

AVIATION & THE ENVIRONMENT



Ian A. Waitz

Professor and Deputy Head

Department of Aeronautics and Astronautics

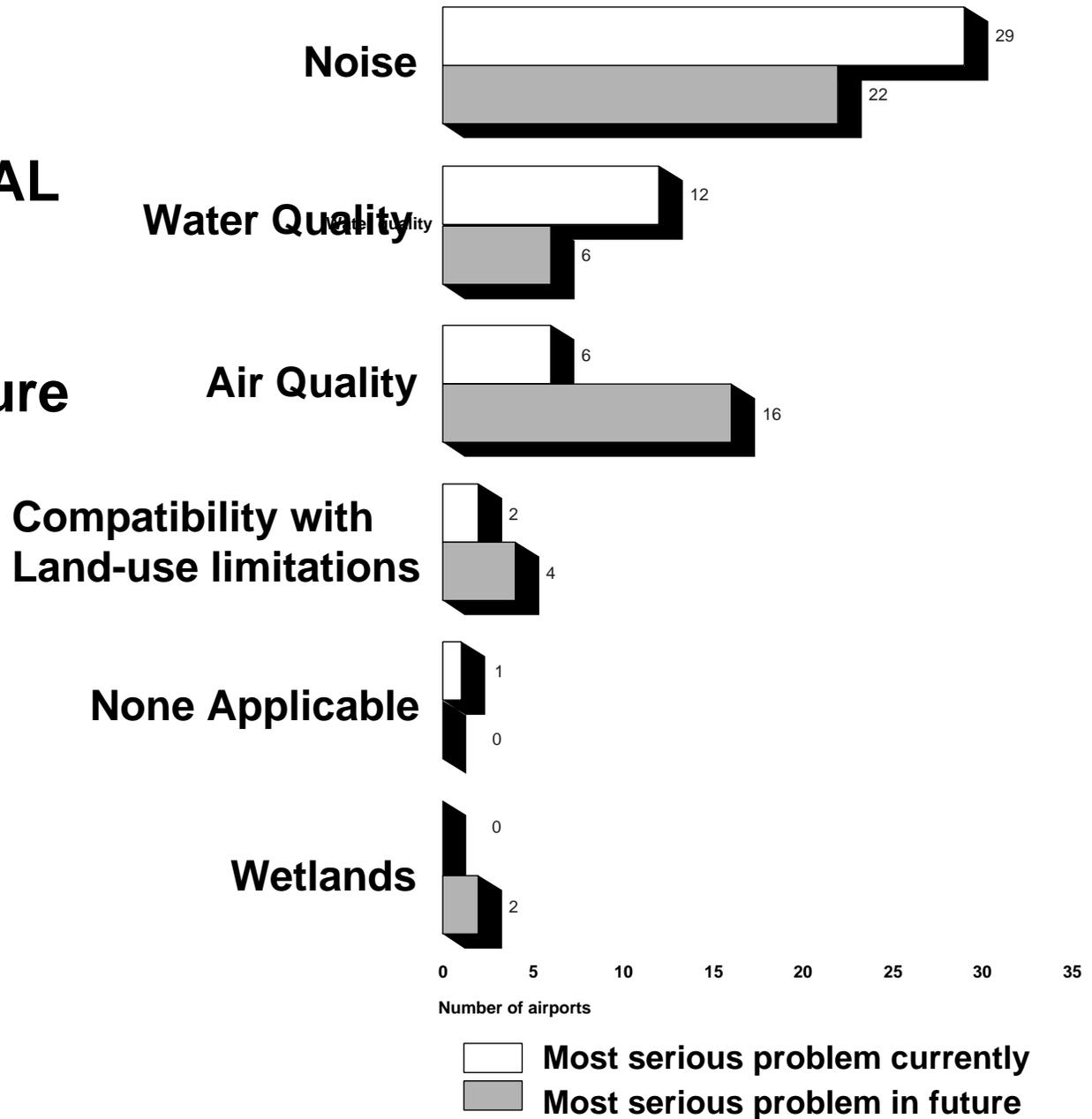
Massachusetts Institute of Technology

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



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: CO₂, H₂O, 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

VALUATION BASIS	SOCIAL (industry + affected public)		INSTITUTIONAL (regulatory policy)		
	Impact Area (objective)	Total \$	\$ / capita	Total \$	\$ / capita
Noise (quiet environs)	\$ 26B	\$ 2100	\$ 2.9B	\$ 6000	11%
Air Quality (safe air)	\$ 11B	\$ 140	\$ 2.5B	\$ 30	22%
Climate Change (stable climate)	~\$100B	\$ 345	\$ 0.0B	\$ 0	0%
TOTAL	~\$137B		\$ 5.4B		5%

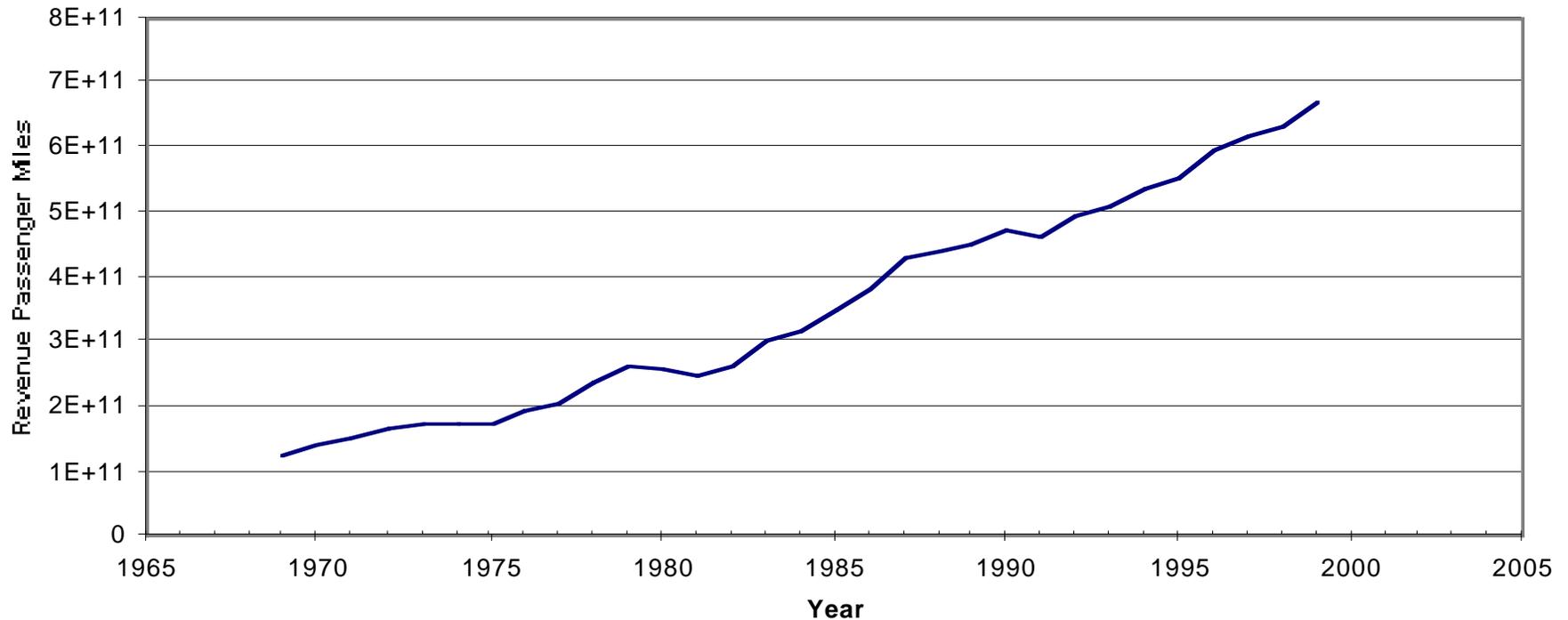
- **Regulatory framework currently accommodates ~ 5% potential internalization of external costs**
- **Noise cost per capita greater than emissions aligns with public opinion and institutional attention**
 - **Most vociferous opposition to noise, but air quality becoming more of an issue (GAO 2000)**

>>PRELIMINARY ESTIMATES ONLY<<
Lukachko, 2003

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 -

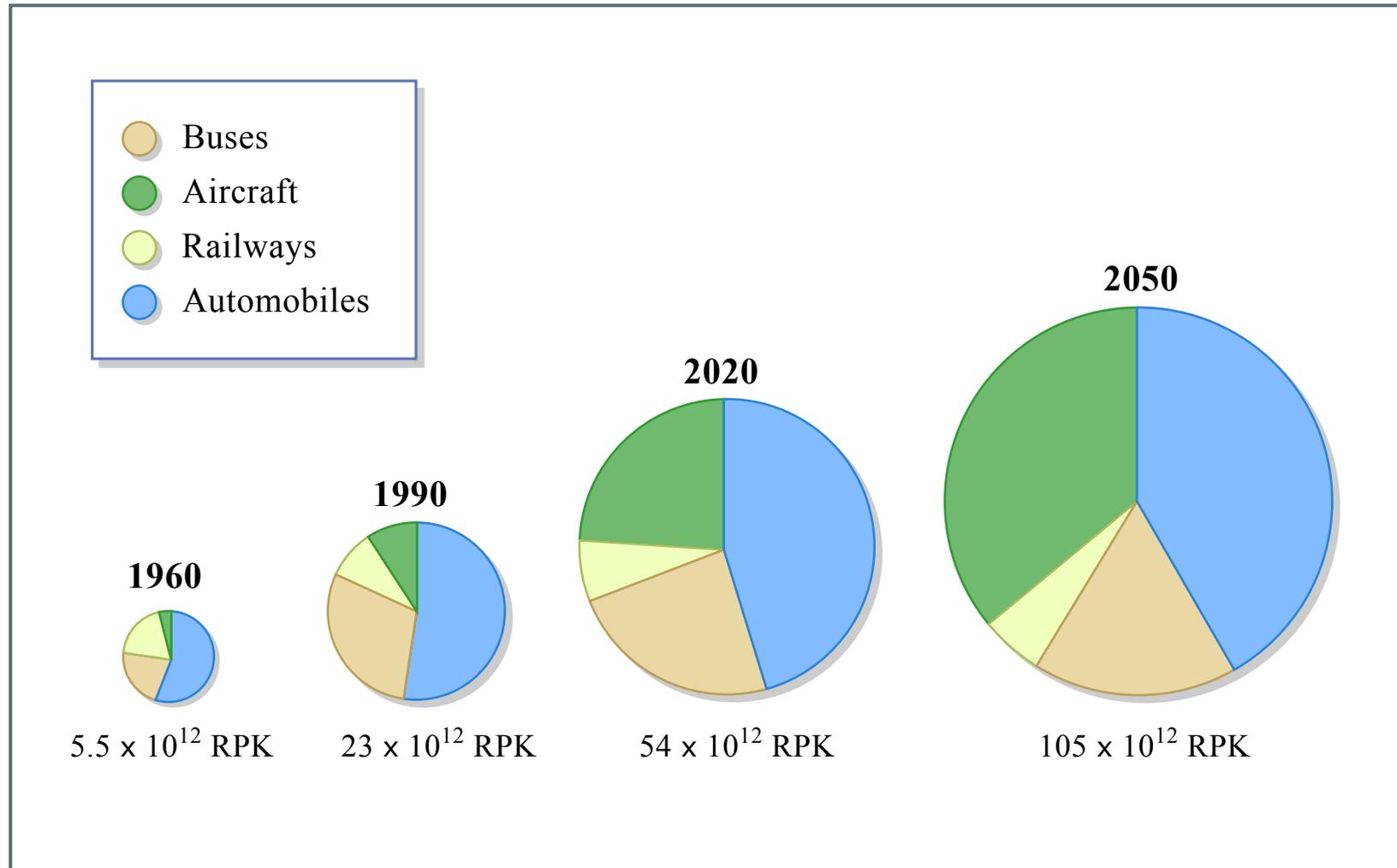


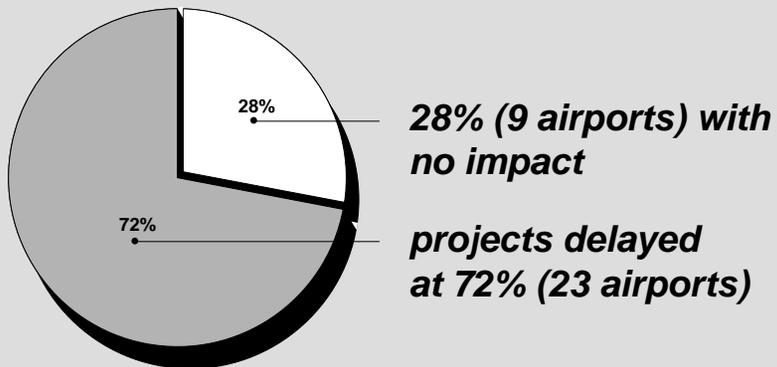
Figure by MIT OCW. Adapted from: Schafer et al. (1998), GDP/cap growth rates from IPCC IS92a Scenario.

MOBILITY AND THE ENVIRONMENT

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

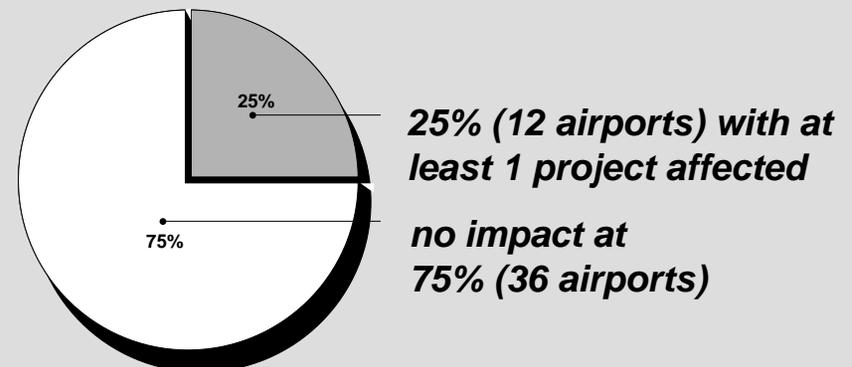
U.S. National Science and Technology Council, 1995

Expansion Projects Delayed due to Environmental Issues



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

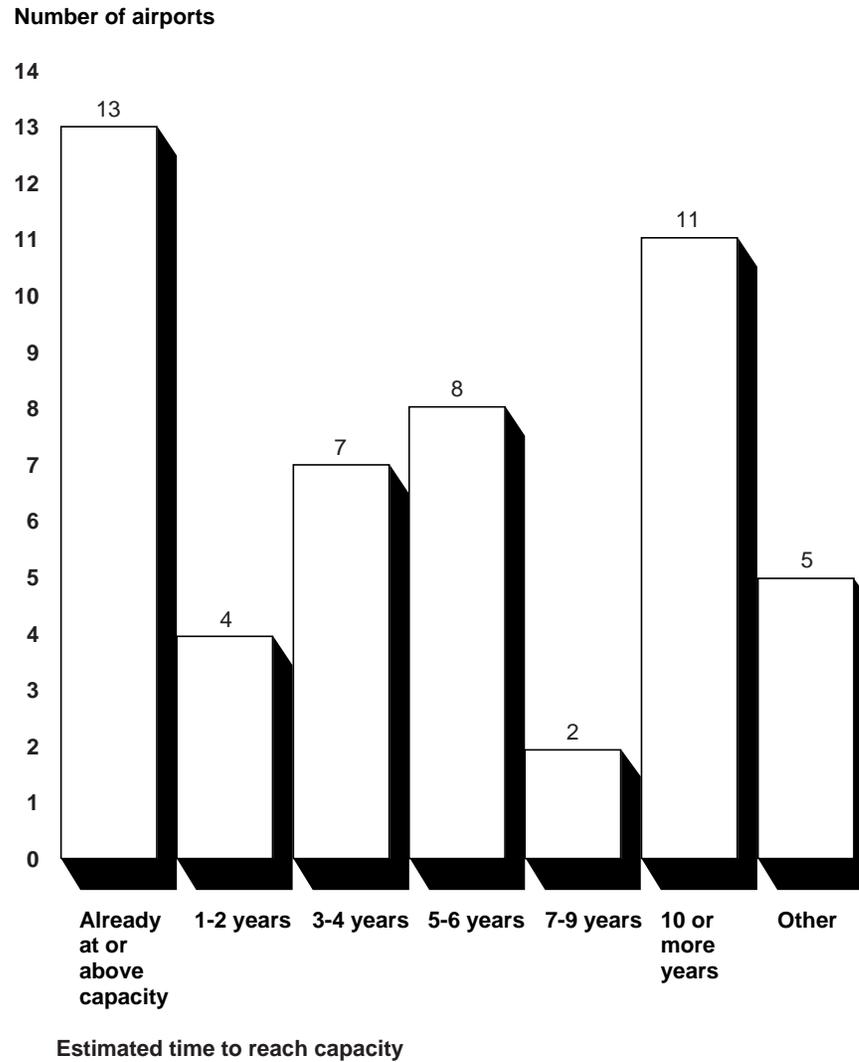
Expansion Projects Cancelled or Indefinitely Postponed due to Environmental Issues



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



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**
- **House of Representatives proposal (2002): National Security Impact Statement with all Environmental Impact Statements**

REGULATIONS: BALANCING PUBLIC GOALS

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

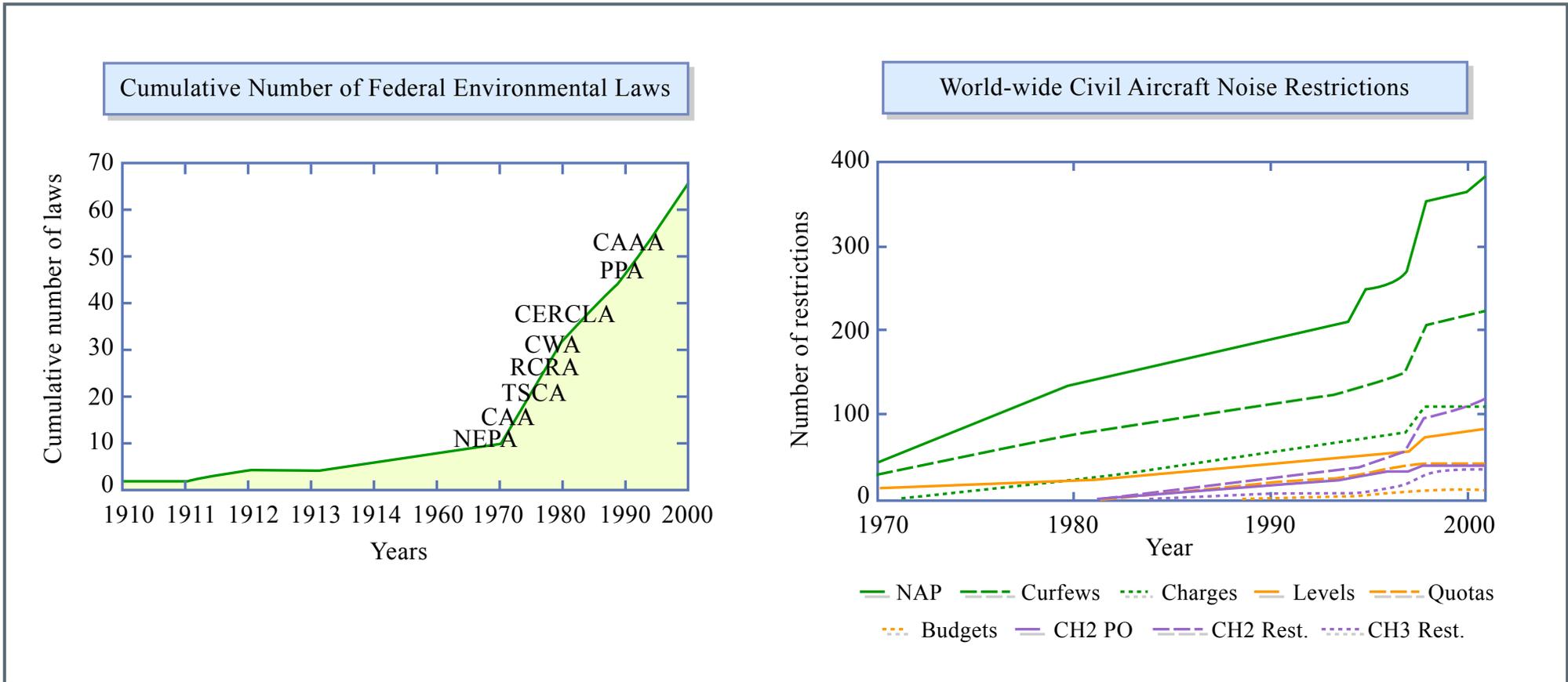
- **Federal Noise Control Act + local noise restrictions**
 - Commercial **yes**
 - Military **no** (Nat. Sec. Exemption, but NEPA EIS)

- **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



Figures by MIT OCW.

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

www.boeing.com

AIRCRAFT REGULATIONS

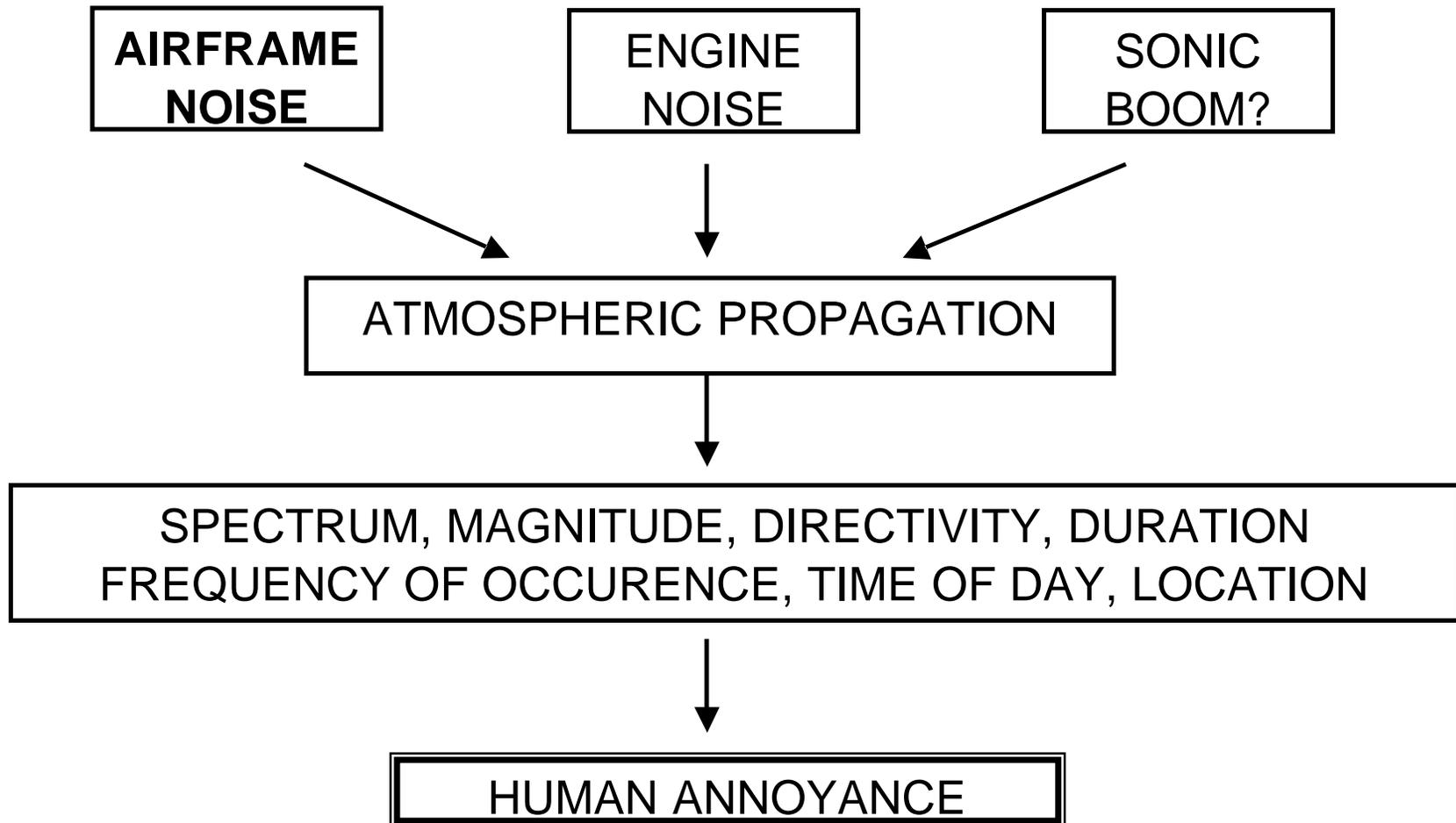
- Local , National, International -

- **Noise**
 - **Certification standards**
 - **Phase-outs**
 - **Curfews**
 - **Flight control**
 - **Landing fees**
 - **Ticket taxes**
- **Emissions**
 - **Certification standards**
 - **Phase-outs**
 - **Limited local rules in place**

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AIRCRAFT NOISE GENERATION



NOISE RADIATION AS MEASURED ON THE GROUND

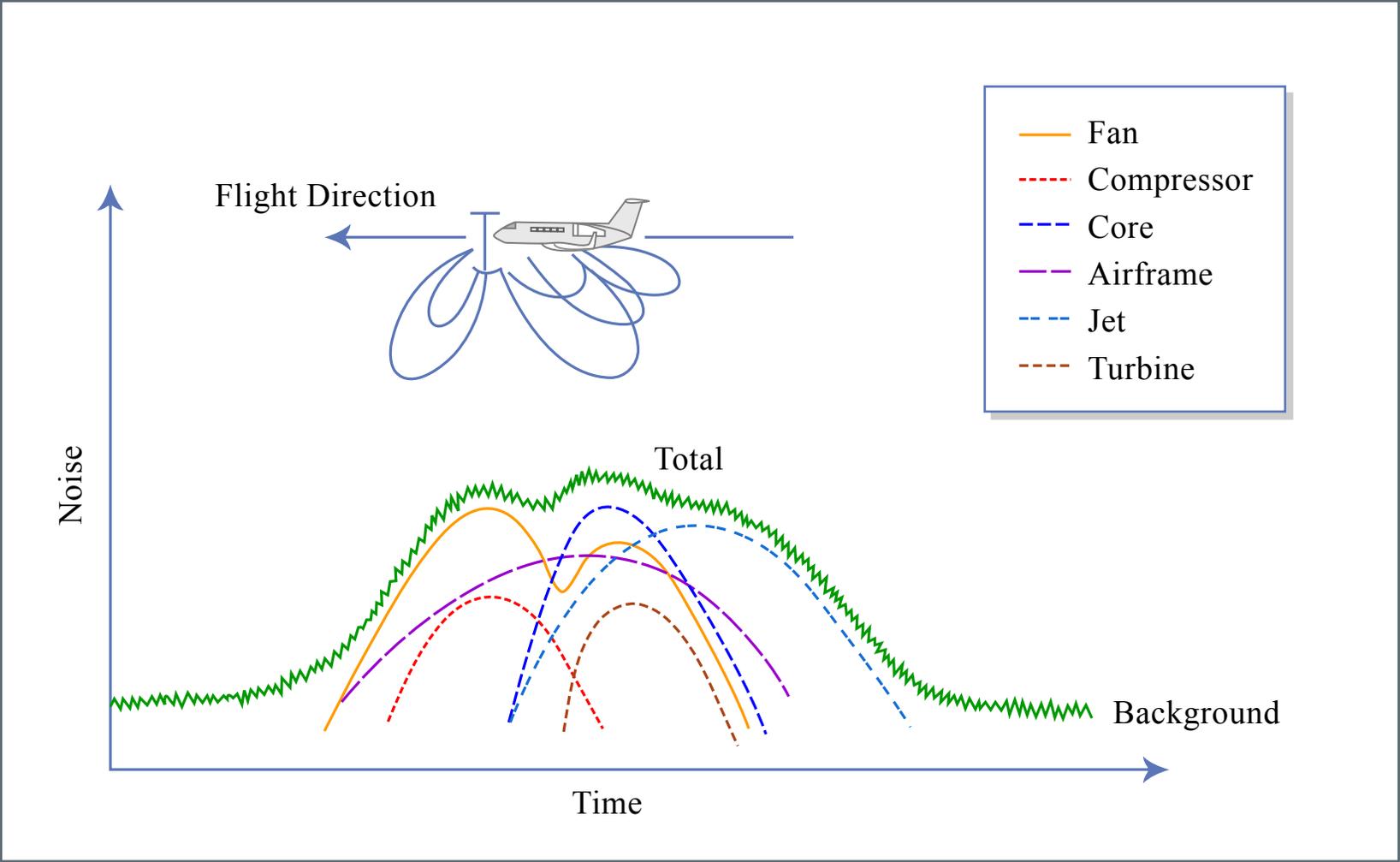


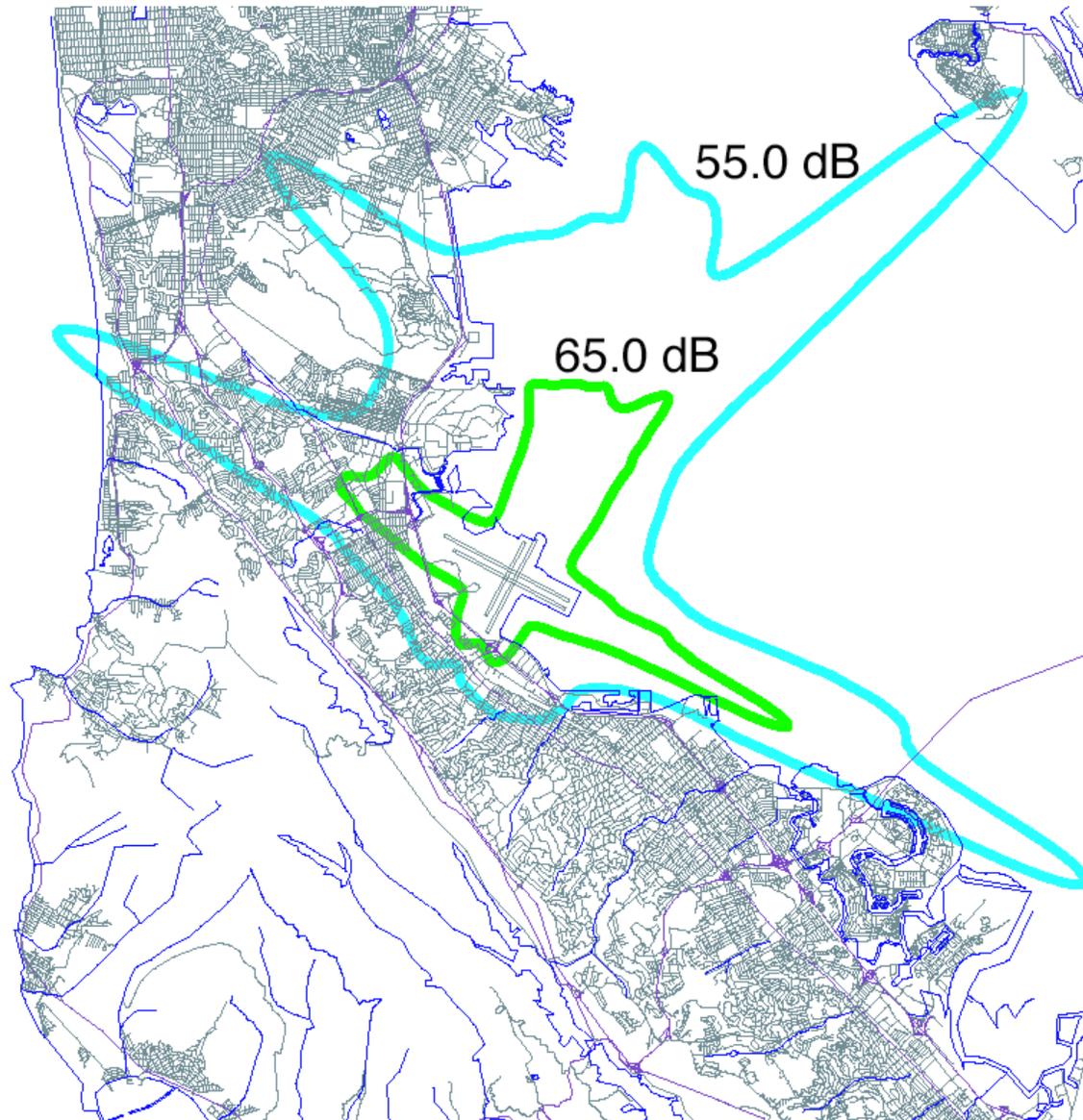
Figure by MIT OCW. Adapted from: Mathews, P & W Lecture, 1994.

NOISE EFFECTS ON PEOPLE

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

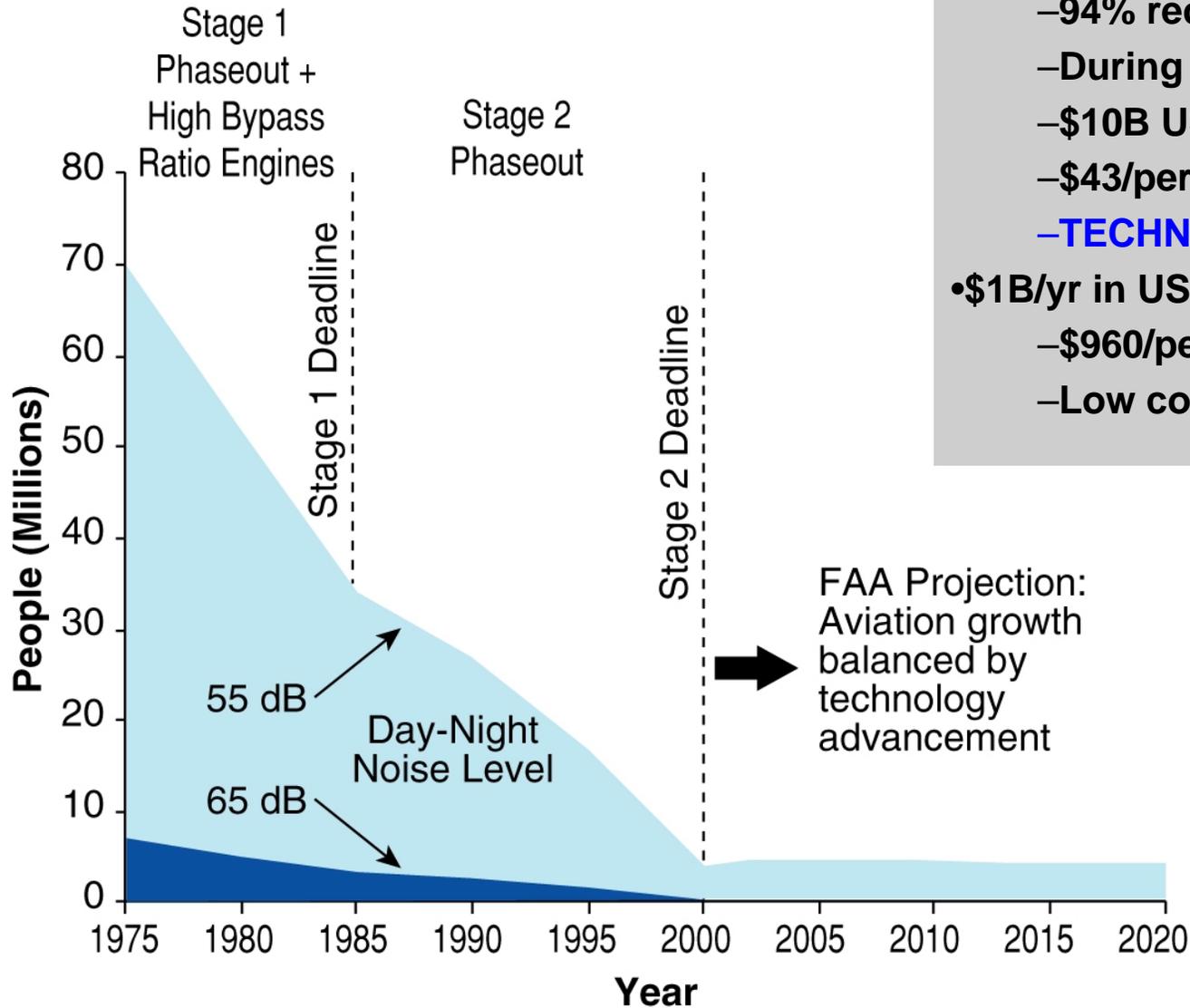
(FICON, 1992)

COMMERICAL AIRPORT NOISE EXPOSURE MAP (DNL levels)



(INM, 1999)

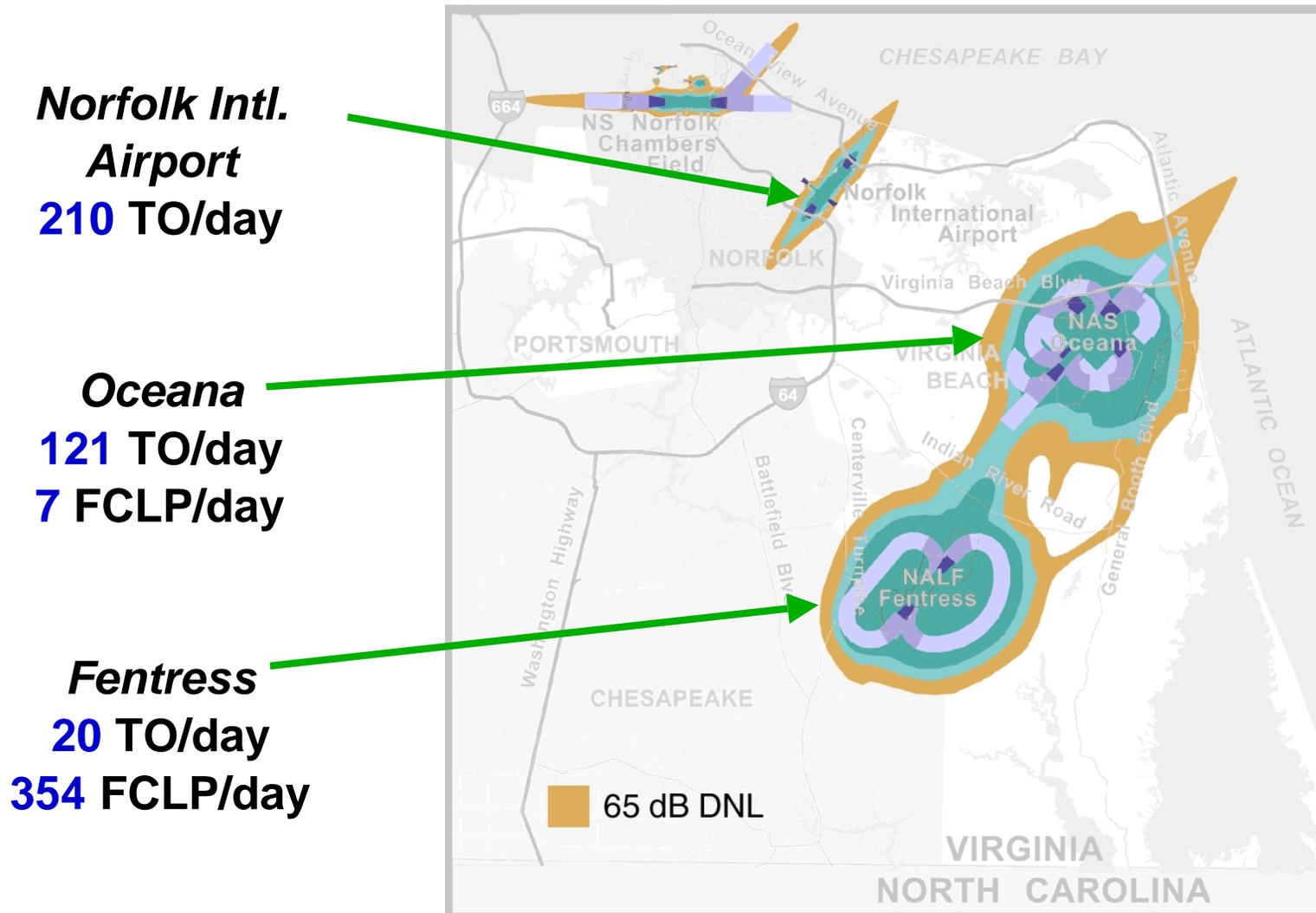
NOISE IMPACT TRENDS



•Phase-out

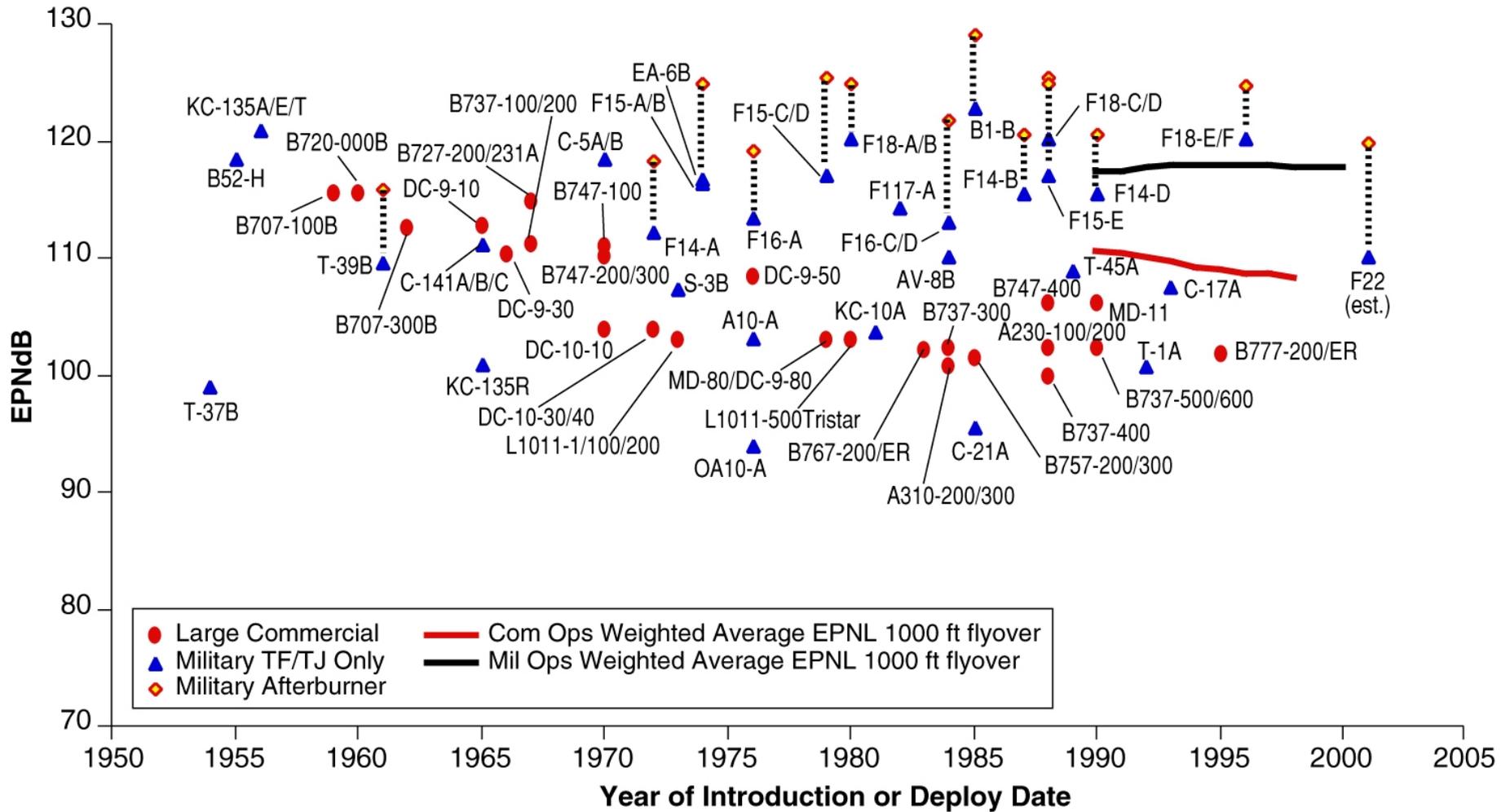
- 55% of U.S. fleet
- 94% reduction in impact
- During 6X mobility growth
- \$10B US cost
- \$43/person/DNLdB
- TECHNOLOGY foundation**
- \$1B/yr in US for sound abatement
- \$960/person/DNLdB
- Low cost effectiveness

COMMERCIAL AND MILITARY NOISE IMPACTS



<http://www.norfolkairport.com>, http://www.nasoceana.navy.mil/AICUZ_files/frame.htm

AIRCRAFT NOISE TECHNOLOGY TRENDS



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

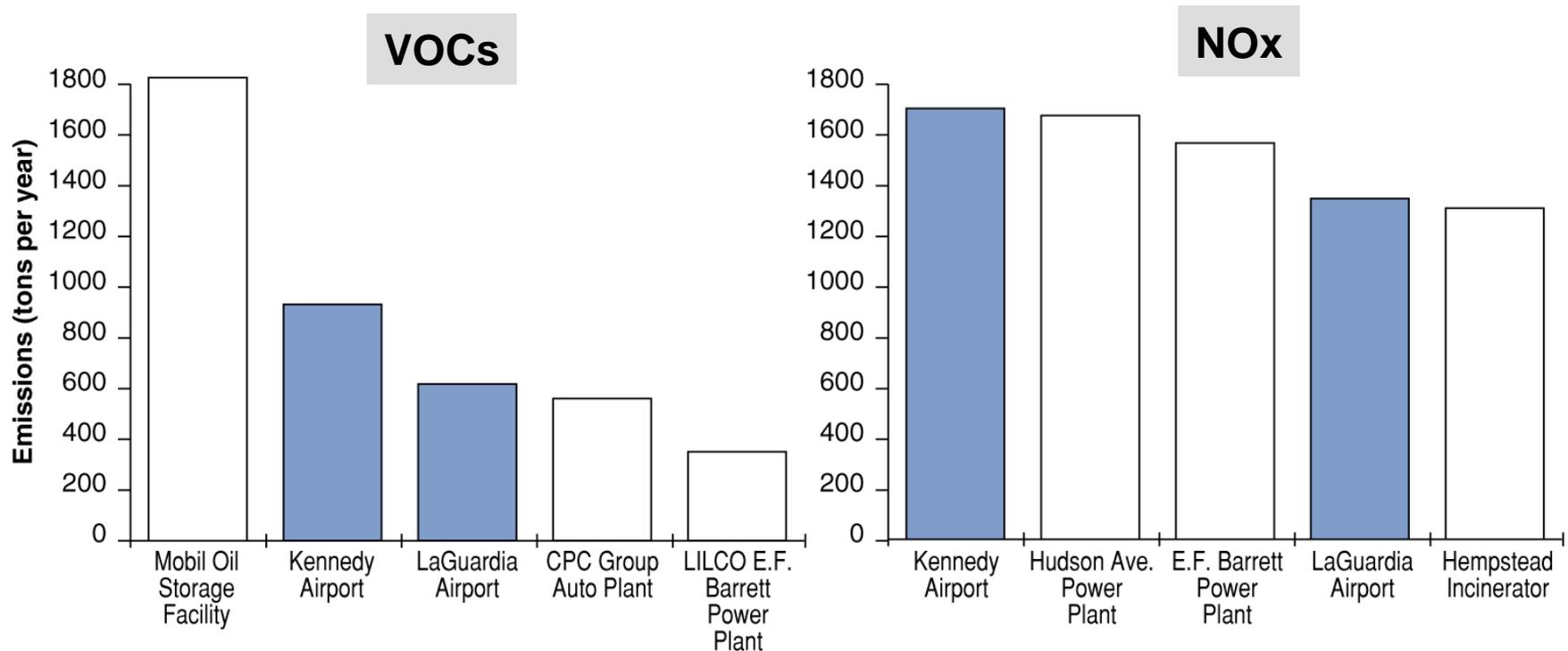
- **Local air quality** (NO_x , CO, UHC, PM)
 - Focus of current regulations
- **Regional/global atmospheric effects**
 - 1) **Stratospheric ozone depletion** (time-scale=10 years)
 - Largely a concern for supersonic aircraft (NO_x)
 - 2) **Climate change** (time-scale = 100-1000 years)
 - Subsonic and supersonic aircraft
 - CO_2 and H_2O
 - NO_x through ozone production
 - Particulates (SO_x and soot) through heterogeneous chemistry and cloud nucleation

AIRCRAFT ENGINE EXHAUST

- **Composition**
 - Reservoir and primary combustion products
 CO_2 , H_2O , N_2 , O_2 : O(10000-100000) ppmv
 - Secondary products and pollutant emissions
 CO , NO_x , HC, soot: O(1-100) ppmv
 - Trace species constituents
 NO_y , SO_x , HO_x : O(0.0001-0.1) ppmv
- **Most constituents play some role in atmospheric processes**
 - e.g. If 100% of SO_2 in engine oxidizes to 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

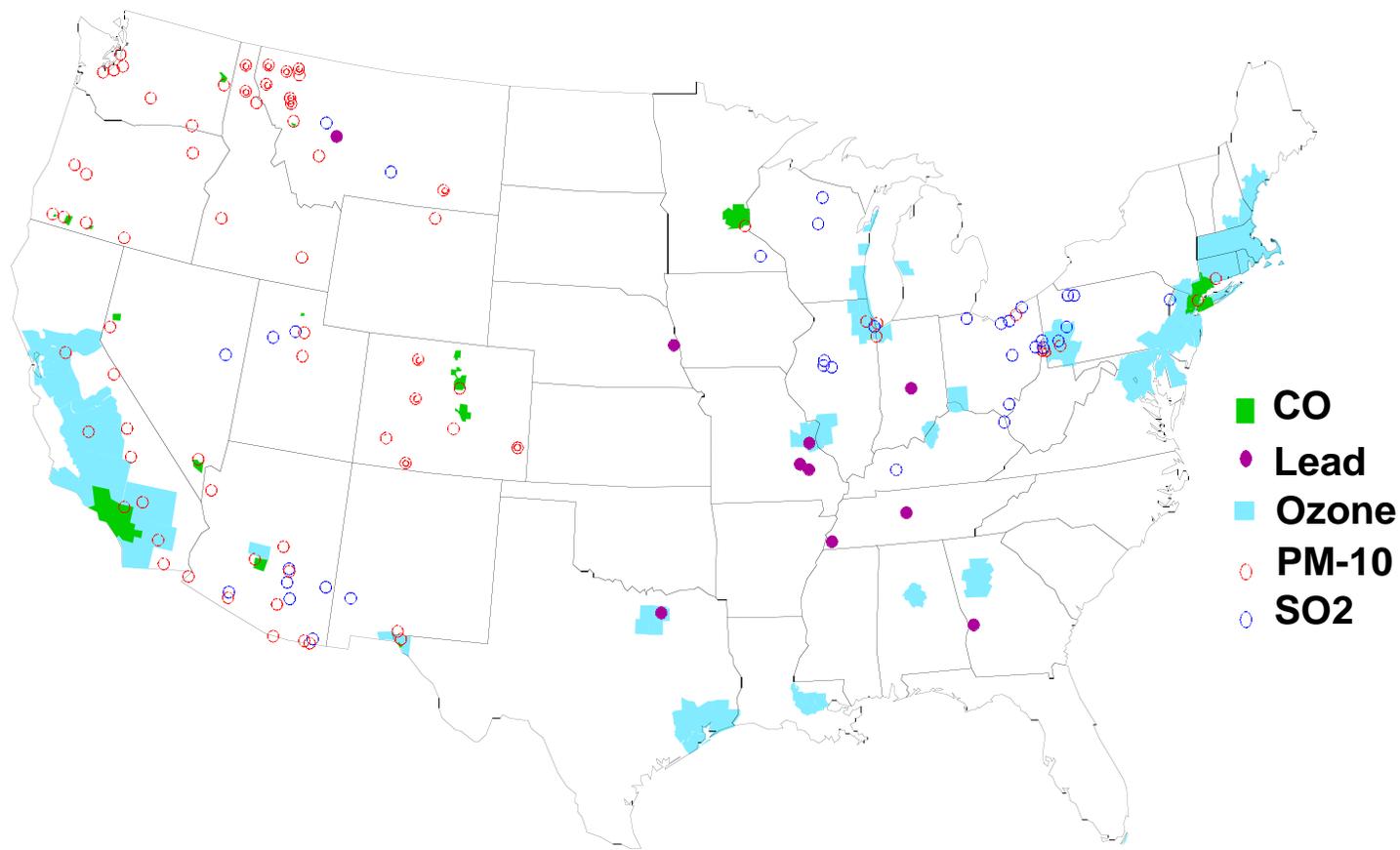
LOCAL AIR QUALITY

- Approx. 1% of US mobile source NO_x emissions are from aircraft
- NO_x, particulate matter, VOCs, CO -- ozone
 - Lung function, cardiovascular disease, respiratory infection



New York City Major Local Air Pollution Sources
(NRDC, 1996)

LOCATION OF “NON-ATTAINMENT” AREAS FOR CRITERIA POLLUTANTS AS OF SEPTEMBER, 1998

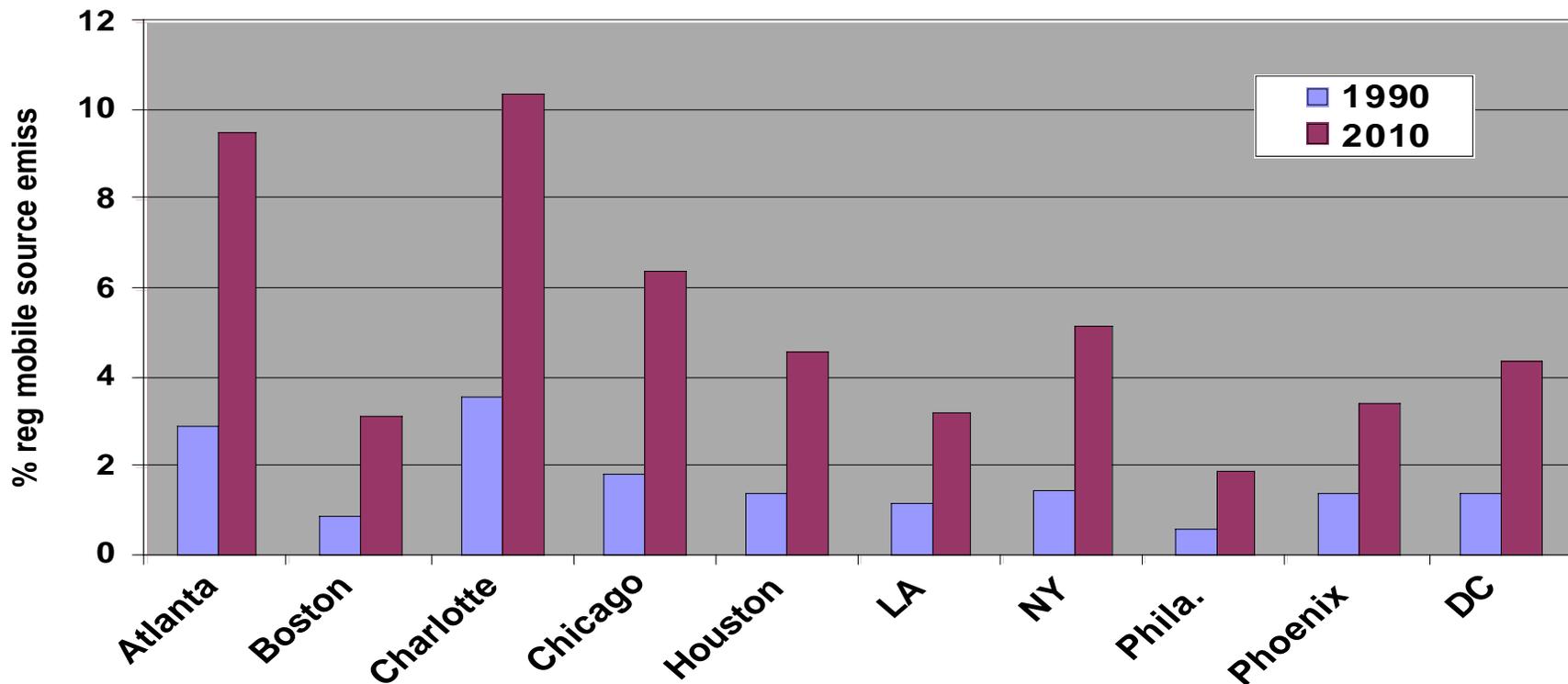


Notes: Incomplete data, not classified, and Section 185(a) areas are not shown. Ozone nonattainment areas on map based on pre-existing ozone standard. Nonattainment designations based on revised 8-hour ozone standard will not be designated until 2000. PM-10 nonattainment areas on map are based on pre-existing 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_x EMISSIONS AT SELECTED US CITIES IS ESTIMATED TO INCREASE

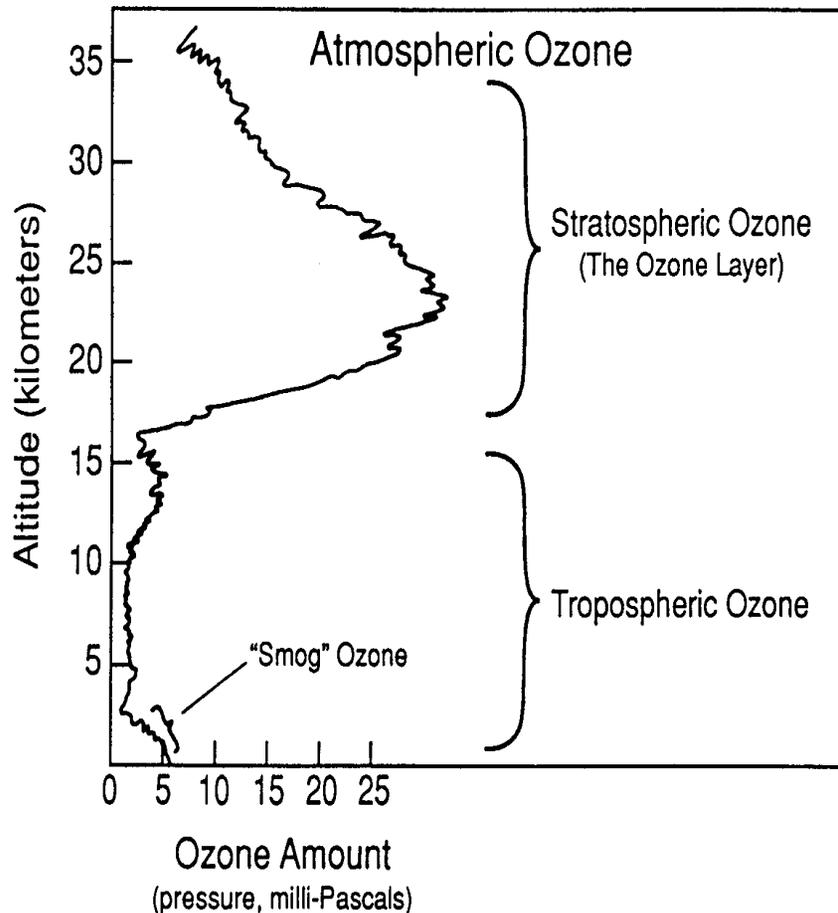
Estimated commercial aircraft contribution to regional mobile source emissions of NO_x



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



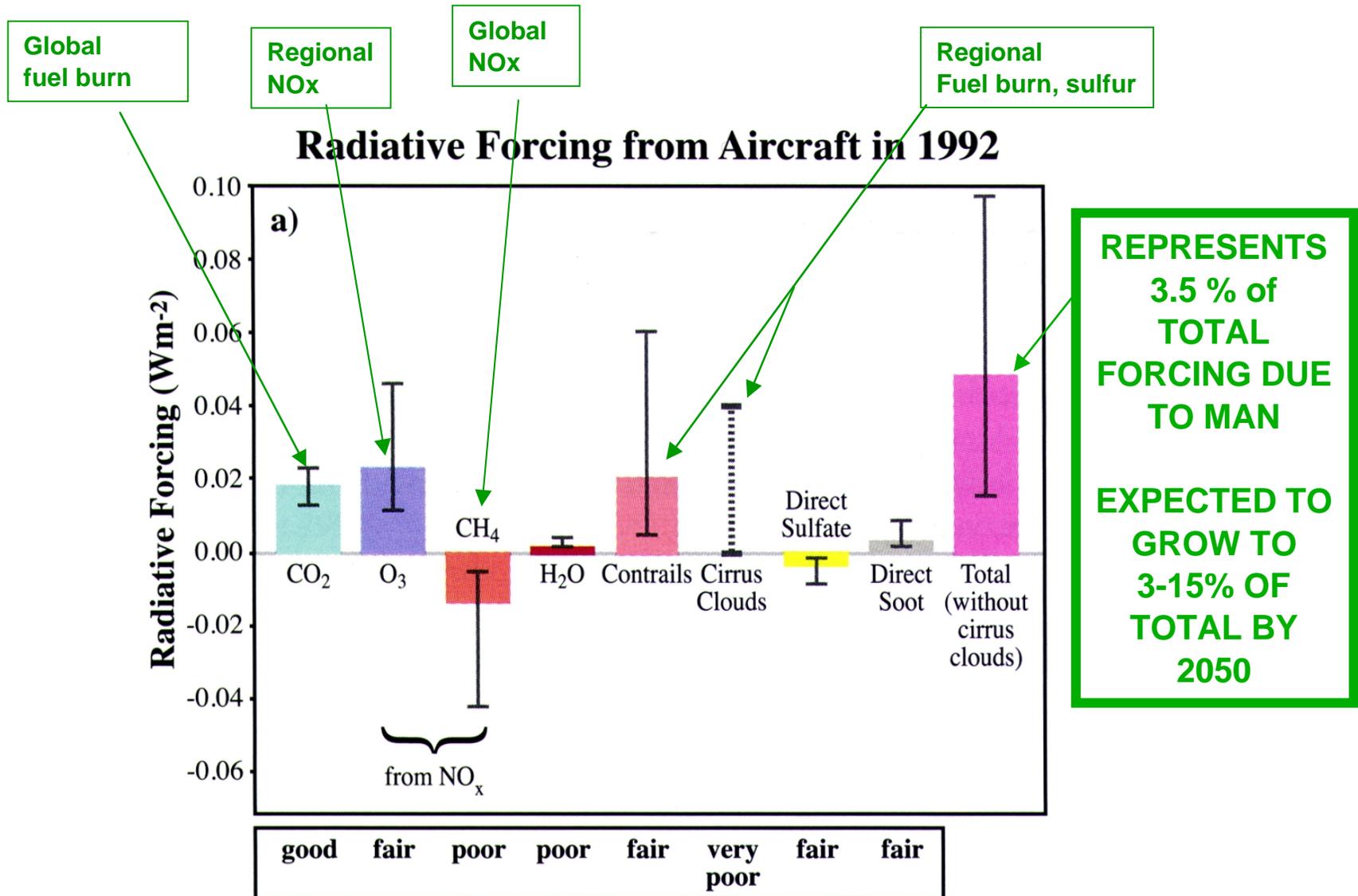
(NOAA, NASA, UNEP, WMO, "Scientific Assessment of Ozone Depletion: 1994")

- 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



(IPCC Special Report on Aviation, 1999)