# Analyzing Flow Between Intermeshing Rotors to Aid in Urban Air Mobility Vehicle Design

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## Background

- Urban Air Mobility (UAM) is a promising transportation concept for populated areas
  - Shortened commutes due to more direct travel routes
  - Alleviates ground traffic
  - Reduce carbon emissions with use of electric propulsion
- Major challenge left unsolved is vehicle size
  - Accessibility required to be competitive with ground transportation
  - Small size means more flexibility for "stops"
- One method of minimizing size: intermeshing rotors
  - NASA's Reference Model 2, a six-seater UAM vehicle design
  - Studies deemed Ref. Model 2 flightworthy, but only used CFD models

## Objectives

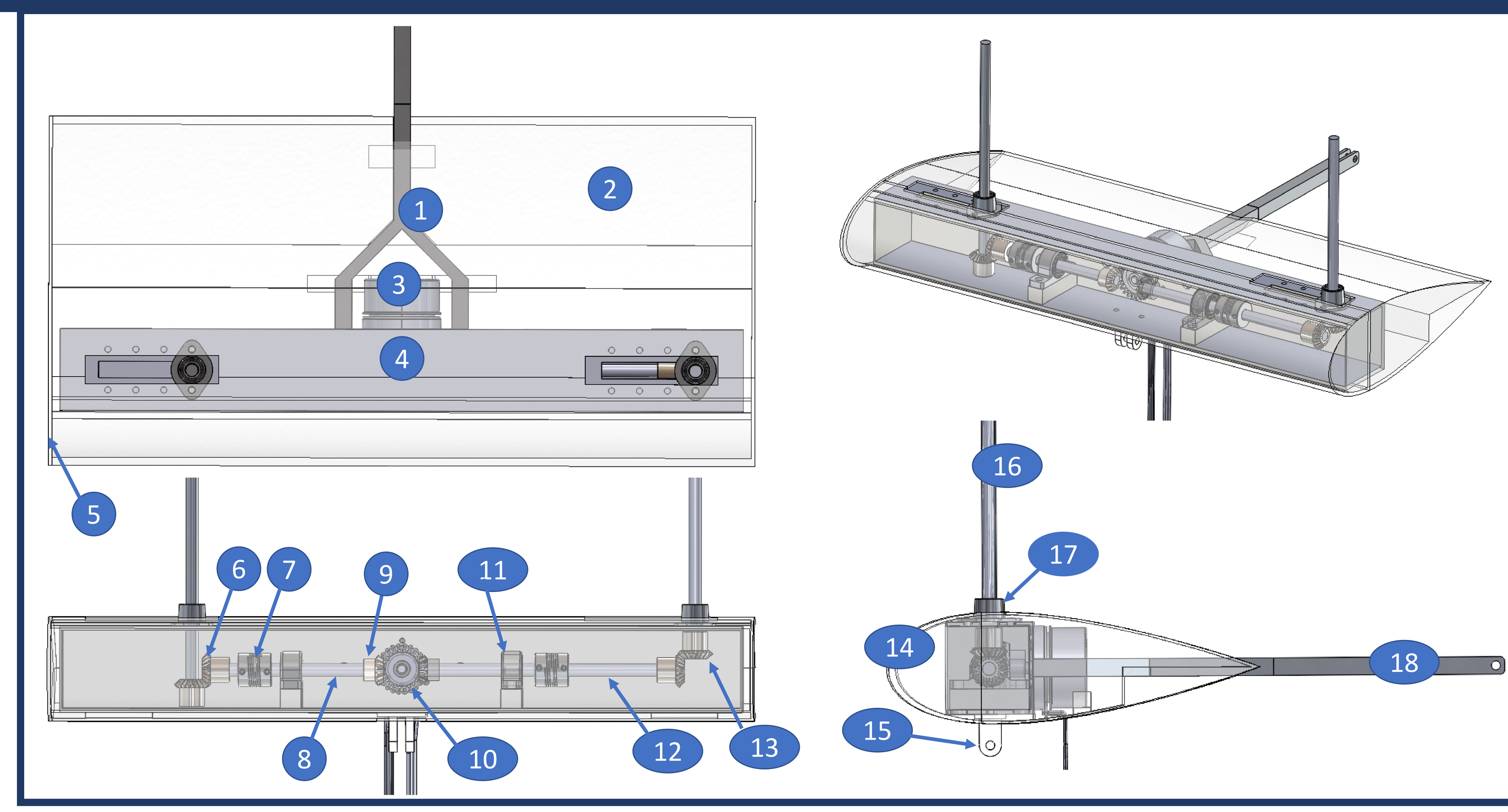
- Gain a better understanding of flow between intermeshing rotors using empirical data
  - Formulate relationship between rotor spacing & operational efficiency
  - Visualize and observe blade-vortex interactions
  - Determine pressure distribution on rotor blades
  - Use vortex interaction observations and pressure distributions to obtain acoustic properties
  - Compare results with computational data on NASA's Ref. Model 2

## Methods

- Design & construct simplified model of NASA's Ref. Model 2
  - Variable-length shafts that allow for various levels of rotor intermeshing
  - Pressure sensitive paint applied to rotor blades
  - Minimize apparatus drag to highlight drag from rotors
  - Must be compatible with ERAU Low-Speed Wind Tunnel
- Conduct testing on model using the low-speed wind tunnel housed at the ERAU Micaplex
  - Force Balance can aid in determination of efficiency
  - Particle Image Velocimetry (PIV) used to visualize flow interactions
  - Record pressure distributions along rotor blade surfaces

| | CFD Simulation | Wind Tunnel Test Plan | |
|---|---|---|---|
| Rotor Speed [RPM] | 500 | 6000 | 7500 |
| Airspeed [ft/s] | 195 | 155 | 195 |
| Tip Speed [Mach] | 0.484 | 0.39 | 0.484 |
| Freestream Reynolds # | 707,900 | 37,500 | 47,200 |
| Advance Ratio | 0.3526 | 0.350 | 0.3527 |

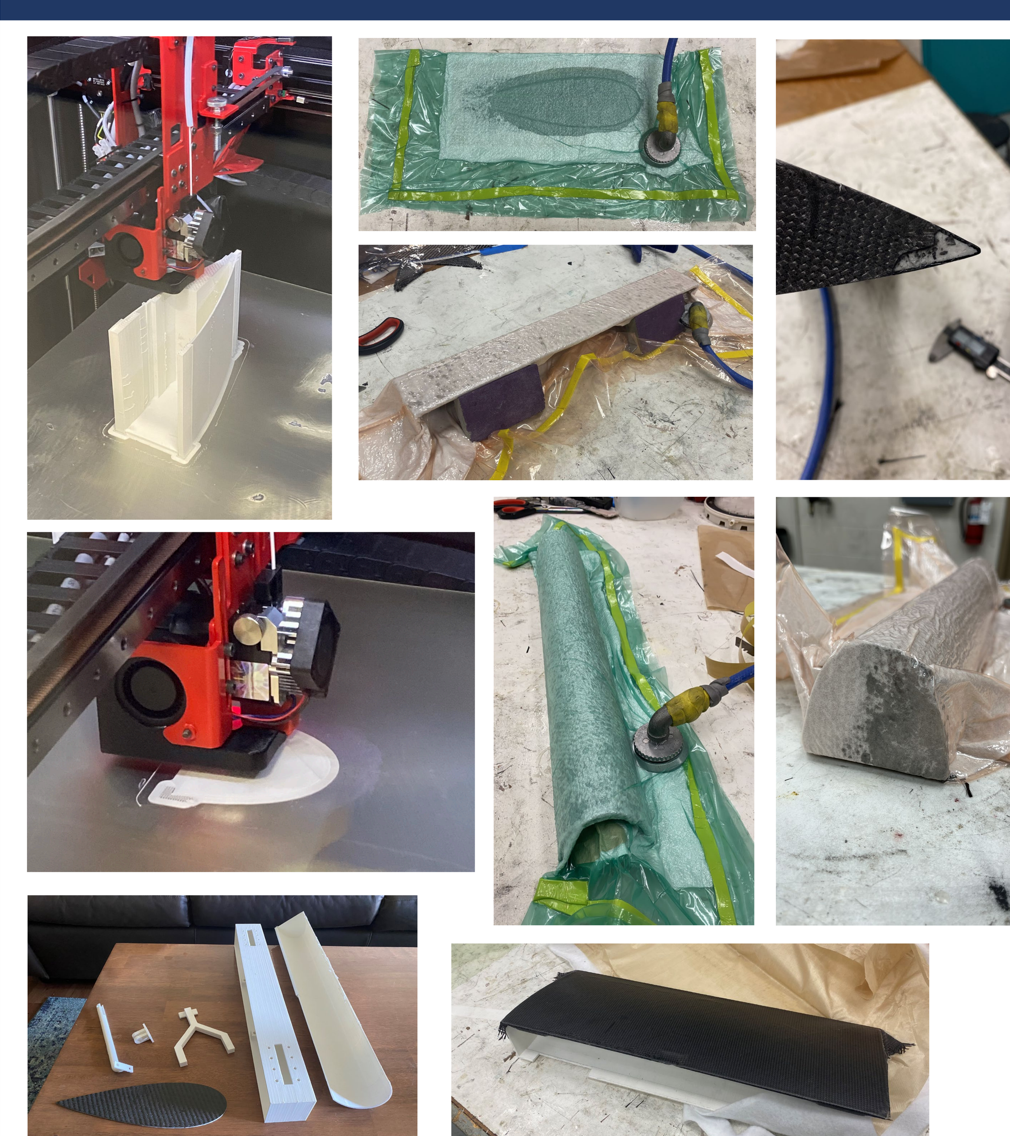
## Apparatus Design Features




**Components of Rotor Test Apparatus**

| Label | Part Description | Label | Part Description | Label | Part Description |
|---|---|---|---|---|---|
| 1 | Y-Strut | 7 | Shaft Coupling | 13 | Rotor Miter Gear |
| 2 | Rear Airfoil Fairing | 8 | Drive Shaft | 14 | Front Airfoil Fairing |
| 3 | Maxon EC 60 Flat Motor | 9 | Motor Bevel Pinion | 15 | Force Balance Mount |
| 4 | Casing Box | 10 | Motor Bevel Gear | 16 | Rotor Shaft |
| 5 | Side Airfoil Fairing | 11 | Roller Bearing | 17 | Flange Bearing |
| 6 | Shaft Miter Gear | 12 | Variable Shaft End | 18 | Pitch Strut |

## Manufacturing Results

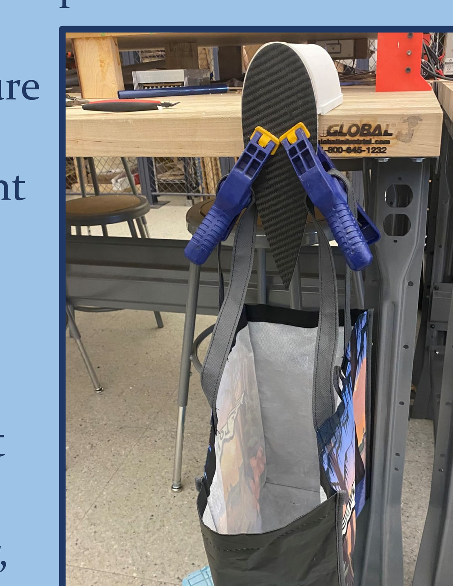


**Summary of Composite Layups**

| Part | Fabric Material | # of Layups |
|---|---|---|
| Front Airfoil Fairing | 3 Carbon | 3 – Front Face Center, Front Face Edges, Side Face |
| Side Airfoil Fairing | 3 Carbon | 2 - Top Face, Bottom Face |
| Rear Airfoil Fairing | 3 Carbon | 3 – Top Face, Bottom Face, Side Face |
| Casing Box | 3 Carbon + 1 Glass Fiber | 3 - Top/Bottom Faces, Back Face, Side Faces |

## Current Project Status

- Completed and received approval for design of iteration I test apparatus
- Minor redesign conducted to facilitate parts fabrication and assembly of rotor test stand
  - Y-Strut given square cross section, threaded ends to bolt into casing box, and threaded hole to connect with pitch strut
  - Pitch Strut given square cross-section, and threaded end to screw into Y-strut
  - Connection between airfoil faring pieces reconfigured for hinging front and side fairing
- Nearly completed assembly phase of test apparatus
  - Large, thin-walled components (i.e. fairing pieces) 3D printed from PLA and laminated with carbon fiber
    - Casing box wrapped in outer layer of glass fiber to prevent corrosion of connecting metal components
  - Drive system components bought from hardware distributors to ensure quality
  - Struts, mounting parts & shafts sent to be machined for aluminum and steel
- Destructive test conducted for epoxy connection between front fairing and side fairing
  - Connection resisted 18 lb of shear, fracture point unknown



## Next Steps

- Complete fabrication/acquisition of components & assemble test apparatus
  - Receive machined parts
  - Assemble drive system within casing box, fastening with bolts
  - Assemble hinged fairing, and attach to rear fairing
  - Attach casing box within rear fairing
- Conduct preliminary testing of assembly (structural tests, low-RPM drive system tests, etc.)
  - Structural tests to validate durability
  - Low-RPM active drive system tests

## Acknowledgements

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