The Future of Green Aviation

Dr. Thomas Edwards
Director of Aeronautics
NASA Ames Research Center

Celebrate the Earth
Future of Flight Foundation
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The aviation industry is vital to the nation’s economic well-being

- Aviation directly or indirectly provides 997,000 Americans with jobs
- In 2008, aviation provided the nation with a trade surplus of $57.4B
- 25% of all companies’ sales depend on air transportation
- In the U.S., more than 60 certified domestic carriers operate every day
  - They operate more than 6500 aircraft
  - They service almost a million travelers daily on 28,000 flights
  - In 2008, they had an annual operating revenue for commercial flights of $168B
Aviation’s Economic Impact in the U.S.
The Advancement of Commercial Aircraft Design

THE FUTURE

Today...

The beginning...

Back then..
The primary technology driver during The Golden Age was attaining high speed.
The Modern Era experienced a shift in technology drivers to

- reducing noise pollution around the 1950’s, and
- improving energy efficiency in the 1970’s with the energy crisis.
Aviation’s Impact on Environment and Energy

The aviation industry also has a negative impact on the environment and energy usage in the U.S.

- Worldwide aviation fuel use is 8% of 1.3 T gals. of refined fossil fuel products
- Fuel is 20% of operating cost for our 18,000 commercial airplanes
- Aviation releases 600 M tons of CO2 per year
- Aviation contributes 3% of greenhouse gases, but 13% of overall climate impact
- Impact of aviation-produced water vapor and oxides of nitrogen remain uncertain
- Noise complaints continue to indicate a problem despite FAA’s airport noise abatement programs
Aviation’s Impact on Environment and Energy
Reducing **noise pollution** and improving **energy efficiency** remain strong technology drivers for **The Next Generation**, but

- reducing aviation’s **impact on climate change** is also a high priority.
NASA is targeting ambitious goals to sustain growth of the aviation industry and improve aviation’s environmental compatibility and energy efficiency.

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** ERA's time-phased approach includes advancing "long-pole" technologies to TRL 6 by 2015.

‡ CO₂ emission benefits dependent on life-cycle CO₂e per MJ for fuel and/or energy source used.
Technology Drivers: Community Noise

Community Noise Reduction Goal: Contain objectionable noise within the airport boundary.

Current Rule:
Stage 4
Baseline Area

Next Generation Goal
Stage 4 – 42 dB CUM
Area = 8% of Baseline

State of the Art
Stage 4 – 10 dB CUM
Area = 55% of Baseline

Credit: NASA.
Technology Advancements: Community Noise

\[ \text{Noise} \approx \frac{\text{Disrupted Airflow at Source}}{\text{Noise Propogation Profile}} \]

NASA Technology Onboard Commercial Fixed-Wing Aircraft
Technology Advancements: Community Noise

Quiet Airframe

- Conformable surfaces to eliminate gaps between surfaces
- Fairing over landing gear

High-lift system concept. Credit: NASA.

Landing gear fairing concept. Credit: NASA.

Computed flow visualization behind traditional landing gear. Credit: NASA.
Technology Advancements: Community Noise

Engines Mounted above the Wing or Body

- Wing or body of aircraft shields community from engine noise

Impact is a 66% reduction in ground area
Modern Aircraft Fuel Efficiency

For a flight from Seattle to Washington D.C., each passenger needs about 29 gallons of fuel:

2,325 mi, 3,709 gal, 162 pax, 80% load factor

\[
\frac{3,709 \text{ gal}}{130 \text{ pax}} = 29 \text{ gal/pax} \quad (81 \text{ PMPG})
\]

Typical car in SF bay area:

25 mpg * 1.3 pax = 32 PMPG

(Similar to Amtrak)
Technology Advancements: Energy Efficiency

\[
\text{Weight}_{\text{Fuel Consumed}} \approx \left( \text{Weight}_{\text{Payload}} + \text{Weight}_{\text{Vehicle}} \right) \left( \frac{\text{Propulsive Efficiency}}{\text{Velocity}} \right) \left( \frac{\text{Drag}}{\text{Lift}} \right) (\text{Range})
\]

**NASA Technology Onboard Commercial Fixed-Wing Aircraft**
Technology Advancements: Energy Efficiency

Strong, Lightweight Structures

- Stitched composites for non-circular pressurized aircraft bodies
- Structural element layout designed to carry unique loads
Technology Advancements: Energy Efficiency

Propulsive efficiency has improved significantly over last 60 years, but appears to have leveled off from Lee, 2000.

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![Graph showing cruise thrust specific fuel consumption over years of introduction, with a significant decrease from B-707 to B-777.](image)

- 40% decrease

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from Lee, 2000
Advanced Turbomachinery

- Fan blades capable of adapting to unique air flow characteristics for an embedded engine.

Analysis of fan aerodynamic and structural response to airflow. Credit: NASA.

Adaptive fan blades. Credit: NASA.
Technology Advancements: Energy Efficiency

Electric Propulsion

- Electric propulsion challenging for commercial aircraft due to specific energy and specific power requirements
- Hybrid electric propulsion under consideration
Increases to the ratio of lift over drag (L/D) have been limited over the last 60 years.
Technology Advancements: Energy Efficiency

Smooth Airflow around Wing

- Shape the wing or apply blowing or suction to improve flow along wing

FAST-MAC wind tunnel model with active flow control. Credit: NASA.

Laminar flow wing. Credit: NASA.
Technology Advancements: Energy Efficiency

Gate-to-Gate Operations

Flow and Airspace Planning

En Route with Weather Avoidance

Surface Operation

Dense Terminal

Surface Operation

Departure

Arrival
Technology Advancements: Energy Efficiency

Efficient Traffic Flow Management

• An integrated airport arrival solution reduces flight delays by an average of three minutes per flight

• “No-stop” taxi operations improve movement on the ground
Technology Advancements: Energy Efficiency

Continuous Climbs Departure and Descent Approaches

San Francisco International Airport
OTA Flight Test
OTA Arrival

December 19, 2006
UAL76
Technology Drivers: Emissions

Fleet Emissions Goal: By 2050, substantially reduce carbon emissions, while significantly reducing emissions of oxides of nitrogen.

Carbon Neutral Growth and Reduction Timeline

- Forecasted Carbon Emissions Growth (Without improvements)
- Technology Development—Ongoing Fleet Renewal
- Operational Improvements—ATC/NowGen/
- Additional Technology Advancement and Low Carbon Fuels

Baseline reduced by 50%

Credit: NASA.
Technology Advancements: Emissions

Emissions \approx (\text{Weight} \div \text{Fuel Consumed}) \left( \frac{\text{Combustion Efficiency}}{\text{Atmospheric Conditions}} \right)

- Jet Engine Combustors
- Engine Nozzle Chevrons
- Air Traffic Management
- Computational Fluid Dynamics (CFD)
- Wind Tunnels
- Turbo AE

NASA Technology Onboard Commercial Fixed-Wing Aircraft
Technology Advancements: Emissions

Advanced Fuel Combustors

• High temperature material for combustor liners
• Combustion control

High temperature Material. Credit: NASA.

High frequency fuel delivery system. Credit: NASA.

High temperature electronics. Credit: NASA.

Combustor liner. Credit: NASA.
Technology Advancements: Emissions

Alternative Synthetic Fuels

- Developing an understanding of alternative aviation fuels
- First test of 100% Fischer-Tropsch fuel in February 2009
Technology Drivers: Emissions

Contrails and Aviation-Induced Cloudiness: Effect on climate is uncertain.

✈ Persistent contrails formed in super-saturated and cold air.
Technology Advancements: Emissions

Optimal Aircraft Trajectories to Reduce Contrails

• Alternative operations concept significantly reduces (28-72%) contrails for a small (2%) increase in fuel
Simultaneous achievement of improvements to aviation’s environmental compatibility and energy efficiency is required to sustain aviation’s growth.

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** ERA's time-phased approach includes advancing "long-pole" technologies to TRL 6 by 2015.

‡ CO₂ emission benefits dependent on life-cycle CO₂eq per MJ for fuel and/or energy source used.
Advanced vehicle concept studies and integrated system-level research in promising concepts to explore, assess, or demonstrate the benefits in a relevant environment
Technology Advancements: Integrated System Solution

Advanced Tube and Wing

- Traditional configuration incorporates advanced technology to meet aviation’s challenges

120Pax
1600nm
M.75
Advanced Regional Transport

- Traditional configuration incorporates advanced technology to meet aviation’s challenges
- Offers point-to-point travel to reduce the total distance and time traveled
Truss Braced Wing

- Long, thin wings (high aspect ratio) supported with a truss brace

- Hybrid electric / turbine propulsion, with fuel cells and batteries considered
Truss Braced Wing

- Long, thin wings (high aspect ratio) supported with a truss brace
- Wing tips fold for ground operations
- Thrust from propulsion system vectored to control vehicle; no tail required
Technology Advancements: Integrated System Solution

Double Bubble

- Wide “double bubble” fuselage provides lift
- Large lifting control surfaces (flaps) eliminated from wing
- Engines embedded on aft of body

180 Pax
3000 nm
M.74
Double Bubble

- A subscale model of the Double Bubble tested in an MIT wind tunnel
Hybrid Wing Body

- Hybrid wing-body provides significant lift
- Engines mounted above body to shield noise
- Beneficial for large, long haul aircraft
Hybrid Wing Body

- The unique X-48B Blended Wing Body aircraft has flown more than 80 flights at NASA’s Dryden Flight Research Center on Edwards Air Force Base, California.
Technology Advancements: Integrated System Solution

Turboelectric Distributed Propulsion

- Large engines at wingtips drive superconducting generators
- Electric power from generators powers many small motor-driven propulsors
Cruise Efficient Short Take Off and Landing

- Enables operation from short runways
- Advanced technologies improve fuel efficiency and noise as compared to state-of-the-art short take off and landing aircraft
Technology Advancements: Integrated System Solution

Cruise Efficient Short Take Off and Landing

- Subscale model in the NFAC Wind Tunnel located at NASA’s Ames Research Center

- Wind tunnel test studied the aerodynamics and acoustics of advanced technologies
Civil Tiltrotor

- Enable simultaneous achievement of vertical take off and landing and high speed cruise
Technology Advancements: Integrated System Solution

Civil Tiltrotor

- Flight simulations in the Vertical Motion Simulator at NASA’s Ames Research Center study how to improve pilot’s ability to maneuver a large civil tiltrotor concept.
Supersonic Configuration

• Optimized geometry softens sonic boom and airport noise
Supersonic Configuration

- Wind tunnel tests at NASA’s Ames Research Center provide sonic boom data for validation of aircraft geometry design and optimization tools
Unmanned Aircraft Systems

• Enable new markets in civil applications where it’s not feasible or practical to rely on extended human-pilot flights
Airships

• Lighter-Than-Air Airship operations are inherently energy efficient and low noise

• Beneficial for heavy lift and slow transport
Personal Air Vehicle

- The Puffin (pictured) is an electric powered, 12-foot long, 14.5-foot wingspan personal air vehicle.
Sustained growth of the aviation industry will require a wide range of research to improve aviation’s environmental compatibility and energy. Government, industry and academia are working together to make it happen!
NASA Aeronautics Video
“with you when you fly”
Technology Advancements: The Next Generation

Café challenge?
The Beginnings of Commercial Aircraft Design

Leonardo da Vinci (1452 – 1519) was one of the world’s greatest thinkers.

Sir George Cayley (1773 – 1857) built the world’s first glider capable of carrying a human.

Otto Lilienthal (1848 – 1896) would bend and manipulate the wings of his gliders to control direction.

Octave Chanute (1832 – 1910) sponsored the biplane glider that formed the basis of the Wright biplane design.
The Beginnings of Commercial Aircraft Design

The Wright Brothers

first sustained, powered flight under the control of the pilot near Kitty Hawk, North Carolina, on December 17, 1903

Wilbur Wright (1867 – 1912)

Orville Wright (1871 – 1948)

Photograph of Orville Wright at Fort Myer, Virginia, on June 29, 2009

Reached a top speed of 42.583 miles per hour and an altitude of 400 feet on June 30, 2009

Orville Wright (1871 – 1948)
The Advancement of Commercial Aircraft Design
Aviation’s Impact on Environment and Energy

In 2008, U.S. major commercial carriers burned 19.6B gallons of jet fuel, and DoD burned 4.6B gallons. At an average price of $3.00/gallon, fuel cost was $73B

U.S. commercial carriers and DoD release more than 250 million tons of CO$_2$ into the atmosphere each year

In 2007, aircraft in the U.S. spent 213 million minutes taxiing and in ground holds

Airline delays in the U.S. cost industry and passengers $32.9B in 2007

The high cost of certification for new or upgraded aviation systems is prohibitive

40 of the top 50 U.S. airports are in areas that do not meet EPA local air quality standards

Aircraft noise continues to be regarded as the most significant hindrance to NAS capacity growth

FAA’s attempt to reconfigure New York airspace resulted in 14 lawsuits due to noise complaints

Since 1980 FAA has invested over $5B in airport noise abatement programs in homes
Congressional Legislation in 1915

The National Advisory Committee for Aeronautics, or the NACA, was established on March 3, 1915, to “… supervise and direct the scientific study of the problems of flight, with a view to their practical solutions.”
The Space Act of 1958

“…The aeronautical and space activities of the United States shall be conducted so as to contribute materially to…the improvement of the usefulness, performance, speed, safety, and efficiency of aeronautical and space vehicles…[and] the preservation of the role of the United States as a leader in aeronautical and space science and technology…”
National Aeronautics Research and Development Policy

“The National Aeronautics and Space Administration (NASA) should maintain a broad foundational research effort aimed at preserving the intellectual stewardship and mastery of aeronautics core competencies so that the nation’s world-class aeronautics expertise is retained”
Technology Advancements: The Modern Era

NASA Technology Onboard Commercial Fixed-Wing Aircraft

- Glass Cockpit
- Digital fly-by-wire
- Turbo AE
- Area rule
- Supercritical airfoil
- Wind tunnels
- Runway grooves
- Jet engine combustors
- Engine nozzle chevrons
- Icing detection
- Air traffic management
- Composite structures
- Computational fluid dynamics (CFD)
- NASA structural analysis (NASTRAN)
- Airborne wind shear detection
- Damage-tolerant fan casing
- Lightening protection standards
- NASA technology onboard commercial fixed-wing aircraft.
Technology Advancements: ????

- DIGITAL FLY-BY-WIRE
- AREA RULE
- COMPOSITE STRUCTURES
- WINGLETS
- ICING DETECTION
- SUPERCRITICAL AIRFOIL
- JET ENGINE
- COMBUSTORS
- ENGINE NOZZLE CHEVRONS
- AIR TRAFFIC MANAGEMENT
- NASA STRUCTURAL ANALYSIS (NASTRAN)
- COMPUTATIONAL FLUID DYNAMICS (CFD)
- WIND TUNNELS
- TURBO AE

NASA Technology Onboard Commercial Fixed-Wing Aircraft
Technology Advancements: Community Noise

- Chevrons – The Road From Idea to Deployment

**Systems Assessment 2001–2005**
- Ground-test evaluation in engine test stands
- Flight evaluation in relevant environments

**Fundamental Research 1996–2000**
- Computational and experimental research to develop a fundamental understanding of the fluid mechanics governing the effectiveness of the concept
- Development of practical implementations (chevrons)
- Team effort involving industry, universities, and NASA

**Seedling Idea 1994–1996**
Basic studies on jet mixing suggest that tabs can enhance jet mixing, with the potential to reduce noise
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Fundamental Research: 1996-2000
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Initial service entry, 2002