Fundamental Aeronautics Program

Subsonic Rotary Wing Project

Progress in Conceptual Design and Analysis of Advanced Rotorcraft

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2012 Technical Conference
March 13-15, 2012

Multi-Disciplinary Analysis and Technology Development

What are the objectives of MDATD in the Subsonic Rotary Wing project?

- Provide focal point for integrating discipline technologies and tools for system analysis
- Perform analysis and conceptual design of advanced rotorcraft systems and operations

How will the MDATD objectives be met?

- Develop, enhance, and integrate efficient design tools
- Conduct assessments of advanced technology for rotorcraft systems
- Study operations of advanced rotary wing configurations in NextGen

MDATD Team

Ames Research Center

Wally Acree

Wayne Johnson

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Larry Young

Glenn Research Center

Christopher Snyder

Recent MDATD Highlights

- Completed 3-year study "Modeling High-Speed Civil Tiltrotor Transports in the Next Generation Airspace" via a GSA contract. Contractor Team: SAIC (prime), Bell Helicopter, Sensis, Optimal Synthesis. Year 3 focused on disaster relief.
- Conducted 3 separate investigations of advanced civil configurations (lift-offset rotor, compound helicopter, and large tiltrotor) and presented results at the AHS Future Vertical Lift Aircraft Design Conference, January 2012.
- Validated RotCFD, an Integrated Design Environment tool developed specifically for rotorcraft (Sukra Helitek, Inc.), against established data sets and presented results at the AHS Future Vertical Lift Aircraft Design Conference, January 2012.
- Sukra Helitek, Inc. awarded SBIR Phase 2 entitled "RotCFD: A Viscous Design Tool for Advanced Configurations."
- Performed first cut at aerodynamic optimization of airfoils for large civil tiltrotor

Highlight: Civil Tiltrotor Fleet Effectiveness in Disaster Response

- Evaluated effectiveness of CTR executing hurricane post-disaster relief operations
- Evaluated rotorcraft fleet mixes:
  - CTR-10, -30, -120 passengers
  - Light, Medium and Heavy conventional rotorcraft
- Evaluated missions
  - Evacuation (ambulatory & non-ambulatory)
  - SAR
  - Cargo transport
- Modeled rotorcraft missions using discrete event simulation

Conclusions

- Higher speed and range of tiltrotors, compared to conventional rotorcraft, can improve the overall effectiveness of hurricane post-disaster operations
- Augmenting a fleet of CRC by 10% with tiltrotors can reduce overall mission response time significantly

Ref: Gibson, T. L., Jagielski, M. J., and Barber, J. R., "Disaster Response Effectiveness of a Fleet of Civil Tiltrotor Aircraft Operating in the Next Generation Air Transportation System (NextGen)," NASA/CR-2012-216000, January 2012.

Highlight: Advanced Configurations - Lift-Offset Rotorcraft for Short-Haul Missions

Objectives

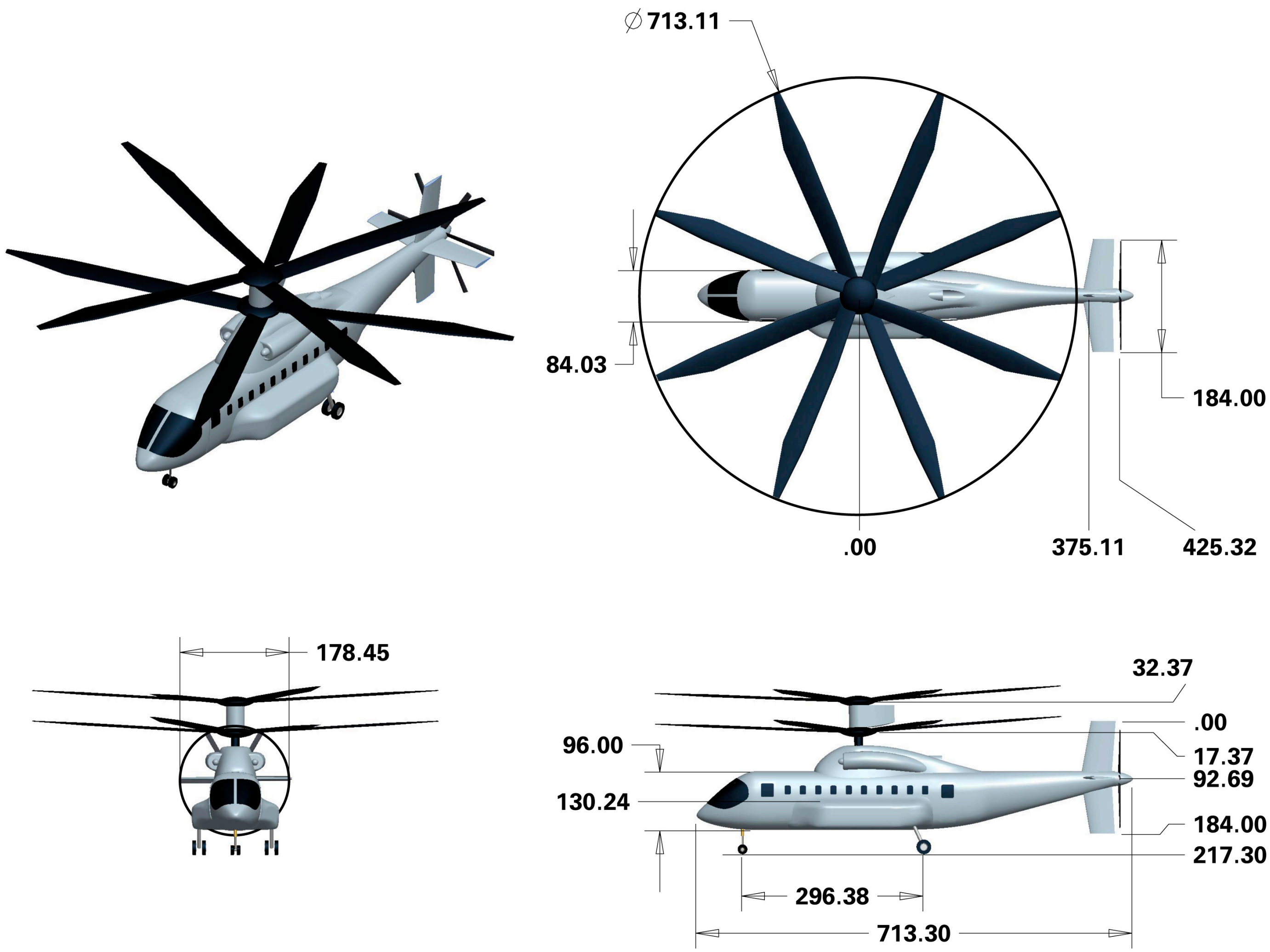
- Examined design and performance of compound helicopters utilizing lift-offset rotors
  - Short-haul, medium-size missions
    - Civil and military
  - 30 passengers or 6600 lb payload
  - Range = 300 nm

- Investigated impact of key technologies on design of rotorcraft with lift-offset rotors
  - Rotor performance
  - Rotor weight
  - Aircraft aerodynamics

Analysis tools

- CAMRAD II
- NDARC

Lift-Offset Civil Design Using Scaled Rotor Weight Model



Lift-Offset Rotorcraft Study Conclusions

- Analysis shows lift-offset rotor can achieve good performance at speeds of 200–250 knots
  - Confidence in calculated performance based on correlation with helicopter test data
  - Need wind tunnel tests of advanced lift-offset rotors to confirm calculated performance and continue development of analytical models

- For short-haul, medium-size aircraft with lift-offset rotors
  - Low weight of rotor system is key requirement for effective and competitive designs
  - Two rotor weight models used here: scaled and regression
    - Produced different results, different optimum designs
    - Need blade and hub designs for range of aircraft size, to support choice of model and development of better weight estimation methods
  - Need additional work on impact of advanced materials, innovative design approaches, load and deflection requirements, and load control

Ref.: Johnson, W., Moodie, A. M., and Yeo., H., "Design and Performance of Lift-Offset Rotorcraft for Short-Haul Missions," AHS Future Vertical Lift Aircraft Design Conference, San Francisco, CA, January 2012.

Highlight: Advanced Configurations – Compound Helicopter

Objective

• Determined how competitive a slowed-rotor compound helicopter is for a civil transport mission

- 90 passengers, 500 nm range
- Compare against tiltrotor and conventional helicopter
  - tiltrotor: LCTR2 layout resized for 500 nm range
  - helicopter: conventional layout, size between CH-53E and Mi-26
- Evaluate in terms of both airframe and operating costs

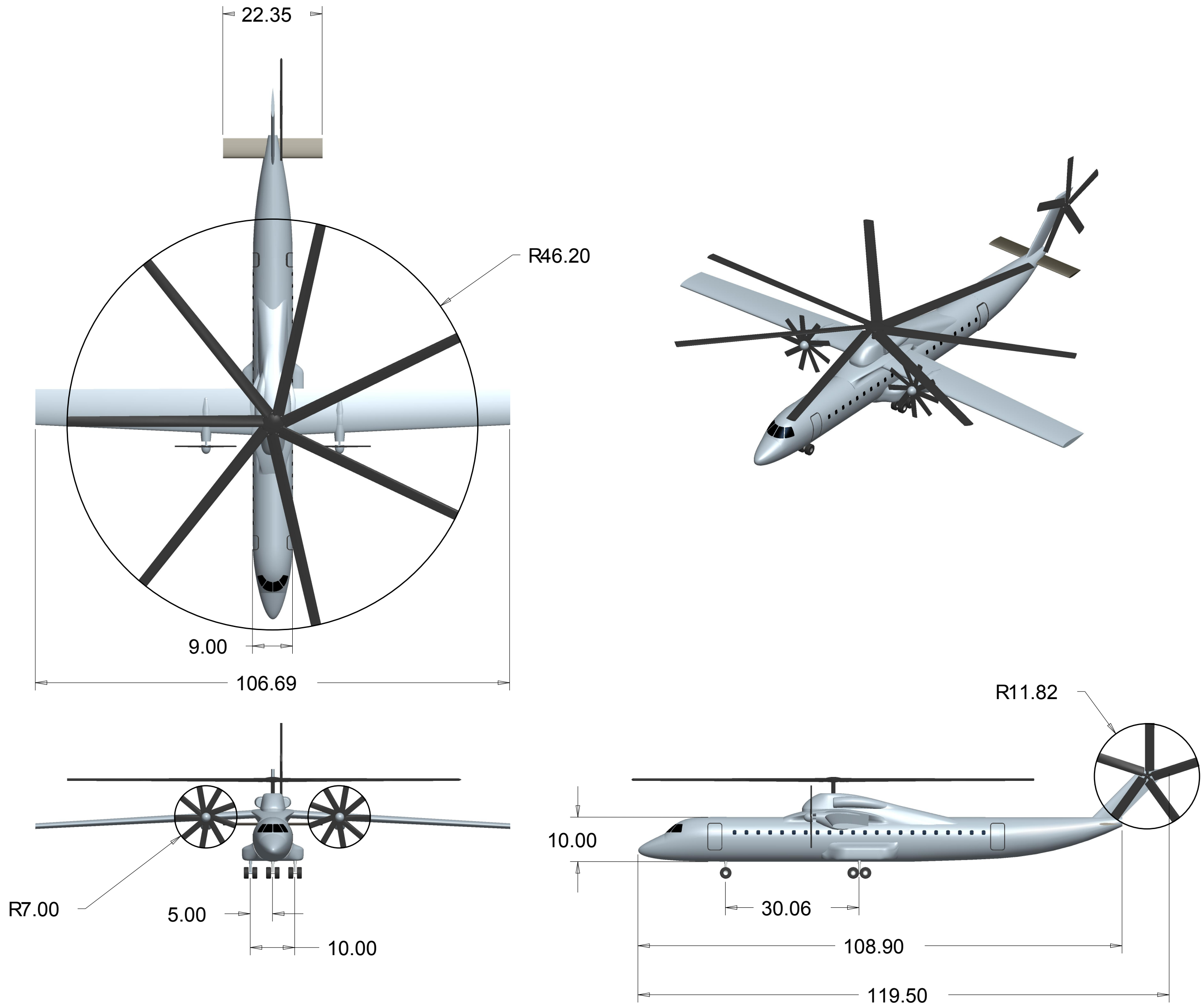
Design Requirements

- Payload 90 passengers (19,800 lb)
- 500 nm range
- One engine inoperative hover at design gross weight and 5,000 ft ISA +20°C
- Minimum speed at cruise altitude and MCP
  - Compound: 220 kt
  - Tiltrotor: 300 kt
  - Helicopter: 150 kt

Analysis Tools

- CAMRAD II
- NDARC

Compound Helicopter Design



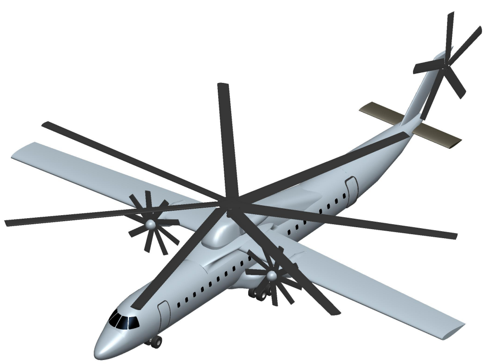
Civil Compound Helicopter Study Outcomes

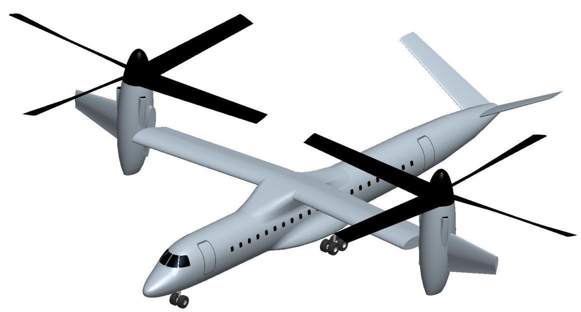
Conclusions

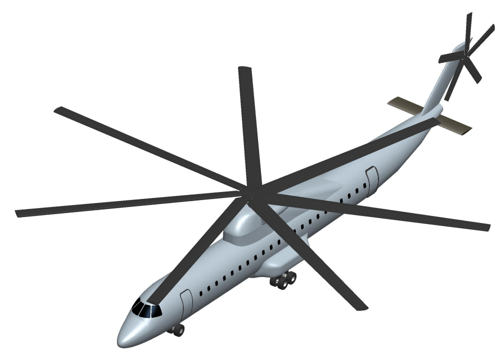
- Compound design was not competitive with either the tiltrotor or the conventional helicopter

Future research topics

- Evaluate sensitivity to hub drag
- Design to different mission specifications
- Assess environmental performance
- Study other compound configurations







Ref.: Russell, C. R. and Johnson, W., "Conceptual Design and Mission Selection for a Large Civil Compound Helicopter ," AHS Future Vertical Lift Aircraft Design Conference, San Francisco, CA, January 2012.

Highlight: Advanced Configurations – Large Civil Tiltrotor (LCTR2) Propulsion Concepts

Objective

• Combined aeromechanics & turbomachinery analyses with vehicle sizing code to get coupled optimization.

Considered two propulsion concepts

- Advanced Conventional Engine (ACE+2SG):
  - optimized at single rpm, needs two-speed gearbox
  - shifting modules add ~10% to gearbox weight
- Fixed Geometry, Variable-Speed Power Turbine (FG-VSPT):
  - wide operating rpm range, needs four-stage turbine

Analysis tools

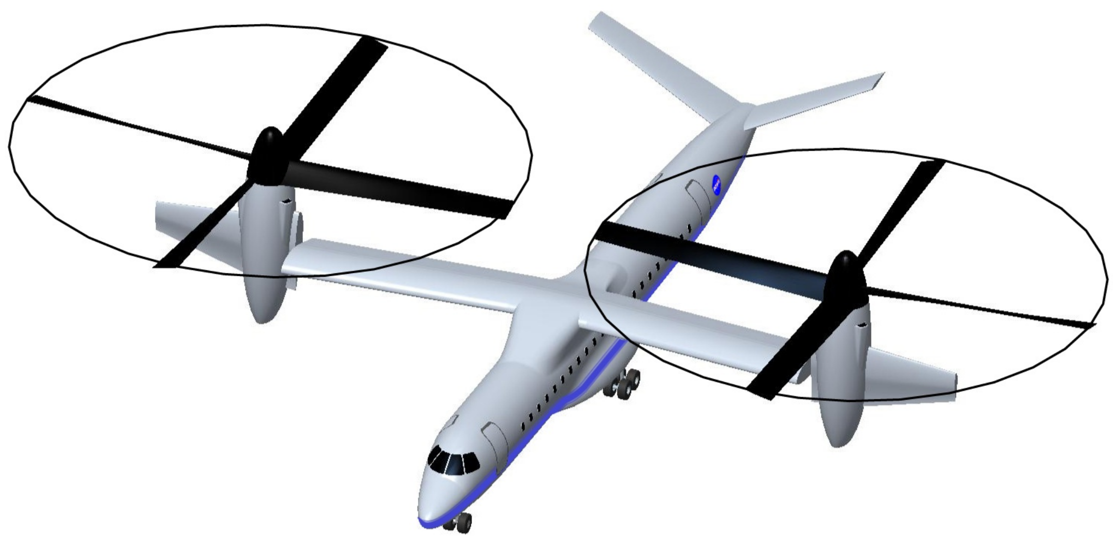
- CAMRAD II – rotor/wing performance
- NPSS and WATE – engine design
- NDARC - sizing

LCTR2 Propulsion Concepts Study Conclusions

- LCTR2 weight, power, fuel < 1% different ACE+2SG vs. FG-VSPT
  - Trends are nearly flat near optimum cruise V_{tip}
  - (Caveat: depends on technology assumptions)

- Little change in ACE+2SG vs. FG-VSPT with altitude or range
  - 30,000 ft cruise, V_{tip} = 300-350 ft/sec are optimal
  - (Higher altitudes & lower tip speeds being investigated)

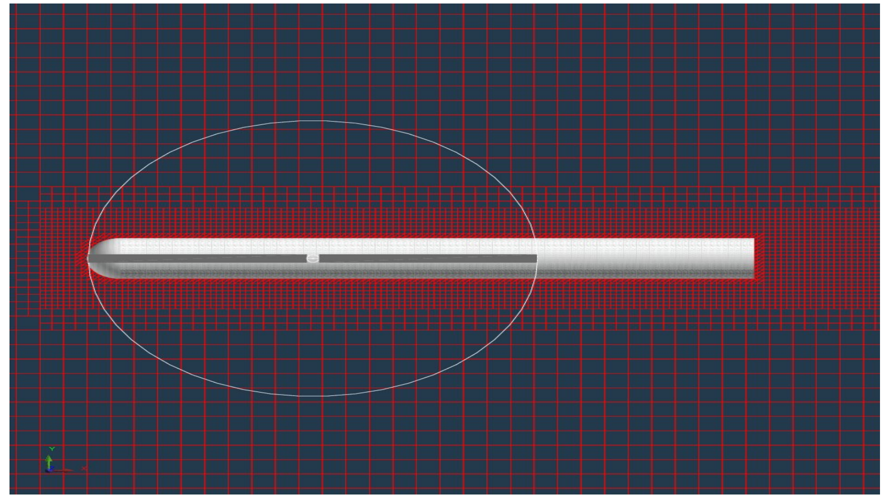
- OEI speed criterion has a large effect on design.

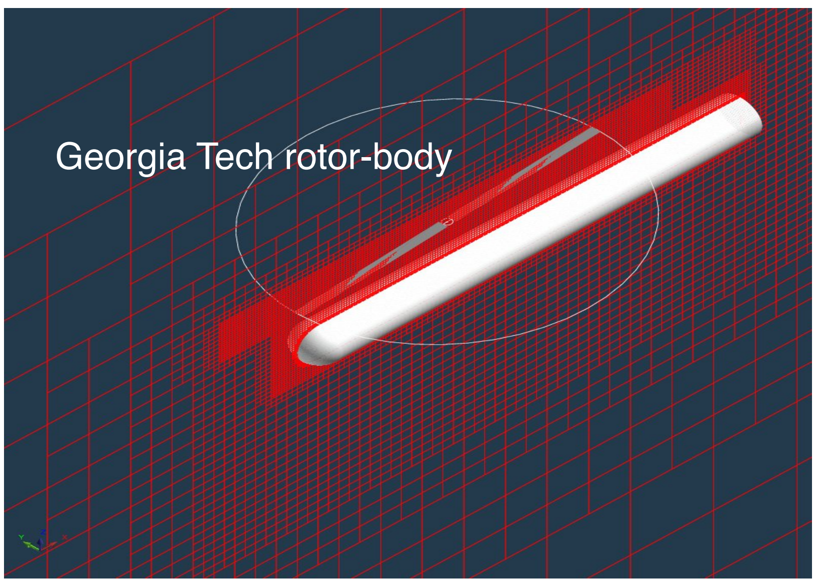


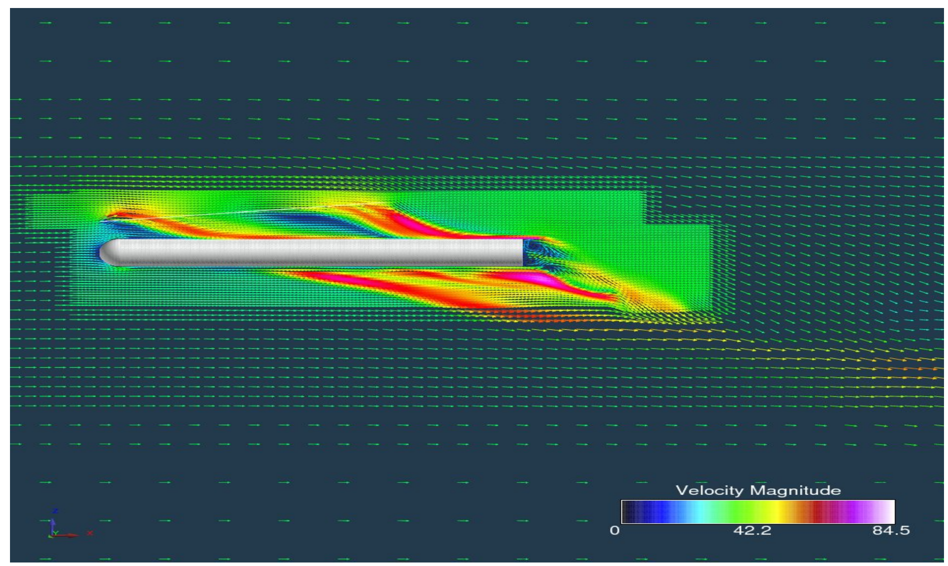
Ref.: Acree, C. W. and Snyder, C. A., "Influence of Alternative Engine Concepts on LCTR2 Sizing and Mission Profile," AHS Future Vertical Lift Aircraft Design Conference, San Francisco, CA, January 2012.

Highlight: RotCFD – Integrated Design Environment Tool

- RotCFD developed by Sukra Helitek through NASA SBIR funding
- Validated RotCFD calculations using data from two isolated rotor tests and two rotor-body tests
- New SBIR will incorporate a viscous near-body grid



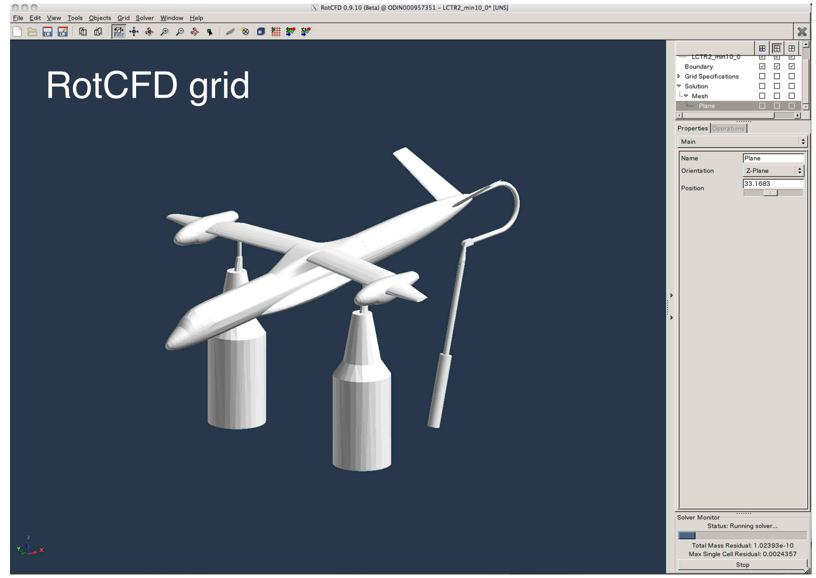


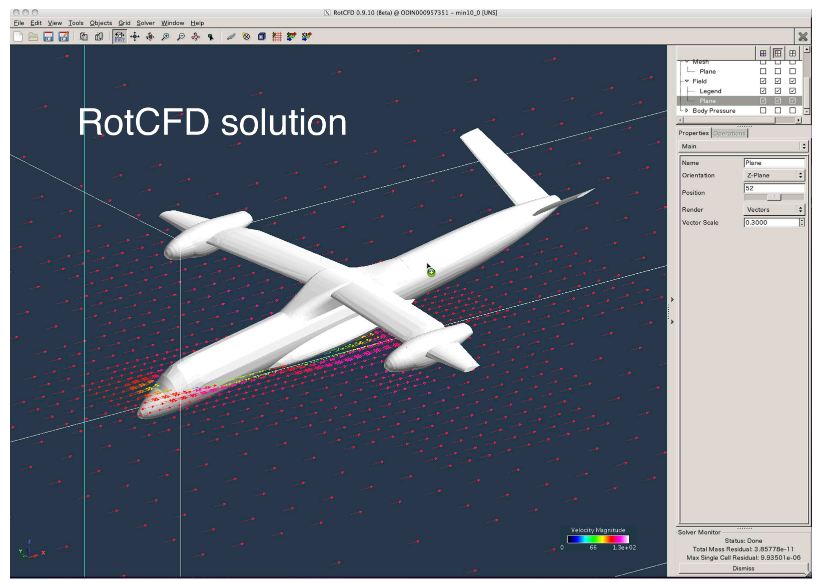


Ref.: Rajagopalan, R. G., Baskaran, V., Hollingsworth, A., Lestari, A., Garrick, D., Solis, E., and Hagerty, B., "RotCFD - A Tool for Aerodynamic Interference of Rotors: Validation and Capabilities," AHS Future Vertical Lift Aircraft Design Conference, San Francisco, CA, January 2012.

Efficient Transition from Conceptual Design to CFD Model Using RotCFD

Large Civil Tiltrotor (LCTR) model installed in the Army 7x10-Ft Wind Tunnel at NASA Ames Research Center



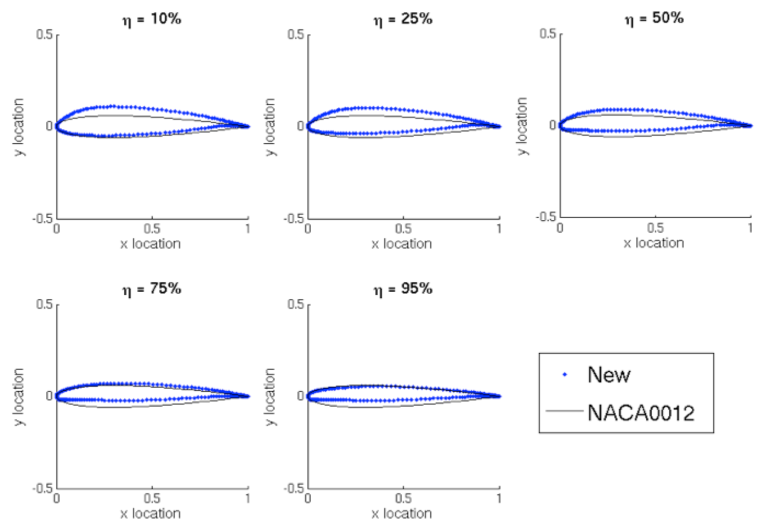


Highlight: LCTR2 Optimized 2D Airfoil Database

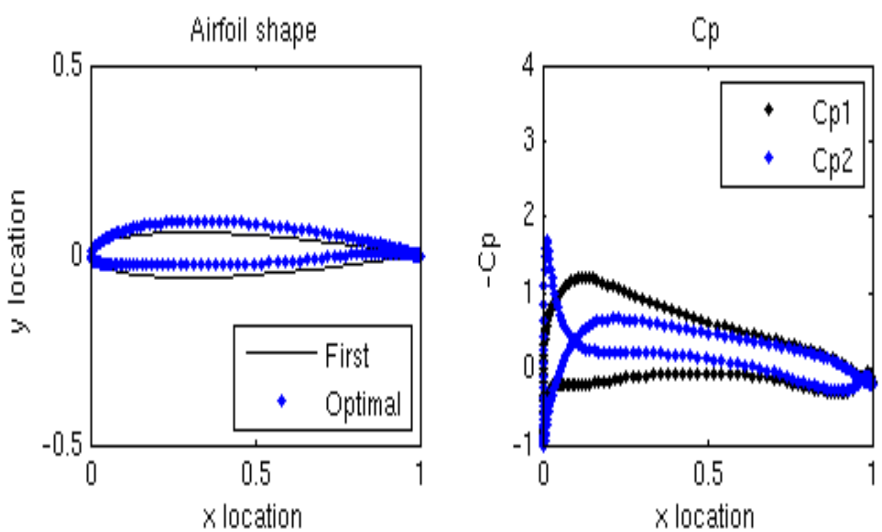
- Aerodynamic shape optimizer: OPTIMA2D
  - Navier Stokes Solver, ARC2D
  - Gradient is computed using a discrete adjoint
- Parameterization
  - B-spline knots define airfoil (15 total)
  - Knots can be selected as design variables
- Multi-point optimization is performed here:
  - Hover
  - Airplane Mode
  - Turn/Maneuver
- 1 design per span station (5 total)
- Objective Function
  - Weighted Combination of Multi-point Designs
  - Lift, Drag and Thickness Constraints
- Database:
  - 5,733 cases (M, alpha, RE) per airfoil span
  - 5 airfoil span sections
  - 28,665 cases total
  - Parallel Analysis Computations

Highlight: LCTR2 Optimized 2D Airfoil Database

Developing a process for creating a family of tiltrotor airfoils to be used by other analyses (CAMRAD II, RotCFD, etc.)



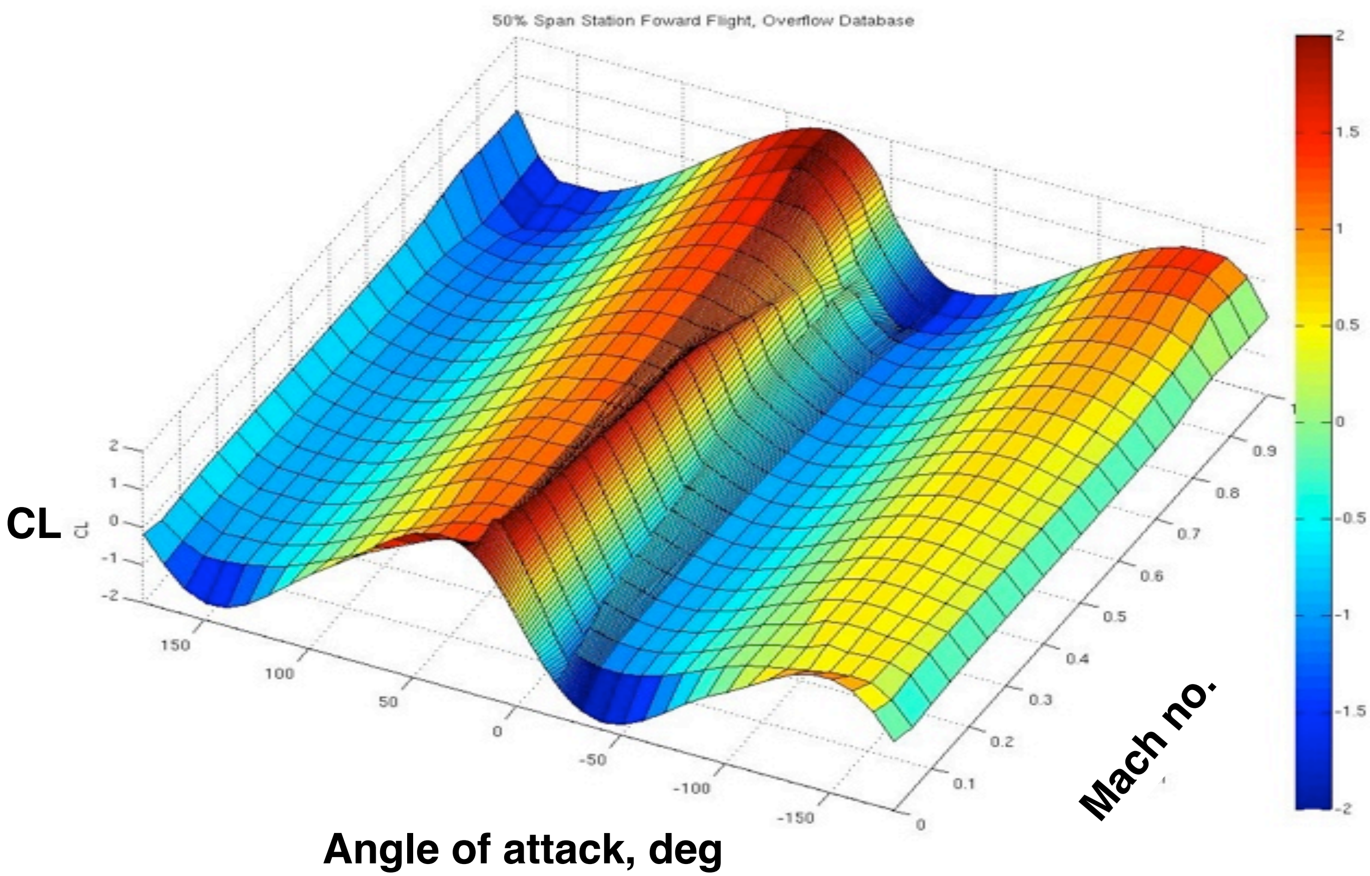
Designed airfoils at span stations



Sample analysis

POC: Tom Pulliam, NASA Ames

Database for airfoil at 50% span station



POC: Tom Pulliam, NASA Ames

Recent Publications

- Robuck, M., Wilkerson, J., Zhang, Y., Snyder, C. A., and Vonderwell, D.: Design Study of Propulsion and Drive Systems for the Large Civil TiltRotor (LCTR2) Rotorcraft. American Helicopter Society 67th Annual Forum, Virginia Beach, VA, May 2011.
- Snyder, C. A.: Defining gas turbine engine performance requirements for the Large Civil TiltRotor (LCTR2). American Helicopter Society 67th Annual Forum, Virginia Beach, VA, May 2011.
- Young, L., Chung, W., Paris, A., Salvano, D., Young, R., Gao, H., Wright, K., and Cheng, V.: Civil Tiltrotor Aircraft Operations. 11th AIAA Aviation Technology, Integration, and Operations (ATIO) Conference, Virginia Beach, VA, September 2011.
- Acree, C. W. and Snyder, C. A., “Influence of Alternative Engine Concepts on LCTR2 Sizing and Mission Profile,” AHS Future Vertical Lift Aircraft Design Conference, San Francisco, CA, January 2012.
- Johnson, W., Moodie, A. M., and Yeo, H., “Design and Performance of Lift-Offset Rotorcraft for Short-Haul Missions,” AHS Future Vertical Lift Aircraft Design Conference, San Francisco, CA, January 2012.
- Russell, C. R. and Johnson, W., “Conceptual Design and Mission Selection for a Large Civil Compound Helicopter ,” AHS Future Vertical Lift Aircraft Design Conference, San Francisco, CA, January 2012.
- Rajagopalan, R. G., Baskaran, V., Hollingsworth, A., Lestari, A., Garrick, D., Solis, E., and Hagerty, B., “RotCFD - A Tool for Aerodynamic Interference of Rotors: Validation and Capabilities,” AHS Future Vertical Lift Aircraft Design Conference, San Francisco, CA, January 2012.
- Chung, W., Salvano, D., Rinehart, D., Young, R., Cheng, V., and Lindsey, J., “An Assessment of Civil Tiltrotor Concept of Operations in the Next Generation Air Transportation System,” NASA/CR-2012-215999, January 2012.
- Gibson, T. L., Jagielski, M. J., and Barber, J. R., “Disaster Response Effectiveness of a Fleet of Civil Tiltrotor Aircraft Operating in the Next Generation Air Transportation System (NextGen),” NASA/CR-2012-216000, January 2012.

Future Publications

- Snyder, C. A. and Acree, C. W., "Assessing Variable Speed Power Turbine Technology on LCTR2 Size and Performance," 68th AHS Annual Forum & Technology Display, Fort Worth, TX, May 1-3, 2012.
- Gibson, T. L., Jagielski, M. J., Barber, J. R., Chung, W. W., and Young, L. A., "Employment of Conceptual Tiltrotor Aircraft in Disaster Response," 68th AHS Annual Forum & Technology Display, Fort Worth, TX, May 1-3, 2012.

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