
# NASA Aeronautics Strategic Implementation Plan

## Strategic Thrust 3A Roadmap Overview

## Ultra-Efficient Commercial Vehicles - Subsonic Transports

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NASA Aeronautics Research Mission Directorate

1 June 2016

# Outline

- Context for briefing – Strategic Plan/Roadmaps
- Thrust 3A Context & Introduction
- Outcomes, Strategies, & Research Themes
- Roadmap Details
- Stakeholder Roles
- Risks & Opportunities
- Feedback Mechanisms

# Three Aviation Mega Drivers

**NASA Aeronautics research strategy proactively addressing critical long-term needs**

**NASA has identified three Aviation Mega Drivers that will impact aviation community future needs**

Traditional measures of global demand for mobility - economic development and urbanization - are growing rapidly and creating transportation and competitive opportunities and challenges


Large and growing energy and environmental issues create enormous affordability and sustainability challenges

Revolutions in the integration of automation, information, communication, energy, materials and other technologies enable opportunity for transformative aviation systems



# NASA Aeronautics Six Strategic Thrusts

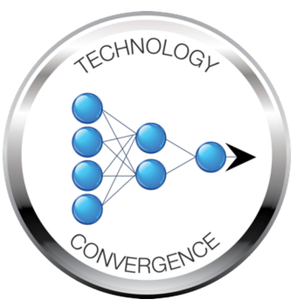
**NASA has identified Six Strategic Thrusts to focus research in response to Three Aviation Mega-Drivers. Subsonic Transport and Vertical Lift are considered separately.**


**T1** — **Safe, Efficient Growth in Global Operations**
- Enable full NextGen and develop technologies to substantially reduce aircraft safety risks

**T2** — **Innovation in Commercial Supersonic Aircraft**
- Achieve a low-boom standard


**T3A ST** / **T3B VL** — **Ultra-Efficient Commercial Vehicles**
- Pioneer technologies for big leaps in efficiency and environmental performance

**T4** — **Transition to Low-Carbon Propulsion**
- Characterize drop-in alternative fuels and pioneer low-carbon propulsion technology




**T5** — **Real-Time System-Wide Safety Assurance**
- Develop an integrated prototype of a real-time safety monitoring and assurance system

**T6** — **Assured Autonomy for Aviation Transformation**
- Develop high impact aviation autonomy applications

# Thrust Relationships

## Vehicle-centric look & some vehicle-dependent context

**The six Thrusts are not independent. Dependencies exist between all thrusts.**

**Supersonic transports, subsonic transports, and vertical lift vehicles have different capability strengths and research needs.**

CONVERGENT TECHNOLOGY OPPORTUNITIES

- Low-Carbon Propulsion
- Real-Time System-Wide Safety
- Autonomy

### What I Fly

Vehicles

**MISSION CAPABILITY**

Combination of:
Payload, Range, Speed, Field-Length, Hover, Endurance

Environmentally Friendly, (e.g. Noise, Emissions)
Safety, Cost/Affordability

### How I fly

Operations

**365/24/7 OPERATIONS**

Rules of the Road:
Safe, Efficient, Flexible, Resilient

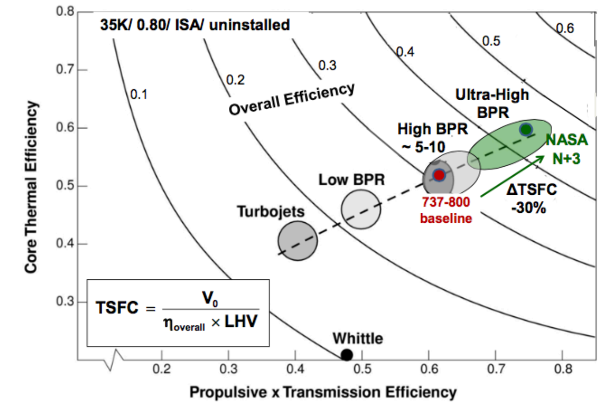
**Supersonic Transports**
***Speed 2X*** subsonic with minimal efficiency and environmental compatibility differences

**Subsonic Transports**
Backbone of air transportation, ***Environmental*** Compatibility while reducing cost, increasing range, maintaining safety

**Vertical Lift**
***Accessibility***—Field Length/Noise/ Hover with more range/speed/payload/ safety/comfort

# Thrust Relationships

## What Distinguishes Thrust 4 from Thrust 3 (and 2) Propulsion?

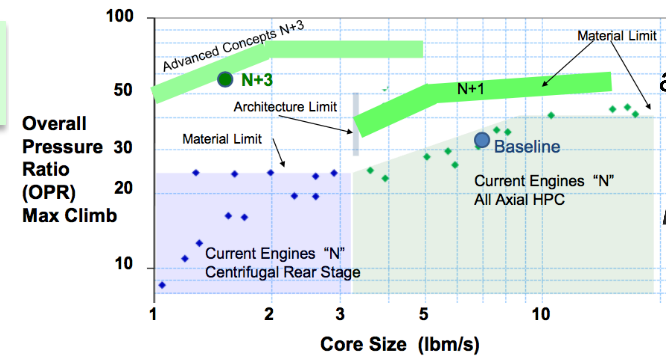



## Ultra-Efficient Commercial Vehicles

Efficiency (use less energy)
Emissions (use less energy)
Noise (less perceived noise)

Airframe
**Propulsion - Advanced Gas Turbines and Propulsors**
Vehicle System Integration

Lord, et. al., AIAA SciTech15, AIAA-2015-0071




*adv gas turbine*
**Small Core**
*fuel flexibility*
*hybrid systems*

## Transition to Low-Carbon Propulsion

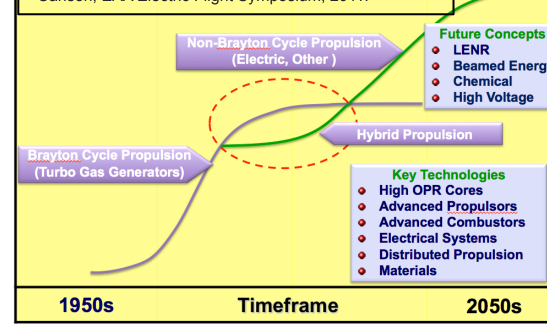
### Aviation Alternative Fuels (Drop-In)

Reduce specific carbon (use cleaner energy)
Clean, compact combustion
Gas turbines needed for the foreseeable future

### Alternative Energy/Power Architectures

Energy sector convergent technology*
Promise of cleaner energy
Potential for vehicle system efficiency gains (use less energy)
Leverage advances in other transportation sectors
Address aviation-unique challenges (e.g. weight, altitude)
Recognize potential for early learning and impact on small aircraft`

Carlson, EAA Electric Flight Symposium, 2011.




*energy sector includes other government agencies, industry, and academia

# NASA Aeronautics Strategic Implementation Plan (SIP) – A Living Document

**The SIP contains information about Research Themes and System-Level Metrics for each Thrust. The SIP will be updated as part of developing roadmaps for each of the Thrusts.**


**Community Vision**

**Community Outcomes**

**Research Themes**

**System-Level Metrics**

**Roadmaps for each of the six Thrusts in the SIP are being developed**

- **Update the SIP Outcomes, Research Themes and Metrics**
- **Drafts are being vetted for comments internal and external to NASA**

# NASA Aeronautics Strategic Implementation Plan (SIP) – Roadmaps

**The Roadmaps will be updated with feedback received from internal and external sources.**

Roadmaps are

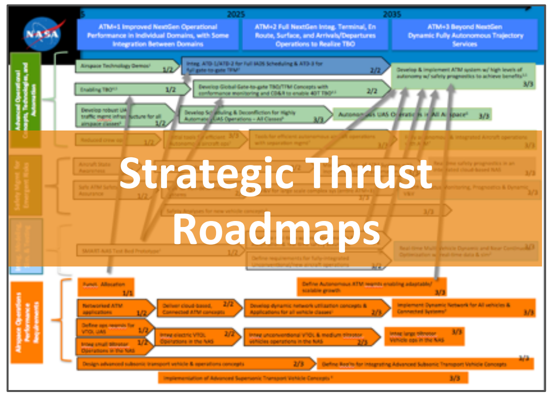
- A high-level look at what technology is needed to accomplish the community outcomes
- A community roadmap; NASA does not expect to accomplish all roadmap goals within NASA programs
- Guidance for NASA project and NASA Centers for innovation and planning
- Part of the process to determine the strategic contribution of NASA portfolio investments in Technical Challenges in each project

- Roadmaps ARE NOT
  - A funded program or project plan
  - A commitment by NASA to accomplish all roadmap objectives
  - A determination of specific technology or investment

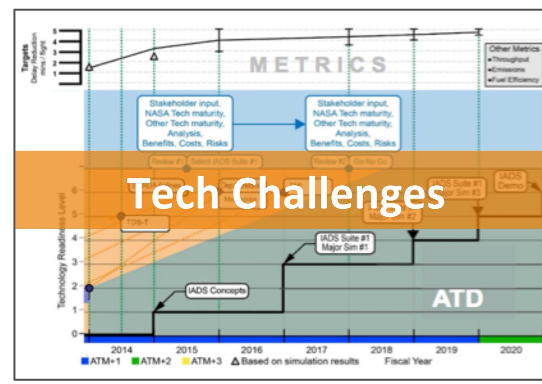
# ARMD Strategic Portfolio Model

**The SIP and the Roadmaps are used to help guide NASA project planning.**
**Feedback from partners and research results informs updates to the Thrusts and Roadmaps.**

SIP Outcomes Drive Top-Down Planning




Roadmaps Provide Guidance for NASA Project / Center Innovation and Planning




Partnerships & Performance Create a Feedback Loop

## 6 Strategic Thrusts

**Safe, Efficient Growth in Global Operations**
Enable full NextGen and develop technologies to substantially reduce aircraft safety risks

**Innovation in Commercial Supersonic Aircraft**
Achieve a low-boom standard

**Ultra-Efficient Commercial Vehicles**
Pioneer technologies for big leaps in efficiency and environmental performance

**Transition to Low-Carbon Propulsion**
Characterize drop-in alternative fuels and pioneer low-carbon propulsion technology

**Real-Time System-Wide Safety Assurance**
Develop an integrated prototype of a real-time safety monitoring and assurance system

**Assured Autonomy for Aviation Transformation**
Develop high impact aviation autonomy applications

# Outline

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- Thrust Outcomes & Research Themes
- Roadmap Details
- Community Development
- Risks & Opportunities
- Feedback Mechanisms

# Vision

- Long-haul subsonic transports will remain the backbone of the 365/24/7 global & domestic air transportation system for the foreseeable future
- Sustainable growth of the air transportation system is required for US economic health, national security, and overall quality of life
- Transport passengers and cargo with dramatically smaller carbon and noise footprints
  – Economical and Safe
  – Energy Efficient for economics and environmental friendliness
  – Quiet Efficiency for community friendliness and system capacity growth
- Game-changing commercial transport technology development is required to meet the challenge of sustainable growth and to maintain US leadership in the global market place

# Introduction - Context

## Community & External Drivers & Influences

- Airlines – IATA (Global), A4A (US) (A4A = Airlines for America, formerly Air Transport Assoc of America)
- Standards/Regulators – ICAO (Global), FAA (US)
- Manufacturers – US Airframers & Propulsion Companies
- International Competition - Europe ACARE – Clean Sky 2020, FlightPath2050, Brazil, China, Canada, Russia, Japan, etc

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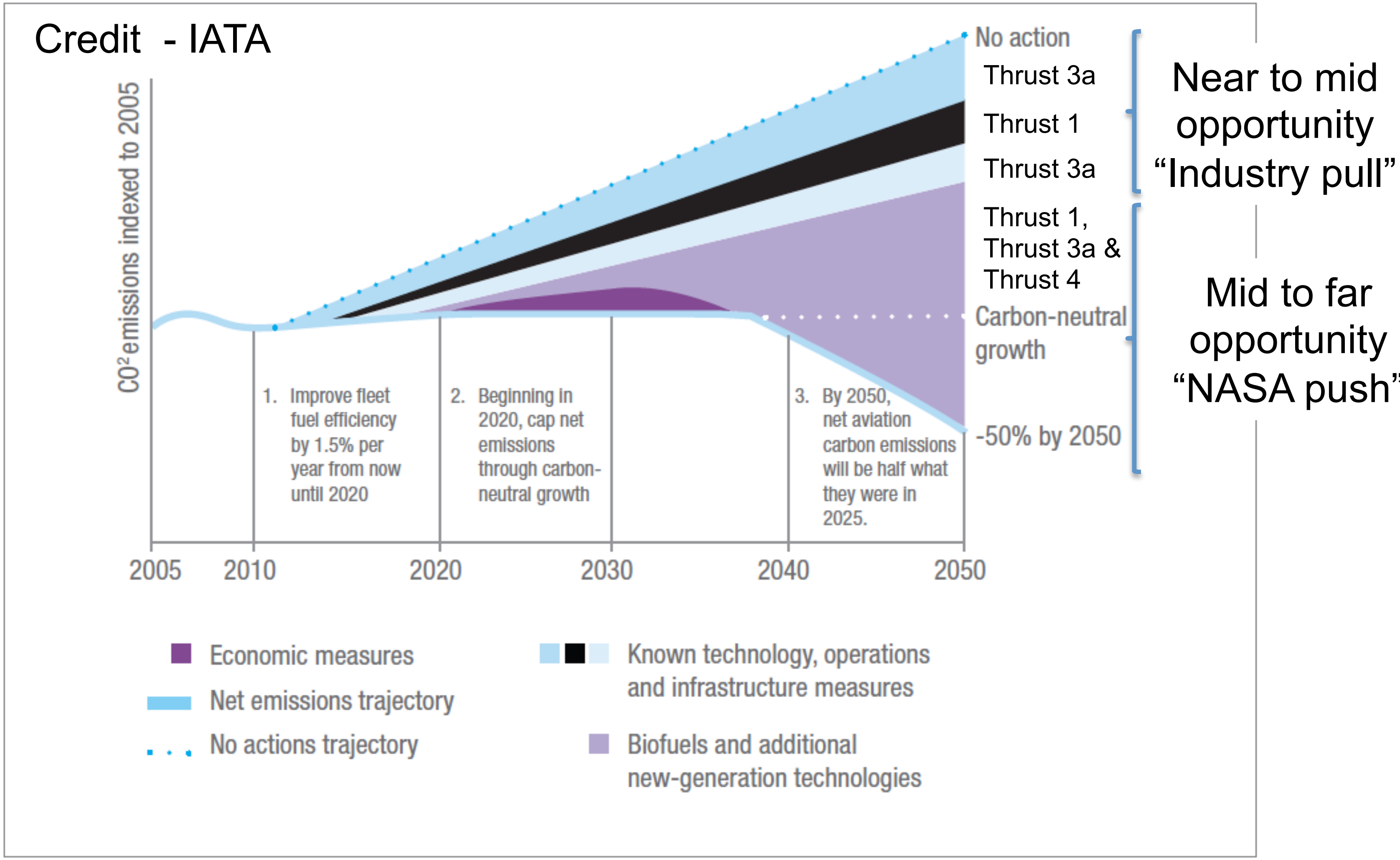
- 1.5-2% fuel burn reduction per year (depending on org)
- Noise standards continue to get tougher
- LTO NOx standards continue to get tougher
- CO2 regulation on the near horizon
- Particulate Matter regulation a good possibility also

Tougher Regulations and Cost/Economics Drivers ….

….. not enough to just improve performance at current rate, must accelerate & must reduce development, manufacturing, and operational cost at the same time, without compromising safety

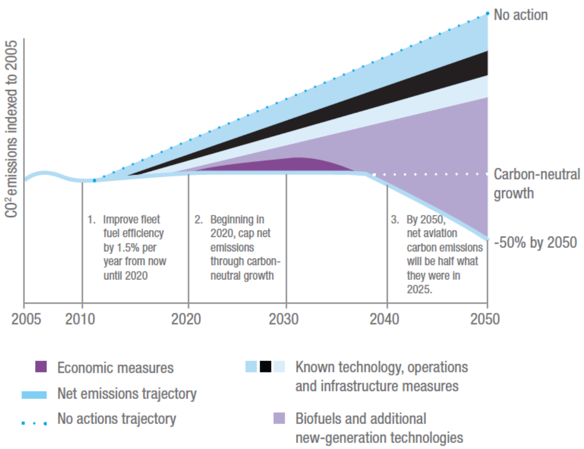
# Introduction - Major Aviation Community "Driver" Reduce carbon footprint by 50% by 2050 …..




**…. in the face of increasing demand, and while reducing development, manufacturing and operational costs of aircraft & meeting noise and LTO NOx regulations**

# Outcomes
## Ultra-Efficient Commercial Vehicles, Subsonic Transport

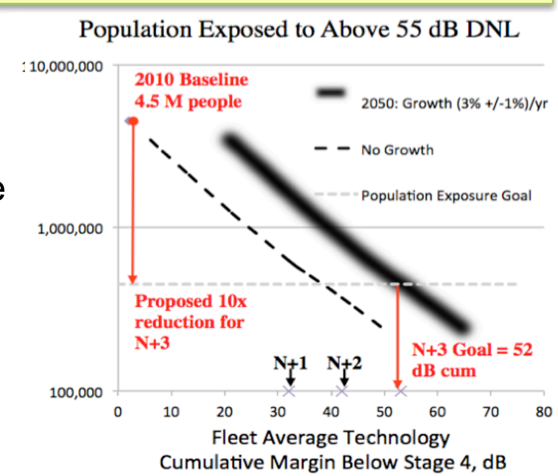
**The Roadmap Team reviewed the current SIP Outcomes and is recommending significant changes**




carbon

**Subsonic Transports**
Backbone of air transportation, ***Environmental*** Compatibility while reducing cost, increasing range, maintaining safety

noise




## NEW DRAFT Community Outcomes (proposed for the updated SIP):

| 2015 | 2025 | 2035 |
|---|---|---|
| Aircraft meet the economic and environmental demands of airlines and the public, and are on a defined path to fleet-level carbon neutral growth | Aircraft meet the economic demands of airlines and the public with revolutionary improvements in community noise and energy efficiency to achieve fleet-level carbon neutral growth relative to 2005 | Aircraft meet the economic demands of airlines and the public with transforming capabilities in community noise and energy efficiency enabling a 50 percent reduction in fleet-level carbon output relative to 2005 |

# Outcomes, Benefits, Capabilities Community

| | 2015 | 2025 | 2035 |
|---|---|---|---|
| ***COMMUNITY OUTCOMES*** | Aircraft meet the economic and environmental demands of airlines and the public, and are on a defined path to fleet-level carbon neutral growth | Aircraft meet the economic demands of airlines and the public with revolutionary improvements in community noise and energy efficiency to achieve fleet-level carbon neutral growth relative to 2005 | Aircraft meet the economic demands of airlines and the public with transforming capabilities in community noise and energy efficiency enabling a 50 percent reduction in fleet-level carbon output relative to 2005 |
| ***Benefits*** | - Continued Improvement of fleet efficiency by 1.5 percent per year<br>- Established technology path for achieving carbon neutral, then reduced, growth<br>- Competitive R&D & manufacturing processes for cost reduction<br>- Minimize need for market-based economic measures | - Accelerated improvement of fleet efficiency beyond 2 percent per year<br>- Highly competitive, environmentally friendly US aircraft products enabling carbon neutrality<br>- Minimized effect of market based economic measures for carbon neutrality on US aviation industry | - Cost-effective, technology driven US aviation products enabling continuation of US leadership position<br>- 50 percent reduction of fleet-level carbon output by 2050 compared to 2005 levels<br>- Aircraft that produce less than half the perceived noise compared to 2005 best in class |
| ***Capabilities*** | Efficient manufacturing and development tools and processes<br><br>Lower weight, drag, noise airframes<br><br>Higher propulsive and thermal efficiency for low noise, Brayton cycle UHB turbofans<br><br>Advanced, conventional aircraft propulsion integration | Efficient manufacturing and development tools and processes<br><br>Lower weight, drag, noise airframes<br><br>Higher propulsive and thermal efficiency for low noise, Brayton cycle UHB turbofans, perhaps pervasive use of geared, low FPR designs<br><br>Revolutionary unconventional airframe propulsion integration | Efficient manufacturing and development tools and processes<br><br>Lower weight, drag, noise airframes<br><br>Advanced propulsive cycles and associated technologies for very low carbon output (Thrust 4 vehicle integration synergy)<br><br>Transformational, highly coupled and integrated wing body nacelle aircraft configurations |

# Strategy – NASA Response to Community Drivers

| COMMUNITY OUTCOMES | 2015 | 2025 | 2035 |
|---|---|---|---|
| | Aircraft meet the economic and environmental demands of airlines and the public, and are on a defined path to fleet-level carbon neutral growth | Aircraft meet the economic demands of airlines and the public with revolutionary improvements in community noise and energy efficiency to achieve fleet-level carbon neutral growth relative to 2005 | Aircraft meet the economic demands of airlines and the public with transforming capabilities in community noise and energy efficiency enabling a 50 percent reduction in fleet-level carbon output relative to 2005 |

**NASA Strategies**

| | |
|---|---|
| Impact Design Trades | Prove practicality of revolutionary and transformational aircraft concepts and technology via *large-scale integrated demonstrations* |
| Expand the Possible | Early-stage *exploration and development of game-changing concepts and technology* to overcome the technical challenges of efficient, quiet flight |
| Foundation | Development and validation of *enabling tools, methods, and processes* |

# Strategy – NASA Response to Community Drivers

Impact Design Trades

- Prove practicality of revolutionary and transformational aircraft concepts and technology via *large-scale integrated demonstrations*
  - Flight demonstration of integrated aero/structure/propulsion/control systems
  - Ground demonstration of integrated propulsion systems
  - Ground demonstration of integrated structural systems
  - Focused collaboration with industry/OGA/regulators to transition technology (near- to mid-term "industry pull", mid- to far-term "NASA push")

Expand the Possible

- Early-stage *exploration and development of game-changing concepts and technology* to overcome the technical challenges of efficient, quiet flight
  - Feasible, multidisciplinary solutions for aerodynamic, structural, and propulsion energy efficiency
  - Feasible, multidisciplinary solutions for quiet, environmentally friendly flight
  - Focused collaboration with industry/OGA/academia (mid- to far-term focus, leverage to near-term application)

Foundation

- Development and validation of *enabling tools, methods, and processes*
  - Multidisciplinary, physics-based modeling and simulation via computation, experiment, and theory
  - Rapid, accurate design and development leveraging advances in IT and manufacturing
  - Validated by test with quantified uncertainties with move towards certification by analysis
  - Focused collaboration with industry/OGA/academia

# NASA Subsonic Transport System Level
## Measures of Success

Use industry pull to mature technology that enables aircraft products that meet near-term metrics, enabling *community* outcome 1, and push to mature technology that will support development of new aircraft products that meet or exceed mid- and far-term metrics, enabling *community* outcomes 2 and 3

v2016.1

| TECHNOLOGY BENEFITS | TECHNOLOGY GENERATIONS (Technology Readiness Level = 5-6) | | |
|---|---|---|---|
| | **Near Term** 2015-2025 | **Mid Term** 2025-2035 | **Far Term** beyond 2035 |
| **Noise** (cum below Stage 4) | **22 - 32 dB** | **32 - 42 dB** | **42 - 52 dB** |
| **LTO NOx Emissions** (below CAEP 6) | **70 - 75%** | **80%** | **> 80%** |
| **Cruise NOx Emissions** (rel. to 2005 best in class) | **65 - 70%** | **80%** | **> 80%** |
| **Aircraft Fuel/Energy Consumption** (rel. to 2005 best in class) | **40 - 50%** | **50 - 60%** | **60 - 80%** |

# Research Themes

## NASA Long Term Research Areas That Will Contribute to the Community Outcomes

- **Ultra-efficient Airframes**
  - Research and development of technologies to enable new airframe systems with high levels of aerodynamic performance, lower structural weight, and innovative approaches to noise reduction
- **Ultra-efficient Propulsion**
  - Research and development of technologies to enable new propulsion systems with high levels of thermal, transmission, and propulsive efficiency, reduced harmful emissions, and innovative approaches to noise reduction
- **Ultra-efficient Vehicle System Integration**
  - Research and development of innovative approaches and technologies to reduce perceived noise and aircraft energy consumption through highly coupled, synergistic vehicle system integration including but not limited to airframe-propulsion integration
- **Modeling, Simulation, and Test Capability**
  - Research and development of (computational, experimental, and analytical) tools and methods to improve vehicle mission capability in less time with reduced uncertainty and cost.

# Roadmap to Opportunity
## Ultra-Efficient Commercial Vehicles, Subsonic Transport

**COMMUNITY OUTCOMES**

| 2015 | 2025 | 2035 |
|---|---|---|
| Aircraft meet the economic and environmental demands of airlines and the public, and are on a defined path to fleet-level carbon neutral growth | Aircraft meet the economic demands of airlines and the public with revolutionary improvements in community noise and energy efficiency to achieve fleet-level carbon neutral growth relative to 2005 | Aircraft meet the economic demands of airlines and the public with transforming capabilities in community noise and energy efficiency enabling a 50 percent reduction in fleet-level carbon output relative to 2005 |

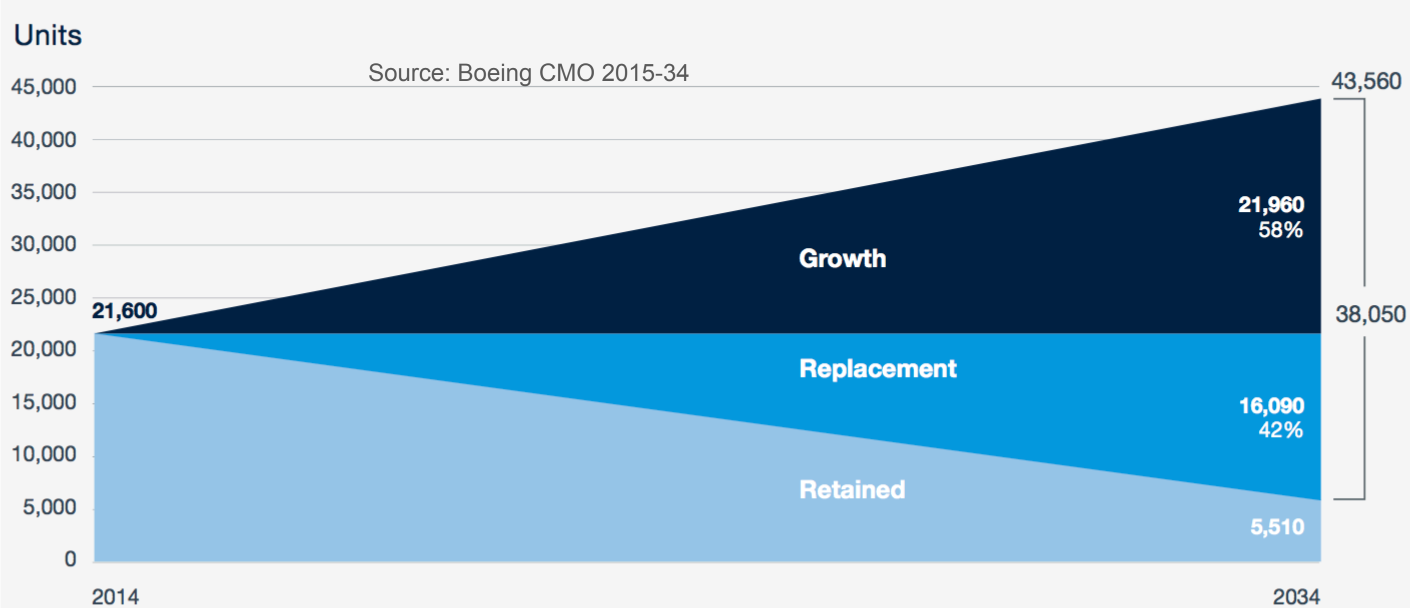
**Key Dates**

*Assume ~10-20 year time from TRL 4 to EIS*

Research Themes

- Ultra-Efficient Airframe
- Ultra-Efficient Propulsion
- Ultra-efficient Vehicle System Integration
- ModSim & Test Capability

***>38,000 new commercial transports by 2034 (replacements/growth) uncertain market-driven timing of insertion opportunities***




***NASA believes that advanced technology must be applied to unconventional vehicle configurations with alternative propulsion systems using alternative fuel/energy to meet the far term outcome***

# Roadmap
## Ultra-Efficient Commercial Vehicles, Subsonic Transport

**COMMUNITY OUTCOMES**

- **2015:** Aircraft meet the economic and environmental demands of airlines and the public, and are on a defined path to fleet-level carbon neutral growth
- **2025:** Aircraft meet the economic demands of airlines and the public with revolutionary improvements in community noise and energy efficiency to achieve fleet-level carbon neutral growth relative to 2005
- **2035:** Aircraft meet the economic demands of airlines and the public with transforming capabilities in community noise and energy efficiency enabling a 50 percent reduction in fleet-level carbon output relative to 2005

**Key Dates**

Noncirc PV
IATA CNG
Ch 14 Noise Rule
CO2 Rule
NAH Flight Demo
Adv Fuselage
Small Core Demo
Adv Comp Wing
-50% FB/Noise
Chapter 14+ Noise?
CO2 Rule Update?
Alt Engine Demo
Alt Config/Alt Prop
IATA Carbon -50%

*Assume ~10-20 year time from TRL 4 to EIS*

Research Themes

**Ultra-Efficient Airframe**
- Advanced Airfoil/Wing w/ Less Sweep → AFC-enhanced high-lift/control → High-speed AFC drag/control
- Hybrid WB/Lifting Fuselages, Truss-Braced Wings → Low viscous drag fuselage
- Quiet, conformal, adaptive edges → Proactive load alleviation → Active flutter suppression
- Damage Arresting, Unitized Structure → Tailored Loadpath, Out of Autoclave Structure
- Beyond CFRP Mat'l Sys & Secondary Structure → Beyond CFRP Structure, MultiFunctional Mat'l

**Ultra-Efficient Propulsion**
- Low Drag Acoustic Liners → Low FPR Ducted → Low FPR Unducted
- Integrated Inlet/Fan/GuideVane → Distortion Tolerant Systems → Active Distortion Control
- High OPR compatible combustor → High Power Density Small Core
- Next gen CMC/Coatings → Beyond CMC Mat'l Sys → Integrated Aero/Mat'l Core Design

**Ultra-efficient Vehicle System Integration**
- Compact Nacelle → Propulsion Noise Shielding
- Over-the-Wing/Body Nacelle → Aero-Propulsive Flight Control
- Fuselage BLI (tail cone like) → Fuselage BLI (flush mount)
- Quiet Landing Gear → Distributed (Electric) Propulsion
- Propulsion Airframe Aeroacoustics

**ModSim & Test Capability**
- Increasing Certification by Analysis
- Physics-based models → High Fidelity MDAO with UQ
- Trustworthy full potential CFRP → Designer Materials
- Laminar Scaling → Hi-Fi Diagnostics for RDT&E → Algorithms for Exa-scale computing

Clean, low-carbon propulsion systems (Thrust 4) & Efficient flight operations (Thrust 1)

# Stakeholder Roles

| | Foundational research, including conceptual design assessment of configuration benefits and barriers | Define Market; Establish product requirements; Assess business case | Conceptual design and trade studies; Focused, specific research for product; Preliminary design; Detailed design | Component design and test; Increase TRL for technology and components; Testing and qualification | Manufactur-ing process and investm[ent]; Certification activities; Marketing and sales | Establish/ Enforce Economic Measures | Operations; Upgrades; Maintenance and customer service |
|---|---|---|---|---|---|---|---|
| **Industry (OEM or operator)** | ✔ | ✔ | ✔ | ✔ | ✔ | | ✔ |
| **NASA** | ✔ | | | ✔ | | | |
| **FAA/ Regulators** | | | | | ✔ | ✔ | ✔ |
| **DoD** | ✔ | ✔ | ✔ | ✔ | ✔ | | ✔ |
| **University** | ✔ | | | | | | |

# Top 5 Risks/Opportunities/Dependencies

- **Cost/Affordability is key driver of commercial industry**
  - May stifle technology infusion
- **Oil Price Instability**
  - In time of increase, more incentive for technology infusion
  - In time of stability or decrease, less incentive for technology infusion
- **Time lag/design cycle limits “timeliness” of technology infusion**
- **Environmental regulations**
  - If stricter due to global warming, technology infusion will be accelerated
  - If stagnant, then not much incentive for accelerated technology infusion
- **Foreign competitors make the leap to novel configurations/ systems before the US and take significant majority of market**

# Give Us Feedback!

- **Download this presentation from the NARI website**
  - http://nari.arc.nasa.gov/thrust3a
  - Identify gaps or areas that are missing from the roadmap (the roadmap is rolled up to a high level, so we are looking for general categories, not specific technology)
  - Identify additional high level risks or dependencies that are not captured
  - Identify areas that are currently on the roadmap that you believe do not require further investment and should be removed

- **Two ways to provide feedback:**
  1) Email to fayette.s.collier@nasa.gov and richard.a.wahls@nasa.gov with subject line FEEDBACK
  2) Give feedback in person to NASA representatives at the upcoming AIAA Aviation Meeting (June 13-17)

- **AIAA Aviation2016 Forum 360 Session – 14 June 2016**
  - Overview of NASA Aeronautics Strategic Direction

# Concluding Remarks

- **NASA Aeronautics has developed a Strategic Implementation Plan (SIP) that contains Community Vision, Community Outcomes, Research Themes, and System Metrics for each of the six Thrusts**

- **Each Thrust has a roadmap planning exercise underway. Thrust 3 for Ultra-efficient Commercial Vehicles is split into Subsonic Transports (3A) and Vertical Lift (3B)**

- **The NASA Thrust 3A Subsonic Transports Roadmap team is seeking your comments and input on the draft roadmap**

- **Feedback may be through email or in-person communications at upcoming conferences and events**

# Thank You for Participating!

# Thrust 3A Subsonic Transports

**Ultra-Efficient Commercial Vehicles**

- Pioneer technologies for big leaps in efficiency and environmental performance

Thrust 3a – Team Fixed Wing kick-off 6/5/15

Mission: Develop Strategic Roadmap for Thrust 3 (fixed wing commercial transport portion)

Scope: Fixed Wing Commercial Vehicles Carrying PAX or CARGO Point to Point
Civil Missions, Dual-Use Military

Co-leads **Fay Collier**/Rich Wahls

AAVP: covered by lead
AAVP/AATT: DelRosario/Anders/Heidmann
AAVP/AC: Rick Young
IASP: covered by lead
ARMD: Dell Ricks

TACP/TTT: Mike Rogers
AFRC: Mark Mangelsdorf
ARC: Kevin James
GRC: Ken Suder
LaRC: Tony Washburn