Deutsche Forschungsgemeinschaft

DFG

Aero-Thermodynamic Design of a Scramjet Propulsion System: The graduate school GRK 1095/2 funded by the "Deutsche Forschungsgemeinschaft" (DFG)

B. Weigand

Universität Stuttgart

Institut für Thermodynamik der Luft- und Raumfahrt

University of Stuttgart Germany

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RHEINISCH-WESTFÄLISCHE TECHNISCHE HOCHSCHULE AACHEN

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Contents

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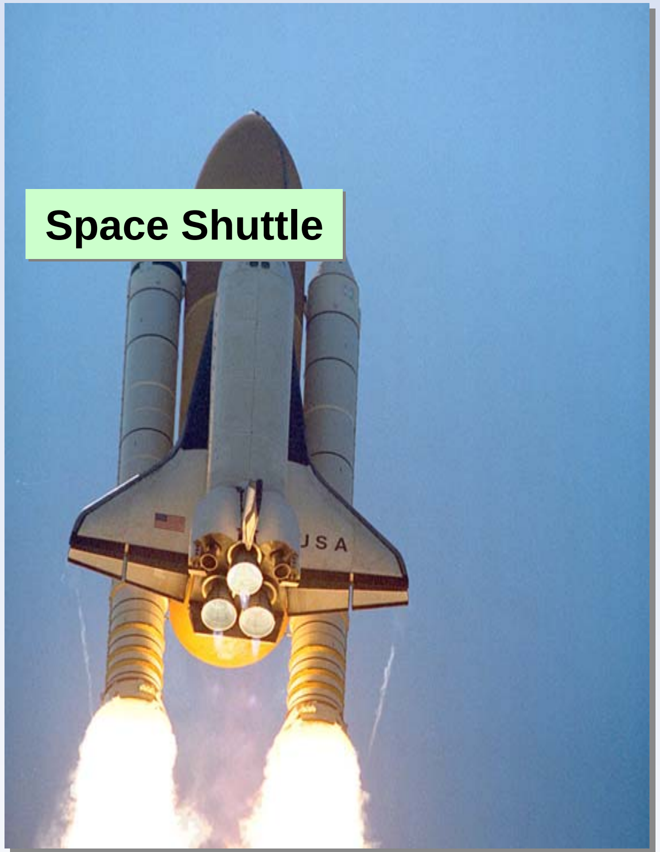
Introduction

Startschub: ca. 12 MN
Nutzlast: 6,5 to
Brennstoff: LH_2 26 to, LO_x 132 to



Startschub: ca. 29 MN
Startgewicht: 2000 to
Nutzlast: 28 to
Brennstoff: LH_2 100 to, LO_x 600 to

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Introduction – What is a “Scramjet”?

Ramjet:
- No moving parts; ram compression
- Compression of the soaked up mass flow by reducing the flow speed to subsonic velocity inside the intake → subsonic combustion
- Mach number range: 2 ÷ 6

But:
Increase of airspeed $M_{\infty}>6$
a) increasing shock losses inside the intake
b) increasing stagnation temperature at the entry of the combustion chamber → increasing dissociation

Way out:
- Reducing the flow speed inside the inlet to 30 - 50 % of the airspeed
- Supersonic flow inside combustion chamber
  ⇒ supersonic combustion
- Mach number range: 5 ÷ ~25

➔ **Scramjet:** Supersonic Combustion Ramjet

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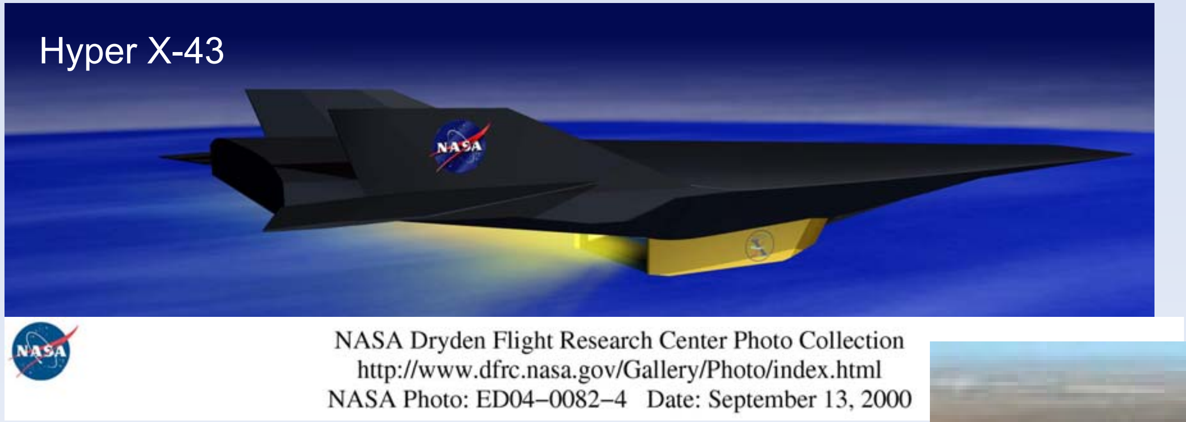
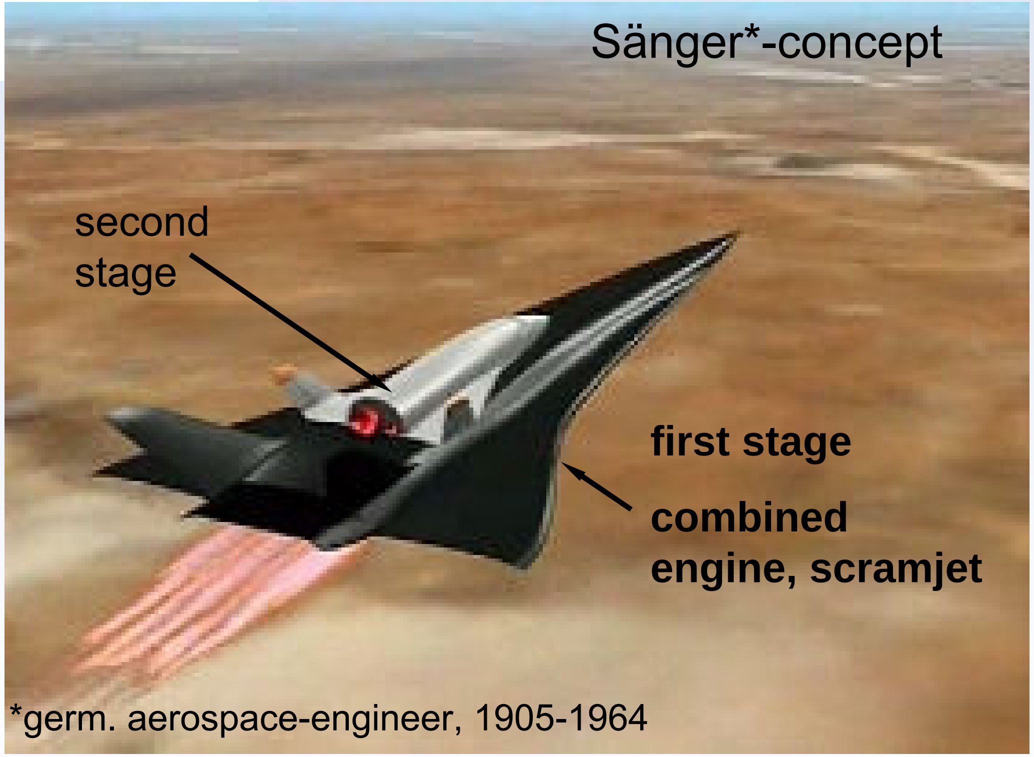
Introduction – Examples





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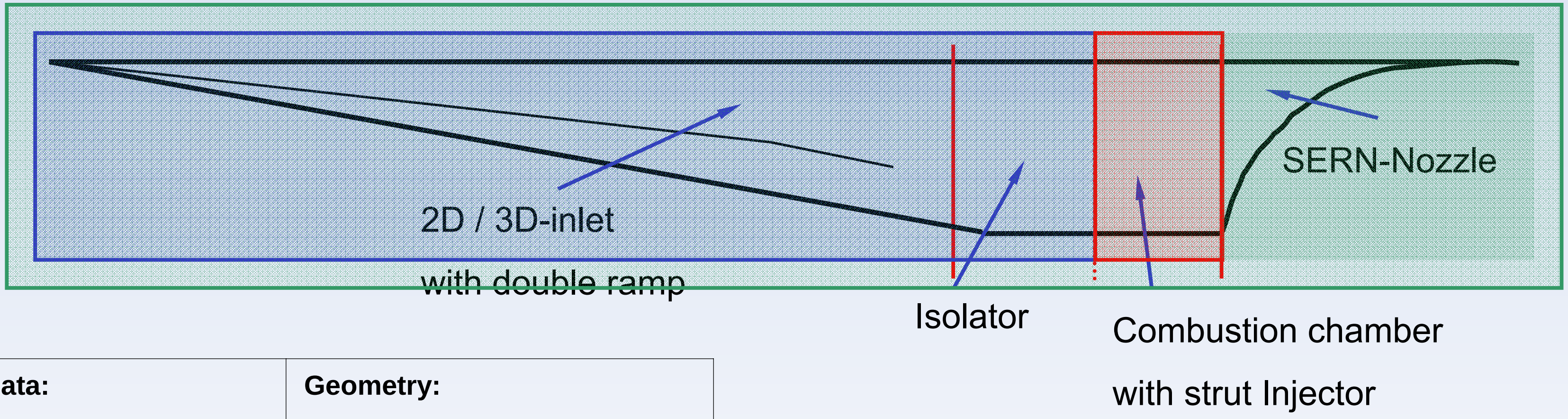
Basic Concept

Topic: Aero-thermodynamic design of a scramjet propulsion system for future reusable space transportation systems and hypersonic flight



Inflow data:	**Geometry:**
H=30 km	$\alpha_1 \approx 7{,}5°$
M=8	$\alpha_2 \approx 19°$
p_∞=11.7 hPa	b≈76 mm
T_∞=226.7 K	h=228 mm
$\rho_\infty = 1.801 \cdot 10^{-2}$ kg/m³	L_F=450 ÷ 500 mm
dm/dt: =1.45 kg/s	L_{tot}>1000 mm

- Group A: Aero-thermodynamical analysis
- Group B: Combustion
- Group C: Nozzle flow and system analysis

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Structure and sub-projects

Group A: Aero-thermodynamic investigations

A1: Experimental investigations of the boundary layer transition of a double ramp configuration.

A2: Experimental investigation of the shock boundary layer interaction of a double ramp configuration at different inflow conditions.

A3: Design and characterization of a 3D scramjet inlet.

A4: Experimental investigation of the internal flow conditions of a scramjet engine.

A5: Investigation of 3D flow structures caused by side wall effects of a scramjet engine.

A6: Numerical simulations of the unsteady effects in a scramjet intake.

A7: Computational analysis of the relaminarisation in hypersonic intake flows.

A8: Numerical investigation of the sensitivity on the design of a hypersonic intake.

Structure and sub-projects

Group B: Combustion

B1: Experimental investigations of the fuel injection and mixing and stability of a supersonic combustor.

B2: Numerical investigation of a supersonic combustion chamber for different flight conditions.

B3: Thermal and mechanical investigations of a central injector in a scramjet combustor.

B4: Numerical investigation of the turbulence-chemical reaction interaction and the emission production in a scramjet combustor.

B5: Unsteady simulations of supersonic combustion chambers.

B6: Development of a numerical efficient combustion model for the interaction between chemical reaction and turbulence for LES.

B7: Shock-boundary layer interaction for reactive flows.

B8: Prevention of thermal cocking in supersonic combustors by using staged injection..

Structure and sub-projects

Group C: Nozzle flow and system analysis

C1: Aerodynamic design of a flight configuration and the related instrumentation.

C2: Numerical simulation of a nozzle flow with cooling.

C3: Experimental investigation of the expansion flow of an air breathing propulsion system under consideration of the temperature gradient between jet and outer flow.

C4: Multi-field formulation for functionally graded high-temperature materials.

C5: Coupled simulations for the systematic design optimization of scramjets.

C6: Investigation of the thermal loads of a hypersonic propulsion system.

C7: Modeling of a scramjet propulsion system.

Germany

Locations:

Köln

DLR

(Cologne)

Aachen

(Aix-la-Chapelle)

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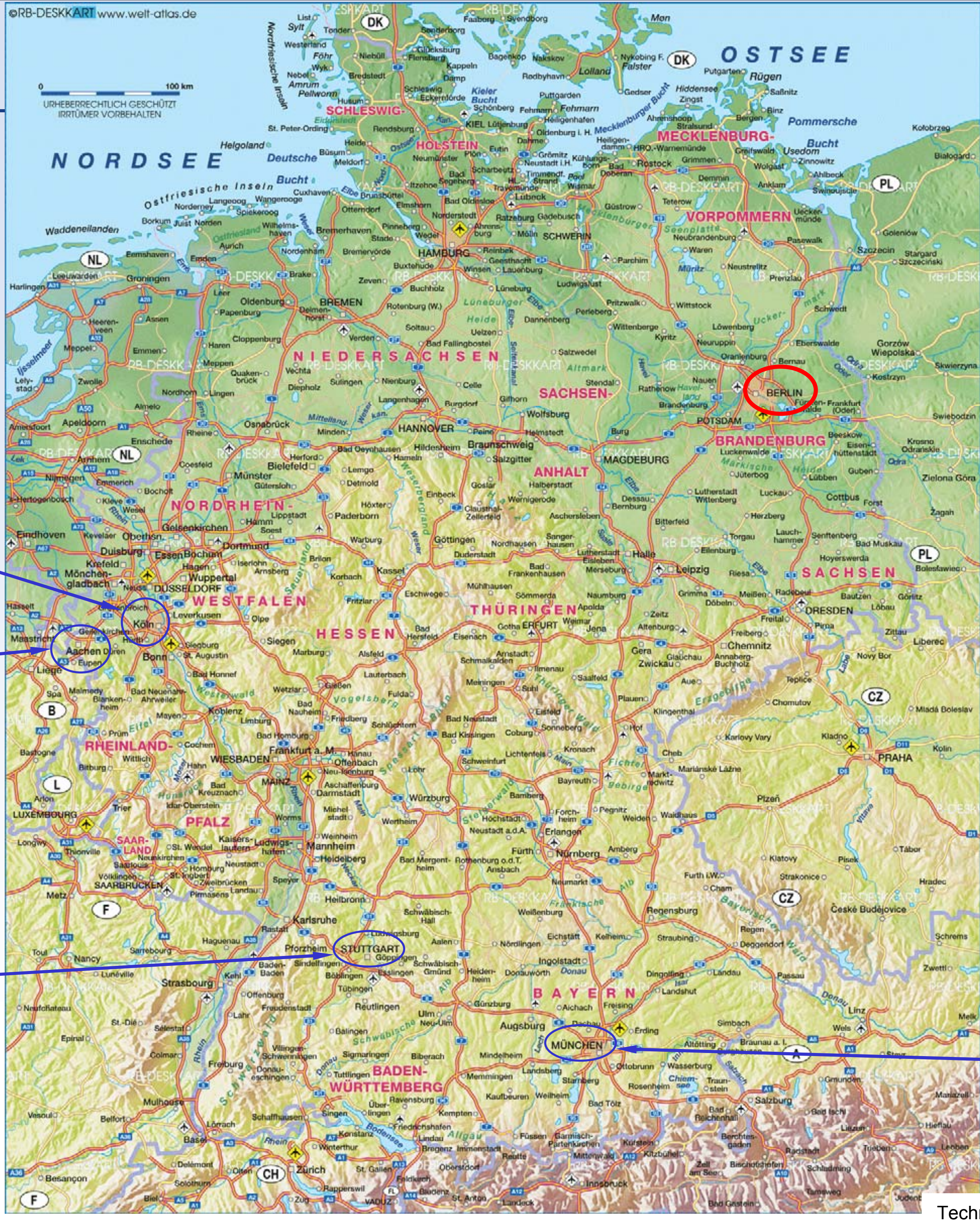

München

(Munich)

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Structure - Members

Speaker of the GRK 1095/2:

-Prof. Dr. B. Weigand, ITLR Stuttgart University

Project leaders:

- **Stuttgart:** E. Krämer, C.D. Munz, B. Kröplin, S. Staudacher, J. von Wolfersdorf, M. Aigner, P. Gerlinger, B. Weigand
- **Aachen/DLR Köln:** H. Olivier, W. Schröder, A. Gülhan, M. Behr
- **München:** H.P. Kau, T. Sattelmayer, N. Adams

Scholars and Postdocs:

-**Stuttgart (9):** A.M. Schreyer, M. Banica, M. Staudenmaier, J. Vellaramkalayil, A. Hell, B. Rust, C. Messe, J. Groß, V. Shevchuk

-**Aachen (4)/DLR Köln (2):** O. Hohn, C. Fischer, T. Nguyen, J. Riehmer, M. Konapka, F. Bramkamp

- **München (3):** D. Bruno, O. Petrache, S. Kirstein

And a lot of Associated members: U. Gaisbauer, B. Reinartz, G. Lamanna, T. Scheuermann, T. Langener,…

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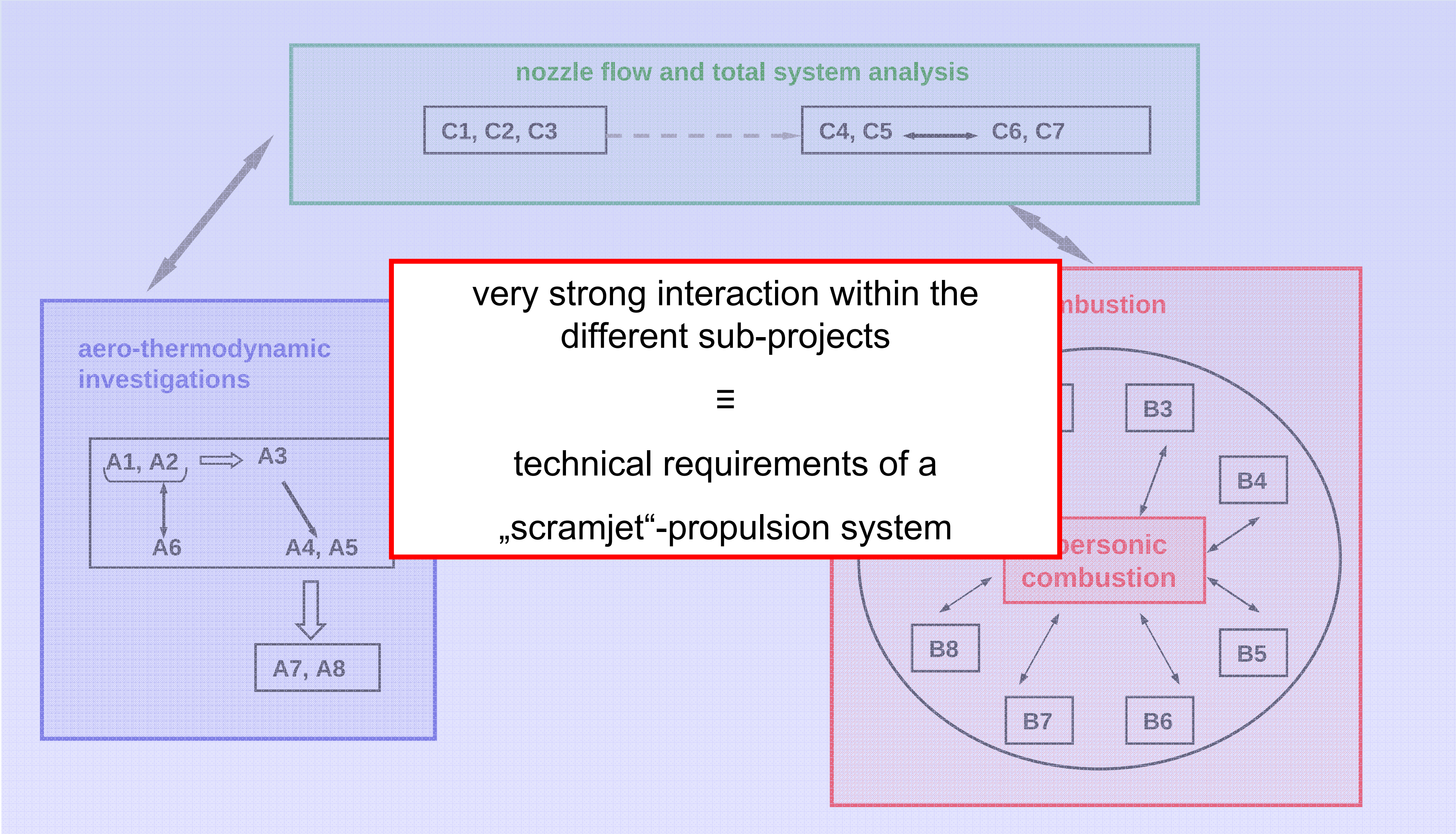
Structure - interactions



very strong interaction within the different sub-projects

≡

technical requirements of a

„scramjet“-propulsion system

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Structure - Educational-program

Standard Elements:

- Individual training program with specific courses
- Lectures by the involved scientists and guests
- Courses and lectures by international specialists
- Meetings and discussion forums
- Regular internal conferences

Special Features:

- A stay abroard for all members for 6 months
- Self organised summer schools and workshops with international specialists (by the PhD-students)
- Discussion forums with partners from industry
- Integration of an external patent agent

Educational-Program - Summer Schools

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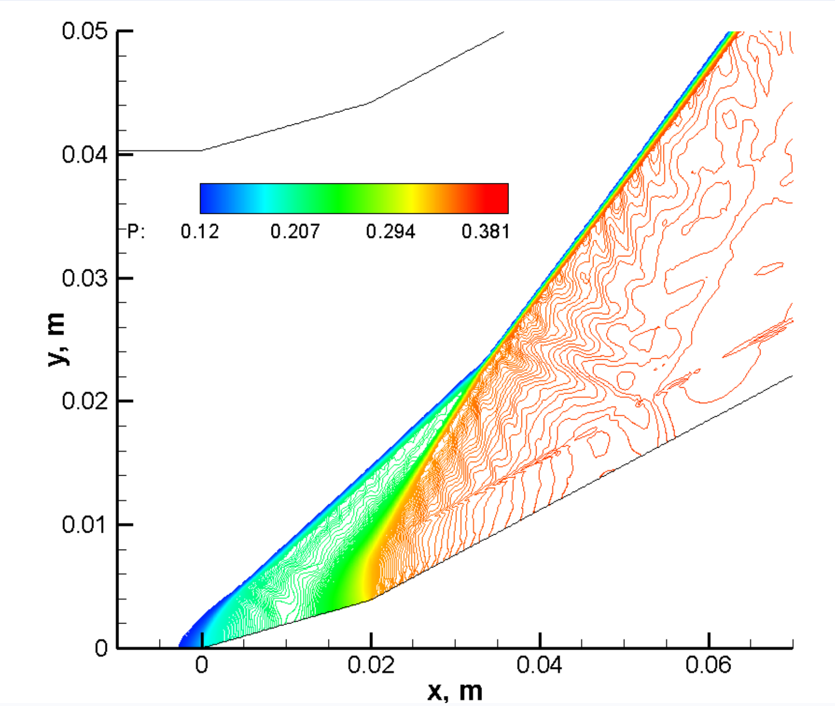
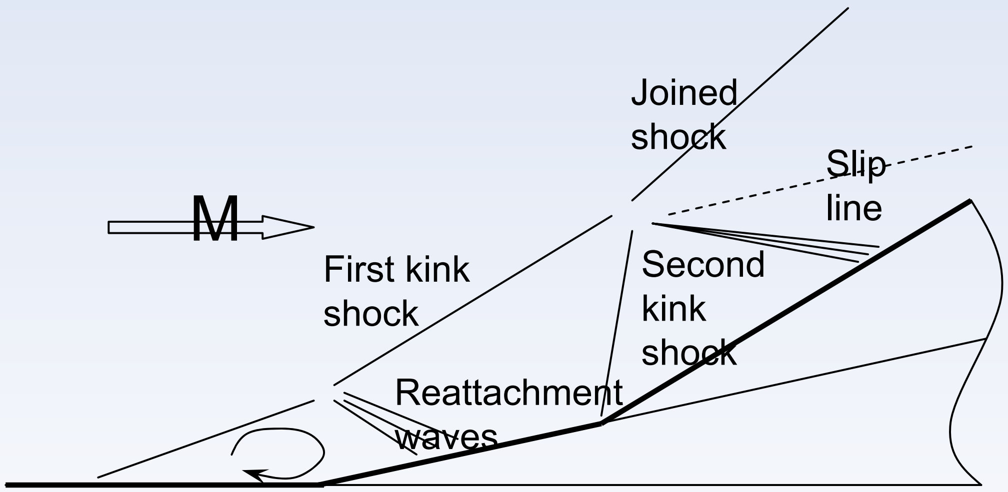
Research Training Group 1095/2: Aero-Thermodynamic Design of a Scramjet Propulsion System

Content

Selected Results

A2: Numerical investigations of a double ramp configuration with different initial conditions (Dr. Irina Fedorchenko, Institut für Aerodynamik und Gasdynamik, Universität Stuttgart, Khristianovich Institute of Theoretical and Applied Mechanics SB RAS, Novosibirsk, Russia)





static pressure field

$M=2.5$, $Re/m=9.82\cdot10^{6}$

double ramp configuration

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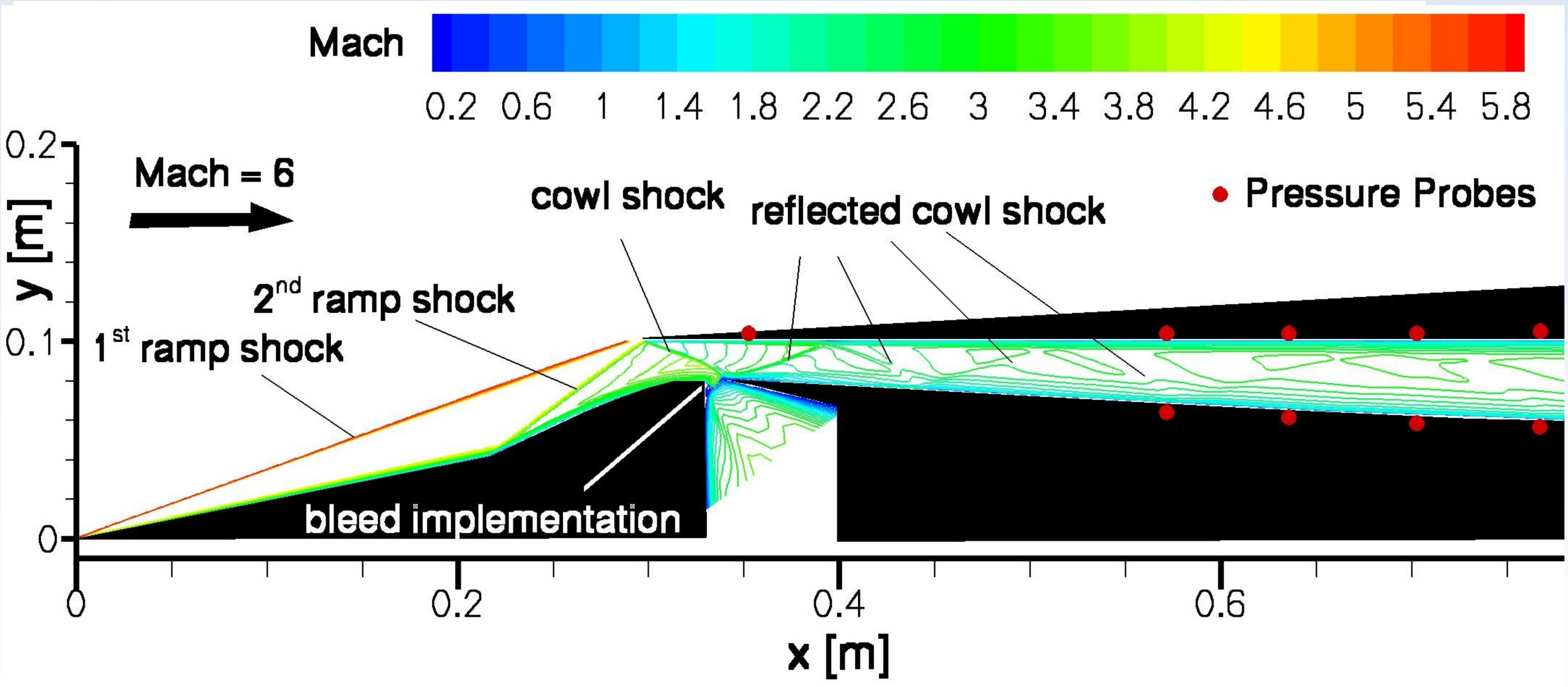
Selected Results

A7: Numerical investigation of the influence of laminar turbulent transition on hypersonic inlets (Martin Krause, Lehr- und Forschungsgebiet für Mechanik, RWTH Aachen)



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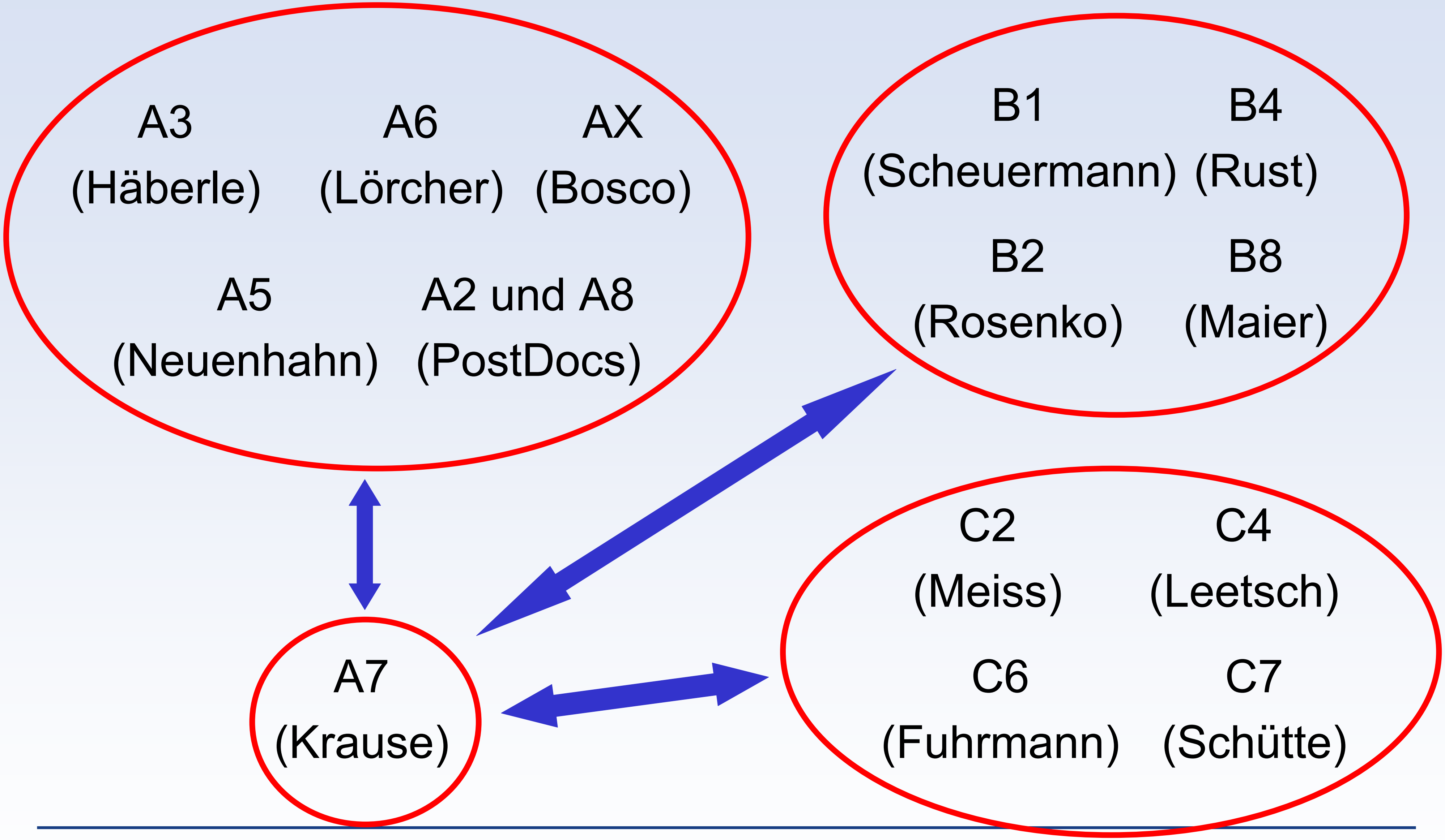
Cooperation shown as an example for the Project A7



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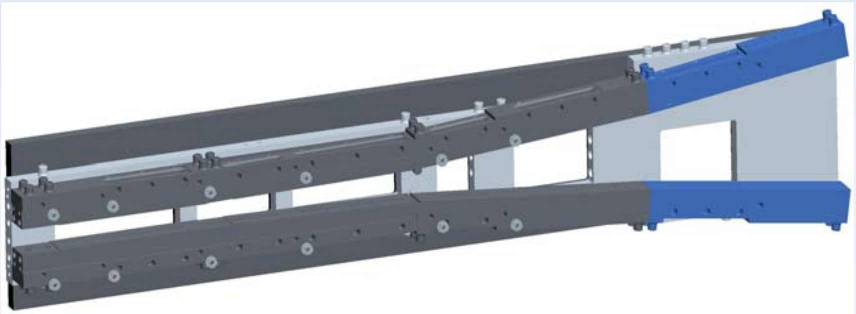
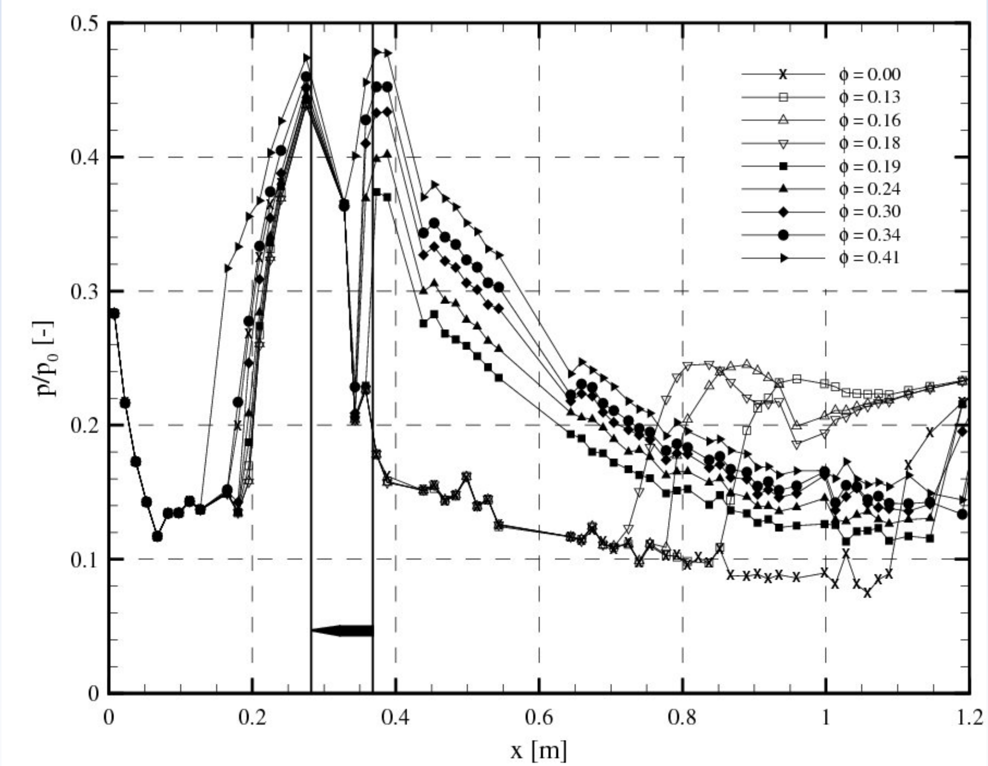
Selected Results

B1: Experimental investigation of the design of a subersonic combustion chamber
(Tobias Scheuermann, Institut für Thermodynamik der Luft- und Raumfahrt, Universität Stuttgart)



modified geometry of the combustion chamber

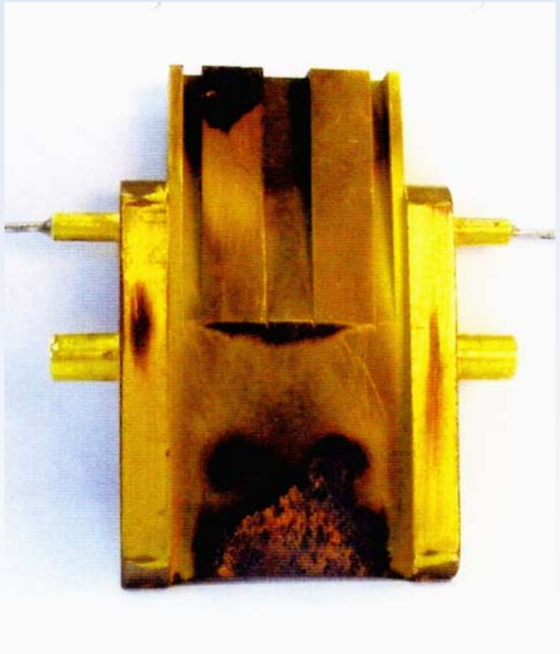


Strong and weak combustion –normalized wall pressure distribution for different equivalence ratios (Φ)

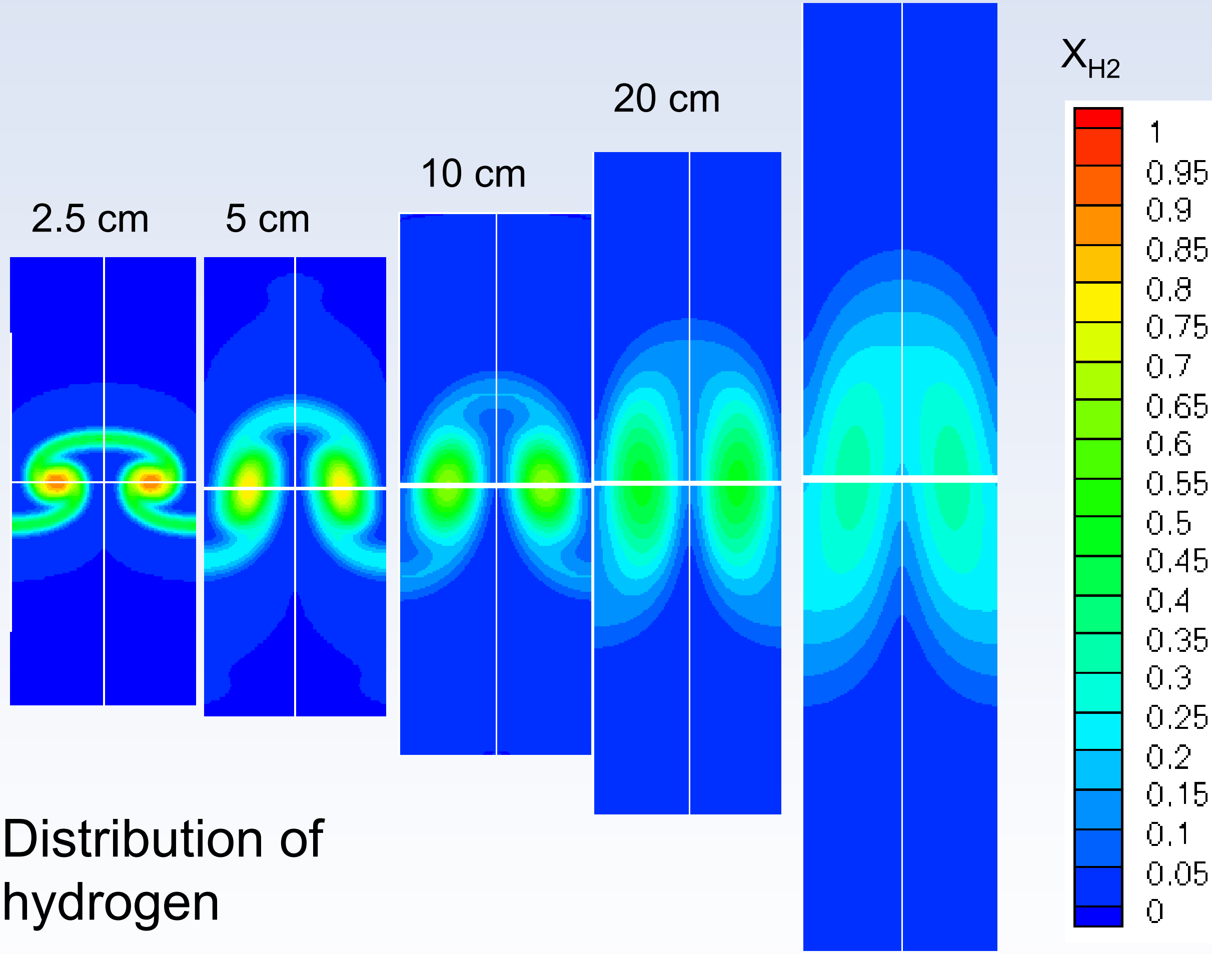
Selected Results

B5: Numerical investigation of the turbulent chemistry interaction

(B. Rust, Institut für Verbrennungstechnik der LRT, Universität Stuttgart)



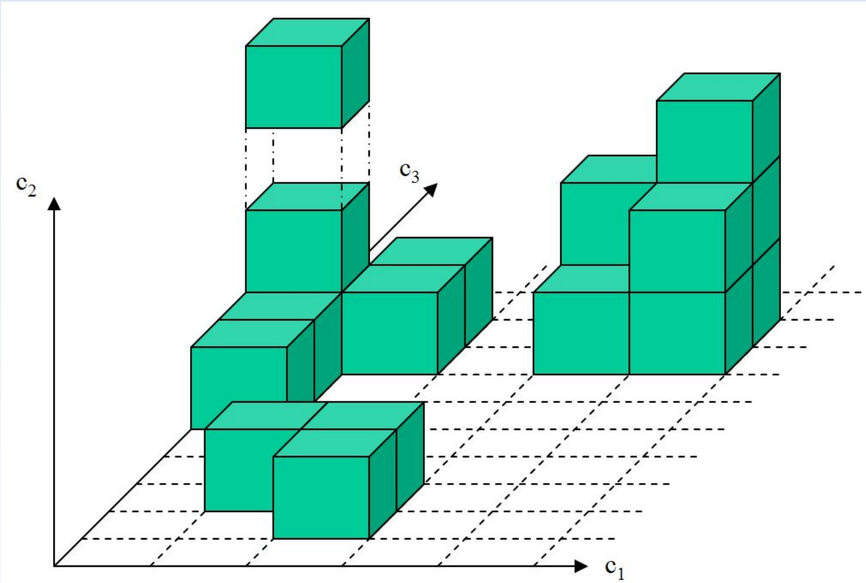
Lobed strut injector



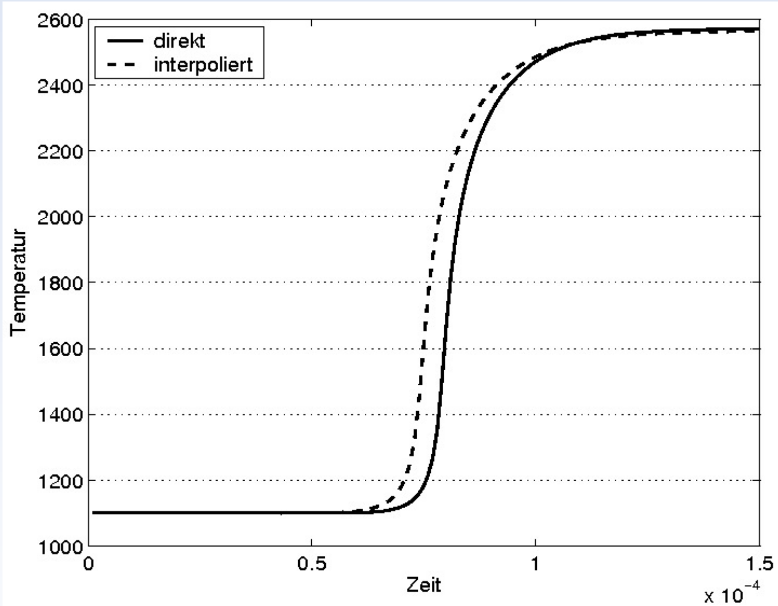
Distribution of hydrogen

Selected Results

B6: Turbulence-Chemistry Interaction
(Henrik Förster, Lehrstuhl A für Thermodynamik, TU München)



Example of an *in situ* tabel for a 3D thermodynamic state variable. Between the cells, the results can be interpoated.



Ignition delay time for a Hydrogen-air mixture, directly calculated and interpolated from 36 cells.

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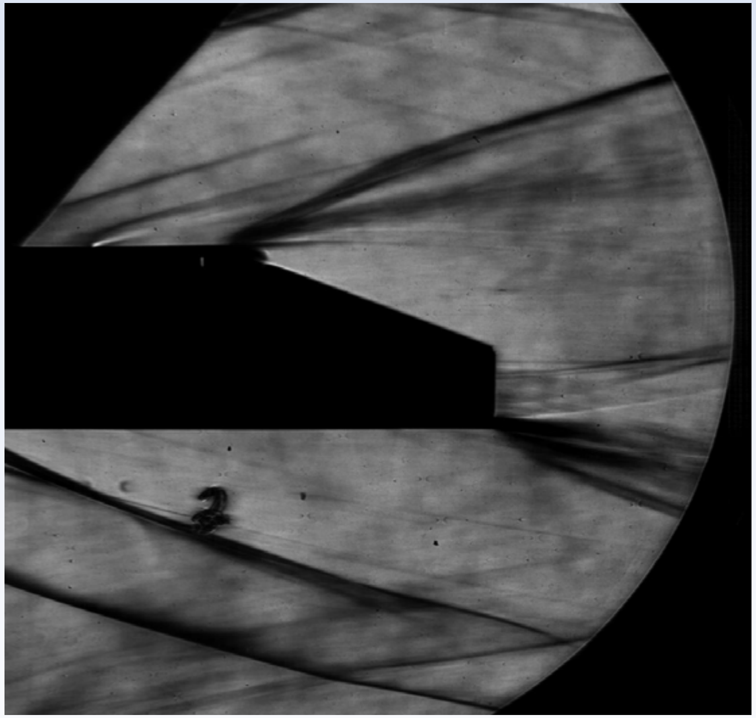
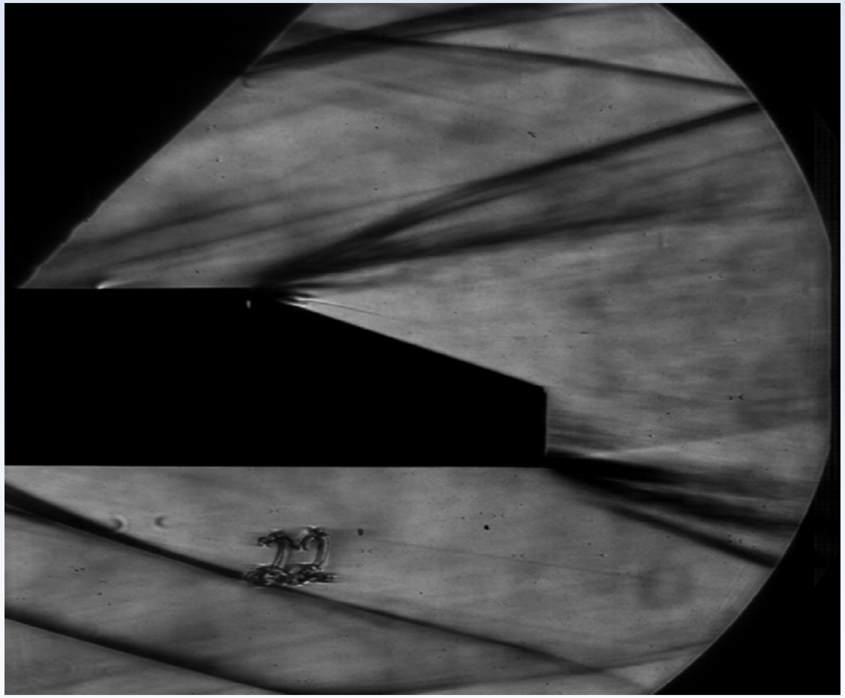
Selected Results

C1: Experimental investigation of a scramjet nozzle (Christian Hirschen, DLR, Abteilung Windkanäle des Instituts für Aerodynamik und Strömungstechnik)





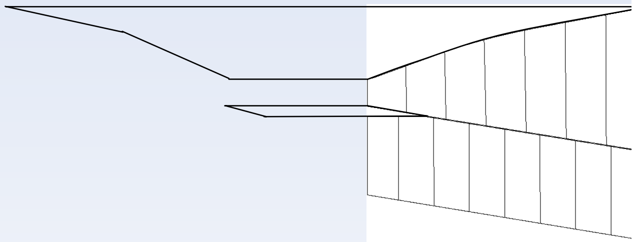
Schlieren picture with air (left) und argon (right) for $p_{0,D}$ = 3,2 bar

→ Influence of the ratio of the specific heats

Selected Results

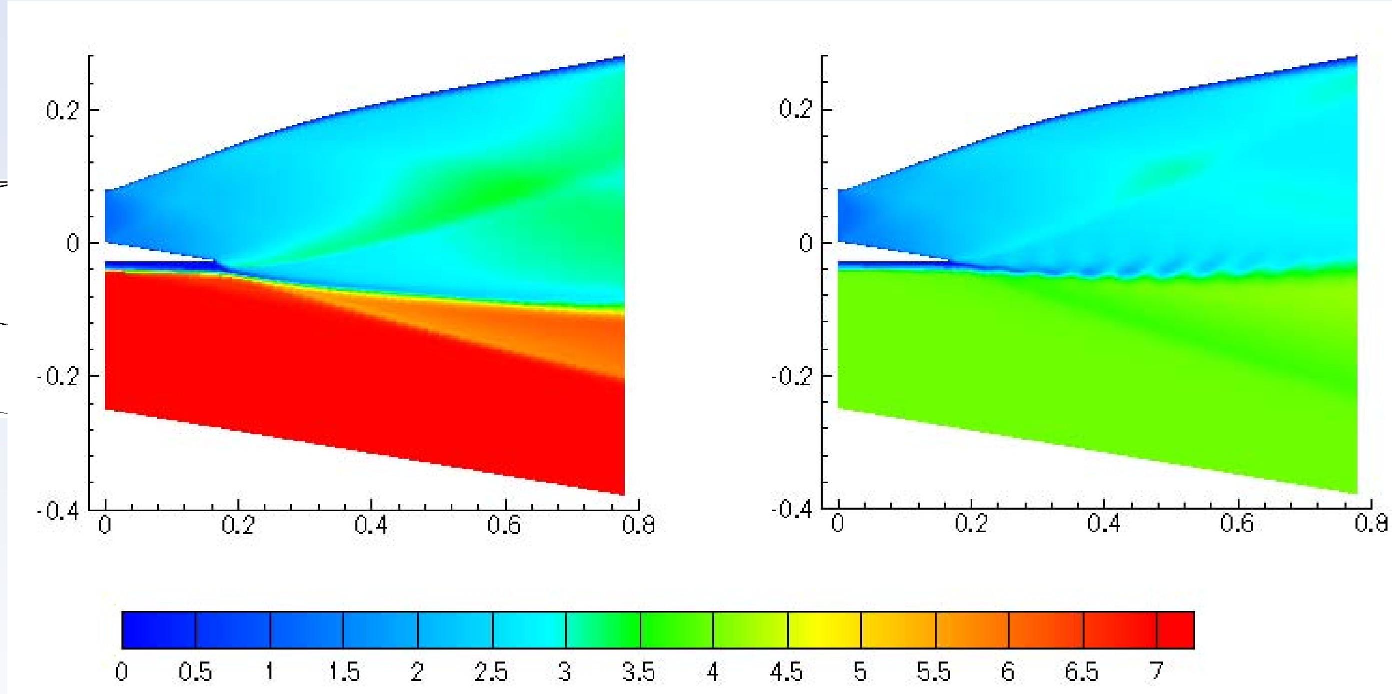
C2: Simulation of the interaction between nozzle flow and outside flow

(Jan Hendrik Meiß, Aerodynamisches Institut, RWTH Aachen)



SERN (grid)

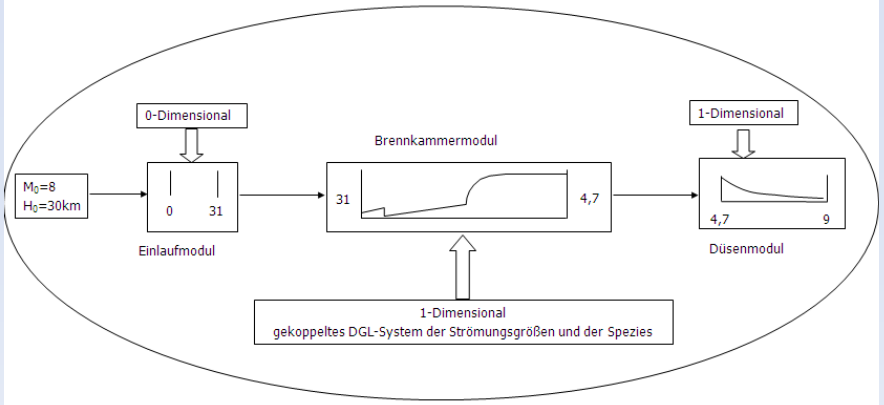
<u>S</u>ingle <u>E</u>xpansion
<u>R</u>amp <u>N</u>ozzle

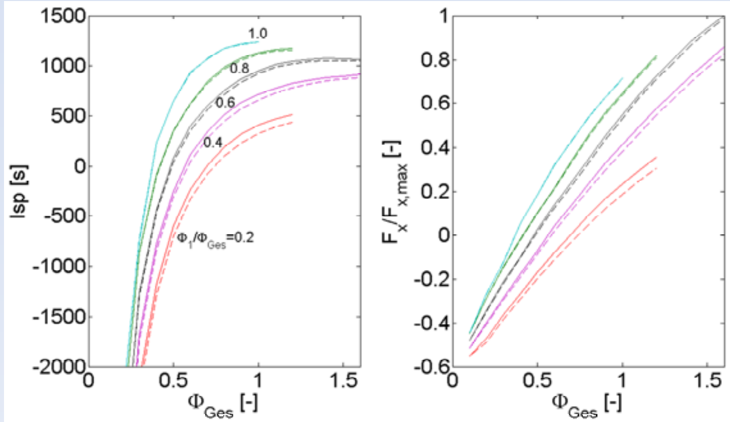


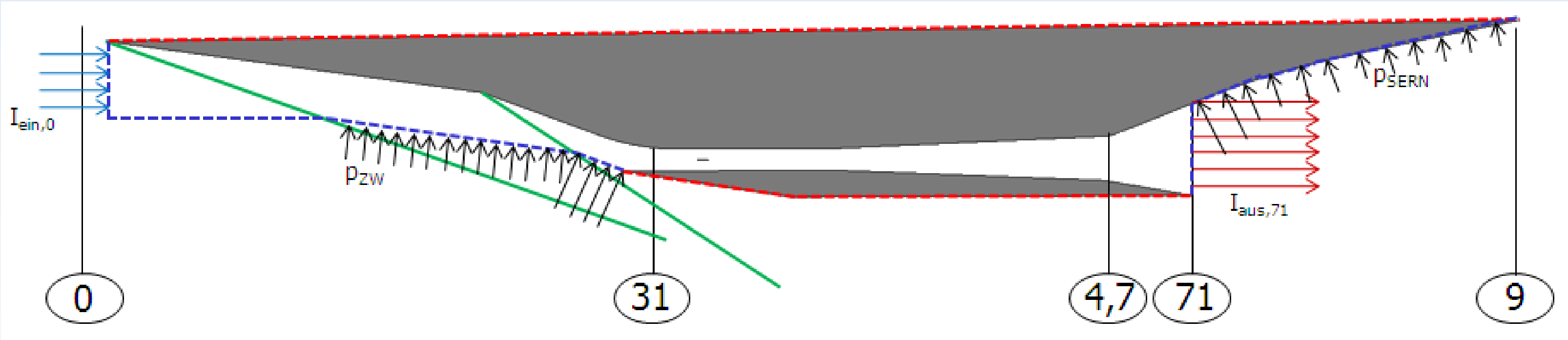
Mach number distribution, M=7 (left), M=4 (right)

C6 & C7: GRK-Design Tools (T. Fuhrmann, G. Schütte)

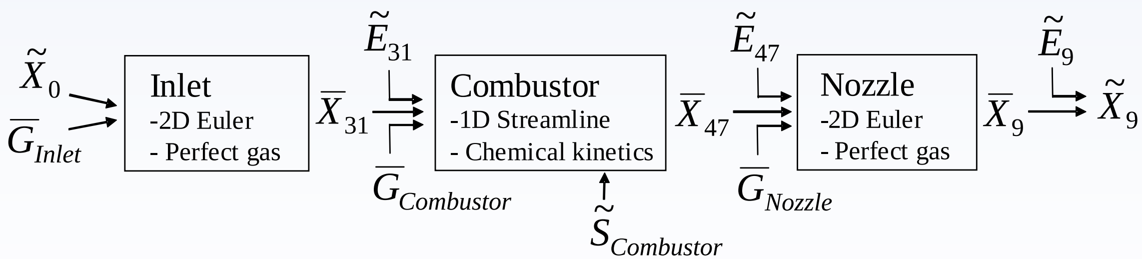
C6

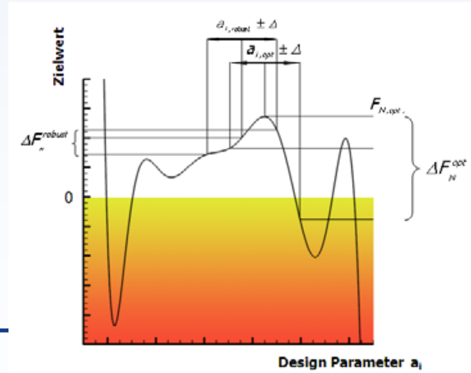






C7





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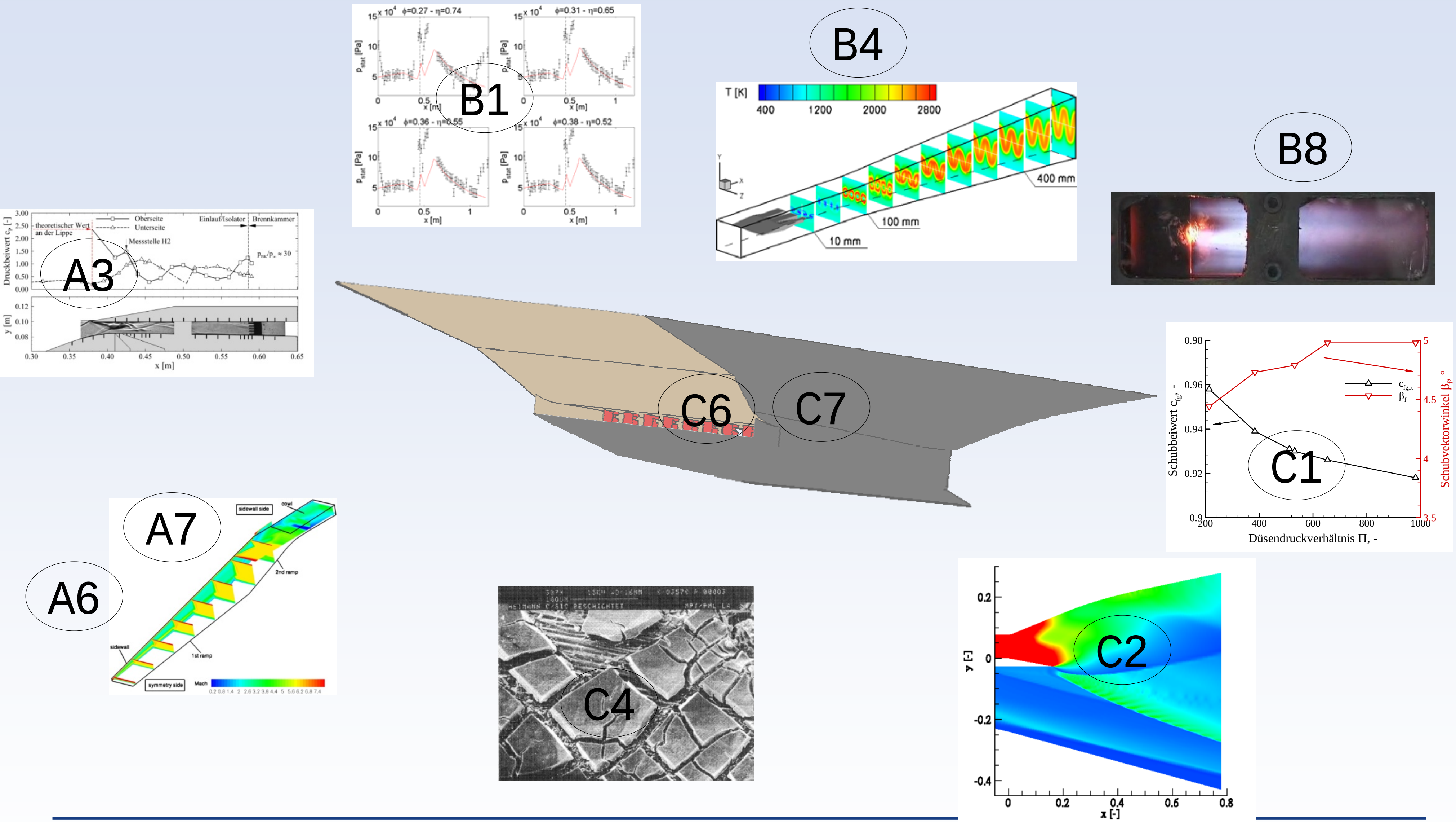
Research Training Group 1095/2: Aero-Thermodynamic Design of a Scramjet Propulsion System

Cooperation shown as an example for the Projects C6 & C7



Research Training Group 1095/2: Aero-Thermodynamic Design of a Scramjet Propulsion System

Summary

- Research Training Group GRK 1095 – started April 2005
- Involved institutions: RWTH Aachen, DLR Köln, TU München and Universität Stuttgart
- Comprehensive educational program
- Integration of international experts in scramjet technology / international scientific exchange
- High level of integration and networking between all members and institutions within Germany and with foreign partners
- First results demonstrate the efficiency of the philosophy
- Upgrading of the national know how and continuation of the long „scramjet history“ in Germany
- Strict focus on hydrogen combustion with lobed strut injectors

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Summary - Outlook

- Aim for the first project stage (4.5 years): development of a successfull design of a scramjet propulsion system with focus on a lobed strut injector concept
- Verification of the functionality in tests associated project: wind tunnel test of a scramjet propulsion system (GA1332/1, financed by DFG)

⇒ **Project GRK 1095/1 has been evaluated by DFG in 2009.**

Because of the very good achievements, the project got elongated by another 4,5 years, starting from 1.10.2009

Acknowledgement

All members of the Graduate School GRK 1095 would like to thank the Deutsche Forschungsgemeinschaft (DFG) for the support and the financing of the presented scramjet research activities.