

NASA Sustainable Aviation Overview

RAeS Applied Aerodynamics Conference
London, UK

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September 15, 2022

Outline

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

CONTEXT

NASA Aeronautics is One of Five Mission Directorates

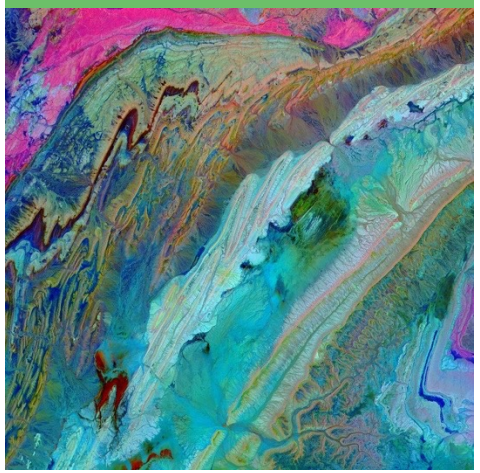
Aeronautics



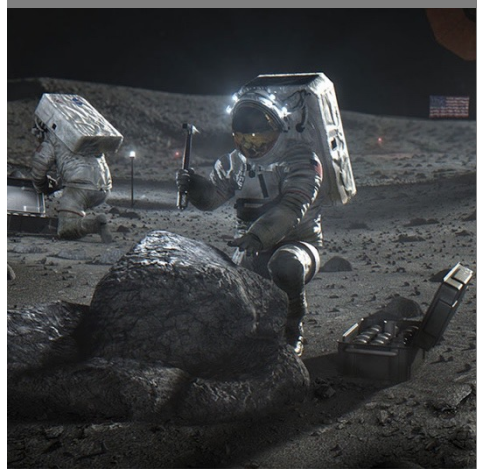
Space Technology



Science



Exploration Systems Development



Space Operations

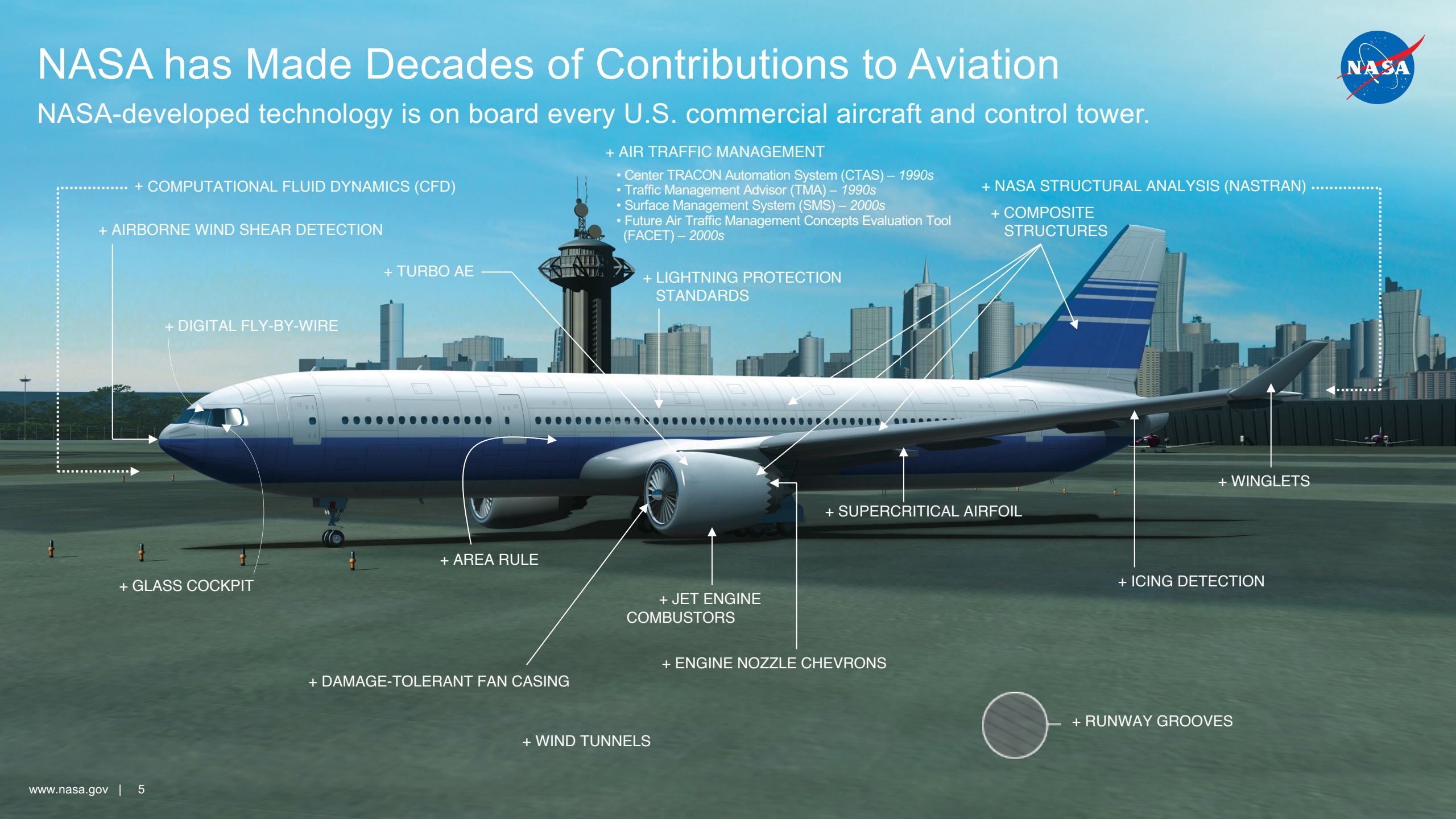


National Advisory Committee
for Aeronautics
March 3, 1915

National Aeronautics and Space Administration
October 1, 1958

NASA has Made Decades of Contributions to Aviation

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











Four Transformations for Sustainability, Greater Mobility, and Economic Growth

SUBSONIC COMMERCIAL TRANSPORTS

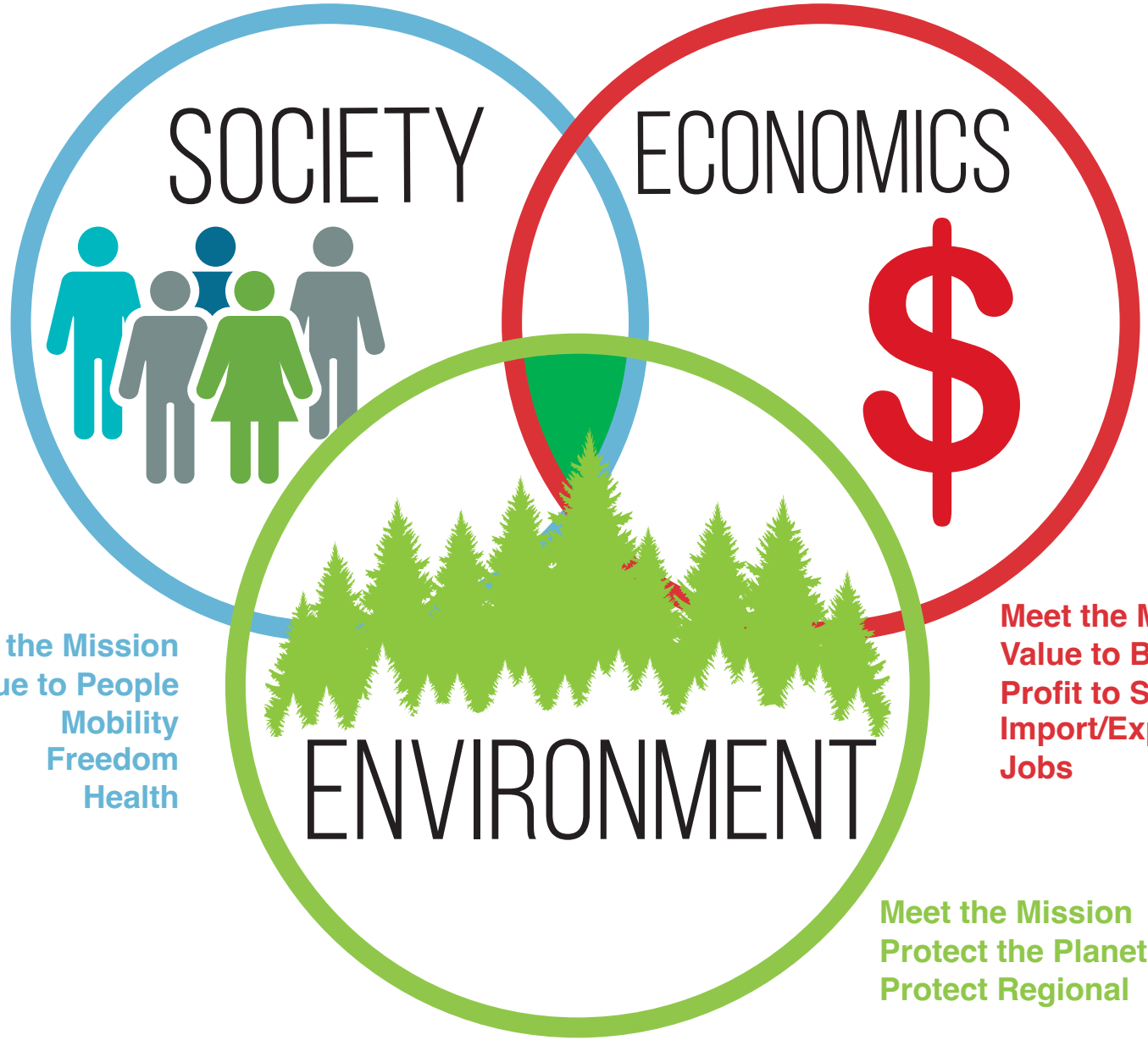
the 24/7 global backbone
of air transportation
now and into the forseeable future

and the key to 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



Environmental Impacts of Aviation

COMBUSTION EMISSIONS

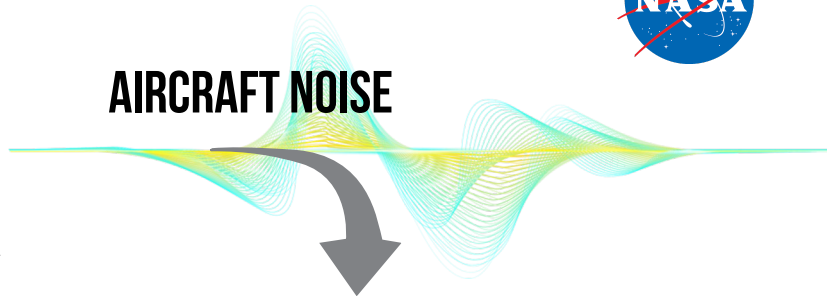


CO_2: 71%

Water: 28%

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

AIRCRAFT NOISE



ATMOSPHERIC CHEMISTRY & PHYSICS

- Primary $PM_{2.5}$
- SO_x → Secondary $PM_{2.5}$
- NO_x → Secondary $PM_{2.5}$, Ozone
- UHC → Ozone
- CO → Ozone



POPULATION EXPOSURE AND HEALTH IMPACTS

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

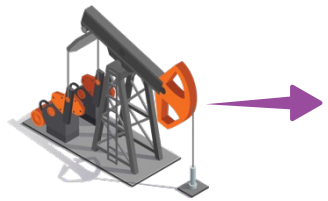
GLOBAL CLIMATE CHANGE



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

Environmental Standards Landscape

Fleet Level – airplane, energy, & operations dependent

CORSIA Market-Based Measure (2020) FAA Population Impacted by 65 (& 55) dB DNL

ATAG Goal for Net-Zero Carbon by 2050

Airplane & Engine Level



CO_2 standard Airplane-level CAEP/10	Noise regulation Airplane-level Chapter 14/Stage 5
New for 2020	**Existing periodic updates**
nvPM standards Engine-level CAEP/10 (/11 in 2023)	LTO NOx regulation Engine-level CAEP/8

Flight shaming, new standards, noise-limited capacity

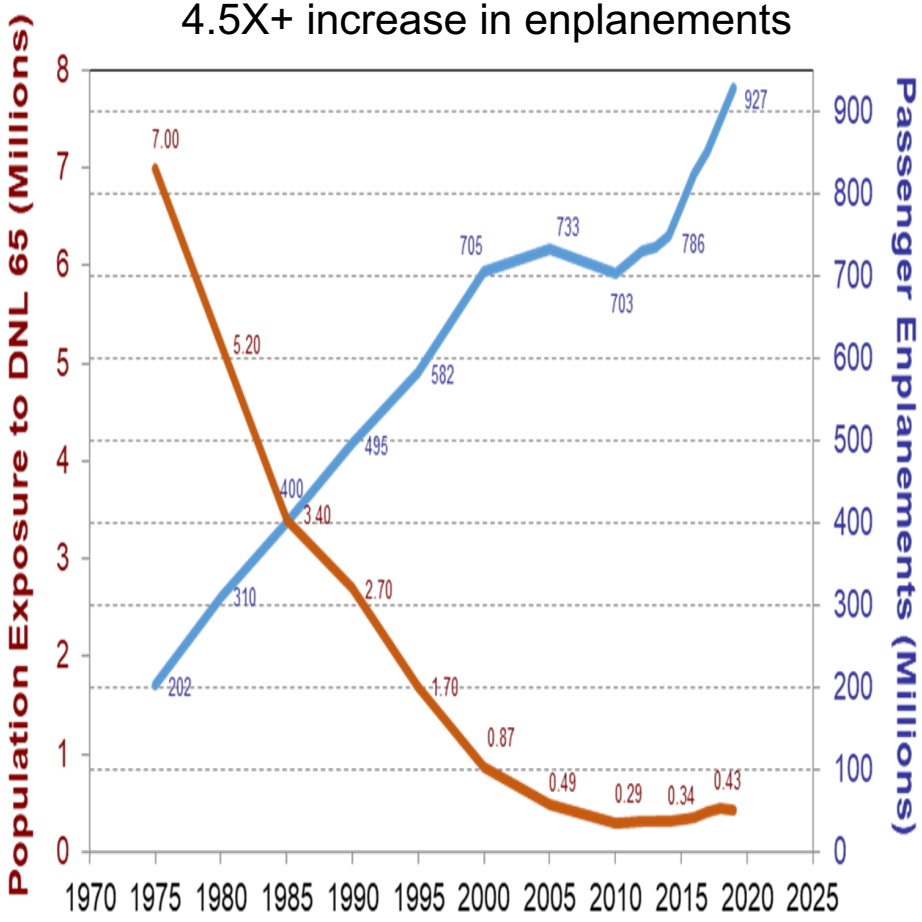
ICAO CAEP exploring the feasibility of a “long-term aspirational goal” for carbon

Aviation Noise Impact

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

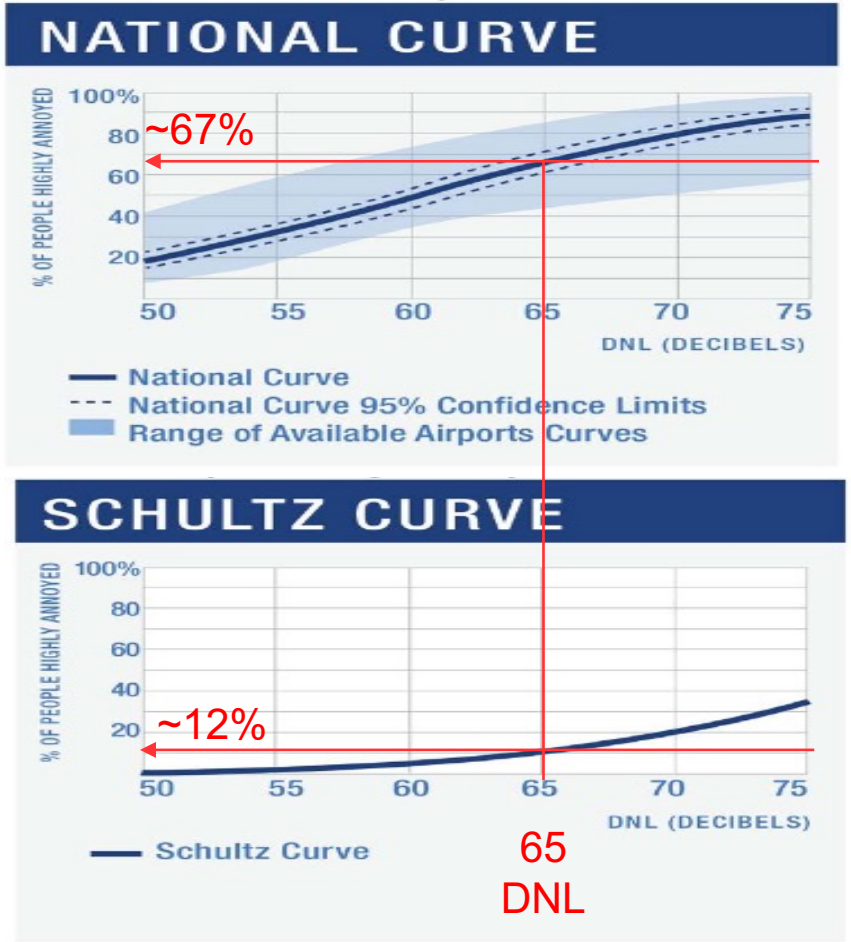
History – FAA Data

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



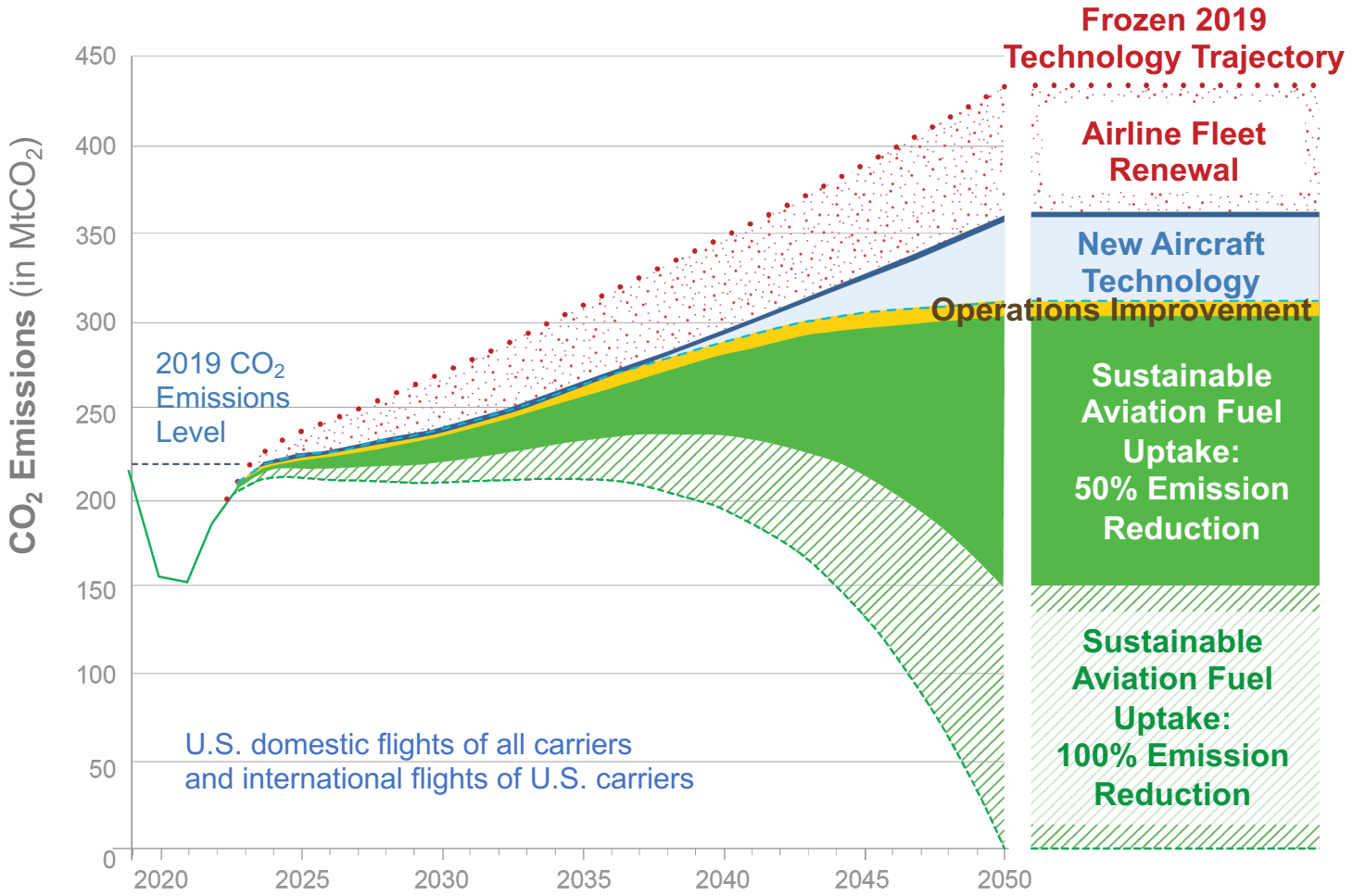
Noise Reduction Remains a Key Environmental Driver

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

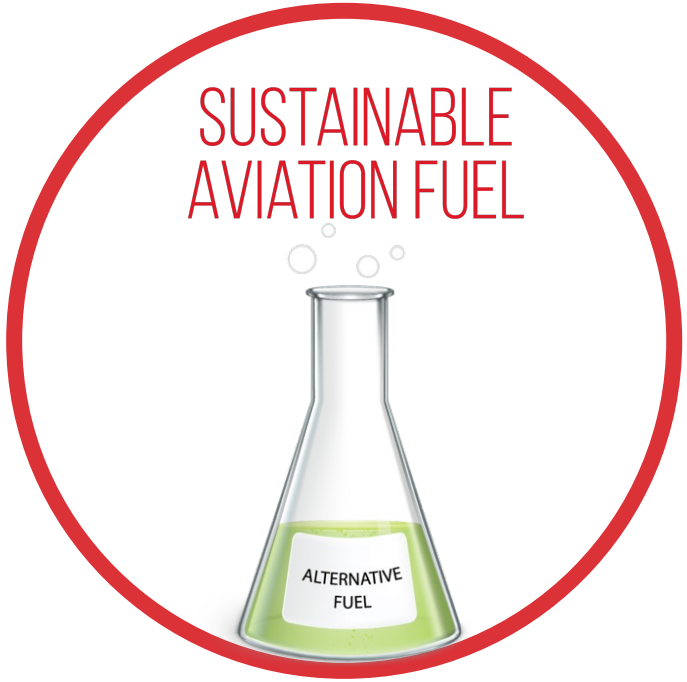
The U.S. is working with the global community to achieve net-zero greenhouse gas emissions by 2050 using a common basket of measures.

Aviation Pillars for a Sustainable Future

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



NASA = Primary Role



NASA = Supporting Role



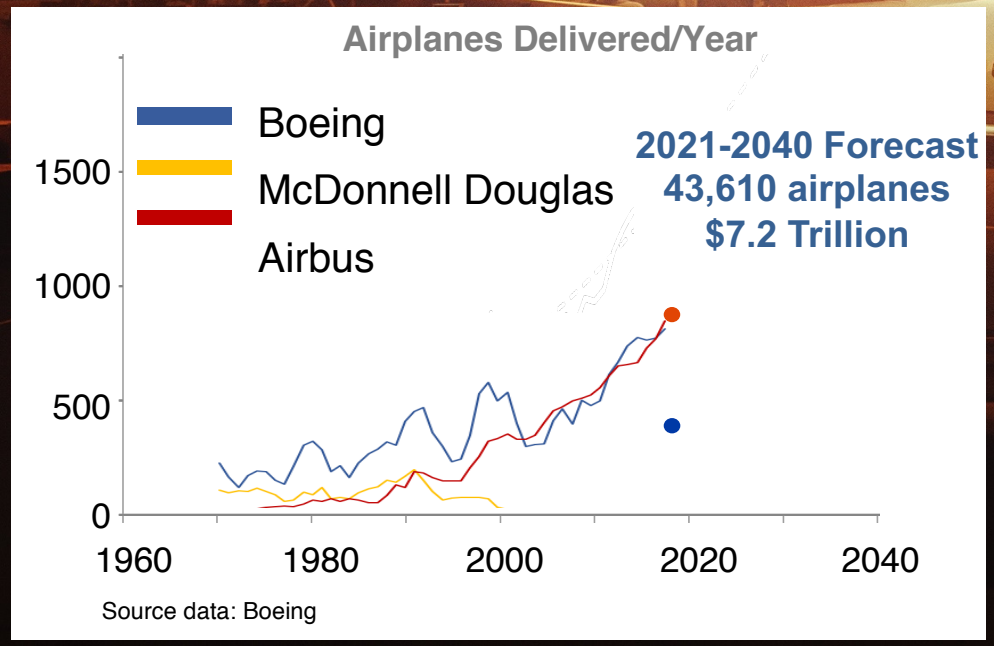
NASA = Primary Role

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



- Airline industry particularly hard hit by COVID-19
- Global Competition among manufacturers growing

Single-Aisle Transport Airplane Market & Timing for Impact



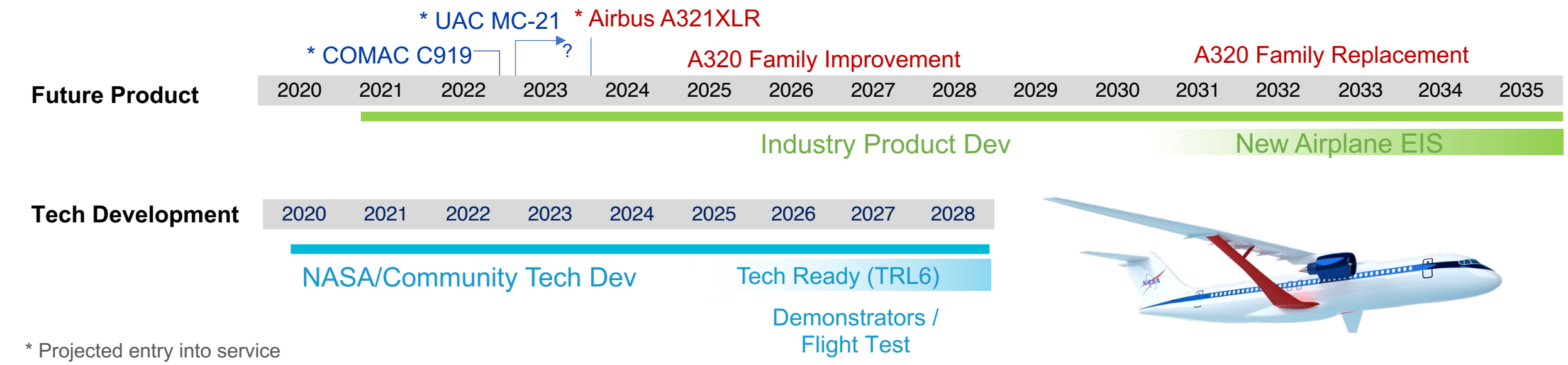
COMAC C919
Image Credit: Weimeng



UAC MC-21
Image Credit: Denis Fedorko



Airbus A321
Image Credit: Huy Bùi



* Projected entry into service

Tomorrow's competition requires investment today.

Sustainable Flight National Partnership (SFNP)

Sustainable Flight National Partnership

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

Advance engine efficiency and emission reduction

Enable integrated trajectory optimization



Advance airframe efficiency and manufacturing rate

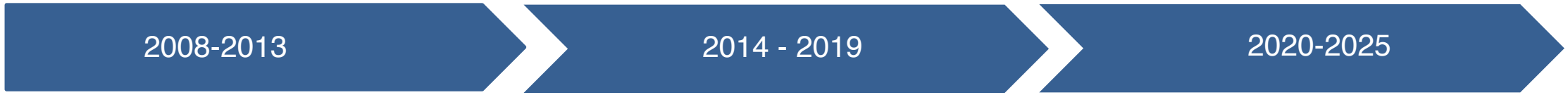
Enable use of 100% sustainable aviation fuels

The goal is to enable 25 – 30% energy efficiency improvements in next-generation transports with the capacity to utilize 100% sustainable aviation fuel and fly optimal trajectories.

Subsonic Transport Technology

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

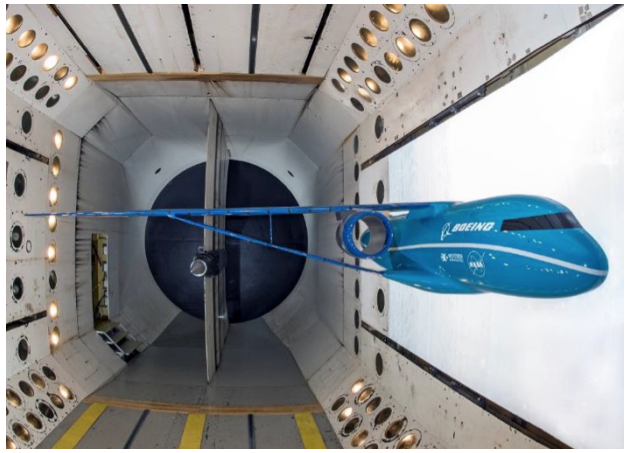
FAA CLEEN* III

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)

Ultra-Efficient Subsonic Transport (UEST) Concepts

Examples of Progress Through FY16



TTBW Aeroservoelastic • FY14
Langley Transonic Dynamics Tunnel



BWB/UHB Low Speed Operability • FY15
National Full-Scale Aerodynamic Complex at Ames



D8/BLI Integrated Benefit • FY13&14
Langley 14- By 22-Foot Subsonic Tunnel



TTBW Aerodynamic Integration • FY16
Ames 11-Foot Transonic Wind Tunnel



BWB Non-circular Fuselage • FY15
Langley Combined Loads Test System (COLTS)



HWB/OWN Performance • FY15
Langley National Transonic Facility

Ultra-Efficient Subsonic Transport (UEST) Flight Demonstrator Concepts
FY17-18 Studies







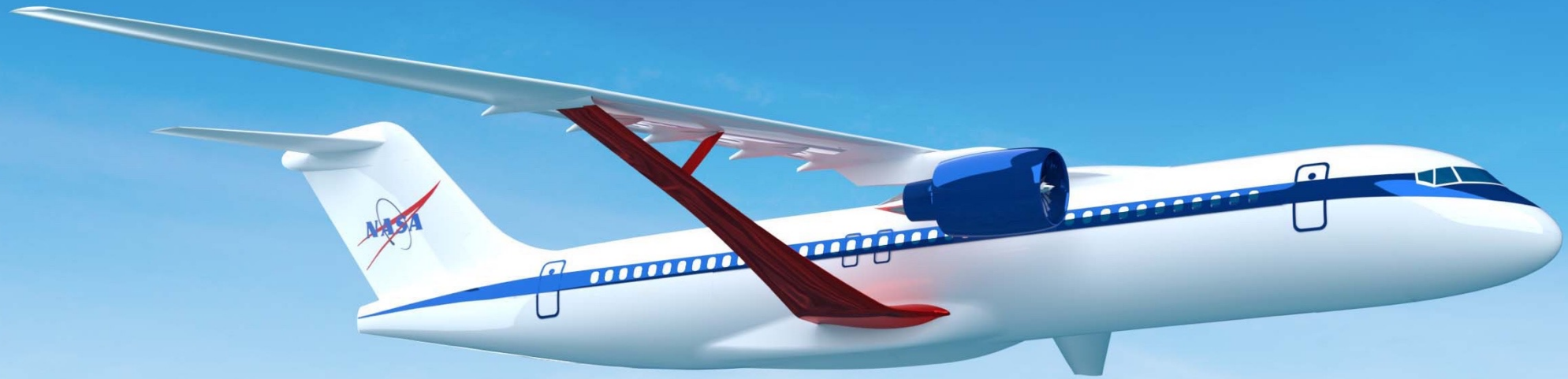


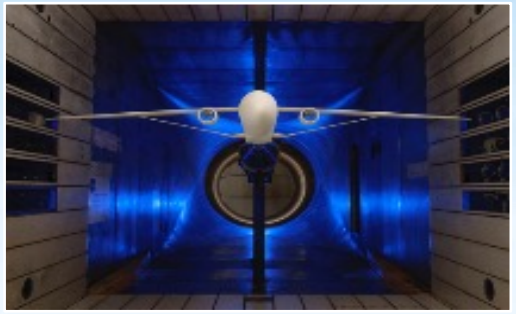


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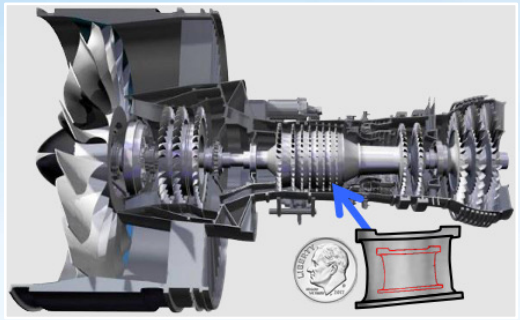
Subsonic Transport Technologies

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

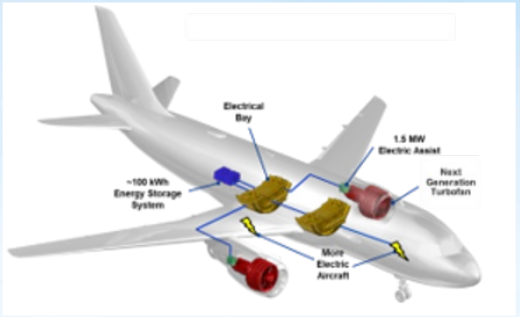




Transonic Truss-Braced Wing
5-10% fuel burn benefit



Small Core Gas Turbine
5-10% fuel burn benefit



Electrified Aircraft Propulsion
~5% fuel burn and maintenance benefit



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

Breguet Range Equation

Aerodynamic efficiency –
Transonic Truss-Braced Wing

Integrated Aircraft System Efficiency –
Electrified Aircraft Propulsion

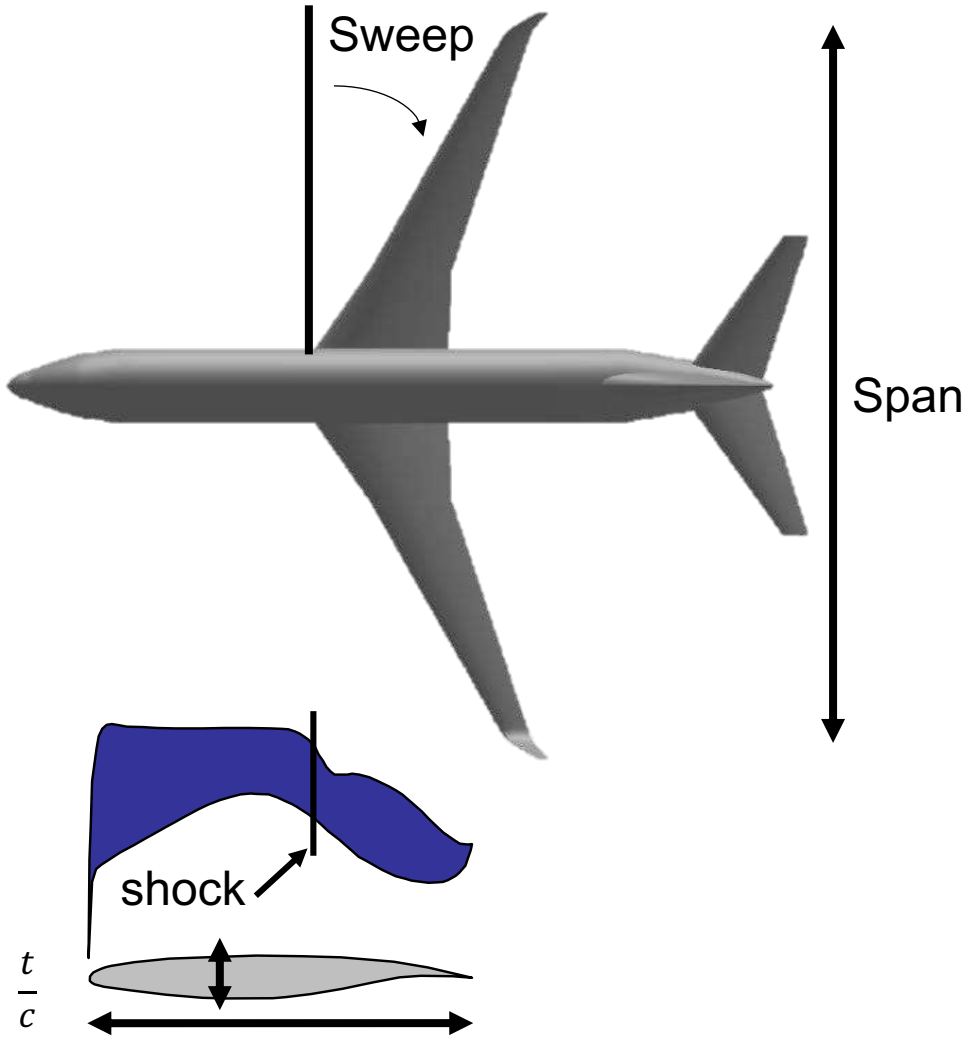
$$Range = \frac{V}{SFC}\left(\frac{L}{D}\right)\ln\left(1 + \frac{W_{fuel}}{W_{payload} + W_0}\right)$$

Engine efficiency –
Small Core Gas Turbine

Weight –
High-Rate Composite Manufacturing

No “silver bullets” – holistic strategy opens design space on multiple fronts

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

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

The Challenge

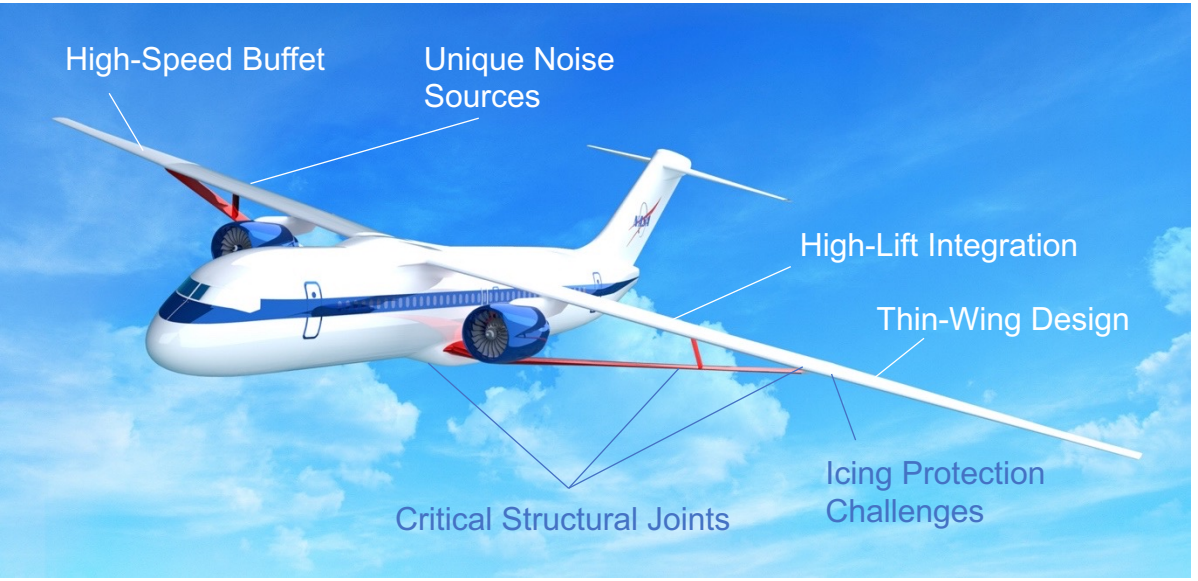
Improving L/D without offsetting weight increase due to high span and thin airfoils

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

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.

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

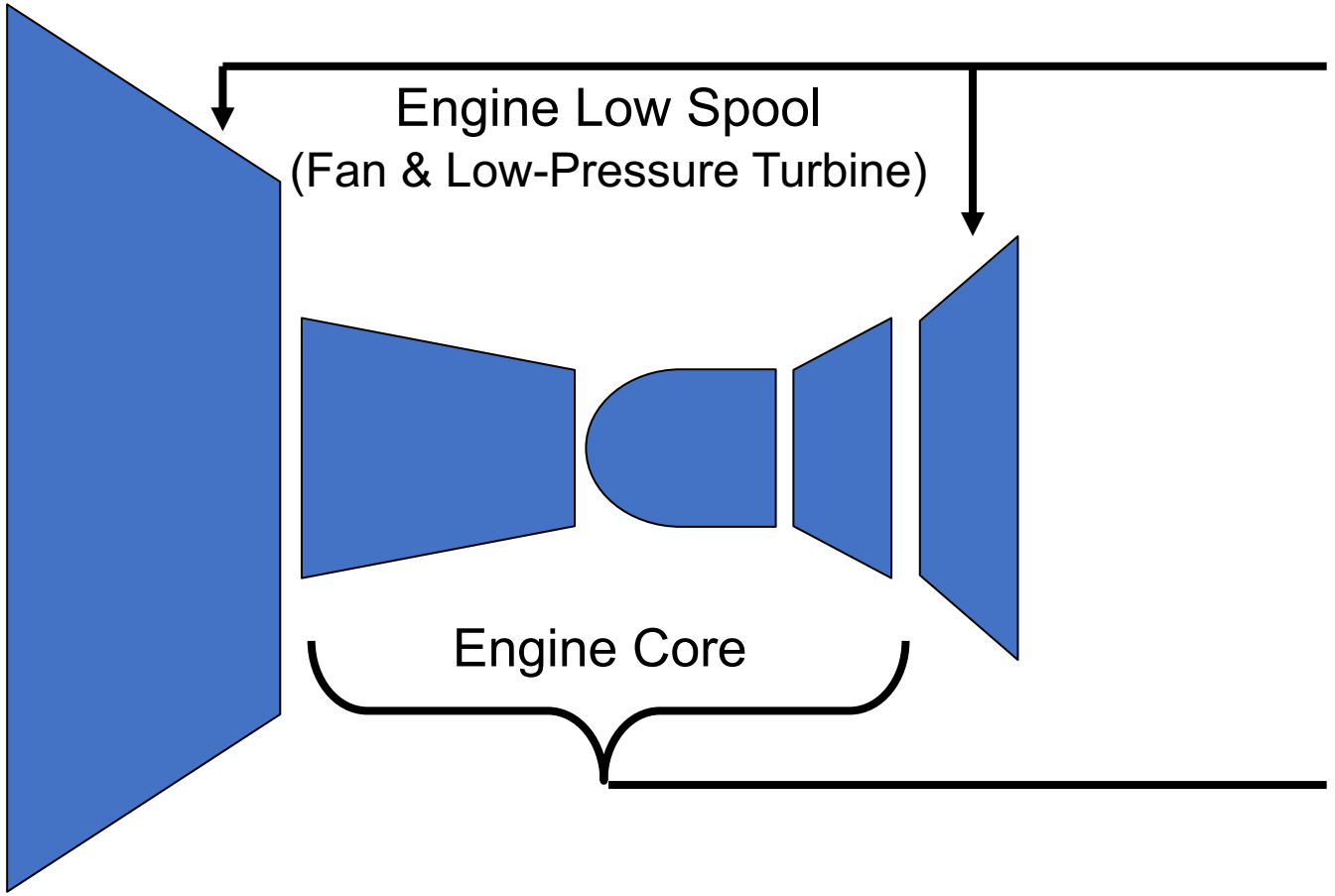
- Validate promising technologies, retire technical risks, and mature to TRL 6 key synergistic commercial transport vehicle technologies. Combined, these technologies could support efficiency and environmental performance goals for the 2030s.

Approach

- Request for Information supporting Project Formulation 2020-21
- Project Formulation and Risk Reduction in 2021-22
- Competitive Request for Proposals released 6/29/2022

Risk Reduction Contract Awards Made August 2021
Design/Build Contract Award Anticipated Late 2022

Engine Efficiency (SFC)



Propulsive X Transfer Efficiency

Conversion of mechanical energy to thrust

- Bypass Ratio
- Fan Pressure Ratio

Thermal Efficiency

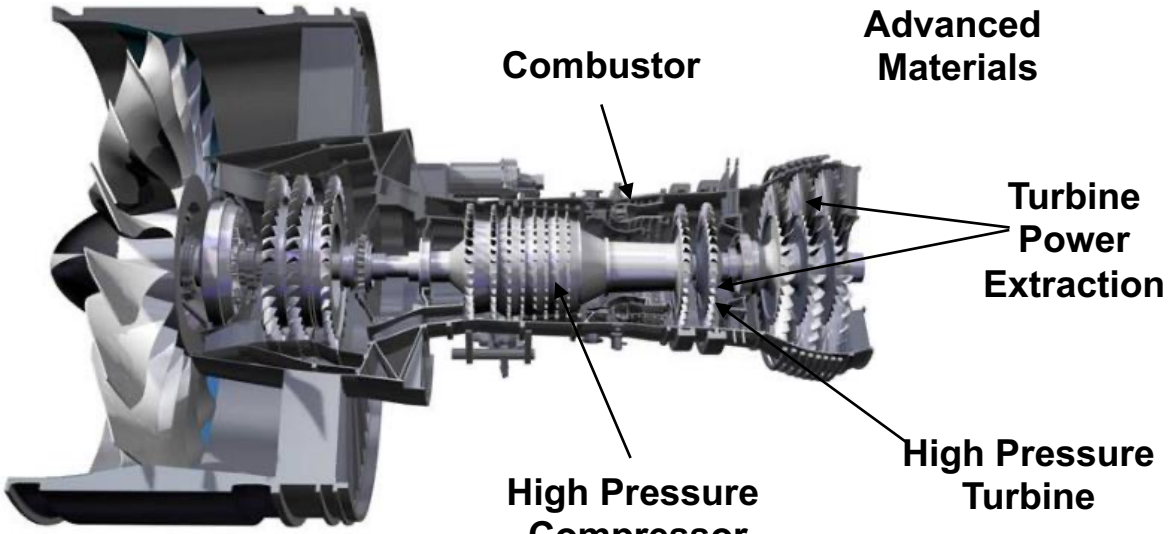
Conversion of chemical energy to mechanical energy

- 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



HyTEC
Hybrid Thermally Efficient Core

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

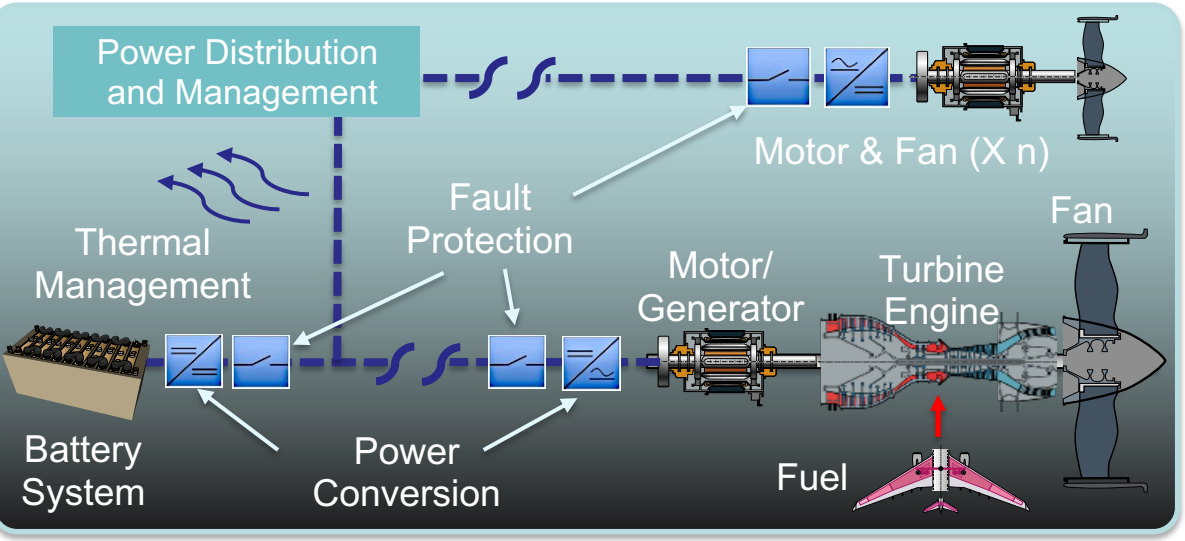
Approach

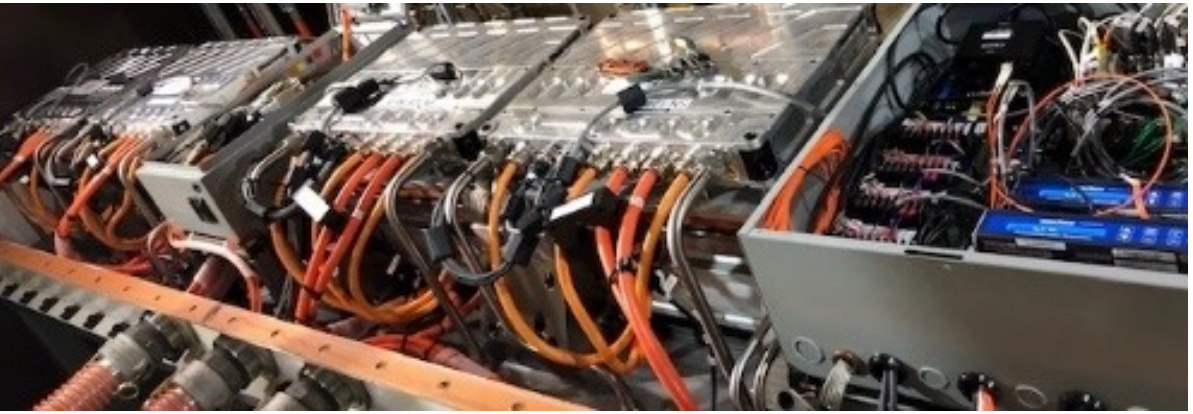
- Partner with industry to mature and demonstrate promising technologies

Small-core turbofan technology
contract awards were made in September 2021.

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

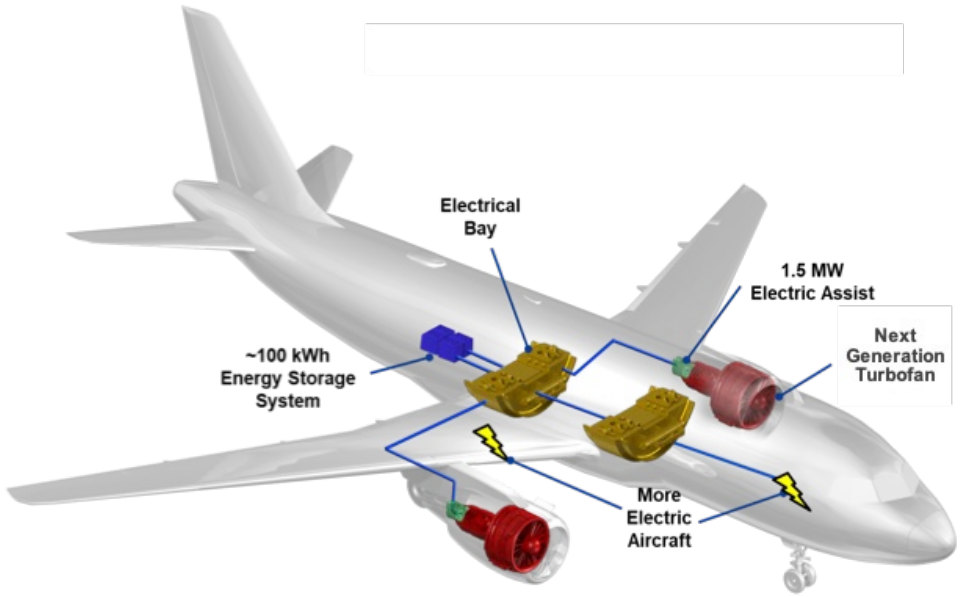
Approach

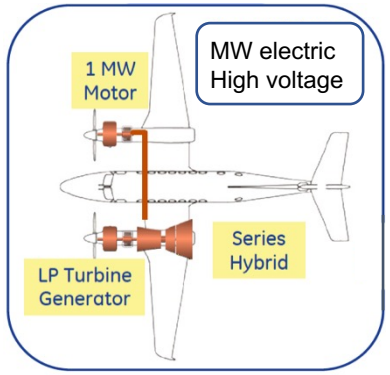
- Conduct technology-focused integrated ground tests
- Partner with industry on testing of electrified propulsion architectures and component technologies
- Leverage prior electric aircraft propulsion advances (TRL ~4)

Architecture development and high-power component tests are underway.

Electrified Powertrain Flight Demonstration

Demonstrate integrated electrified powertrains in flight using industry platforms





FY21	FY22	FY23	FY24	FY25
Test 1 Prel/detail design, fab & integration				
			First flight Test 1	
Test 2 Prel / detail design, fab & integration				
				First flight Test 2

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

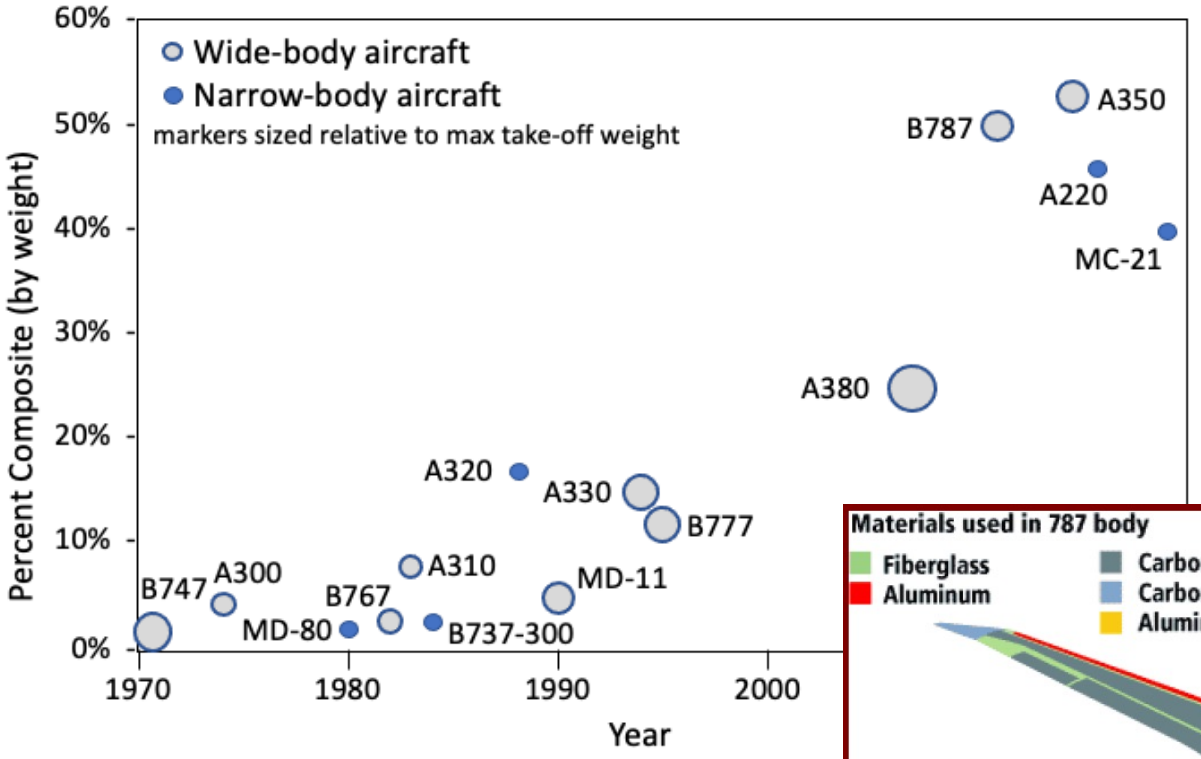
- Engage with U.S. industry to integrate and demonstrate megawatt-class EAP machines in flight.
- Engage with the FAA, SAE, ASTM, etc. to contribute data that inform EAP standards and regulations.

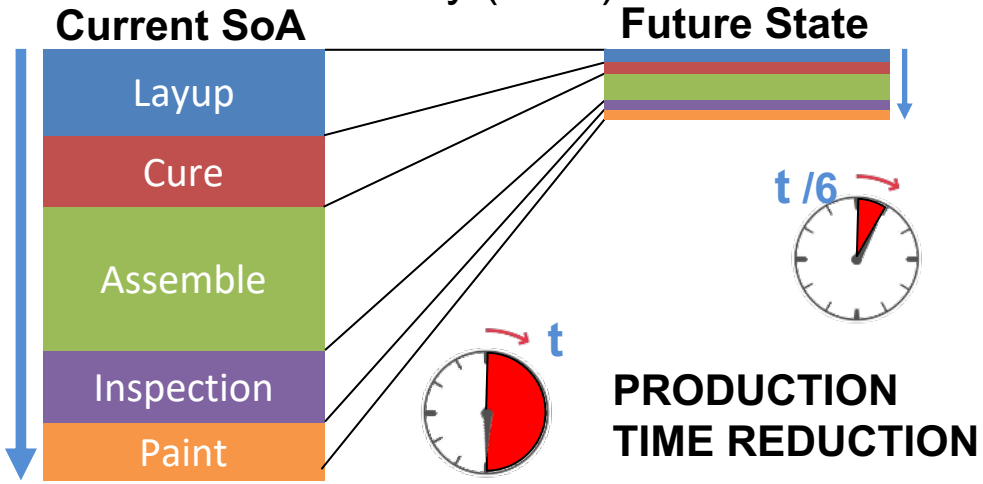
Two Flight Demonstration Contracts Awarded in September 2021

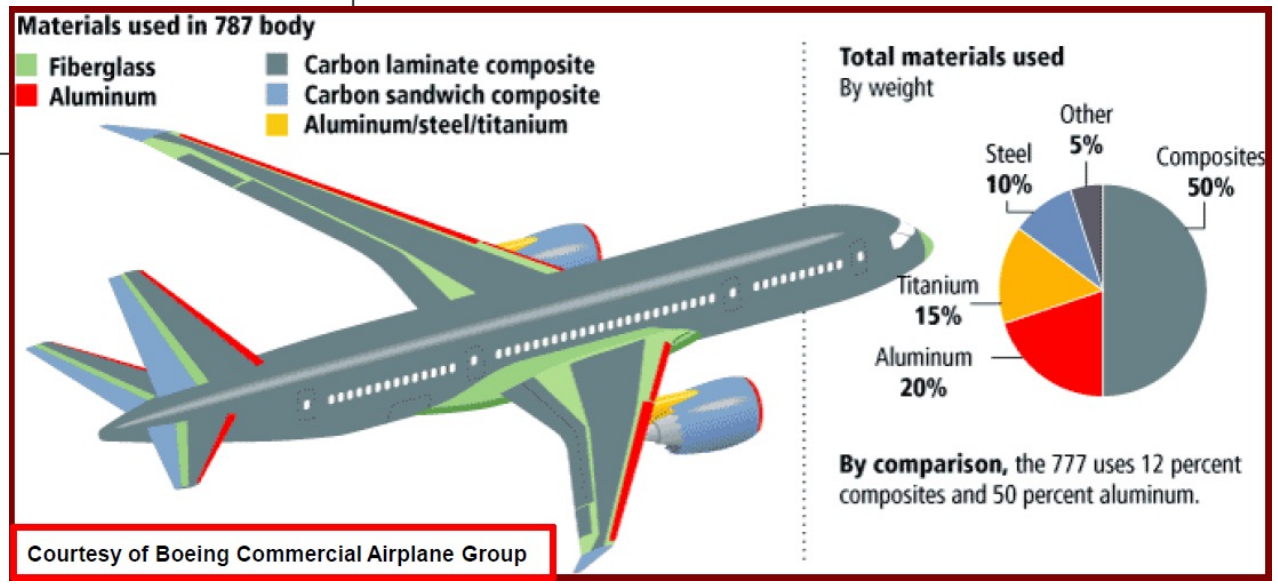
Structural Efficiency (W_0) at Rate

Two Relevant Environments

Flight (Weight) ← Cost → Factory (Rate)







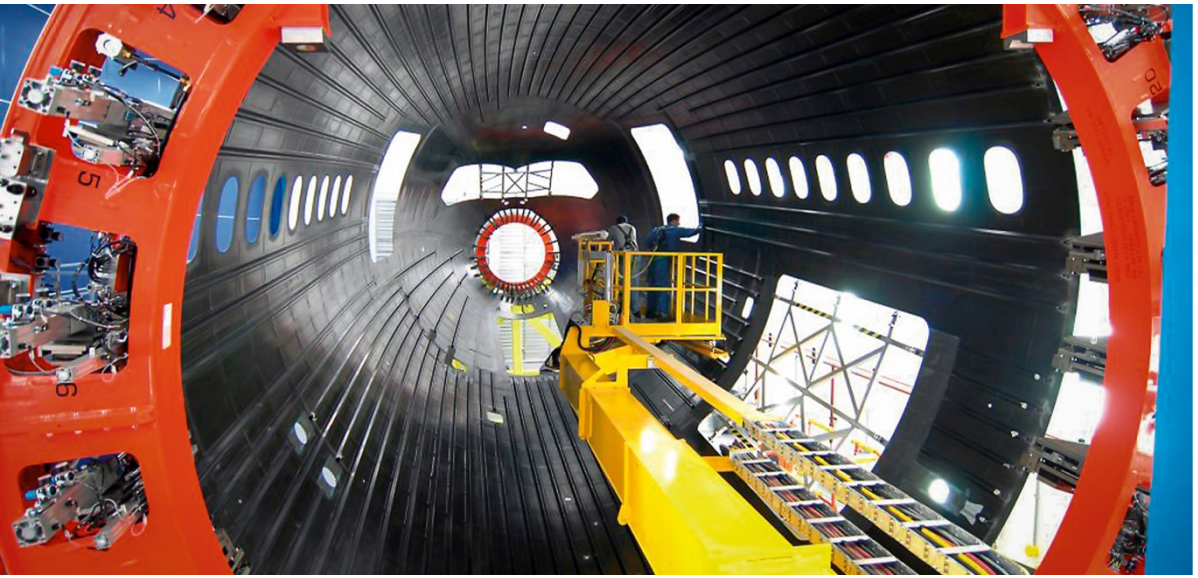
Hi-Rate Composite Aircraft Manufacturing

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

12 Cooperative Tasks Awarded to Inform HiCAM Plans

Model-Based Systems Analysis/Engineering

Systems-level Digital Integration across SFNP projects capped by a Digital Flight Test

Advanced Aerodynamic Ground & Flight Tests (AATT & SFD)





High-Rate Composite Manufacturing Processes (HiCAM)





MBSA&E

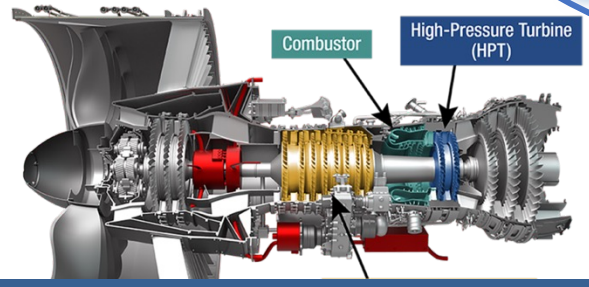
Digital Integration & Knowledge Capture on Vision Vehicles

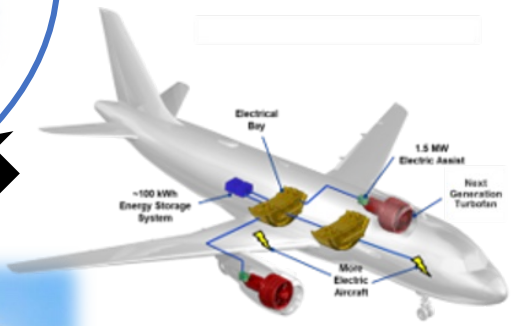






Small Core Engine Tests (HyTEC)







Electric Propulsion Ground & Flight Tests

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

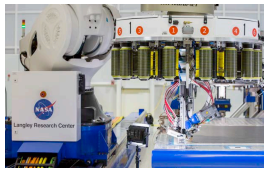


Sustainable Flight Demonstrator (SFD)

Flight Test

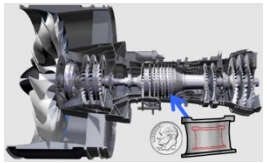
AATT - Transonic Truss Braced Wing

TC Completion



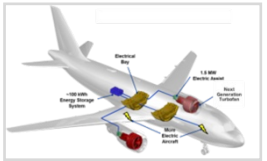
Hi-Rate Composite Aircraft Manufacturing (HiCAM)

Mfg Demo & Structural Test



Hybrid Thermally Efficient Core (HyTEC)

Core Demonstration & Test



Electrified Powertrain Flight Demonstration (EPFD)

Flight Tests

AATT - Electrified Aircraft Propulsion Integrated Ground Test

TC Completion

Technologies being worked concurrently

Sustainable Aviation Fuels, Low Emission Combustion, Engine Propulsors, Operational Concepts and Enabling Aircraft Technologies

Achieve TRL 6 in time for industry product decision-making

Leverage the Asset – Future Spirals

Planned

Notional

Sustainable Aviation Fuel and Non-CO_2 Impacts

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

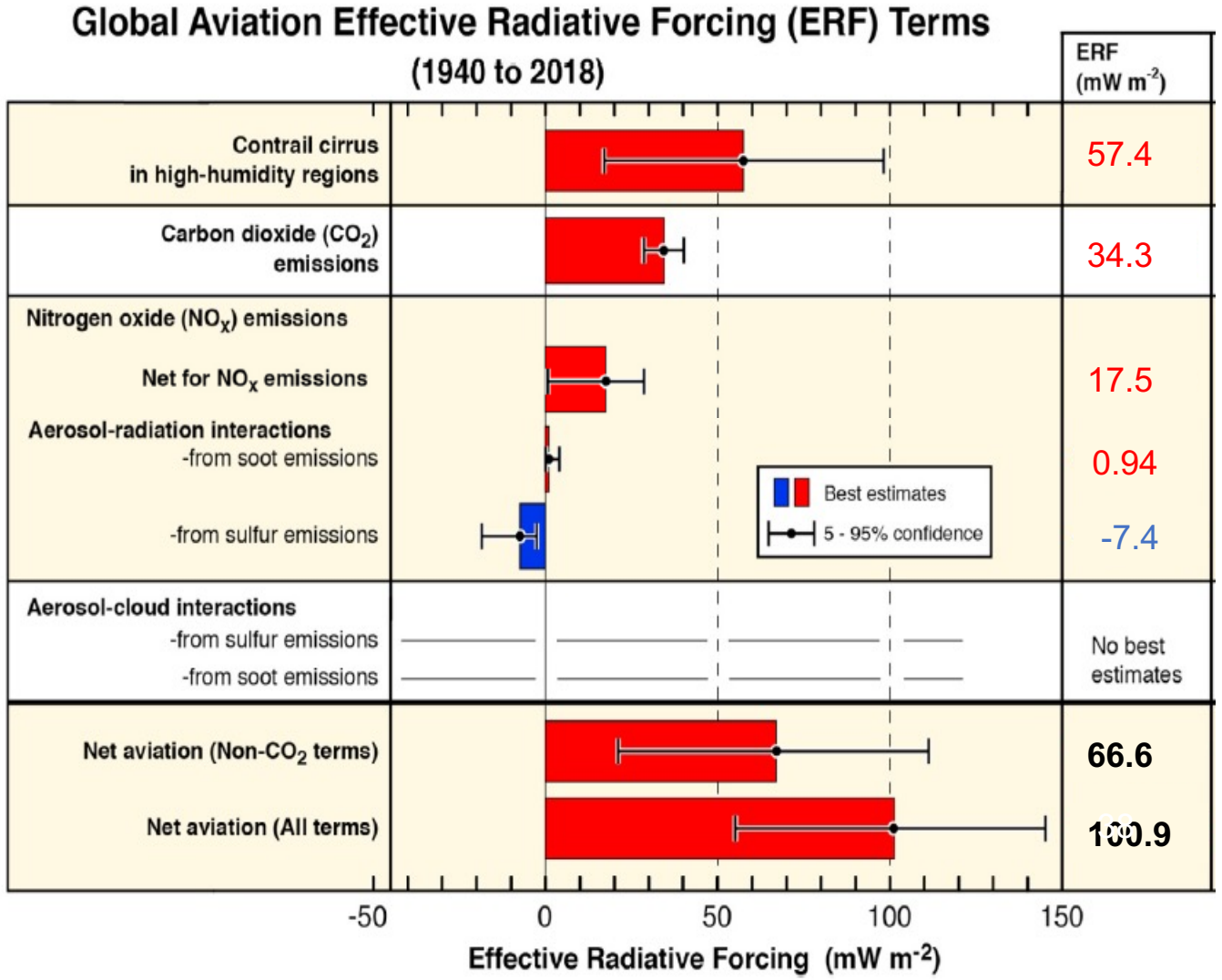
Approach

- 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)

SAF Emissions and Contrails Research

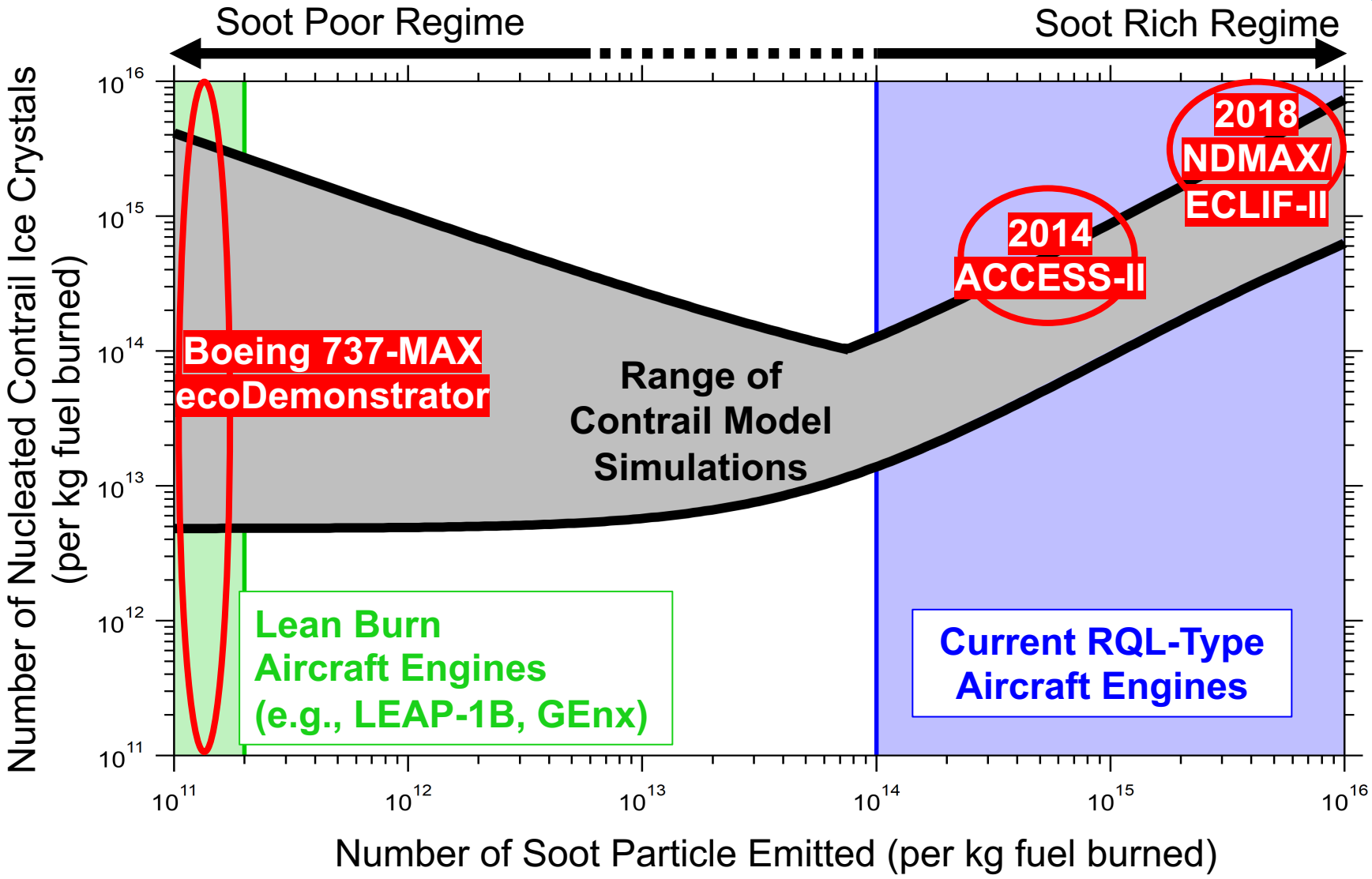
October 2021 Emissions Ground Test at Boeing Field

- 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

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 Aviation Operations Demonstrations

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)

Saved **1,101,768** gallons of fuel

FUEL

Saved **23,211,172** lbs. of CO_2 = **172,597** urban trees

EMISSIONS

Saved **6,016** hours of engine run time

MAINTENANCE



REDUCED DELAY BY 933.6 hours

Saving passengers an estimated **$4,481,569** in value of time and operators an estimated **$1,375,224** in flight crew costs

BENEFITS TODAY

Sustainable Aviation Operations Demonstrations

SA-1: Collaborative Digital Departure Re-Route (FY22 - 25)
Demonstrate CDDR via Trajectory Option Set (TOS) by rerouting flights and departures starting at North Texas, scaling to a high-density operational area

Benefits:
Reduced fuel burn and emissions through reduced surface departure delay. Benefits rerouted flight as well as all departures

SA-3 Irregular Operations Recovery/Disruption Management (FY27- 28)
Develop and demonstrate predictive analytics services for recommending intelligent irregular operations (IROP) recovery strategies

Benefits:
Reduce wasteful fuel-burn due due to long taxis, returns to gate, diversions, etc. during IROP events

SA-2: Multi-regional Trajectory Based Ops (FY26 - 27)
Demonstrate digitally connected flight deck service for efficient trajectories and scheduling in multi-region and oceanic airspace leveraging surveillance and navigation

Benefits:
Reduced emissions and fuel-burn on long-haul oceanic flights

SA-4: 4D Trajectory Optimization (FY28-29)
Demonstrate digitally connected flight deck services to optimize en-route 4D trajectories based on traffic and weather constraints.

Benefits:
Reduced fuel burn and emissions while motivating the development of the flight deck of the future

ATM Services | Flight Deck Services

Sustainable Aviation Operations Demonstrations

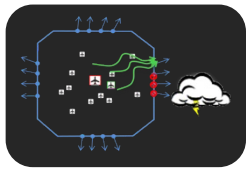


Digital Information Platform Development

Validate service-oriented architecture and ML services

Validate cloud-based deployment

Transfer to Industry and to FAA through RTP via DMTA RTT



Collaborative Digital Departure Reroute (SA-1a)

Tech Transfer

Complex Airspace (SA-1b)

Tech Transfer

Validate Scalability and New Interfaces



Multi-regional Trajectory Based Operations (SA-2)

Tech Transfer

Validate Scalability and New Interfaces to Flight Deck



Irregular Ops Recovery/Disruption Management (SA-3)

Tech Transfer



4D Trajectory Optimization (SA-4)

Tech Transfer

FY20 FY21 FY22 FY23 FY24 FY25 FY26 FY27 FY28 FY29

Planned

Notional

ATM Services

Flight Deck Services

Beyond SFNP

requires early-stage R&D today

Sustainable Aviation

with safe, clean, quiet, economical, operable, and marketable products

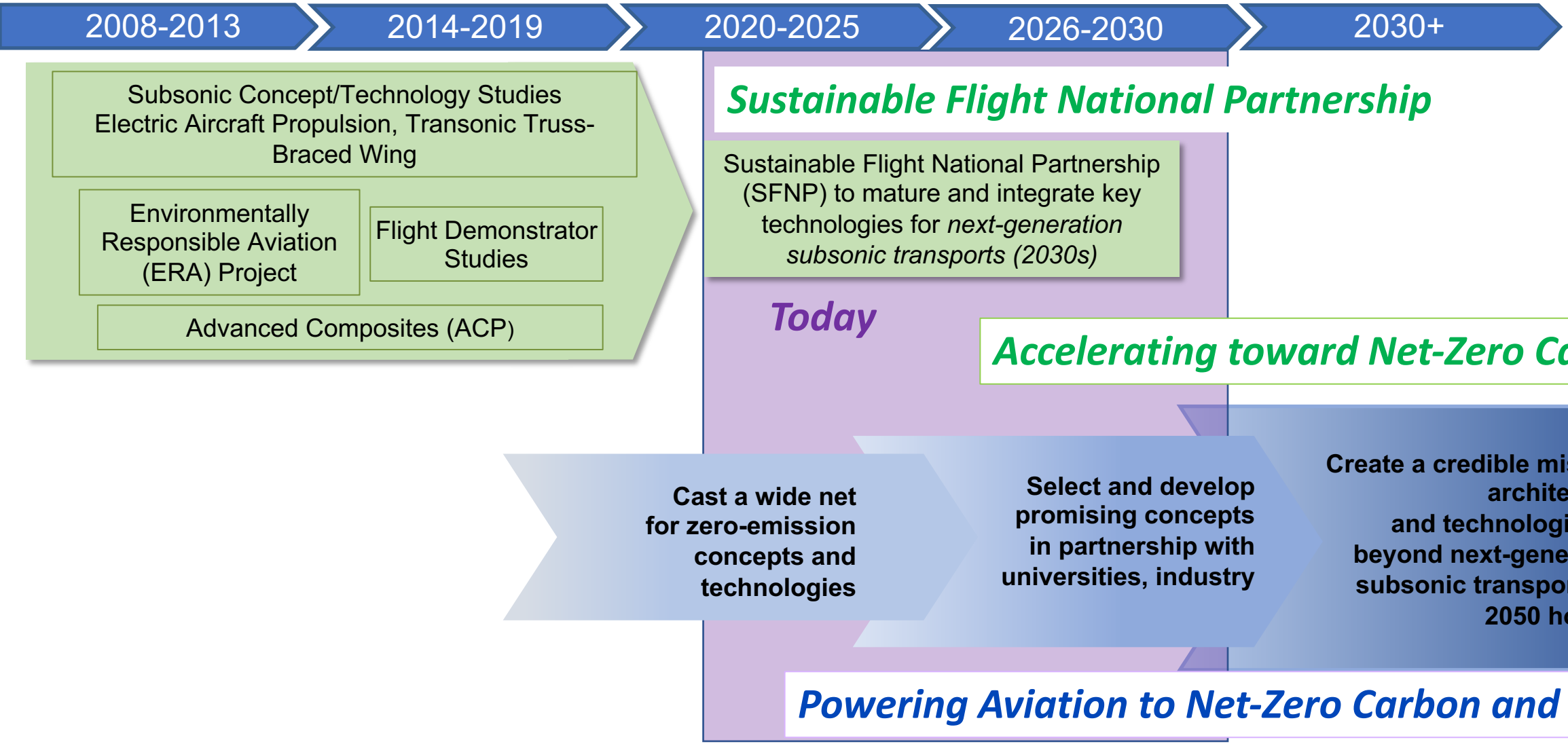
Sustainable Flight National Partnership (SFNP)
(fully active projects now)

- Accelerating aviation towards net-zero carbon
- Focus on energy efficiency improvements and drop-in 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
(initial activity ongoing)

- 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 avoidance 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

NASA Aviation Sustainability Strategy



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

Long-Term Transport Technology and Innovation

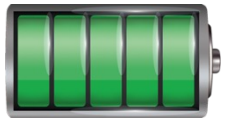
Generational studies to inform future technology investments

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

Net-Zero Aviation Emissions Innovation

Foster radical aviation technology advancement – new energy sources, aircraft architectures – necessary for large aircraft with extremely low or zero emissions

Low Technology Readiness Level concepts can be further conceptualized, researched, developed, ground and flight-tested and advanced for late 2030s / early 2040s

Recent University Leadership Initiative awards included teams working on net-zero emissions topics



Research currently underway at low Technology Readiness Levels

NASA Distributed Propulsion Concept

- Turbo-Electric with superconducting electric drivetrain
- Over 70% reduction in energy use



University of Illinois, Urbana-Champaign (NASA ULI) All-electric Concept

- Hydrogen fuel cell, superconducting electric drivetrain
- Zero carbon emissions

NASA AACES 2050 Studies

Advanced Aircraft Concepts for Environmental Sustainability

2008-2019 | 2020-2029 | 2030 - 2039 | 2040 - 2050

FY10-15 ERA N+2 for the 2020s Impact

FY09 N+3 Adv Concept Studies Target 2030-35 Impact



FY23 "N+4" AACES Studies - Explore 2020s, Demo 2030s, Impact 2040s

- *2040s Marketplace (payload/range/speed), 2050 Environmental Goals*
- *Alternative Energy Scenarios (LH2, LNG, Increased Electrification, 100% SAF)*
- *Advanced Airframes (clean energy compatible, shielding, adaptive, unconventional structures)*
- *Alternative propulsion (clean energy compatible, BLI, distributed propulsion, hybrid electric)*
- *Tools & Methods for Reduced Lifecycle Cost & Environmental Impact*

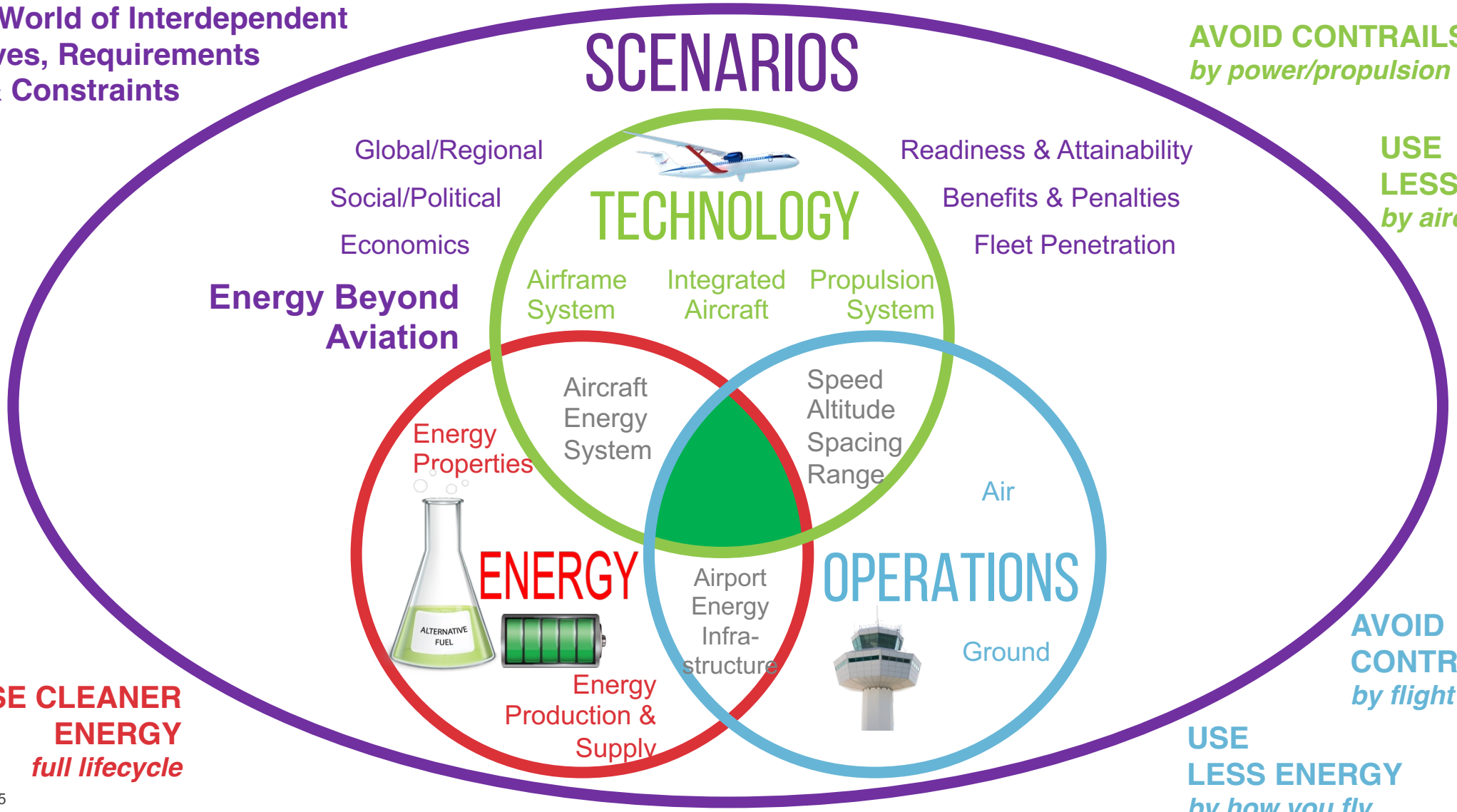
H_2 Hydrogen

RFI Released 5/19/22, RFP Fall 2022, Awards Early CY23

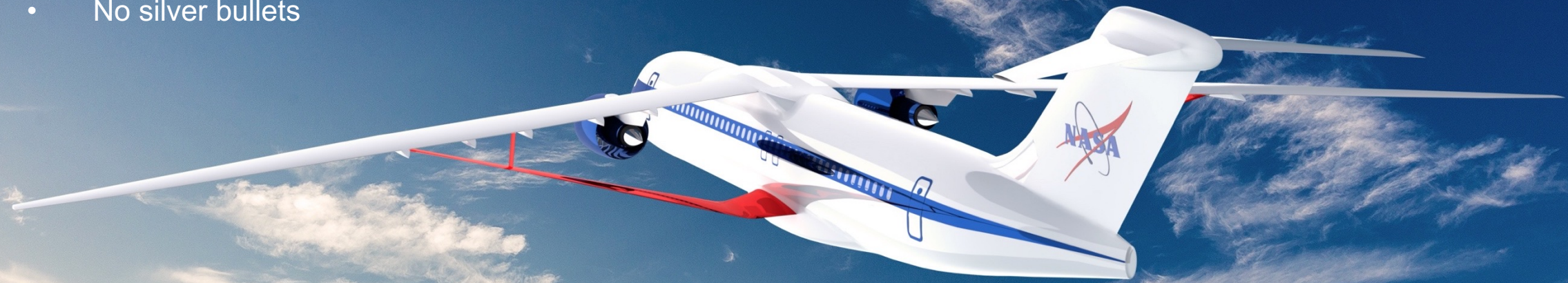
Concluding Remarks

Integrated Aviation Pillars for Sustainable Aviation

in broader context



- 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+

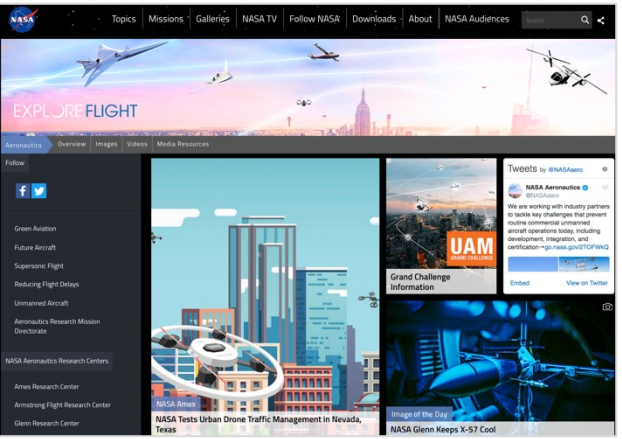
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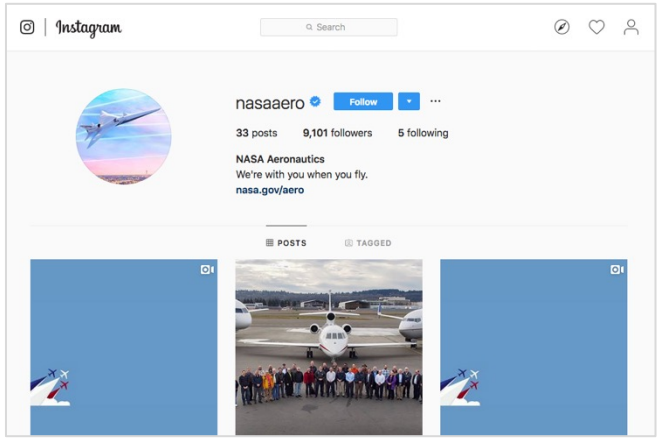
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