4D Space
Preliminary Design Review

University of Oslo
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1.0 Mission Overview

Name of Presenter
Mission Overview: Action Items from CoDR

• **Weight**
  - Estimated to 40lbs, will probably be a bit lower
  - Includes full module (doors and all daughters). May be different when NASA produces the skin
  - The daughters will be statically balanced.
  - The balance of the full module is estimated to be near the axis of rotation and 6 cm from the top of the module. The module can be spin balanced if necessary.

• **Battery**
  - 1 cell 500mAh LiPo battery for each daughter
  - Charging through standard USB cable (MCP7381 charging circuit)
  - Charging circuit is powered from USB. Circuit is dead when cable is disconnected.
  - Charging only planned while daughters are not installed in main module
  - Charging current: 0.5C (ca. 250mA), well within capacity of batteries
  - Very little self discharging. No lifetime test performed so far.
Mission Overview: Action Items from CoDR

• Pyro
  – Wallops will be in charge of triggering the pyro (agreement made with ASC)

• Skin
  – Wallops will produce skin (agreement with ASC)
Mission Overview: Mission Statement

The experiment will demonstrate the feasibility of multipoint high-resolution electron density measurement using the 4DSPACE payload module:

- Multipoint measurement will facilitate the understanding in the ‘big picture’ of ionospheric plasma condition.

- Characterizing the plasma density at kinetic scale.

- The obtained data can be used to study plasma turbulence and instability for space weather forecast. And increase reliability of GNSS systems.
Mission Overview: Mission Objectives

- Successfully release six sub-payload modules, a.k.a. ‘daughters’, into space.
- Successfully establish communication
  - All daughter sub-payloads can communicate with the access point on the ‘mother’ payload section.
  - Daughters contact each other for localization purpose.
- Successfully measure electron density using Langmuir probe systems deployed on the daughters.
  - multi-Needle Langmuir probe (m-NLP) or single Needle Langmuir probe (NLP) systems are used to characterize plasma structures with high sampling rate up to several kHz.
  - Measure platform potential of the daughters after being released.
  - Electron emitter are successfully deployed to mitigate the sub-payload modules charging effect.
  - Measured data is transmitted to the control board on the mother payload section.
- Post-flight data analysis to study plasma turbulence and instability.
  - The in-situ measurement can then be compared with other indirect measurement.
Mission Overview: Theory and Concepts

- **Positioning and attitude**
  - Localization in a wireless network of the six daughters will be based on RSSI.
  - by onboard gyro, magnetometer and accelerometer

- **multi-Needle Langmuir probe (m-NLP) system:**
  - Has long been developed and deployed on more than 7 sounding rockets.
  - Measure absolute electron density at high sampling rates (several kHz) - high spatial resolution (up to meters)
  - Determine the spacecraft floating potential.

- **Spacecraft charging mitigation by electron emitter.**
  - The daughter platforms likely charge to a negative potential as a result of the current balance in ionosphere. The more collected electrons by the onboard probe system, the more negative the spacecraft floating potential, that deteriorates the electron density measurement performance.
  - Electron emitter is deployed to shoot out ‘redundant’ electrons, and/or strips of metal foil are used to increase the conductive area of the daughters.
Mission Overview: Concept of Operations

1. **Launch**
   - Power/Telemetry begins

2. **Launch to Apogee**
   - Power/Telemetry continues
   - Daughters released
   - Min release time ~ 10 s
   - Daughter flight time ~ 275 s
   - Max separation ~ 1200 m
   - Separation speed ~ 4.4 m/s

3. **Apogee**
   - Nose cone separation
   - Skin separation
   - De-spin to TBD rate
   - Power/Telemetry continues
   - Daughter separation at apogee ~ 500 m

4. **Descent**
   - Power off at TBD time
   - Telemetry continues

6. **Splashdown**
   - Telemetry terminates
<table>
<thead>
<tr>
<th>Event</th>
<th>Time On</th>
<th>Dwell</th>
<th>Event Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>GSE 1</td>
<td>T-300 sec</td>
<td>635 sec</td>
<td>Power main payload module</td>
</tr>
<tr>
<td>GSE 2</td>
<td>T-300 sec</td>
<td>635 sec</td>
<td>Power main payload module</td>
</tr>
<tr>
<td>TE-1</td>
<td>T+000 sec</td>
<td>360 sec</td>
<td>NA</td>
</tr>
<tr>
<td>TE-2</td>
<td>T+000 sec</td>
<td>360 sec</td>
<td>NA</td>
</tr>
<tr>
<td>TE-3</td>
<td>T+000 sec</td>
<td>360 sec</td>
<td>NA</td>
</tr>
<tr>
<td>TE-RA</td>
<td>T+60 sec</td>
<td>1 sec</td>
<td>Pyro to trigger release of doors</td>
</tr>
<tr>
<td>TE-RB</td>
<td>T+61 sec</td>
<td>10 sec</td>
<td>Start carousel to eject daughters</td>
</tr>
</tbody>
</table>

Based on Mission Time Line of 335 sec.

Release of sub-payloads some time after burnout but before de-spin.
Mission Overview: Expected Results

• We expect to see that all six daughter sub-payloads are released well.

• If everything works as designed, each of the daughter modules should execute its measurement mission and transmit data to the control board on the mother payload section, then the data can be transmitted to the ground station via telemetry in real-time.
  
  - We expect to receive transmitted data that includes measured currents by the probe system (which then give ambient electron density and daughter platform potential), attitude information given by the gyro, magnetic field and acceleration sensors, and RSSI information for daughter localization purpose.
  
  - And that multipoint electron density measurement would be able to provide the separation of temporal and spatial variations in electron density, as well as provide bases to study plasma turbulence and instability.
Mission Overview: Success Criteria

**Minimum Success Criteria:**
- Deliver and qualify 4DSPACE module and sub-modules for flight (educational objective)
- Release of the daughters and establish communication to the rocket and further to ground

**Comprehensive Success Criteria:**
- Continuous data retrieval for whole traveling path of the daughters,
- Retrieve valid data for calculation of electron density and platform potential
- Retrieve valid housekeeping data and RSSI for calculation of the daughter’s position/path
2.0 System Overview

Name of Presenter
Design Overview: Science Design

Main payload (4DSPACE module):
- Mother payload section consists of six sub-payload modules, a.k.a daughters.
- ‘Puck’ shaped daughters are released by the mother payload section to measure temporal and spatial variations of ambient plasma density.

Sub-payload Instrumentation:
- Each of the daughters accommodates an instrumentation section, which includes either multi-Needle Langmuir probe (m-NLP) or single Needle Langmuir probe (NLP) system to characterize ambient plasma with high sampling rate up to several kHz.
Design Overview: Engineering Design Overview

Main payload (responsible: ASC):
- Main payload design will be done by Andøya Space Center.
- The design has heritage from the previous Maxidusty project and will be modified to the RockSat-X platform.
**Design Overview: Engineering Design Overview**

- **Sub-payload:**
  - **Science Instrument (UiO)**
    - The probe system design has heritage from our sounding rocket and satellite versions of the probe instrumentation with some modifications to accommodate the requirement of available space and power consumption of the daughters.
    - Daughters will employ electron emitter with tungsten filament taken from light-bulb to control the sub-payload potential.
    - A probe of m-NLP (4 probes) or NLP has a length of few centimeters, together with its bootstrap section. Where each probe is supported by a spring-loaded boom.
  - **Communication and power board (ASC)**
    - Each daughter sub-payload will be powered by 1 cell 500mAh Lipo battery and have a transceiver system with around 2 Mbits data speed. Attitude information of the daughters will be given by onboard gyro, magnetic field and acceleration sensors.
## Top Level Requirements:

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Verification Method</th>
<th>Description</th>
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</thead>
<tbody>
<tr>
<td>Ejection of the daughters and correct release of probes.</td>
<td><strong>Test</strong></td>
<td>Remove lid to demonstrate release of probes</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Spin test to verify release mechanisms</td>
</tr>
<tr>
<td>Communication</td>
<td><strong>Test</strong></td>
<td>Test communication between daughters and main payload</td>
</tr>
<tr>
<td>• between daughters and main payload</td>
<td></td>
<td>Test communication between main payload and RockSat-XN using the Equipment (GSE) suitcase. Can this be provided earlier than the first integration? E.g. in Norway?</td>
</tr>
<tr>
<td>• Between payload and RockSat-XN</td>
<td></td>
<td></td>
</tr>
<tr>
<td>The main payload shall fit on the RockSat-XN rocket.</td>
<td><strong>Inspection / Analysis</strong></td>
<td>Specification from Wallops used for CAD design. CAD design should be validated and approved by Wallops? Visual inspection during first integration</td>
</tr>
<tr>
<td>The system shall survive the vibration, spinn characteristics prescribed by the RockSat-XN program.</td>
<td><strong>Test</strong></td>
<td>The system will be subjected to these vibration, spin loads in June during testing week.</td>
</tr>
</tbody>
</table>
Design Overview: Payload Mechanical Concept

- Daughter sub-payload
- Neatly stacked on mother payload
- Released in pairs

- Payload mechanical development will be done by Andøya Space Center.
Design Overview: Main payload electronics design

Design will be done by ASC.
Design Overview: Sub-payloads electronics

- Instrument
  - SPI
  - I2C
  - GPIO/ADC

- Microcontroller board
  - JTAG Port (ISP)
  - header J×X
  - header J×X

- nRF24l01 PA module

- 2.5GHz

- 9DOF Gyro, Accel., mag.
  - I2C

- 5V

- UART

- Micro Switch

- FTDI

- LiPo bat. charging circuit and power conv.

- Battery (3.7 V) LiPo

- USB connector

PDR
Design Overview: Sub-payload Instrument

- **Langmuir Probe**
- **Microcontroller (TI Hercules)**
  - Bias ctrl
  - Gain select
  - ADC ctrl
  - ADC data
- **ADC**
- **FPGA IGLOO**
- **Electron Emitter**
- **Voltage regulator**

Connections:
- To ASC microcontroller board (Communication and power)
- Regulated 5V from ASC uC board
- SPI

Blocks:
- ADC ctrl
- ADC data
- SPI
- SPI
- SPI
Design Overview: Sub-payload Instrument

- First prototype of Hercules-based mNLP
- CubeSat version
  - Parallel development for different project
- Will be modified to sub-payload form factor.
- Integrates analog and digital on single board
## User Guide Compliance: Summary

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Status/Reason (if needed)</th>
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<tbody>
<tr>
<td>Center of gravity in 1&quot; plane of plate?</td>
<td>N/A</td>
</tr>
<tr>
<td>Weight 30.0+/- 1.0 (15.0 +/- 0.5) lbs?</td>
<td>40 lbs (may be reduced)</td>
</tr>
<tr>
<td>Max Height &lt; 10.75&quot; (5.13&quot;)</td>
<td>9&quot;</td>
</tr>
<tr>
<td>Bottom of deck has flush mount hardware?</td>
<td>N/A</td>
</tr>
<tr>
<td>Within Keep-Out Zone</td>
<td>N/A</td>
</tr>
<tr>
<td>Using &lt; 10 A/D Lines</td>
<td>Using 2 lines</td>
</tr>
<tr>
<td>Using/Understand Parallel Line</td>
<td>Yes</td>
</tr>
<tr>
<td>Using/Understand Asynchronous Line</td>
<td>Not using</td>
</tr>
<tr>
<td>Using X GSE Line(s)</td>
<td>GSE-1 and GSE-2</td>
</tr>
<tr>
<td>Using X Non-Redundant PWR Lines (TE-1, TE-2, TE-3)</td>
<td>No</td>
</tr>
<tr>
<td>Using X Redundant Power Lines (TE-R)</td>
<td>Yes</td>
</tr>
<tr>
<td>Using &lt; 1 Ah (.5 Ah for half payload)</td>
<td>0.3 Ah</td>
</tr>
<tr>
<td>Using &lt;= 28 V</td>
<td>Yes</td>
</tr>
<tr>
<td>Using RF (If yes, list frequency and TX Power)</td>
<td>Yes, 2.5 GHz at &lt;130mW .</td>
</tr>
<tr>
<td>Using deployable?</td>
<td>Yes, 6 deployable circular «pucks»</td>
</tr>
<tr>
<td>Using ITAR and/or Export Controlled hardware</td>
<td>Holex 2800, provided by NSROC</td>
</tr>
</tbody>
</table>
System Overview: Special Requests

- Separate section on RockSat-XN. Not standard instrument deck.
  - To fit 4DSPACE module.

- Knowledge of spin before and after spin stabilization

- Time of spin stabilization

- Updated mission time line (input to simulation for daughter localization)

- Auroral activity as desired launch condition
Subsysystem Design: Detailed Weight Budget

- Weight of full 4DSPACE module is estimated to ~40 lbs.
- With skin made by NASA Wallops, this may change
- The weight of one sub-module is ~0.77 lbs (350 g)
- These estimates are subject to change due to redesign.

<table>
<thead>
<tr>
<th>Subsystem</th>
<th>Total Weight (lbf)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4DSPACE module, incl all</td>
<td>~ 40 lbs (18 kg)</td>
</tr>
<tr>
<td>1 Sub-payload</td>
<td>~ 0.77 lbs ()</td>
</tr>
<tr>
<td>Total</td>
<td>40</td>
</tr>
<tr>
<td>Over/Under</td>
<td>10.00</td>
</tr>
</tbody>
</table>
**Subsystem Design: Detailed Power Budget**

- Main payload: 160 mA, 28V during full flight (4.5 W)
- Except for when the carousel is used to eject the daughters: 360 mA, 28V for 10 seconds (10 W)
- These are estimates based on most recent test.
- However, electronics will be redesigned and values may change
- Calculation based on 335 seconds (~0.1h) flight from Mission Time Line Excel sheet.
  - \( Ah = \text{Current [A]} \times \text{Active time [h]} \)
- Sub-payloads are not included as they run independently on battery and will not affect the power consumption of the main modules connected to the rocket.

<table>
<thead>
<tr>
<th>Subsystem</th>
<th>Voltage (V)</th>
<th>Current (A)</th>
<th>Time On (min)</th>
<th>Amp-Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main payload Carousel inactive</td>
<td>28V</td>
<td>160 mA</td>
<td>300 + 325 sec</td>
<td>0.028</td>
</tr>
<tr>
<td>Main payload Carousel active</td>
<td>28V</td>
<td>360 mA</td>
<td>10 sec</td>
<td>0.002</td>
</tr>
<tr>
<td><strong>Total (A*hr):</strong></td>
<td></td>
<td></td>
<td></td>
<td><strong>0.030</strong></td>
</tr>
<tr>
<td>Under</td>
<td></td>
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<td><strong>0.970</strong></td>
</tr>
</tbody>
</table>
Description of Partnerships

• As of this point no official partnerships
3.0 Subsystem Design

Name of Presenter
Subsystem Design: Structures

- Weight balance of main payload is estimated to be near the spin axis and about 6 cm from the top.
  - Can be spin balanced if necessary.

- Sub-payload has static balancing while 4D-space module is estimated to be near spin-axis and ca 6cm from the top of the module. If necessary it could be spin-balanced

- Sub-payload can be installed after 4D-space module has been assembled
Subsystem Design: Structures Main module

![Diagram of Structures Main module with various views.](image)
Subsystem Design: Structures Sub-payload
Subsystem Design: Power

- Power is provided by the communication board.
- Each sub payload is powered by a one cell 500mAh LiPo battery, charged at 250mA outside of the 4DSpace module, not possible to charge while installed to the module.
- The batteries are charged by standard usb-mini and charging is controlled by IC MCP7381 as shown in the picture below. The charge circuit is usb powered so the circuit is dead when there is no charging.
- No need for charging after installation, due to low self discharging.
- mNLP voltages is 5V
Subsystem Design: Science (mNLP)

Multi-Needle Langmuir Probe (m-NLP)*
- 4 fixed biased needle probes
- kHz sampling rate (~m resolution)
- Design heritage from MaxiDusty & QB50
- Communication link & mechanical design by ASC
Subsystem Design: Science

Cathode  Anode  Focus

Assembly held together by four hex nuts
Hex nuts as spacers during prototyping
Conductive outer shell as spacers in final product
Miniaturized light bulb
Electron gun elements aligned by four miniature screws

Plated through-hole on PWB as electrode

Faraday cup
Anode
Grid
Filament
Filament emitter
Acceleration voltage
Simulator voltage

PDR
Subsystem Design: Command and Data Handling

• All command and data handling will be conducted by onboard microcontrollers.

• Takes raw data from instrument on sub payloads and transmit to main payload in data windows of 20ms, so that no sub payload will transmit data at the same time. Each data window will send a package with housekeeping from each sub payload (IMU data, current/voltage, temp, time) and the rest of the window will be sensor data
  • Radio: nRF24L01+PA+LNA

• Communication between main payload and rocket is thought to be done through 16 bit-parallel data line (a redesign is needed to adapt to NASA interface)
Design Overview: Data flow

Langmuir Probe → FPGA IGLOO

DMA interrupt
12000 bytes/s (1000 samples/s)

Sample buffer

Get 1 sample from SPI DMA buffer

Average

RAW_DATA

Process data (electron density)

Create packet

Packet buffer

2000 packets

28 bytes/packet

Send packets to microcontroller board

Hercules Microcontroller

10000 samples

12 bytes/sample

more

Y

N

Send packets to microcontroller board
Subsystem Design: Antennas

- Standard S-band blade antenna on module
- Planar inverted-F antenna (PIFA) on sub-payloads
4.0 Risk Matrices

Name of Presenter
Risk Matrix: Main payload

MP.R1: Mission objectives aren’t met IF daughters won’t release
MP.R2: Mission objectives aren’t met IF communication with main payload isn’t established
Risk Matrix: Sub-payload

SP.R1: Mission objectives aren’t met IF communication with main payload isn’t established
SP.R2: The m-NLP does not release
SP.R3: Current drawn from the battery before launch
5.0 Test/Prototyping Plan

Name of Presenter
Test/Prototyping Plan

Test plan for sub-payloads
- Battery test (how long does the battery last)
- Communication test to between sub and main payload
- Test electron gun
- Test probes and full readout of data (source current to probe)
  - Calibration of probes
  - Need electronics from ASC and system (rocksat emulator) to communicate with this electronics.

Test plan for main payload
- Release of Sub-Payloads
- Build sub payload and 4dspace electronics for testing in lab.
6.0 Project Management Plan (PMP)

Name of Presenter
Management: Team Organization

Team supervisor
Ketil Røed

Technical support
UiO ELAB
Andøya Space Center

Senior engineer
Espen Trondsen

Team members
Fredrik Lindseth Winje (*)
Henrik Bjoner Lie (Science)
Andrei Costescu (Instrumentation)
Ole Martin Vister (Positioning)
Huy Minh Hoang (Instrumentation, Science)
Tom Morten Berge (Communication, pos.)
Eirik Nobuki Kosaka (Software)

(*) Team lead
## Management: Preliminary schedule (CoDR)

### Table: Schedule Overview

<table>
<thead>
<tr>
<th>Tasks</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
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<td>Sub-payload integration</td>
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### Diagram: Timeline

- Today

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**Note:**
- CoDR (Conceptual Design Review) is scheduled for April 2017.
- Instrumentation design is scheduled to start in June 2017 and continue through to October 2017.
- Sub-payload integration is scheduled to begin in January 2018 and continue through to May 2018.
- Full Mission Sims are scheduled for May 2018.
Management: Preliminary schedule (PDR)

<table>
<thead>
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Management: Budget

• **Funding has been secured from the Norwegian Space Center (NRS)**
  – to cover engineering of payload module at Andøya Space Center
  – to cover the RockSat-XN program fee

  – Students can apply for 50% coverage of travel and registration fee costs from NRS
  – Students may look for sponsoring options
  – Instrument expected to be covered by associated research projects at UiO. Strong overlap with parallel development for e.g. ICI5 and ongoing CubeSat activities.
  – Plan to apply for SiU funding.
## Management: Contact Matrix

### Team Name/School Here: University of Oslo

<table>
<thead>
<tr>
<th>Role</th>
<th>Name</th>
<th>Day Phone</th>
<th>Cell Phone</th>
<th>Receive Texts?</th>
<th>Email</th>
<th>Citizenship</th>
<th>Add to mailing list?</th>
</tr>
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<tbody>
<tr>
<td>Supervisor</td>
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<tr>
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<td><a href="mailto:t.m.berge@fys.uio.no">t.m.berge@fys.uio.no</a></td>
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<td><a href="mailto:e.n.kosaka@fys.uio.no">e.n.kosaka@fys.uio.no</a></td>
<td>Norway</td>
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</table>
Risks/Worries:

- Communication between the six daughter payloads and the mother payload section.
- If the communication link fails to establish, we would not get any measurement data from the daughters.
Conclusion

• Multipoint high-resolution electron density measurement is significantly needed to understand the ‘big picture’ of ionospheric plasma condition by providing the separation of temporal and spatial variations in ambient electron density.

• Success of the program will enable us to deploy constellations of even more sub-payloads for multipoint scientific studies of ionospheric plasma, as well as to provide viable solutions to deal with spacecraft charging effect in tiny spacecraft.

• **Looking forward toward the CDR, the team’s next step will be:**
  – **ASC**
    • Continue redesign of sub-payload electronics
    • Continue modification of main payload (elec. + mech.) for RockSat platform
  – **UiO:**
    • Testing/Debugging of new Hercules based board
    • Implement SW for Hercules board
    • Adopt board to sub-payload form factor
    • Modification and testing of electron emitter
    • Mechanical implementation of electron emitter in the sub-module
    • Further development and validation of positioning concept