THE STUTTGART MOON ORBITER LUNAR MISSION BW1

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OVERVIEW

The "Stuttgart Small Satellite Program" was initiated in 2002 at the Institute of Space Systems (IRS) of the Universitaet Stuttgart, Germany incorporating students (diploma/masters and Ph.D.) and academic/industrial partners. Being the fourth mission of this program the Lunar Mission BW1 is a 1 m cube small satellite of approx. 200 kg planned to be launched end of the decade as a piggyback payload from a geostationary transfer orbit (GTO). The challenging lunar exploration project will focus on technology demonstration and experiments beyond low Earth orbit.

Lunar Mission BW1 will be a test bed for innovative technologies and will perform technology demonstration and experiments in cis-lunar space and at the Moon. Various tasks for cis-lunar and lunar experiments were identified for the cruise phase of up to 24 months and the operations phase of min. 6 months. The small satellite will demonstrate the ability of an academic institution to participate and contribute to space exploration by designing, building and operating a complete space probe.

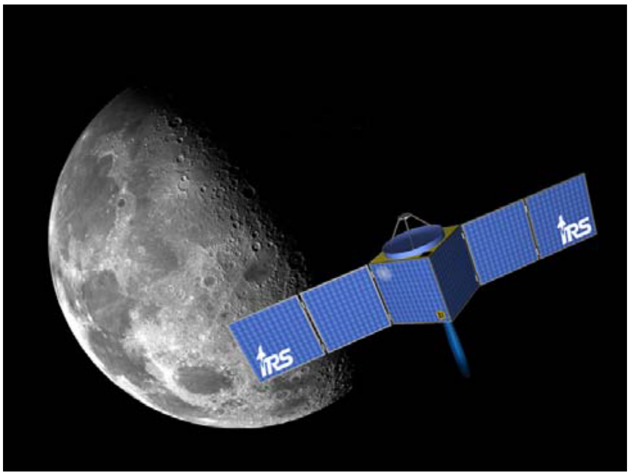

FIG 1. LUNAR MISSION BW1 orbiting the Moon

Examples of technology demonstrations are: the main electric propulsion systems, new carbon-fibre-sandwich-structure (developed at the Institute of Aircraft Design, Stuttgart), advanced on-board-computers, high bandwidth radio frequency/microwave communication systems, sensor systems concepts. The ammonia-driven thermal arcjet of approx. 1 kW input power will provide min. 100 mN thrust during the ascent above the Van-Allen belt and is currently under long-run test. A cluster of min. four pulsed instationary magneto-plasma-dynamical thrusters offering 1.5 mN each and using solid PTFE (Polytetraflourethylene a.k.a. Teflon) will be the main propulsion system during the cruise phase.

1. INTRODUCTION – RETURN TO THE MOON

For a few years now there is an increasing new and world wide interest in our closest neighbour in space: the Moon. Especially since the announcements of different nations (e.g. Japan, India and China) of sending probes for scientific exploration as well as the announcements of the US-president in January 2004 of a human return to the Moon before 2020 – starting with and robotic exploration program before end of 2008 – many more countries and agencies started own studies and implemented own plans.

In September 2006 ESA's technology demonstration mission SMART-1 (Small Missions for Advanced Research in Technology) was completed with a controlled impact of the spacecraft on the lunar surface in the Lake of Excellence region nearly three years after launch. In addition to the main objective of testing and validating of new system and instrument technologies SMART-1 spend 22 months (including mission extension) into lunar orbit and performed scientific remote sensing experiments of the surface of the Moon.

In the upcoming 18 months a "fleet" of Moon orbiting missions from different countries will fly to our natural satellite. The Japanese SELENE is planned to be launched in Summer 2007 while the Chinese CHANG'E-1 should follow later this year. In the first half of 2008 India's probe CHANDRAYAAN-1 with scientific instrument contributions from Europe and the USA is scheduled for its flight. Finally at the end of 2008 the US-American LUNAR RECONNAISSANCE ORBITER and the secondary payload spacecraft LCROSS (Lunar Crater Observation and Sensing Satellite) will be launched.

Since the very beginning universities and research institutes participated in lunar and planetary exploration analyzing data, providing instruments or performing further research. But usually such institutions did not design, build

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and operate their own lunar or planetary spacecrafts.

For more than 25 years small satellites are well known and well proven tools for academic research and development in space. In 1981 the first academic small satellite was launched by the University of Surrey, United Kingdom. UoSat-1 demonstrated successfully the possibilities of academic space science and technology despite of concerns of national agencies and industrial companies. The concerns referred (and sometimes are still referring) to the possibilities of a university to perform serious science in space by their own. Today it is without doubt that academic small Earth orbiting satellites can be important educational instruments, useful technology demonstration tools and promising and serious scientific research platforms.

2. STUTTGART SMALL SATELLITE PROGRAM

In 2002 the "Stuttgart Small Satellite Program" was initiated at the Institute of Space Systems (IRS), Universitaet Stuttgart, Germany incorporating students (diploma/masters and Ph.D) and academic, research as well as industrial partners. It is based on the institute's expertise and knowledge in the fields of electric propulsion, aerothermaldynamics, entry technologies and mission analysis and the experience of two of the authors (H.-P. Roeser, M. von Schoenermark) gained from the successful micro-satellite projects DLR-TUBSAT (launched in 1999) and BIRD (launched in 2001).

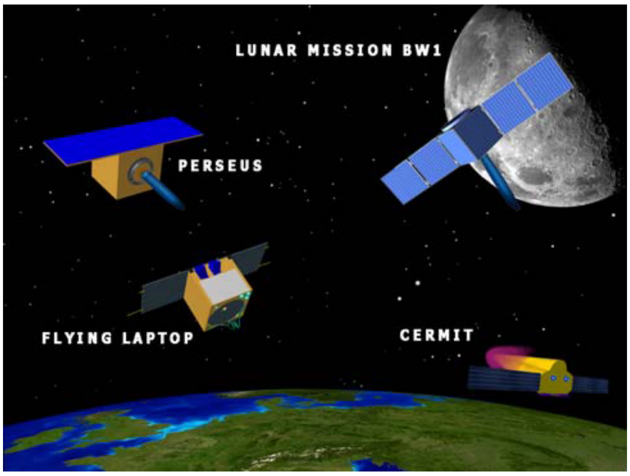

FIG 2. Missions of the Stuttgart Small Satellite Program

Currently the program consists of four small satellite missions (see figure 2) and ground segment facilities (see table 1).

Laboratory Model ILSE (	2003
Ground Station (UHF, VHF & L-band in operation) and Mission Control Center S-band in operation Ka-band in operation	 2007 2008
MDVE (Model-based Development and Verification Environment, provided by EADS Astrium, Friedirichshafen) adaptation for small satellites in operation	2007
OLIMPIA (Outline of Lunar exploration InstruMents and Payloads for Initial Analysis) database	since 2005
GOLEM (General parametric Outline for Lunar Exploration Missions) database	since 2006
Satellite Integration Laboratory	2007
UAV carrying remote sensing instruments	2007
Rent-a-Sat FLYING LAPTOP Earth observation & technology demonstration	2008/09
Propulsion Test-bed PERSEUS Electric propulsion & UV astronomy	2009/10
Return Mission CERMIT Atmospheric entry & autonomous GNC	2010+
Moon Orbiter LUNAR MISSION BW1 Technology demonstration & remote sensing	2010+

TAB 1. Elements of the Suttgart Small Satellite Program

Software models and simulation environments (e.g. MDVE, see table 1) were established in addition to the ground segment facilities to enable and support the small satellite projects as well as education and low-cost design philosophy.

2.1. Projects

FLYING LAPTOP is the first project of the Stuttgart Small Satellite Program. The micro satellite of approx. 120 kg launch mass is designed and will be built and operated in cooperation with the Steinbeis Transfer Center for Space (Steinbeis-Transferzentrum Raumfahrt). The FLYING LAPTOP is planned to be launched by ISRO as a piggyback payload on top of the Indian PSLV (Polar Satellite Launch Vehicle). The mission will provide first and important opportunities to test many subsystems and technologies for later use on-board and during LUNAR MISSION BW1. Beside of technology demonstrations (e.g. FPGA on-board computer, Ka-band high-speed communication, rent-a-satellite mode) the satellite should perform Earth observation remote sensing experiments (e.g. BRDF measurements using target pointing observation, precipitation measurement demonstration, Ka-band atmospheric attenuation).

PERSEUS will base on and use the FLYING LAPTOP satellite bus. Two solar-electric propulsion systems (thermal arcjet, instationary magneto-plasma-dynamical thrusters) will be tested and qualified in space to be used during the LUNAR MISSION BW1. The propulsion test phase of only a few months will be followed by a research phase operating an astronomical payload. An UV-spectrometer in cooperation with the Institute for Astronomy and Astrophysics (IAAT) of the Eberhard-Karls-Universität Tübingen is currently under consideration.

The return mission CERMIT (Controlled Earth Reentry Mission to Improve Technology) is the third small satellite project based on the institute's experience in the field of return technologies. IRS participated in different unmanned atmospheric entry experiments in the past. The test vehicle of approx. 200 kg launch mass will provide valuable own flight experience in the fields of mission and systems analysis, aerothermaldynamics, plasma research and development of diagnostics and sensor systems.

Mission	Experience/Heritage
FLYING LAPTOP	Integration, ground segment facilities, mission operations, FPGA on-board computer, S-/Ka-band communication, VIS/NIR and TIR camera, radio science, GaAs-solar cells, Li-ion battery
PERSEUS	Mission operations, solar-electric propulsion systems (thermal arcjet, instationary magneto-plasma-dynamical thrusters), attitude and orbit control
CERMIT	Real-time mission operations, Complex attitude and orbit control, autonomous guidance, navigation and control

TAB 2. Experience and heritage gained during prior missions for LUNAR MISSION BW1

The operational experience and the subsystems' heritage (see table 2) of the prior missions will enable the next logical step in small satellite development: accepting the challenge of a lunar mission.

3. LUNAR MISSION BW1

The all-electrical small lunar orbiter is a spacecraft of around 200 kg launch mass (see figure 3). The satellite of approx. 1 m cube is planned to be launched as a piggyback payload into a Geosynchronous Transfer Orbit (GTO) not earlier than 2010. Using the solar-electric propulsion systems the probe will be transferred to the Moon into a highly inclined circular low lunar orbit of around 100 km altitude to perform remote sensing and technology demonstration experiments.

During the cruise phase of up to 24 months and the operations in lunar orbit of at least 6 months solar panels of approx. 6 m^2 generates the necessary electrical power of up to 1 kW supported by Li-Ion batteries for power storage. The satellite will be 3-axis stabilized using an adapted AOCS tested during the FLYING LAPTOP and PERSEUS missions. A Ka-band communication system and a 1 m primary dish provides broadband data transfer. An additional S-band system acts as a backup system for telemetry and telecommand. The FPGA computer architecture for command and data handling offers enhanced on-board data processing capabilities. The system will also be tested and qualified during the FLYING LAPTOP mission.

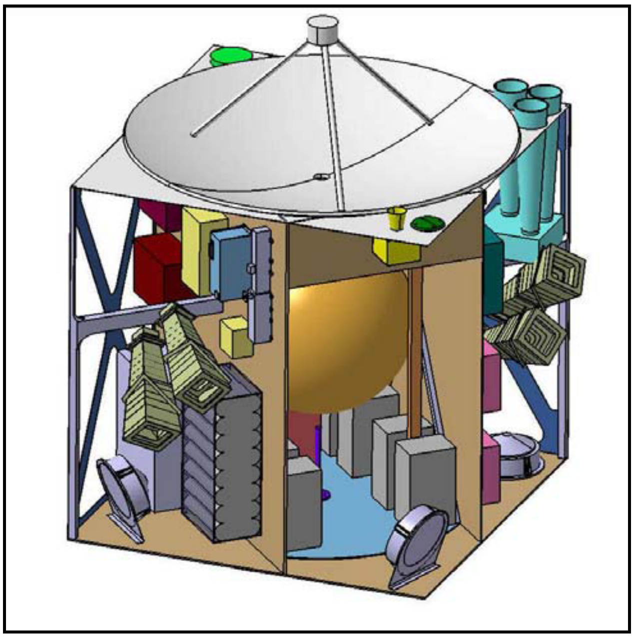

FIG 3. Design study of LUNAR MISSION BW1

Because of different requirements during the mission profile two electric propulsions systems are planned for LUNAR MISSION BW1: TALOS (Thermal Arcjet for Lunar Orbiting Satellite) and SIMPL-LEX (Stuttgart Instationary Magneto-Plasma-dynamical thrusters for Lunar Exploration).

Phase	Description
I – Launch Phase	Separation from launcher, initial operations, systems check-out
II – Ascent Phase	Raise Earth orbit above van-Allen-belt
III – Cruise Phase	Orbit extension up to lunar gravitational influence
IV – Capture Phase	Insertion into high-elliptical lunar orbit
V – Descent Phase	Transfer into highly inclined, circular, low lunar orbit
VI – Science Phase	Remote sensing of the lunar surface
VII – Impact Phase	Controlled impact onto the lunar surface

TAB 3. Phases of the LUNAR MISSION BW1

The ammonia-based thermal arcjet (see figure 4) will provide at least 100 mN thrust at 800 W power using 25 mg/s propellant to offer an specific impulse of approx. 450 s. TALOS will be used mainly during the phases II, IV and finally VII (see table 3) to act as the high-thrust propulsion system for LUNAR MISSION BW1.

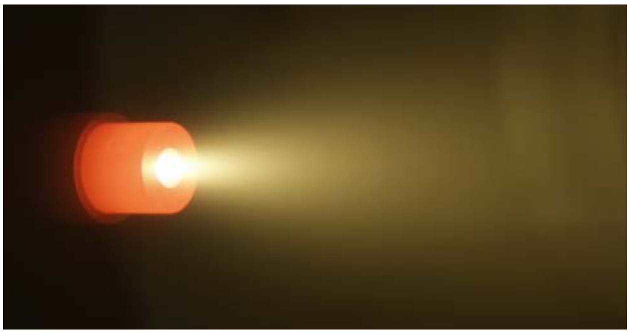

FIG 4. TALOS in operation in a vacuum test chamber

A cluster of SIMP-LEX thrusters will be used especially in the mission phases III and V (see table 3). Each offers up to 1.5 mN throttable thrust with a power demand of less than 200 W per system using solid PTFE (Polytetraflourethylene a.k.a. Teflon). Currently the engineering model (EM) undergoes optimization in preparation for long-duration life-time tests (see figure 5).

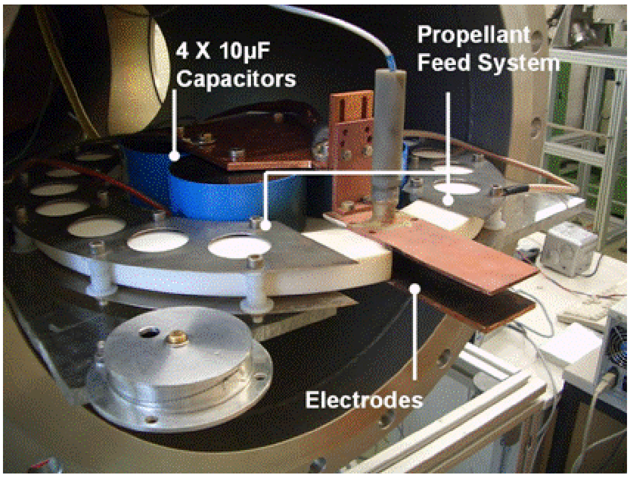

FIG 5. SIMP-LEX EM during propulsion feed system test

3.1. Academic Environment and Partners

The Stuttgart Small Satellite Program and its missions are examples of successful academic-industrial cooperation due to the links within a network of regional and national companies and institutions, e.g. EADS Astrium. EADS Astrium in Friedrichshafen, Lampoldshausen and Ottobrunn participate in many ways: providing software and professional expertise, organizing lectures and workshops, supporting Ph.D. students including coaching, recruitment of graduate students.

Especially the rent-a-sat mode of the FLYING LAPTOP is another example of cooperation with industrial partners to provide access to the satellite for validation and qualification in space.

3.2. Technical and Research Topics

Because of limited on-board and ground segment resources a small lunar satellite is able to perform experiments if operational aspects like e.g. maintenance, communication and battery charging are taken into account. Different technological and research topics were identified at IRS and in cooperation with other academic and research institutes (e.g. MPI Heidelberg , DLR Berlin, IfP Muenster). Due to the limitations not all experiments and demonstrations can and will be performed during one single mission.

Potential technology demonstration topics beyond low earth orbit for LUNAR MISSION BW1 are: solar-electric propulsion systems for complex attitude control and orbit transfer manoeuvres using autonomous guidance and navigation; visible/near-infrared and thermal infrared imaging combined with target pointing observation; radio frequency and microwave technology for broadband communication, relay functions and radar sounding; advanced computer architectures for enhanced on-board processing capabilities, advanced sandwich structures, advanced miniaturized dust detectors, GPS usability beyond GEO, evaluation of degradation effects on satellite subsystems, controlled impact onto the lunar surface.

Possible targets of LUNAR MISSION BW1 in cislunar space for research of Earth and the Earth-Moon-System are: gravitational and magnetic field as well as radiation measurements; Earth influences and Earth-Moon interactions, observation of near earth objects, the Kordylewski clouds at the Earth-Moon libration points L4 and L5, detection of dust and debris.

Possible research targets in lunar space of LUNAR MISSION BW1 are: high resolution multi-spectral data of selected areas of the lunar surface (e.g. for mineralogical observation), search for polar water and future landing site selection as well as remnant localisation of past missions; polarization and reflectance measurement and illumination observation of the lunar surface; surface roughness measurements, gravitational and magnetic field as well as radiation measurements, dust detection, monitoring of transient lunar phenomena (TLPs) coordinated with ground-based observers, detection of lunar impact flashes.

To decide about the research topics and to finalize the payload of LUNAR MISSION BW1 an announcement of opportunity is planned for 2008. Currently an example payload is studied at IRS which consists of the following experiments:

– Visual/Near IR camera system with around 10 m GSD
– Thermal IR camera with better than 20 m GSD
– Visual panoramic camera with up to 30 km swath width and better than 50 m GSD
– Miniaturized dust/debris detector
– Lunar impact flash detection camera
– Ka-band radio science experiment

4. CONCLUSION – NO VIRTUAL EXPLORATION

Virtual exploration is not possible – hence it is not a feasible or useful option as an alternative for building and operating an own exploration mission to provide real experience to students and young professionals and real research data as well as space qualified small satellite technology.

Within the Stuttgart Small Satellite Program the LUNAR MISSION BW1 is used for the benefit of students as an educational tool to provide hands-on-experience in design, integration and operation of a spacecraft as well as an experiment and technology platform for a network of industrial and research partners – demonstrating a radical approach by limited financial resources, volume and mass.

The mission will demonstrate that small probes based on academic small satellites for earth observation and remote sensing are useful low-cost tools to accomplish valuable education as well as exploration and research missions in spite of its limitation. Small probes can meet the demands of future lunar exploration and development like required infrastructure, technology verification and validation and flight opportunities for specific research missions.

Due to the planned schedule for the LUNAR MISSION BW1 and its educational, technological and research objectives the German space agency DLR and IRS agreed upon intense communication in preparation of DLR's own plans for a national lunar orbiter mission.

Finally LUNAR MISSION BW1 will prove that a university, a faculty or even an institute is able to make a significant contribution by its own to space exploration – able to create new scientific knowledge or new innovative technology visible within the community and in the public as well as having an enduring effect in the space arena.

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