NASA's Aeronautics Research Strategy: A Reflection of Research Continuity, Strategic Analysis, and Community Dialogue

Robert Pearce
Director – Strategy, Architecture & Analysis
NASA Aeronautics Research Mission Directorate
“ARMD provides critical support to our nation’s aeronautics research efforts. They have a strong track record of leading complex, collaborative research with multiple federal agencies, academia, government labs, and industry”

Marion Blakey, Chair – NAC Aeronautics Research Committee
Why is aviation so important?

The air transportation system is critical to U.S. economic vitality.

- **$1.3 Trillion**
  Total U.S. Economic Activity
  (civil and general aviation, 2009)

- **$47.1 Billion**
  Positive Trade Balance
  (civil aviation, 2011)

- **10.2 Million**
  Direct and Indirect Jobs
  (civil and general aviation, 2009)

- **5.2%**
  Of total U.S. Gross Domestic Product (GDP)
  (civil and general aviation, 2009)
Why should I care?

Take the system view. You may not have flown today but something you needed did.

-$1.6$ trillion
VALUE OF FREIGHT TRANSPORTED BY AIR
(exports, domestic, indirect spending, 2008)

-$636.1$ billion
SPENT BY AIR TRAVELERS IN U.S. ECONOMY
(foreign and domestic travelers, 2008)

-$728$ million
PASSENGERS ON U.S. CARRIERS
(domestic and international, 2011)
## Civil Aeronautics Manufacturing*

<table>
<thead>
<tr>
<th>Year</th>
<th>Jobs</th>
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<tbody>
<tr>
<td>2008</td>
<td>1,096,000 jobs</td>
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<tr>
<td>2009</td>
<td>1,112,000 jobs</td>
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“Sales orders for all four versions of the GTF engine, which each have an estimated price of $12 million, have prompted Pratt to add nearly 500 engineers at its East Hartford, Conn., headquarters. "We haven't done this in some time," says Sue Gilbert, director of human resources. Every business in the area, from real estate to dentists to pizzerias, could benefit.” – *Time Magazine*

* FAA 2011
NASA Technology Onboard Commercial Fixed-Wing Aircraft

- Glass Cockpit
- Digital Fly-by-Wire
- Turbo AE
- Area Rule
- Damage-Tolerant Fan Casing
- Wind Tunnels
- Jet Engine Combustors
- Engine Nozzle Chevrons
- Supercritical Airfoil
- Icing Detection
- Composite Structures
- Lightning Protection Standards
- Air Traffic Management
- NASA Structural Analysis (NASTRAN)
- Computational Fluid Dynamics (CFD)
- Airborne Wind Shear Detection
- Runway Grooves
- Wind Tunnels
- Winglets
Where do we see NASA's benefits today?

NASA's fundamental research can be traced to ongoing innovation.

Boeing 787

NASA's work on these technologies
- Advanced composite structures
- Chevrons
- Laminar flow aerodynamics
- Advanced CFD and numeric simulation tools
- Advanced ice protection system

Was transferred for use here

824 confirmed orders through August 2012

Benefits
- 20% more fuel efficient/reduced CO₂ emissions
- 28% lower NOₓ emissions
- 60% smaller noise footprint

Source: Boeing

Boeing 747-8

NASA's work on these technologies
- Advanced composite structures
- Chevrons
- Laminar flow aerodynamics
- Advanced CFD and numeric simulation tools

Was transferred for use here

106 confirmed orders through August 2012

Benefits
- 16% more fuel efficient/reduced CO₂ emissions
- 30% lower NOₓ emissions
- 30% smaller noise footprint than 747-400

Source: Boeing

P&W PurePower 1000G Geared Turbofan

NASA’s work on these technologies
- Low NOₓ Talon combustor
- Fan Aerodynamic and Acoustic Measurements
- Low noise, high efficiency fan design
- Ultra High Bypass technology
- Acoustics Modeling and Simulation tools

Was transferred for use here

Proposed for Airbus A320neo, Bombardier C-Series, Mitsubishi Regional Jets

Benefits
- 16% reduction in fuel burn/reduced CO₂ emissions
- 50% reduction in NOₓ emissions
- 20dB noise reduction

Source: Boeing

CFM LEAP-1B

NASA’s work on these technologies
- Compression system aerodynamic performance advances
- Low NOₓ TAPS II combustor
- Low pressure turbine blade materials
- High-pressure turbine shroud material
- Nickel-aluminide bond coat for the high pressure turbine thermal barrier coating

Was transferred for use here

Proposed for Airbus A320neo, Boeing 737MAX

Benefits
- 15% reduction in fuel burn/reduced CO₂ emissions
- 50% less NOₓ
- 15dB noise reduction

Source: CFM
Where do we see NASA’s benefits today?

NASA’s fundamental research can be traced to ongoing innovation.

**EDA**

**NASA’s work on these technologies**
- Human-in-the-loop simulations
- Joint flight trials with FAA and airlines
- Automated decision support tools
  - Traffic Management Advisor
  - 3-Dimensional Path Arrival Management
- Trajectory and arrival modeling and solutions

**Was transferred for use here**

**Phased deployment by the FAA of Efficient Descent Advisor starting 2014; full deployment by 2020.**

**Benefits**
- Fuel-efficient continuous descents
- Potential $300 million jet fuel savings per year (savings vary per spot fuel costs)
- Reduced delays in congested airspace
- Reduced noise and emissions around airports
- Retained safety
- Reduced controller workload through increased automation

**Federal Aviation Administration**
Source: FAA

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**Ice Protection**

**NASA’s work on these technologies**
- Understanding of icing physics
- Icing test methods and facilities
- Icing computational simulation and certification tools

**Was transferred for use here**

**Included in manufacture of new models such as Boeing 787**

**Boeing 787**
Source: Boeing

**Benefits**
- Reduced cost for aircraft certification
- Reduced time for aircraft certification
- Increased safety

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Last updated 10/02/12
Where do we see NASA’s benefits today?

NASA’s fundamental research can be traced to ongoing innovation.

**Synthetic and Enhanced Vision Systems**

**NASA’s work on these technologies**
- Sensor-based imaging
- World-wide terrain database
- 3D display avionics
- In-flight data integrity monitoring
- Synthetic Vision
- Gate-to-gate “virtual visual” concepts

**Was transferred for use here**

Honeywell, Rockwell-Collins and GE Aviation manufacture synthetic and enhanced vision systems.

**Honeywell SVS in G450**

Source: Gulfstream

**Benefits**
- Improved ability to "see" in poor conditions
- Improved ground hazard avoidance
- Useful for civilian, military and unmanned flight
- Reduced landing ceiling and threshold minimums
- Safe, intuitive training environment for newer pilots

**Data Mining**

**NASA’s work on these technologies**
- Massive datasets
- High-end computing
- Data mining algorithms for different data types
- Knowledge discovery of anomalies

**Was transferred for use here**

FAA’s ASIAS system receives data from entire U.S. civil aviation community. NASA partners with individual airlines.

**Aviation Safety Information and Analysis Sharing (ASIAS)**

Source: Southwest Airlines

**Benefits**
- Improved discovery by individual airlines of relevant operational events
- Increased identification of safety-related incidents
- Increased sharing of safety-related trends across airlines
- Reduced rate of incidents system wide

Last updated 9/18/12
ARMD Investment Strategy

Seeking New Ideas

Integrated System-Level Research

Fundamental Research

Technology Transfer

Enabling “Game Changing” concepts and technologies
NASA Aeronautics Programs

**Fundamental Aeronautics Program**
Conducts fundamental research to generate innovative concepts, tools, technologies and knowledge to enable revolutionary advances for a wide range of air vehicles.

**Integrated Systems Research Program**
Conducts research at an integrated system-level on promising concepts and technologies and explore, assess and demonstrates the benefits in a relevant environment.

**Aviation Safety Program**
Conducts cutting-edge research to produce innovative concepts, tools, and technologies to improve the intrinsic safety attributes of current and future aircraft and air traffic management systems.

**Airspace Systems Program**
Directly addresses the fundamental air traffic management research needs for NextGen by developing revolutionary concepts, capabilities, and technologies that will enable significant increases in the capacity, efficiency and flexibility of the NAS.

**Aeronautics Test Program**
Preserves and promotes the testing capabilities of one of the United States' largest, most versatile and comprehensive set of flight and ground-based research facilities.
Collaboration with External Partners

- Other Government Agencies
- U.S. Industry
- Academia
- International Organizations

Aeronautics
Strategic analysis
Approach to Planning

NASA Strategic Plan

Sets the Framework

Develops Concepts, Technical Challenges & Priorities

Performs Technical Planning

ARMD Strategic Implementation Plan

- **Strategic Trend Analysis**
  - Sets the Framework

- **Systems & Portfolio Analysis**
  - Develops Concepts, Technical Challenges & Priorities

- **Community Dialogue**
  - Performs Technical Planning

- **Subject Matter Experts**
  - ARMD Strategic Implementation Plan
Exploring Strategic Trends
Challenges Traditional Approaches

China & India Growing Economically at Historically Unprecedented Rates

| Average increase in percentage point share of global GDP, per decade |
|------------------|------------------|------------------|------------------|
| 6                | 5                | 4                | 3                |
| 2                | 1                | UK, 1820-70      | US, 1900-50      |
|                  |                  | Japan, 1950-80   | China, 2000-20   |
|                  |                  |                  | India, 2010-30   |

They will have the Largest Middle-Class

<table>
<thead>
<tr>
<th>Share of global middle-class consumption, 2000-2050 (percent)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Others</td>
</tr>
<tr>
<td>Japan</td>
</tr>
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</table>

The World will be Predominantly Urban

<table>
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<tr>
<th>Percent urban population</th>
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<tbody>
<tr>
<td>80</td>
</tr>
<tr>
<td>60</td>
</tr>
<tr>
<td>40</td>
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<td>20</td>
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Technology Development & Adoption is Accelerating

Source: National Intelligence Council
Why are these trends important?
Challenges are multiplying and accelerating – technology is a key lever!

They drive global demand growth for air travel…

![Graph showing passenger numbers in Asia Pacific](image)

Source: IATA

They drive expanding competition for high tech manufacturing…

![Comparison of aircraft performance](image)

Source: COMAC, Airbus, Boeing

They enable “leapfrog” adoption of new technology/infrastructure…

![Map of India and Myanmar with ADS-B sites](image)

They drive resource use, costs, constraints and impacts…

![Graph of oil consumption](image)

Data after 2011 are forecasts
These Trends Create Aviation Mega-Drivers

Three critical vectors

- Global Growth in Demand for High Speed Mobility
- Global Climate Change, Sustainability, & Energy Transition
- Technology Convergence
Aviation Mega-Drivers

*Three critical vectors*

1. **Global Growth in Demand for High Speed Mobility**
2. **Global Climate Change, Sustainability, & Energy Transition**
3. **Technology Convergence**

- **Net-Centric**
- **Embedded Intelligence**

**Global Temperatures**
- Annual Average
- Five Year Average
Air Transportation - A Critical Global Capability

Century long trend toward urbanization...

Urbanization is occurring at the rate of 7 “Chicagos” a year

Source: United Nations

International Air Transport Association (IATA) – Vision 2050
The world in 2050: “Traffic has grown from 2.4 billion to 16 billion passengers in the last 40 years…Technologically advanced aircraft operating on advanced renewable energy sources and capable of carrying anywhere from 2 to 2000 passengers connect intercontinental traffic through a dozen global gateways feeding them to 50-75 regional hubs which redistribute onwards to local airports.”
Aviation Mega-Drivers

*Three critical vectors*

- Global Growth in Demand for High Speed Mobility
- Global Climate Change, Sustainability, & Energy Transition
- Technology Convergence
Escalating Fuel Prices have a Large Aviation Impact

“Fuel is the only major cost item that has become significantly larger over time”
IATA

Fuel as Percentage of Total Airline Costs

Airline Energy Costs Continue to Rise

Source: EIA Weekly Petroleum Status Report for U.S. Gulf Coast jet fuel prices per gallon

Source: MIT Airline Data Project
Global Warming Imperative
How do we sustainably satisfy global demand for air transportation?

Strategies for Reducing Transportation-Related Greenhouse Gas Emissions

- Reduce the total volume of transportation activity;
- Shift transportation activity to modes that emit fewer GHGs per passenger-mile or ton-mile;
- Reduce the amount of energy required to produce a unit of transport activity (that is, increase the energy efficiency of each mode); or
- Reduce the GHG emissions associated with the use of each unit of energy

“We will respond to the threat of climate change, knowing that the failure to do so would betray our children and future generations.”

President Barack Obama
Inaugural Address - January 2013

Source: GAO

Source: NAS

Source: IATA
Aviation Mega-Drivers

Three critical vectors

Global Growth in Demand for High Speed Mobility

Global Climate Change, Sustainability, & Energy Transition

Technology Convergence
Summary of Strategic Trends

Traditional measures of demand for mobility growing rapidly
- Rapid growth of developing economies
- Global urbanization

Severe energy and climate issues create enormous affordability and sustainability challenges

Revolution in automation, information and communication technologies enable opportunity for safety critical autonomous systems
Core Technologies support needed capacity growth and enable simultaneous reduction in energy use, noise and emissions

- Structural, Aerodynamic & Propulsion Component Efficiency
- New Configurations
- Automation for Efficient TBO Operations

However, performance gaps remain to fully account for future challenges in mobility, cost and climate.

Low Carbon Fuels and Propulsion closes gaps in carbon emissions

Autonomy closes gaps in cost and enables mobility innovation.
Stakeholder Dialogue
Generating Ideas and Insights into Community Priorities

Advance ongoing research in NextGen, Safety, Green Aviation, and UAS Access

Undertake or Expand upon Transformational Enablers
- Autonomy
- Composite Structures
- More Electric Aircraft

Need Tools for More Rapid Innovation
- Virtual Testing
- V&V of Complex Systems

Demonstrate Low-Boom Supersonic Flight

Flight Research is a Critical Element of Technology Maturation and Public-Private Partnership
Strategic Response

3 Mega-Drivers

6 Strategic Research & Technology 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 Transports
- 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
Vision: A Revolution in Sustainable, High Speed Global Mobility

Transformative

On-Demand

Sustainable

Fast

Global

Intelligent

Low-Carbon

Safety, NextGen, Efficiency, Environment
Continuing to evolve ARMD Programs to respond to new needs and new approaches to innovative research

Doing business differently
Strategic Management Actions Since 2008
Build Upon Strong Fundamental Research and Excellent Technical Progress to Improve Relevance

Reorganized Programs & Strengthened Tech Transfer

Established Top-Down Strategy & Systems Analysis

Instituted High TRL Integrated Systems Research and Seedling Fund

Strengthened Interactions and Partnership with the Aviation Community

Aeronautics Research

Relevant Game Changing
Next Steps in Strategic Management
Promoting Innovation and Convergent Research

Objectives

- Pursue Innovative Solutions Aligned to the Strategic Thrusts
- Incentivize Multi-Disciplinary “Convergent” Research
- Enable Greater Workforce and Institutional Agility and Flexibility

Actions

- Improve Seedling Fund based on lessons learned and add Challenge Prize to promote focus, excitement and action on innovative solutions to the critical problems aligned with the Strategic Thrusts
- Develop an initiative to organize universities around ground-breaking research directed toward critical problems aligned with the Strategic Thrusts
- Incentivize use of Innovative approaches to Research, such as Open Source Development and more Agile Flight Research
- Expand partnerships beyond traditional aeronautics industry, to capture leverage from energy innovation, autonomy, and other fast developing technologies
- Continue to work with the Agency through the TCAT process to evolve and transform Agency aeronautics capabilities
ARMD Strategic Management Focus

Relevance
- Reorganized Programs & Strengthened Tech Transfer
- Established Top-Down Strategy & Systems Analysis
- Aeronautics Research
- Relevant Game Changing

Innovation
- Objectives
  - Pursue Innovative Solutions Aligned to the Vision
  - Incentivize Multi-Disciplinary “Convergent” Research
  - Enable Greater Workforce and Institutional Agility and Flexibility
- Actions
  - Increase Seedling Fund and Challenge Prize money tied to Vision and Convergent Research approaches
  - Enforce turnover of funded teams to encourage research teams in and Convergent Research approach
  - Incentivize user/Development and

Vision & Strategy
- Transformative Mobility
  - On-Demand
  - Fast
  - Sustainable
  - Integrated
  - Safety, NextGen,
Synergy with STMD
### Relationship to the NASA Strategic Space Technology Investment Plan (SSTIP)

#### Technology Investments

<table>
<thead>
<tr>
<th>Technology Investments</th>
<th>Associated NASA SSTIP Technical Challenge Areas</th>
<th>Associated NRC High Priorities</th>
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</thead>
<tbody>
<tr>
<td><strong>Launch and In-Space Propulsion</strong></td>
<td>Launch Propulsion Systems; High Power In-Space Propulsion; In-Space Propulsion; Cryogenic Storage and Transfer</td>
<td>Electric Propulsion; (Nuclear) Thermal Propulsion; Turbine Based Combined Cycle (TBCC); Rocket Based Combined Cycle (RBCC); Micro-Propulsion; Propellant Storage and Transfer</td>
</tr>
<tr>
<td><strong>Robotics and Autonomous Systems</strong></td>
<td>Autonomous Systems; Robotic Maneuvering, Manipulation, Sensing and Sampling; Autonomous Rendezvous and Docking; Structural Monitoring; Robotic Maneuvering</td>
<td>Extreme Terrain Mobility; GNC (includes Relative Guidance Algorithms, Onboard Autonomous Navigation and Maneuvering); Docking and Capture Mechanisms/Interfaces; Small Body/Microgravity Mobility; Dexterous Manipulation; Robotic Drilling and Sample Processing; Supervisory Control; Vehicle System Management and FDIR</td>
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<td><strong>Entry, Descent, and Landing</strong></td>
<td>Advanced Entry, Descent, and Landing; Entry, Descent, and Landing</td>
<td>EDL TPS (includes Rigid TPS, Flexible TPS, and Ascent/Entry TPS); GNC (includes GNC Sensors and Systems [EDL]); EDL Instrumentation and Health Monitoring; EDL Modeling and Simulation; EDL System Integration and Analysis; Atmospheric and Surface Characterization; Deployable Hypersonic Decelerators</td>
</tr>
<tr>
<td><strong>Lightweight Space Structures and Materials</strong></td>
<td>Lightweight Space Structures and Materials; Structural Monitoring</td>
<td>Lightweight and Multifunctional Materials and Structures (includes: [Nano] Lightweight Materials and Structures; Structures: Innovative, Multifunctional Concepts; Structures; Lightweight Concepts; Materials: Lightweight Structure; and Structures: Design and Certification Methods)</td>
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ARMD Efforts in Hypersonics

With the lack of civil aviation need for hypersonics and the establishment of the space technology program, ARMD is transitioning and reducing investments.

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<td>Propellant Storage and Transfer</td>
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ARMD investment in air-breathing hypersonic systems is focused on sustaining core competence and reimbursable activities with DoD to support military requirements.

| Entry, Descent, and Landing            | Advanced Entry, Descent, and Landing; Entry, Descent, and Landing                       | EDL TPS (includes Rigid TPS, Flexible TPS, and Ascent/Entry TPS);        |
|                                        |                                                                                         | GNC (includes GNC Sensors and Systems [EDL]);                             |
|                                        |                                                                                         | EDL Instrumentation and Health Monitoring;                               |
|                                        |                                                                                         | EDL Modeling and Simulation;                                             |
|                                        |                                                                                         | EDL System Integration and Analysis;                                    |
|                                        |                                                                                         | Atmospheric and Surface Characterization;                                |
|                                        |                                                                                         | Deployable Hypersonic Decelerators                                     |

ARMD has transitioned the EDL investment to the Space Technology Program.
Promising Areas of Planned Collaboration Between ARMD and Space Technology

ARMD is planning an expanded investment in composite materials and structures as well as greater focus in autonomous systems

- Opportunity to plan cooperative research activities

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Summary
Summary

Urgent Drivers

Innovative Solutions & High Payoff Technologies

Economic Growth
High Quality Jobs
Revolutionary Mobility
Long-Term Sustainability