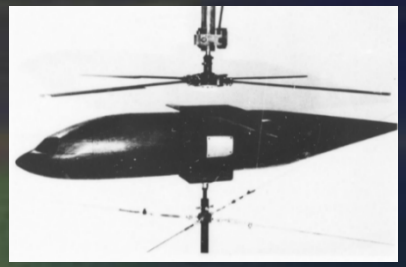
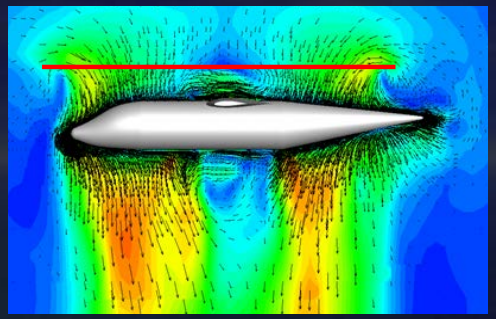
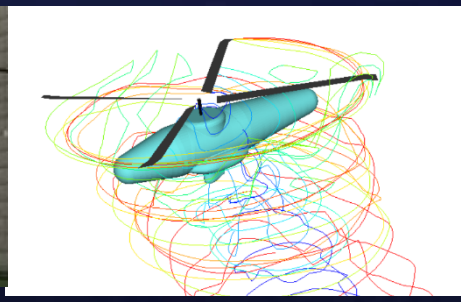
Continuum Dynamics, Inc.



Recent Work on Download and Installed Rotor Performance in Near-Hover Conditions

T.R. Quackenbush, G.R. Whitehouse, and P.V. Danilov

Continuum Dynamics, Inc.

VFS Forum 76

October 7, 2020

Background and Motivation

- Installed performance of rotors in hover and near-hover flight depends critically on airframe/rotor interaction.
  - hover download
  - thrust recovery ('partial ground effect')
- A significant factor for single rotor helos, especially with stores
- Winged compound and tiltrotor designs typically strongly affected
  - potentially complex behaviors for aircraft in near hover conditions
- Experimental data is limited and it is a challenge to find suitable methods to support design and performance studies of these configurations

Past And Current Compound Rotorcraft and Tiltrotors

Resources from past efforts…..

McDonnell XV-1

Lockheed AH-56

Boeing Model 347

Piasecki X-49

…and current design concepts…..

Bell and Sikorsky FARA, FLRAA Candidates

Advanced AH-64

Ongoing Method Development

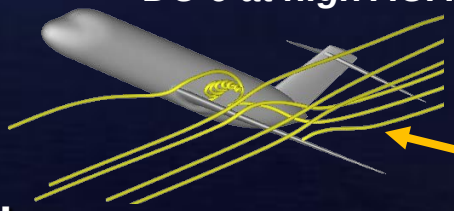
- High-end CFD models are challenging to apply in conceptual and preliminary design.
- Goal: identify and validate physics-based - but "low- to mid-fidelity" - tools for fast-turnaround analysis in early stage design efforts.
- Desired attributes:
  - not tied to empirical data bases or over-simplified models
  - capture airframe download and 'thrust recovery' ('partial ground effect')
  - applicable to multiple rotor configurations, IGE operation, and operation near hover (low advance ratio) cases with full airframe interaction
  - applicable to both high and low blockage configurations
- Foundations of the work summarized in papers from AHS Forum 73 and 74, as well as AIAA SciTech 2018 and 2020.

CGE: General Cartesian Grid Flow Solver

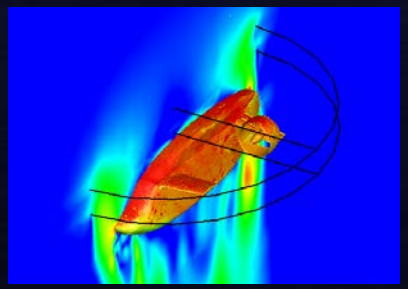
- Octree cut-cell Cartesian grid
- Automatic grid generation
  - Supports imperfect (non-water-tight/non-singular) geometries
  - "Push button" mesh generation
  - Faster setup vs. body-conforming grids
- Steady/unsteady flow model:
  - Multi-grid acceleration
  - Solution-based grid adaptation
  - Rotor and propulsion models (actuator disk momentum source)
  - Unsteady motions (perturbation/ transpiration formulation)
- New: viscous boundary layer modeling and rotating blades

Prior Applications

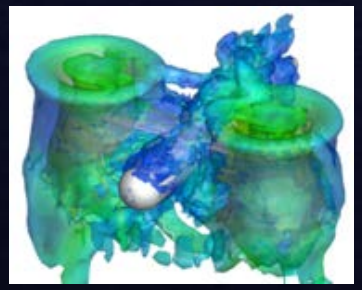
DC-9 at high AOA



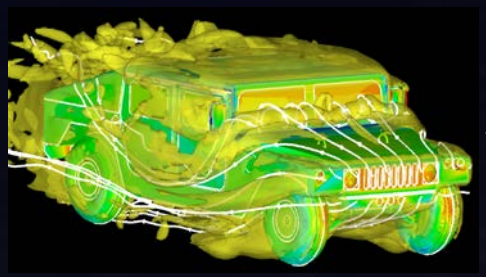
Cartesian grid



Co-ax Helo



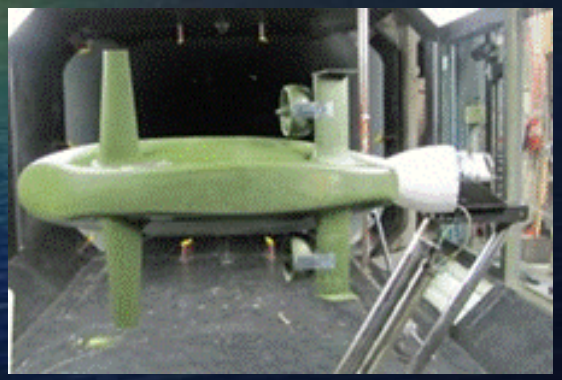
Generic tiltrotor



Flow over a HMMWV slung-load for helo transport

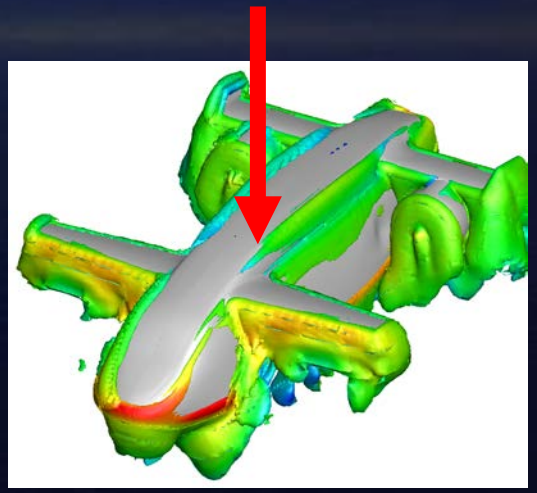
Vertical Drag in Uniform Flow: AVX CCH Airframe

Coaxial Compound Helicopter

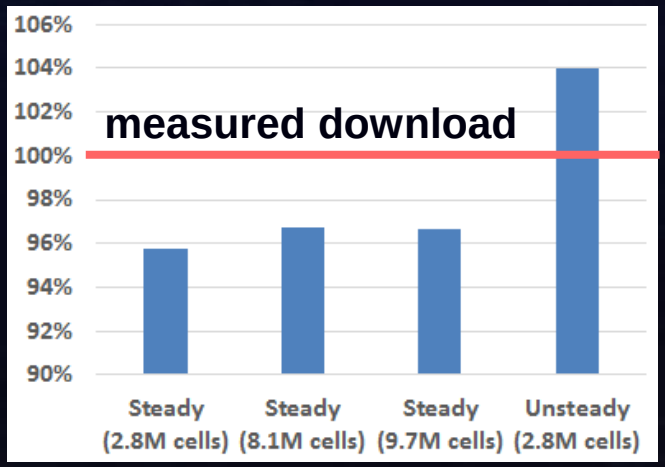


Subscale wind tunnel model of an early variant of the CCH airframe at -90^{o} angle of attack

free stream flow



CGE computation: full body vorticity field, showing separation from canard, stabilizer, and ducts

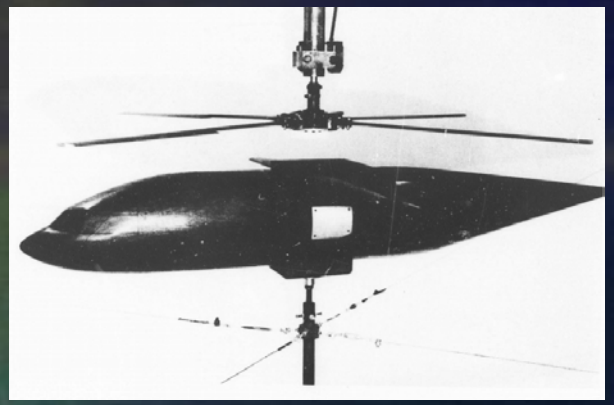


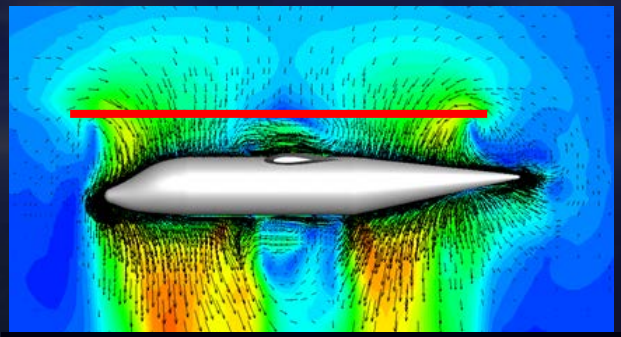
Both steady and averaged unsteady cases

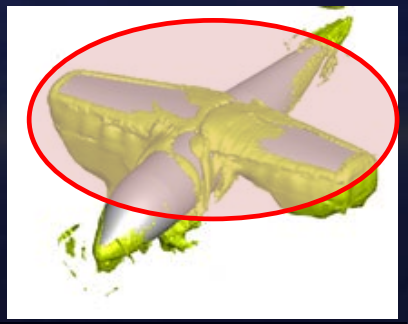
Vertical drag measured to within +/- 4% accuracy

Agreement W911W6-13-2-0004 with the U.S. Army. DISTRIBUTION STATEMENT A. Approved for public release. Distribution is unlimited.

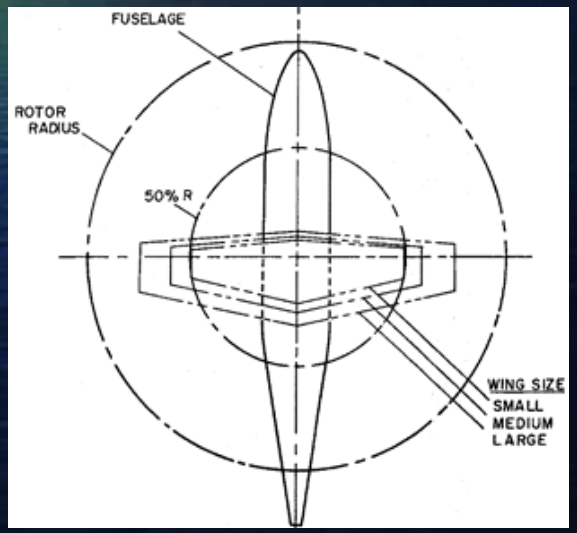
Download in Hover with CGE



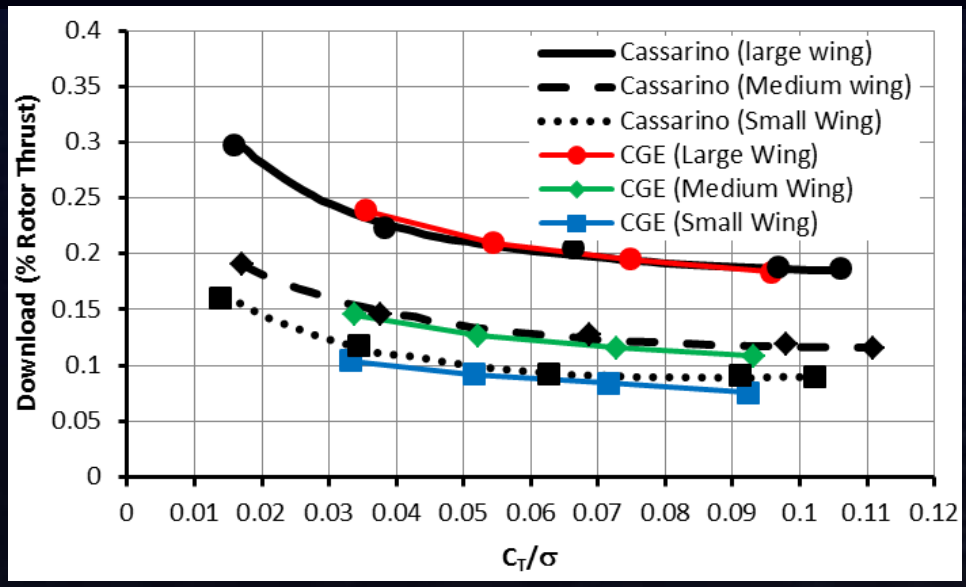




Prediction of velocity contours (left) and vorticity (right) for the Large Wing case; location of the actuator disk rotor model shown in red.

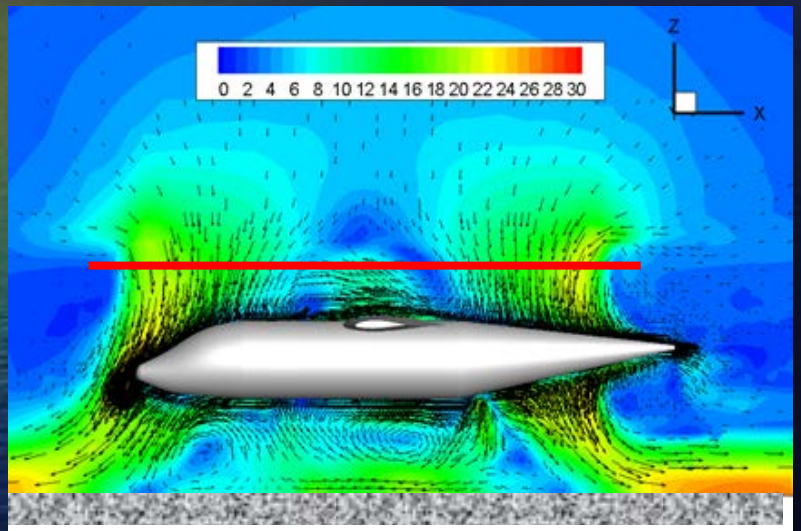


Cassarino (1970) compound helicopter download data: three different wing sizes, 15% to 27% disk area blockage

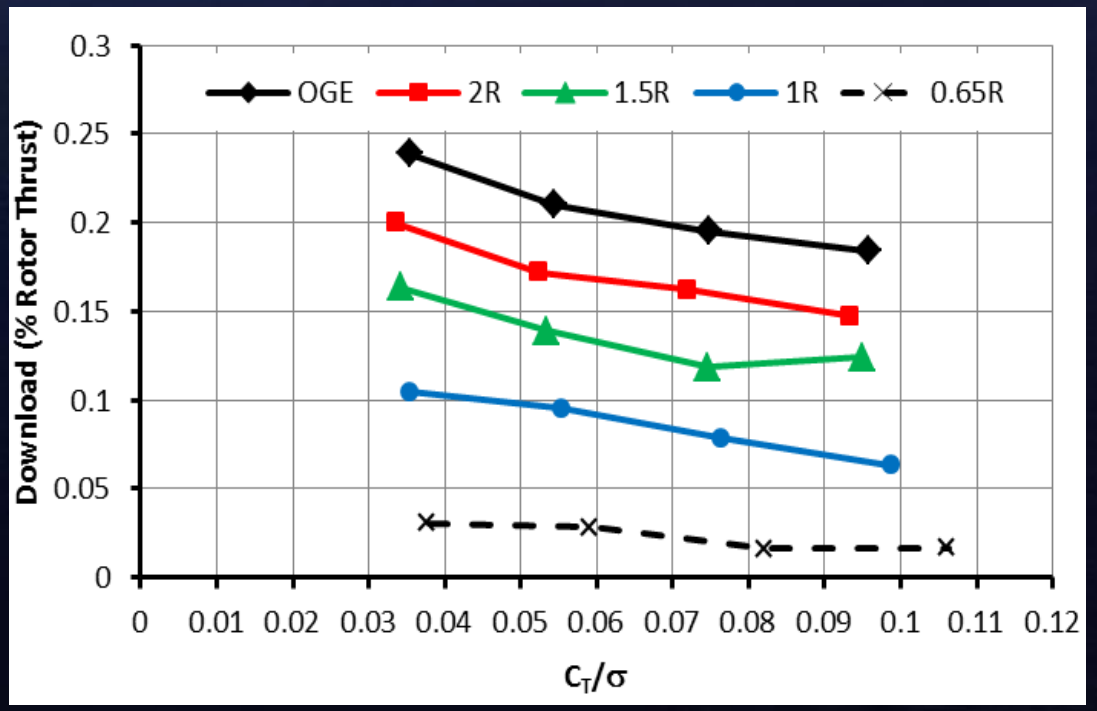


Good accuracy in predicted download for the all three blockage levels.

Computed Flow Fields and Download: Large Wing Case In Ground Effect (IGE)

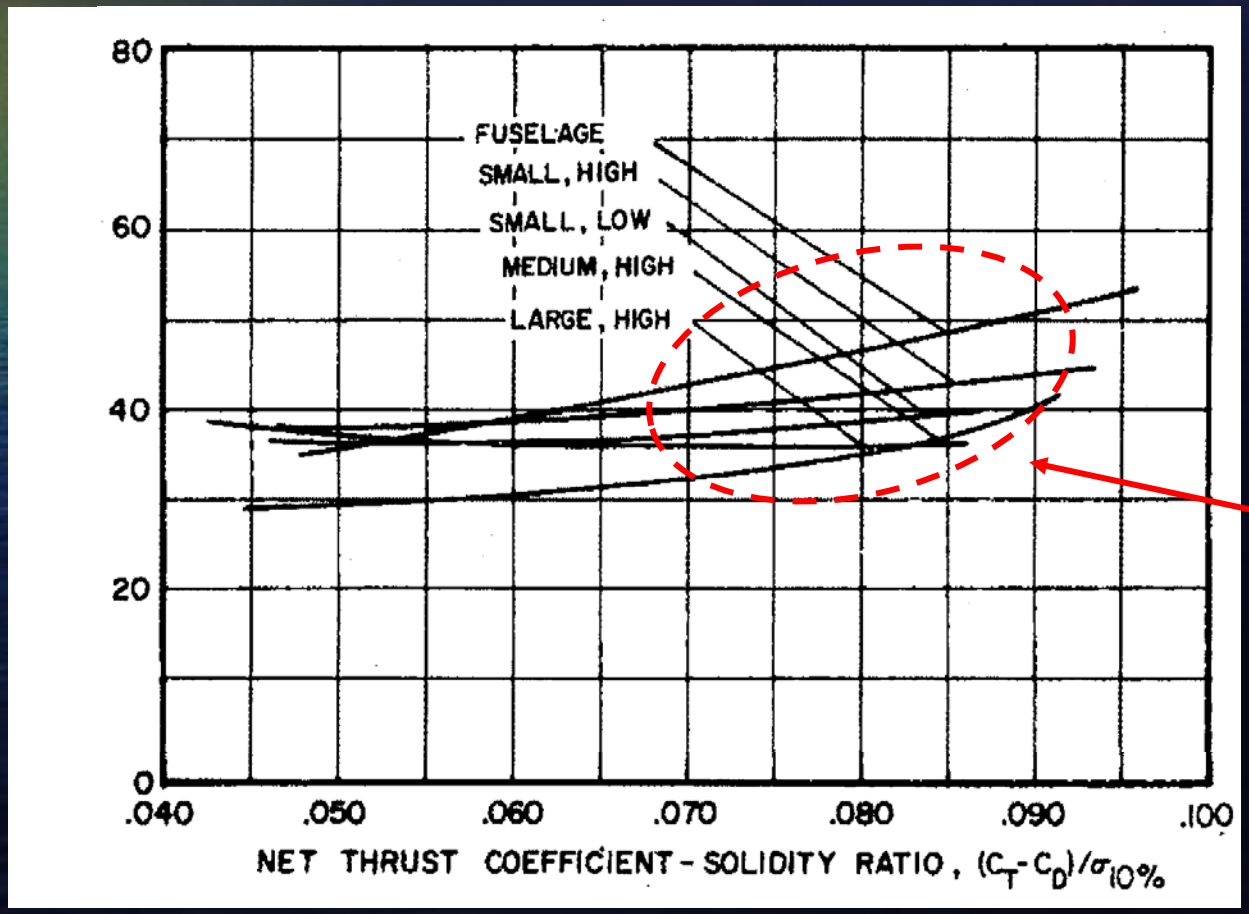


ground plane



Prediction of velocity contours (m/sec) for the Cassarino Large Wing case IGE at z/R=1.0 (left) - location of the actuator disk rotor shown in red; IGE download (% of rotor thrust) for multiple rotor heights (right)

Cassarino Thrust Recovery Data



Strong airframe interaction leads to ~ 30 to 50% mitigation of effective download

Typical rotor operating conditions

Installed Performance - Large Wing Case

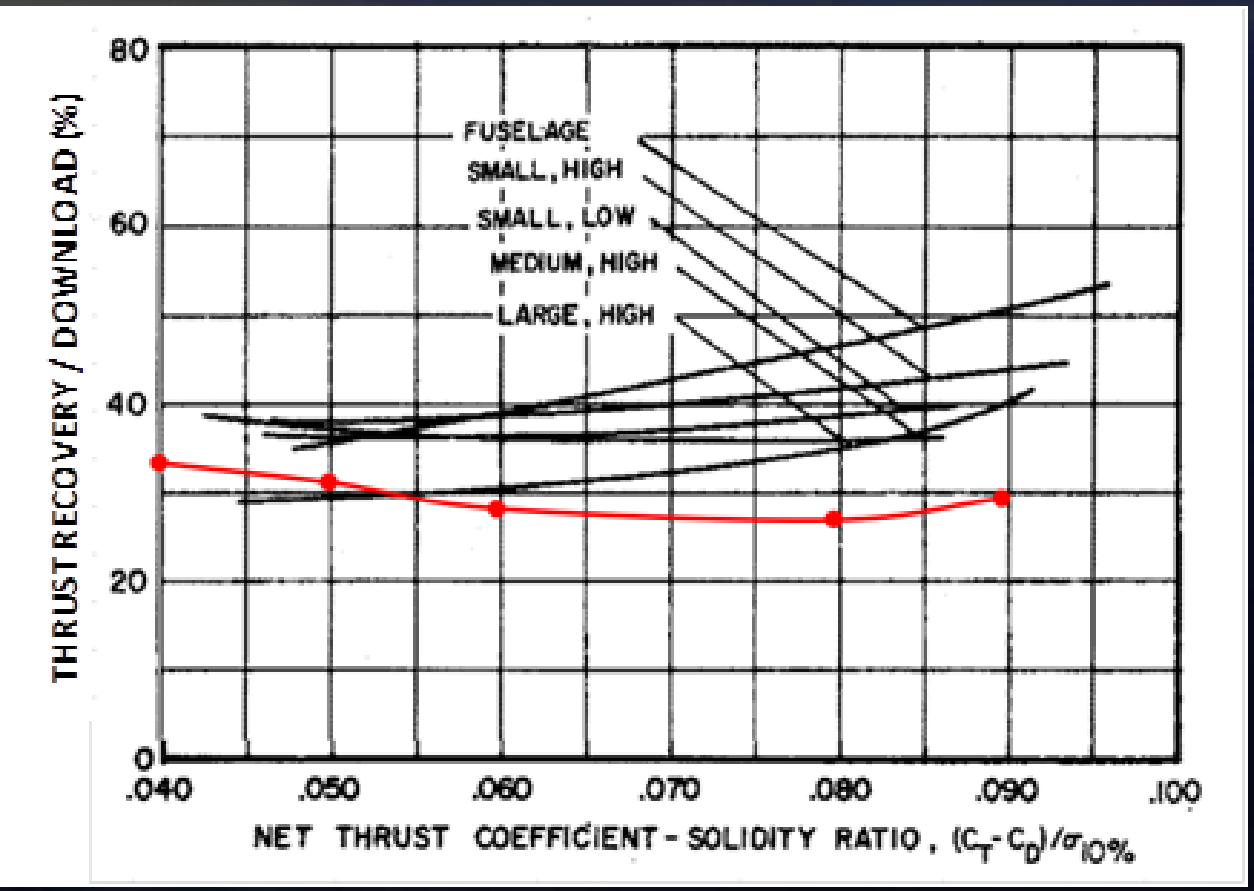
Predictions of thrust and download versus power for the isolated and installed Large Wing cases

Simplified blade element model:

$C_{L\alpha}$ = 6.04 / rad

C_{D0} = 0.008

Comparison to Measured Thrust Recovery

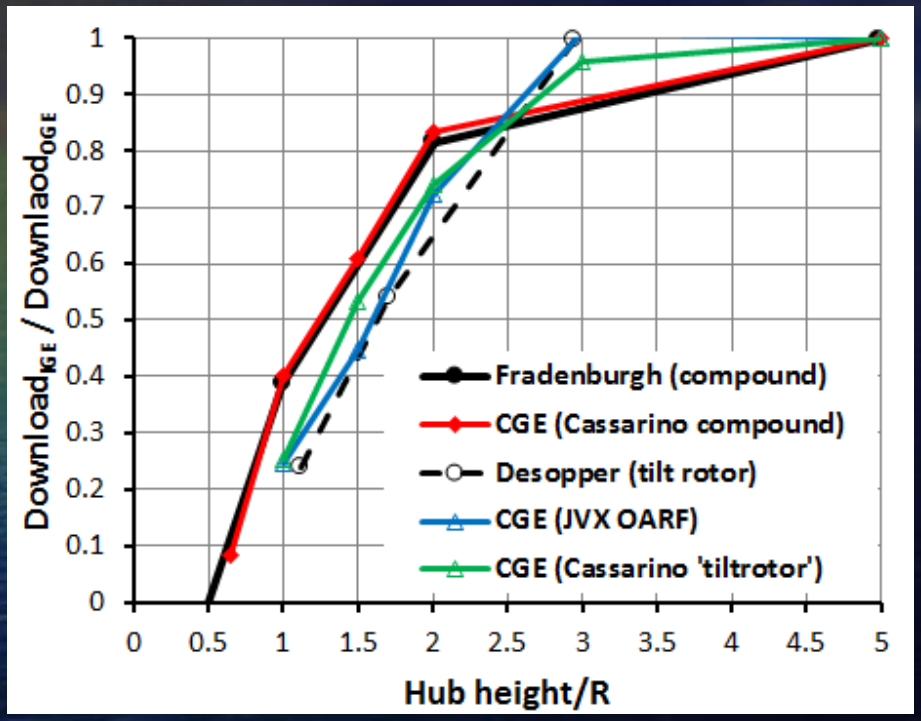


Comparison of predicted (red) CGE results for thrust recovery for the Large Wing case to superimposed on measured results

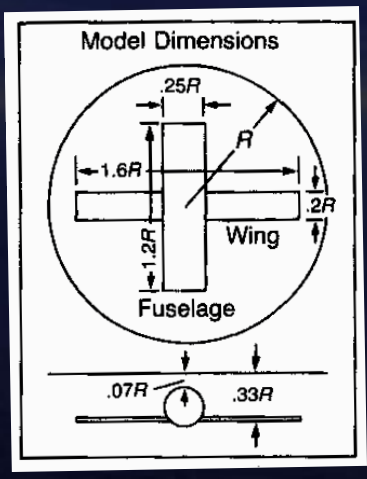
Additional refinement of the actuator disk model (additional elements spanwise) and full C81 tables for drag should improve high thrust results

Parallel studies with CHARM indicate including high resolution drag model can add .05 to .07 in thrust recovery

Overall Trends in Download IGE for Compound and Tiltrotor Configurations



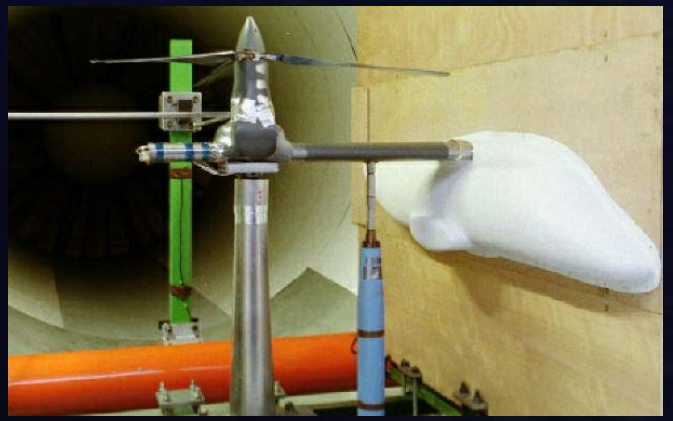
Schematic of Fradenburgh (1972) model; also see Putman (1971) tests.



IGE download as a function of rotor height / radius from 1970s era compound rotorcraft tests (Fradenburgh 1972).

ONERA wind tunnel data (Desopper 2002) trends similarly but with a steeper gradient.

CGE predictions of these cases (plus the JVX NASA/Ames OARF test with a ground plane added) follow a similar trend



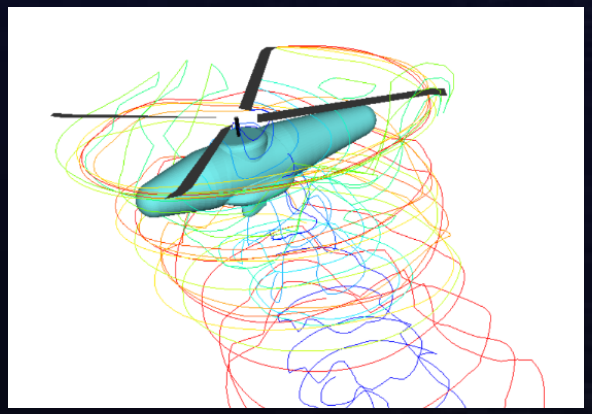
ONERA wind tunnel model (Desopper 2002)

Low Blockage Case for Download: UH60 Wind Tunnel Test

- Full scale UH-60 wind tunnel test (Shinoda, et al. 2002, 2004) in the NASA/Ames 80 x 120 ft wind tunnel.
  - Hover and near-hover operation (in an enclosure)
  - 'Fuselage' interaction with Large Rotor Test Apparatus (LTRA)
  - A resource both for full scale rotor performance and download
  - Approximately 9-10% fuselage area blockage

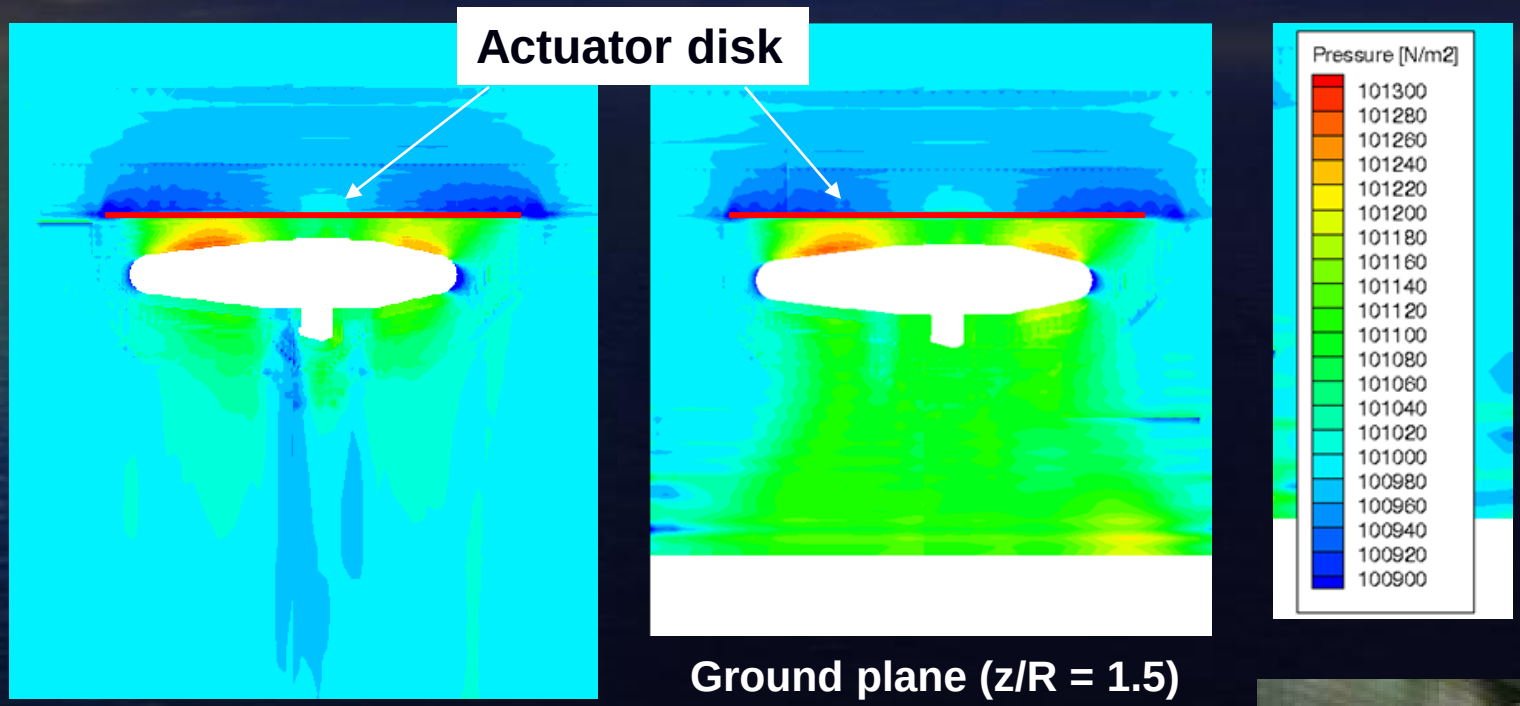
Shinoda, P.M., Yeo, H., and Norman, T., "Rotor Performance of a UH-60 Rotor System in the NASA Ames 80- by 120-Foot Wind Tunnel," AHS Forum 2002, JAHS 2004.

UH-60 rotor on the LTA in the NASA/Ames 80x120 wind tunnel



CHARM model of the UH-60/LRTA system in low speed forward flight.

Predicted Pressure Fields Around LRTA

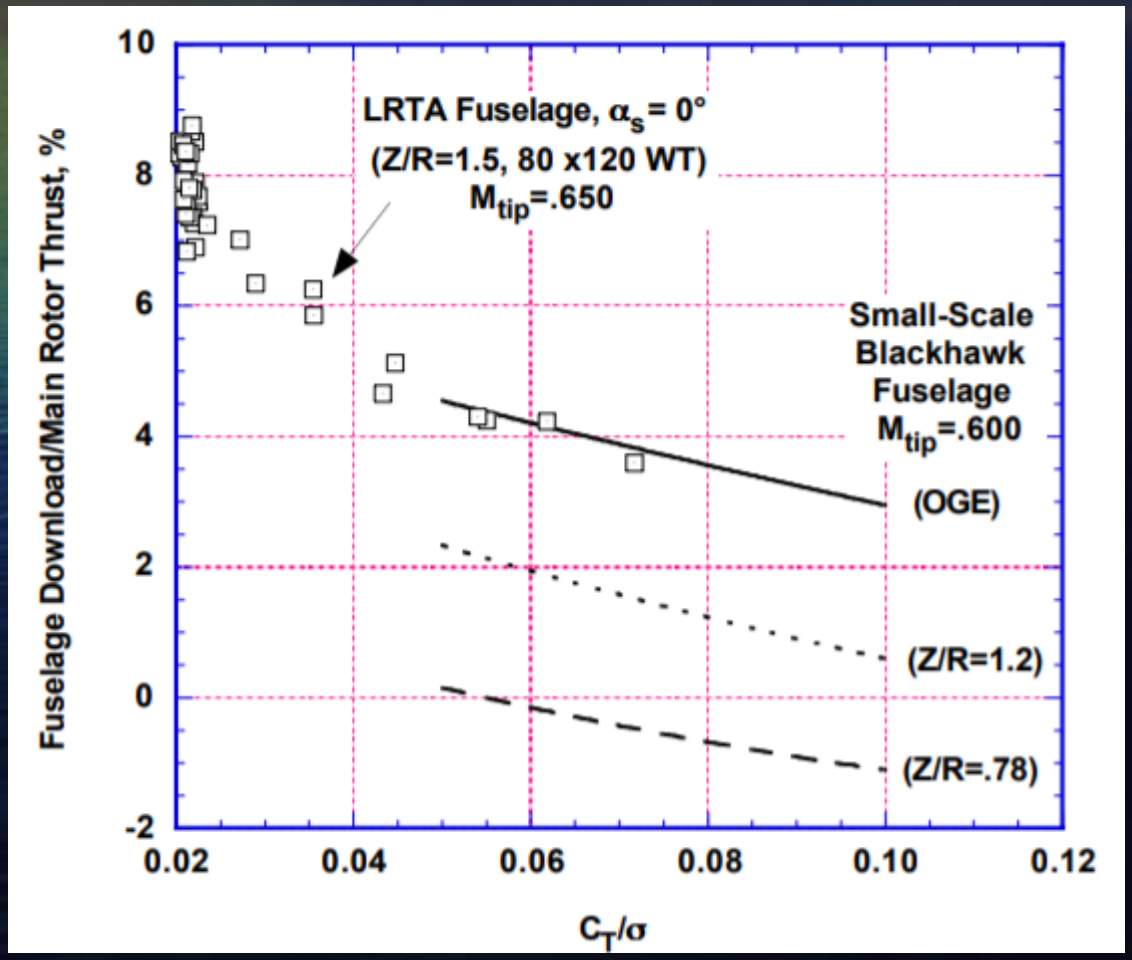


OGE operation

Ground plane (z/R = 1.5)
infinite, no enclosure

Prediction of the pressure field around the UH-60 rotor/LRTA combination in hover - OGE and with infinite ground plane.

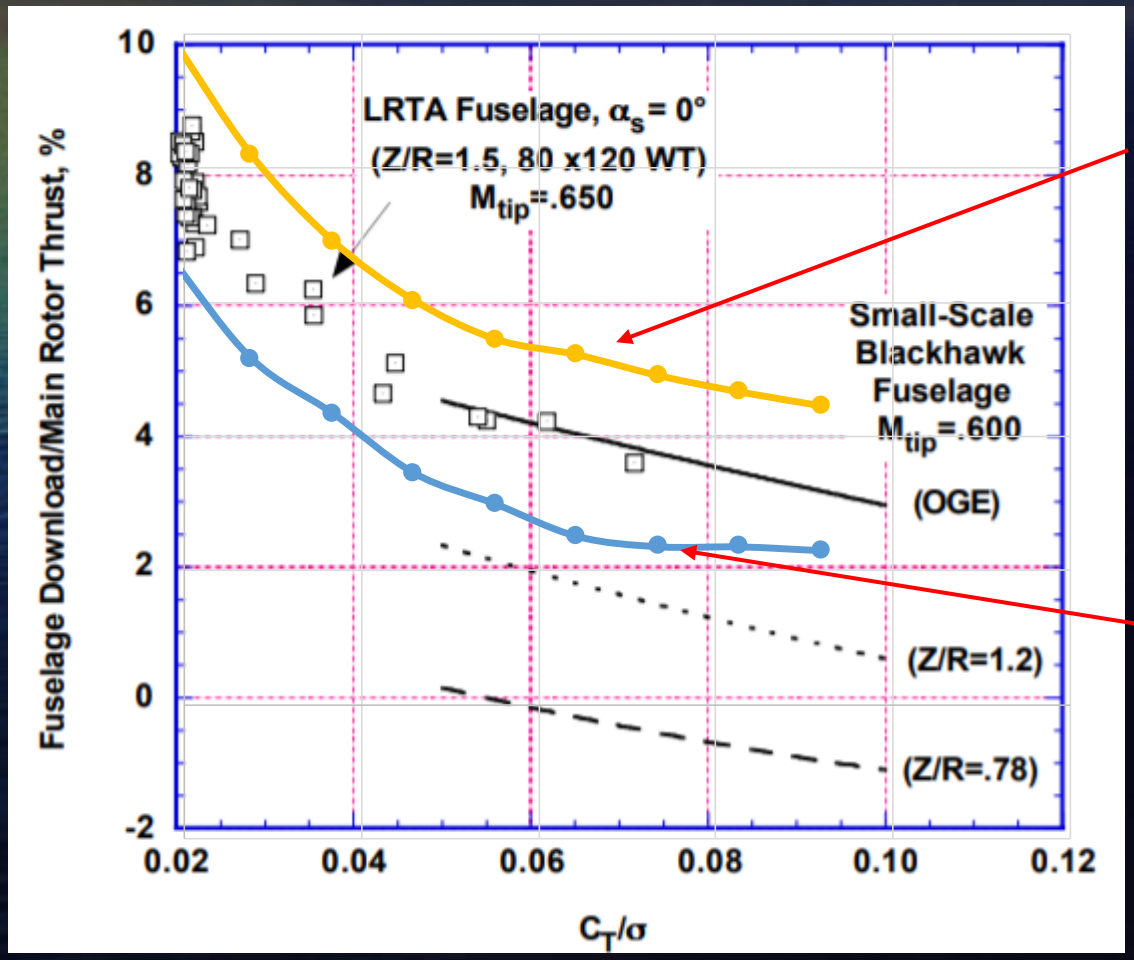
Analysis of Download on LRTA



- Download in hover with zero shaft angle of attack measured as a function of rotor thrust
- Prior data (Balch 1985) shown for reference and to support assessment of possible ground plane effects

Figure with measurements from Shinoda, et al. JAHS 2004

Analysis of Download on LTRA (cont'd)

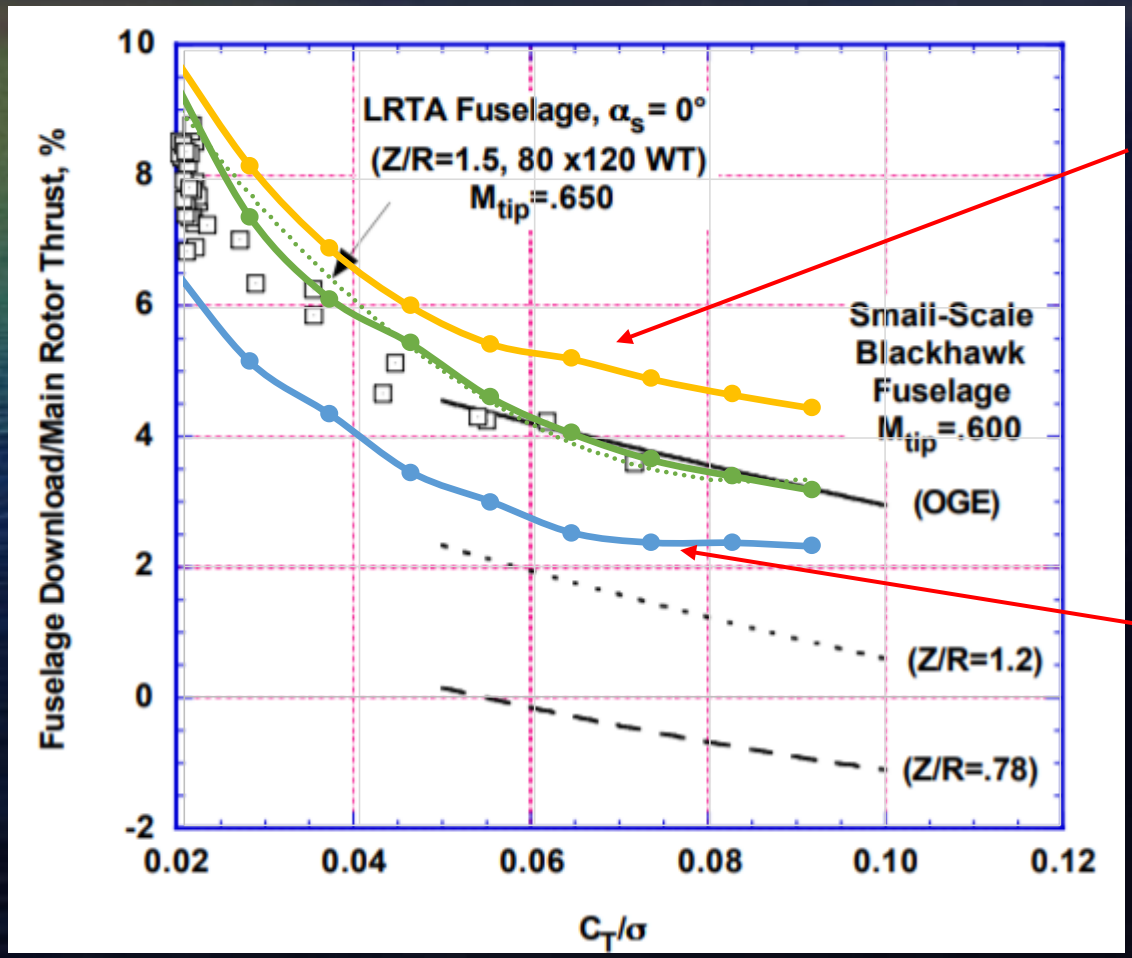


OGE computation (yellow) over-predicts download

IGE computation (infinite ground plane) (blue) under-predicts download

Figure with measurements from Shinoda, et al. JAHS 2004

Analysis of Download on LRTA (cont'd)



OGE computation (yellow) over-predicts download

Including enclosure model (green) moves calculation toward the measured data

IGE computation (infinite ground plane) (blue) under-predicts download

Figure with measurements from Shinoda, et al. JAHS 2004

Summary

- Ongoing development and test of physics-based download models for support of early stage design and analysis, based on the CGE analysis.
- Initial application to single main rotor/low blockage cases
  - Download on rotor airframe
  - Promising initial results on enclosure modeling
- Additional application to compound configuration results
  - Underpredicts thrust recovery at high rotor thrust levels
  - Parallel work indicates a more general blade element model necessary
- Priorities identified for follow-on work
  - Continue studies of enclosure effects
  - Extend CGE blade element model
  - Assess actuator line blade analysis and unsteady modeling
  - Examine other data correlation targets (e.g., RSRA, model scale UH60, and alternate compound/single rotor configurations)