Course Outline, Introduction

kroo@stanford.edu,
jjalonso@stanford.edu

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Administrative Information

• Instructor office hours
  • Juan J. Alonso: TBD
  • Ilan M. Kroo: TBD

• E-mail addresses
  • Juan J. Alonso: jjalonso@stanford.edu
  • Ilan M. Kroo: kroo@stanford.edu

• Course e-mail list
  • Send e-mail to aa260-class-join@lists.stanford.edu with no subject, no body.

• Course materials on http://adl.stanford.edu/AA260
Administrative Information

• No textbook required. Class notes will be passed out, readings will be assigned. Materials available from different sources will be added to the course web site

• Grading & Exams:
  • No exams: neither midterm nor final
  • 2 short assignments
  • Mid-term and Final papers
  • Final Paper (50%), assignments (20%), mid-term paper (15%), class participation (15%)

• Ask lots of questions any time.

• Very broad topic. Hard to have all expertise in one person (even two!). We will be inviting a number of guest lecturers to complement the background of the instructors

• Prerequisites: none
• Throughout the course we will be using materials from a variety of sources (FAA, NASA, ACCRI, IATA, PARTNER, DoD, DoE, etc, etc.) and the source will be acknowledged in every lecture.

• This is the first time we teach AA260 and, therefore, it is a bit of an experiment. Please contribute to the discussions as they will influence the format/content of future editions of this course. Do not hesitate to give feedback directly of via e-mail.

• Introductions. Who are you and why are you here? What is your background in this topic and in aircraft design? Policy?
Sustainability

• Definition of sustainability

A sustainable aviation enterprise is one where the demand for growth can be enabled by ensuring that the environmental impact is reduced to acceptable levels.
Sources of Information

• Much of the material for this introductory presentation is taken from a presentation by Carl Burleson, FAA Director of the Office of Energy and Environment, to the NASA Fundamental Aeronautics Program Annual Meeting, November 2007.

• Some additional information from IATA’s web page and from researchers in the ACCRI program (David Lee, Malcolm Ko, Mohan Gupta) has also been used.
2003 marked the 100th Anniversary of Flight and…

The 92nd Anniversary of the flight editorial complaining about aircraft noise…
Aviation plays a key role in the world economy. Aviation supports 8% of global economic activity and carries 40% of the value of freight. Aviation activity outpaces economic growth. Over 2 billion people travel each year. 2002 U.N. World Summit on Sustainable Development affirmed that economic growth is a prerequisite for improving earth’s environment.
Aviation Noise: Technology & Policy Produce Gains
Aviation Noise: Large Gains Coupled with Growth

Trends in Aircraft Noise Exposure and Capacity Expansion

Number of People (Millions) Exposed to Significant Aircraft Noise

Year


Population Exposed

Enplanements

7.0  5.2  3.4  2.7  1.7  0.8  0.5

0.0  1.0  2.0  3.0  4.0  5.0  6.0  7.0  8.0

705  582  495  400  310  202  70

731

Aviation Emissions: Significant Improvements

Aircraft Energy Efficiency has improved substantially, especially when compared to the other form of US mass transit that moves passengers.

Local air quality pollutants have declined steadily over the past several years. NO\textsubscript{x} has been the most challenging pollutant to constrain.
While all transportation makes up more than 55 percent of the total national NO$_x$ inventory, aviation represents only about 0.4 percent.
Aviation Environmental Issues- Year 2000

Aviation Noise: As Predicted, Has Not Gone Away

Compiled by Tam et al., 2007
from Boeing data 9/13/05

Noise Abatement Procedures
Curfews
Noise Charges
Noise Level Limits
Operating Quotas
Chapter 3 Restrictions

Airports with Restrictions

1980 1990 2000
Aviation Noise: Returning As An Issue

National Noise Exposure Trends vs. FAA Targets

Percent Change in Number of Residents Exposed to Aircraft Noise
(DNL 65 dB or more)

FAA Flight Plan Target
1% per year reduction of exposed residents

FAA Flight Plan Updated Target
4% per year reduction

Year

2002 2003 2004 2005 2006 2007 2008 2009 2010

Percent Change from 3-Year Average (2000 - 2002)

-40% -30% -20% -10% 0% 10% 20%

Actual Projection Target
Aviation Emissions: U.S. Growth Down

FAA Fuel Efficiency Target

Source: FAA

US Commercial Aviation Performance

Total U.S. Aviation Fuel Consumption

Source: FAA
As Predicted, Local Air Quality Issues Growing In Importance
New Issue: Concern About Reliance of Transport on Oil

Transportation continues to have the largest reliance on oil...

...while some are predicting that we are nearing the peak of oil supply.
New “Emphasis” Issue: Shift in Airline Cost Equation

Source: Air Transport Association
A Leading Issue: Aviation GHG Emissions Internationally

- United Nation Framework Convention on Climate Change (UNFCCC) 1992
  - General commitment to reduce certain greenhouse gas emissions
  - Specific targets for reductions
  - Developing countries exempt (for now)
  - Coverage of domestic aviation up to each country
  - International aviation subject to ICAO plan (per Article 2.2)
- ICAO Decisions in 2004 & 2007
  - Limit or reduce the impact from aviation greenhouse gas emissions on climate change
  - High Level Group on Aviation & Climate
New Issue: Market Changes Increase Complexity of Challenge

Source: NextGen Integrated Plan, 2004
Aviation Environmental Issues – Year 2007

- Community Noise Impacts
- Air Quality
- Energy
- Global Climate
- Water Quality
NextGen Vision

Provide environmental protection that allows sustained aviation growth

Factors:

2X increase in system by 2025
Fundamental system changes
Increased importance of environment
Vision to grow aviation while reducing significant environmental imp

As NextGen evolves, it is unclear whether environmental constraints are being looked at as an auxiliary objective (which can be traded off with other objectives (capacity, efficiency, safety?)) or as a true constraint that may prevent the realization of the current Integrated Work Plan
NextGen Environmental Goals as Proposed by the FAA

**Noise**
NextGen goal to reduce noise exposure (65, 55 DNL) 1%/year measured from base of 2000-2002 average (FAA goal)

FAA goal is now 4%/year (65 DNL) through Flight Plan (2008-2012)

**Local Air quality**
NextGen goal analyses computed lbs emissions
Engine emissions standards limit lbs emissions; ≠ significance
National Ambient Air Quality Standards (NAAQS) establish significance for all sources combined
Establishing aircraft contribution challenging

**Climate**
NextGen analyses done against goal to improve aviation fuel efficiency per revenue plane-mile by 1%/year measured from base of 2000-2002 average (FAA goal)

Historical average ~2.2%; FAA goal likely to become more stringent
Fuel burn can be translated to lbs pollutants; ≠ significance
Establishing metrics/aviation contribution challenging

**Water**
No analyses to date
The Way Forward: Understanding the Problem (FAA)

Better science-based understanding of the impacts of aviation emissions on climate change

Improved metrics, measurement techniques, and modeling capability to quantify and predict impacts and to understand inter-relationships of aviation environmental factors

*Significant* and *appropriate* are policy decisions which are informed – but not established by - science
The Way Forward: New Integrated Tools & Approach (FAA)

APMT PARTIAL EQUILIBRIUM BLOCK
- Operations
- Demand (Consumers)
- Supply (Carriers)
- Fares
- New Aircraft
- Schedule & Fleet

AEDT
What are the noise and emission characteristics?

APMT BENEFITS VALUATION BLOCK
- CLIMATE IMPACTS
- LOCAL AIR QUALITY IMPACTS
- NOISE IMPACTS
- Emissions
- Noise
- Collected Costs
- Emissions & Noise
- Monetized Benefits

APMT COSTS & BENEFITS

EDS
What are the environmental implications & costs associated with a vehicle design?

Policy and Scenarios
The Way Forward: Integrated Assessment (FAA)

- US emissions
  - Yearly cost: $16B/yr

- Local Air Quality
  - Yearly cost: $2.8B/yr

- Noise
  - 89 US airports
  - $0.5B/yr

(when annualized on a 30 year basis = $10B “one-time” cost)

3% discount rate
Opportunities

• New technologies to improve air traffic management will help reduce emissions. An example is RVSM – Reduced Vertical Separation Minimums. Full implementation of RVSM may reduce fuel use by ~500 million gallons each year.

• Other operational approaches, such as continuous descent arrivals, can reduce fuel burn as well as noise

• Reducing congestion, and optimizing airport ground and terminal air space operations offer great promise for future reductions of noise and emissions

Louisville CDA Flight Trials
The Way Forward: New Aircraft Technology

Opportunities

Historically new technology accounts for 90% of environmental footprint reduction

New concepts offer promise for improvement

Need a balance in maturing technologies and enabling revolutionary concepts
The Way Forward: Pursuit of New Fuels

Opportunities
Synthetic Fuels may be
- Environmentally Friendly
- Help Manage Interdependencies

Commercial Aviation Alternative Fuel Initiative (CAAFI)
Securing a stable fuel supply
Furthering research and analysis
Assessing environmental impacts
Improving aircraft operations
The Emissions, Climate Change, Impact Sequence

Aircraft emissions and climate change

Fuel: \( C_n H_m + S \)

Complete combustion products:
\( CO_2 + H_2O + N_2 + O_2 + SO_2 \)

Actual combustion products:
\( CO_2 + H_2O + N_2 + O_2 + NOx + CO + HC + soot + SO_x \)

Engine fuel combustion

Direct emissions

Atmospheric processes

Changes in radiative forcing components

Climate change

Impacts

Damages

Increasing policy relevance

Changes in temperatures, sea level, ice/snow cover, precipitation, etc.

Agriculture and forestry, ecosystems, energy production and consumption, human health, social effects, etc.

Social welfare and costs
Emissions over time

Lee et al. 2009

Aviation Fuel Use and RPK

Aviation CO₂ Emissions
Where do we want to go?

• The range of IPCC SRES-based overall scenarios indicate increases in global mean temperature of somewhere between **1.8 °C** (B1 scenario, likely range **1.1 to 2.9 °C**) and **4 °C** (A1FI scenario, likely range **2.4 to 6.4 °C**) in 2090 – 2099, relative to 1980 – 1999 temperatures (IPCC, AR4, 2007)

• (so add on ~**0.5 °C** for from preindustrial period to target date)

• If we stabilized CO2 concentrations at **450 ppm**, there is a 50% chance of exceeding **2 °C** by 2100

• (we are at **385 ppm** CO2 right now)
Mixing a 450 ppm stabilization world with aviation A1, B2 type scenarios

Data sources: IPCC Ar4

A1 = 12.6% 2050
B2 = 8.8% 2050
## Aviation’s contribution to RF

### Aviation Radiative Forcing Components in 2005

<table>
<thead>
<tr>
<th>RF Terms</th>
<th>Spatial scale</th>
<th>LO SU</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon dioxide</td>
<td>0.0280 (0.0253)</td>
<td>High</td>
</tr>
<tr>
<td><strong>NO\textsubscript{x}</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ozone production</td>
<td>0.0263 (0.219)</td>
<td>Med-Low</td>
</tr>
<tr>
<td>Methane reduction</td>
<td>-0.0125 (-0.0104)</td>
<td>Med-Low</td>
</tr>
<tr>
<td>Total NO\textsubscript{x}</td>
<td>0.0138 (0.0115)</td>
<td>Med-Low</td>
</tr>
<tr>
<td>Water vapour</td>
<td>0.0028 (0.0020)</td>
<td>Low</td>
</tr>
<tr>
<td>Sulphate aerosol</td>
<td>-0.0048 (-0.0035)</td>
<td>Low</td>
</tr>
<tr>
<td>Soot aerosol</td>
<td>0.0034 (0.0025)</td>
<td>Low</td>
</tr>
<tr>
<td>Linear contrails</td>
<td>0.0118 (0.010)</td>
<td>Low</td>
</tr>
<tr>
<td>Induced cirrus cloudiness</td>
<td>0.033</td>
<td>Very Low</td>
</tr>
<tr>
<td>Total aviation (Excl. induced cirrus)</td>
<td>0.055 (0.0478)</td>
<td>Low</td>
</tr>
<tr>
<td>Total aviation (Incl. induced cirrus)</td>
<td>0.078</td>
<td>Low</td>
</tr>
</tbody>
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Lee et al., 2009
Some Technology Solutions - NASA

### SFW System Level Metrics

...technology for dramatically improving noise, emissions, & performance

| CORNERS OF THE TRADE SPACE | N+1 (2015)**
|-----------------------------|----------------------------------
|                             | Generation Conventional Tube and Wing (relative to B737/CFM56) | N+2 (2020)**
|                             | Generation Unconventional Hybrid Wing Body (relative to B777/GE90) | N+3 (2025)**
|                             | (relative to user defined reference) |
| Noise                      | -32 dB (cum below Stage 4) | -42 dB (cum below Stage 4) | 55 LDN (dB) at average airport boundary |
| LTO NOx Emissions (below CAEP 6) | -60% | -75% | better than -75% |
| Performance: Aircraft Fuel Burn | -33%** | -40%** | better than -70% |
| Performance: Field Length | -33% | -50% | exploit metro-plex* concepts |

*** Technology readiness level target = 6
** Additional gains may be possible through operational improvements
* Concepts that enable optimal use of runways at multiple airports within the metropolitan area

### Approach

- Enable Major Changes in Engine Cycle/Airframe Configurations
- Reduce Uncertainty in Multi-Disciplinary Design and Analysis Tools and Processes
- Develop/Test/Analyze Advanced Multi-Discipline Based Concepts and Technologies
- Conduct Discipline-based Foundational Research

Fundamental Aeromechanics Program
Subsonic Fixed Wing Project
Some Technology Solutions - NASA

Ultra High Bypass Engine Cycle Collaborative Research

➢ General Electric Open Rotor
  • Space Act Agreement
    • Signed August 2008
    • Initiates collaborative research on Open Rotor propulsion concepts in NASA Glenn 9'x15' and 8'x6' wind tunnels in 2Q 2009
  ➢ Test Objectives
    • Investigate performance and noise
    • Produce shareable open rotor fan design
    • Generate shareable database of test results
  ➢ Plan
    • NASA refurbish 1980s counter-rotation propfan drive rig
    • GE will design, fabricate and test 1980s technology based open rotor fan as Historical Baseline

Hughes, GEAE, et al
Some Technology Solutions - NASA

Boeing

Subsonic Ultra-Green Aircraft Research (SUGAR)

A Wide Variety of Concepts Will Be Considered

- Joined Wing
- Hydrogen Powered
- Strut-braced Wing
- Aerial Refueling
- Hybrid Wing Body
- Formation Flight
- $\Delta$ Mach Number
- $\Delta$ Altitude
- Improved Navigation
- Continuous Descent
- Changes in Mission & Operation
- Pylon or Conformal
- Podded or Integral Batteries
- Other Concepts from Workel

Fundamental Aeronautics Program
Subsonic Fixed Wing Project
Course Syllabus

- Introduction to the topic
- Projections for Growth: Fleet-Level Forecasting Details
- Noise Impact of Aviation
- Local Emissions Impact of Aviation
- Aviation and the Global Climate
- Quantitative Assessment of Environmental Impact
- Aircraft Operations
- Technology Impacts
- Alternative Fuels
- Beyond 20 years...where can new technology lead?
- New Regulations / Standards for Fuel Burn / CO2