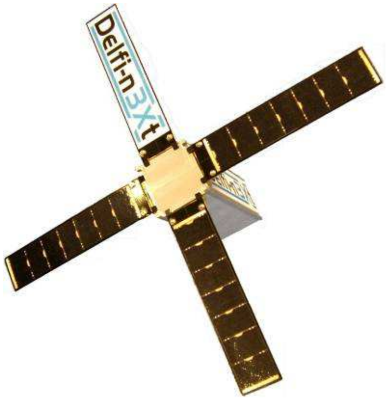
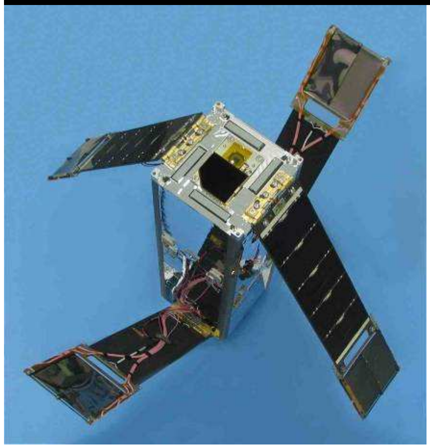


From the Delfi-C3 nano-satellite towards the Delfi-n3Xt nano-satellite

Geert F. Brouwer, Jasper Bouwmeester



Delft University of Technology, The Netherlands
Faculty of Aerospace Engineering
Chair of Space Systems Engineering

SSC09-XII-12

23rd Annual AIAA/USU Conference on Small Satellites

Content

- Delfi program objectives
- Delfi-C^3 key mission characteristics and operations
- Delfi-C^3 Lessons Learned
- Changing from Delfi-C^3 to the n3xt project
  - similarities, differences, challenges, payloads -
- Summary of lessons learned on Delfi-C^3
- Summary on Delfi-n3Xt

Delfi Program Objectives

- Main objective:
  Give students hands-on experience of a real life satellite project

- Secondary objective:
  Provide a means for fast and (relatively) cheap in-orbit technology demonstration

Delfi-C^3 Key Mission Characteristics

- 3-unit CubeSat of 2.2kg
- Transceiver doubles as Radio Amateur transponder
- No battery
- Passive ADCS, UHF uplink, VHF downlink
- 635 km sun-synchronous orbit
- Thin Film Solar Cells payload (Dutch Space)
- Autonomous Wireless Sun Sensor payload (TNO)
- 3 years development time
- ~60 students involved, 4 FTE staff (man hour ratio ~ 6:1)
- 314 registered radio amateurs around the world

Delfi-C^3 Launch & Operations

28 April 2008, 03:53 UTC	Launch
06:39:08 UTC	First ground contact (radio amateur in California, USA)
11:49:51 UTC	First contact Delft Ground Station
30 April 2008, 10:50:42 UTC	Delfi-C^3 CDHS set to Read-Only mode to prevent early flash memory failure
29 July 2008, 10:00 UTC	Switch from Science Mode to Transponder Mode
End of September 2008	First signs of transponder degradation
14 October 2008, 11:00 UTC	Switch to Basic Mode to investigate problem
29 Jan. 2009, 09:33:17 UTC	Switch to Science Mode

Operations are continuing

Lessons Learned on Delfi-C^3 (1)

- Structure Subsystem

  The bought-out body from Pumpkin presents limitations in design.
  E.G. Top- and Bottom platforms were replace by custom design; other items needed modifications.
- POD

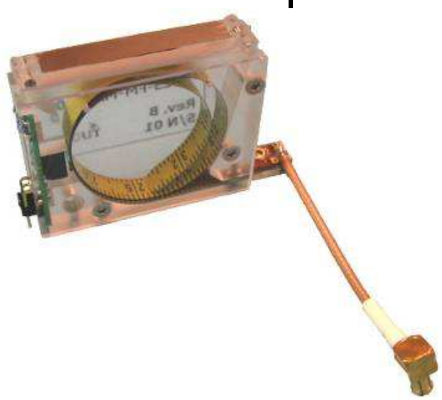
  We needed a larger POD to launch because of deployable solar panels and ordered a custom design type
- On Board Computer

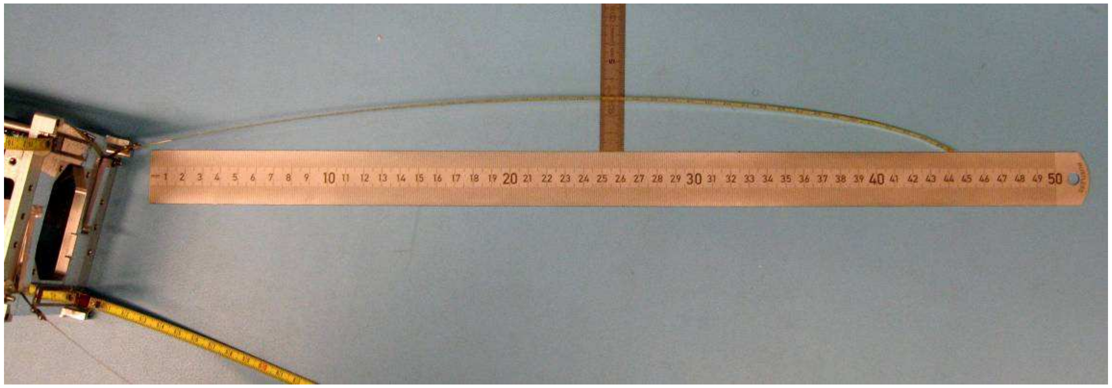
  The OBC from Pumpkin functions well in Delfi-C^3.
  However more than half of the PCB is not used in our design and uses room that could have been applied more efficient. Also the interface did not match with our system bus; so a work around was made

POD - Poly Picosatellite Orbital Deployer

Lessons Learned on Delfi-C^3 (2)

- Deployable items
  - Thermal cutting of Dyneema wire for deployables functions well. COTS resistors were used as thermal knife on the solar panels and the antennae.
- Modular Antenna Box
  - The VHF/UHF antennae of Delfi-C3 are stored in a box during launch.
  - After deployment of a spare antenna (20 month in its box) we saw plastic deformation (3 cm displacement).





Lessons Learned on Delfi-C^3 (3)

- Thermal Control
  - DRAWBACK: Too many wired thermocouples for test can disturb results by heat leaks during thermal vacuum test.
    Therefore more temperature sensors should be incorporated in the design for temperature monitoring of the satellite.
    As well as in flight and for on-ground testing.
- Assembly integration and test
  - The tube body of the cube sat kit limits the accessibility to the hardware inside
  - An electronics stack with rods is time consuming in assembly and in particular when you need to replace a PCB
  - EMC provisions After experiencing loss of a number of PICs, we obliged wearing EMC wrist straps, when working on hardware.

PIC - Programmable Interrupt Controller

Lessons Learned on Delfi-C^3 (4)

- Vibration testing
  - We experienced several shut downs of the vibration test due to rattling of the push-out spring of the POD. Damping was applied.
- Ground Support Equipment
  - We designed a <u>modular</u> integration rig matching with cube sat standard; it proved to be very useful
  - Many other custom made MGSE items (>20) facilitated assembly, integration and test activities
  - For electrical testing mostly standard equipment was used.

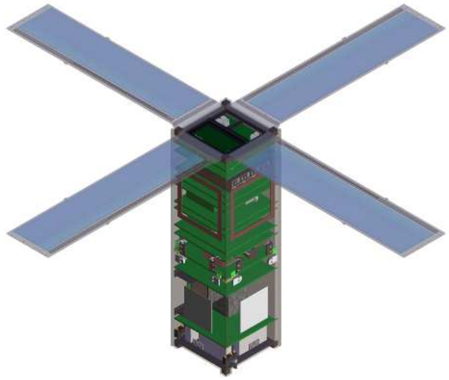
- Launch and operations
  - Launches tend to delay. Keep sufficient people in project in last phase; *students graduate and disappear*

Lessons Learned on Delfi-C^3 (5)

- Cooperation with industry
  - Delfi-C3 project had good cooperation with the Dutch industry and institutions on advice, testing, delivery of small quantities space grade materials
  - Sponsoring was obtained in products, manufacturing and software usage.
  - It was noticed, that many students, that worked on Delfi-C^3, could rather easily get a job in domestic space industry and abroad. Industry show appreciation for students with hands-on experience.
  - In turn the project provides early flight opportunities to test new technological developments at relatively low cost.
  - It is worthwhile to maintain these relations.

It works out beneficial for both parties.

Changing to Delfi-n3Xt
- General characteristics -



Delfi-C^3	Delfi-n3Xt
• 1st Dutch University Satellite • (4th Dutch satellite) • 3 unit CubeSat • 8 deployable antennae • 4 Deployable solar panels • Single point failure free • Sun powered without battery	• 2nd Dutch University Satellite • 3 unit CubeSat • 4 Deployable UHF/VHF antennae • 1 S-band antenna • 4 Deployable solar panels • Single point failure free • Sun powered with battery

Changing to Delfi-n3Xt

- Attitude Determination & Control -

Delfi-C^3	Delfi-n3Xt
• Passive rotational rate damping • 2 magnetic hysteresis rods • 1 permanent magnet • 2 wireless sun sensors • 4 photodiodes on solar panels	• Active 3-axis control • 2-axis sun pointing • 1-axis control for: payloads & S-band antenna • 6 redundant sets of photodiodes • 1 fine sun sensor • 3 MEMS gyros • 3 magnetometers (COTS) • 3 Reaction wheels • 3 custom made magnetorquers

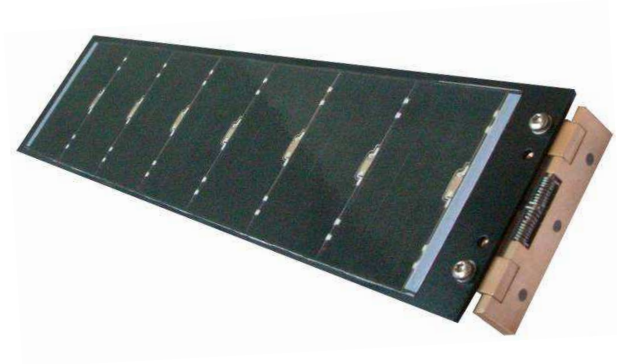
Changing to Delfi-n3Xt
- Command and Data Handling -

Delfi-C³	Delfi-n3Xt
• Pumpkin FM430 OBC (TI MSP-430 at 8 MHz) • 17 local microcontrollers (PICs at 31 kHz - 20 MHz) • I^2C bus, max. 15 kbps • Decentralized backup mode • Integrated redundant system bus	• 2 redundant OBCs (TI MSP-430 at 8 MHz) • 20 local microcontrollers (MSP-430s at > 1 MHz) • I^2C bus, 100 kbps • Fault-tolerant design • Redundant Kapton flex-rigid system bus

Changing to Delfi-n3Xt
- Communication -

Delfi-C3	Delfi-n3Xt
• 2 UHF-VHF radios • VHF downlink: 1200 bps • UHF uplink (Delft ground station) • 4 VHF antennae (omni-directional) • 4 UHF antennae (omni-directional) • 1 linear transponder for radio amateur use	• 2 UHF-VHF radios, • VHF downlink: 1200 - 9600 bps • UHF uplink (Delft ground station) • 9.6 – 250 kbps S-band downlink • 4 shared UHF-VHF antennae (omni-directional; Delfi-C3 design) • 1 S-band patch antenna (uni-directional) • linear transponder for radio amateur use

Changing to Delfi-n3Xt
- Electrical Power -



Delfi-C³	Delfi-n3Xt
• 4 panels in omni-directional configuration • 2.4 W of guaranteed power • Direct energy transfer method • No battery • 12 V standard bus • System tolerance for discontinued power	• 4 panels in one plane • 18 W max power, 10 W average • Maximum power point tracking method • 4 Li-ion batteries (failure protection to prevent total failure, degradation only) • Single point failure free electrical power system • 12 V standard & variable voltage bus

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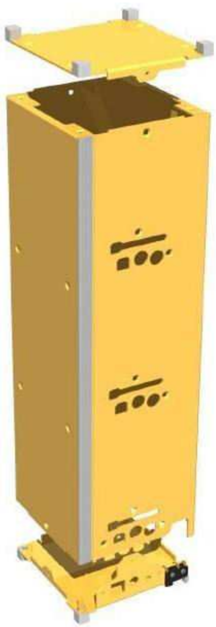
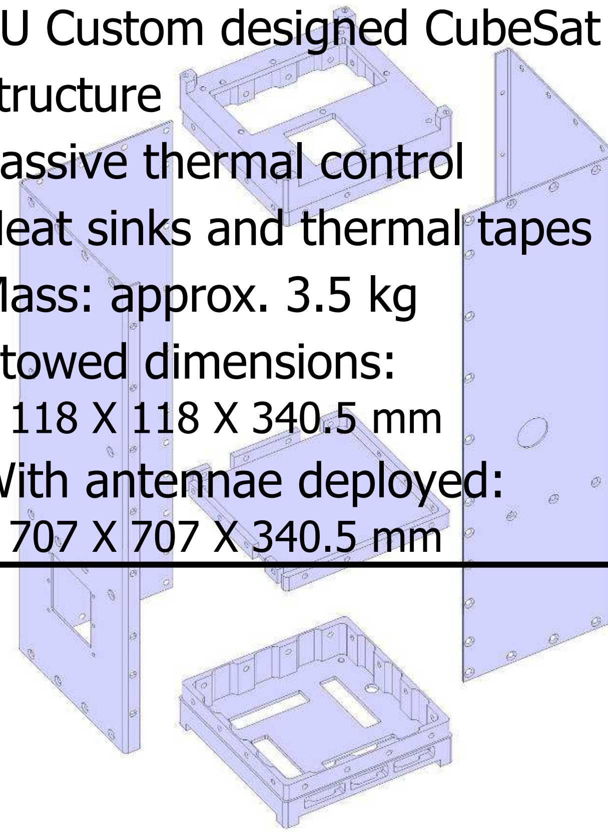
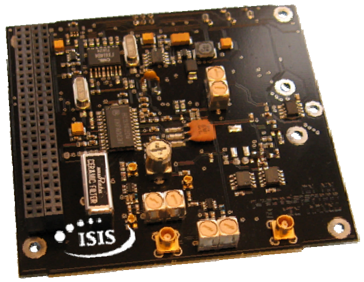
Changing to Delfi-n3Xt
- Structure Subsystem & Thermal Control -



Delfi-C³	Delfi-n3Xt
• 3U CubeSat structure from Pumpkin • Passive thermal control • Heat sinks and thermal tapes • Mass: 2.2 kg • Stowed dimensions: 118 X 118 X 340.5 mm • With antennae deployed: 770 X 770 X 800 mm	• 3U Custom designed CubeSat structure • Passive thermal control • Heat sinks and thermal tapes • Mass: approx. 3.5 kg • Stowed dimensions: 118 X 118 X 340.5 mm • With antennae deployed: 707 X 707 X 340.5 mm

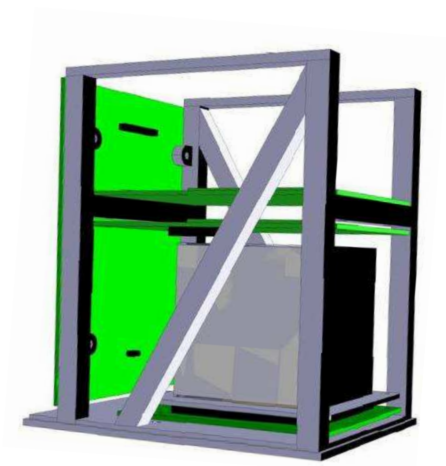


Changing to Delfi-n3Xt
- Payloads – (1)



1. ITRX

- In orbit test of High Efficiency UHF-VHF Transceiver with switching power amplifier.
- Transceiver is specifically intended for CubeSats.
- Key characteristics: VHF downlink in 145 MHz radio amateur band, UHF uplink in 435 MHz radio amateur band, 1200–9600 bps downlink data rate, 1.5 W total power consumption and 400 mW RF power.
- The ITRX is under development at ISIS B.V.



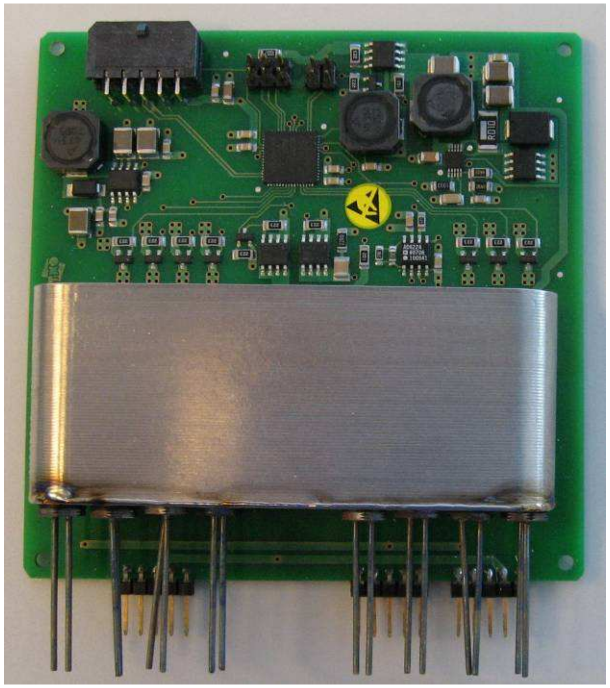
2. Multifunctional Particle Spectrometer (MPS)

- In-flight demonstration spectrometer to detect and differentiate the energy level, type and incidence angle of individual incoming radiation particles.
- Key characteristics: detection of γ, e-, p+, 3He, 4He, C, N, O and Ne particles, 10° incidence angle accuracy
- 3 W total power consumption and 80 mm x 80 mm x 65 mm in size, mass about 0.5 kg. Mounted on intermediate platform.
- The MPS is under development at cosine B.V.

Changing to Delfi-n3Xt
- Payloads – (2)

3. T3µPS

- Space-qualification of cold-gas micro propulsion system with gas produced by cold gas generators.
- The unit is not pressurized at launch and therefore very safe.
- Key characteristics:
  fixed thrust level (selectable at manufacturing between 6 and 150 mN).
  The GN2 propellant is stored in cool gas generators (CGG).
  Ignition power: 11 W for ~10 s.
  Mass < 140 grams;
  dimensions are 90 x 90 x 21 mm.
- T3µPS is under development at TNO together with TU Delft and University of Twente, the Netherlands



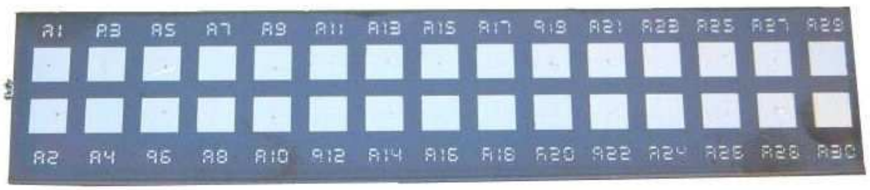
Changing to Delfi-n3Xt
- Payloads – (3)

4. SPLASH

- In-orbit proof of concept of radiation tolerant implementation of commercial flash memory cards, with latch-up protection and error detection and correction (EDAC).
- Key characteristics:
- 2 x 4 GB of data storage on SD card,
  max. 1 W of power consumption, dimensions approx. 50 x 50 x 10 mm
- SPASH is under development at NLR Laboratories

5. Space degradation measurement of silicon solar cells

- Low cost in-orbit verification of lab research on 14 hydrogenated amorphous silicon solar cells for degradation by radiation.
- I-V curves and temperature are measured.
- SDM is being build by DIMES.



Changing to Delfi-n3Xt

Optional Payloads

- **Micro Sun Sensors**

  TNO Science and Industry proposed to provide a set of four micro sun sensors as an optional experiment.

  It can be combined with the fine sun sensor in a common housing

- **Orbiting Low Frequency Array** (OLFAR)

  The TU Delft Faculty of EEMCS is developing a prototype transponder for transferring low frequency (30 kHz – 20 MHz) signals from deep space.

  The possibility of implementation is currently being investigated

  The experiment might not take more room on a PCB than 30x30 mm and will use available communication lines of the satellite.

  - In-orbit proof of concept.

Lessons learned on Delfi-C^3

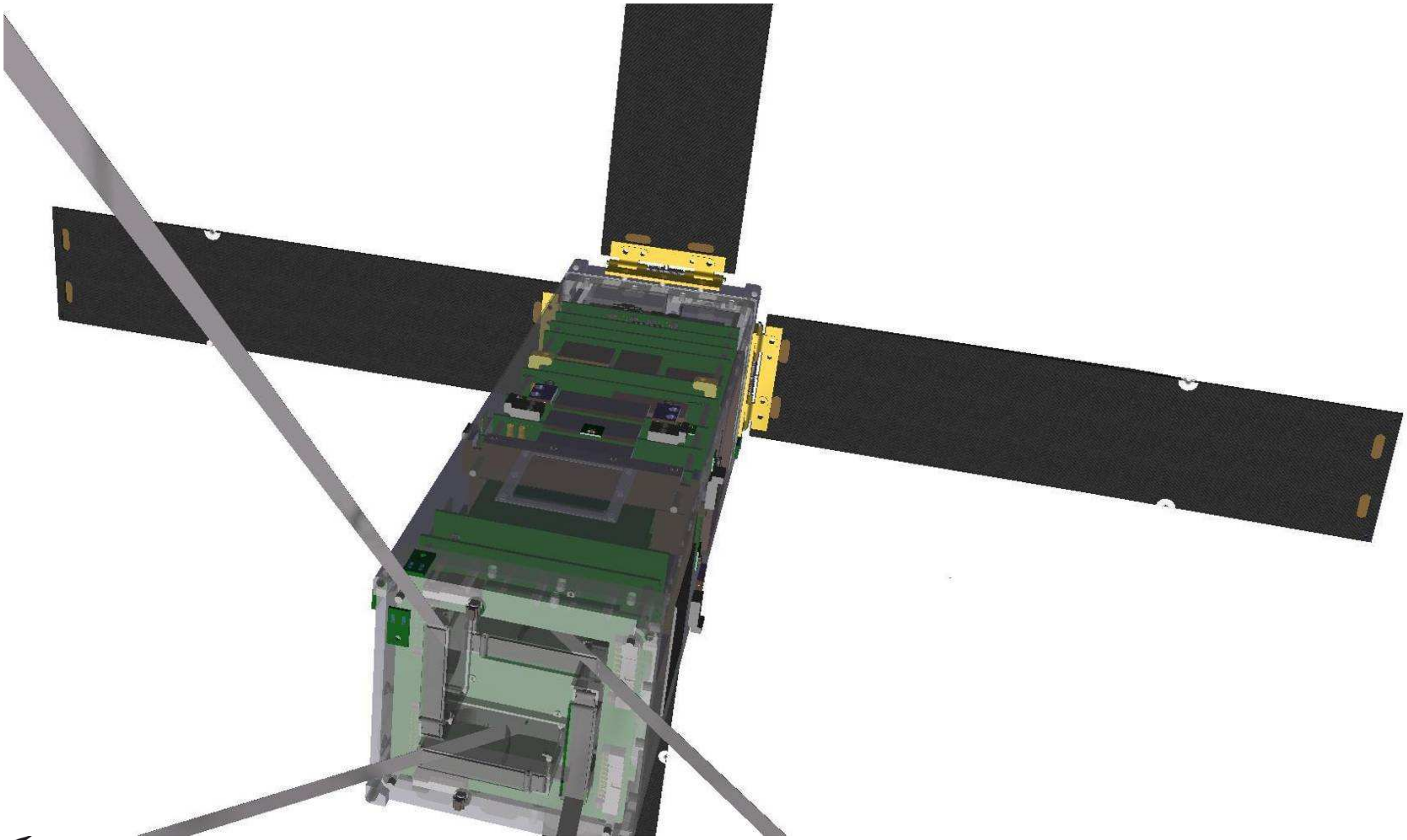
- Delfi-C^3 mission is a full success
  (434984 datasets obtained by July 21st 2009)
- Bought-out CubeSat kit can be a limiting factor to design
- Some more room for deployable items inside standard Pods' would be advantageous
- All 12 deployables using thermal cutting of Dyneema thread on Delfi-C^3 functioned well
- Use sufficient temperature sensors in your design (rather than thermocouples during thermal vacuum test)
- COTS photodiodes are very suitable as sun sensors
- Rolled up tape measure material as antenna may deform when stored for a longer period of time
- Take measures for continuity on a university project:

  students graduate and disappear

Summary on Delfi-n3Xt

- Delfi-n3xt puts a lot of challenges to the team:
  - Single point failure free
  - Sun powered with 4 Li-ion batteries
  - 3-axis active attitude control with sun pointing
  - 5 payloads and 2 optional payloads
  - Custom designed structure
  - Redundant OBC
  - Passive thermal control
  - Combined VHF-UHF antennae
  - S-band downlink at Delft ground station

Delfi-n3Xt



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