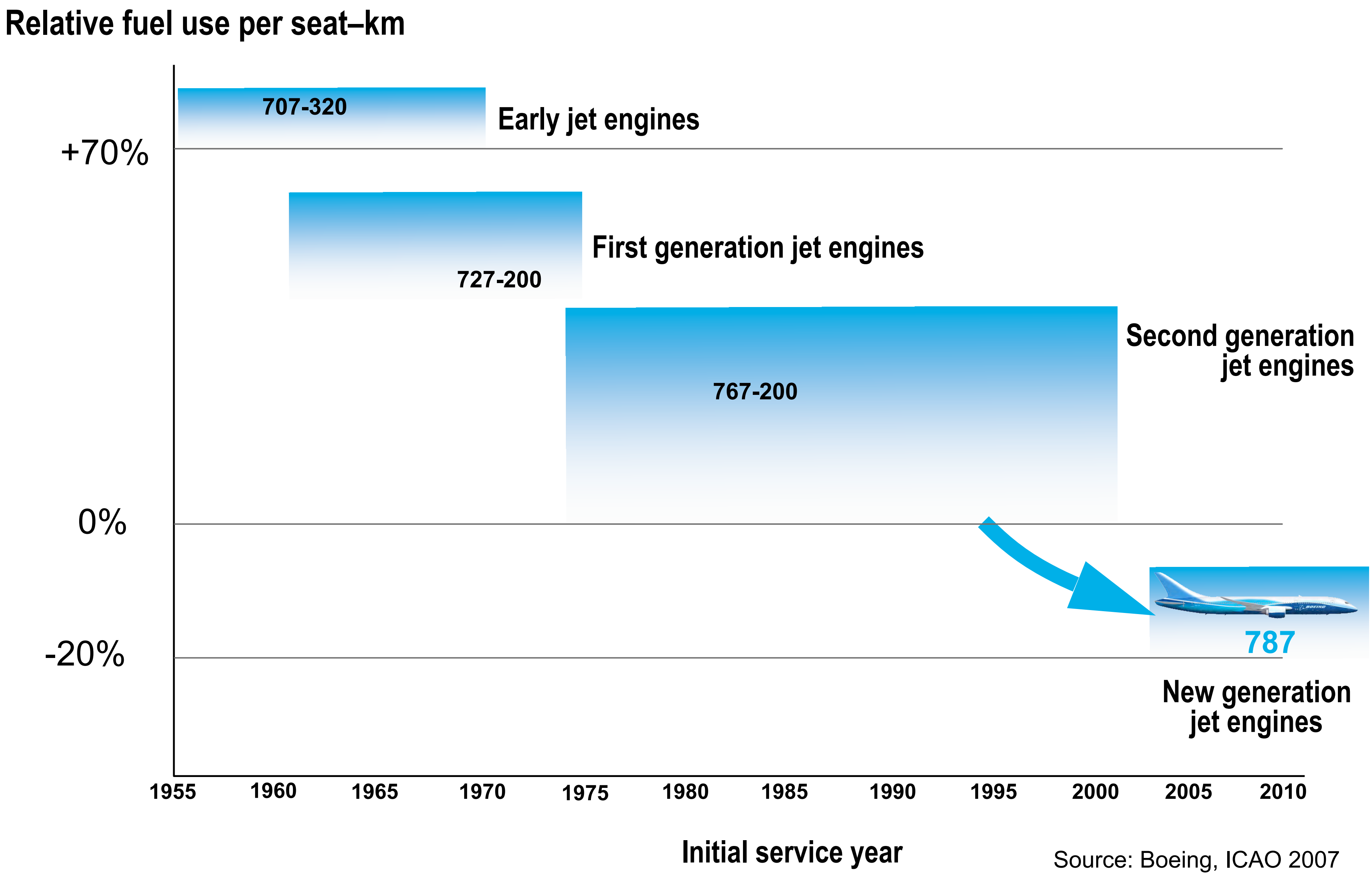
Sustainable Aviation:

Future Air Transportation and the Environment

Ilan Kroo

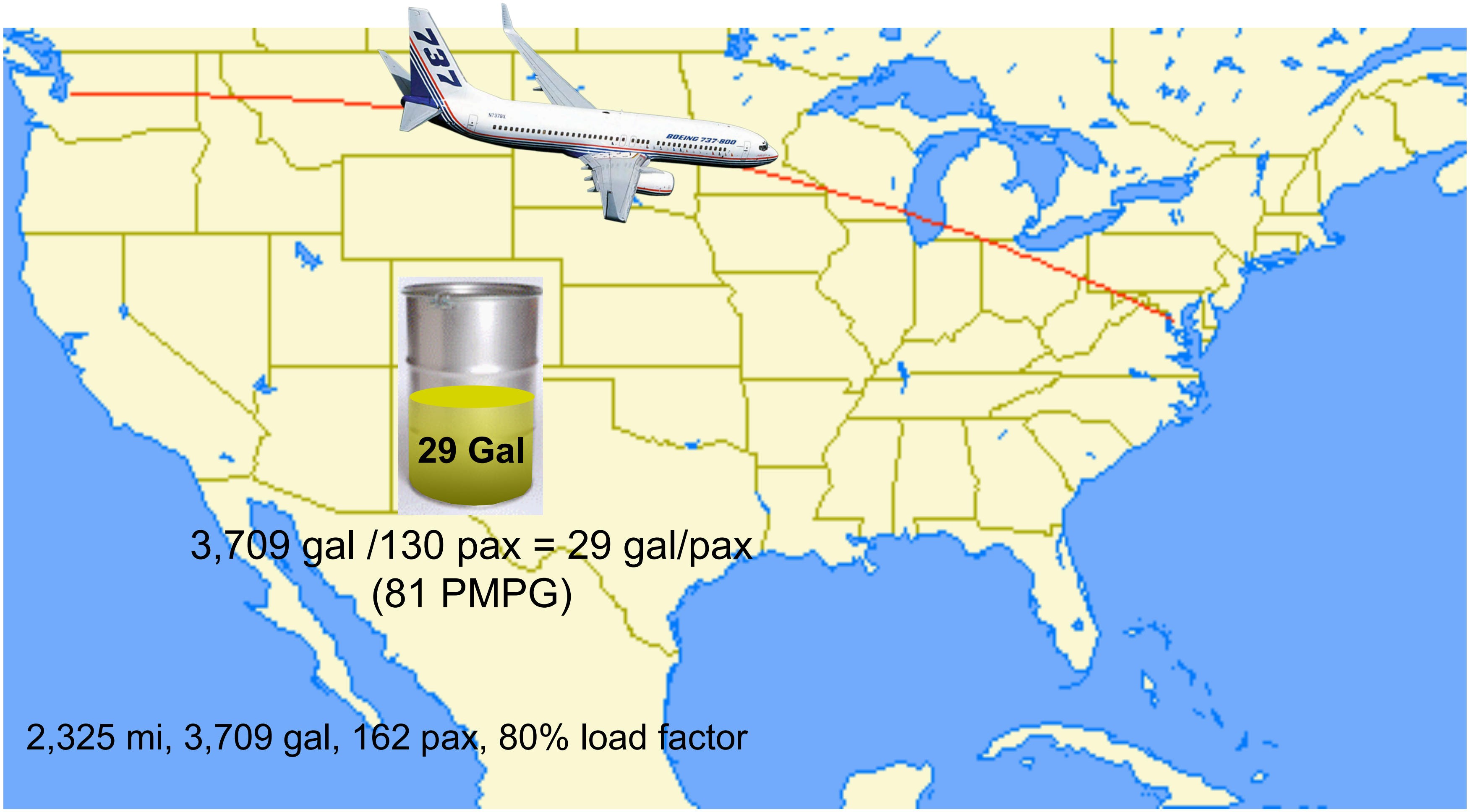
Modern Aircraft Fuel Efficiency



Source: Boeing, ICAO 2007

Modern Aircraft Fuel Efficiency

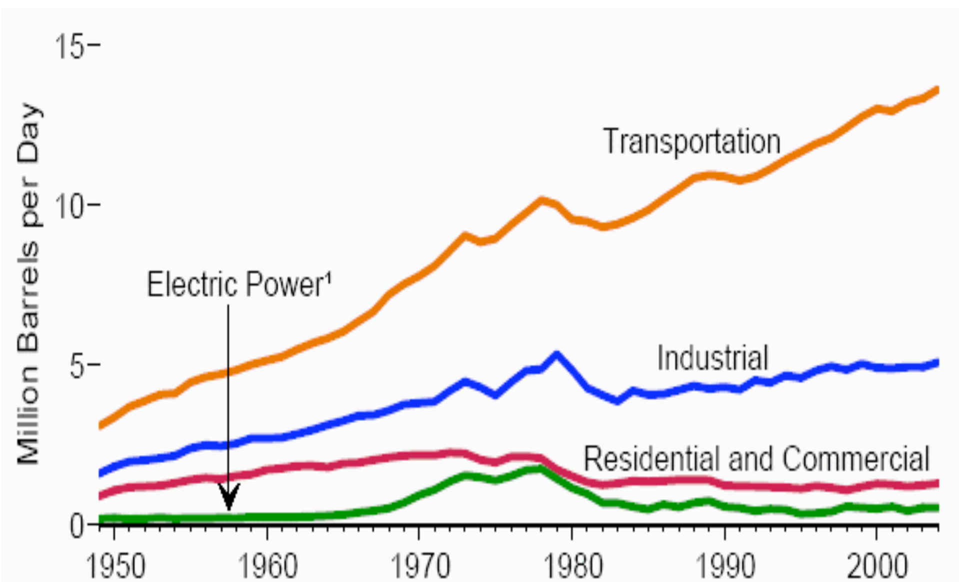
For a flight from Seattle to Washington D.C., each passenger needs about 29 gallons of fuel

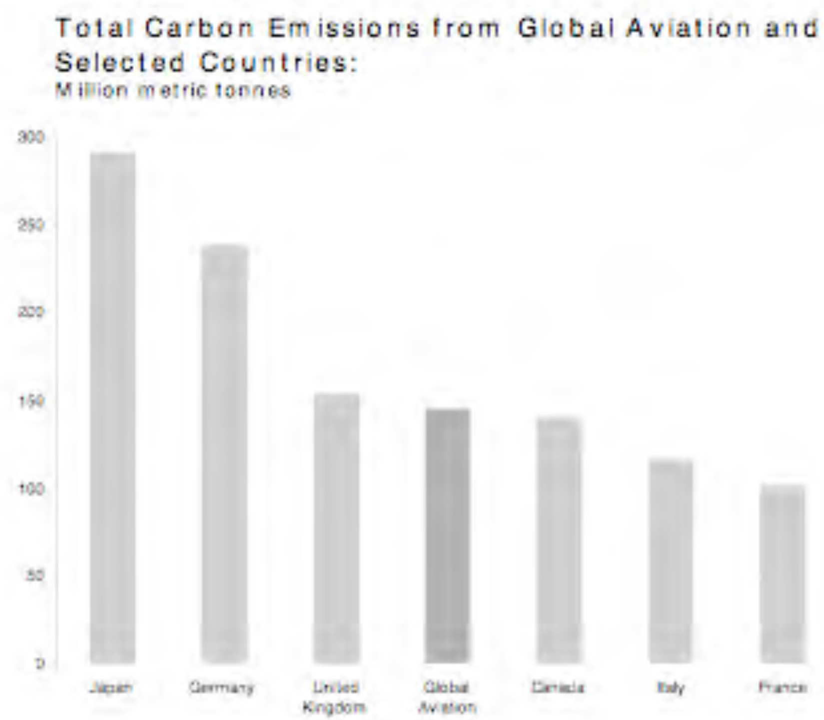


Aviation Contribution to CO_2

Transportation sector leads in petroleum use

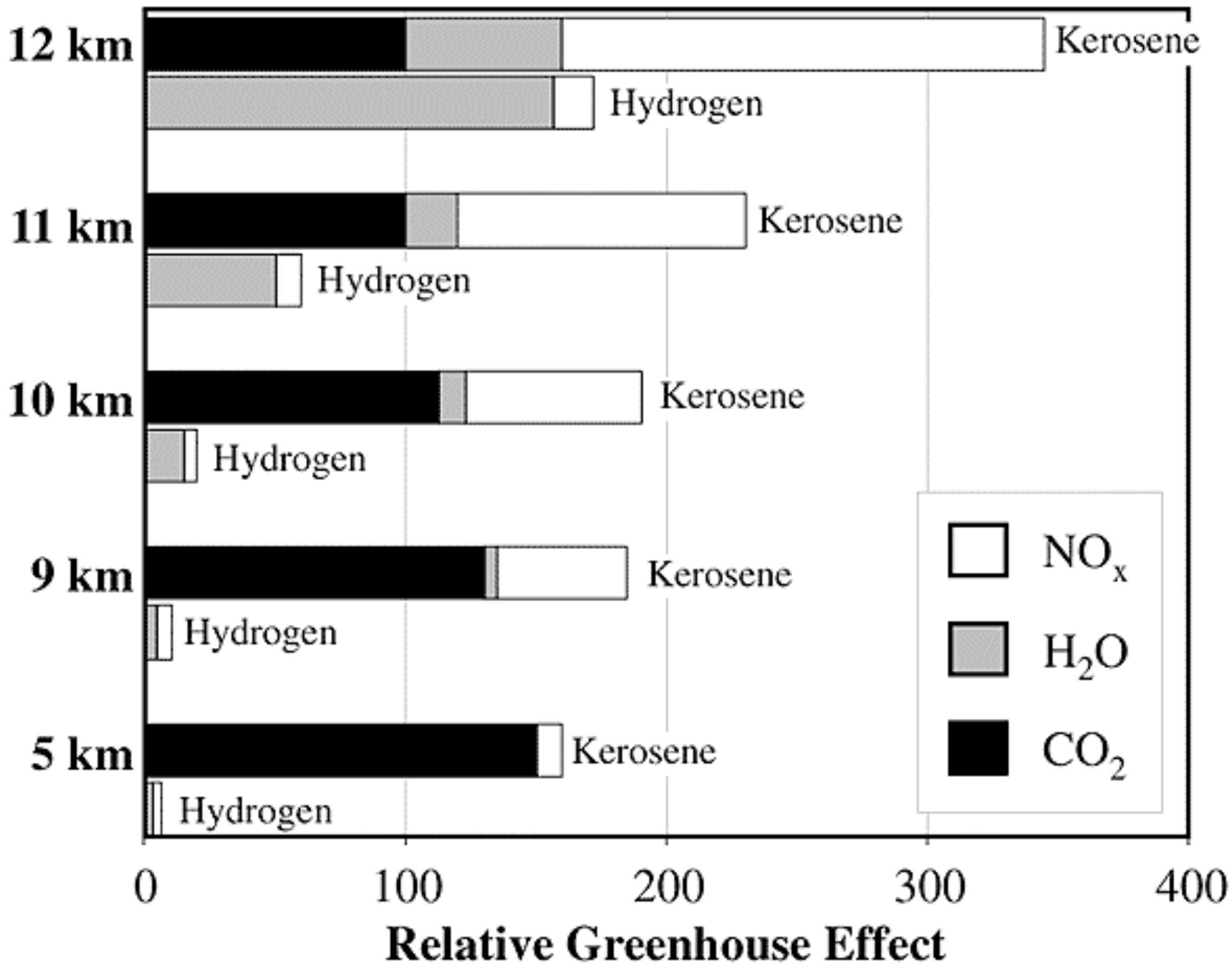
Carbon emissions from global aviation exceed the total output of many countries





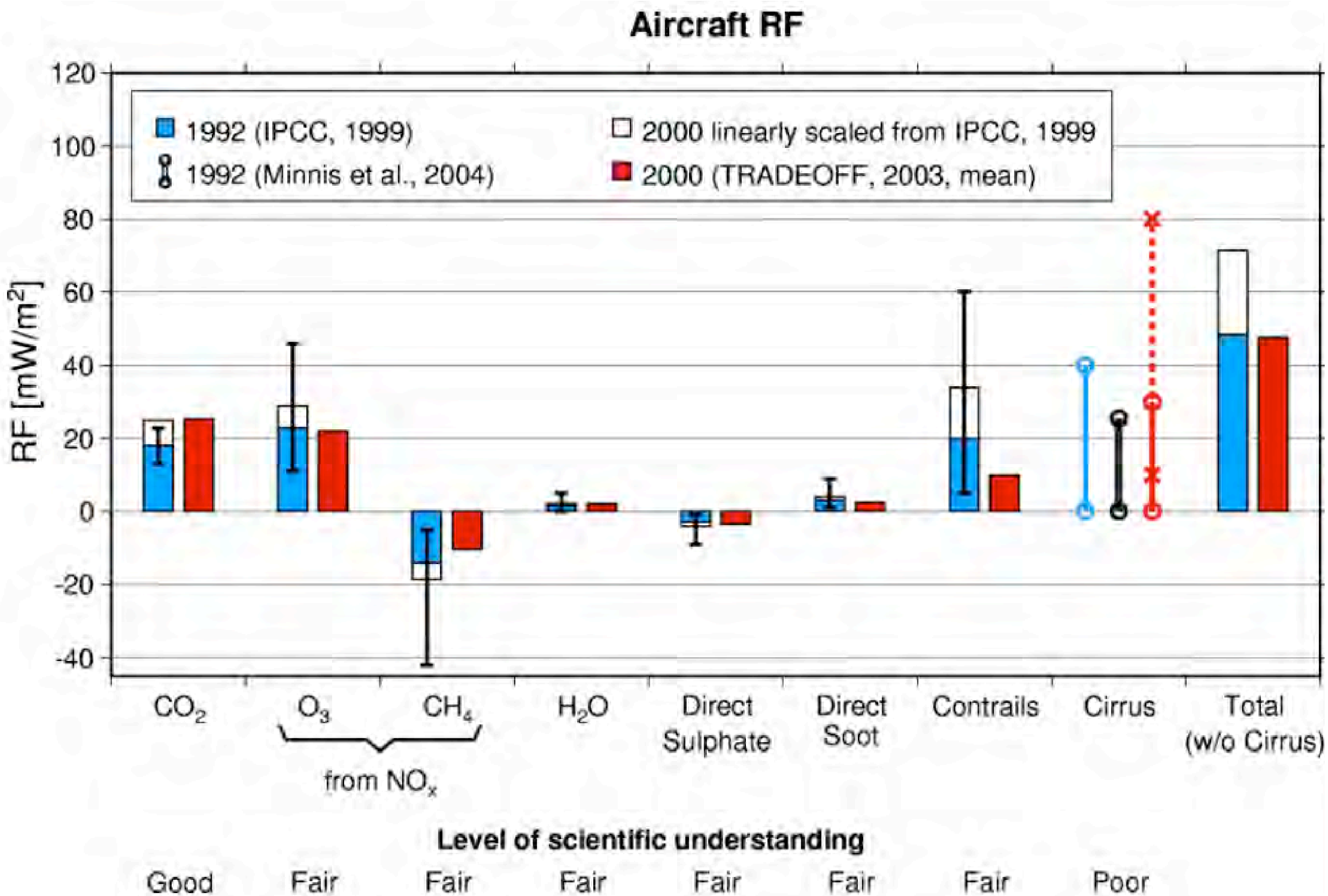
Source: GAO 1999

Effect of Altitude on Emissions Impact

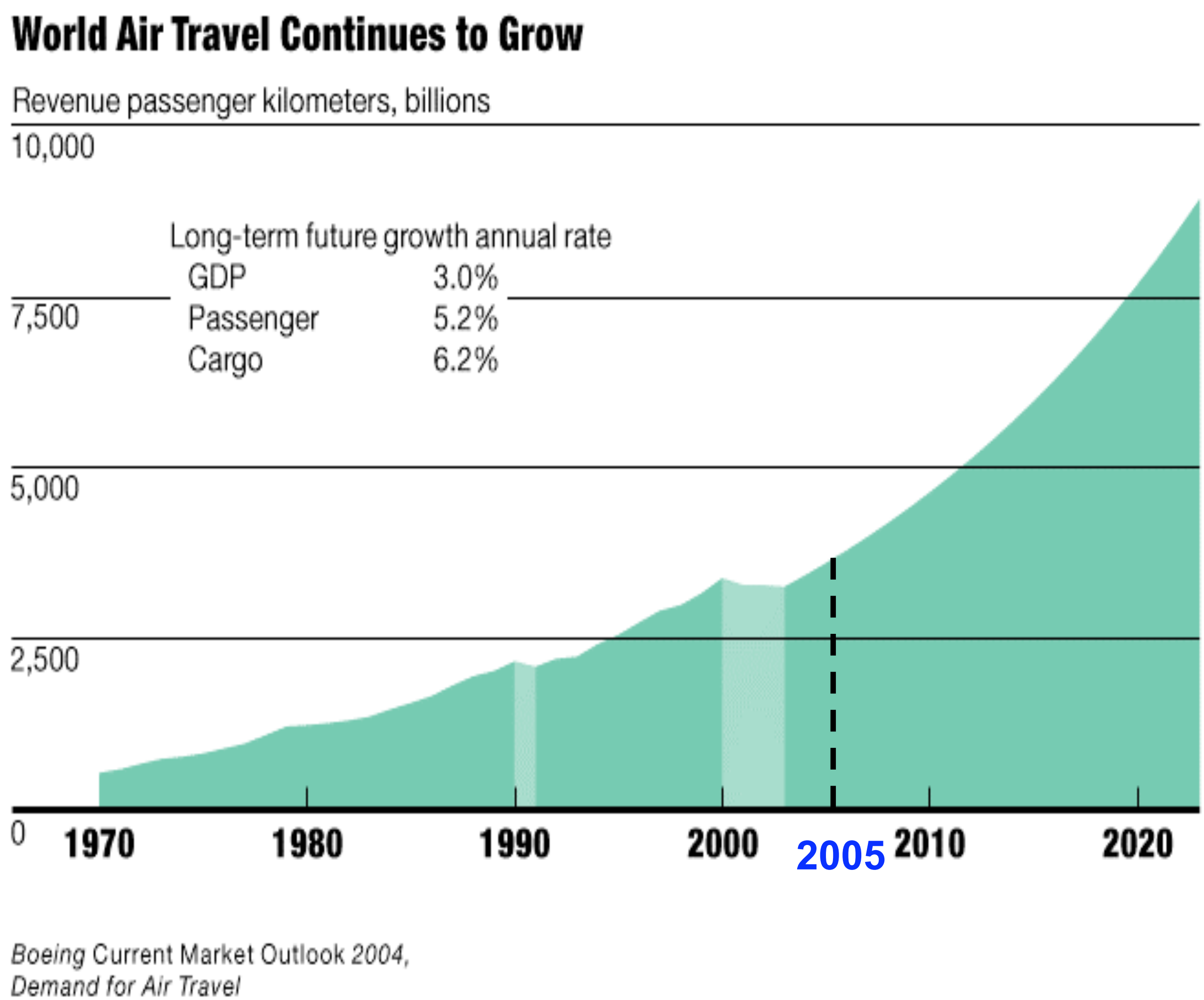


Source: Klug et al., 1996

Sustainable Aviation — The Problem

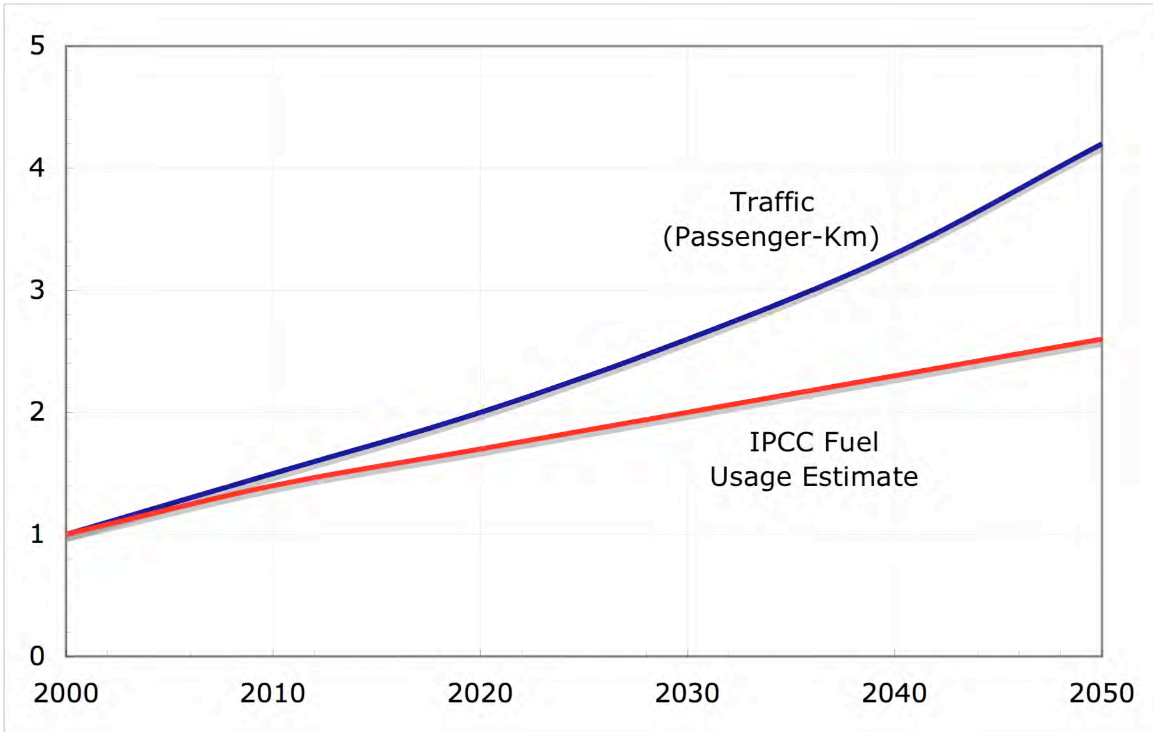


Sustainable Aviation — The Problem



Sustainable Aviation — The Problem

With the expected three-fold increase in global air travel over the next 30 years, the reliability and environmental impact of aviation are becoming critical issues for the future of flight.



Issues:

Safety

Efficiency

Noise

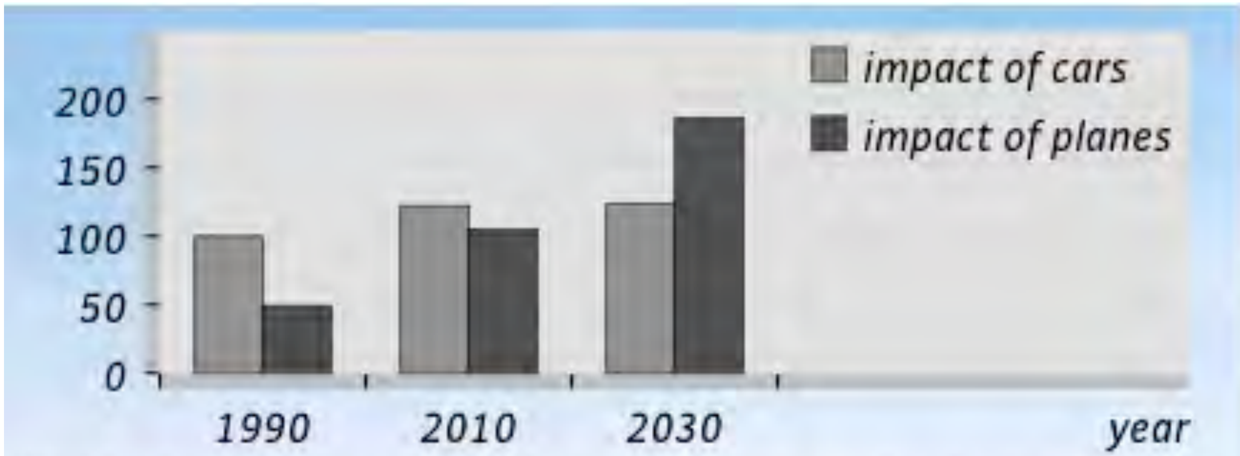
NO_x

CO_2

H_2O

Sustainable Aviation — The Problem

"Air travel is the world's fastest growing source of greenhouse gases." --CNN Nov. 6, 2007 and Friends of the Earth. Public and political pressure is mounting.



Worldwide comparison cars and planes, impacts on climate change. Scale: cars in 1990 = 100. Source: OECD 2000

Each long distance flight of a 747 adds approximately 400 tons of CO_2 to the atmosphere.

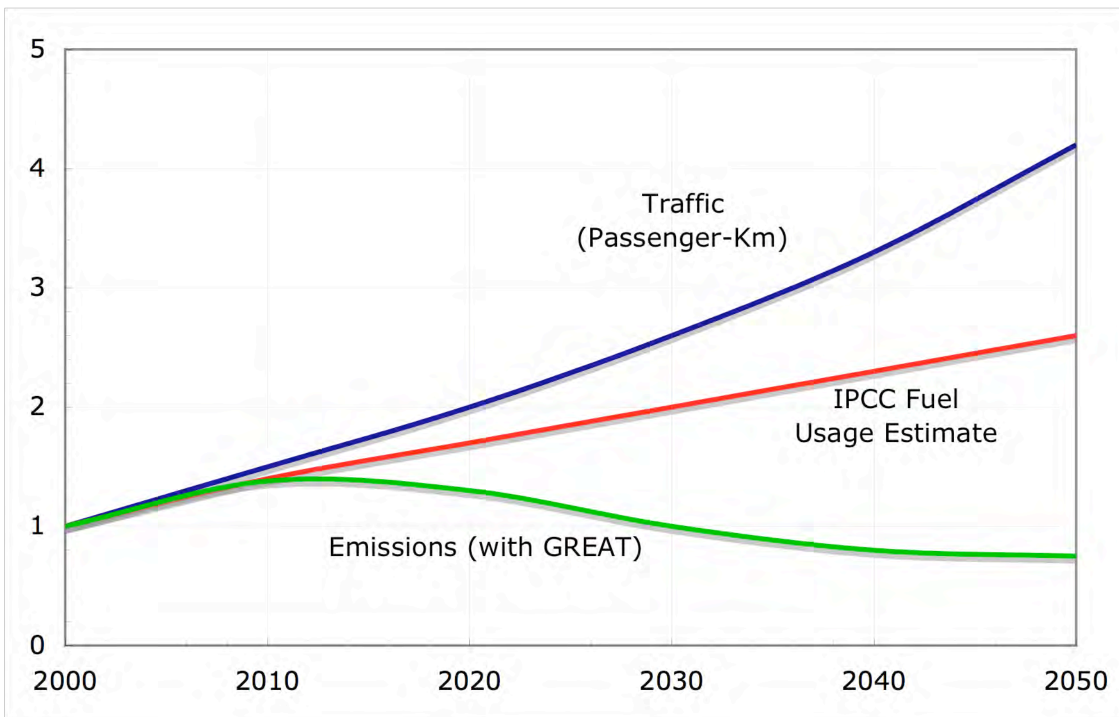
Sustainable Aviation — The Problem

Without significant action we will have major delays, large economic and environmental impact.

New government initiatives (US, Europe, Canada) are starting.

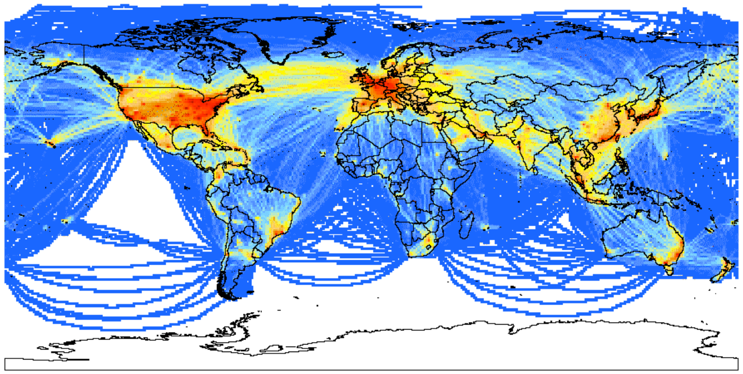
Sustainable Aviation — The Initiative

Goal: Develop technologies that will allow a **tripling** of capacity with a **reduction** in environmental impact.

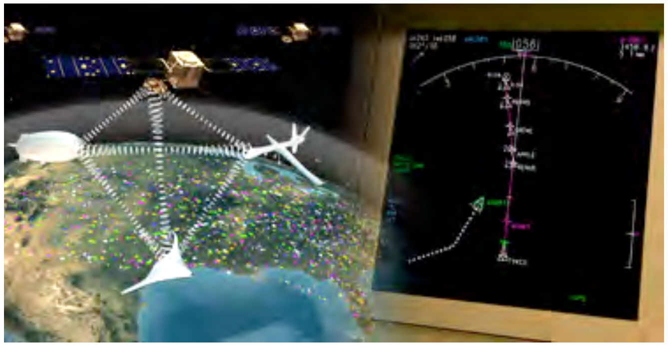


Research Thrusts

- Active monitoring and managing air transportation's environmental footprint



- Safely increase the capacity of the airspace system



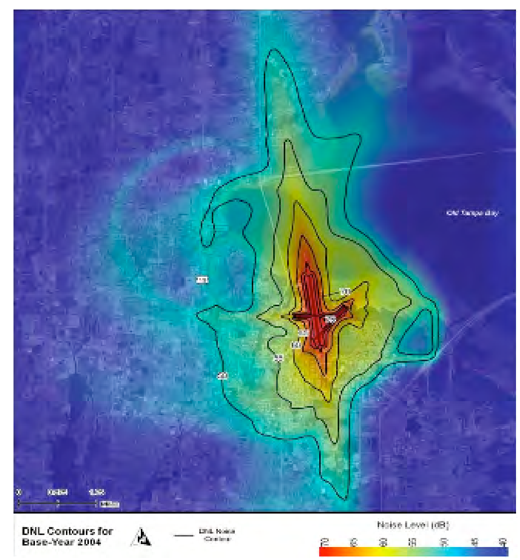
- Aerospace system design for the environment

Research Thrust:
Managing Air Transportation's Environmental Footprint

Goals: Active flight management from the vehicle level to the complete air transportation system

Critical technologies:

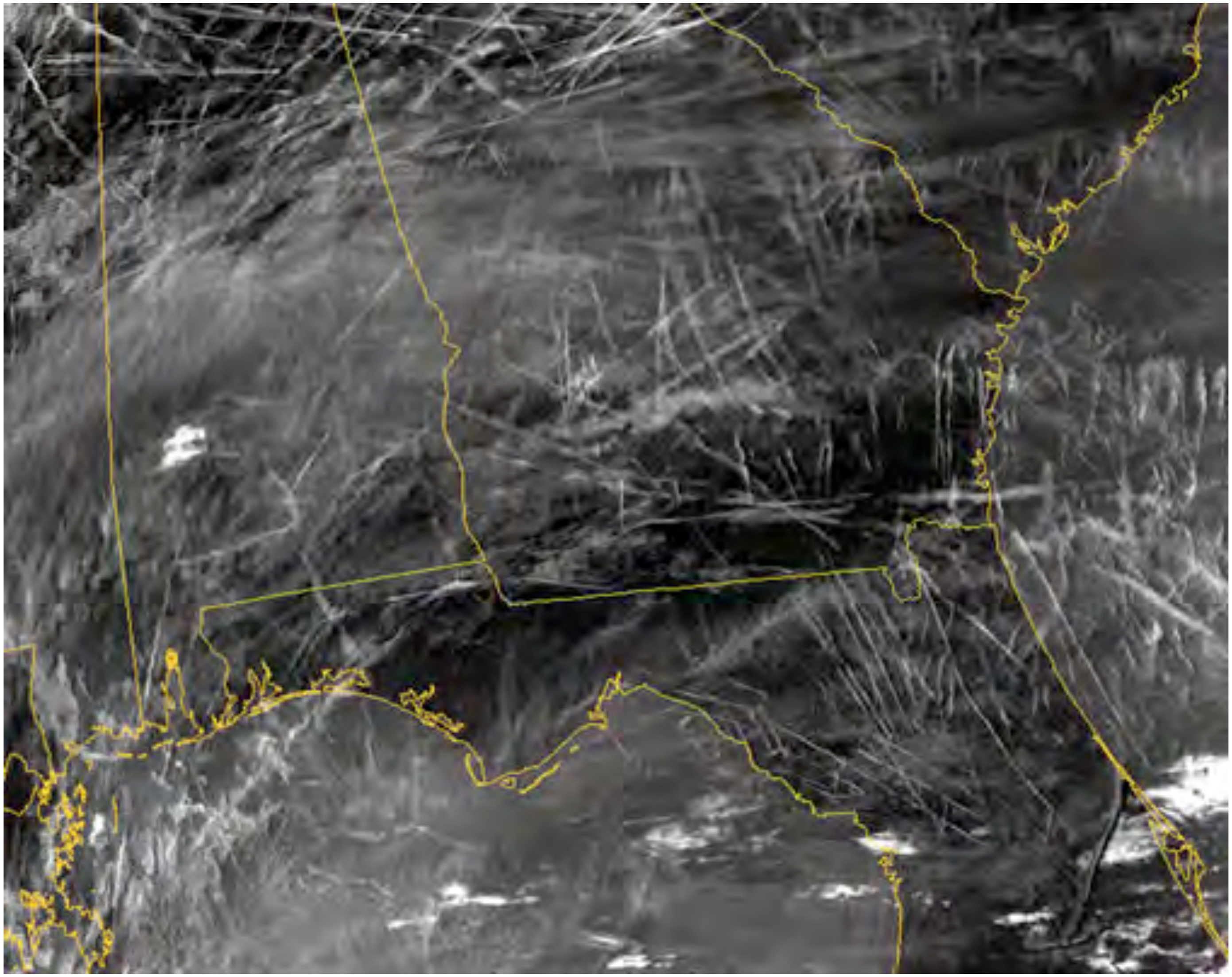
- Safety-critical control techniques
- Real-time, massively distributed, sensing and modeling



Example 1: Active monitoring of contrail formation and cirrus cloud formation using GPS and real-time flight path re-planning

Example 2: Real-time near-terminal area flight path planning to alleviate noise footprint

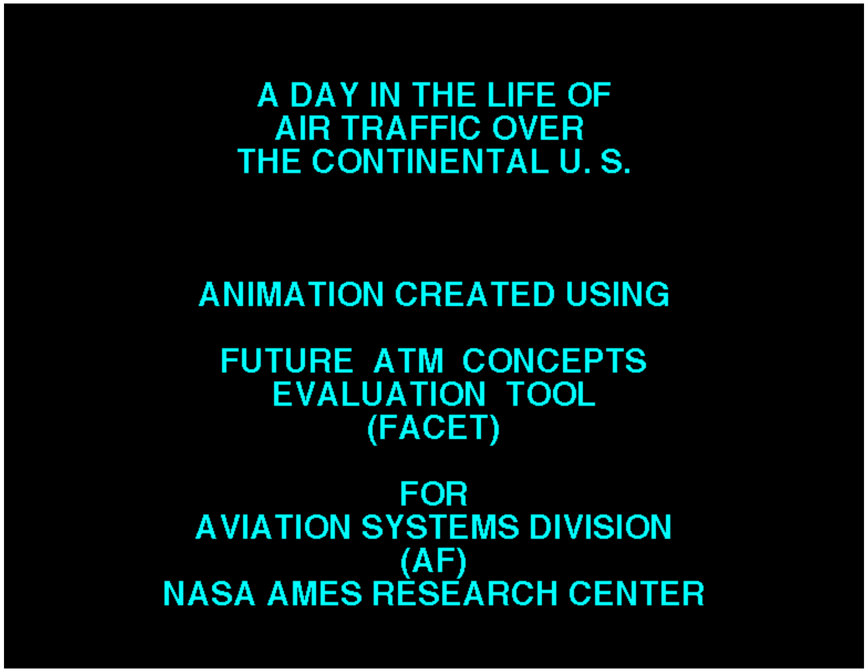

Persistent contrails formed in
super-saturated and cold air

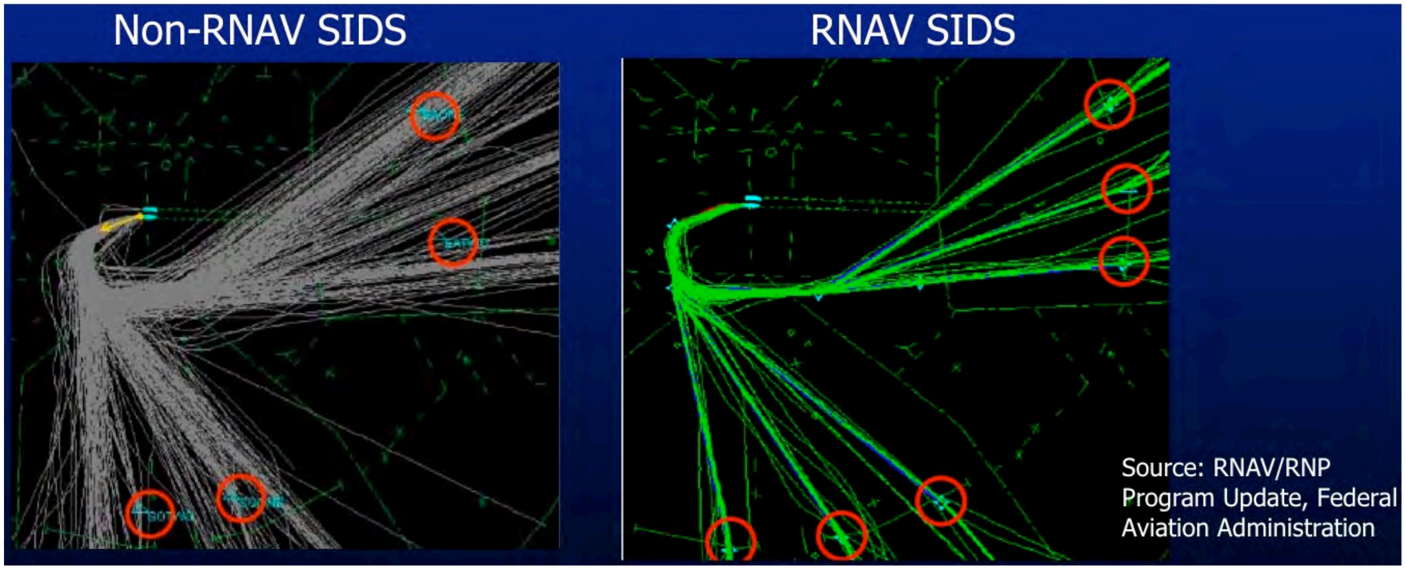


Research Thrust:
Safely Increase Air Transportation System Capacity

Next generation air traffic management system is vital to achieve worldwide goals:

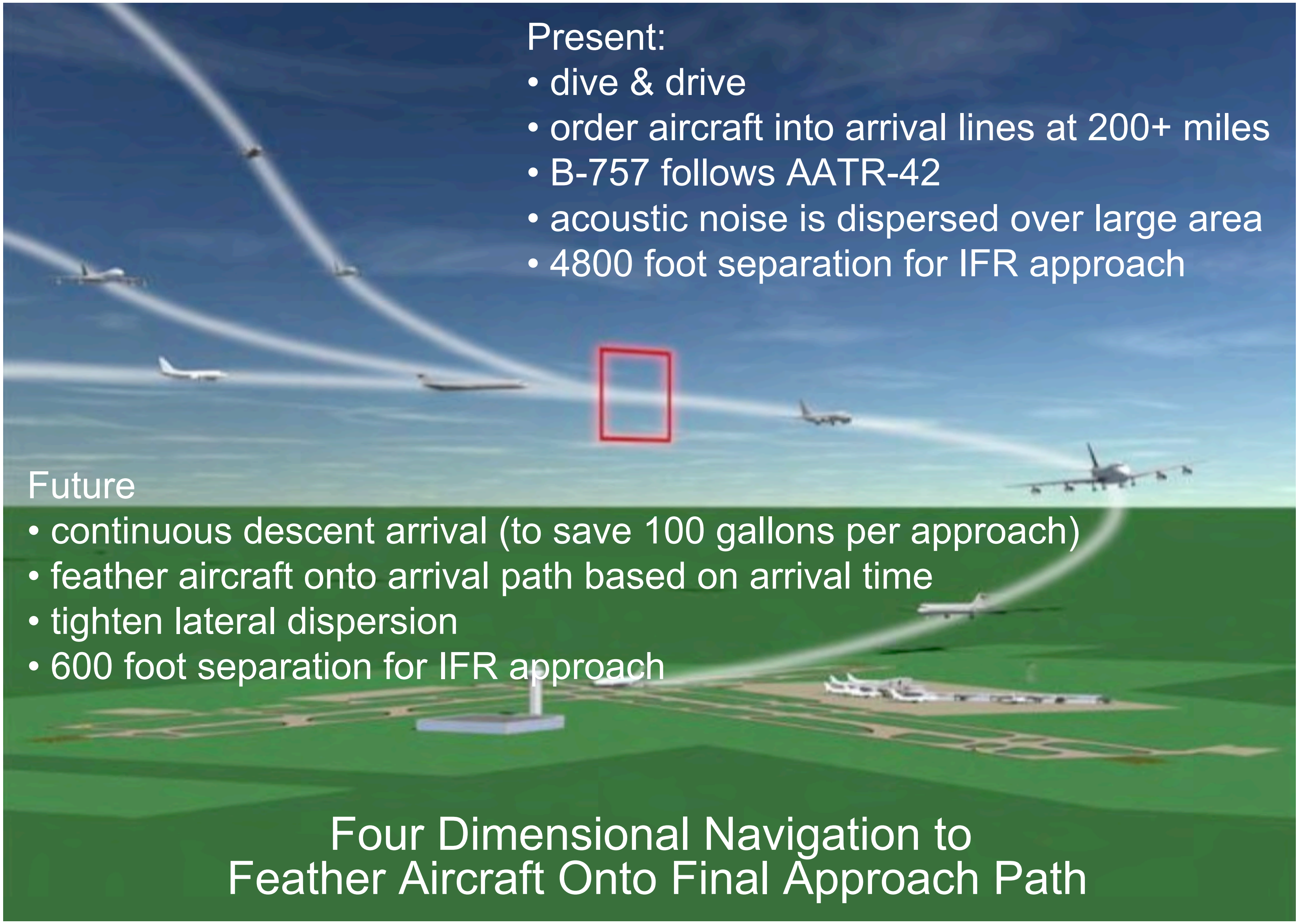
- Improve capacity
- Reduce environmental impact
- Improve security
- Sustain safety
- Include autonomous aircraft





Source: RNAV/RNP Program Update, Federal Aviation Administration

Safely Increase Air Transportation System Capacity



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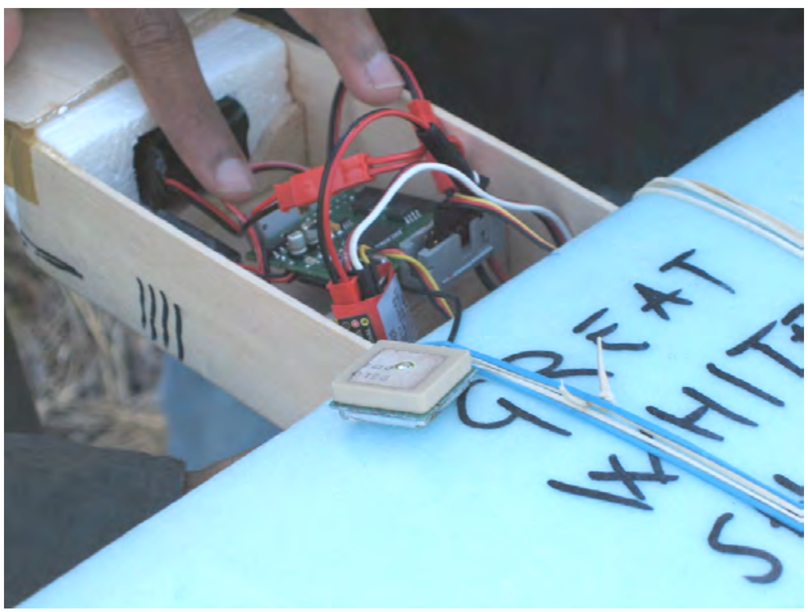
AA241X: Autonomous Aircraft

- Goal: To design, build, and fly an autonomous aircraft which can stay aloft within a three-dimensional box for as long a time as possible.

- Provides hands-on experience with aircraft design, autonomous systems, flight control, embedded software, flight testing.

Sketch to Flight in 90 Days

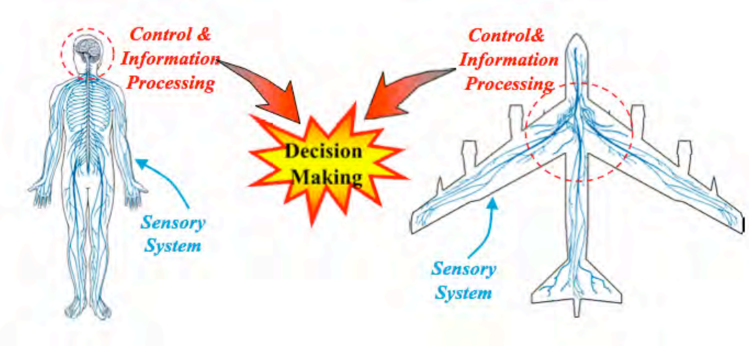


Research Thrust: Aerospace Design for the Environment

Goals: Active/intelligent aircraft design for dramatic efficiency increases

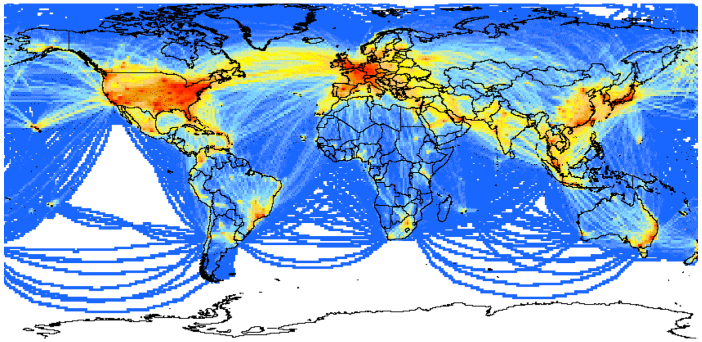
Critical Technologies:

- Integrated modeling of vehicles, atmospheric impact, and noise
- Optimization of new aircraft concepts and operations including environmental impact
- Distributed, adaptive sensing and control

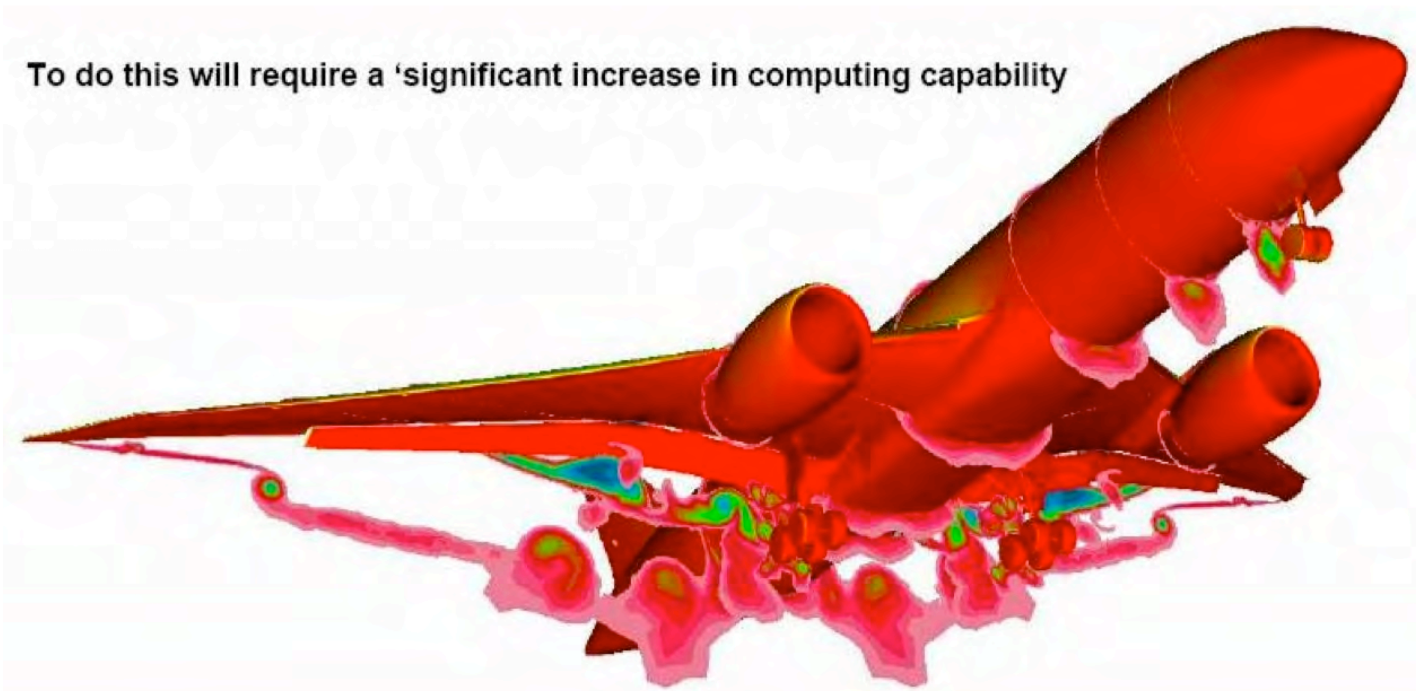


Example 1: Reliable prediction of the noise radiation for novel designs, e.g. "silent aircraft"

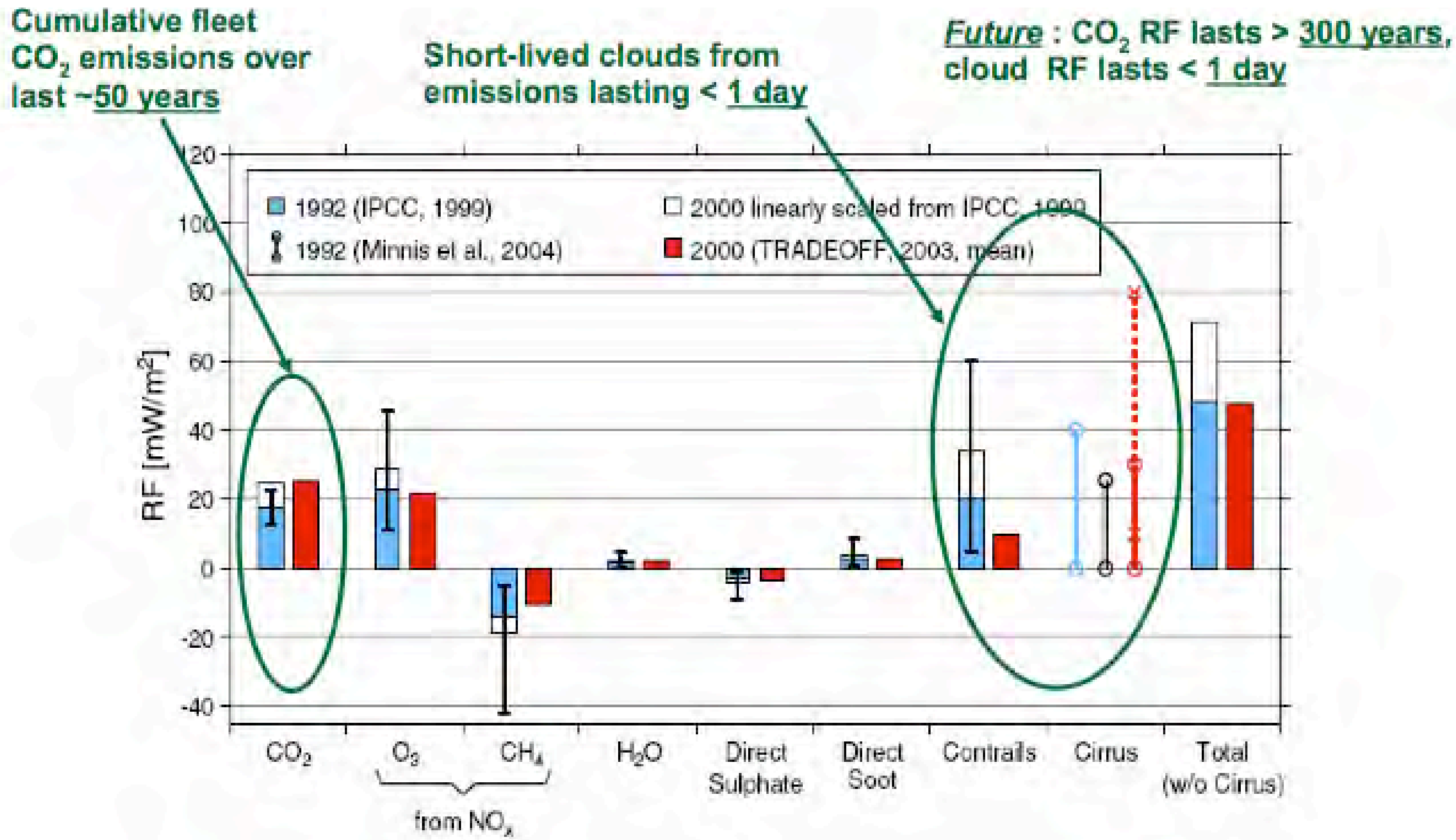
Example 2: Design for dramatic reductions in regional and global environmental footprints, e.g. 50% fuel reduction



Example: Compute acoustic signature of an airplane at take-off.

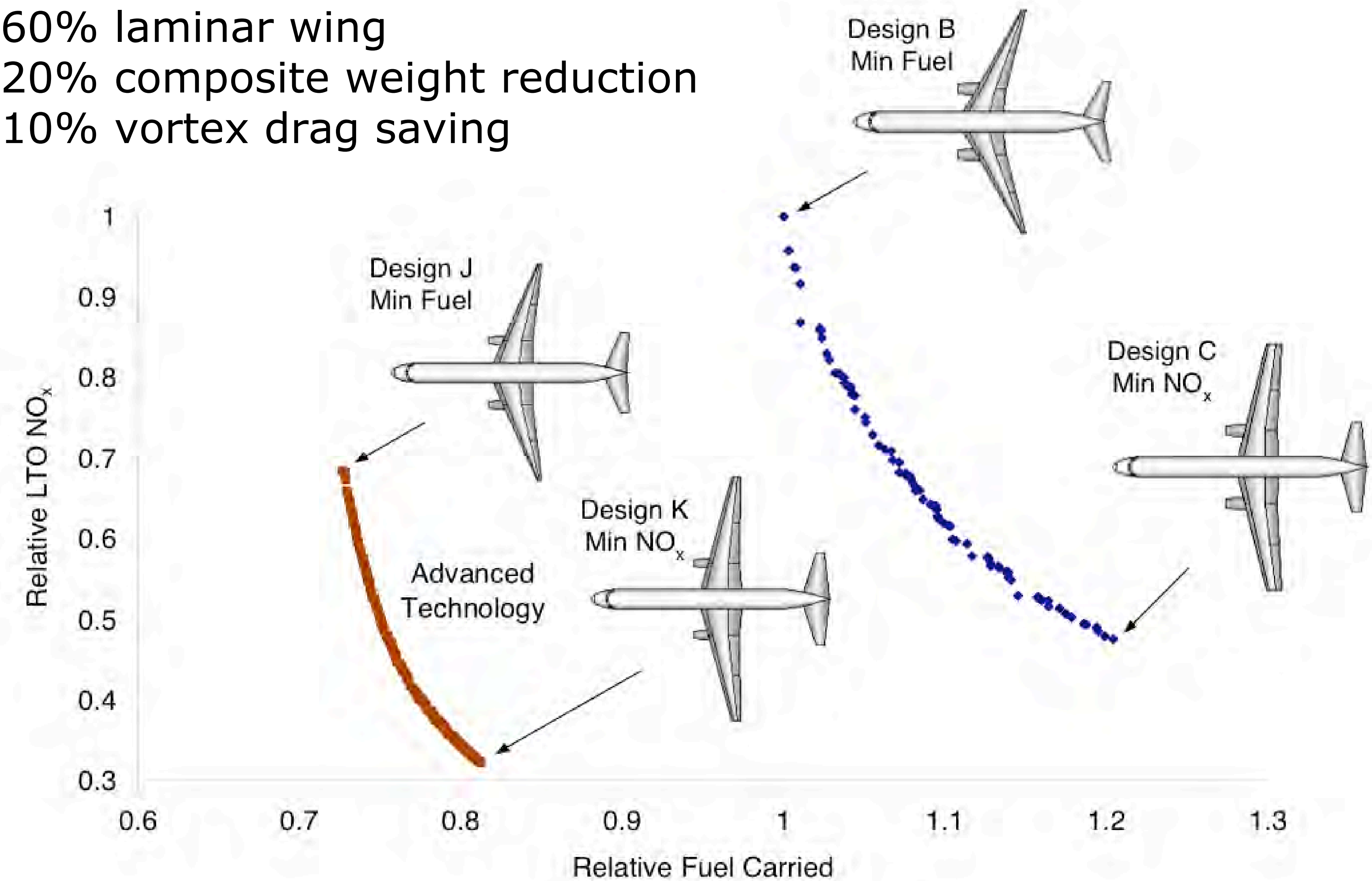


Example: Compute impact of enroute emissions on atmosphere

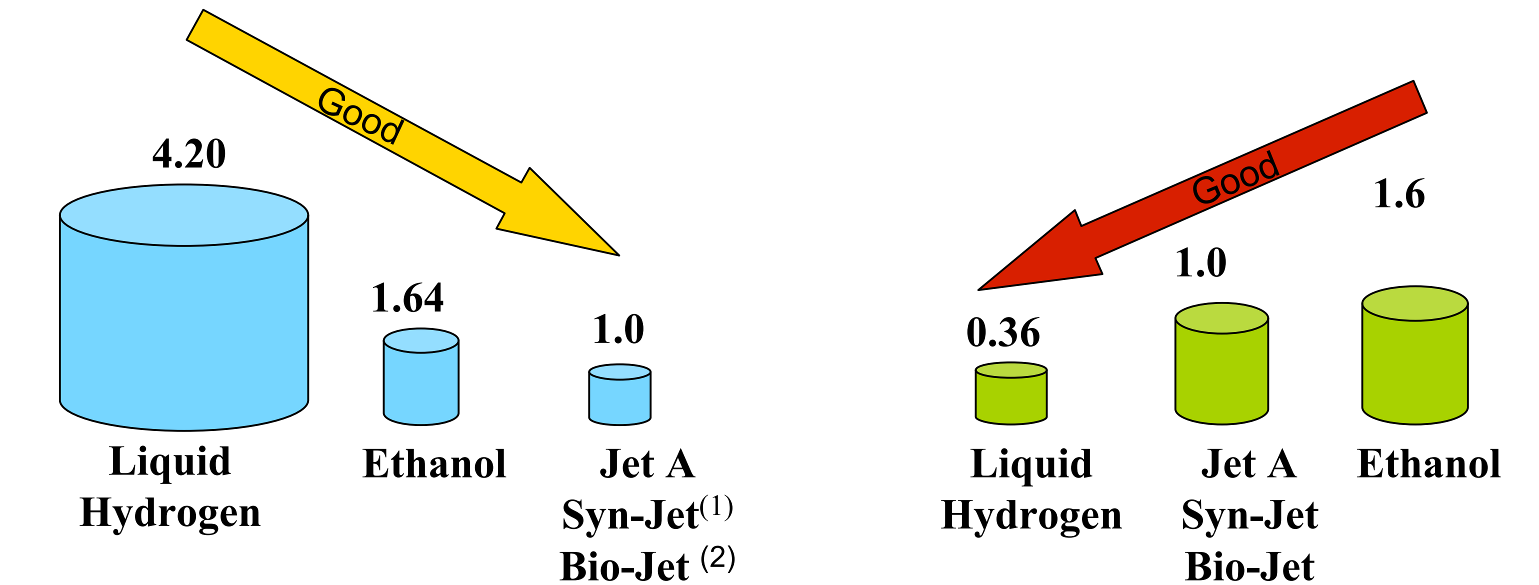


Aerospace Design for the Environment

- 60% laminar wing
- 20% composite weight reduction
- 10% vortex drag saving



Alternative Fuels for Aviation



Volume
(BTU/ft^3)

Jet-A is best per unit volume

Hydrogen is best per unit weight

Weight
(BTU/lb)

Equivalent Energy

(1) Synthetic Jet fuel such as from Fisher-Tropsch process
(2) Bio-derived jet fuel similar to a refined bio-diesel fuel

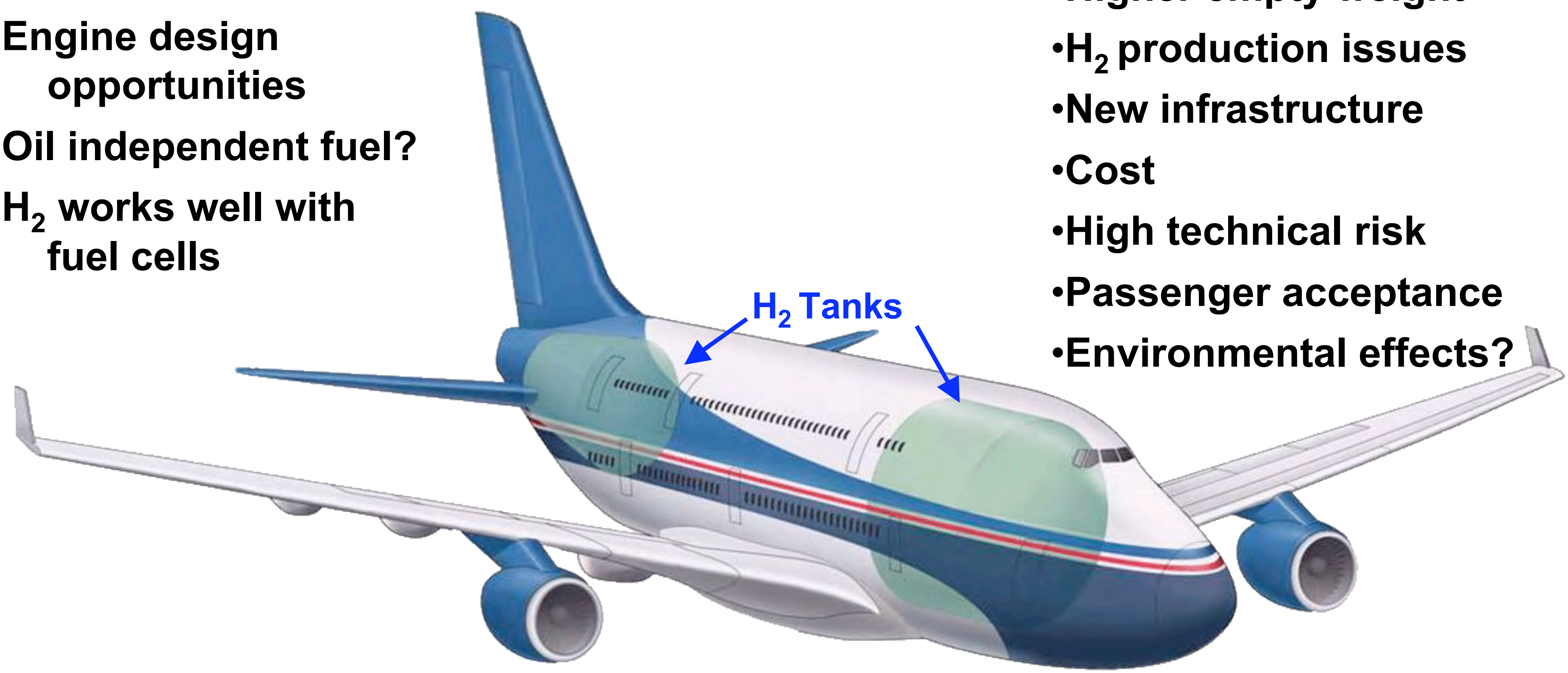
Hydrogen fueled airplanes face many challenges

Advantages:

- **Reduced emissions**
- **Lower takeoff weight**
- **Better long haul fuel efficiency**
- **Engine design opportunities**
- **Oil independent fuel?**
- **H_2 works well with fuel cells**

Challenges:

- **4X larger fuel tanks**
- **Higher drag**
- **Higher empty weight**
- **H_2 production issues**
- **New infrastructure**
- **Cost**
- **High technical risk**
- **Passenger acceptance**
- **Environmental effects?**



Liquid Hydrogen Study Airplane

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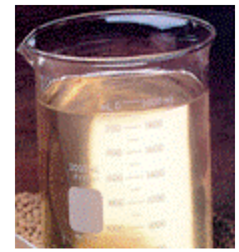
Alternates to supplement jet fuel

Bio Jet Fuel

Plants

Oil base

Jet fuel processing



Bio-Jet Fuel

Gas-to-Liquid (GTL) Synthetic Jet Fuel

Natural Gas

GTL plant

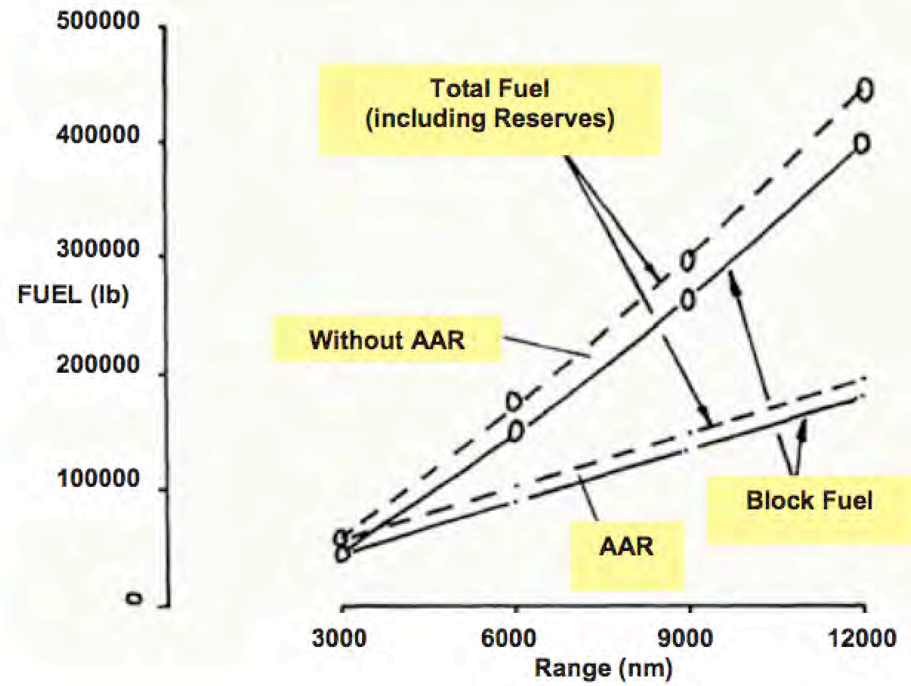
Jet-A Synthetic

Energy Source | **Processing** | **End Product**

In-flight refueling avoids burning fuel to carry fuel

Air-to-air refueling:

- Effects on long range fuel consumption with aircraft redesign
- Net effect ~40% on 6,000 - 9,000 nmi flights
- Source: Nangia 2006



	FUEL	Range 3,000nm	Range 6,000nm	Range 9,000nm
Aircraft *L/D* = 20 Conventional	Aviation Block	46,147	161,269	263,073
With AAR	Aviation Block		92,294 [43%]	138,441 [47%]
Air Tanker			9,000	18,000
TOTAL			101,294 [37%]	156,441 [41%]

Autonomous Aerial Refueling

Air-to-air refueling:

- More feasible with automated system
- Progress on automated aerial refueling for military -- of particular interest for UAV's

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Configuration Concepts: Formation Flight

- Potential for large induced drag reduction
  - Direct effect on emissions
  - Indirect (but large) effect on noise via reduced take-off weight
  - Virtual refueling concept provides additional benefits

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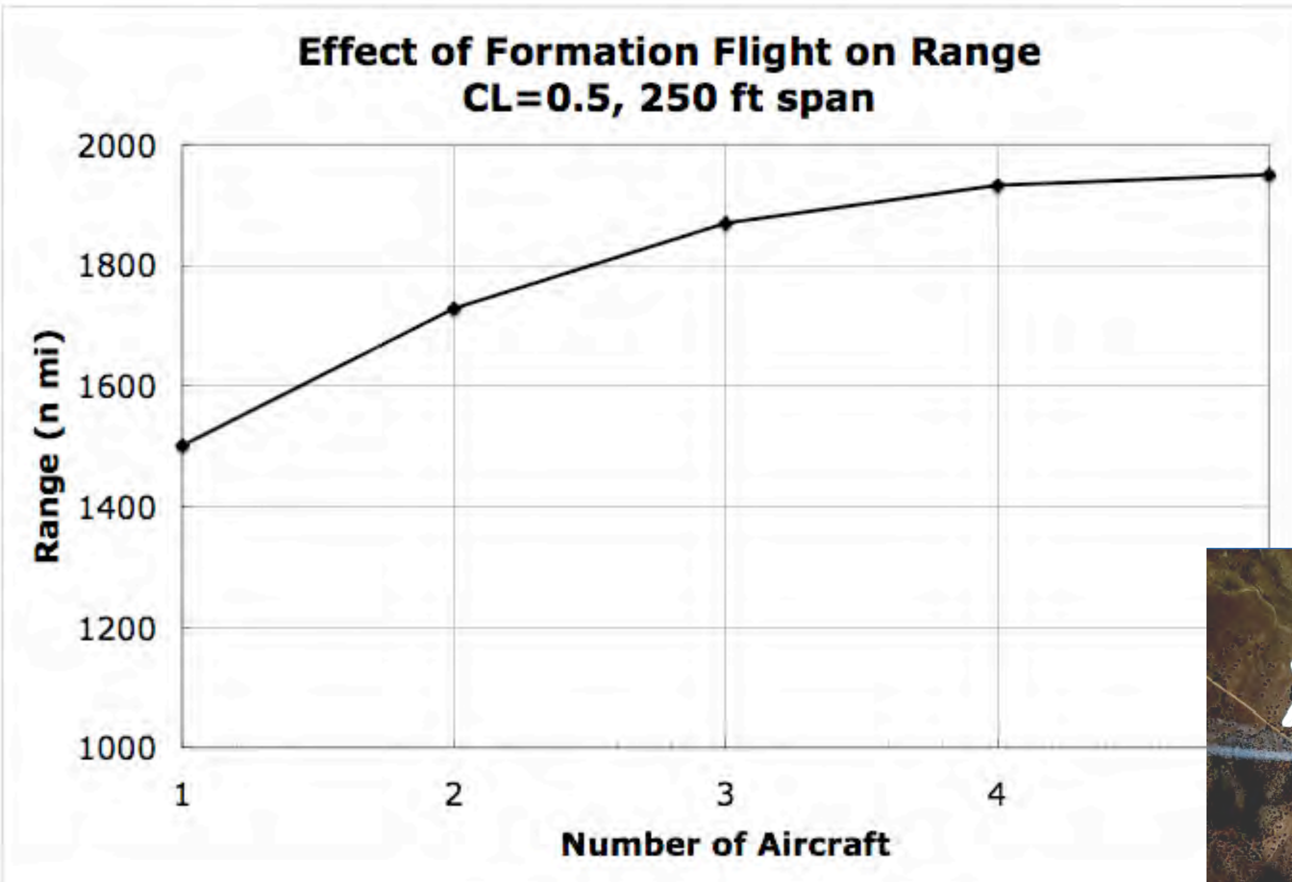
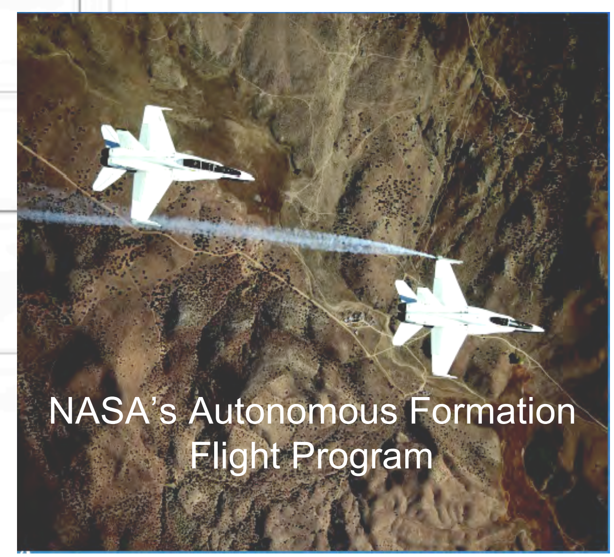
Effect of Formation Flight on Aircraft Range





NASA's Autonomous Formation Flight Program

Aerospace Design for the Environment

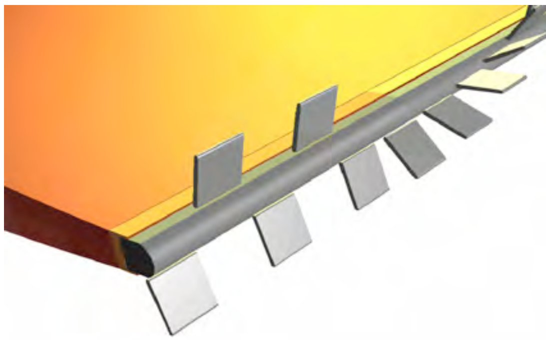
20% fuel savings

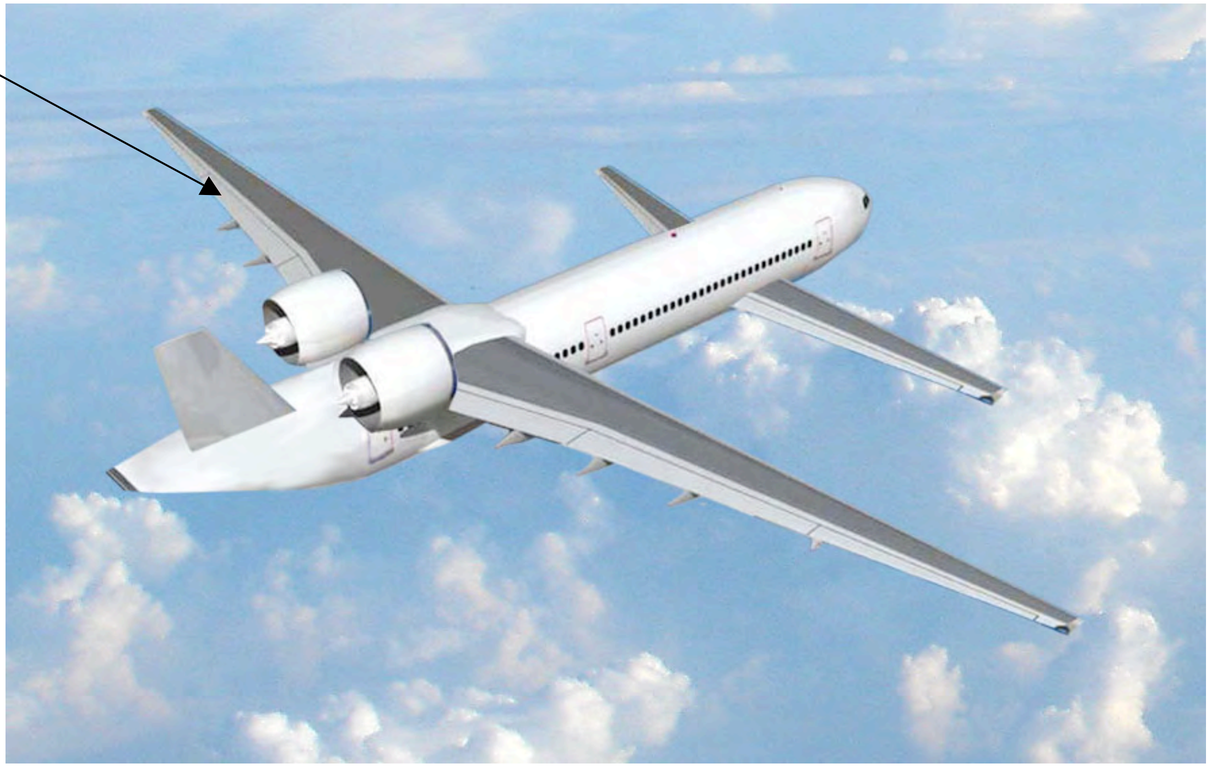
8% better SFC

Courtesy Boeing

Aerospace Design for the Environment

Aerospace Design for the Environment





Active distributed control using micro-trailing edge flaps:

Aeroelastic control

Maneuver/gust load control

Green Supersonics

- Mach 1.4 - 1.6
- Natural laminar flow
- Good field performance with low sweep, low take-off weight
- Existing engines
- Shielded fans

Summary

New initiative for sustainable aviation provides:

- A framework for integrating research in Aero/Astro
- A vital field of study for future students
- A focus on the most important problem in aviation