Airlines, Air Pollution, & Global Warming: THE CHEMISTRY

The airline industry's contributions to air pollution and global warming are relatively small, but "not negligible."

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You have the T-shirt, the coffee mug, *and* the bumper sticker—the ones that read, "I love the smell of Jet-A in the morning." That's O.K.—you're among friends here.

But we're outnumbered—so we better have good ammo, and lots of it, for the fight ahead.

What fight? Defending the airline industry (read, "your job") against those who would burden it with overly zealous restrictions (for example, numbers of flights) and costs (taxes, charges, or fees) for burning carbon-based fuel and creating noise and emissions.

But first, you need to know the facts—and the degrees of uncertainty—about the airline industry's contributions to both local air quality (i.e., local air pollution) and greenhouse gas (GHG) emissions implicated in global warming and climate change. (We'll deal with noise in an upcoming issue of *Air Line Pilot*.)

"Aviation makes a relatively small, but not negligible, contribution to both air quality and GHG emissions," says Dr. Lourdes Maurice, chief scientific and technical advisor for environment of the FAA Office of Environment and Energy. Maurice explained the chemistry in a presentation to the symposium, *Aviation and the Environment: A Primer for North American Stakeholders*, held March 19–20 in Washington, D.C., and sponsored primarily by ALPA and the Air Transport Association (see "Toward 'Greener' Skies," May). What follows is based mainly on Maurice's presentation.

Aviation emissions

When you mix a hydrocarbon fuel such as Jet-A (kerosene) with air—mostly nitrogen (N_2) and oxygen (O_2)—in an engine and ignite the mixture, you get several combustion byproducts. These include carbon dioxide (CO_2, the principal GHG), carbon monoxide (CO), oxides of nitrogen (NOx), oxides of sulfur (SOx), water vapor (H_2O), volatile and nonvolatile particulate matter (PM), and unburned hydrocarbons (UHCs); some of the UHCs are hazardous air pollutants (HAP). The NOx leads to nitrous oxide (N_2O), methane (CH_4), and ozone (O_3). Precursor gases (SO_2, NOx, and UHCs) also lead to secondary PM.

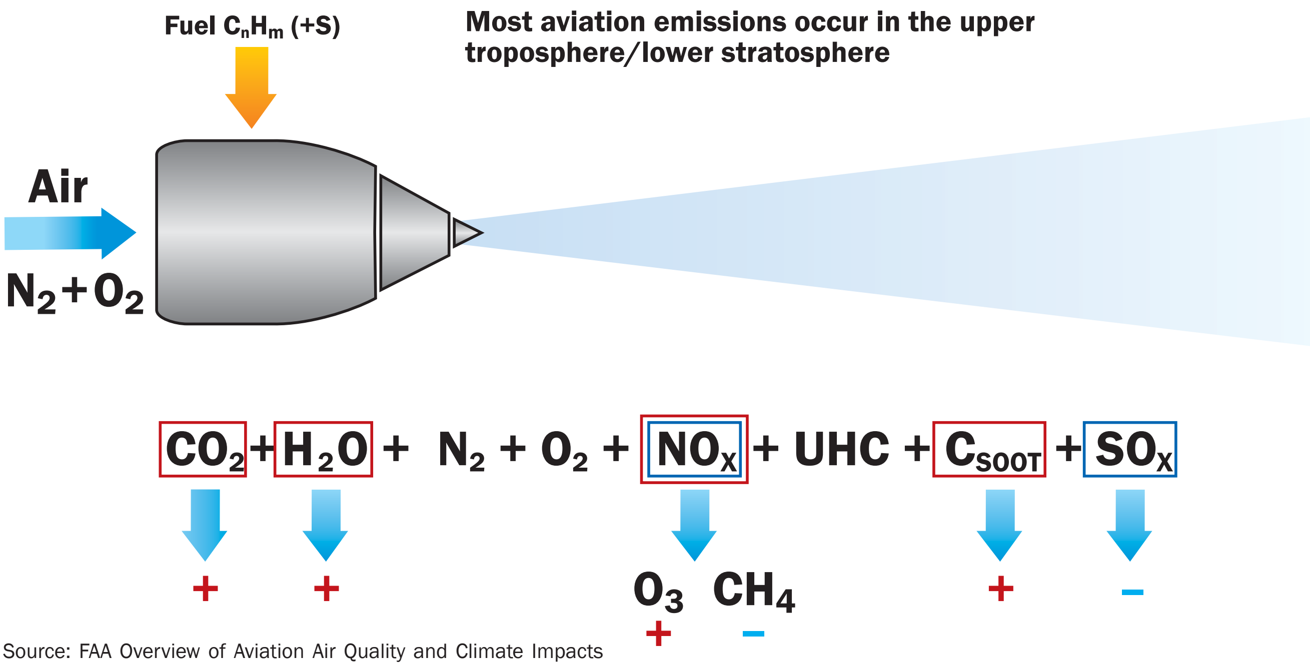
Aircraft emissions are four-dimensional in nature—i.e., they must be understood in relation to their distribution vertically, over the earth's surface, and over time. The vertical extent of aviation emissions ranges from the surface to cruise altitude. Typically, about 10 percent of aviation emissions occur below 3,000 feet AGL. However, local and global effects are not independent; contributions to local effects may come from

Second in Series

"The Chemistry" is the second article in *Air Line Pilot*'s "Flying Green" series, which deals with ALPA's participation in the current environmental debate and efforts to reduce air transportation's carbon footprint.

ALPA's Task Force on Aviation Sustainability and the Environment, chaired by the recently appointed Capt. Mary Ann Schaffer (United) spearheads this effort, advising ALPA's president, Capt. John Prater, on all matters "green."

Aircraft Emissions of Concern to Climate



Source: FAA Overview of Aviation Air Quality and Climate Impacts

Schematic of the basic chemistry of jet engine combustion byproducts shows some of the interrelationships among the emissions. Carbon dioxide, water vapor, ozone (created by oxides of nitrogen), and soot contribute to global warming; however, the oxides of nitrogen, by increasing ozone, remove another greenhouse gas, methane, and thus have a cooling effect globally, as do the sulfates.

emissions above 3,000 feet, and assessments of air quality must consider regional effects.

Air *quality* concerns include respiratory irritation, asthma flares, acute bronchitis, restricted activity days, lost school and work days, emergency room visits, hospital admissions, cancer, and premature mortality. According to data presented by MIT Professor Ian A. Waitz, estimates of the number of premature deaths caused annually in the United States by aviation *pollution* range from 64 to 270. Compare those numbers with the 22 passenger accidental deaths per year, on average, attributed to U.S. airlines operating under FAR Part 121 during the period 2002–2006.

Aircraft emissions of concern to *climate* include CO_2, H_2O, O_3 formed via NOx, and soot, all of which increase global warming. On the other hand, an increase in O_3 as a result of NOx results in reduced CH_4 which, along with SOx, has a *cooling* effect on the atmosphere. Most aviation emissions occur in the upper troposphere and lower stratosphere.

How emissions affect climate

Concerns stemming from climate changes (temperature, precipitation, severe weather, sea-level rise, and winds) include possible effects on health, agriculture, forests, water resources, coastal areas, ecosystems, and economics and infrastructure.

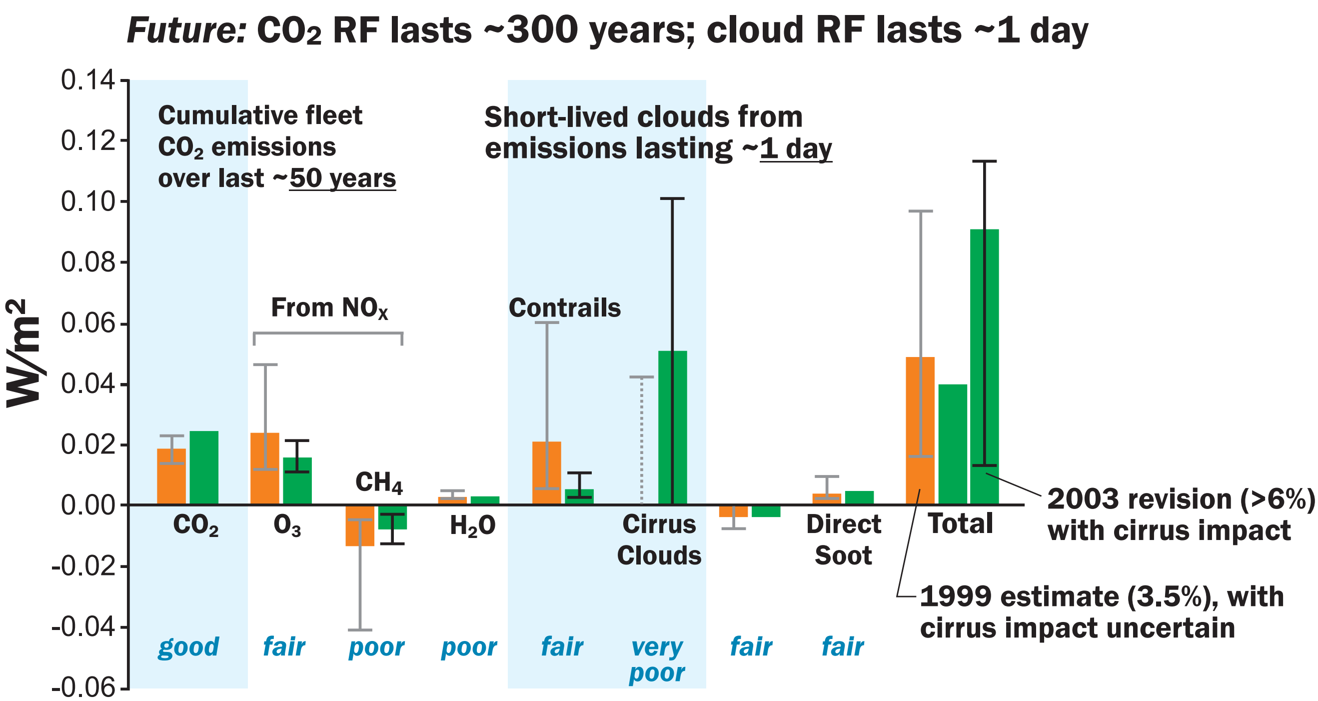
The effects of aviation emissions on climate are complex and occur over varying spans of time, from minutes to centuries. CO_2 survives in the atmosphere for a century or more. This longevity makes CO_2 the focus of market-based strategies like the European Union's proposed cap-and-trade system.

Direct effects result from CO_2 emissions, aerosols (particles) either emitted directly (e.g., soot) or produced from emitted precursor gases (e.g., SO_2 and UHCs), and water vapor emissions in the stratosphere.

Indirect effects are caused by NOx emissions, which produce more ozone (a GHG) where aircraft fly, thus creating a warming effect regionally; however, increased ozone leads to methane removal, which has a cooling effect globally.

Water vapor and particle emis-

Uncertainties in Understanding Climate Impacts



Source: FAA Overview of Aviation Air Quality and Climate Impacts

Bars shaped like I-beams indicate the range of uncertainties in understanding climate effects—i.e., radiative forcing (warming effect)—of various greenhouse gases. The cumulative effects (far right) thus incorporate considerable cumulative uncertainty.

Aviation Emissions in Context

Putting aviation emissions in context, remember that aviation contributes less than 3 percent of total GHG emissions from all sources, and less than 1 percent of local NOx emissions. According to 2005 U.S. Environmental Protection Agency (EPA) data, while all transportation produces more than 58 percent of the total U.S. NOx emissions, aviation contributes only about 0.5 percent. However, although aviation pollutants that affect air quality have declined steadily over the past several years, NOx has been the most challenging pollutant to constrain.

The record regarding emissions improvements (the BTUs expended per passenger mile) shows that aircraft energy efficiency has improved substantially, especially when compared to the other forms of U.S. mass transit that move passengers.

An EPA report issued in April showed that the U.S. aviation industry has cut its GHG emissions by 13 percent since 2000 and that U.S. airlines reduced fuel consumption from a record 20.4 billion gallons in 2000 to 19.6 billion in 2006, while flying 18 percent more miles. According to the report, DOT data show that aircraft efficiency measured in fuel burned per mile flown improved by 23 percent between 2000 and 2006, while U.S. automobile fuel efficiency increased only 2 percent.

Nevertheless, California-based Earthjustice and other environmental groups petitioned the EPA in December 2007 to regulate aviation GHG emissions, asserting, "Voluntary measures alone will not be sufficient."

Squeezing More MPG Out of Future Airliners

Aviation industry leaders believe that, over the next couple of decades, they will be able to achieve even more efficiencies than those already achieved during the first half-century of jet airline travel, when manufacturers reduced fuel burned per passenger mile by some 70 percent. The expected future decreases in fuel burn would come from a variety of sources:

- 5 percent from optimal use of advanced materials to build lighter airliners;
- 5–15 percent from NextGen and similarly advanced air traffic management systems in other countries, and associated procedures such as RNAV, RNP, and the continuous descent approach (CDA) concept;
- 10 percent from tweaking airframe aerodynamics; and
- as much as 25 percent from innovative engine designs.

Altogether, that adds up to reducing fuel burn by as much as 55 percent when compared to today's airline operations.

BOEING

Boeing engineers say that their X-48B Blended Wing Body concept (shown here during its 50th test flight) is about 30 percent more fuel efficient than a conventional airplane of similar size that carries the same payload.

sions produce indirect effects by creating contrails and their corresponding effects on cloudiness. Contrails and contrail-induced cirrus clouds produce a warming effect regionally (again, where the aircraft fly), and water emissions in the stratosphere can have a strong warming influence.

But scientists admit to facing varying uncertainties about their understanding of climate effects. We have good certainty about the cumulative CO_2 emissions of the airline fleet during the last half-century, but only fair certainty regarding ozone resulting from NOx emissions, fair certainty about the direct effects of sulfates and soot, and poor certainty regarding the effects of methane and water vapor.

Moreover, regarding the effects of short-lived clouds from emissions lasting about one day, we have fair certainty on contrails, and very poor certainty on contrail-induced cirrus clouds. The "radiative forcing" (warming effect) of cirrus clouds lasts only about one day, while the radiative forcing of CO_2 lasts *hundreds of years,* but we need to enhance our understanding of aviation-induced cirrus clouds before we can make any definitive pronouncements.

Pathways for emissions effects

Reducing the effects of emissions requires a shift from assessing emissions "inventories" to focusing on the climate and air quality *effects* of those emissions. That focus, in turn, requires considering local, regional, and global effects.

Perhaps even more important, the scientific and policymaking perspectives on uncertainty are diametrically opposed: From the scientific standpoint, we often encounter increasing uncertainty as we progress from engine fuel combustion to emissions to atmospheric processes to changes in atmospheric warming to climate response to climate change to effects on human health, agriculture, forestry, ecosystems, energy production and consumption, and social effects to (finally) damages. From the standpoint of making policy decisions, however, that long and intricate progression is a path of increasing relevance.

So don't throw out the "I Love the Smell of Jet-A in the Morning" T-shirt, but understand that a growing number of very vocal folks don't share the love. Dealing with them and their elected representatives is already taking on greater importance for your future.