Development and Flight Results of TalTech University CubeSat Mission

Muhammad Shadab Khan[1], *Rauno Gordon*[2], *Martin Simon*[3], *Kristjan Tonismae*[4], *Dzmitry Kananovich*[5], *Veljo Sinivee*[6], *Marko Karm*[7], *Kaarel Repän*[8]

Abstract

Student Satellite program at TalTech, Tallinn University of Technology, Tallinn, Estonia was initiated in 2014 with an aim to impart space technology knowledge to the Estonian students as well as assist towards development of new Space Technologies in Estonia. Two 1-Unit CubeSat named Koit and Hämarik that translates respectively as Dawn and Twilight in Estonian are part of the TalTech Satellite Program. The main scientific mission of the CubeSats was to demonstrate Earth observation and Optical Communication technology. Satellites had two types of cameras, an RGB Camera and an NIR Camera to carry out Earth Observation over Estonia. Testing High Speed Optical communication technology from LEO (Low Earth Orbit) was the second major scientific goal and for this purpose the CubeSats had LED (Light Emitting Diode). Koit CubeSat was successfully launched to space on-board Soyuz rocket on July 5, 2019 and Hämarik CubeSat was launched to Space on September 3, 2020 on-board Arianespace Vega Rocket. Koit CubeSat did not contact the Ground station for more than a year since its launch and it was assumed to be lost but on November 21, 2020 it made the first contact with the Ground Station. Hämarik CubeSat was first contacted on November 15, 2020. The team has been successful in updating software of Hämarik and further work is being done on the software with broader functions. Optical communication has not been tested yet because ground station for optical communication has not been developed yet but a good achievement in the path to optical communication was to see the satellites with small hobby telescope and one of the satellite team member was successful to detect the Hämarik CubeSat on 17 August 2021 which was at a distance of about 792 Kilometres. Satellite team is in contact with the Hämarik and has been successful to download a few thumbnails and is working to establish a quick data connection with it and determine its exact position so that the cameras can be focused towards the Earth in order to get the whole images captured by the CubeSat.

Keywords

CubeSat, TalTech, Estonia

[1] Corresponding author: École Nationale Supérieure d'arts et Metiers, France, shadab_khan@msn.com

[2] TalTech, Tallinn University of Technology, Estonia
[3] TalTech , Tallinn University of Technology, Estonia
[4] TalTech , Tallinn University of Technology, Estonia
[5] TalTech , Tallinn University of Technology, Estonia
[6] TalTech , Tallinn University of Technology, Estonia
[7] TalTech , Tallinn University of Technology, Estonia
[8] Fachhochschule Wiener Neustadt, Austria

Abbreviations

ESA ***European Space Agency***
EPS ***Electrical Power System***
ADCS ***Attitude Determination and Control System***
LED ***Light Emitting Diode***
SSMS ***Small Satellite Mission Service***
LEO ***Low Earth Orbit***
COTS ***Commercial off the shelf***
POD ***Poly-Picosatellite Orbital Deployer***
NIR ***Near Infra-Red***
OBC ***On-Board Computer System***
FPGA ***Field programmable Gate Array***
UHF ***Ultra High Frequency***

1. Introduction

CubeSats are a class of Nano-Satellites that are small in size and low in cost. The standard CubeSat size uses a "one unit" or "1U" measuring 10x10x10 cm^3 and is extendable to larger sizes; 1.5, 2, 3, 6, and sometime more larger version in 12U format [1]. There is growing demand of CubeSat Technology globally for various applications considering its low cost of development. While CubeSat technology provides a cheap and low cost access to Space, it is also helpful to provide training to University students to help them get first-hand experience in Spacecraft Engineering in different aspects like Design, Manufacturing, Testing and Project Management to help them prepare to contribute to the Space Technology activities in their respective countries. Space Technology activity in Estonia was initiated with the successful launch of the First Estonian Satellite “ESTCUBE-1” in 2013 that was designed and built by the students of University of Tartu [2]. The success of the mission inspired other Estonian Universities to start Student Satellite Missions and in this regard the Satellite Program started at TalTech University of Technology, Tallinn, Estonia in 2014 to not only provide hand on training to the students of the University in Spacecraft Engineering but also to propel Estonia to higher Orbits in the field of Space Technology. The Satellite program at TalTech University is supported and funded through Estonian Government and the European Commission to encourage scientific research in Estonia. DATEL and several other Estonian companies are also sponsoring the Satellite program. In the framework of the Student Satellite Program, 1-Unit CubeSat mission was chosen to be built by the University students from different backgrounds with the support of the Professors, University Laboratories and other partner laboratories in Estonia. The Satellite Program [3] is operated at the Mektory Space Centre of the University and is led by Dr. Rauno Gordon and there were about 70 students working on different aspects of the CubeSats including some interns from other countries.

Figure 1. European Union Development Fund

2. Satellites

1-Unit CubeSat according to the CubeSat Design Standard was chosen to be developed as part of the Satellite program and Mission concept and top level requirements including feasibility study and preliminary design was completed in 2015 and. During 2016-2017 construction of the CubeSat subsystems and Frequency permits and legal documentation were obtained. The CubeSats were named as Koit and Hämarik that translates respectively as Dawn and Twilight in Estonian. Koit was the first CubeSat (Fig.3) to be developed and readied for launch and its flight Model was ready in early 2019. Hämarik was the second CubeSat (Fig.2) to be developed and its flight model was ready by January 2020.

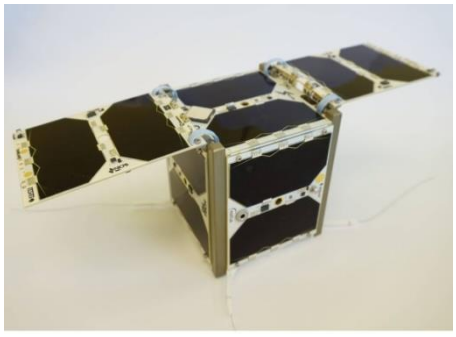

Figure 2. Hämarik CubeSat Flight Model

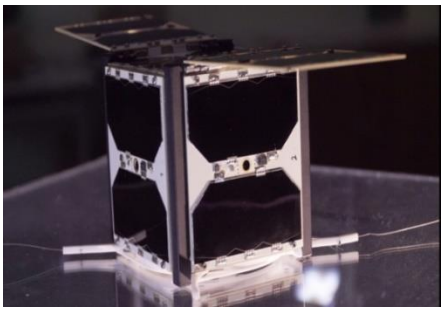

Figure 3. Koit CubeSat Engineering Model

3. Scientific Mission

The primary scientific mission of Koit and Hämarik CubeSat is Earth observation and demonstration of Earth observation technology. The satellites include two cameras (RGB and Infrared), image processing and communication with ground station. For cameras RGB sensor for visual light image and NIR (Near Infra-Red) sensor for near-infrared image was used to help in assessing vegetation growth, climate, geology and sea conditions. Image processing on the satellite makes sure that only those images that provide valuable information are downloaded. The main objective was to provide Satellite Imagery about the water and vegetation in Estonia and for this purpose the camera angle orientation was such that it points to the Estonian geography as shown in the Fig.4.

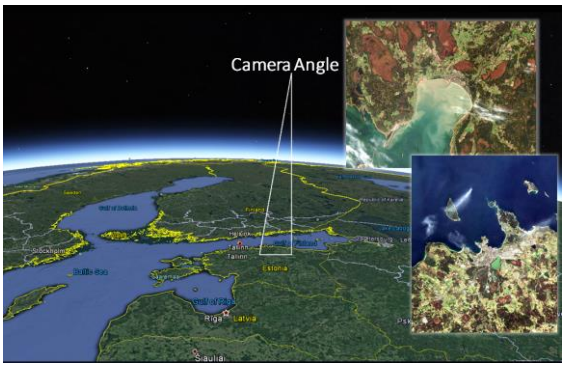

Figure 4. Camera Orientation over Estonia

In addition to Earth observation technology there are scientific experiments: computational fault tolerance and optical communication. The experiment for fault tolerance of computers is carried out on a reprogrammable FPGA integrated circuit. Different computer hardware configurations can be implemented in this chip. For optical communication experiment LEDs and laser-diodes were integrated in the satellite to transmit signals. The blinking satellite was to be observed by a tracking telescope with optical sensors that can see the satellite and decode the data. Satellite is able to turn the LEDs and lasers towards ground and transmit test signals. Telescope tracks the motion of the satellite and it is possible to see slow blinking. This way it is possible to send data to ground from the satellite.

4. CubeSat Subsystems

System and Subsystems components on both the CubeSats Koit and Hämarik were same. The location of the subsystems in the Satellite can be seen in the Fig 5.

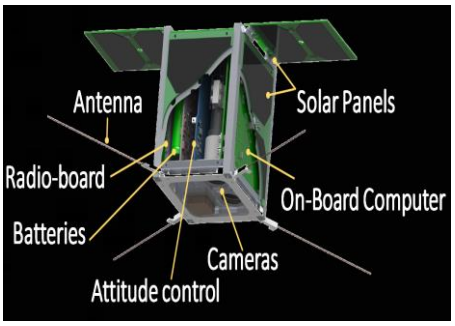

Figure 5. CubeSat Subsystems

Most of the CubeSat subsystems were COTS but some of the subsystems including EPS was developed in-house at TalTech University.

- On-Board Camera
- Attitude Determination and Control System (ADCS)
- Electrical Power System (EPS)
- Communication Subsystem
- On-Board Computer System (OBC)

5. Satellite Testing

The two CubeSats were taken to University of Tartu Space Facility in Tartu, Estonia for the Vibration Test, Shock Test (Fig.6) and Thermal Vacuum Testing (Fig.7) and all these tests were performed at this facility throughout the development of the two CubeSats.

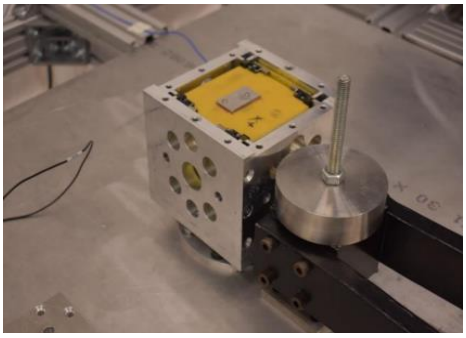

Figure 6. Shock Test on the Koit CubeSat

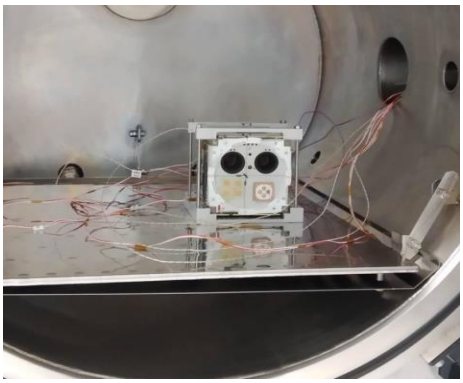

Figure 7. Thermal Vacuum Test of Hämarik CubeSat

Some of the tests like Magnetism Test on the CubeSat components were done at the NICP Laboratory of the TalTech University to analyse the magnetic behaviour of the CubeSat components like Battery Connectors, Battery Cover, Screws, Deployment Switch and Resistor [4]. The tests results showed most of the components showed paramagnetic behaviour so it was concluded that it will not have any effect on the CubeSat in the orbit.

6. Ground Station

The ground Station for the Satellites has two different types of Antennas. A UHF Antenna and a 5m parabolic dish S-Band antenna. Initially only a UHF Antenna was ready and later the 5m parabolic dish S-Band was developed atop the Mektory Space Centre Facility as shown in the Fig.8. List of equipment at the ground station includes software-defined transceiver and two steerable antenna systems operating in 432 MHz and 10 GHz amateur radio frequency bands. Ground station computer controls satellite tracking by antennas and remote operation of transceiver.

Figure 8. Parabolic Dish S-Band Antenna

Communication with the ground station works on two modes: two-way communication on 435.450 MHz radio band and one-way data download on 10.460 GHz (Koit) and 10.465 GHz(Hämarik).During two way communication, satellite shares its data and information about the status of subsystems, whereas ground station shares the information about next mission – what kind of pictures to take and which test to start. During one-way communication it is possible to download the pictures taken by the satellite. Since the data transmission is not fast enough to download all the pictures taken, image processing system in the satellite has to decide which ones are more valuable and worth to be kept. Satellite's communication protocol is AX 25.

7. Launch

Koit (TTÜ101) was integrated to the POD by Exolaunch GmbH in Germany (Fig.9) which was transported to Vostochny Cosmodrome in Russia where it was integrated with the Soyuz Rocket.

Figure 9. Koit (TTÜ101) integration in POD in Germany

It was launched (Fig.10) from Vostochny Cosmodrome in Russia on 5 July 2019 onboard Soyuz 2.1b mission [5].

Figure 10. Soyuz-2.1b Launch

Hämarik CubeSat was integrated into the Arianespace Vega Rocket by SAB Aerospace (Fig.11).

Figure 11. Hämarik (TTÜ100) integration in POD in Netherlands

The CubeSat was initially to be launched in the beginning of 2020 but due to the pandemic the launch was delayed and it was successfully launched (Fig.12) onboard the Arianespace VEGA SSMS (Small Satellite Mission Service) VV16 on 2 September 2020 from Europe's Spaceport in Kourou, French Guiana [6].

Figure 12. Vega VV16 Launch

8. Flight Results

The first contact with Koit (TTU101) CubeSat was made on 21st November 2020 after more than a year since its launch in 2019. It was the only satellite from the Soyuz launch that was above the horizon at the time, the correct assignment was found in the aforementioned catalog (NORAD 44401, provisionally named Object R). The satellites for this launch are highlighted in white as shown in Fig.13. A three-meter-diameter satellite dish and a 2 kW transmitter power of the Tõravere Observatory were used to send commands .Yagi Antennas in Tõravere and on the roof of the University of Tartu received messages from the satellite.

Figure.13 The first contact with Koit (TTU101)

Hämarik (TTÜ100) was launched in September 2020 it successfully separated from the launch vehicle and by the beginning of October; almost all the objects of this launch had been defined, with one exception, which was Hämarik (TTÜ100). Because of this, it was obvious it could be Hämarik (TTÜ100) (NORAD 46312, temporarily named Object AS). The position of Hämarik (TTÜ100) calculated from the start vectors is indicated in turquoise (Fig.14). The correct position is marked in red. All other satellites from this launch are marked in white.

Figure.14 Position Vector of Hämarik (TTÜ100)

Optical communication testing was one of the scientific missions of the CubeSats and for this purpose the CubeSats had LEDs. A small telescope on Earth could be used to observe their fly-by and also see the flashing. On the late evening of August 17 in 2021 at about 22:55 (Estonian Time), Dzmitry Kananovich, a senior researcher at TalTech University was able to capture the first image (Fig.15) of the Hämarik (TTÜ100) CubeSat in fly-by mode [7]. The distance from the satellite was about 792 km at the time image was taken and it had a brightness of ~ 10 magnitudes.

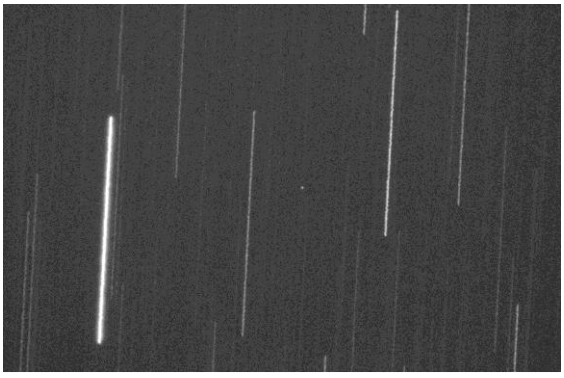

Figure.15 The little dot in the center is the Hämarik (TTÜ100) CubeSat

For this purpose a specific little tracker that could be fitted with camera systems weighing up to a few kilos was used. A consumer

camera lens was chosen as the telescope. It turned out that with this technique, an object flying by in the sky can be observed over 10 minutes so smoothly that even a subject with very low brightness can be viewed if the shutter speed of each frame is set to 2 seconds on the camera. There has not been any concrete communication with the Koit CubeSat that allows keeping regular contact with the CubeSat but Hämarik Cubesat is functional and the Satellite team at TalTech University continues to be in contact with the Hämarik satellite and its software has also been updated, though software with wider functions is still being developed. The main goal is to get the feature of taking pictures of the Earth to function. TalTech Satellite Team is working in coordination with DATEL, an Estonian IT Company with experience in space technology to achieve quick data connection, so that pictures of space taken by Hämarik could be sent back to Earth. Until today a few thumbnail images have been downloaded from the CubeSat and the next mission of the team is to determine the exact location of the satellite and focus the satellite's cameras towards the Earth so that the data received from the position control system's sensors can be displayed and complete images taken by the CubeSat can be downloaded. There is an optical sensor on each side of the satellite that acts like a small camera.

9. Conclusion

CubeSat development activity at TalTech University, Estonia has taken a good start with the successful development and launch of the two 1-Unit CubeSats and the preliminary results from these CubeSat missions has paid way to further continue the Satellite development activities at the University. The future goals for the Mektory Space Centre Satellite team includes analysing the results from the CubeSat missions that includes issues with long delay in contact with Koit CubeSat to prepare for the future Nano-Satellite activities to contribute towards Estonian Space technology activities. The Satellite team is currently planning to design and develop a PocketQube Mission as part of continuation of the Satellite development activities at TalTech University.

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