National Aeronautics and Space Administration

The Future of Green Aviation

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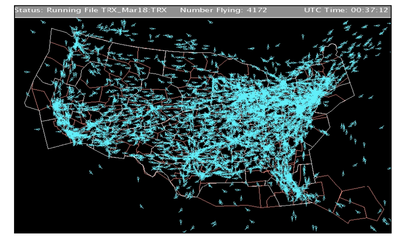
Director of Aeronautics
NASA Ames Research Center

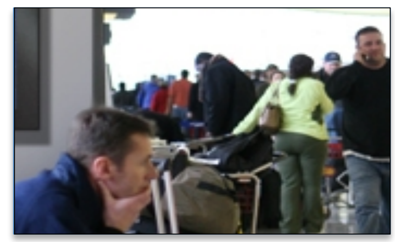
Celebrate the Earth
Future of Flight Foundation
22 April 2012
Mukilteo, WA

Aviation's Economic Impact in the U.S.

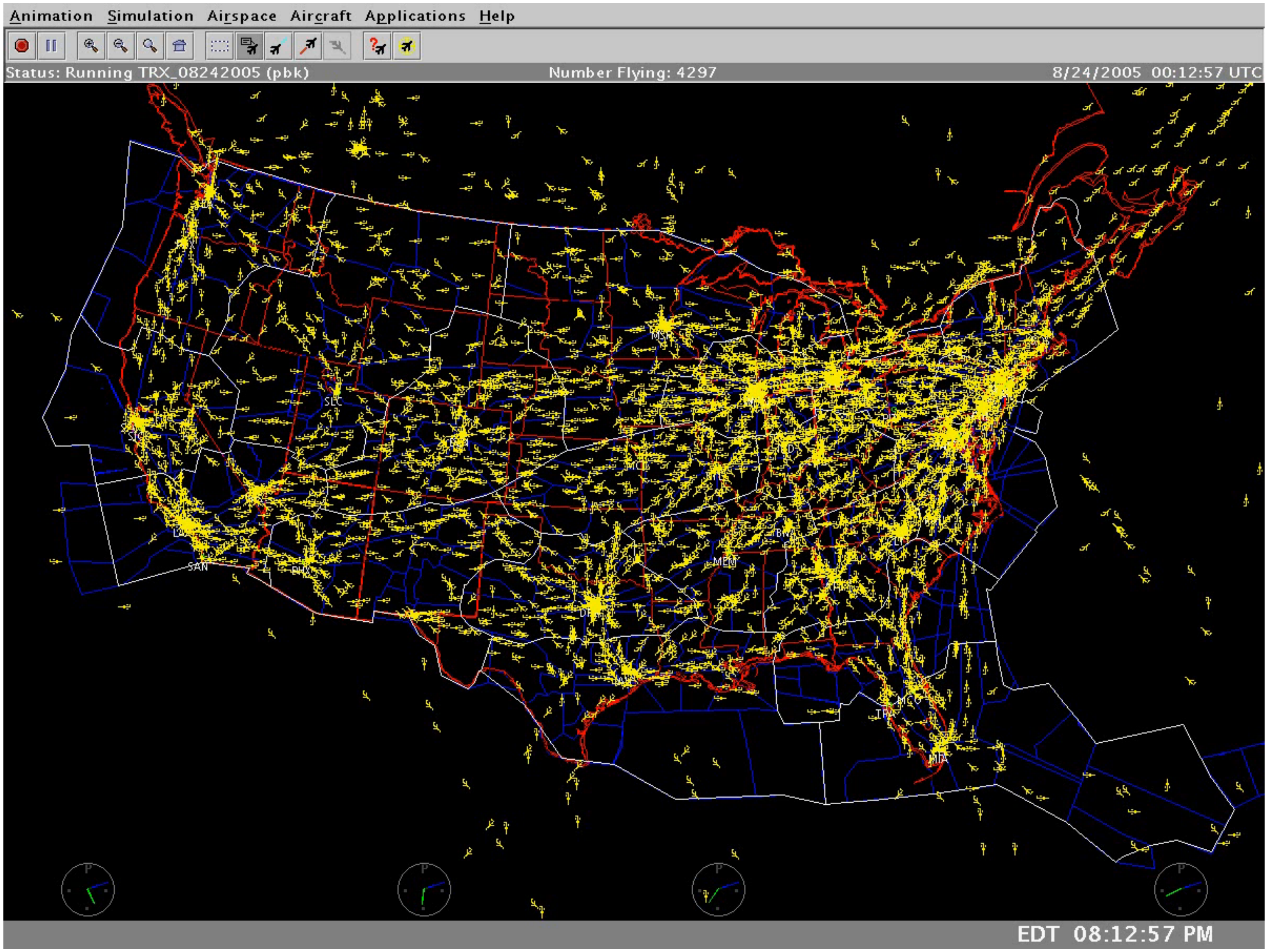
The aviation industry is vital to the nation's economic well-being

- 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





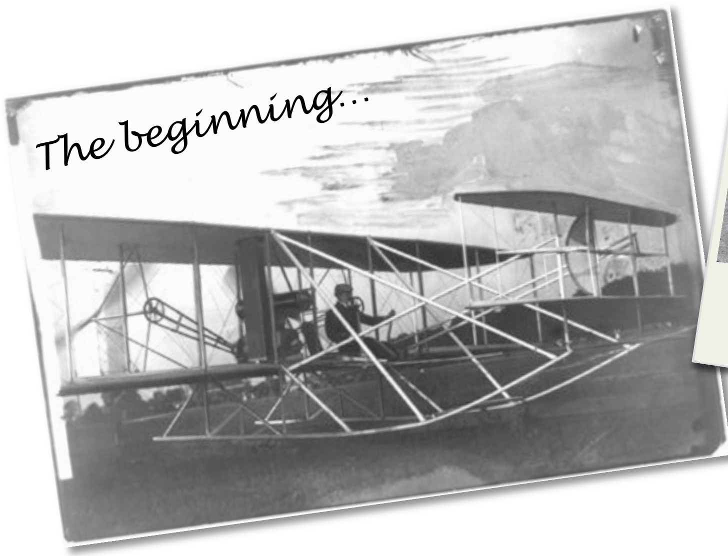
Aviation's Economic Impact in the U.S.



The Advancement of Commercial Aircraft Design

Technology Drivers: The Golden Age

The primary technology driver during **The Golden Age** was attaining **high speed**.



Technology Drivers: The Modern Era

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

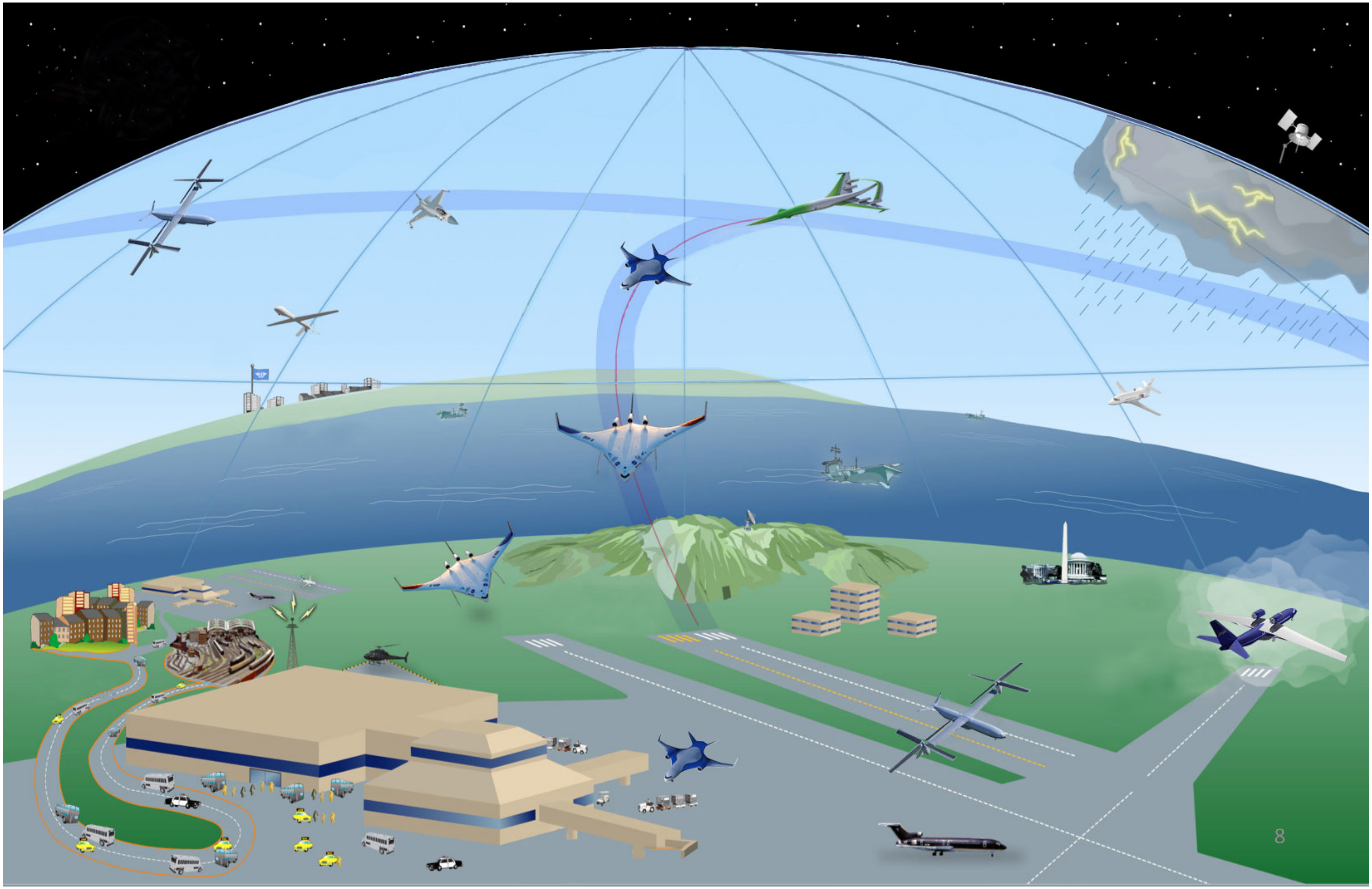
The aviation industry also has a negative impact on the environment and energy usage in the U.S.

- 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



Technology Drivers: The Next Generation

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.

Aviation's Impact on Environment and Energy

NASA is targeting ambitious goals to sustain growth of the aviation industry and improve aviation's environmental compatibility and energy efficiency

TECHNOLOGY BENEFITS*	TECHNOLOGY GENERATIONS (Technology Readiness Level = 4-6)		
	N+1 (2015)	N+2 (2020**)	N+3 (2025)
Noise (cum margin rel. to Stage 4)	-32 dB	-42 dB	-71 dB
LTO NOx Emissions (rel. to CAEP 6)	-60%	-75%	-80%
Cruise NOx Emissions (rel. to 2005 best in class)	-55%	-70%	-80%
Aircraft Fuel/Energy Consumption‡ (rel. to 2005 best in class)	-33%	-50%	-60%

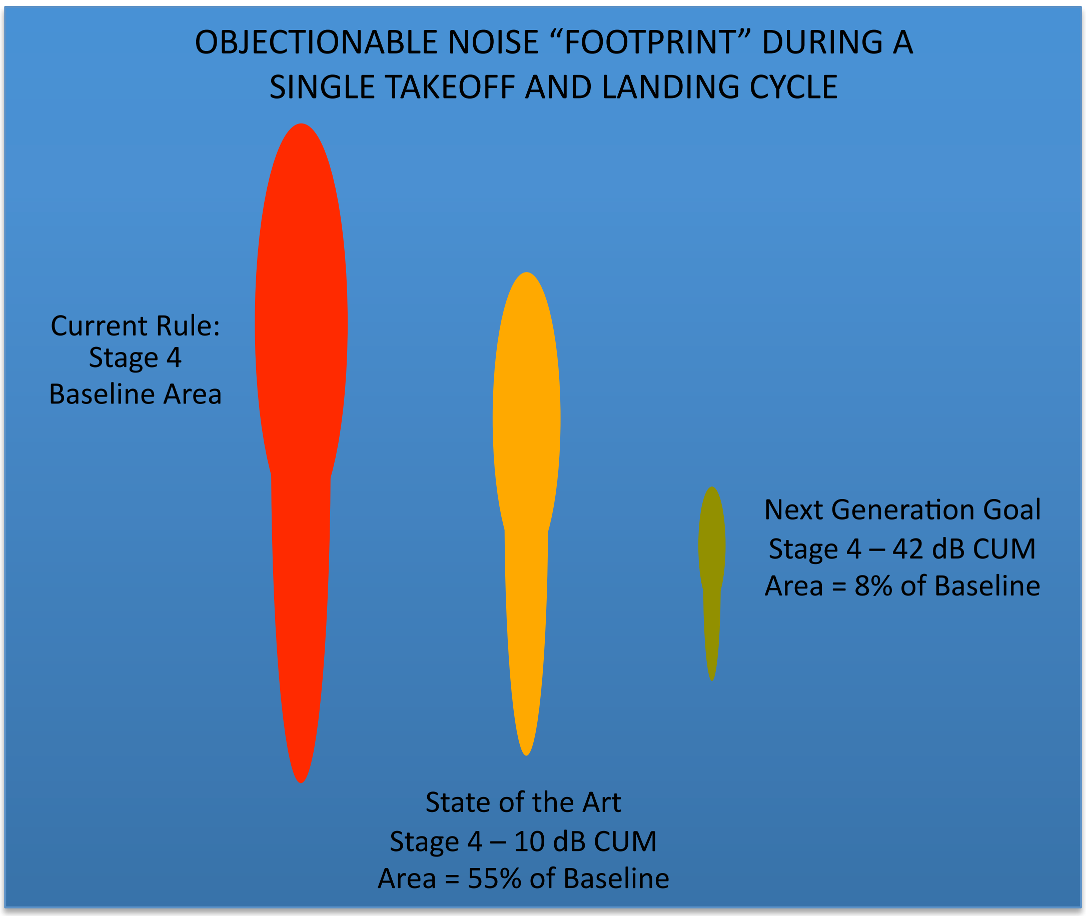
* Projected benefits once technologies are matured and implemented by industry. Benefits vary by vehicle size and mission. N+1 and N+3 values are referenced to a 737-800 with CFM56-7B engines, N+2 values are referenced to a 777-200 with GE90 engines

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

‡ CO_2 emission benefits dependent on life-cycle CO_{2e} per MJ for fuel and/or energy source used

Technology Drivers: Community Noise

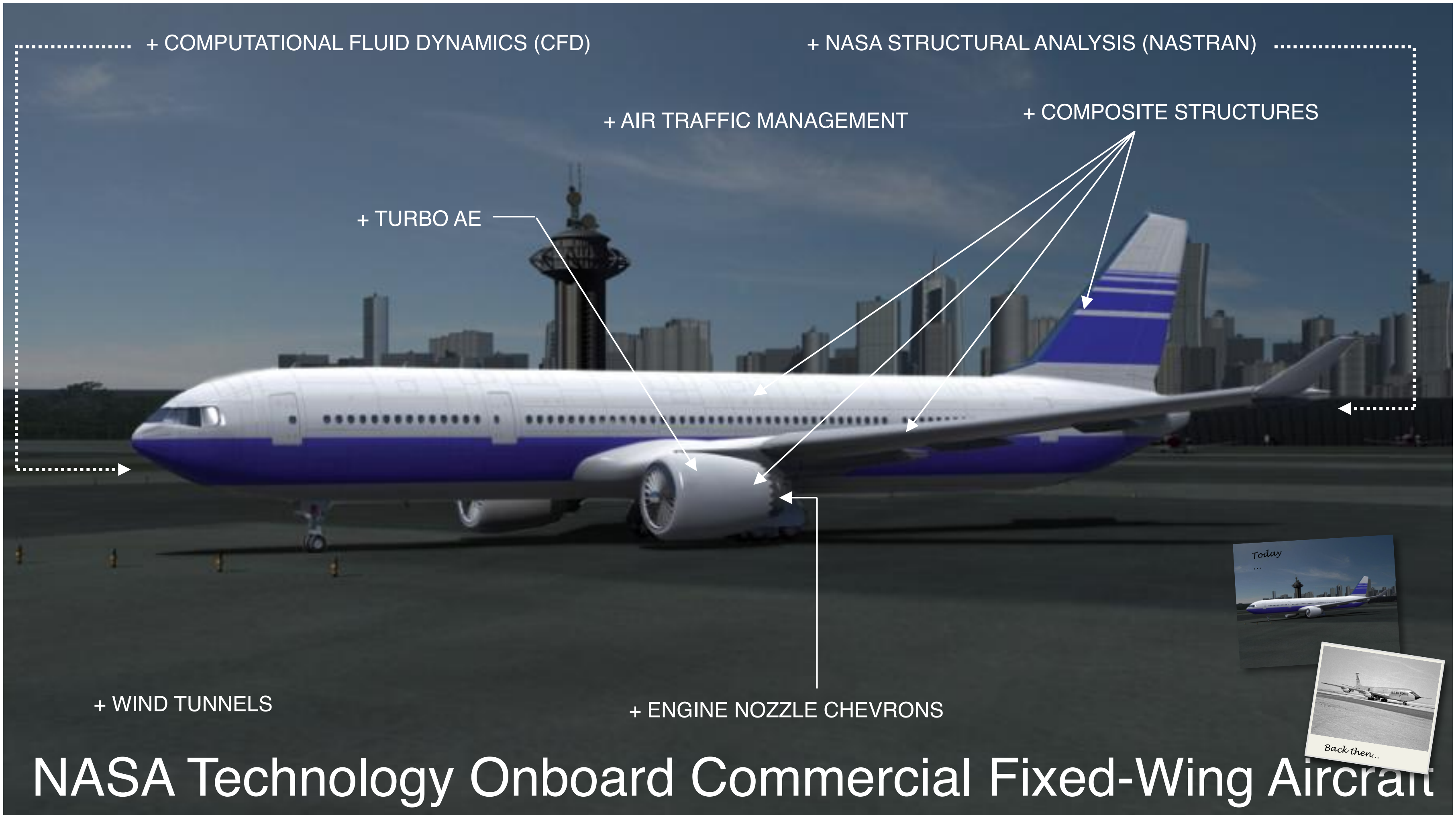
Community Noise Reduction Goal: Contain objectionable noise within the airport boundary.



Credit: NASA.

Technology Advancements: Community Noise

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



Technology Advancements: Community Noise

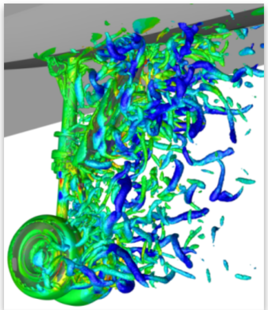
Quiet Airframe

- Conformable surfaces to eliminate gaps between surfaces

High-lift system concept. Credit: NASA.

- Fairing over landing gear

Landing gear fairing concept. Credit: NASA.

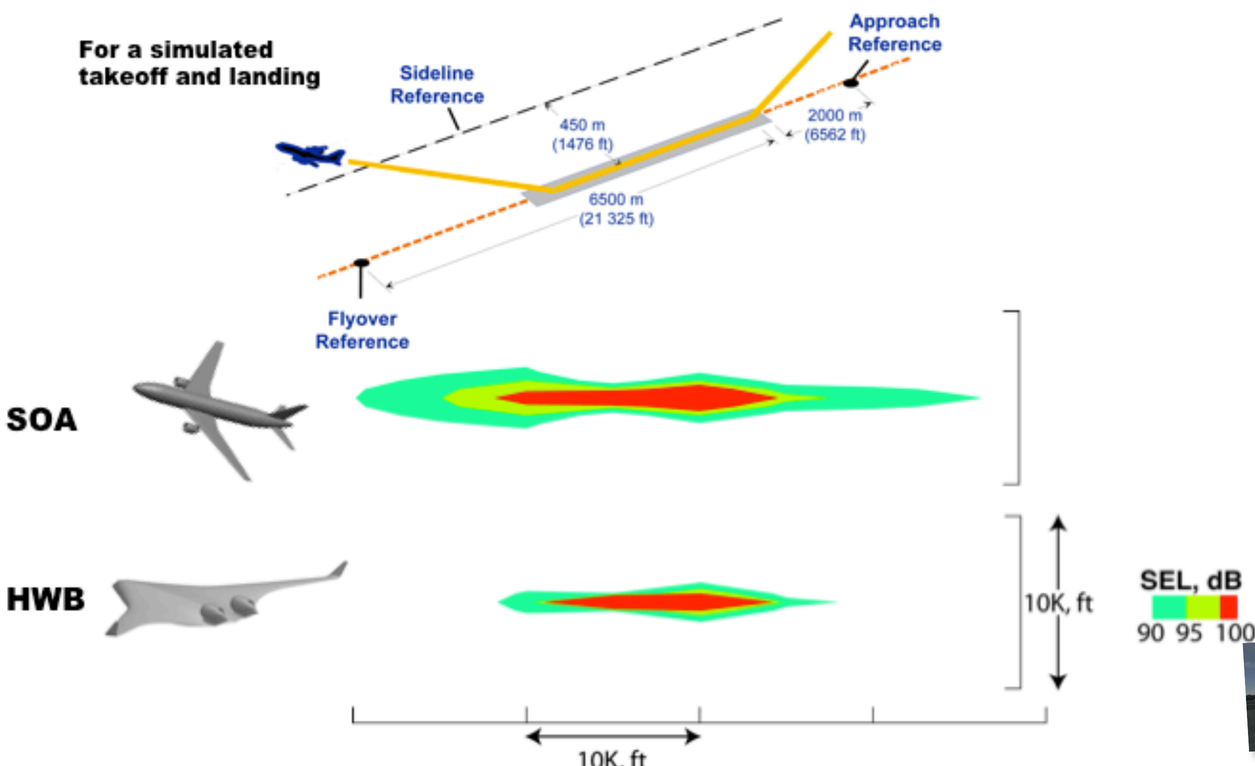


Computed flow visualization behind traditional landing gear. Credit: NASA.

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

AIAA Papers - AIAA 2010-3912, and 3913

Technology Drivers: Energy Efficiency

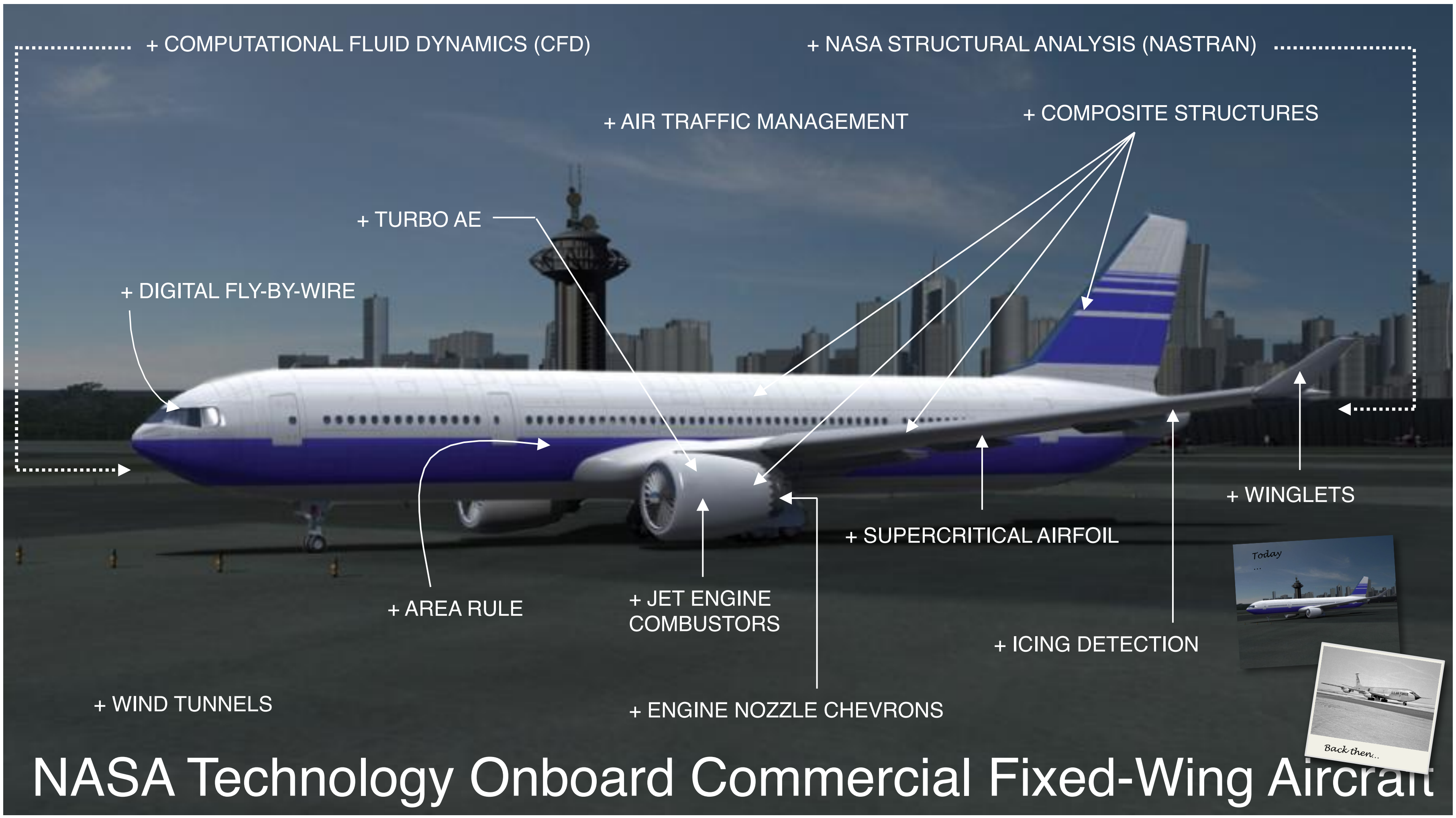
Modern Aircraft Fuel Efficiency

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

Technology Advancements: Energy Efficiency

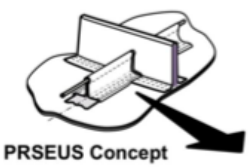
$$\text{Weight}_{\text{Fuel Consumed}} \approx \left(\text{Weight}_{\text{Payload}} + \text{Weight}_{\text{Vehicle}}\right)\left(\frac{\text{Propulsive Efficiency}}{\text{Velocity}}\right)\left(\frac{\text{Drag}}{\text{Lift}}\right)(\text{Range})$$

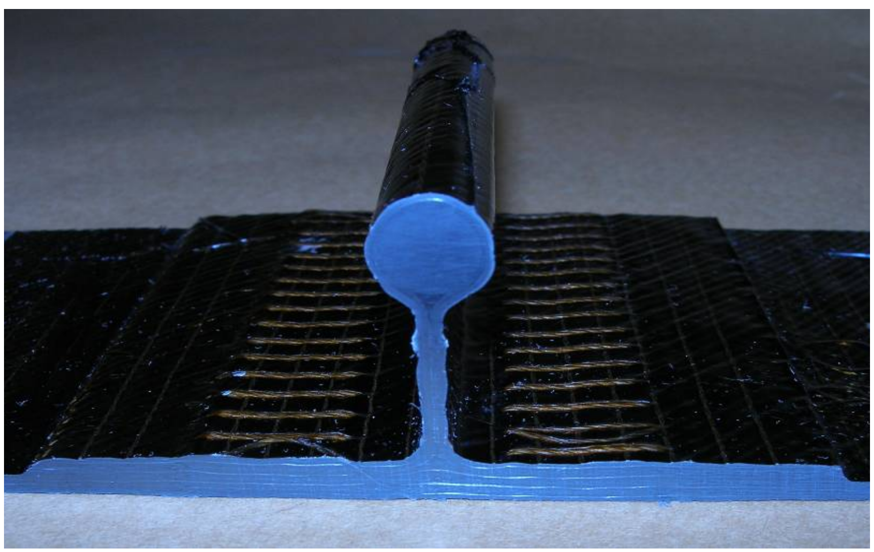


Technology Advancements: Energy Efficiency

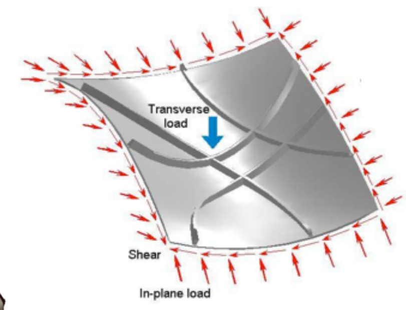
Strong, Lightweight Structures

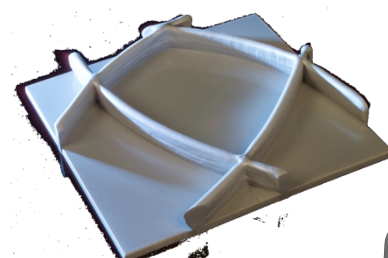
- Stitched composites for non-circular pressurized aircraft bodies





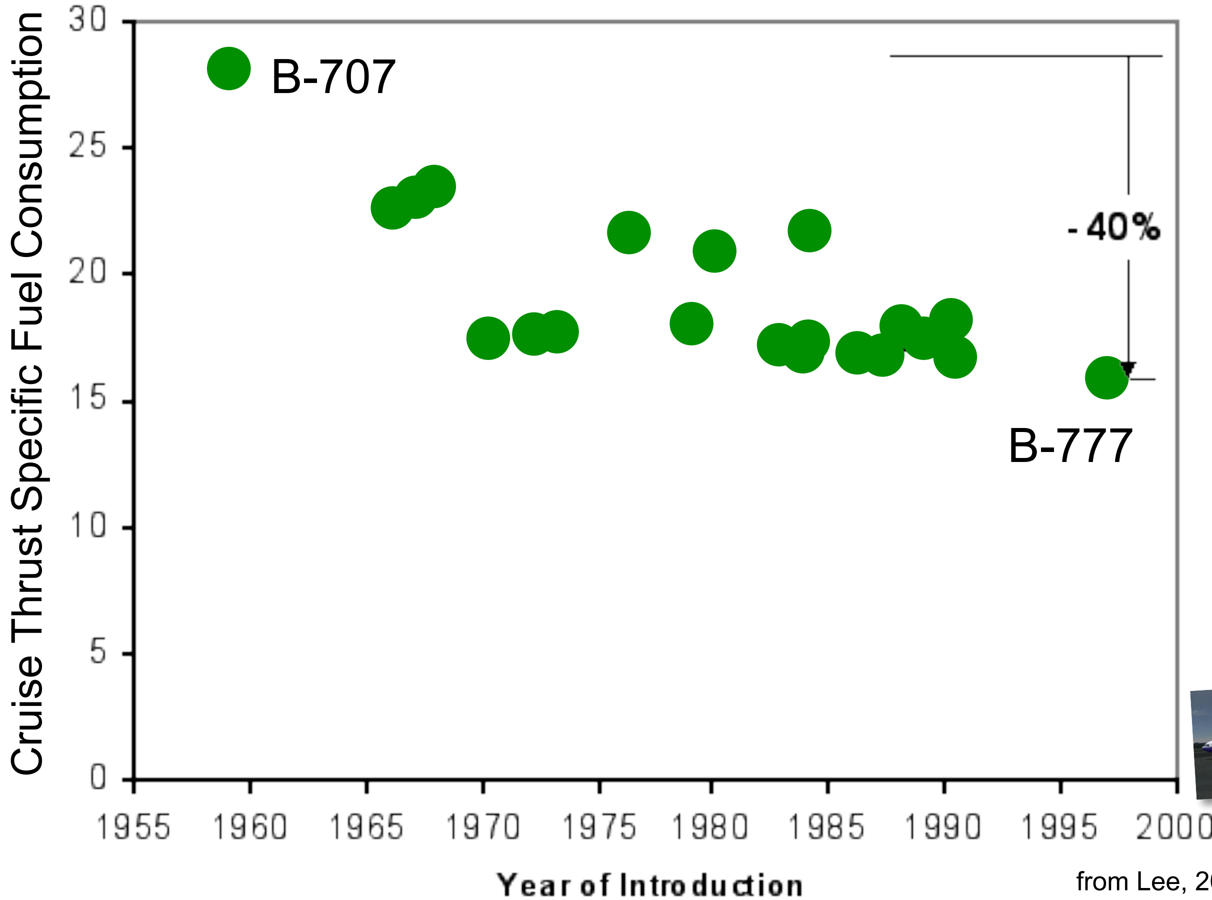
- Structural element layout designed to carry unique loads





Technology Advancements: Energy Efficiency

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

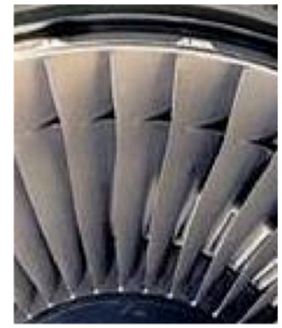


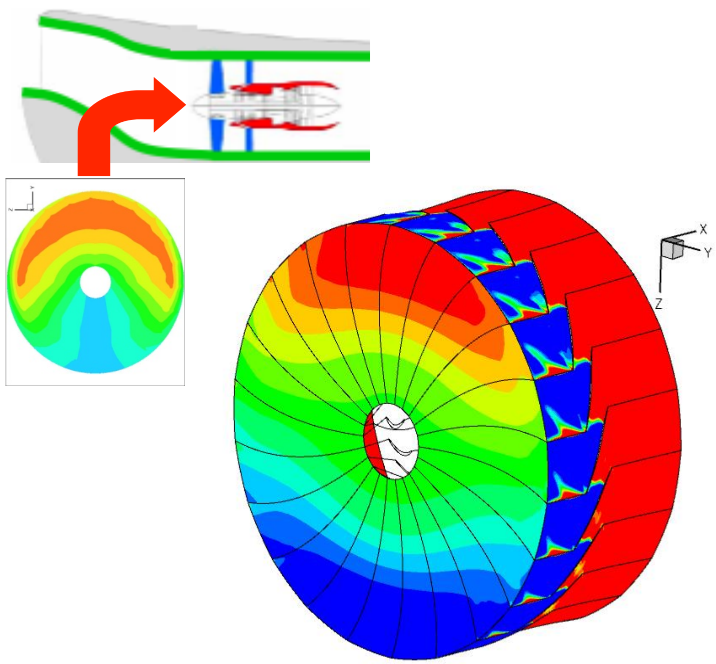
from Lee, 2000

Technology Advancements: Energy Efficiency

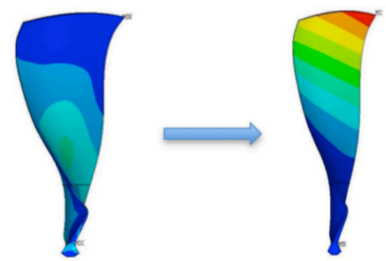
Advanced Turbomachinery

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





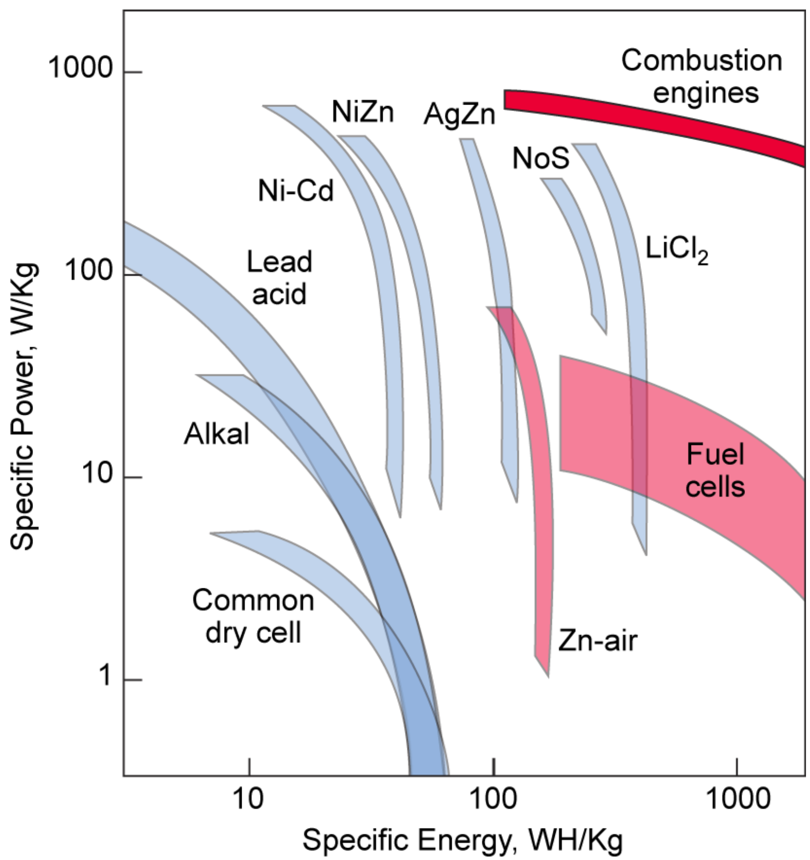
Analysis of fan aerodynamic and structural response to airflow. Credit: NASA.



Adaptive fan blades. Credit: NASA.

Technology Advancements: Energy Efficiency

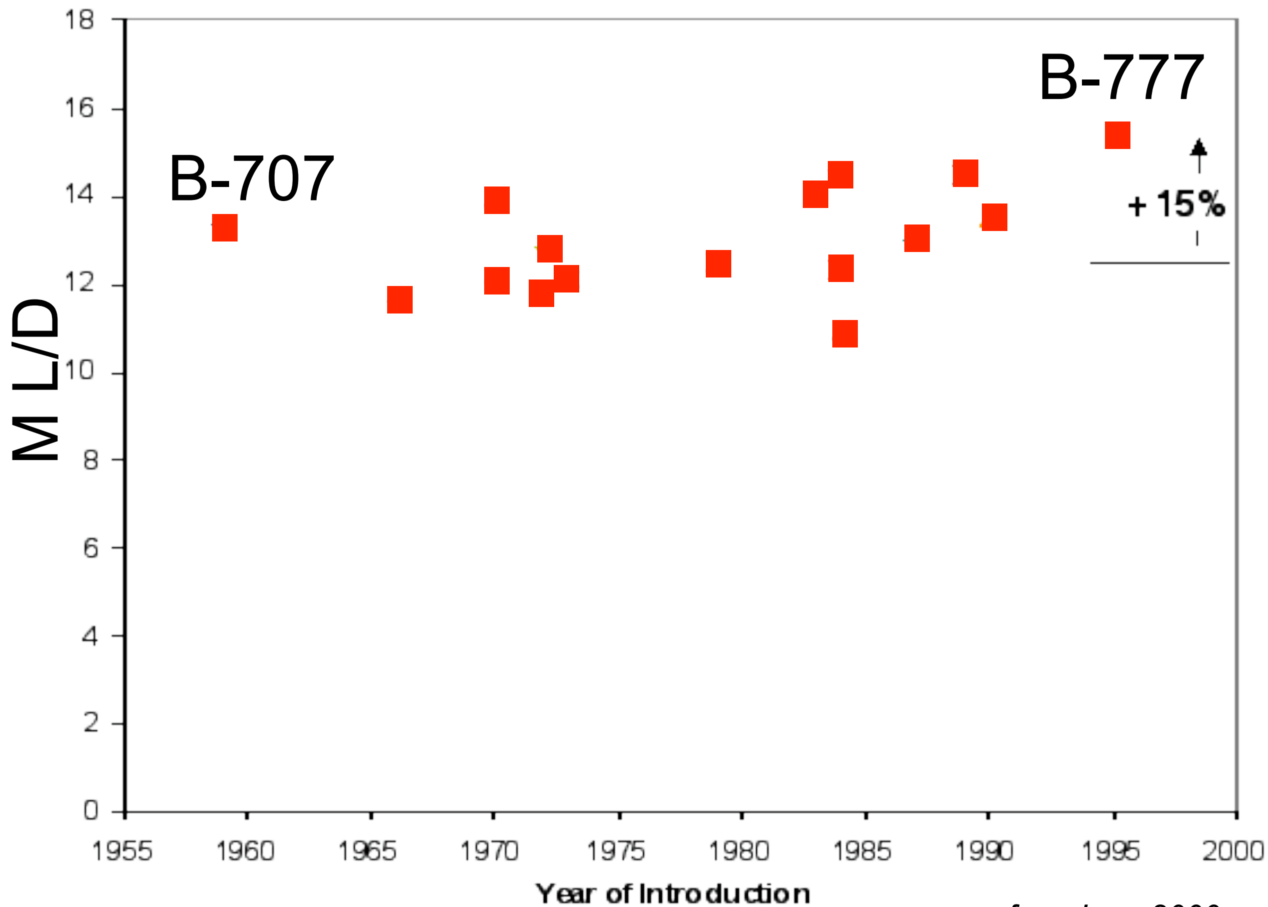
Electric Propulsion



- Electric propulsion challenging for commercial aircraft due to specific energy and specific power requirements
- Hybrid electric propulsion under consideration

Technology Advancements: Energy Efficiency

Increases to the ratio of lift over drag (L/D) have been limited over the last 60 years

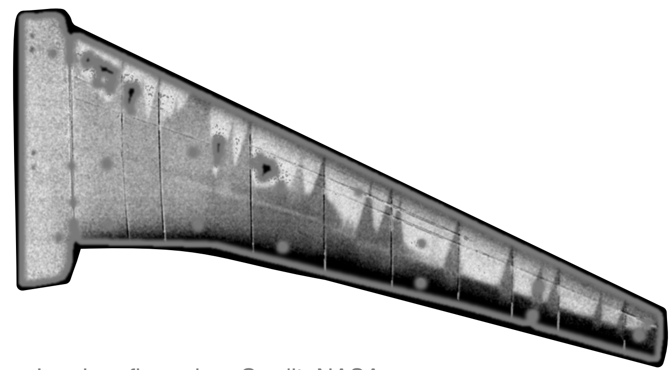


from Lee, 2000

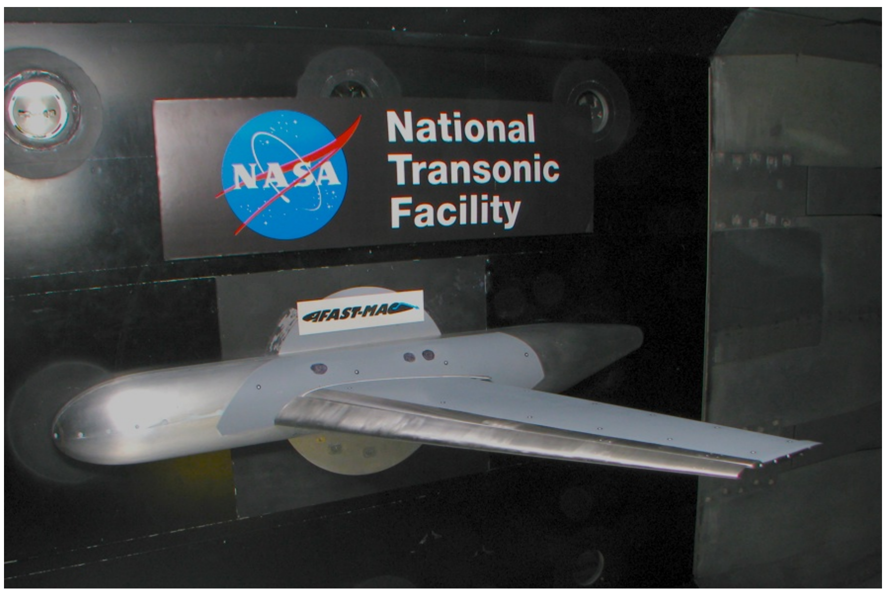
Technology Advancements: Energy Efficiency

Smooth Airflow around Wing

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



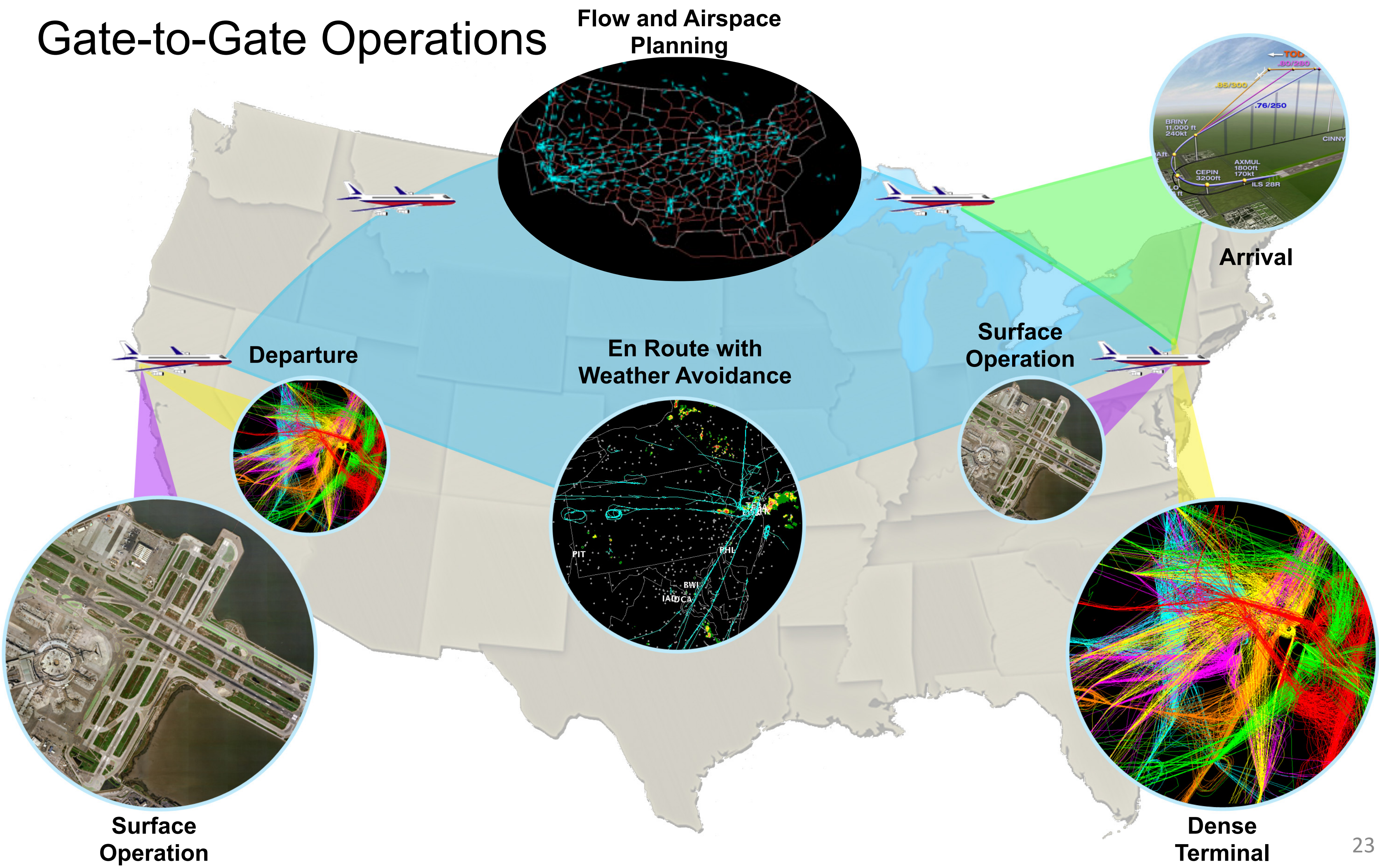
Laminar flow wing. Credit: NASA.



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

Technology Advancements: Energy Efficiency

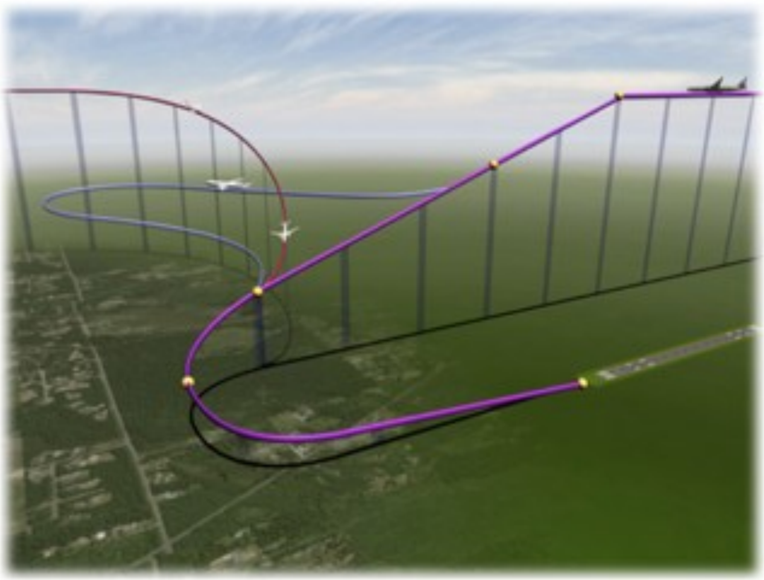
Gate-to-Gate Operations



Technology Advancements: Energy Efficiency

Efficient Traffic Flow Management

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



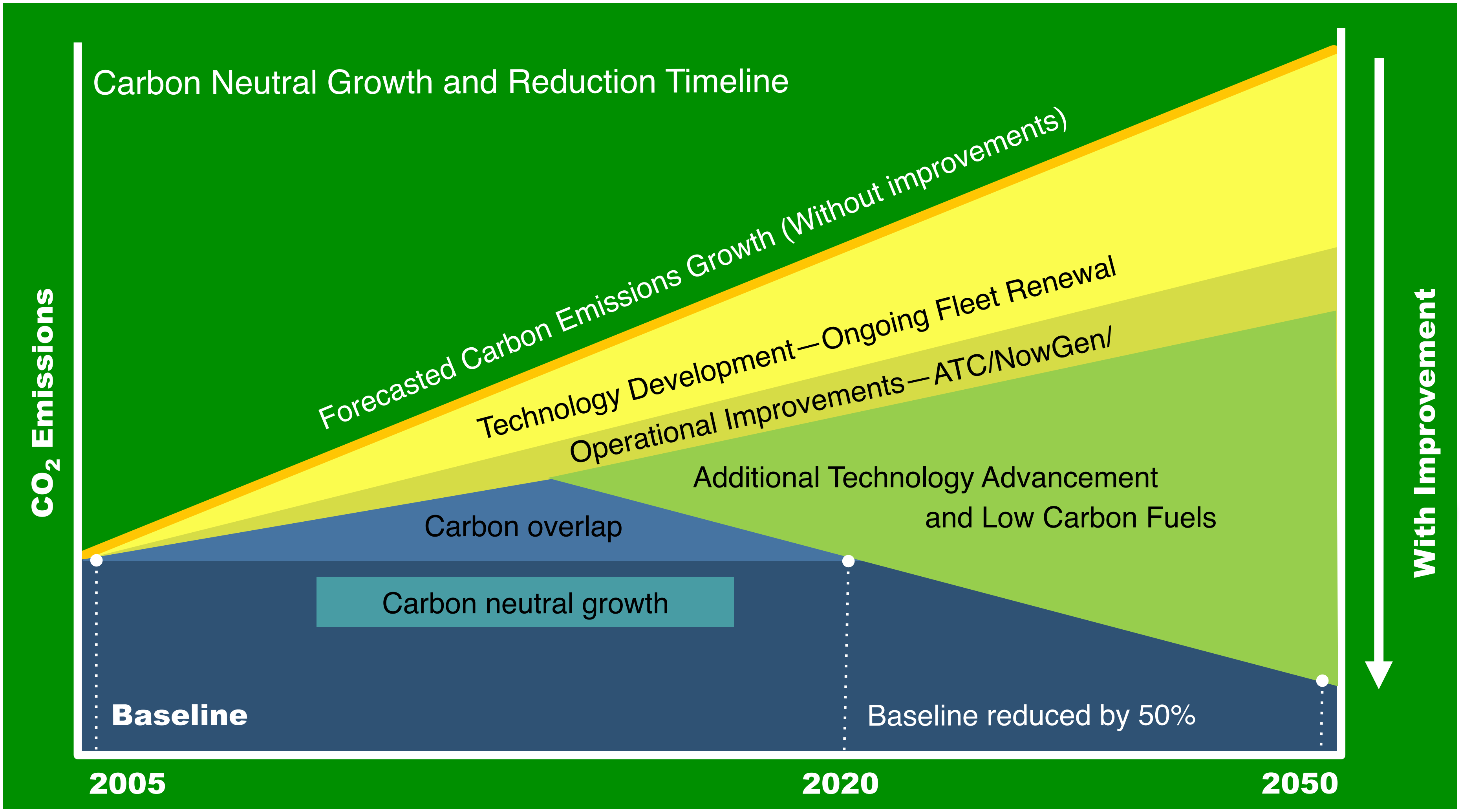
- "No-stop" taxi operations improve movement on the ground

Technology Advancements: Energy Efficiency

Continuous Climbs Departure and Descent Approaches

Technology Drivers: Emissions

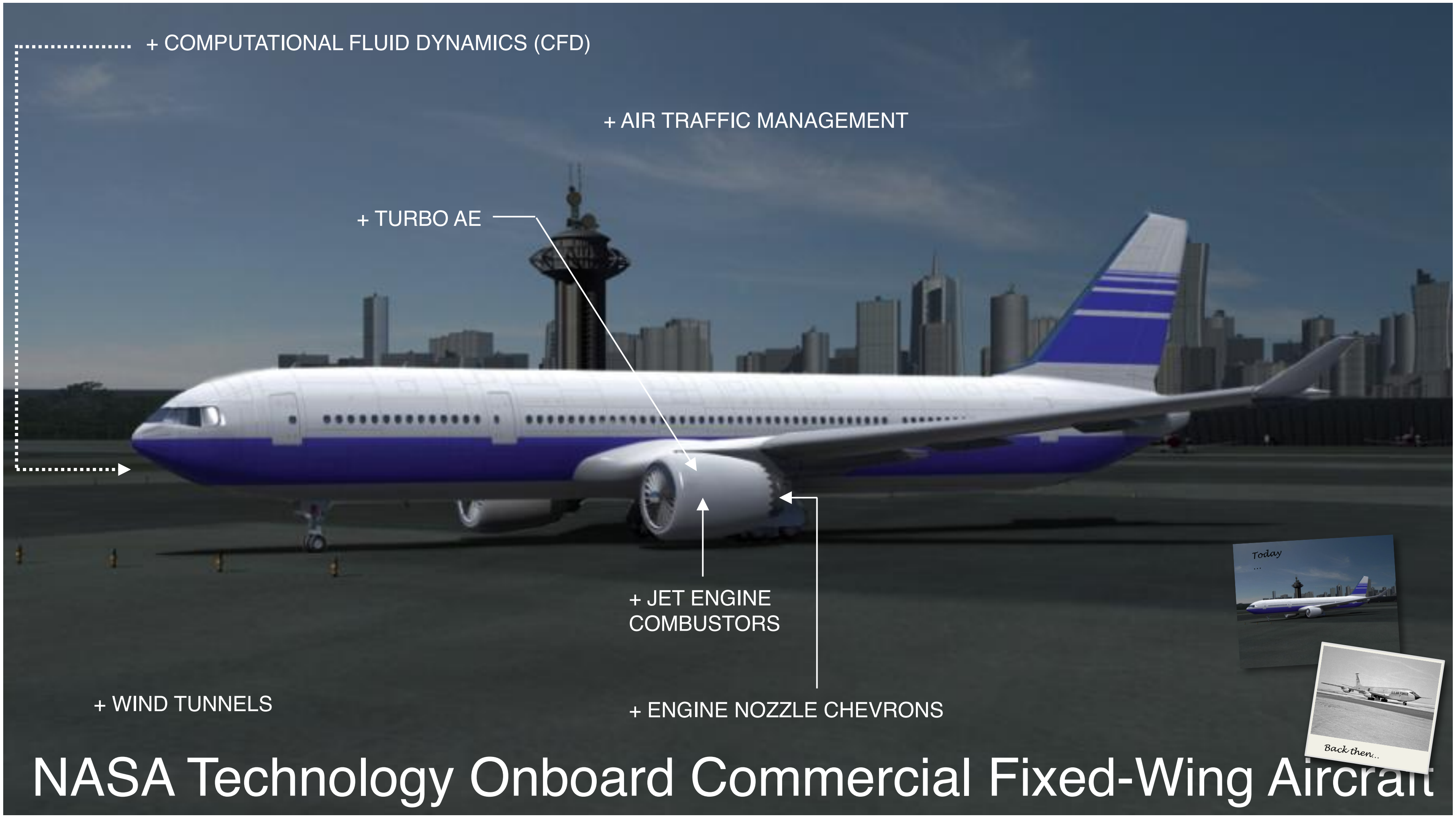
Fleet Emissions Goal: By 2050, substantially reduce carbon emissions, while significantly reducing emissions of oxides of nitrogen



Credit: NASA.

Technology Advancements: Emissions

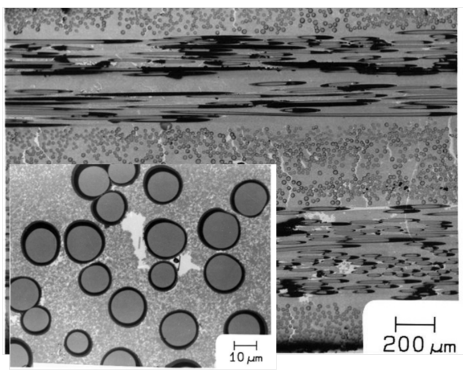
$$\text{Emissions} \approx \left(\text{Weight}_{\text{Fuel Consumed}}\right)\left(\frac{\text{Combustion Efficiency}}{\text{Atmospheric Conditions}}\right)$$



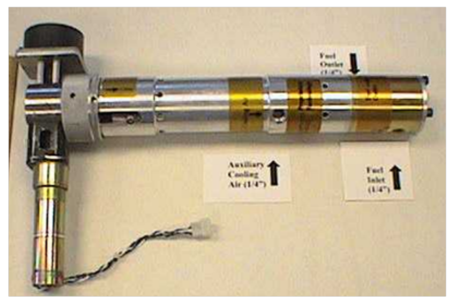
Technology Advancements: Emissions

Advanced Fuel Combustors

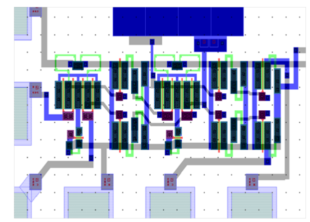
- High temperature material for combustor liners
- Combustion control



High temperature Material. Credit: NASA.



High frequency fuel delivery system. Credit: NASA.



High temperature electronics. Credit: NASA.

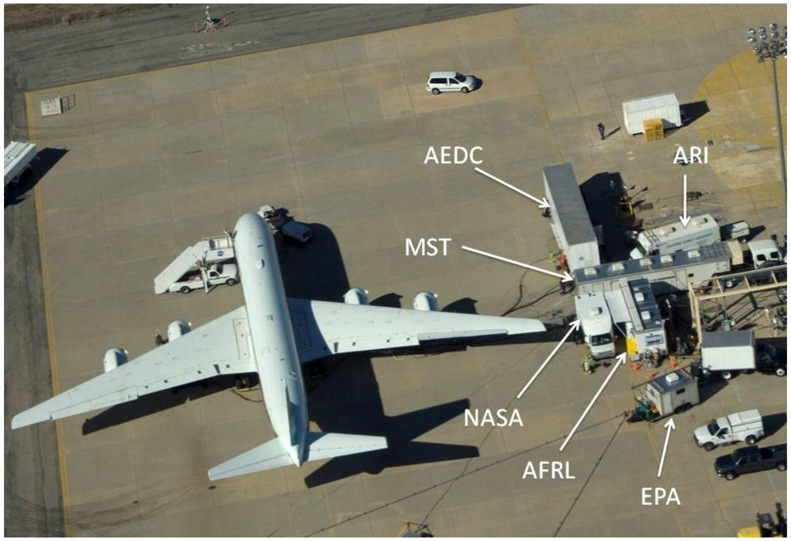
Combustor liner. Credit: NASA.

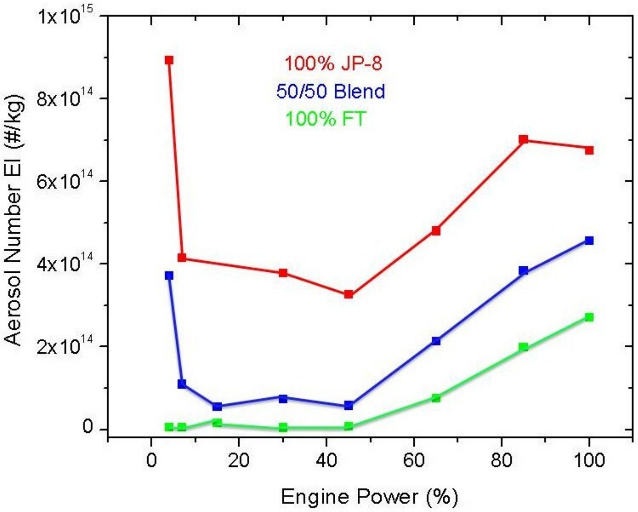
Technology Advancements: Emissions

Alternative Synthetic Fuels

- Developing an understanding of alternative aviation fuels

- First test of 100% Fischer-Tropsch fuel in February 2009

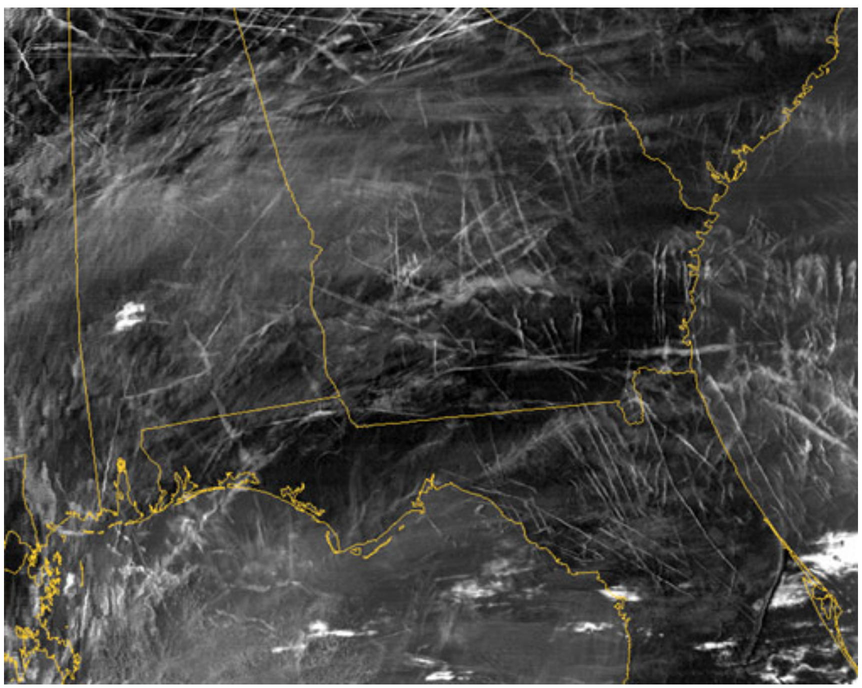




Technology Drivers: Emissions

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

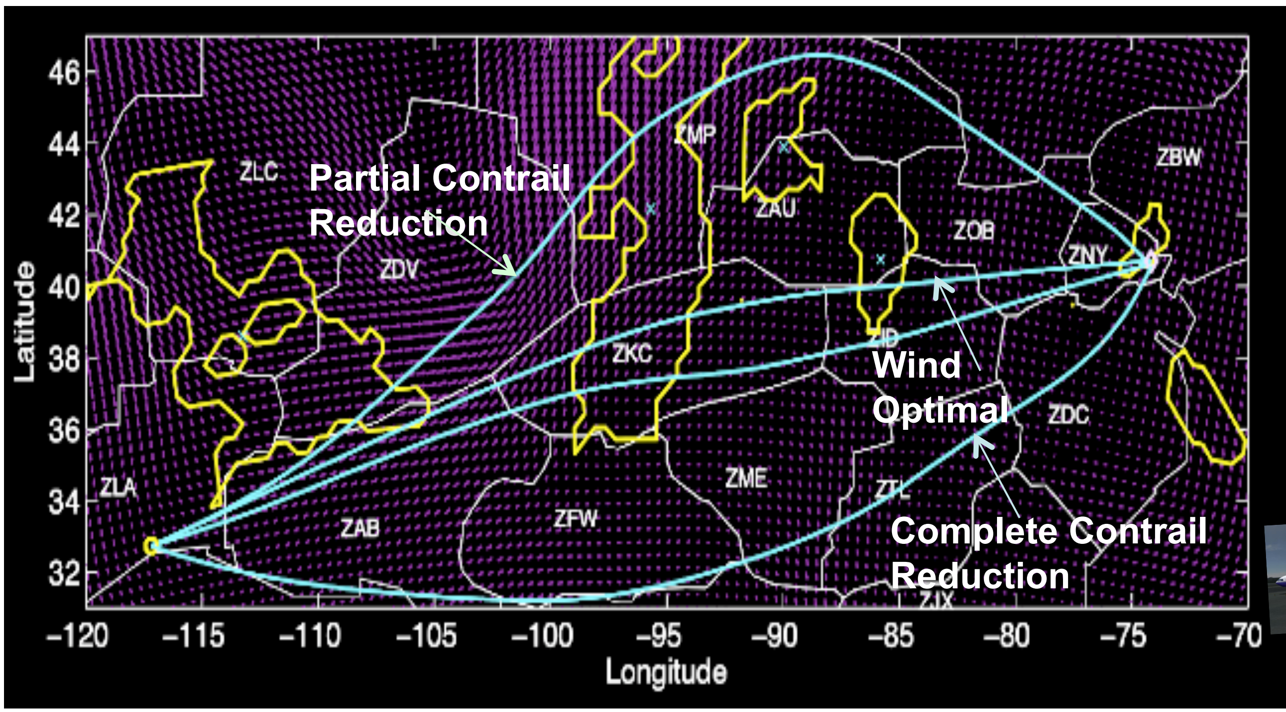
- ✈ Persistent contrails formed in super-saturated and cold air.



Technology Advancements: Emissions

Optimal Aircraft Trajectories to Reduce Contrails

- Alternative operations concept significantly reduces (28-72%) contrails for a small (2%) increase in fuel



Technology Drivers: Integrated System Solution

Simultaneous achievement of improvements to aviation's environmental compatibility and energy efficiency is required to sustain aviation's growth

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	N+1 (2015)	N+2 (2020**)	N+3 (2025)
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** ERA's time-phased approach includes advancing "long-pole" technologies to TRL 6 by 2015

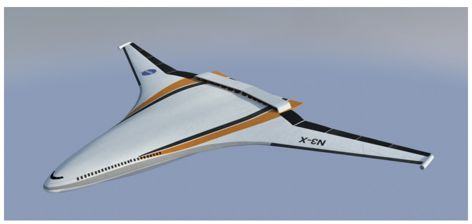
‡ CO_2 emission benefits dependent on life-cycle CO_{2e} per MJ for fuel and/or energy source used

Technology Advancements: Integrated System Solution

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

NORTHROP GRUMMAN Rolls-Royce Sensis Tufts UNIVERSITY SPIRIT AEROSYSTEMS

Technology Advancements: Integrated System Solution

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

imagination at work
Cessna
Georgia Institute of Technology

Technology Advancements: Integrated System Solution

Truss Braced Wing

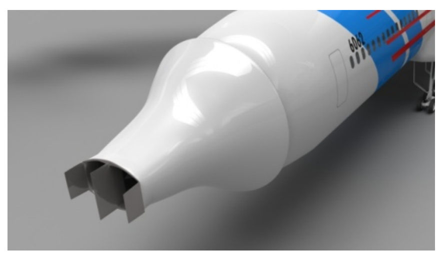
- Long, thin wings (high aspect ratio) supported with a truss brace

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

Technology Advancements: Integrated System Solution

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



NASA VirginiaTech Georgia Institute of Technology

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

Massachusetts Institute of Technology

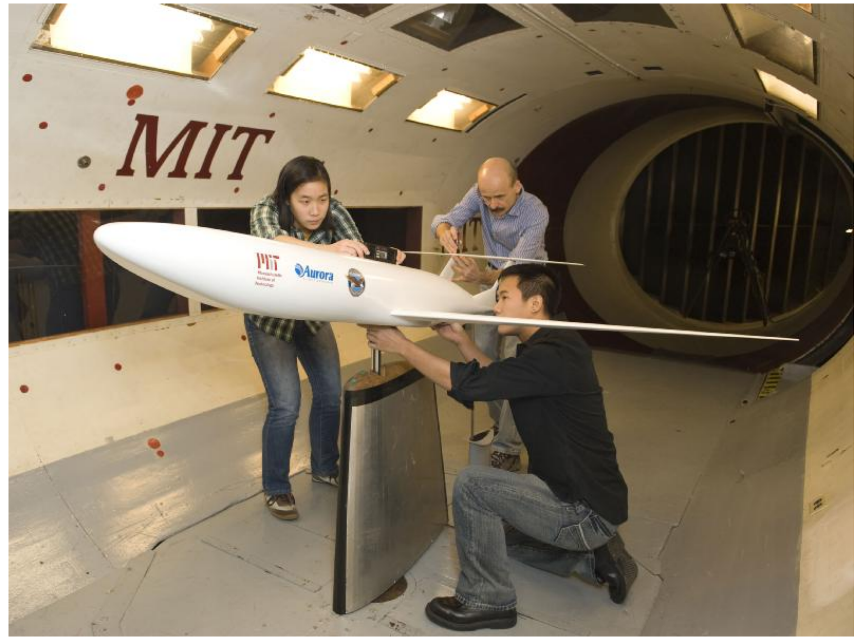
Aurora Flight Sciences

Pratt & Whitney
A United Technologies Company

Technology Advancements: Integrated System Solution

Double Bubble

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



Massachusetts Institute of Technology

Aurora Flight Sciences

Pratt & Whitney
A United Technologies Company

Technology Advancements: Integrated System Solution

Hybrid Wing Body

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

Massachusetts Institute of Technology   Aurora Flight Sciences   Pratt & Whitney A United Technologies Company

Boeing   GE imagination at work   Georgia Institute of Technology

Technology Advancements: Integrated System Solution

Hybrid Wing Body

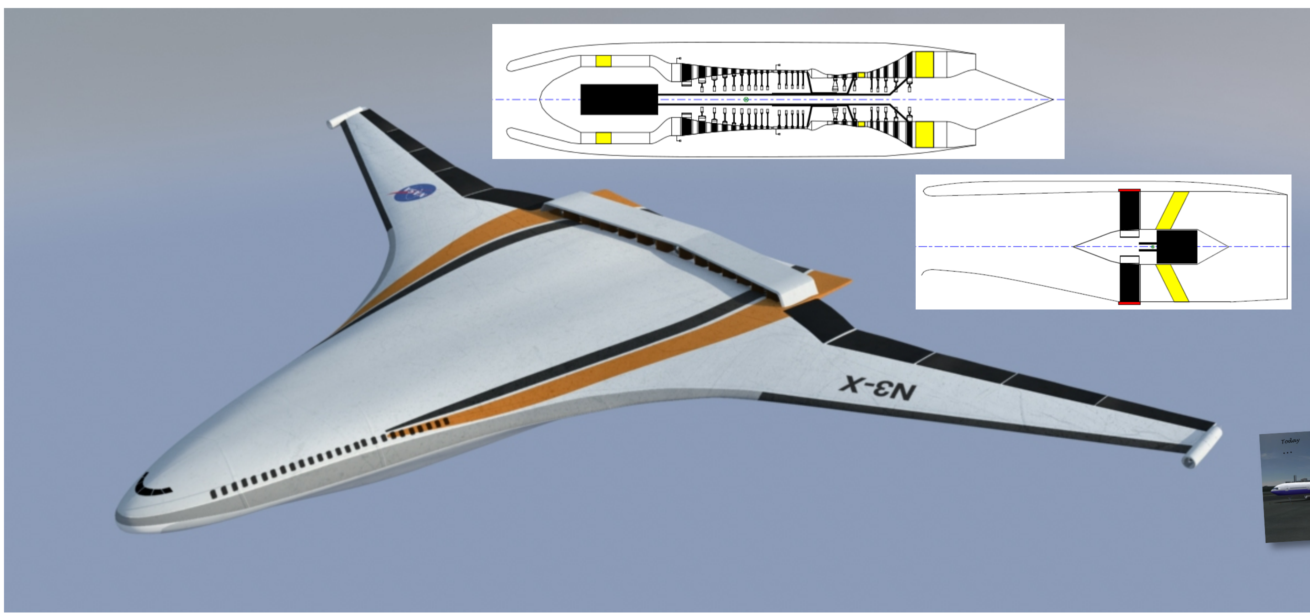
- The unique X-48B Blended Wing Body aircraft has flown more than 80 flights at NASA's Dryden Flight Research Center on Edwards Air Force Base, California

BOEING
CRANFIELD AEROSPACE

Technology Advancements: Integrated System Solution

Turboelectic Distributed Propulsion

- Large engines at wingtips drive superconducting generators
- Electric power from generators powers many small motor-driven propulsors



Technology Advancements: Integrated System Solution

Cruise Efficient Short Take Off and Landing

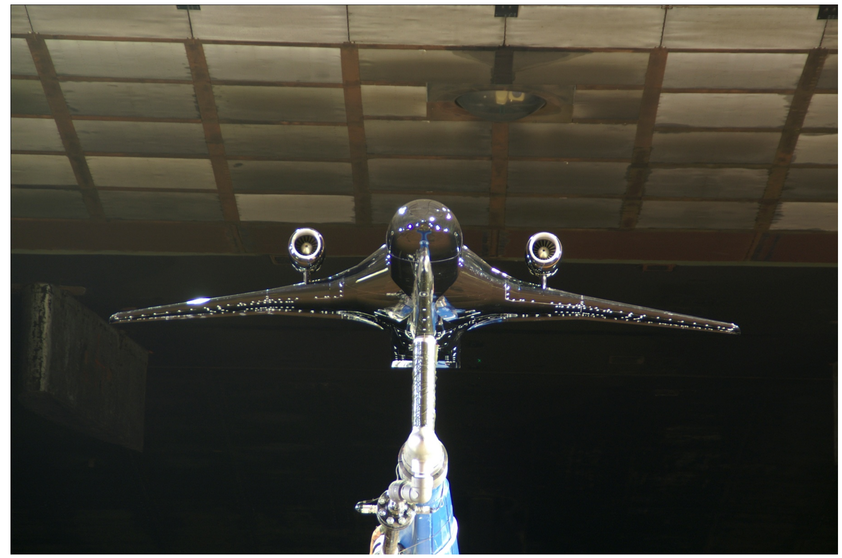
- Enables operation from short runways
- Advanced technologies improve fuel efficiency and noise as compared to state-of-the-art short take off and landing aircraft

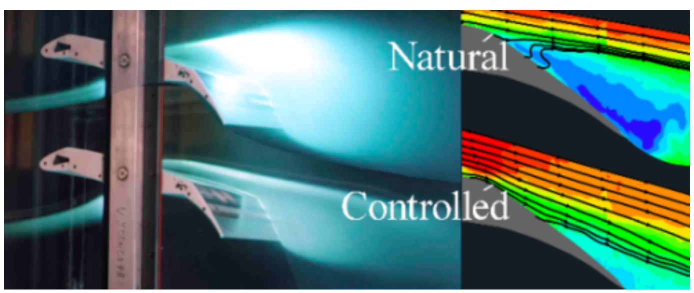
CAL POLY | Georgia Tech Research Institute | DHC ENGINEERING | Patersonlabs

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





CAL POLY | Georgia Tech Research Institute | DHC ENGINEERING | Patersonlabs

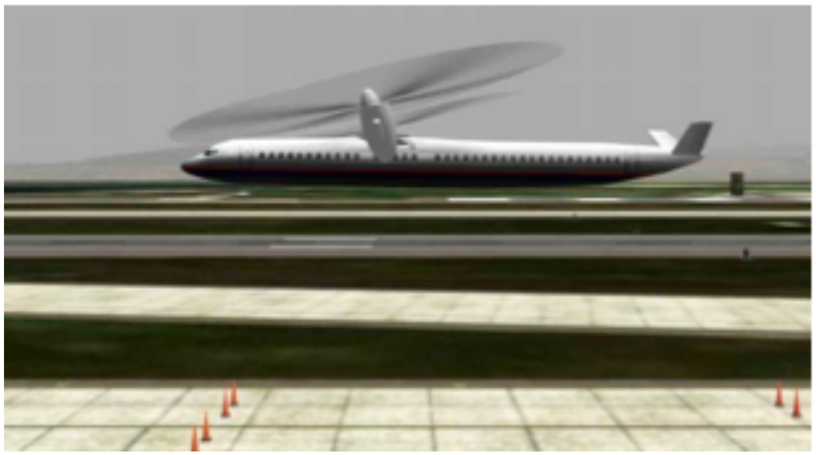
Technology Advancements: Integrated System Solution

Civil Tiltrotor

- Enable simultaneous achievement of vertical take off and landing and high speed cruise

Technology Advancements: Integrated System Solution

Civil Tiltrotor

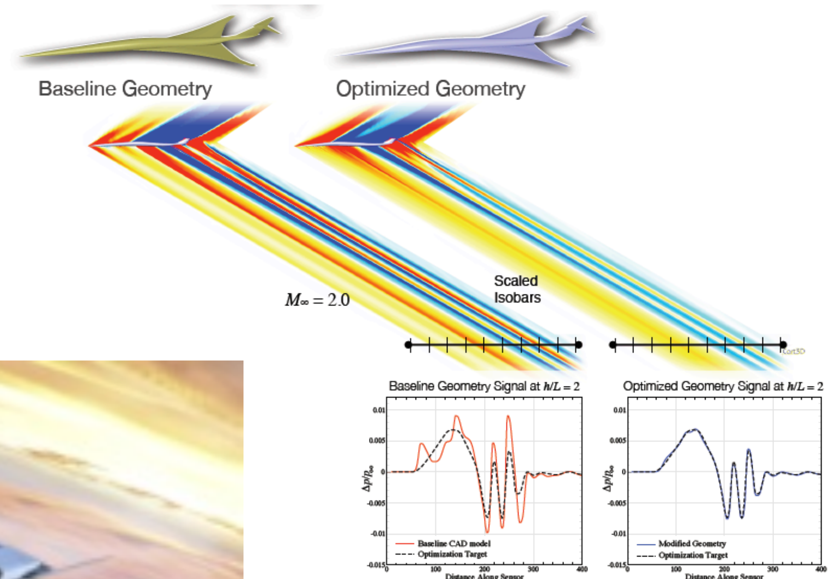


- Flight simulations in the Vertical Motion Simulator at NASA's Ames Research Center study how to improve pilot's ability to maneuver a large civil tiltrotor concept

Technology Advancements: Integrated System Solution

Supersonic Configuration

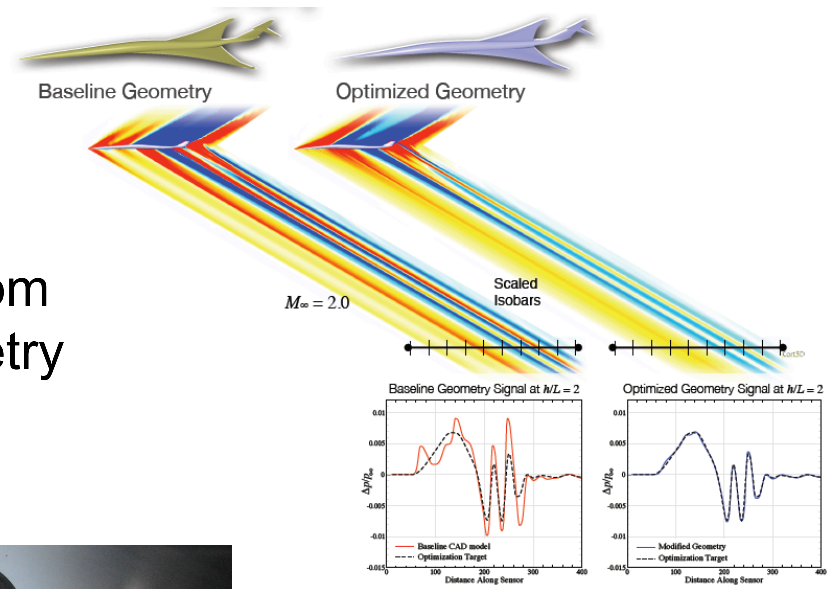
- Optimized geometry softens sonic boom and airport noise

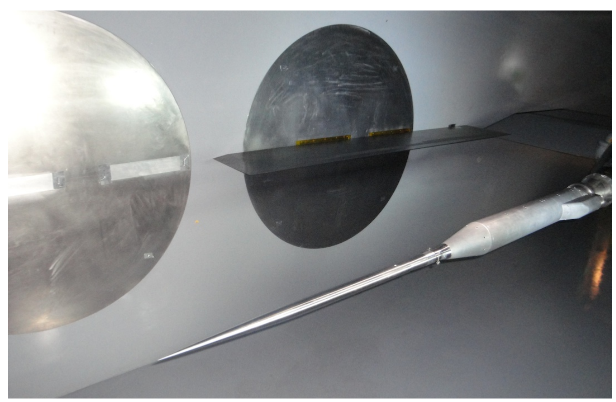


Technology Advancements: Integrated System Solution

Supersonic Configuration

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



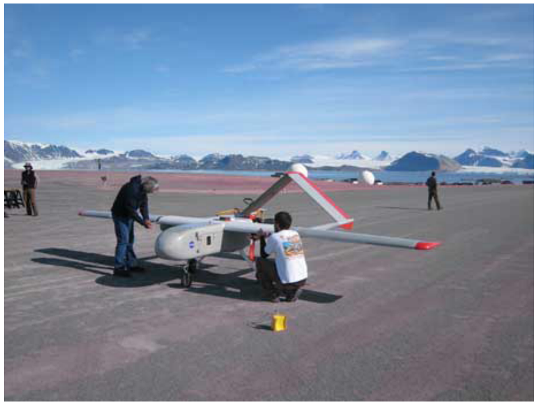


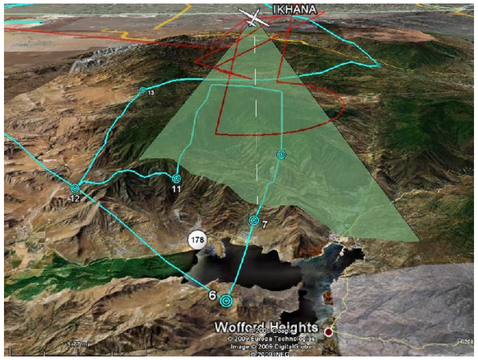
NASA LOCKHEED MARTIN BOEING

Technology Advancements: Integrated System Solution

Unmanned Aircraft Systems

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





Technology Advancements: Integrated System Solution

Airships

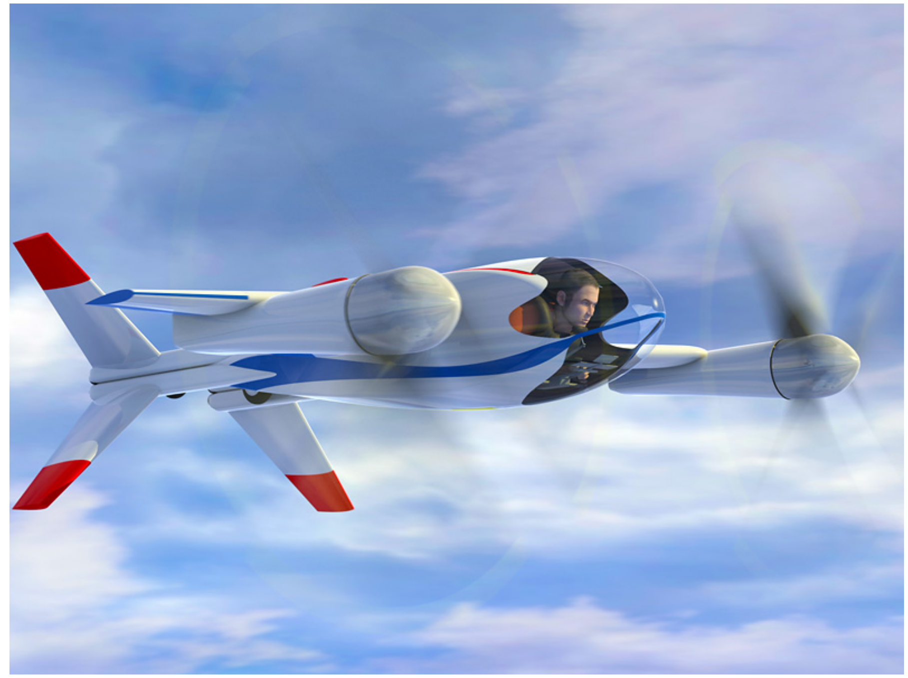
- Lighter-Than-Air Airship operations are inherently energy efficient and low noise

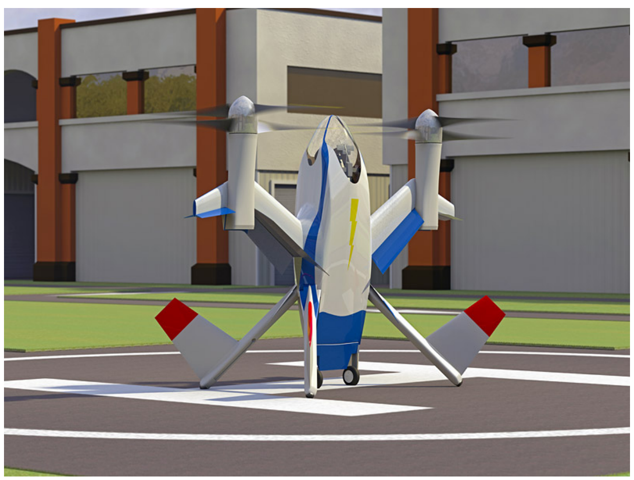
- Beneficial for heavy lift and slow transport

Technology Advancements: Integrated System Solution

Personal Air Vehicle

- The Puffin (pictured) is an electric powered, 12-foot long, 14.5-foot wingspan personal air vehicle





Massachusetts Institute of Technology

Georgia Institute of Technology

National Institute of Aerospace

M-DOT Aerospace

The Advancement of Commercial Aircraft Design

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

BACK-UP

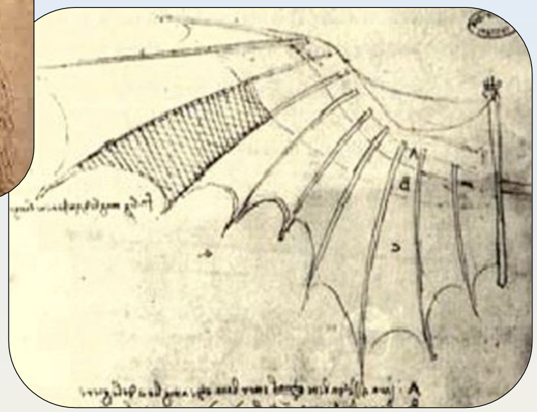
NASA Aeronautics Video
"with you when you fly"

Technology Advancements: The Next Generation

Café challenge?

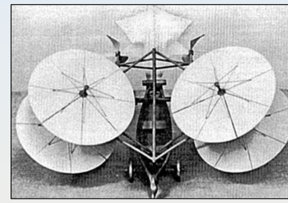
The Beginnings of Commercial Aircraft Design

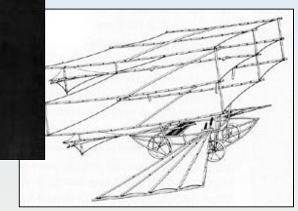
Leonardo da Vinci
(1452 – 1519)



one of the world's greatest thinkers

Sir George Cayley
(1773 – 1857)

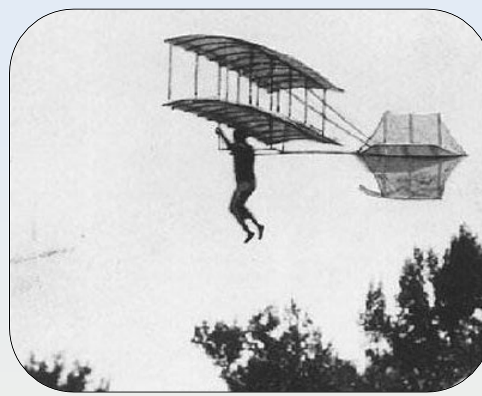




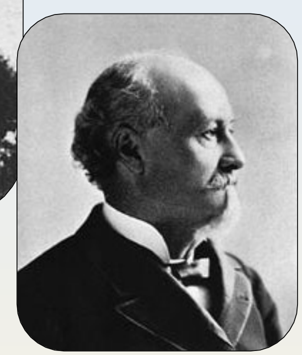
built the world's first glider capable of carrying a human

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

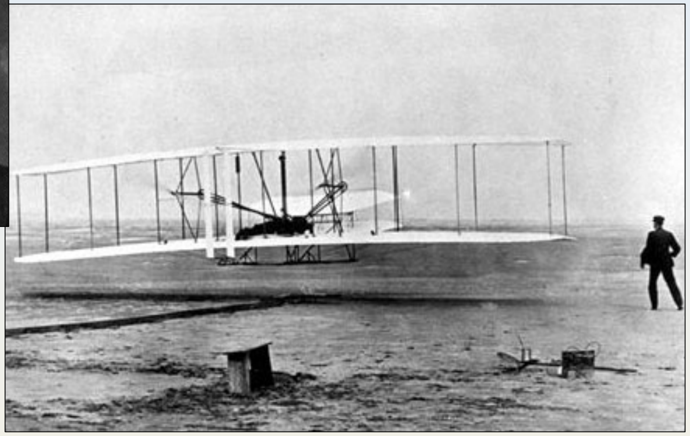
The Beginnings of Commercial Aircraft Design

The Wright Brothers

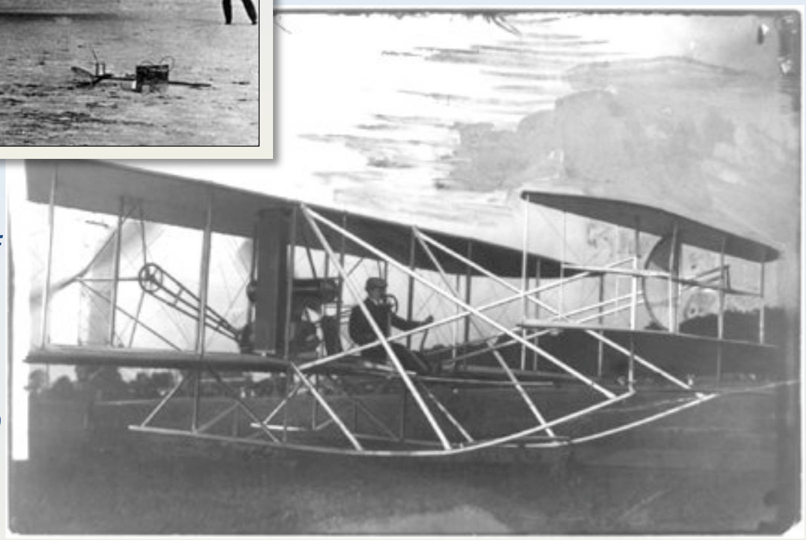
Wilbur Wright
(1867 – 1912)

Orville Wright
(1871 – 1948)

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



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

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

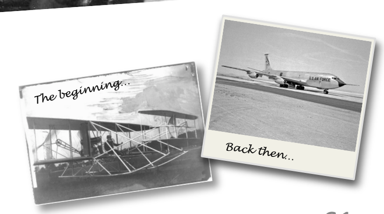
FAA's attempt to reconfigure New York airspace resulted in 14 lawsuits due to noise complaints

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

Technology Advancements: The Golden Age

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."



Technology Advancements: The Modern Era

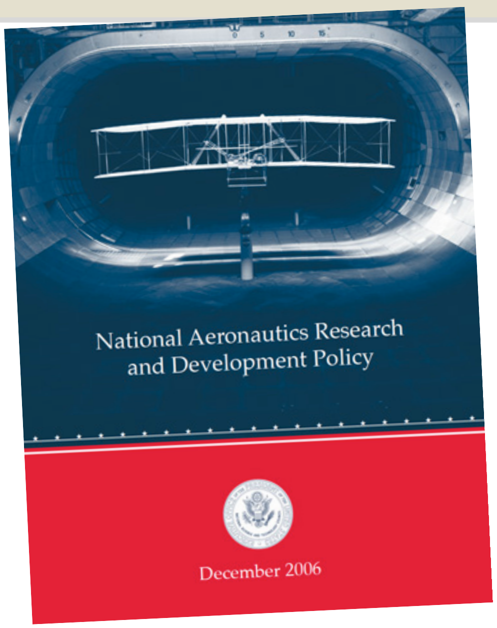
The Space Act of 1958

"…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…"

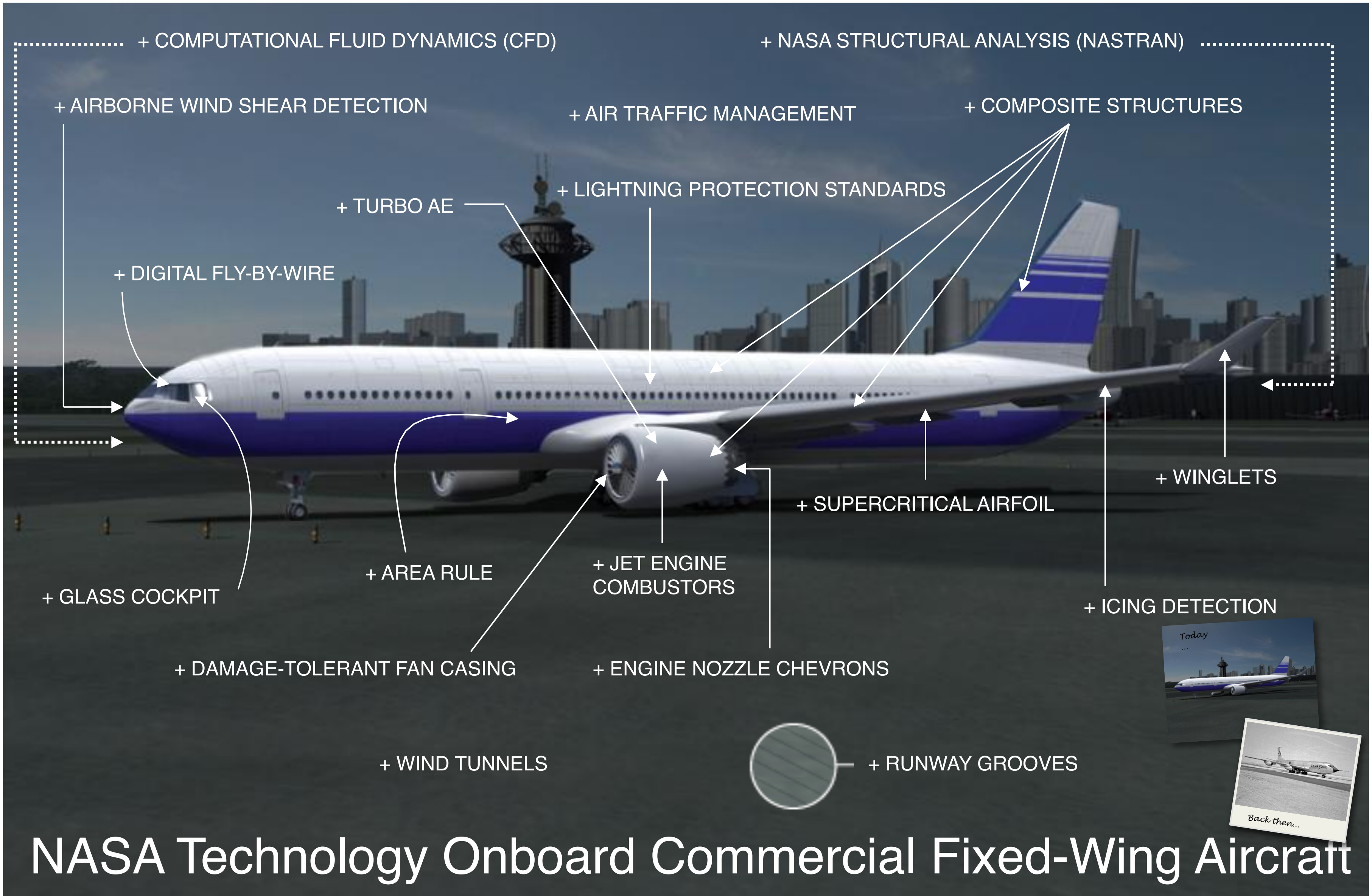
Technology Advancements: The Next Generation

National Aeronautics Research and Development Policy

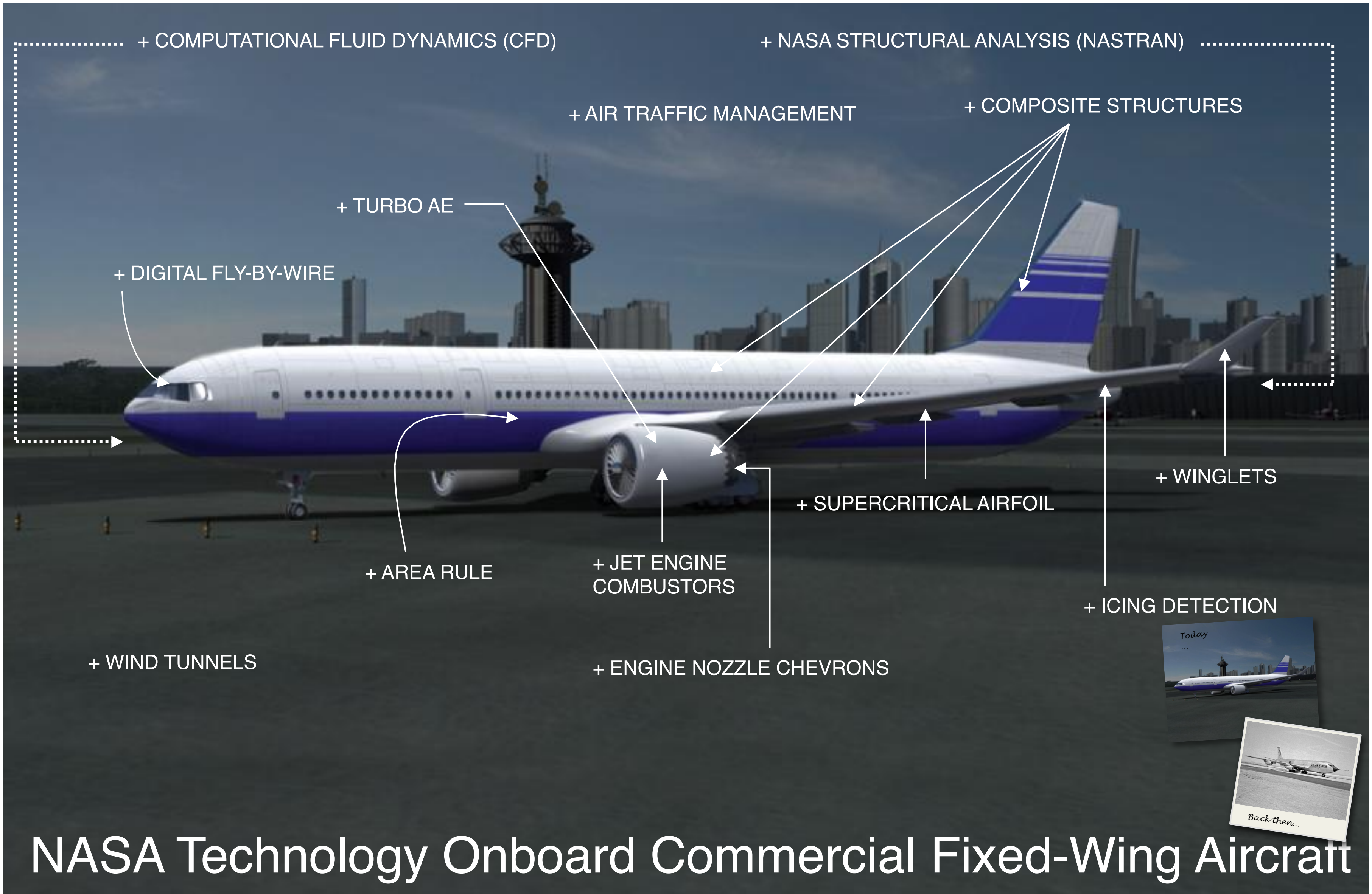
"The National Aeronautics and Space Administration (NASA) should maintain a broad foundational research effort aimed at preserving the intellectual stewardship and mastery of aeronautics core competencies so that the nation's world-class aeronautics expertise is retained"



Technology Advancements: The Modern Era



Technology Advancements: ????



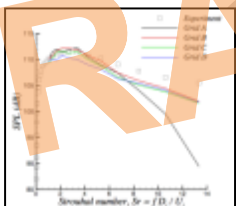
Technology Advancements: Community Noise

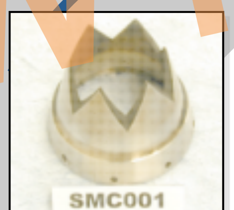
- Chevrons – The Road From Idea to Deployment

Initial service entry, 2002

Systems Assessment: 2001-2005

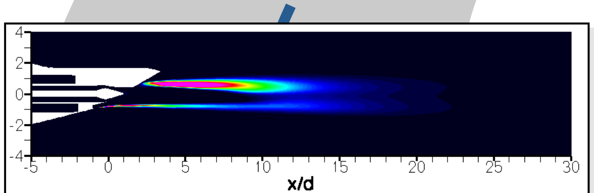
- *Ground-test evaluation in engine test stands*
- *Flight evaluation in relevant environments*





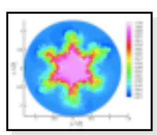
Fundamental Research: 1996-2000

- *Computational and experimental research to develop a fundamental understanding of the fluid mechanics governing the effectiveness of the concept*
- *Development of practical implementations (chevrons)*



Seedling Idea: 1994-1996

Basic studies on jet mixing suggest that tabs can enhance jet mixing, with the potential to reduce noise



67