THE AQUASONIC PROJECT AT HOCHSCHULE BREMEN

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Abstract

The AQUASONIC project is aimed to develop a sounding rocket including a hybrid propulsion system based on the propellant combination Nitrous Oxide and Polyethylene. It takes place in the frame of the STERN (Student Experimental Rockets) programme founded by the German Space Agency (DLR) in order to promote students in the area of launch vehicles. Main element of the project is the AQUASONIC rocket, which shall reach an altitude of 5-6 km and a velocity of MACH 1. All major activities like design, manufacturing, verification and finally the launch campaign, which shall take place at Esrange Space Centre in April 2016, are done by students. Thus, students are able to apply their skills and knowledge to a real project like it is conducted by the space industry or research organisations.

1. INTRODUCTION

Hochschule Bremen is one of eight Universities and Universities of Applied Sciences participating in the DLR STERN programme. The duration of the programme is planned to be 36 months, during which students shall pass through all project phases of an aerospace project starting with Phase 0 (feasibility studies) and ending with Phase E (operation). Basic requirements of DLR are a minimum altitude of 3 km, a minimum velocity of MACH 1 and the utilization of a telemetry payload, which transmits major flight parameters via a radio frequency link in real-time to a ground station. In addition the rocket shall be reusable. The development of the rocket as well as testing is conducted in cooperation with experts of DLR. All major project phases have to be closed with a successful review. [1]

2. PROJECT ORGANISATION

The AQUASONIC project is broken into three different segments: Programme segment, flight segment and ground segment. All project management tasks including mission definition and analysis, controlling, interface and risk management as well as system engineering are allocated to the programme segment. All elements located inside the AQUASONIC rocket, thus the subsystems and the payload are combined in the flight segment while all ground support equipment like the Telemetry/Telecommand station or the Mission Control Centre belong to the ground segment. Furthermore the three different segments are split up into several work packages with precisely defined tasks and required results.

In addition the AQUASONIC project is organised into five temporal phases like it is done in “real” space industry projects. The project started in autumn 2013 with some feasibility studies, in which two different double-staged concepts were investigated. Both concepts shared a hot-water rocket as lower stage and utilized a Nitrous Oxide/Polyethylene hybrid rocket engine or rather a Hydrogen Peroxide/Gasoline liquid rocket engine as upper stage. The two concepts were elaborated in parallel within the preliminary design phase (Project Phase B). After the Preliminary Design Review (PDR) it has been decided to continue with a hybrid engine powered single-stage design due to cost, complexity and safety reasons. This design including a pressure-fed 2500 N hybrid rocket engine was presented to the review board during Critical Design Review (CDR) in April 2015. Currently, the AQUASONIC project is in the Assembly, Integration and Verification (AIV) phase and is heading for the Integration Progress Review (IPR), which is scheduled for December 2015. The launch campaign, which corresponds to Project Phase E, shall take place in April 2016 at Esrange Space Centre.

The AQUASONIC team is composed of Bachelor and Master Degree students, who are supported by one Professor, one Research Assistant and two Technical Assistants. Furthermore the AQUASONIC project is integrated in the lectures “Space Transportation and Orbital Systems” and “Lightweight Design Project” of the bachelor study course “Luft- und Raumfahrttechnik B. Eng.” as well as in “Design and Modelling of Space Propulsion Systems” and “Interdisciplinary Project” of the master study course “Aerospace Technologies M.Sc.”. Lots of work packages have been finished within final thesis work of the students. Until now, 5 bachelor and 6 master theses have been done within the project.

3. MISSION ANALYSIS

For the calculation of the rocket’s trajectory including key parameters regarding flight performance and stability, a numerical simulation model based on MATLAB/Simulink has been developed. The mathematical model includes equations for 6 degrees of freedom and respects aerodynamic forces introduced by angle of attack and sideslip angle. In addition the two-staged recovery phase and a wind model are implemented.

The trajectory is calculated by integration of the accelerations acting on the rocket: the gravitational force, the thrust generated by the engine and the aerodynamic forces acting on the centre of pressure. The equations of motion are solved by the Simulink software, which provides lots of different numerical solvers. For the case of the AQUASONIC rocket a medium order method solver based on a variation of the Runge-Kutta-procedure is utilized. The accuracy of the simulation's results depends on the quality of the aerodynamic parameters of the rocket. They were determined by the semi-empirical Missile DATCOM code, a well-proven computer code for accurate aerodynamic predictions. By implementing the aerodynamic model, the stability margin of the rocket from lift-off until apogee can be predicted. At apogee the drogue parachute is ejected and the recovery phase begins. This phase is modelled by the specified rate of descent of the respective parachutes and the actual condition of the atmosphere.

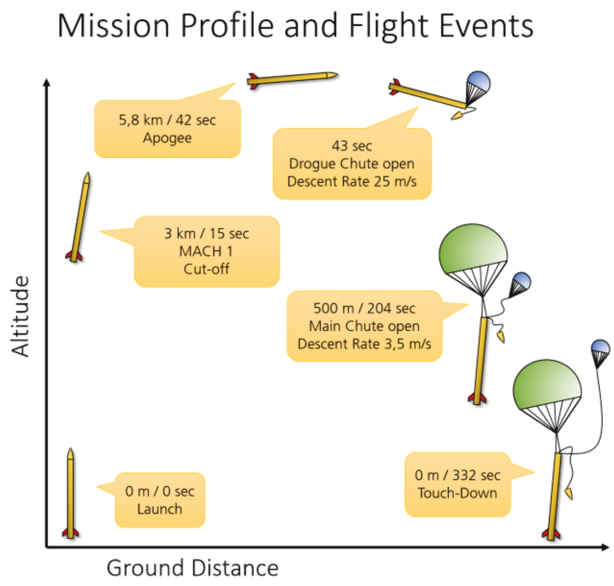

FIG 1. Mission Profile

The trajectory key parameters that were calculated with the mission analysis software are depicted in FIG 1. At t_0 the rocket lifts-off at a launch elevation angle of 80°. This is a safety requirement of the launch site. Full thrust of 2500 N is generated for 15 seconds by the hybrid engine. At cut-off the maximum velocity of MACH 1.05 at an altitude of about 3 km is reached. Hence the rocket climbs on its parabola-shaped trajectory till apogee, which is passed 42 seconds after lift-off at an altitude of 5.8 km. Apogee is detected by two independent on-board computers, which trigger the nosecone ejection. By this the drogue parachute gets into the air stream and inflates. The rate of descent is limited to approximately 25 m/s. At 500 m above ground the main parachute is released so that the rate of descent is reduced to 3.5 m/s to allow for a smooth landing. Assuming zero wind conditions the landing point will be 3.2 km away from the launch pad.

4. FLIGHT SEGMENT

The AQUASONIC flight segment is set up by the rocket subsystems (propulsion, structure, electrical power, on-board data handling, communication, thermal, recovery) and the payloads. Central subsystem is the propulsion subsystem because it accounts of 70% of the entire rocket's length and 65% of the total rocket's mass. The entire rocket has a length of 5037 mm, an outer diameter of 200 mm and a lift-off mass of 80 kg.

To make handling, transport and integration easy, the rocket is split into five so called "compartments" which are joined prior to launch. The mechanical interface is established via identical interface adapters while D-Sub connectors form the electrical interface. All pyrotechnical circuit wiring is completely independent from all other cables and utilizes Molex connectors with an increased cross section.

4.1. Propulsion Subsystem

The propulsion subsystem is established by two basic parts: the hybrid rocket engine and the propellant feeding and storage assembly. A hybrid propulsion system is a bipropellant system that uses propellants in different states of matter. The fuel is stored as a solid grain made of high-density Polyethylene inside the combustion chamber of the engine. It belongs to the thermosoftening plastics and is commonly used for packaging. Central advantages are simple handling and storage as well as low cost. Furthermore it can be machined easily on milling and drilling machines. The inner geometry of the fuel grain is a key parameter for the behaviour of the engine. In case of the AQUASONIC rocket, an almost constant thrust of 2500 N is desired. As the oxidizer mass flow remains constant during the entire burning time, a constant fuel mass flow is required to ensure a constant oxidizer-to-fuel ratio (O/F). The optimum O/F for the AQUASONIC hybrid rocket engine has been calculated to 6.9. A central problem in designing the optimum fuel grain geometry is that every time step of the combustion process has new characteristics. During burn time the combustion chamber volume and the effective chamber cross section increase due to the regression, but the regression rate of the fuel grain cannot be predicted with high accuracy. Thus the best way to find a geometry with an almost linear characteristic is to first simulate it with a numerical simulation and second to verify the simulation results by test.

Another challenge is to design a reliable ignition system. As the original concept of the AQUASONIC mission was to use the hybrid rocket engine as upper stage engine, an ignition system that is capable of an inflight-ignition was required. The ignition sequence is conducted in multiple steps. First a glow plug, which is usually used in small radio controlled cars, ignites a small charge of black powder. Second, the black powder ignites a piece of igniter cord, which is routed through the first fuel grain into a piece of solid sugar propellant called "rocket-candy". The candy is produced in-hose by dissolving potassium nitrate and dextrose in water. After boiling off the water, the creamy mass can be formed freely and is put into the fuel grain. During all test campaigns conducted so far, the ignitions system worked nominal. The ignition delay, meaning the timespan between ignition command and opening of the main oxidizer valve, is 200 ms.

In FIG 2 a drawing of the engine front section is shown. The upper part is formed by the injection head, which acts as the mechanical interface between the engine and the rocket structure. In houses the injection head plate made of stainless steel and consisting of 40 drill holes with a conical inlet and a diameter of 0.8 mm each. This design enables an oxidizer mass flow of 1.14 kg/s if a temperature of 15°C and an oxidizer density of 850 kg/m³ is assumed. To protect the injection head plate from the hot combustion gases a layer of phenolic resin/cotton fabric is placed in front of it. Phenolic resin with cotton cloth reinforcement is an ablative material with a very low thermal conductivity of 0.3 W/mK and a sufficient mechanical stability. This type of material is also used to protect the engine housing made of aluminium and in the engine aft section to fixate the nozzle. The fuel grain is split into several segments so that it can be manufactured in-house on drilling and milling machines. The first fuel grain, which is shown in FIG 2, has a conical inlet to prevent a turbulent flow in the injection area. In total the engine houses ten fuel grain segments, which are intercepted by two swirl rings. These circular shaped parts are used to generate a turbulent flow inside the combustion chamber and by this to increase the combustion efficiency. In the engine aft section a bell-shaped nozzle made of graphite with a throat diameter of 33 mm is located. The total engine structural mass (without fuel grain) is estimated with 7.4 kg.

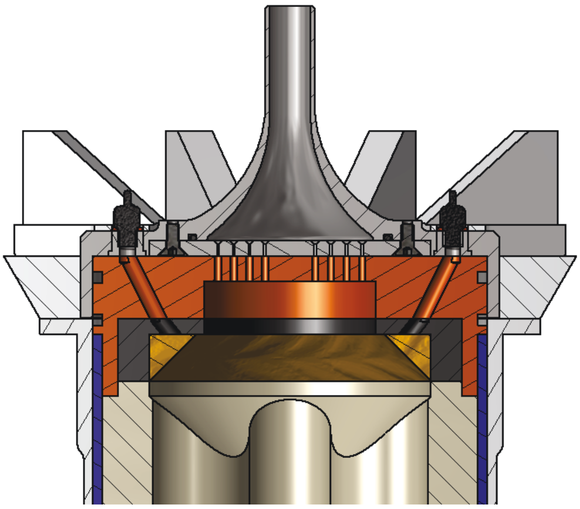

FIG 2. Engine Front Section

The valve located between the engine injection head and the oxidizer tank is an in-house developed pyrotechnical valve (see FIG 3). Like the ignition system of the hybrid engine, an electrically driven glow plug ignites a small amount of black powder.

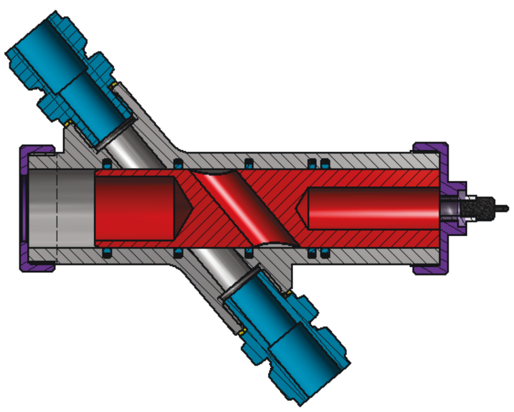

FIG 3. Pyro Valve (closed position)

Due to the expansion of the gases, a piston is moved so that the Nitrous Oxide can pass the valve in a straight line. The pressure loss has been calculated by a computational fluid dynamics simulation to 0.5 bar. Valve housing as well as the piston are made of aluminium alloy EN AW 7075 while the sealings against the flow path are made of silicon to ensure compatibility with Nitrous Oxide. A finite element method (FEM) calculation has shown that structural stability is given until a pressure of 150 bar, which is three times the operational pressure.

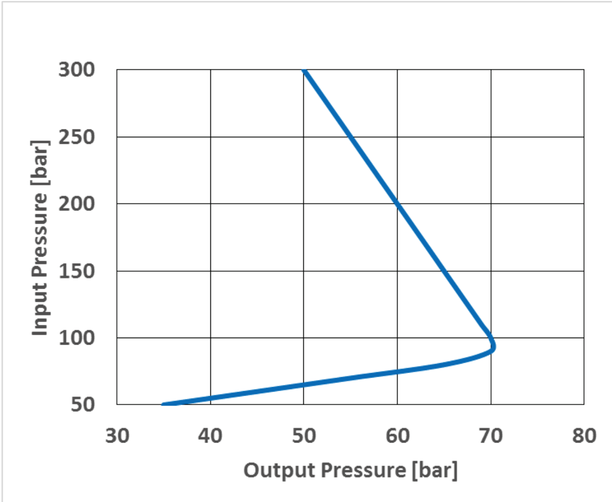

FIG 4. Pressure Regulator Characteristics

To achieve an almost constant flow of liquid Nitrous Oxide to the engine, a pressure-fed system is utilized. Helium pressurized to 300 bar is stored in a 4.7 l commercial-off-the-shelf vessel made of carbon fibre reinforced plastics including a thin metal inlay that is usually used as breathing apparatus for firefighters. A small pressure regulator with a mass of 0.47 kg reduces the pressure to about 50 bar and acts as interface between high pressure tank and oxidizer tank. The characteristics regarding in- and output pressure of the regulator are indicated in FIG 4. An interesting fact is that the output pressure increases by 10 bar if the input pressure decreases by 100 bar. This behaviour changes when the input pressure is 20 bar above the output pressure. Thence the output pressure decreases almost proportional to the input pressure.

The oxidizer tank, which stores 16 kg of liquid Nitrous Oxide, is made of aluminium and has a volume of 23 l. It is designed according to the German ordinance on pressure vessels (AD2000) for an operational pressure of 60 bar and has an empty mass of 9 kg. Both ends are equipped with a standard G1/2 threads. The entire oxidizer storage and feeding system is equipped with temperature sensors and pressure transducers for monitoring and with relief valves for safety reasons.

4.2. Avionics

The Electrical Power Subsystem (EPS), the On-Board Data Handling Subsystem (OBDH) and the Communication Subsystem (COM) are summarized with the term avionics. All major elements of the avionics like on-board computers (OBCs), modems or batteries are located in the electronics compartment, which is placed in the upper section of the rocket. The elements itself are fixed on the so called electronics mounting (shown in FIG 5), which can be easily removed for testing or maintenance. It is a 3D-printed part made of polyactic acid (PLA).

4.2.1. Electrical Power Subsystem

Central objectives of the rocket's EPS are to provide, condition and distribute electrical energy throughout the rocket as well as to transfer signals and measurement data. After ground power supply is switched off, the entire rocket has to be powered by batteries. To account for different voltage levels, three independent batteries are utilized: A main bus battery, a pyrotechnical bus battery and a separate battery for the secondary on-board computer. All power busses are completely independent and galvanically isolated. The batteries for the main and the pyrotechnical bus are of Lithium Iron Phosphate (LiFePo4) type as they are more safe and robust compared to Lithium Polymer batteries and have a higher energy density compared to the classical Nickel Metal Hydride batteries. A major advantage of the LiFePo4 batteries is the wide temperature range from -30 to +55°C and their robustness against deep discharge. The main battery consists of two battery packs in series with four cells each. The battery for the pyrotechnical circuit consists of two cells in series and is suited for a maximum current of 120 A at 6.6 V. A single cell Lithium-Ion battery of 3.7 V powers the secondary OBC. To enable a galvanic isolation all circuit switching is realized via solid state relays, which do not contain any mechanical parts. Thus they are very tolerant against vibration.

FIG 5. Electronics Mounting

4.2.2. On-Board Data Handling Subsystem

The On-Board Data Handling Subsystem (OBDH) is formed by two independent OBCs and a sensor platform. A National Instruments sbRIO-9636 is acting as primary OBC of the AQUASONIC rocket. All devices of the NI sbRIO platform combine a reconfigurable Field Programmable Gate Array (FPGA), a processor (CPU) as well as lots of analogue and digital in- and outputs on an embedded single Printed Circuit Board (PCB) that is programmed with the graphical programming language NI Laboratory Virtual Instrumentation Engineering Workbench (LabVIEW). The analogue and digital in- and outputs (I/O) are directly connected to the FPGA, which can for example be used to implement discrete logic, high-speed data processing, complex timing and triggering routines or state-machine-based control algorithms. When the program code is compiled, it is directly implemented into the hardware, meaning the logic gates within the FPGA are routed permanently. As an FPGA does not require an operating system, it offers true parallel processing at maximum performance, determinism and reliability as well as lowest latency with loop rates up to 40 MHz. The FPGA is connected via a Peripheral Component Interconnect (PCI)-Bus to the CPU, which is running a real-time operating system (RTOS). A RTOS guarantees to run programs at specific rates without interruption and without a reboot for even years. In addition any jitter is reduced to a very small amount. The single-core CPU running at 400 MHz has access to 256 MB Random Access Memory (RAM) and has several additional external interfaces.

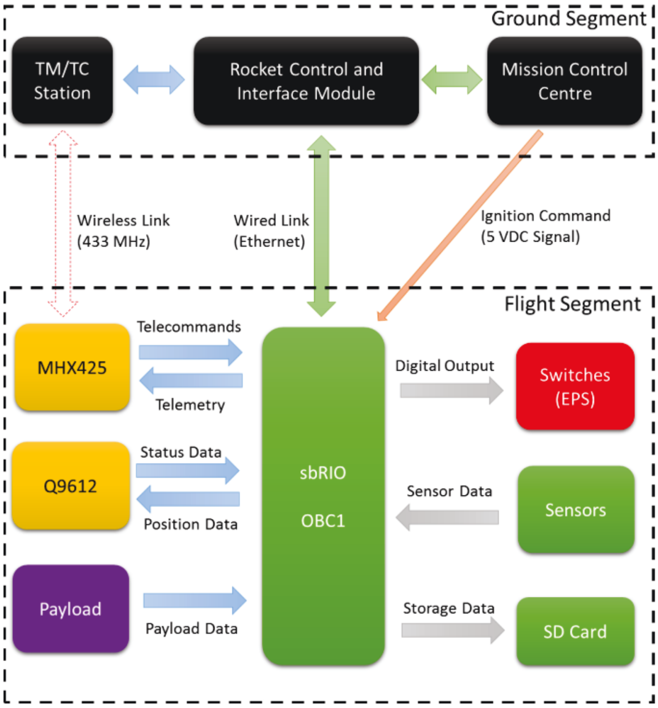

FIG 6. Block Diagram of OBC1 Interfaces

The interfaces of sbRIO OBC1 are outlined the simplified block diagram shown in FIG 6. This block diagram indicates the interfaces within the different segments as well as the connections between them. Central element is the primary OBC sbRIO which exchanges data with the other elements of the flight segment and via an Ethernet connection with the ground segment. All solid arrows in FIG 6 indicate one or multiple wired connections. For example, the sensors distributed all over the rocket transmit their data to the sbRIO. The sbRIO processes this data and sends them as Telemetry frames to the MHX425 wireless modem. In addition the data is saved to a SD-card. An example in the other direction could be the transmission of a telecommand (TC). First the TC is transmitted from the TM/TC Station via the 433 MHz wireless link to the modem. Afterwards the modem transmits the telecommand via the RS-232 interface to the sbRIO. If the contents of the TC is for example a switching command, the sbRIO will change the respective digital output connected to the switches of the Electrical Power Subsystem (EPS). The sensor platform, which is connected to OBC1, consists of a barometric pressure sensor, a Global Navigation Satellite System (GNSS) module and an Inertial Measurement Unit (IMU), which consists of a triaxial accelerometer, three rate gyroscopes manufactured with MEMS (microelectromechanical system) technology and a magnetometer. An outstanding feature of the IMU is its ability to act as an Attitude Heading Reference System. In contrast to a “simple” IMU, the raw data of the sensors is processed by an on-board microcontroller running an extended Kalman Filter. By this, all sensor data plus position and attitude estimates are provided at the output port.

For redundancy reasons a commercial off-the-shelf altimeter is utilized as secondary on-board computer. The TeleMega manufactured by AltusMetrum is one of the most advanced and powerful altimeters on the market with regard to size, mass and cost. It was especially developed for amateurish sounding rockets and supports a dual-deployment recovery system like it is used in the AQUASONIC rocket. In principle the TeleMega provides all basic functions of the OBDH and COM besides some complex operations like arming and disarming, fuelling or ignition of the engine. To detect launch, apogee and main altitude the TeleMega is equipped with a Barometric Pressure Sensor, a three-axis IMU and a single-axes accelerometer. The position of the rocket is determined by a GPS module. On-board flash memory is used to store sensor data at a rate of 100 Hz during ascent and 10 Hz during descent. Simultaneously all data is downlinked via a transceiver chip to the so called TeleDongle located in the TM/TC station. The TeleMega is equipped with a standard antenna connector and is connected to a half-wave dipole antenna with an almost omnidirectional pattern.

4.2.3. Communication Subsystem

The objectives of the communication subsystem are to transmit real-time trajectory, housekeeping and payload data during flight and to support locating of the rocket after landing. To be in compliance with the AQUASONIC requirements, a communication architecture based on three independent links has been established. FIG 7 shows a block diagram of the flight and the ground segment and the respective connections between them. Link 0 is set between an IRIDIUM modem located inside the rocket and the IRIDUM satellite network located in the Low Earth Orbit. The purpose of this link is to transmit GPS-based position data to the IRIDIUM network even after rocket touch down when the other two links will break down. By this the time for rocket locating can be reduced.

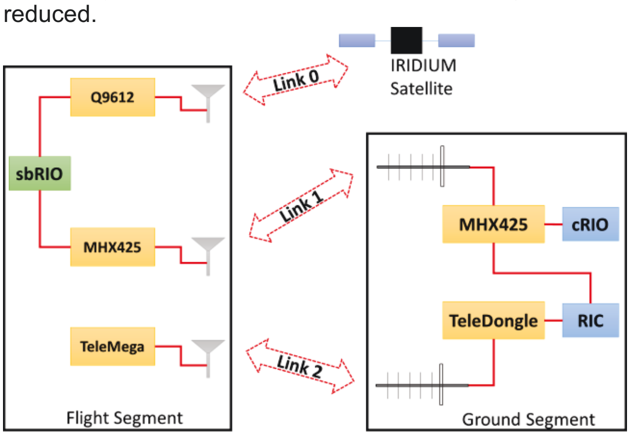

FIG 7. Communication Architecture

Link 1 and Link 2 are established in parallel. Link 1 is the primary TM/TC (telemetry/telecommand) link between the two MHX425 devices while Link 2 is the secondary TM/TC link between the TeleMega and the TeleDongle.

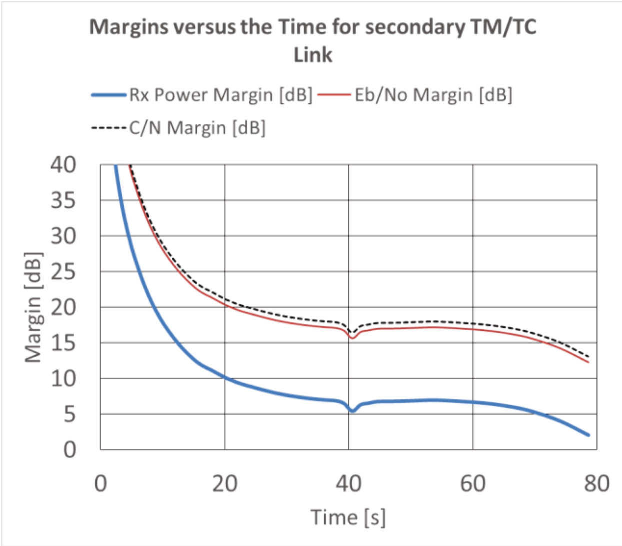

FIG 8. Link Margins for Secondary TM/TC Link

A half-wave dipole antenna has been selected as Ultra-High Frequency (UHF) antenna for the AQUASONIC flight segment. This type of antenna has an almost omnidirectional pattern and does not require an electrically conductive surface for reflection of the RF waves like a quarter-wave dipole antenna does. The antenna selected is designed especially for low power applications up to 10 W transmitter power. The AQUASONIC rocket will house two of these antennas. One will be connected to the MHX425, the other to the TeleMega. A link budget analysis has been done to evaluate both communication paths from the transmitter to receiver (and vice versa). It considers all losses and gains within the transmitter system, the receiver system and through the medium. It has been calculated for a worst-case scenario (e.g. bad weather, maximum expected pointing errors). FIG 8 shows the margin plots for the secondary TM/TC link, which is more the critical one, because the TeleMega has less transmitter power than the MHX425. Assuming a ballistic flight without recovery phase, it can be concluded that there are no problems as all margins are above the 3 dB threshold. Nevertheless the margins for the relation of energy per single bit versus the Spectral Noise Density (E_b/N_0) and the Carrier-to-Noise-Ratio (C/N) depend on the local noise environment at the launch site. The noise temperature was assumed with 900 K for the calculation.

4.3. Recovery Subsystem

Due to the requirement of reusability the AQUASONIC rocket is equipped with a double-staged recovery system based on parachutes. Shortly after passing apogee the first stage of the recovery system is triggered by both on-board computers in parallel. Three glow plugs ignite independent black powder charges, which are located in the upper recovery adapter (see FIG 9).

FIG 9. Upper Recovery System Adapter

The combustion gases generate a very high pressure so that the nose cone located at the top of the rocket is ejected (see FIG 10, step 2). Prior to the ejection, the Kármán-shaped nosecone made of glass fibre reinforced plastics is fixed by nylon shear pins. As soon as the nose cone is removed, the drogue parachute gets into the air stream and inflates. As drogue parachute a Rocketman Ballistic Mach II with a size of 7 ft has been chosen. This type of parachute is especially suited for high velocity release. Main purpose of the drogue chute is to stabilize the rocket during descent through the atmosphere as well as to limit the rate of descent. An additional task is to reduce the drift due to wind in order to ensure that the rocket touches down in the designated area.

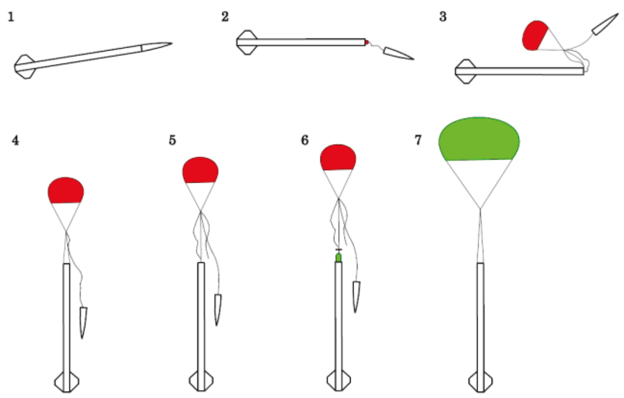

FIG 10. Recovery Sequence

Once the OBCs detect an altitude of 500 m above ground, two hot-redundant pyro cutters are activated. These devices are developed in-house and consist of a blade and a small black powder charge including a glow plug encased by a thin aluminium housing. When the charge is ignited by the glow plug, the blade cuts a rope, which is used to retain the main parachute prior to that. By this, the drogue parachute pulls the main parachute out of its 3D-printed cylindrical shaped box. The main parachute selected is a Skyman Ultra Cross 100 with a surface of 25 m² and a mass of 0.975 kg. This parachute is normally used by skydivers. As the parachute is designed for humans, it allows for a very low descent rate of 3.5 m/s and thus a smooth landing. It is planned that the rocket is oriented vertical during main recovery phase and touches down with the engine section first.

A major challenge is the load application from the parachute into the rocket structure. The most critical load case appears during opening of the drogue parachute. As the drag force, which is generated by the opened parachute, acts inclined to the rocket's longitudinal axis, shear, bending, torsion, compressive and tensile forces are introduced into the upper structure. The worst case drag force is estimated with 19770 N. To reduce the occurring shock force, bungee ropes are implemented. FIG 11 depicts the structural compartment, which houses the recovery subsystem. The colour gradient shows the stress intensity that has been calculated during a mechanical event simulation (MES). Result of this calculation is a maximum stress of 317 N/mm² which is much below the yield strength of 460 N/mm² (EN AW 7075). Another result of the analysis is that in the area, where the load is applied, no stability failure occurs and that the tube does not bulge.

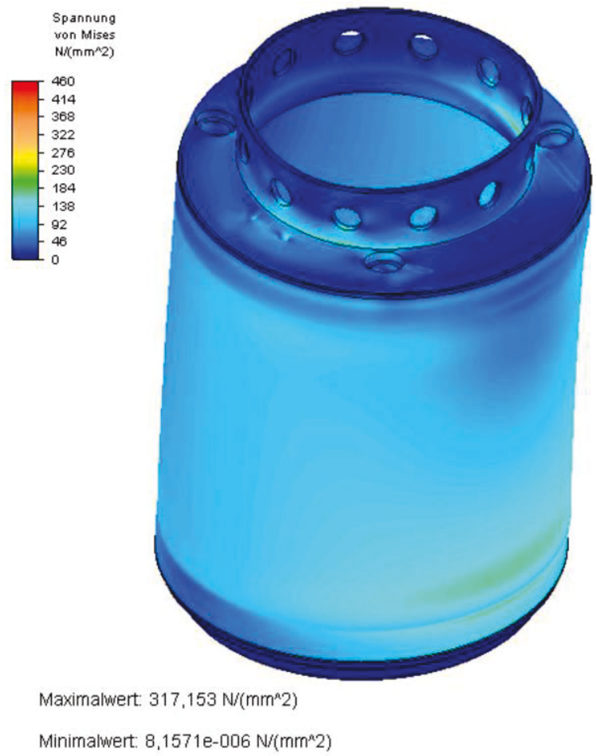

FIG 11. Stress Intensity (Drogue Chute Load Case)

4.4. Payload

It has been set in the requirements that the AQUASONIC rocket shall carry a payload with a mass of 2 kg. For all payloads a separate payload compartment is available, which is located below the recovery system and above the electronics compartment. In total three individual payloads are planned. The first payload is designed in cooperation with a partner high school of Hochschule Bremen, which offers an "Aerospace Profile" to the students of the upper secondary level. Some of the students participated in the German CANSat competition that took place in the surroundings of Bremen in October 2014. A CANSat is a small experiment in the form factor of a common 0.33 l beverage can that is launched by a rocket and usually ejected at apogee. Due to the environment at the launch site in Sweden, the CANSat carried by the AQUASONIC rocket will not be ejected. The high school students plan to measure the rocket's flight path based on accelerometer and barometric pressure data.

The second payload is a high definition video camera that shall record the entire flight of the rocket. In order to record a wide field of view, a camera with a fisheye lens has been selected. Finally a third payload is realised in cooperation with Airbus Defense and Space. In the frame of a research programme for future launcher technologies thermo-electric generators (TEGs) are placed in a high temperature environment close to the nozzle. The TEGs utilize the so called "Seebeck-effect", which is the direct conversion of a temperature difference into an electric voltage. By placing the TEGs around the nozzle, heat that would normally be "lost" is used to generate a small amount of electrical power that drives a sensor measuring voltage and current. The data of the sensor is wirelessly transmitted to an access point which is located in the rockets electronics compartment and connected to the on-board data handling subsystem.

5. GROUND SEGMENT

The AQUASONIC ground segment incorporates all infrastructure used for testing, rocket integration, launch preparation and flight. It can be separated into an electrical and a mechanical part.

5.1. Electrical Ground Support Equipment

Purpose of the Electrical Ground Support Equipment (EGSE) is to supply all ground segment elements with electrical energy and to transfer data between them during tests, integration, launch preparation and finally flight. Major elements of the EGSE are the Rocket Control and Interface Module (RCIM), the Telemetry and Telecommand (TM/TC) Station and the Mission Control Centre (MCC).

The RCIM acts as central interface between ground and flight segment and is located next to the launch pad. It houses power supply units, an uninterruptible power supply, an Ethernet switch and a National Instruments cRIO-9067 Data Acquisition and Control Unit (DACU) equipped with several in- and output modules. All sensors and actuators of the ground segment are connected to the DACU. Like the primary on-board computer of the rocket, the cRIO is programmed with NI LabVIEW. Furthermore, the RCIM houses a switching unit consisting of 24 VDC relays, which control the actuators of the ground segment and are also used to remotely arm and disarm the flight segment.

Objective of the TM/TC Station is to establish a wireless interface between ground and flight segment. It is set up close to the RCIM and houses two modems as well as its respective Yagi antennas. The antennas are two-dimensional three-element Yagi antennas that are fed in quadrature. Unique feature of this antenna type is the circular polarization to account for the unknown orientation of the linear polarized flight segment antenna. The three elements provide a maximum gain of 8.15 dBiC at a -3 dB beamwidth of 62° in both horizontal and vertical direction in the 433 MHz band. This configuration has been chosen to avoid a complex antenna tracking mechanism.

The Mission Control Centre (MCC) will be set up at a safe distance and includes all required equipment to operate the flight and ground segment remotely. Most of the MCC equipment acts as man-machine interface and is used to monitor as well as to control all systems during ground and flight phase. Moreover an Ethernet network is utilized to distribute data from the RCIM to all mission control computers and to the central file server.

5.2. Fuelling System

An important safety requirement demands that the rocket has to be fuelled on the launch pad shortly before lift-off. Therefore a partly automated fuelling system that is remotely controlled has been developed. The fuelling systems provides 30 kg of Nitrous Oxide (N_2O) at 50 bar and up to 1 kg of Helium (He) at 300 bar. The tanks of the rocket have a capacity of 16 kg N_2O and 0.3 kg He respectively. Probes like thermocouples, pressure transducers and valve position sensors and monitored by the ground operations team located in the MCC. In addition the actuators like valves, heaters or the decoupling mechanism can be controlled. The liquid N_2O is stored in four gas cylinders with a capacity of 7.5 kg each that are mounted upside down. This is necessary to extract the liquid phase from the gas cylinders without eliciting a phase change during transfer to the oxidizer tank of the rocket. If the gas cylinders were aligned upright, the N_2O would be extracted as a gas. The volume extracted is replaced by evaporation of some parts of the remaining liquid. By this the pressure inside the gas cylinder remains nearly constant. Nevertheless the N_2O becomes cooler and by this the pressure decreases according to the vapour pressure curve. Two gas cylinders are combined to a so called cluster, which is equipped with a pressure transducer, a pressure gauge, a thermocouple, a pneumatically actuated ball and a relief valve for safety reasons. The entire assembly is mounted to a frame made of aluminium beams as shown in FIG 12.

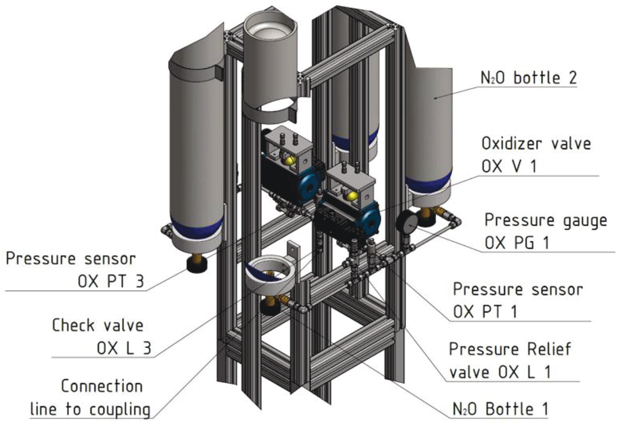

FIG 12. N_2O Cluster Assembly

The process of fuelling is divided into five steps that are executed subsequently. First the oxidizer tank of the rocket is pre-pressurized with Helium to the pressure present in the Nitrous Oxide gas cylinders (usually around 50 bar). By this the evaporation of N_2O is diminished. Afterwards the first cluster valve is opened, while a pressure control valve located on top of the oxidizer tank is opened to slowly dump the Helium to the atmosphere. The N_2O enters the tank from the lower end. Several test campaigns have shown that up to 85% of the N_2O available in the gas cylinders can be removed. During dumping, the pressure control valves becomes very cold so that a heater prevents the valve from freezing. Transfer one is finished by closing the first cluster valve. At this point the pressure inside the gas cylinders of cluster one and inside the oxidizer tank is at around 35 bar. Now the tank the re-pressurized to the pressure present in the N_2O gas cylinders of the second cluster. After opening the second cluster valve the same transfer procedure as explained for cluster one is conducted. The fuelling process is finished when the oxidizer mass reaches its target value of 16 kg. This can be detected as the launch pad is equipped with a load cell measuring the entire mass of the rocket.

As a part of the fuelling system a special connector for the fuelling process is used as interface to feeding system of the rocket. Therefore a de-coupling mechanism is installed that remotely releases the connector and pulls it out of the quick-lock. For the N_2O fuelling line a HyLok Q-series quick-lock coupling is utilized. This coupling can be used for pressures up to 206 bar and it is suitable for N_2O saturated ambiences. The coupling consists of a stem (male part) that is sitting in the rocket and a body (female part) that remains outside the rocket. The body consists of a sleeve that is pushed towards the stem that is released when a click noise appears. Now the stem can be removed from the body. As the stem is spring loaded within the body, the removal is done without any load on the rocket structure. Care must be taken that the fuelling line has to be depressurized prior to decoupling because the maximum allowed disconnection pressure is 17 bar.

6. VERIFICATION

The recent engine test campaign has been conducted at DLR Trauen in July 2015. Key parameters regarding thrust, chamber pressure and mass flow were satisfactorily. Due to a minor issue with the fuelling system a burn time of 14 s instead of 15 s has been achieved. The thrust gradient depicted in FIG 13 shows an almost constant thrust of 2400 N. It has been slightly lower than expected because of a small leakage in the area of the first fuel grain segment. The leakage can be explained with imprecise manufacturing.

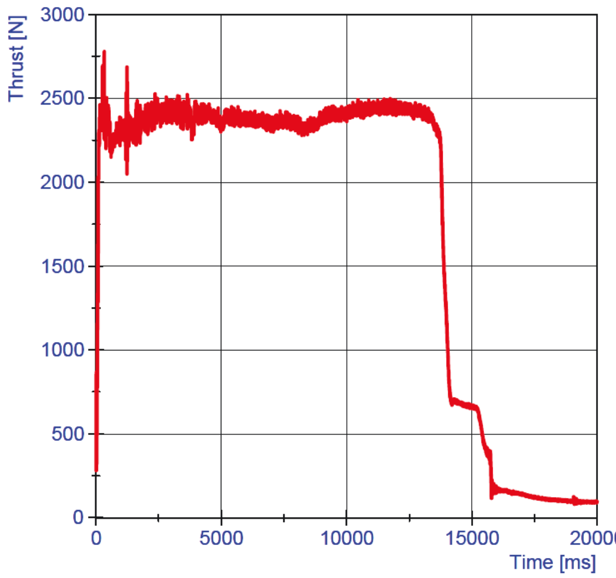

FIG 13. Thrust Gradient (Hot Test 2015-07-18)

The oxidizer feeding system as well as the data acquisition and control system behaved nominal. The next test campaign will be conducted in the frame of the Integration Progress Review (IPR) at DLR Trauen in December 2015. It is planned to extend the verification to other subsystems like on-board data handling or electrical power subsystem. Main objectives of the IPR are to demonstrate the functionalities and the performance at acceptance stage. This includes the flight model hybrid rocket engine and the oxidizer feeding system in flight configuration. The rocket avionics shall monitor and control the elements that will be inside the rocket, for example the pressure control valve, the pyrotechnical main oxidizer valve or the pressure transducers for combustion chamber, oxidizer tank and high pressure tank.

7. OUTLOOK

The launch campaign of the AQUASONIC rocket shall take place at Esrange Space Centre (Sweden) in April 2016. Therefore the assembly, integration and verification (AIV) phase has to be completed until end of 2015. In addition small test campaigns are scheduled. This includes for example ejection tests with the recovery subsystem and a flight of the electronics mounting with a paraglider to identify the characteristics of the sensors and to evaluate the communication paths.

The last review prior to transport to Esrange is the Rocket Acceptance Review, which is scheduled for February 2016. Within this review, experts of DLR decide if all requirements have been successfully verified and if the rocket is ready for transport. If anything proceeds nominal the team will travel in April 2016 to Esrange Space Centre. The launch campaign will last for nine days.

8. REFERENCES

[1] K. Lappöhn, D. Regenbrecht, D. Bergmann, M. Schmid and P. Rickmers: "STERN – Raketenprogramm für Studenten", Deutscher Luft- und Raumfahrtkongress 2012