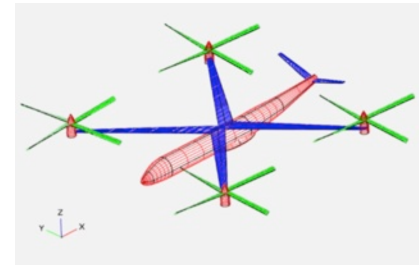
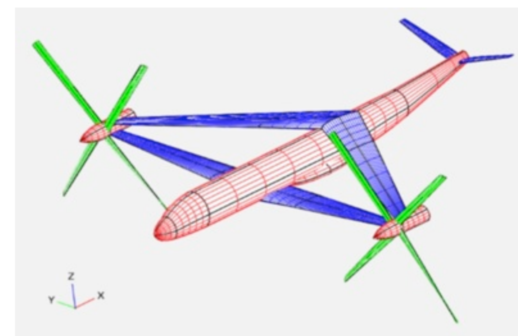


NASA Technology for Next Generation Vertical Lift Vehicles



Susan A. Gorton
Project Manger
Revolutionary Vertical Lift Technology

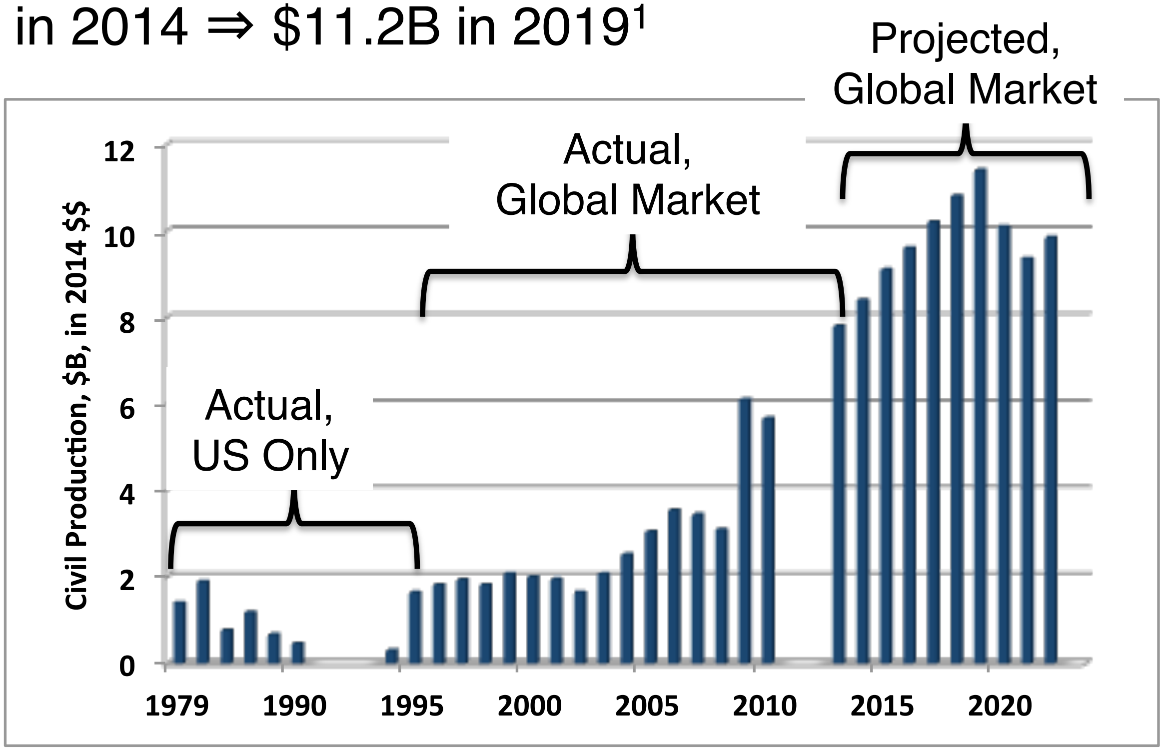
Acoustics Technical Working Group
Langley Research Center
April 21-22, 2015

Outline

- Market Outlook
- Future Challenges for Vertical Lift
- NASA's Revolutionary Vertical Lift Technology Project
- NASA Research Areas in Acoustics
- Concluding Remarks

Civil Rotorcraft Market Growth

- Civil Market is projected to grow significantly over next decade
  - "The civil market has been improving since 2011… and continued growth in civil demand will be key to the overall prospects of rotorcraft manufacturers in the years ahead."[1]
- Projected growth in new civil production per year:
  - \$8.3B in 2014 ⇒ \$11.2B in 2019[1]



[1] The World Rotorcraft Market, Vertiflite, Vol. 60, No. 3 and 4, 2014
The World Rotorcraft Market, Vertiflite, Vol. 59, No. 3, 2013
The World Rotorcraft Market, Vertiflite, Vol 50. No 1, 2004
The World Rotorcraft Market, Vertiflite, Vol 46 No. 1, 2000
The World Rotorcraft Market, Vertiflite, Vol 53, No 1, 2007
http://www.census.gov/prod/2001pubs/statab/sec22.pdf

Market Outlook for Civil Vertical Lift

- Near-term – Projections show civil sector sales will exceed military sales in 5-7 years
  - Emergency Medical Service operations in new global markets
  - Oil and gas sector, especially long-range off-shore operations
  - Search & rescue, medical, law enforcement, surveillance
  - Corporate/executive transport/ tourism

- Long-term – New markets will open 5-30 years
  - Autonomous missions (cargo, pipeline patrol, surveillance, etc.)
  - Urban commuter transport
  - Regional passenger service

- Community noise is the primary barrier to more widespread use of rotary wing/vertical lift vehicles. Performance and affordability are also major barriers.
- Under the Clean Sky Initiatives, the EU has started two major vertical lift initiatives (one helicopter & one tiltrotor).

Envisioned Common Civil Configurations and Missions in 2030 & beyond

	Configurations				
	Very Light	Light	Medium	Heavy	UltraHeavy
Missions	•inspection •photography •filming •spraying •mapping •weather •surveillance •delivery	•police •training •traffic/ news •power line service •spraying •cargo	•police •EMS •traffic/news •tourism •executive •charter •oil platforms •SAR •cargo	•oil platforms •disaster relief •cargo •logging •construction •firefighting •commuter (30 pax)	•commercial transport (90-120 pax) •disaster relief •civil reserve aircraft fleet •cargo
	autonomous capability				
Configura-tions					

blue highlight: new mission and/or new configuration

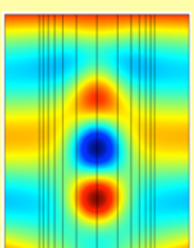
Challenges for Future Vertical Lift Aircraft
(Noise, speed, payload, efficiency, safety)

Active Rotor Systems

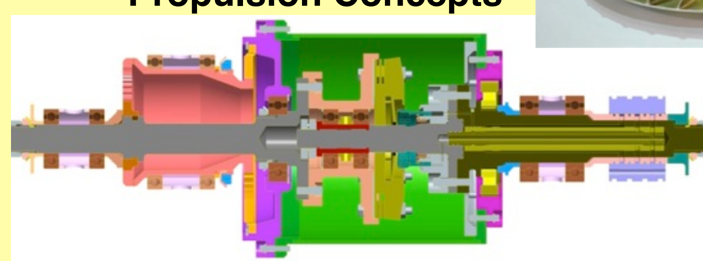
NextGen Operations

Modeling and Validation

Low Noise: External and Internal



Efficient Engines and Drive Systems; New Propulsion Concepts



Revolutionary Vertical Lift Technology Project

Develop and Validate Tools, Technologies and Concepts to Overcome Key Barriers for Vertical Lift Vehicles

Vision

- Enable next generation of vertical lift vehicles with aggressive goals for efficiency, noise, and emissions to expand current capabilities and develop new commercial markets

Scope

- Technologies that address noise, performance, efficiency, safety, community acceptance and affordability
- Conventional and non-conventional very light, light, medium, heavy and ultra-heavy vertical lift configurations

NASA Vertical Lift Project Research Areas

Ames Research Center

- Aeromechanics
- Computational Methods
- Flt Dyn & Ctrl
- Experimental Capability
- System Analysis
- Autonomy

Glenn Research Center

- Drive Systems
- Engines
- Hybrid Electric Systems
- Icing
- System Analysis
- Condition Based Maintenance

Langley Research Center

- Acoustics
- Aeromechanics
- Experimental Capability
- Computational Methods
- Crashworthiness
- Autonomy

Resources and Facilities

FY15 Vertical Lift Summary

~65 Civil Service Workforce
~ $20M per year (includes salary)

Anticipate similar level of funding for FY16-20

Ames Research Center

- National Full-Scale Aerodynamics Complex (NFAC)
- Supercomputing Complex (NAS)
- Vertical Motion Simulator

Glenn Research Center

- Compressor Test Facility (CE-18)
- Transonic Turbine Blade Cascade Facility (CW-22)
- Transmission Test Facilities (ERB)
- Icing Research Tunnel

Langley Research Center

- 14- by 22-Foot Subsonic Tunnel
- Transonic Dynamics Tunnel
- Landing and Impact Research
- Exterior Effects Synthesis & Sim Lab
- Mobile Acoustic Facility

NASA RVLT Project Areas of Investment, FY15

Multi-Speed Propulsion

Variable-Speed Turboshaft Engines

- Variable-speed power turbine
- High-efficiency gas generators

Multi-Speed Lightweight Drive Systems

- Advanced gearbox components and configurations
- Variable-speed transmission
- Condition based maintenance

Multi-Disciplinary Design, Analysis, and Optimization

Validated Multi-Disciplinary Design Tools

- High-fidelity modeling
- Conceptual design and sizing tools
- Experimental validation and methods

Optimization Environment for Conceptual Design

- OpenMDAO framework

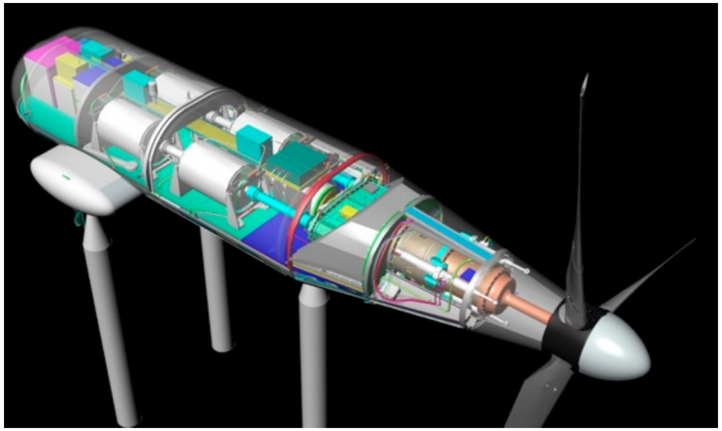
Safe and Certifiable VTOL Configurations

Low Noise Optimized Rotor

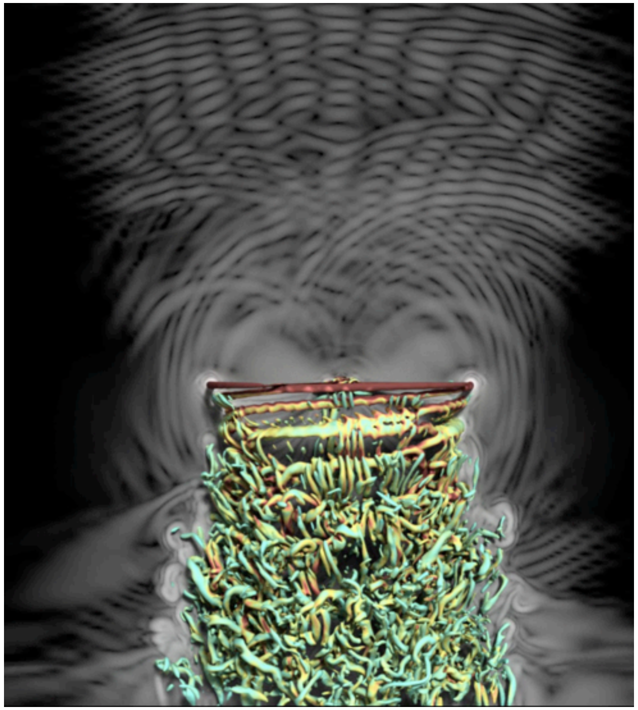
- Acoustics
- Aeromechanics and Rotor Performance

Safety and Environment

- Impact Dynamics
- Community Noise and Response
- Icing



Tiltrotor Test Rig drive system schematic



High-resolution hover calculation.

Variable Speed Power Turbine Tech Demo

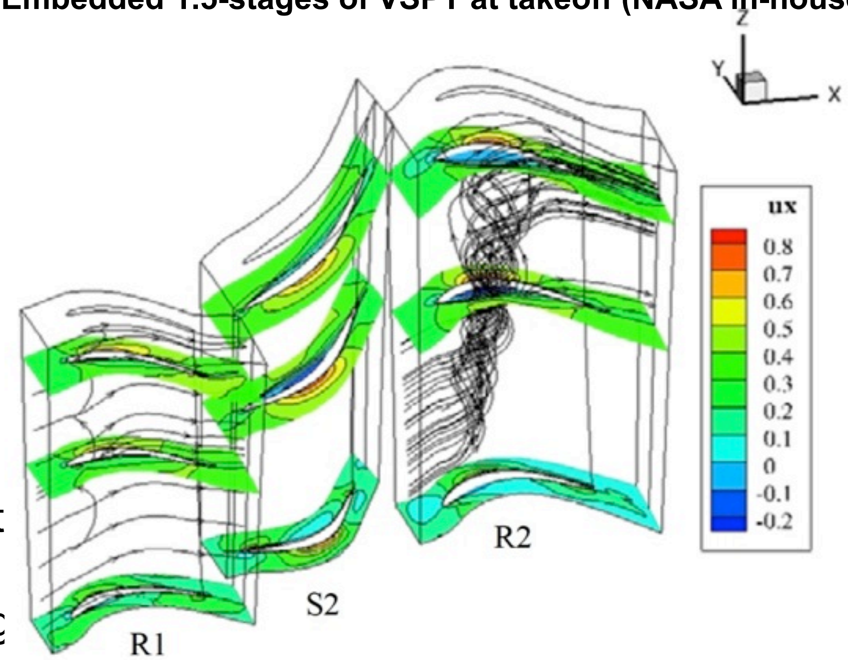
Objective

Demonstrate 50% improvement in efficient operational capability using a Variable Speed Power Turbine concept

Technical Areas and Approaches

- Aerodynamics research: high-efficiency turbine component design for a wide-range of incidence angle variation; efficient turbine operation at low Reynolds number; reduce wake-induced unsteadiness
- Rotordynamics research: address mechanical challenges resulting from variable shaft speeds
- Component test: Joint with the Army, demonstrat VSPT rig at flight Mach and Reynolds number conditions to advance technology to TRL 4 throug contracted research

Embedded 1.5-stages of VSPT at takeoff (NASA in-house)



Benefit/Pay-off

- Varying main rotor rpm will dramatically improve speed capability & efficiency of conventional, compound, & tiltrotor configurations.
- Efficient variable engine rpm capability enables higher cruise and takeoff efficiency levels.

Two-Speed Drive System Tech Demo

Objective

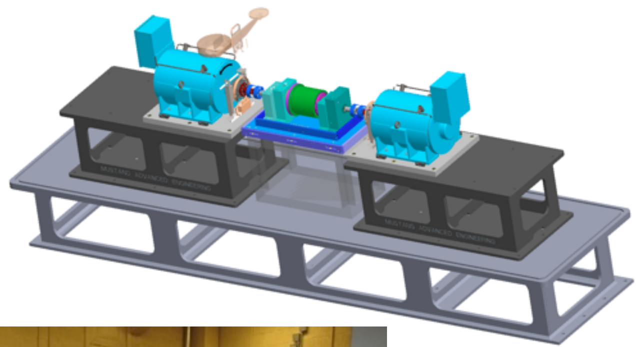
Demonstrate two-speed drive system with less than 2% power loss while maintaining current power-to-weight ratios

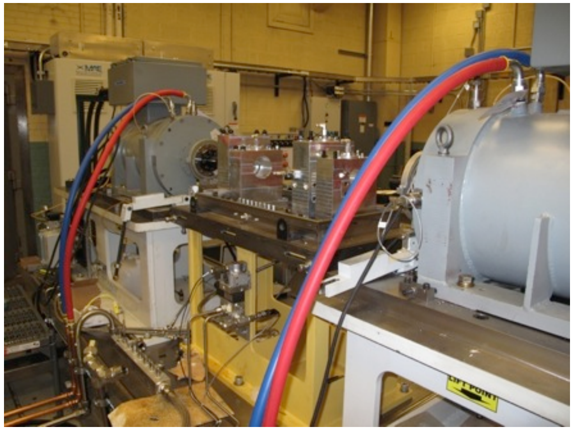
Technical Areas and Approaches

- Design and test viable concepts for both a two- and variable-speed drive transmission configuration
- Develop a unique facility to test scaled transmission configurations
- Evaluate new technologies to reduce system weight, losses and cost – e.g., hybrid metal/ composite gears, health monitoring, operation under loss of lubrication, windage

Benefit/Pay-off

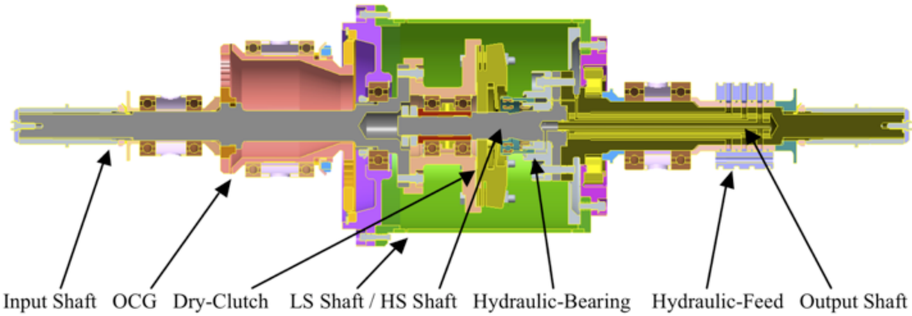
- Improved rotorcraft aerodynamics performance, empty weight fraction and safety
- Demonstration of innovative multi-speed drive system designs
- Development & demonstration of advanced drive system components and technologies
- Improvement in maintenance & operational costs





Variable Speed Transmission Test Rig

Patent # 8,091,445 received on Offset Compound Gear Drive for Variable Speed Transmission



Active Rotor Concepts Evaluation

Objective

Quantify performance, noise and vibration benefits of active rotor concepts by test & analysis.

Technical Areas and Approaches

- Two concepts tested; analysis shows noise & vibration reduction:
  - Smart Materials Actuated Rotor Technology (SMART), a flapped rotor concept
  - Individual Blade Control (IBC), active pitch link control in the rotating system
- Third concept, active twist rotor did not complete testing, but generated knowledge

SMART Rotor in NFAC, 2008

IBC Rotor in NFAC, 2009

Benefit/Pay-off

- Active rotor concepts are key to lower vibration, lower noise, decreased loads, & improved speed/range performance
- Comparison of three types of active rotor control technology concepts for advanced, high-performance, low-noise, low-vibration rotorcraft.

ATR-A Rotor in TDT, 2012

Active Rotor Concepts—Major Conclusions 1 of 3

Active Flap: The test demonstrated on-blade smart material control of flaps on a full-scale rotor for the first time in a wind tunnel. The effectiveness of the active flap control on noise and vibration was conclusively demonstrated. Results showed **reductions up to 6dB in blade-vortex interaction** and in-plane noise, as well as **reductions in vibratory hub loads of about 80%**. Trailing edge flap deflections were controlled with less than 0.2 degrees error for commanded harmonic profiles of up to 3 degrees amplitude. The impact of the active flap on control power, rotor smoothing, and performance was also demonstrated. Finally, the reliability of the flap actuation system was successfully proven in more than 60 hours of wind tunnel testing.

Active Rotor Concepts—Major Conclusions 2 of 3

Individual Blade Control: The test demonstrated **rotor power reductions (up to 5%)**, multi-parameter hub load reductions, multi-frequency pitch link load reductions, **and in-plane noise reductions.** Additional results indicate **the benefits of IBC for in-flight tuning** and show minimal coupling of IBC with UH- 60A rotor flight dynamics.

Active Rotor Concepts—Major Conclusions 3 of 3

Active Twist: Although there was no performance, vibration or noise data acquired for either ATR rotor, there were substantial gains in capability through the execution of the research. In particular, the ATR-A blade performed without failures in hover and benchtop testing, indicating that **the design philosophy is robust**. Actuation was nominally what was predicted in the design process; however **the magnitude of the actuation would not be sufficient for primary rotor controls**. During the STAR pre-test predictions, **the US analysis capability was enhanced** to enable the ability to predict the effect of individual blades, such as for a configuration with modulated blade spacing, etc.

UTRC/Sikorsky/GaTech NRA

Objective: Demonstrate Active Flow Control on an oscillating airfoil can delay dynamic stall at Mach numbers up to 0.5

Approach: COMPACT actuator developed by GaTech installed in Sikorsky oscillating airfoil rig and tested to high Mach numbers in the Icing Research Tunnel (this is not an icing test, but facility has right Mach range and Sikorsky rig for that facility was available.)

Accomplishments: Initial testing completed in January 2015. Second phase of testing scheduled for May 2015. Testing for 9 days in IRT accomplished major

Significance: Significant lift recovery was seen from dynamic stall in first phase. System enhancements to next test will move the technology closer to application in a rotating blade.

• *NRA is cost-shared with UTRC*

Altitude Variation Flight Test

Partnership with Army AFDD

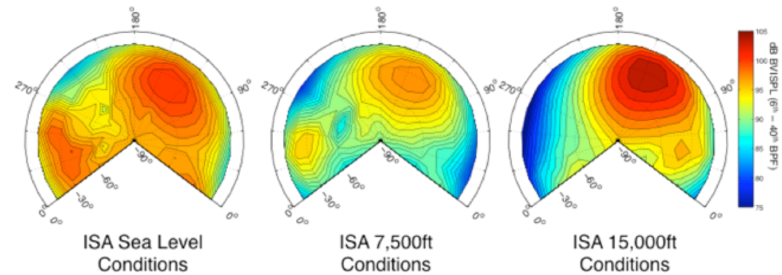
PROBLEM Noise data used in acoustic analyses have been measured at one altitude and then subsequently applied to all altitudes. However, predicted acoustics data show substantial variation in the magnitude and directivity of radiated noise as ambient conditions change.

OBJECTIVE Acquire flight test data from two aircraft (with significant difference in gross weight) at three altitudes. Use data to validate altitude variations and maneuvers in FRAME (Fundamental Rotorcraft Acoustic Modeling from Experiments)

ACCOMPLISHMENTS Testing logistics arranged for 2 aircraft, 3 Calif. sites, involving multiple organizations. A total of 1510 data points were acquired at the three sites in 65.5 data acquisition flight hours (135 total flight hours including all ferry and instrumentation checkout flights.) Preliminary examination shows the data are high quality and confidence is high that sufficient data were acquired to validate the altitude variation predictions of the FRAME model. Data were also acquired on the EH-60L at the Amedee site to validate maneuvering acoustic predictions.

Sweetwater USMC Auxiliary Airfield	6800 ft ✔	Sept 22-Oct 11, 2014
Amedee Army Auxiliary Airfield	4000 ft ✔	Oct 20- Nov 22, 2014
USNAC Salton Sea	sea level ✔	Feb 3-Feb 16, 2015

SIGNIFICANCE FRAME will use test data to model estimated noise radiation that accounts for altitude and gross weight variations. Acoustic prediction accuracy for flight envelope will be greatly improved.



FRAME Predicted Acoustics at 3 Altitudes for Bell 206B at 60 KIAS, -6° FPA

Light vehicle, AS350

Medium lift vehicle, EH-60L

CFD Accuracy Improvements

Objective

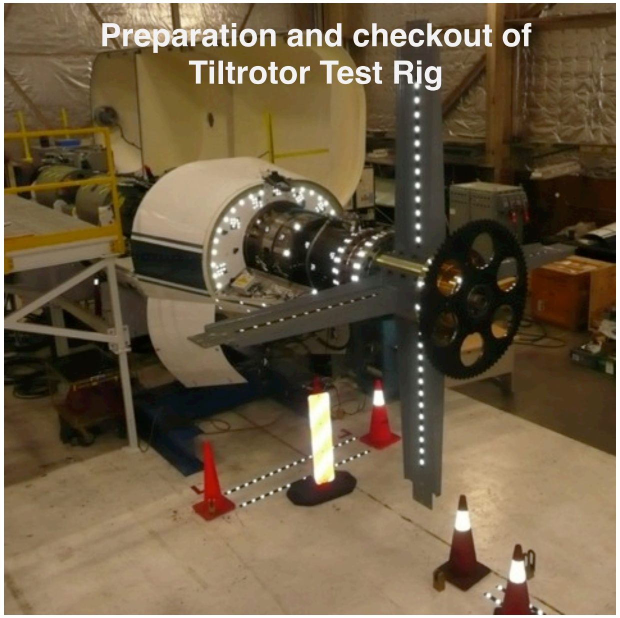
To enhance SOA tools in order to improve the accuracy of predictions for rotor loads and performance for both hover and forward flight.

Technical Areas and Approaches

- Unstructured code development (FUN3D)
- Structured code development (OVERFLOW)
- Collection of high-quality validation data from comprehensive flight and wind tunnel tests using multiple advanced measurement techniques.

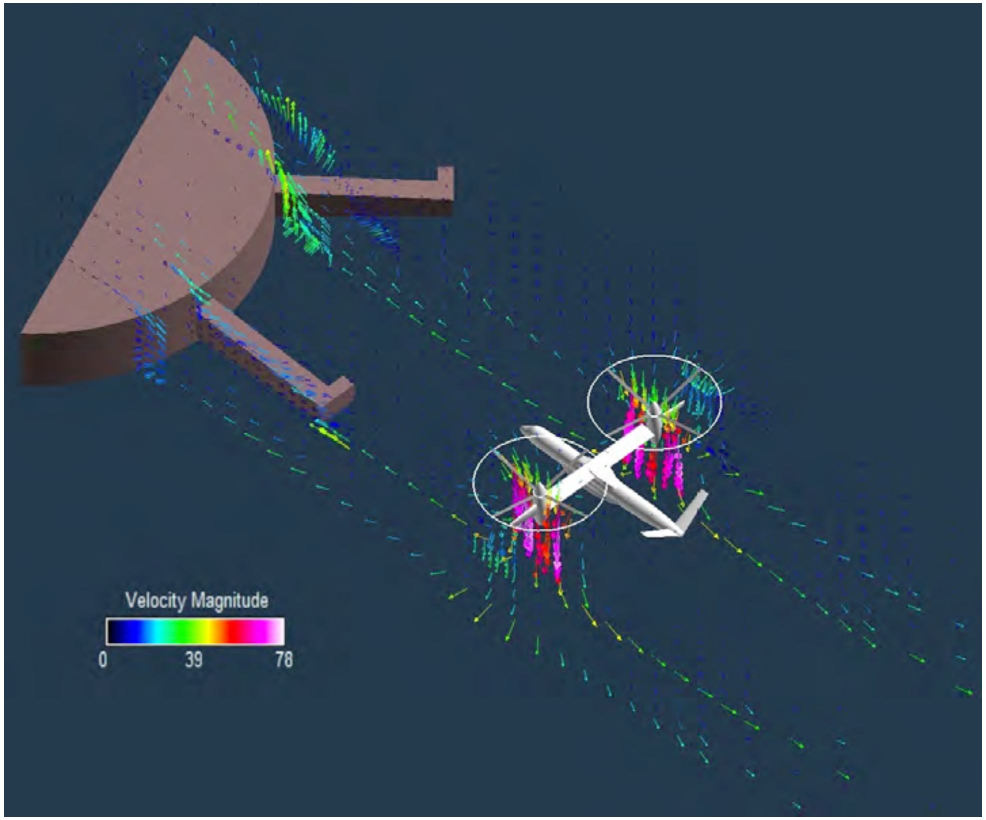
Benefit/Pay-off

- Current SOA methods cannot accurately predict rotor performance in some key configurations, therefore NASA investments in this area are designed to improve simulation utility, accuracy, robustness and efficiency for rotorcraft applications through algorithm and method development.
- Collection of high-quality validation data to be used by NASA and US rotorcraft community.



Concluding Remarks

- Exciting times for Aeronautics and Vertical Lift!
- Challenges and opportunities abound in many discipline and multi-disciplinary areas
- NASA research addresses several challenge areas for future vertical lift capability
- NASA future work focus
  - Multi-speed propulsion concepts
  - Optimization of low-noise characteristics for multiple configurations



Calculation of flow environment in terminal area for tiltrotor using RotCFD.

NASA