1 Introduction

In 1989 the Deutsche Forschungsgemeinschaft established three Collaborative Research Centres concerned with hypersonic vehicles at the Rheinisch-Westfälische Technische Hochschule Aachen, the Technische Universität München and the Universität Stuttgart. The final report presents a selection of recent research results and an overview of the activities and the organization of the network which evolved during the past fifteen years.

The research was focused on basic aspects of future reusable space transportation systems and covered the areas of overall design, aerodynamics, thermodynamics, flight dynamics, propulsion, materials, and structures. The underlying configuration which served as a guideline for detailed research consisted of a two-stage-to-orbit vehicle with the ability to start horizontally. The first stage had an airbreathing propulsion, the second stage a rocket propulsion. Both stages were designed to return to earth and land horizontally on adequate airports.

A major part of the research dealt with experimental and numerical aerodynamic topics ranging from low-speed to hypersonic flow past the external configuration and through inlet and nozzle. The low-speed flow past the lower stage was investigated for a large range of Reynolds numbers in different wind tunnels including a test period at high Reynolds numbers with a large model in the German-Dutch Wind Tunnel (DNW). The studies at high Mach numbers included the very complex interference between the lower stage and the upper stage during the initial flight and during stage separation and the aero-thermodynamic heating. In all cases experimental and numerical approaches were employed.

Another major part of the research was concerned with flight mechanics. One aspect was trajectory optimization which was dealt with in cooperation of mathematicians and engineers. A further aspect relates to stability, control and flying qualities, the treatment of which includes a collaboration with the NASA Dryden Flight Research Center using their unique simulation and flight test facilities. Moreover, the flight dynamics of the separation manoeuvre was subject of the research activities, employing also wind-tunnel tests at the Institute of Theoretical and Applied Mechanics of the Russian Academy of Sciences in Novosibirsk.

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The re-entry phase was investigated both experimentally and numerically. Plasma wind tunnels were built to generate high-enthalpy plasma flows and to investigate the interactions with heat shield materials. The experimental investigation was accompanied by numerical simulation of the flow field inside the ground test facility and around a space vehicle re-entering the Earth's atmosphere. New aero-thermodynamic models enabled a successful post-flight analysis of the MIRKA re-entry. Re-entry experiments for in-flight investigation of plasma flow and material response were successfully flown on capsules such as EXPRESS and MIRKA; others are about to be flown on missions such as EXPERT.

For the overall design investigations a propulsion simulation model including the jet and ramjet modes was developed. The efficiency of supersonic and hypersonic airbreathing propulsion depends strongly on the efficiency of inlets and nozzles. Therefore, several numerical and experimental projects dealt with these components of future space planes. In other projects methods to reach stable supersonic combustion were investigated.

Structural research and development was predominantly coupled to the needs for high-temperature resistant structures for space vehicles. During the re-entry phase from orbit to earth temperatures of more than 1600 °C are reached. For the application in a thermal protection system (TPS) and also as a material for the use in hot structures, like control surfaces, a new type of ceramic matrix composite was developed on the basis of carbon fibres that is called C/C-SiC. The technology of thermal protection systems reached a maturity that allowed a flight experiment with a representative TPS structure on the surface of a Russian FOTON research capsule that was scheduled for a micro-gravity mission in orbit with subsequent re-entry to earth.

This final report presents some of the most recent results obtained in the disciplines required for the design of future space planes. In additional chapters the unique model established for the cooperation of three cooperative research centres at different universities is described and analyzed.

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