Advancing nano-satellite platforms: The Delfi Program

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ADVANCING NANO-SATELLITE PLATFORMS: THE DELFI PROGRAM

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ABSTRACT

The Delfi Program aims to launch a nano-satellite every 2.5 years with the objectives to give the best education for space engineering, to test and qualify novel space technology and to enhance the nano-satellite platform to open doors for new applications. With Delfi-C^3 in orbit, Delfi-n3Xt in development for a launch in 2010 and preliminary plans for the future, TU Delft wants to put itself at the top level of small satellites engineering. Although the size of nano-satellites puts some constraints on the potential performance and applications, the theoretical limits are still far ahead and nano-satellites might have more potential than typically assumed. This potential can only be made possible if the development goal for each satellite matches the availability of resources and a realistic planning in time.

1. INTRODUCTION

Nano-satellites developed by universities have a mass range of 1-10 kg, which are orders of magnitude smaller than typical scientific and commercial satellites developed by the large space organizations. Their applications until 2008 were restricted to technology demonstration, qualification of small subsystems and limited scientific objectives. This paper will provide insight in new opportunities of very small satellites when continuous advancement in nano-satellite technology is guaranteed.

Delfi-C^3, the first nano-satellite of Delft University of Technology (TU Delft) [1], was launched on the PSLV-C9 launch on 28 April 2008 [3] (FIG 1). After four months of operations, all systems are performing well and Delfi-C3 can be considered a full mission success [2]. The second nano-satellite of TUDelft, Delfi-n3Xt, is close to its preliminary design review and planned for a launch in the summer of 2010.

Figure 1 – PSLV-C9 launch (source: ISRO)

2. DELFI PROGRAM OBJECTIVES

The Delfi Program aims to launch a nano-satellite every 2.5 years. Two of the objectives in this program are similar to most nano-satellite projects. The first objective focuses on the educational aspects. The second objective is to provide a platform for micro-systems for the purpose of in-orbit testing and qualification. The third objective aims for an advancement of the nano-satellite platform.

2.1 Educational Objective

The Delfi Program will provide students an optimal education and preparation for careers in space industry. MSc and BEng students can perform their thesis or internship on the project. All benefits of theoretical studies can also be applied to theses on a more practical Delfi project, including improvement of (scientific)

writing skills and gaining in-depth knowledge and expertise. This is complemented with an improvement of team skills, hands-on experience and management skills.
The educational objective will be the main driver for Delfi projects and mission success will mostly be based on this objective.

2.2 Technical Objective

The technical objective is to perform testing and (pre-) qualification of novel space technology. This could mean a miniaturization of existing space technology, integration of several sensors or actuators into one package or completely new features for space applications. Most of the payloads on Delfi-satellites are supported by the MicroNed subsidiary program of the Netherlands, in which the MISAT cluster is focusing on micro-technology for space applications in small satellites [4].

2.3 Development Objective

The development objective is to advance the nano-satellite platform, adding a long-term vision for the development and thereby distinguishing itself from many nano-satellite programs world-wide. The level of advancement will be determined at the start of each satellite project within the program and will create a technology push. It will enable the TU Delft to gain more expertise and explore new disciplines in the space sector. Higher performance and more functionality will open the door for new payloads and scientific experiments with demanding satellite bus requirements. Another reason to have more ambitious objectives than only supporting the payloads and the educational benefits, is the motivating force to move the nano-satellite to a mature satellite platform and beyond. As long as the boundaries of ambitious plans are realistic, excitement amongst staff and students will be very valuable to the individual projects and the program. Constraining the size of the satellites in the Delfi program to a three-unit Cubesat standard (30 cm x 10 cm x 10 cm) in combination with the ambitious objectives will also cause a technology pull. Optimization of the sizing of subsystems in terms of power, volume and mass will be necessary to fulfill the growing needs set by these objectives. It also allows for proper comparison between the individual satellites, because those important design drivers are kept constant.

3. DELFI PROJECTS

There is currently one Delfi satellite in orbit (Delfi-C^3), one satellite under development (Delfi-n3Xt) and preliminary plans for the future. The educational objectives for all satellites are the same, although expansion of involved faculties and disciplines at the TU Delft is expected. The technical objectives are driven by the payload proposals from industry and the development objectives are increased for each project.

3.1 Delfi-C^3

The Delfi-C^3 project [1] (FIG 2) started in November 2004 and supported over 30 students performing an MSc thesis at the TU Delft chairs of space systems engineering, micro-electronics engineering and computer engineering on a part of Delfi-C^3 topic. Over 40 BEng students from various universities of applied sciences performed their thesis or internship on the project. Looking at the amount of graduated students and the fact that all who pursued a career in space industry succeeded in finding a job in the space sector (more than 10 people), the educational objective of Delfi-C^3 is well met [3].
The technical objective of Delfi-C^3 is to perform in-orbit testing and qualification of an Advanced Wireless Sun Sensor (AWSS) from TNO and Thin Film Solar Cells (TFSC) from Dutch Space. The first three months after launch, Delfi-C^3 collected and transmitted many payload data in science mode and therefore the technical mission objectives are also met.
Currently Delfi-C^3 is used successfully as a linear transponder for radio amateurs worldwide and is therefore also known under the name OSCAR-64. Almost weekly, Delfi-C^3 is switched back to science mode to measure the long term performance of the payloads.

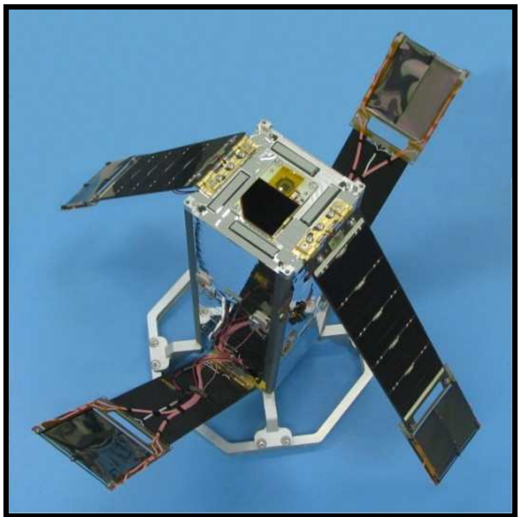

Figure 2 – Delfi-C^3 with deployed solar panels

3.2 Delfi-n3Xt

The Delfi-n3Xt project [5] (FIG 3) started in November of 2007 and is currently approaching the Preliminary Design Review (PDR). It will support five payloads: a radiation tolerant commercial-off-the-shelf memory implementation (NLR), a multiple particle spectrometer (cosine Research), a high efficiency transceiver for CubeSats (ISIS – Innovative Solutions in Space), amorphous silicon solar cell degradation performance measurement (DIMES) and micro-thruster based on cold gas generators (TNO, TU Delft, UTwente). Development objectives are set in an electrical power subsystem with fault-tolerant energy storage and maximum power point tracker, autonomous three-axis stabilized attitude determination and control a variable data-rate transmitter on the S-band and an easy accessible structural subsystem. Furthermore, like on Delfi-C^3 there will also be a linear transponder for radio amateurs and it is currently investigated if it is possible to receive and pass very low frequency bands through the transponder for radio astronomy applications.

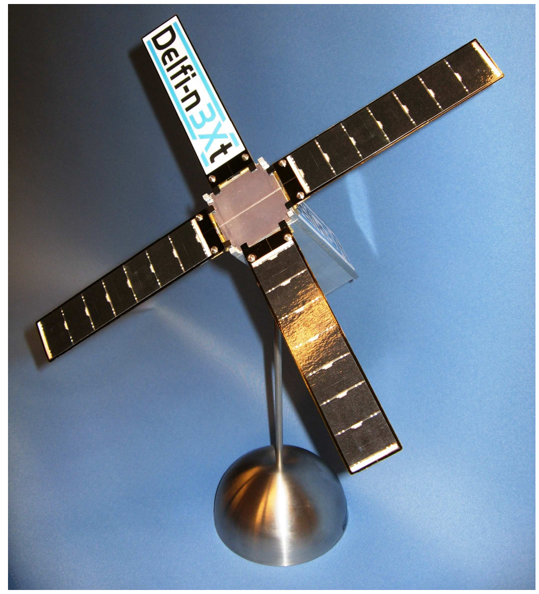

Figure 3 – Delfi-n3Xt Artist Model

3.3 Future Delfi Satellites

Delfi-Star is the working title for the third TU Delft nano-satellite. Although no official call for payloads have been issued, there are already some candidates which have a development time matching the schedule for this project (starting 2010, launch in 2012/2013). A selection of those candidates: an inflatable de-orbit device [6], a GPS receiver in a small package and a micro-gravity-gradient meter.

For the development objective, autonomous formation flying seems to be a likely candidate together with better performance on most satellite bus subsystems. Scientific mission objectives will be considered after the selection of payloads. There is also the possibility that femto-satellites will be developed at the TU Delft in the future, either as stand-alone or child satellites of a nano-satellite using intra-satellite links. Femto-satellites have a mass range between 10 and 100 grams and can be regarded as a satellite-on-one-PCB, and imply even further miniaturization and integration of satellite subsystems. A potential application is monitoring of the upper parts of the atmosphere, in very low Earth orbits.

4. OPPORTUNITIES AND LIMITATIONS FOR NANO-SATELLITES

Opportunities for nano-satellites can be found in niche applications on the short term and conventional satellite applications in the long term if advancement in performance continues. Lack of creativity and physical limitations are the only real showstoppers for many applications, but there is still an abundance of opportunities for nano-satellites to be explored. However, nano-satellites are often regarded as unsuitable for many space applications and branded to be only suitable for academic excercises. In the next paragraphs, a few subsystems are worked out to show that the limitations of nano-satellites are less stringent then one would typically think.

4.1 Power

Power available is limited by the sizing of the solar array and the onboard energy storage. For this analysis it is assumed that the incoming (solar) power is the most important driver for space applications.

There are developments to increase the efficiency of conventional solar arrays, but there are no realistic indications that this will increase the efficiency by more than a few percent. Other developments are thin film solar cells, like the payload onboard Delfi-C^3, which have higher power to mass ratio but lower efficiency. For very small satellites this would mean a relatively large area of solar cells. Deployment mechanisms would be needed which add complexity and mass, reducing the effective power to mass ratio. For TFSC, a 100 Watts per kilogram performance is expected in the near future. Delfi-C^3 uses conventional GaAs solar panels. If Delfi-C^3 panels would all face the sun, and the total mass of solar panels (cut to its minimum size), mechanisms and electric circuits is considered, an effective power to mass ratio (including conversion efficiency) of 51 W / kg would be generated. If 75 Watts per kilogram is taken as an upper limit for effective power to mass ratio in the future, including mechanisms and electrical power conversion circuits, this would still mean a large potential. Note that this is only true if the satellite has two axis stabilized sun pointing attitude control, to get the maximum out of incoming solar light. If 50% of the total satellite mass could be assigned to the electrical power subsystem, this would yield a maximum of 375W for a 10 kg nano-satellite.

4.2 Communication

The performance limitations for communication depend on a large number of variables. Available electrical power, attitude control and antenna directionality are the main drivers for the communications design from a satellite bus perspective. Current payloads in the Delfi program do not require high amounts of data rate. Therefore a technology push is chosen from the development objective. While Delfi-C^3 downlink is limited to 1200 bits per second on the VHF band (FIG 4), Delfi-n3Xt will be equipped with an S-band transmitter capable of delivering much higher data-rates. The minimum is set to 9.6 kilobits per second, but the radio can be dynamically adjusted in orbit to allow for discovering the end-to-end limits in a real-life situation. Another step in development is a technology change from linear to switching mode power amplification in the radio system, which increases typical efficiencies from 30% to approximately 80%, which is a significant improvement. This will first be tested on Delfi-n3Xt in the VHF band.

Commercial potential of communication systems in nano-satellites could be found in some niche markets in the near future, but considering the maximum potential power as calculated in section 4.2, constellations of nano-satellites could even be interesting for the large commercial applications such as television, radio and telephone signals.

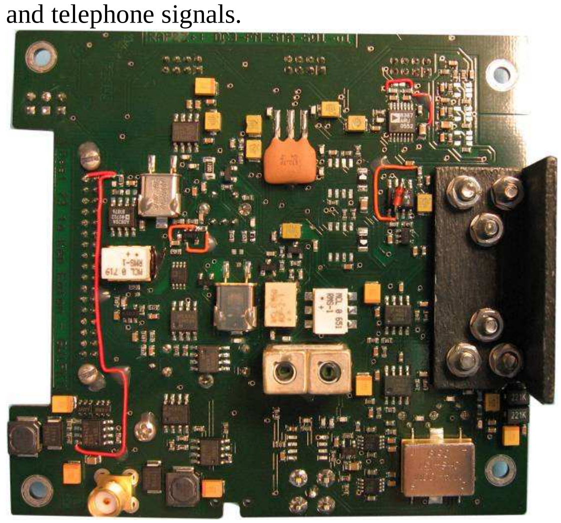

Figure 4 – Transceiver with linear transponder of Delfi-C^3

4.3 Attitude Control and Determination

Attitude determination is limited by sensor technology rather than the algorithms used. Horizon scanners and magnetometers cannot be made more accurate than a few degrees. Small sun sensors can be made accurate to decimals of degrees. Only star trackers seem to be capable of delivering better accuracies, but these are still quite large. There are developments going on for very small multi-baffled star trackers which might be capable of arcminutes accuracy for the size of nano-satellites. These star trackers are eventually photon limited for its size, which means that there are boundaries at the amount of stars visible and hence the accuracy.
Controls for actuators have fewer limitations, since Micro-Electrical-Mechanical Systems (MEMS) is still in early development and is physically limited to the size of molecules. This would yield control torques on nano-scale, which is currently unnecessary for space application. It is more likely that natural vibrations will be the limiting factor in satellites, even for the sizes of nano-satellites. Since the full control loop includes both determination *and* control, the theoretical limits lie mostly at the sensor side.

5. RATE OF ADVANCEMENT

In chapter 4, it is made clear that nano-satellites still have a large potential for advancement compared to the level at which most of the nano-satellites worldwide are at the moment.
It is very tempting to increase functionality and performance requirements in an academic environment. To achieve performance near the theoretical limits is a very motivating goal. However, care should be taken that theories have to be proven in real practical applications to receive acknowledgement and belief. For the Delfi program, a two-and-a-half year period is chosen to launch a nano-satellite. For the development time, one year needs to be subtracted for proper mission definition at the beginning and the assembly, integration and test phase at the end. This leaves one-and-a-half year to implement the performance upgrade for each subsystem. The upgrade of satellite bus performance between Delfi-C^3 and Delfi-n3Xt is significant, as indicated in Table 1, but does not take the design close to the theoretical limits. Delfi-C^3 was designed as a robust first satellite but its quantifiable performance indicators are not very impressive. It is designed for reliability and also has a few unique features which make it notable; especially looking at the radio which is equipped with a linear transponder for radio amateurs (the first nano-satellite) and the two innovative payloads. Delfi-n3Xt will already place itself amongst the top of nano-satellites in quantifiable performance, without compromising the reliability of the systems and the presence of innovative unique features. Availability of human resources, technical expertise, finance and an effective development time of one-and-a-half year are the drivers for the step-size of advancement for each satellite. Assuming that resources remain constant through time, one could expect that the difference between performances of the sequential satellites will decrease when those are closer to the theoretical limits. On performance level, advancement in the field of nano-satellites can be regarded as evolutionary. Looking at novelties, nano-satellites are ideal test-beds for revolutionary technology in the space sector.

Table 1: Performance Comparison Delfi-C3 & Delfi-n3Xt

Subsystem	Delfi-C^3	Delfi-n3Xt
Attitude Determination and Control	passive rotation damping, spin rate 0.2–10 ^{o}/s	3-axis, 2^o determ. accuracy, 5^o control accuracy
Communication	1.2 kb/s downlink in VHF, 0.6 kb/s uplink in UHF	1.2 kb/s downlink in VHF, >9.6 kb/s (variable) downlink in S-band , 0.6 kb/s uplink in UHF
Command and Data Handling	redundant: I^{2}C & voltage controlled	faile-safe I^{2}C
Electrical Power	2.8W, omni-directional, no power in eclipse	12W average (also eclipse), sun-pointing
Payloads	2 payloads, ~20% of total volume	5 payloads ~50% of total volume
Structural	Standard CubeSat structure	Improved structure for better accessibility
Thermal	passive	passive

ACKNOWLEDGEMENT

Delfi-C^3, Delfi-n3Xt and the whole Delfi program in general could not have been possible without the work of all students, staff, project partners, financial support of subsidiary programs, support in kind of various project sponsors and the radio amateur community. In arbitrary order we would like to thank the following partners and sponsors:
Alstom, Amsat-UK, cosine Research, Cyner, DIMES, Dutch Space, Harwin, ISIS – Innovative Solutions In Space, Logica, MAVOM, MicroChip, MicroNed , NLR, Systematic Design and TNO.

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