# SACOMAR

## *Technologies for Safe and Controlled Martian Entry*

**SPA.2010.3.2-04**

**EU-Russia Cooperation for Strengthening Space Foundations (SICA)**

**Re-entry Technologies and Tools**

**Theme 9 - Space**

| | |
|---|---|
| **Grant Agreement number:** | **263210-SACOMAR** |
| **Deliverable Reference Number:** | **D 1.1, Issue 1.1** |
| **Deliverable Title:** | **Interim Progress Report** |
| **Covered Period:** | **1.1.2011 – 30.9.2011** |

Due date of deliverable: 30tt September 2011, update 30th November 2011

Actual submission date: 16th December 2011

Start date of project: 20th January 2011

Duration: 18 months

Organisation name of lead contractor for this deliverable: DLR

Revision #: 0

| **Project co-funded by the European Commission within the 7th Framework Programme** | | |
|---|---|---|
| **Dissemination Level** | | |
| **PU** | Public | X |
| **PP** | Restricted to other programme participants (including the Commission Services) | |
| **RE** | Restricted to a group specified by the consortium (including the Commission Services) | |
| **CO** | Confidential, only for members of the consortium (including the Commission Services) | |

## Approval

| Title | issue | revision |
| --- | --- | --- |
| *Interim Progress Report* | 1 | 1 |

| Author(s) | date |
| --- | --- |
| A. Gülhan, V. Mareschi, P. Nöding, R. Kovalev, A. Kolesnikov, A. Skuratov, P. Catalano, M. Ivanov, B. Esser, J. Martinez-Schramm, M. Fertig | *16.12.11* |

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Approval 2

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## Nomenclature

| | |
|---|---|
| AD-PM | DLR Administration Department |
| AS-RF | Spacecraft Department of the DLR Institute for Aerodynamics and Flow Technology |
| AS-WK | Windtunnel Department of the DLR Institute for Aerodynamics and Flow Technology |
| ATD | Aerothermodynamics |
| CFD | Computational Fluid Dynamics |
| DLAS | Diode Laser Absorption Spectroscopy |
| DNS | Direct Numerical Simulation |
| DSMC | Direct Simulation Monte Carlo Method |
| HEG | DLR Shock Tunnel in Göttingen |
| IR | Infrared Thermography |
| IT-2 | Hot Shot Wind Tunnel of TsAGI |
| ITAM | Institute of Theoretical and Applied Mechanics |
| L2K | 1.4 MW Arc Heated Facility of DLR in Cologne |
| LIF | Laser Induced Fluorescence |
| MW | Micro wave |
| RANS | Reynolds-Averaged Navier-Stokes Equations |
| REA | Research Executive Agency |
| RTD | Research, Technology & Development |
| SICA | Specific International Cooperation Actions |
| TN | Technical Note |
| WP | Workpackage |

### Subscripts

| | |
|---|---|
| 0 | Stagnation condition |
| $\infty$ | Free stream |

**Acronyms**

| | |
|---|---|
| CIRA | Centro Italiano Ricerche Aerospaziali |
| DLR | German Aerospace Centre |
| IPM | Institute for Problems in Mechanics |
| TsAGI | Central Aerohydrodynamic Institute |
| TsNIImash | Central Research Institute of Machine Building |

# 1 Declaration of the scientific representative of the project coordinator DLR

I, as scientific representative of the coordinator of this project and in line with the obligations as stated in Article II.2.3 of the Grant Agreement declare that:

- The attached periodic report represents an accurate description of the work carried out in this project for this reporting period;
- The project (tick as appropriate) [1]:

  ☐ has fully achieved its objectives and technical goals for the period;

  ■ has achieved most of its objectives and technical goals for the period with relatively minor deviations.

  ☐ has failed to achieve critical objectives and/or is not at all on schedule.

- The public website, if applicable

  ■ is up to date

  ☐ is not up to date
- To my best knowledge, the financial statements which are being submitted as part of this report are in line with the actual work carried out and are consistent with the report on the resources used for the project (section 3.4) and if applicable with the certificate on financial statement.
- All beneficiaries, in particular non-profit public bodies, secondary and higher education establishments, research organisations and SMEs, have declared to have verified their legal status. Any changes have been reported under section 3.2.3 (Project Management) in accordance with Article II.3.f of the Grant Agreement.

Name of scientific representative of the Coordinator: Dr.-Ing. Ali Gülhan

Date: 30/ 09/ 2011

For most of the projects, the signature of this declaration could be done directly via the IT reporting tool through an adapted IT mechanism.

[1] If either of these boxes below is ticked, the report should reflect these and any remedial actions taken.

## 2 Publishable Summary

When entering a planetary atmosphere the high speed deceleration of blunt bodies leads to a strong bow shock formation in front of a capsule and heating of the gas and subsequent heating of the vehicle. The internal structure of the vehicle is thermally protected using a Thermal Protection System (TPS). Most of the capsules use a TPS based on ablation materials. The modelling of complex chemical processes in the boundary layer flow around the ablation and inside the ablation materials is very challenging and needs reliable experimental data gained by means of sophisticated measurement techniques. In order to extract the influence of different parameters on the aerothermal heating during Martian entry a study on selected and well defined materials is an important step. **Figure 1** shows a typical test configuration on the sample in Martian atmosphere.

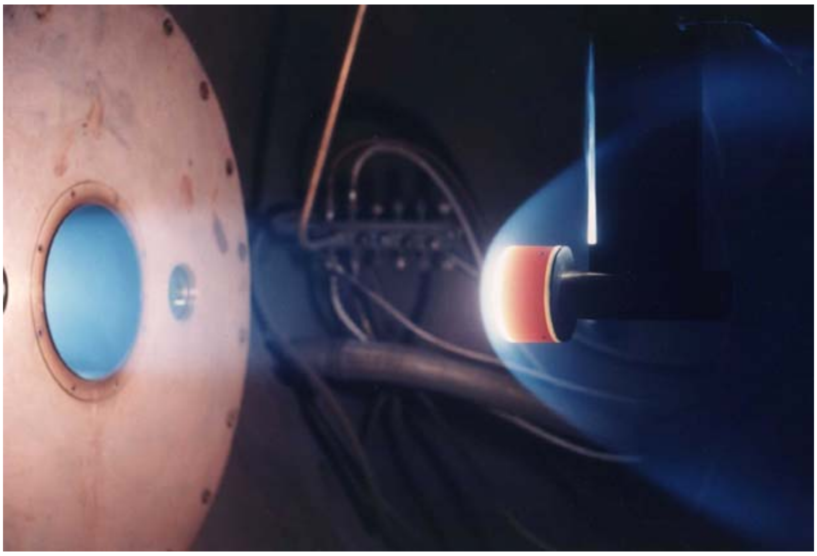

**Figure 1: High temperature non-equilibrium flow phenomena around a capsule**

### 2.1 Objectives

The main objective of SACOMAR is the experimental and numerical study of gas-surface interaction phenomena in the high enthalpy flow field behind the bow shock in front of a model at Martian entry flow conditions. The improvement of physical modelling using experimental data and its implementation into numerical simulation codes is essential to understand and interpret the physical processes. At the end the project will allow to estimate the aerothermal loads on the vehicle more accurately. Main activities of the project are:

- Definition of requirements on experiments, modelling and CFD codes using realistic Mars mission profiles
- Experiments on the measurement of flow parameters in the free stream and behind the shock and stagnation point heat flux rate
- Improvement of existing physical models with respect to non-equilibrium effects, transport properties and gas-surface interaction chemistry
- Implementation of improved physical models into the CFD codes and simulation of experiments
- Synthesis of the data and reporting

## 2.2 Achievements in the 1st reporting period

In the 1st reporting period following goals were achieved:

- A project ftp server and project portal on web-site base have been established,
- A new deliverable on the 'Validation Strategy' has been created and reported (D 2.2),
- Requirements on the experimental and numerical tools have been defined and reported in the delivery D 4.1 (issue 1.1),
- Specification of the test plan for experiments has been completed and reported in the delivery D 5.1,
- Experiments in Plasmatron facilities IPG 4 and U-13 have been completed and reported in deliverables 5.4 (issue 1.1) and D5.5,
- Experiments in the L2K facility are completed and reported in the delivery D 5.6,
- Review of physico-chemical modelling has been completed and reported in the delivery D 6.1 (Issue 1.1),
- Activities on improvement of modelling for the transport properties, gas phase chemistry and surface chemistry has already started,
- Activities on validation of the CFD code modelling are going on.

## 2.3 Expected final results

The SACOMAR consortium consists of four EC institutions and four research organizations in Russia. The European team members TAS-I, ASTRIUM, DLR and CIRA have been involved in most of the major European re-entry projects. TsNIImash, TsAGI, IPM and ITAM belong to the core research team of almost all Russian re-entry projects.

Following final results are expected:

- A reliable data base resulting from experimental and numerical studies for the design of future Mars missions,
- New knowledge will be transferred for future interplanetary missions. A new generation of researchers will take advantage of working on long term activities that can meet the future needs of aerospace industry.
- Intensified co-operation between EC and Russia in space programmes
- A selected, well structured and efficient EC-Russian team with reasonable resources to develop the experimental and numerical aerothermodynamic tools for future missions,
- Dissemination activities beyond the consortium, of the numerical tools and technology produced, including publications, conferences and exploitation of the results produced by the team.

# 3 Core of the report for the period: Project objectives, work progress and achievements, project management

## 3.1 Project objectives for the 1st reporting period

The main objectives of the 1st reporting period of the project are:

- Definition of requirements on the experimental and numerical tools,
- Specification of the test plan for experiments
- Performance of experiments in Plasmatron facilities IPG 4 and U-13,
- Review of physico-chemical modelling,
- Begin of improvement of modelling for the transport properties, gas phase chemistry and surface chemistry,
- Begin of validation of the CFD code modelling validation

## 3.2 Work progress and achievements for the 1st reporting period

### 3.2.1 WP1

**WP title: Project Management**

**Responsible partner: DLR**

**Workplan according to DoW**

- Effective management and coordination of the project to ensure high technical and economical efficiency
- The overall legal, financial and administrative management
- Control of financial and budgetary means of the project and supply of all necessary deliverables
- Decision on the evolution of the project as it progresses with respect to its milestone achievements

**Achievements**

Most of the milestones of the project in this reporting period have been achieved. There is a slight delay in experimental work and implementation of improved physico-chemical modelling into the CFD codes.

### 3.2.2 WP2

**WP title: Technical Coordination**

**Responsible partner: DLR**

**Workplan according to DoW**

Each work package will provide bi-monthly a short status report on the work progress obtained, inform about possible delays and indicate any problems. Critical points will be reported in particular those which endanger the objectives of the project or delay the input towards other work packages.

Depending on the progress made, dedicated teleconferences will be organized by the coordinator with the work package leaders, to discuss the possible problems, propose solutions for the sake of the project.

**Achievements**

Based on the requirements on the experiments and study of the performance of facilities a test matrix has been defined. For the definition of the final test matrix several teleconferences and an intense e-mail exchange have been organized.

### 3.2.3 WP3

**WP title: Dissemination**

**Responsible partner: DLR**

**Workplan according to DoW**

Project information and objectives for the outside world will be made available by a dedicated portal on the web-site of the coordinator. The coordinator will also represent the project at symposia, conferences, etc. to disseminate and present as widely as possible general or detailed technical information about the project and technical achievements.

**Achievements**

For the presentation of the project and information exchange with the project partner and European scientific community, a ftp server (sacomar@ftp.dlr.de) and a project portal on the web-site ([www.dlr.de/as/sacomar](http://www.dlr.de/as/sacomar)) have been established.

### 3.2.4 WP4

**WP title: Requirements and Synthesis**

**<u>Task 4.1: Requirements</u>**

**Responsible partner: TAS-I**

**Workplan according to DoW**

This task has the following main objective:

- Definition of the requirements for the modelling, simulation and testing activities to be conducted in the framework of the SACOMAR project.

**Achievements**

According to the workplan, the following main activities have been performed by TAS-I:

- Overview on the current physico-chemical modelling techniques for CO2 high enthalpy flows, including transport properties, gas phase kinetics and surface chemistry, their status and chances for improvement.
- Identification of type of CFD simulations needed to gather information about the implementation of the developed models, and of a standard method for data exchange,
- Definition of the requirements on the experimental activity to be performed to exploit the Martian atmosphere's relevant properties in a typical entry trajectory,
- Definition of criteria for the validation of numerical simulations results over experimental data, and of their use for the extrapolation to flight task.

Complete details are provided in the SACOMAR deliverable D4.1 (Requirements on Modelling and Simulation).

**<u>Task 4.2: Synthesis</u>**

**Responsible partner: TAS-I**

**Workplan according to DoW**

This task has the following main objective:

- Synthesis of achieved results with respect to their application for future missions.

**Achievements**

No work was foreseen in this reporting period.

### 3.2.5 WP5

**WP title: Aerothermal tests**

**Task 5.1: Test plan**

**Responsible partner: DLR**

**Workplan according to DoW**

This task has the following main objectives:

- Review of experience and facility capabilities of DLR, TsNIImash, TsaGI and IPM with respect to $CO_2$+ $N_2$ high enthalpy flows
- Definition of test conditions in terms of total enthalpy and Pitot pressure

**Achievements**

After a detailed analysis of the performance of testing facilities and their comparison with the important trajectory data points of the Exomars entry phase, a test plan has been defined. With reference to the EXOMARS trajectory four test conditions were identified which enable direct facility-to-facility comparison

- at identical total enthalpy conditions in the reservoir
- and comparable free stream enthalpies in different thermochemical regimes.

The test model geometry was chosen to be a flat-faced cylinder geometry with rounded edges. This geometry

- is a good representation of the windward surface of a capsule,
- provides largest possible shock stand-off distance in hypersonic flow maximizing the experimental possibilities of probing gas properties in the shock layer, and
- does not introduce geometrical complexity to numerixal simulations.

Finally, a test matrix was defined specifying test conditions in terms of total enthalpy and Pitot pressure for each test facility. Based on experiences and capabilities of the facilities, measurement techniques were specified to be applied for heat flux measurements and flow characterization. The test matrix and test models including the instrumentation have been described in the SACOMAR deliverable D5.1 (Test plan for Experiments).

## Task 5.2: Tests in HEG shock tunnel

**Responsible partner: DLR**

**Workplan according to DoW**

According to the description in the DoW, the test model has been manufactured, instrumented and installed in the test section of HEG. The model is instrumented with 10 thermocouples in order to determine the heat flux on the surface. The instrumentation is defined as shown in Figure 2 on page 8 on the left side.

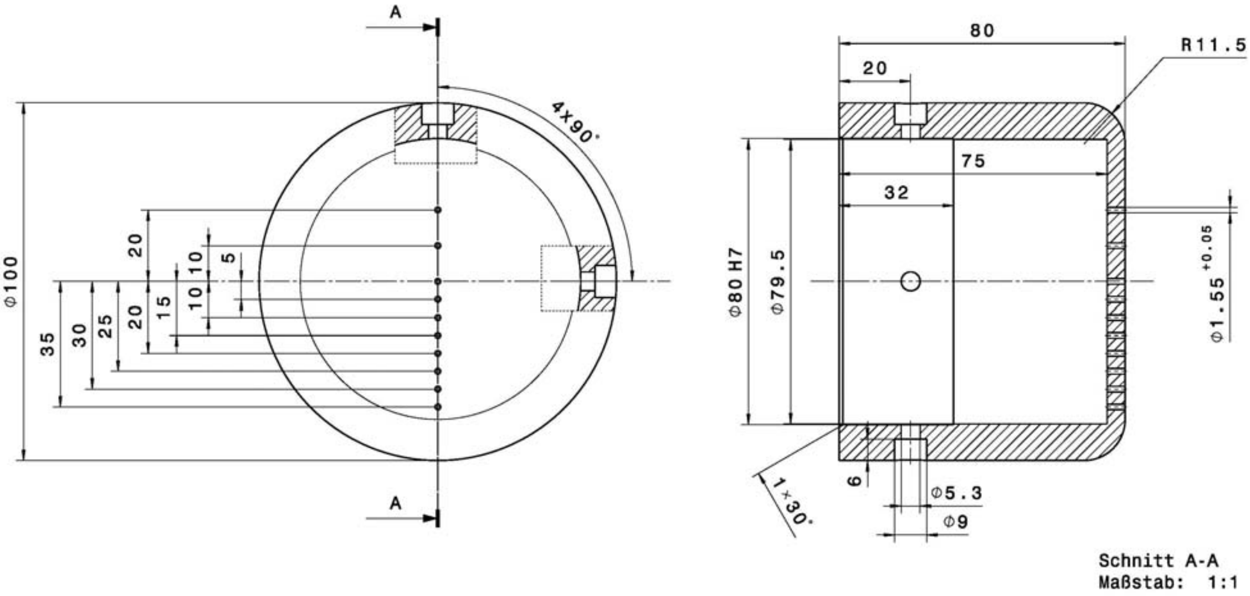


**Figure 2: Technical drawing oft he SACOMAR test model for HEG.**

The photographs in Figure 3 on page 8 show the SACOMAR model instrumentation and the model installed in the HEG test section. The test are currently performed. Two test conditions as defined in the DoW will be used in HEG. The free stream will be calibrated experimentally before the tests. Some preliminary results will be shown and discussed on the Midterm Review Meeting held in Moscow in October of this year.

**Figure 3: Photographs showing the SACOMAR test model for HEG. The instrumented head is shown on the left side. The inside of the model including the connector for the thermocouple instrumentation is shown in the middle. The right image shows the instrumented model installed in the HEG test section.**

**Achievements**

The test model manufacturing is finalized and the model is instrumented and ready for testing. The test model has been adapted to the HEG test section and installed. The tests with CO2 flow have started. Some preliminary results will be shown on the Midterm Review Meeting held in Moscow in October of this year.

**Task 5.3: Tests in IT-2 facility**

**Responsible partner: TsAGI**

**Workplan according to DoW**

This task has the following main objectives:

- Model designing, manufacturing and equipping with heat flux and pressure gages
- Measurement of stagnation pressure and heat flux distributions in the test section
- Model tests in IT-2 wind tunnel in $CO_2$ flow at $M_\infty$=12 using Schlieren visualization according test plan

**Achievements**

- Designing and manufacturing of the model are completed, model is under gages equipping. Approximately 30 heat flux sensors and 15 pressure gages will be installed in the model
- IT-2 wind tunnel, heat flux and Pitot pressure rakes and acquisition system are prepared for the test campaign. Some efforts are made to increase total enthalpy in comparison with standard facility regime

**Task 5.4: Tests in Plasmatron facility IPG-4**

**Responsible partner: IPM**

**Workplan according to DoW**

This task has the following main objectives:

- Manufacturing of the test models for experiments in IPG-4
- Measurement of the free stream and boundary layer spectra with emission spectroscopy
- Measurement of enthalpy in plasma free stream

- Measurement of the heat flux rate to the model and to reference probe with silver coating (fully catalytic) and quartz coating (non-catalytic surface)

**Achievements**

A 50-mm-diam water-cooled test model from copper and brass, and water-flow heat flux probe from stainless steel are manufactured in the Laboratory for Plasma/Surface Interaction.

Subsonic heat transfer tests with pure CO2 plasma have been performed in the wide range of enthalpy (17.2 – 4.2 MJ/kg), stagnation pressure (80 and 40 hPa) and gas flow rate (1.5 – 2.5 g/s).

The special water-cooled cylindrical nozzle was used, and generator power, pressure in test chamber, and distance from model surface to the nozzle were altered in order to meet requirements of the test plan. The four tests regimes were selected and realized according the test plan at the specified enthalpy and stagnation pressure.

Measurements of the heat flux rates to the model with the reference probe with silver surface at selected generator power and stagnation pressures have been performed. Evidence of silver surface oxidation was observed. The time history of the stagnation point heat flux to the silver wall was registered. The saturation time for reaching maximum heat flux is found to be about 15 min.

Indirect numerical rebuilding by GAMMA CFD code of the flow enthalpy through calculated heat flux rates to cooled fully catalytic wall and comparison with the data of stagnation point heat fluxes to oxidized stable silver surface of the reference probe was carried out.

Preliminary measurements of the stagnation heat flux to Ag, Mo, Cu and $SiO_2$ at the pressure 80 hPa as functions of the generator power have been performed. Significant heating effect of surface catalycity in dissociated carbon dioxide was demonstrated.

Preliminary registration of the emission spectra in subsonic $CO_2$ free stream and boundary layer in dissociated air was carried out.

**Task 5.5: Tests in Plasmatron facility U-13**

**Responsible partner: TsNIImash**

**Workplan according to DoW**

This task has the following main objectives:

- Design and manufacturing of a test model with instrumentation
- Characterization of the flow field using Emission Spectroscopy technique
- Tests performance in CO2 + N2 environment in the TsNIImash U13 Plasmatron facility

**Achievements**

Test model (water-cooled calorimeter shaped as ESA standard geometry of 50 mm in diameter) with three receiving elements (silver, copper and quartz) were designed and manufactured in accordance with the Test plan (SACOMAR deliverable D5.1).

Emission spectra of CO2 + N2 flow were measured for all flow regimes of test matrix.

Tests with the experimental models were performed for all the cases described in the Test matrix and corresponding heat fluxes to the surfaces made of different materials were measured.

Test matrix, test model, measurement techniques and test results have been described in the SACOMAR deliverable D5.5 (Results of experimental study in the TsNIImash Plasmatron facility U13).

## Task 5.6: Tests in arc heated facilities

**Responsible partner: DLR**

**Workplan according to DoW**

- Design and manufacturing of a test model with instrumentation
- Characterization of the flow field using spectroscopic techniques like Emission Spectroscopy, LIF, DLAS and Micro-Wave Interferometry
- Measurement of the heat flux rate and pressure on the model surface at defined flow conditions in $CO_2$+ $N_2$ environment in the arc heated facility L2K

**Achievements**

In the frame of the SACOMAR project an experimental test campaign was performed in DLR's arc heated facility L2K. The campaign was run in order to gather experimental data that can be used for the validation of thermo-chemical models that are applied in CFD simulation schemes for Martian entry flow problems. Therefore, all tests were performed at high enthalpy flow conditions in a mixture of 97% carbon dioxide and 3% nitrogen, which represents the chemical composition of the Martian atmosphere.

Two different test conditions had been defined in the SACOMAR test plan. The first test condition FC-1 is characterized by a high total enthalpy of 13.8 MJ/kg. The enthalpy level of the second test condition FC-2 is considerably lower at 9.0 MJ/kg. For these two conditions a large number of measurements was performed both, in the free stream and in the shock layer of two flat-faced cylinder models with diameters of 50 mm and 100 mm.

In a first step, compliance to the specified test condition was demonstrated by Pitot pressure measurements. Additionally, radial homogeneity of the flow field was proved by Pitot pressure profiles.

In addition to the heat flux measurements several spectroscopic measurement techniques were applied for free stream characteri¬sation. NO molecules were observed by laser induced fluorescence (LIF), while CO was probed by diode laser absorption spectroscopy (DLAS).

From NO-LIF measurements spatially resolved temperature profiles were obtained in the free stream and in front of the flat-faced cylinder models. The absolute temperature level in the free stream was found higher for the low enthalpy test condition FC-2 compared to high enthalpy condition FC-1. This result can only be explained by differences in the chemical gas composition inside the facility's reservoir which shows a higher fraction of $CO_2$ for FC-2. Since the reservoir condition can be determined from accurate measurements of gas mass flow rate and reservoir pressure, the L2K nozzle flow is an excellent test case for validation of thermochemical models of Martian atmosphere.

Measurements with NO-LIF in the shock layer at different distances to the model surface provided an almost constant temperature level along the stagnation point stream line until the edge of the boundary layer. In addition, the good spatial resolution allowed to extract the position of the bow shock from the lateral profiles and to estimate the shock shape and the shock's stand-off distance. The stand-off distance was found to be 21 mm for the 100 mm model, while it was only about 11 mm for the 50 mm model.

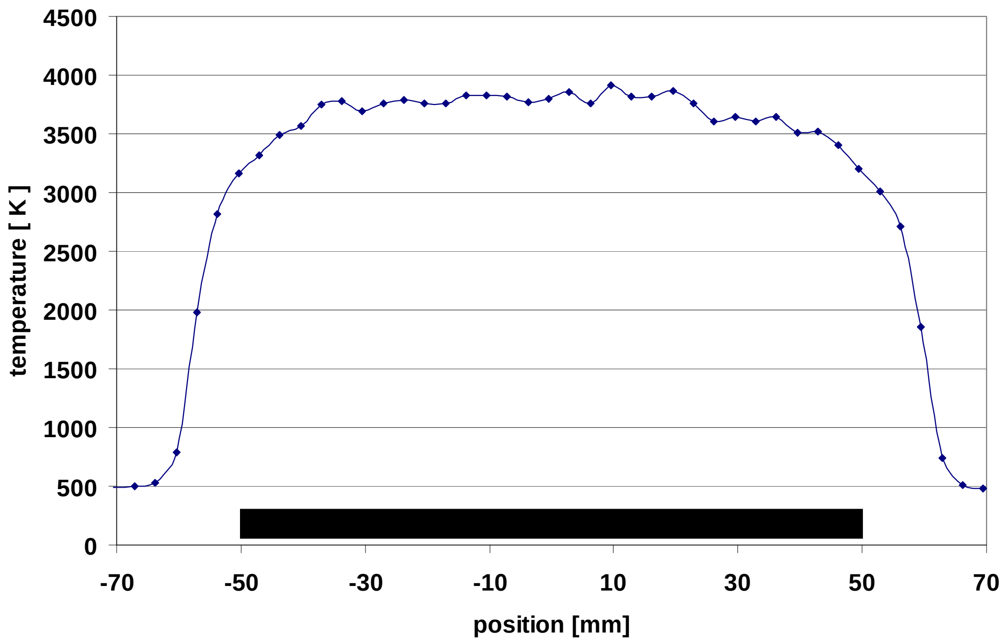


**Figure 4: Measured temperature profile with LIF 3 mm in front of the 100 mm model at test condition FC-1.**

The cold wall heat flux in the stagnation point of the models was measured with different techniques, i.e. a so-called heat flux microsensor (HFM) and a slug calorimeter made of stainless steel. The results obtained with these techniques are compared in Table 1. The listed values indicate that the slug calorimeter generally provides lower heat fluxes when compared to the HFM measurements. Taking HFM as reference the reduction is between 28% and 36%, i.e. nearly constant. Therefore, the differences might be regarded as systematic. A possible explanation could be the different surface catalycity. The surface of the HFM sensor is known to be almost fully catalytic, while stainless steel is only partly catalytic. The heat flux reduction of about 30% fully agrees to the measurements in the IPM plasmatron facility in the frame of SACOMAR task 5.4. Figure 5: Slug calorimeter measurement at test condition FC-2 (p = 20 hPa, D = 100 mm).

**Table 1: Comparison of heat flux measurements**

| Test condition | Model diameter | Pitot pressure | Heat flux rate [kW/m$^2$] | |
|---|---|---|---|---|
| | [mm] | [hPa] | HFM | Slug calorimeter |
| FC-1 | 100 | 20 | 891 | 640 |
| | 50 | 20 | 1091 | 740 |
| | 50 | 80 | - | 1380 |
| FC-2 | 100 | 20 | 518 | 355 |
| | 50 | 20 | 694 | 440 |
| | 50 | 80 | - | 630 |

### 3.2.6 WP6

### WP title: Physical-Chemical Modelling

**Task 6.1: Review of physical-chemical modelling**

**Responsible partner: ASTRIUM**

#### Workplan according to DoW

The objective of this task is a review of the existing thermochemical models for the Mars atmosphere's gas mixture including transport, dissociation, ionization and surface catalysis and the related validation status / associated uncertainties. Suggestions for further improvements of the modelling serve as basis for further careful discussion within WP1 and WP2, so as to refine the further course of action regarding implementation of the most promising model improvements and the related experimental conditions rebuilding.

#### Achievements

The current state of the art regarding physico-chemical modelling of the Mars atmospheric gas mixture has been reviewed with respect to:

- Modelling of Thermal State
- Chemical Kinetics
- Transport Properties
- Surface Catalysis

Uncertainties related to the current models as well as the related directions within the experimental and numerical rebuilding work foreseen in the SACOMAR study are identified for each of these areas.

The suggestions regarding the modelling are used as basis for careful discussion within WP1 and WP4, so as to refine the further course of action regarding implementation of the most promising model improvements and the related experimental conditions rebuilding.

## Task 6.2: Gas Transport Properties

**Responsible partner: TsNIImash**

### Workplan according to DoW

This task has the following main objectives:

- Development of library of thermodynamic and transport properties for the Mars mixture
- Assist in development of interface for the CFD codes

### Achievements

Appropriate thermodynamic information for constituent species has been gathered.

Available interaction potentials have been gathered and collision integrals required for calculation of transport phenomena have been estimated.

## Task 6.3: Gas Phase Chemistry

**Responsible partner: DLR**

### Workplan according to DoW

This task has the following main objectives:

- Selection of a non-equilibrium model for the gas compositions used in the experiments
- Implementation of the model in the CFD code

### Achievements

After review of suitable $CO_2$ reaction models an appropriate reaction scheme containing 27 reactions for the species $CO_2$, CO, C, $O_2$, O and $C_2$ and 103 reactions for the species $CO_2$, NCO, CO, $N_2$, $O_2$, $C_2$, CO, NO, N, C and O has been implemented. Note that thermal nonequilibrium is currently not taken into account.

Transport properties are modelled via Wilke's mixing rules which require single species viscosities as input. Diffusion is determined from mixture viscosity employing a user defined Schmidt number. For the simulation of $CO_2$ flows a Schmidt number of 0.7 is proposed.

A detailed report on the implementation is in preparation.

**Task 6.4: Surface Chemistry**

**Responsible partner: IPM**

**Workplan according to DoW**

This task has the following main objectives:

- Gather appropriate information for surface catalycity
- Gather appropriate information for diffusion on the surface
- Comparative analysis all of the heat transfer data and determination catalycity of different surfaces (metals and quartz)

**Achievements**

The main references of literature related to O and CO catalytic recombination have been selected. The appropriate data of catalytic recombination coefficients of atomic oxygen on cold and hot surfaces of some metals and quartz were gathered. The structure of electronic library is chosen providing the data of effective recombination coefficients, actual recombination coefficients and energy accommodation coefficients for O atoms and CO molecules. Existing models of catalytic recombination of O atoms and CO molecules were considered, analyzed and one model is chosen for further modelling catalycity heating effect on metals and quartz. Through qualitative comparative analysis of measured stagnation point fluxes the catalytic scale is estimated as follows: $Ag > Mo \cong Cu > SiO_2$.

### 3.2.7 WP7

**WP title: CFD simulation**

**Task 7.1: CIRA code modelling validation**

**Responsible partner: CIRA**

**Workplan according to DoW**

- Implementation of modelling and numerical improvements to the CIRA code.
- Validation of modelling and numerical improvements to the CIRA code

**Achievements**

CIRA did not start the work yet.

**Task 7.2: TAU code modelling validation**

**Responsible partner: DLR**

**Workplan according to DoW**

- Implementation of modelling and numerical improvements to the TAU code.
- Validation of modelling and numerical improvements to the TAU code

**Achievements**

Following the implementation from Task 6.3 the verification of the modelling has started.

**Task 7.3: TsNIImash code modelling validation**

**Responsible partner: TsNIImash**

**Workplan according to DoW**

This task has the following main objectives:

- Implementation of modelling and numerical improvements to the TsNIImash code.
- Validation of modelling and numerical improvements to the TsNIImash code

**Achievements**

A robust numerical scheme for CO2 flows simulation was implemented into TsNIImash code.

**Task 7.4: ITAM code modelling validation**

**Responsible partner: ITAM**

**Workplan according to DoW**

- Implementation of robust numerical scheme for CO2 flows to the SMILE code.
- Implementation of modelling and numerical improvements to the ITAM code SMILE.
- Validation of modelling and numerical improvements to the ITAM code SMILE.

**Achievements**

Improvements aimed at SMILE computation speedup and robust numerical scheme for CO2 flows were implemented into the code. The CO2/N2 flow around a streamwise aligned cylinder with rounded edges was computed for conditions the DLR Cologne wind tunnel (Mach number 7.25 and Reynolds number 880). The translational temperature flowfield is presented in Figure 6.


**Figure 6: Translational temperature (DSMC computation by the SMILE code).**

The free stream conditions are as follows:

p = 14.7 Pa, T = 362 K, v = 2970 m/s

The gas is partly dissociated in the free stream with the following mass fractions:

$CO_2$: 0.107

CO: 0.550

$O_2$: 0.126

O: 0.181

$N_2$: 0.023

NO: 0.013

The validation against the DLR experimental data will be carried out at the next stage of the project.

## <u>Task 7.5: Simulation of Shock Tunnel Tests</u>

**Responsible partner: ASTRIUM**

### Workplan according to DoW

- Numerical rebuilding of HEG experiments with the TAU code.
- Numerical rebuilding of IT-2 experiments with the TAU code.

### Achievements

No work was foreseen in this reporting period.

## Task 7.6: Simulation of IPG-4 Plasmatron Tests

**Responsible partner: IPM**

### Workplan according to DoW

This task has the following main objectives:

- Numerical rebuilding of the experiments in the IPM Plasmatron facility with the ALPHA, BETA and GAMMA codes.

### Achievements

In order to rebuild the enthalpy and velocity in the subsonic free stream for the specified test conditions CFD modelling has been performed using ALPHA code for carbon dioxide plasma flows in the IPG-4 torch at different anode power, pressure and $CO_2$ mass flow rate. New grid geometry was constructed according geometry of the plasma torch with 40-mm-diam lengthened cylindrical nozzle. For the same input parameters and calculated profiles of all flow parameters at the plasmatron exit, subsonic dissociated carbon dioxide flow fields around a cooled test model were carried out by using code BETA for different distances from Plasmatron exit to model surface. Necessary flow parameters at the edge of boundary layer were calculated as well and have been used in Task 5.4 by GAMMA code with boundary conditions for fully catalytic wall to rebuild flow enthalpy and velocity in subsonic free stream.

## Task 7.7: Simulation of U13 Plasmatron Tests

**Responsible partner: TsNIImash**

### Workplan according to DoW

The objective of this task is numerical rebuilding of the experiments in the TsNIImash Plasmatron facility with the TsNIImash code.

### Achievements

No work was seen in this reporting period.

## Task 7.8: Simulation of Arcjet Tests in L2K

**Responsible partner: CIRA**

### Workplan according to DoW

- Numerical rebuilding of L2K experiments with the CIRA code.

### Achievements

No work was seen in this reporting period.

## 3.3 Project Management

Most of the milestones of the project in this reporting period have been achieved. There is a slight delay in experimental work and implementation of improved physico-chemical modelling into the CFD codes. But these delays are minor and do not have any impact on the success of the project.

The spending given by the partners cover mostly only the first seven months. Therefore the tables of explanation of resources show a slight underspending in the project.

For the presentation of the project and information exchange with the project partner and European scientific community, a ftp server (sacomar@ftp.dlr.de) and a project portal on the web-site (www.dlr.de/as/sacomar) have been established.

Besides several teleconferences and intensive e-mail exchange, following meetings were organized:

| **Meeting** | **Location** | **Date** |
|---|---|---|
| Kick-off | Cologne, Germany | 20./21.01.2011 |
| Progress Meeting | Korolev, Russia | 10./11.10.2011 |

There were no changes to the legal status of any of the beneficiaries. The project does not have any sub-contractors.

# 4 Deliverables and milestones tables

## 4.1 Deliverables

**TABLE 2. DELIVERABLES**

| Deliverable no. | Deliverable title | Lead beneficiary | Delivery date from Annex I dd/mm/yyyy | Achieved Yes/No | Actual / Forecast achievement date dd/mm/yyyy | Nature |
|---|---|---|---|---|---|---|
| D1.1 | Interim Progress Report | 1 (DLR) | 30.09.2011 | Yes | 30.09.2011 | R |
| D2.1 | Project ftp-site | 1 (DLR) | 31.03.2011 | Yes | 31.03.2011 | O |
| D2.2 | Report: Validation Strategy | 1 (DLR) | 30.11.2011 | Yes | 16.12.2011 | R |
| D3.1 | Project portal | 1 (DLR) | 31.03.2011 | Yes | 31.03.2011 | O |
| D4.1 | Report: Requirements on Modelling and Simulation | 4 (TAS-I) | 31.03.2011<br>30.11.2011 | Yes | 30.04.2011<br>30.11.2011 | R |
| D5.1 | Technical report on test plan | 1 (DLR) | 31.03.2011 | Yes | 30.06.2011 | R |
| D5.4 | Report: Results of experimental study in the IPG-4 facility | 6 (IPM) | 30.09.2011 | Yes | 30.09.2011 | R |
| D5.5 | Report: Results of experimental study in the TsNIImash Plasmatron facility U13 | 7 (TsNIImash) | 30.09.2011 | Yes | 30.09.2011 | R |
| D5.6 | Report: Results of the Experimental Study in the L2K Facility | 1 (DLR) | 30.10.2011 | Yes | 30.11.2011 | R |
| D6.1 | Review of Physical-Chemical Modelling | 2 (ASTRIUM) | 31.03.2011<br>30.11.2011 | Yes | 30.04.2011<br>30.11.2011 | R |

## 4.2 Milestones

**TABLE 2. MILESTONES**

| Milestone no. | Milestone name | Work package no | Lead beneficiary | Delivery date from Annex I dd/mm/yyyy | Achieved Yes/No | Actual / Forecast achievement date dd/mm/yyyy | Comments |
|---|---|---|---|---|---|---|---|
| MS1 | Kick-off | WP1 | 1 (DLR) | 01.01.2011 | Yes | 20.01.2011 | |
| MS3 | Technical report on requirements | WP4 | 4 (TAS-I) | 31.03.2011 | Yes | 30.04.2011 | |
| MS5 | Technical report on test plan | WP5 | 1 (DLR) | 31.03.2011 | Yes | 30.06.2011 | |
| MS8 | Report and electronic data of IPG-4 experiments | WP5 | 6 (IPM) | 30.09.2011 | Yes | 30.09.2011 | |
| MS9 | Report and electronic data of TsNIImash U13 Plasmatron experiments | WP5 | 5 (TsNIImash | 30.09.2011 | Yes | 30.09.2011 | |
| MS10 | Report and electronic data of L2K experiments | WP5 | 1 (DLR) | 30.10.2011 | Yes | 30.11.2011 | |
| MS11 | Report on the status of physical-chemical modelling and necessary improvements | WP6 | 2 (ASTRIUM) | 31.03.2011 | Yes | 30.04.2011 | |