Evaluating Environmental Impacts

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The work we present here is preliminary. We expect the results will change as we continue to develop and improve our methods.
The debate is intense and intensifying

“Flying — the worst thing to do … The dirtiest industry in the world.”
B. Sewill, Fly Now, Grieve Later, 2005

“… unrelenting carbon-efficient improvement is business as usual for commercial airlines … We are the greenest form of mass transportation.”
J. C. May, ATA President and CEO, Congressional Testimony, 2007

• Bishop of London says vacation flying is a sin
  http://www.timesonline.co.uk/tol/news/uk/article691423.ece

• EU seeking unilateral inclusion of aviation in emissions trading system

• California and other states petition EPA to regulate greenhouse gas emissions from aviation (December 2007)

• Boeing and Virgin Atlantic B747 demo on alternative fuels (February 2008)
What matters?
To whom does it matter?
Why does it matter?
How do we know?

• Noise?
• Surface air quality?
• Climate change?
• Energy use?
• Movement of goods and people?
Choices exist; how should we choose?

- Every airplane design represents a different balance of noise, performance, emissions
- Every operational procedure represents a different balance of noise, performance, emissions
- Capital costs are high (e.g. $10B for a new airplane program)
- Time-scales are long (20-30 years)
Even simple changes may lead to complex trade-offs

• For example…

• One aspect of airplane operations changed
  – Throttle setting reduced during take-off

• Emissions and noise change
  – CO2 increases
  – NOx decreases
  – SOx increases
  – PM decreases
  – Noise decreases

• Affects aviation economics
How are choices made today?

• ICAO CAEP/6 engine NOx stringency
• Did not include estimate of averted health impacts
• Did not include estimate of impacts of additional fuel/CO2
• Did not include impacts of costs on consumer demand for aviation
• $5-$15 billion decision

Source: ICAO FESG CAEP/6-IP/13; estimates assume high level of manufacturers’ NRC and lost fleet value, discount rate 3%
How will the FAA make decisions in the future?

New Tool Suite (FAA+NASA+Transport Canada)

**Policy scenarios**
- Certification stringency
- Market-based measures
- Land-use controls
- Sound insulation

**Market scenarios**
- Demand
- Fuel prices
- Fleet

**Environmental scenarios**
- CO₂ growth

**Technology and operational advances**
- CNS/ATM, NGATS
- Long term technology forecasts

**Cost-effectiveness**
- $/kg NOx reduced
- $/# people removed from 65dB DNL
- $/kg PM reduced
- $/kg CO₂ reduced

**Benefit-cost**
- Health and welfare impacts
- Change in societal welfare ($)

**Distributional analyses**
- Who benefits, who pays
- Consumers
- Airports
- Airlines
- Manufacturers
- People impacted by noise and pollution
- Special groups
- Geographical regions

**Inputs**
- Global, Regional, Airport-local

**Outputs**
- Focus of presentation
Climate impacts of aviation are complex and occur over varying time-scales (minutes to centuries)

- Climate impacts go beyond the long term effects of CO2
  - Not unique to aviation, true for other sources, but the specific combination of effects is unique to aviation

- NOx emissions lead to increased ozone where aircraft fly, a **warming effect** regionally

- NOx emissions lead to methane removal, a **cooling effect** globally

- Contrails and contrail-induced cirrus produce **warming effect** regionally (where aircraft fly)
  - **Topic of highest scientific uncertainty for aviation climate impacts**

- Other effects (soot, sulfates, water emissions) less significant
  - Except water emissions in stratosphere which can have a strong warming influence
30-year aviation scenario: D surface temperature
A relevant time period for policy and technology, impacts of U.S. ops only

How important is CO₂?
... NOₓ?
... Contrails?

CO₂ impacts shaded in gray

Total impacts
Health impacts of surface air quality

Consistent with US EPA and EU practice, considering effects of ozone and particulate matter (PM)

\[ \Delta \text{health costs} = \Delta \text{emissions} \times \frac{\Delta \text{ambient concentration}}{\Delta \text{emission}} \times \frac{\text{health incidence}}{\Delta \text{ambient concentration}} \times \text{cost} \]

- All-sources Emissions
- Local Air Quality Modeling
- Changes in Ambient Concentration
- Concentration – Response Functions
- Change in Health Endpoint Incidence
Aircraft surface air quality health impacts

Very likely less than 0.6% of total health impacts due to poor local air quality in the U.S.

- Changes in annual particulate matter (mg/m³ PM2.5) concentrations due to aircraft SOx, NOx, soot
- Aircraft contribution to PM concentration less than 0.1% on average

Highway vehicle pollution:
~ 25,000 premature mortality incidences/year

Aviation pollution:
~ 64-270 premature mortality incidences/year

22/year
Average U.S. Airline passenger fatalities 2002-2006 (Part 121)
http://www.ntsb.gov/aviation/Table5.htm

45,000/year
U.S. motor vehicle fatalities, 2004
http://www.cdc.gov/nchs/fastats/acc-inj.htm

US Total? >25,000-70,000 mortality incidences/year
US aviation particulate matter health costs


- This graphical equation is a simplification of the more complicated analysis that we perform
Comparing aviation climate damage estimates to other environmental impacts: community noise

- Noise Depreciation Index (NDI) used to correlate noise levels with housing capital depreciation
- Adding additional noise metrics:
  - sleep awakenings
  - % highly annoyed
  - location of schools
Revisiting increased engine certification stringency for NOx
For an illustrative sample case; impacts of U.S. ops only
Revisiting increased engine certification stringency for NOx

For an illustrative sample case; note that results are very sensitive to manufacturing cost and fuel penalty assumptions; impacts of U.S. ops only
Under most assumptions and scenarios climate damage dominates other environmental impacts

30 year scenario, 3.5% discounting, U.S. operations only

These results are for one particular set of assumptions and scenarios: they are not general. However, for most assumptions and scenarios, climate impacts are larger than local air quality and noise impacts.
What’s missing (that may be important)?

- Direct health impacts of noise
- Broader economic impacts of noise (e.g., through delayed airport expansion)
- Impacts on rental units
- Impact of cruise emissions on surface air quality
- Some localized effects very close to airport
- Long-term climate feedbacks, threshold events
- Regionalized impacts

2005 US$ x 10⁹

- Noise
- Air Quality
- Climate
Summary

• FAA has made a commitment to use these tools
  – to inform their decision-making for the ICAO/CAEP meeting in 2010
  – to help establish trades among noise, local air quality and climate impacts to better quantify and manage the impacts associated with US NextGen

• We are still developing and improving these methods
  – they are not accepted for CAEP decision-making

• Our purpose
  – is not to provide “one answer” or a single “best estimate”
  – but to provide a framework that may be used to communicate potential outcomes and uncertainties using a variety of metrics, under a variety of assumptions and scenarios
Final words

• These tools will not make decision-making easier (they may well make it harder)

• However, our goal is to make decision-making better informed (not to make it easier)