



RVLT

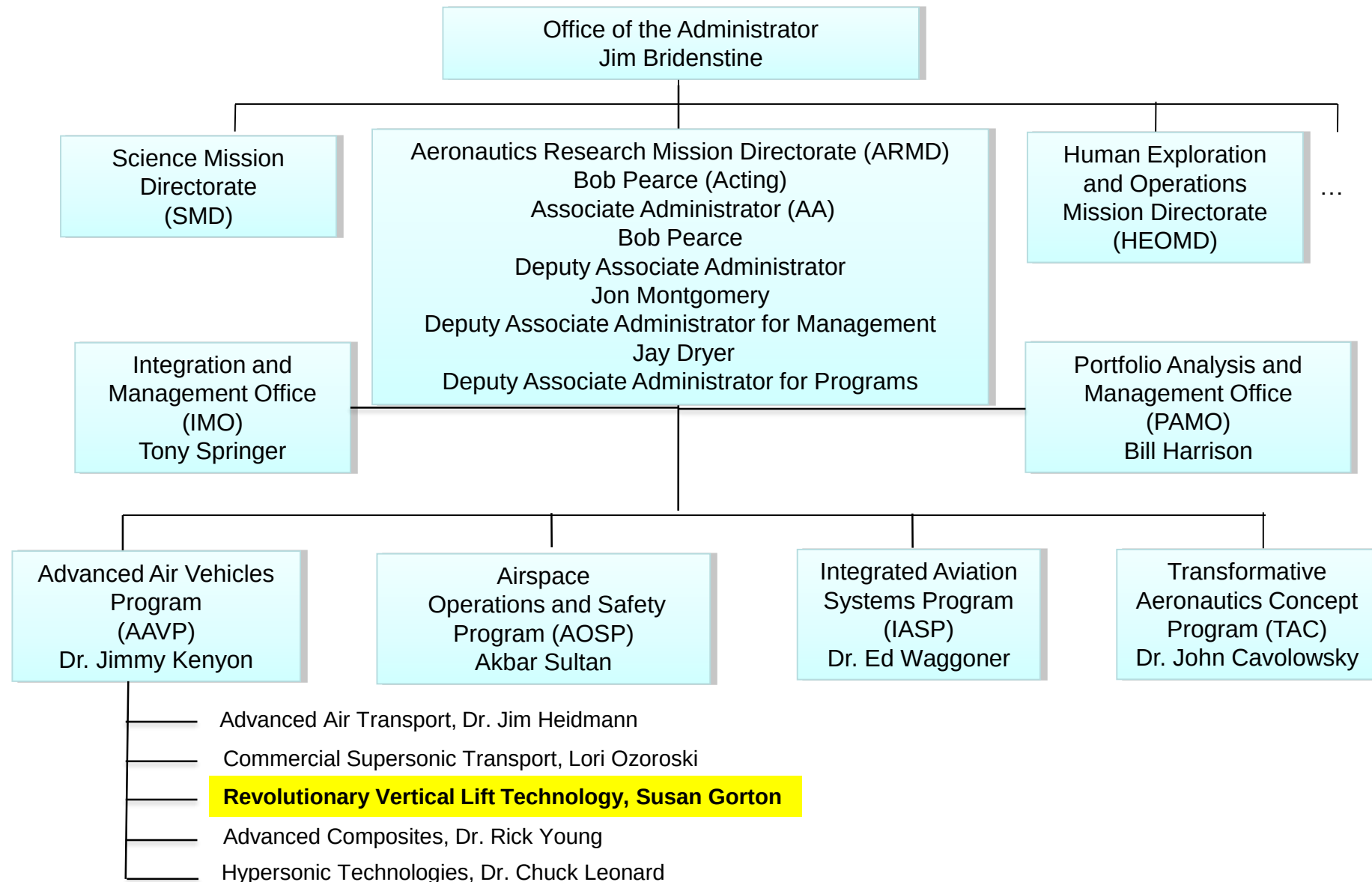
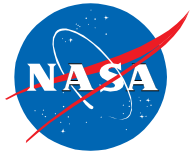
Revolutionary Vertical Lift Technology Project

Project Manager: Susan A. Gorton

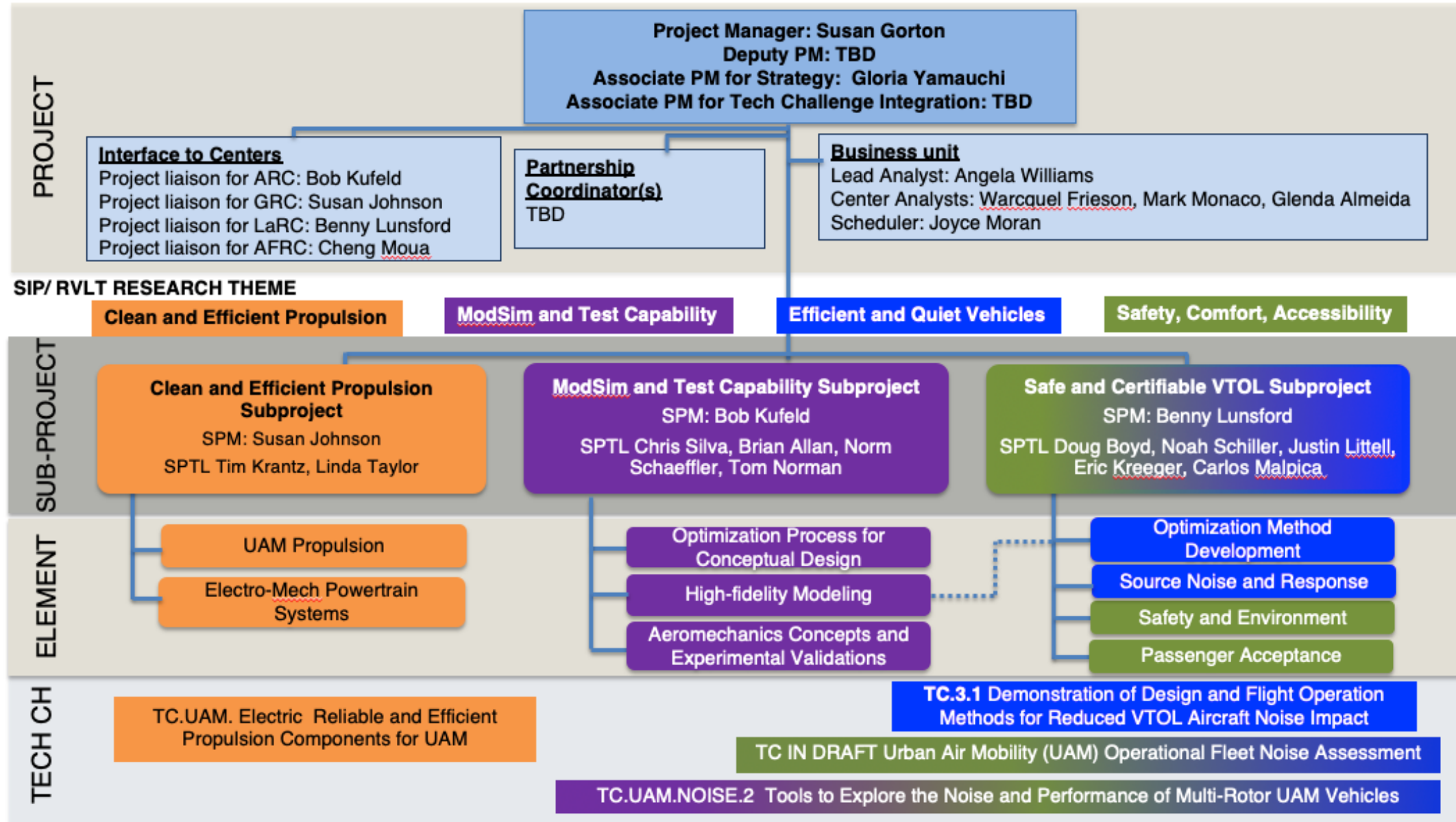
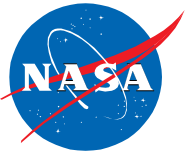
SubProject Manager for Safe and Certifiable VTOL: Benny Lunsford

October 2019

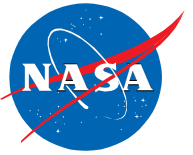
NASA 2019 Aeronautics Research Mission Directorate Organization



RVLT Project Structure – FY20



Revolutionary Vertical Lift Technology Project



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

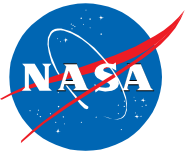
Vision

- 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, safety, speed, mobility, payload, efficiency, environment
- Conventional and non-conventional very light, light, and medium vertical lift configurations

NASA RVLТ Project Research Areas, FY20



Ames Research Center

- Aeromechanics
- System Analysis
- Computational Methods
- Experimental Capability
- Flight Dynamics & Control
- Acoustics

Armstrong Flight Research Center

- Grand Challenge execution
- UAM electric system and flight control integration
- eVTOL reliability

Glenn Research Center

- Hybrid/ Electric Systems
- Electro-Mech Powertrains
- Small Turboshaft Engines
- Icing
- System Analysis
- Impact Dynamics
- Acoustics

Langley Research Center

- Acoustics
- Computational Methods
- Aeromechanics
- Experimental Capability
- Impact Dynamics
- System Analysis



- Typical NASA research is TRL 1-5, sometimes 6
- Typical NASA products are feasibility studies, technology demonstrations, research reports
- Partnerships enable faster technology transition to DoD and industry

Resources and Facilities



FY19/20 RVLTL Summary

**~80/85 Civil Service
Workforce
~ \$28M/27M per year
(includes salary)**

Ames Research Center

- National Full-Scale Aerodynamics Complex (NFAC)
- Supercomputing Complex (NAS)
- Vertical Motion Simulator
- 7x10 (Army)

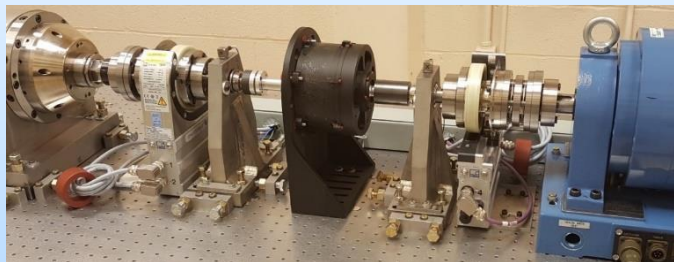


Armstrong Flight Research Center

- Test Range
- Simulation Laboratories



Glenn Research Center



- Electric Propulsion Test Facilities
- Electro-Mechanical Powertrain Testing
- Icing Research Tunnel
- Advanced Compressor Test Facility

Langley Research Center

- 14- by 22-Foot Subsonic Tunnel
- Transonic Dynamics Tunnel
- Landing and Impact Research
- Mobile Acoustic Facility
- Low-Speed Aero-acoustic Wind Tunnel



- Exterior Effects Synthesis & Sim Lab

Energy and Excitement About Urban Air Mobility

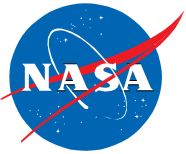


- NASA ARMD UAM Capability and Assessment Team (UCAT) 2017-2019 Framework and Systems Engineering Assessment
- Two ARMD UAM Market Studies
- Three Aeronautics Round Table hosted by National Academies
- Three Annual Uber Elevate Summits
- Six Transformative Vertical Flight Workshops with sold out capacity
- Three Urban Air Mobility Noise Working Group meetings (NASA-led, industry support)



212 UAM vehicle configurations tracked by Evtol.news

Primary Differences Between UAM Vehicles and Legacy Rotorcraft



	Most UAM Vehicles	Most Legacy Rotorcraft
Number of passengers	1-6	1-25
Number of rotors or propellers	1 to many	1 or 2
Propulsion	electric, hybrid-electric	turboshaft
Gear box	maybe	1 or 2 per rotor
Number of motors/ engines	1 to many (one motor per rotor)	1 or 2
Blade hinges	no	yes
Aircraft trim control	rotor speed	rotor collective/cyclic

Research Areas for UAM eVTOL Vehicles

PROPULSION EFFICIENCY

high power, lightweight battery
 light, efficient, high-speed electric motors
 power electronics and thermal management
 light, efficient diesel engine
 light, efficient small turboshaft engine
 efficient powertrains

SAFETY and AIRWORTHINESS

FMECA (failure mode, effects, and criticality analysis)
 component reliability and life cycle
 crashworthiness
 propulsion system failures
 high voltage operational safety

OPERATIONAL EFFECTIVENESS

disturbance rejection (control bandwidth, control design)
 Ops in moderate to severe weather
 passenger acceptance/ ride quality
 cost (purchase, maintenance, DOC)

PERFORMANCE

aircraft optimization
 rotor shape optimization
 hub and support drag minimization
 airframe drag minimization



ROTOR-WING INTERACTIONS

conversion/transition
 interactional aerodynamics
 flow control

ROTOR-ROTOR INTERACTIONS

performance, vibration, handling qualities
 aircraft arrangement
 vibration and load alleviation

NOISE AND ANNOYANCE

low tip speed
 rotor shape optimization
 flight operations for low noise
 aircraft arrangement/ interactions
 cumulative noise impacts from fleet ops
 active noise control
 cabin noise
 metrics and requirements

STRUCTURE AND AEROELASTICITY

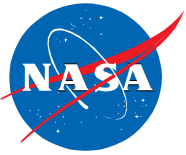
structurally efficient wing and rotor support
 rotor/airframe stability
 crashworthiness
 durability and damage tolerance
 high-cycle fatigue

AIRCRAFT DESIGN

weight, vibration
 handling qualities
 active control

Red = primary RVLT research area
 Blue = secondary RVLT research area

NASA Concept Vehicles – A Useful Way to Focus Research



NASA reference vehicles ♦ Widely shared ♦ Fully documented ♦ Realistic performance ♦ Realistic set of compromises ♦ Common context for dialogue ♦ No plans to build or fly these concepts

- Vehicles contain relevant features and technologies
 - Battery, hybrid, diesel propulsion
 - Distributed electric propulsion
 - High efficiency rotors
 - Quieter rotors
 - Autonomy
- Communication mechanism for NASA, academia, industry
 - Communicate NASA's Urban Air Mobility research
 - Design and analysis tool development
 - Identify benefits of technology improvements
- Help NASA understand the Urban Air Mobility Market
 - Quantify the impact of regulations
 - Identify the economic drivers
 - Find feasible solutions
 - Model operational scenarios



RVLT Will Launch New Technical Challenges in Response to UAM Study Recommendations



Identified areas of high-impact/ recommended areas for research:

- System safety and reliability
- Vehicle noise
- Vehicle design

RVLT.TC.UAM.Electric.1 “Reliable and Efficient Propulsion Components for UAM”

Because there is a lack of data for propulsion systems and thermal management systems for UAM vehicles, NASA will develop design and test guidelines, acquire data, and explore new concepts that improve propulsion system component reliability, culminating by demonstrating 2-4 orders of magnitude improvement in 100kW-class electric motor reliability.

RVLT.TC.UAM.Noise 1 “Urban Air Mobility (UAM) Operational Fleet Noise Assessment” (approval pending)

Because community response to the noise of UAM fleet operations is a barrier to the emerging UAM market, NASA will develop a method that can be used to assess the noise footprint generated by UAM fleet operations, use the tool to optimize UAM flight operations that include noise as a constraint, and provide noise assessments for nominal flight profiles including takeoff, cruise and landing.

RVLT.TC.UAM.Noise 2 “Tools to Explore the Noise and Performance of Multi-Rotor UAM Vehicles”

Provide the community a validated and documented set of tools for assessing tradeoffs between the noise and performance of UAM VTOL aircraft, completed by delivering tool chain software at TRL = 5 with documentation, test cases, and best practices.

RVLT Will Launch New Technical Challenges in Response to Study Recommendations



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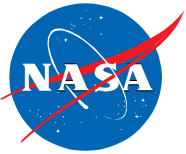
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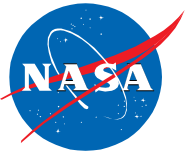
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SOA Analysis Tools and Methods (in the U. S.) for Rotary Wing VTOL Aircraft



Characteristic	Technology	Examples of Tools (Tools in BLUE are commonly used by NASA)
airfoil aero	CFD	MSES, XFOIL, C81Gen(ARC2D), OVERFLOW, FUN3D , Fluent
blade/wing section structure	2D FEM	IXGEN/VABS , VABS, UM/VABS, X3D, various FEM
airframe structural dynamics	3D FEM	NASTRAN, LS-DYNA , ANSYS
aerodynamics airframe optimization rotor/airframe download rotor blade optimization aeroacoustics	CFD	OVERFLOW, FUN3D, RotCFD , Helios, TURNS, U2NCLE, CART3D, Fluent, CFD++, STAR-CCM+, VSAERO, elsA, FLOWer, HMB2, rFlow3D, ROSITA, TAU, company proprietary Note: geometry often starts with OpenVSP output that is imported to CAD to generate improved grid, then grid is manually refined for CFD
rotor performance, aircraft performance, rotor/hub loads, vibration, wing/rotor interaction, aeroelastic stability	rotorcraft comprehensive analysis	CAMRADII, DYMORE , RCAS, FLIGHTLAB, CHARM, DYMORE, UMARC, MBDyn, HOST, company proprietary
icing	ice accretion	LEWICE, Glenn ICE (to be released)
noise	linear, nonlinear	ANOPP2, AARON (user code for ANOPP2), APET, FRAME , PSU-WOPWOP, RNM
propulsion	cycle analysis	NPSS , company proprietary
system identification, flight control design/optimization, flight dynamics models	flight dynamics and control	CIFER, CONDUIT, GenHel, GTRSim , FLIGHTLAB, FlightCODE (under development)
aircraft system design	surrogate	NDARC , company proprietary
system optimization	design environment	OpenMDAO , ModelCenter, company proprietary

RVLT.TC.UAM.Noise2: Tools to Explore the Noise and Performance of Multi-Rotor UAM Vehicles (1 of 2)



What is the problem/barrier being addressed by this Technical Challenge?

Noise is identified as a likely barrier to public acceptance of multi-rotor UAM VTOL aircraft. ***A validated and documented methodology for assessing tradeoffs between the noise and efficiency of these aircraft does not exist.*** Without a documented methodology, NASA and the UAM vehicle developers cannot assess the noise impact of these vehicles on the community, explore feasible noise mitigation strategies for the different vehicles, or assess the performance reductions that are required to design a low-noise UAM vehicle.

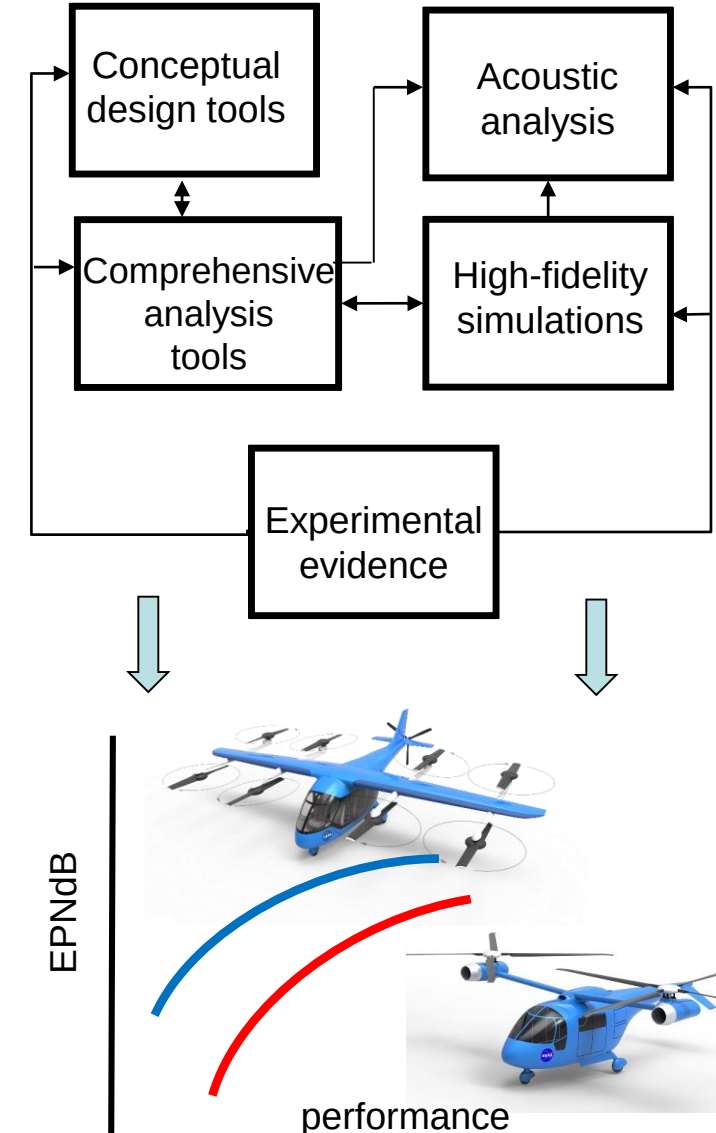
What are we trying to do?

Develop, demonstrate, validate, and document a set of conceptual design tools capable of assessing the tradeoffs between UAM vehicle noise and efficiency.

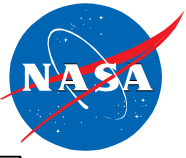
What is the State of the Art (SOA) in conceptual design tools for VTOL aircraft?

- VTOL aircraft conceptual design requires a spectrum of tools of varying fidelity in multiple disciplines. Legacy rotorcraft OEMs, NASA, and the Army have developed and validated specialized tools over decades of research.
- Even within the government, streamlined toolchains combining multiple discipline tools are not common and expertise is needed to run individual tools.
- Many prototype UAM vehicles are built without comprehensive understanding of multirotor vehicle "system" challenges and how to optimize or minimize: noise, aerodynamic efficiency, rotor loads, vibration, etc.

Evaluation of UAM Vehicle Noise vs Performance



RVLT.TC.UAM.Noise2: Tools to Explore the Noise and Performance of Multi-Rotor UAM Vehicles (2 of 2)



Why is NASA uniquely suited for this Technical Challenge?

- NASA has developed, collaborated on, can expertly use, and/or funded many of the SOA tools for VTOL aircraft
- NASA has the expertise and facilities to acquire validation data for tools
- NASA completed a Technical Challenge in FY18 that began interfacing tools (sizing+comprehensive analysis, comprehensive analysis+acoustics) to streamline the conceptual design process
- In a very competitive emerging UAM market, NASA has “no horse” in the race, so Technical Challenge deliverables (reports, data, software) will be pre-competitive and can be shared widely with appropriate permission

What is new in our approach?

- Developing new interfaces between comprehensive analysis-CFD-acoustics analysis to account for multirotor vehicle trim using rotor RPM control
- Investing in new test rigs representative of UAM-like configurations
- Focusing on “usability” of tools and toolchains by holding user workshops and documenting best practices for performing trade studies of UAM multirotor vehicles

NASA/TP-2015-218751



NDARC
NASA Design and Analysis of Rotorcraft

Theory

Appendix 3
Release 1.11
October 2016

Wayne Johnson
NASA Ames Research Center, Moffett

NASA/TM-2016-219342



ANOPP2 User's Manual
Version 1.2

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**Documentation for RotorCraft
Optimization Tools (RCOTOOLS)**
Release 1.2.2

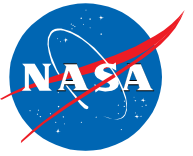
Larry Meyn
NASA Ames Research Center

User's Manual for OVERFLOW 2.2

Version 2.2o, 7 March 2019

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Thank you for your time!