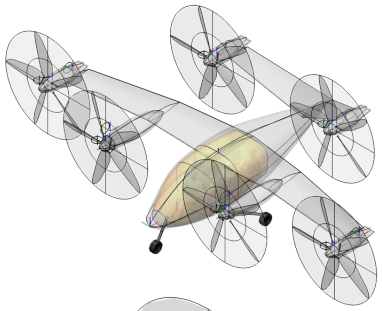


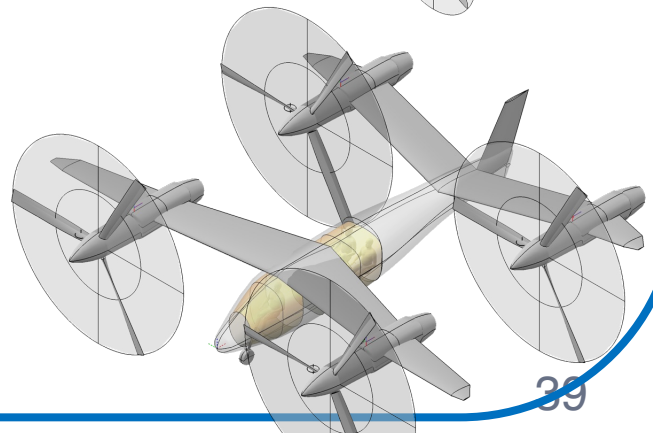




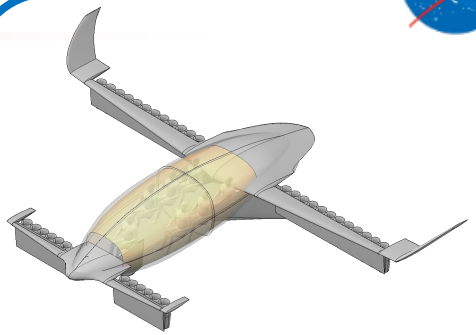
Tilting for cruise





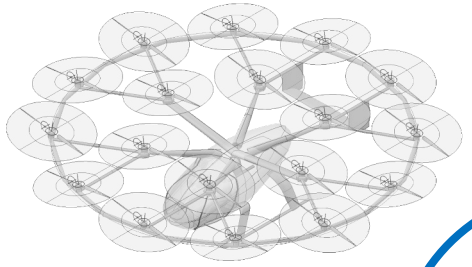


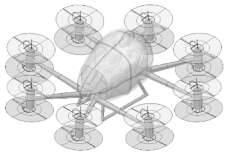
# UAM Requirement: Less noise

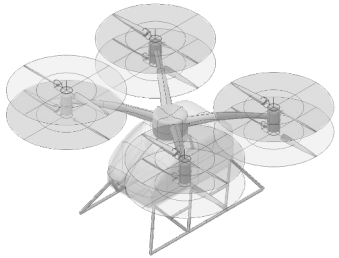


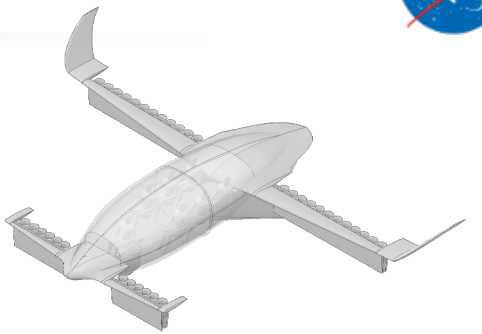
Ducted rotors

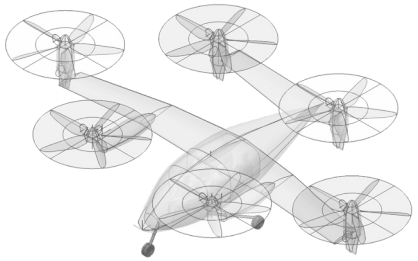
# UAM Requirement: Less noise

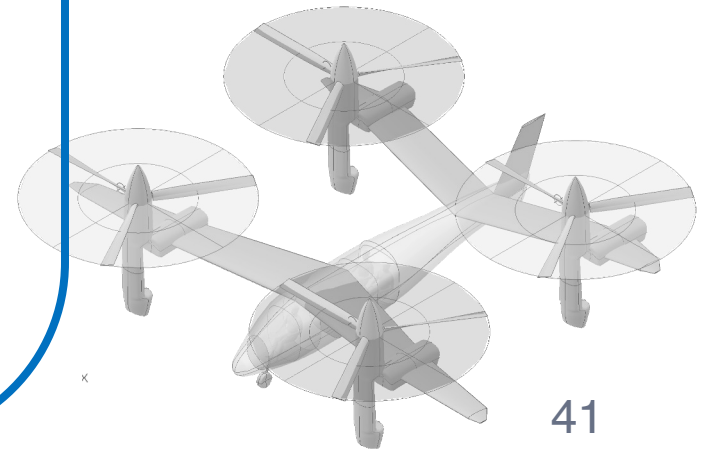


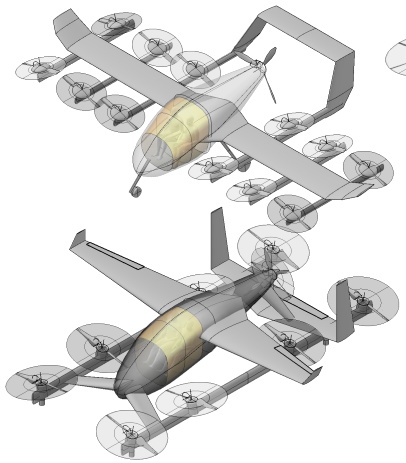


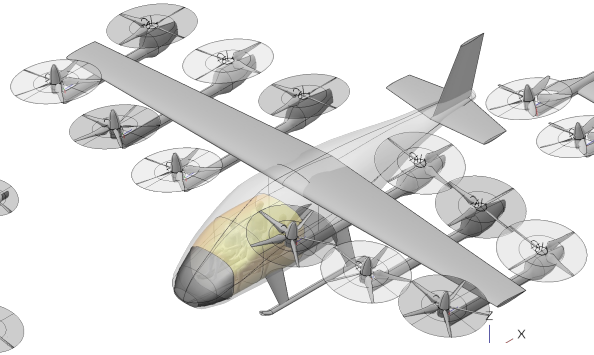


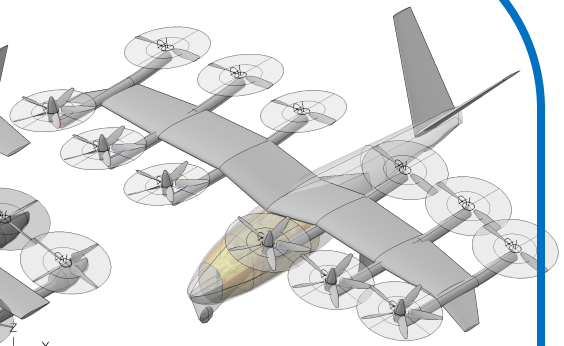




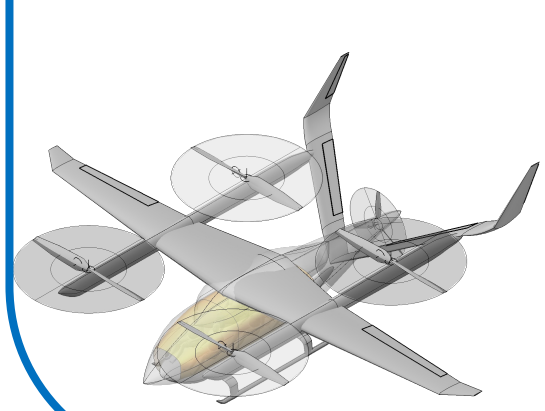


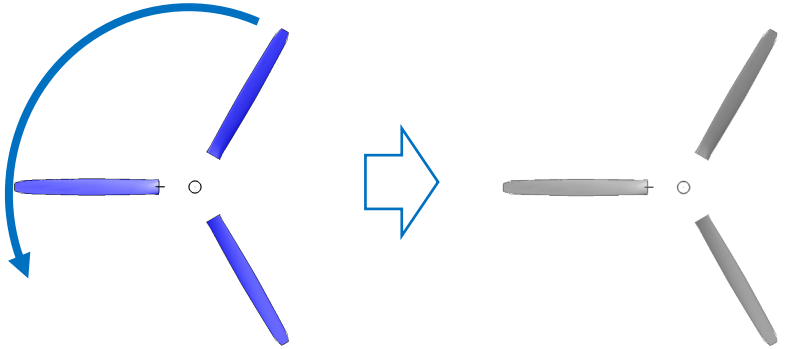




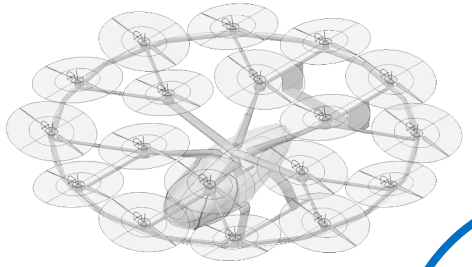


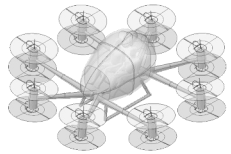
Stopping rotors for cruise

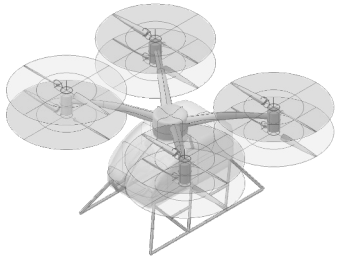


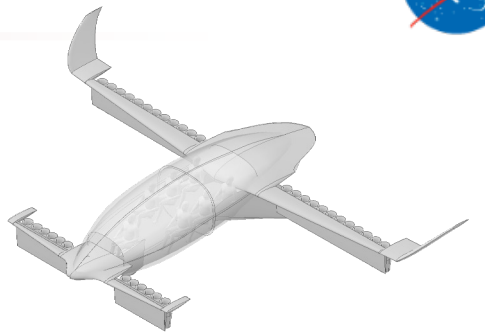


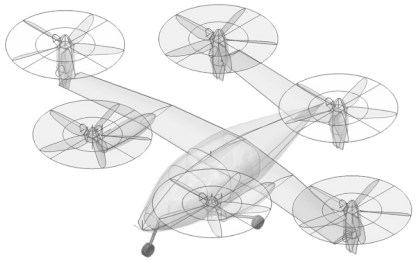
# UAM Requirement: Less noise

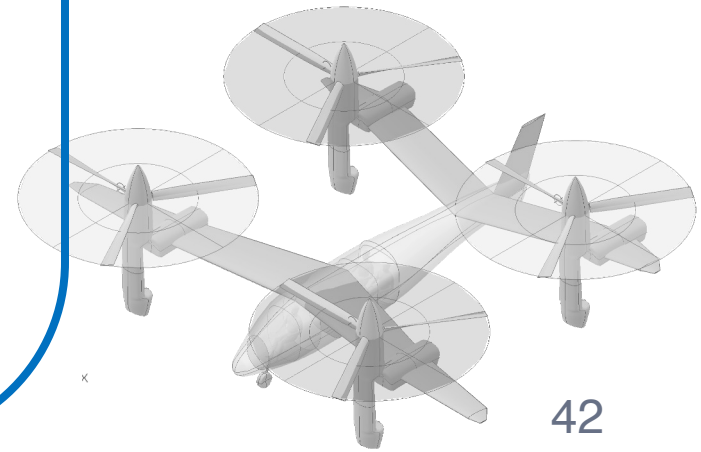


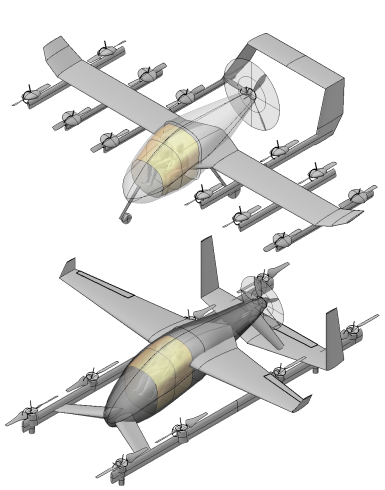


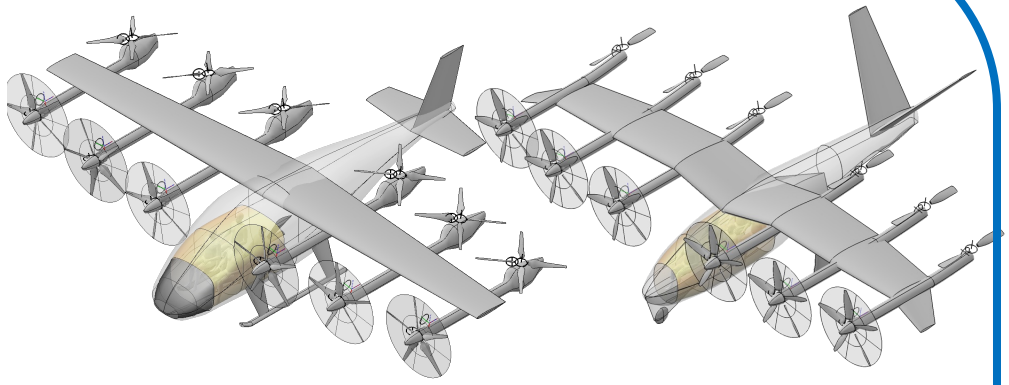




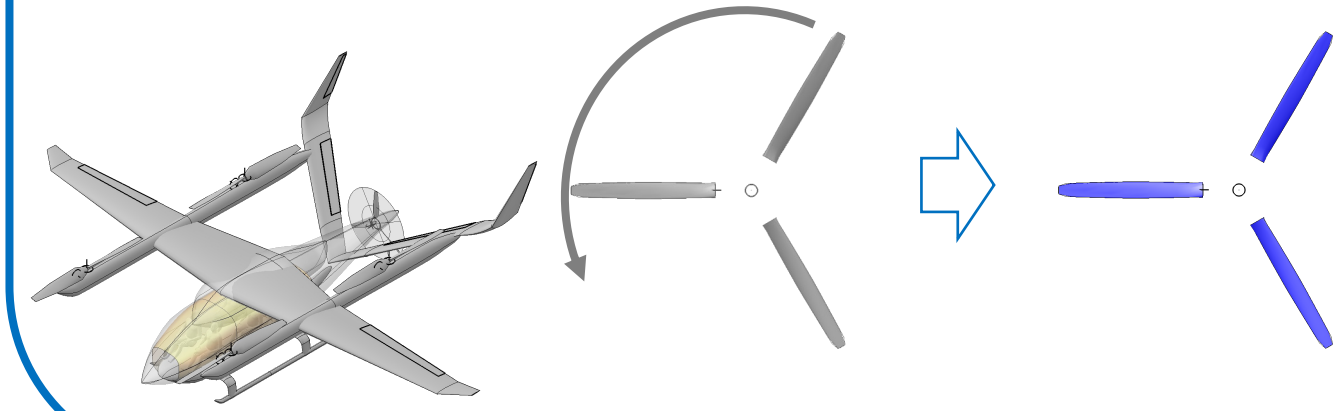




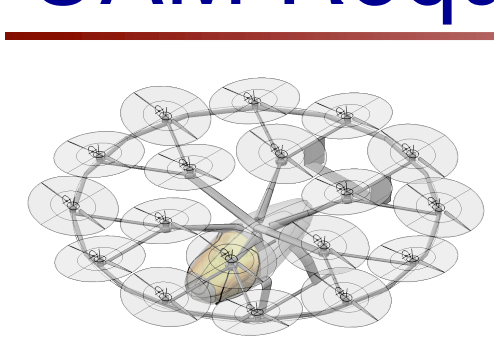


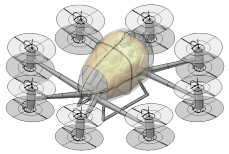


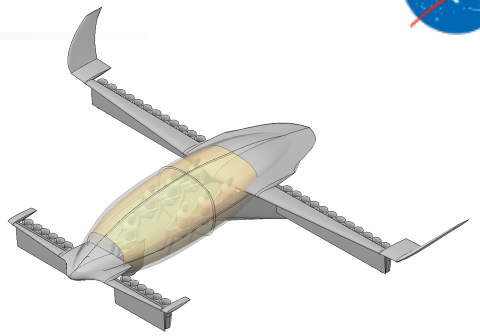
Stopping rotors for cruise

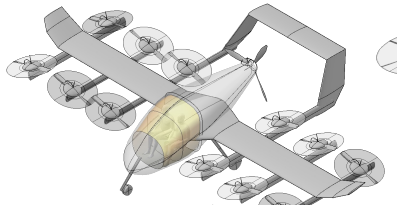


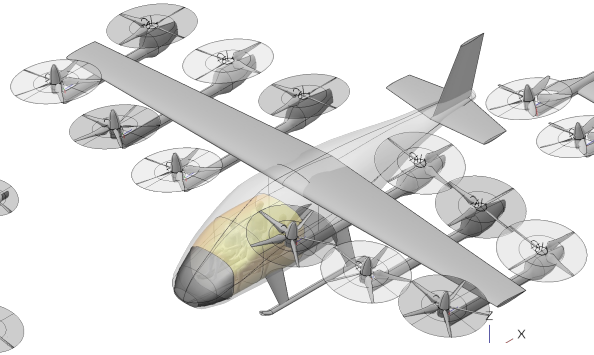
# UAM Requirements: More good, less bad

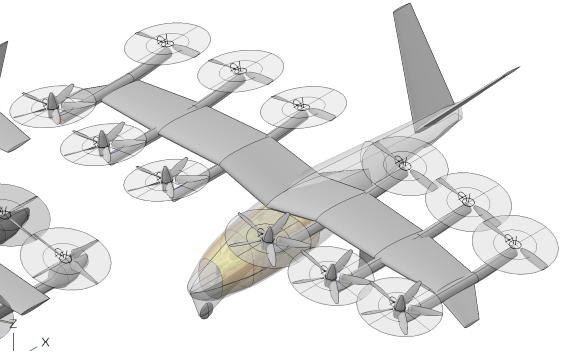


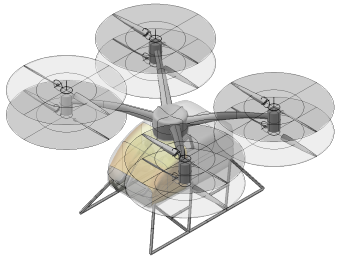


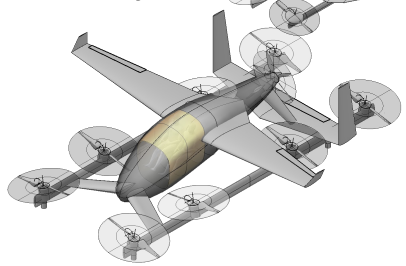


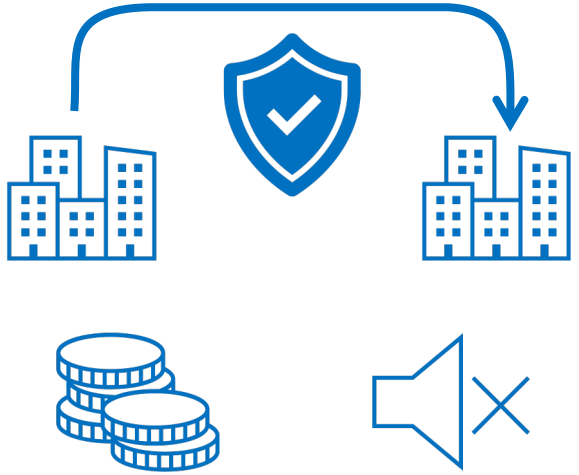


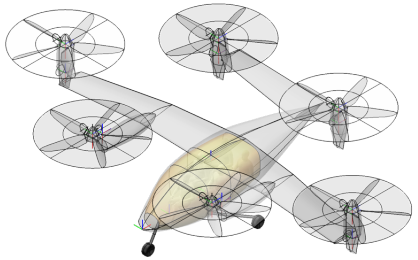


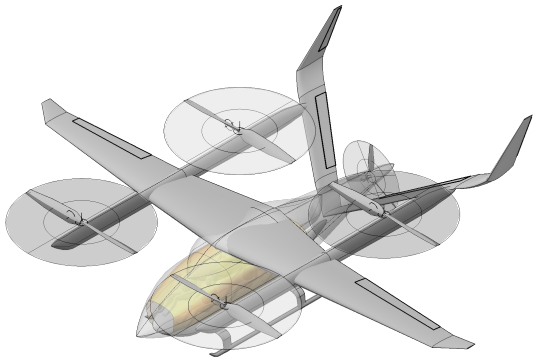


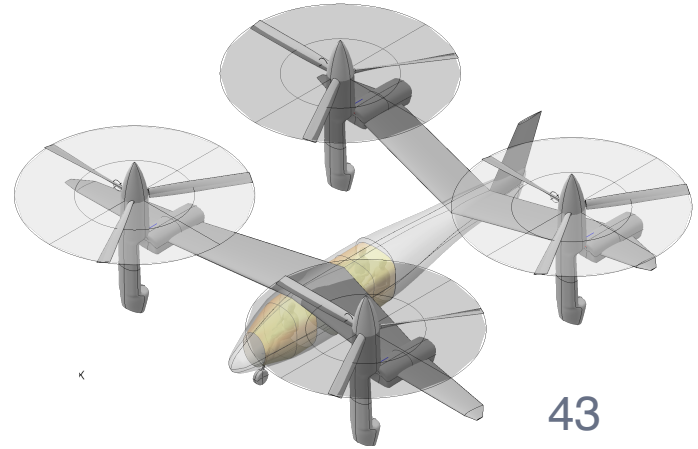






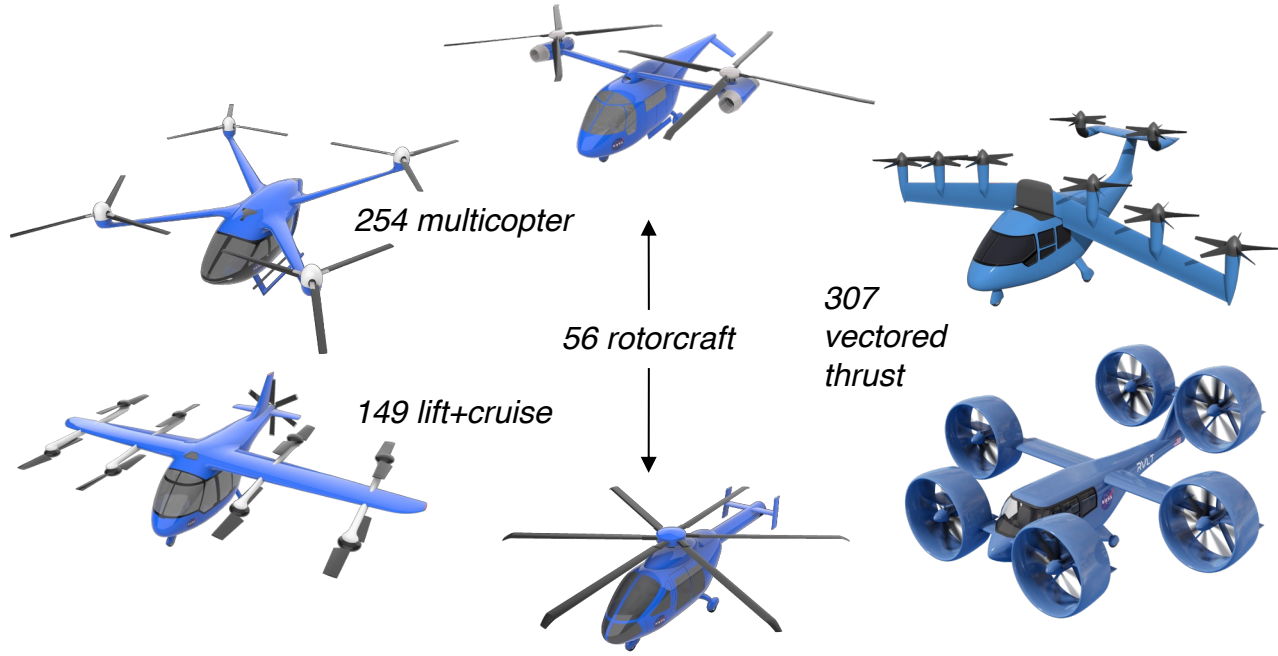






# Why we designed the NASA reference vehicles

- Vehicle model inputs and outputs publicly available
  - Discussions can be quantitative
  - Demonstration cases for training
  - Features representative of vehicles
  - Missions and design conditions
  - Margins and reliability requirements
- Focus and guide government research
  - Enable contracted work to be published
  - Assess technology payoff
  - Guide tool development
  - Scope validation tests
- No plan or desire to build the vehicles

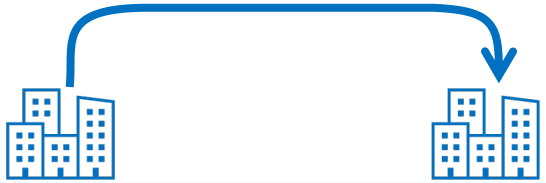



*Count of vehicles in evtol.news listing as of 30 August 2023*

# NASA Reference Vehicles quantify relative merits of solutions

**More convenient**

Vertical takeoff and landing
Flights of 50 - 100 km
Many operations per hour
High speed



**More safe**

Many rotors for redundancy
Electrical redundancy
Electrical isolation
Robust fly-by-wire
Autorotation
Mechanical redundancy
Energy margins

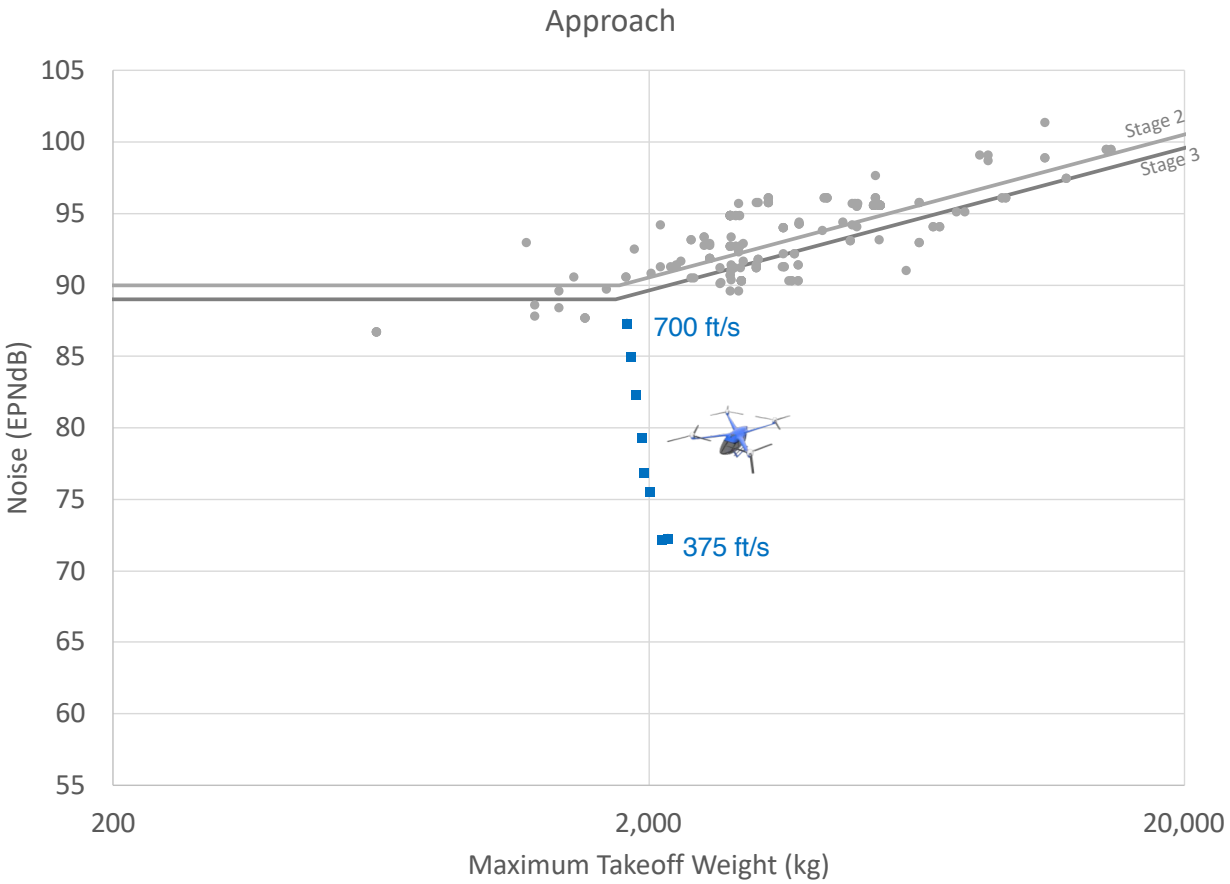
**Less Cost**

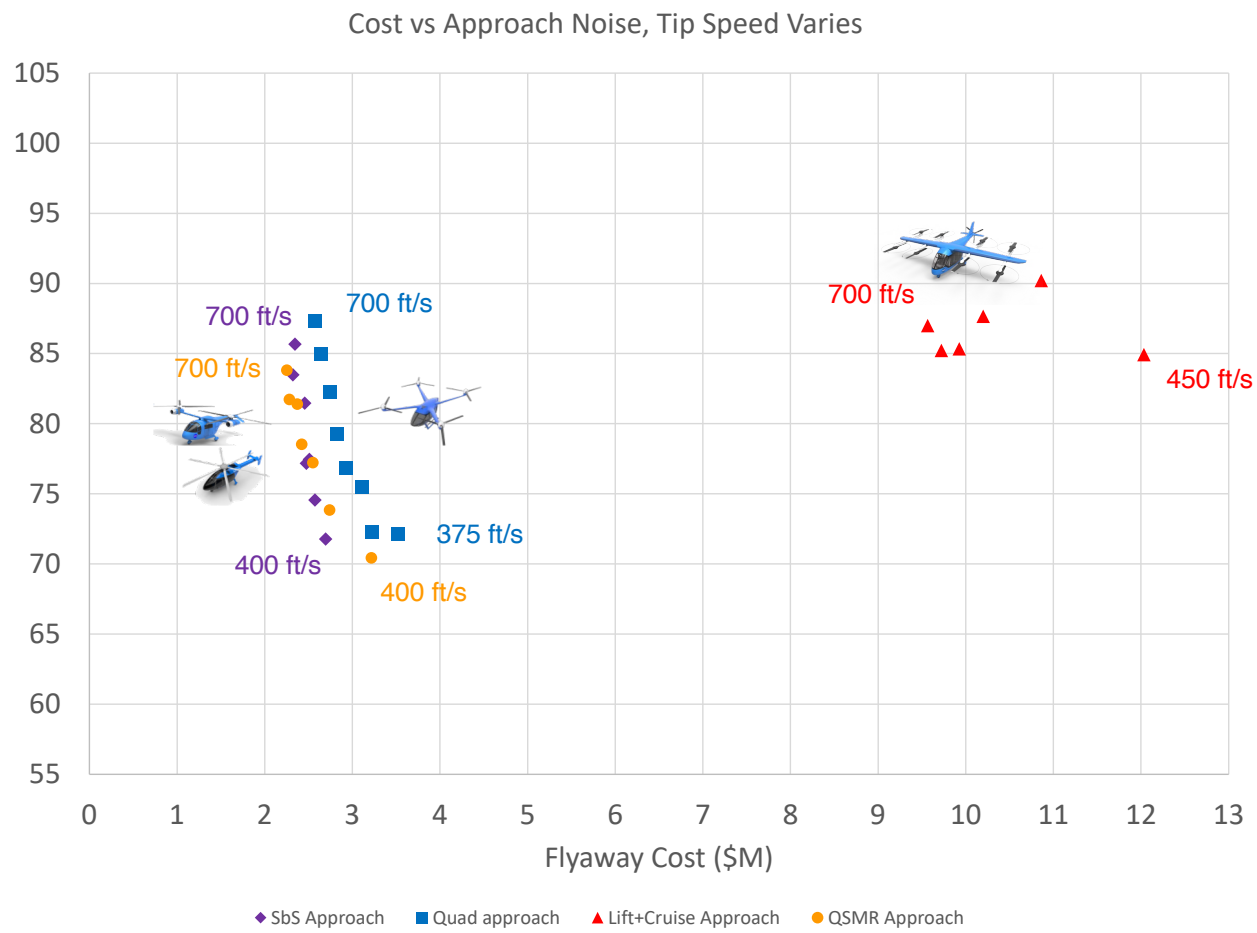
Cheap electric energy
Cheap electric motors
Cheap pilots or no pilots
Simple rotors
No gearboxes
No swashplates
Automotive-scale production

**Less noise**

Slower rotor tip speeds
Tilting rotors
Stopping rotors
More blades
Tip shapes
Higher-harmonic rotor control

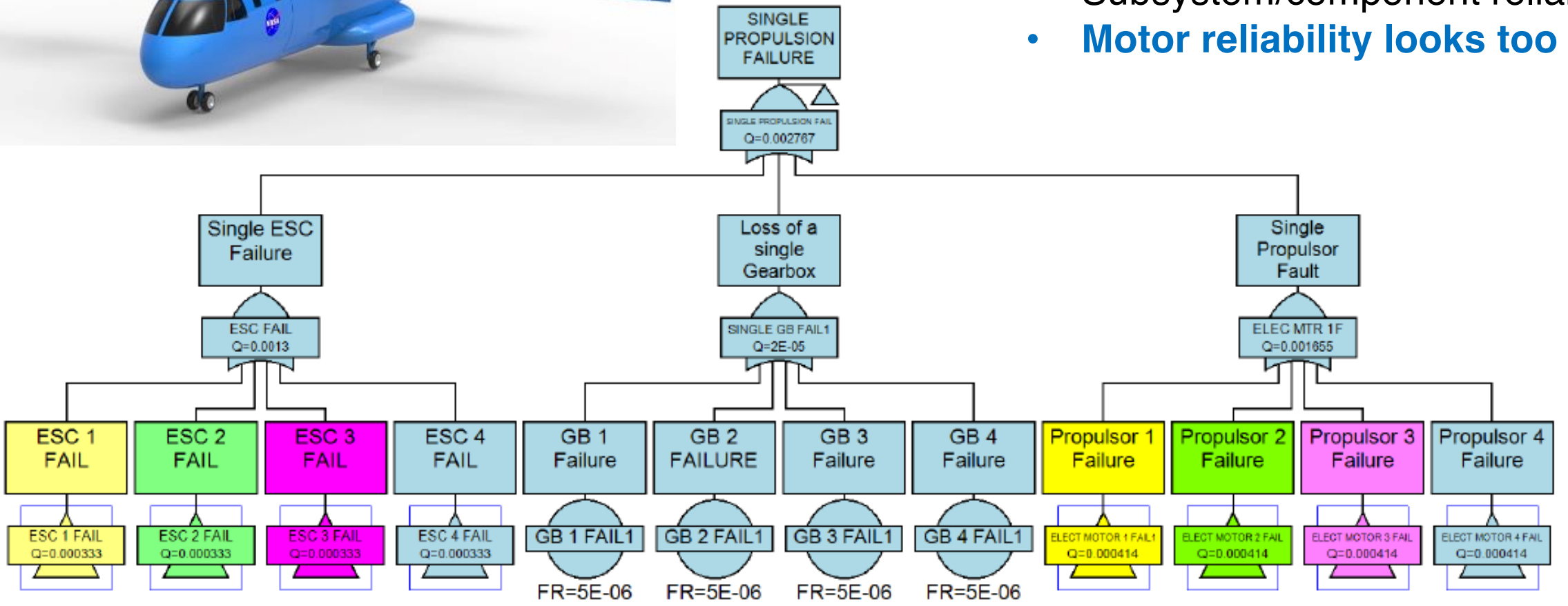
# Quantifying the cost of reducing noise via tip speed reduction



# Quantifying the safety of UAM vehicles with varying architectures and components

- Part of rigorous systems engineering
- A lot to learn about electric systems
  - Probabilistic assessments
  - Subsystem/component reliability
  - **Motor reliability looks too low**




*Ref: NASA/CR-2019-220217*

# NASA Research Areas for UAM eVTOL Vehicles

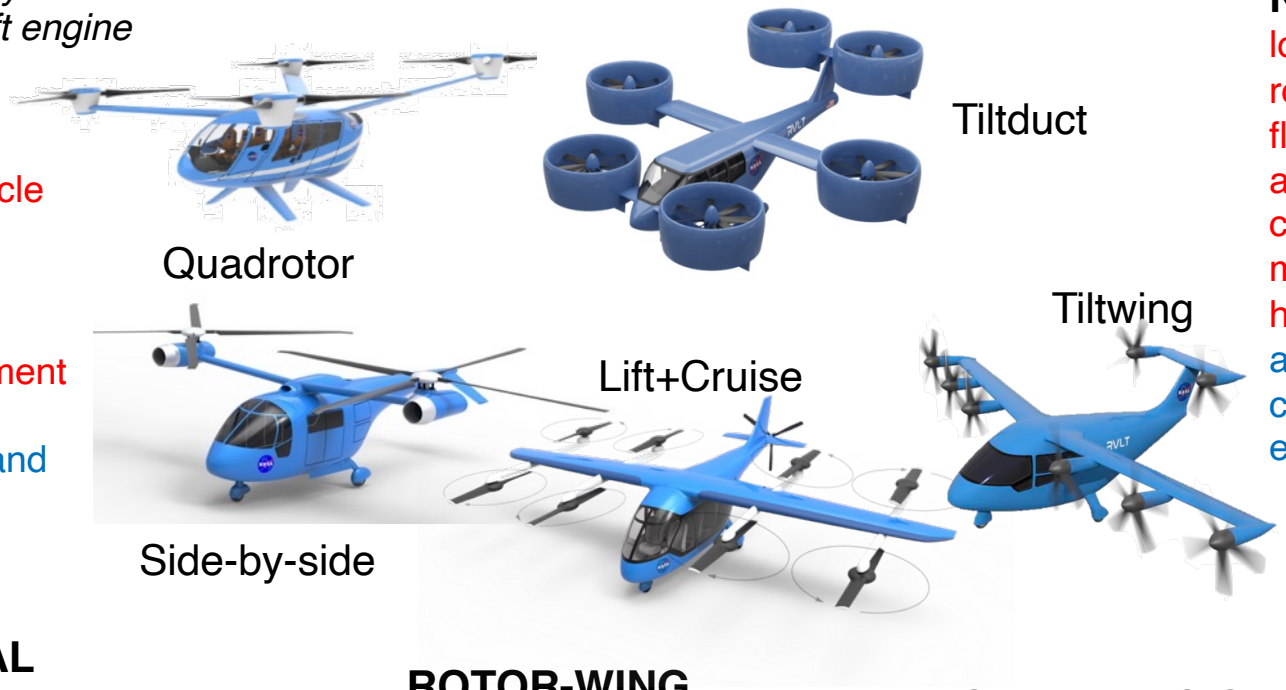
## PROPULSION EFFICIENCY
light, efficient, high-speed electric motors
power electronics and thermal management
efficient powertrains
*high power, lightweight battery*
*light, efficient small turboshaft engine*

## PERFORMANCE
aircraft optimization
rotor shape optimization
*hub and support drag minimization*
*airframe drag minimization*

## ROTOR-ROTOR INTERACTIONS
performance, noise, handling qualities, aircraft arrangement
*vibration and load alleviation*

## NOISE AND ANNOYANCE
low tip speed
rotor shape optimization
flight operations for low noise
aircraft arrangement/ interactions
cumulative noise impacts from fleet ops
metrics and requirements
human response to noise
active noise control
cabin noise
electric motor noise

## SAFETY and AIRWORTHINESS
component reliability and life cycle
crashworthiness: airframe, occupant, battery
bird strike
electric motor reliability assessment
propulsion system failures
FMECA (failure mode, effects, and criticality analysis)
high voltage operational safety
high voltage protection devices



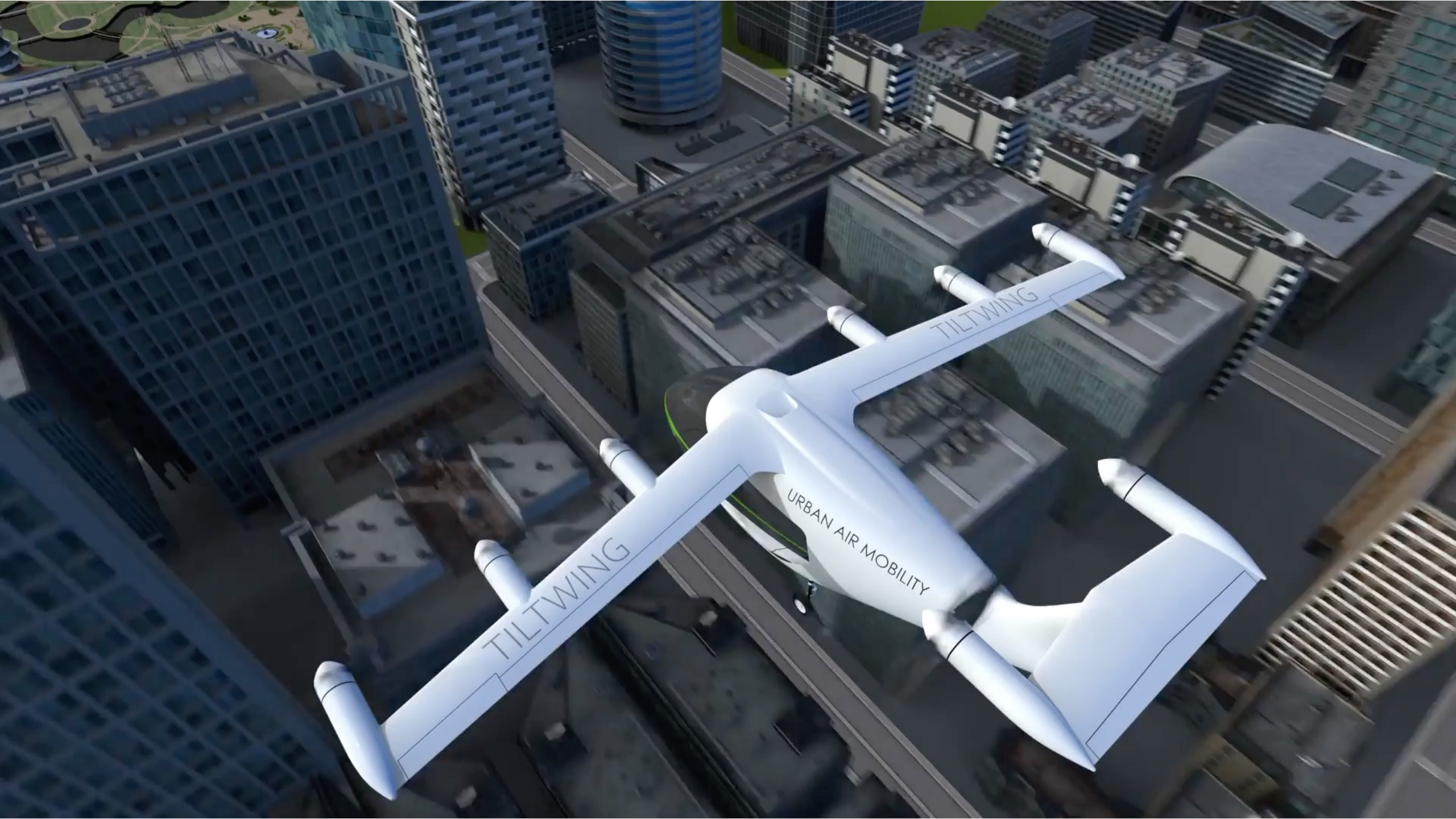

## OPERATIONAL EFFECTIVENESS
Ops in moderate to severe weather
passenger acceptance/ ride quality
disturbance rejection (control bandwidth, control design)
*cost (purchase, maintenance, DOC)*

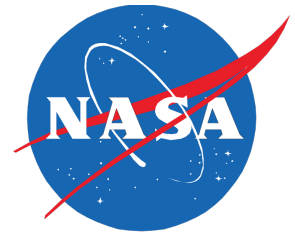
## ROTOR-WING INTERACTIONS
conversion/transition
interactional aerodynamics
*flow control*

## AIRCRAFT DESIGN
weight, vibration
handling qualities
*active control*

## STRUCTURE AND AEROELASTICITY
crashworthiness
durability and damage tolerance
*structurally efficient wing and rotor support*
*rotor/airframe stability*
*high-cycle fatigue*

**Red = primary NASA research area**
**Blue = secondary NASA research area**


TILTWING
TILTWING
URBAN AIR MOBILITY


NASA