National Aeronautics and Space Administration

Fundamental Aeronautics Program

Subsonic Rotary Wing Project

Overview of Recent OVERFLOW Code Enhancements and Applications for the Subsonic Rotary Wing Project

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Outline

Motivation / Objective

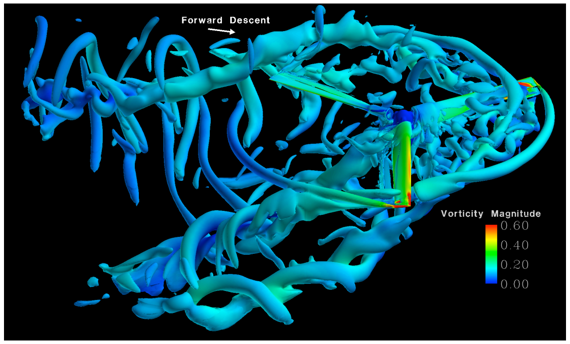
OVERFLOW Improvements and Results

- Fuselage Drag Reduction Via Active Flow Control
- Turbulence Model Assessment for Rotorcraft Flows
- Rotorcraft Transition Modeling—Future
- Simulation of V22 Rotor System in Hover
- Simulation of UH60 Rotor System In Forward Flight
- Near Body Adaptive Mesh Refinement
- Heavy Lift Slowed-Rotor Compound Helicopter Flow Computations
- Isolated Rotorblade Flutter Computations

Motivation / Objective

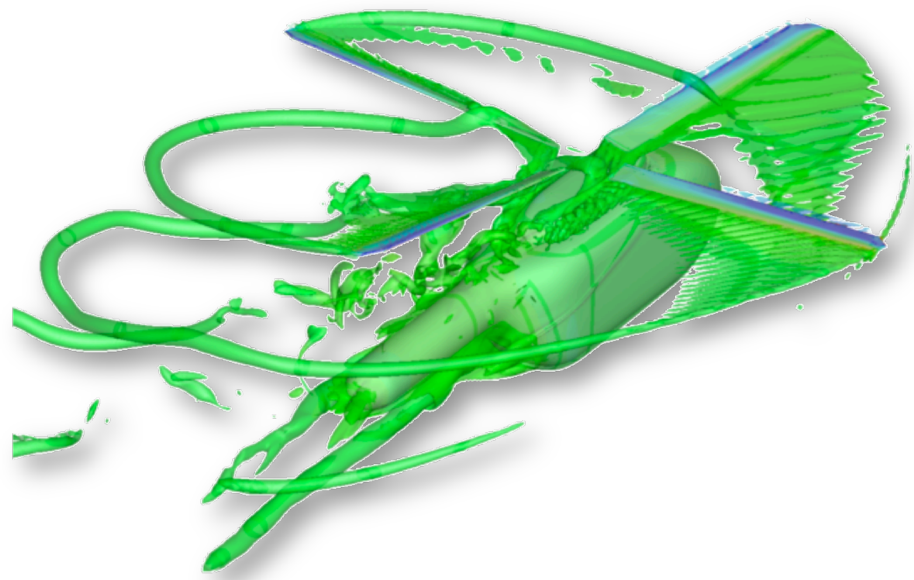
- Helicopters/Tiltrotor Aircraft Provide Many Crucial Services
  - Emergency medical/rescue evacuation, security, offshore oil platforms, heavy-lift, military operations

- Challenging Phenomena Associated with Rotorcraft
  - Aerodynamic performance and noise prediction
  - Vortex wakes and vortex blade interaction (BVI)
  - Rotor blade flexibility and vibration
  - Moving components
  - Multidisciplinary (aerodynamics, structures, trim)



- Many of These Phenomena Are Poorly Understood and Difficult to Accurately Predict
  - One objective of NASA's Subsonic Rotary Wing (SRW) Project is to develop physics-based computational tools to address these issues

Fuselage Drag Reduction via Active Flow Control



Problem
- Helicopter fuselage drag significantly reduces forward flight performance and must be reduced to enable high-speed flight

Objective
- Use CFD to provide guidance on design of active flow control system for fuselage drag reduction in forward flight for a mid-scale wind tunnel test

Approach
- Study placement of flow control actuators and actuator parameters using CFD
    - Generic fuselage shape (ROBIN-mod7)
    - OVERFLOW2/CAMRAD II loose coupling

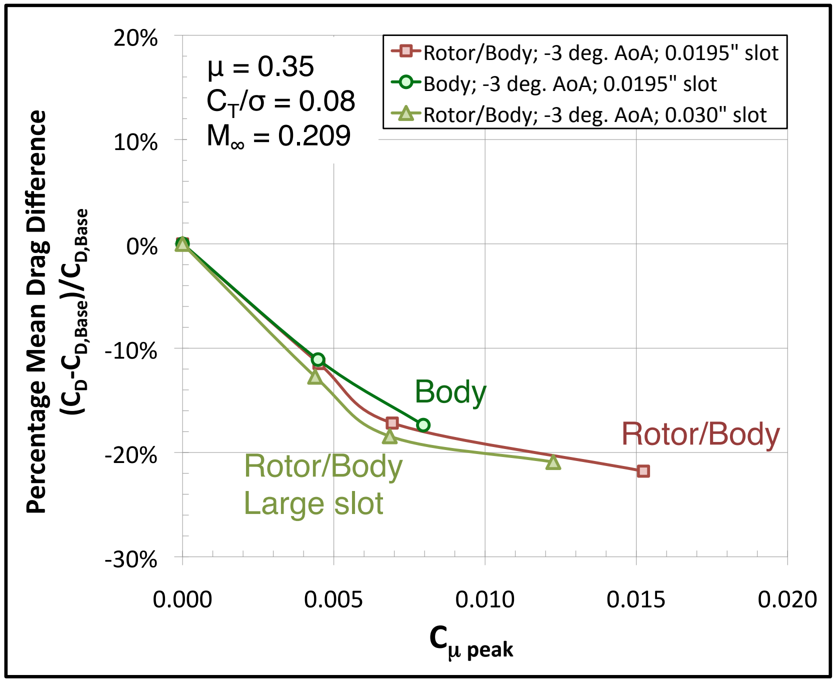
Results
- Validated CFD using small scale isolated fuselage wind tunnel test
- Identified blowing slot locations and actuator parameters for maximum predicted fuselage drag reduction (~20% in forward flight)
- CFD also predicts maximum fuselage download reduction of 30%

Significance
- Drag reduction with simultaneous download reduction offers potential to significantly improve helicopter performance in forward flight.
    - Drag reduction enables higher speeds
    - Download reduction allows increased payload and/or maneuver performance

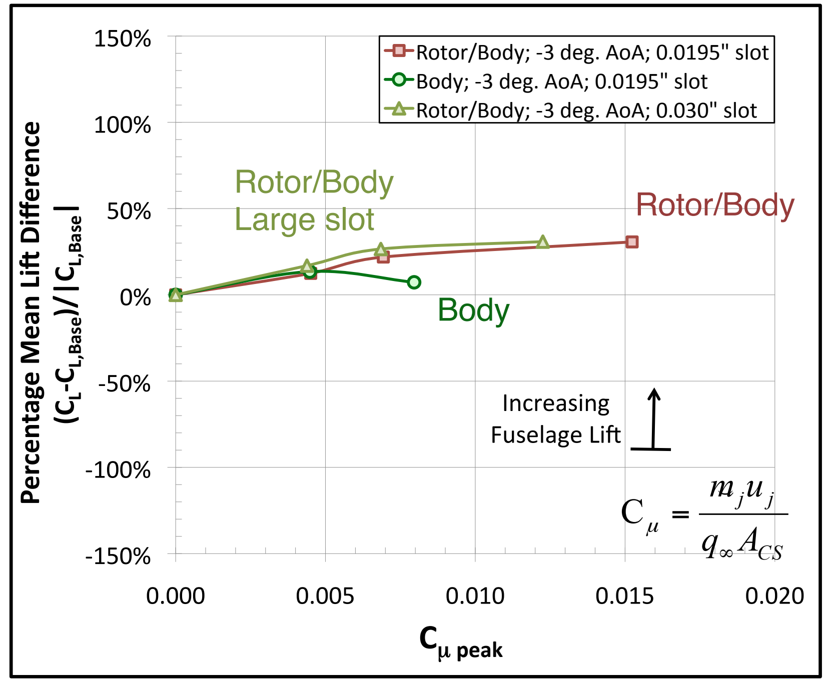
POCs: Brian Allan and Norman Schaeffler, NASA LaRC

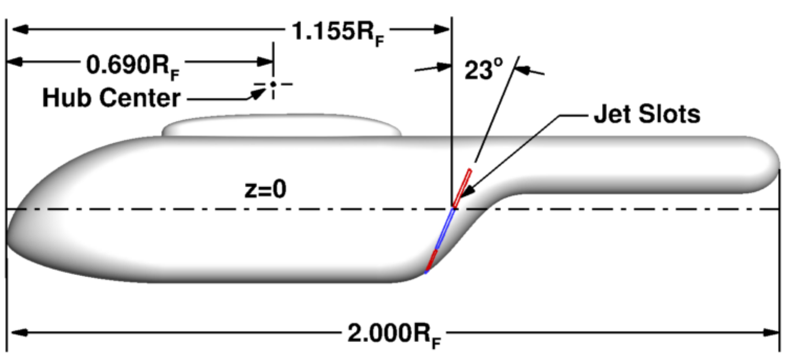
Fuselage Drag Reduction via Active Flow Control

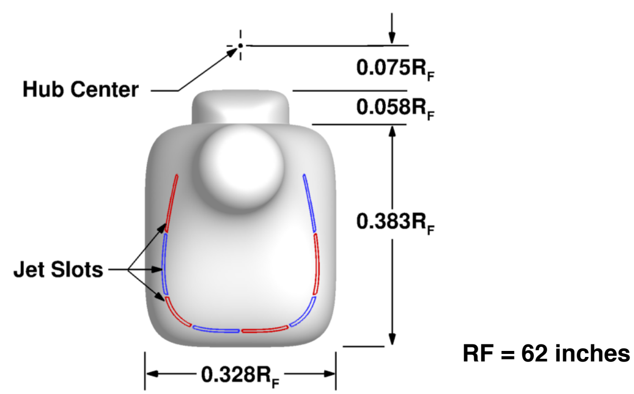
CFD Drag Performance



CFD Lift Performance







POCs: Brian Allan, Norman Schaeffler, NASA LARC

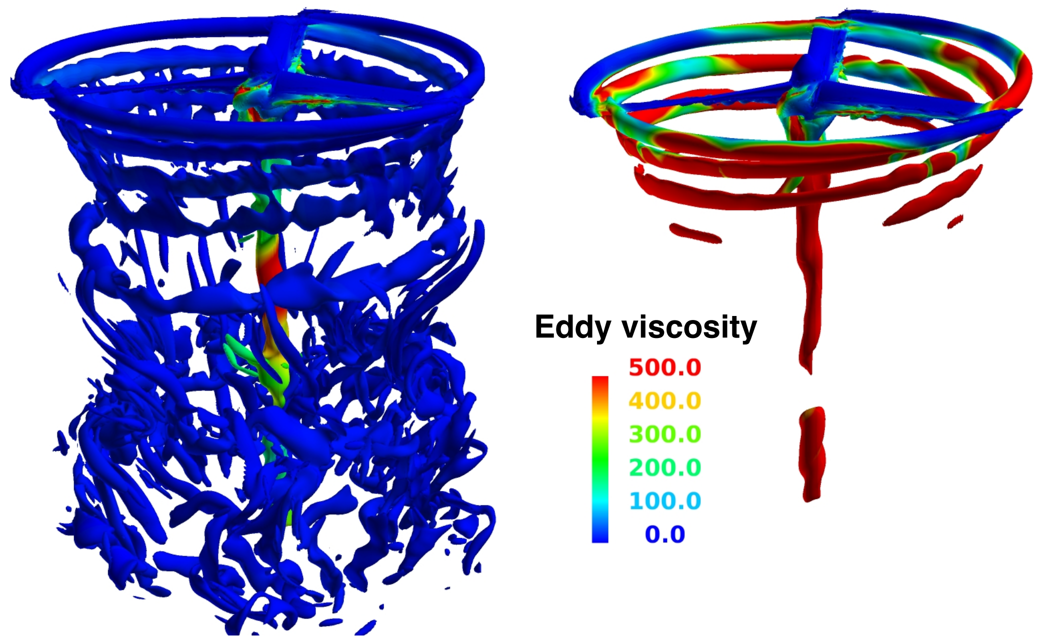
Turbulence Model Assessment for Rotorcraft Flows

- Most rotorcraft RANS computations use fixed-wing turbulence models (TM) >> Difficulties
- Effect of TM on rotorcraft flows largely unexplored
- Objective: Assess effect of TM on rotorcraft flows
- Study guidelines:
  - OVERFLOW flow solver
  - Hover & forward flight conditions
  - Two geometries: XV15, UH60
  - Near body (NB) & off body (OB) grids treated independently
  - NB & OB viscous terms activated independently
- Example results at right
  - Grid size: NB=19x10^6, OB=28x10^6
  - NB TM = Spalart-Almaras (SA)
  - NB viscous = RANS

- High levels of eddy viscosity (right) diffuse flow structure > large errors in FM

Iso-surface of vorticity colored by eddy viscosity

Inviscid OB | **Fully RANS**



OB grid:
SA (source term OFF)
Viscous terms OFF
FM = 0.777

OB grid:
SA (source term ON)
Viscous terms ON
FM = 0.730

POC: Tom Pulliam, NASA Ames

Turbulence Model Assessment—Grid Refinement

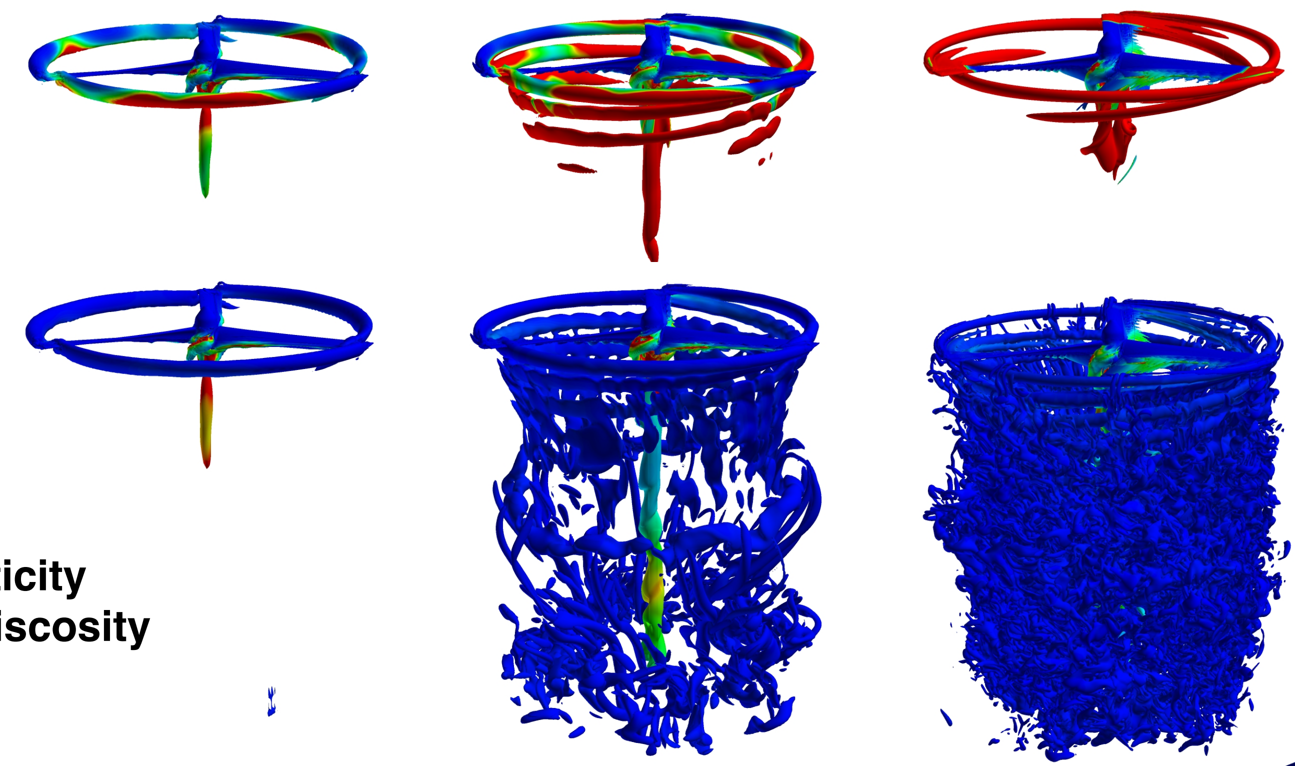
- XV15 in Hover
- θ=10°
- Spalart-Almaras
- 14 Revolutions
- FM_{exp} ~ 0.77

Grid ($x10^6$)	NB	OB	FM (Inv OB)	FM (RANS OB)
Coarse	5.3	4.4	0.785	0.752
Medium	19	28	0.777	0.730
Fine	80	207	0.772	0.715

Coarse grid | Medium grid | Fine grid

OB grid:
Source term OFF
Viscous terms OFF

OB grid:
Source term ON
Viscous terms ON



Iso-surface of vorticity colored by eddy viscosity
RED ~ High
Blue ~ Low

POC: Tom Pulliam, NASA Ames

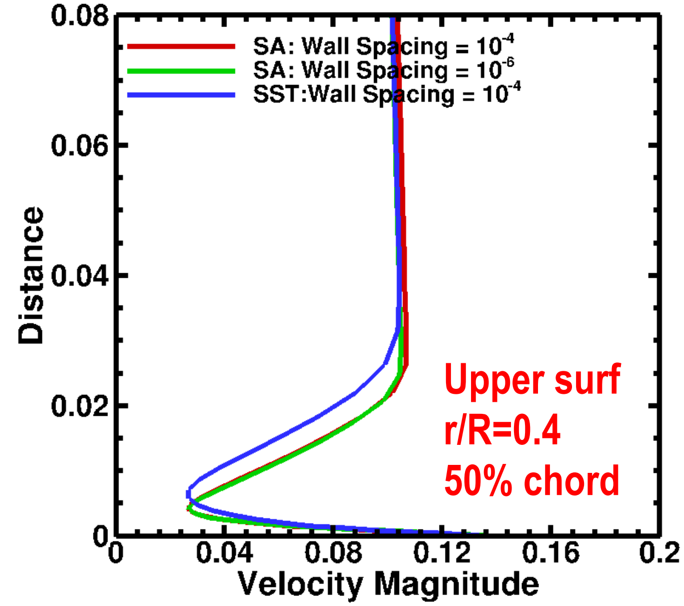
Turbulence Model Assessment—UH60A Rotor

Hover results

- OVERFLOW with 5th O convection in OB, 2nd O time
- Isolated rotor with no trim tab
- Aeroelastic deflections based on exp measurement
- M_{TIP}=0.65, θ=10.5°

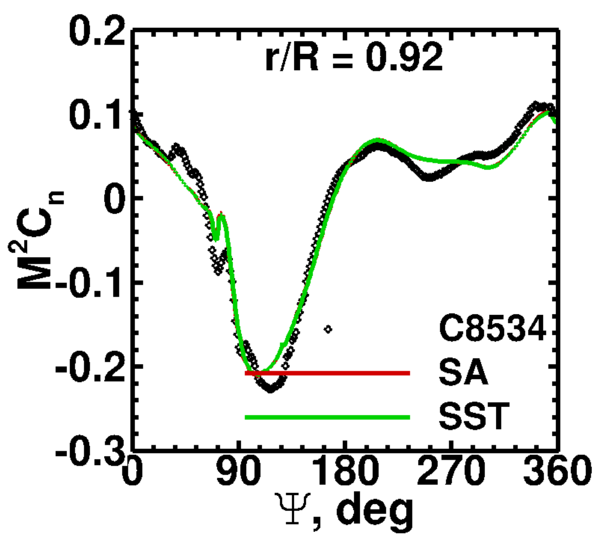
Model	FM	OB turb model options
SA-DES	0.7571	Hybrid RANS/LES
SA	0.7578	Source terms OFF, Inviscid
SST	0.7612	Source terms OFF, Inviscid
SA	0.7557	RANS
SST	0.7627	RANS

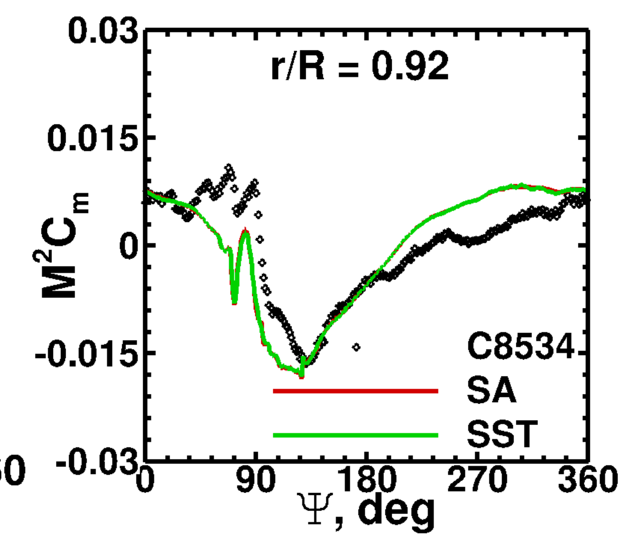
Boundary layer profile comparisons



Forward flight results

- OVERFLOW/CAMRAD II, loose coupling
- High Speed Flight Counter (C8534: M_∞=0.236, μ=0.368)
- SA and SST TM models





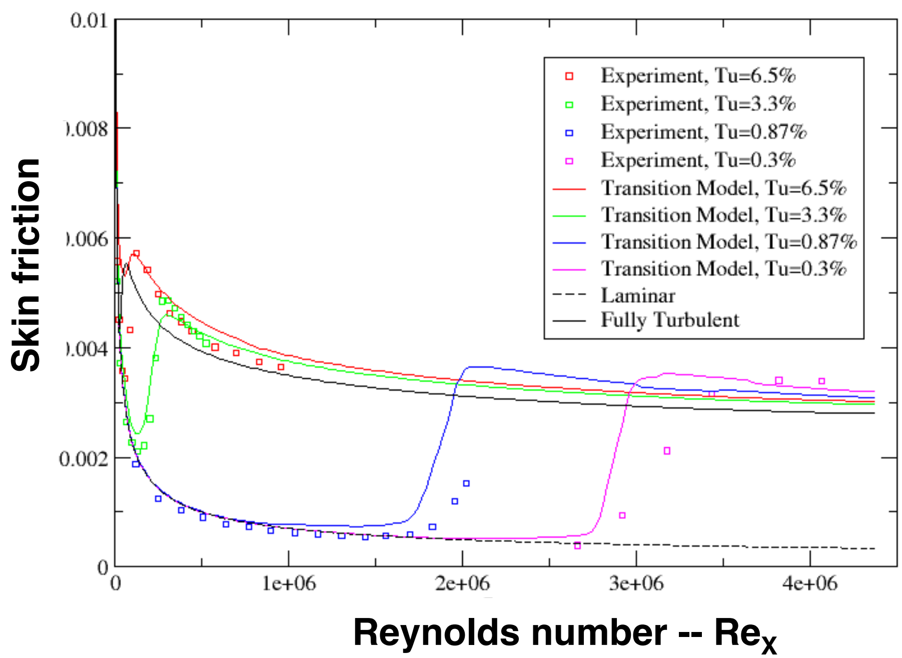
POCs: Jasim Ahmad - NASA ARC

Rotorcraft Transition Modeling--Future

- Langtry-Menter transition model incorporated into OVERFLOW
  - Improves accuracy for cases with laminar-to-turbulent transition
  - Future effort: Include/evaluate Langtry-Menter model for rotorcraft flows to improve rotor blade stall prediction

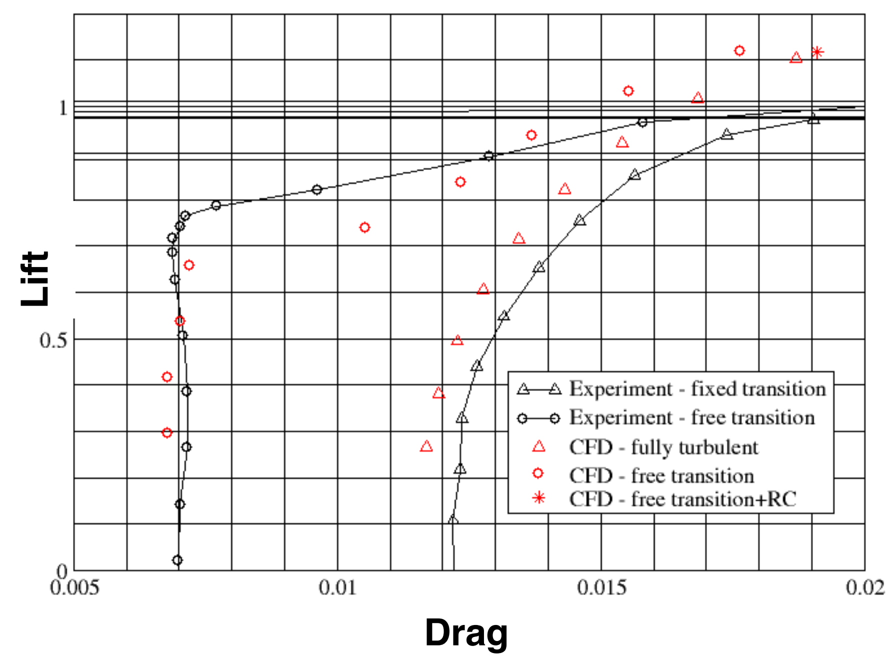
Flat plate skin friction

Different free-stream turbulence levels illustrate effect of Langtry-Menter transition model



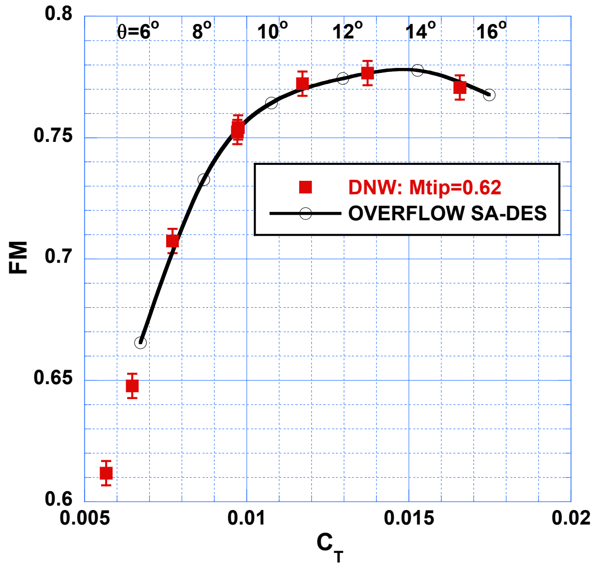
S809 airfoil drag polar

Comparisons between transitional and fully turbulent simulations.



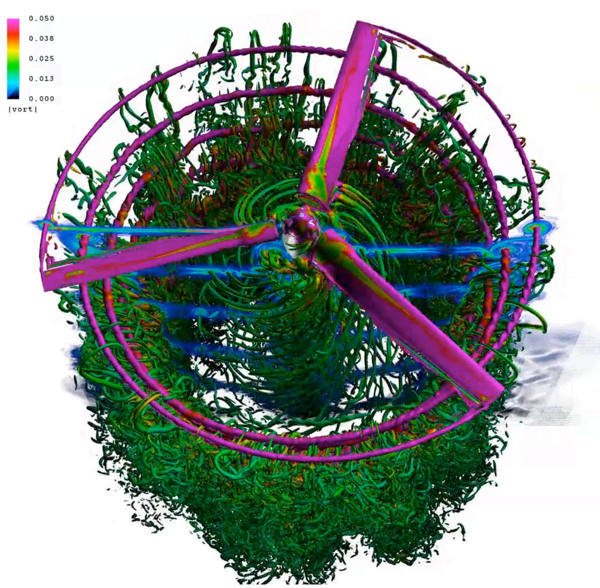
POC: Pieter Buning, NASA Langley

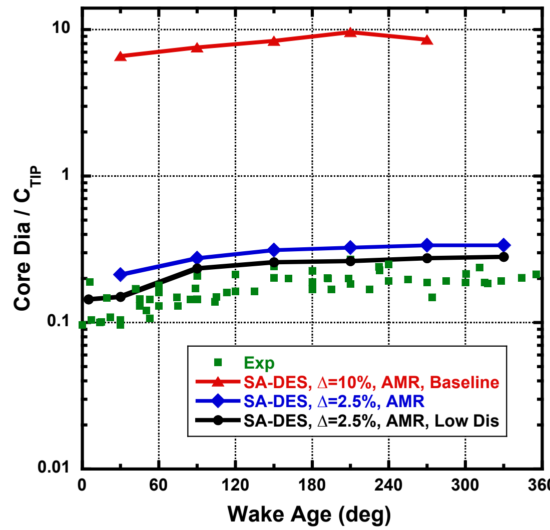
Simulation of V22 Rotor System in Hover

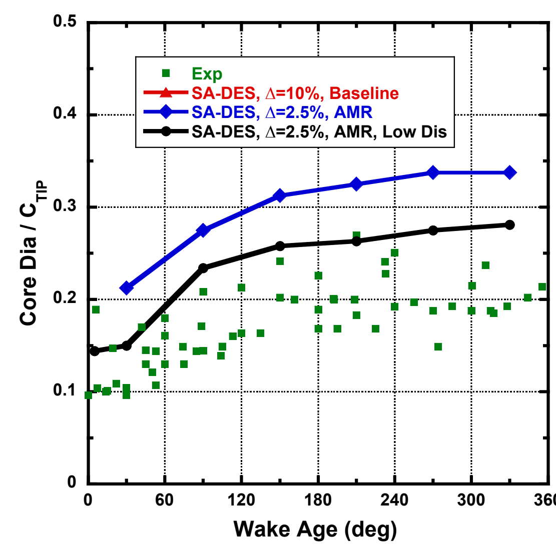


FM within Experimental Error
- Improved body resolution
- 5th-order spatial accuracy (OB convective terms)
- Detached Eddy Simulation (DES)

Adaptive Mesh Refinement
- Vortical worms produced due to blade wake shear-layer entrainment into vortex cores
- Prediction of vortex-core diameter growth more closely agrees with experiment
- Reduced dissipation







POC: Neal Chaderjian, NASA Ames

Simulation of UH60 Rotor System In Forward Flight

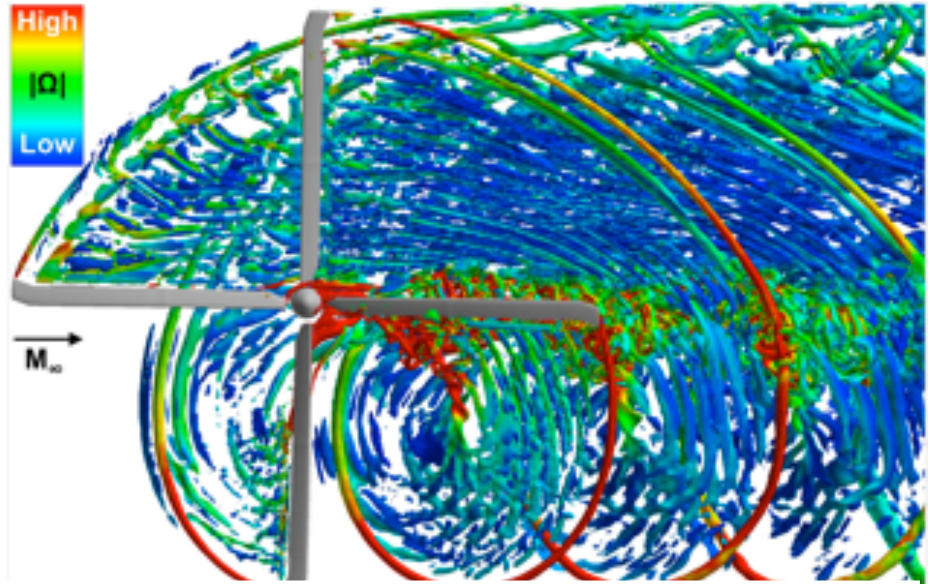
Baseline

- Flight Counter C8534 (High-Speed Case)
  - $M_\infty = 0.236$
  - $\mu = 0.37$
- Uniform spacing in off body grid: $\Delta = 10\%\ C_{tip}$

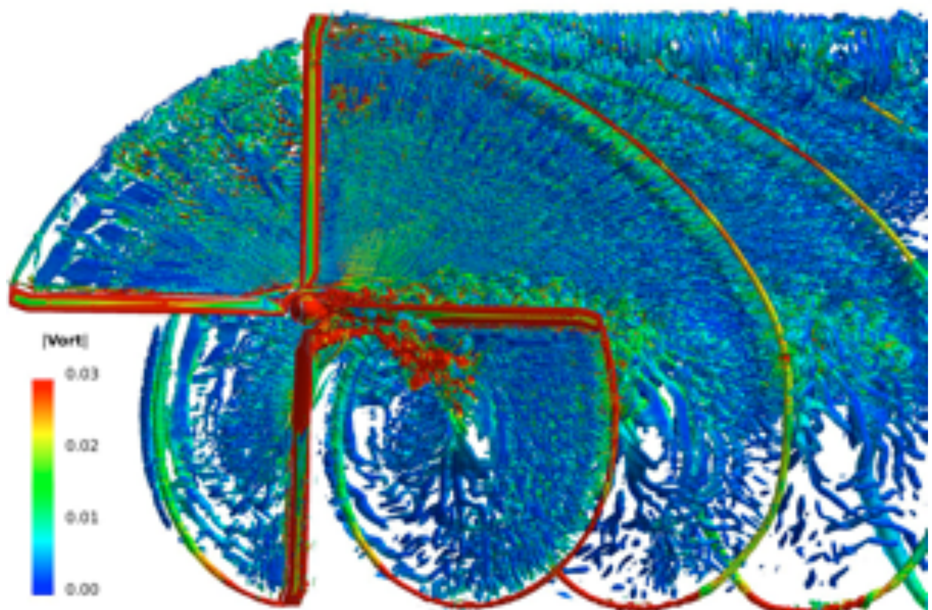
Adaptive Mesh Refinement (AMR)

- Three-level AMR used for off body grid:
  - Δ, $\Delta/2$, $\Delta/4$ = 10%, 5%, 2.5% C_{tip}
- Improved resolution of vortex core size
- Improved resolution of wake shear layer

POC: Neal Chaderjian, NASA Ames



Baseline Wake Grid 69×10^6 Pts

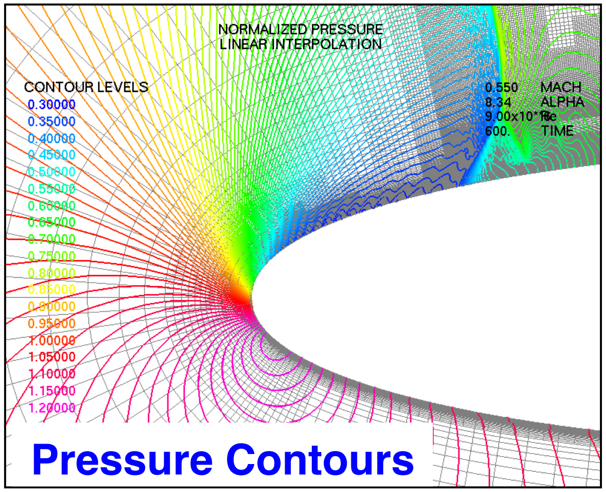


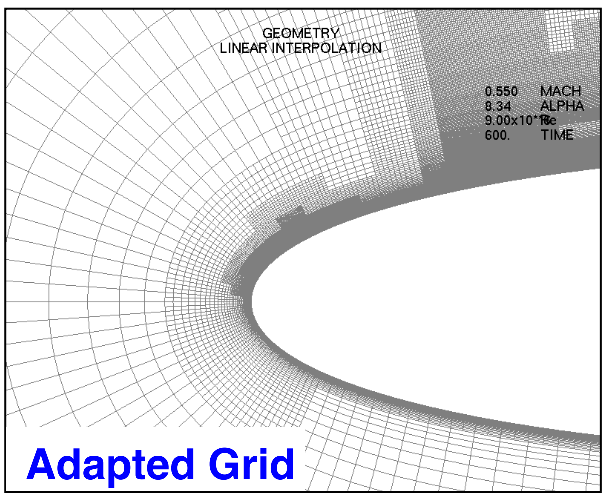
AMR Wake Grid 465×10^6 Pts

Near-Body Adaptive Mesh Refinement (AMR)

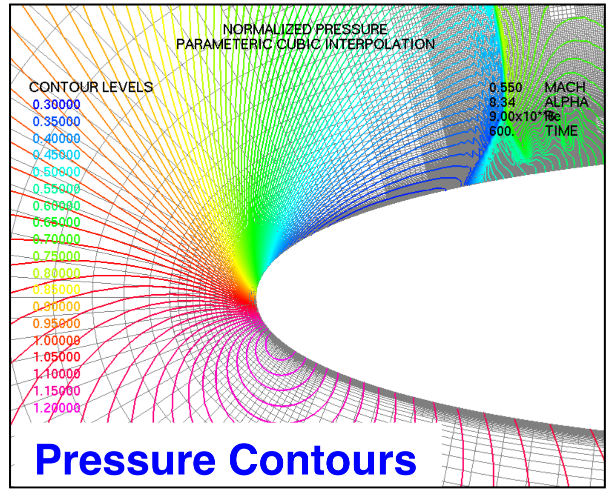
Cubic Interpolation Used to Avoid Oscillations Due to Faceted Surface Representation

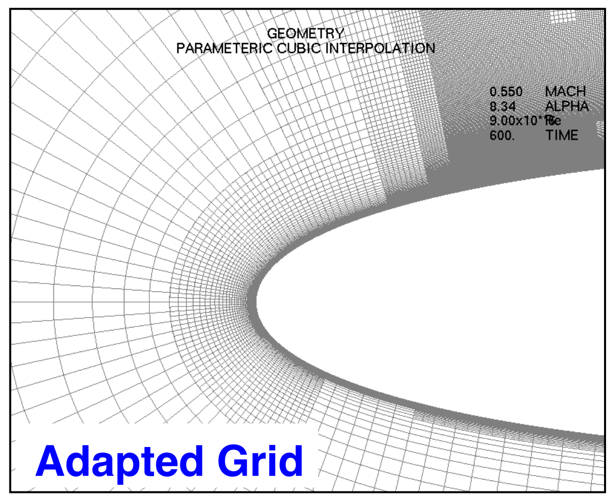
Bilinear Interpolation





Cubic Interpolation



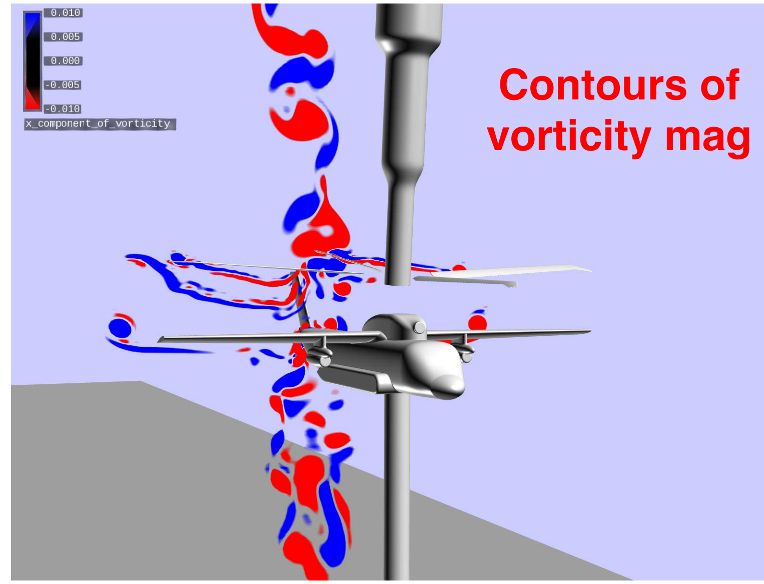


POCs: Pieter Buning, NASA LARC, Tom Pulliam, NASA ARC

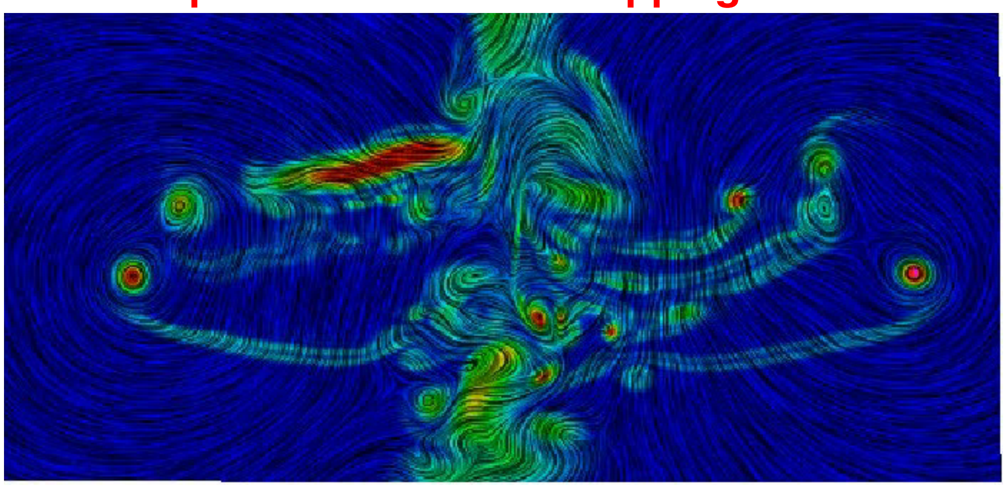
Heavy Lift Slowed-Rotor Compound Helicopter Flow Computations

OVERFLOW2 computations

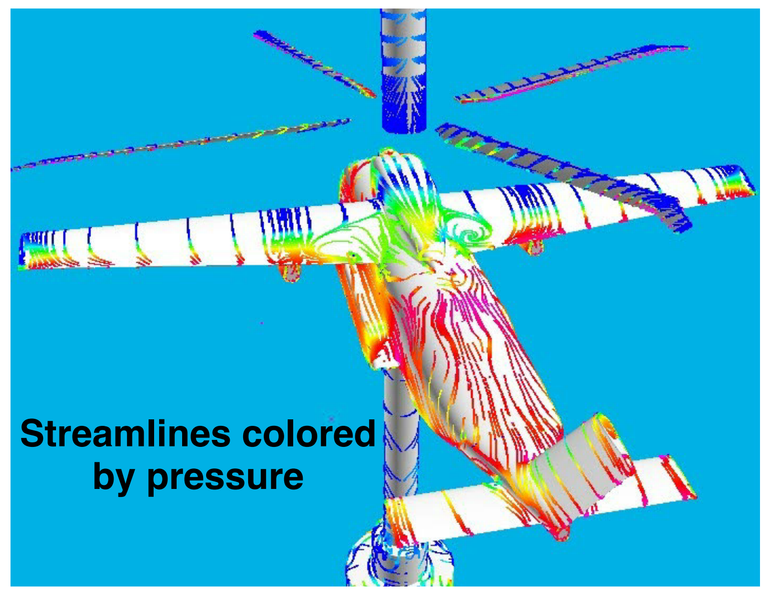
- 5^{th} O convection terms in OB, 2^{nd} O time
- SST turbulence model
- Structured grid (113×10^6 points)
- Test performed in LaRC 14x22-ft subsonic tunnel
- Tunnel ceilings, support structure modeled
- Rotor radius = 0.8966m with non-uniform twist and tapered planform
- $\mu=0.54$, $M_\infty=0.21$



Vorticity contours superimposed on PIV plane with texture mapping



Surface flow



POCs: Jasim Ahmad, David Kao, NASA ARC; Brian Allan, NASA LaRC

Isolated Rotorblade Flutter Computations

Codes utilized
- **OVERFLOW2.2**
- **MODFLU (U-g method)**

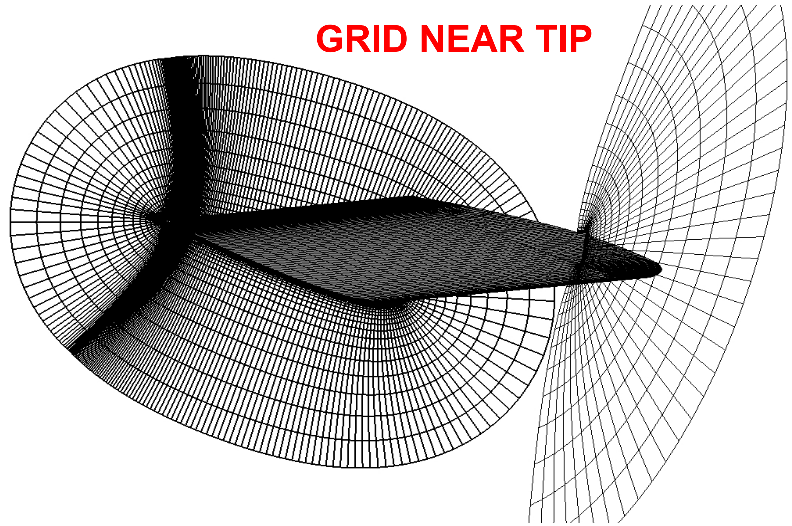
Coupling Approach
- **Lagrange equations**
- **Frequency domain**
- **UNIX script**
- **RUNMOD using MPIEXEC**

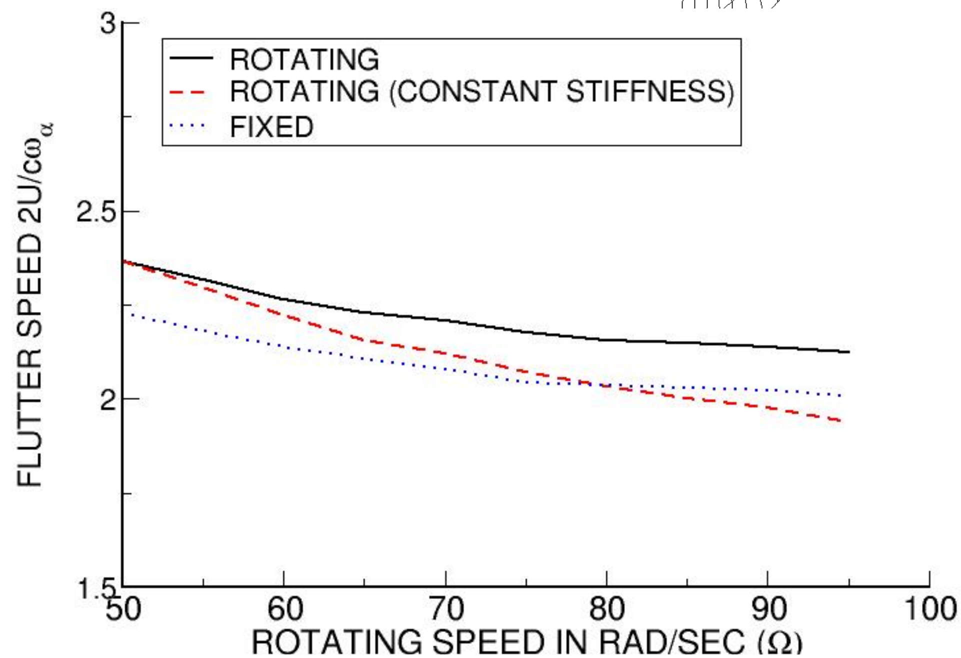
Geometry
- **NACA0012 isolated blade**

Grid
- **1.8x10^6 points**

Modes
- **Bending**
- **Torsion**

Computational cost
- **Flutter Boundary in 24 hrs using 1000 cores**





POC: G. Guruswamy, NASA Ames

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