OVERVIEW OF THE CURRENT WORK ON THE FLIGHT AND THE MGSE HARDWARE OF THE STUDENT ROCKET DECAN-AQUARIUS AT THE TU BERLIN

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Abstract

For more than 27 years students and scientists of the Technische Universität (TU) Berlin are developing experimental sounding rockets within hands-on courses. These practical courses teach the knowledge in (sub-) system design, manufacturing, assembly, integration and testing (AIT) and operation of rockets. The applied processes in development, AIT and operation as well as the quality standards are related to the ones in the aerospace industry.

The DECAN/AQUARIUS experimental sounding rocket project team, which is also a DGLR junior research group, works on a two-stage rocket where the upper stage is equipped with a solid fuel rocket (DECAN SHARK) and the lower stage with an environmentally friendly water engine (DECAN AQUARIUS). This paper provides an overview of the latest developments of the DECAN AQUARIUS lower stage since the last publication at the DLRK Congress in 2019.

The developments of the electrical components include the breadboard and the testing of an alternative telemetry configuration (Design B). On the mechanical side of the rocket, the recovery system is being finalized. Furthermore, the new nozzle release MGSE, which is needed for the launch of the rocket, was assembled and is currently being tested.

Acronyms/Abbreviations

AIT	Assembly, Integration and Test
CAD	Computer Aided Design
CDR	Critical Design Review
DECAN	German CanSat Sounding Rocket (Deutsche CanSat-Höhenrakete)
FEM	Finite Element Method
GPS	Global Positioning System
ILR	Department of Aeronautics & Astronautics, TU Berlin (Institut für Luft- und Raumfahrt der TU Berlin)
MGSE	Mechanical Ground Support Equipment
SHARK	Student Hight Altitude Rocket

1. THE DECAN ROCKET

1.1. DECAN – a two-stage rocket

The DECAN rocket, which is a two-stage rocket, is being developed by students and scientists at the TU Berlin. The possibilities of participation in this hands-on project are educational courses, Bachelor and Master Thesis, internships as well as a membership in the student/university association "Aquarius", which is also part of the development team of the rocket and a DGLR junior research group.

The two-stage system consists of an upper stage, the DECAN SHARK, and a lower stage, the DECAN AQUARIUS. The total lift off mass of the system will be about 150 kg. The lower stage will lift the whole system to an altitude of approximately one kilometer, where a stage separation system releases the upper stage. Afterwards the DECAN SHARK will climb up to the destination altitude of 7 km in which a small payload – a CanSat – will be ejected.

For a damage free landing of the stages, both stages use a recovery system and beacons will ease the recovery of the rocket. Both stages feature an independent telemetry unit which sends the in-flight data to the ground and stores the information as well. This telemetry board is also responsible for the automatic triggering of the stage separation system and the parachute ejection of the DECAN SHARK and AQUARIUS.

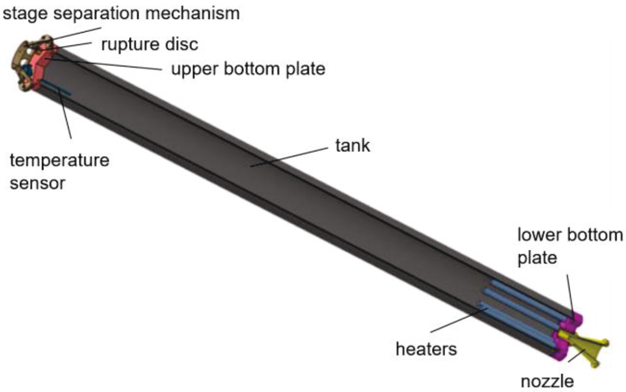

FIG 1. DECAN AQUARIUS Propulsion System.

Single stage test flights were accomplished by both stages. DECAN SHARK, which is propelled by a solid engine, absolved two flights, reaching altitudes of 5.5 km and 5.7 km, from the Esrange Space Center in Kiruna, Sweden in 2015. DECAN AQUARIUS' first flight took place at a facility of the Bundeswehr in 2017. The rocket reached an altitude of 550 m instead of 1200 m (which can be achieved in a single stage flight) because of a recovery system malfunction. Since the whole flight of the AQUARIUS takes place in the visible range, troubleshooting is made easier. Currently the work is concentrating on improving the lower stage of the DECAN rocket, therefore this paper is focusing on the current status of the DECAN AQUARIUS.

1.2. DECAN AQUARIUS

The lower stage of the DECAN rocket is equipped with an environmentally friendly hot water engine. The propellant tank, consisting of a lower plate, a tube and an upper plate, is made of a suitable heat resistant stainless steel in which heaters, a temperature sensor and the nozzle are installed (FIG 1).
For launching the AQUARIUS, the nozzle will be sealed with a specially designed launch MGSE which is part of the launch tower. The heaters in the tank are powered electrically to heat the water (which is the propellant) along the boiling curve to approximately 270 °C. Due to the partially evaporation of water a pressure of 55 bar is built up within the tank. A rupture disc installed to the tank and a pressure relief valve which is part of the launch MGSE help to control the process and increase the safety.
To lift-off the rocket, the nozzle is being released pyrotechnically from the Launch MGSE. The gaseous phase in the tank pushes the remaining water in the nozzle. Since the water is overheated for an ambient environment, it evaporates in the nozzle leading to a volume expansion and therefore thrust. The DECAN AQUARIUS generates an average thrust of 3,000 Newton over approximately 4 seconds using 30 kg of water.

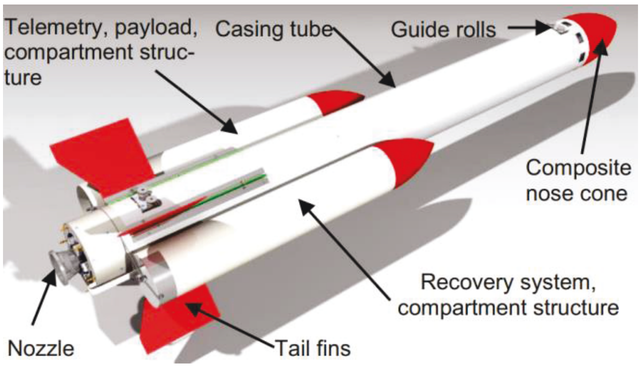

FIG 2. DECAN AQUARIUS rocket.

The propulsion system is the main part of the rocket. Dedicated metallic rings are used to connect all other systems to the tank, like the guiding rolls, that are the interface to the launch tower, the two compartments, which are housing the telemetry unit, the recovery system and the tail fins, which enable the AQUARIUS to fly stable.
The telemetry unit is situated in the left-hand compartment of the rocket as can be seen in FIG 2. The main task of the telemetry board is to trigger the parachute ejection, to collect in flight data, to send this data live to the ground, to store this information on the board itself and to track the AQUARIUS via GPS.
An aluminum crash box was designed for the protection of the telemetry board in case of an anomaly in the recovery flight phase of the rocket. This enables the recovery of the recorded flight data making possible a better data analysis, since the data recorded on the board is more detailed than the data which is sent down. An antenna outside the crash box makes possible the downlink of the data in real time.
The recovery system consists of two parachutes, a small and a big main chute. The small one will be ejected in the apogee of the trajectory to pull out the main parachute. Subsequently, the main chute will realize a safe landing of the AQUARIUS. Therefore, the small parachute is connected to the main one, which itself is connected to the rocket using a steel cable and cable clamps.
FIG 2 shows the lower stage and its main subsystems and TAB 1 provides an overview of the main parameters of the rocket.

Parameter	DECAN AQUARIUS
Take off mass	90 kg
Dry mass	60 kg
Propellant mass	30 kg (water)
Hight	2.5 m
Diameter	0.2 m
Average thrust	3,000 N
Acceleration time	4 s
Apogee	1200 m
Ascent time	19 s

TAB 1. Technical properties DECAN AQUARIUS.

1.2.1. Flight test of DECAN AQUARIUS

Since no suitable test stand was available for the propulsion system, the only means of assessing the properties of the AUQARIUS' engine was by calculations, simulations and test flights. Therefore, the theoretical assumptions could not be confirmed by engine tests.
The first test flight of the lower stage took place on 31st of March 2017. After the nominal launch tower set up and rocket preparation the release system pyro actuator was triggered and the launch MGSE released the AQUARIUS normally. The assumption for the efficiency of the engine, which was significant for the design process of the lower stage, slightly differed from the reality. This led to unexpected accelerations and velocities during the test flight and thereby to the rupture of the steel cable connecting the parachutes to the AQUARIUS. Also, the elevation, which was set to 79° by the launch tower, was slightly reduced, leading to a higher horizontal distance covered. The key data of this flight can be seen in TAB 2.
The telemetry unit worked partially nominal. The data transmission to the ground as well as the collection and storage of the flight data worked well. After the touchdown of the AQUARIUS the flight computer could be recovered. The crash box was able to protect the board from damage and the stored data could be recovered for further investigation. Unfortunately, the crash box narrowed the view window of the telemetry board, which made it impossible to lock in with enough GPS satellites. Therefore, only limited GPS data was available. Nevertheless, the first flight of the new developed DECAN AQUARIUS was a success since a lot of subsystems

could be qualified such as the propulsion system or the main structure.

Parameter	Test flight data
Max. altitude	550 m
Flight time	22 s
Max. speed	120 m/s
Time to apogee	10.6 s
Acceleration time	3.3 s
Horizontal distance	1100 m

TAB 2. Measured test flight data DECAN AQUARIUS.

1.2.2. Challenges to tackle concerning the AQUARIUS rocket hardware

After analyzing the data and the rocket itself, three main issues regarding the flight hardware were identified:

1) The information which was stored on the board showed that the triggering of the parachute ejection was performed in the apogee of the rocket's trajectory and therefore normally. That led to the conclusion, that the malfunction of the parachute ejection was caused by a mechanical issue. The measured acceleration at the launch of the rocket was significantly higher than assumed since modelling of a turbulent multiphase flow is a challenging issue which is still ongoing. The parachute ejection system was not designed to handle such loads.
2) The maximal estimated velocity of the AQUARIUS was assumed to be lower than the measured speed at the test flight. The drag and shock force of a parachute during deployment increases quadratically to the velocity. Therefore, higher loads on the connection of the parachutes to the AQUARIUS need to be considered.
3) The metallic crash box was able to protect the telemetry board from damage. To have more information available after each flight, GPS data shall be recorded and sent down in-flight as well. Therefore, the GPS visibility needs to be improved.

All other systems shall be altered as little as possible since they have worked nominally during the first test flight and therefore have flight heritage.

2. IMPROVEMENTS OF THE FLIGHT HARDWARE OF THE DECAN AQUARIUS

2.1. Improvements of the mechanical components

In 2018/19 a recovery system redesign including a wind tunnel test and a parachute connection redesign including various tensile test were successfully performed. For further information regarding these subjects the 2019 DLRK DECAN AQUARIUS Paper [1] is available.

2.2. Finalization of the parachute system

The optimization of the parachute connection was one of the processes with the most attention because of the criticality of the subsystem. If the parachute ejection or the connection fails, the whole rocket could be lost. In addition to this, every change conducted in the parachute connection influences the mass distribution which affects the stability and therefore the flight path of the rocket.

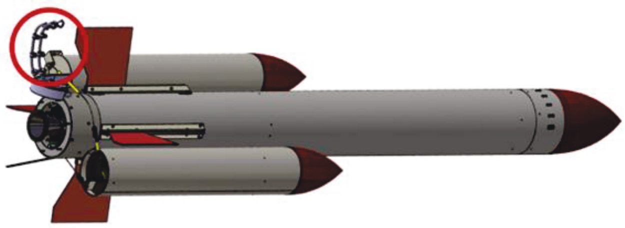

FIG 3. CAD image of the DECAN AQUARIUS rocket. In the circled area the parachute junction can be seen.

The newly designed parachute connection consists of two redundant steel cables in connection with dedicated cable clamps. The new design was successfully tested. Therefore, it will be able to compensate the high loads when the parachute will be activated in the apogee of the flight. The addition of a second steel cable and further changes have led to a shift of the centre of gravity. Furthermore, at the tail of the DECAN AQUARIUS a part of the steel cable was routed outside of the rocket to function as the parachute junction as can be seen in FIG 3. This chute connection needed to be fixated to prevent unwanted vibration or movement since this could lead to damages on the nozzle or the fins which are in proximity. In case the parachute junction would move into the exhaust stream the thrust vector and therefore the flight path could be altered. Furthermore, the path of the chute being ejected needs to stay clear and collisions with the launch MGSE must be prevented.

To avoid the mentioned risks, a comprehensive requirements list for the fixation of the parachute junction was defined. These requirements can be classified under following aspects:

1) Mechanical compatibility of the fixation with other subsystems of the rocket,
2) compatibility of the fixation with both, the newly developed launch MGSE and the current one,
3) maintenance of the rocket stability and
4) resistance of the fixation to the loads and stresses during launch.

These loads and stresses are mainly the high temperatures of about 270 °C caused by the rocket engines heating process and the hight acceleration after the release of the DECAN AQUARIUS. During the first test flight in 2017 the acceleration of the rocket was measured for the first time and was used as an input for the parachute junction fixation design process. Lastly the aerodynamic effects of the fixation on the rocket stability need to be minimized. That is why flat surfaces which may behave like a fin need to be avoided as much as possible.

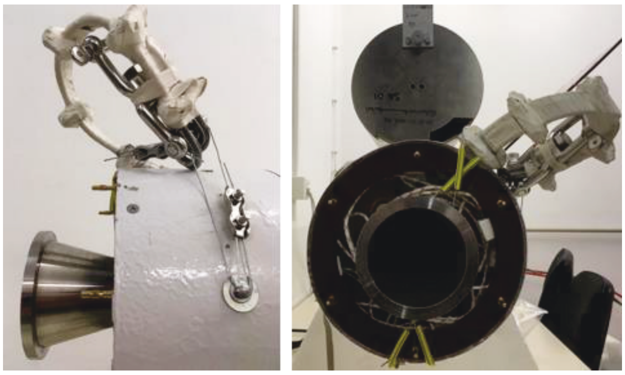

FIG 4. Fixation wires on the parachute junction.

To meet all the requirements the parachute junction was fixated by additional small steel wires. The main one was used to form the steel cable to an arc. This led to the shortening of the protruding length of the parachute junction in half by guying the cable on itself (see FIG 4). This was necessary to make the chute connection compatible to both launch MGES and to avoid the interference with the exhaust stream. Three additional steel wires were used to prevent sideway movements.
The diameters and materials of the steel wires of the parachute junction fixation were chosen to withstand the mechanical and thermal stresses at the launch. During the ejection of the parachute the fixation wires will break since the chute deployment loads are an order of magnitude higher. To protect the parachute against the high temperature and possibly edges a temperature resistant tape was used to wrap the parachute junction as can be seen in FIG 4.
To qualify the design for flight, several test campaigns were performed. To simulate the loads during the launch a pulley system was used. This system pulled on the test item with a defined force in a defined direction. The stress applied to the fixation system was calculated based on the assumed worst-case acceleration, the mass of the fixation system and a safety factor. The test was performed successfully, the parachute junction fixation system can withstand the loads during the launch and therefore, can keep the parachute junction in place. To check if the parachute junction fixation will not interfere with the parachute during its ejection, a deployment test was performed. The chute was pulled out of its compartment in a worst case set up and orientation. This test was filmed from various angles. Later the filmed material was analysed for critical collisions between the chute and the rocket. The test was successful and the chute could deploy without any interference of the parachute junction fixation on the chute deployment process. Both tests lead to the result that the design meets the requirements. For the final flight qualification, a wind tunnel is planned at the ILR test facility in 1.QT 2021.

2.3. Improvements of the electrical subsystems

In 2018/19 a redesign of the baseline telemetry system, the so-called Design A, was developed and qualified for flight. For further information regarding this subject the 2019 DLRK DECAN AQUARIUS Paper [1] is available.
Furthermore, an alternative design, the so-called Design B, was introduced.

2.4. Design B – external GPS antenna

The DECAN AQUARIUS rocket uses the TeleMetrum board by Altus Metrum as the flight computer. This circuit board includes an inertial measurement unit, a barometric sensor as well as a GPS receiver. The flight computer will monitor the acceleration, velocity and height of the rocket and will store the data on board. During the flight, telemetry packages containing the flight data will be send to the ground station via UHF radio. In the apogee of the trajectory the flight computer will trigger the release of the parachute.
Since the flight heritage, Design B ought to continue to use the metallic crash box. The TeleMetrum board provides an SPI-interface which enables it to communicate with microcontroller boards through a specific protocol.
This enables the Design B to utilize additional sensors and process the collected data in the corresponding microcontroller boards. This processed and prepared data can now be sent to the TeleMetrum board where it will be downlinked to the ground station alongside the regular data. For example, an additional GPS receiver with an external GPS antenna can be used to complement the GPS data collected by the TeleMetrum board. Furthermore, additional temperature sensors or atmospheric pressure sensors could be utilized with Design B. FIG 5 shows the layout of the breadboard currently in development. This layout utilizes a GPS sensor and a SD card for data storage since the TeleMetrum board is not able to save additional GPS data.

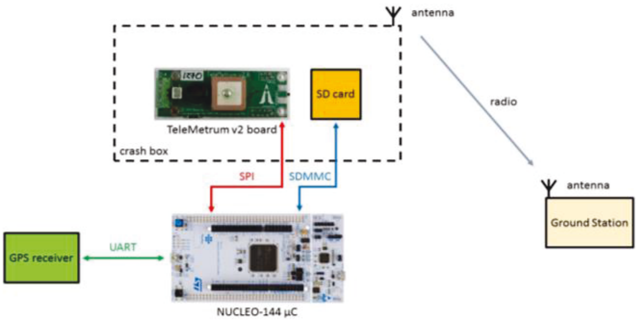

FIG 5. Design B breadboard.

The communication protocols for the TeleMetrum Board to microcontroller interaction are currently being investigated. To protect the SD card and the microcontroller during a recovery flight phase, both parts will be protected by an additional crash box.

3. WORKS ON THE GROUND SUPPORT EQUIPMENT

3.1. MGSE - New launch MGSE for the AQUARIUS

A new hot water rocket release system is currently under development within the DECAN AQUARIUS Project. The design process was supported by FEM analysis and tests. After a successful CDR, the procurement and manufacturing of the parts for the system were performed. The integration process of the MGSE was started and successfully finalized in 2019. The fully integrated system can be seen in FIG 6.
A detailed design description and the operation principle can be found in the 2019 DLRK DECAN AQUARIUS

Paper [1]. At the date of the issue of the paper qualification testing of the system is being performed to qualify it for the launch operations.

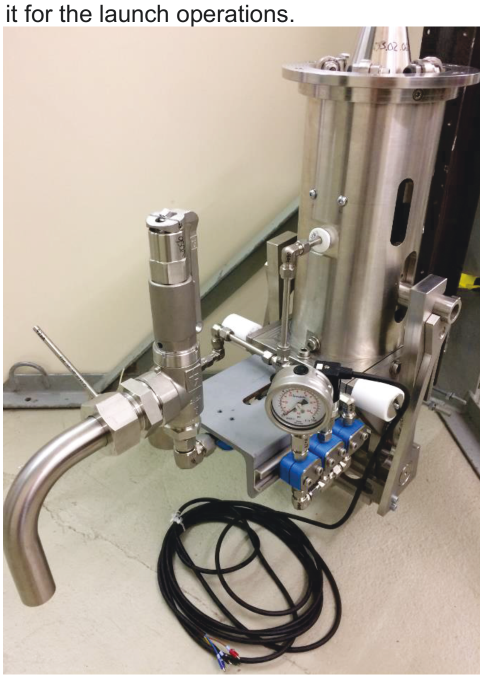

FIG 6. Fully integrated rocket release system.

3.2. Qualification of the MGSE

To qualify the system for the launch operation the MGSE was subjected to extensive testing to ensure that the system is safe and fit to perform the required tasks. The system needs to be able to withstand pressures as high as 55 bar and temperatures of about 270 °C.
The leakage tests are performed in two separate tests: ambient leakage test and hot leakage test. Furthermore, two release tests and a heating test were performed.

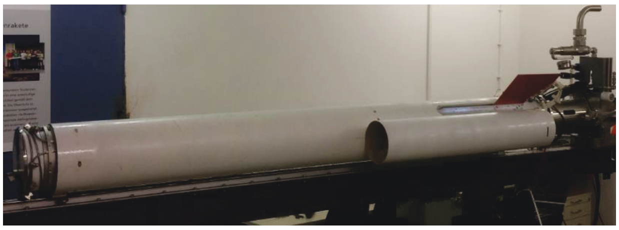

FIG 7. The DECAN AQUARIUS mounted to the MGSE and the launch tower.

For the ambient leakage test the rocket is mounted to the launch tower. The launch MGSE is part of the launch tower and can be seen on the lower end of the structure in FIG 7. The nozzle of the rocket is sealed by tightening the MGSE, so the whole system of DECAN AQUARIUS and launch MGSE are leakproof. The structure is tilted to launch position, which is close to being vertical, and then filled with water. The water is than pressurized to an increased pressure level at ambient temperature using a dedicated pump. This test was done twice, the pressure gage can be seen in FIG 8. The system was able to hold the pressure for more than 30 minutes without any leakage. Therefore, the first leakage qualification test was successful and qualified the MGSE for the hot leakage test.

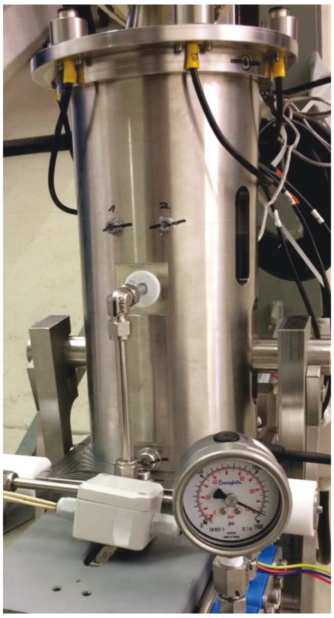

FIG 8. Release System B with mounted lower stage under pressure of 100 bar.

Since the MGES is a complex system, the release tests are necessary to ensure the launch operation of the DECAN AQUARIUS. The release is executed through a lever mechanism initiated by a dedicated pyro actuator (see FIG 9).

FIG 9. Successfully initiated release mechanism with pyro-actuator.

The first release test was done manually. The rocket was again mounted to the launch tower and the MGSE was tightened. To simulate the force of the pyro actuator a pulley system was used. Gradually the simulated force was increased by increasing defined counterweights until the MGES released the rocket successfully. Therefore, the necessary pyro actuator force was identified. The force determined in the test was equal to the one calculated in the design process. With the rocket now being released the pulley system was then used to determine the force necessary to pull DECAN AQUARIUS out of the MGSE. Since the necessary pull out force was smaller than one tenth of the rockets lift-off thrust the DECAN AQUARIUS is easily able of lifting itself from of the MGSE.
For the second release test the pyro actuator was used. Since the pyro actuator force was now determined the

pyro could be set up accordingly. The MGSE and the rocket were again mounted, tightened and tilted vertically to achieve the most realistic test setup. The pyro was ignited by a remote trigger to ensure the safety of the test equipment. The MGSE pyro was able to release the rocket, therefore the lever mechanism and the pyro are qualified for launch operation.
The heating test qualified the harness of the MGSE which enables the system to power the rocket with 400 V. The test was performed successfully by heating the distilled water in the rocket within only few minutes.

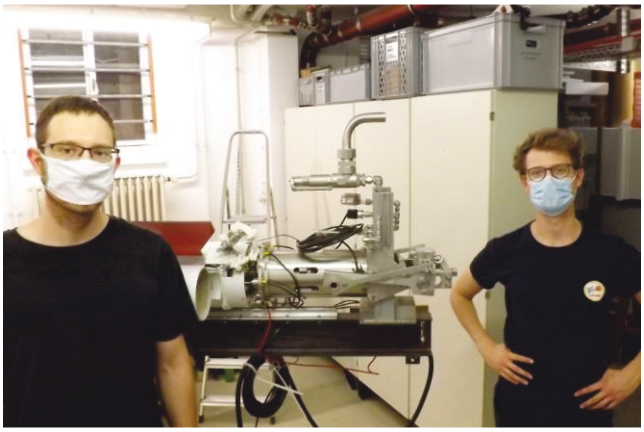

FIG 10. DECAN AQUARIUS Team members after a successful MGES test.

3.3. Finalization of the Qualification of the MGSE

To fully qualify MGSE the next steps are already planned: hot leakage test. The hot leakage test is performed in accordance with the conditions during a launch campaign, which means the launch pressure of 55 bar and the launch temperature of about 270°C. This test is planned for the winter term 2020/2021.

4. SUMMARY AND CONCLUSION

The first test flight of the AQUARIUS helped to understand which subsystems of the rocket needed improvements. By analyzing the flight data, the team was able to understand that the acceleration during lift off was significantly higher than expected. That led to a redesign of the recovery system. The qualification of the parachute junction fixation is another milestone for the flight qualification of the new recovery system. The full qualification will be reached with a wind tunnel test, which is planned for early 2021.
To increase the GPS visibility and to widen the possibilities of sensor utilization the alternative telemetry Design B is currently under development. After the successful programming and testing of the breadboard communication protocols the CAD Design is the next step in the development process.
The new launch MGSE was tested extensively and successfully. The last remaining tests which will qualify the system will take place in the next month. The most important test to be passed is the hot leakage test which is planned for the winter term 2020/2021.

5. ACKNOWLEDGEMENTS

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Bibliography

[1] R. Lippmann, A. Mayer, P. Mattausch, D. Maurer, T. Planitzer, L. Kletschke, I. Skrypnyk, H. Adirim, „OVERVIEW OF THE CURRENT WORK ON THE FLIGHT AND THE MGSE HARDWARE OF THE STUDENT ROCKET DECAN-AQUARIUS AT THE TU BERLIN", Deutscher Luft- und Raumfahrtkongress, Darmstadt, 2019.

[2] R. Lippmann, H. Adirim, „DGLR-NACHWUCHSGRUPPE AQUARIUS ENTWICKELT HÖHENRAKETEN AN DER TU BERLIN", DGLR Magazine 2/2019, Bonn, 2019.

[3] M. Buscher, S. Grau, S. Kapitola, L. Kryza, M. Lehmann, R. Lippmann, S. Lange, J. Großhans, C. Avsar, O. Homakova, H. Adirim, K. Brieß, „HANDS-ON EDUCATION AND STUDENT RESEARCH AT TU BERLIN: SATELLITES, ROVERS, ROCKETS AND SPACE SYSTEM EXPERIMENTS DEVELOPED BY STUDENTS IN AN INTERNATIONAL ENVIRONMENT", 69th International Astronautical Congress (IAC), Bremen, 2018.

[4] T. Nitschke, H. Adirim, A. Balke, J. Léglise, E. Melan, M. Riekeles, M. Schmid, P. Wüstenberg, „LAUNCH CAMPAIGN OF THE DECAN UPPER & LOWER STAGE AND DEVELOPMENT OF A 3D-PRINTED EXPERIMENTAL ROCKET AT TU BERLIN", Deutscher Luft- und Raumfahrtkongress, München, 2017.

[5] E. Melan, D. Weber, T. Nitschke, P. Wüstenberg, H. Adirim, „MISSIONSPLANUNG UND -BETRIEB DER HÖHENFORSCHUNGSRAKETEN SHARK I-II", Deutscher Luft- und Raumfahrtkongress, Braunschweig, 2016.

[6] T. Nitschke, J. Kolbeck, R. Wolf, R.A. Court, P. Wüstenberg, E. Melan, M. Schmid, „THE DECAN PROJECT AT TU BERLIN", Deutscher Luft- und Raumfahrtkongress, Rostock, 2015.

[7] M. Schmid, „DEUTSCHE CANSAT-HÖHENRAKETE DECAN AN DER TECHNISCHEN UNIVERSITÄT BERLIN", Deutscher Luft- und Raumfahrtkongress, Stuttgart, 2013.

[8] M. Schmid, P. Fleischer, F. Sliwowski, H. Adirim, N. Pilz, "DECAN (DEUTSCHE CANSATHÖHENRAKETE) – A SOUNDING ROCKET PROJECT AT TU BERLIN", EUCASS 2013, München, 2013

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