The German Microgravity Programme In Physical Sciences

Rainer KUHL

DLR, German Aerospace Center, Space Agency,
Koenigswinterer Str. 522-524, D-53227 Bonn, Germany
fax: +49-228-447-735 tel: +49-228-447-387
e-mail: rainer.kuhl@dlr.de

Abstract

The German Microgravity Programme covers research in physical as well as life sciences. This paper deals with research on physical and chemical processes exposed to microgravity conditions. The Physical Sciences Programme goal, structure, priorities, research disciplines, scientific topics, hardware developments, and flight opportunities are outlined. All German microgravity activities are performed within the corresponding ESA Programmes, the National Space Programme, and the DLR R&D Programme in an integrated manner. The aim is to maximize the gained scientific knowledge for developing new materials, advanced technologies and to reveal some mysteries of the physical world.

1. Introduction

As a major research establishment, the German Aerospace Center DLR plays an important role in the areas of aeronautics, space flight, transport and energy with about five thousand employees. As the German Space Agency, DLR manages the German Space Programme. This programme integrates the German participation in the ESA Programmes, the activities in the National Space Programme as well as the R&D activities of the research establishment DLR. The space agency provides the respective add-on funding for scientists at universities and other research institutes and places contracts to industry for the development of facilities or the provision of short-duration microgravity flight opportunities.

One core element of the National Space Programme is Research under Space Conditions, which covers life and physical sciences in equal shares. This paper provides an overview on the Physical Sciences Programme that currently deals exclusively with gravity effects on physical and chemical processes.

2. Programme structure and budget

Germany participates in the microgravity related programmes of the European Space Agency ESA with considerable financial contributions, e. g. 33 M€ in 2007. Basically, the ESA Programmes care for the development of research facilities and provide different microgravity flight opportunities. The main on going programme ELIPS-2 is planned to be continued for another five years in 2008.

The second component of space activities, the National Space Programme, is complementary and well coordinated with the ESA Programmes. In reality, the National Space Programme is to a large extent based on co-operations with space agencies and research institutions of other countries.

The third component of German space activities represents the DLR R&D Programme. In the case of physical sciences, this programme is implemented at the Institute of Materials Physics in Space and the Microgravity User Support Center (MUSC), respectively. Their core competencies concern materials design from the melt and, respectively, support of scientists during performing of experiments on ground and in space. Their annual budget amounts to about 2 M€.

The annual budget of all German microgravity related activities (life and physical sciences) amounts to about 6 % of the total space expenditures (732 M€ in 2007).

The structure of the Physical Sciences Programme as part of the National Programme is determined by three elements:

Experiments: preparation, performance and analysis of microgravity experiments,
Facilities: development of flight hardware,
Missions: provision of microgravity flights.

In financial terms, 3.5 M€ are allocated to Experiments, 2.5 M€ to Facilities and 2 M€ to Missions. The main research disciplines are materials research, fluid physics, combustion, and fundamental physics.

4. Implemented microgravity experiments

During more than three decades of research activities, 19% of all German physical sciences experiments were performed on manned orbital missions like Skylab, Spacelab, Spacehab, Space Shuttle, the Soviet/Russian space stations Salyut/MIR, and the International Space Station ISS.

On microgravity sounding rockets, 24% of all experiments were flown. In this context, the German TEXUS rocket programme proved to be of utmost importance. It formed the backbone to implement 6 min

duration microgravity experiments in Europe. This programme celebrates the 30th anniversary of its first flight in this year. It represents worldwide the only permanent microgravity flight programme over three decades.

The number of experiments on ballistic airplane flights and on drop towers/shafts/balloons amounts to 26% and 21%, respectively. Long duration experiments on orbital payloads without a crew intervention summarize to 10%. Examples of such flight opportunities are the EURECA free flyer, FOTON retrievable satellites and GAS Shuttle payloads.

Since 1975, Germany has performed microgravity experiments in the field of physical sciences nearly each year. The annual frequency of experiments significantly varies over the time. In 1983 and 1985, during the first Spacelab and the German D-1 Spacelab missions, 34 respectively 41 experiments could be implemented. After the first Shuttle accident in 1986, only about ten experiments per year were realised during several years. In 1993, the German D-2 Spacelab mission was launched and the European retrievable platform EURECA was flown. This resulted in an absolute annual peak of 53 performed German experiments.

Since 1992, a rather high mean level in the order of 30 experiments per year could be maintained till now. Therefore, more than two thirds of all performed experiments fall in the share of the last 15 years. This is mainly due to the increased number of available suborbital missions on drop towers and parabolic flights.

With respect to the share of microgravity experiments in different research disciplines, 50% of the investigations were performed in materials research. The share of investigations in fluid physics amount 33%, followed by fundamental physics with 12% and combustion with 5%.

5. Programme goal and research priorities

The main programme goal of the German Physical Sciences Programme is to gain scientific knowledge and to disclose new application potentials by microgravity research, especially utilising the ISS.

A key criterion of selecting research proposals is the “best science” principle for fundamental and application-oriented research. As a result of international peer panel reviews DLR has defined the following research priorities of its Physical Sciences Programme:

- <u>materials design from the melt</u>

considering gravity affected solidification processes as well as measurements of thermophysical properties of metallic melts,

- <u>structure and dynamics of fluid flow</u>

in open capillaries, spherical gaps, and at liquid/liquid and liquid/solid interfaces,

- <u>basic combustion mechanisms</u>

of fuel droplets and sprays,

- <u>fundamental particle interactions</u>

in quantum, plasma, atmospheric, and astrophysical systems.

Under microgravity, buoyancy driven fluid flow, sedimentation of components with different density, and the hydrostatic pressure can be greatly reduced. This situation often permits a better study and control of phase transformations and precise measurements of physical quantities. It constitutes the overall motivation of the investigations addressed.

Currently, 27 scientific institutions are involved in the programme and 36 scientific projects are funded by DLR. For implementation on the ISS, 41 experiments with German principal investigators or team coordinators are selected.

In the following, major DLR funded scientific projects shall be characterized in more detail. They are grouped in the related research disciplines.

6. Materials research

THERMOLAB project

Measurements of thermophysical properties such as surface tension, viscosity, and the specific heat capacity, are very often complicated in the case of molten metals by their high chemical reactivity. In particular, this holds for high melting Ti-Al alloys, which are currently of high technological interest. On the other hand, such property data are needed for numerical simulations of industrial casting and solidification processes, indispensable in the modern metallurgical process development.

Containerless processing in an electromagnetic levitation device enables to overcome a major part of the problems. Microgravity conditions are needed to provide a chemically clean, quiescent, non-distorted spherical molten specimen, which is decisive for radiometric precision measurements.

In the last years, several test experiments could be performed in an electromagnetic levitator on parabolic airplane flights and TEXUS 42. The accuracy of thermophysical data of industrially relevant alloys measured in microgravity proved to be higher than achieved on ground. Finally, containerless processing experiments will be implemented on the ISS in an even more precise and systematic manner.

SOLIDIFICATION DYNAMICS project

The precise determination of dendrite growth velocities as a function of the undercooling prior to solidification of metallic melts is a further challenge. Such investigations are needed to verify solidification models used in the metallurgy. Dendrite growth is controlled by the heat and mass transport ahead the solid-liquid interface. This transport is strongly influenced by melt convection if the flow velocity is in the same order as the dendrite growth velocity. This type of investigations will benefit from future investigation on the ISS in an electromagnetic levitator by triggering the solidification onset of

undercooled melts and covering a wider range of processing parameters.

Another topic concerns the solidification of a metallic matrix containing ceramic particles and to study the interaction of the particles with the advancing solidification front. On parabolic flights, engulfed and entrapped submicron Ta-oxide particles could already be realised in solidified Ni-Ta alloys.

EVALU project

This project studies the solidification dynamics of application relevant Al alloys. The ESA selected projects CETSOL, MICAST, SETA and XRMON are thematically coupled with EVALU. Microgravity experiments are primarily planned in the Materials Sciences Lab of ESA on the ISS.

The investigations deal with columnar-equiaxed transitions of grain growth in dependence on the processing parameters and the effect of added grain refiners. In 2006, three precursor experiments were successfully flown on the rocket MAXUS 7 during 12 minutes of microgravity. The resulting properties of Al alloys were characteristically influenced by the microstructure change during processing.

The influence of a defined melt flow, induced by a rotating magnetic field, on the microstructure of binary and ternary Al alloys is another research topic. Moreover, the eutectic solidification of an Al-Cu-Ag alloy is planned in comparison to an experiment with a ternary transparent organic alloy. In this case, the future DIRSOL facility of ESA will allow a direct microscopic observation of the collective growth of the transparent phases.

ARTEX project

In order to better control solidification parameters and measure in-situ and precisely the temperature field, an aerogel is used as furnace cartridge material. This transparent material exhibits an extremely low thermal conductivity and enables measurements of the solidification velocity optically.

With the aim to study the influence of convection on the dendrite microstructure evolution, Al-Si alloys were processed on TEXUS and MAXUS flights in the timeframe 2001-2006. The samples solidified with and without the influence of forced convection by a rotating magnetic field. The results clearly reveal the dramatic effects of changing fluid flow conditions on the dendrite arm spacing.

SEMICONDUCTOR CRYSTALS project

Many microgravity experiments have shown that thermocapillary (Marangoni) convection is the dominant source of time-dependent convection in radiation heated float zones of germanium and silicon. Possible countermeasures to control the convection are mechanical vibrations of the zone or dynamic magnetic fields. Both methods were applied in several German experiments on TEXUS and MAXUS flights during the last years.

In September this year, doped Ge, Ge-Si, and Cd-Zn-Te crystals were grown on the Russian retrievable satellite FOTON-M3 under diffusive, vibrational and magnetically induced convective conditions. Also other techniques were applied to improve the quality of the grown single crystals: the detached melt growth from the wall and growth from the vapour phase. The detailed results of this very successful mission are expected soon.

7. Fluid physics

GEOFLOW project

Thermal convection in a spherical gap is an important model in fluid dynamics and geophysics. Specifically, thermal convective instabilities with a simulated central force field can provide details for the understanding of large scale geophysical motions. As an example, flows in the liquid outer core of the Earth can be simulated.

Focusing on the main acting forces and neglecting magnetic effects, GEOFLOW investigates the stability and pattern formation of thermal convection in a rotating spherical gap. To turn off the effect of the unidirectional gravitation on the spherical fluid on Earth, the experiment requires weightlessness.

DLR has funded the related theoretical, numerical, and experimental studies since 2001. GEOFLOW will be the first investigation in the Fluid Sciences Lab of ESA on COLUMBUS beginning early 2008.

CCF project

The versatile experiment Capillary Channel Flow will study a variety of inertial-capillary dominated fluid flows key to spacecraft systems that cannot be studied on Earth. Applications of the results are in the context with containment, storage, and handling of large liquid inventories (fuels, cryogens, water) on board spacecrafts. This refers to liquid management systems for current orbiting, design stage, and advanced spacecrafts of the future.

As an example, open capillary channels are used in surface tension tanks to transport liquid fuel to reservoirs or directly to the thruster. CCF will provide the verification for the flow rate limit and corresponding critical flow velocities. If a certain critical flow is exceeded, the flow does not remain steady. The surfaces collapse and gas ingestion occurs at the outlet. The geometry of the channels to be tested is parallel plate, groove and wedge.

This DLR-NASA cooperative experiment will be implemented in the Microgravity Science Glovebox on board the ISS in late 2009. DLR will develop the experiment facility and NASA will provide all ISS resources needed to operate the equipment.

CDIC project

A Chemically Driven Interfacial Convection experiment was already performed on the sounding

rocket MASER 10 in 2005. It will be succeeded by further investigations on MASER 11 in spring 2008.

The transport of chemical species across liquid interfaces is crucial to many processes in the chemical and pharmaceutical industry. When chemical reactions are affecting the properties of the fluids, the situation becomes more complex and can cause hydrodynamic instabilities otherwise not observable. To get deeper insights into the interplay between chemistry and interfacial-tension driven hydrodynamic instabilities, two immiscible liquids in contact along a plane interface are studied. The liquid phases are hexane and water, respectively, and contain dissolved reacting species. The interface reaction leads to surface active species (surfactants), implying that they reduce the interfacial tension. The pattern formation along the interface leads to a characteristic deformation of an initially plane interface.

DOLFIN project

The aim of this Dynamics of Liquid Film/Wall Interaction study is to clarify the hydrodynamics and heat transfer associated with spray impact onto a heated target and to improve the modelling of spray cooling. The model is necessary for the design of future spacecrafts, since spray cooling of electronic devices is part of a new spacecraft technology. Various industrial applications on the ground also rely on liquid sprays.

Gravity influences the splash of a single drop, particularly the height of the uprising sheet and the duration of its propagation. It influences also the average thickness and the stability of the liquid film on a mechanically or chemically structured surface. Thus, the heat flux associated with the spray impact is affected.

Currently, DLR develops a dedicated research module for TEXUS 45, which will be flown in February 2008. So far, preparative work has been implemented on parabolic airplane flights using the DOLFIN laboratory set-up.

8. Combustion

DROPLET and SPRAY project

Investigations on the selfignition of fuel droplets and sprays at elevated temperature and pressure aim for a fundamental understanding of the physical and chemical processes involved. This shall enable the development of more precise numerical simulations of the combustion process predicting the behaviour of reactors. The latter need either controlled selfignition for a proper operation (diesel engines) or have to avoid unwanted selfignition (gas turbines).

Microgravity conditions are applied to avoid the masking effect of natural convection on a flow field. On Earth, a more dense fuel vapour drops off the droplet and reduces the local density in its vicinity.

However, micro-sized droplets of a technical spray do not strongly interact with the turbulent flow field on Earth. Therefore, natural convection plays a minor role during the milliseconds lifetime of such droplets. Hence, the transfer of results from microgravity experiments executed with comparably large droplets (easy to handle and diagnose) to technical applications has to bridge only a small gap.

The current DLR supported research activities aim on the selfignition of droplets (n-heptane) under the influence of an acoustic field and are implemented at the DROP TOWER BREMEN.

Another type of investigations deals with the identification of the share of different burnt gases, in particular NOx, in a linear array of n-decane droplets. The execution of this joint experiment of JAXA, ESA, and DLR is planned on TEXUS 46 in 2009.

9. Fundamental physics

PLASMA CRYSTALS project

Plasma is generally considered as the most disordered state of matter. In 1994, it was discovered that micro-sized particles embedded in an electric discharge plasma at room temperature can form regular patterns - the so called plasma crystals. On Earth, because of the sedimentation of the heavy particles, only more or less 2-dimensional crystal structures are formed. To create large homogeneous 3-dimensional crystal structures in the plasma volume, microgravity conditions are needed.

Dusty or complex plasmas are widespread in nature. Examples are interstellar molecule clouds, planetary ring systems, and the tail of comets. Moreover, dusty plasmas often appear on Earth in technological processes as a disturbing environment.

Today, it is unquestionable that plasma crystals play an important role as a model system for fundamental research in the fields of fluid and solid state physics as well astrophysics. But there are also application fields in a long-term perspective, e. g. the manipulation of particles in the plasma for coating of substrates.

DLR supported the first microgravity studies on TEXUS 35 and 36 in 1996 and 1998, respectively. In March 2001, a series of plasma experiments started on the ISS in collaboration with Russia. This step can be seen as the beginning of the scientific research on the ISS at all. Until today, several investigations on phase transitions, fluid motion and wave phenomena in complex plasmas were carried out leading to more than 30 scientific publications. Some first observations could be made under microgravity. Based on a second facility generation provided by DLR and currently on board the ISS, the investigations are expected to be continued even in the next decade.

ICAPS project

This project investigates Interactions in Cosmic and Atmospheric Particle Systems in microgravity. The studies deal with particle-particle, particle-light and particle-gas interactions, whereby the particles are solid or liquid, isolated or aggregated.

It is still unknown how micrometer-sized dust particles

in the young solar system accumulated into one-km-sized planetesimals, the first planetary bodies with substantial gravitational attraction. On the other hand, it is unquestionable that clouds in the Earth atmosphere play the key role in weather phenomena. But how do aerosol and airborne particles affect climate and weather?

First cosmic dust experiments were performed on a Space Shuttle flight (GAS programme) in 1998 and on the sounding rocket MASER 8 in 1999. In the meantime, some tests of dust and ice particle agglomerations have been implemented on parabolic airplane flights and at drop towers. As a next step, an ICAPS Precursor Experiment (IPE) on the ISS is planned by ESA in 2010.

Droplet collectives as representatives for clouds were produced on parabolic airplane flights by a generator for electrically charged mono-disperse droplets. During the next campaign in November 2007, the growth velocity of cloud droplets will be measured by a high resolution laser spectrometer.

QUANTUS project

In 1995, Bose-Einstein Condensates (BEC) were discovered, i. e. ultra low temperature quantum gases. The Nobel Prize in physics was awarded to the discoverers in 2001. Today, several laboratories worldwide are investigating this new state of matter. In 2003, the technology seemed mature enough for DLR to support studies exploring the feasibility of a BEC in the harsh environment of a drop tower.

The ultimate goal of quantum gases under microgravity is to advance to lower energy scales. The preparation of atomic ensembles with temperatures in the Femto-Kelvin regime seems to be achievable. This is because of lowering the trapping potential for the gas atoms adiabatically without the need of levitation fields to compensate for gravity. The time for the free and undisturbed evolution of the condensate can be significantly enlarged. A further advantage exists in the case of mixtures of quantum gases, as atoms with different masses do not experience different gravitational potentials. Furthermore, the effect of ultra-weak long-range forces becomes important in such condensates, which promises the discovery of new kinds of low-energy phase transitions.

Currently, DLR funds a research team composed of six institutions to demonstrate a BEC under microgravity at the DROP TOWER BREMEN.

10. Main hardware developments

For the different flight opportunities the following major research facilities exist or are currently under development by DLR:

- DROP TOWER BREMEN: ADL for combustion spectroscopy; QUANTUS for studying quantum gases
- AIRBUS Parabolic Flights: TEMPUS electromagnetic levitator; facilities for complex plasma, cosmic dust, and aerosol research, DOLFIN facility for liquid spray cooling studies
- TEXUS: ARTEX aerogel solidification furnace; TEMPUS and DOLFIN like research modules; mirror furnace for semiconductor crystal growth
- ISS: PK-3 PLUS for complex plasma research, CCF for capillary channel flow studies, EML for containerless processing.

In the following, some of the new facilities shall be described in more detail.

ADL facility

So far, combustion studies were implemented by a laser diagnostic system accommodated at the top of the DROP TOWER BREMEN. In this case, the laser beam follows the falling capsule and enters it from above. The UV excimer laser system allows a repetition rate of 250 Hz and enables the study of fast combustion processes.

To achieve an even higher temporal and spectral resolution, DLR has developed the Advanced Disk Laser system (**Fig. 1**). This diode pumped solid state laser system is accommodated inside the falling capsule. It enables non-intrusive laser diagnostics of combustion processes, especially by planar Laser Induced Fluorescence. A high pulse energy of 20 mJ at 1 kHz repetition rate and 1030 nm fundamental mode wavelength is achievable. ADL is a tuneable system. By using the second harmonic mode (510 to 530 nm), the spectroscopy of C_2 and NO_2 species is possible. By frequency conversation into the UV spectral region (343 and 256 nm) a variety of other combustion relevant species (OH, HCHO, HCO, NO) becomes detectable. DLR intends to bring this unique facility into full operation by the end of 2007.

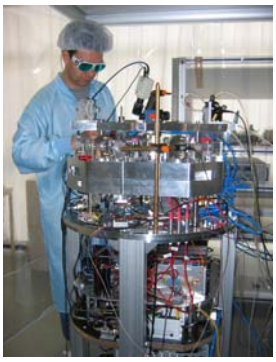


Fig. 1 ADL set-up in the drop capsule

QUANTUS facility

The realisation of a BEC and its interferometric diagnostics requires a compact, robust and mobile set-up at the DROP TOWER BREMEN. The facility uses a so-called atom chip providing a magnetic micro-trap for ^{87}Rb atoms with strong magnetic confining potentials and moderate electrical currents. The equipment needs ultra-high vacuum conditions and a magnetic shielding from the environment (**Fig. 2**). The laser light for the

manipulation of the atoms (laser cooling, optical pumping, detection) is created by a robust and ultra-compact diode laser system. The first microgravity experiments of the fully assembled facility are planned by the end of 2007.

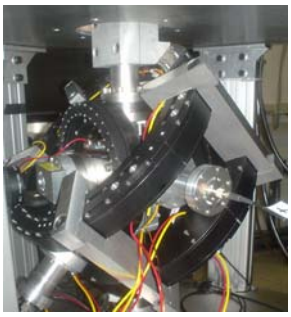


Fig. 2 QUANTUS set-up in the drop capsule

PK-3 PLUS and PK-4 facilities

The term PK stands for Plasma Crystal and PLUS indicates significant improvements with respect to the first facility PK-3, which was operational on board the ISS during 2001-2005. DLR funded the development of both facilities for long-duration complex plasma research.

PK-3 PLUS was accommodated on board the Russian Service Module in January 2006. It is operated in collaboration of German and Russian research institutes. The facility consists of a hermetically seald experiment unit, which accommodates the radio frequency plasma chamber, particle detection, and plasma diagnostics equipment. Complex plasmas with six different particle sizes and their mixtures can be investigated. An electronic control unit equipped with video tape recorders allows remote and manual operations by the crew. The facility is designed to operate on the ISS at least until 2009.

The next facility generation PK-4, relying on DC generated plasmas, will be developed by ESA until 2010. So far, DLR has funded the related basic technology development and its testing on parabolic airplane flights. As a further step, DLR will start a feasibility study of sophisticated plasma chambers in the context of a dedicated PLASMALAB on the ISS. This project is discussed to be realised in the timeframe 2012/13.

Fig. 3 PK-3 PLUS on the ISS operated by the German ESA astronaut T. Reiter (courtesy ESA)

GEOFLOW facility

This facility allows the study of thermal convection in a fluid gap between two concentric spheres under a central symmetric force field. The force field, similar to the gravity field acting on planets, is produced by applying a high voltage between the inner and outer sphere using the effect of the dielectrophoretic force field in the fluid. This principle has been successfully demonstrated on earlier microgravity missions on drop capsules and a sounding rocket.

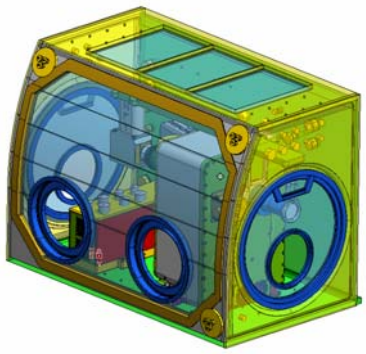
GEOFLOW represents an insert of the Fluid Science Lab of ESA. The launch of the flight model is planned with COLUMBUS at the end of 2007. DLR has funded the development of technological models for ground testing since 2001.

Fig. 4 Spherical convection cell set-up

CCF facility

To achieve enough flexibility in capillary flow investigations, CCF was designed as a modular system compatible with the requirements of the Microgravity Science Glovebox on the ISS (**Fig. 5**).

Fig. 5 CCF accommodated in the MSG (courtesy Astrium)



CFF consists of a fluid management system, a board computer, and two exchangeable test units. The latter contain the capillary channels of different geometry, namely parallel plates, groove and wedge. Mechanical oscillations of the flow and injected gas bubbles can be applied. The fluid behaviour in the channels is recorded by two video cameras.

CCF will be launched with the Space Shuttle by the end of 2009 and cooperatively operated on the ISS by German and US research institutes.

EML facility

The Electromagnetic Levitator will be installed in the European Drawer Rack of ESA on COLUMBUS. EML relies on a fully modular concept and offers containerless processing by positioning and heating of the samples due to alternating electrical fields. Samples of 5-8 mm diameter can be processed in an ultra-high vacuum or high-purity gas atmospheres at 500 °C to 2200 °C. In contrast to levitation on Earth, the levitated melt drop is perfectly spherical and the necessary positioning forces are very weak under microgravity allowing more precise investigations.

Solidification velocities can be determined by an ultra high-speed video camera at different levels of undercooling of the melt due to nucleation triggering. Thermophysical properties can be measured in a wide temperature range and concern surface tension, viscosity, heat capacity, melting enthalpy, electrical conductivity, thermal expansion as well as volume change with melting. Apart from pure metals, technical alloys and doped semiconductors can be processed.

EML capitalizes on the experience acquired on three Spacelab flights (1994, two times in 1997) with the TEMPUS facility developed by DLR. EML is a joint undertaking: ESA funds the Experiment Carrier and DLR the Experiment Module.

The delivery of the flight model is planned by 2010 enabling a launch with the European cargo ship Automated Transfer Vehicle to the ISS by 2011. EML will enable experiment series by exchanging the process chamber regularly.

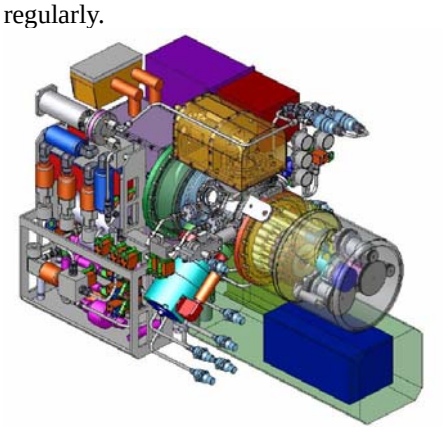


Fig. 6 Experiment Unit of the EML (courtesy Astrium)

11. DLR provided flight opportunities

Short-duration microgravity platforms have proven to be extremely useful not only for preparing longer duration experiments, but also for conducting self-standing research programs. They represent a low cost and uncomplicated access to microgravity conditions on a regular basis. DLR provides the following research platforms:

DROP TOWER BREMEN

This drop tower went into operation in 1990. It provides 4.7 s of microgravity (quality better than 10^{-5} g). Up to now, more than 4000 drops with research equipment have been carried out.

The autonomous experiment package is dropped inside an evacuated tube of 110 m height. The drop capsule itself is pressurized and allows automatic experiment runs. Data and video images are recorded on board the capsule. The deceleration of the capsule occurs in a tank filled with polystyrene pellets and does not exceed a peak of 50 g for a few ms. Since mid 2007, an unique catapult system inside the drop tower can be used. Thus, the available microgravity period is extended to 9 s.

AIRBUS Parabolic Flights

An Airbus that is controlled during a parabolic flight trajectory, experiences microgravity levels of 10^{-1} to 10^{-2} g for about 22 s. These conditions appear many times during the flight (31 parabolas per flight, 3-4 flight days per campaign). Special advantages of this fight opportunity are to use common laboratory hardware for hands-on experimentation, to modify the experiment set-up during a campaign, the direct involvement of the investigator on board the airplane as well as short turn-around times.

Since 1999, DLR has performed own campaigns with an Airbus A-300 procured from the company Novespace. The flights took place from Bordeaux or Cologne. In November this year, the 11th DLR campaign will be implemented.

TEXUS

TEXUS rockets on a ballistic trajectory enable 6 min of microgravity (quality better than 10^{-4} g) with a scientific payload of 250 kg. Since the first flight in 1977, in total 43 successful TEXUS campaigns have been performed by DLR and ESA.

TEXUS provides real time control of the experiment via bi-directional data transmission. The scientific payload consists of 4 to 6 experiment modules, each with its own power supply and data handling system.

Campaigns consisting of one or more launches are usually scheduled for spring or autumn and take place at ESRANGE near Kiruna in northern Sweden. DLR provides this flight opportunity every 1-2 years.

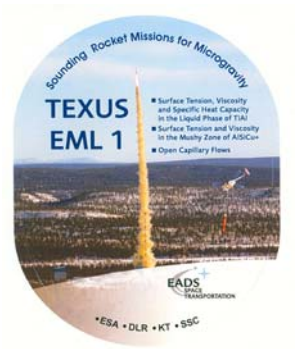


Fig. 7 Logo of TEXUS 42 launched in 2005 and equipped with the EML research module

12. International collaboration and outlook

International collaboration is an important aspect of the German microgravity programme. DLR offers its own facilities and microgravity platforms as a bartering tool to other partners. In exchange of this, DLR may have access to other facilities and flight opportunities in a quid pro quo arrangement.

For the cooperative facility development EML, an agreement between ESA and DLR has been concluded. Each partner will be responsible for and finance its own part. In the case of the development and operation of the CCF facility, a Memorandum of Understanding was signed between NASA and DLR in early 2007. In order to develop PK-3 PLUS and to perform related plasma research in the Russian ISS segment, an agreement was directly concluded between the associated research institutes in Russia and Germany.

During the next years the collaborative effort will be strengthened. The main goal of the German Physical Sciences Programme will basically remain unchanged, i.e. to gain scientific knowledge by fundamental and application-oriented microgravity research. DLR will further on provide its own microgravity flight opportunities and research facilities. New research equipment will be mainly developed in the field of fundamental physics. A key issue of the DLR activities in the upcoming years will be the effective utilisation of the ISS in collaboration with other partners.