



## EDITORIAL

## RESEARCH ON THE EFFECTS OF AIRCRAFT AND SPACECRAFT UPON THE ATMOSPHERE

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The question of how engine exhaust emissions or shock-wave-induced species from subsonic and hypersonic aviation and rockets induce chemical or meteorological changes in the climatic state of the atmosphere was discussed intensively within studies performed in the early 1970s when plans to build a fleet of supersonic transport aircraft (SST) were under discussion (Johnston, 1971; Crutzen, 1971; CIAP, 1975). After the decision not to build such a large fleet of supersonic transport aircraft, the global impact of emissions from aviation and space transport systems was conceived to be relatively minor because of their small share in global emissions of nitrogen oxides and related pollutants.

At the end of the 1980s, the effects of emissions from aircraft and spacecraft upon the atmosphere became again a topic of large interest (Brühl and Crutzen, 1988; Held, 1990; Deutscher Bundestag, 1994). Reasons were the rapid long-term growth of air traffic, visible impact by means of contrails, various studies for future high-speed civil transport systems, hypersonic space-transport systems and rockets, and new proposals for supersonic transport systems.

In 1990, an international Colloquium provided an overview on the state of knowledge with respect to the impact of global air traffic on the atmosphere (Schumann, 1990). It became obvious that the state of knowledge was by far not enough to assess the impact of air and space transport to sufficient accuracy (WMO, 1992, 1995). Compared to existing studies on supersonic transport systems, relatively little was known on the emissions and impact of present subsonic aviation and planned hypersonic spacecraft.

Open questions were identified in particular with respect to the physical and chemical processes in the tropopause region including the upper troposphere and lower stratosphere. Of great importance was the development and application of the three-dimensional dynamical and chemical models of the atmosphere and studies which address chemical or cloud forming properties of particles. The emissions of

spacecraft were considered to be of potential importance for the state of the mesosphere. Refined knowledge was required on the emissions and dispersion properties behind aircraft which could be obtained only by interdisciplinary cooperation between engineers and atmospheric scientists. In view of the complexity of the problem, the wide scale range from the sources of the emissions to the global dimension, and the requirement for field experiments and extensive computations, the program could not be successful without international cooperation and access to large-scale facilities.

Therefore, in 1991, the German Research Association (Deutsche Forschungsgemeinschaft, DFG) initiated a priority programme (Schwerpunktprogramm) to support research on the following topics: (1) emissions from subsonic aircraft and spacecraft; (2) turbulent dispersion in the wake of aircraft; (3) contrail formation and contrail properties; (4) stratosphere-troposphere exchange and global atmospheric chemistry; (5) homogeneous and heterogeneous physical and chemical processes at particles; (6) optimized design of aircraft under environmental constraints. Initially, 26 research projects were started, later two more projects got funded.

The programme was set up in coordination with the German Ministry of Research (BMFT, now BMBF, Bundesministerium für Bildung, Wissenschaft, Forschung und Technologie) and the DLR (now Deutsches Zentrum für Luft- und Raumfahrt) who performed a national research programme "Schadstoffe in der Luftfahrt" (Pollution from Aviation) to investigate the impact of subsonic aviation. At European level, the Commission of the European Communities supported research on the atmospheric effects of subsonic transport since 1992. This international cooperation opened access to aviation traffic data, engine test facilities, research aircraft, satellite data and large-scale computing facilities. In the USA, research on the stratospheric impact of supersonic aircraft emissions became of renewed interest in 1990 (Stolarski and Wesoky, 1993), and a research

programme for subsonic aviation assessment similar to those in Europe was begun in 1993 (Thompson *et al.*, 1996). Progress was presented and discussed at several international conferences (e.g., Schumann and Wurzel, 1994; ONERA, 1997).

This special issue collects 15 papers resulting from the DFG research programme. Several of the papers include the results obtained in cooperation with and support by other European projects. Further results were published during the last five years in other journals, see, e.g., the special issues of *Annales Geophysicae* **12**(5), and **12**(10/11), (1994), and *Atmospheric Environment* **31**(12), (1997).

The programme's objective was basic research, not assessment studies. Nevertheless, the results confirm that the global climatic impact from space transport systems presently is small (the nitrogen oxide emissions from all rocket starts are at present about 10,000 times smaller than from subsonic aviation) while the emissions from present subsonic aviation and potential future supersonic aviation are of non-negligible magnitude. Much progress has been made in quantifying and understanding of ozone changes due to nitrogen oxides emissions. In particular, it became clear that subsonic aviation emissions cause an increase of ozone concentration in the tropopause region. Still, large uncertainties exist with respect to particle emissions and their impact on chemistry, cloudiness and climate. Sulphur emissions have been shown to contribute considerably to particle formation, and the lifetime of contrail particles is affected by various trace substances resulting from the emissions. The mixing processes in the vortex system behind aircraft have been quantified and the dynamical behaviour of the tropopause is now far better understood than before.

On behalf of all project participants, it is my pleasure as coordinator of this programme to express our gratitude to the Deutsche Forschungsgemeinschaft for the support of this research programme, and I thank all authors and reviewers of this issue and the editors of *Atmospheric Environment* for the excellent cooperation in the course of preparation of this special issue.

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