NASA’S AERONAUTICS VISION
Dr. Darrel R. Tenney

Director
Aerospace Vehicle Systems Technology Program Office
NASA Langley Research Center
MS 208
Hampton, Virginia 23681-2199

Telephone 757-864-6033
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NASA’s Vision

• To improve life here
• To extend life to there
• To find life beyond

NASA’s Mission

• To understand and protect our home planet
• To explore the universe and search for life
• To inspire the next generation of explorers

...as only NASA can
Aerospace Technology Enterprise
Strategic Themes

Aeronautics Technology

Mission and Science Measurement Technology

Space Launch Initiative

Innovative Technology Transfer Partnerships
Integrated Advancements in Airspace and Vehicles

Airspace Capacity

Systemic Operation (Flocking)

Ubiquitous Airspace

Cost Environment
Safety/Security

Future State
Revolutionary Vehicles
Operating in an
Integrated Airspace

Current State
Hub & Spoke; Long-Haul

Aircraft Capability

UAV's
Pt. to Pt.
Green Aft
Aviation is Critical to Society

- **Economic Growth**
  - Productivity
  - Global

- **National Security**
  - Air Superiority and Mobility

- **Quality of Life**
  - Freedom of Movement

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**Aviation Contributes and Enables Economic Growth**

- Cargo Traffic
- Passenger Traffic
- GDP

**Aviation Contributes >$21.7 Billion to Positive U.S. Balance of Trade**

- Military Aircraft
- Commercial Aircraft
- General Aviation
- Corporate Aircraft

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Balance of Trade by Manufacturing Sector for Year 2000
Aviation Extends and Accelerates the E-Commerce Revolution

Aviation Initiative that leverages Information Technology to brings every community in America into the global economy.
Global Trends in Transportation Mode
Market Shares

As per capita income rises, per capita annual travel rises, personal daily travel time budgets remain constant,
And high-speed modes gain market share

Demand for transportation, especially high-speed air travel, will soar beyond supply early in the 21st century.
The demand for air travel in 2020 could exceed the volume of ALL auto travel in 1990.
Indicators of Demand
Air Cargo Growth

Air cargo revenues are $40 billion per year

Air cargo traffic is expected to triple and outpace passenger growth in next 20 years

(Source: Boeing, 2000)
There are Major Issues in Aviation

- **Capacity Limits**
- **Noise & Emissions**
- **Safety & Security**
Congestion is an Issue

Highways are not the solution
On Demand
(Airspace and Airports are Abundant, not Scarce)

We Have an Abundance of Airspace—But only if we innovate new Air Traffic Management and transportation services concepts!

- Aggregate customers by e-commerce and wireless networks
- Serve low-density, price sensitive markets
- Provide mass customization of air service
- Open up America like the interstate highway system, but with five times the speed

Affordable Air Service is Constrained to only a Limited Number of Hub-and-Spoke Airports
- Need expanded and more distributed service
- Need safe accessibility to any airport
- Need hub-like affordability at any community

 Expanded Accessibility to thousands more destinations creates economic opportunity independent of location

We Have an Abundance of Airspace—But only if we innovate new Air Traffic Management and transportation services concepts!

- Aggregate customers by e-commerce and wireless networks
- Serve low-density, price sensitive markets
- Provide mass customization of air service
- Open up America like the interstate highway system, but with five times the speed
## Safety

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<tr>
<th>Today’s Challenges:</th>
<th>Future Opportunities:</th>
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<tr>
<td>• Limited Visibility</td>
<td>• Synthetic Vision Provides Visibility in all Conditions</td>
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<td>• Human Error</td>
<td>• Human-Centered Designs</td>
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<td>• Component Failures</td>
<td>• Self-healing, Fault Detection and Reconfigurable systems</td>
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<td>• Weather Hazards</td>
<td>• Weather Precisely Known</td>
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<td>• Hidden/Emerging Risks</td>
<td>• Aviation Risks Monitored and Managed</td>
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<tr>
<td>• Asymmetrical Threats</td>
<td>• “Refuse to Crash” Digital Terrain Technology</td>
</tr>
</tbody>
</table>
Synthetic Vision
Example of How Technology Will Transform Aviation

Safety
Controlled Flight into Terrain
Approach & Landing
Loss of Control
Runway Incursion

Efficiency
All Weather
Visual Departures &
Visual Approaches
Visual Spacing

Accessibility
Virtually any runway end or heli-pad in the nation becomes accessible in near-all-weather, without traditional ground infrastructure expense
Environmentally Friendly Aircraft

Noise within airport boundaries
Constrain objectionable noise to within airport boundaries

Smog-free
Minimize the contribution of air vehicles to the production of smog

No impact on global climate
Minimize the impact of air vehicles on global climate
Today’s Challenges:

• 825 (and growing) airports with noise restrictions
• $4B (and growing) to condition homes
• To keep noise inside airport boundaries
• Understanding the sources of noise
• Integrate emerging materials, structures, flow control technologies

Future Opportunities:

• Revolutionize How Citizens View Airports
• Quiet Design Engines, Landing Gear, and Airframes
• Revolutionary Vehicles (BWB)

Noise Reduction

People Impacted:

- Baseline*: 620,000
- -10 dB: 55,000
- -20 dB: 0

Airport Boundary

* DNL 55 is the EPA outdoor noise exposure level
* requisite to protect the public health and welfare with an adequate margin of safety.
Technology Discovery, Maturation, and Implementation

**Engine Noise Reduction**
- Swept & Leaned Stators

- Component Benefit: -3 dB fan noise

**Scarfed Inlet**

- Component Benefit: -2 dB fan inlet noise

**Chevron Nozzle**

1997 Model Tests → 2000 TFE731-60 Engine
- Component Benefit: -3 dB Jet noise

**Airframe Noise Reduction**
- Flap Edge Fence

- Component Benefit: -3 dB flap edge noise
Chevron Nozzle Technology for Engine Noise Reduction

Chevron nozzles will enable commercial aircraft to meet stringent noise restrictions.
Noise Reduction

Gap Analysis: Technical Challenges, Objectives, and Investment Areas

Engine Systems
- Fan
- Core
- Exhaust
- Liners
- PAI
- Aerodynamics
- Airframe Noise
- Flap
- Slat
- Gear
- Weight

Airframe Systems
- 3 dB
- 5 dB
- 8 dB

Operations
- 8 dB total source noise
- 8 dB
- 3 dB
- 2007
- 20 dB
- 10 dB
- 1992
- 1997

AST Noise Reduction
- 5 dB
- 3 dB source
- 2 dB Ops

Impact/Effects
- Modeling & Metrics
- 4 dB
- 2022
- 26
Environment

• Reducing CO$_2$ emissions by 50% and NOX emissions by 80% in 25 years will require radically new propulsion and airframe concepts
  • CO$_2$ reduction directly related to fuel burn
    – Smart vehicles, structures and active flow control technology to reduce drag, improve propulsion/airframe integration and optimize performance
    – Advanced propulsion systems (e.g. fuel cells)
  • NOX reduction related to combustion properties/design and fuel burn
    – Advanced materials and designs for turbines, fans, and compressors
    – New combustion cycles
  • Operational environmental issues with painting, de-icing, etc.
    – Application of riblets/coatings & smart wing de-icing systems
Other Environmental Issues

• Deicing
  – New systems required to stop runoff of harmful chemicals
  – Some European cities using Infrared heating

• Painting
  – Some manufacturers are flying unpainted aircraft off the assembly line to remote locations for painting
Issues and Technologies: Emissions

GAO SURVEY OF FUTURE ENVIRONMENTAL IMPACTS ON AIRPORTS

BREAKDOWN OF TARGET OPPORTUNITIES

CO\textsubscript{2} Emitted 1995

\textit{Δ CO\textsubscript{2} Emitted - 25%}

\textit{Δ CO\textsubscript{2} Emitted - 60%}

CO\textsubscript{2} Emitted 2007

CO\textsubscript{2} Emitted 2022

Water Quality (12%)

Wetlands (4%)

Land Use Compatibility (8%)

Air Quality (32%)

Noise Impact (44%)

AERODYNAMICS 9%

STRUCTURES 24%

PROPELLATION 19%

SYSTEMS 8%
Issues and Technologies: Emissions Impact on 21st Century Mobility

Possible Future Technologies

GAO Survey of Future Environmental Impacts on Airports

Quiet-Green Blended Wing Body Concept

Electric Aircraft Concepts

Water Quality (12%)

Wetlands (4%)

Land Use Compatibility (8%)

Air Quality (32%)

Noise Impact (44%)
Emissions - Fuel Burn “Waterfall”
Scenario-Based Vehicle Technologies

**325 PAX CONVENTIONAL SUBSONIC TRANSPORT**
2-Engine, 6500 nmi Design Range, 10000 ft Field Length

- **AERODYNAMICS**
  - Δ CO₂ Emitted = - 7 to 9%

- **STRUCTURES**
  - Δ CO₂ Emitted = - 20 to 24%

- **PROPULSION**
  - Δ CO₂ Emitted = - 16 to 19%

- **SYSTEMS**
  - Δ CO₂ Emitted = - 7 to 8%

- **Laminar Flow Control**
- **Design Optimization**
- **Excessence Drag Reduction**

- **Composite Wing & Tails**
  - **Composite Fuselage**
  - **Light Weight Landing Gear**
  - **Advanced Metals**
  - **Aeroelastic Tailoring (AR)**

- **Propulsion Aero-Mechanical Design**
  - **Propulsion Hot Section**
  - **Propulsion Materials**
  - **Propulsion Secondary Systems**

- **Relaxed Static Stability**
- **All Flying Control Surfaces**
- **Fly-By-Light/Power-By-Wire**
- **High Performance Navigation**
- **Intelligent Flight Systems**

**Emissions - Fuel Burn “Waterfall”**

**Scenario-Based Vehicle Technologies**

- **1995 EIS Technology**
  - Δ CO₂ Emitted = - 7 to 8%

- **CO₂ Emitted = 133.3 k lbs**

- **2007**

- **2022**

- **CO₂ Emitted**
  - 55.8 to 66.5 k lbs

- **Δ CO₂ Emitted**
  - -15% engine
  - -10% airframe

- **- 66.5 to 77.5 k lbs (- 50 to 60%)**

- **- 25%**

- **-10%**
Aircraft for Public Mobility

More Convenient
Expand access to aviation to more locations and make it available on-demand

More Affordable
Make air travel available to the entire population

Faster
Increase the speed of air travel

...without compromising safety
Indicators of Demand
Regional Jet Growth

- New regional jets fly faster and farther and are adding new direct connections
  - 550 RJs in use by end of 2000
- Older 19-seat turboprops used by regional airlines declining
  - down 40% in last decade to 405 in 1999
- However, fewer cities are being served as airlines consolidate markets for profitability

Canada and Brazil are the leading makers of regional jets.
A New Generation of Revolutionary Light Jet Products

- Strong Growth between 1994-1999
  - Billings up 235%
  - Deliveries up 172%
  - 636 Business & Corporate jets ($7.9 B) delivered in 1999
    - In comparison, 287 fighter planes ($9.7 B) delivered in 1999
    - Strong export market (>30%)

- Several new model jets
  - From low (<$1M) to high (>$$40M) products
  - New engines stimulate new aircraft development

- New Aircraft Revolutionize the Cost of Speed
  - $1.00/aircraft mile (total for 5 passenger jet travel)
  - Ultimately propeller travel becomes obsolete
  - On-Demand jet trips become affordable for most travelers
Highway in the Sky (HITS)

Graphically intuitive pilot interface system that provides a general aviation aircraft operator with the attitude and guidance inputs required to safely fly an aircraft in close conformance to air traffic procedures.

A multi function display showing a moving map and the path to any destination is available to the operator.

Demonstration of the AGATE Highway In The Sky (HITS) in a General Aviation Aircraft
Emerging New Applications for Composite Structures
UAV Systems

Operational

RQ-1 Predator
RQ-2 Pioneer
RQ-5 Hunter

Developmental

RQ-4 Global Hawk
Fire Scout
RQ-7 Shadow 200
Autonomous control Level Trends

Source: Unmanned Aerial Roadmap 2000-2025
Personal Air Vehicle (PAV) Sector (Goal Based)

Ease of Use Equivalent to Automobile
- Blunder resistant controls, co-pilot on a chip, obstacle avoidance, etc...
- Seamless integration of airspace communication, navigation and surveillance

Improved Propulsion
- Engine-out robustness
- Efficient, simplified propulsors
- Alternative cycle engines
- Propulsion-airframe integration

Affordable Ownership
- Certification of automotive processes
- Lean design and manufacturing
- Advanced software certification
- Health monitoring systems
- Design to certification toolsets

Low Community Noise
- Engine noise management systems
- Quiet propulsors

Lower Weight Systems
- Durable, damage-tolerant structures
- Minimum gage materials and design
- Active control simplified high-lift
The links (operations) from a few of NetJet’s nodes in NJ to their top ten destinations from NJ nodes (originations) follow a power law distribution.

For NetJets, this distribution of nodes with links extends out to about 1250 airports annually.
Power Law Distribution in Air Transportation
(Mobility & Capacity Layers)

Small World Behaviors in Air Transportation Topologies
- Hub-and-spoke exhibits single-scale (truncated)
- Regional jet operations exhibit single-scale (truncated)
- SATS Jet-taxi operations (5,000 airports) exhibits broad scale
- Self-operated rural/regional PAVs exhibits broader scale
- Intra-urban PAVs approach scale-free
Air Vehicles for New Missions

Science platforms
Develop innovative air vehicles for science missions in the earth’s atmosphere and beyond

Hazardous environments
Enable uninhabited air vehicles to fly in hazardous environments
HALE UAV for Earth Science Measurements

Goal: Long-endurance, high altitude, unmanned flight

Pathfinder (1995)
- Reached 50,000 ft during a 12-hr flight

ERAST program begins (1994)

Technology Development (TRL1-6)

Pathfinder Plus

Technology Demonstration (TRL7-9)

Helios (2001)
- Reached 96,000+ ft

Mobile Imaging Demonstration (2002)

Cloud-free images of coffee plantation obtained after 4-hr loiter showed areas ready for harvest.
Superior Air Power

Technological superiority
Cooperatively develop technologies that enable air superiority

Partners in freedom
Support the development of advanced military aircraft
Passive Porosity Technology for F/A-18E/F Wing Drop

Technology Applied to Production F/A-18E/F (1998)

Passive Porosity Wing Fold Fairing


Adverse F/A-18E/F Wing Drop discovered in flight tests (1996)

Base Research and Technology Program (1980's)

Technology Development (TRL1-6)

Fundamental Research

Applied Research to Airfoil

Passive Porosity technology enabled F/A-18E/F to meet full-flight envelope maneuvers for Navy acceptance
F-22 Tail Buffet Survey

Support of DOD Programs - F-22

13.5% Scale F-22 in LaRC Transonic Dynamics Tunnel

Port Fin - Rigid

Starboard Fin - Flexible

Pressure Transducers

Active Rudder

Accelerometers
LONG HAUL/HIGH CAPACITY BWB
SUBSONIC TRANSPORT

Sized Tri-Jet, 800 Passengers, 8500 nmi Design Range, 10000 ft. Field Length

TOGW = 1,345,204 lbs
1995 EIS Technology

TOGW = 730,401 lbs
2020 EIS Technology

-614,803 lbs (-45.7%)
819,243 lbs (+12.2%)
12,000 nmi
8,000 TOFL

Tri-Jet

Laminar Flow Control
Design Optimization
Excrecence Drag Reduction

Composite Wing
Composite Fuselage
Light Weight Landing Gear
Aeroelastic Tailoring (AR)

Propulsion Aero-Mechanical Design
Propulsion Hot Section
Propulsion Materials
Propulsion Secondary Systems
Boundary Layer Ingestion

Fly-By-Light/Power-By-Wire
High Performance Navigation
Intelligent Flight Systems

AERO
\[ \Delta \text{TOGW} = -11.8\% \]

STRUCTURES
\[ \Delta \text{TOGW} = -19.1\% \]

PROPULSION
\[ \Delta \text{TOGW} = -12.2\% \]

SYSTEMS
\[ \Delta \text{TOGW} = -2.6\% \]

TOGW = 749,801 lbs
(+2.7%)

819,243 lbs
(+12.2%)

12,000 nmi
8,000 TOFL
Tri-Jet

Twin
Vehicle Systems

Vehicle Sectors

- **Subsonic**
  - Vehicle capabilities defined within each sector

- **Supersonic**

- **Personal Air Vehicle**

- **Uninhabited Air Vehicle**

- **Runway Independent Aircraft**

Technology goals defined to support capabilities
### Innovative Vehicle Concepts to Identify Key Technology Requirements

<table>
<thead>
<tr>
<th>Concept</th>
<th>Description</th>
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<tr>
<td><strong>Clean Transport</strong></td>
<td>Minimum environmental impact, maximum efficiency</td>
</tr>
<tr>
<td><strong>Global Strike</strong></td>
<td>Strengthen national security through rapid deployment and global reach</td>
</tr>
<tr>
<td><strong>Planetary Flight Vehicles</strong></td>
<td>Conduct extended science and exploration missions</td>
</tr>
<tr>
<td><strong>Santa Monica at Midnight</strong></td>
<td>All hour access to any location without noise disturbance</td>
</tr>
<tr>
<td><strong>Global Reach Transport</strong></td>
<td>Global reach and on-demand delivery</td>
</tr>
<tr>
<td><strong>Personal Air Vehicle</strong></td>
<td>Rural, regional, and intra-urban transportation</td>
</tr>
<tr>
<td><strong>Heartland Express</strong></td>
<td>Rural and regional economic growth, time critical transport</td>
</tr>
<tr>
<td><strong>Tanker</strong></td>
<td>Automated refueling capability, ultra-long endurance, wide speed range</td>
</tr>
<tr>
<td><strong>V/STOL Commuter</strong></td>
<td>Enables city center access in all weather</td>
</tr>
<tr>
<td><strong>Extreme STOL Transport</strong></td>
<td>Expands the use of existing airport infrastructure</td>
</tr>
<tr>
<td><strong>Supersonic Overland</strong></td>
<td>Reduce passenger flight time by at least a factor of 2</td>
</tr>
<tr>
<td><strong>High Altitude Long Endurance</strong></td>
<td>High altitude observations for science and defense</td>
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</table>
### Runway Independent Aircraft (RIA) Technology Goals

**RIA is one of 5 vehicle sectors**

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<th>Technology Areas</th>
<th>Goal</th>
<th>SOA</th>
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<td>$C_{\text{max}}$</td>
<td>10</td>
<td>7</td>
</tr>
<tr>
<td>$L/D$</td>
<td>16</td>
<td>12</td>
</tr>
<tr>
<td>Community Noise (Outside Fence)</td>
<td>55 EPNdB</td>
<td>Stage 3</td>
</tr>
<tr>
<td>Flight Controls</td>
<td>CAT IIIC</td>
<td>Special VFR</td>
</tr>
<tr>
<td>Hover Efficiency (EW/HOGE GW)</td>
<td>0.56</td>
<td>0.68</td>
</tr>
<tr>
<td>SFC</td>
<td>SOA -35%</td>
<td>SOA</td>
</tr>
<tr>
<td>Engine T/W</td>
<td>SOA +120%</td>
<td>SOA</td>
</tr>
<tr>
<td>Empty Weight Fraction</td>
<td>0.52</td>
<td>0.63</td>
</tr>
<tr>
<td>Cabin Noise</td>
<td>75dBA</td>
<td>88dBA</td>
</tr>
<tr>
<td>Cabin Vibration</td>
<td>0.03g’s</td>
<td>0.10g’s</td>
</tr>
</tbody>
</table>
Strategic Technology Focus Areas

Six long-term technology focus areas
- Key long-term investment areas
- Primary places where technology advances will occur
- Projects achieve finite steps within these areas

- Environmentally Friendly, Clean Burning Engines
  **Focus:** Develop innovative technologies to enable intelligent turbine engines that significantly reduce harmful emissions while maintaining high performance and increasing reliability

- New Aircraft Energy Sources and Management
  **Focus:** Discover new energy sources and intelligent management techniques directed towards zero emissions and enable new vehicle concepts for public mobility and new science missions

- Quiet Aircraft for Community Friendly Service
  **Focus:** Develop and integrate noise reduction technology to enable unrestricted air transportation service to all communities
• **Aerodynamic Performance for Fuel Efficiency**  
  Focus: Improve aerodynamic efficiency, structures and materials technologies, and design tools and methodologies to reduce fuel burn and minimize environmental impact and enable new vehicle concepts and capabilities for public mobility and new science missions

• **Aircraft Weight Reduction and Community Access**  
  - Focus: Develop ultralight smart materials and structures, aerodynamic concepts, and lightweight subsystems to increase vehicle efficiency, leading to high altitude long endurance vehicles, planetary aircraft, advanced vertical and short takeoff and landing vehicles and beyond

• **Smart Aircraft and Autonomous Control**  
  Focus: Enable aircraft to fly with reduced or no human intervention, to optimize flight over multiple regimes, and to provide maintenance on demand towards the goal of a feeling, seeing, sensing, sentient air vehicle
Future Vision

• Inherently Multidisciplinary

• Exploit vehicle flexibility and adaptability (e.g. localized and large-scale vehicle shape change)

• Colonies of distributed sensors and actuators

• A paradigm shift from
  – Steady to the unsteady world (e.g. flow control, adaptive morphing)
  – Passive to active,
  – Rigid to design for flexibility,
  – Few discrete to many distributed (e.g. sensors, control surfaces)
  – To obtain a vehicle that is always at optimum performance.

• Therefore, the greatest technical challenges and opportunities occur at the intersection of disciplines
  – but the real barrier may be cultural, not technical
• Materials and structures technology advancements are required to achieve performance goals for next generation air vehicles

• Smart Materials and adaptive structures which enable flow control can significantly improve aerodynamic performance

• Advancements in process and manufacturing technologies critical to cost effective air vehicle structures

• Computational modeling essential to design of nano-materials and bio-inspired materials and structures