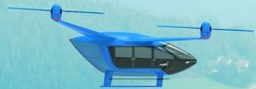
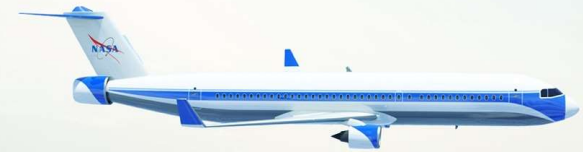
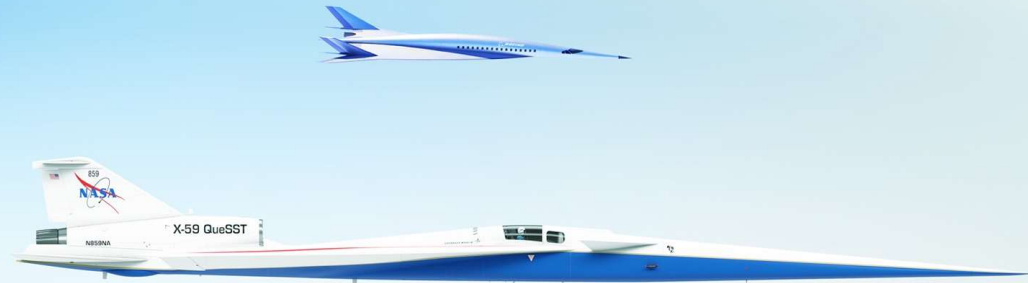


National Aeronautics and Space Administration



NASA Sustainable Aviation Overview

Dr. Martiqua Post
Sustainable Flight National Partnership Technical and Partnership Advisor
Aeronautics Research Mission Directorate
Sun 'n Fun, 2023

The First “A” in NASA stands for Aeronautics



Why is “Aeronautics” the First “A” in NASA?



The nation's early aeronautics research led to creation of NASA.

AERONAUTICS



National Advisory Committee for Aeronautics
March 3, 1915

7,500 NACA employees
\$300 million in NACA research facilities
(Langley, Lewis Field, Ames)
NACA research process



National Aeronautics and Space Administration
October 1, 1958

NASA Aeronautics is 1 of 5 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



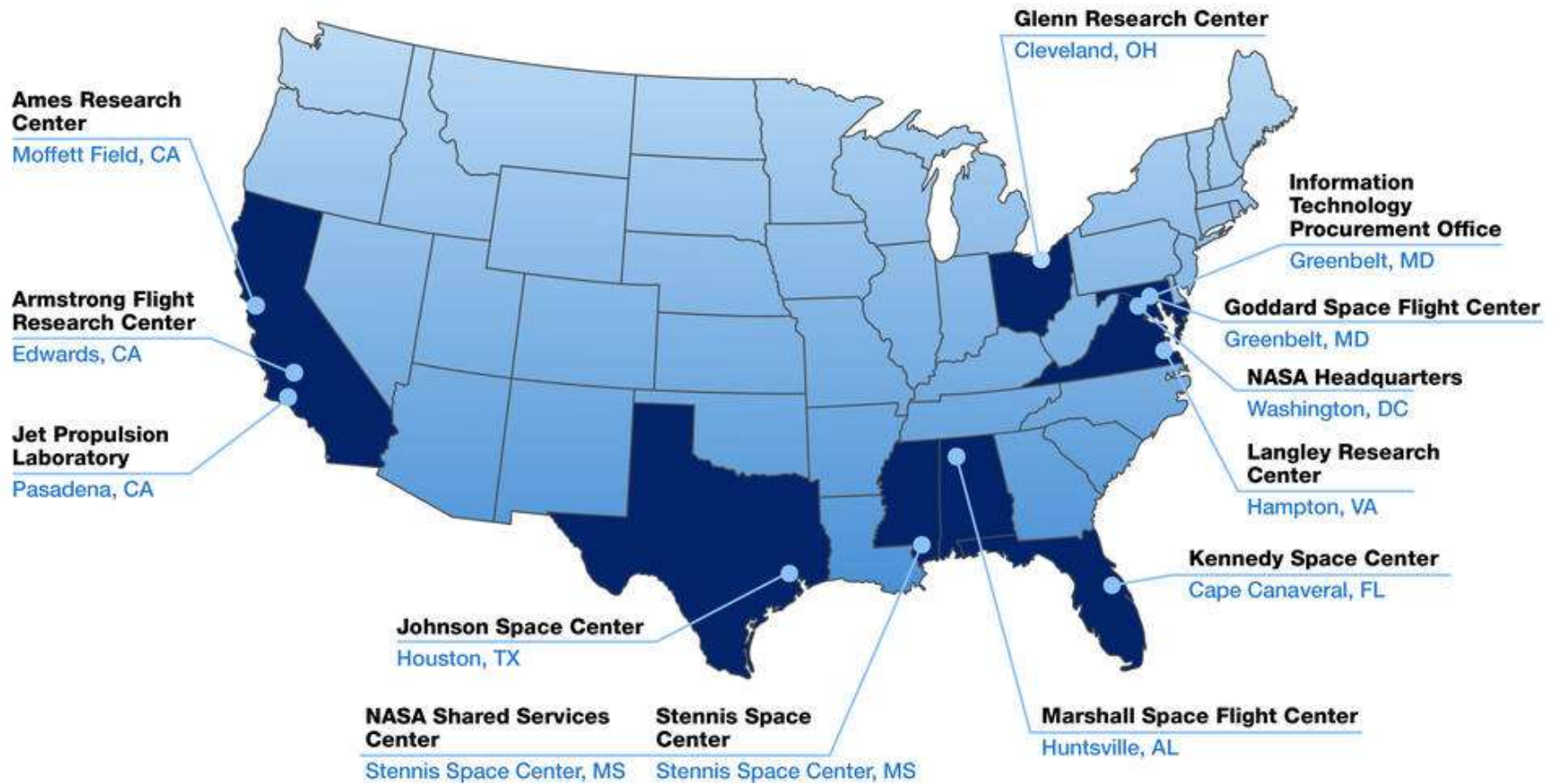
NASA's Artemis program is defining and creating the steps path from Earth back to the Moon and on to Mars, including the Orion capsule, the Space Launch System, Exploration Ground Systems, the Gateway, and Human Landing System.

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.

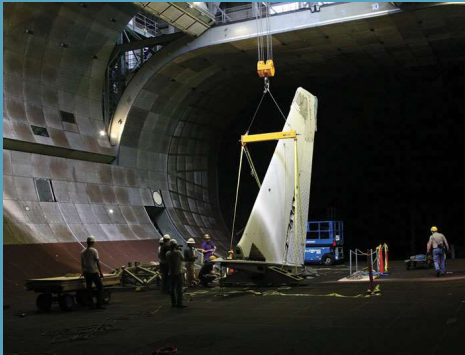
NASA Center Locations





4 NASA Centers Conduct Aeronautics Research

Ames Research Center
Moffet Field, CA



**National Full-Scale
Aerodynamics Complex**

Enables exploration through selected developments, innovative technologies, and interdisciplinary scientific discovery.

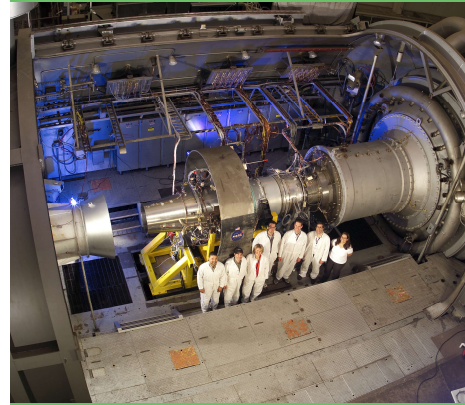
**Armstrong Flight
Research Center**
Edwards, CA



Bell X1-E

Performs flight research.

Glenn Research Center
Cleveland, OH



**PSL = Propulsion Systems
Laboratory**

Advancements in propulsion, power, communications, nuclear, and human-related aerospace systems.

Langley Research Center
Hampton, VA



**High-speed wind tunnel
spheres**

Pioneers the future through research and development of technology.



5 Space Centers

Kennedy Space Center
Cape Canaveral, FL



Artemis I 1st launch attempt Aug 29, 2022
Success on Nov 16

Responsible for the Agency's space launch processing and services.

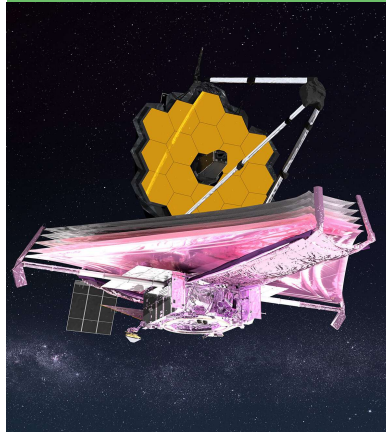
Johnson Space Center
Houston, TX



Mission Control

Provides leadership for human space exploration & operations

Goddard Space Flight Center
Greenbelt, MD



James Webb Space Telescope

Expands the knowledge of Earth and its environment, the solar system, and the universe through observations from space

Stennis Space Center
Stennis Sp Ctr, MS



RS-25 engine testing

Manages rocket propulsion testing

Marshall Space Flight Center
Huntsville, AL

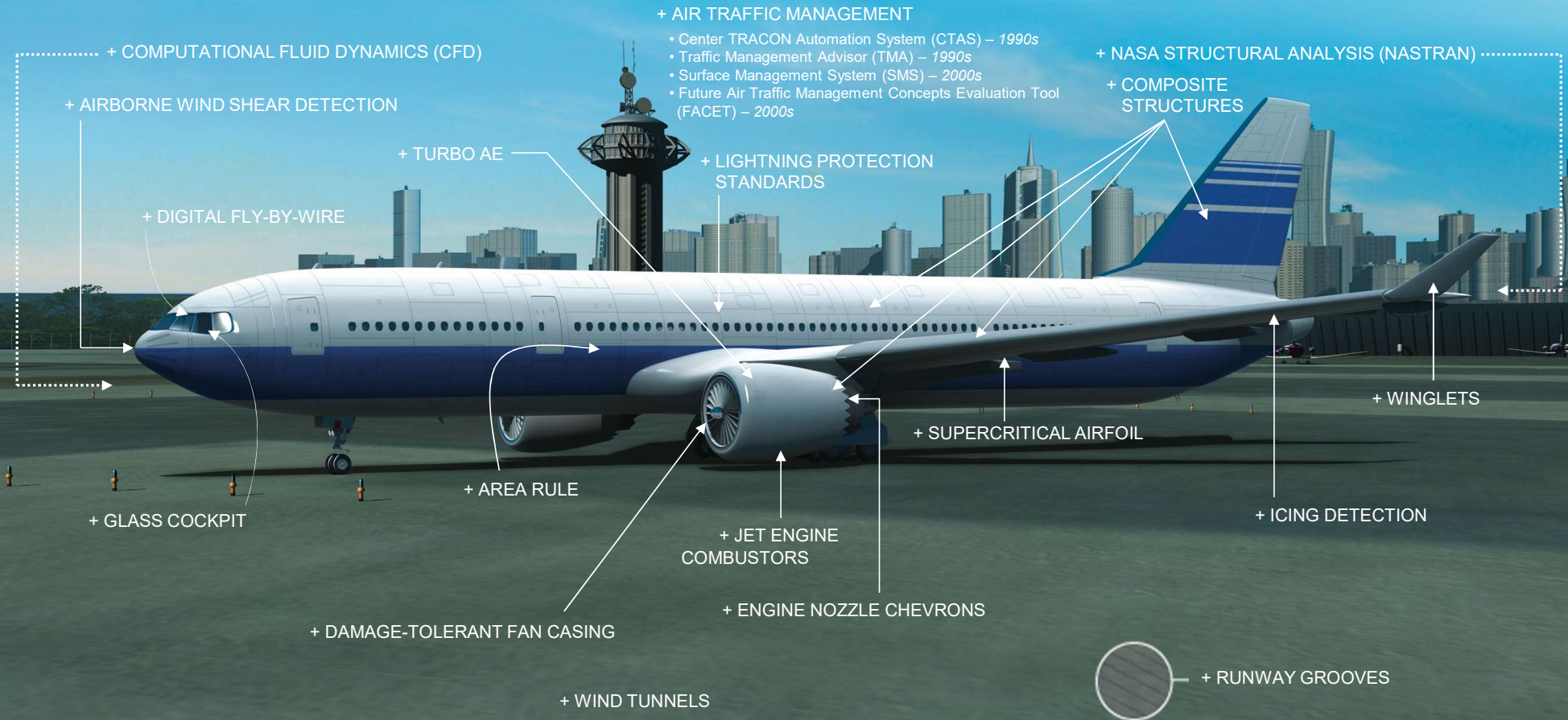


Rockets developed at MSFC on display

Serves as a systems developer and integrator for exploration and science missions

NASA has Made Decades of Contributions to Aviation

NASA-developed technology is on board every U.S. commercial aircraft and control tower.



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





Airspace Operations and Safety Program



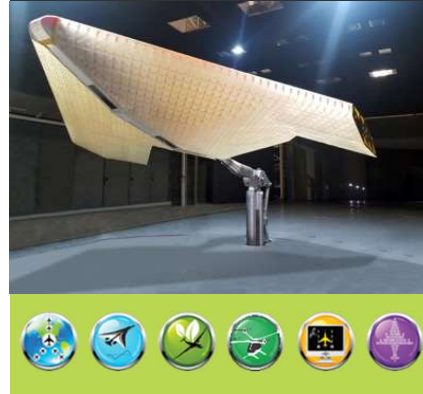
Advanced Air Vehicles Program



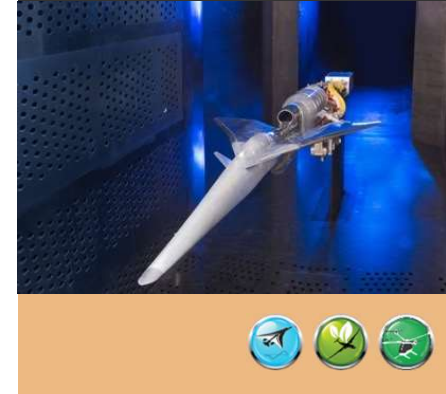
Integrated Aviation Systems Program



Transformative Aeronautics Concepts Program



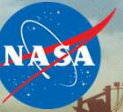
Aerosciences Evaluation and Test Capabilities Portfolio



ARMD PROGRAMS

Aviation is Vital to our Nation's Economy

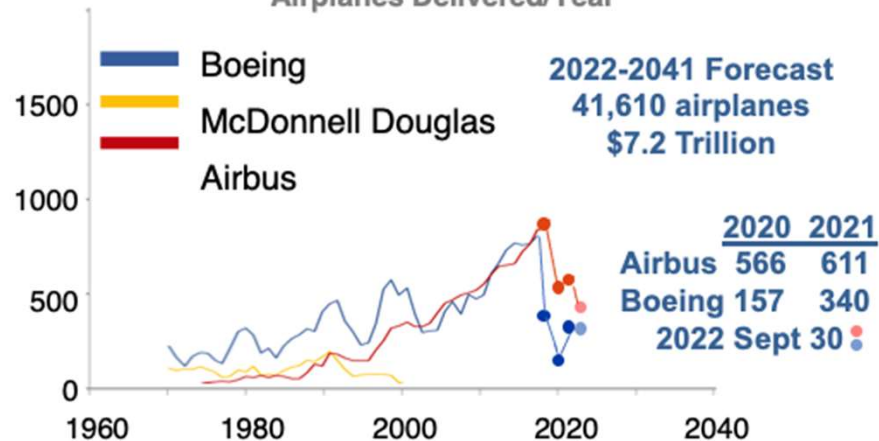
Subsonic Transport Market - Global competition expanding



Pre-COVID

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

Airplanes Delivered/Year



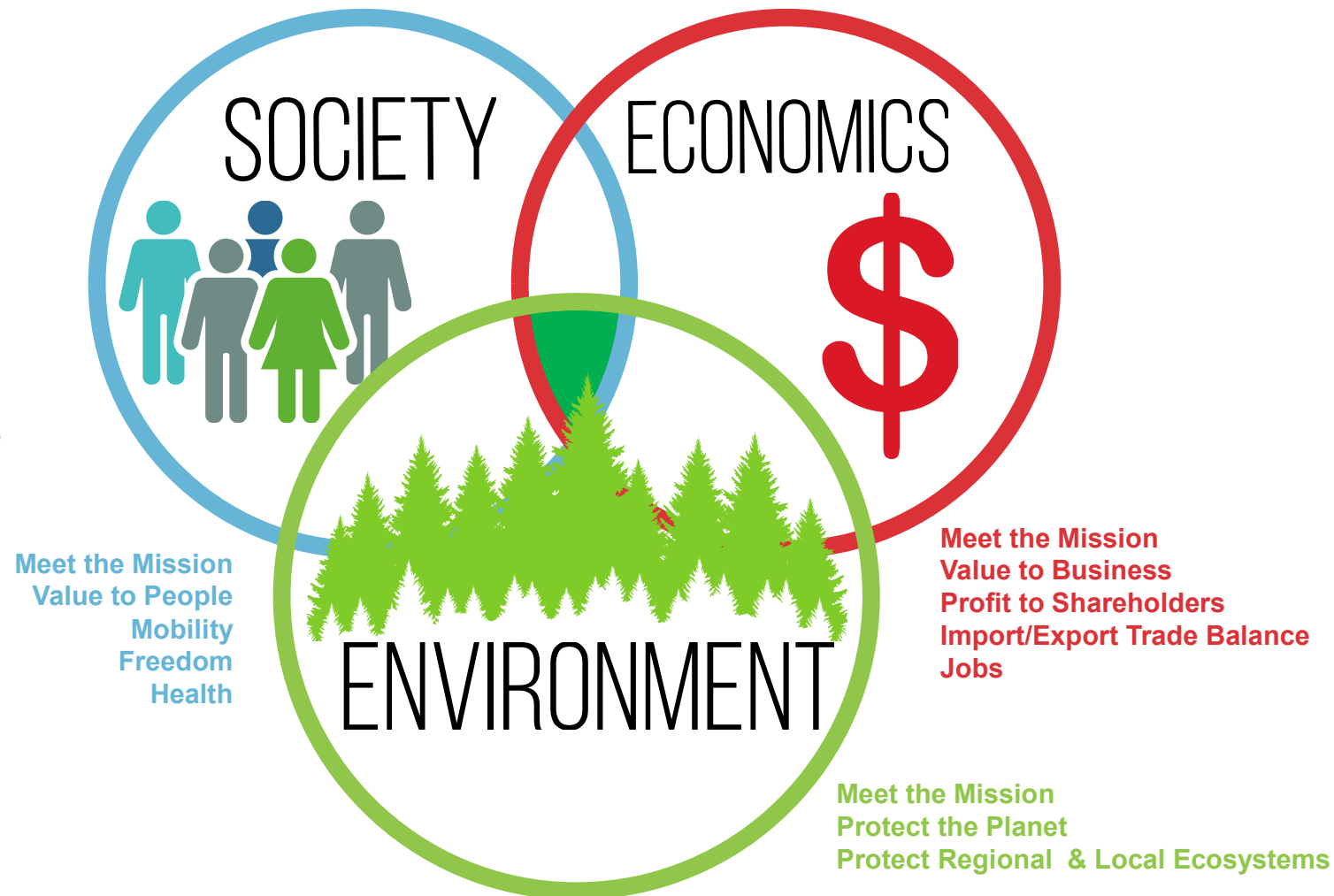
U.S. propulsion & aerostructures competes for global market share

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.”

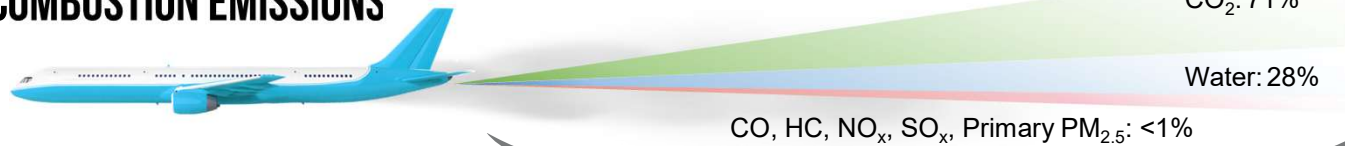
- UN World Commission on Environment and Development



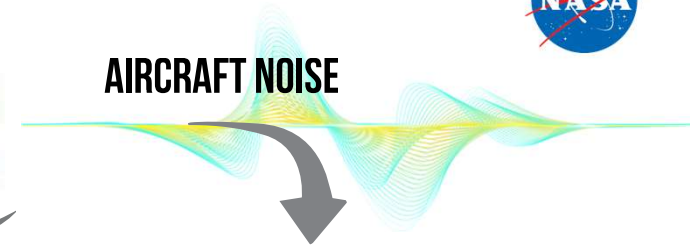
Environmental Impacts of Aviation



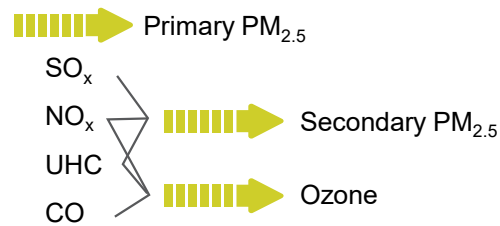
COMBUSTION EMISSIONS



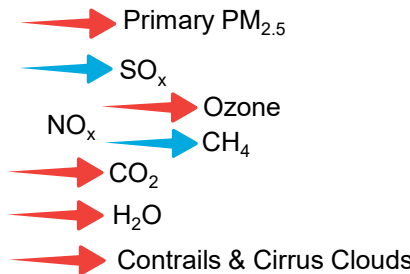
AIRCRAFT NOISE



ATMOSPHERIC CHEMISTRY & PHYSICS



POPULATION
EXPOSURE
AND HEALTH
IMPACTS

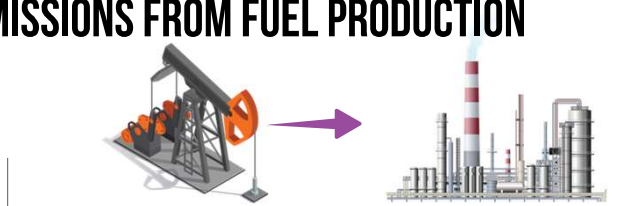


GLOBAL CLIMATE CHANGE



Cooling
Effects
Warming
Effects

EMISSIONS FROM FUEL PRODUCTION



CH_4 , N_2O , CO_2

OZONE LAYER

SUSTAINABILITY IMPACTS

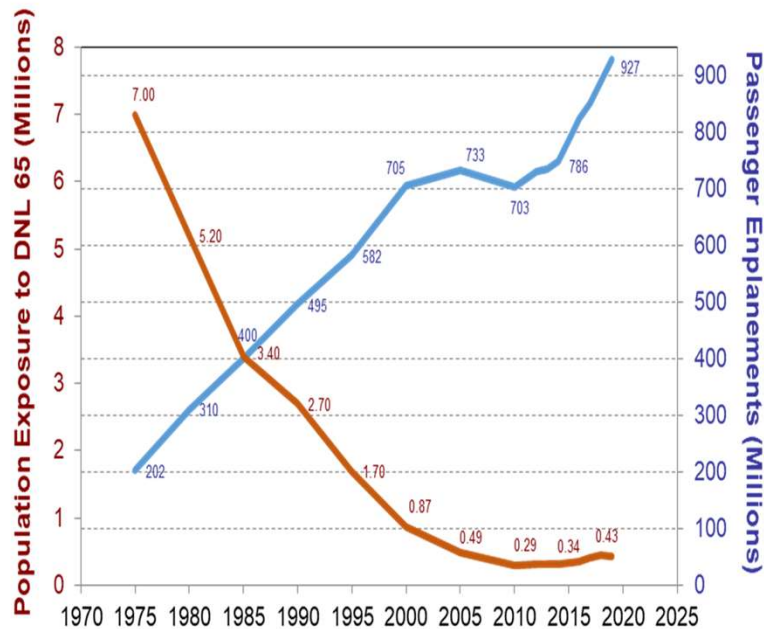
Aviation Noise Impact

Population exposed is a key societal metric dependent on aircraft technology, and number of ops and procedures



History – FAA Data

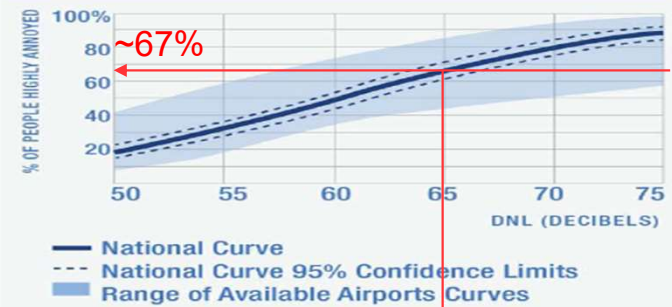
90%+ reduction in exposure with
4.5X+ increase in enplanements



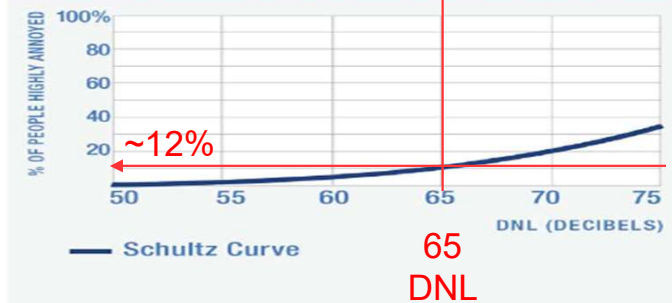
FAA Neighborhood Noise Survey 2021

People are significantly more annoyed by 65 dB DNL now than in the 1970s

NATIONAL CURVE



SCHULTZ CURVE



Noise Reduction Remains a Key Environmental Driver

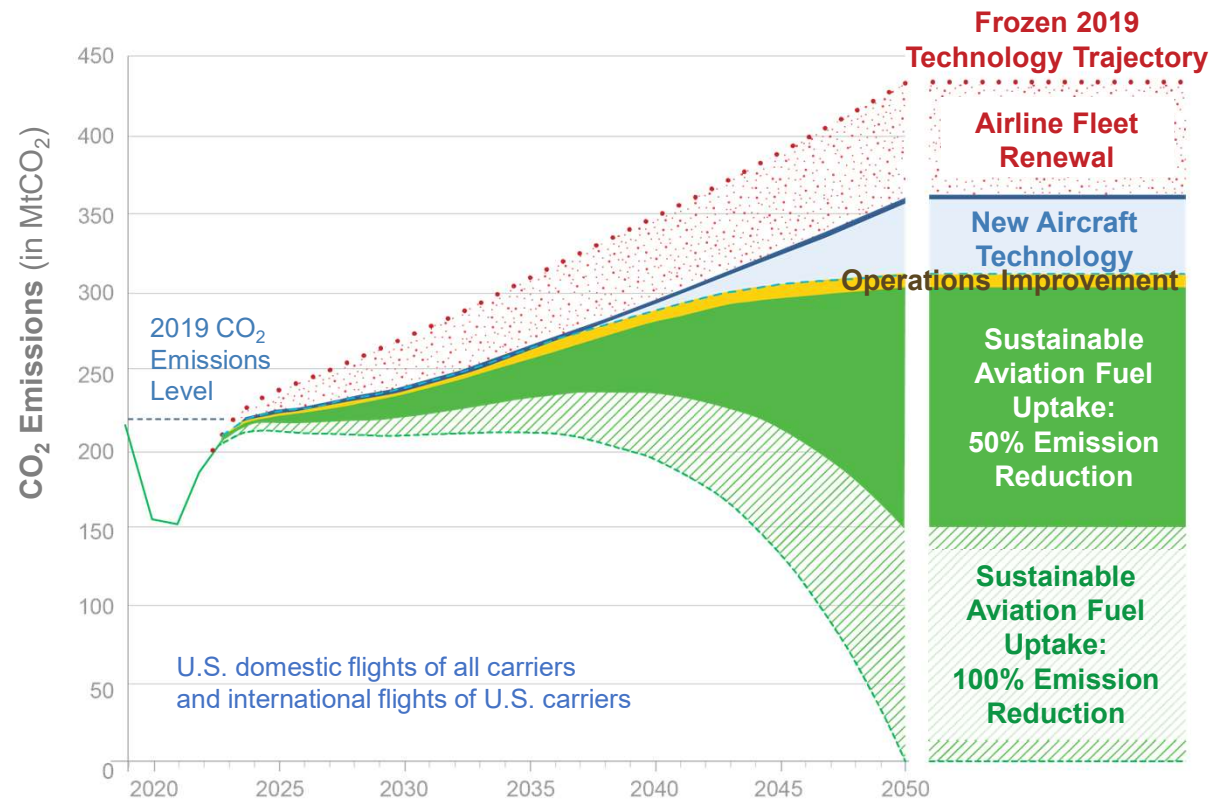
U.S. Aviation Climate Action Plan

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

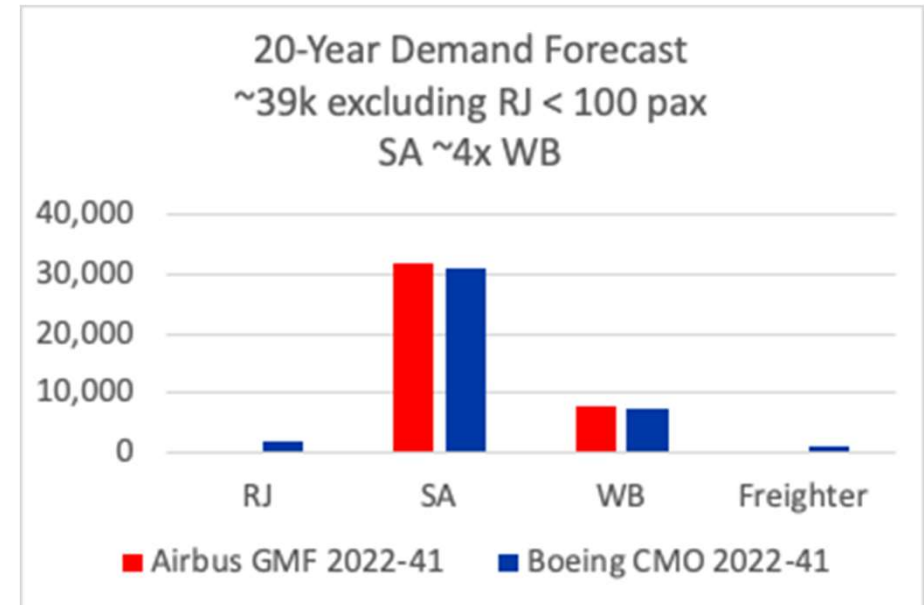
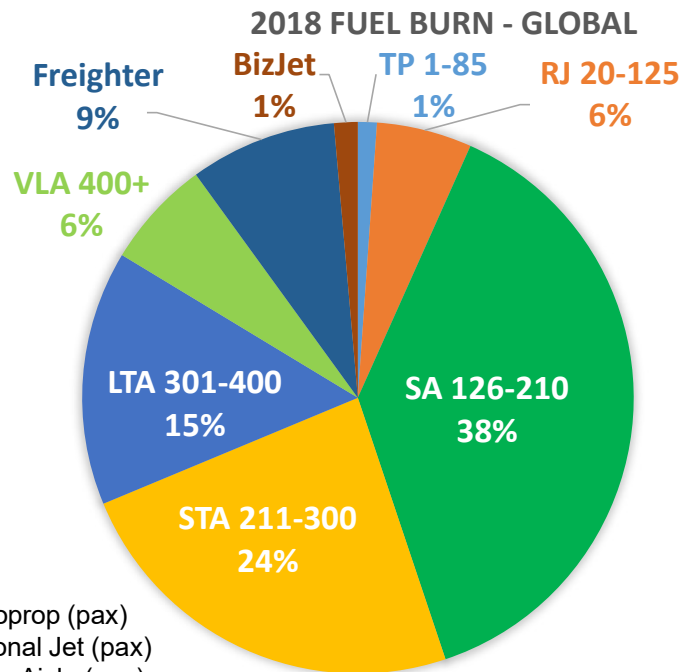
- U.S. economy-wide goal
- International Civil Aviation Organization (ICAO)
- Air Transport Action Group (ATAG)



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.

Carbon Emissions and 20-Year Market Demand Forecast – Global



- Single-Aisle (SA) Aircraft Families**
- Emit the most carbon (38%)
 - Highest demand
 - 2030's clean sheet design?

TP: Turboprop (pax)
RJ: Regional Jet (pax)
SA: Single Aisle (pax)
STA: Small Twin Aisle (pax)
LTA: Large Twin Aisle (psx)
VLA: Very Large Twin Aisle (pax)
WB: Widebody (STA+LTA+VLA)

Source data:
DoT/Volpe Center, Flemming et al.; basis of 2022 ICAO Environmental Report, Chapter 1, p24
<https://www.icao.int/environmental-protection/Documents/EnvironmentalReports/2022/ICAO%20ENV%20Report%202022%20F4.pdf>
Airbus Global Market Forecast (GMF) 2022-41: <https://www.airbus.com/sites/g/files/jlcbta136/files/2022-07/GMF-Presentation-2022-2041.pdf>
Boeing Current Market Outlook (CMO) 2022-41: <https://www.boeing.com/commercial/market/commercial-market-outlook/index.page?>

Aviation Pillars for a Sustainable Future

Global Aviation Industry GOAL: net-zero carbon emissions by 2050



TECHNOLOGY



NASA = Primary Role

SUSTAINABLE AVIATION FUEL



NASA = Supporting Role

OPERATIONS AND INFRASTRUCTURE



NASA = Primary Role



Sustainable Flight National Partnership (SFNP)

Sustainable Flight National Partnership

Accelerating Toward Net-Zero Greenhouse Gas Emissions and Reduced Non-CO₂ Climate Impact in the 2030s



Advance engine
efficiency and
emission reduction

Enable integrated
trajectory optimization

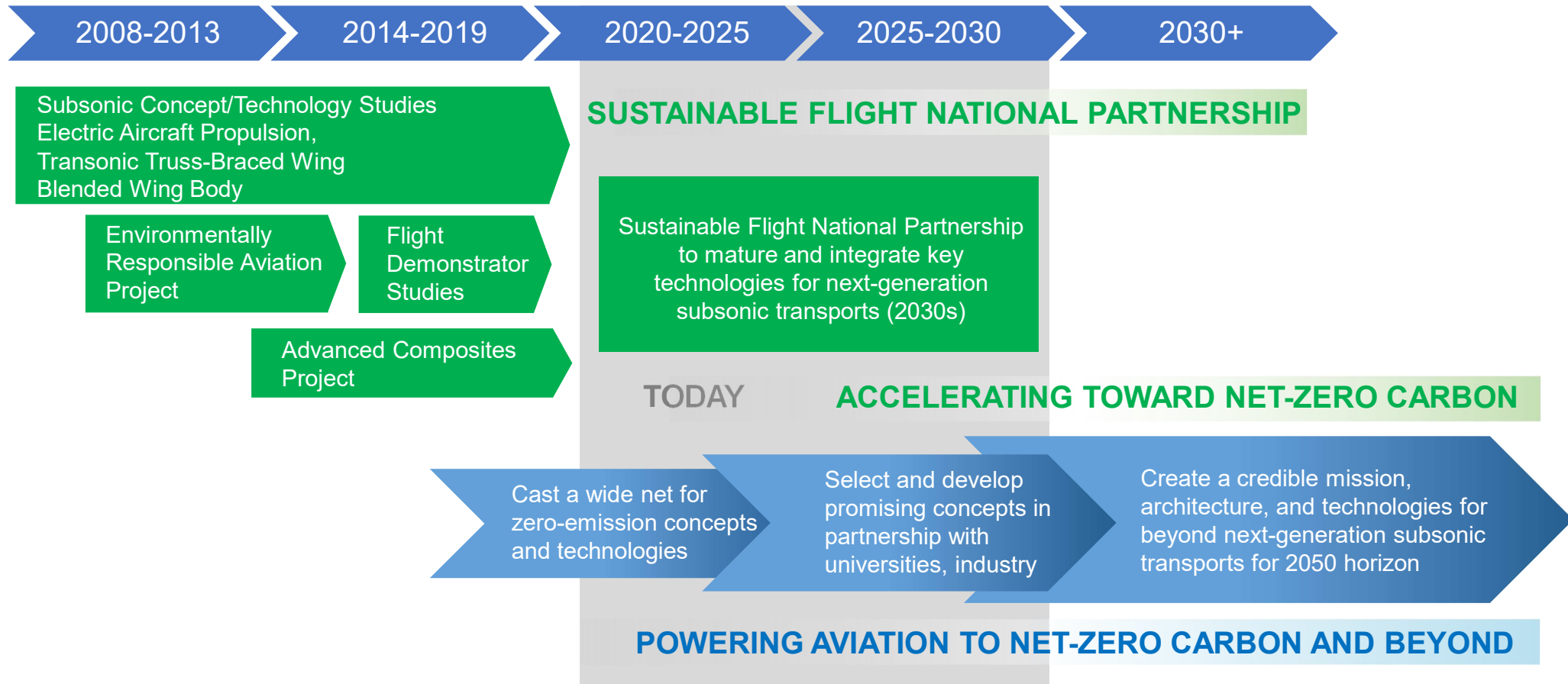


Advance airframe
efficiency and
manufacturing rate

Enable use of 100%
sustainable aviation fuels

Next-generation transports using up to 30% less fuel, current & future fleet flying optimal trajectories, and engines burning SAF with greater than 50% reduction in lifecycle GHG emissions

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 Industry GOAL: net-zero carbon emissions by 2050



TECHNOLOGY



NASA = Primary Role

SUSTAINABLE AVIATION FUEL



NASA = Supporting Role

OPERATIONS AND INFRASTRUCTURE



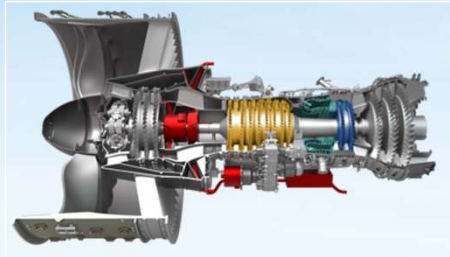
NASA = Primary Role

Subsonic Transport Technologies

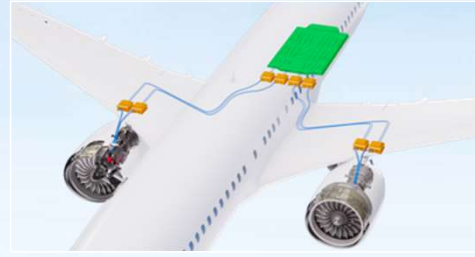
Ensure U.S. industry is the first to establish the new technology “S Curve” for the next 50 years of transports



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



Small Core Gas Turbine
~5-10% fuel burn benefit



Electrified Aircraft Propulsion
~5% fuel burn & maintenance benefit



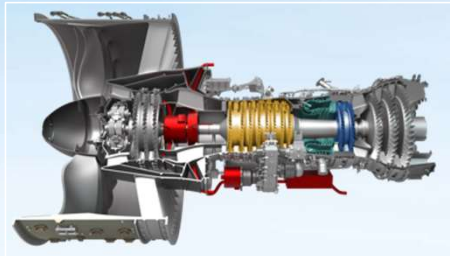
High-Rate Composite Manufacturing
4-6x manufacturing rate increase

Subsonic Transport Technologies

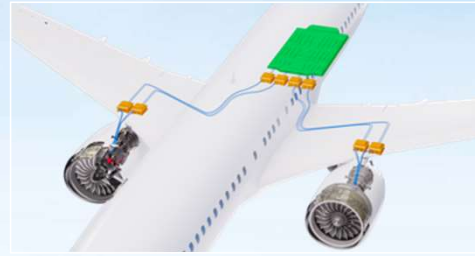
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High-Rate Composite Manufacturing
4-6x manufacturing rate increase

Breguet Range Equation



Aerodynamic Efficiency
Transonic Truss-Braced Wing

Integrated Aircraft System Efficiency
Electrified Aircraft Propulsion

$$Range = \frac{V}{SFC} \left(\frac{L}{D} \right) \ln \left(1 + \frac{W_{fuel}}{W_{payload} + W_0} \right)$$

Engine Efficiency
Small Core Gas Turbine

Weight
High-Rate Composite Manufacturing

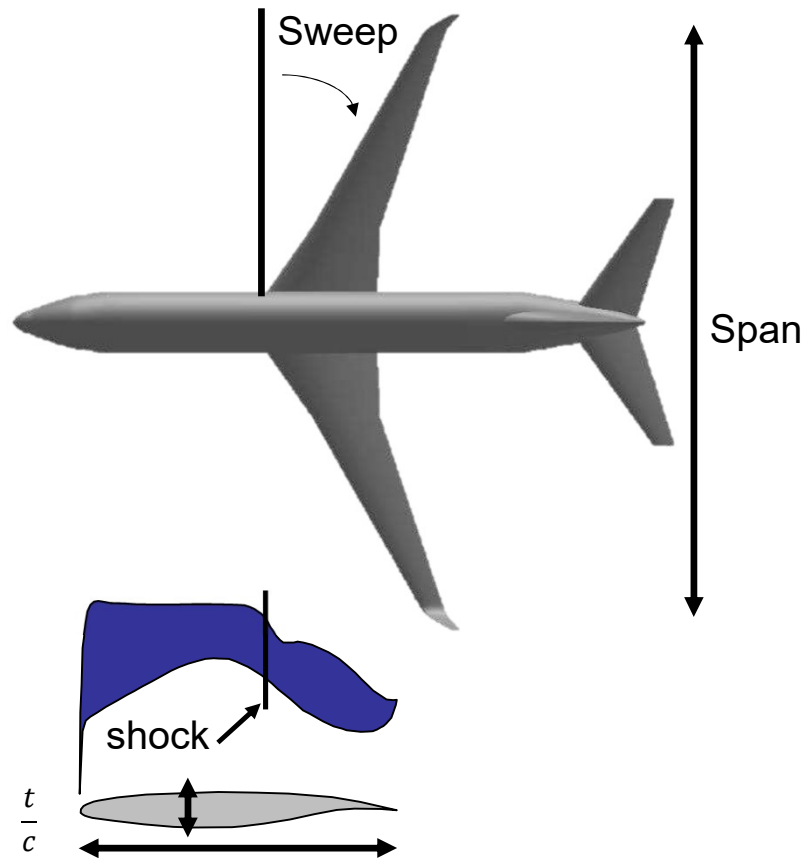
Subsonic Transport Technologies

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





Aerodynamic Efficiency (L/D & ML/D)



Drag = parasite + lift induced + compressibility

$$C_D = C_{D0} + \frac{C_L^2}{\pi e AR} + C_{D, \text{wave}}$$

$$C_{D0} \sim \text{total wetted area (laminar/turbulent)} \quad AR = \frac{\text{span}^2}{\text{area}_{ref}}$$

Airfoil/Wing Technology

speed, sweep, thickness, & lift trades

$$\sim M_\infty \cos \lambda + \frac{\left(\frac{t}{c}\right)}{\cos \lambda} + \frac{c_l}{10 \cos^2 \lambda}$$

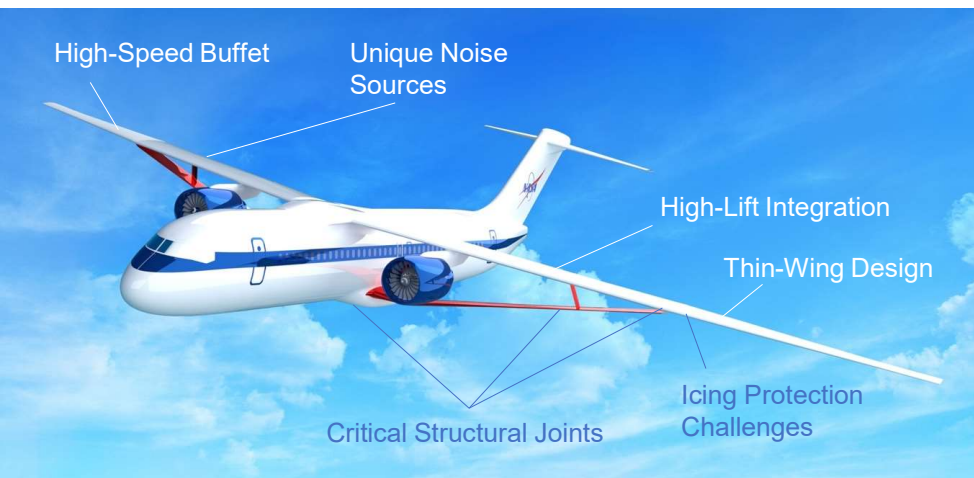
The Challenge

Improving L/D without offsetting weight increase due to high span and thin airfoils

$$\eta_{aerodynamic} \sim \frac{\text{span}}{\sqrt{\text{wetted area}}}$$

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

Sustainable Flight Demonstrator (SFD)

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 2030's.

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 2030's.

Approach

- Competitive selection through Funded Space Act Agreement
- Partner with industry to demonstrate promising integrated airframe-focused technologies in flight including nontraditional configuration

Risk Reduction Contracts: August 2021 – September 2022
Design/Build/Fly Funded Space Act Agreement Awarded: 18 January 2023
1st Flight: 2028

Sustainable Flight Demonstrator (SFD)



NASA Awards Boeing With Sustainable Flight Demonstrator Contract

Both entities will develop a full-scale demonstrator aircraft which will have its first flight in 2028.

BY DANIEL MARTÍNEZ GARCÍA

This 'airliner of the future' has a radical new wing design

NASA and Boeing are collaborating to create the Sustainable Flight Demonstrator, which will feature long wings supported by trusses. It could first fly in 2028.

NASA Issues
Efficient Airli

Boeing Selected for NASA Sustainable Flight Demonstrator Award

- NASA, Boeing and partners aim to cut fuel use and emissions up to 30% in single-aisle airplanes
- Advances in sustainable technology are crucial to reaching civil aviation's goal to be net zero carbon emissions by 2050



Sustainable Flight Demonstrator (SFD)

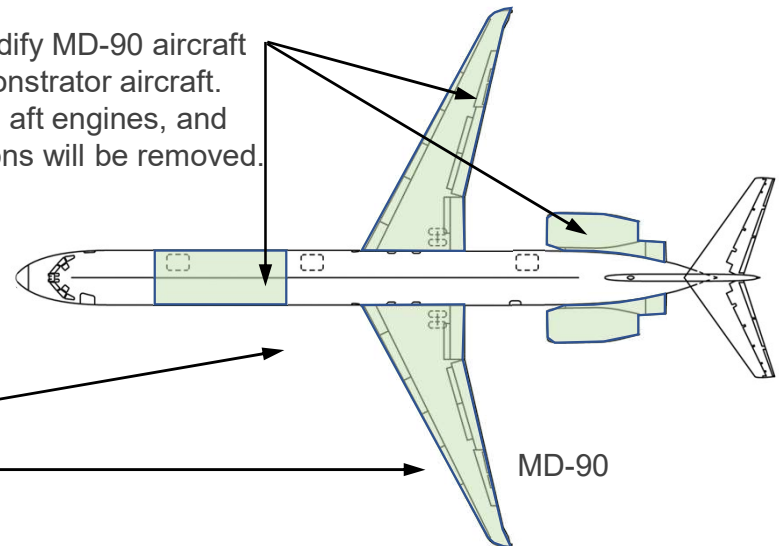


- Awarded a Funded Space Act Agreement (FSAA) to Boeing in January 2023 to design, build, test and fly an advanced airframe configuration demonstrator aircraft and related technologies to dramatically reduce fuel burn and CO₂ emissions.
 - \$425M direct NASA investment
 - ~\$125M over 7 years NASA facilities/ labor o
- Boeing's Transonic Truss Braced Wing (TTBW)
 - high aspect ratio
 - thin
 - truss-braced wing design
- Sustainable Flight Demonstrator (SFD) aircraft
 - MD-90 aircraft with TTBW and shortened fuselage
 - 2028 first flight planned
 - 2020's complete flight tests
 - 2030's industry to evaluate the utilization into market



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

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

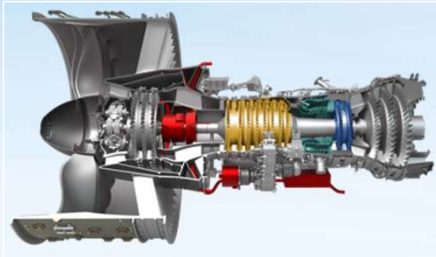


Subsonic Transport Technologies

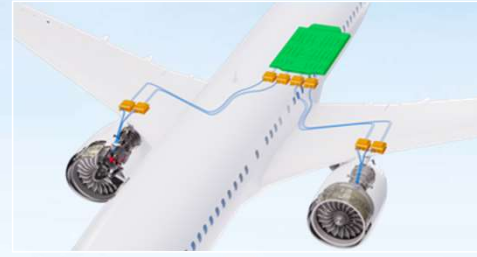
Ensure U.S. industry is the first to establish the new technology “S Curve” for the next 50 years of transports



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



Small Core Gas Turbine
~5-10% fuel burn benefit

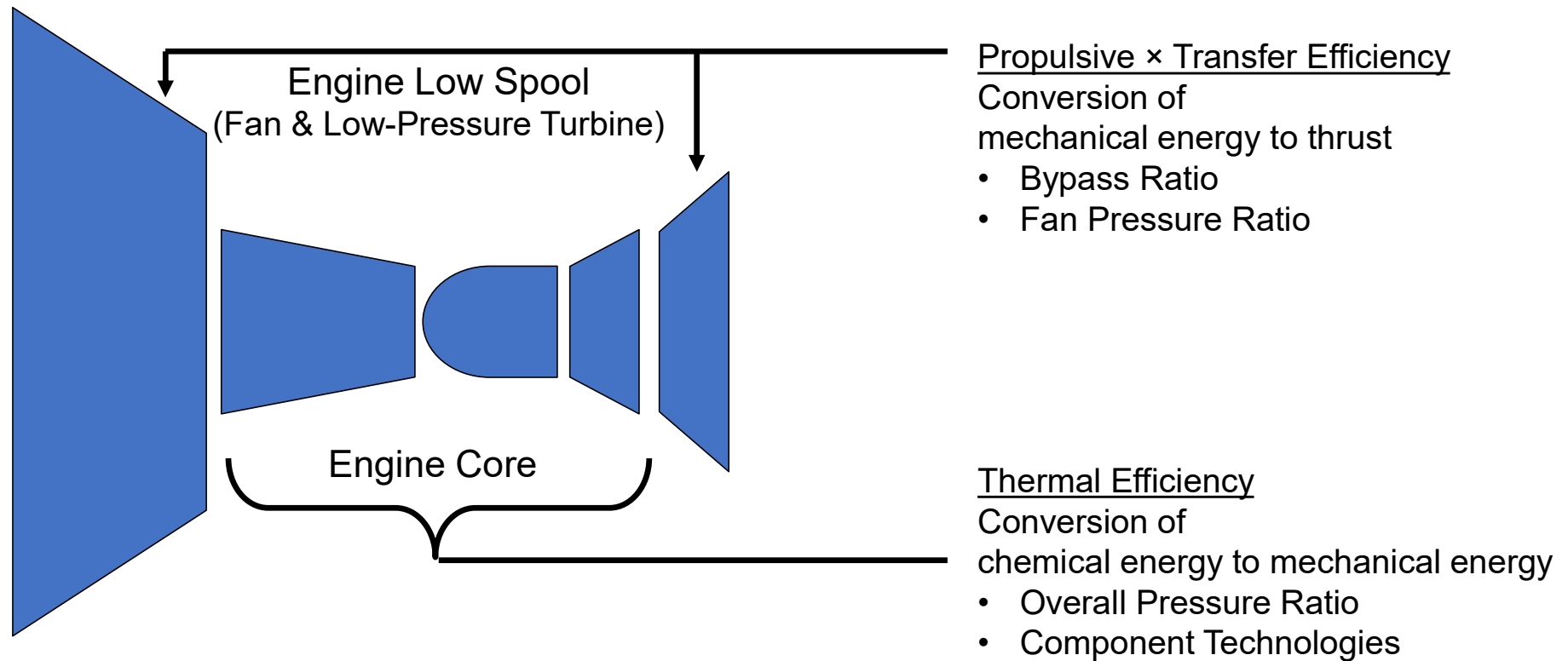


Electrified Aircraft Propulsion
~5% fuel burn & maintenance benefit



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

Engine Efficiency (Specific Fuel Consumption)



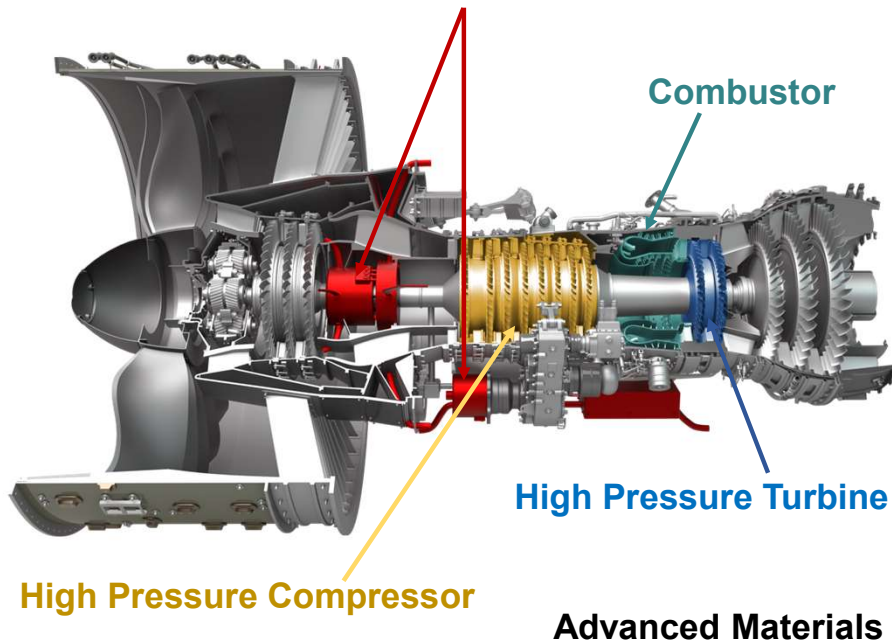
$$\eta_{overall} = \eta_{thermal} \times \eta_{propulsive} \times \eta_{transfer}$$

Hybrid Thermally Efficient Core (HyTEC)

Accelerate development and demonstration of advanced turbine engine technologies



Turbofan Power Extraction



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

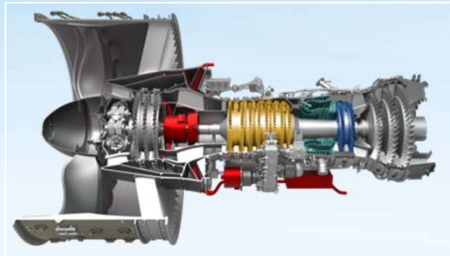
Small-core turbofan technology contracts awarded: September 2021
Additional technology contract awarded: September 2022

Subsonic Transport Technologies

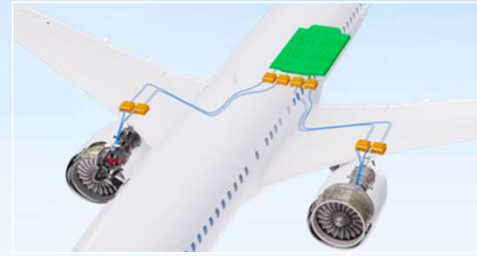
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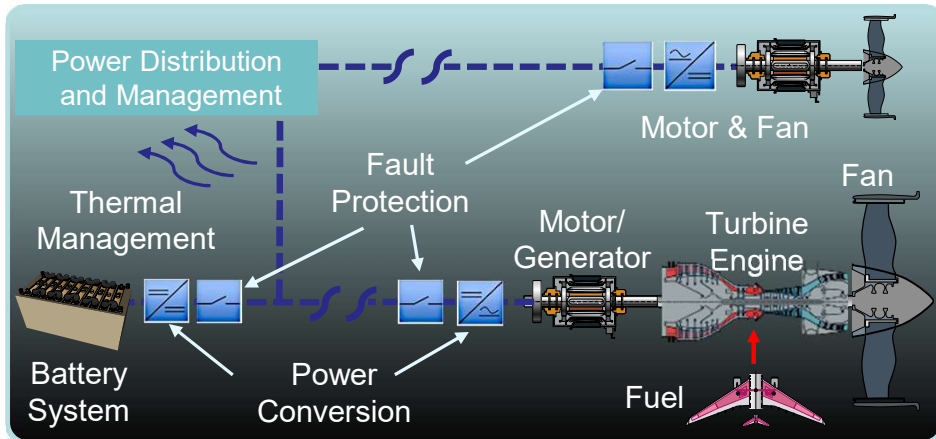


High-Rate Composite Manufacturing
4-6x manufacturing rate increase

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)

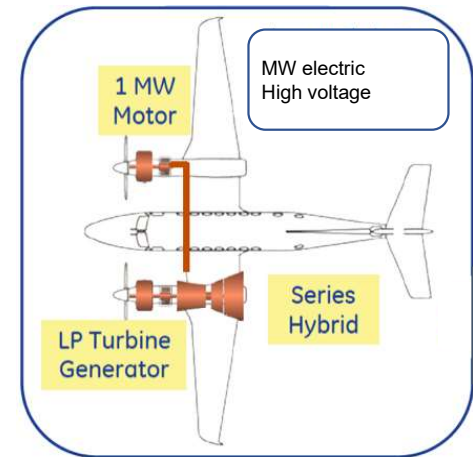
Architecture development and high-power component tests are underway
Completed Altitude Integrated Test of high-power, high-voltage powertrain FY22

Electrified Powertrain Flight Demonstration (EPFD)

Demonstrate integrated electrified powertrains in flight using industry platforms



NASA concept vehicle



Electrified Powertrain Flight Demonstration (EPFD)

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.

Approach

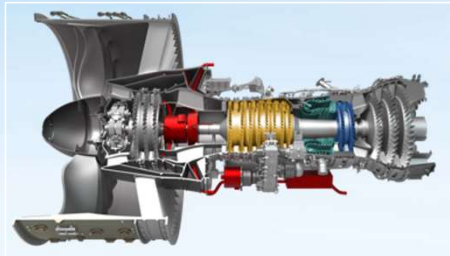
- Engage with U.S. industry to integrate and demonstrate megawatt-class EAP machines in flight.
- Engage with the FAA, SAE, ASTM, etc. to contribute data that inform EAP standards and regulations.

Subsonic Transport Technologies

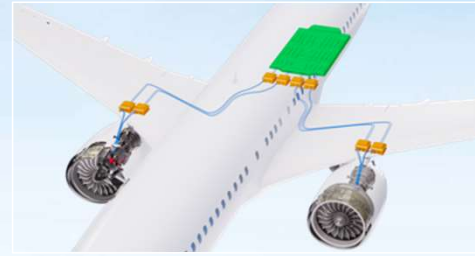
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Electrified Aircraft Propulsion
~5% fuel burn & maintenance benefit



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

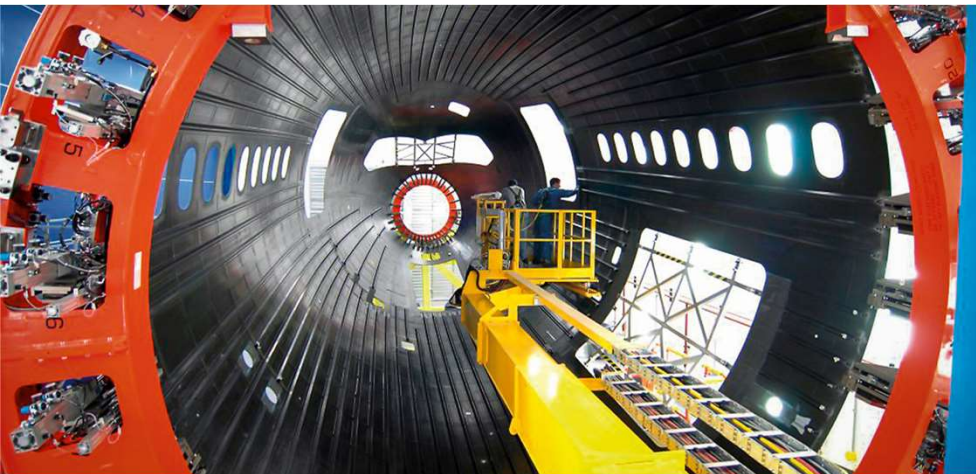
Hi-Rate Composite Aircraft Manufacturing (HiCAM)

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

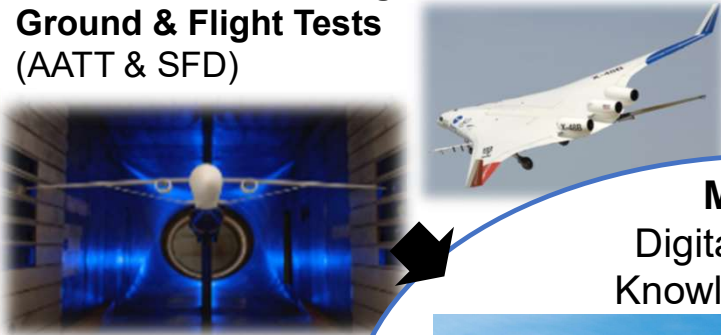
- Leverage advances in simulation including methods from Advanced Composites project
- Partner with industry for rapid prototype and evaluation of manufacturing concepts
- Demonstrate technologies in large structural ground tests

Model-Based Systems Analysis & Engineering

SFNP Vision



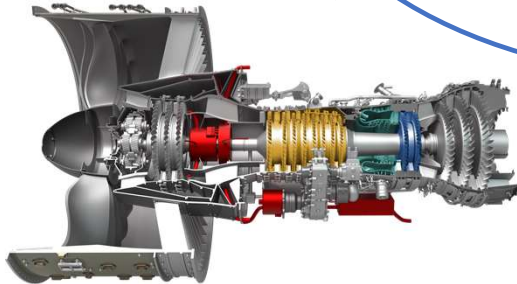
**Advanced Aero-Configuration
Ground & Flight Tests
(AATT & SFD)**



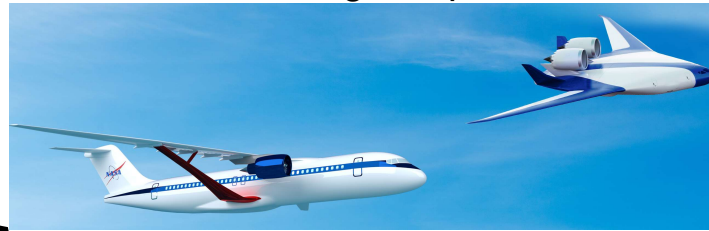
**High-Rate Composite
Manufacturing
Processes (HiCAM)**



**Small Core Engine
Ground Tests
(HyTEC)**



MBSA&E
Digital Integration
Knowledge Capture



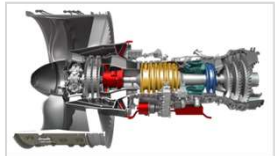
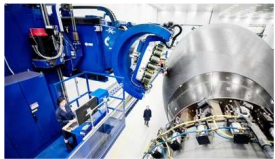
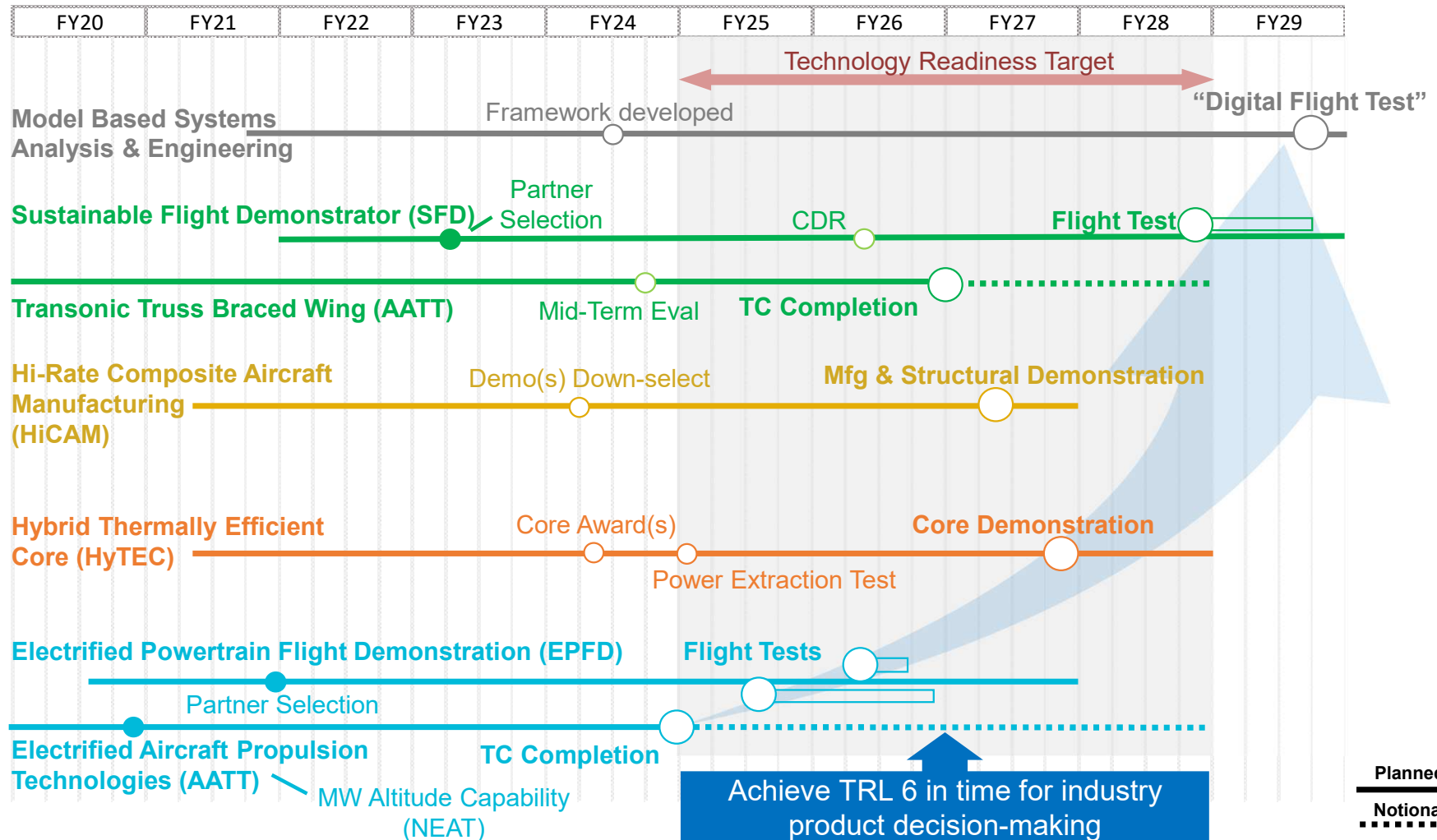
Vision Vehicles
System of Systems

**Electrified Propulsion
Ground & Flight Tests
(AATT & EPFD)**



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

Subsonic Transports: Integrated Technology Development

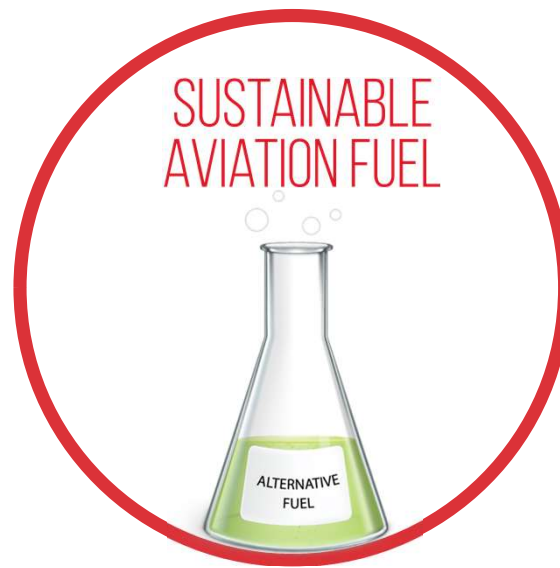


Aviation Pillars for a Sustainable Future

Global Aviation Industry GOAL: net-zero carbon emissions by 2050



NASA = Primary Role



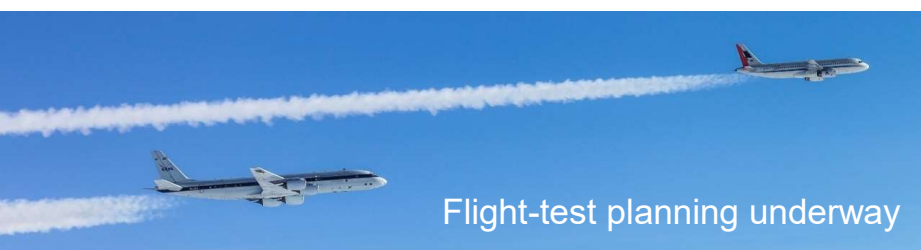
NASA = Supporting Role



NASA = Primary Role

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

Sustainable Aviation Fuel (SAF) Emissions and Contrails Research



October 2021 Emissions Ground Test at Boeing Field

- Goal to quantify on-wing emissions relevant for contrails & air quality
- Ultra-low-emitting CFM LEAP-1B engines on the 2021 ecoDemonstrator 737 MAX 9
- Four fuels: 100% SAF, Jet A, 2 blends
- Test covered the range of engine thrust conditions from engine idle to takeoff
- Burning 100% SAF in the LEAP-1B engines gave lowest possible emissions achievable with in-service technology



Photo Credit: Boeing / Paul Weatherman

Aviation Pillars for a Sustainable Future

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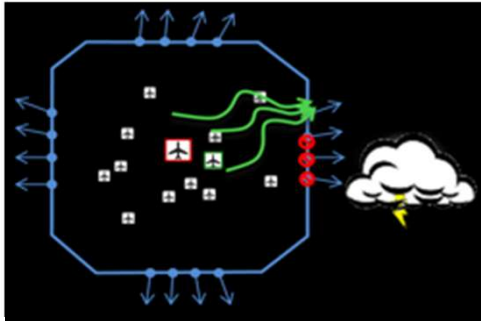
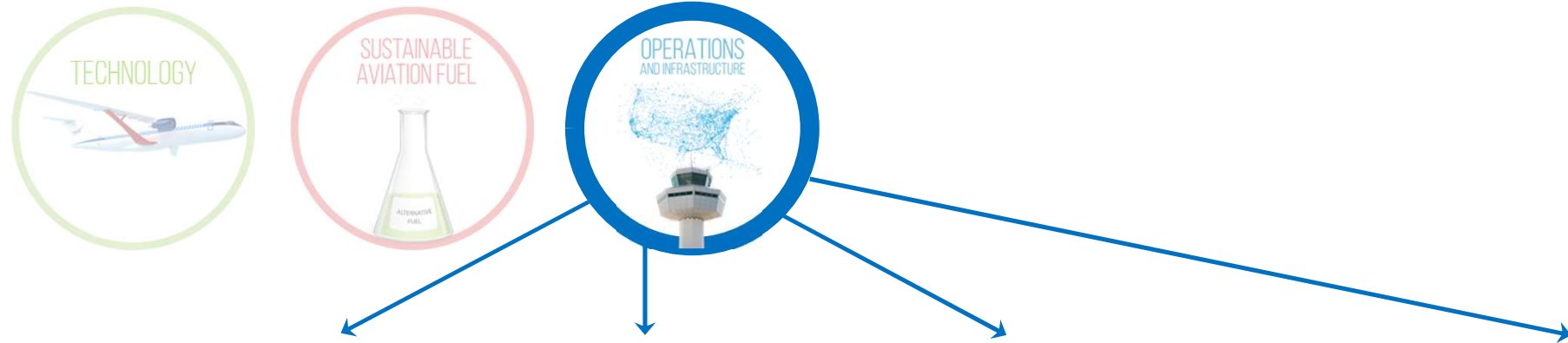


NASA = Supporting Role



NASA = Primary Role

NASA-Led SFNP Operations Demonstrations



Collaborative Digital Departure Reroute (SFNP-Ops-1, FY22-25)



Sustainable Oceanic Airborne Re-Routing (SFNP-Ops-2, FY26)



Irregular Ops Recovery/Disruption Management (SFNP-Ops-3, FY27)



4D Trajectory Optimization (SFNP-Ops-4, FY28)

SFNP-Ops = Sustainable Flight National Partnerships - Operations

Sustainability Goals: Deliver reduction in emissions, fuel, and noise of aviation operations through digital services technology

NASA's Vision for Sustainable Aviation Operations ~2035



- Integrated trajectories optimized for environmental benefit
- Advanced flight deck capabilities to operate on those trajectories
- Tailored services that support safe integration of all diverse operations

Increased operational efficiency reduces fuel burn, carbon emissions, contrail formation, and ozone impact

Airspace Operational Tools Yield Immediate Benefits



Airspace Technology Demonstration (ATD)

Benefits to date from field demonstrations of ATD-2 technologies at the Charlotte Douglas International Airport
(29 Sep 2017–30 Sep 2021)

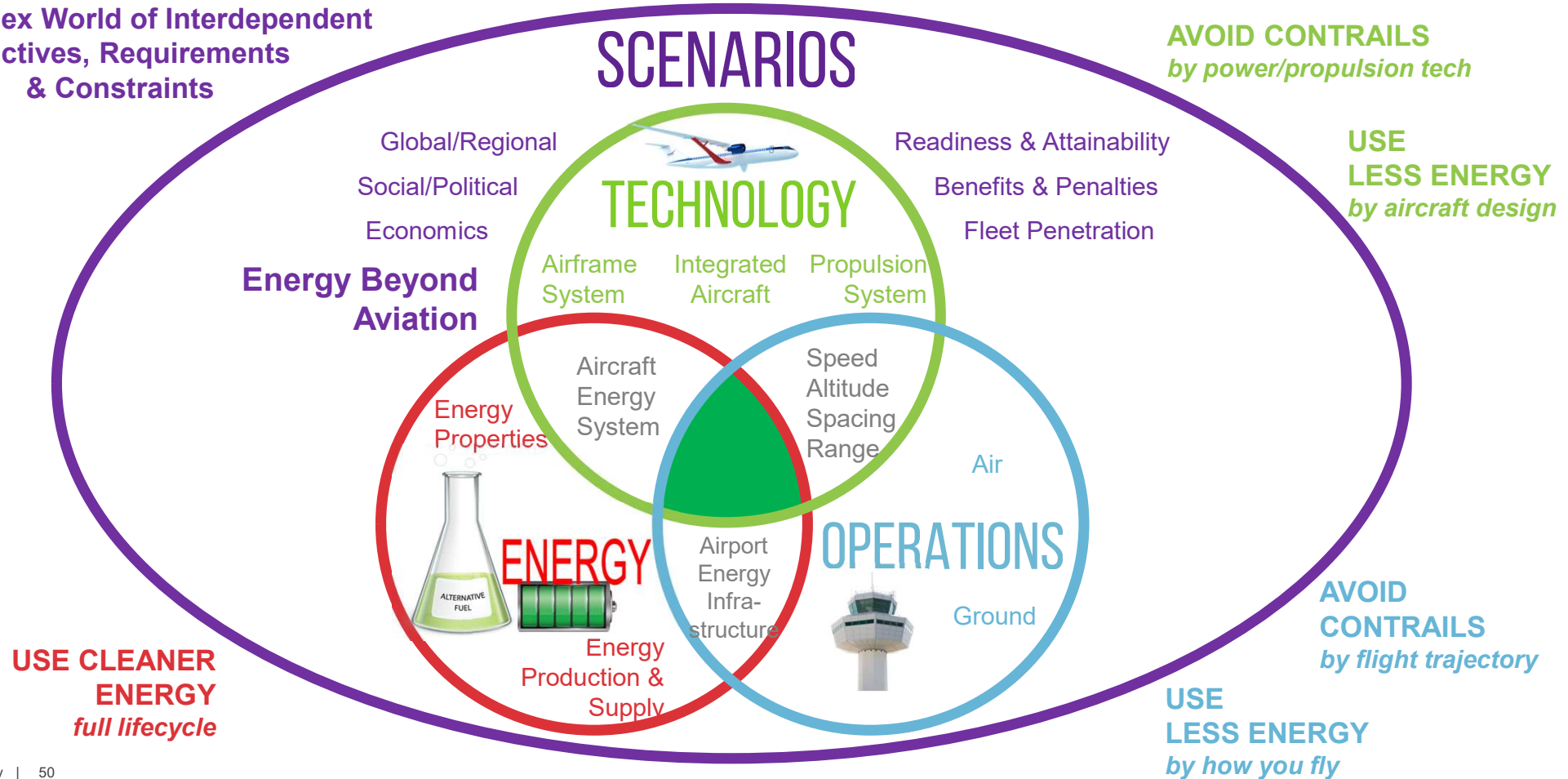


BENEFITS TODAY

Integrated Aviation Pillars for Sustainable Aviation



Complex World of Interdependent
Objectives, Requirements
& Constraints



2023: The Year of NASA Aeronautics





X-57 1st Flight Planned

- Small, experimental plane powered by electricity
- All-electric technology will make flying cleaner, quieter, and more sustainable
- Recent successful thermal testing of its cruise motor controllers



X-59 1st Flight Planned



- Addresses unique barriers to sustainable, environmentally responsible high-speed flight
 - Fly 1.4 times speed of sound at a fraction of the sound of the Concorde
 - Gather data to convince regulatory bodies to allow over ground supersonic flight





X-59 Technology

- Uses parts from existing fighters
 - T-38 cockpit; F-177 control stick, F-18 throttle & engine, F-16 landing gear
- Fuselage shape is all new
- No forward-facing cockpit
 - pilot uses high-def display with augmented reality





Future Aeronautics

requires early-stage R&D today

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



- **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)
 - Challenges require multiple, often interdependent, solutions across technology, operations, and energy domains

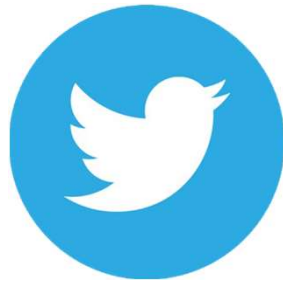


- **NASA Aeronautics addressing the challenges of Sustainable Aviation**
 - Maturing and demonstrating the most promising solutions for application in the 2030's
 - Exploring innovative solutions for application 2040+

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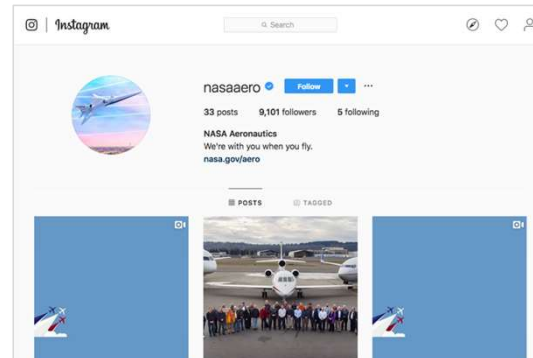
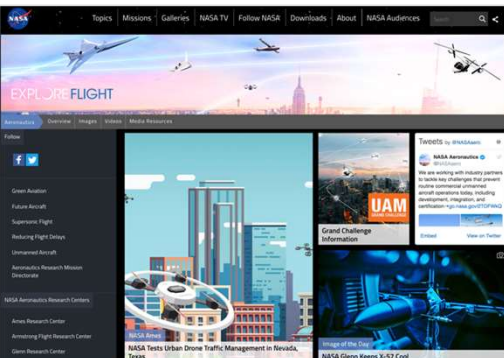
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