NASA Sustainable Flight National Partnership

NASEM: Aeronautics Research and Technology Roundtable

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Outline

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

CONTEXT

Four Transformations for Sustainability, Greater Mobility, and Economic Growth

SUBSONIC COMMERCIAL TRANSPORTS

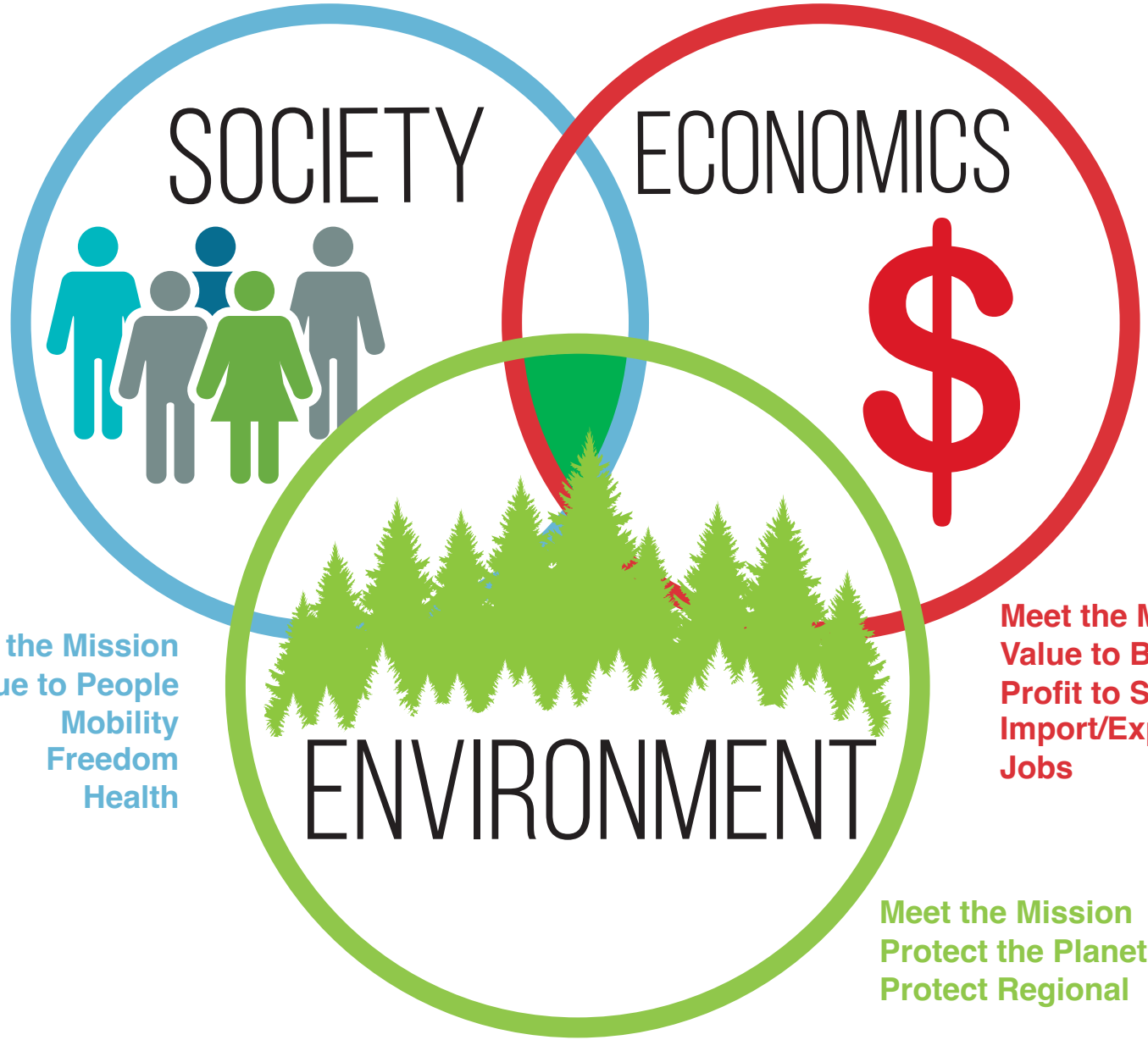
the 24/7 global backbone
of air transportation
now and into the foreseeable future

key to U.S. economic competitiveness
and global leadership in a **sustainable** aviation future

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

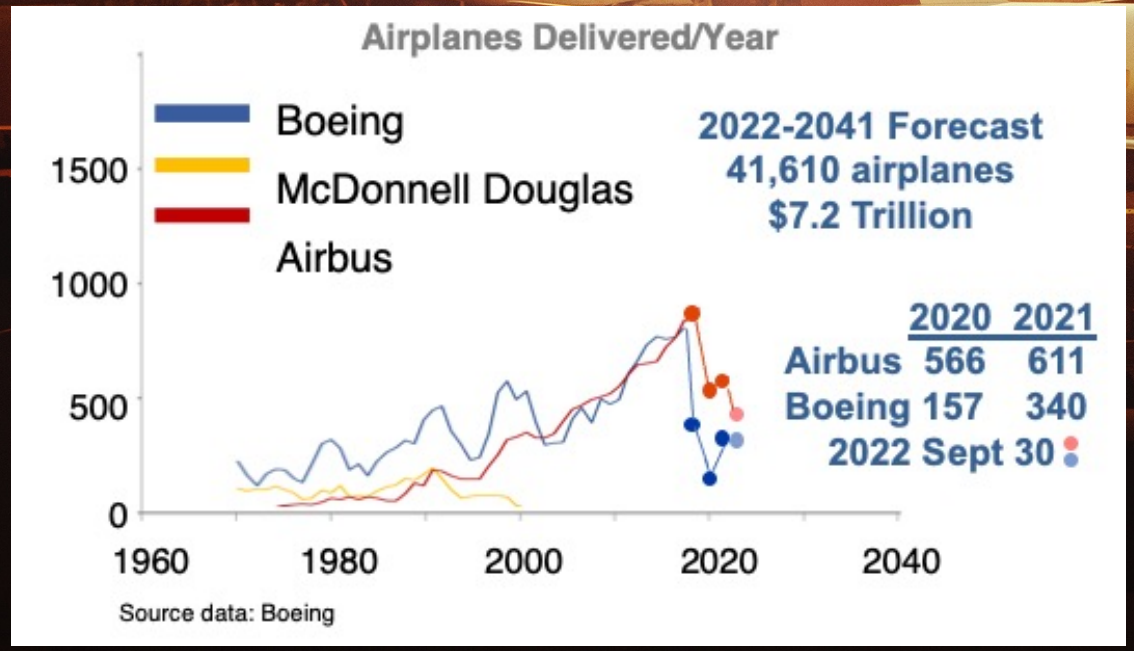


Aviation is Vital to our Nation's Economy

Subsonic Transport Market - Global competition expanding

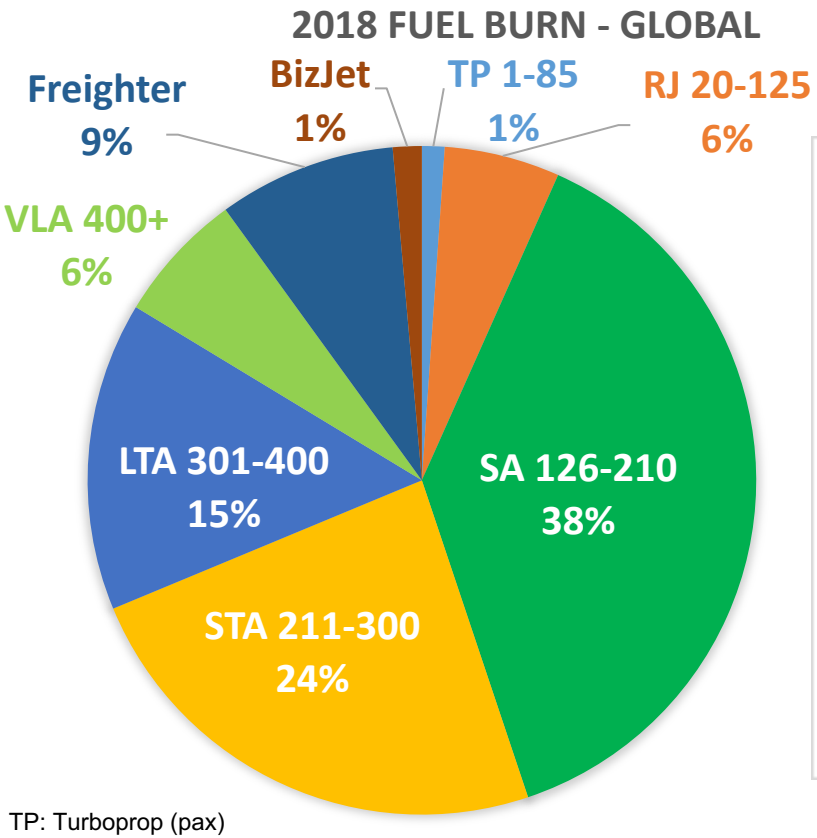
Pre-COVID

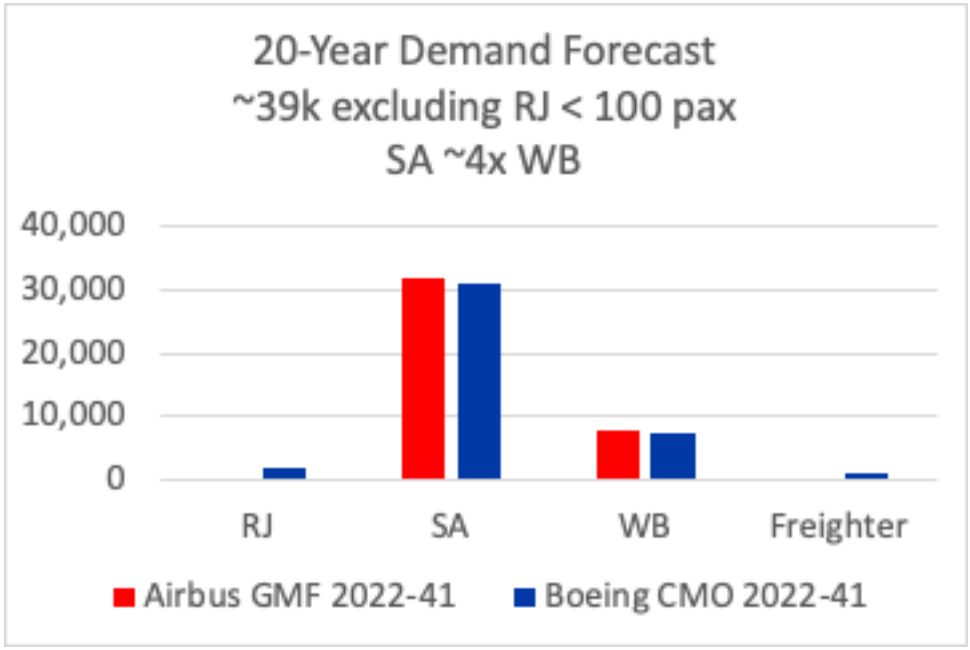
- $78 billion positive trade balance; the largest positive trade balance of any U.S. manufacturing sector
- $1.8 trillion total U.S. economic activity
- 10.9 million direct/indirect jobs
- 21.3 billion tons of freight transported by U.S. airlines in 2019



U.S. propulsion competes for global market share

Carbon Emissions and 20-Year Market Demand Forecast – Global





- 289 million metric tons of fuel burned in 2018 (96 billion gallons)
  - 912 Mt carbon
  - 65% International 35% Domestic

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)

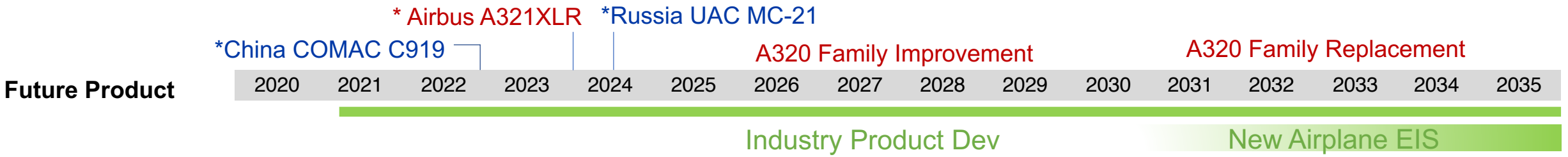
Source data:
DoT/Volpe Center, Flemming et al,: basis of 2022 ICAO Environmental Report, Chapter 1, p24
https://www.icao.int/environmental-protection/Documents/EnvironmentalReports/2022/ICAO%20ENV%20Report%202022%20F4.pdf
Airbus Global Market Forecast (GMF) 2022-41: https://www.airbus.com/sites/g/files/jlcbta136/files/2022-07/GMF-Presentation-2022-2041.pdf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

Single-Aisle Transport Airplane Market

COMAC C919
Image Credit: Weimeng

UAC MC-21
Image Credit: Denis Fedorko

Airbus A321
Image Credit: Huy Bùi



Extensive European funding for commercial aviation technology, including COVID-mitigation efforts –

- Horizon Europe (Clean Aviation **$4.6b**, Clean Hydrogen **$2.2b**, Made in Europe **$2.2b**)
- Next Generation EU Recovery fund fostering hydrogen economy, sustainable fuels
- Country level aviation R&D – Germany, France, UK **($800m** plus)

Policy issues:

- Emissions/efficiency could become market access barrier (countries contemplating fuel efficiency/ emissions restrictions for future entry into EU airspace)
- Energy infrastructure will significantly impact ability to adopt alternative energy sources for aviation (Hydrogen, alternative fuels)

Environmental Impacts of Aviation

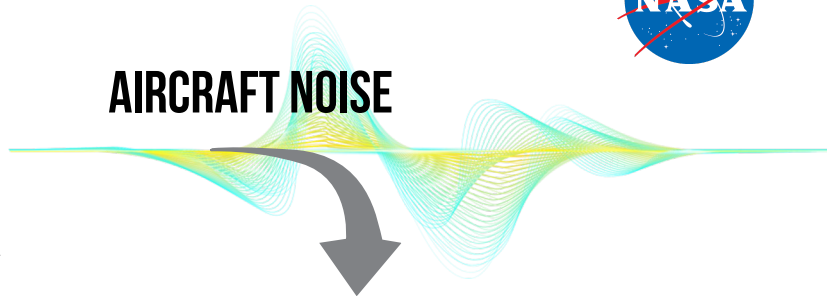
COMBUSTION EMISSIONS

CO_2: 71%

Water: 28%

CO, HC, NO_x, SO_x, Primary $PM_{2.5}$: <1%

AIRCRAFT NOISE



ATMOSPHERIC CHEMISTRY & PHYSICS

- Primary $PM_{2.5}$
- SO_x
- NO_x
- UHC
- CO

→ Secondary $PM_{2.5}$

→ Ozone

- Primary $PM_{2.5}$
- SO_x → Ozone
- NO_x → Ozone, CH_4
- CO_2
- H_2O
- Contrails & Cirrus Clouds

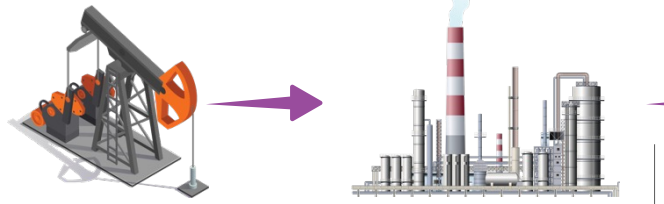
POPULATION EXPOSURE AND HEALTH IMPACTS

GLOBAL CLIMATE CHANGE

OZONE LAYER

- → Cooling Effects
- → Warming Effects

EMISSIONS FROM FUEL PRODUCTION



→ CH_4, N_2O, CO_2

SUSTAINABILITY IMPACTS

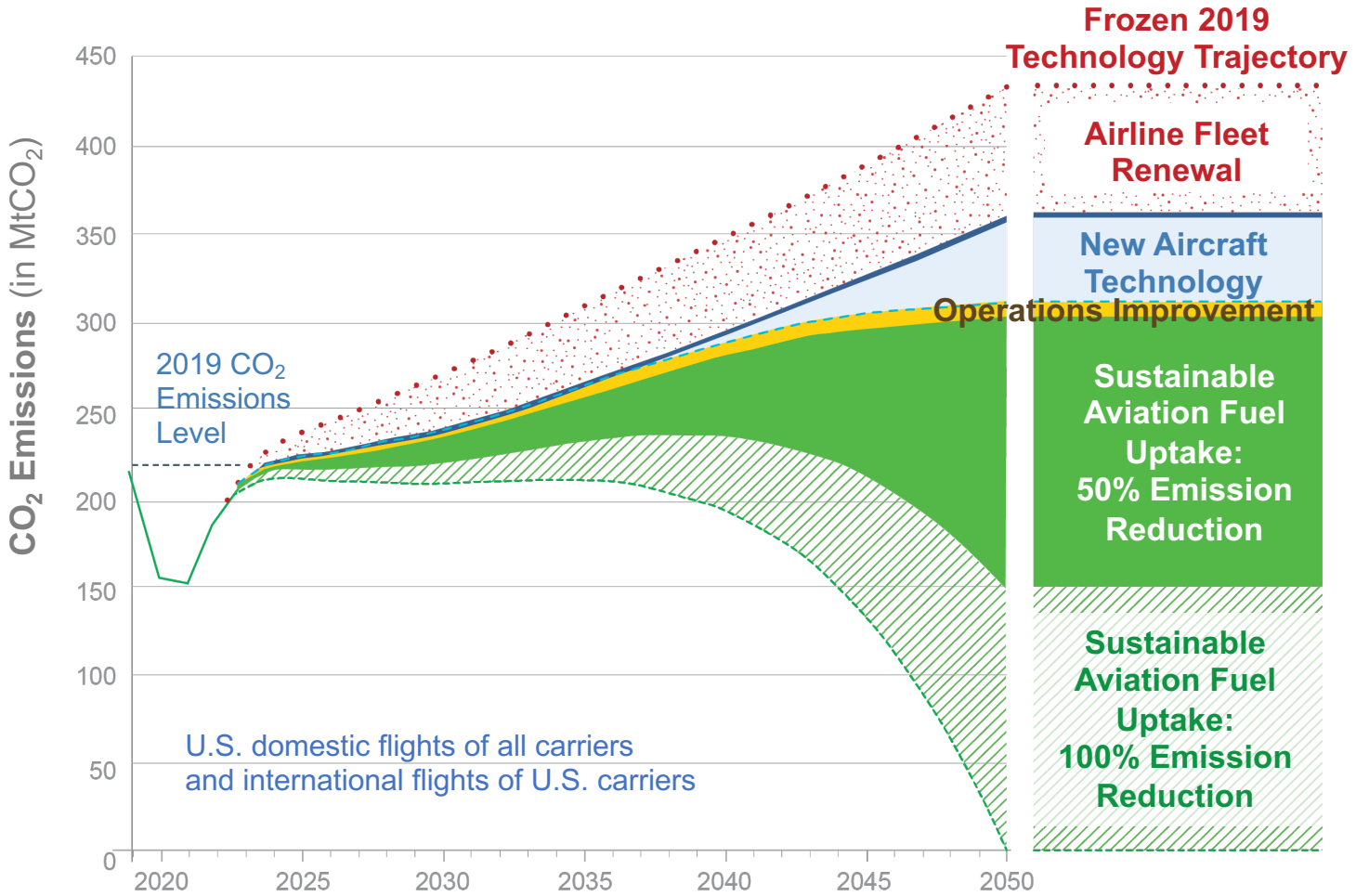
Slide created in collaboration with FAA Office of Environment and Energy

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

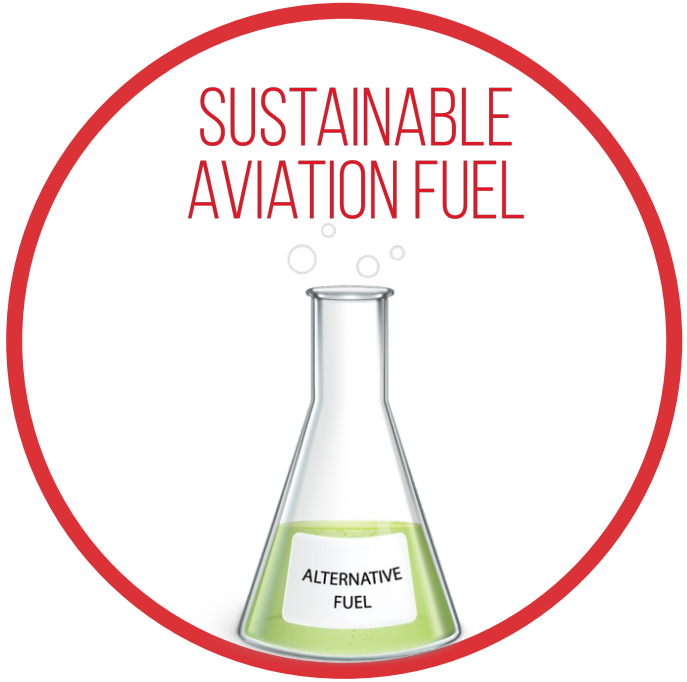
The U.S. is working with the global community to achieve net-zero greenhouse gas emissions by 2050 using a common basket of measures.

NASA Sustainable Aviation Strategy

Aviation Pillars for a Sustainable Future

Global Aviation GOAL: net-zero carbon emissions by 2050

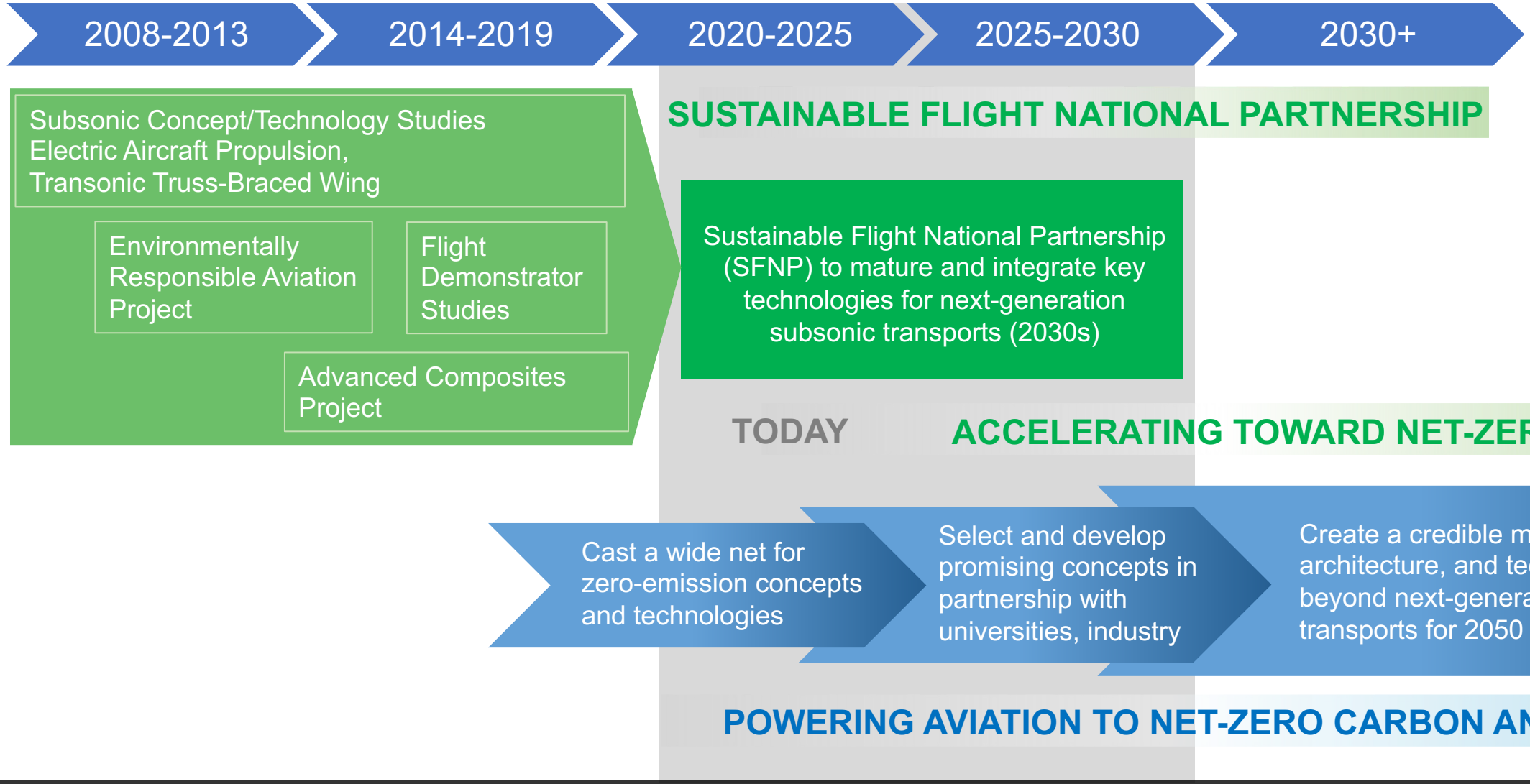
NASA = Primary Role



NASA = Supporting Role

NASA = Primary Role

NASA Sustainable Aviation Strategy



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

SFNP Scope

within broader sustainable aviation strategy

Sustainable Aviation

safe, clean, quiet, economical, operable, marketable

Sustainable Flight National Partnership (SFNP)

- Accelerating aviation towards net-zero carbon
- Focus on energy efficiency improvements and Sustainable Aviation Fuels (SAF)
- Demonstrate/transfer promising/likely technology and concepts beyond current next-gen baseline today
- Impact next-generation transport aircraft (2030s) and near-term and future operations (2020s)
- Significant near-term market opportunities

Beyond SFNP

- Powering aviation to net-zero carbon and beyond
- Focus on alternative energy and propulsion architectures and non-CO_2 driven climate impacts
- Explore/early development of technology and concepts for more radical change, demonstrate contrail management for current-gen and beyond aircraft
- Impact beyond next-gen transport aircraft (2040s) and near-term and future aircraft operations (2020s)
- Catalyze and stimulate new energy paradigms

Sustainable Flight National Partnership (SFNP)

Sustainable Flight National Partnership

Next-Generation Capability on the Path to Net-Zero Greenhouse Gas Emissions by 2050

Advance engine efficiency and emission reduction

Enable integrated trajectory optimization

Advance airframe efficiency and manufacturing rate

Enable use of 100% sustainable aviation fuels

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.

ARMD PROGRAMS

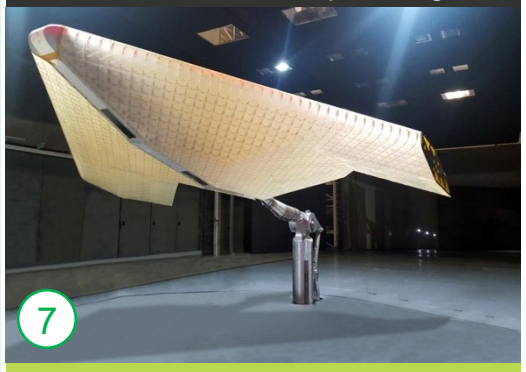
Partnering with Aviation Community

Airspace Operations and Safety Program

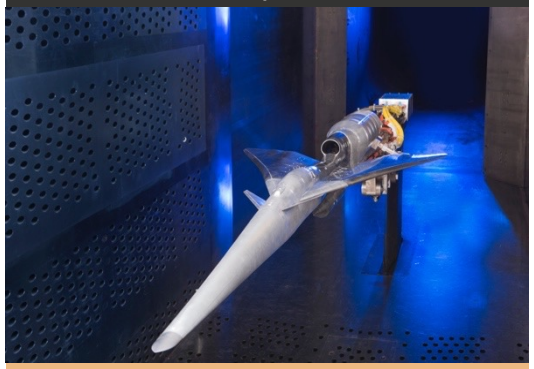
Advanced Air Vehicles Program

Integrated Aviation Systems Program

Transformative Aeronautics Concepts Program



Aerosciences Evaluation and Test Capabilities Portfolio



Sustainable Flight National Partnership (SFNP)

NASA Projects

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)

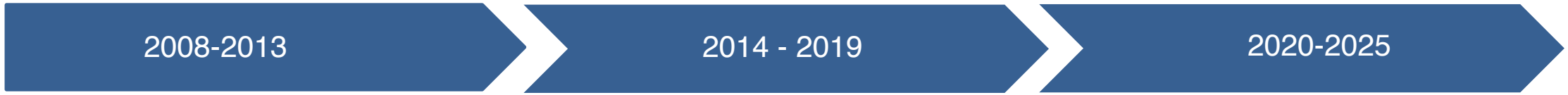
** focused SFNP*

Subsonic Transport Technology

NASA = Primary Role

Subsonic Transport Technology Prioritization

NASA Aeronautics Vision and Strategy Established



Subsonic Concept/Technology Studies
Electrified Aircraft Propulsion, Transonic Truss Braced Wing

Environmentally Responsible Aviation (ERA) Project

Flight Demonstrator Studies

Advanced Composites (ACP)

Next Step

Maturation and Integration of Four Key Technologies that will Create a New "S Curve" for Future Subsonic Transports

FAA CLEEN* I

FAA CLEEN* II

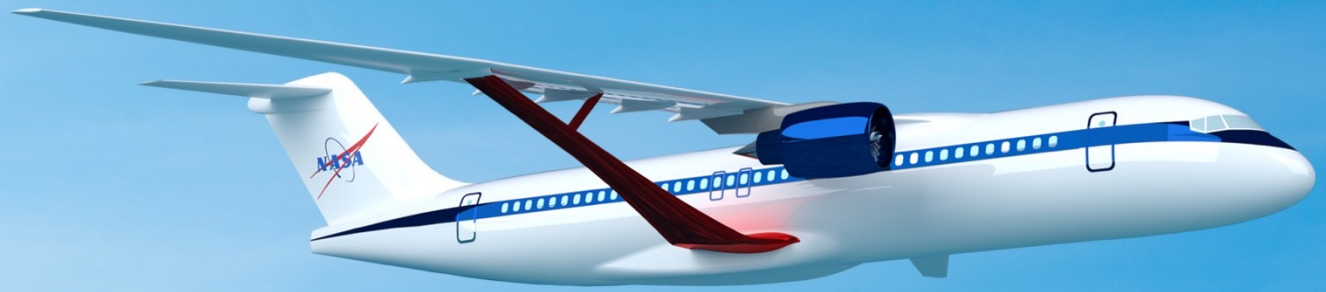
FAA CLEEN* III

Subsonic Transport Strategy Based on over a Decade of Research, Concept and Technology Development, and NASA-Industry Partnership

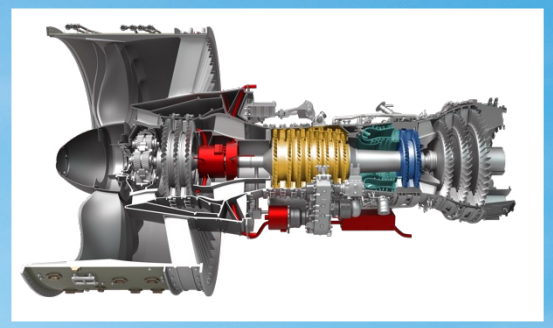
* Sponsored by FAA Office of Environment & Energy (AEE)

Subsonic Transport Technologies

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

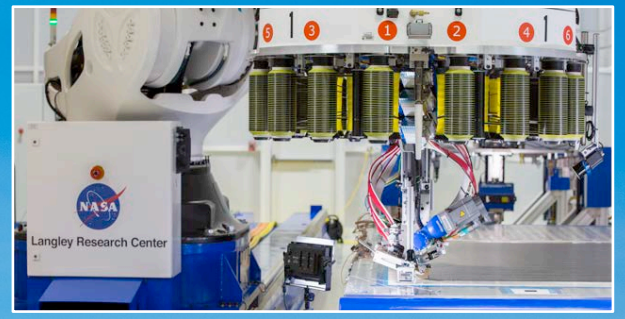


Transonic Truss-Braced Wing
5-10% fuel burn benefit



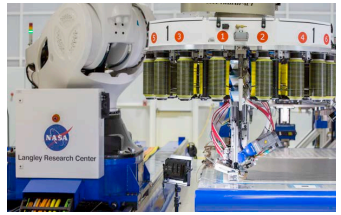
Small Core Gas Turbine
5-10% fuel burn benefit

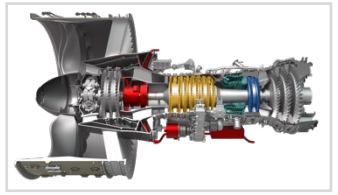
Electrified Aircraft Propulsion ~5%
fuel burn and maintenance benefit

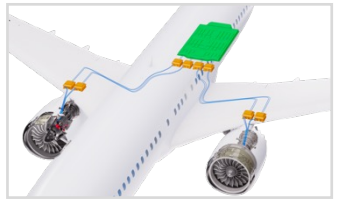


High-Rate Composite Manufacturing
4-6x manufacturing rate increase

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

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)

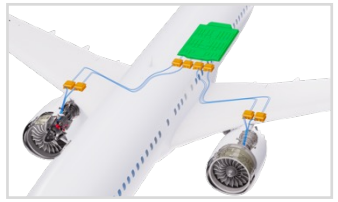
TC Completion

Achieve TRL 6 in time for industry product decision-making

Planned

Notional

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

EPFD
- 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 Preliminary Design Review (PDR) completed in 4QFY22.
- magniX PDR will be in 1QFY24 after completion of configuration trade studies

AATT/Electrified Aircraft Propulsion
- Completed Altitude Integrated Test (AIT) with General Electric, demonstrating high-power, high-voltage EAP powertrain at altitude conditions.
- Completed MW-class circuit breaker technology with 3 partners (Navy, GE & Raytheon) as part of EAP Fault Management contracts - one of the key challenges for MW-class EAP powertrains.

Electrified Powertrain Flight Demonstration (EPFD)

Partner Selection

Flight Tests

Electrified Aircraft Propulsion Technologies (AATT)

TC Completion

MW Altitude Capability (NEAT)

Achieve TRL 6 in time for industry product decision-making

Planned

Notional

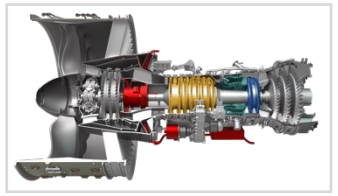
Subsonic Transports: Integrated Technology Development

FY20	FY21	FY22	FY23	FY24	FY25	FY26	FY27	FY28	FY29

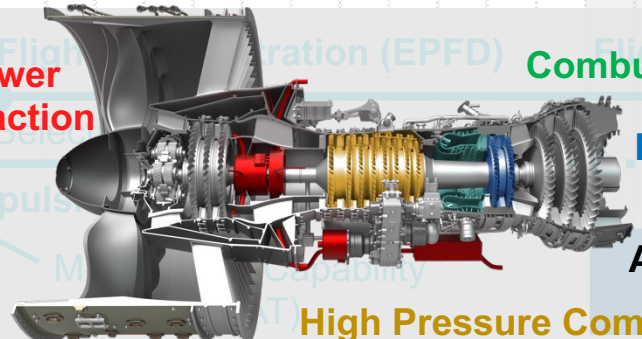
Technology Readiness Target

Model Based Systems Analysis & Engineering — "Digital Flight Test"

- Small core technologies contracts (9/2021) to GE & P&W targeting TRL 4/5 by 2023. Technology development efforts progressing as planned.
- Additional technology development award (P&W 9/2022) for Small Core Combustor Design with Sustainable Aviation Fuel (SAF) Compatibility.
- Recently completed a Detailed Design Review for TRL 5 dual spool Power Extraction test with GE.



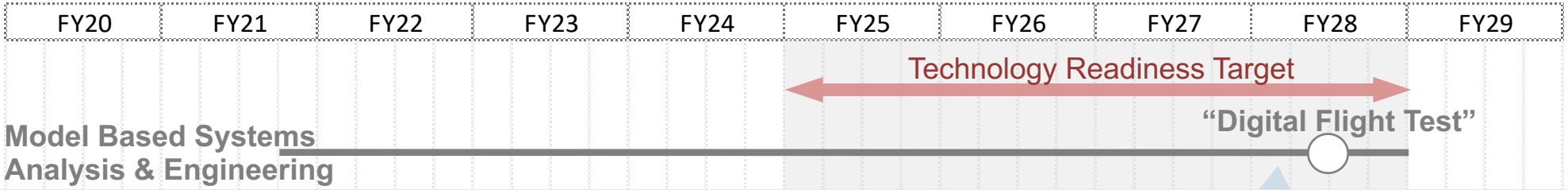
Hybrid Thermally Efficient Core (HyTEC) — Core Award(s) — Power Extraction Test — Core Demonstration

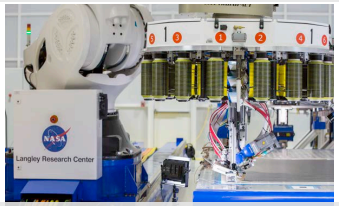


Planned

Notional

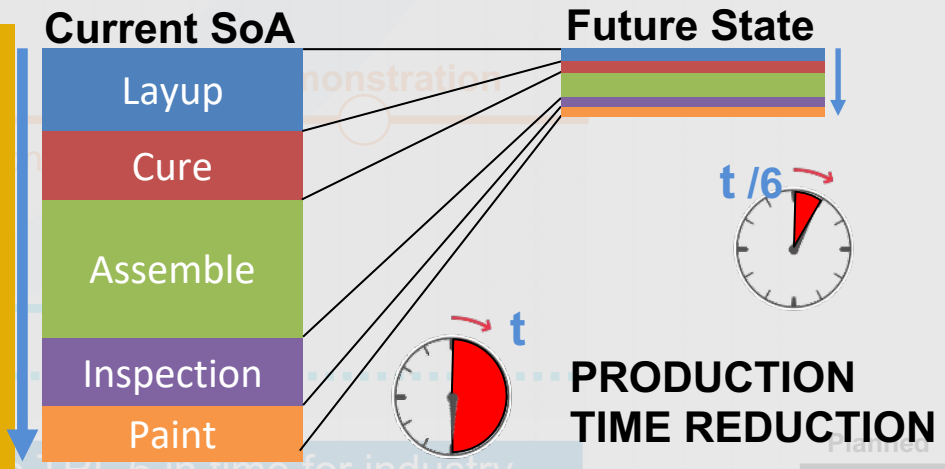
Subsonic Transports: Integrated Technology Development



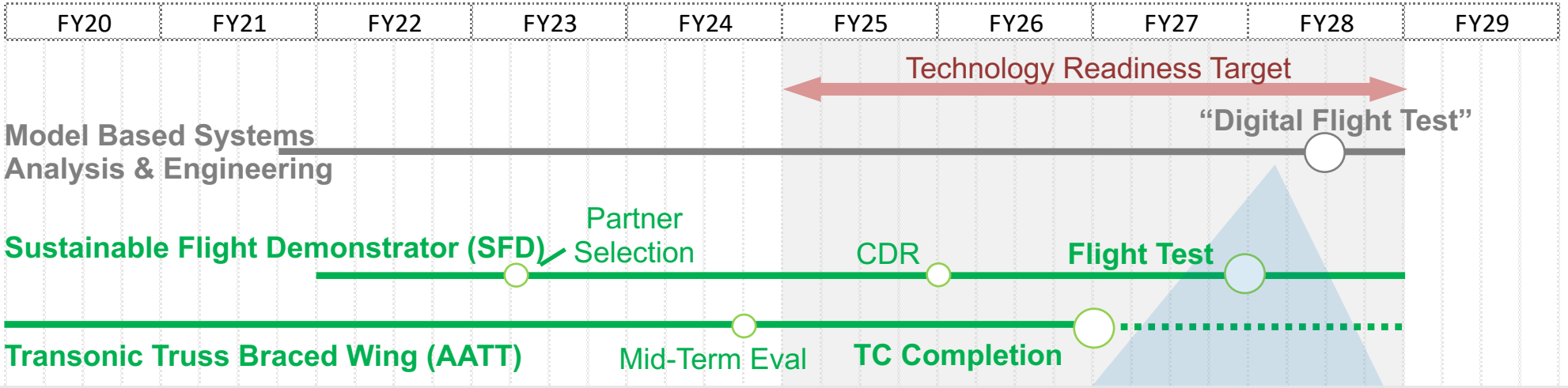


Project implementing Technology Development Phase

- Completed System Requirements, Baseline Definition, Technology Assessments & Development Roadmaps
- Conducted experiments of high-rate materials & manufacturing concepts at coupon/element levels. Data to help estimate potential impact on production rate and to assess material properties & failure mechanisms.
- Multi-party Cooperative Research Teams formed & integrated plans developed. Making awards of Cooperative Agreements for work to be performed July 2022 to June 2024
- Leveraging Advanced Composites Consortium (19 partners)



Subsonic Transports: Integrated Technology Development



Sustainable Flight Demonstrator
- Technical risk reduction contracts completed; final reviews 9/2022.
- Solicitation for demonstrator vehicle closed 9/1/22; partner selection for Funded Space Act Agreement anticipated 1/2023

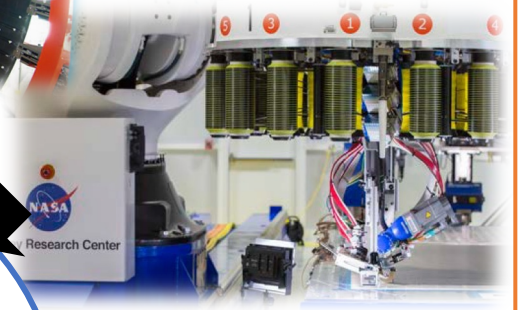
Ultra Efficient Wing (TTBW)
- High-Speed Buffet Test completed a 4-week investigation in the NASA Ames 11x11 Transonic Wind Tunnel in 2022. Data reduction complete and sufficient buffet margin demonstrated. Final review 9/2022.
- Upcoming aeroelastic wind-tunnel test of a higher aspect ratio wing planned for Feb. and June 2023.

Model-Based Systems Analysis & Engineering

SFNP Vision

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

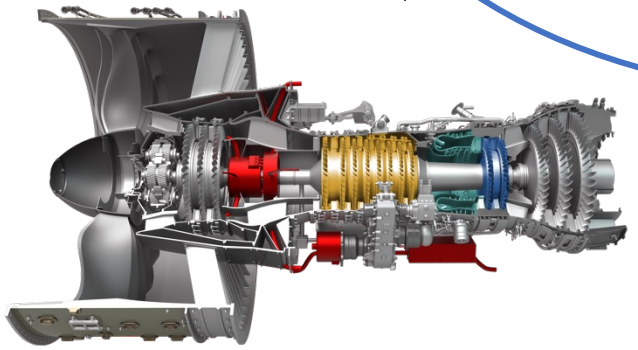
High-Rate Composite Manufacturing Processes (HiCAM)

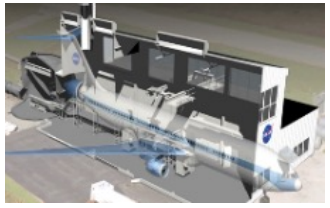


MBSA&E
Digital Integration
Knowledge Capture

Vision Vehicles
System of Systems

Small Core Engine Ground Tests (HyTEC)

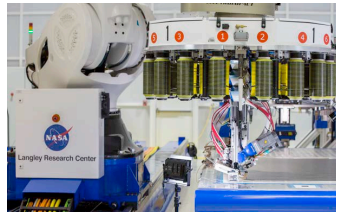


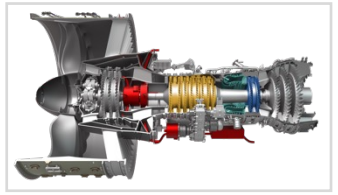


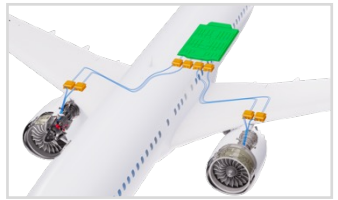
Electrified Propulsion Ground & Flight Tests (AATT & EPFD)

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

Subsonic Transports: Integrated Technology Development







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)
Core Award(s)
Power Extraction Test
Core Demonstration

Electrified Powertrain Flight Demonstration (EPFD)
Partner Selection
Flight Tests

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

Achieve TRL 6 in time for industry product decision-making

Planned
Notional

Sustainable Aviation Operations Demonstrations

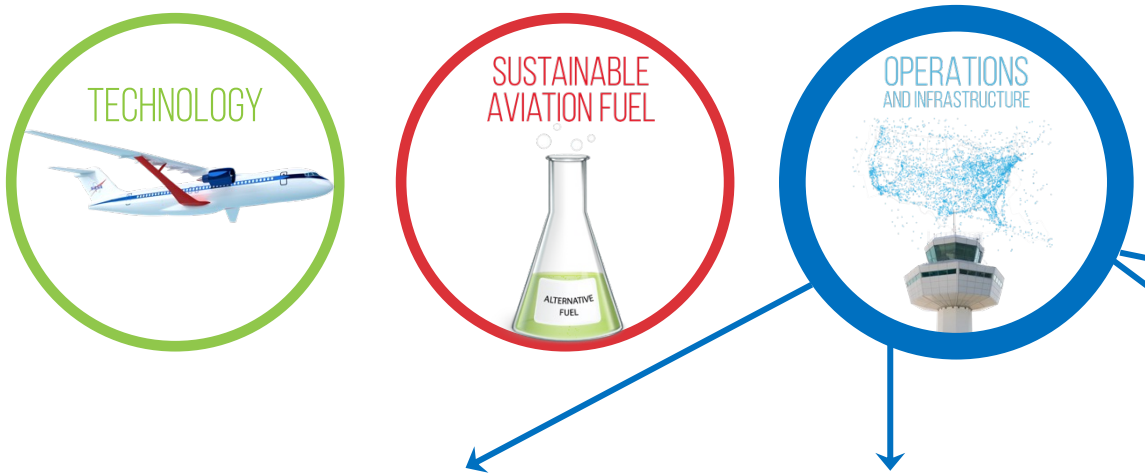
NASA = Primary Role

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

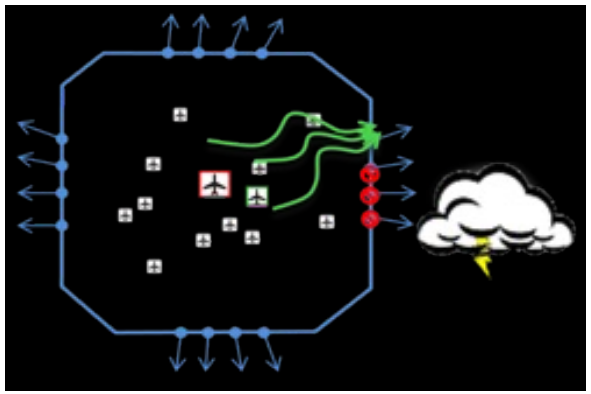
Increased operational efficiency reduces fuel burn, carbon emissions, contrail formation, and ozone impact.

NASA Led SFNP Operations Demonstrations



Flight Deck Services

Ground Services



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

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

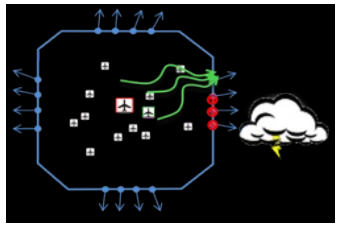
Irregular Ops Recovery/Disruption Management (SFNP-Ops-3, FY27)

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

Sustainable Aviation Operations Demonstrations



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

Digital Information Platform Development

Validate service-oriented architecture and ML services

Validate cloud-based deployment

Collaborative Digital Departure Reroute

Tech Transfer

Transfer to Industry and to FAA through RTP via DMTA RTT

Complex Airspace

Tech Transfer

Validate Scalability and New Interfaces

Multi-regional Trajectory Based Operations

Tech Transfer

Validate Scalability and New Interfaces to Flight Deck

Irregular Ops Recovery/Disruption Management

Tech Transfer

4D Trajectory Optimization

Tech Transfer

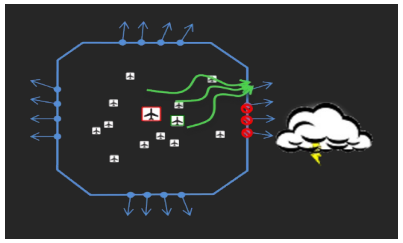
Planned

Notional

Flight Deck Services

ATM Services

FY 2022 Realized Benefits



Collaborative Digital Departure Re-Route
Joint partner flight demonstration of re-Routing Technology via Trajectory Option Set (TOS) by rerouting flights and departures at Dallas Fort Worth (DFW) and Dallas Love Field (DAL) International Airports with FAA, American Airlines, Southwest Airlines, and Envoy Air.

American Airlines envoy Southwest FEDERAL AVIATION ADMINISTRATION

Fuel Savings

Over **24,000** lbs.

Emissions Savings

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

Over **569** urban trees

Delay Savings

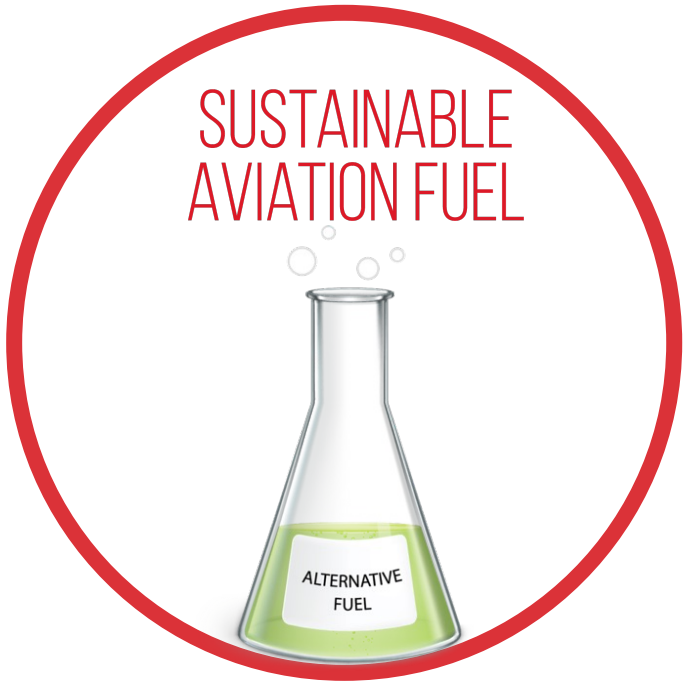
OFF delay	**IN** delay
3.9+ hrs	**4.7+** hrs

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 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

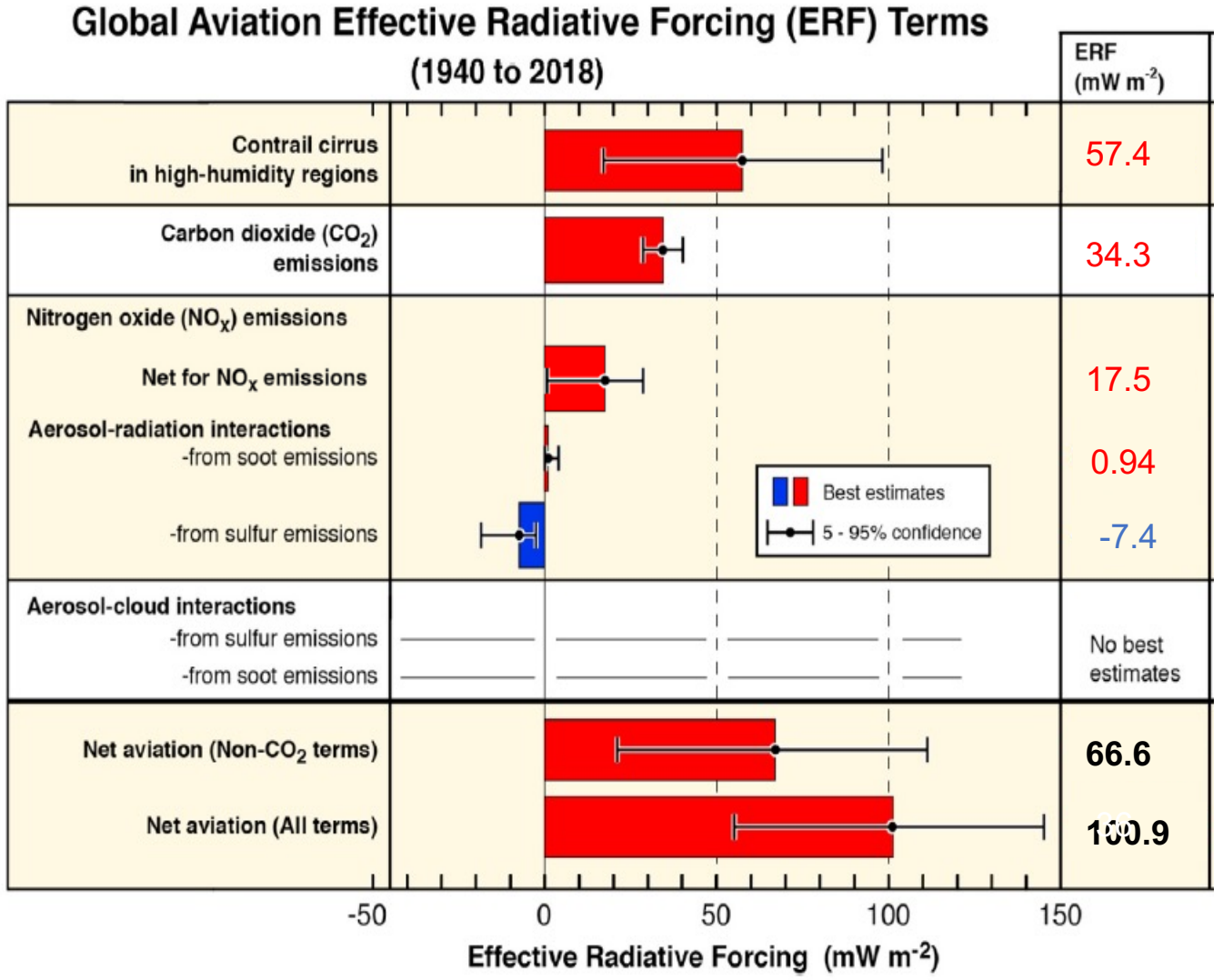
Approach

- 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

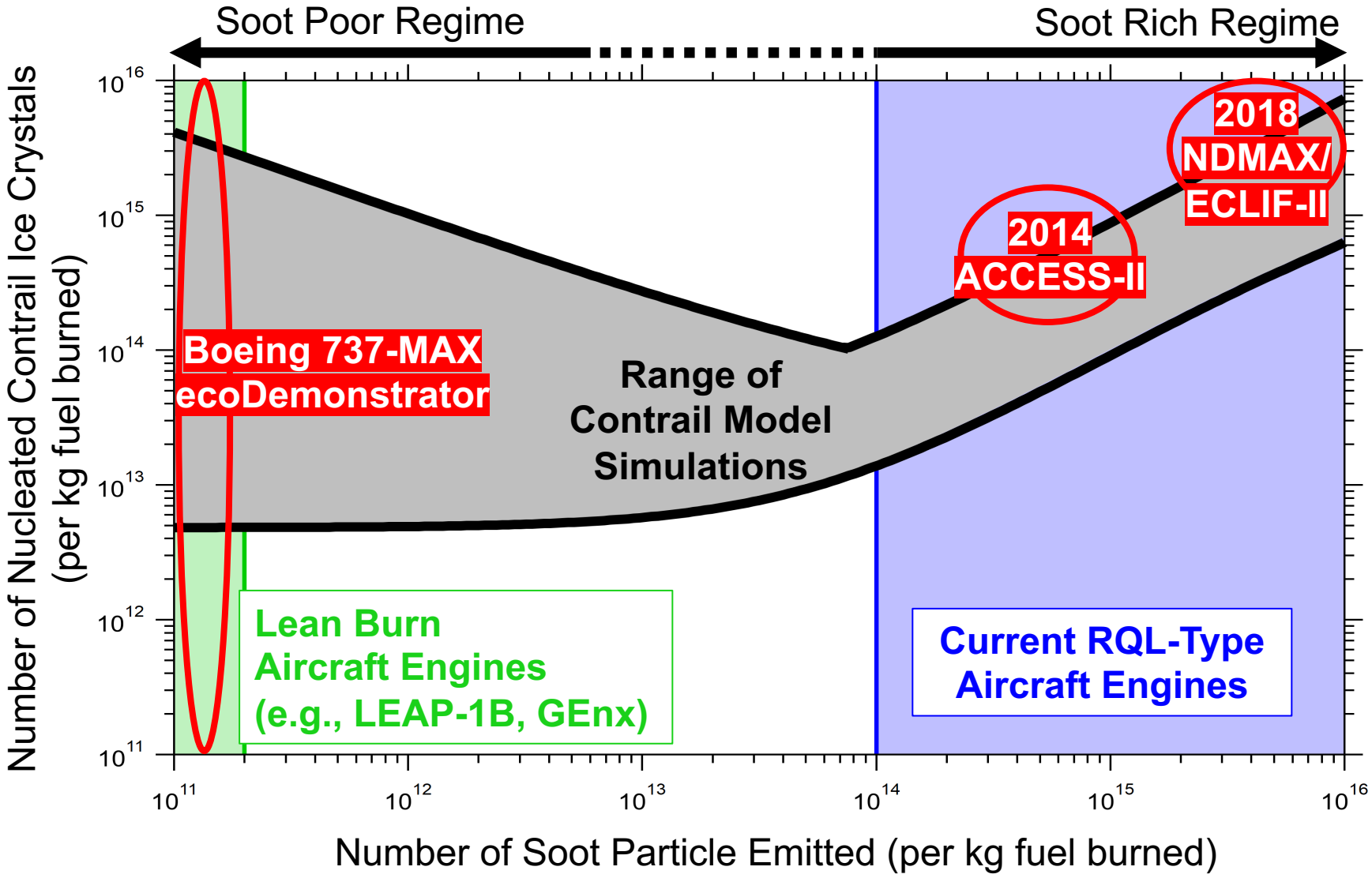
- **Lee et al. (2021) represents latest and most comprehensive assessment of aviation's climate impacts**
- **Non-CO_2 impacts comprise two-thirds of the net radiative forcing from aviation**
- **Lot of uncertainty in these estimates. Cruise observational data critically lacking!**



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

Sustainable Flight
National Partnership

the baseline projects are established and active

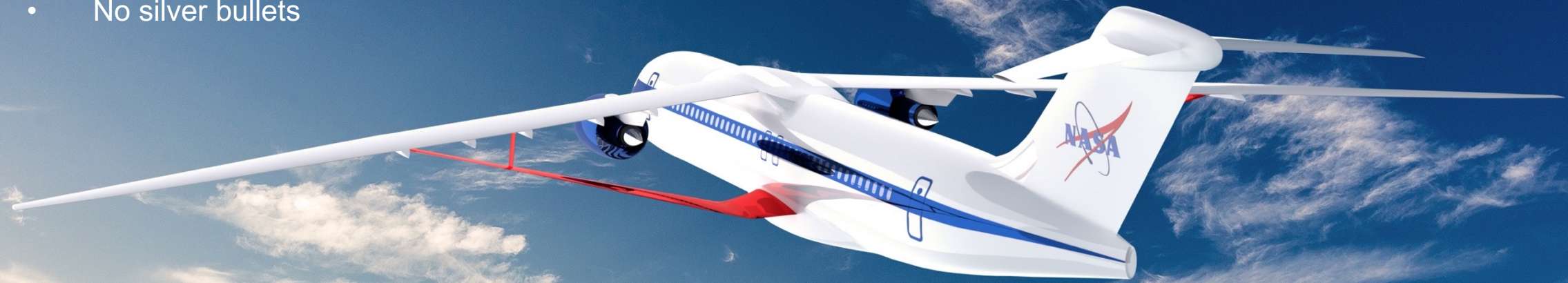
opportunity now to up-level and strengthen the partnership
between the elements and organizations
“TEAM USA”

Exploratory Stage

- **Precompetitive discussion on mutually beneficial topics**
  - **priorities/advocacy for U.S. aviation competitiveness**
  - **inspiring/insuring the next generation aviation workforce**
  - **other**
- **Conceptually no head, but NASA de facto leadership**
  - **NASA + Other Gov’t Agencies**
  - **U.S. aviation community participation based on funded collaborative partnerships**

Concluding Remarks

- 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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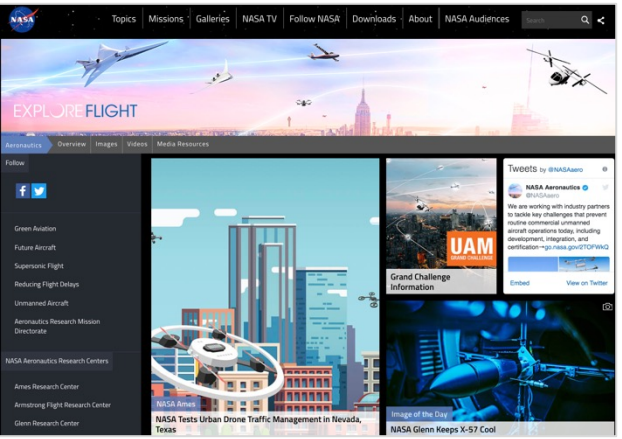

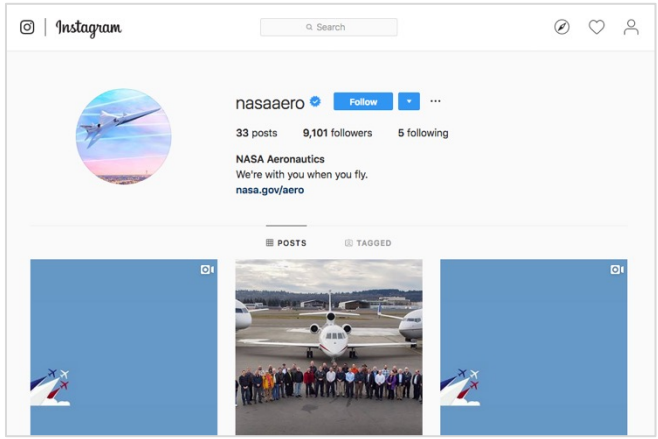

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