Overview of Aviation Air Quality and Climate Impacts

Presented to: Aviation and the Environment: A Primer for North American Stakeholders

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Overview of Aviation Air Quality and Climate Impacts

Federal Aviation Administration
March 19, 2008

Outline

- The Characteristics of Aviation Emissions
- Aviation Emissions Context and Trends
- Aviation Emissions Impacts Pathways
- Closing Observations
Aircraft emissions are four-dimensional in nature.

Vertical extent of aviation emissions ranges from surface to cruise altitude.

Local and Global impacts are not independent (contributions to local impacts may come from emissions > 3,000 feet).
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Aircraft Combustion and Air Quality Emissions

Fuel $C_nH_m (+S)$

Typically ~10% of aviation emissions occur below 3,000 feet

Assessments of air quality must consider regional impacts

Air

$N_2 + O_2$

$NO_x + UHC + CO + C_{soot} + SO_x$

$NO_2$  $O_3$  HAPs

Precursor gases
($SO_2$, UHCs)
Air Quality Concerns

- Premature Mortality
- Hospital admissions
- Emergency room visits
- Asthma attacks
- Acute bronchitis
- Cancer
- Respiratory irritation
- Lost school/work days
- Restricted activity days
Aircraft Emissions of Concern to Climate

Fuel $C_nH_m (+S)$

Air

$N_2 + O_2$

Most aviation emissions occur in the upper troposphere/lower stratosphere

$CO_2 + H_2O + N_2 + O_2 + NO_x + UHC + CO + C_{soot} + SO_x$

$O_3$ $CH_4$

+$+$ $-$
The Complexities of Climate Effects of Aviation

- **Direct effects on climate from** carbon dioxide (CO₂) emissions
- **Indirect effects from** changes in ozone and methane from NOx emissions
  - At these altitudes, NOx emissions produce O₃
  - Increase in ozone results in increased tropospheric OH and reduced CH₄
- Indirect effects from water vapor and particle emissions due to contrail formation and corresponding effects on cloudiness
- Direct effects from aerosols (particles) either emitted directly (e.g., soot) or produced from emitted precursor gases (e.g., SO₂, HCs)
- Direct effects from water vapor emissions in stratosphere
Uncertainties Understanding Climate Impacts

Figure adapted from IPCC (1999) with additional data from Schumann (2003)

Cumulative fleet CO₂ emissions over last ~50 years

Short-lived clouds from emissions lasting ~1 day

Future: CO₂ RF lasts ~300 years, cloud RF lasts ~1 day

2003 revision (>6%) with cirrus impact

1999 estimate (3.5%), cirrus impact uncertain
Climate Concerns

Climate Changes

Temperature
Precipitation, Severe weather
Sea Level Rise
Winds

Adapted from EPA, courtesy of Don Wuebbles

Health Impacts
Agriculture Impacts
Forest Impacts
Water Resource Impacts
Coastal Area Impacts
Ecosystem Impacts

Economics & Infrastructure

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North America Aviation Activity Context

World’s Land Mass

Kilometers Flown, today

From Worldmapper, The University of Sheffield
While all transportation makes up more than 58 percent of the total national NOx inventory, aviation represents only about 0.5 percent.

Source: U.S. EPA DATA - 2005
Aircraft Energy Efficiency has improved substantially, especially when compared to the other form of US mass transit that moves passengers.

Source: BTS, National Transportation Statistics 2002
Local air quality pollutants have declined steadily over the past several years. NOx has been the most challenging pollutant to constrain.

Source: EPA National Air Quality 2001 Status and Trends, September 2002
Transport Related Emissions in Context

Eyring et al., Part 1, JGR, 2005
Relative Pollutant Contributions From Various Sources

Data from air quality analyses at select airport
"Heavier-than-air flying machines are impossible."

Lord Kelvin, president, Royal Society, 1895

“Follies of Science: 20th Century
Visions of Our Fantastic Future”
Future North American Emission Trends

Predictions computed using Aviation Environmental Design Tool (AEDT)
Very aggressive replacements flatten growth – but is it affordable or even feasible?
A Note of Caution On Predicting Trends

US Commercial Aviation Fuel Consumption

Millions of Gallons

Year

Source: BTS

Very unlikely we would have predicted this trend!
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- *Aviation Emissions Impacts Pathways*
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Impacts Pathways Concept

- Traditionally used for air quality, climate but extendable to noise
- Relate emission to background levels using physical models
- Use scientific knowledge to estimate impact

Emission of Pollutant / Noise

Change in Concentration

Estimated Impact
Air Quality Impact Pathway

Emission of Pollutant

Change in Concentration

Estimated Impact

Aircraft emissions of primary particulate matter and secondary particulate matter pre-cursors (SO$_x$, NO$_x$, and hydrocarbons); ozone pre-cursors (NO$_x$ and hydrocarbons); and HAPs

Ambient air concentrations of PM$_{2.5}$, ozone, and HAPs

1. Population exposure
2. Incidence of premature mortality and morbidity
Climate Impact Pathway

Emission of Pollutant

Change in Concentration

Estimated Impact

Aircraft emissions: CO$_2$, NO$_x$, SO$_x$, H$_2$O, and soot

Atmospheric concentration of forcing agents such as CO$_2$, CH$_4$, O$_3$, H$_2$O, aerosols, contrails, contrail-induced cirrus clouds

Temperature change, climate change, sea level rise, ...
Scientific vs. Policy-making Perspectives on Uncertainty

Scientific & Modeling Impact chain

(a) Inventories

(b) Physical changes (e.g., noise levels, air quality, temperature change)

(c) Health and welfare impacts (e.g., # of people exposed, annoyance, mortality incidence)

(d) Comparing costs and benefits (CBA)

Increasing uncertainty

Increasing relevance

Decision Making
But how do we go from This ...

... to This.
Assessment of Aviation Impacts on the Environment and Society

Aircraft Operational Variables
- airside operations
- ground operations
- T/O, landing profiles
- engine type
- aircraft type
- others.....

Physical Impacts
- Noise
  - duration, intensity
  - frequency
  - others...

- Local Air Quality
  - NOx, NO2
  - ozone
  - particulate loadings
  - HAPs
  - others...

- Climate Change
  - temperature change
  - precipitation change
  - sea level rise
  - cryosphere changes
  - air quality change
  - others...

Society/Environmental Impacts
- Human health/welfare
- Ecosystem health/welfare
- Future climate change

Value structure (e.g., monetization)

Mitigation Feedbacks

Tools & Data

Policy decisions

Prioritized Society/Environmental Impacts

Source: ICAO Impacts Workshop Report
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Closing Observations

• Aviation relatively small, but not negligible contribution to both air quality and greenhouse gas emissions inventories
• Reducing emissions impacts requires a shift from assessing emissions inventories toward an emphasis on climate and air quality impacts
• When assessing emissions must consider local, regional and global impacts
• Uncertainties remain in our understanding of climate and air quality impacts – addressing these uncertainties critical to defining significant and charting the way forward
Closing Observations

• Aviation greenhouse gas emissions may prove the most difficult long-term challenge – but cannot ignore air quality (and noise)

• Aspirational goals in fuel efficiency are essential – can we achieve emissions neutrality? Can we afford not to?

• How we operate the system- the pilots flying- can have a significant impact on aviation's emissions (and noise)
Thanks!