National Aeronautics and Space Administration

NASA Sustainable Flight National Partnership Overview

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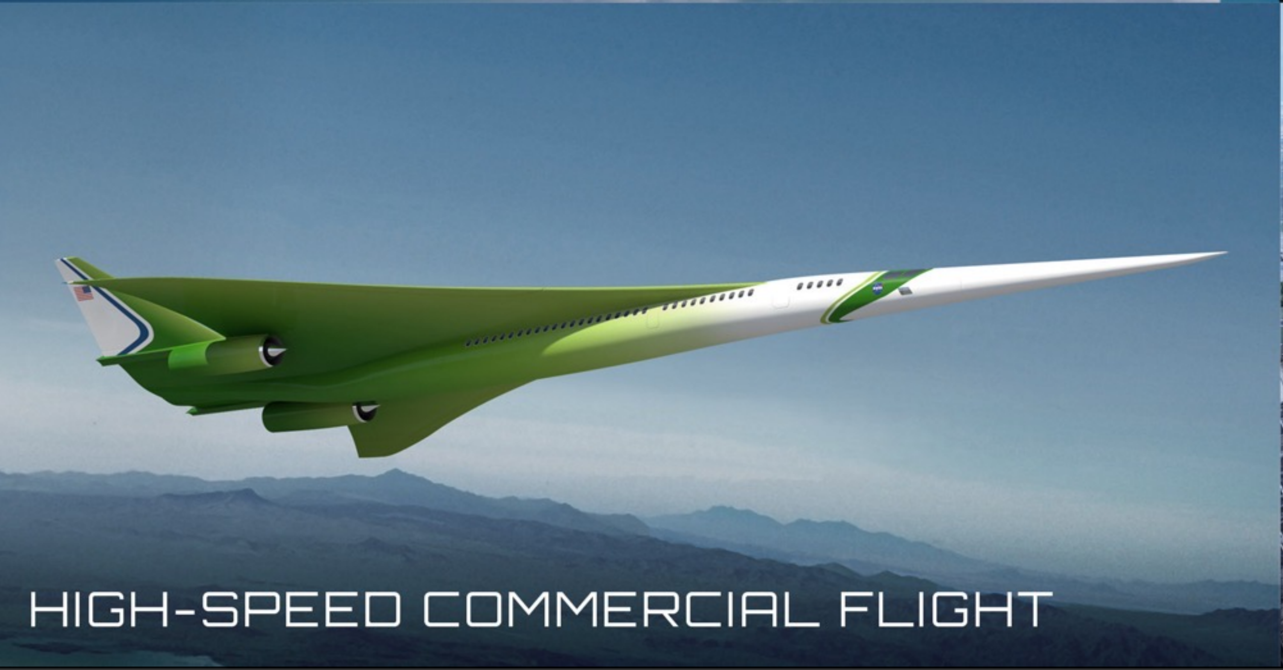
www.nasa.gov

Outline

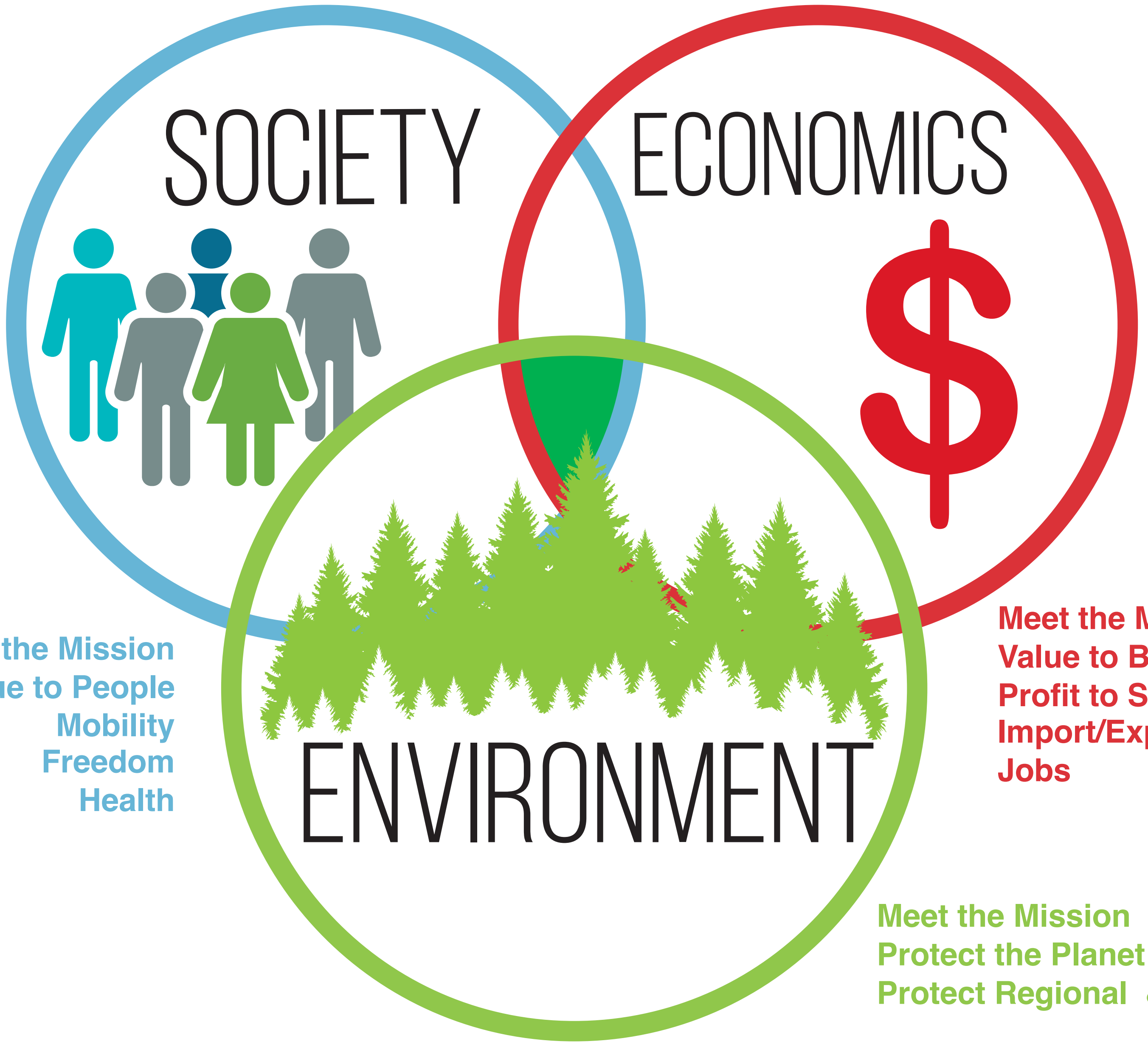
- Introductory Remarks
  - NASA & Global Context
- Sustainable Flight National Partnership (SFNP)
  - Elements
- Concluding Remarks

CONTEXT
NASA Aviation Transformations



Four Transformations for Sustainability, Greater Mobility, and Economic Growth

Sustainability – a Global View



Meet the Mission
Value to People
Mobility
Freedom
Health

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

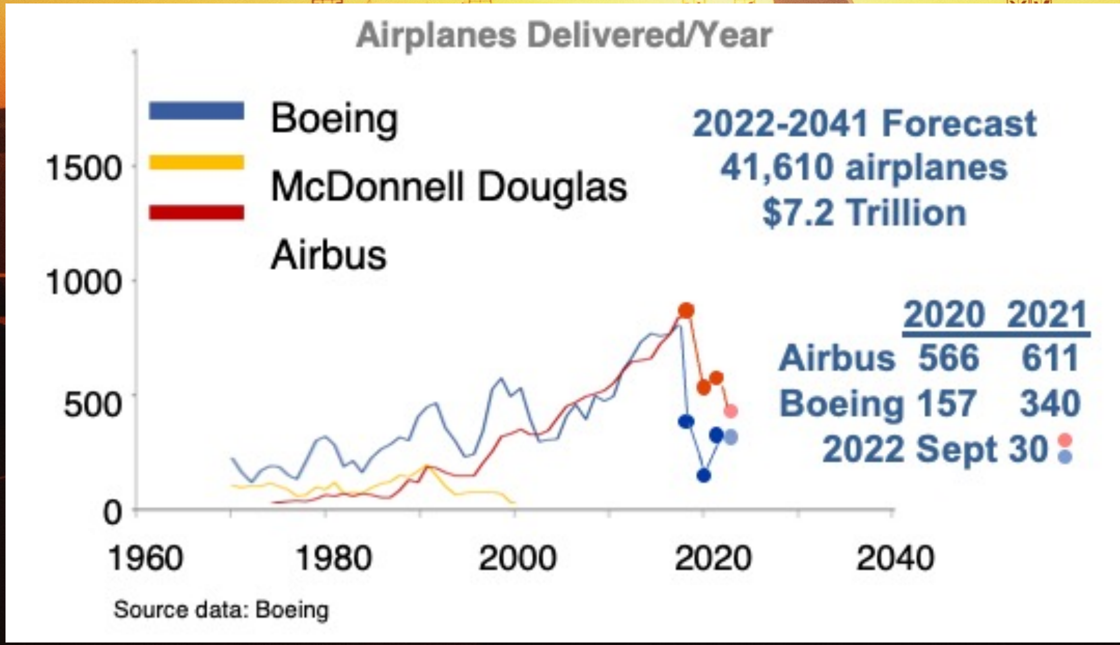
Meet the Mission
Protect the Planet
Protect Regional & Local Ecosystems

Aviation is Vital to our Nation’s Economy

Subsonic Transport Market - Global competition expanding

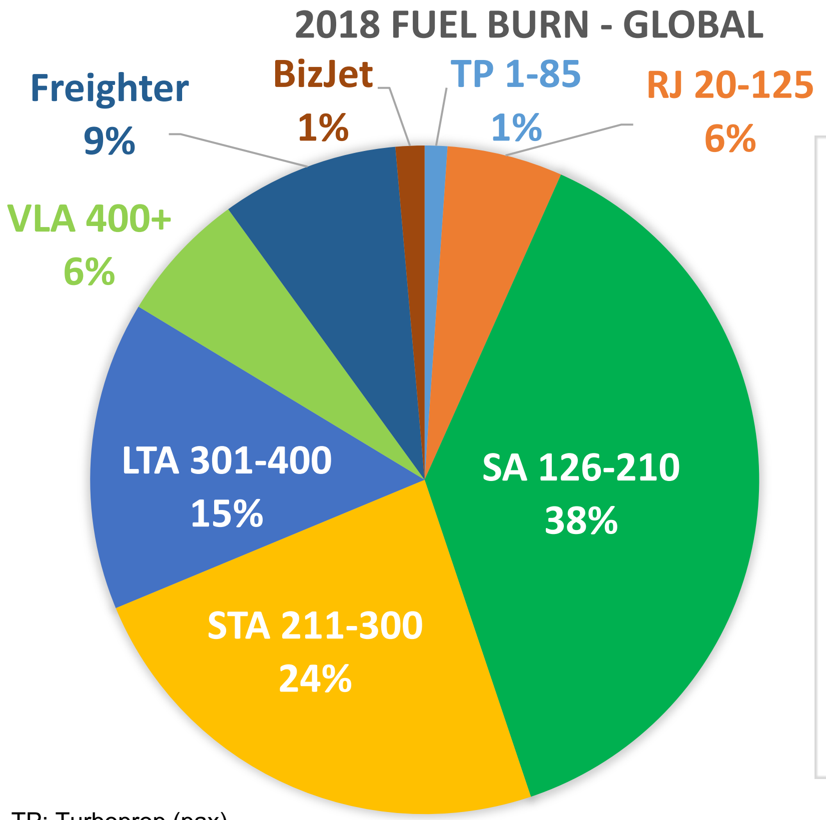
Pre-COVID

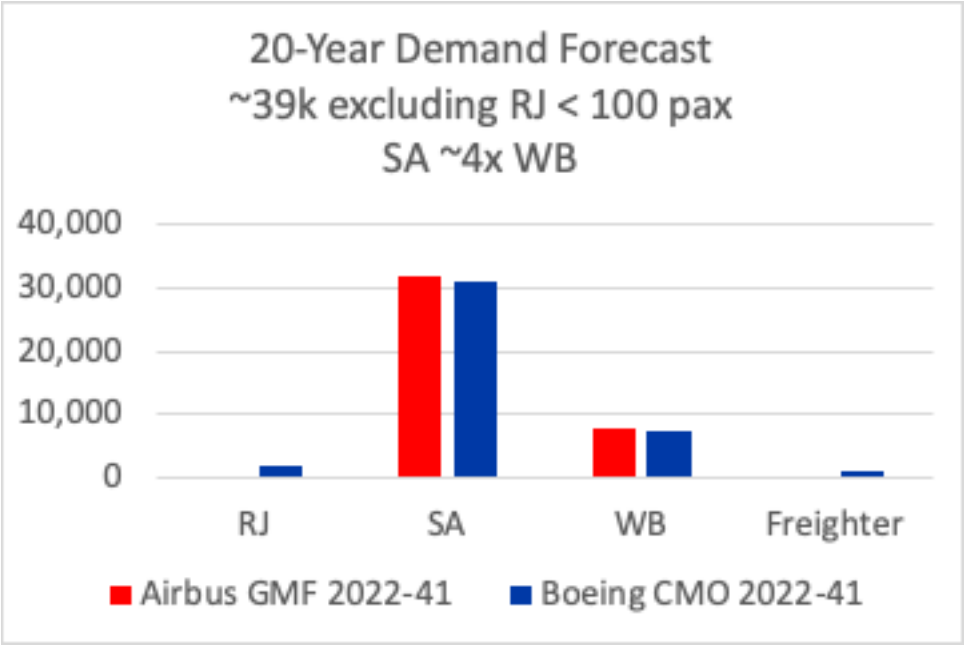
- $78 billion positive trade balance; the largest positive trade balance of any U.S. manufacturing sector
- $1.8 trillion total U.S. economic activity
- 10.9 million direct/indirect jobs
- 21.3 billion tons of freight transported by U.S. airlines in 2019



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

Carbon Emissions and 20-Year Market Demand Forecast – Global



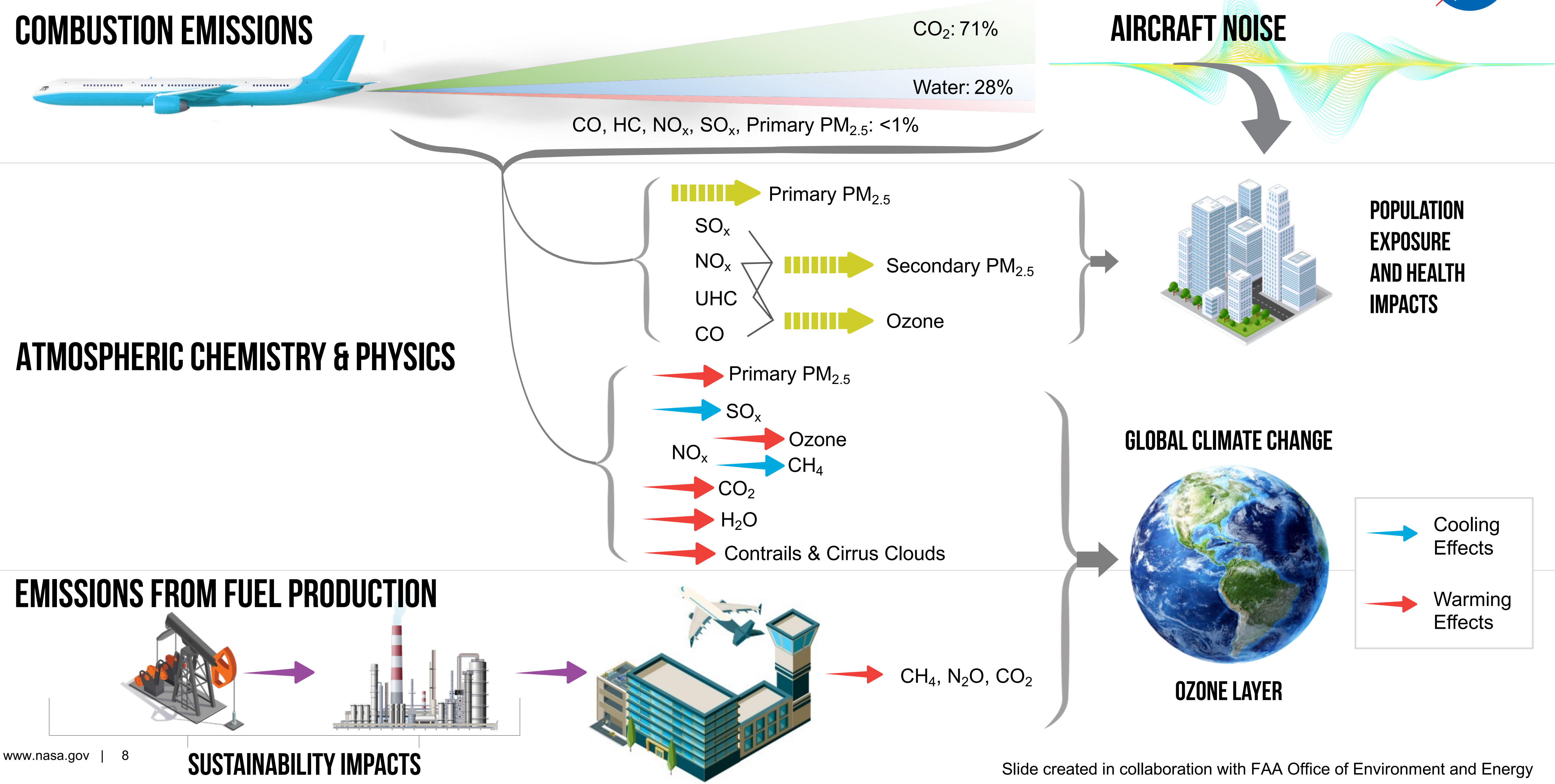


- Single-Aisle (SA) Aircraft Families
  - Emit the most carbon (38%)
  - Highest demand
  - 2030s clean sheet design?

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?

Environmental Impacts of Aviation



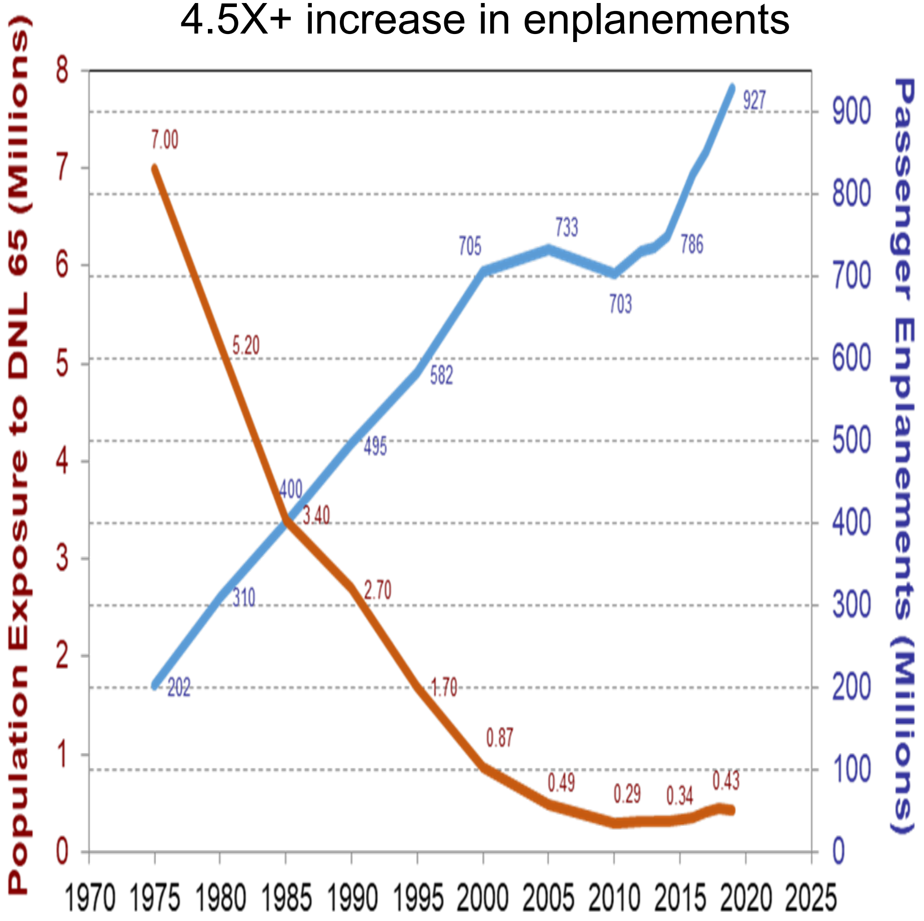
Slide created in collaboration with FAA Office of Environment and Energy

Aviation Noise Impact

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

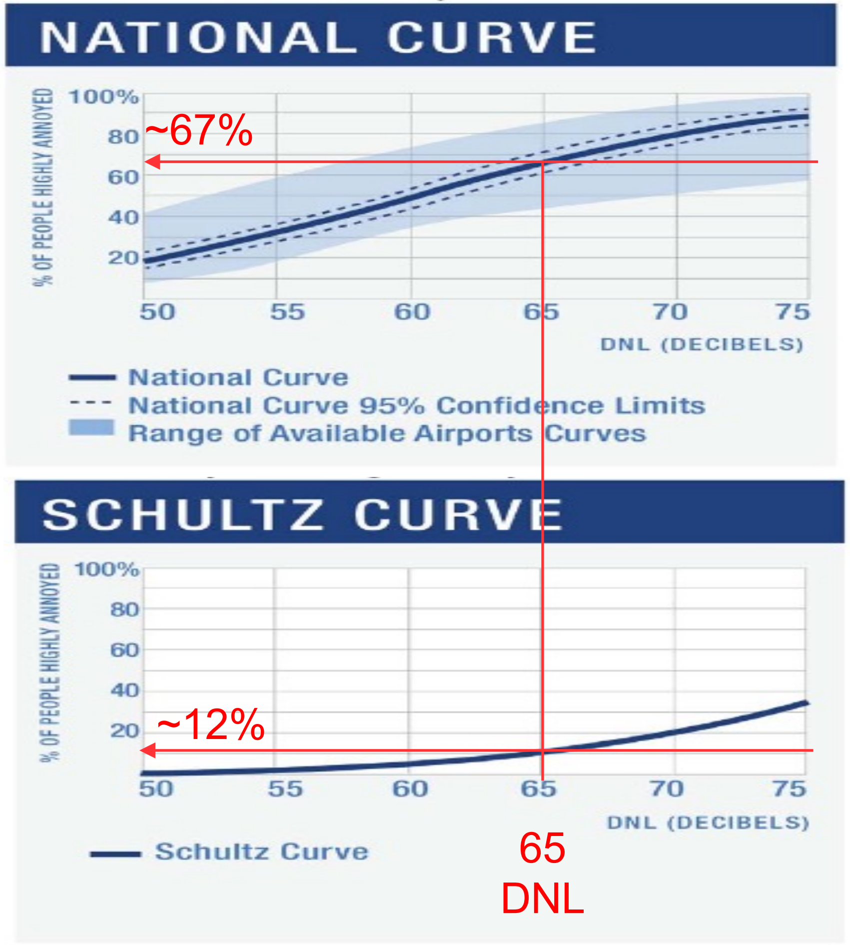
History – FAA Data

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



Noise Reduction Remains a Key Environmental Driver

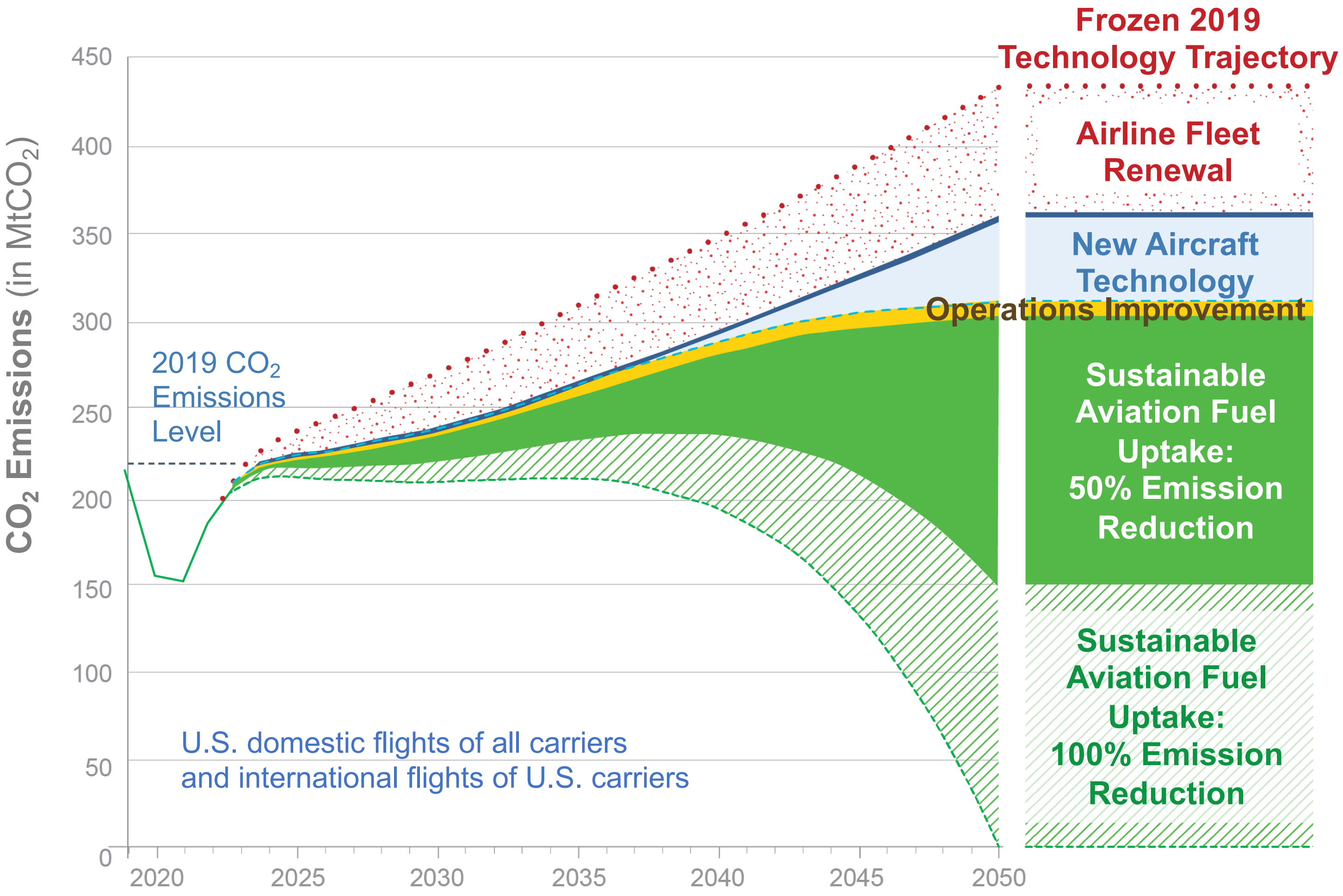
U.S. Aviation Climate Action Plan

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
- Air Transport Action Group



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

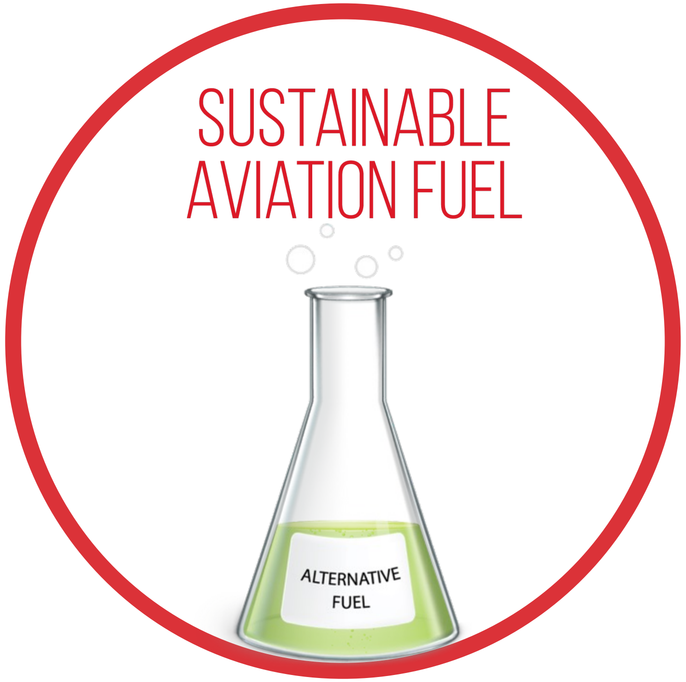
The U.S. is working with the global community to achieve net-zero greenhouse gas emissions by 2050 using a common basket of measures.

CONTEXT
NASA Sustainable Aviation Strategy

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

NASA Sustainable Aviation Strategy

2008-2013 | 2014-2019 | 2020-2025 | 2025-2030 | 2030+

Subsonic Concept/Technology Studies
Electrified 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.

Sustainable Flight National Partnership (SFNP)

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 & future fleet flying optimal trajectories, and engines burning SAF with greater than 50% reduction in lifecycle GHG emissions

ARMD PROGRAMS

Airspace Operations and Safety Program

Advanced Air Vehicles Program

Integrated Aviation Systems Program

Sustainable Flight National Partnership (SFNP)

<u>NASA Projects</u>

1 Advanced Air Transport Technology (AATT)

2 Hi-rate Composite Aircraft Manufacturing (HiCAM)*

3 Hybrid Thermally Efficient Core (HyTEC)*

4 Electrified Powertrain Flight Demonstrations (EPFD)*

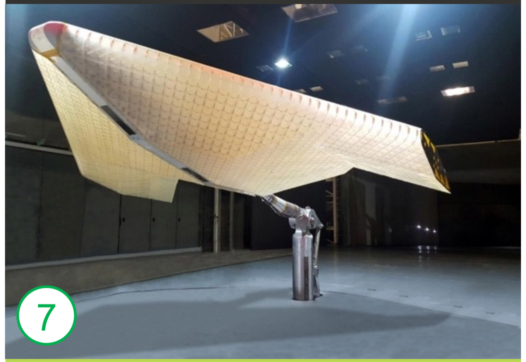
5 Sustainable Flight Demonstrator (SFD)*

6 Air Traffic Management Exploration (ATM-X)

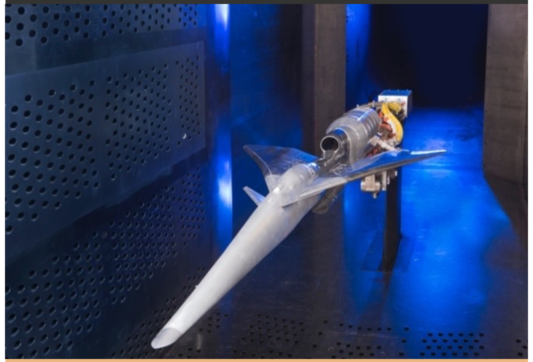
7 Transformational Tools and Technology (TTT)

*** focused SFNP***

Transformative Aeronautics Concepts Program



Aerosciences Evaluation and Test Capabilities Portfolio



Subsonic Transport Technology

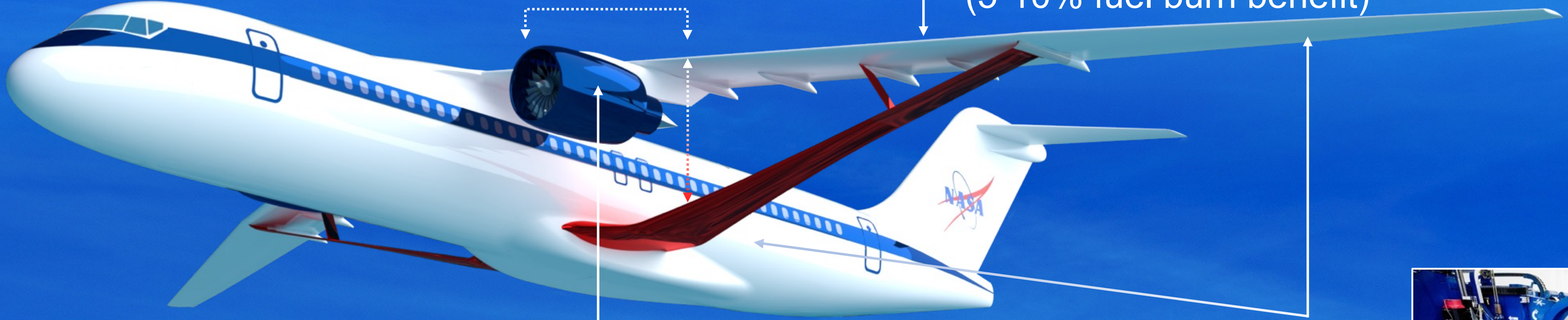
NASA = Primary Role

Subsonic Transport Technologies

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

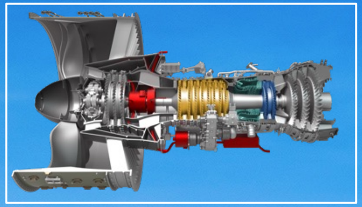
Integrated Aircraft System Efficiency
Propulsion Airframe Integration Opportunity

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



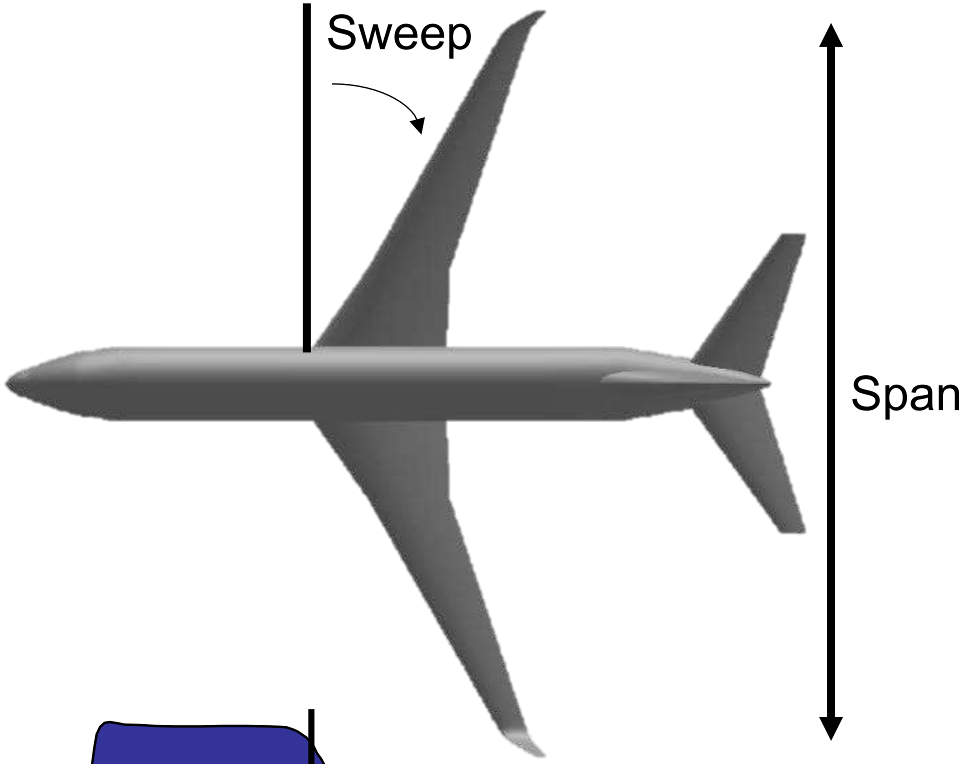
Weight
High-Rate Composites
(4-6x manufacturing increase)

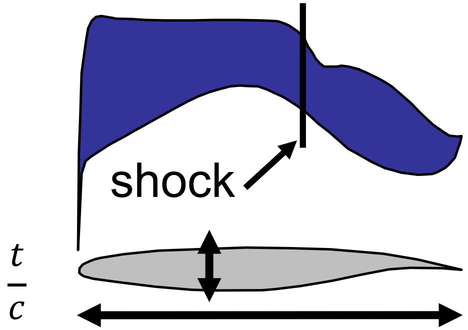
Electrified Aircraft Propulsion
~5% fuel burn and maintenance benefit



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

Aerodynamic Efficiency (L/D & ML/D)





Drag = parasite + lift induced + compressibility

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

C_{D0} ~ total wetted area (laminar/turbulent)

$$AR = \frac{span^2}{area_{ref}}$$

Airfoil/Wing Technology

speed, sweep, thickness, & lift trades

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

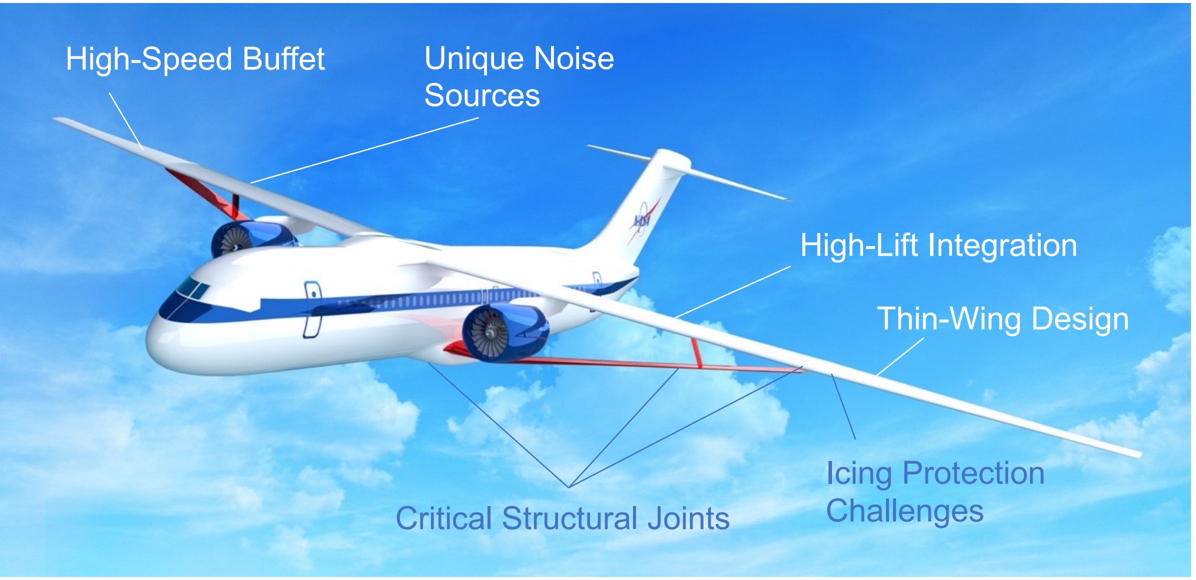
The Challenge

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

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

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

Design/analysis studies and wind-tunnel tests are underway.
Completed high-speed buffet wind-tunnel test in FY22.

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.

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

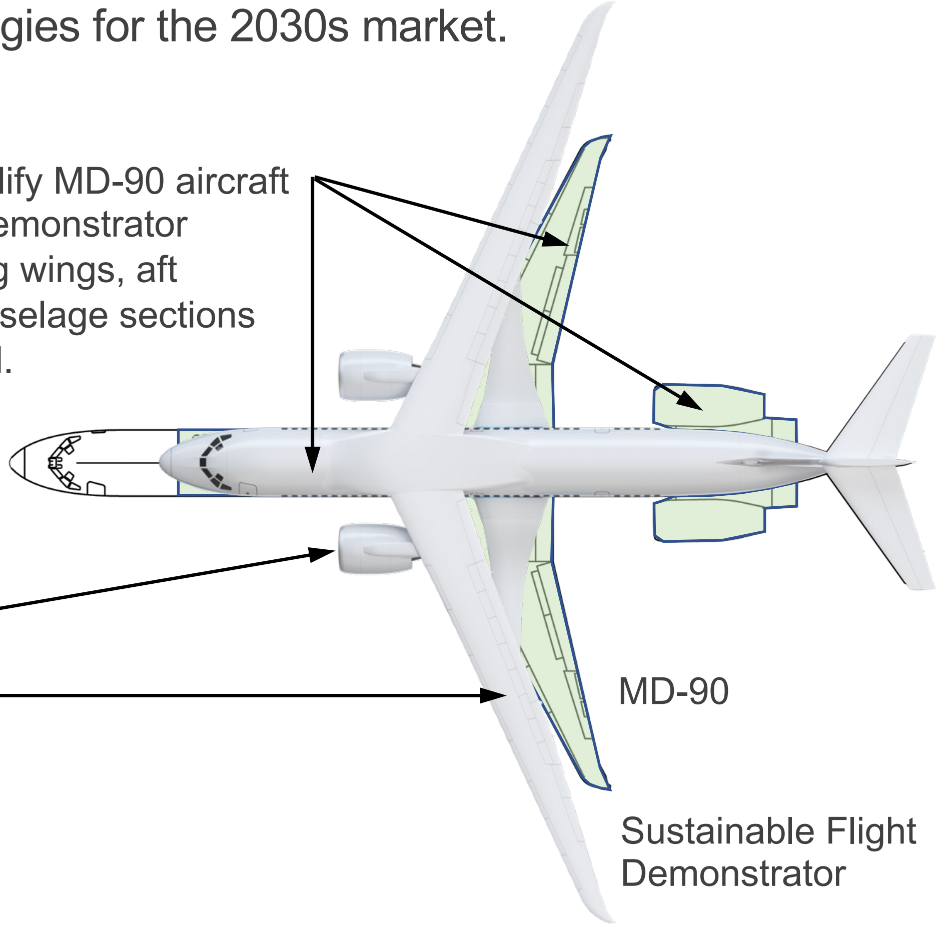
Design/Build/Fly Funded Space Act Agreement Awarded January 18, 2023 - 1st Flight 2028

Sustainable Flight Demonstrator (SFD) Project

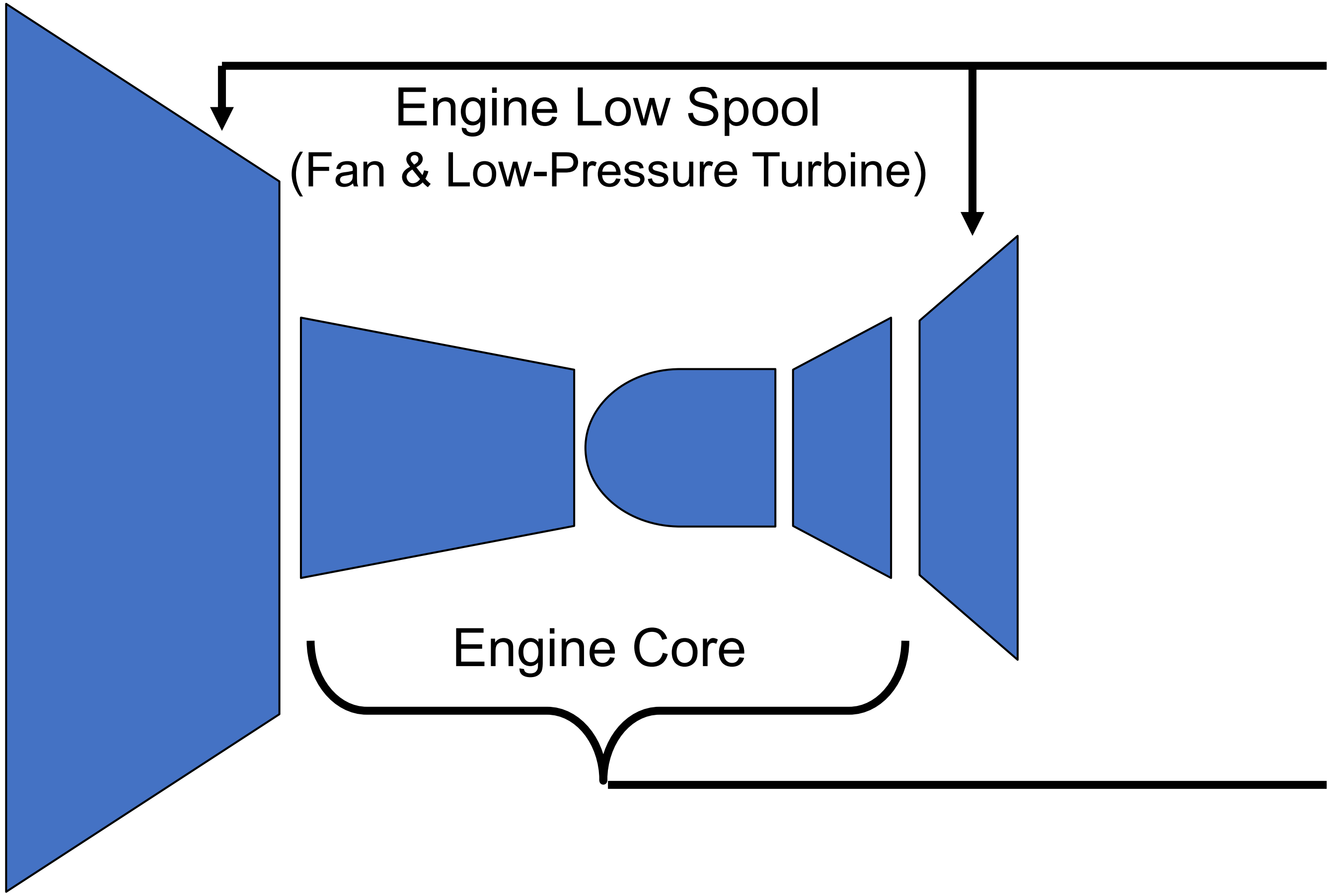
- Awarded a Funded Space Act Agreement (FSAA) to Boeing in January 2023 to design, build, test and fly an advanced airframe configuration demonstrator aircraft and related technologies to dramatically reduce fuel burn and CO_2 emissions.
  - $425M direct NASA investment + NASA facilities/ labor of ~$125M 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.
- 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.

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



Engine Efficiency (SFC)



<u>Propulsive X Transfer Efficiency</u>

Conversion of mechanical energy to thrust

- Bypass Ratio
- Fan Pressure Ratio

<u>Thermal Efficiency</u>

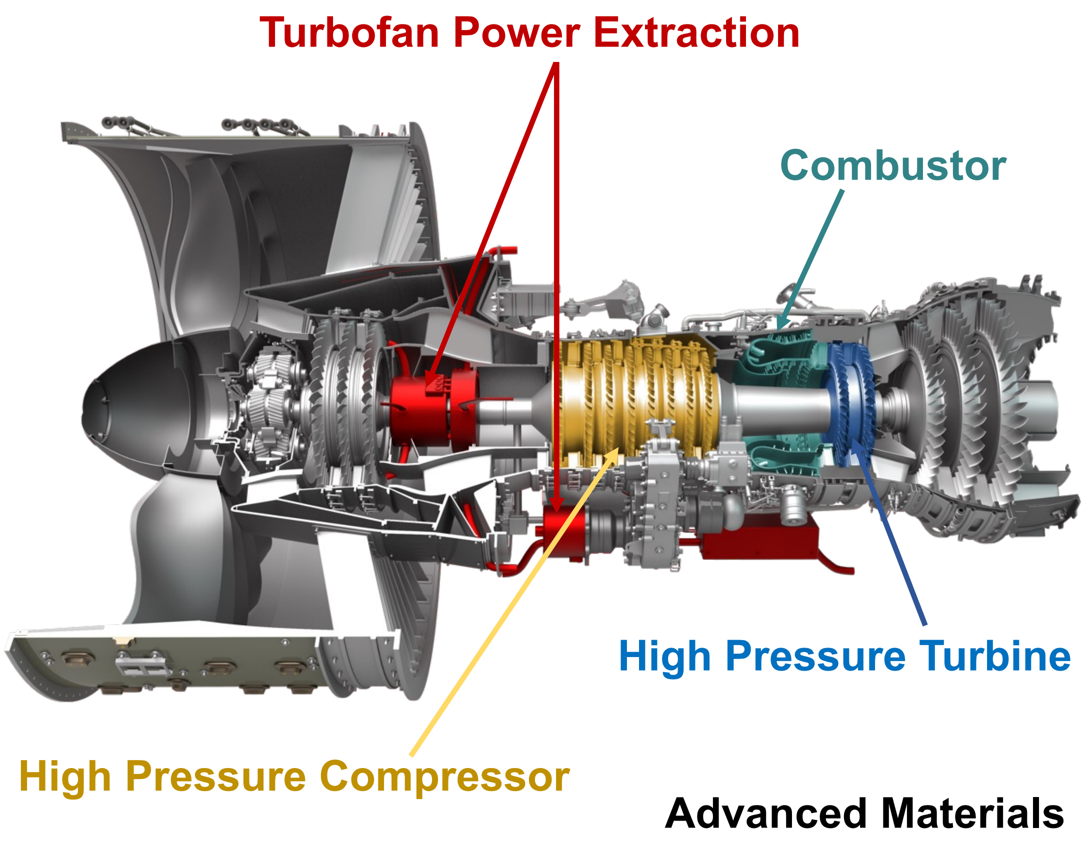
Conversion of chemical energy to mechanical energy

- Overall Pressure Ratio
- Component Technologies

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

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)

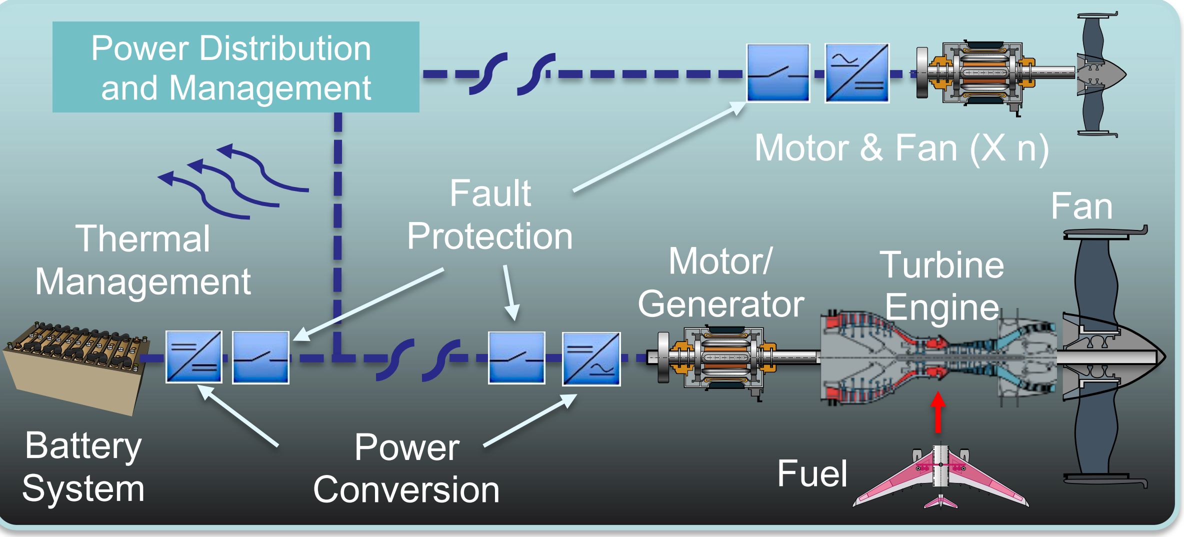
Approach

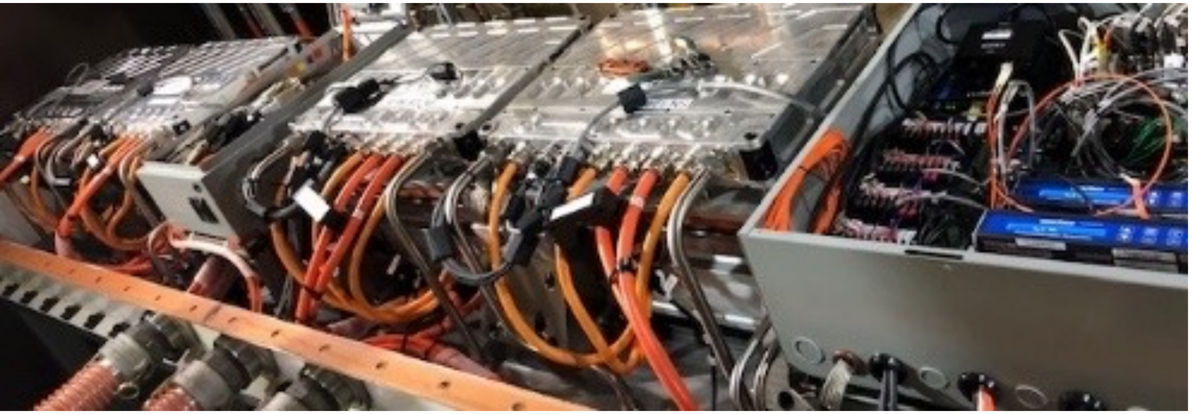
- Partner with industry to mature and demonstrate promising technologies

Phase 1 Small-core turbofan technology contract awards were made in September 2021.
Phase 2 Engine core demonstration proposals received 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

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

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

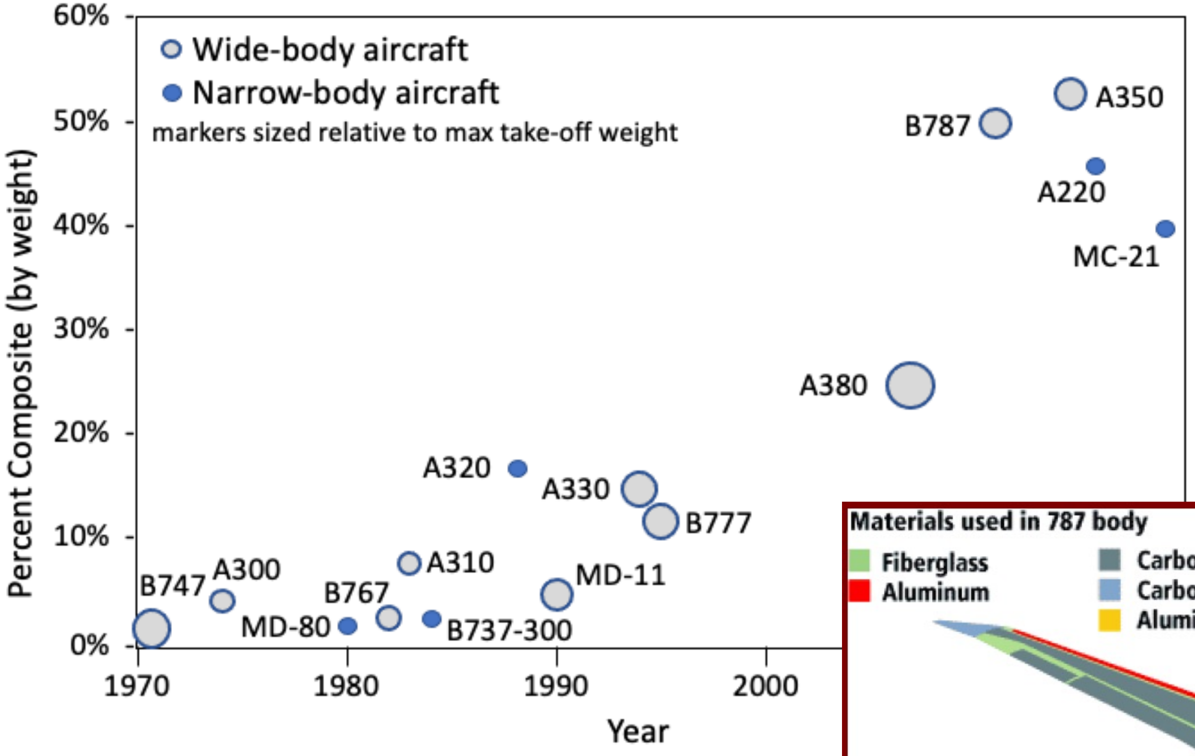
- Engage with U.S. industry to integrate and demonstrate megawatt-class EAP machines in flight.
- Engage with the FAA, SAE, ASTM, etc. to contribute data that inform EAP standards and regulations.

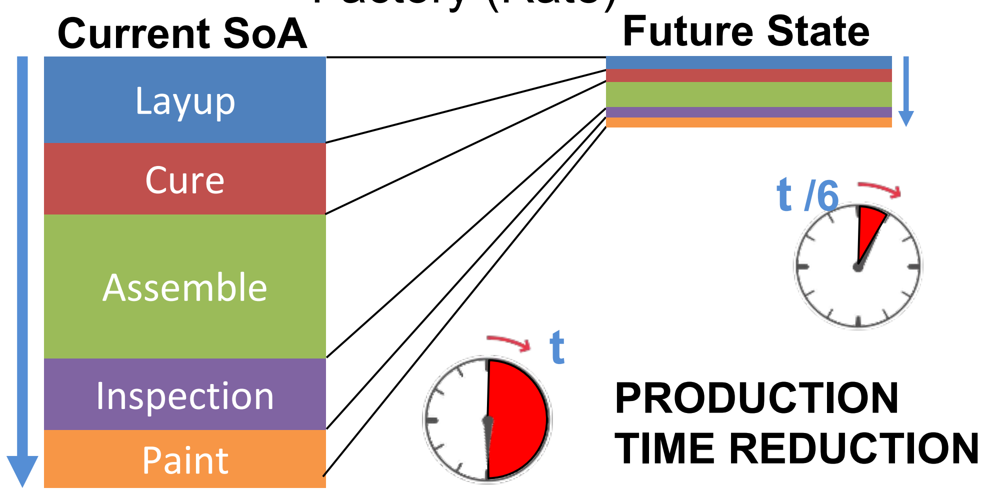
Flight demonstration contracts awarded in September 2021.
Baseline unmodified flight testing of GE's Saab 340B conducted February-March

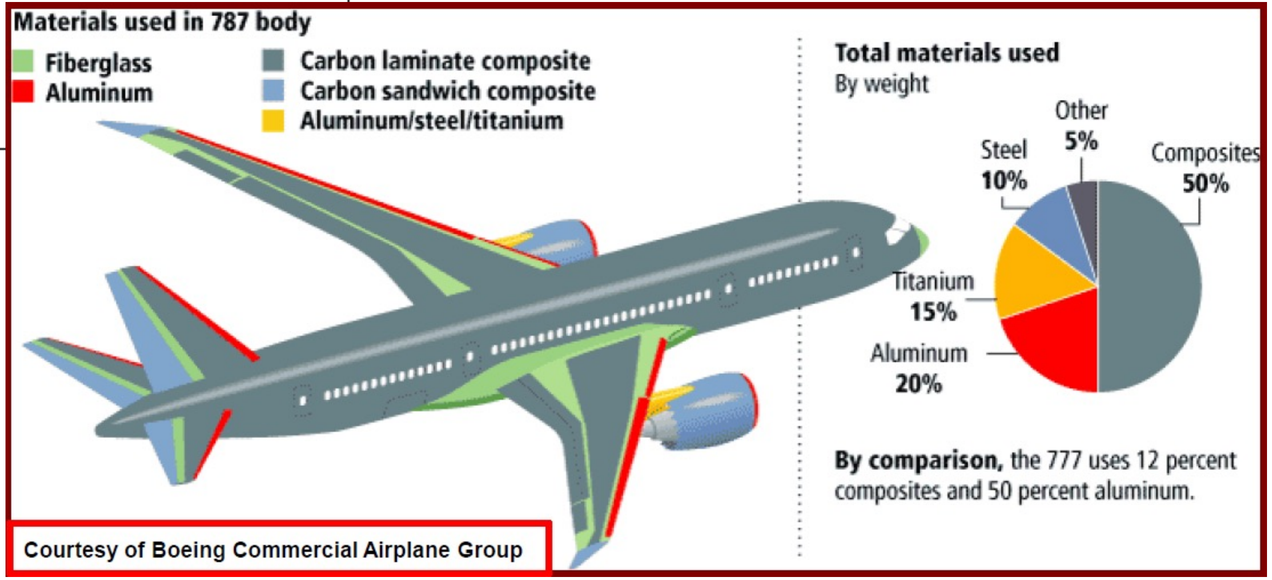
Structural Efficiency (W_0) at Rate

Two Relevant Environments

Flight (Weight) ← Cost → Factory (Rate)





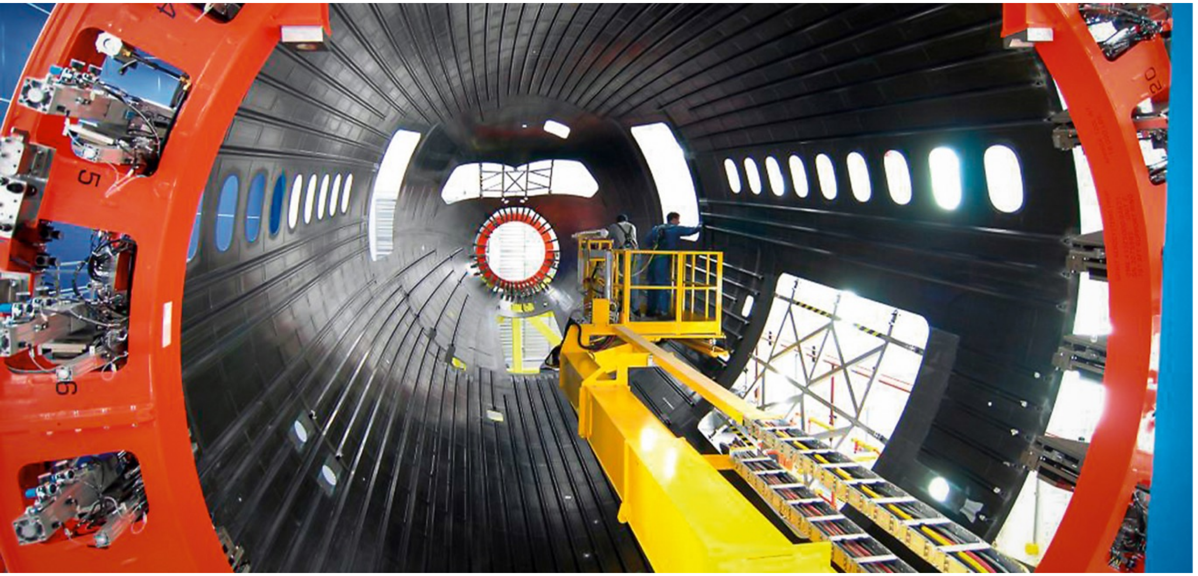


Hi-Rate Composite Aircraft Manufacturing

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

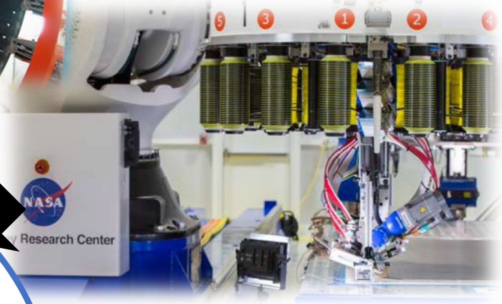
8 multi-party cooperative research teams developing technology.
Phase 1 awards made March 2023 to advance manufacturing process work.

Model-Based Systems Analysis & Engineering

SFNP Vision

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

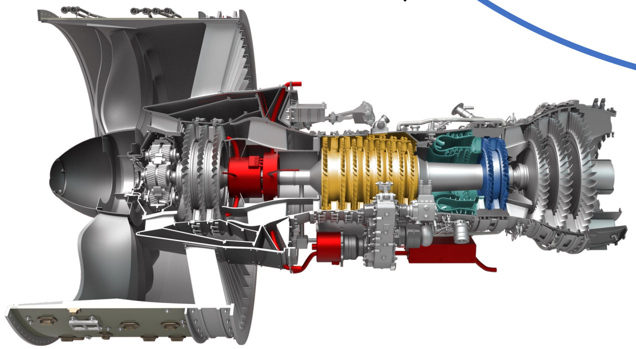
High-Rate Composite Manufacturing Processes (HiCAM)

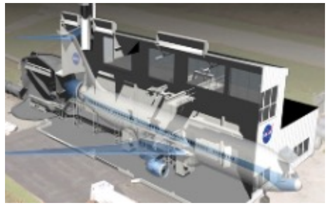


MBSA&E
Digital Integration
Knowledge Capture

Vision Vehicles
System of Systems

Small Core Engine Ground Tests (HyTEC)

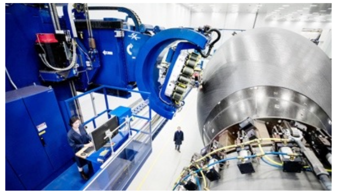


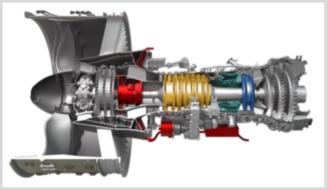


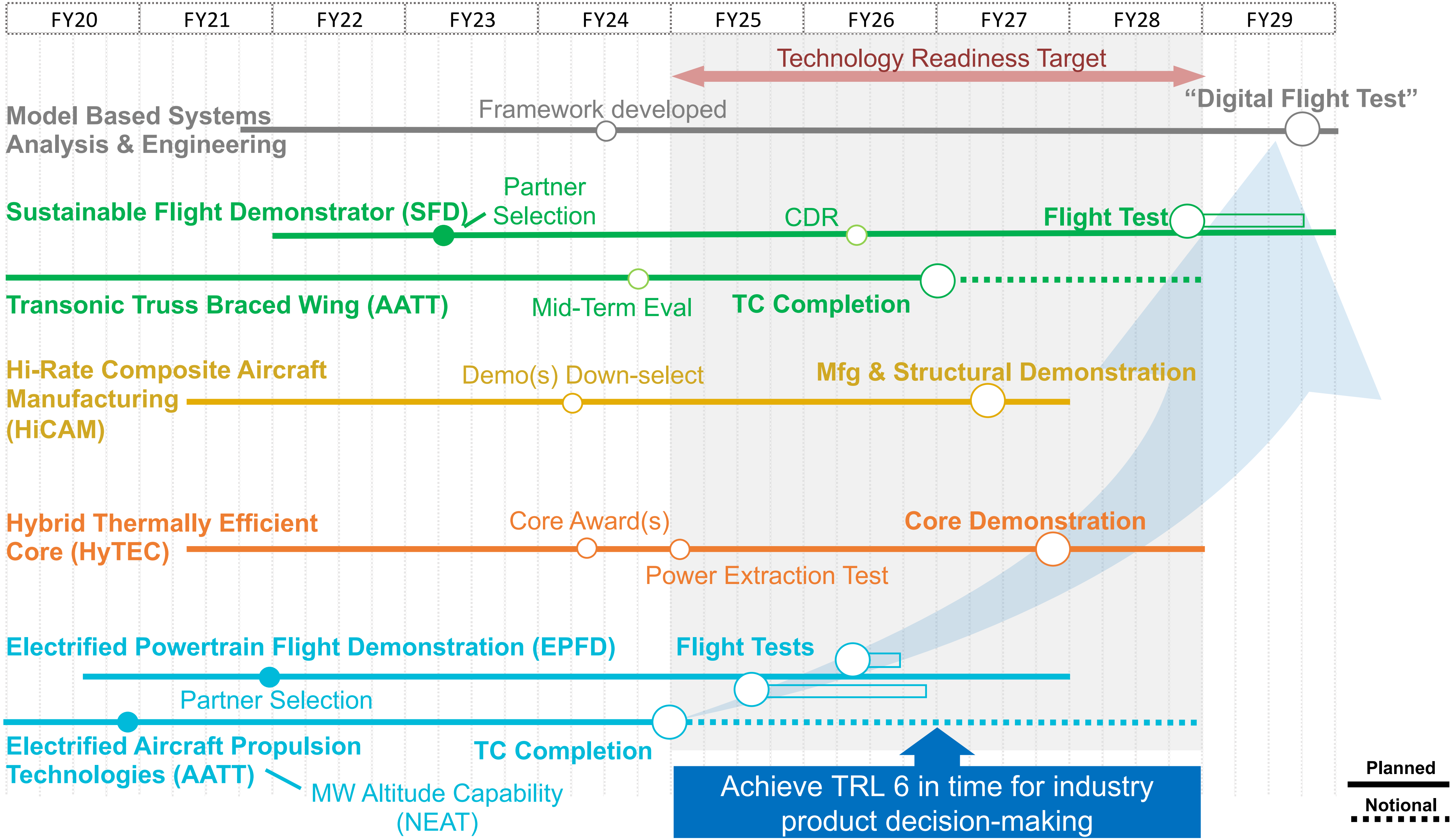
Electrified Propulsion Ground & Flight Tests (AATT & EPFD)

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

Subsonic Transports: Integrated Technology Development



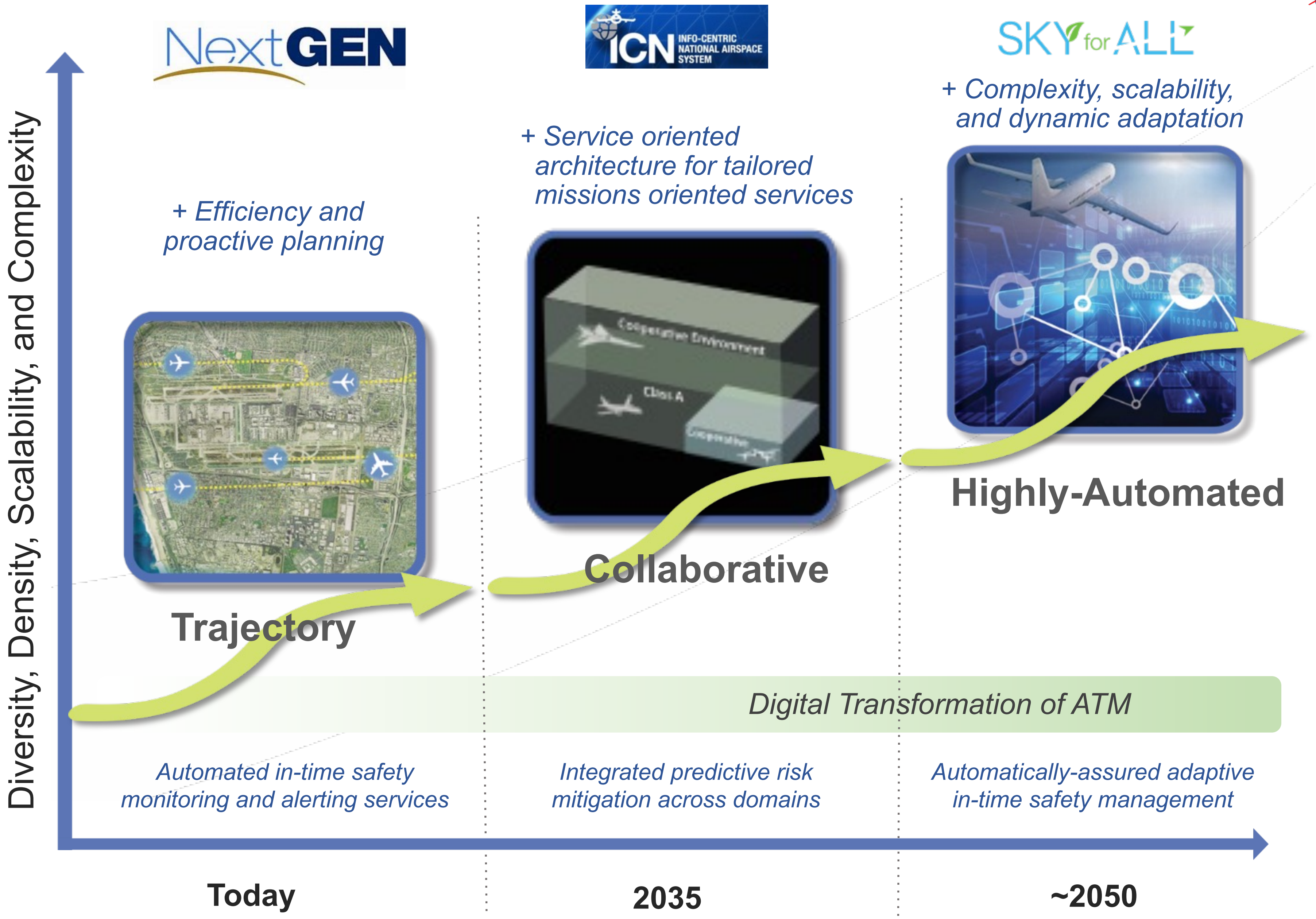




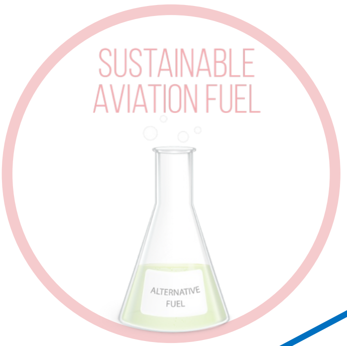
Sustainable Aviation Operations Demonstrations

NASA = Primary Role

Evolution of Airspace Operations and Safety

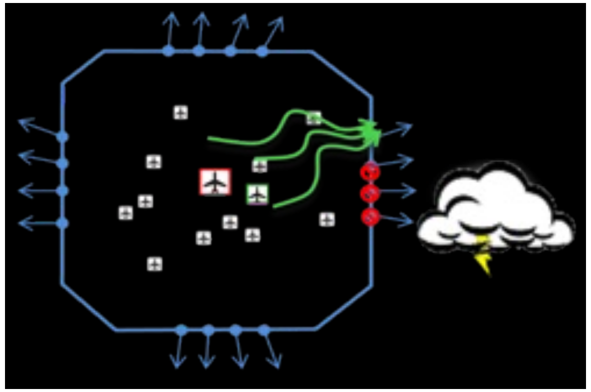


NASA Led SFNP Operations Demonstrations



Flight Deck Services

Ground Services



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

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

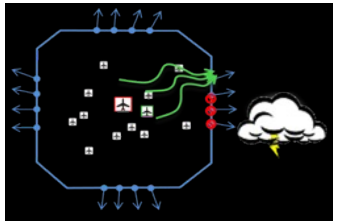
Irregular Ops Recovery/Disruption Management (SFNP-Ops-3, FY28)

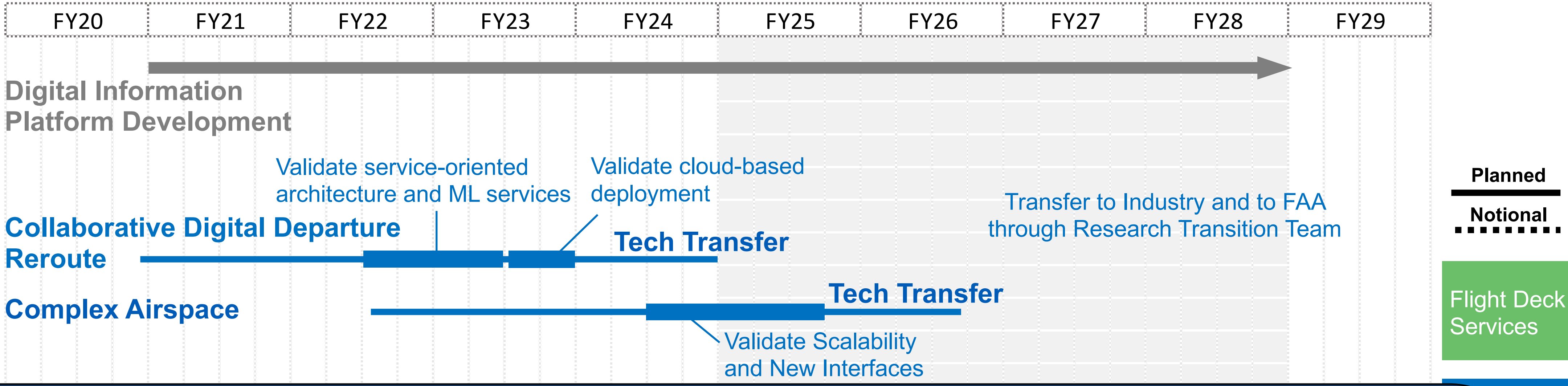
4D Trajectory Optimization (SFNP-Ops-4, FY30)

SFNP-Ops = Sustainable Flight National Partnerships - Operations

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

Sustainable Aviation Operations Demonstrations





SFNP-Ops-1 Collaborative Digital Departure Rerouting (CDDR)

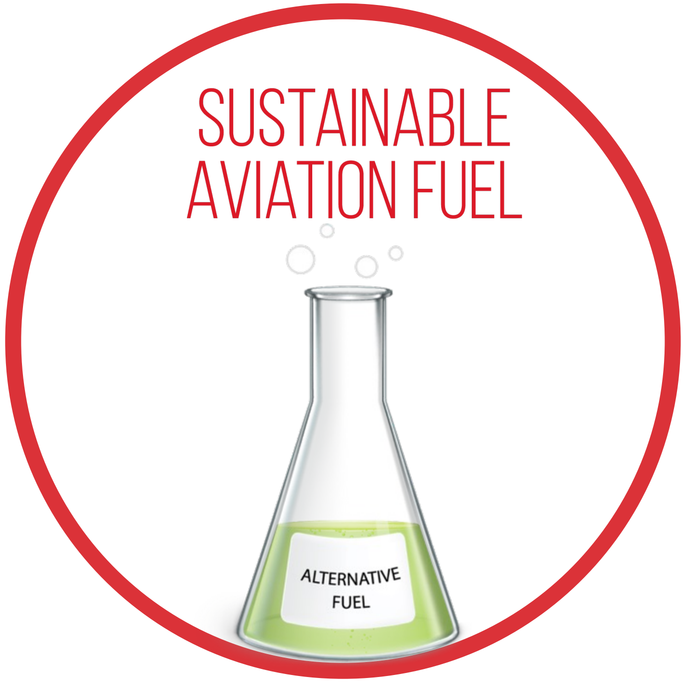
FY2022 North TX campaign with 3 airlines demonstrated real-world savings:

Fuel Savings	Emissions Savings	Delay Savings		Cost Savings	
Over **24K** lbs.	Over **76.6K** lbs. CO^2	**OFF** delay	**IN** delay	Passenger	**$31.7K**
	Over **569** urban trees	**3.9+** hrs	**4.7+** hrs	Flight Crew	**$6.9K**

FY2023 North TX campaign features additional capabilities to unlock more savings:

- Full cloud-based implementation for nation-wide scalability
- Provide information to broader range of airline decision makers
- Provide additional information to Air Traffic Control decision makers

Sustainable Aviation Fuel and Non-CO_2 Impacts



NASA = Supporting 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

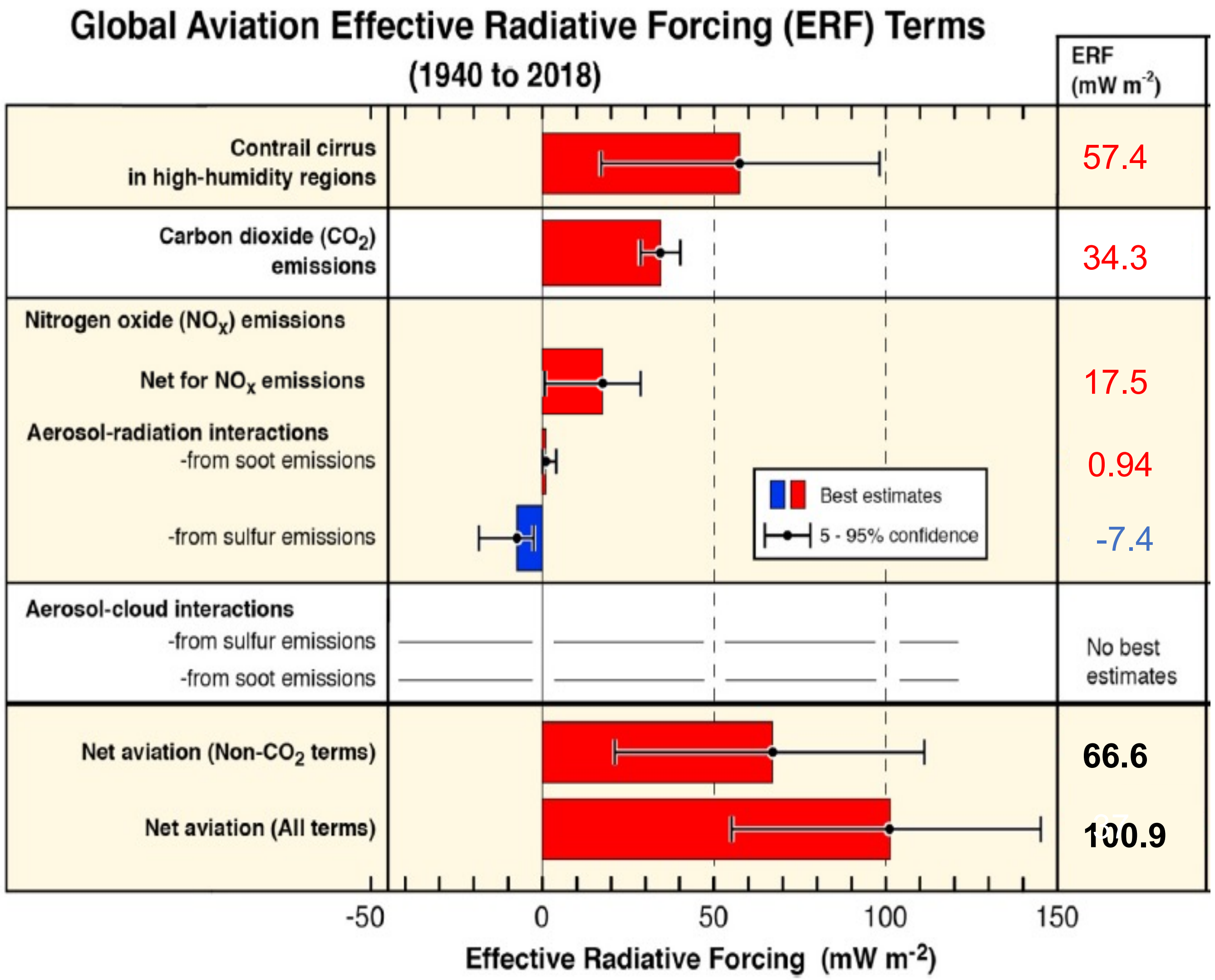
Approach

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

Future SAF Research Plans in Development

Climate Scientists' View of Aviation Impacts

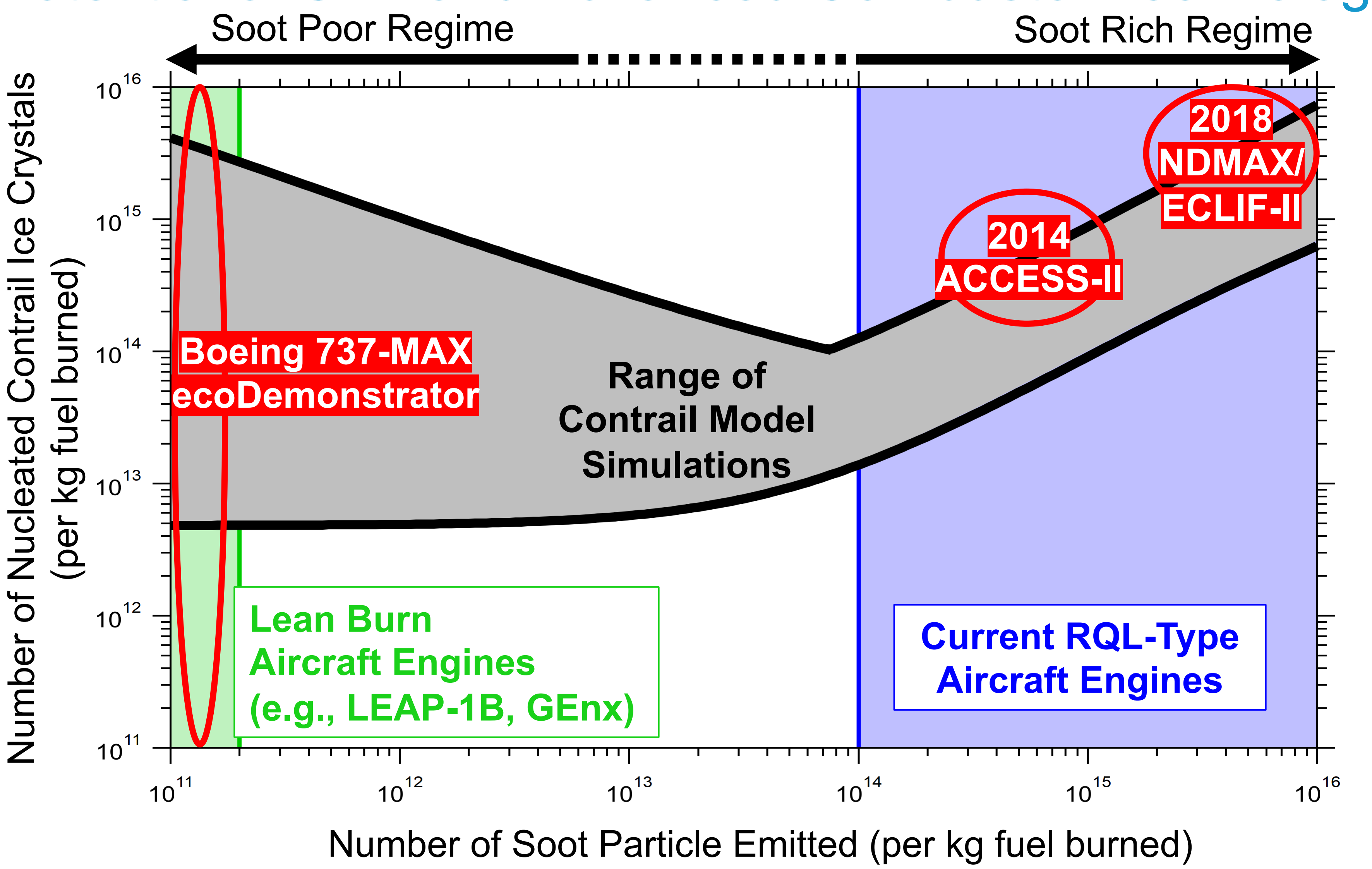
- **Lee et al. (2021) represents latest and most comprehensive assessment of aviation's climate impacts**
- **Non-CO_2 impacts comprise two-thirds of the net radiative forcing from aviation**
- **Lot of uncertainty in these estimates. Cruise observational data critically lacking!**



Lee et al. (2021) "The contribution of global aviation to anthropogenic climate forcing for 2000 to 2018" *Atmospheric Environment*, https://doi.org/10.1016/j.atmosenv.2020.117834

"…to halt aviation's contribution to global warming, the aviation sector would need to achieve net-zero CO_2 emissions and declining non-CO_2 radiative forcing ..: neither condition is sufficient alone." Lee et al. (2021)

Motivation for Flight Campaign - Contrails
Potential of SAF and Advanced Combustor Technology



Need to understand the "soot-poor" regime and do it at flight altitude to understand contrails

Need to fly aircraft with lean burn combustor tech (e.g. 737-MAX) at flight altitude to understand contrails

Figure adapted from Kärcher, *Nature Communications*, 2018.

Red circles show the approximate Number EIs observed during the 2014 ACCESS-II and 2018 ND-MAX/ECLIF-II flight test series.

Moore et al., Nature, 2017; Voigt et al., Nature Comms. Earth & Environ., 2021

Flight Required to Link Emissions to Contrails – Combustor Tech + SAF Important
Future SAF/Emissions Research Plans in Development

Beyond SFNP

requires early-stage R&D today

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 Emissions Concepts
- Promising Technologies and Architectures
- Support Aviation Community with NASA-unique Contributions

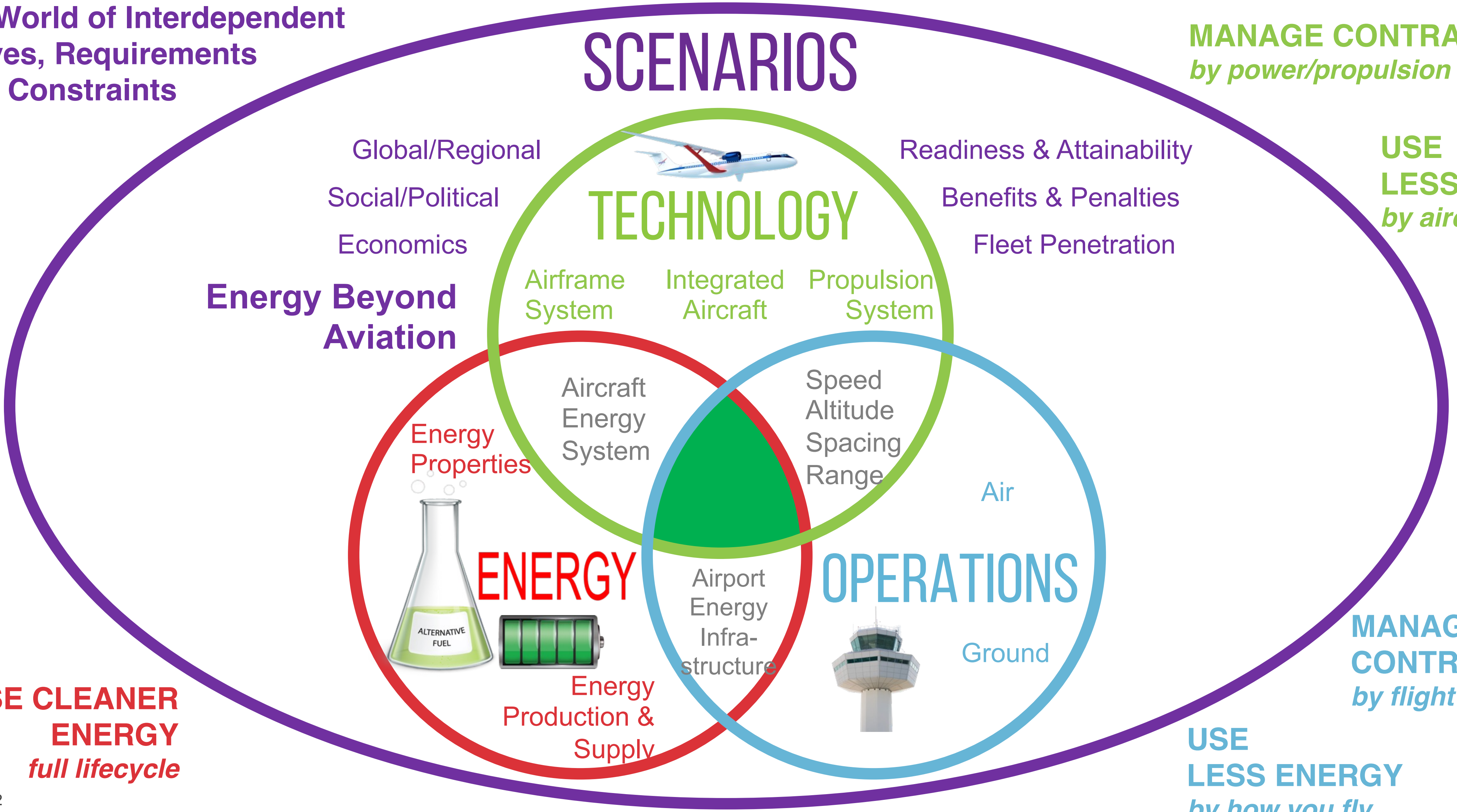
Innovations for 2040s and Beyond

Concluding Remarks

Integrated Aviation Pillars for Sustainable Aviation

in broader context

Complex World of Interdependent Objectives, Requirements & Constraints



MANAGE CONTRAILS
by power/propulsion tech

USE LESS ENERGY
by aircraft design

MANAGE CONTRAILS
by flight trajectory

USE LESS ENERGY
by how you fly

USE CLEANER ENERGY
full lifecycle

- 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
  - No silver bullets

- 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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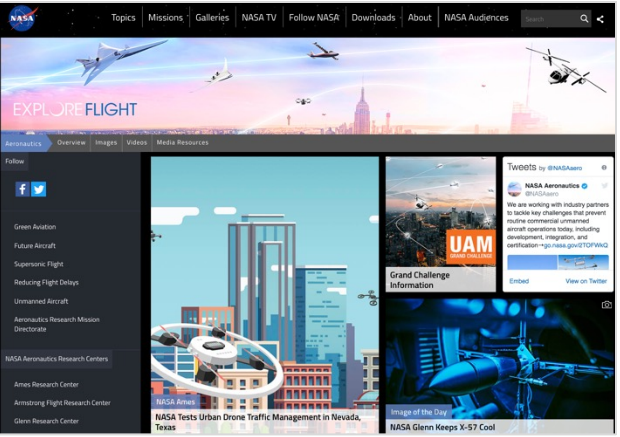

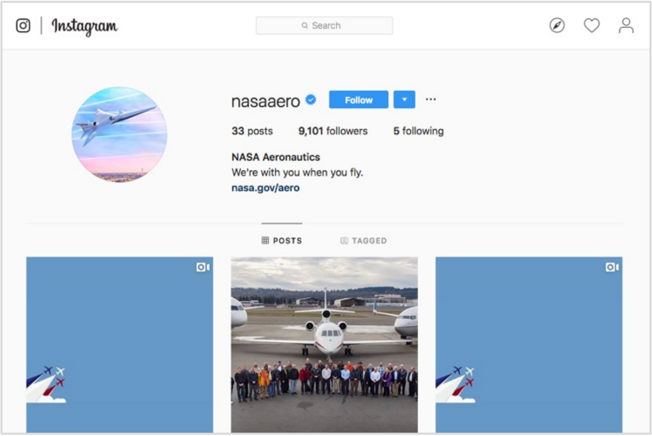

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