National Aeronautics and Space Administration

NASA ARMD Overview

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FAA CLEEN III Spring Meeting

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NASA Aeronautics – Vision for Aviation in the 21st Century

ARMD continues to evolve and execute the Aeronautics Strategy *https://www.nasa.gov/aeroresearch/strategy*

6 Strategic Thrusts

- Safe, Efficient Growth in Global Operations
- Safe, Quiet, and Affordable Vertical Lift Air Vehicles
- Innovation in Commercial Supersonic Aircraft
- In-Time System-Wide Safety Assurance
- Ultra-Efficient Subsonic Transports
- Assured Autonomy for Aviation Transformation

U.S. leadership for a new era of flight

Four Transformations for Sustainability, Greater Mobility, and Economic Growth

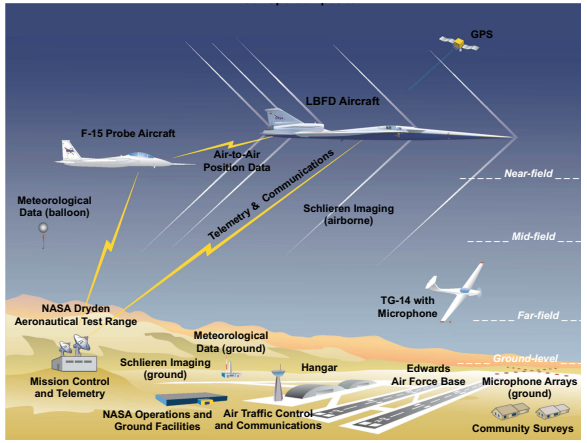
High-Speed Commercial Flight - Supersonics

Ultra-Efficient Transports - Subsonics

Quesst Mission Overview

Phase 1 – Aircraft Development

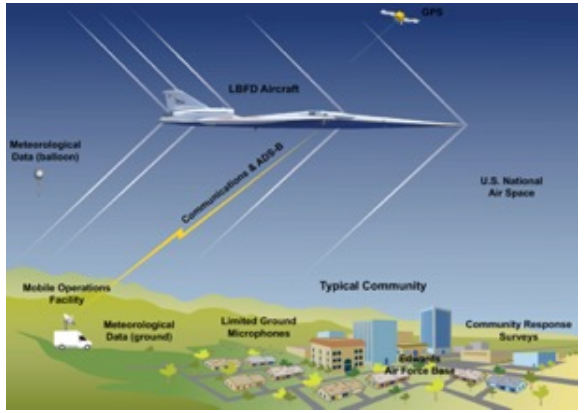
- Detailed design
- Fabrication, integration, ground test
- Checkout flights
- Subsonic envelope expansion
- Supersonic envelope expansion



Phase 2 – Acoustic Validation

- Aircraft operations & support, range operations, support aircraft
- In-flight measurement capabilities
- Ground measurement capabilities
- Validation of X-59 boom signature and prediction tools
- Development of acoustic prediction tools for Phase 3

Systematic Approach Leading to Community Testing



Phase 3 – Community Response Testing

- Aircraft operations & support, deployment
- Ground measurement capabilities
- Ground crew operations
- Noise exposure design
- Community response surveys
- Data analysis and database delivery

Commercial Supersonics LTO Noise & Prediction Uncertainty

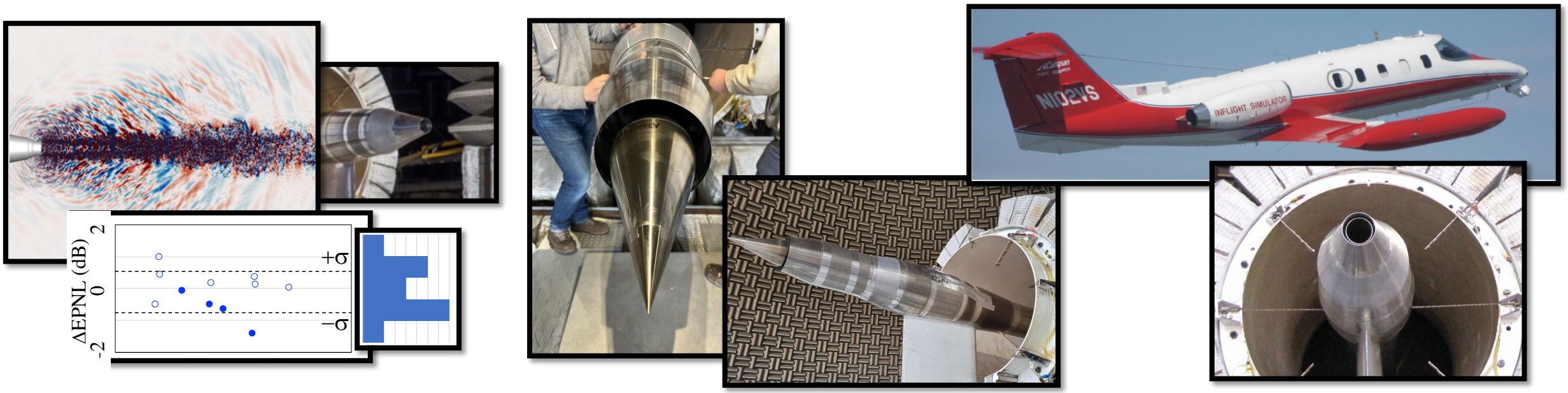
Improvements to noise prediction models used in studies of a supersonic market.

- Models based on current OEM-based aircraft designs for representative near-term aircraft.
- Data obtained by physics-based simulations, validated by model-scale tests which are validated by flight tests

Recent activities

- Acoustic flight test to acquire far-field noise from jet-noise dominated aircraft (Learjet 25), Sept 2022
- Complementary model-scale rig test using flight test variables (engine conditions, flight speeds), Sept 2022
  - Traces accuracies from simulations through flight.
- Completed external review (with FAA participation) validating NASA simulation methods for fan noise, Feb 2023

➢ **System level prediction uncertainty already showing significant reduction**



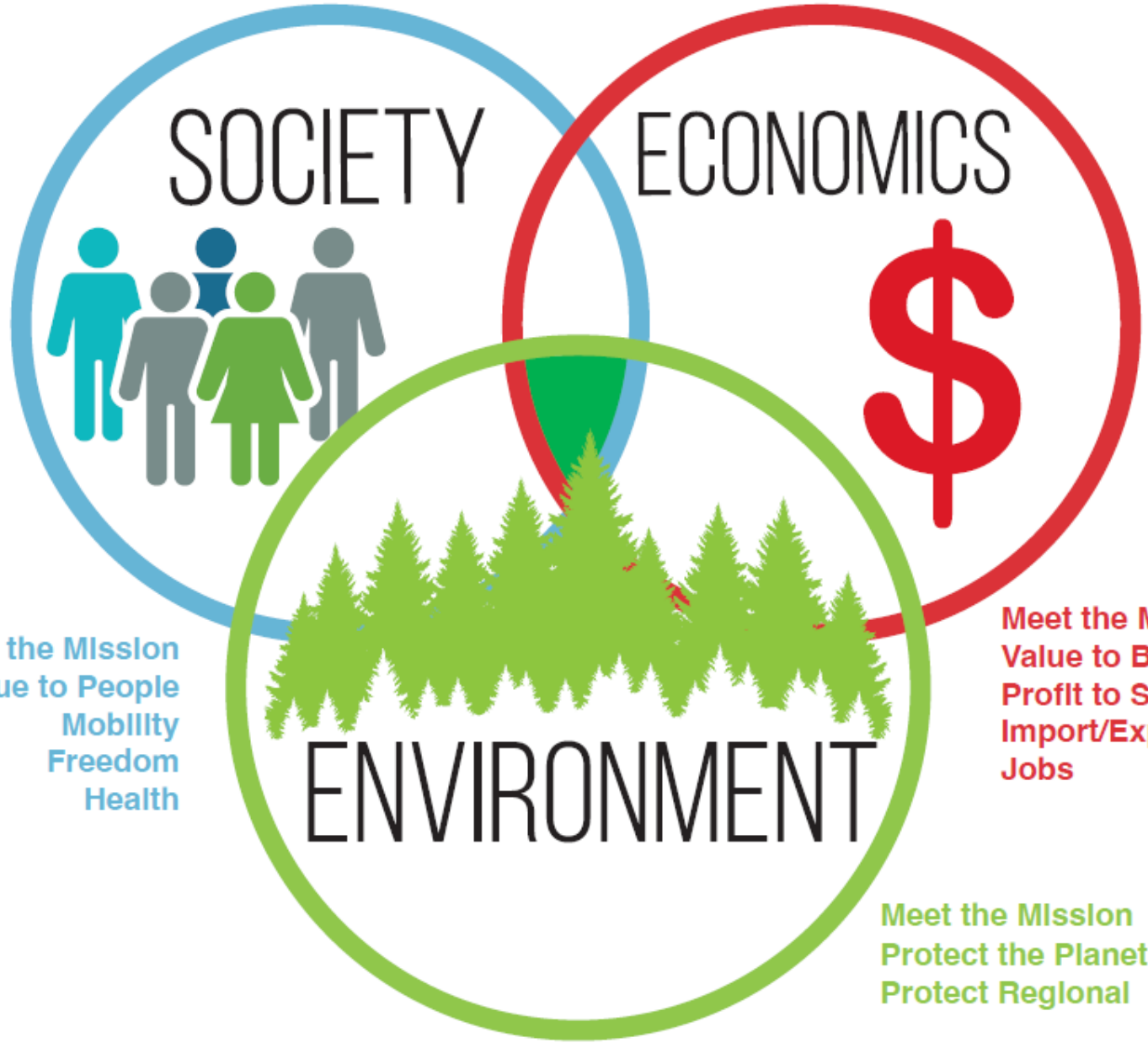
High-Speed Commercial Flight - Supersonics

Ultra-Efficient Transports - Subsonics

Sustainability – a Global View

"Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs."

- UN World Commission on Environment and Development



NASA Sustainable Aviation Strategy

Subsonic Concept/Technology Studies
Electric Aircraft Propulsion,
Transonic Truss-Braced Wing
Blended Wing Body

Environmentally Responsible Aviation Project

Flight Demonstrator Studies

Advanced Composites Project

SUSTAINABLE FLIGHT NATIONAL PARTNERSHIP

Sustainable Flight National Partnership to mature and integrate key technologies for next-generation subsonic transports (2030s)

TODAY

ACCELERATING TOWARD NET-ZERO CARBON

Cast a wide net for zero-emission concepts and technologies

Select and develop promising concepts in partnership with universities, industry

Create a credible mission, architecture, and technologies for beyond next-generation subsonic transports for 2050 horizon

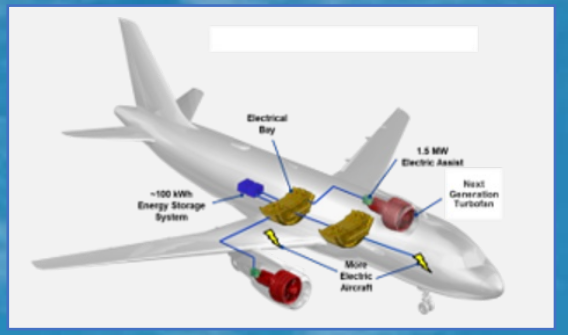
POWERING AVIATION TO NET-ZERO CARBON AND BEYOND

Investment in innovation today paves the way to a net-zero carbon and beyond aviation future.

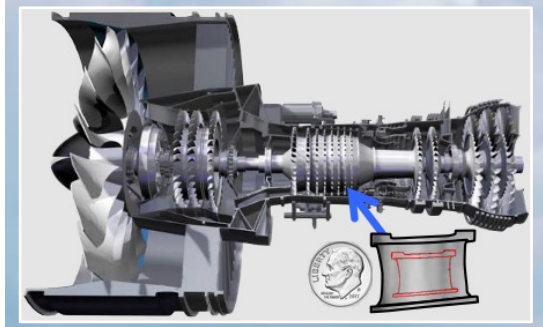
Subsonic Transport Technologies

Ensure U.S. industry is the first to establish the new “S Curve” for the next 50 years of transports

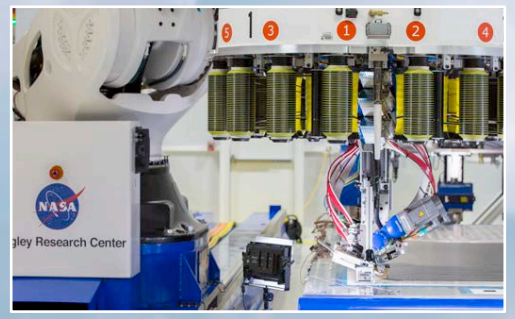
Transonic Truss-Braced Wing
5-10% fuel burn benefit



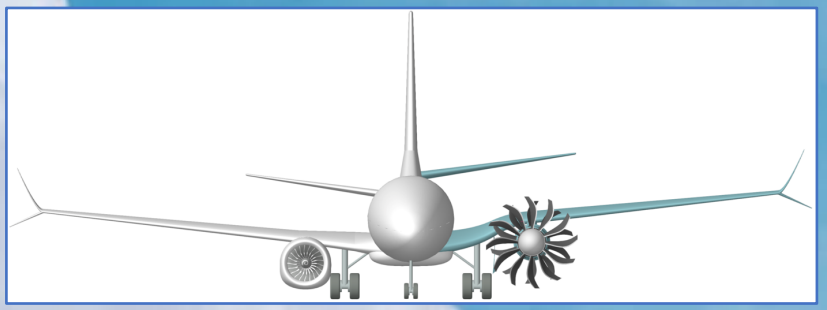
Electrified Aircraft Propulsion
~5% fuel burn and maintenance benefit



Small Core Gas Turbine
5-10% fuel burn benefit

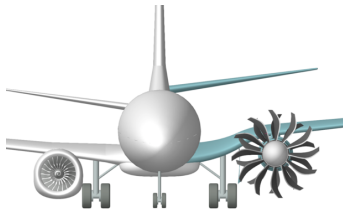


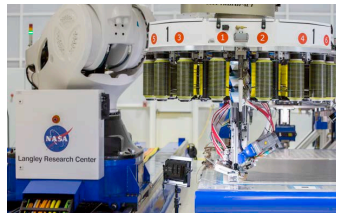
High-Rate Composite Manufacturing
4x-6x manufacturing rate increase

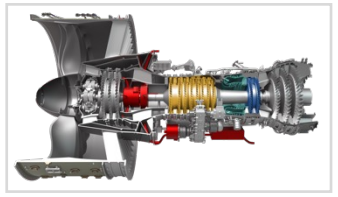


Integrated Propulsor Technology
5%+ Fuel Burn Benefit

Subsonic Transports: Integrated Technology Development







FY20 | FY21 | FY22 | FY23 | FY24 | FY25 | FY26 | FY27 | FY28 | FY29

Technology Readiness Target

"Digital Flight Test"

Model Based Systems Analysis & Engineering

Sustainable Flight Demonstrator (SFD)

Flight Test

Transonic Truss Braced Wing (AATT)

TC Completion

Efficient Quiet Integrated Propulsors (EQuIP)

Hi-Rate Composite Aircraft Manufacturing (HiCAM)

Mfg & Structural Demonstration

Hybrid Thermally Efficient Core (HyTEC)

Core Demonstration

Electrified Powertrain Flight Demonstration (EPFD)

Flight Tests

Electrified Aircraft Propulsion Technologies (AATT)

TC Completion

Achieve TRL 6 in time for industry product decision-making

Planned

Notional

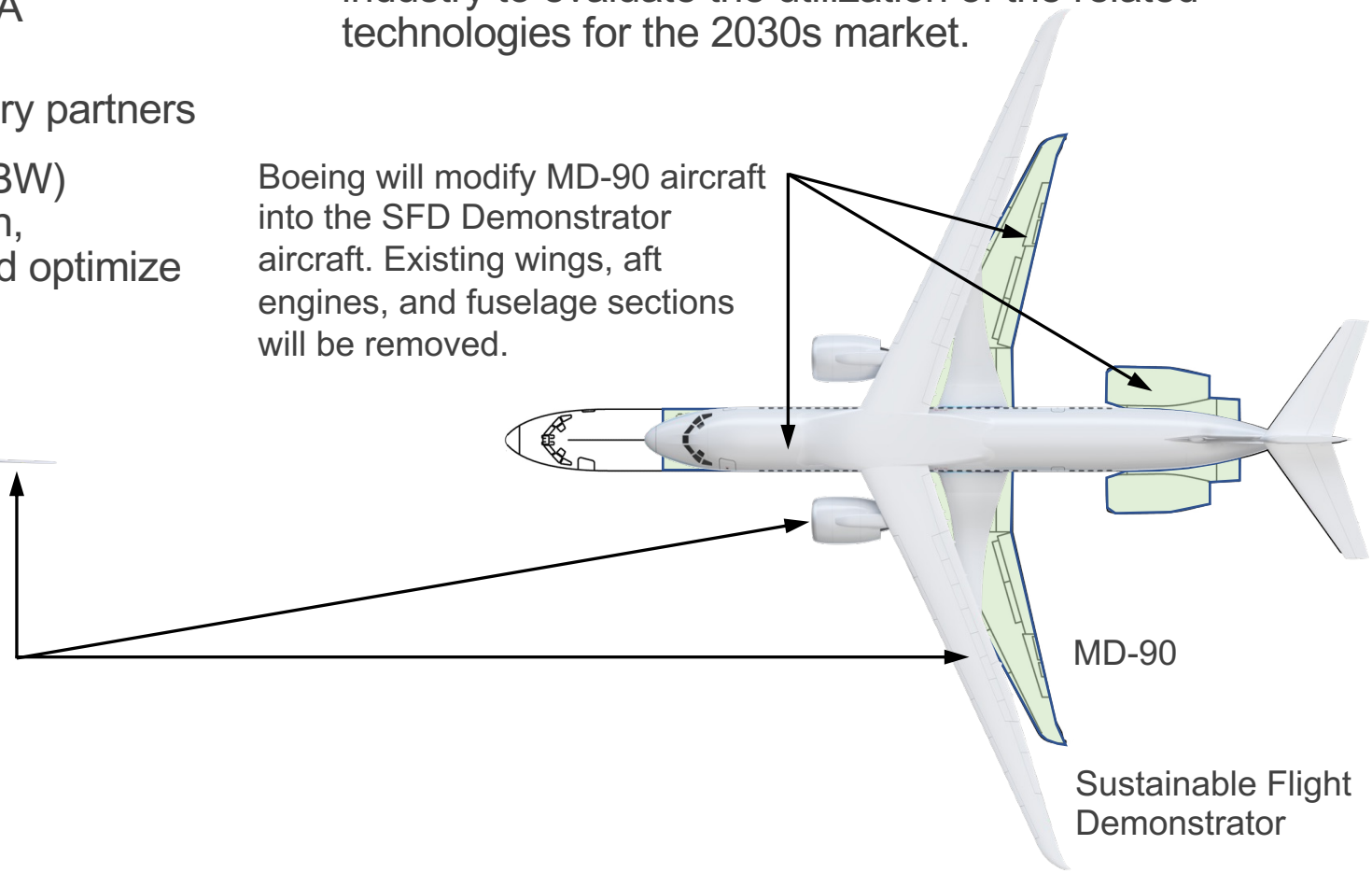
Sustainable Flight Demonstrator (SFD) Project

- **Awarded a Funded Space Act Agreement (FSAA) to Boeing in January 2023** to design, build, test and fly an advanced airframe configuration demonstrator aircraft and related technologies to **dramatically reduce fuel burn and CO_2 emissions**.
  - $425M direct NASA investment + NASA facilities/labor of ~$125M over 7 years
  - $725M funding from Boeing and industry partners
- Boeing's Transonic Truss Braced Wing (TTBW) configuration utilizes a high aspect ratio, thin, truss-braced wing design to reduce drag and optimize fuel efficiency.

SFD modification includes addition of Transonic Truss-Braced Wing and subsystems, modern turbofan engines, and instrumentation.

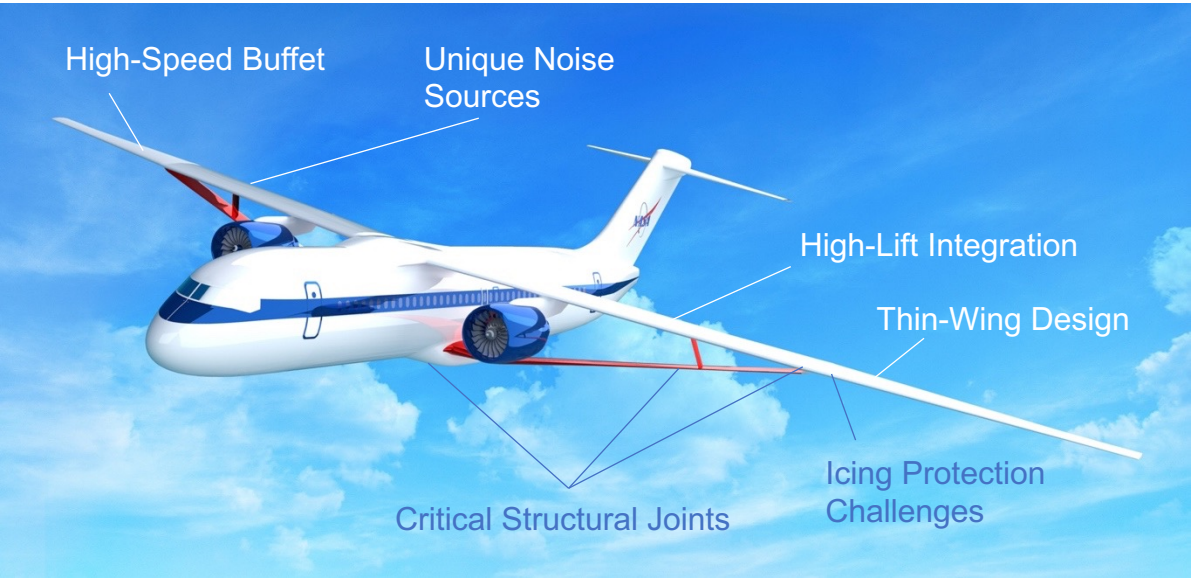
- Demonstrator aircraft will be a MD-90 aircraft modified with a truss-braced wing and shortened fuselage.
  - First flight planned for 2028.
- Completing the flight tests in the 2020s to enable the industry to evaluate the utilization of the related technologies for the 2030s market.

Boeing will modify MD-90 aircraft into the SFD Demonstrator aircraft. Existing wings, aft engines, and fuselage sections will be removed.



Transonic Truss-Braced Wing Technology Maturation

Increase confidence in technology to be robustly integrated in the aircraft system



Scope

- Mature and reduce risk of Transonic Truss-Braced Wing (TTBW) technology

Benefit

- Achieve 5-10% reduction in fuel burn through reduced drag

Approach

- Concept studies through scale model testing
- Perform high-fidelity prediction, testing and validation to increase confidence in fuel burn benefit

Update

- Documented high-speed buffet interaction tests (Fall 2022)
  - Sufficient buffet margin demonstrated
- Ongoing maturation focused on TTBW-unique issues
  - Icing, acoustics, structures, high-lift integration
- Aeroelastic wind-tunnel test of higher aspect ratio wing planned for 2023

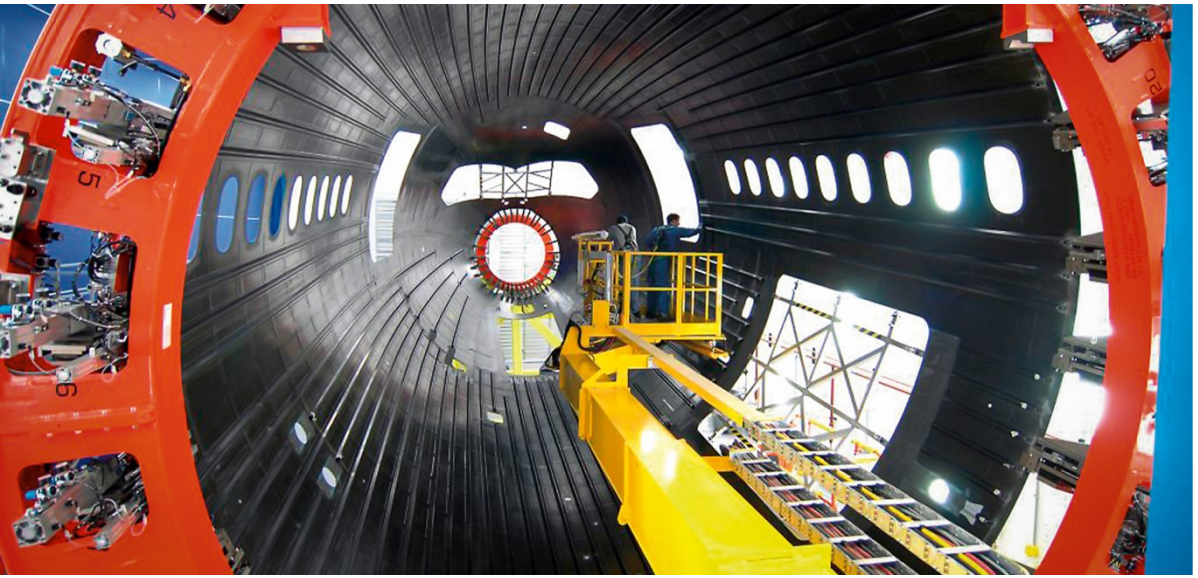
Design/Analysis/CFD studies and wind-tunnel tests are ongoing

Hi-Rate Composite Aircraft Manufacturing

4–6x production rate increase without cost or weight penalty

Production Rate per Month

• Metals	SOA:	60
• Composites	SOA:	10-15
	Target:	80-100



Scope

- Explore and advance high-rate composite manufacturing and assembly technologies
  - Evolving State-of-Art (SOA) thermosets, thermoplastics, resin transfer molding
  - Materials, processes, and architectures
  - Develop model-based engineering tools for high-rate manufacturing concepts

Benefit

- Increased manufacturing rates for composite aircraft structures to meet future production requirements and enable market penetration for lightweight composite materials

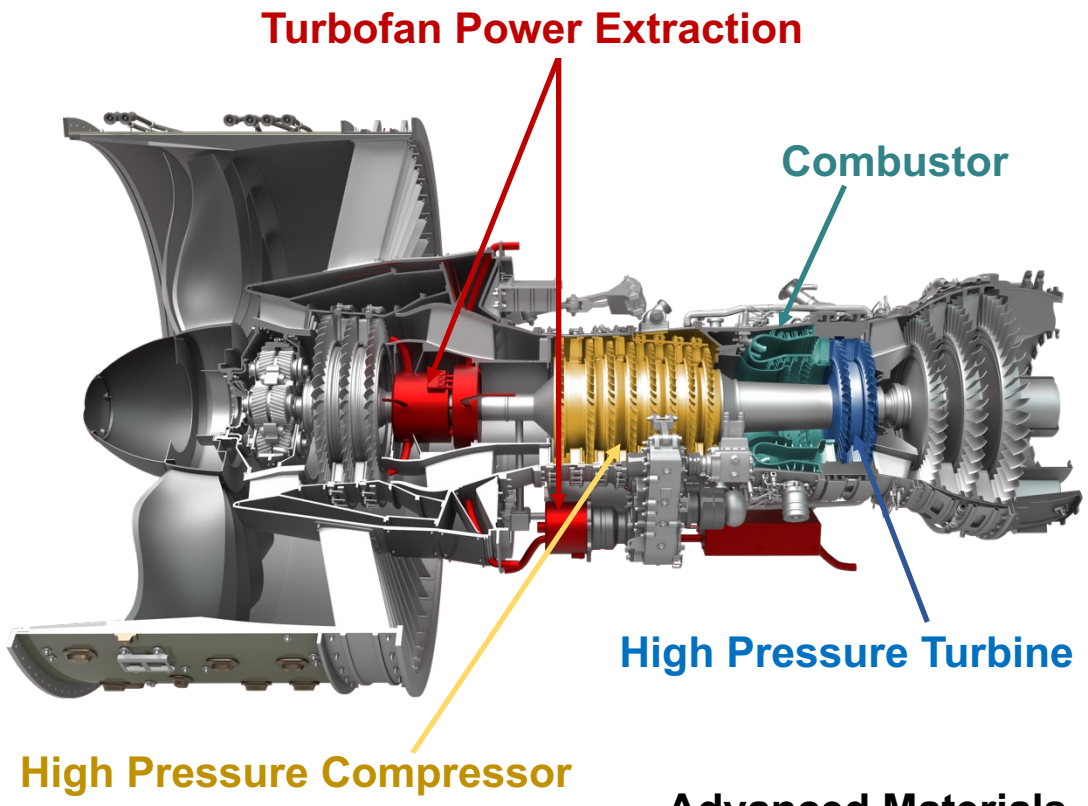
Update

- $50M (plus cost-match) in awards to 14 organizations in Advanced Composites Consortium to develop manufacturing processes and advanced composite materials for aircraft structures (March 2023)
- Developing and evaluating next-gen thermosets, resin-infused and thermoplastics composites at small-scale; including experiments in material processing, assembly, inspection, and performance

HiCAM will select the most promising concepts for full-scale demonstration (fuselage or wing) by FY27

Hybrid Thermally Efficient Core

Accelerate development and demonstration of advanced turbine engine technologies



Scope

- Develop and demonstrate in integrated ground tests engine core technologies to Increase thermal efficiency, reduce engine core size and facilitate hybridization

Benefit

- Achieve **5-10% fuel burn reduction** versus 2020 best in class
- Achieve **up to 20% power extraction** (4 times current state of the art) at altitude to optimize propulsion system performance and enable hybridization

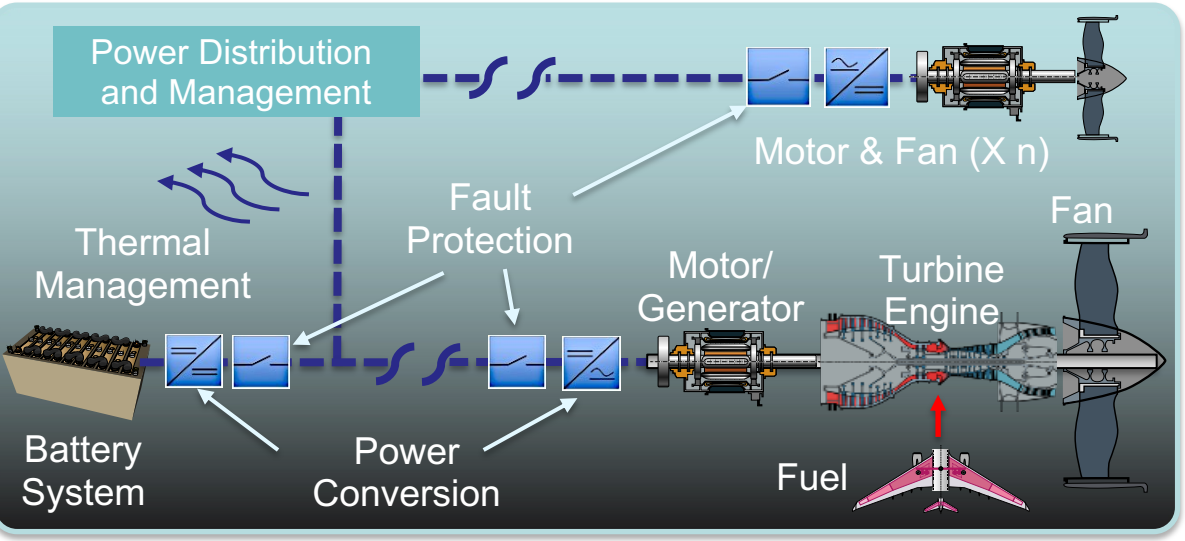
Update

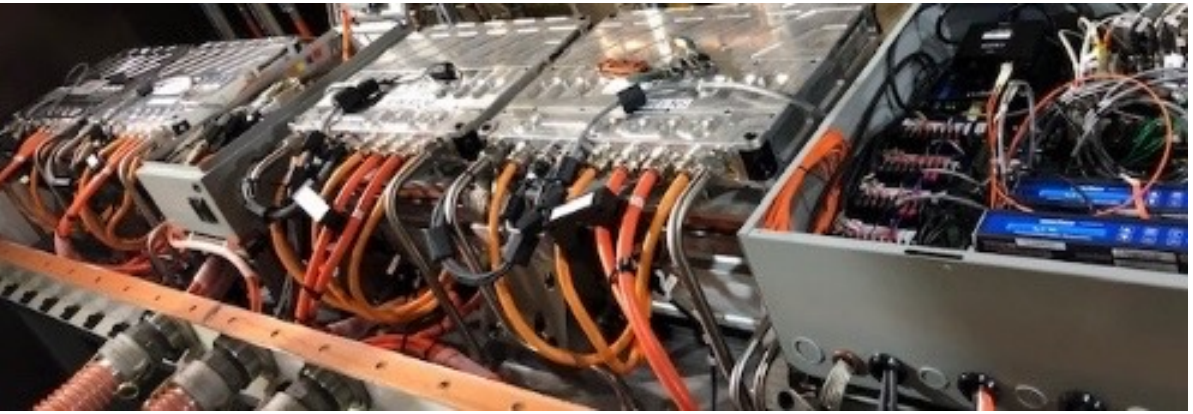
- Phase 1 small core technology development contracts are progressing toward TRL 4/5
- Supplemental awards added to initial compressor, turbine, and materials awards in Sept. 2022 for Small Core Combustor Design and SAF Compatibility technology development

Small-core turbofan technology contract awards were made in September 2021 and September 2022. Phase 2 solicitation released in March 2023 with responses due May 3, 2023.

Focused Technologies for Electrified Aircraft Propulsion

Retire barrier technical and integration risks for megawatt-class electrified aircraft propulsion systems





Scope

- Address critical challenges for electrified aircraft propulsion by maturing and reducing risk for Electrified Aircraft Propulsion (EAP) technology, focused on:
  - Mass and weight reduction
  - Electrical losses
  - Reliability
  - EMI, power quality, dynamic stability
  - Limits on DC voltage levels
  - System design and integration

Benefit

- Accelerate U.S. industry readiness to transition to EAP-based commercial transport aircraft.
- Reduce key risks for a range of future applications and help enable new standards that are needed for EAP-based aircraft certification

Update

- Prototypes complete and TRL 6 ongoing for MW-class circuit breaker technology with Navy, GE, and Raytheon as part of EAP Fault Management contracts – results favorable and highly relevant
- Testing MW motor/inverted at NEAT with ULI in 2023
- Preparing for 2 additional tests with industry partners

Completed Altitude Integrated Test of high-power, high-voltage powertrain FY22
Architecture development and high-power component tests continue in FY23

Electrified Powertrain Flight Demonstration

Demonstrate integrated electrified powertrains in flight using industry platforms

NASA concept vehicle

EPFD awardees
GE and MagniX

Scope

- Demonstrate practical vehicle-level integration of megawatt-class electrified aircraft propulsion systems, leveraging advanced airframe systems to reinvigorate the regional and emerging smaller aircraft markets and strengthen the single aisle aircraft market.
- Assess gaps in regulations/standards to support future Electrified Aircraft Propulsion (EAP) certification requirements.

Benefit

- Accelerate U.S. industry readiness to transition to EAP-based commercial transport aircraft.
- Enable new standards that are needed for EAP-based aircraft certification.

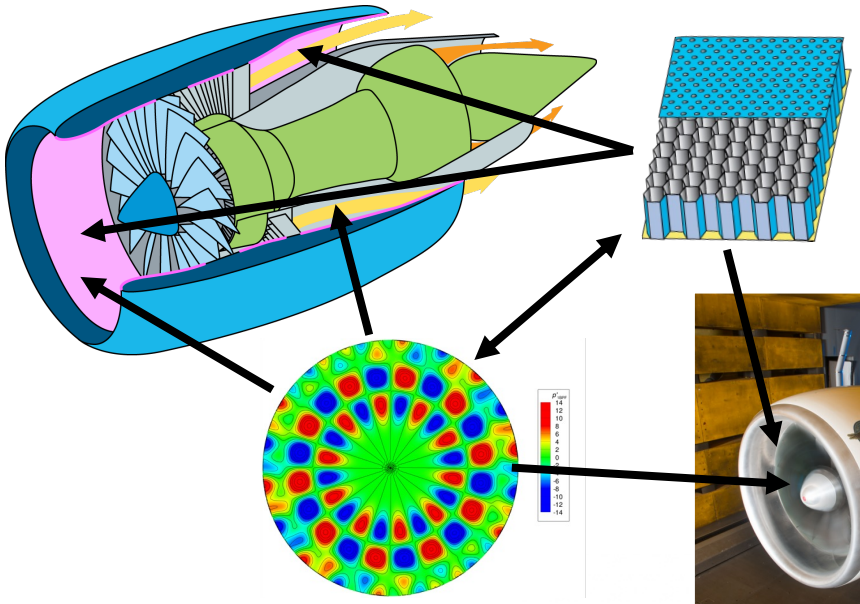
Update

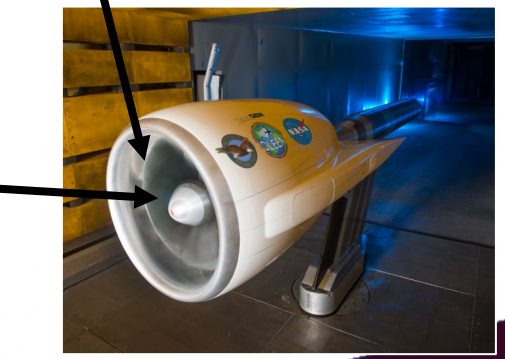
- GE Aviation and magniX USA Inc. contracts are in place to:
  - Mature MW-class hybrid electric propulsion systems
  - Demonstrate flight readiness for single-aisle aircraft
- GE CDR is planned for mid-summer 2023
- magniX PDR planned for fall 2023

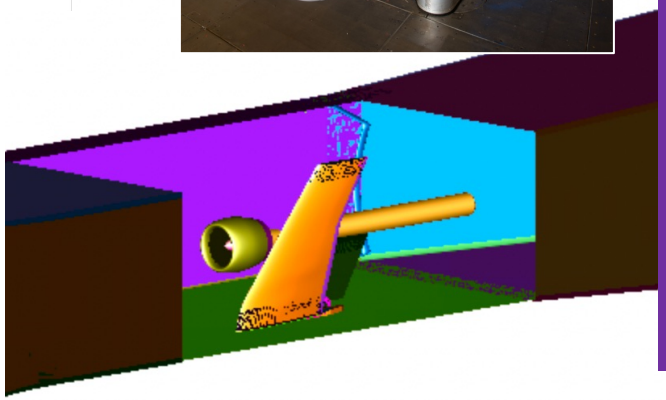
Two Flight Demonstration Contracts Awarded in September 2021
Critical Design Reviews Planned for 2H CY23

Efficient Quiet integrated Propulsors (EQuiP) TC

Support MBSA&E and industry to develop next-generation propulsors technology for SFNP goals







Scope

- Predict, model, and assess the ability for next-generation propulsor to meet market-driven noise and fuel burn reduction goals *with integration effects* and reduce risk to a new single-aisle aircraft in the 2030's.

Benefit

- Accelerate next-generation propulsor development for 5-10% fuel burn reduction and 4 EPNdB noise reduction relative to 2021 best in class propulsors
- Support MBSA&E efforts with validated models and predictions in relevant time

Approach

- Partner with industry and FAA CLEEN under the SFNP to mature and demonstrate promising technologies
- Initial in-guide scope is on propulsor but interested in partnerships for effect of propulsor-on-wing studies

Modern high bypass ratio propulsors are a dominant aircraft noise source with potential for significant efficiency gains regardless of power source but with new airframe integration challenges

2023 SAF Emissions & Contrails Flight Test Builds Upon Successful Ground Tests in 2021, 2022

eco Demonstrator PROGRAM

NASA

- Burning 100% SAF in the lean-burn CFM LEAP-1B engines on the Boeing 737-MAX shows dramatic soot reductions on the ground!

- However, we know that engine conditions at cruise altitudes are very different than those on the ground.

- Also, we need to link engine particle emissions to changes in contrail ice properties and test the skill of current contrail forecast models

Photo Credit: Boeing / Paul Weatherman

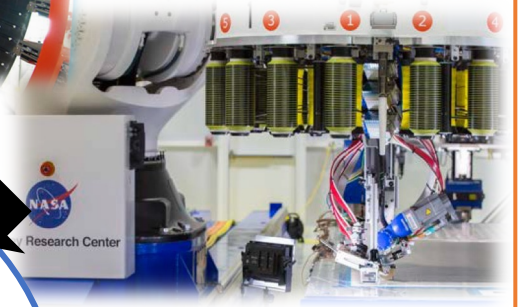
- Next step is the 2023 flight test:
  - Chase the 737-MAX with the NASA DC-8 containing comprehensive scientific instrument payload
  - Multiple cruise altitudes, spanning the range of contrail and clear air conditions
  - Multiple fuels (still to be determined); Likely candidates: 100% SAF, Low-Sulfur Jet A

Model-Based Systems Analysis & Engineering

SFNP Vision

Advanced Aero-Configuration Ground & Flight Tests (AATT & SFD)

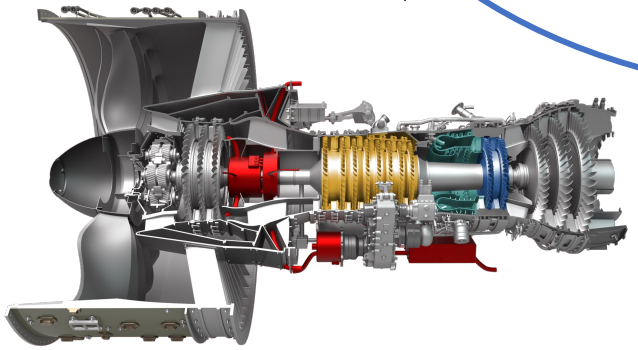
High-Rate Composite Manufacturing Processes (HiCAM)

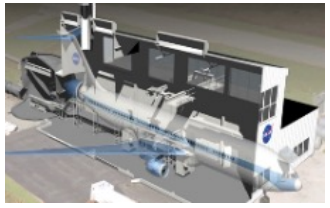


MBSA&E
Digital Integration
Knowledge Capture

Vision Vehicles
System of Systems

Small Core Engine Ground Tests (HyTEC)





Electrified Propulsion Ground & Flight Tests (AATT & EPFD)

Systems-level, digital integration across SFNP projects capped by a Digital Flight Test

University Leadership Initiative (ULI)
Engaging the University Community

6 rounds of solicitations
$178M of awards

Seeking & awarding proposals addressing all Strategic Thrusts and Special Topics

- 26 awards with 80 universities
- 11 HBCUs and 16 other MSIs
- 507 proposals submitted
- 377 different proposing Principal Investigators
- 4023 team members
- 2616 different people
- 20–50 students per team

In ULI, the universities take the lead, build their own teams, and set their own research path.

Long-Term Transport Technology and Innovation

Generational studies to inform future technology investments

Opportunities to Define Future Aviation Systems and Concepts

- Advanced Concept Studies for 2040+ EIS
- Net-Zero Emissions Concepts
- Promising Technologies and Architectures
- Support Aviation Community with NASA-unique Contributions

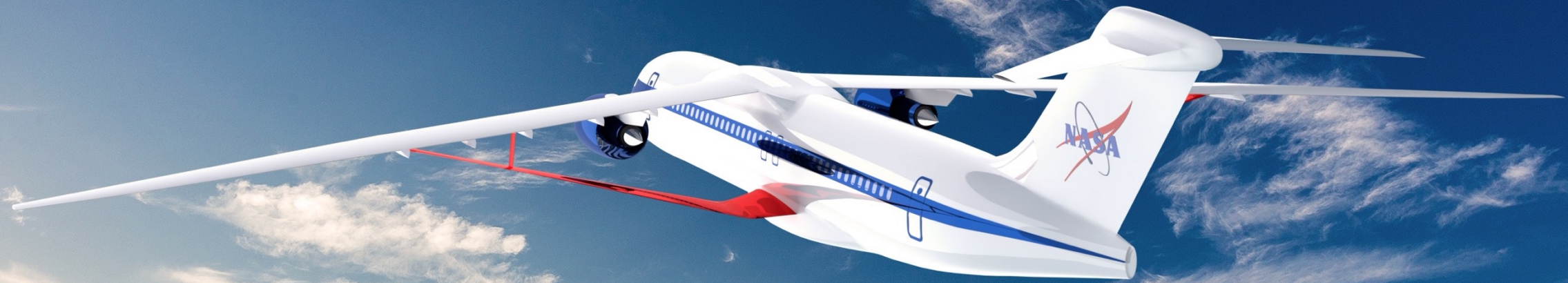
Innovations for 2040s and Beyond

Highlights and Other Important Items

- Jan. 2023 announcement of **formalized partnership between NASA and Boeing for the Subsonic Flight Demonstrator (SFD)** – to advance the transonic truss-braced wing configuration technology to TRL 6 in flight.
- NASA recognizes the challenge of achieving the aggressive 2050 climate goals requires approaches that go beyond current SFNP. **Currently undertaking studies to inform investment decisions beyond SFNP**:
  - Advanced Aircraft Concepts for Environmental Sustainability (AACES) 2050 study
  - Leveraging zero-emission aviation partnerships with universities to power toward net zero carbon and beyond.
- ARMD remains committed to maintaining a **balance between foundational research and larger flight demonstrations**.
- ARMD research efforts are well synchronized with FAA and are consistent with Administration's environmental sustainability priorities. Recognized value in continuing to actively strengthen communication and coordination with other departments and agencies including DOE, FAA, and DOD.
- **Overall support from key stakeholders continues to be strong** – ARMD research efforts focused on both environmental impact and US economic growth.

Global aviation faces significant challenges to sustainable growth

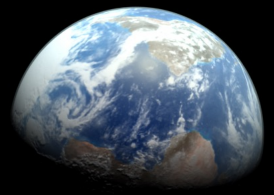
- Halt aviation's contribution to global warming without suppressing flight demand and without out-of-sector offsets, while remaining a viable and valued cornerstone of transportation (safe, clean, quiet, efficient, operable, economical, marketable – Economic, Social, Environment)
- Challenges require multiple, often interdependent, solutions across technology, operations, and energy domains
- No silver bullets



NASA Aeronautics is addressing the challenges of Sustainable Aviation

Maturing and demonstrating the most promising solutions for application in the 2030s

Exploring innovative solutions for application 2040+



Sustainable development “meets the needs of the present without compromising the ability of future generations to meet their own needs.” Sustainability “does imply limits – not absolute limits but limits imposed by the present state of technology”; but technology can be “improved to make way for a new era of economic growth.”

-- U.N. Commission on Environment and Development, “Our Common Cause”, 1987

“Earthrise in 4K”, https://svs.gsfc.nasa.gov/4593

Backup Slides

“Earthrise in 4K”, https://svs.gsfc.nasa.gov/4593

Phase 1 X-59 Aircraft Development

Progress being made, with continued challenges

- Significant delays encountered in completion of wiring and final systems integration
- Powered systems check-outs have resumed, but many tests with high schedule risk remain
- First flight now not likely until late CY 2023
- Current focus is on delivering a safe, robust aircraft that can support the accomplishment of the mission goals

Major assembly complete

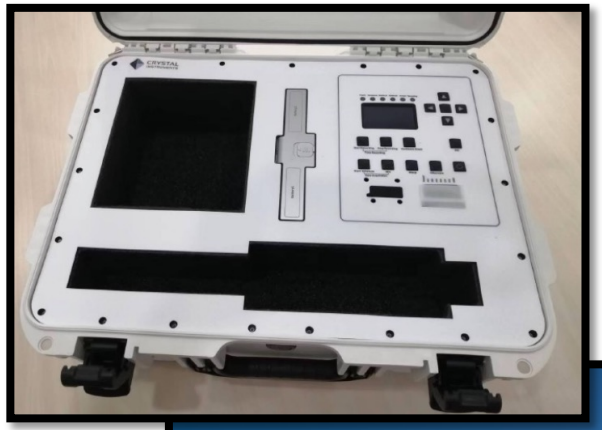
Engine installation

Cockpit systems installation

Quesst Mission - Phase 2 and 3 Status

Acoustic Measurement

- Ground Recording System (GRS) being developed by Crystal Instruments, Inc
  - First 10 production quality units have been through V&V testing @NASA
- Risk reduction tests for Phase 2 logistics and GRS deployment continue
- Progress continues on airborne acoustic measurement systems



GRS System in New White Enclosure

Community Test Planning & Execution

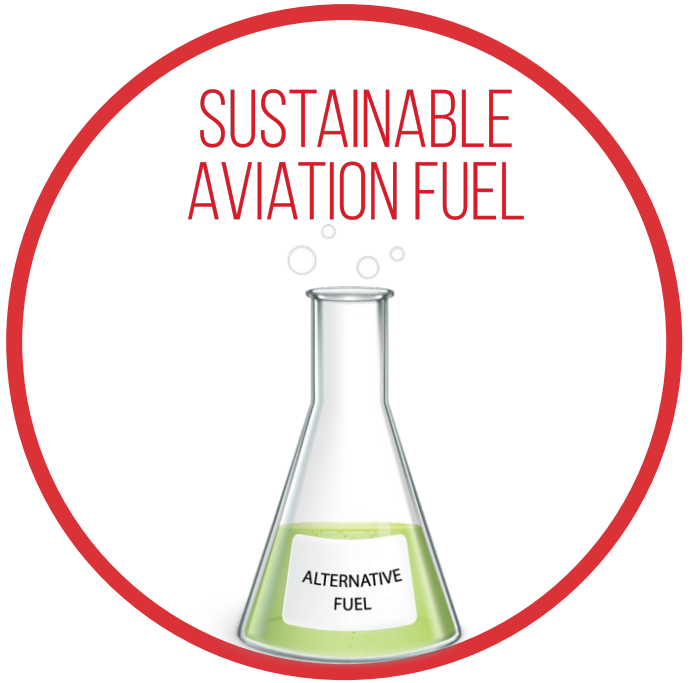
- Significant progress on test, exposure and survey plans
- Airfield and community selection process ongoing
- Conducting test of survey methods in coming months (no actual flights)
  - Including recruitment approach & survey questionnaires

International Standards Development

- Continued engagement with FAA/AEE, ICAO/CAEP & international research community
- Providing regular updates on Quesst mission status & anticipated data availability to SSTG and WG1
- Provided responses to feedback on test plans at most recent WG1 meeting

Aviation Industry Pillars for a Sustainable Future

NASA = Primary Role



NASA = Supporting Role

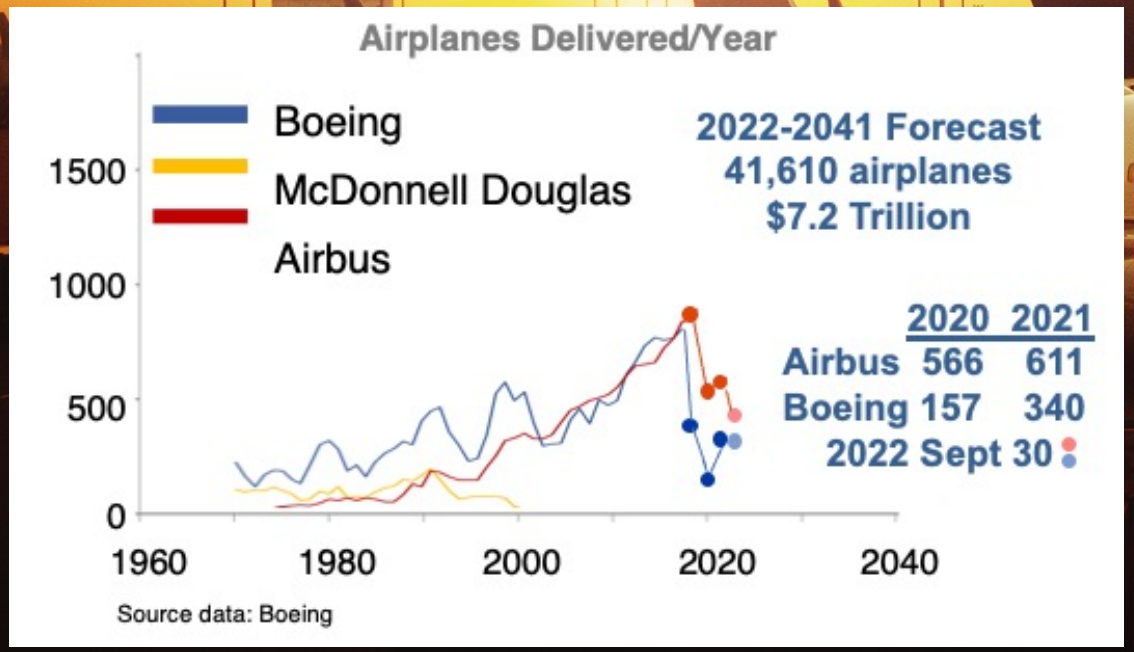
NASA = Primary Role

Accelerate toward net-zero greenhouse gas emissions by 2050 through 25-30% energy efficiency improvements in next-generation transports, 100% sustainable aviation fuel, and optimal trajectories.

Aviation is Vital to our Nation's Economy

Pre-COVID

- $78 billion positive trade balance; the largest positive trade balance of any U.S. manufacturing sector
- 21.3 billion tons of freight transported by U.S. airlines in 2019
- $1.8 trillion total U.S. economic activity
- 10.9 million direct/indirect jobs



U.S. engine companies compete for global market share and are subject to a global regulatory environment

Subsonic Transport Market – An Expanding Global Competition

Sustainable Flight Demonstrator

Demonstrate integrated airframe-focused technologies in flight

Scope

- Develop and fly integrated airframe-focused technology flight demonstrator with U.S. industry to mature technologies that enable the next-generation single-aisle aircraft in the 2030s.

Benefit

- Validate promising technologies, retire technical risks, and mature to TRL 6 key synergistic commercial transport vehicle technologies. Combined, these technologies could support efficiency and environmental performance goals for the 2030s.

Update

- Funded Space Act Agreement awarded to Boeing in Jan. 2023
  - Kickoff meeting held in Feb. 2023
- Conceptual Design Review and System Requirements Review milestones upcoming in 2023

First flight of a TTBW demonstrator aircraft with associated technologies scheduled for September 2028

Sustainable Aviation Fuels

Enable the use of 100% sustainable aviation fuels (SAF) and reduce climate impact

Scope

- Support adoption of high-blend ratio sustainable aviation jet fuels

Benefits

- Reduced aviation environmental impact
- Reduced uncertainty for climate impact of aviation-induced cloudiness
- Improved efficiency/emissions with drop-in synthetic and biofuels

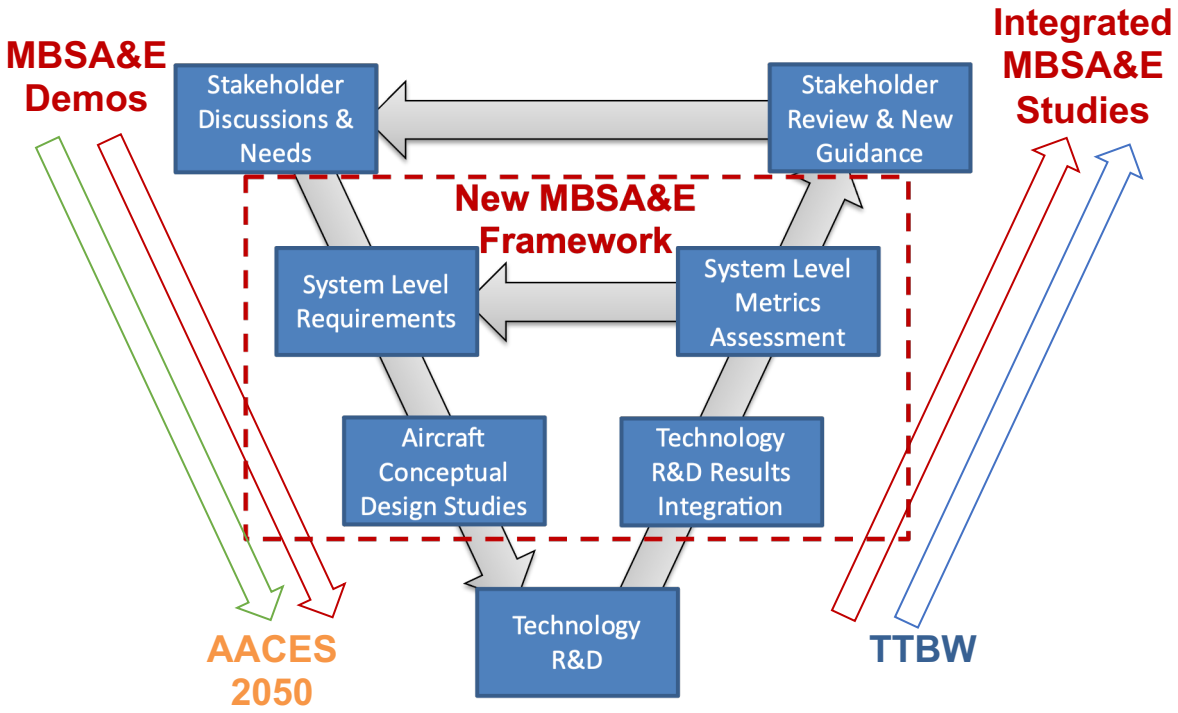
Approach

- Characterize high-blend sustainable aviation jet fuel emissions on ground and in flight

Future SAF Research Plans in Development

Model Based Systems Analysis and Engineering

Digitally integrate cross-discipline research into a system-level analysis capability



Scope

- Integrate propulsion, geometry, structures, aerodynamics, and cost analysis tools within a common system-level framework to inform future aircraft concept studies and research investment decisions

Benefits

- Integrate previously disparate tools for vehicle sizing and mission analysis into a single code base
- Retain capability to execute legacy codes with traceability back to those tools

Update

- Formalized internal SFNP MBSAE Working Group
- Completed development of Aviary v0.1.0 in Feb. 2023 (TTT)
  - Started process for public release of the code
- Request proposals (NRA) from industry/academia on development of framework, methods, tools, and models (Q3FY23, AATT)

MBSA&E and NASA Aviary code seek to streamline system-level aircraft analysis to study future aircraft concepts and inform research investment decisions