TECHNOLOGY DEMONSTRATION WITH THE MICRO-SATELLITE FLYING LAPTOP

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ABSTRACT
The Flying Laptop is a micro-satellite currently under development by the Institute of Space Systems. Several promising technologies will be implemented. A high performance attitude control system with a pointing accuracy of 11 arcseconds, operating in a target pointing mode for image acquisition is necessary to achieve the planned scientific measurements. For communication a high speed Ka-band link using a traveling wave tube will be utilized. The on-board computer consists of a reconfigurable, redundant and self-controlling field programmable gate array with high computational power. In addition to the new technologies for the satellite bus a capable functional verification environment is under development applicable to the Flying Laptop.

1. INTRODUCTION
The Flying Laptop will be the first micro-satellite of the University of Stuttgart, Small Satellite Program. The primary mission objective is to demonstrate and qualify new small-satellite technologies for the future projects. As a secondary objective, multiple scientific earth observation experiments are planned. The satellite body has a cubical shape with an edge length of 60 cm and a mass of less than 100 kg. Figure 1 shows the general design of the satellite including its components. The launch as a piggyback payload is planned for the end of 2006. A polar, sun-synchronous, low earth orbit below 1000 km is being pursued. As scientific payload the satellite is equipped with a 3-camera system (VIS/NIR), a thermal infrared (TIR) camera and a Ka-band communication system. The last two are intended to make dual use of a cassegrain mirror system.

![Figure 1: Design of the Flying Laptop](image-url)
2. SATELLITE BUS

The mechanical structure of the *Flying Laptop* is divided into the service module, the core module and the payload module as shown in Figure 2. The launch adapter is attached to the back plane of the service module. All modules are made of aluminium due to its high heat conduction properties. In order to ensure the alignment of the cameras (VIS/NIR) to each other and to the star cameras, all components are attached to an optical bench made of carbon-fiber-reinforced plastic (CFRP) for thermal stability. The focus distance of the TIR camera and the Ka-band antenna is also influenced by thermal extension. Hence, the primary mirror and the retaining structure of the secondary mirror will also be produced from the temperature stable CFRP. For the TIR the primary mirror demands a medium surface roughness of approx. 0.8 µm.

The thermal system of the *Flying Laptop* is intended to be passive by using the dissipated heat of the internal components. The surface is most entirely covered by multi layer insulation (MLI) and the heat is released by a radiator on the back plane of the service module.

2.1 Attitude Control System

The *Flying Laptop* is a 3-axis stabilized micro-satellite. The attitude control system (ACS) needs to provide high accuracy pointing (11 arc-seconds or 0.00306°) and maneuvering capabilities in accordance with the selected earth observation instruments.

This is a big challenge for a micro-satellite and can only be achieved by a thorough control concept and high performance sensors/actuators.

Figure 1 shows the actuators and sensors of the ACS. The actuators consist of reaction wheels and magnetic torquers. Four Teldix RSI 01-5/28 reaction wheels are aligned in a tetrahedron configuration and each has an angular momentum capacity of 0.12 Nms. 

Three magnetic torquers (torque rods) dump the momentum accumulated by the reaction wheels. The moment of inertia in the x, y and z axis of the satellite is estimated to be around 4 kgm².

The attitude motion is monitored by five different types of sensors: a 3-axis magnetometer, six Coarse Earth Sun Sensors (CESS), rate sensors, autonomous star sensor and GPS receivers. The ZARM AMR-magnetometer uses a magneto-resistive sensor and has a digital interface. The EADS Astrium CESS measures the sun vector within an accuracy of 6° rms and the earth vector with an accuracy of 11° rms. For the measurement of the angular velocity, four fiber optical rate sensors will be used. A star tracker, the micro Advanced Stellar Compass (µASC), from the Technical University of Denmark will provide a pointing knowledge of better than 2 arcseconds. After the satellite is stabilized and rotates with a slew rate of less than 1.2 °/s the star tracker delivers regular attitude updates. To provide full accuracy about all axes and to decrease the probability of blinding during maneuvers, a second camera head unit is mounted on the satellite with its optical axis tilted away from the first one. To support accurate
target-pointing of the spacecraft during imaging and ground station contacts, the satellite will be equipped with a GPS navigation system. Three Phoenix GPS receivers are provided by DLR/GSoc and are locked to an ultra stable 10 MHz crystal oscillator for an orbit and attitude determination experiment.

For image acquisition three different attitude control modes are defined and shown in Figure 3: inertial-pointing mode, nadir-pointing mode and target-pointing mode. In the target-pointing, also known as spotlight mode, the satellite points to a fixed spot on the surface of the earth during a flyover. This allows longer integration times for the cameras which is a significant advantage for the scientific measurements. The slew rate for this maneuver is 1 °/s (max.) and follows a non-linear bell-shaped curve over time. This is the most demanding mode of the satellite in terms of control algorithms.

2.2 FPGA On-Board Computer System

The Flying Laptop will probably be the first micro-satellite using a fully processor-less primary on-board computer (OBC) that consists of field programmable gate arrays (FPGAs). The OBC is based on a Xilinx Vertex-II Pro with approx. 3 million system gates and a clock frequency of 200 MHz. The OBC will further consist of 4 MB of synchronous static RAM for high speed data processing, 2x 128MB DDR RAM and 1 GB Flash. Via a modem, a user programmable EEPROM can be reconfigured from the ground station. In case of failure, the original FPGA configuration is restored from a PROM.

With a software-to-hardware compiler it is possible to directly generate the logical configuration of FPGA gates from a C-like high level language without producing the machine code for a processor. Through this approach massive parallel processing is possible. To make the system fault-tolerant and to address radiation issues, four equal independent nodes will work together. Depending on the state of the system 1-4 nodes will run at the same time and are dynamically switched on or off. A complete start-up of a single node takes only 10 ms. The high flexibility of the on-board computer system will be used to operate the Flying Laptop in a so-called Rent-A-Sat mode. It is possible to configure the system for customer preferences (i.e. the characteristics of a certain processor can be simulated through the hardware). With this versatility the system is well-suited for OBC software or component firmware validation in space.

The OBC system is currently under development by the Steinbeis Transferzentrum Raumfahrt in cooperation with the Fraunhofer Institute for Computer Architecture and Software Technology.

2.3 Communication System

For telemetry and telecommand UHF (low gain) and S-band (low and high gain) antennas will be installed on the satellite. Beside S-band communication, UHF offers the possibility to utilize amateur radio equipment. As payload the Flying Laptop will be equipped with a Ka-band traveling wave tube (TWT) amplifier. During a ground station
fly-over, the TWT will operate with an RF transmission power of 57 W (170.5 W DC input) which is unique for a micro-satellite. With this subsystem a data rate of 100 Mbit/s will be available. The satellite's cassegrain system with its 50 cm primary dish provides the antenna reflector for the Ka-band communication and is also used as the optical system for the thermal infrared camera. The TWT is the design driver for the battery system to handle its high power requirement.

3. FUNCTIONAL VERIFICATION APPROACH FOR THE FLYING LAPTOP

Setting up a verification environment for reliable system-wide tests is new to micro-satellite projects, but it is one of the enabling technologies for proving the required attitude control system accuracy. In this context a software-based functional verification reduces the check-out environment complexity and huge costs can be saved. This model-based verification environment for small satellite applications is under development in close cooperation with EADS Astrium and will be set up in parallel to the *Flying Laptop* development. It is characterized by high real-time capabilities to represent the spacecraft hardware system-wide in its exact operational modes and response times. Software models of the spacecraft components will be created successively in adequate detail in order to provide the particular test bench functionality. Latest commercial improvements in hardware and software technology allow the real-time test benches to be set up using standard computers and a Linux operating system kernel which supports real-time performance.

A Software Verification Facility is in progress to support the on-board software development process. It is used to debug, validate and verify the on-board software and prove the overall system dataflow functionality. Consisting of a real-time simulator, an on-board computer simulator and a central control system, it supports real-time or accelerated software simulation of the whole spacecraft system by implementing all components by its hardware-specific software models into the simulation environment. In the next step a FlatSat test bench with real-time performance will be arranged as first hardware check-out environment including only the on-board computer as hardware in the loop. It will be set up well before spacecraft integration using a test harness to maintain single component up to system-wide check-out procedures. All component software models, especially those of the attitude control system, will be re-used in this environment to verify correct operation. The third test bench is created as an expansion of the FlatSat test bench and integrates additional spacecraft hardware in the simulation loop. Single component check-out tests will be followed by complete mission scenario simulations. Finally the protoflight test bench supports a functional verification test environment throughout the flight hardware qualification process.

4. CONCLUSION

A new on-board FPGA computer system, a broadband Ka-band communication system and a highly accurate attitude control system are the crucial technologies under development for the satellite bus. Furthermore a low-cost but reliable simulation and test environment is under implementation to support system-wide functional verification during the *Flying Laptop* qualification process.