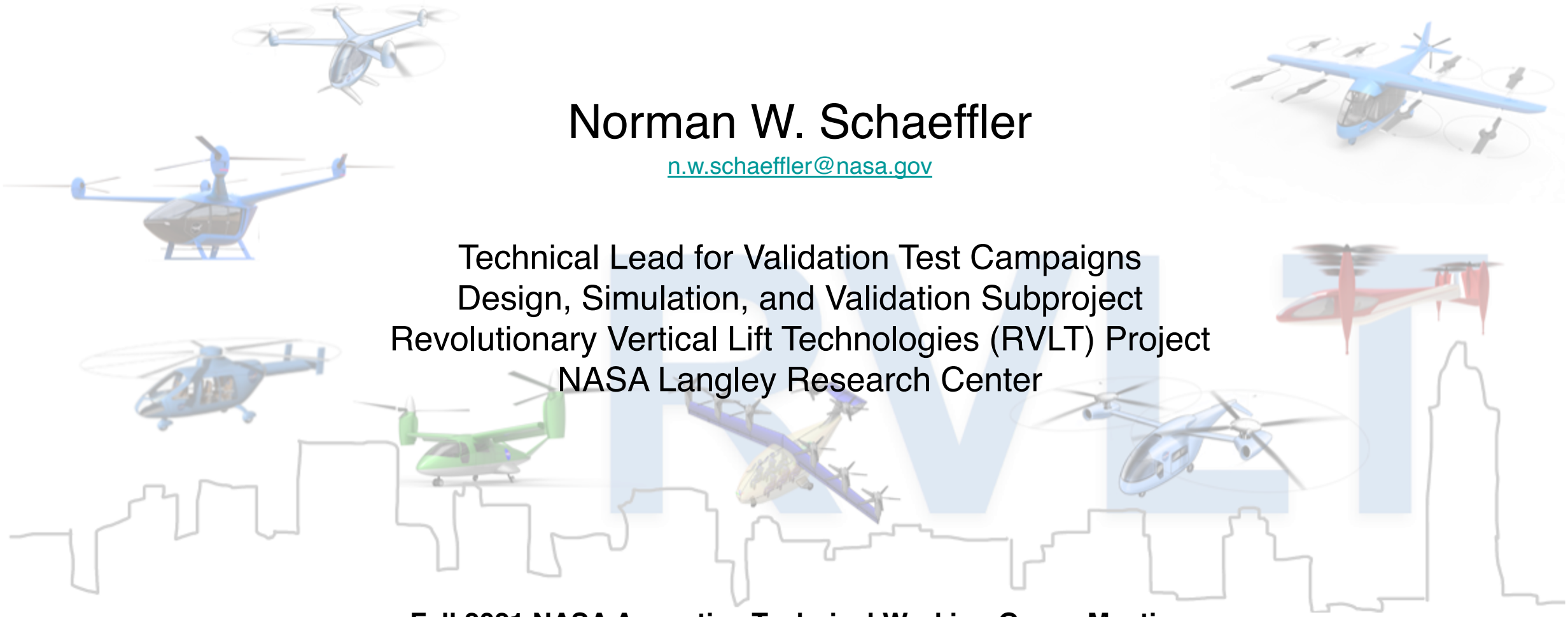
RVLT Validation Test Plan



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Why did RVLT develop a Validation Test Plan?

The RVLT Validation Test Plan:

- Supports the Technical Challenge RVLT.TC.UAM.Noise.2, "Tools to Explore the Noise and Performance of Multi-Rotor UAM Vehicles"

- Enables the goal of the TC to provide the community with a validated and documented set of tools for assessing tradeoffs between the noise and performance of UAM VTOL aircraft by providing validation data from experiments and high-fidelity CFD.

- Enables the RVLT Project to identify key personnel and prioritize resources to the tests by having the required tests identified and laid out on a realistic schedule.

- Establishes a linkage between the planned experimental and computational efforts and the design tools that will utilize the data for validation. Early and continued collaboration between the experimentalists, computationalists, and the design tools power users is vital to the success of the validation effort.

Tech Challenge: Tools to Explore the Noise and Performance of Multi-Rotor UAM Vehicles

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.

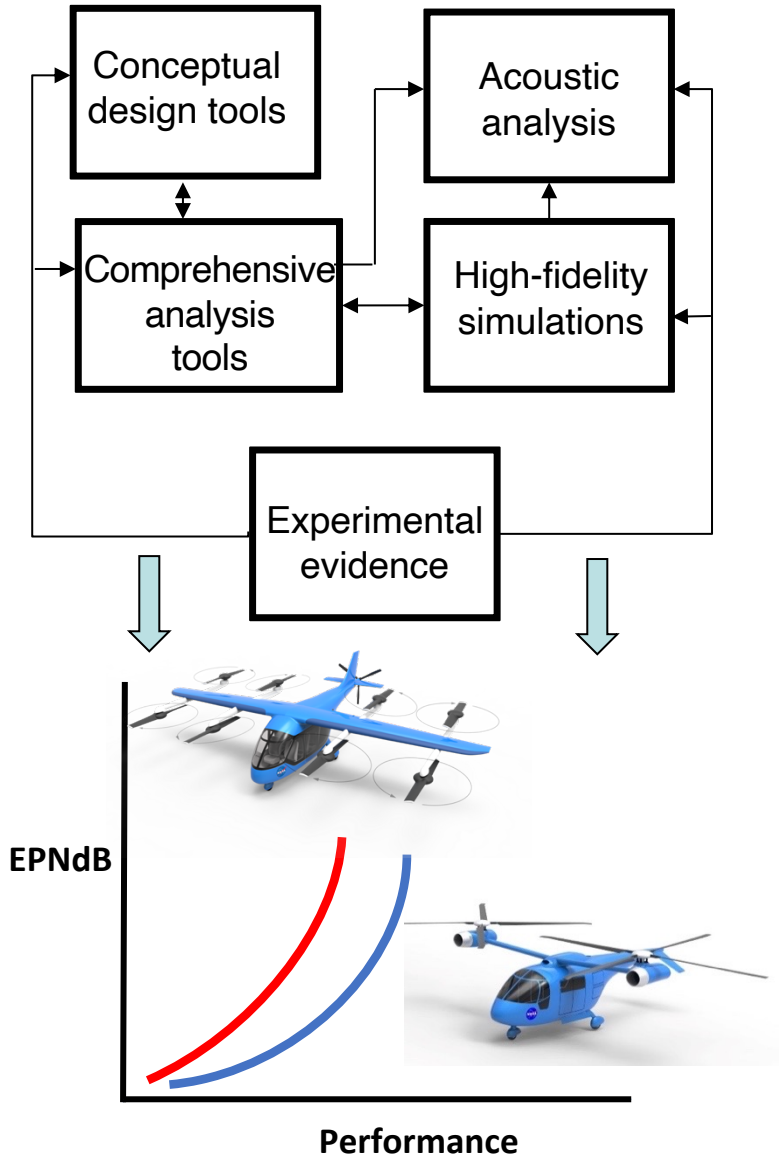
What are we trying to do?

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

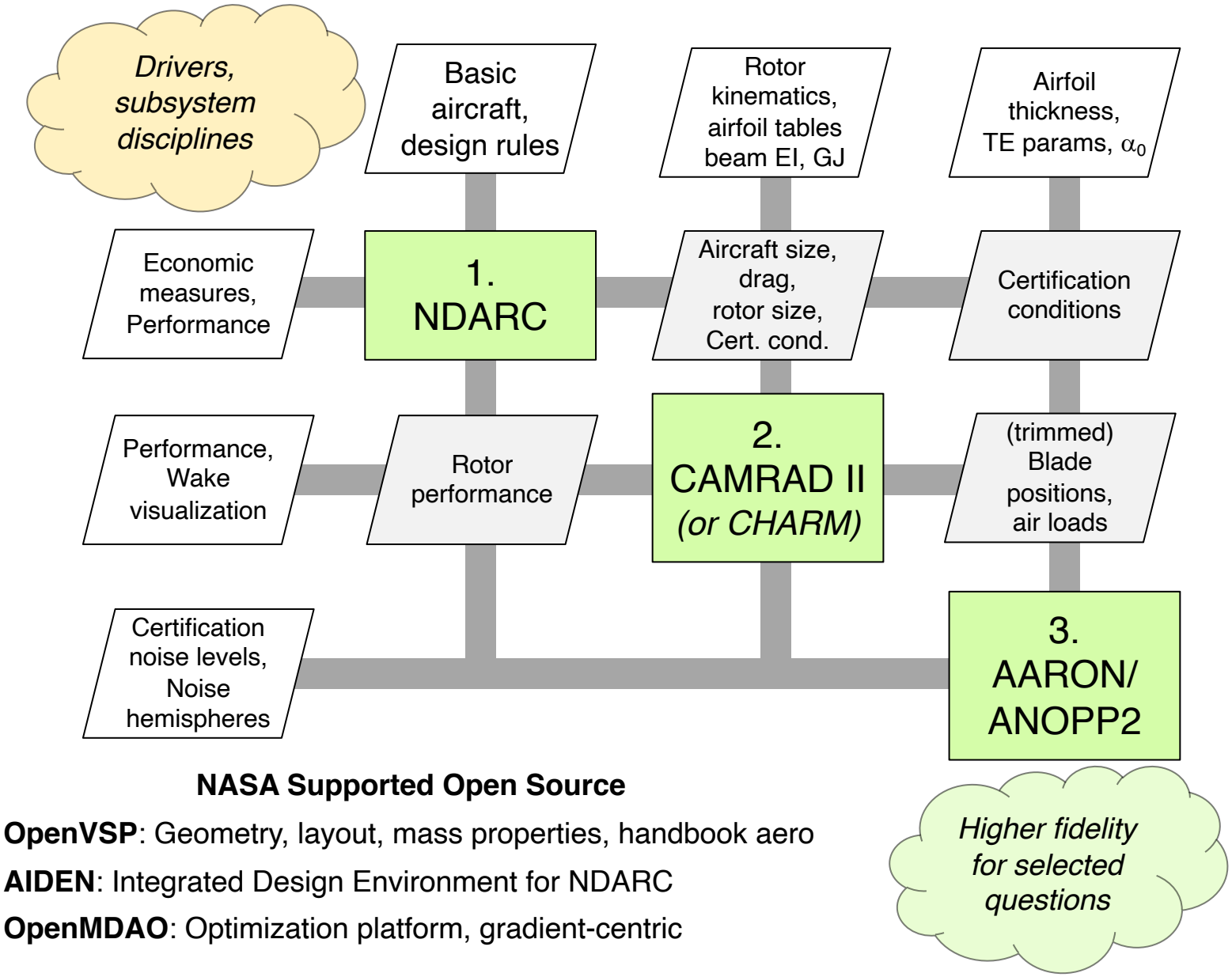
What is the State of the Art (SOA) in conceptual design tools for VTOL aircraft?

- 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.

Evaluation of UAM Vehicle Noise vs Performance



Rotorcraft Conceptual Design Primary Toolchain and Interfaces



NASA Supported Open Source

OpenVSP: Geometry, layout, mass properties, handbook aero

AIDEN: Integrated Design Environment for NDARC

OpenMDAO: Optimization platform, gradient-centric

NASA Software

NDARC: Aircraft Design and Analysis

RCOTOOLS: Interface and utilities for connecting codes in Python and connecting to OpenMDAO

AARON/ANOPP2: Noise analysis

ALPINE: Python interface between NDARC and OpenVSP

FlightCODE: Flight dynamics model generation and handling qualities design/assessment

Chimera Grid Tools: Grid generation for CFD

Commercial Tools

CAMRAD II: Rotorcraft comprehensive analysis

CHARM: Rotorcraft comprehensive analysis

IXGEN/VABS: Rotor blade cross-sectional structural analysis

AFTGen: Rotor blade airfoil aerodynamic table generation

NPSS: Turbine engine and electric motor design and analysis

M4SS/NASTRAN: Airframe structural analysis

Rhinoceros: Refine geometry for CFD grid generation and visualization

Tests in the RVLT Validation Test Plan

FY20

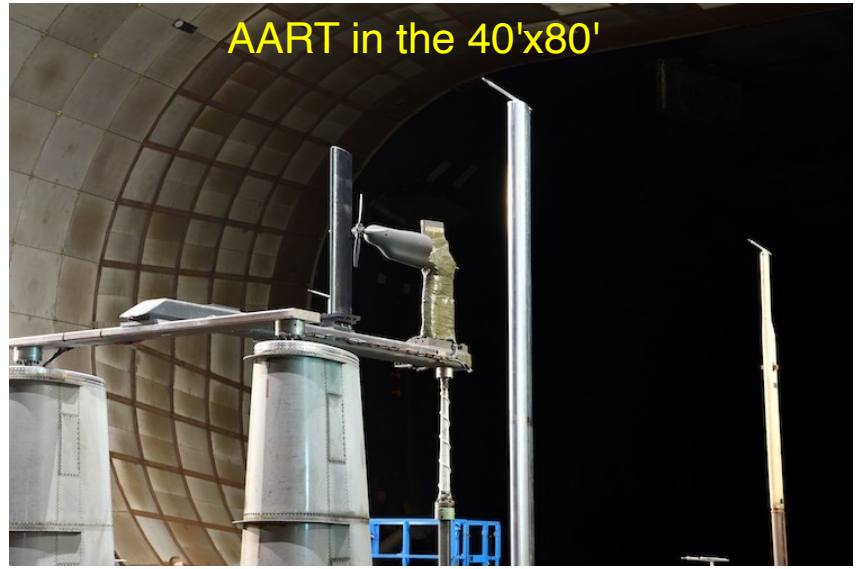
- *Multirotor Test Bed (MTB) - Entry 1 (7'x10')*
- *Aerodynamic and Acoustic Rotorprop Testing (AART)(40'x80')*
- *Propeller Test Stand - Acceptance Test* (Low-Speed Aeroacoustic Wind Tunnel - *LSAWT)*

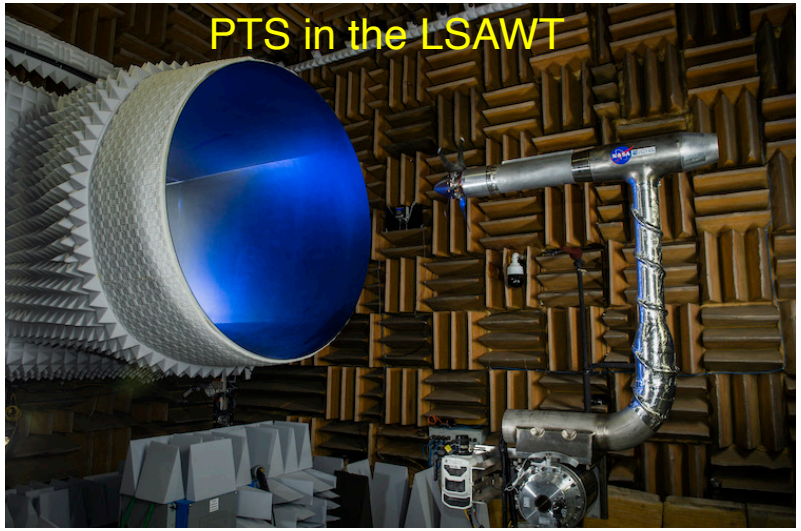
FY21

- *Electric Motor Noise Test (Acoustic Testing Laboratory - ATL)*
- *Background Noise Test (14'x22')*
- *sUAS Optimized Noise Test (LSAWT)*
- *Small Ducted Rotor Acoustic Test (Small Hover Anechoic Chamber - SHAC)*

MTB – Entry 1 concluded in November 2019 and AART started up in the 40'x80' that same month.

Formalization of the Validation Test Plan started in January 2020





Multirotor Test Bed (MTB)

The MTB was designed to provide validation data on the highly complex interacting flows of the multirotor systems seen on many of the aircraft targeting the Advanced Air Mobility (AAM) and the Unmanned Aircraft System (UAS) markets.

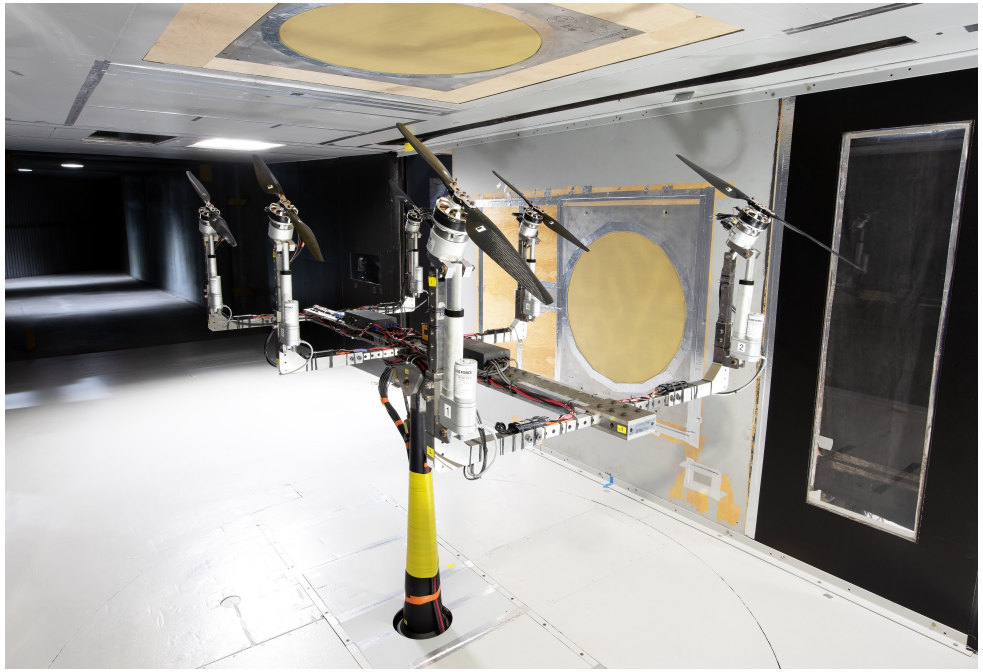
The MTB is comprised of a maximum of six rotor modules, which support rotors up to 24 inches in diameter.

Each of the rotor modules has:

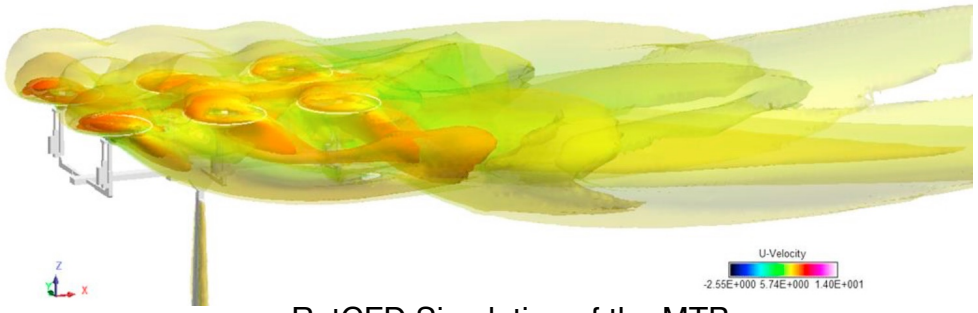
- A 6-axis load cell
- Remote control of RPM, phasing (2nd Entry), and rotor tilt.
- Removability for testing different combinations of rotors
- Lateral, longitudinal, and vertical adjustment of its position

Additionally, the entire MTB can be tilted as a unit.

The MTB will undergo extensive performance testing in the 7'x10' and then transition to the 40'x80' for acoustic testing.



MTB in its highest, most extended configuration, installed in the 7- by 10-ft Wind Tunnel

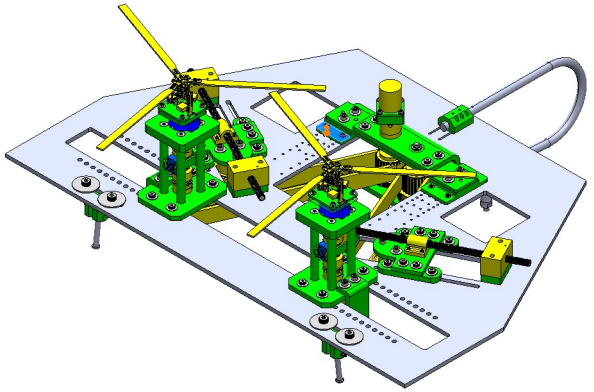


RotCFD Simulation of the MTB

Tests in the RVLT Validation Test Plan

FY22

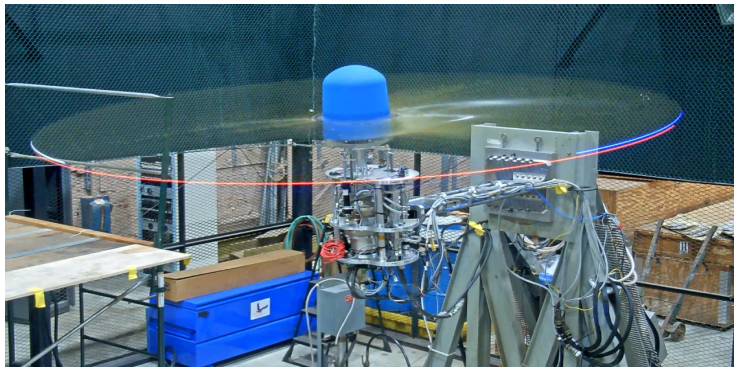
- *Side-By-Side (SbS) Rig Entry 1 (7'x10')*
- *Moog SureFly Flight Tests*
- *Benchmark Hover Test (80'x120')*
- *Tiltrotor Aeroelastic System Testbed (TRAST) (TDT)*
- *Multirotor Test Bed (MTB) - Entry 2 (7'x10')*
- *Vertical Lift Prop Noise Performance Test (14'x22') (Test starts in FY22 and completes in FY23)*



Side By Side (SbS)



Hover Test - HVAB Checkout in 14'x22' RTC



Initial TRAST Rotor Operations in the TDT Rotor Test Cell

Validation Test Plan – What other areas are in need of data?

A “Gap” analysis was conducted by RVLT, using the RVLT Reference Vehicles as a context. From this several key gaps were identified, as were tests to produce the required validation data.

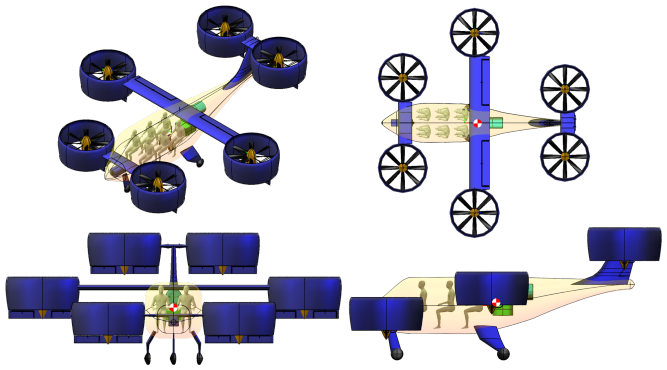


“For the **Quadrotor**, the identified priority is to assess the effect of **rotor vertical, longitudinal, and horizontal spacing** among multiple rotors on the **performance and acoustics** in hover, conversion, and forward flight. This priority can be addressed by testing of the Multirotor Test Bed (MTB) in facilities suitable for performance and acoustic data.”

“For the **Side-by-Side**, the identified priority is to document the effect of **rotor horizontal spacing/overlap on performance and acoustics**. This priority can be addressed by testing of the Side-by-Side (SbS) rig in facilities suitable for performance and acoustic data.”



Validation Test Plan – What other areas are in need of data?



"For the TiltDuct, the identified priority is to assess the **effect of duct configuration, specifically length, on the performance and acoustics** for hover, transition, and forward flight. The satisfaction of this priority will require the **development of a new test rig**."



"One additional priority, within the context of the TiltWing reference vehicle, was identified by receiving a number one ranking from 75% of the reviewers. It is to assess the effect of **rotor vertical and horizontal spacing on performance and acoustics**. This priority will also require the **development of a new test article**."



Validation Test Plan – Expected Outcome

The Validation Test Plan is a means to an end. The end product of executing these tests will be data of sufficient quality to validate the tools in the toolchain.

To facilitate the usefulness of the data, the tests should:

- Be specifically designed to be component tests, the “building blocks” of future vehicles.
- Utilize fully open geometry to the largest extent possible.
- Provide database with sufficient detail to validate analyses.
- Have the resulting data be publicly available.

Tests in the RVLT Validation Test Plan

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- *Propeller Test Rig - Acceptance Test (LSAWT)*

FY21
- *Electric Motor Noise Test (GRC ATL)*
- *Background Noise Test (14'x22')*
- *sUAS Optimized Noise Test (LSAWT)*
- *Small Ducted Rotor Acoustic Test (SHAC)*

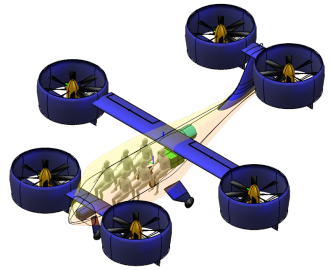


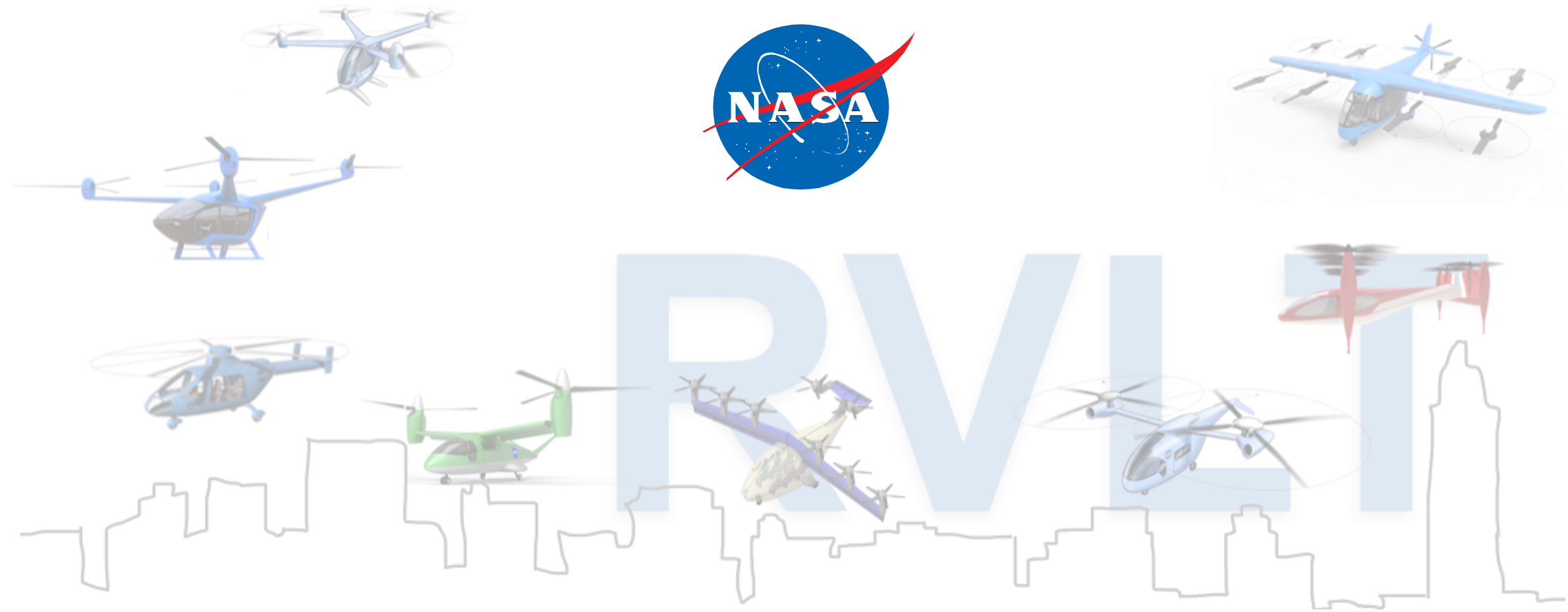
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- *Multirotor Test Bed (MTB) - Entry 2 (7'x10')*
- *Vertical Lift Prop Noise Performance Test (14'x22') (Test starts in FY22 and completes in FY23)*



FY23-FY25
- *Side-By-Side Rig - Entry 2 (7'x10')*
- *Tilt Duct Checkout and Entry 1 (7'x10')*
- *Vertical Lift Prop Noise Acoustic Test (14'x22')*
- *Joint MTB and Tilt Duct Acoustic Test (40'x80')*
- *Tiltwing Performance Test (14'x22')*
- *Large MTB Performance/Acoustic Test (40'x80')*
- *Tiltwing Acoustic Test (14'x22')*






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