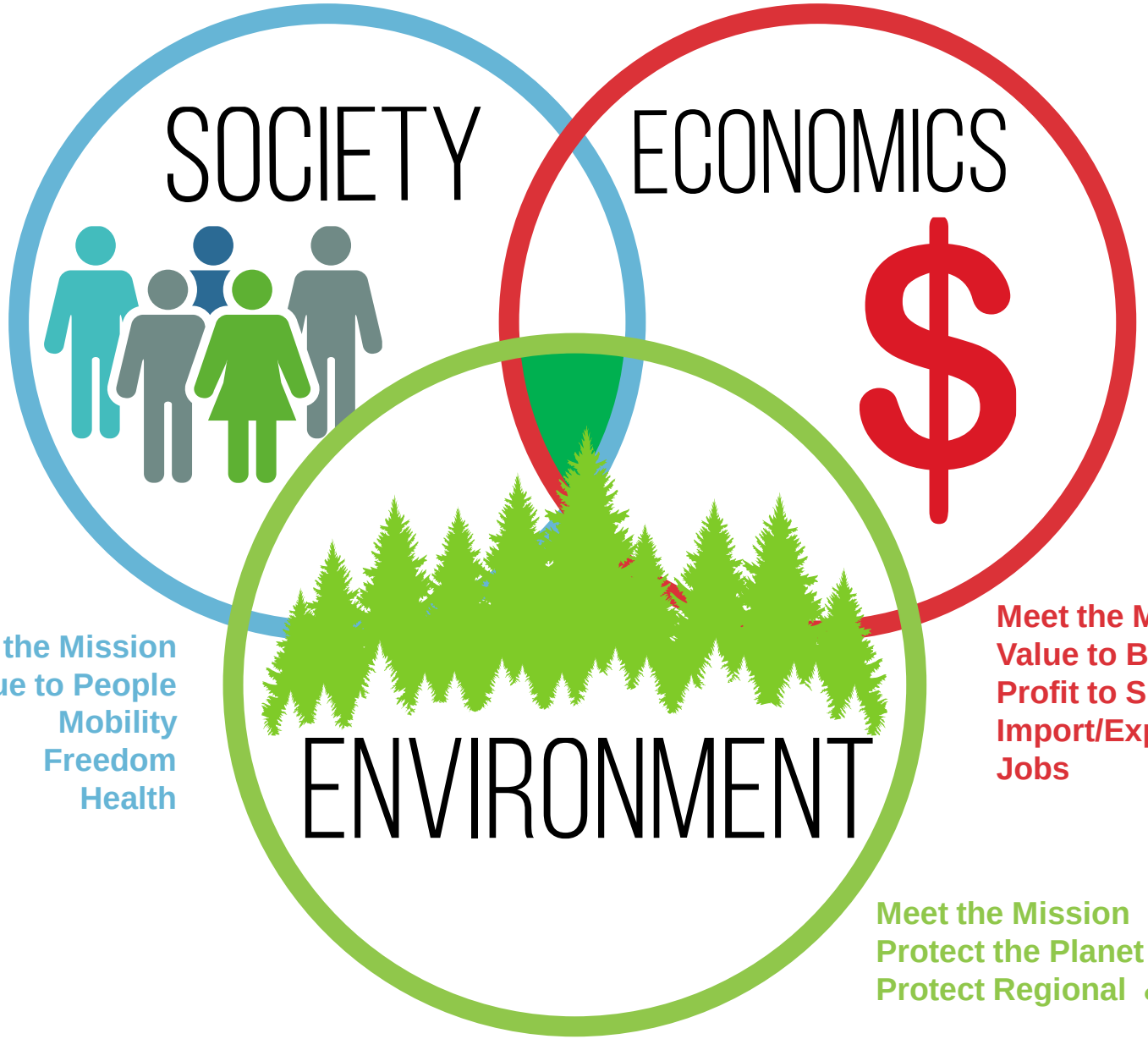
NASA Aeronautics Sustainable Aviation Overview

Jennifer Cole
Sustainable Flight National Partnership Mission Integration deputy Manager, Aeronautics Research Mission Directorate
2024

Sustainability



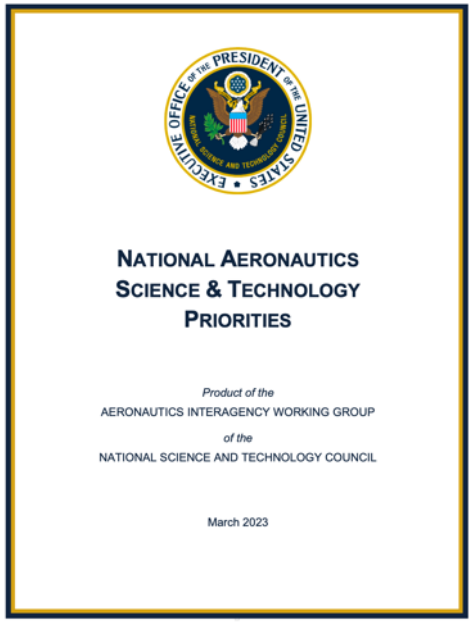
Meet the Mission
Value to People
Mobility
Freedom
Health

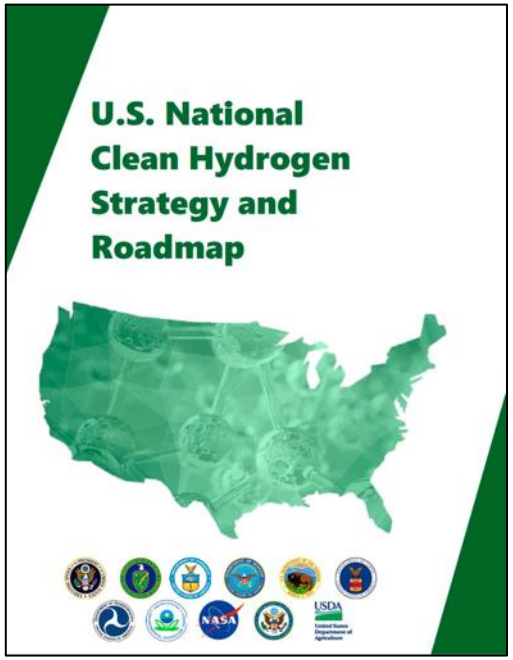
Meet the Mission
Value to Business
Profit to Shareholders
Import/Export Trade Balance
Jobs

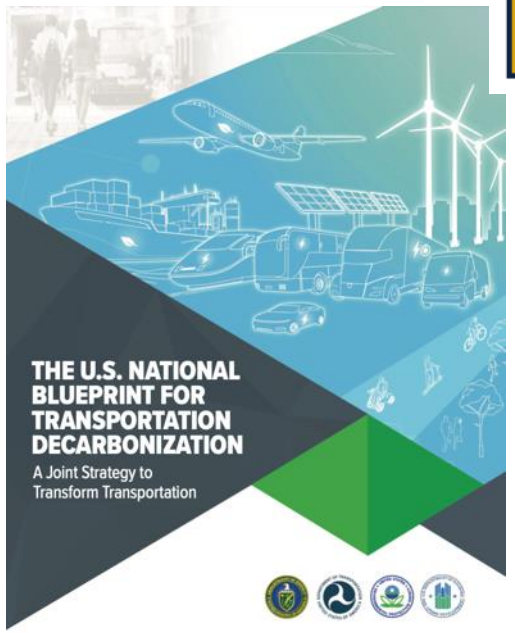
Meet the Mission
Protect the Planet
Protect Regional & Local Ecosystems

Four Transformations for Sustainability, Greater Mobility, and Economic Growth

NASA Aeronautics as Part of National Strategy







Sustainable Flight National Partnership

NASA – U.S. Industry Partnership to Enable Transformational 2030's Commercial Vehicles

Airspace Operations and Safety Program

Advanced Air Vehicles Program

Integrated Aviation Systems Program

Transformative Aeronautics Concepts Program

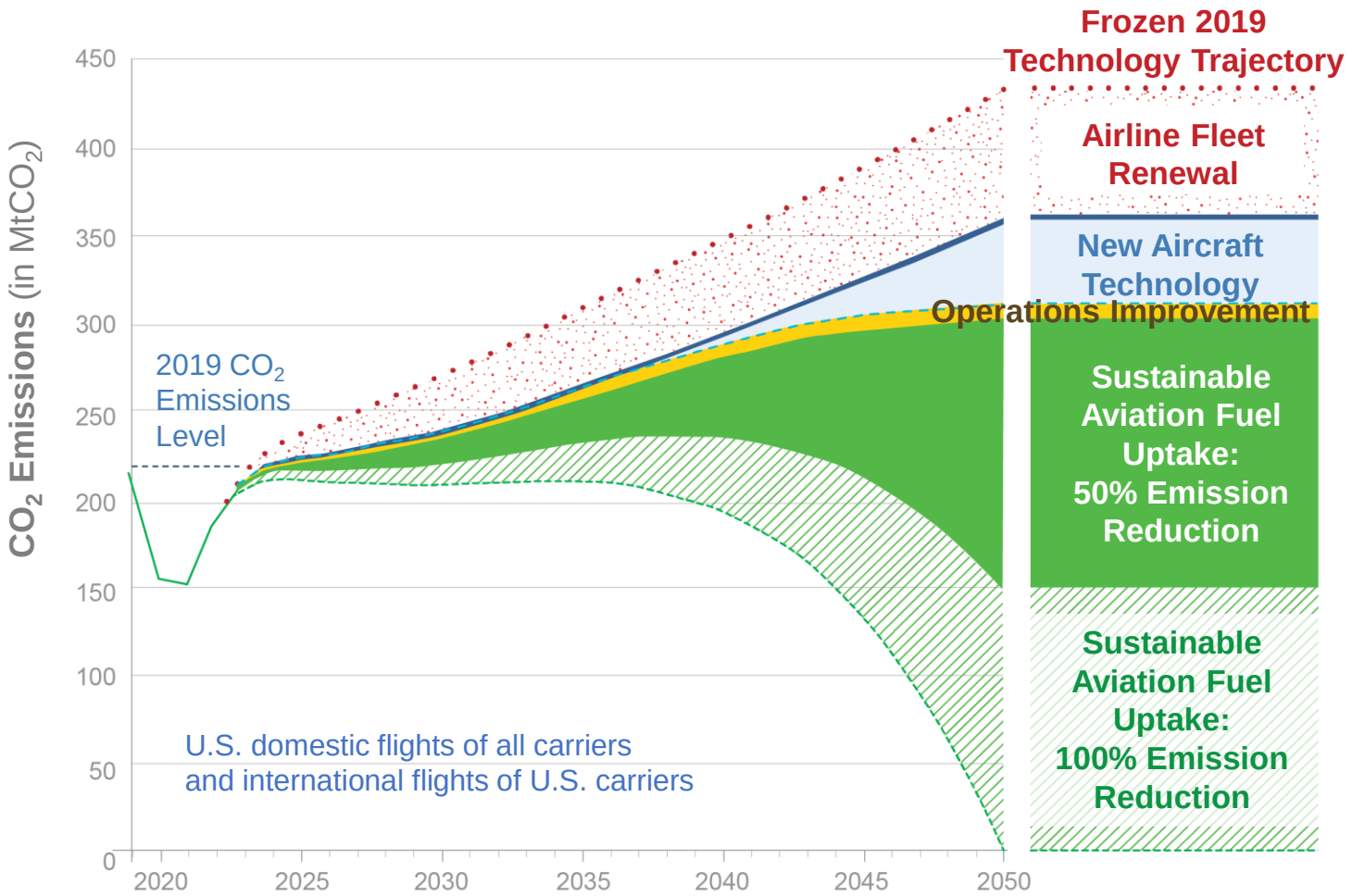
Aerosciences Evaluation and Test Capabilities Portfolio

U.S. Aviation Climate Action Plan - 2021

Global Context for Sustainable Aviation

U.S. aviation goal is to achieve
net-zero greenhouse gas emissions by 2050.

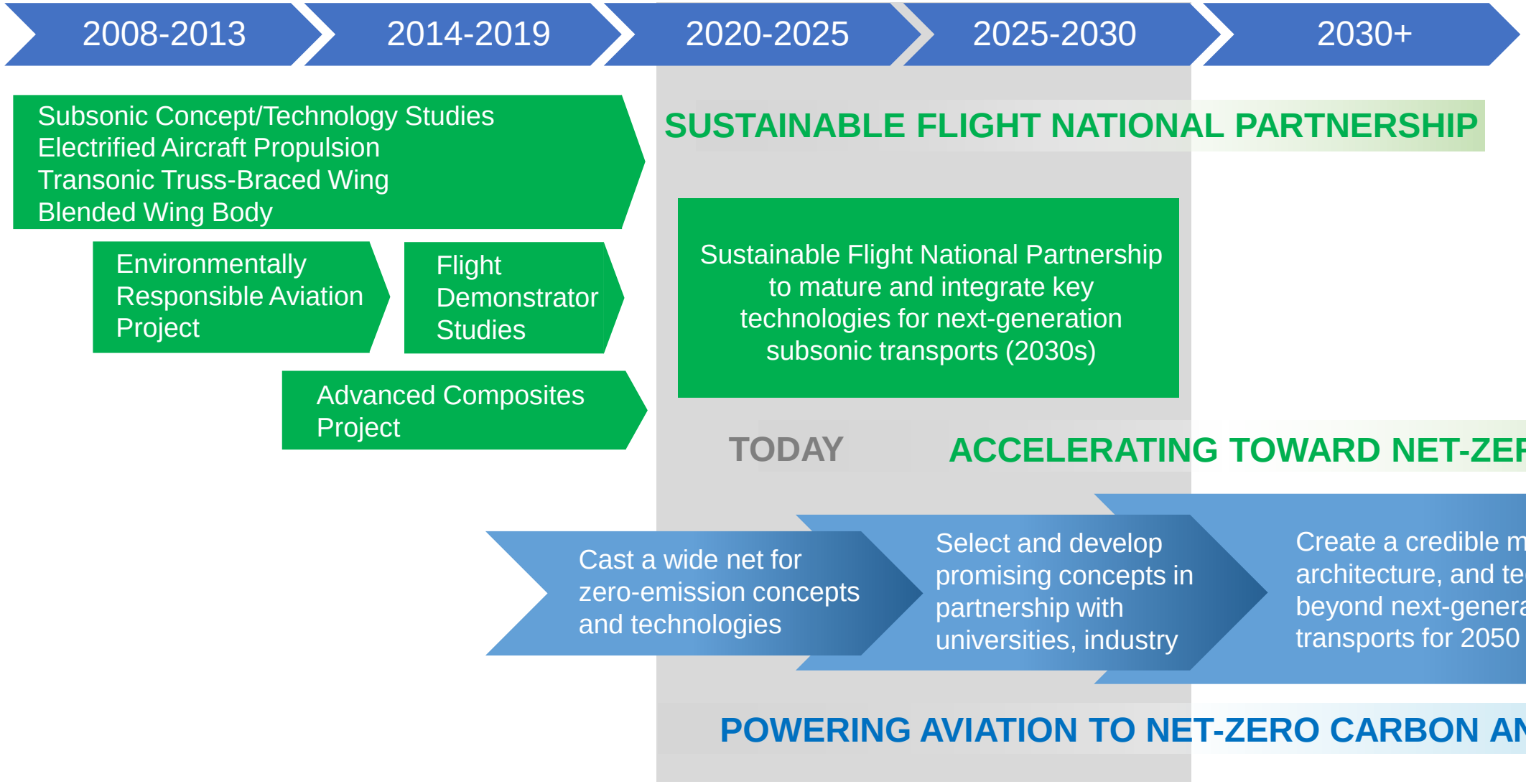
U.S. Aviation Climate Action Plan is aligned with
- U.S. economy-wide goal
- International Civil Aviation Organization
- Air Transport Action Group



https://www.faa.gov/sites/faa.gov/files/2021-11/Aviation_Climate_Action_Plan.pdf

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

NASA Sustainable Aviation Strategy



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

Aviation Pillars for a Sustainable Future

Global Aviation GOAL: net-zero carbon emissions by 2050

NASA = Primary Role

NASA = Supporting Role

NASA = Primary Role

Sustainable Flight National Partnership

Accelerating Toward Net-Zero Greenhouse Gas Emissions and Reduced Non-CO_2 Climate Impact in the 2030s

Advance engine efficiency and emission reduction

Enable integrated trajectory optimization

Advance airframe efficiency and manufacturing rate

Enable use of 100% sustainable aviation fuels

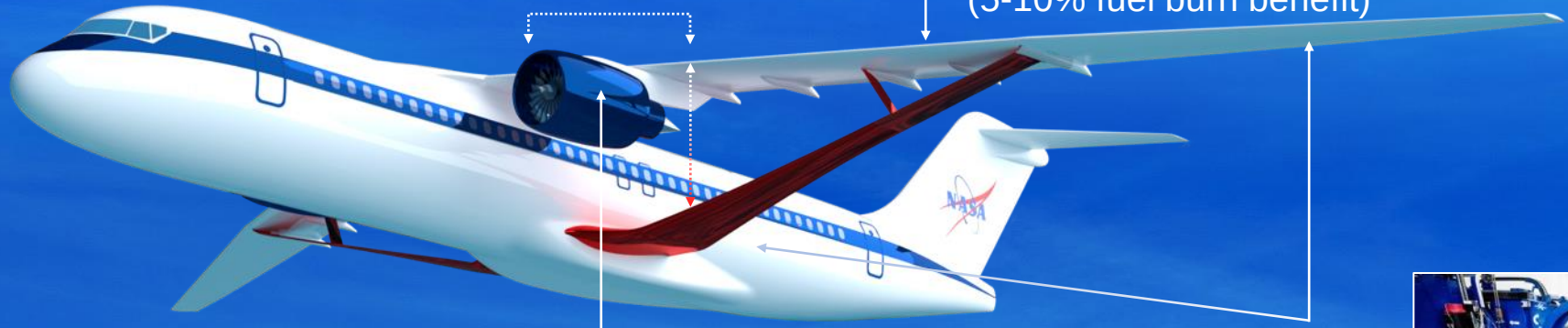
Next-generation transports using up to 30% less fuel, current and future fleets flying optimal trajectories, engines burning sustainable aviation fuels for greater than 50% reduction in lifecycle greenhouse gas emissions

Ultra-Efficient Airliner Technologies

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

Integrated Aircraft System Efficiency
Propulsion Airframe Integration Opportunity

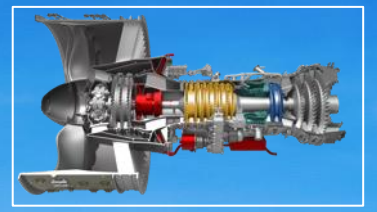
Aerodynamic Efficiency
Transonic Truss-Braced Wing
(5-10% fuel burn benefit)



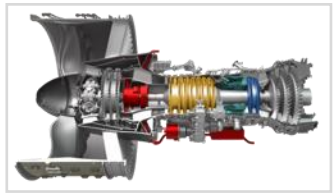
Weight
High-Rate Composites
(4-6x manufacturing increase)

Electrified Aircraft Propulsion
~5% fuel burn and maintenance benefit

Engine Efficiency
Small Core Gas Turbine
(5-10% fuel burn benefit)



Ultra-Efficient Airliners: Integrated Technology Development



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

Technology Readiness Target

Model Based Systems Analysis & Engineering
Framework developed
"Digital Flight Test"

Sustainable Flight Demonstrator (SFD)
Partner Selection
CDR
Flight Test

Transonic Truss Braced Wing (AATT)
Mid-Term Eval
TC Completion

Hi-Rate Composite Aircraft Manufacturing (HiCAM)
Demo(s) Down-select
Mfg & Structural Demonstration

Hybrid Thermally Efficient Core (HyTEC)
Partner Selection
Power Extraction Test
Core Demonstration

Electrified Powertrain Flight Demonstration (EPFD)
Flight Tests
Partner Selection

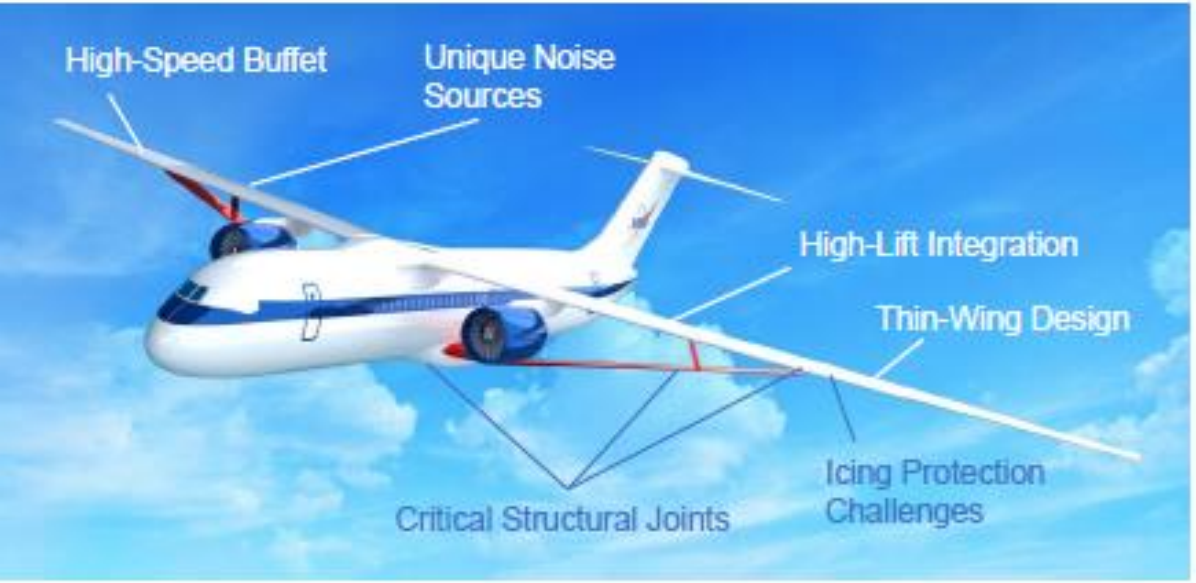
Electrified Aircraft Propulsion Technologies (AATT)
MW Altitude Capability (NEAT)
TC Completion

Achieve TRL 6 in time for industry product decision-making

Test Duration
Planned
Notional

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, focused on:
  - Buffet boundary prediction
  - Stall characteristics
  - High-lift system integration
  - Acoustic assessment
  - Icing impact
  - Thin wing structural design
  - Unique structural joints

Benefit

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

Approach

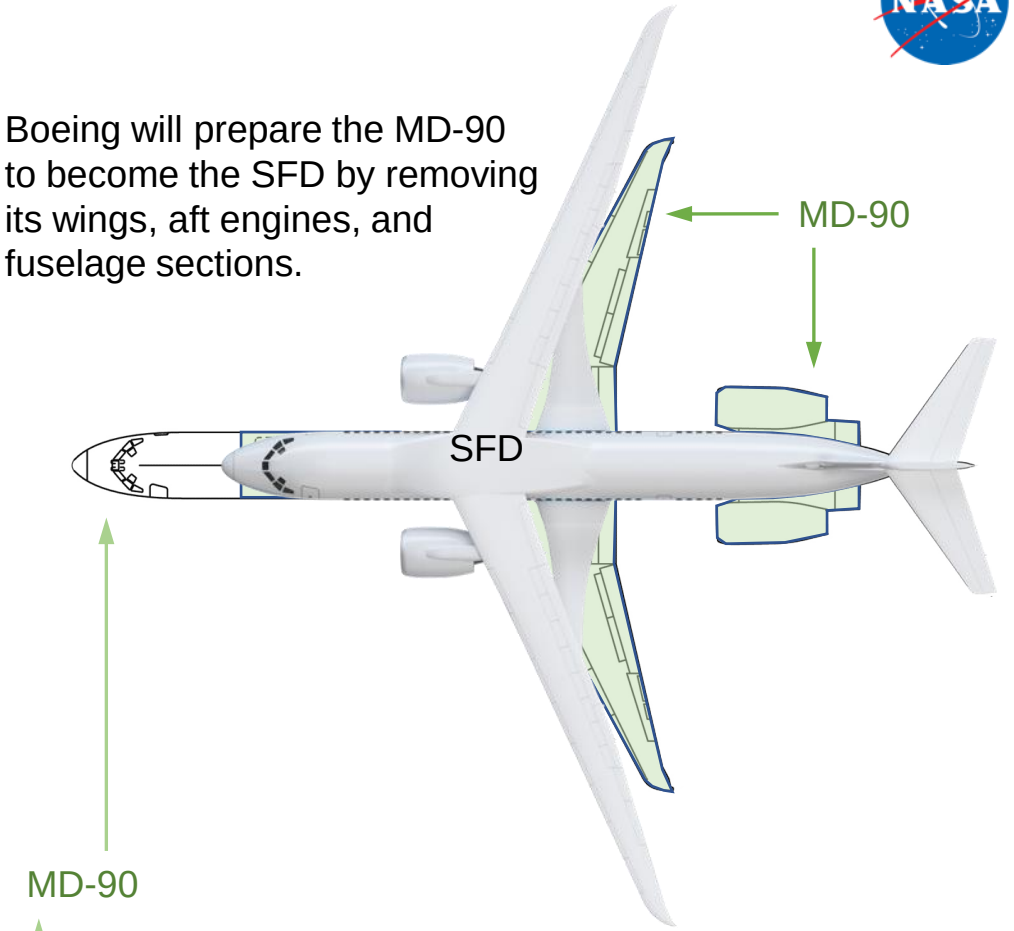
- Concept studies through scale model testing
- Perform high-fidelity prediction, testing and validation to increase confidence in fuel burn benefit

Maturation of the concept through progressive design/analysis studies and wind-tunnel tests since 2009
2024 testing focused on icing, high-lift system integration, and deep stall

Sustainable Flight Demonstrator Project

- NASA awarded a Funded Space Act Agreement 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 configuration utilizes a high aspect ratio, thin, truss-braced wing design to reduce drag and optimize fuel efficiency.

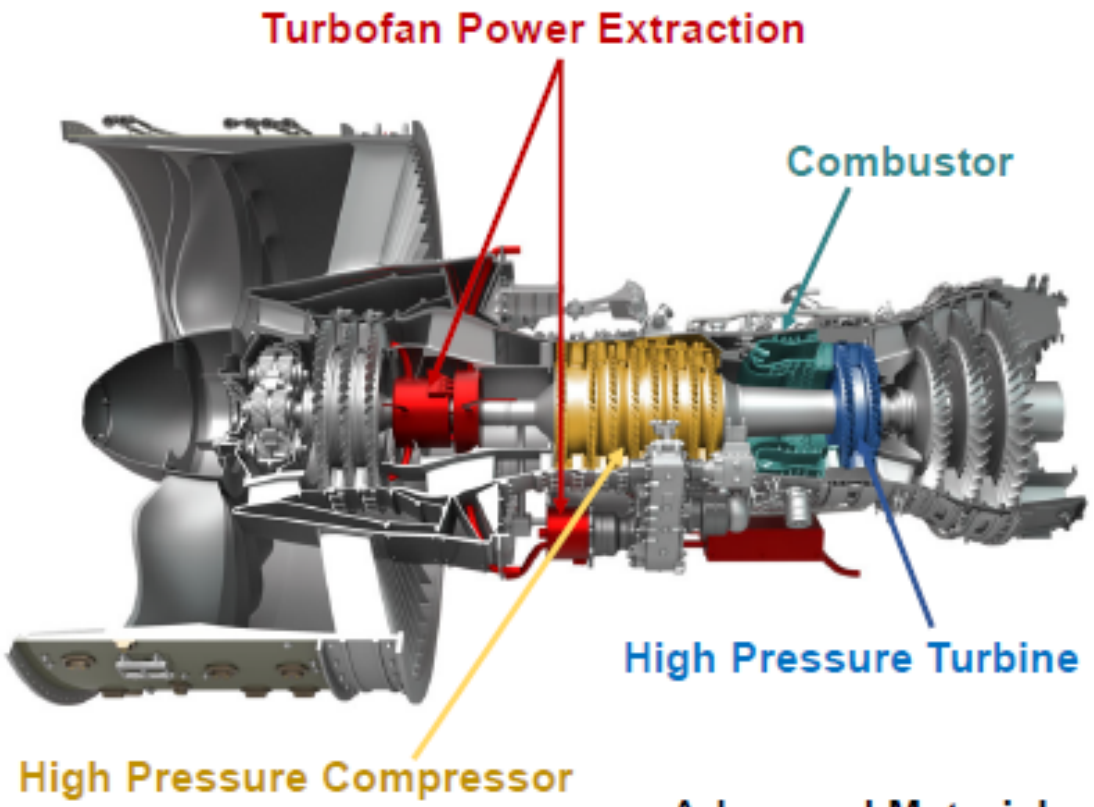
Boeing will prepare the MD-90 to become the SFD by removing its wings, aft engines, and fuselage sections.



SFD modifications include the Transonic Truss-Braced Wing and subsystems, modern turbofan engines, and instrumentation.

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
- Achieve small core combustors with efficient, effective operability using high blend (>80%) Sustainable Aviation Fuels (SAFs)

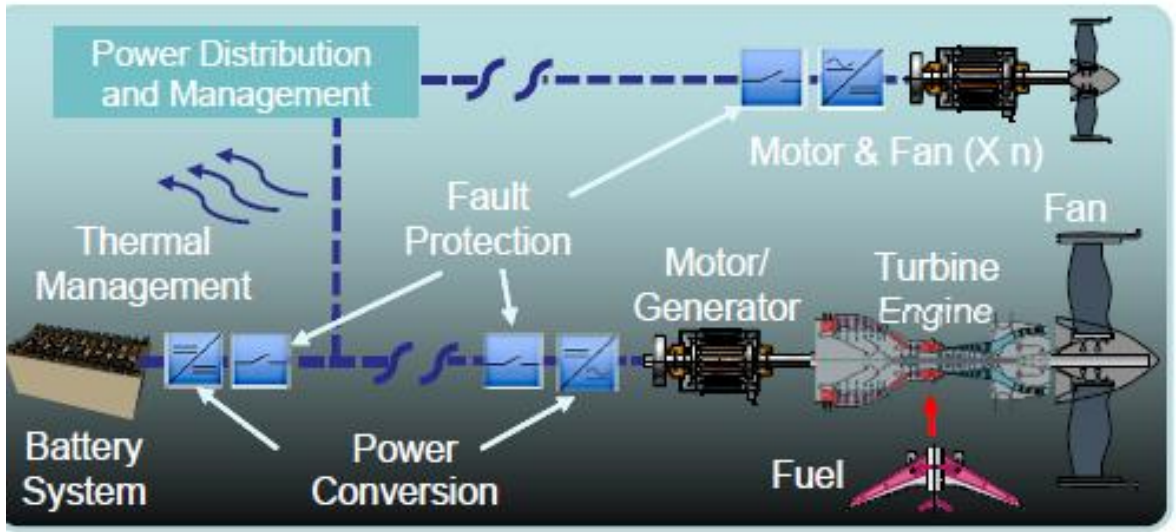
Approach

- Partner with industry to mature and demonstrate promising technologies

Phase 1 Small-core turbofan technology contract awards were made in September 2021.
Phase 2 Engine core demonstration awarded December 14, 2023 – demonstration 2028.

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

Approach

- Conduct technology-focused integrated ground tests
- Partner with industry on testing of electrified propulsion architectures and component technologies
- Leverage prior electric aircraft propulsion advances (TRL ~4)

In FY23 matured to TRL6 flight-weight flight-like EAP components relevant to demonstrators, including fault management systems and power conversion components

Electrified Powertrain Flight Demonstration

Demonstrate integrated electrified powertrains in flight using industry platforms

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.

Approach

- Engage with U.S. industry to integrate and demonstrate megawatt-class EAP machines in flight.
- Engage with the FAA, SAE, ASTM, etc. to contribute data that inform EAP standards and regulations.

Flight demonstration contracts awarded in September 2021.
Baseline unmodified flight testing of GE's Saab 340B conducted February-March 2023.

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

Approach

- Leverage advances in simulation including methods from Advanced Composites project
- Partner with industry for rapid prototype and evaluation of manufacturing concepts
- Demonstrate technologies in large structural ground tests

8 multi-party cooperative research teams developing technology.
Phase 1 awards made March 2023 to advance manufacturing process work.

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

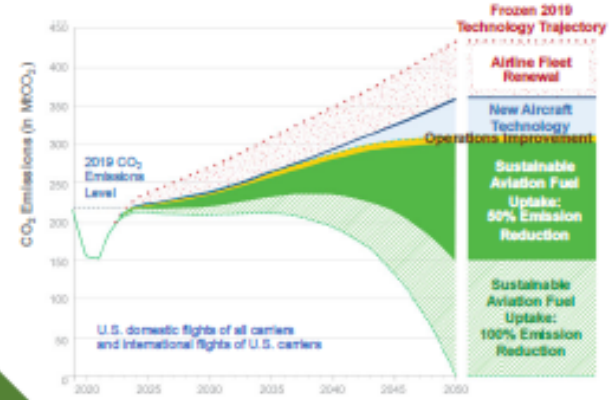
The Long Game: Aviation Eras on the Path Toward Sustainability

Accelerating Toward Net-Zero →

Net-Zero GHG, 2050

2020s | 2030s | 2040s | 2050s | 2060s

Reducing Non-CO_2 Impacts →



Era One: Evolution *(Change is Coming)*

Tube-and-Wing, Existing Infrastructure, Transition to Drop-In SAF, Increasing Electrification

Growing Risk

Era Two: Revolution *(SFNP Realized)*

Vehicle Architecture Change, Major SAF Adoption, Mild Hybrid EAP, Minor Infrastructure Change

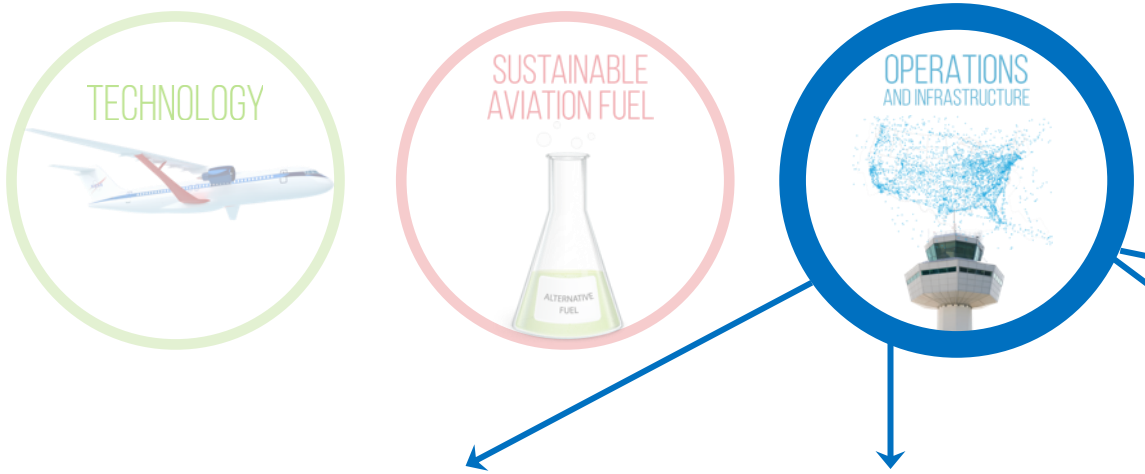
Era Three: Transformation *(Paradigm Shift)*

Major Vehicle Architecture Change, Non-Drop-In Fuel Adoption, Many-MW EAP, Major Infrastructure Change

Growing Potential Impact

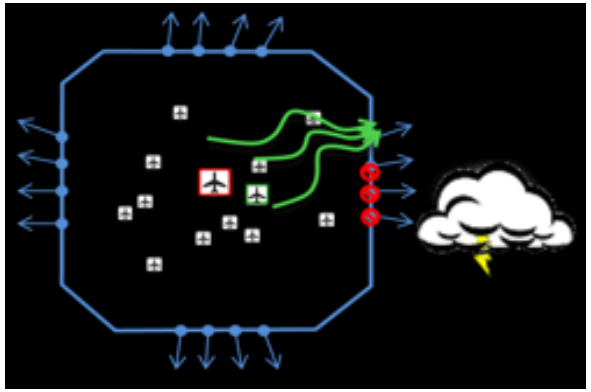
Transformation doesn't happen overnight; ARMD is making deliberate, long-term investment in broad-ranging technologies beyond industry's risk tolerance

NASA-led SFNP Operations Demonstrations



Flight Deck Services

Ground Services



Collaborative Digital Departure Re-route (SFNP-Ops-1, FY22-26)

Sustainable Oceanic Airborne Re-Routing (SFNP-Ops-2, FY27)

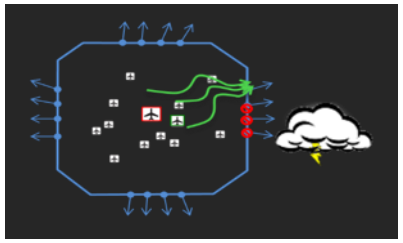
Irregular Ops Recovery/ Disruption Management (SFNP-Ops-3, FY28)

4D Trajectory Optimization (SFNP-Ops-4, FY30)

SFNP-Ops = Sustainable Flight National Partnerships - Operations

Digital Information Platform (DIP) Sustainability Goals
Deliver reduction in emissions and optimize air operations through digital services

Benefits from Ops-1 Sustainable Flight Ops Demonstration



Collaborative Digital Departure Re-Route (SFNP Ops-1)
The first nine months of this ongoing demonstration yielded savings for the environment, passengers, and airlines. This is a joint partner flight demonstration with the FAA, American Airlines, Southwest Airlines, and Envoy Air that uses tech with Trajectory Option Set to re-route flights and departures at Dallas Fort Worth and Dallas Love Field International.

American Airlines envoy Southwest

Fuel Savings

Over **24,000** lbs.

Emissions Savings

Over **76.6K** lbs. **CO^2**

Over **569** urban trees

Delay Savings

OFF delay	**IN** delay
3.9+ hrs	**4.7+** hrs

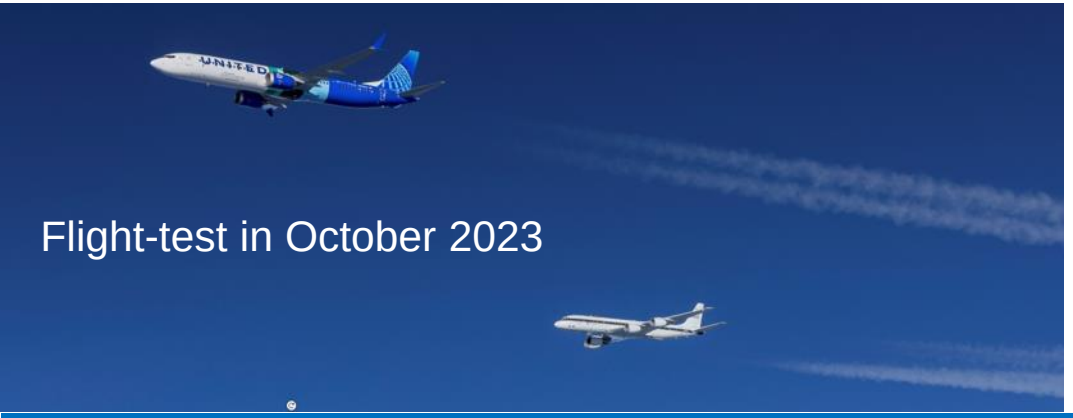
Cost Savings

Passenger	**$31.7K**
Flight Crew	**$6.9K**

System-wide aggregated savings (individually re-routed + other flights)
at **D10 North Texas Metroplex** (01 Jan 2022 – 16 Sep 2022)

Sustainable Aviation Fuels & Non-CO2 Impacts

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



Scope

- Support adoption of high-blend ratio sustainable aviation jet fuels & advance contrail science

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, including formation and persistence of contrails

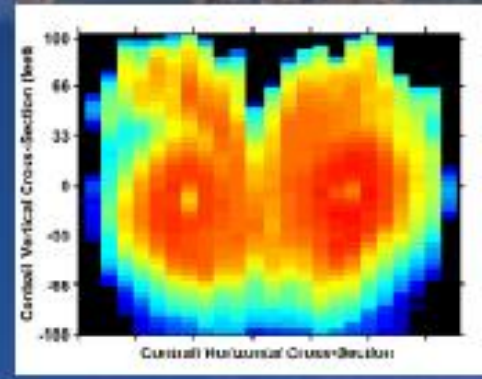
Future SAF & Contrail-related Research Plans in Development

Cruise Conditions Are Very Different From The Ground, Which Necessitates In-Flight Testing

2023 Emissions Flight Test with the NASA DC8 Chasing the Boeing ecoDemonstrator Explorer 737-10 with LEAP-1B Engines

- 11 joint science sorties
- >100 combined DC-8 and 737-10 flight hours
- 3 fuels: 100% SAF and Two Different Jet A Fuels
- Sampling in both contrail & clear air conditions

In-Flight Testing With 100% Sustainable Aviation Fuel Completed In October 2023 In Collaboration With Boeing, US, & International Partners



eco Demonstrator PROGRAM

UNITED

DLR Deutsches Zentrum für Luft- und Raumfahrt German Aerospace Center

GE Aerospace

Transport Canada

Transports Canada

Beyond SFNP, Long-Term Transport Technology and Innovation

Generational studies to inform future technology investments

2008-2019	2020-2029	2030 - 2039	2040 - 2050
Subsonic Fixed Wing	**N+2 Studies, ERA for the 2020s Impact**	**N+3 Advanced Concept Studies for 2030s Impact**	***Concept Studies and Technology Development Needed for 2040s Impact***

Opportunities to Define Future Aviation Systems and Concepts

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

CONCLUDING REMARKS

- Global aviation faces significant challenges to sustainable growth
- Aviation must exist in global harmony within sector and beyond
- Time matters, climate change doesn't wait

- NASA Aeronautics addressing the challenges of Sustainable Aviation
  - Maturing and demonstrating the most promising solutions for application in the 2030s
  - Exploring innovative solutions for application 2040+

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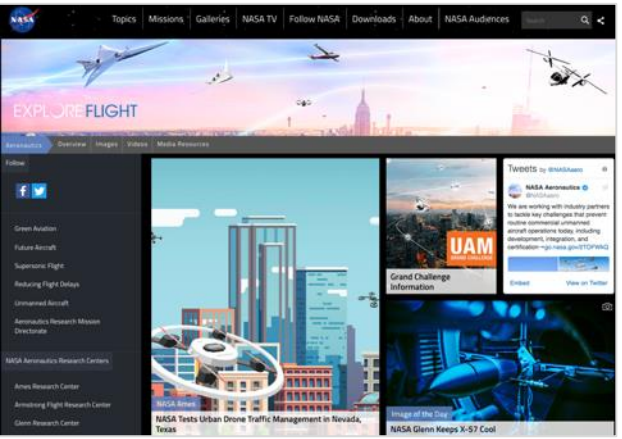
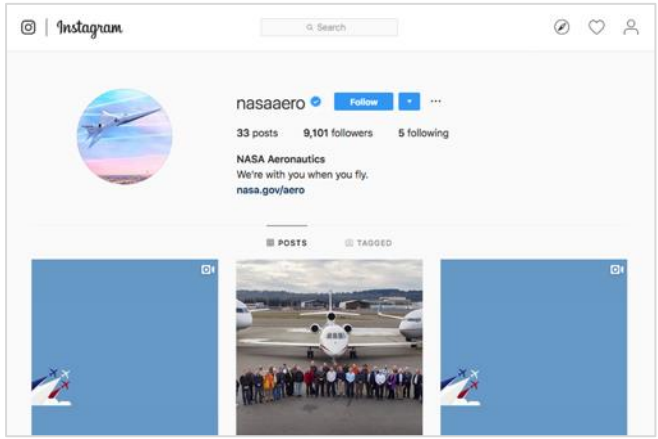




www.nasa.gov/aeroresearch/strategy | www.nasa.gov/aeroresearch/solicitations

NASA Aeronautics is One of Five Mission Directorates

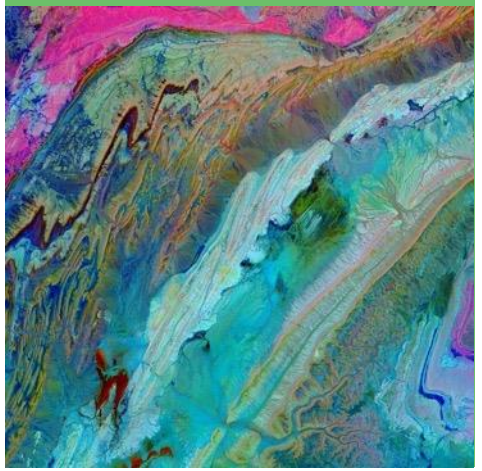
Aeronautics

NASA explores technologies that reduce aircraft noise and fuel use, get you gate-to-gate safely and on time, and transform aviation into an economic engine at all altitudes.

Space Technology

NASA technologies developed for spaceflight benefit our everyday life. The Artemis program proves and matures what those technologies can do and reduces risk for exploration of Mars and beyond.

Science



NASA and the nation's science community use space observatories conduct scientific studies of the Earth from space to visit and return samples from other bodies in the solar system, and to peer out into our galaxy and beyond.

Exploration Systems Development

NASA's Artemis program is defining and creating the steps path from Earth back to the Moon and on to Mars, including the Orion capsule, the Space Launch System, Exploration Ground Systems, the Gateway, and Human Landing System.

Space Operations

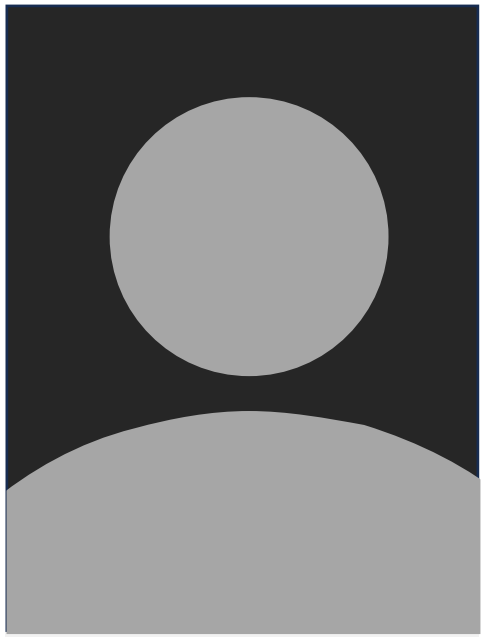
NASA's work in beyond low-Earth orbit includes commercial launch services to the International Space Station, exploration systems, space transportation systems, and broad scientific research on orbit.

Aeronautics Research Mission Directorate (ARMD) Leadership

Robert Pearce
Associate Administrator* ARMD
*(AA)

Carol Carroll
Deputy AA ARMD

Jon Montgomery
Deputy AA for Policy ARMD



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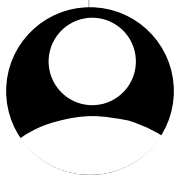

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Quesst Mission Integration Manager

Dr. Rich Wahls
Sustainable Flight National Partnership Mission Integration Manager

Supplemental Slides for SFNP Presentation

Jennifer Cole / SFNP Deputy Mission Integration Manager
5/1/2024

Sustainable Flight National Partnership with ...

NASA and Boeing ecoDemonstrator Test SAF Impact on Contrails

BOEING
ecoDemonstrator PROGRAM
GE Aerospace
Transport Canada
Transports Canada
FEDERAL AVIATION ADMINISTRATION
AERODYNE RESEARCH, Inc.
UNITED
MIT
DLR Deutsches Zentrum für Luft- und Raumfahrt German Aerospace Center
MISSOURI S&T

Progress

- Contrail-cirrus clouds are net climate warming and form on engine-emitted particles
- Ground tests in 2021-22 lay groundwork for joint flight test in FY24
- Initial data reveals substantial cruise altitude soot particle reductions from burning 100% SAF in advanced GE lean-burn aircraft engine combustors
- Discovered the role of engine oil
- Small businesses developed and tested novel water vapor sensors through the NASA Small Business Innovation Research program
- Partnered with manufacturers, airlines, universities, and government agencies to design and execute the tests and to gather the data needed by national stakeholders
- Initiated National Academy of Sciences study to develop a national research agenda on potential mitigations for the impacts of persistent contrails (aviation-induced cloudiness)

A Look Ahead

- Test results guide and motivate industry investment in SAF and engine technology R&D and jobs
- Unique in-flight data will be publicly available in Nov 2024 for use in climate and aviation model assessments, university research, industry model validation
- Beginning to develop future contrails research plans

FY 2025 request includes funds to continue research in aviation contrail formation modeling and mitigation.

Airspace Operations and Safety Program with …

INDUSTRY

EXISTING + EMERGING

American Airlines, jetBlue, wisk, Joby, DELTA, Alaska AIRLINES, XWING, RELIABLE ROBOTICS, Southwest, UNITED, AURA, easyJet, SKYGRID, BOEING, NORTHROP GRUMMAN, Pratt & Whitney Dependable Engines, SCEYE, AEROSTAR, GE, BELL, THE LONGBOW GROUP LLC, OneSky, DELPHIRE, ANRA TECHNOLOGIES, Collins Aerospace, FREQUENTIS, METRON AVIATION, AVISION, UNMANNED EXPERTS, AVIONCO, casa, RESILIENX

DOD and OGA

FEDERAL AVIATION ADMINISTRATION, AFRL THE AIR FORCE RESEARCH LABORATORY, DARPA, dot, FOREST SERVICE USDA, UAS INTEGRATION PILOT PROGRAM, CAL FIRE SINCE 1885, Cal OES GOVERNOR'S OFFICE OF EMERGENCY SERVICES, NATIONAL TRANSPORTATION SAFETY BOARD, FEMA, MITRE, PORT AUTHORITY NY NJ AIR LAND RAIL SEA

SDO and NON-PROFIT

RTCA, FLIGHT SAFETY FOUNDATION, ASTM INTERNATIONAL, SAE INTERNATIONAL, CAST, DRONERESPONDERS, Drone Safety Team, GAMA, UL Standards & Engagement, NIST

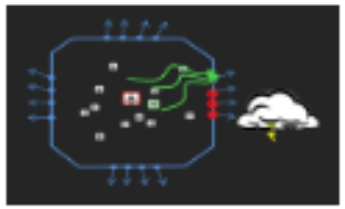
ACADEMIA

Stanford, MIT, TEXAS The University of Texas at Austin, STATE, VANDERBILT UNIVERSITY, UCF, PennState, EMBRY-RIDDLE Aeronautical University, VCU, THE GEORGE WASHINGTON UNIVERSITY WASHINGTON, DC, UNT UNIVERSITY OF NORTH TEXAS, LONE STAR UAS CENTER OF EXCELLENCE & INNOVATION

INTERNATIONAL

DLR, KARI, JAXA, ICAO · OACI · ИКАО, JARUS, IATA, SWISS, IFAR INTERNATIONAL FORUM FOR AVIATION RESEARCH

Benefits from Sustainable Flight Ops-1 Demonstration



Collaborative Digital Departure Re-Route (SFNP Ops-1)
The first nine months of this ongoing demonstration yielded savings for the environment, passengers, and airlines. This is a joint partner flight demonstration with the FAA, American Airlines, Southwest Airlines, and Envoy Air that uses tech with Trajectory Option Set to re-route flights and departures at Dallas Fort Worth and Dallas Love Field International.

American Airlines envoy Southwest

Fuel Savings

Over **24,000** lbs.

Emissions Savings

Over **76.6K** lbs. **CO^2**

Over **569** urban trees

Delay Savings

OFF delay	**IN** delay
3.9+ hrs	**4.7+** hrs

Cost Savings

Passenger	**$31.7K**
Flight Crew	**$6.9K**

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Progress towards FAA's NAS 2040 by demonstrating digital services on the cloud and reducing the impact of aviation on the climate