CUBESATS FOR IN ORBIT OBSERVATION OF MM SIZED SPACE DEBRIS

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ABSTRACT

In paper we present our upcoming CubeSat missions aimed at detecting millimeter sized space debris on orbit. The detection will be done by a space debris radar currently in development. As space debris objects in this size range are shielded from detection with ground based radars by the ionosphere, the space born radars will allow us to improve current models and deliver invaluable real world data on the densities present in the selected orbits.

Keywords: Space debris; radar; satellite.

1. INTRODUCTION

Space debris has always been a risk when operating spacecraft in orbits around the Earth, but the large growth in launch activity the last years, see figure 1, have greatly increased the number of objects, both payloads and space debris in orbit. With the increase of objects in orbit follows an increased risk of collisions. As space debris mitigation is stil being implemented too slowly, there is a rising probability of collisions in low earth orbits (LEO), as shown by predictions done in ESA's annual space environment report [2]. The report further goes on to show that even if we stop launching new objects into space, there will still be a growth in the number of space debris particles due to collisions between objects already in orbit.

Monitoring of space debris is generally carried out in two ways. Ground based radars can track larger pieces of debris, with the limit being a couple of millimeters in LEO [6]. Sub-millimeter particles have been studied by returned shuttle windows, radiators and solar panels [5]. Within active detection of sub-millimeter objects, a CubeSat was launched in 2019 which measured these with a piezoelectric dust detector [1] and recently the ADLER-1[1] 3U satellite launched with an active impact detector and a CW radar with a claimed range of a $100\,\mathrm{m}$. This leaves the $1\,\mathrm{mm}$ to $3.2\,\mathrm{mm}$ without any reported observations in the last $10+$ years, meaning that models need to interpolate here [5]. As particles as small as $0.1\,\mathrm{mm}$ can penetrate space suits [6], there is a need to improve our knowledge on these. From the latest available numbers on space debris from ESA [3], based on the MASTER-8 model [4] there are 130 million space debris objects between 1 cm and 1 mm in size. Only 32 800 objects of any size are currently tracked [3]. Thus it is evident that there is a need for an active, on orbit, measurement technique to characterise the debris smaller than 1 cm.

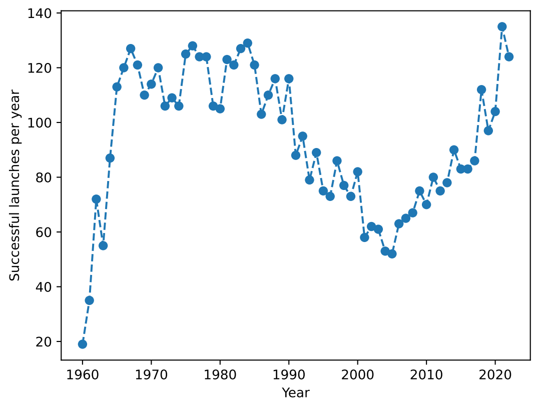

Figure 1. The number of successful launches per year. Data downloaded from DISCOSweb (https://discosweb.esoc.esa.int/) December 2022.

In this work we will present one ongoing and one upcoming projects aimed at detecting millimeter sized space debris particles using a radar. The first project, UNICube (UiT Narvik IVT Cube), is a university funded 2U CubeSat and the other, QBDebris (A CubeSat formation for space debris characterisation), is a 3U CubeSat funded by the Norwegian Research Council. UNICube aims for a launch in 2024/2025, and its primary aim is teaching

[1]Only information available: *https://adler.oewf.org/*

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students how to plan, design and build a satellite. Its secondary aims, which are dependent on the satellite working in orbit, is to demonstrate the successful operation of the space debris radar payload and some novel attitude-coordinated control algorithms. If the radar works, we hope to be able to calculate some orbital parameters, and statistics on the space debris encounters.

The second project, QBDebris, has a planned launch in 2026, and will consist of a modified commercial 3U CubeSat, which, when in orbit, will split into a 2U and a 1U satellite. Both satellites are planned to carry the space debris radar. The project's primary goal is to investigate leader–follower coordinated attitude control based on atmospheric drag. The secondary goal is to demonstrate the space debris radars and use them to detect millimeter sized space debris. By employing two satellites, measuring the same volume with the radars, it is expected that we will be able to calculate more of the orbital parameters.

In the following section, we will go through the theoretical justification for using a radar, the mission goals and plans, and what data is expected to be collected.

2. THEORY

Both of the projects presented here plan to use a millimeter wavelength radar to detect the millimeter sized space debris objects. Placing the radar in close proximity to the objects achieves two benefits. Firstly, the close proximity to the object results in a higher returned power due to the R^{-4} relation of the returned power with distance (R). This relationship means that even though the satellite radar will be much weaker than a ground radar, the return power will be higher if the radar is close enough to the target. Secondly due to the radar scattering cross-section, the returned radar power from an object is proportional to λ^{-2}. Shorter wavelengths (higher frequencies) are therefore advantageous for detecting these small pieces of space debris. As millimeter wavelengths are attenuated by the Earth's atmosphere, detection with them, requires them to be placed on a satellite.

If we assume that we are successful in adapting the shelf millimeter radar into one capable of measuring the Doppler shifts and sizes of the millimeter sized space debris, we can do a rough estimate of the number of objects detected per day using the ORDEM model [5]. If we assume a radar capable of detecting a 1 millimeter object at a range of 500 meters placed in a 400 kilometer orbit, we get an expected detection rate of 100 objects a day. With this number of detections per day, it would be possible to gather statistical data useful for verifying different space debris models and improving them. Even if the radar ends up having a shorter range, which depends on the radar gain, the radar should still be able to get a larger amount of detections than impact based detectors.

3. THE SATELLITES

In total, we have planned to launch a total of three satellites, all of them CubeSats. The first satellite will be a 2U CubeSat, built as part of a combined educational and research project UNICube. The main goal of UNICube is to teach the students how to build a working satellite and how to operate it, given that it has a successful launch. As our bachelor's and master's programs are focused on satellite technology, aerospace control system engineering and electrical engineering, the students are mostly interested in the satellite subsystems during their education, and not necessarily the payload. As a consequence, we included a research part related to the detection of space debris on orbit using a millimeter radar. As the satellite will be built by students without previous experience, under the guidance of supervisors, there is a chance the satellite might not operate as expected once in orbit. From an educational standpoint, this is still fine, as the students will still have learned a lot. However from a perspective of wanting to demonstrate the radar on orbit, it means that care will be taken to make sure the project will develop a working prototype of the radar, and demonstrate it in a laboratory setting. From there a working prototype in the lab will be integrated on the satellite. If for any reason the satellite fails, the radar will then get its first demonstration in the QBDebris project instead. However, if it is successful, we gain a great opportunity to improve on it before launching it as part of QBDebris.

The second project, QBDebris, is a research project planning to fly the radar. It is mainly aimed at showing leader–follower formation control of two satellites using differential drag, as well as synchronised rotation using coordinated attitude control. At launch, the two satellites will be joined together into one 3U satellite, which once in orbit, will be split into two satellites when given the command. One of the satellites will be a 2U satellite. In addition to the normal subsystems it will contain subsystems for ground communications, intra-satellite communication and a space debris radar. The second satellite will be a 1U satellite, which contains a space debris radar and an intra-satellite communication link, but no module for ground communication. By setting the satellites up in this way, it will be possible to maximise the space and power available for the space debris radar in both satellites. It does however mean that a failure of the 2U satellite results in a failure of both satellites. In order to minimise the risk of a failure, the project plans to use commercially constructed satellite busses with a flight record for the 2U and 1U satellites. Though, a custom separation interface between the two satellites will be needed. As this interface will only be triggered once the satellites are found to be ready for the separation, there will be an opportunity to run one of the radars before separation. By collecting data before the separation, we could ensure that some data will be collected in the event of a loss of the 1U or both satellites.

Both projects plan to launch the satellites from Andøya Spaceport, currently under construction. As the launches are currently planned for 2025 and 2026, it is expected that the spaceport will be operational by then. As these are small CubeSats, they will not be the main payloads on the launches, limiting the choices for which orbits are available. The location of Andøya Spaceport by the coast in Northern Norway means that it will be launching into polar orbits. We are hoping to be able to place the satellite in a polar orbit at between 400 and 500 km, which ensures a fairly high atmospheric drag and short lifetime (time to re-entry). As the satellites are planned without any active de-orbiting subsystems, it is important that they are placed in orbits that naturally de-orbit within a couple of years, thereby minimising the likelihood of them becoming space debris.

4. SPACE DEBRIS RADAR PAYLOAD

The planned radar will be a millimeter wavelength frequency-modulated continuous-wave (FMCW) radar based on a single chip design with a phased array transceiver. By integrating the chip, amplifier(s) and phased arrays on a PCB, it will be possible to reduce the size of the device enough that it can be placed on a small CubeSat, while keeping within the power budget of the satellite. Design considerations will be needed to cool the amplifier(s) in an adequate way. Additionally, there will need to be close monitoring of the power usage, allowing for reductions if there is a risk of power outages on the satellite.

As explained in section 3, both of the projects are going to fly the radar payload. Since the projects are different in design and maturity, care will be needed for the radar to fit both of them. As we are starting to develop the radar now, we have the ability to ensure that it can be used in both projects. This means that it will need to fit on the 1U-sized satellite. It is expected that the main scaling factor for size, weight and power usage will be the radar gain and antenna. The amplifier gain is controlled by its power draw. One of the challenges in the development of the radar is finding a small and powerful enough amplifier at the required frequencies around $80\,\mathrm{GHz}$. Another limitation of the 1U, is the available size for the antenna on one of the sides of the satellite. One size has roughly $100\,\mathrm{cm}^2$, while the 2U has twice the size. An antenna with a directivity of $20\,\mathrm{dB}$ requires an area of $25\,\mathrm{cm}^2$. With a fill factor of around $50\,\%$, this would amount to $50\,\mathrm{cm}^2$ for a phased array, which can be accommodated on the side of a 1U CubeSat.

To achieve successful detections of the speed of the space debris object in the millimeter range at relative orbital velocities of up to $16\,\mathrm{km\,s^{-1}}$ the radar will need to be able to detect Doppler shifts up to $9\,\mathrm{MHz}$. This should be achievable with current industrial grade radars, but it is a topic of the ongoing research to show that these devices can detect these Doppler shifts, as they are commonly used on much slower targets.

In total this means that the capabilities of the radar will need to be adjusted to the size of the satellite. The uptime of the radar will be limited by the power budget of the satellite. Important parameteres here is how large batteries and solar panels can be fitted. From this it is expected that the 2U satellites will have higher uptime on the radars. Alternatively the extra power could be spent on increasing the detection range.

4.1. Expected data

The goal of launching these radar payloads into orbit it to detect space debris. Ideally one would want to extract the raw radar data, transmit it to ground and process it there. Due to the link budgets on the satellites (they are planned to use S-band), data must be processed on the satellite itself. Processing will involve identifying detections of space debris, extracting the detection data and compressing it for downlinking. What exactly the transmitted data will contain will depend on the exact design of the radars. That said, we are aiming to be able to extract the point of detection (range and angle) with respect to the satellite, and the objects speed, from the measured Doppler Shift. Depending on the duty cycle of the radar it might be possible to get more than one detection per particle. More then one detection improves the quality and opens the possibility of being able to calculate a trajectory. Once a trajectory is estimated, a rough orbit can be found.

The number of detections per space debris object will be one of the design parameters optimised for when choosing how to operate the radar. The more detections per particle, the easier it will be to calculate a trajectory. This is valuable information, but there will most likely be a trade-of between the repetition rate in the radar and the probed volume. A smaller volume would result in fewer detections overall, but maybe at an increased accuracy. We plan on having the ability to adjust this on orbit. This would allow for different measurement campaigns focusing on optimising for different types of measurement, depending on how easy it is to reconfigure the radar. Additionally, the two satellites in QBDebris allow for the measurement of an overlapping volume of space. This lowers the total number of detections, with the befit of improving the trajectory determination.

Another parameter that we would like to say something about, is the object. This is somewhat trickier, as the only measurement we will have is the strength of the returned signal. In order to use the strength to calculate the size of the object one would have to make an assumption on the radar cross-section of the object and its relation to the size. It is unclear if such an assumption would be well-founded, as the radar cross-section depends on a lot of factors, from material and shape to orientation and size.

5. SUMMARY

We have presented our plan for the upcoming projects related to flying a space debris radar on small CubeSats with the aim of detecting millimeter sized particles. Over the next years we plan on launching a total of 3 satellites, two 2U CubeSats, and one 1U CubeSat, on two launches. All the satellites are planned to fly a millimeter wavelength frequency modulated continuous wave space debris radar we are currently developing. By flying these satellites we hope to fill the gap in current detections of space debris in the size range from $1\,\mathrm{mm}$ to $10\,\mathrm{mm}$.

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