Climate Impact of Aviation: Issues and present Assessment
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Introduction

This presentation is based on research since 1992, IPCC (1999, 2007), and several DLR, EU and EU/US projects.

Issue: What is the aviation contribution to climate change?

Previous talk (IPCC result):
- Global warming is a reality
- Climate protection requires considerable reductions in greenhouse gas emissions from all sources within a few decades.
Climate Impact of Aviation

Global aviation contributes to climate change by emissions of carbon dioxide (CO$_2$), nitrogen oxides (NO$_x$), water vapour, particles, contrails and cirrus changes.

Carbon dioxide is the most important greenhouse gas. Its effect is independent of the altitude at which the emission occurs.

Nitrogen oxides from aviation at subsonic cruise altitudes enhance ozone formation and reduce methane; both are greenhouse gases.

Water vapour and particles (soot etc.) emitted at altitudes near the tropopause can induce contrails and cirrus cloud formation, likely enhancing the greenhouse effect.

Because of different lifetimes (CO$_2$: order 60 years, NO$_x$ and H2O: order 1 week, contrails: order hours) the impact depends on the periods and scenarios considered.
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Global distribution of aviation emissions

Aviation Fuel: 169 - 213 Tg/a (about 2 % of all CO₂-emissions)
NOₓ: 2.6 -3 Tg(NO₂)/a (about 1.5 % of all NOₓ-emissions)

(AERO2K, 2005)
About 40% of all emissions occur above the tropopause.
O₃-contribution (%) from aviation and other NOx sources

Grewe, DLR, 2007
Contrails and soot from cruising aircraft cause cloud changes
Contrails and soot from cruising aircraft cause cloud changes

Contrails are caused by water vapor emissions from aircraft flying in cold and humid air masses.

Contrails evolve into “contrail cirrus” in humid air masses.

Soot and other particles change contrails and cirrus properties and may cause cirrus far away from air routes (“soot cirrus”).

Line-shaped contrails are detectable from space.

The total cirrus change is estimated with still large uncertainty.

Cirrus and contrails heat during night.

They heat or cool during day.
Line-shaped contrail cover: 0.5 % of Europe

(Meyer et al., DLR, 2002, 2007)
Cirrus Cloud Cover Trends from Satellite Data: 2%/decade

- N. American region (high air traffic)
- N. American region (low air traffic)

Based on cloud cover from satellite data (ISCCP) (Zerefos et al., 2003)
Contrail Cirrus Trends from Satellite Data: 0.2%/decade

Data from TOVS satellite data
No trend for cirrus in all situations
Positive trend of cirrus cover for atmospheric situations favorable for contrail formation

(Stubenrauch und Schumann, 2005)
Soot impact and contrail-cirrus formation modeled

Soot impact on cirrus for two extreme nucleation models

Fresh and aged contrail cirrus

(Hendricks et al., DLR, 2005)

(Burkhardt & Kärcher, DLR, in preparation)
Radiative Forcing until 2000 from Global Aviation

(Sausen et al., TRADEOFF, 2005)
Radiative Forcing until 2100 for constant emissions

For constant aviation emissions: RF$_{CO_2}$ increases from 25 to 90 mW m$^{-2}$ (Forster et al., 2006)
Radiative Forcing and Temperature Change induced by Aviation

Global aviation contributed to Radiative Forcing so far about 0.05 W/m².

These are about 3 % of the total radiative forcing from all anthropogenic effects as assessed in IPCC (2007).

Global aviation contributed to the observed global warming of 0.7°C about 0.03°C (ca. 4 %).

Very little uncertainty on aviation CO₂ impact. CO₂ emissions reduction has highest priority in the long term.

The largest uncertainty comes from aviation contributions to changes in cirrus clouds, which are not included in the total therefore.

Including the presently know uncertainties, the aviation contribution is estimated within the range 2 to 8 %.
Trends

1991-2004:

- **Passenger-km:** 4.6 %/a
- **Freight-km:** 6.4 %/a
- **Kerosene:** 2.1 %/a

(Schumann, 2007)

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Trends (Schumann, 2007)
Entkopplung von Transportleistung und Umweltbelastung
Veränderung gegenüber 1991 in Prozent, Angaben für die Flotte des Lufthansa-Konzerns

Lufthansa
transport: 9 %/a
NOx: 6.8 %/a
fuel: 5.7 %/a
CO
UHC

(Lufthansa, 2006)
Trends

Aviation fuel consumption (CO₂ emissions) grew globally by 2-3 % per year from 1990 – 2004.
Aviation NOx emissions grew by 4-5 %/year from 1990 – 2004.
For the near future, further growth of global fuel consumption and global emissions of CO₂ and NOx is to be expected.

Scenarios of civil aviation CO₂ emissions in 2050 show a potential increase by factors 3.3 - 5 (see David Lee)
If aviation emissions continue to grow while other emissions get reduced, the relative importance of aviation contributions grows.

CO₂ emissions reduction has highest priority in the long term.
Reductions of NOx and contrails has largest impact on climate mitigation at short term.
What can be done to avoid contrails?

Improved engines to not reduce contrails

Fly higher or fly lower?

Frequency of ice supersaturation, %

(Spichtinger et al., DLR, 2003)
Fly higher or fly lower?

Vertical distribution of all ice-supersaturated regions

Required altitude change: 2 km

Frequency of ice supersaturation, %
Fly higher or fly lower?

Vertical distribution of **individual** ice-supersaturated regions

Required altitude change: 300 m
Conclusions

The aviation share in CO$_2$ emissions is presently about 2 %

CO$_2$ is the most important greenhouse gas. Its effect is independent of the emission altitude. Its radiative forcing is well assessed.

NO$_x$ from aviation enhance O$_3$ and reduce CH$_4$. The radiative forcing has been assessed with fair certainty.

Water vapour and particles (soot etc.) emitted in cold and humid air induce contrails and cirrus clouds. Contrail cirrus may form largest RF-contribution.

The aviation share in radiative forcing is presently 3 % (range 2-8%)

The relative importance of short-lived (NO$_{x}$, contrails) and long-lived (CO$_2$) emissions depends on the scenario and choice of timescale.

Possible mitigation options include: aircraft/engine with less emissions, fuel saving operation, contrail-avoiding routing

Reducing short-lived emissions (NO$_x$, soot, contrails) may be more effective for climate mitigation than reducing long-lived effects (CO$_2$).