ARMD Strategic Thrust 3:
Ultra-Efficient Commercial Vehicles Subsonic Transport

Fay Collier, Rich Wahls, and the Roadmap Team 3A
Aeronautics R&T Roundtable, Washington DC
May 24, 2016
Thrust 3a Subsonic Transport

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: Del Rosario / Anders / Heidmann
AAVP / AC: Rick Young
IAKP: covered by lead
ARMD: Dell Ricks

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

• Background
• Vision
• Introduction
• Outcomes, Benefits, Capabilities
• Strategies
• Research Themes
• Roadmaps
• Stakeholder roles, partnerships
• Top 5 Risks / Dependencies
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 Ultra-Efficient Commercial Vehicles**
- Pioneer technologies for big leaps in efficiency and environmental performance

**T3B VL**

**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.

Value Proposition of Air Transportation

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

Transition to Low-Carbon Propulsion
Aviation Alternative Fuels (Drop-In)
Reduce specific carbon (use cleaner energy)
Clean, compact combustion
Gas turbines needed for 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

*energy sector includes other government agencies, industry, and academia
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 – International Air Transport Association (IATA) (Global), A4A (US) (A4A—Airlines for America, formerly Air Transport Association of America)
- Standards/Regulators – International Civil Aviation Organization (ICAO) (Global), FAA (US)
- Manufacturers – US Airframers & Propulsion Companies
- International Competition – Europe Advisory Council for Aviation Research in Europe (ACARE) – Clean Sky 2020, FlightPath 2050, Brazil, China, Canada, Russia, Japan, etc.

- 1.5 – 2% fuel burn reduction per year (depending on org)
- Aircraft noise standards continue to get tougher
- Engine LTO NO\textsubscript{x} standards continue to get tougher
- Aircraft CO\textsubscript{2} regulation on the near horizon
- Engine participate 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 NO\textsubscript{x} regulations
The Roadmap Team reviewed the current SIP Outcomes and is recommending significant changes.

**New DRAFT Community Outcomes (proposed for the updated SIP):**

<table>
<thead>
<tr>
<th>Year</th>
<th>2015</th>
<th>2025</th>
<th>2035</th>
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<tbody>
<tr>
<td><strong>Aircraft meet economic and environmental demands of airlines and the public, and are on a defined path to fleet-level carbon neutral growth.</strong></td>
<td>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</td>
<td>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</td>
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## Outcomes, Benefits, Capabilities

### Community

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### Benefits

- Continued improvement of fleet efficiency by 1.5 percent per year
- Established technology path for achieving carbon neutral, then reduced, growth
- Competitive R&D & manufacturing processes for cost reduction
- Minimize need for market-based economic measures

- Accelerated improvement of fleet efficiency beyond 2 percent per year
- Highly competitive, environmentally friendly US aircraft products enabling carbon neutrality
- 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
- 50 percent reduction of fleet-level carbon output by 2050 compared to 2005 levels
- Aircraft that produce less than half the perceived noise compared to 2005 best in class

### NASA Outputs/Capabilities

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<tr>
<th>2015</th>
<th>2025</th>
<th>2035</th>
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<tr>
<td>Efficient manufacturing and development tools and processes</td>
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<td>Lower weight, drag, noise airframes</td>
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</tr>
<tr>
<td>Higher propulsive and thermal efficiency for low noise, Brayton cycle UHB turbofans</td>
<td>Higher propulsive and thermal efficiency for low noise, Brayton cycle UHB turbofans, perhaps pervasive use of geared, low FPR designs</td>
<td>Advanced propulsive cycles and associated technologies for very low carbon output (Thrust 4 vehicle integration synergy)</td>
</tr>
<tr>
<td>Advanced conventional aircraft propulsion integration</td>
<td>Revolutionary unconventional airframe propulsion integration</td>
<td>Transformational, highly coupled and integrated wing nacelle aircraft configurations</td>
</tr>
<tr>
<td>Outcomes</td>
<td>2015</td>
<td>2025</td>
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**NASA Strategy**

- **Prove practicality of revolutionary and transformational aircraft concepts and technology via large-scale integrated demonstrations**

- **Execute Early-stage exploration and development of game-changing concepts and technology to overcome the technical challenges of efficient, quiet flight**

- **Develop and validate enabling tools, methods, and processes**
Strategy – NASA Response to Community Drivers

- 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”)

- Execute 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)

- Develop and validate *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 NASA 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.

<table>
<thead>
<tr>
<th>TECHNOLOGY BENEFITS</th>
<th>TECHNOLOGY GENERATIONS (Technology Readiness Level = 5-6)</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Near Term 2015-2025</td>
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<tr>
<td>Noise (cum below Stage 4)</td>
<td>22 – 32 dB</td>
</tr>
<tr>
<td>LTO No$_x$ Emissions (below CAEP 6)</td>
<td>70 – 75%</td>
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<tr>
<td>Cruise No$_x$ Emissions (rel. to 2005 best in class)</td>
<td>65 – 70%</td>
</tr>
<tr>
<td>Aircraft Fuel/Energy Consumption (rel. to 2005 best in class)</td>
<td>40 – 50%</td>
</tr>
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Evolutionary  Revolutionary  Transformational
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

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Key Dates

>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.

www.nasa.gov
# Roadmap

Ultra-Efficient Commercial Vehicles, Subsonic Transport

<table>
<thead>
<tr>
<th>Community Outcomes</th>
<th>Noncircular Pressure Vehicle</th>
<th>IATA CNG</th>
<th>NAH Flight</th>
<th>Small Core</th>
<th>-50% FB/Noise</th>
<th>Alt Engine Demo</th>
<th>Alt Config/Alt Prop</th>
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</thead>
<tbody>
<tr>
<td>2015</td>
<td>Ch 14 Noise Rule CO₂ Rule* CO₂ Rule*</td>
<td>Adv Fuselage</td>
<td>Demo</td>
<td>Demo</td>
<td></td>
<td></td>
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<tr>
<td>2025</td>
<td>Advanced Airfoil/Wing w/ Less Sweep</td>
<td>AFC-enhanced high-lift/control</td>
<td>High-speed AFC drag/control</td>
<td>Low viscous drag fuselage</td>
<td></td>
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<tr>
<td>2035</td>
<td>Quiet, conformal, adaptive edges</td>
<td>Proactive load alleviation</td>
<td>Active flutter suppression</td>
<td>Tailored Loadpath, Out of Autoclave Structure</td>
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## Ultra-Efficient Airframe

- Damage Arresting, Unitized Structure
- Beyond CFRP Mat’l Sys & Secondary Structure
- Low Drag Acoustic Liners
- Integrated Inlet/Fan/Guide Vane
- Next gen CMC/Coatings
- Compact Nacelle
- Over-the-Wing/Body Nacelle
- Quiet Landing Gear
- Increasing Certification by Analysis

## Ultra-Efficient Propulsion

- Low FPR Ducted
- High Power Density Small Core
- Beyond CMC Material System
- Integrated Aero/Material Core
- Low FPR Unducted
- Distortion Tolerant Systems
- Active Distortion Control
- High OPR compatible combustor
- Fuselage BLI (tail cone like)
- Distributed (Electric) Propulsion
- Propulsion Airframe Aeroacoustics

## Ultra-Efficient Vehicle System Integration

- Over-the-Wing/Body Nacelle
- Fuselage BLI (flush mount)
- Quiet Landing Gear
- Propulsion Airframe Aeroacoustics

## ModSim & Test Capability

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

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

*PM Rule is forthcoming. Noise Noₓ and CO₂ Rules will be revised in future ICAO cycles.*
## Stakeholder Roles

- **Foundational research**, including computational 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**
- **Component design and test**
- **Increase TRL for technology and components**
- **Testing and qualification**
- **Detailed design**
- **Manufacturing process and investment**
- **Certification activities**
- **Marketing and sales**
- **Operations**
- **Upgrades**
- **Establish/Enforce Economic Measures**
- **Maintenance and customer service**

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<tr>
<th>Industry (OEM or operator)</th>
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<td>FAA/Regulators</td>
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www.nasa.gov

v2 05-24-16
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