Overflow Simulations of Unmanned Aircraft Systems

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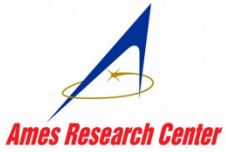
Outline



- Problem Formulation
- Overview
- Geometry Description
- Computational Grids
- Numerical Analysis
- Computed Results
- Conclusions/Recommendations

Problem Formulation

Simulate Flow About Small Drone Quadcopters for the Unmanned aircraft system Traffic Management (UTM) program and compare with measured Wind-tunnel (WT) Data

- Aerodynamic Predictions Improves Safe Operation in National Airspace
  - Interaction with Flow about Buildings and Urban Environments
  - Reaction to Varying Onset Flow to Enable Autonomous Operation
- Flow Simulation Data Comparison with Measured Data Provides a Foundation for Free Flight and Urban Flight Analysis

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Overview

Model Flow About IRIS Quadcopter
- NASA Ames 7x10 foot WT
- Comparison of Simulation Data With Measured Data

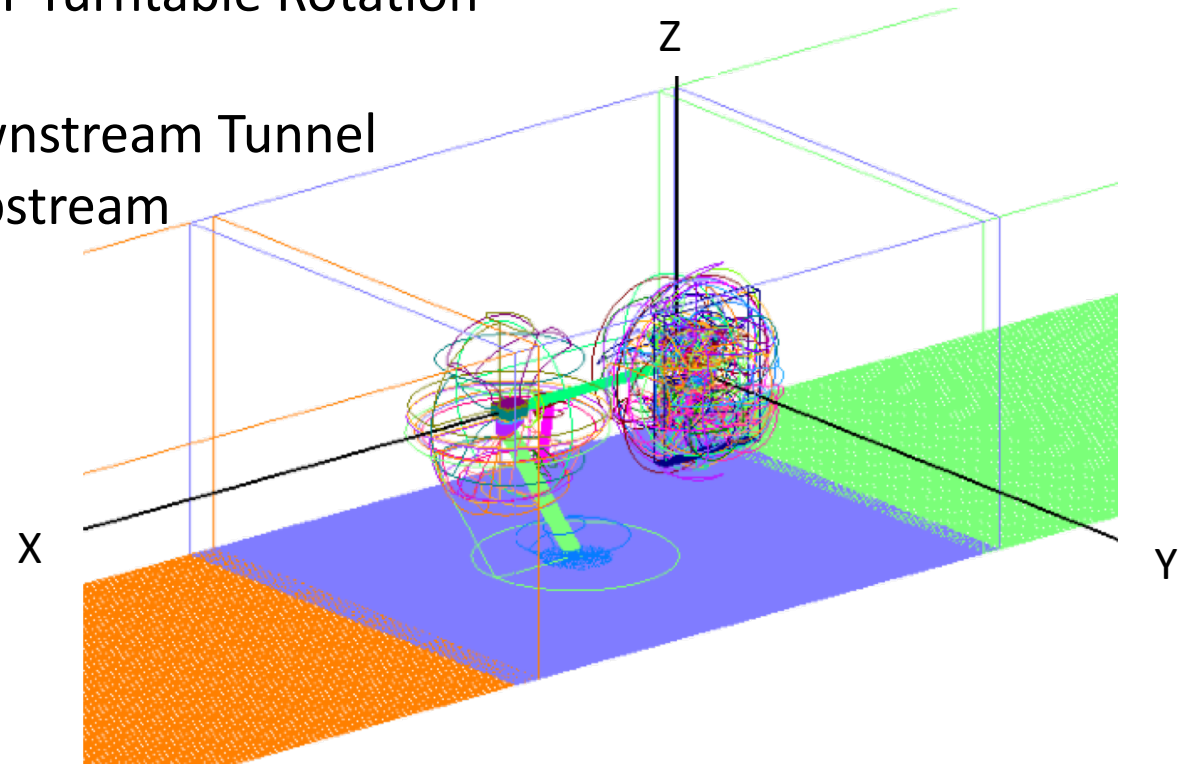
Overflow Rotor Disk Model Simulation
- Blade Element Methodology, 2D Airfoil Representation
  - Source Term Implementation Using an Actuator Disk
  - Individual Blades Projected onto Actuator Disk
  - Force Computations from Individual Blade Representations
  - Define Chord, Twist, Rotation Direction, and Tip Mach Number
  - Incorporate Airfoil Table Data

Overflow Individual Blade Simulation
- Model Individual Blades Using OVERFLOW-D

Geometry Description

Overflow Grid for IRIS Quadcopter

- IRIS Quadcopter Tested in NASA Ames 7x10 foot WT
- Load Cell Mounted on WT Sting/Support
- Model Mounted on Load Cell
- Model Pitch From WT Turntable Rotation
- Coordinates
  - X = Centerline Downstream Tunnel
  - Y = Right Facing Upstream
  - Z = Vertical Up



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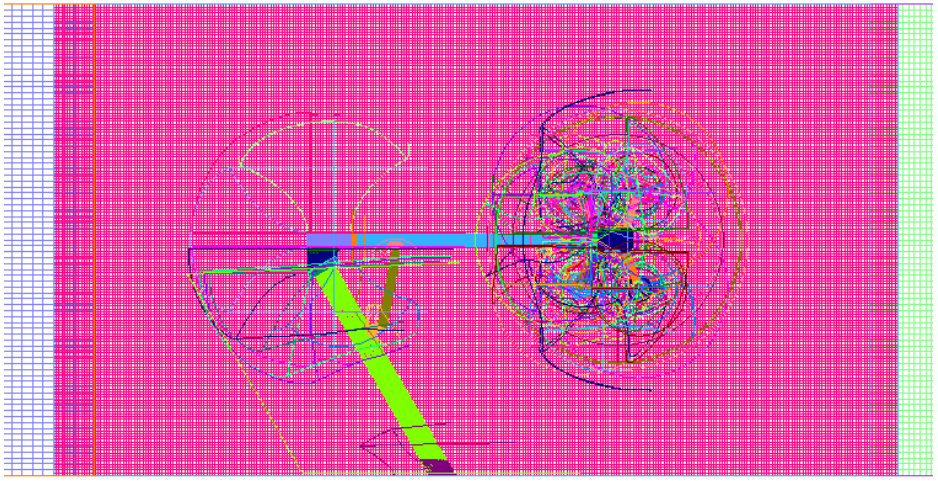
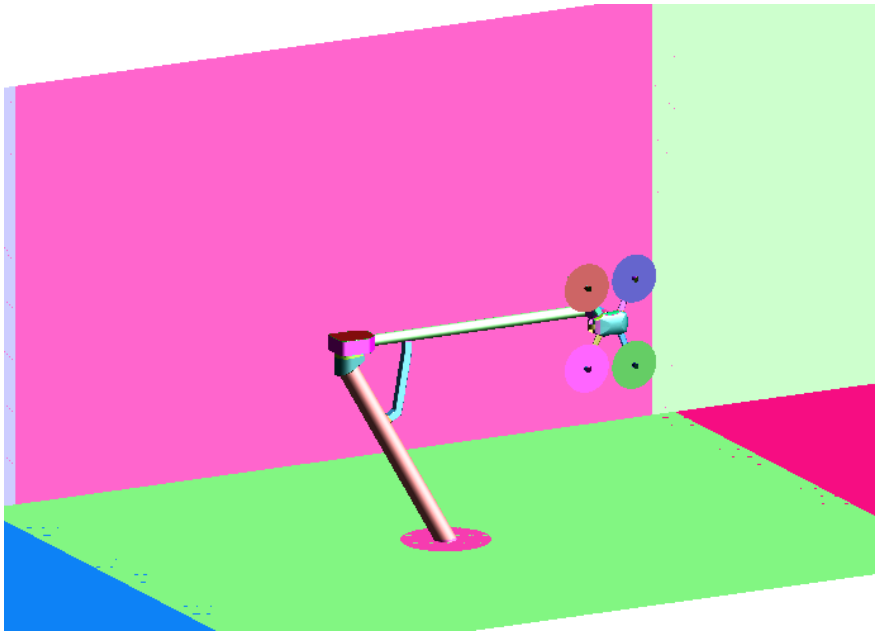
Computational Grids

Ames 7x10Ft WT, IRIS Quadcopter

- Constant Cross Section Tunnel





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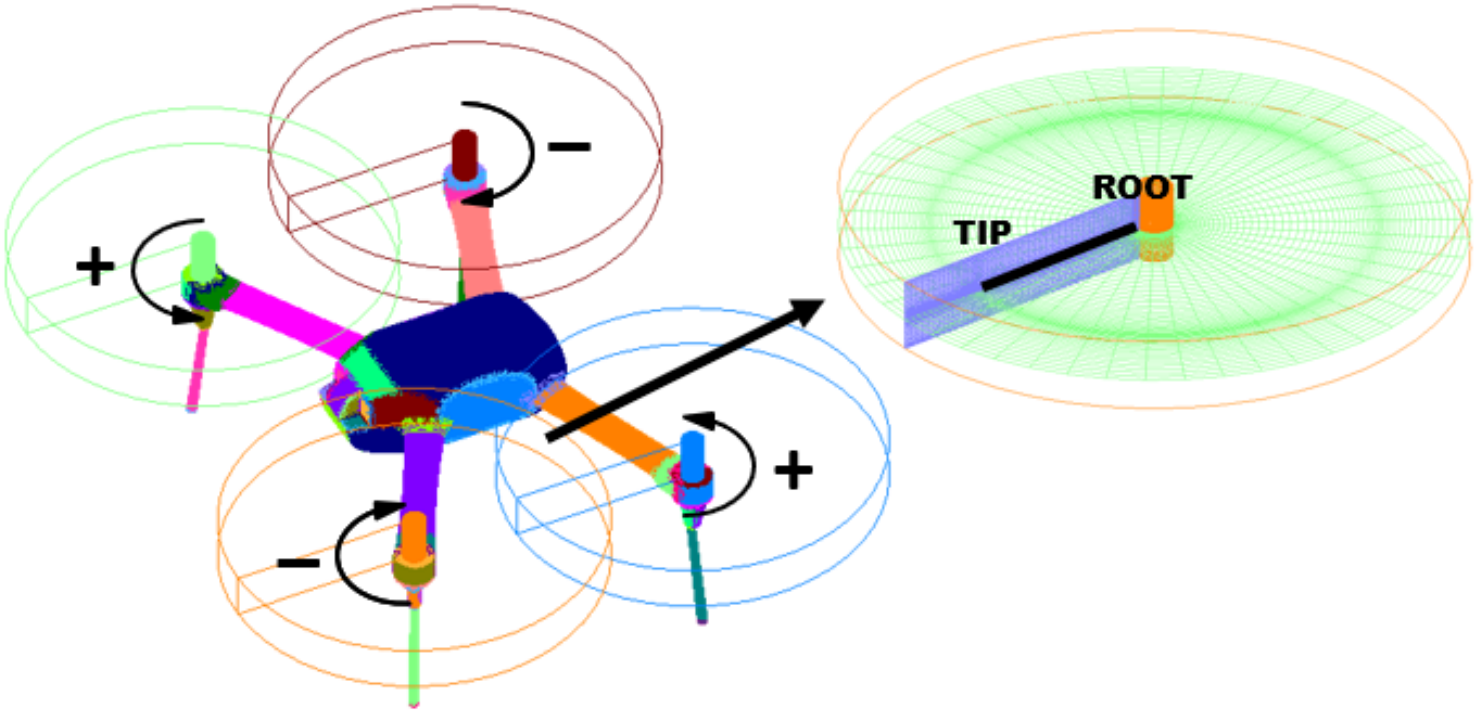
Computational Grids

Overflow Rotor Disk Model Implementation

- IRIS Quadcopter
  - Quad Rotor with 2 Blades per Rotor



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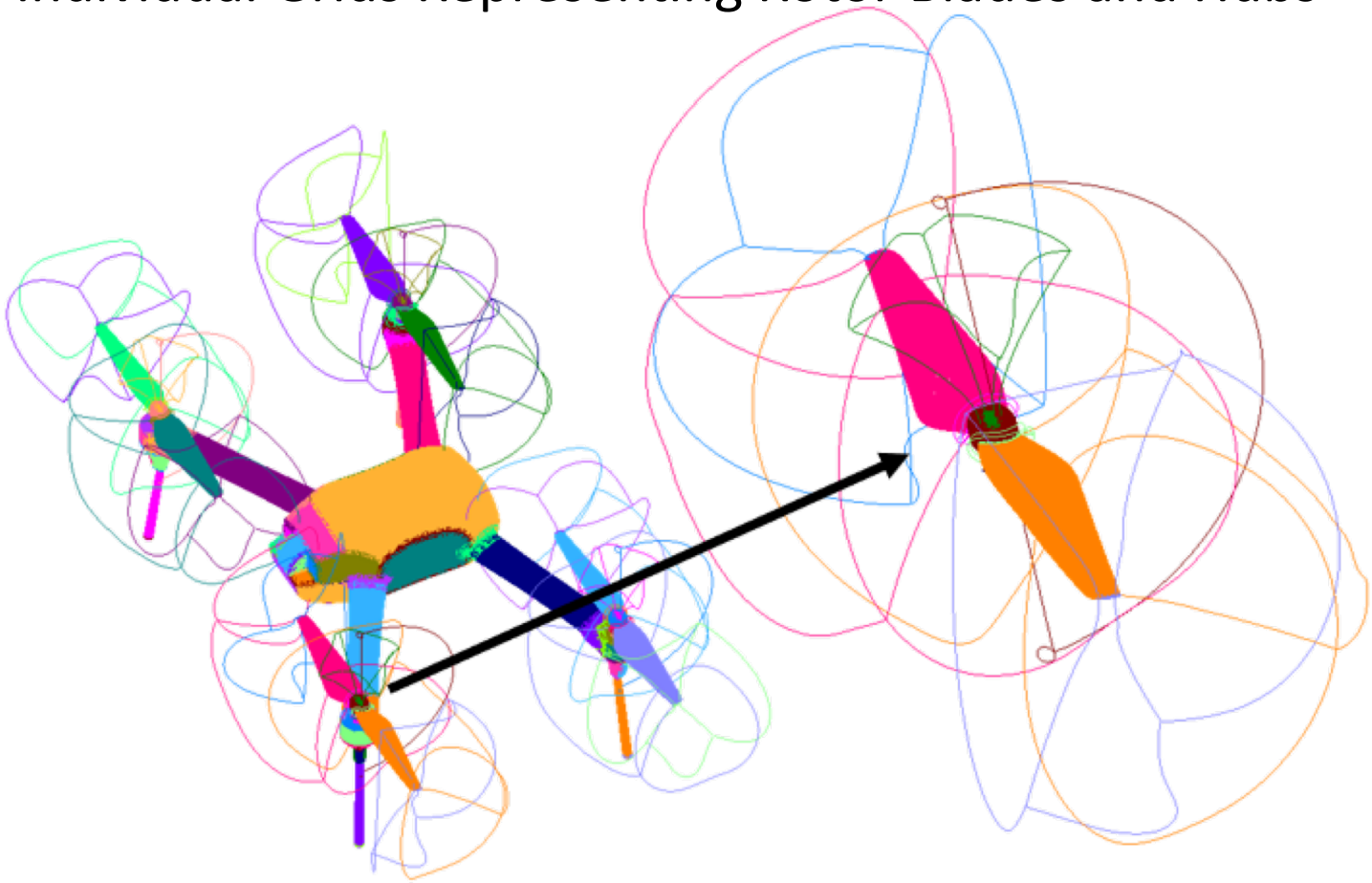
Computational Grids

Overflow Individual Blade Implementation

- Individual Grids Representing Rotor Blades and Hubs



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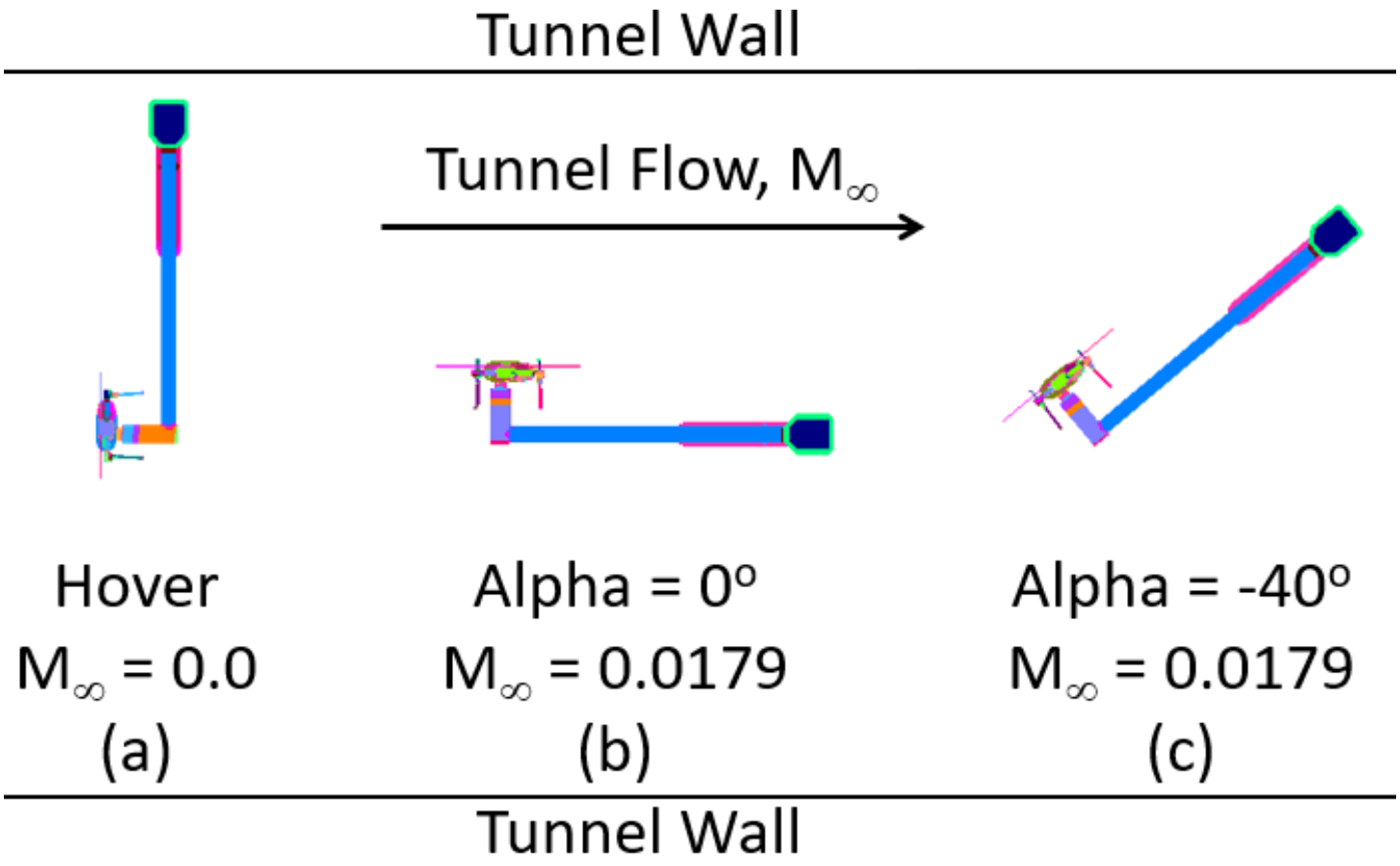
Numerical Analysis

Model Orientation in Wind Tunnel for Various Flow Conditions



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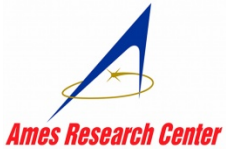

Blade Element Disk Model Results

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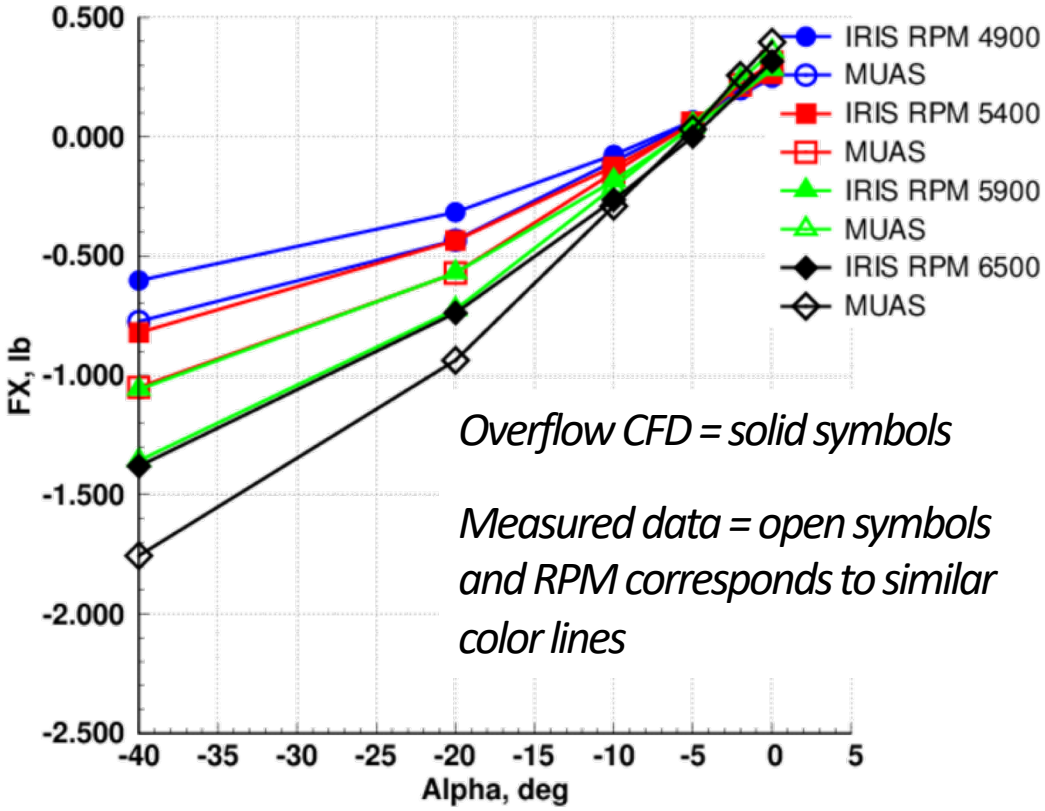
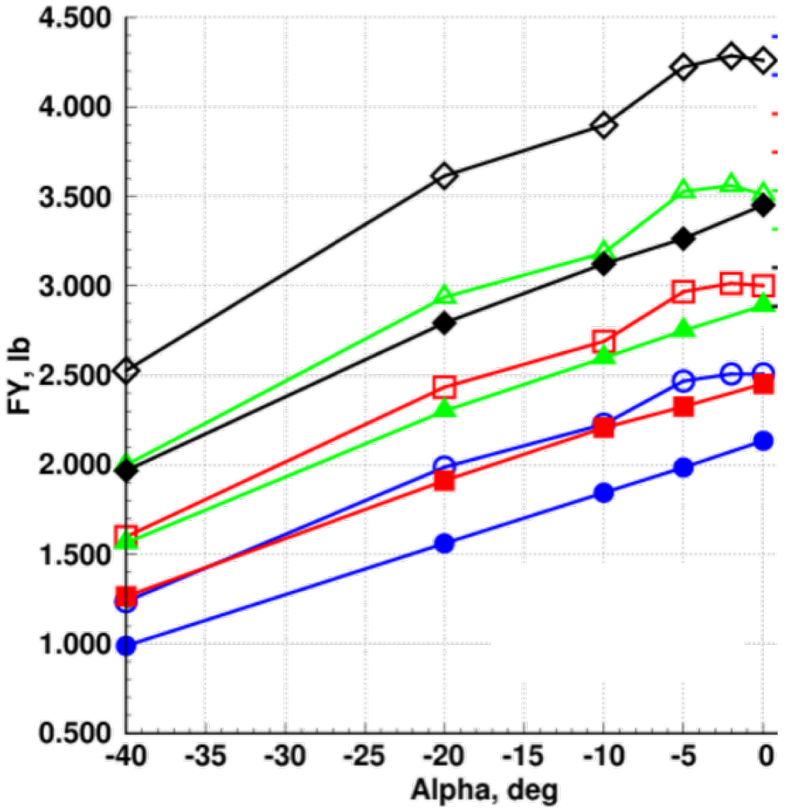
OVERFLOW Theoretical Rotor Disk Model Simulations

Forces in X, Y (FX, FY) vs. Angle-of-attack (Alpha) @ Mach=0.0179





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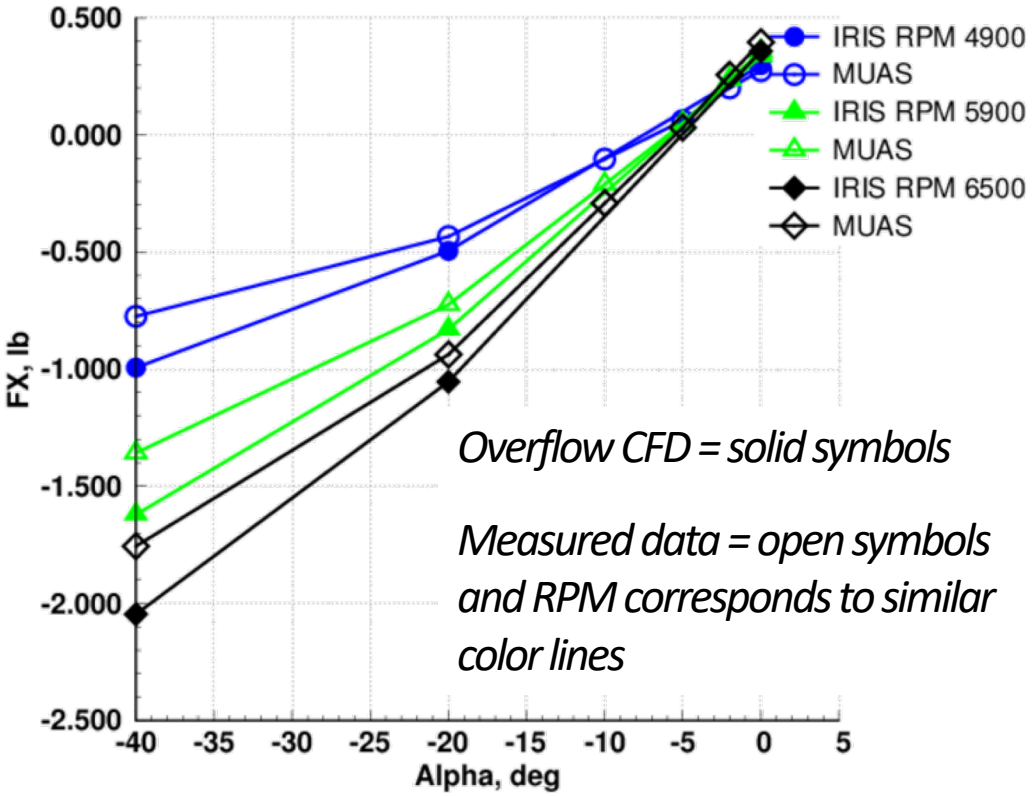
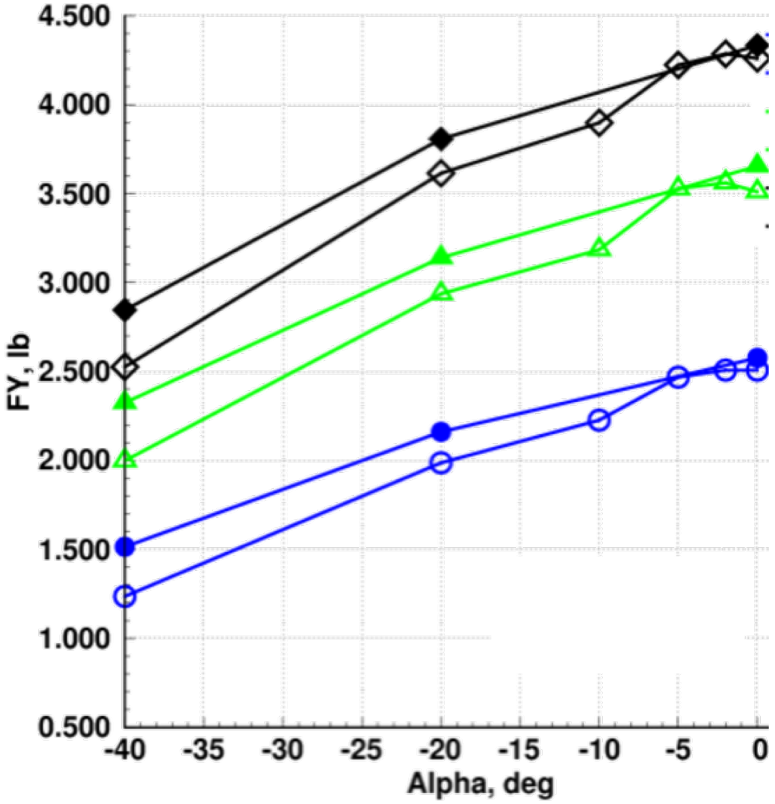
OVERFLOW SUI074 Airfoil Table Rotor Disk Model Simulations

Ames Research Center

Forces in X, Y (FX, FY) vs. Angle-of-attack (Alpha) @ Mach=0.0179





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Comparison of OVERFLOW Rotor Disk Model Simulations in Hover

Force in X (FX) vs. RPM

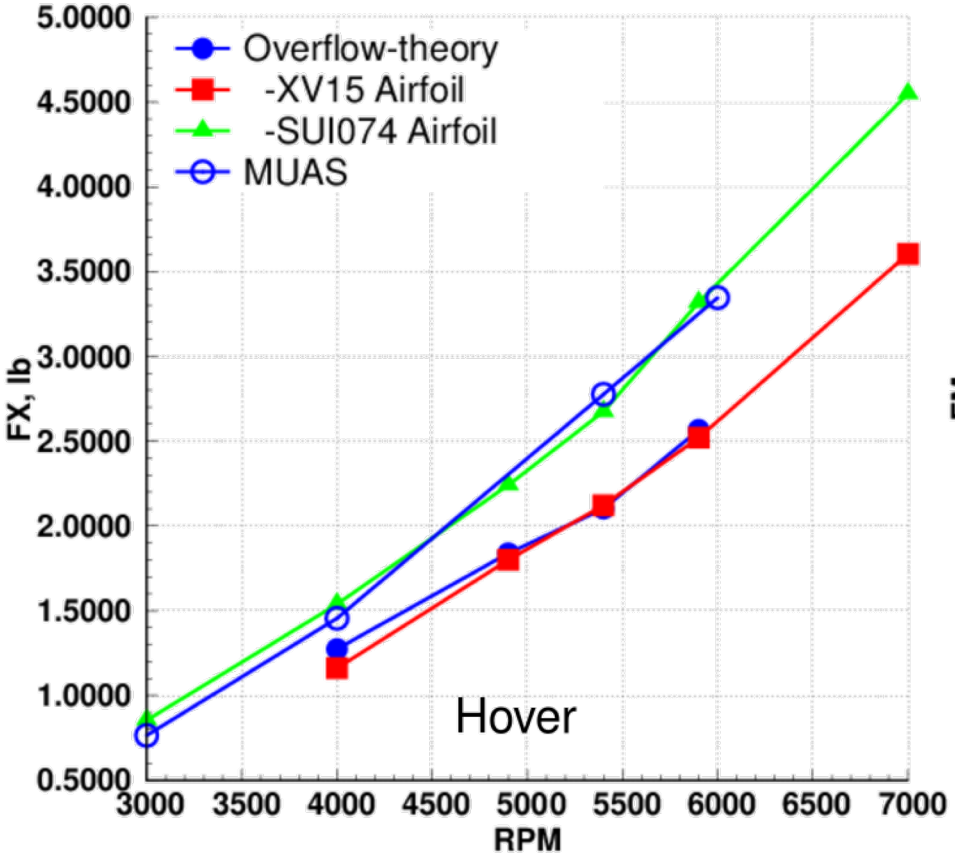
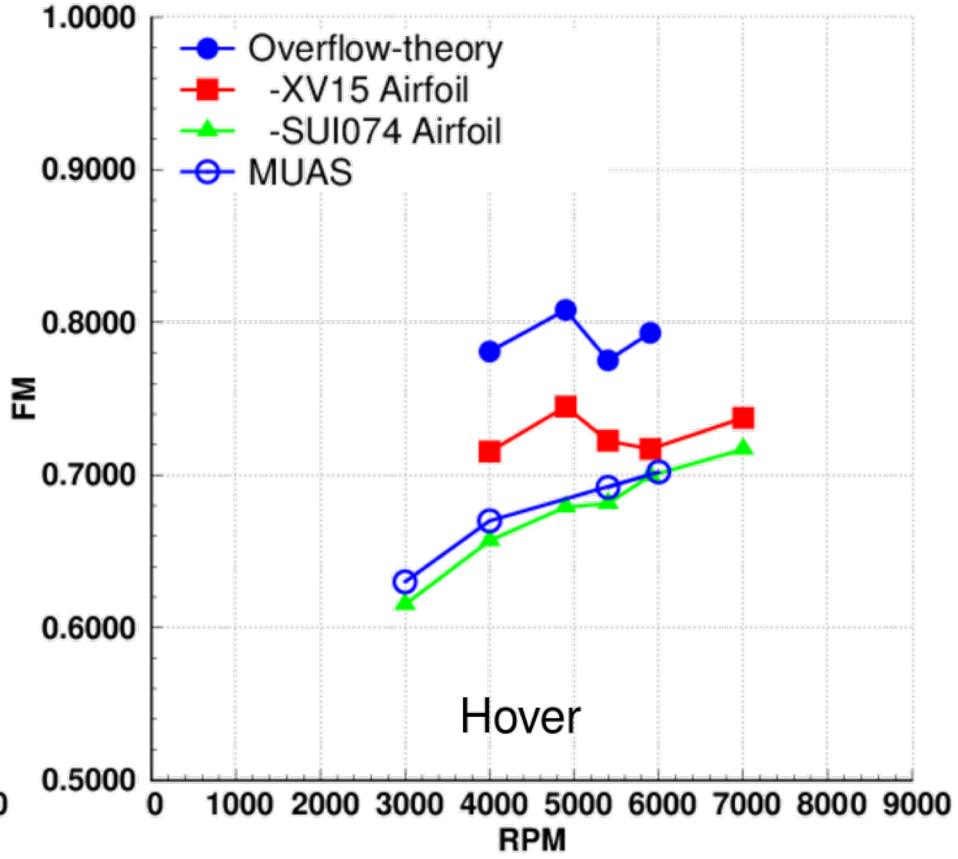


Figure of Merit (FM) vs. RPM



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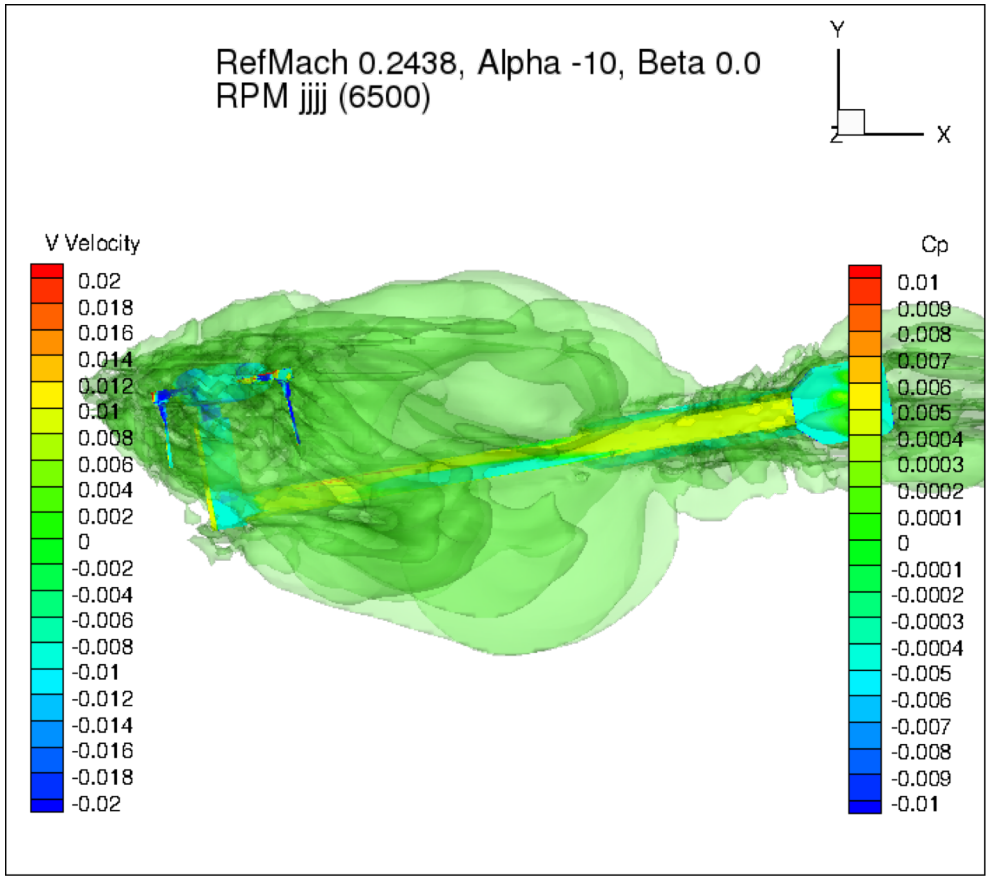
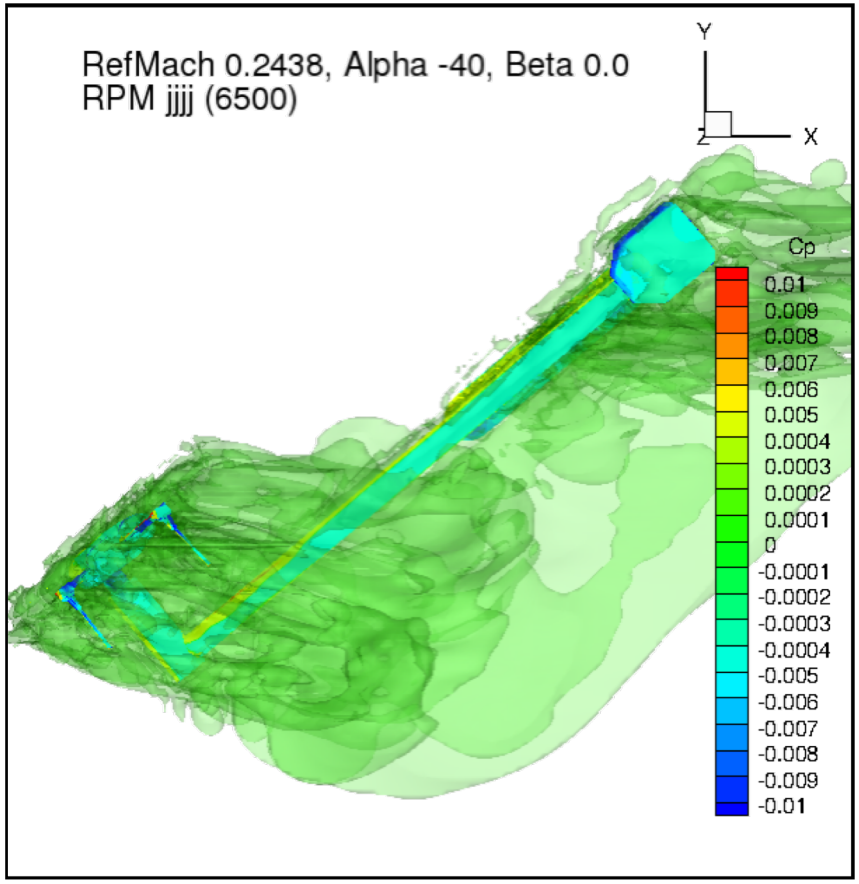
Sample OVERFLOW Theoretical Rotor

Disk Model Simulations @ Alpha -10° & -40°

Off body Flow Field, Y-Velocity (V) and Surface Cp Contours





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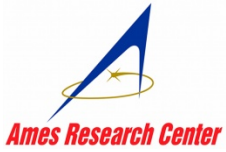

Individual Blade Simulation Results

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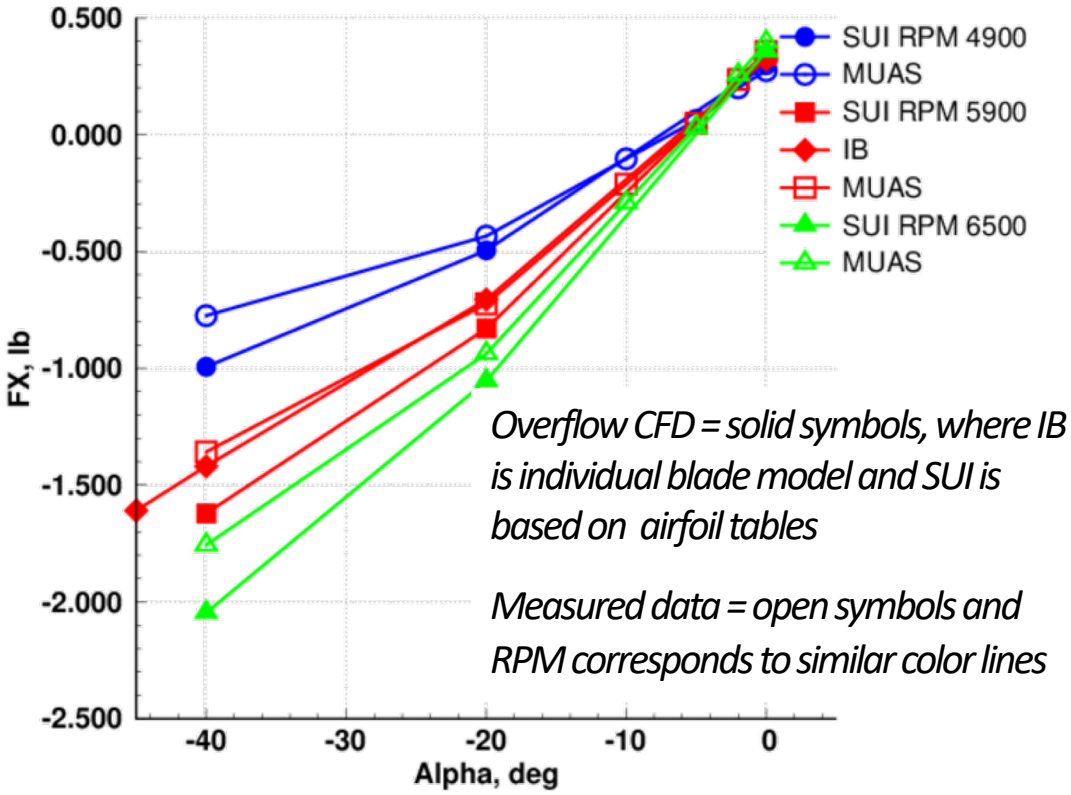
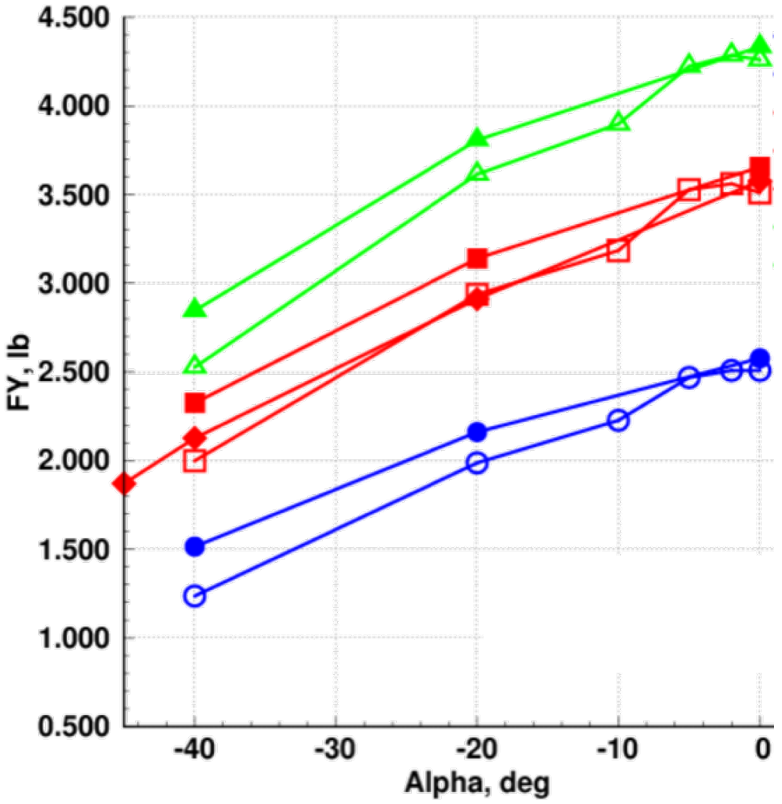
OVERFLOW Individual Blade Simulations

Forces in X, Y (FX, FY) vs. Angle-of-attack (Alpha) @ Mach=0.0179



Overflow CFD = solid symbols, where IB is individual blade model and SUI is based on airfoil tables

Measured data = open symbols and RPM corresponds to similar color lines



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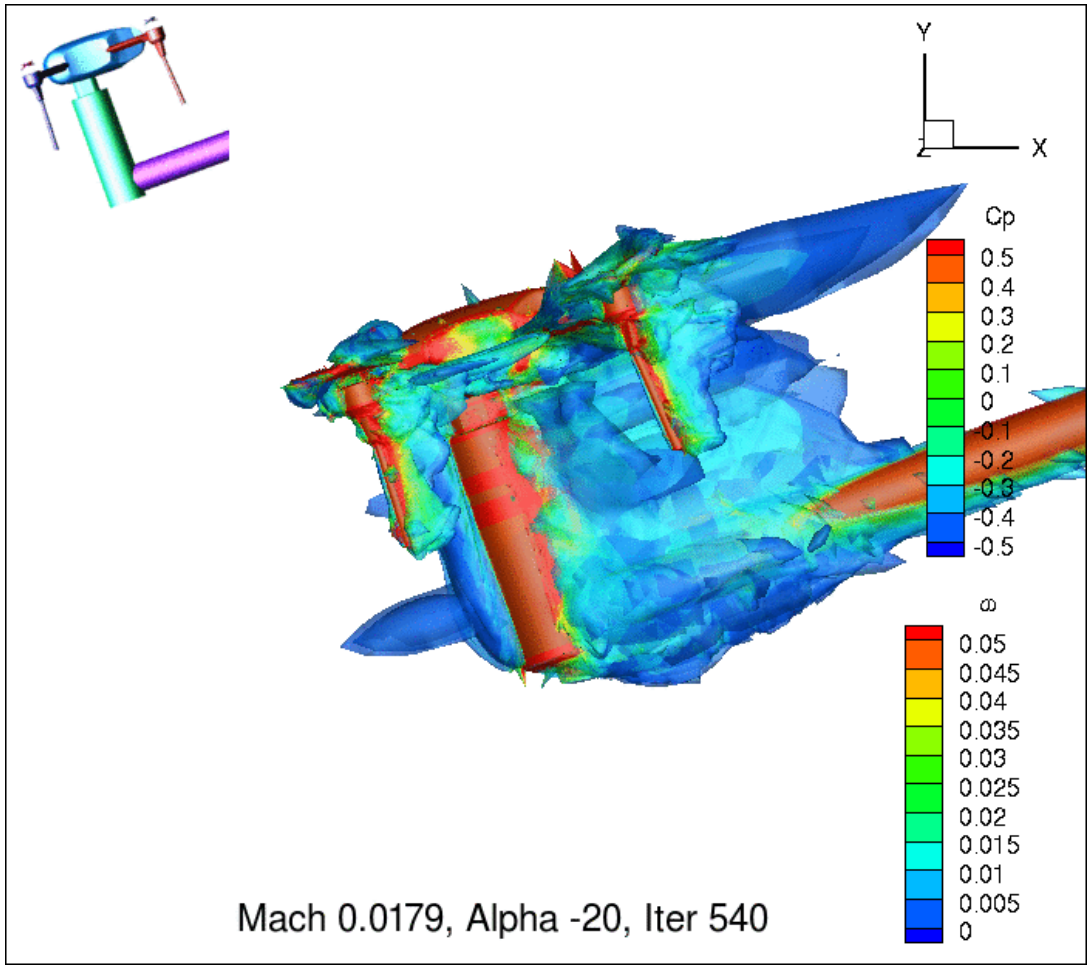
OVERFLOW Individual Blade

Simulation @ α = -20°

Side View: Flow Field Vorticity and Model Surface Cp Contours



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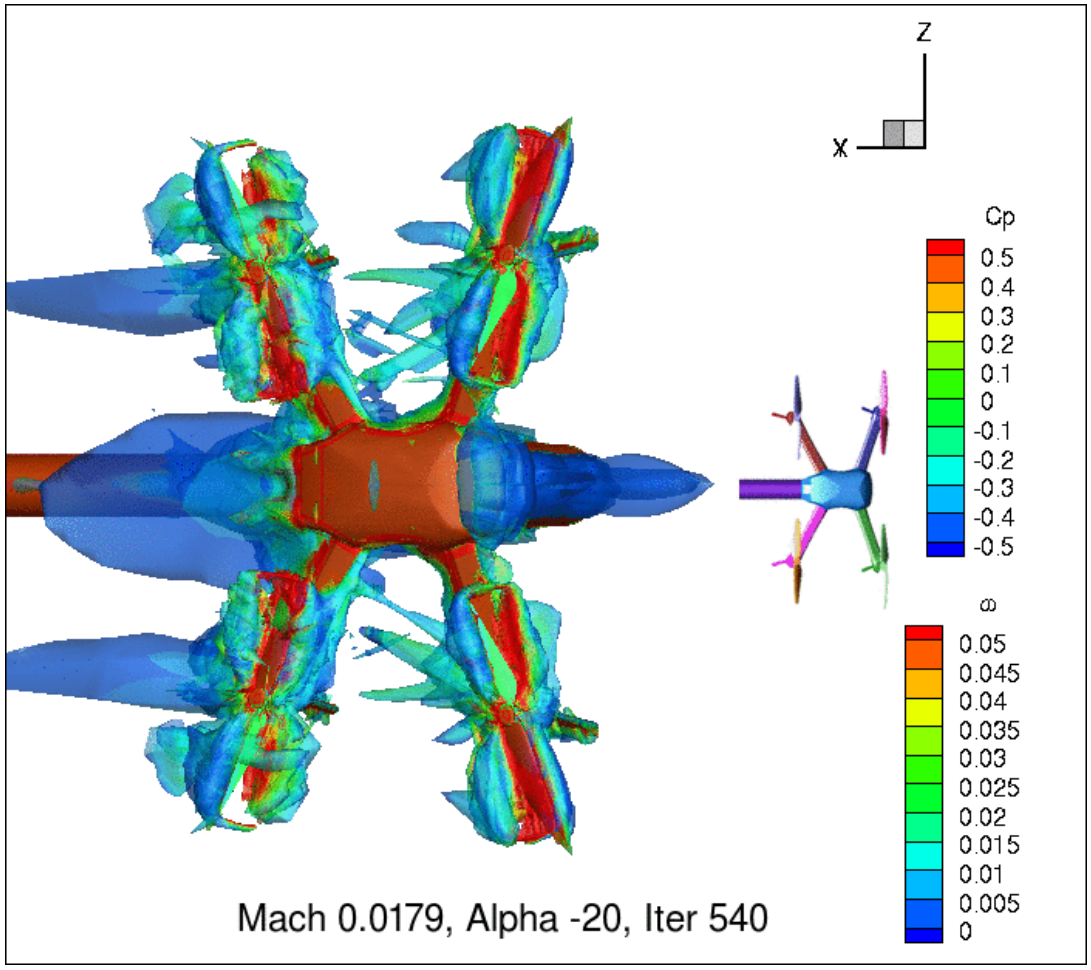
OVERFLOW Individual Blade

Simulation @ α = -20°

Top View: Flow Field Vorticity and Model Surface Cp Contours



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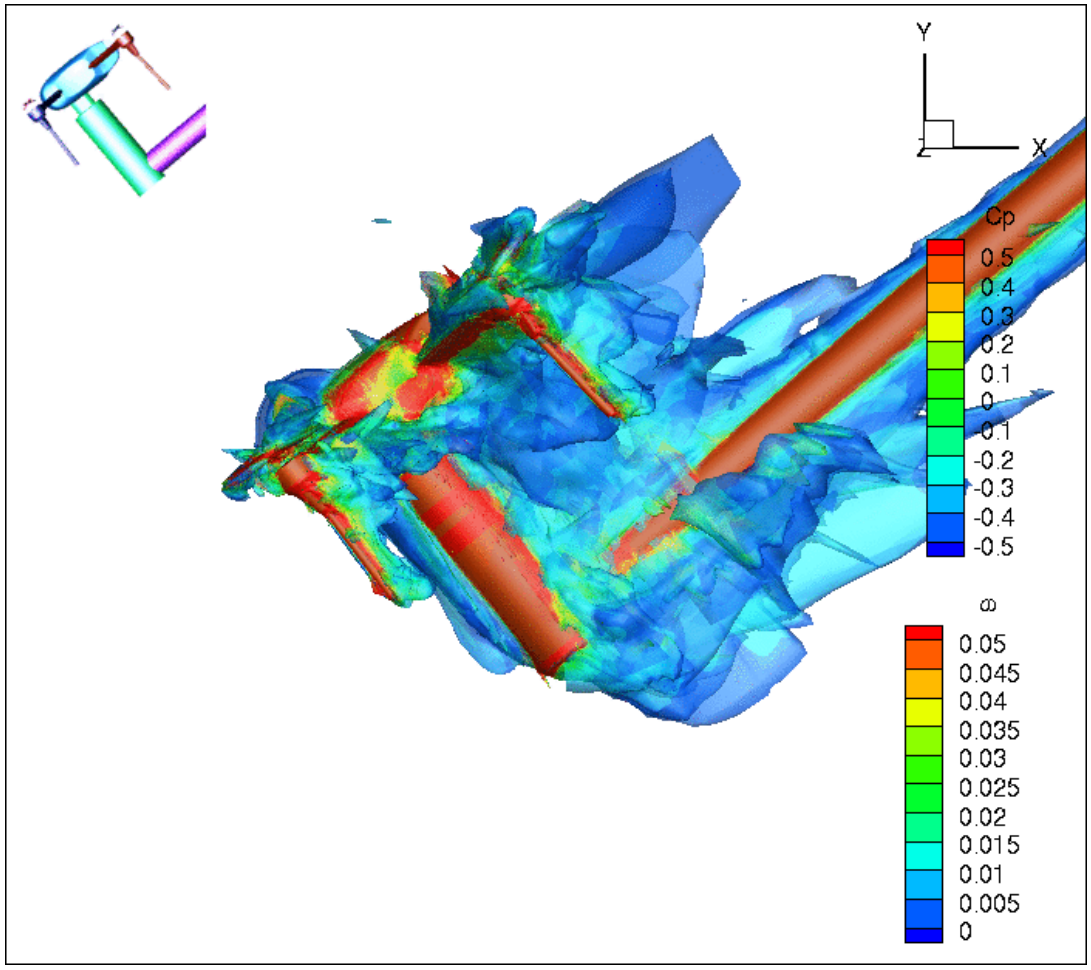
OVERFLOW Individual Blade

Simulation @ α = -40°

Side View: Flow Field Vorticity and Model Surface Cp Contours



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OVERFLOW Individual Blade

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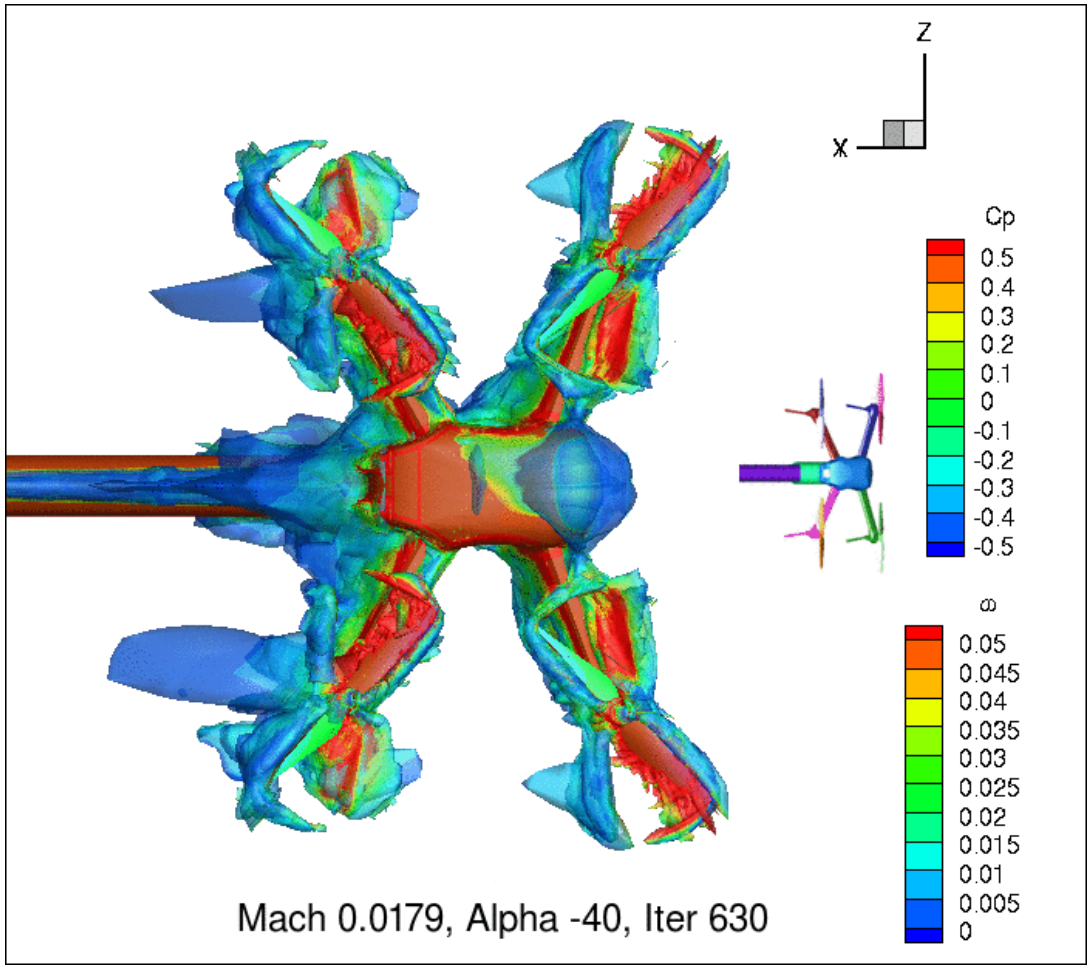

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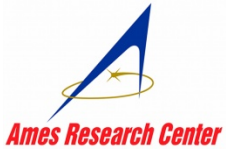
Conclusions

- Comprehensive comparison of OVERFLOW Rotor Disk Model and Individual Blade Analysis for small UAS has been completed
- Comparison of Overflow Simulation Results of IRIS Quadcopter with Ames 7x10ft WT Experimental Values
  - OVERFLOW Theoretical Rotor Disk Model Simulation Results Under Predict WT Data
  - Better Agreement of OVERFLOW SUI074 Airfoil Table Rotor Disk Model with WT Data
  - Excellent Agreement of OVERFLOW Individual Blade Simulations with WT Data
- OVERFLOW Individual Blade Simulations Provide Confidence to Model Quadcopters in Free Flight and Urban Environments



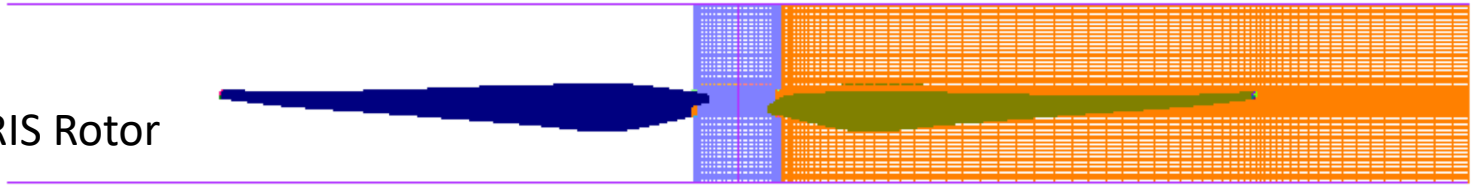
Backup

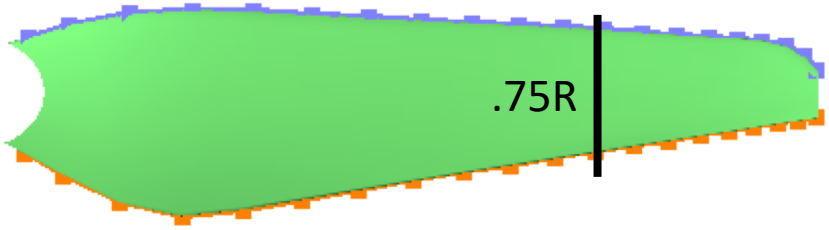
Numerical Analysis

Rotor Chord/Twist Inputs, R = 4.8”, CAD Representation

- Chord, 20 stations, Normalize by radius (R)
- Twist 20 Stations w/r to .75 R, Collective = Twist at .75R (13.18°)

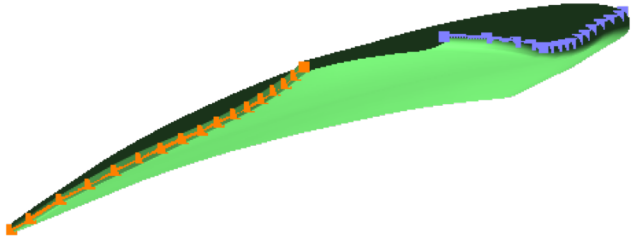
Disk Model Grid





Chord

cordr = 0.1398, 0.1830, 0.2347, 0.2566, 0.2455, 0.2277, 0.2112, 0.1960, 0.1822, 0.1697, 0.1578, 0.1468, 0.1368, 0.1272, 0.1188, 0.1113, 0.1034, 0.0927, 0.0772, 0.0571,



Twist

twstr = 0.377, 2.615, 5.400, 6.352, 5.845, 4.926, 4.202, 3.202, 2.266, 1.477, 0.609, 0.000, -0.483, -1.213, -1.943, -2.675, -3.119, -3.009, -2.283, -1.243,

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Numerical Analysis

Comparisons with Ames 7x10 ft. WT Results

- Multicopter Unmanned Aircraft System (MUAS)
- "Wind Tunnel and Hover Performance Test Results for Multicopter UAS Vehicles," Russell, C., et. al., AHS 72nd Annual Forum, West Palm Beach, FL, May 16-19, 2016.
- Alpha: -40°,-20°,-20°,-5°, 0°, Beta: 0°
- Rotor RPM: 4900, 5400, 5900, 6500 (all rotors)
- L_{ref} =4.8 in (rotor radius), A_{ref} = 72.3823 in^2 (rotor disk area)

Tunnel Conditions

- Velocity = 20 (ft/s), 13.636 (mph), q = 0.476, Mach number 0.0179

Rotor Values

rpm = 4900(d), rps = 81.667, circ = 2.513 (ft), Vtip = 205.25072 (ft/s), Mtip 0.1838
rpm = 5400(f), rps = 90.000, circ = 2.513 (ft), Vtip = 226.19467 (ft/s), Mtip 0.2025
rpm = 5900(h), rps = 98.333, circ = 2.513 (ft), Vtip = 247.13862 (ft/s), Mtip 0.2213
rpm = 6500(j), rps = 108.333, circ = 2.513 (ft), Vtip = 272.27136 (ft/s), Mtip 0.2438