AVIATION & THE ENVIRONMENT

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LECTURE OUTLINE

• Overview of environmental effects of aircraft

• Aircraft noise
  – Impacts and regulatory issues
  – Technology trends

• Aircraft pollutant emissions
  – Impacts and regulatory issues
  – Technology and emissions trends

• Summary and references
## AIRPORT RANKING OF ENVIRONMENTAL ISSUES

### Current and Future

<table>
<thead>
<tr>
<th>Issue</th>
<th>Most serious problem currently</th>
<th>Most serious problem in future</th>
</tr>
</thead>
<tbody>
<tr>
<td>Noise</td>
<td>29</td>
<td>22</td>
</tr>
<tr>
<td>Water Quality</td>
<td>6</td>
<td>12</td>
</tr>
<tr>
<td>Air Quality</td>
<td>6</td>
<td>16</td>
</tr>
<tr>
<td>Compatibility with Land-use limitations</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>None Applicable</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Wetlands</td>
<td>0</td>
<td>2</td>
</tr>
</tbody>
</table>

**Source:** GAO's survey of the nation's 50 busiest commercial service airports. (GAO, 2000)
CHARACTERISTICS OF NOISE AND EMISSIONS ISSUES

• Noise
  – Local
  – Persistence = minutes
  – Well-established metrics
  – Impacts: annoyance, sleep disturbance, domestic animals?, endangered species?, health impacts?

• Emissions
  – Local, regional, global
  – Effluents: CO$_2$, H$_2$O, NO$_x$, CO, VOC’s, soot, others
  – Persistence = 1 day -1000 years
  – Drastic change in public/scientific perception and regulatory frameworks
  – Impacts: human health, ecosystem health
AVIATION ENVIRONMENTAL IMPACTS

• “EXTERNALITIES”
  – A large fraction of current aviation health and welfare impacts are real costs to society but are not accounted for by the providers or users of the service

“The government’s objectives for aviation are that...the polluter should pay and aviation, like other industries, should meet its external costs, including environmental costs.”

(From UK Department of Transport, Aviation and the Environment, Using Economic Instruments, March 2003)
## EXTERNAL COSTS OF AVIATION

<table>
<thead>
<tr>
<th>Impact Area (objective)</th>
<th>SOCIAL (industry + affected public)</th>
<th>INSTITUTIONAL (regulatory policy)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total $</td>
<td>$ / capita</td>
</tr>
<tr>
<td>Noise (quiet environs)</td>
<td>$ 26B</td>
<td>$ 2100</td>
</tr>
<tr>
<td>Air Quality (safe air)</td>
<td>$ 11B</td>
<td>$ 140</td>
</tr>
<tr>
<td>Climate Change (stable climate)</td>
<td>~$100B</td>
<td>$ 345</td>
</tr>
<tr>
<td>TOTAL</td>
<td>~$137B</td>
<td></td>
</tr>
</tbody>
</table>

- Regulatory framework currently accommodates ~ 5% potential internalization of external costs

- Noise cost per capita greater than emissions aligns with public opinion and institutional attention
  - Most vociferous opposition to noise, but air quality becoming more of an issue (GAO 2000)

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GROWTH IN MOBILITY PROVIDED BY U.S. AVIATION INDUSTRY (DOT Form 41 data)

Fastest Growing Mode of Transportation (4-6%/yr)

Revenue Passenger Miles Performed by All Airlines Operating Aircraft with >60 Seats
AIR TRAVEL PROJECTED TO BE FASTEST GROWING MODE OF TRANSPORTATION (4-6%/yr)

- DRIVEN BY POPULATION AND GDP GROWTH, AND AVAILABLE DAILY TRAVEL TIME -

Figure by MIT OCW. Adapted from: Schafer et al. (1998), GDP/cap growth rates from IPCC IS92a Scenario.
MOBILITY AND THE ENVIRONMENT

“Environmental issues are likely to impose the fundamental limitation on air transportation growth in the 21st century.”

U.S. National Science and Technology Council, 1995

Expansion Projects Delayed due to Environmental Issues

- 28% (9 airports) with no impact
- projects delayed at 72% (23 airports)

Source: GAO (2000) survey of 50 busiest commercial airports. N=33 for this question, 1 airport did not respond.

Expansion Projects Cancelled or Indefinitely Postponed due to Environmental Issues

- 25% (12 airports) with at least 1 project affected
- no impact at 75% (36 airports)

Source: GAO (2000) survey of 50 busiest commercial airports. N=50 for this question, 2 airports with no projects planned.
AIRPORTS ARE REACHING CAPACITY LIMIT

Figure 2: Anticipated Date for Airports to Reach Capacity

<table>
<thead>
<tr>
<th>Estimated time to reach capacity</th>
<th>Number of airports</th>
</tr>
</thead>
<tbody>
<tr>
<td>Already at or above capacity</td>
<td>13</td>
</tr>
<tr>
<td>1-2 years</td>
<td>4</td>
</tr>
<tr>
<td>3-4 years</td>
<td>7</td>
</tr>
<tr>
<td>5-6 years</td>
<td>8</td>
</tr>
<tr>
<td>7-9 years</td>
<td>2</td>
</tr>
<tr>
<td>10 or more years</td>
<td>11</td>
</tr>
<tr>
<td>Other</td>
<td>5</td>
</tr>
</tbody>
</table>

Source: GAO’s survey of the nation’s 50 busiest commercial service airports.
DOD ENCROACHMENT

• External factors such as urbanization, increasing environmental restrictions, and competition with civilian demands on airspace, land, seaspace, and radio frequencies

“The overall trends are adverse because the number of external inputs is increasing, and the readiness impacts are growing. Future testing and training needs will only further exacerbate these issues, as the speed and range of test articles and training scenarios increase…” (DOD Sustainable Ranges Outreach Plan, SROC)

Examples: JSF basing, Oceana operations, Navy in Japan

• Senior Readiness Oversight Council (SROC) action plans:
  – Endangered species, ordnance, frequency encroachment, the maritime sustainability, airspace restrictions, air quality, airborne noise and urban growth

REGULATIONS: BALANCING PUBLIC GOALS

• Economy and Mobility vs. National Security vs. Environment
• State vs. National interests and control

• Federal Noise Control Act + local noise restrictions
  – Commercial yes
  – Military no (Nat. Sec. Exemption, but NEPA EIS)

• Federal Clean Air Act + State Implementation Plans
  – Military yes (General Conformity Rule)
  – Commercial “no” (Interstate Commerce & Trade exemption)

• Endangered Species and Marine Mammal Protection Acts
  – Military “yes” (Nat. Sec. Exemption, but never used)
  – Commercial yes
GROWTH OF ENVIRONMENTAL REGULATION

Reflects increasing environmental impacts and increasing valuation of the environment

Adapted from: Materiel Developer's Guide for Pollution Prevention, Army Acquisition Support Office, 1994

Figures by MIT OCW.

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AIRCRAFT REGULATIONS
- Local, National, International -

• Noise
  – Certification standards
  – Phase-outs
  – Curfews
  – Flight control
  – Landing fees
  – Ticket taxes

• Emissions
  – Certification standards
  – Phase-outs
  – Limited local rules in place
LECTURE OUTLINE

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AIRCRAFT NOISE GENERATION

AIRFRAME NOISE
ENGINE NOISE
SONIC BOOM?

ATMOSPHERIC PROPAGATION

SPECTRUM, MAGNITUDE, DIRECTIVITY, DURATION
FREQUENCY OF OCCURENCE, TIME OF DAY, LOCATION

HUMAN ANNOYANCE
NOISE RADIATION
AS MEASURED ON THE GROUND

Figure by MIT OCW. Adapted from: Mathews, P & W Lecture, 1994.
# NOISE EFFECTS ON PEOPLE

<table>
<thead>
<tr>
<th>Day-Night Average Sound Level in Decibels</th>
<th>Hearing Loss Qualitative Description</th>
<th>Annoyance % of Population Highly Annoyed</th>
<th>Average Community Reaction</th>
<th>General Community Attitude Towards Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>75 and above</td>
<td>May begin to occur</td>
<td>37%</td>
<td>Very severe</td>
<td>Noise is likely to be the most important of all adverse aspects of the community environment</td>
</tr>
<tr>
<td>70</td>
<td>Will not likely occur</td>
<td>22%</td>
<td>Severe</td>
<td>Noise is one of the most important adverse aspects of the community environment</td>
</tr>
<tr>
<td>65</td>
<td>Will not occur</td>
<td>12%</td>
<td>Significant</td>
<td>Noise is one of the important adverse aspects of the community environment</td>
</tr>
<tr>
<td>60</td>
<td>Will not occur</td>
<td>7%</td>
<td>Moderate to slight</td>
<td>Noise may be considered an adverse aspect of the community environment</td>
</tr>
<tr>
<td>55 and below</td>
<td>Will not occur</td>
<td>3%</td>
<td>Moderate to slight</td>
<td>Noise considered no more important than various other environmental factors</td>
</tr>
</tbody>
</table>

(FICON, 1992)
COMMERCIAL AIRPORT NOISE EXPOSURE MAP
(DNL levels)

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(INM, 1999)
NOISE IMPACT TRENDS

- Phase-out
  - 55% of U.S. fleet
  - 94% reduction in impact
  - During 6X mobility growth
  - $10B US cost
  - $43/person/DNLdB
  - TECHNOLOGY foundation
- $1B/yr in US for sound abatement
  - $960/person/DNLdB
  - Low cost effectiveness

FAA Projection: Aviation growth balanced by technology advancement

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COMMERCIAL AND MILITARY NOISE IMPACTS

Norfolk Intl. Airport
210 TO/day

Oceana
121 TO/day
7 FCLP/day

Fentress
20 TO/day
354 FCLP/day

AIRCRAFT NOISE TECHNOLOGY TRENDS

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AIRCRAFT NOISE SUMMARY

• Difficult connection between human annoyance and physics
  – Public becoming more sensitive to aviation noise
  – Relatively mature regulatory history
• Step changes in fleet unlikely
• Increased commercial certification stringency likely but probably within current technological capabilities
• Growing problem for the military
• Local restrictions make noise a product differentiator
  – For GE-90 powered B-777 (-6EPNdB cumulative relative to other engines) twice as many t/o and landings allowed at Heathrow
  – Manufacturers willing to trade 2% fuel burn for 2 dB (A380)
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EMISSIONS IMPACTS

• Local air quality \((\text{NO}_x, \text{CO}, \text{UHC}, \text{PM})\)
  – Focus of current regulations

• Regional/global atmospheric effects
  1) Stratospheric ozone depletion (time-scale=10 years)
     – Largely a concern for supersonic aircraft \((\text{NO}_x)\)
  2) Climate change (time-scale = 100-1000 years)
     – Subsonic and supersonic aircraft
     – CO\(_2\) and H\(_2\)O
     – NO\(_x\) through ozone production
     – Particulates \((\text{SO}_x \text{ and soot})\) through heterogeneous chemistry and cloud nucleation
AIRCRAFT ENGINE EXHAUST

• Composition
  – Reservoir and primary combustion products
    \( \text{CO}_2, \text{H}_2\text{O}, \text{N}_2, \text{O}_2: \text{O}(10000-100000) \text{ ppmv} \)
  – Secondary products and pollutant emissions
    \( \text{CO}, \text{NO}_x, \text{HC}, \text{soot}: \text{O}(1-100) \text{ ppmv} \)
  – Trace species constituents
    \( \text{NO}_y, \text{SO}_x, \text{HO}_x: \text{O}(0.0001-0.1) \text{ ppmv} \)

• Most constituents play some role in atmospheric processes
  – \textit{e.g.} If 100\% of \text{SO}_2 in engine oxidizes to \text{SO}_3 it may double stratospheric ozone depletion
  – Primary and secondary species relatively well-understood
  – Relative magnitudes and engine/operations effects on trace species poorly characterized
LOCAL AIR QUALITY

• Approx. 1% of US mobile source NO\textsubscript{x} emissions are from aircraft
• NO\textsubscript{x}, particulate matter, VOCs, CO -- ozone
  – Lung function, cardiovascular disease, respiratory infection

New York City Major Local Air Pollution Sources
(NRDC, 1996)
Notes: Incomplete data, not classified, and Section 185(a) areas are not shown. Ozone nonattainment areas on map based on pre-existing ozone standard. Nonattainment designations based on revised 8-hour ozone standard will not be designated until 2000. PM-10 nonattainment areas on map are based on pre-existing PM-10 standards. Nonattainment designations based on revised PM-10 standards have not yet been made. Source: U.S. EPA, *National Air Quality and Emissions Trends Report, 1997*. (Chang, 1999)
AIRCRAFT CONTRIBUTION TO REGIONAL MOBILE SOURCE NO\textsubscript{X} EMISSIONS AT SELECTED US CITIES IS ESTIMATED TO INCREASE

Estimated commercial aircraft contribution to regional mobile source emissions of NO\textsubscript{X}

Source: Table 4-2, EPA 420-R-99-013, "Evaluation of Air Pollutant Emissions from Subsonic Commercial Jet Aircraft," April, 1999

(Chang, 1999)
AIRCRAFT AND OZONE

- Aircraft: NEGATIVE EFFECT AT ALL ALTITUDES

  - Subsonics: +0.9% total column ozone (global warming)
  - Supersonics (1000, < 5% of fleet): -1.3% total column ozone
  - Combined fleet: -0.4% total column ozone


(IPCC, 1999)
RADIATIVE FORCING FROM AIRCRAFT

Global fuel burn
Regional NOx
Global NOx
Regional Fuel burn, sulfur

Radiative Forcing from Aircraft in 1992

REPRESENTS 3.5 % of TOTAL FORCING DUE TO MAN
EXPECTED TO GROW TO 3-15% OF TOTAL BY 2050

(IPCC Special Report on Aviation, 1999)