“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 \text{ TRILLION}
VALUE OF FREIGHT TRANSPORTED BY AIR
(exports, domestic, indirect spending, 2008)

$636.1 \text{ BILLION}
SPENT BY AIR TRAVELERS IN U.S. ECONOMY
(foreign and domestic travelers, 2008)

728 \text{ MILLION}
PASSENGERS ON U.S. CARRIERS
(domestic and international, 2011)
“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

Civil Aeronautics Manufacturing*

<table>
<thead>
<tr>
<th>Year</th>
<th>Jobs</th>
</tr>
</thead>
<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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* FAA 2011
NASA Technology Onboard Commercial Fixed-Wing Aircraft

- + COMPUTATIONAL FLUID DYNAMICS (CFD)
- + NASA STRUCTURAL ANALYSIS (NASTRAN)
- + AIRBORNE WIND SHEAR DETECTION
- + AIR TRAFFIC MANAGEMENT
- + COMPOSITE STRUCTURES
- + DIGITAL FLY-BY-WIRE
- + LIGHTNING PROTECTION STANDARDS
- + TURBO AE
- + SUPERCRITICAL AIRFOIL
- + WINGLETS
- + GLASS COCKPIT
- + AREA RULE
- + JET ENGINE COMBUSTORS
- + ICING DETECTION
- + DAMAGE-TOLERANT FAN CASING
- + ENGINE NOZZLE CHEVRONS
- + WIND TUNNELS
- + RUNWAY GROOVES
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**

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

**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**

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

**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**

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

**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**

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

**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

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

**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**

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

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

**Boeing 787**

*Source: Boeing*

**Federal Aviation Administration**

*Source: FAA*
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.*

**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)**

**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

Enabling “Game Changing” concepts and technologies

Seeking New Ideas

Integrated System-Level Research

Fundamental Research

Technology Transfer
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.

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
Strategic analysis
Approach to Planning

NASA Strategic Plan

- Strategic Trend Analysis
  - Sets the Framework
- Systems & Portfolio Analysis
  - Develops Concepts, Technical Challenges & Priorities
- Community Dialogue
- Subject Matter Experts
  - Performs Technical Planning

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

- Share of global middle-class consumption, 2000-2050 (percent)

They will have the Largest Middle-Class

The World will be Predominantly Urban

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…

They drive expanding competition for high tech manufacturing…

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

They drive resource use, costs, constraints and impacts…
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

Global Temperatures

Net-Centric

Embedded Intelligence
Aviation Mega-Drivers

Three critical vectors

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

Century long trend toward higher speed transport...

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

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

Global Climate Change, Sustainability, & Energy Transition

Technology Convergence

Global Temperatures

Net-Centric

Embedded Intelligence
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

Source: MIT Airline Data Project

Airline Energy Costs Continue to Rise

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

Source: A4A
Global Warming Imperative
How do we sustainably satisfy global demand for air transportation?

“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

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

Source: GAO

<table>
<thead>
<tr>
<th>Emissions reduction roadmap</th>
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<tbody>
<tr>
<td><strong>CO₂ emissions</strong></td>
</tr>
<tr>
<td>2005</td>
</tr>
<tr>
<td>No action</td>
</tr>
<tr>
<td>Tech Ops Infra</td>
</tr>
<tr>
<td>-50% by 2050</td>
</tr>
</tbody>
</table>

Source: IATA
Aviation Mega-Drivers

Three critical vectors

Global Growth in Demand for High Speed Mobility

Global Climate Change, Sustainability, & Energy Transition

Global Temperatures

- Annual Average
- Five Year Average

Technology Convergence

Net-Centric

Embedded Intelligence
Technology Convergence
Enabling Assured Autonomy for Safety Critical Systems

- Reduce Operations Costs
- Improve Performance
- Increase Safety
- Transform Mobility – On Demand Aviation

Today
- Centralized, Expert Operator

Tomorrow
- More Distributed Management
- More System Intelligence
- Embedded System Intelligence

Net-Centric Information – Big Data
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

Demonstrate Low-Boom Supersonic Flight

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

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

3 Mega-Divers

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
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

Vision & Strategy

Transformative Mobility
- On-Demand
- Fast
- Sustainable
- Integrated
- Safety, NextGen,

Relevance
- Reorganized Programs & Strengthened Tech Transfer
- Established Top-Down Strategy & Systems Analysis
- Aeronautics Research
- Relevant Game-Changing
- Instituted High-Integrated Research
- Interactions and with the Aviation community

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 among projects to improve diversity and reduce barriers between Programs and Convergent Research approaches
  - Incentivize use Development and innovation
Synergy with STMD
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<th>Associated NASA SSTIP Technical Challenge Areas</th>
<th>Associated NRC High Priorities</th>
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<td>Electric Propulsion; (Nuclear) Thermal Propulsion; Turbine Based Combined Cycle (TBCC); Rocket Based Combined Cycle (RBCC); Micro-Propulsion; Propellant Storage and Transfer</td>
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<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>
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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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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

Economic Growth
High Quality Jobs
Revolutionary Mobility
Long-Term Sustainability

Innovative Solutions & High Payoff Technologies

Technology Convergence

Global Temperatures

- Annual Average
- Five Year Average

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