National Aeronautics and Space Administration

Transformational Tools and Technologies (T^3) Project

T^3 Project Overview

Dr. Azlin Biaggi – NASA GRC

Innovative solutions through foundational research and cross-cutting tools

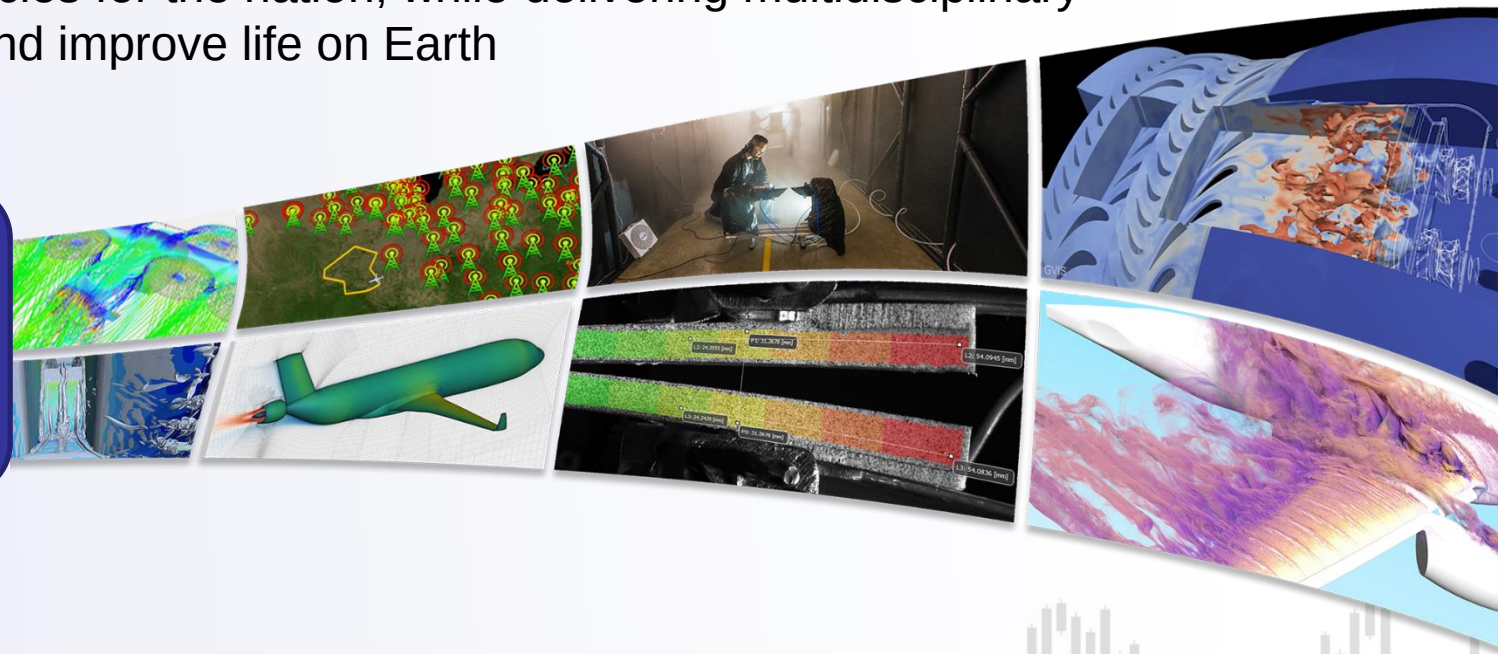
Discussions with University of Puerto Rico for T^3 Strategic Planning Meeting
February 2, 2023

Transformational Tools & Technologies (T^3) Project

Explores the unknown through foundational research that inspires innovation in aeronautics, delivering revolutionary advances in essential areas such as autonomy, certification by analysis, advanced materials, and sustainable aviation

- Conducts exploratory research with breakthrough potential to inspire the world through discovery
- Enables fast, efficient design and analysis of advanced aviation systems from first principles
- Develops innovative tools and technologies to revolutionize air transportation
- Sustains critical aeronautics core competencies for the nation, while delivering multidisciplinary system-level results that benefit humanity and improve life on Earth

Delivering cutting-edge research, leading community vision studies, and providing the community with valuable data and innovations that impact aeronautics research throughout the ARMD portfolio



T³ By The Numbers

8 Enduring Disciplines

9 PATENTS/ LICENSE

4 NASA Centers

253 Publications

11 MISSION PROJECTS SUPPORTED

3 Sub-projects

37 AWARDS

$62M BUDGET

Over 90 Partnerships

187 FTEs

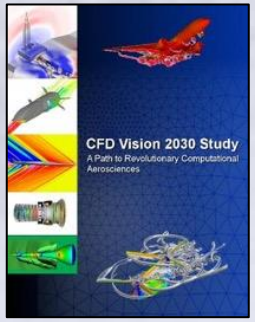
284 Presentations

Continually Considering New Content & Fostering Innovation

T³ focuses on transformational cross-cutting foundational research

T³ supports all six ARMD Thrusts

Vision Studies



AoA Studies

ARMD Strategic Portfolio Management Review

Technical Community (workshops, conferences, etc.)

Selection Criteria

- Foundational & Cross-cutting
- Potential Impact
- Supports Mission Projects
- Stakeholder Buy-in
- Transformational & Innovative
- Resource Constraints
  - Center/Competency balance
  - Labor/Procurement balance

Portfolio

Measures & Metrics

TACP Performance Metrics

ARMD Alignment

Transformation

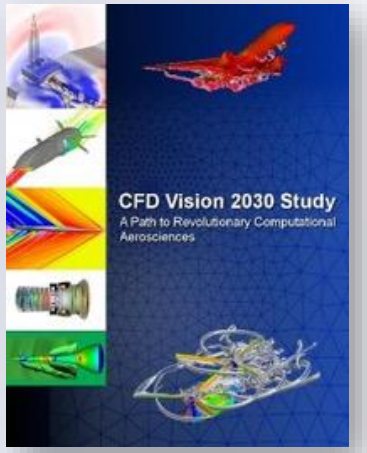
Culture of Innovation

Agility

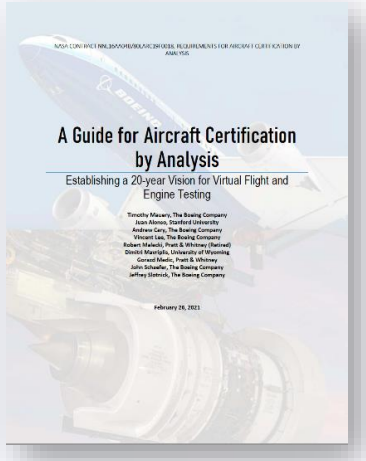
Encourage injection of new ideas, techniques, and approaches

Community Visions and Analysis of Alternatives (AoA) Studies informing T^3 activities

M&S 2040 - A Roadmap for Integrated, Multiscale Modeling & Simulation of Materials & Systems



CFD2030 – CFD Vision 2030 Study



A Guide for Aircraft Certification by Analysis – A 2040 Vision

AoA Study for Subsonic Transport Acoustics, Combustion/Emissions & Icing

Reports generate prioritized list of proposed high-value research appropriate for NASA with input from industry, academia, and OGAs in multiple sectors

Autonomy Verification & Validation Roadmap and Vision 2045

- Jointly funded with AOSP / SWS Project
- PI is Boeing lead for AI/Autonomy V&V technologies
- Technical Advisors from FAA, AFRL, NRL
- Expected completion December 2022

BOEING · Collins Aerospace · GE Research · University of Michigan · Massachusetts Institute of Technology · The University of Texas at Austin

T³ Organizational Structure

Resource & Project Support
Business Lead: Gene Storer (GRC)
Center Analysts: Cecelia Town (ARC), Alee Pacheco (AFRC), Gene Storer (GRC), Tracey Frisby (LaRC)
NRA Manager: Tracey Frisby (LaRC)
Scheduler: Joyce Moran (GRC)
Strategic Comm Specialist: Diana Fitzgerald (LaRC)
Project Support Analyst: Jeanie Feagan (GRC)

Executive Team
Project Manager – Michael Rogers (ARC)
Deputy Project Manager – Dale Hopkins (GRC)
Associate Project Manager – Joe Morrison (LaRC)
Asst Project Managers for Special Topics – Lauren Abbott (ARC), Jon VanHorn (ARC)

Project Center Liaisons

ARC	Andrew Meade
AFRC	Robert Navarro
GRC	Azlin Biaggi-Labiosa
LaRC	Melissa Rivers

Enduring Disciplines Research Areas
Discipline Strategy Management
Dale Hopkins & Joe Morrison

Disciplines	Tech Leads
Autonomous Systems (AS) - Human Machine Teaming	Kelley Hashemi (ARC)
Communications, Navigation & Surveillance (CNS)	Eric Knoblock (GRC)
Multidisciplinary Design, Analysis & Optimization (MDAO)	Ben Phillips (LaRC)
Controls	Dennis Culley (GRC) Steve Riddick (LaRC)
Innovative Measurements (IM)	Mark Wernet (GRC)
Revolutionary Computational Aerosciences (RCA)	Mujeeb Malik (LaRC)
Materials and Structures (M&S)	Steve Arnold (GRC)
Combustion	Jeff Moder (GRC)

Sub-projects
(Aligned with ARMD Priorities)

Foundational Electrified Aircraft Propulsion
MDAO
Controls
M&S
Azlin Biaggi-Labiosa
Sub-project Manager

Revolutionary Aviation Mobility
AS
CNS
MDAO
Controls
Vanessa Aubuchon
Sub-project Manager

Reduced Life Cycle Cost
IM
RCA
Icing
M&S
Melissa Rivers
Sub-project Manager

Fourth Sub-project?
Sustainability?
Supersonics?
M&S
Combustion
Azlin Biaggi-Labiosa
Sub-project Manager

T³ conducts foundational research with its discipline-based expertise to enable innovation in aeronautics & executes multidisciplinary projects to apply concepts in a system-level context

Reduced Life Cycle Cost (RLCC) Sub-project Overview

IM, RCA, Icing and M&S disciplines enable the RLCC sub-project

Purpose: Reduce the life cycle cost of aircraft to enable the U.S. aircraft industry to stay competitive worldwide

Aircraft Life Cycle Phases	**Research, Development, Test & Evaluation**	**Production**	**Operations & Maintenance**	**Disposal**
Challenges	**Significant delays if issues are not discovered until flight testing**	**Time to manufacture and assemble aircraft is costly**	**Maintenance performed on a specified schedule may not be needed at the prescribed time**	Exploring Opportunities
RLCC Project Objectives	**Obj 1: Enabling Certification by Analysis (CbA) to reduce surprises during flight tests**	**Obj 2: Increasing manufacturing rate & reducing weight of materials during production**	**Obj 3: Decreasing amount of required maintenance during Operations and Maintenance Phase**	

Approaches

Develop, implement, and validate computationally efficient, physics-based methods and tools to:

1. Enable aircraft CbA for 1st phase of the life cycle
2. Design and predict the processing and life cycle performance of advanced materials and structures for 2nd phase of the life cycle

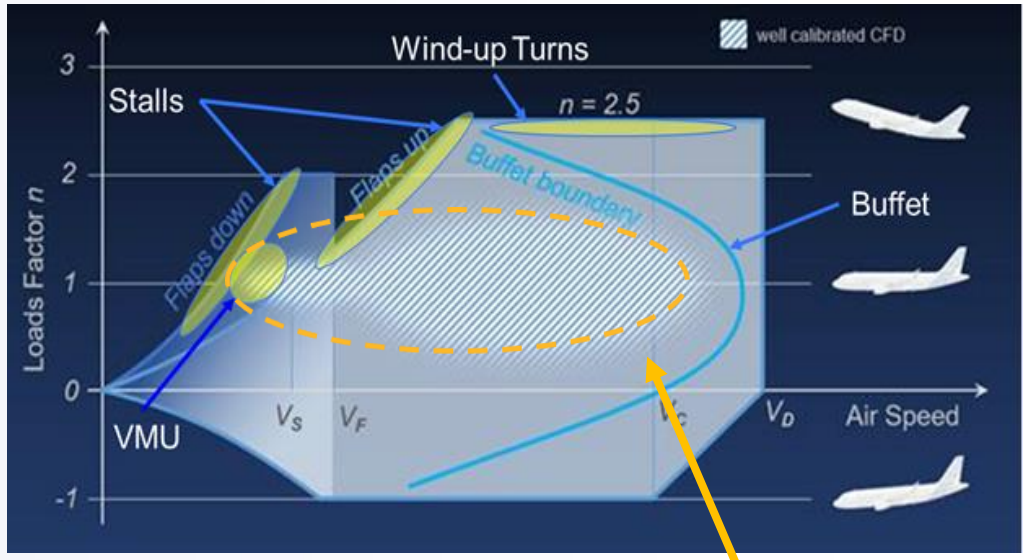
Certification by Analysis: Compliance Through Analytical Means

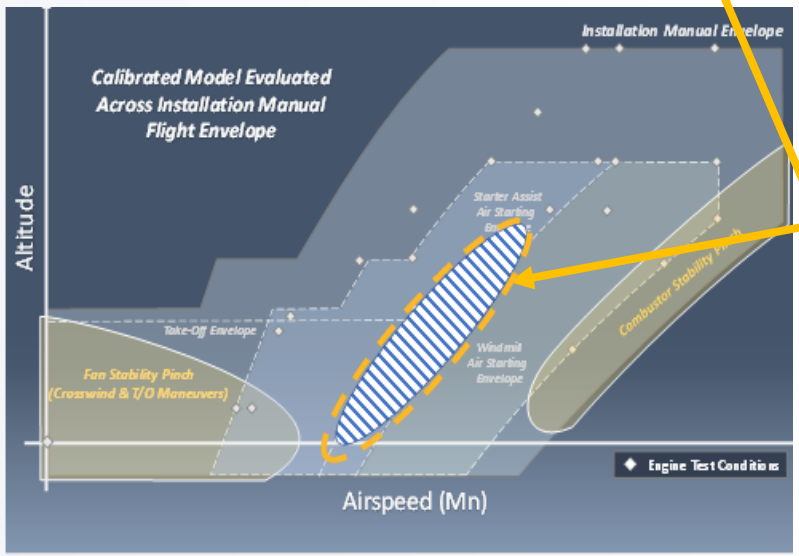
"Continued advances are required to address full-flight envelope predictions and propulsion system operating conditions, reduce design cost and cycle time, reduce ground and flight-testing, and **enable product certification through analysis (CbA)**…"

Recommendation of CFD Vision 2030 Study: A Path to Revolutionary Computational Aerosciences

- **Regulatory Agencies (FAA, EASA) codify the standards and requirements for airworthiness**
  - Aircraft and engines must meet these requirements, before they can be put to service
- **Current compliance with the codes is through flight test for airframes and ground tests for engines**
  - Very time consuming and expensive endeavor
  - CbA is an alternate means of compliance for airplane and engine certification based on analysis

Ability to accurately predict complex turbulent flows involving separation is a key technical challenge





Limits of current CFD

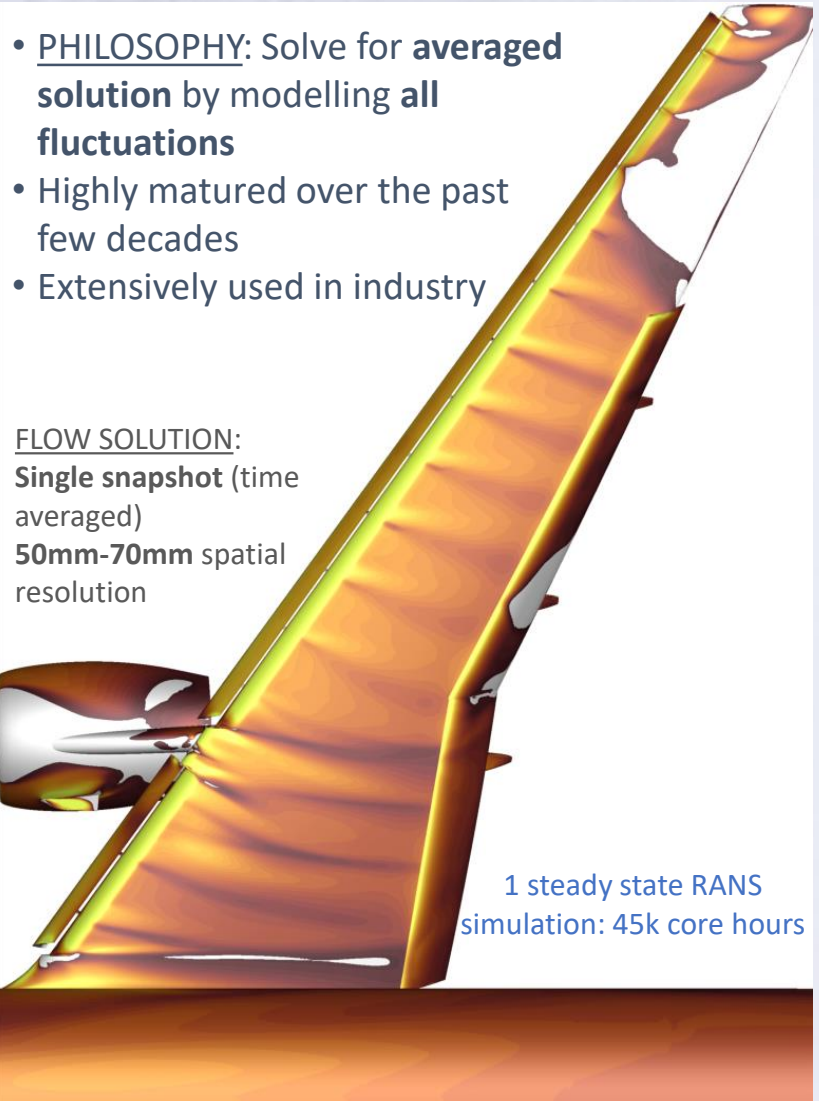
Scale Resolving Simulations: Certification and Qualification by Analysis

REYNOLDS AVERAGED NAVIER STOKES (RANS)

1980s - Present

- PHILOSOPHY: Solve for **averaged solution** by modelling **all fluctuations**
- Highly matured over the past few decades
- Extensively used in industry

FLOW SOLUTION:
Single snapshot (time averaged)
50mm-70mm spatial resolution



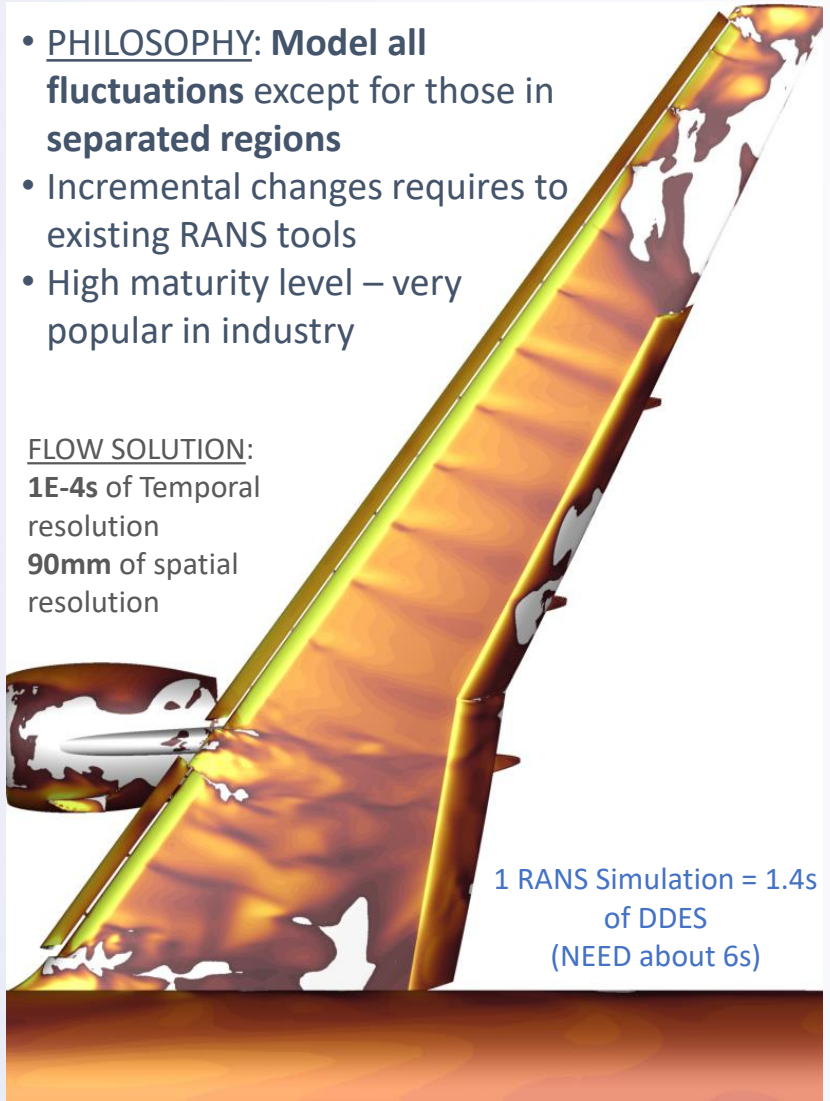
1 steady state RANS simulation: 45k core hours

DELAYED DETACHED EDDY SIMULATIONS (DDES)

1990s - Present

- PHILOSOPHY: **Model all fluctuations** except for those in **separated regions**
- Incremental changes requires to existing RANS tools
- High maturity level – very popular in industry

FLOW SOLUTION:
1E-4s of Temporal resolution
90mm of spatial resolution



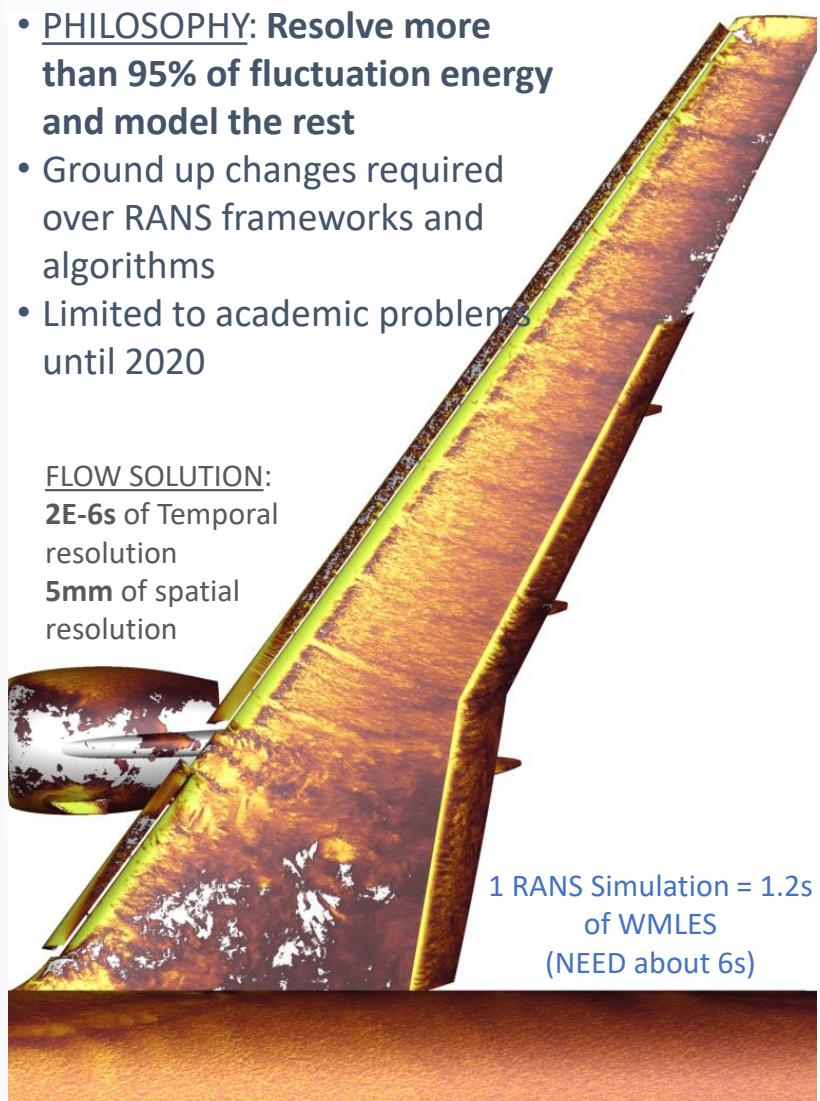
1 RANS Simulation = 1.4s of DDES
(NEED about 6s)

LARGE EDDY SIMULATIONS (WMLES)

2020 - Present

- PHILOSOPHY: **Resolve more than 95% of fluctuation energy and model the rest**
- Ground up changes required over RANS frameworks and algorithms
- Limited to academic problems until 2020

FLOW SOLUTION:
2E-6s of Temporal resolution
5mm of spatial resolution



1 RANS Simulation = 1.2s of WMLES
(NEED about 6s)

Design and Execute CFD Validation Experiments

Testing of the CRM-HL models will expand the CFD validation database

Advancing the State of the Art of CFD to predict $C_{L,max}$

Challenge: To reliably predict the complex flow physics near $C_{L,max}$ and provide high quality experimental data that validates the CFD prediction of critical flow phenomenon.

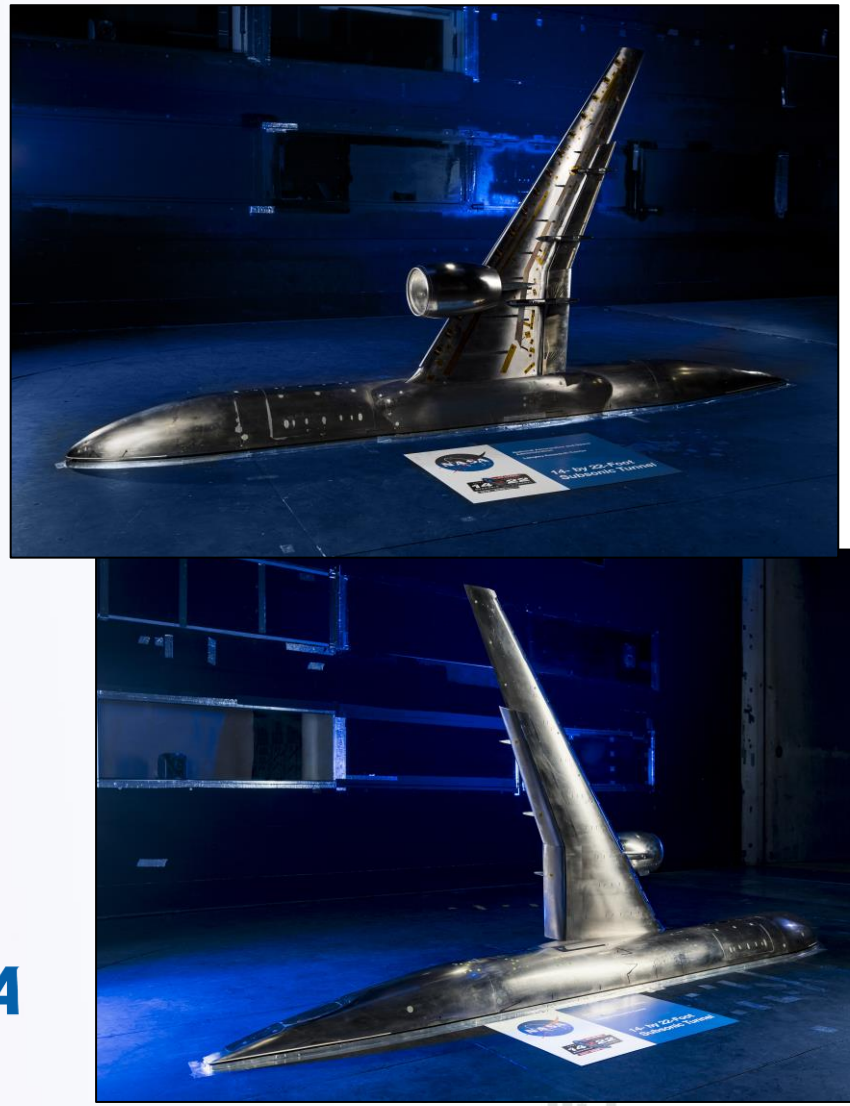
Action: Conduct CFD validation experiments in different wind tunnels to add to the validation database in order to assess transition, turbulence models, and Reynolds number effect predictions.

Impact: Successfully completed first test of a new High Lift Common Research Model (CRM-HL) ecosystem model in the 14x22 wind tunnel.

- Completed the fabrication of a new 5.2% scale CRM-HL cryogenic model in August 2022.
- Executed a check out test of this new model in the NASA LaRC 14x22 wind tunnel facility in September 2022.
- Provided valuable information on installation and testing procedures for this new model before it is tested in other facilities.

DLR BOEING ONERA THE FRENCH AEROSPACE LAB Kawasaki JAXA

Partners in the CRM-HL Ecosystem Development Plan

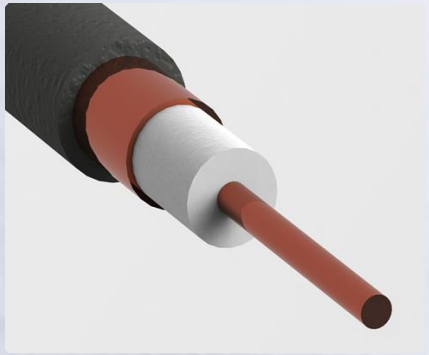


New 5.2% scale CRM-HL model mounted in the 14x22 wind tunnel

Foundational Electrified Aircraft Propulsion (FEAP) Sub-project Overview

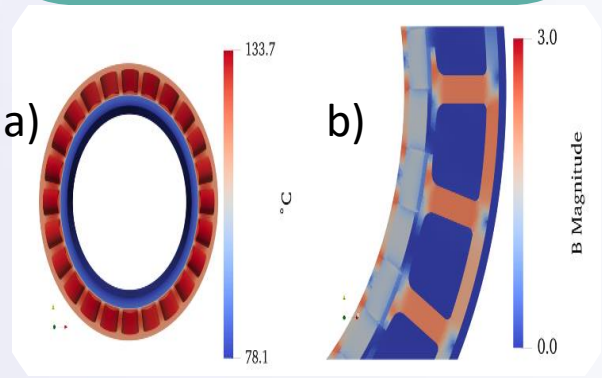
Enables the performance, reliability & durability of electrified propulsion systems by conducting enduring research & developing innovative materials, components, tools & methods that support needs in ARMD mission programs

Objective 1: Enable high voltage and high-power distribution for EAP Systems *(M&S)*



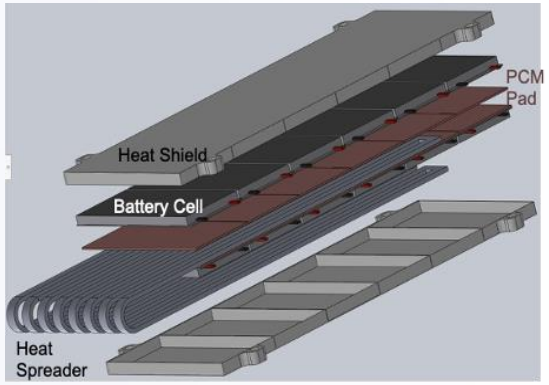
Power Cable Model For Electric Materials

Objective 2: Develop optimization tools and methods for electric and hybrid-electric vehicle design *(MDAO, Controls)*



a) Electric Motor stator thermal analysis
b) Stator magnetic flux-density

Objective 3: Develop safe battery technologies to improve performance metrics for EAP *(M&S, MDAO)*



Preliminary Battery Design Pack Configuration

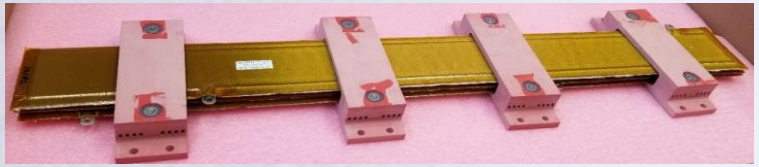
M&S – High voltage power cables to further sustainable aviation

L2 Milestone Demonstration of High Voltage Busbar with Micro-Multi-Layered Electrical Insulation (MMEI)

	NASA MMEI Busbar	SOA Busbar
Avg Weight Insulation	363 grams → ~ 15% ↓	427 grams
Avg. Thickness Insulation/side	0.71 mm (28 mils) → ~ 12% ↓	0.81 mm (32 mils)
Standard HiPot and PD Test up to 15kVAC	Completed and passed	Completed and passed
Dielectric Breakdown up to 15kVAC	NO	NO

Impact: Successfully demonstrated manufacturability of MMEI on Busbar completed on a full-scale 1 meter, 3-phase prototype.

Busbar with SOA insulation



NASA Busbar with MME insulation

New capability investments supported by T³

Automated Materials Experient Lab (AMEL)

- Increases speed of materials experiments by orders of magnitude (100s of experiments in a few days)
- Increases accuracy of experiments

High Voltage Environmental Chamber

- COVID impact; completion Q1 FY23

Capabilities

- Voltage: 0 V to ± 10 KV DC or AC p-p
- Current = 10 mA
- Frequency = 1 µHz to 20 MHz with 1µHz resolution
- Pressure (altitude): 1.7 psia (50 kft) to 14.7 psia (sea level)

Expected delivery, installation & training August 2023

ARMD and STMD Projects, DOE & SAE AeroTech seeking our expertise on this subject matter

- Shaping future requirements with key contributions to 2 SAE AE High Voltage coordinating and standards committees
- Collaborating with AATT & EPFD
- Consulting with RVLT and NEP (STMD)

Battery System Architecture Design and Testing

Rapid design, fabrication, and experimentation to collect data for safely integrating batteries in electric aircraft

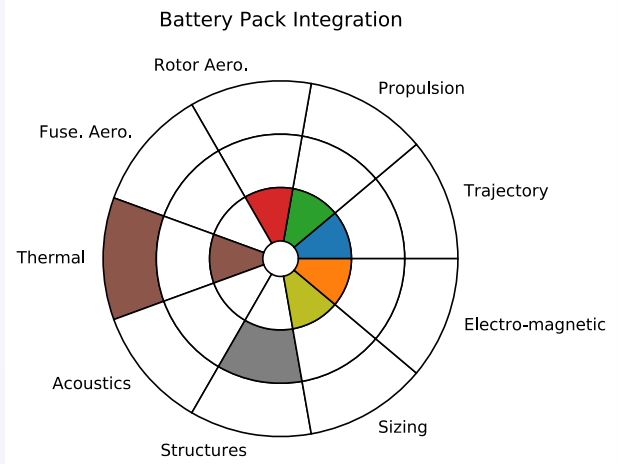
Results

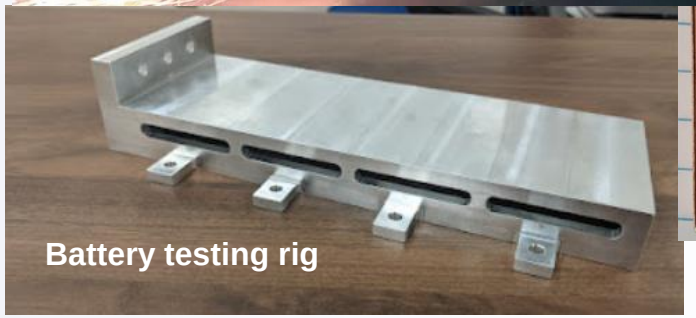
- Amprius silicon nanowire anode cells used at 5.2Ah and 410 Wh/kg
- Required thermal runaway (TR) data to finalize geometry, specify a phase change material (PCM), and validate aerogel
- Aerogel reduced max cell surface temperature compared to no aerogel
- Max temperature on opposite side of aerogel was 38˚C
  - *Good option for preventing heat spread to adjacent cells*

Impact

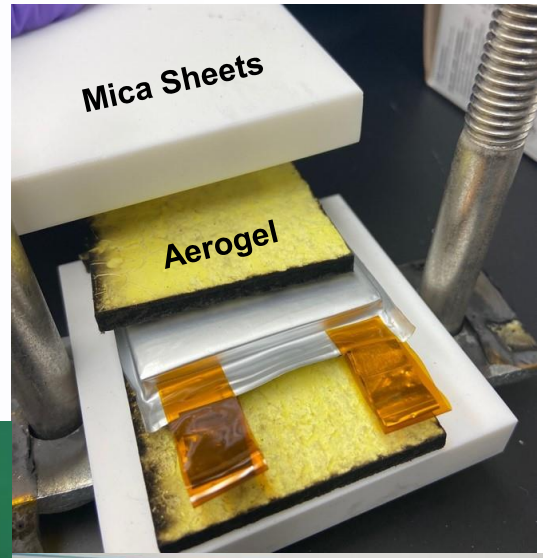
- Leverages T^3 developed tools and methods from enduring disciplines (Mphys, OpenMDAO)
- Rapid design, fabrication, experimentation, and iteration. Multiple design and test cycles complete yearly
- Develop relationships for thermal management weight as a function of battery architecture, size, and composition
- Provide fundamental data needed on battery system architecture for UAM/AAM aircraft

Tests provided unique, previously unavailable data on thermal runaway for these cells





Test setup for TR



Cu-Mo-Cu enclosure for TMS system testing

Revolutionary Aviation Mobility Sub-Project

Overview

Supports ARMD mission programs by providing a pipeline of solutions and knowledge for foundational challenges in enabling an AAM market.

Enables increasingly autonomous transportation in the UML-4+ timeframe

Content supports ARMD Strategic Thrusts 1, 4, 5, and 6

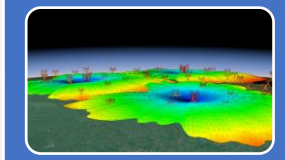





GOAL Provide leading edge tools, technologies, and research findings to enable increasingly autonomous AAM transportation in the UML-4+ timeframe

OBJECTIVES

Enable scalable operations for AAM through development of an m:N operational approval roadmap supported by community coordination and critical tool and technique research (TC/FY27] {AS}



Explore and develop airspace management and operations architectures and tools in expectation of increased heterogeneous air traffic {AS, CNS, MDAO}

Develop modeling, performance, and control tools & techniques for advanced urban capable aircraft {Controls, MDAO, AS}

Explore and demonstrate approaches for scaled vehicle production {M&S}

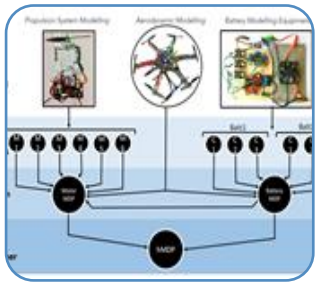
RAM Portfolio Overview

Multidisciplinary approach to tackling the fundamental challenges for ubiquitous AAM

Human Autonomy Teaming

As autonomy increases, need to carefully consider human behavior. It'll require humans and machines to work and think together in new and different ways.

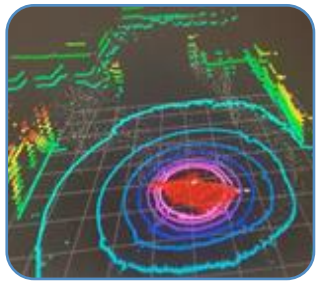
Activities: Research tools & sims with partners, community working group



AutoMitigate Assurance Efficacy

Need to understand the limitations and evidence required for auto-mitigation functions to enable the functions in SWS' In-time Aviation Safety Management System.

Activities: Arguments & artifacts for acceptance of auto-mitigate functions, flight validation



Distributed Sensing

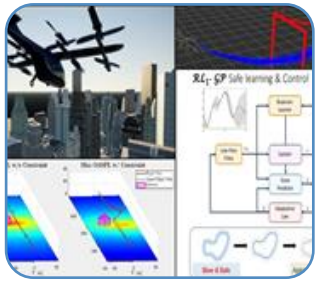
Replacing the "pilot's eyeballs" is no easy feat. Distributed sensing provides a more comprehensive knowledge of the environment, increasing safety and capability of the system.

Activities: Common perception framework with distributed info sources; flight demos

Communication, Navigation, & Surveillance

As air traffic density increases, new strains on the system will occur, such as increased comm interference and spectrum demand.

Activities: Autonomous spectrum allocation, self-optimizing phased array antennas



Intelligent Contingency Management

Need advances in state-of-the-art autonomous vehicle systems. Vehicles will need to deal with predictable and unpredictable scenarios without human intervention.

Activities: Learning-based approaches to handle off-nominal conditions, autonomous decision tools

Efficient design & testing of AAM vehicles

AAM eVTOL vehicles are very complex, resulting in increased time and expense to design and test.

Activities: Novel methods for efficient flight and ground testing; perception-influenced design of propeller blades

Multi-Vehicle (m:N) Operations Research

Informing the design of a scalable, profitable AAM future

Challenge: To achieve scalable, profitable AAM operations, multi-vehicle or m:N ops is required, where a small number, m, of ground operators manages a large number, N, of highly autonomous aircraft

Action: Collect critical human autonomy teaming data that supports safe, efficient command & control of multiple UAS (m:N ops).

Results/Impacts

- Studied trust in human-autonomy teams by collecting and analyzing human factors data from mission project flight tests on CERTAIN range
- Supplied knowledge gained to update ground control station and ops for improved flight-testing capability for mission project goals
- Most recently, worked with MaRERA to achieve multi-vehicle flight capability with 1 remote operator supervising 2 live aircraft with handoffs between operators
- Won ARMD AA Award for Technology and Innovation Group
- Engaged students via internships, dissertation committee service & Center visits

Remote Operations for Autonomous Missions (ROAM) lab with 3 active ground operators

Joint funding for ROAM; provide ops for human factors study in T³

AAM-HDV,
CAS-STEReO, MaRERA,
future: SWS TC-5, ACERO

Developing the foundation of human-autonomy teaming for increasingly autonomous systems by leveraging mission project flight tests

Collaboration on GCS design for m:N ops (in discussion)

Boeing/Wisk
American Robotics

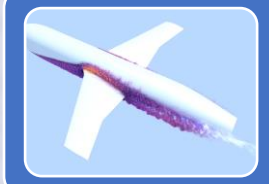
Collaboration on human-in-the-loop studies

ODU

National Aeronautics and Space Administration

POC: Eric Chancey/LaRC

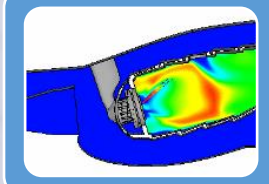
Enduring Disciplines Overview



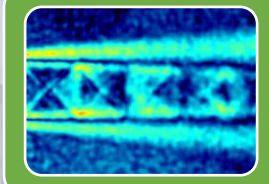
Revolutionary Computational Aerosciences (algorithms, meshing, transition, AI/ML)

Materials & Structures (EBC/CMC, SMAs, part of High Temp Alloys)

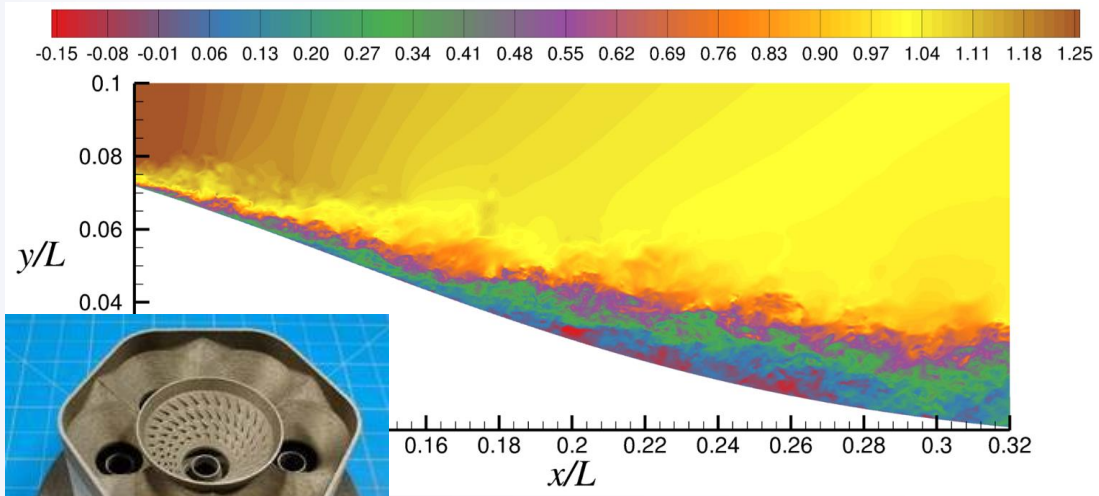
MDAO (Enduring tools, uncertainty)

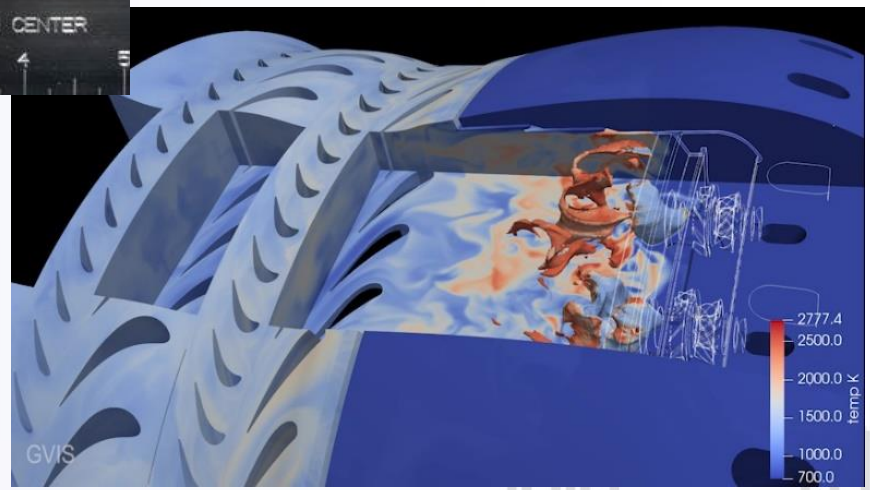


Combustion (Modeling and Experiments)



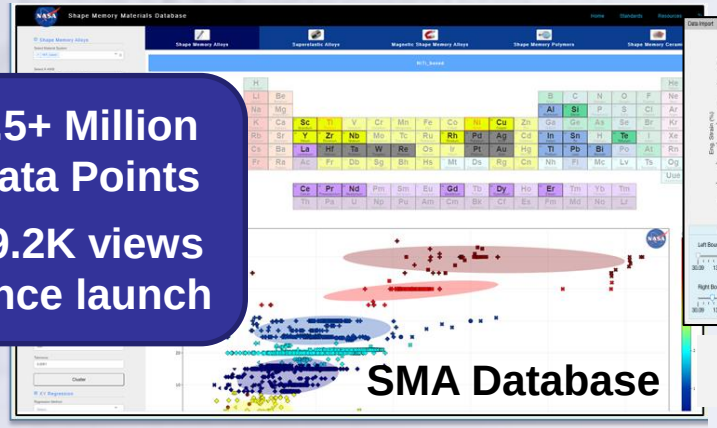
Innovative Measurements (Cutting-edge measurement techniques)





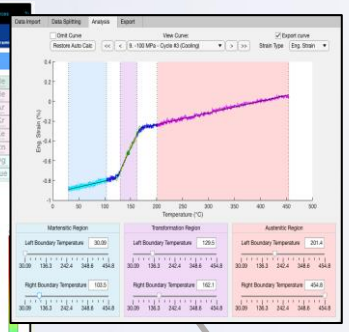
World's Largest Shape Memory Alloy (SMA) Database Enables Development of Two New Alloys in One Year

Dissemination of Information



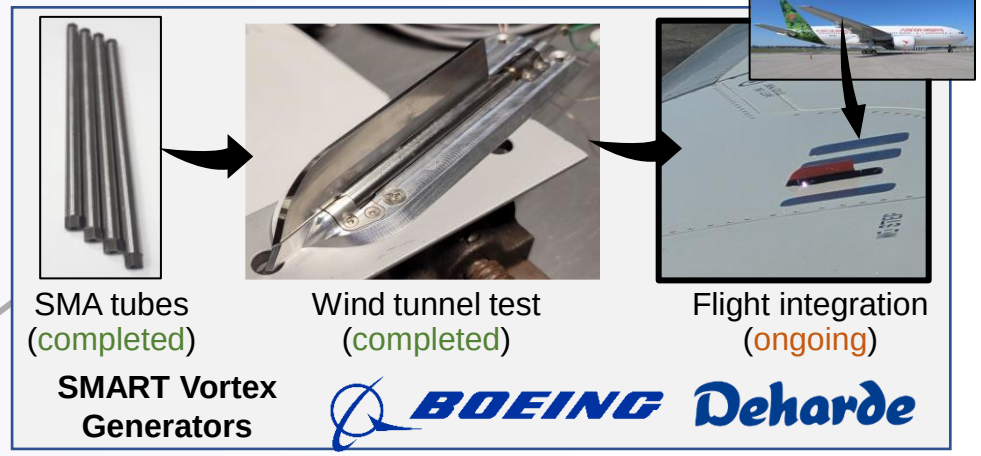
1.5+ Million Data Points

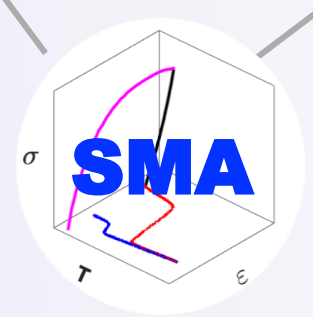
59.2K views since launch



SMAnalytics Tool

Technology Demonstration





Launched Shape Memory Materials Database & Analysis Tool via a web portal

- Completed the database functionality for ALL materials category
  - **Impact**: Enable faster, ***efficient***, accurate design of SMAs (in line with Vision 2040)
- Tool publicly launched via a web application
  - **Impact:** Promote database growth and data mining via direct scientific community contributions

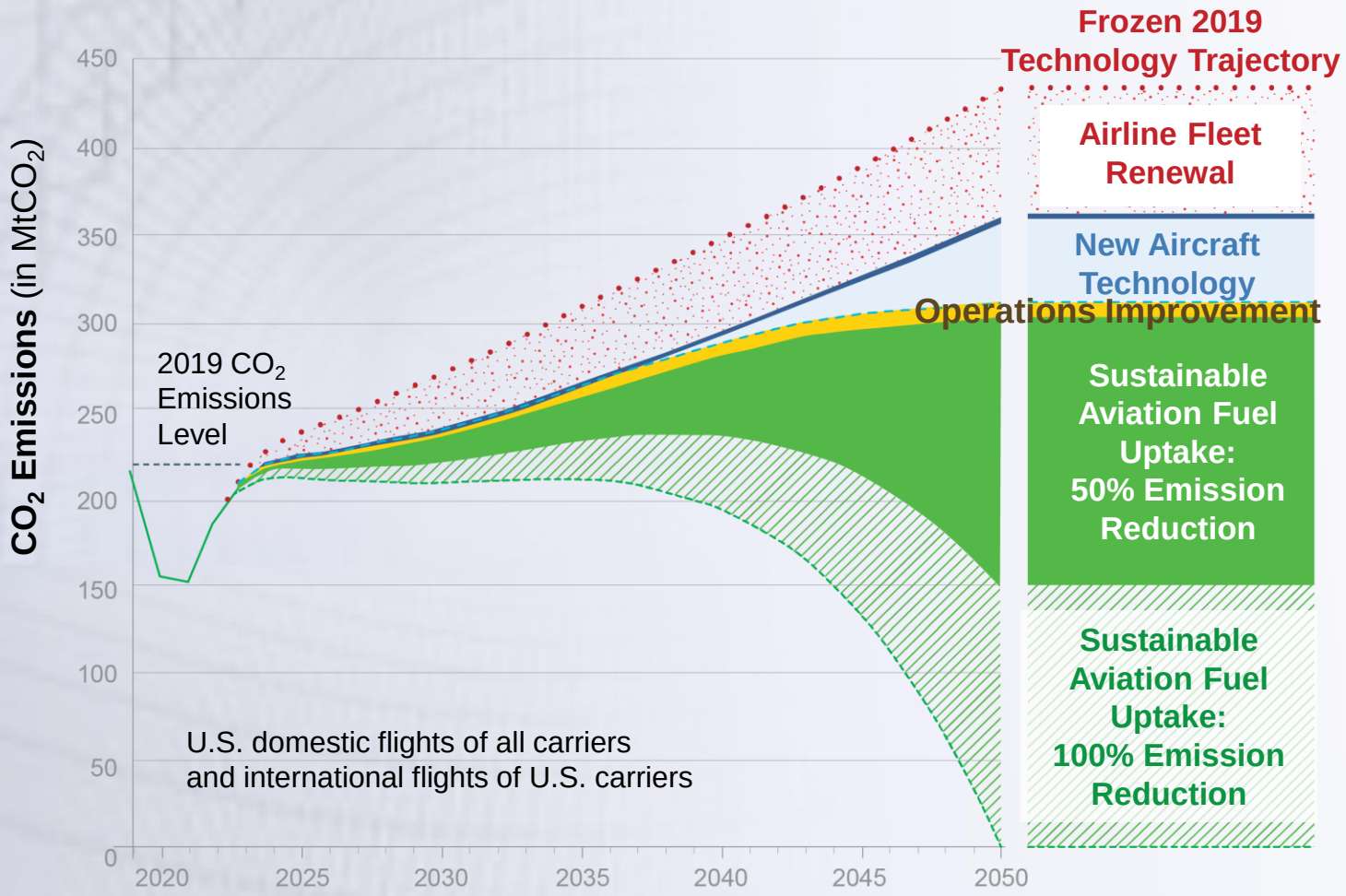
Developed <u>TWO new experimental alloys</u> for FY22 Boeing ecoDemonstrator flight test with two key advancements

- <u>Alloy properties</u>: Improvements in activation temperatures and hysteresis
  - **Impact:** Expand applicability beyond "standard day" flight profile
- <u>Production methods</u>: Newly developed tube production methods helped for fast turnaround (using melt suction casting)
  - **Impact:** Seamless transition to high volume production levels

T^3 established a new FY23 Annual Performance Indicator (API) 23-3.2.3.5 for SMART VGs testing and benefits assessment

U.S. Aviation Climate Action Plan – T^3 Contributions

Global Context for Sustainable Aviation



Insert new technologies into the fleet and accelerate certification

- Improve fuel efficiency
  - Aerodynamic efficiency
  - Engine fuel burn
  - Reduced weight materials & structures
- Certification by Analysis
  - Non-conventional configurations
  - Greater portion of flight envelope
  - Icing
  - Additive Manufacturing

Alternative Power and Propulsion

- Sustainable Aviation Fuels
  - Combustion and Emissions
- Enable more (hybrid) electric aircraft
  - Power cables, batteries
  - Control algorithms

The U.S. is working with the global community to achieve net-zero greenhouse gas emissions by 2050 using a common basket of measures

Potential Future T^3 Sustainability Elements

QUANTIFY THE IMPACT – *Improved tools* for system studies, with adequate fidelity in the required modules, focused throughout the lifecycle, to enable accurate assessment of new ideas

- Tools to quantify lifecycle carbon emissions, including new tools specific to the aircraft life cycle
- Climate chemistry, contrail formation, fuel sensitivity of soot generation

DESIGN AND ANALYZE – *New tools* to support the design, analysis, and optimization of new power architectures and thermodynamic cycles for alternative fuels

- Tools to design, analyze, and optimize power and propulsion architectures for new energy futures (e.g., based on hydrogen, ammonia)
- Tools to design, analyze, and optimize vehicles with tightly integrated power and propulsion

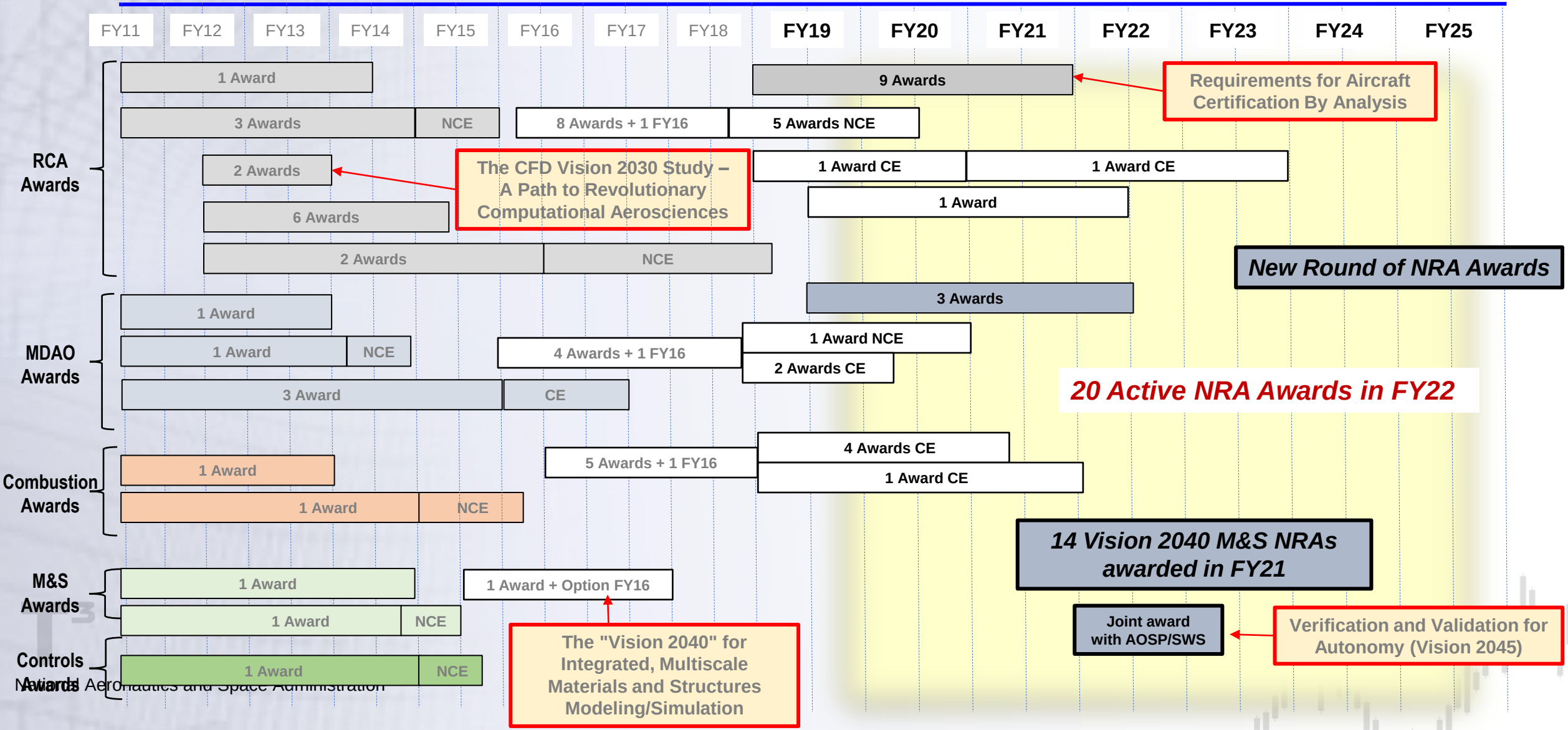
BUILD IT – *New material solutions* to enable electrification and other new power architectures, including survival in harsh environments

- Composite cryotanks for hydrogen, physical understanding/tools to predict hydrogen embrittlement, advanced insulation, multifunctional structures
- Lightweight, additively manufactured, refractory alloys for high temperature applications
- Suitable chemistries and materials for high-power, high-temperature proton-exchange membrane fuel cells, lightweight thermal management systems, lightweight superconductive materials
- Multiphysics modeling tools utilizing Machine Learning and Artificial Intelligence
- Recyclable materials

NRAs: Establishing Visions with the Community

Assessing Promising New Ideas with Universities

T^3 Awards



Join us for imaginAviation on 28 Feb-2 Mar

IMAGINAVIATION

3-day virtual event featuring the latest innovations in Aeronautics

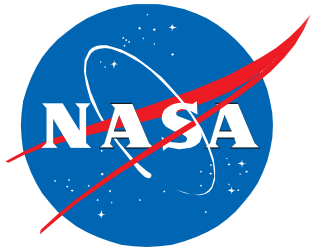
- Engage real-time with industry leaders and NASA subject matter experts
- Listen to invigorating talks on how we can transform the future of aviation
- Learn about STEM engagements with K-12 & University students
- Gain technology insights

SCAN ME

Registration is now open at https://nari.arc.nasa.gov/imaginAviation/

Looking Ahead to T³ Project Major Accomplishments in FY23…

- Complete "**Gen 2" SMART-VG system flight tests on the Boeing ecoDemonstrator** 777-200X airplane, along with high-fidelity analyses of fleet drag reduction and fuel savings benefits ~~(new API Milestone for FY23)~~
- **Common Research Model-High Lift (CRM-HL) wind tunnel testing** (with simulated ice shapes in NTF)
  - DLR testing the **5.2%-scale CRM-HL model** in the Low-Speed DNW-NWB wind tunnel in Braunschweig (May/June 2023)
  - Testing the **2.7%-scale Full-Span CRM-HL model** in the LaRC National Transonic Facility (NTF) wind tunnel (~~July~~ Sep 2023)
  - Testing the **5.2%-scale CRM-HL model** in the LaRC NTF wind tunnel (~~Sep~~ Dec 2023)
- Begin **multi-stakeholder human-in-the-loop (HITL) sims** at ARC investigating operator-controller communication architectures for autonomous multi-vehicle operations informed by ConOps from three partners (Joby, Wisk, Zipline)
- Fielding **new NRA solicitation** with six sub-topics across RCA, Icing, MDAO, and AS
- Complete **V&V for Autonomy Vision 2045 NRA effort** with AOSP/SWS (Dec 2022)


NASA

Acronym List

Acronym	Definition
AAM	(IASP) Advanced Air Mobility
AATT	(AAVP) Advanced Air Transport Technology
AAVP	Advanced Air Vehicles Program
ADaPT	Antenna Deployment and oPtimization Technologies
AePW	Aeroelastic Prediction Workshop
AERoBOND	(CAS) AdhEsive fRee BONDing of Complex Composite Structures
AETC	Aerosciences Evaluation and Test Capabilities
AFRL	Air Force Research Lab
AI	Artificial Intelligence
AI/ML	Artificial Intelligence/Machine Learning
AIT	Adaptive Icing Tunnel
AM	additive manufacturing
AMEL	Automated Materials Experient Lab
AMIO	AAM Mission Integration Office
ANL	Argonne National Laboratory
AoA	Analysis of Alternatives
AOSP	Airspace Operations and Safety Program
ARMD	Aeronautics Research Mission Directorate
AS	Autonomous Systems
ASNP	air service navigation providers
ATAG	Air Transport Action Group
ATM-X	(AOSP) Air Traffic Management eXploration Project
ATTAM	Advanced Turbine Technology for Affordable Missions
AUVSI	Association for Unmanned Vehicle Systems International
AVSI	Aerospace Vehicle Systems Institute
BNNS	Boron Nitride Nanosheet
BOS	Background Oriented Schlieren
BVLOS	beyond visual line of sight
C2QA	Co-design Center for Quantum Advantage
CAS	(TACP) Convergent Aeronautics Solutions
CASMART	Consortium for the Advancement of Shape Memory Alloy Research and Technology
CbA	certification by analysis
CFD	Computational Fluid Dynamics
CLAS-ACT	(CAS) Conformal Lightweight Antenna Structures for Aeronautical Communication Technologies

Acronym	Definition
Clmax	the maximum lift coefficient of the airfoil
CM4QC	Computational Materials for Qualification and Certification
CMC	Ceramic matrix composite
CMH	Composite Materials Handbook
CNS	Communication, Navigation & Surveillance
CST	(AAVP) Commercial Supersonic Transport
DASC	Digital Avionics Systems Conference
DCB	Double Cantilever Beam
DECWG	Distributed Engine Control Working Group
DFT	Density functional theory
DNW-NWB	German-Dutch wind tunnels
DoE PNNL	(DoE) Pacific Northwest National Laboratory
DTU	technical university of Denmark
EAP	Electrified Aircraft Propulsion
EBC	Environmental Barrier Coatings
EPFD	(IASP) Electrified Powertrain Flight Demonstration Project
ESDMD	Exploration System Development Mission Directorate
ESI	early stage innovation
eVTOL	electric vertical takeoff and landing vehicles
FAA	Federal Aviation Administration
FDC	(IASP) Flight Demonstrations & Capabilities Project
FEAP	Foundational Electrified Aircraft Propulsion
HATTB	Human-Autonomy Teaming Task Battery
HDV	High Density Vertiplex (aka the AAM Subproject)
HECC	High Efficiency Centrifugal Compressor
HENAAC	Hispanic Engineer National Achievement Awards Corporation
HiCAM	(AAVP) Hi-Rate Composite Aircraft Manufacturing Project
HiPER	High Performance Electromagnetic Rig
HiPot	high potential
HITL	Human in the Loop
HL-CRM	High-Lift Common Research Model
HLPW4	High-Lift Prediction Workshop – 4
HPC	High performance computing

Acronym List (cont.)

Acronym	Definition
HRLES	Hybrid Reynolds-Averaged Navier-Stokes and Large Eddy Simulation
HT	high temperature
HTP	(AAVP) Hypersonic Technology Project
HV	high voltage
HyTEC	(AAVP) Hybrid Thermally Efficient Core
IASP	Integrated Aviation Systems Program
ICAO	International Civil Aviation Organization
ICCCRD	Interagency Coordinating Committee on Ceramic Research and Dev.
ICME	Integrated computational materials engineering
IFAR	International Forum for Aviation Research
IHMC	Institute for Human & Machine Cognition
IM	Innovative Measurements
IML	inner mold line
L2	level 2 milestone
LBFD	(IASP) Low Boom Flight Demonstration
LOFTID	Low-Earth Orbit Flight Test Inflatable Decelerator
LSAWT	Low Speed Aeroacoustic Wind Tunnel
LSHR	low solvus high refractory
LxC	Likelihood x Consequence
M&S	Materials & Structures
m:N	m is a small number of operations. N is a large number of aircraft
MACCCR	Multi-Agency Coordinating Committee for Combustion Research
MaRERA	Multi-aircraft Remote Emergency Response Assessment
MBSA&E	(AATT) Model-Based Systems Analysis & Engineering
MCAAD	Modeling and Control of Agile Aircraft Development
MDAO	Multidisciplinary Design, Analysis & Optimization
MDM	Material Data Management
MDMC	Material Data Management Consortium
MEC	Multidisciplinary Engineering Challenge
MMEI	Micro-Multi-Layered Electrical Insulation
MPATH	Measuring Performance for Autonomy Teaming with Humans
MPEAs	multi-principal element alloy
MSFC	Marshall Space Flight Center

Acronym	Definition
NESC	NASA Engineering and Safety Center
NETL	National Energy Technology Laboratory
NJFCP	National Jet Fuels Combustion Program
NRA	NASA Research Announcement
NREL	National Renewable Energy Laboratory
NRL	Naval Research Laboratory
NTR	New Technology Report
ODS	oxide dispersion strengthened
ODU	Old Dominion University
OFAT	one-factor-at-a-time
OGAs	other government agencies
OH PLIF	hydroxyl radical planar laser-induced fluorescence
OML	outer mold line
ONR	Office of Naval Research
OPO	optical parametric oscillator
PAAV	Pathfinding for Airspace with Autonomous Vehicles
Pcard	NASA credit card user
PD	partial discharge
PEASA	Power Electronics for AeroSpace Applications
PI	Polyimide
PIV	Particle Imaging Velocimetry
PLGRM	Portable Laser Guided Robotic Metrology
PNNL	Pacific Northwest National Laboratory
PPSA	Propulsion and Power Systems Alliance
PSP	Pressure Sensitive Paint
PSPP	Process-structure-property-performance
PTI	Programmed Test Inputs
Q&C	qualification and certification
RAM	Revolutionary Aviation Mobility
RANS	Reynolds Averaged Navier-Stokes
RAVEN	Research Aircraft for eVtol Enabling techNologies
RCA	Revolutionary Computational Aerosciences
RD&P	research development & deployment

Acronym List (cont.)

Acronym	Definition
RFI	radio frequency interference
RFI	request for information
RLCC	Reduced Life Cycle Cost
ROAM	Remote Operations for Autonomous Missions
RSM	Response Surface Modeling
RTRC	Raytheon Technologies Research Center
RVLT	(AAVP) Revolutionary Vertical Lift Technology
SAA	Space Act Agreement
SABERS	(CAS) Solid-state Architecture Batteries for Enchanced Rechargeability & Safety
SAF	sustainable aviation fuel
SBLI	shock/boundary-layer interaction
SFD	(IASP) Sustainable Flight Demonstrator
SFNP	Sustainable Flight National Partnership
SFW	subsonic fixed wing
SiC	silicon carbide
SLS	Space Launch System
SMA	Shape Memory Alloys
SMART-VG	Shape Memory Alloy Reconfigurable Technology-Vortex Generator
SMMD	shape memory materials database
SMST	Shape Memory and Superelastic Technologies
SPARRCI	(CAS) Sensor-based Prognostics to Avoid Runaway Reactions & Catastrophic Ignition
STEREO	(CAS) Scalable Traffic Management for Emergency Response Operations
STMD	Space Technology Mission Directorate
SUSAN	Subsonic Single Aft Engine
SWS	(AOSP) System-Wide Safety
T^3	Transformational Tools & Technologies
TACP	Transformative Aeronautics Concepts Program
TDT	Transonic Dynamics Tunnel
TEEM	Turbine Electrified Energy Management
THX	turbulent heat flux

Acronym	Definition
TIM	Technical Interchange Meeting
TomoBOS	tomographic BOS
ToR	Terms of Reference
TQR	Technical Quality Review
TSNA	Transformation Strengthened NASA Alloys
TTBW	(AATT) Transonic Truss-Braced Wing
TWGs	technical working groups
UI	(TACP) University Innovation
UIUC	University of Illinois Urbana-Champaign
uPSP	Unsteady Pressure Sensitive Paint
UQ	uncertainty quantification
uRANS	unsteady RANS
USDC	University Student Design Challenge
V&V	verification & validation
VEATE	Versatile Electrically Augmented Turbine Engine
VLPNT	vertical lift propeller noise
WG	working group
WMLES	Wall-modeled Large Eddy Simulation
WPAFB	Wright Patterson Air Force Base
ZOB	Cleveland Air Route Traffic Control Center