DLR-project evaluates the climatic impact of aviation

Aviation impacts our environment and human health in terms of air quality and noise level near airports, and climate. Serious concerns about effects of aircraft emissions on the Earth's climate could hinder the expected growth of air transportation. Climatic effects encompass CO_2 emissions, changes in the properties of high clouds containing ice crystals (cirrus clouds) through the formation of persistent contrails and soot emissions, and changes of ozone resulting from nitrogen oxide emissions. According to the Intergovernmental Panel on Climate Change (IPCC), aviation impact on clouds and climate is the environmental issue of greatest uncertainty. These uncertainties must be reduced before strategies can be developed to mitigate the climatic impacts of aircraft operations.

Under the lead of the DLR-Institute of Atmospheric Physics (IPA), DLR-Institutes in Stuttgart and Cologne, the Helmholtz research centers Karlsruhe and Jülich, and several national and international partners focus on effects of contrails and soot emissions on cirrus clouds and climate within the DLR-project PAZI-2 (Particles and Cirrus Clouds, 2004-2007). These issues are tackled with laboratory and airborne measurements at the high pressure combustion chamber test rig DLR-HBK-S, with the DLR-FALCON aircraft, a suite of model activities, ranging from combustion models simulating soot formation with the DLR-THETA code to global models assessing climatic effects with the DLR-ECHAM code, and with remote sensing from space. The project's mid-term meeting revealed first promising results and showed that the key project goals will be achieved in its upcoming final phase.

Semi-technical scale combustor for new studies of soot formation

Aircraft emissions of soot and other particles containing sulphate and organic compounds at least double the number concentration of soot particles in flight corridors. This renders an impact of soot emissions on cirrus clouds possible. Studies of soot formation in combustors are key components in PAZI-2. Detailed knowledge of soot formation and oxidation processes is required to design low emission engines and for soot model validation.

Results of research carried out at the DLR-Institute of Combustion demonstrates that soot particle concentrations at the combustor exit are 100-1000 times higher than at the engine exit, the interface to the atmosphere. This implies that reductions in soot emissions appear to be only possible by modifications of the combustion process.

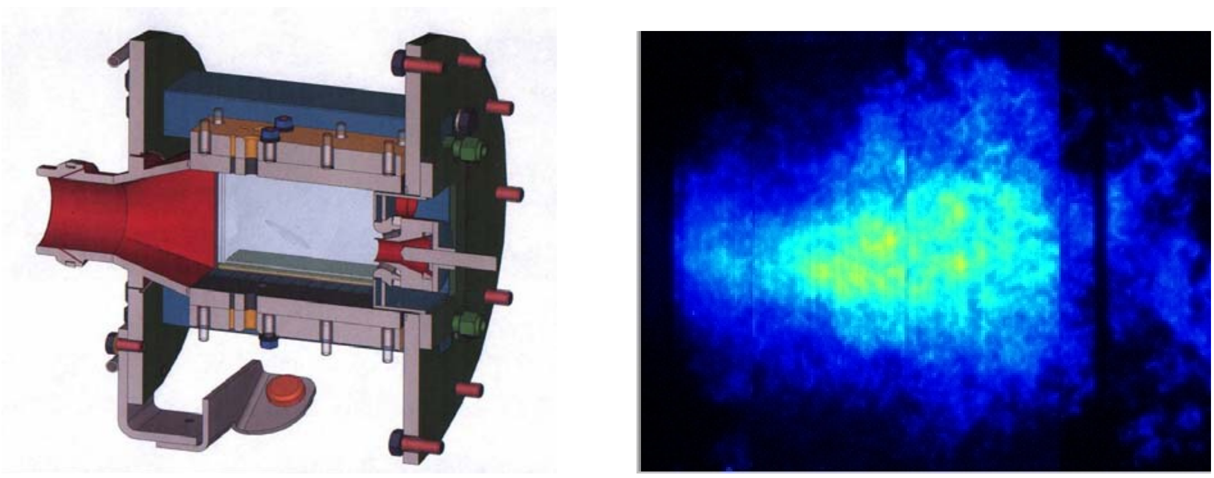


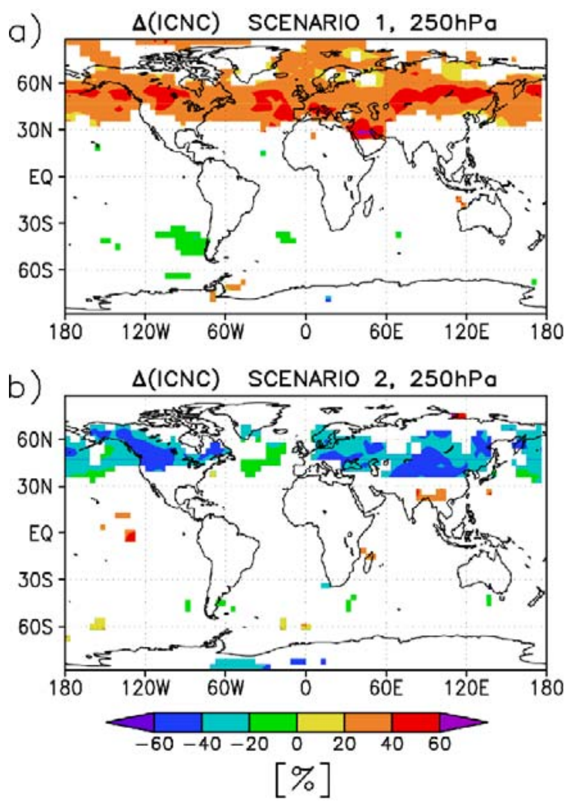
Fig.1: Sketch of the PAZI-2 combustor with optical access (left) and soot observation at 5 bar pressure in the combustor (right).

A semi-technical scale combustor (Fig.1, left) has been designed and built which offers all characteristics of real aero engines (double swirler nozzle, kerosene as fuel, secondary air injection, fully turbulent flow) and which is tested under realistic conditions (high pressure, heated incoming air) at the HBK-S. The combustor has optical access, allowing the use of innovative laser measurement techniques, beside probe measurements.

First results obtained with a newly developed laser-induced incandescence system as shown in Fig.1 (right) indicate a strong increase in soot formation with increasing combustor pressure. Ongoing investigations will help identify key parameters responsible for soot formation and oxidation in fully turbulent spray combustion.

Climate model treats effects of soot emissions

While dispersing in the atmosphere, soot emissions can change number and size of cirrus ice crystals, and thereby cloud radiative properties, by acting as ice nuclei. The efficiency of aircraft soot to alter natural cloudiness depends on their ice-forming ability relative to particles from other anthropogenic and natural sources, which is poorly known.



Measurements carried out during PAZI-2 showed that some soot particles form ice very easily. It is not clear if this holds for engine soot at cruising altitudes. No in-situ measurements exist to address this question, as new instruments to study ice nuclei in flight are not yet available.

Therefore, two extreme cirrus formation scenarios were considered in the climate model ECHAM, leading to the first published study of effects of soot emissions on the ice crystal number concentration (ICNC) (Fig.2). Aviation was found to cause an increase or decrease in ICNC, depending on whether we assume that cirrus formation without aviation emissions is dominated by solid soot and mineral dust particles (a) or by liquid particles (b).

Fig.2: Global simulations of the relative change of the annual mean ice crystal number concentration in cirrus clouds at 10 km altitude induced by soot particles from aviation. Perturbations occur in a zonal band including the main flight corridors.

Both scenarios demonstrate that significant cirrus modifications by aviation are possible. Calculated annual mean changes Δ(ICNC) caused by soot emissions amount to 10-60%. These changes result in corresponding changes in ice crystal sizes (not shown). The results are preliminary because competition between solid and liquid particles during cirrus formation is not yet included in the model.

Remote sensing reveals regional aviation impact on cloudiness

Aircraft emissions of water vapour and particles trigger line-shaped contrails. They can grow into extended cirrus decks (contrail-cirrus) under suitable meteorological conditions. Satellite-based studies on the correlation between cirrus cloud cover and regional aviation traffic occurring at the same time have been carried out in PAZI-2. Surprisingly, the analysis shows that additional contrail-cirrus covers a rather large fraction of the sky, as displayed in Fig.3.

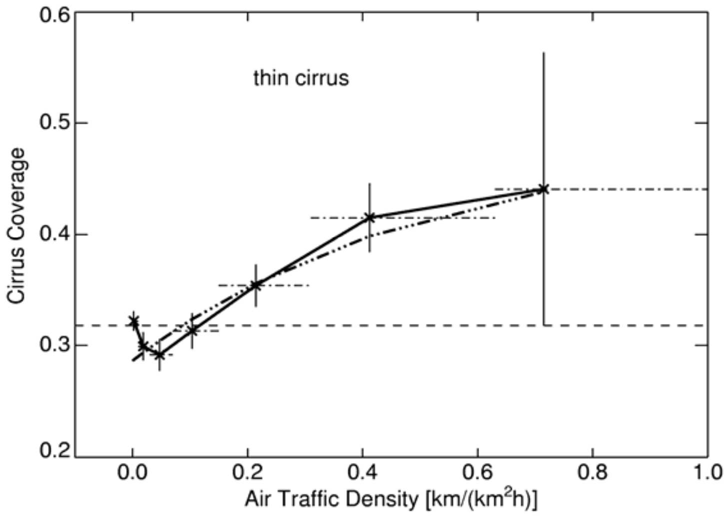


Fig.3: Cirrus coverage derived from METEOSAT data as a function of air traffic density.

The mean cloud coverage within seven air traffic density classes is indicated by the dash-dotted horizontal bars. The vertical bars depict the 95% statistical confidence level derived for individual air traffic density classes. The horizontal dashed line is the mean value of cirrus coverage.

On average, air traffic induces 3% additional cloud cover over central Europe. A follow-on study using METEOSAT-second-generation data and real traffic information provided by EUROCONTROL for 2004 confirmed these findings.

Future developments

The initially line-shaped contrails develop into contrail-cirrus in regions of ice supersaturation (adding water mass to the contrail ice crystals) and strong wind shear (spreading out the contrail coverage). Contrail-cirrus clusters build up regionally and may prevent natural clouds from forming. During their lifetime of hours to days, the clusters can be transported over long distances.

As for the soot effects, contrail-cirrus parametrisations for global models need to be developed and validated, because the processes remain spatially and temporally unresolved. First attempts are being made within PAZI-2 to realise these processes in a comprehensive climate model, allowing the prediction of the global impact of contrail-cirrus on cloud cover and radiation. In an alternative approach, the radiative fluxes at solar and infrared wavelengths induced by contrail-cirrus are currently evaluated from METEOSAT data.

These activities are supported by first studies of how to mitigate contrail effects. Active flight routing, designed to avoid regions of contrail persistence, is a promising option. This requires highly accurate operational predictions of ice supersaturation and contrail-cirrus evolution. First successful attempts within PAZI-2 to improve the European Centre of Medium Range Weather Forecasts model system toward this goal will be continued.