Realizations and prospects

University of Liège,
June 18, 2009
Agenda

13h45: welcome and registration
14h00: presentation « OUFTI-1 : realizations and prospects »
15h00: visits and demonstrations
15h30: « verre de l’amitié »
Outline

A. OUFTI-1 project

B. Technical overview

C. Concluding remarks
Outline

A. OUFTI-1 project
   1. A brief recall about OUFTI-1
   2. System & team overview
   3. Mission objectives
   4. Project organization chart
   5. Lessons learned

B. Technical overview

C. Concluding remarks
1. A brief recall about OUFTI-1

CubeSat standard  Three payloads  VEGA Maiden Flight

ULg, Helmo-Gramme, HEPL ISIL
2. System & team overview

STRU: Gauthier PIERLOT

MIAS: Vincent BEUKELAERS

EPS: Pierre THIRION

OBC: Damien TENEY

THER: Lionel JACQUES

ADCS: Samuel HANNAY

COM: Renaud HENRARD
François MAHY

AX.25: Johan HARDY

MECH: Jérôme WERTZ

GND: Laurent CHIARELLO

Exp.EPS: Philippe LEDENT

MHP: Nicolas EVRARD
3. Mission objectives

1. Fun and education
3. Mission objectives

1. Fun and education
2. Design of the OUFTI-1 system
3. Launch of OUFTI-1
4. Having the satellite alive in space
5. Operating the satellite
6. Having the D-STAR functional
7. Operating the secondary payloads
4. Project organization chart

Work Package 1 (WP1)
- 1 task
- 1 student
- 1 advisor
- 1 specialist

WP2

WP...

WPn

System engineers team

Project Manager(s)

Industrial advisory board
5. Lessons learned (1)

- Technical issues are not the most time-consuming
- Crucial need for rigorous documentation
- Need for full-time project manager and well-defined organization chart
- Multidisciplinary team: not easy to manage, but really enriching
- Autonomy and initiative spirit must be learned
- Interfaces can not be managed by students
5. Lessons learned (2)

- Strong interest & support from academics, ham-radio community, industrial, and general public
- Real & great CubeSat community spirit
- Numerous discoveries and encounters
- Highly motivated team
- Everybody (not only students) learns!
Outline

A. OUFTI-1 project

B. Technical overview
   1. Configuration and structure (STRU)
   2. Attitude Determination and Control System (ADCS)
   3. Thermal subsystem (THER)
   4. Mission analysis (MIAS)
   5. Electrical Power System (EPS)
   6. On-Board Computer (OBC)
   7. Measurements of Housekeeping Parameters (MHP)
   8. Communication subsystem (COM)
   9. Antennas deployment mechanism (MECH)
  10. Ground segment (GND)

C. Concluding remarks
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C. Concluding remarks
1. Configuration

- COM + BCN
- Battery
- Homemade OBC
- Pumpkin OBC
- Antennas deployment mechanism
- Pumpkin structure
- Solar cell
- Solar panel
- Exp. EPS
- EPS

Diagram:

- 1. Configuration
- COM + BCN
- Battery
- Homemade OBC
- Pumpkin OBC
- Antennas deployment mechanism
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- Solar cell
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- Exp. EPS
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Diagram:

- 1. Configuration
- COM + BCN
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- Pumpkin OBC
- Antennas deployment mechanism
- Pumpkin structure
- Solar cell
- Solar panel
- Exp. EPS
- EPS
1. Configuration
1. Structure

Preliminary vibrations tests:
Good correlation between FEM and experimental results (1st frequency above 500Hz)
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C. Concluding remarks
2. ADCS

• Responsible for the orientation
• Two major kinds:
  • Active ADCS
    • More accurate…but
    • More complex
    • Fuel dependant…
  • Passive ADCS
    • Based on magnetic materials
    • Hy-Mu-80, Permenorm 5000H2

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Alnico – 5</th>
<th>Hy – Mu – 80</th>
<th>Permenorm 5000H2</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \rho )</td>
<td>7.3( [g/cm^3] )</td>
<td>8.747( [g/cm^3] )</td>
<td>8.25( [g/cm^3] )</td>
</tr>
<tr>
<td>( H_c )</td>
<td>5.09( \times 10^4[A/m] )</td>
<td>1.59( [A/m] )</td>
<td>5( [A/m] )</td>
</tr>
<tr>
<td>( B_s )</td>
<td>–</td>
<td>0.73( [T] )</td>
<td>1.55( [T] )</td>
</tr>
<tr>
<td>( B_t )</td>
<td>1.28( [T] )</td>
<td>0.35( [T] )</td>
<td>0.755( [T] )</td>
</tr>
</tbody>
</table>
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C. Concluding remarks
3. Thermal subsystem

- 2 cases: hot case and cold case
- Active system for batteries in cold case

- Thermal insulation of batteries
- Influence of the orbit definition
- Influence of the ADCS system
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C. Concluding remarks
4. Mission analysis

- Objectives: quantify the system parameters and the resulting performances

1. Orbit parameters

2. D-STAR in space

3. Space environment
4. Mission analysis: orbit

Main parameters:

- Orbit LEO
- Perigee/ apogee: 354/1447 km
- Inclination: 71°
- Launch on 1/11/2009
- Orbital period (103 min), 75.8% in sunlight,
- 14 revolutions per day
- Mean power available: 3.1 W
- Mean integrated power: 2.4 W
4. Mission: D-STAR in Space (1)

<table>
<thead>
<tr>
<th>Access (min)</th>
<th>Number/day</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>14,33</td>
</tr>
<tr>
<td>Max</td>
<td>20,35</td>
</tr>
<tr>
<td>Min</td>
<td>7,42</td>
</tr>
</tbody>
</table>

Around 30% over oceans!

Footprint length:
Apogee: 6837 km  Perigee: 3183 km

Orbit suitable for using D-STAR in space.
4. Mission: D-STAR in Space (2)

- 2 system-selected Doppler-compensated coverage zones
  - ULg for control
  - Dynamically determined

- Personnal Doppler – compensation possible within OUFTI-1 coverage zone
4. Mission: Space environment

- Radiations: restrictive on the mission lifetime

→ Global and local shielding with aluminium

- Space vacuum (10E-11 Pa)
  → Blowing up
  → 15% mass lost

- Destructive impact probability: 7.2E-4 over one year
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C. Concluding remarks
5. Electrical Power System (EPS)

Energy management in the CubeSat

Production

Conditionning

Storing + charging

3.3V

5V

7.2V
5. Main EPS: architecture
5. Main EPS: engineering model

Command of the antennas deployment system

Measurements circuits

Power dissipation system

Three converters (3.3V, 5V et 7.2V) to supply other parts of CubeSat
5. Future work

- Prototype of the battery-PCB
- Test of Exp.EPS
- Test of the entire EPS
- Interconnect EPS with other subsystems
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C. Concluding remarks
6. OBC: overview

- **Roles of the on-board computer**
  - Perform measurements and handling of housekeeping and scientific parameters
  - Encode telemetry and handle telecommands
  - Perform electrical power supply management
  - Manage the payloads

- **Constraints**
  - Very low power available
  - Desire of very high reliability
6. OBC: hardware solution (1)

- **Reliability through simplicity**
  
  One central processor, handles all tasks

  Doubled for redundancy: only one active at a time

---

Diagram:

- **OBC1** (backup)
- **OBC2** (default)

Periodic « heartbeat » signal

I/Os

...
6. OBC: hardware solution (2)

- Reliability through simplicity
  One central processor, handles all tasks

Doubled for redundancy: only one active at a time

Periodic « heartbeat » signal
6. OBC: hardware solution (3)

- Reliability through simplicity
  One central processor, handles all tasks

  Doubled for redundancy: only one active at a time

  Periodic « heartbeat » signal

  Texas Instruments MSP430

  I/Os

  ...
6. OBC: software solution

• Architecture
  - Modular/flexible software architecture
  - 6 general purpose modules:
    - monitoring (housekeeping, EPS management)
    - measurements
    - communications
    - sequencer (pre-planned sequences of operations)
    - log
    - clock (on-board time reference)

• Implementation
  - Use of FreeRTOS, open-source, lightweight, real-time OS
  - Programmed in C-language
6. OBC: future work

- **Hardware**
  
  OBC hardware 100% functional

  Flight models to be manufactured

- **Software**

  Generic implementation of software functional

  OUFTI-1 mission-specific details to be integrated
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C. Concluding remarks
7. How to take those measurements?

Current sensors (max8838)

ADC (ADS7830)

I2C connectors

ADC (MAX1039)

Temperature sensors connectors (LM94022)

EEPROMS
7. How to take those measurements?

Temperature sensors (lm94022)

Switch (MAX890)
7. Measurements on EPS

- ADC
- Current sensors (max8838)
- Temperature sensors connectors (LM94022)
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C. Concluding remarks
8. COM: 3 means of communication

Diagram showing the flow of communication through different protocols:
- Front-end RF chain (Rx)
- D-Star Rx
- AX.25 Rx
- D-Star Tx
- AX.25 Tx
- Beacon Tx

Connections indicate the flow between these components, with various directions and arrows pointing to and from each module. The diagram also includes an interface to OBC and a clock generator.
8. COM: beacon
8. COM: AX.25

AX.25:
- Ham radio protocol
- Modem G3RUH
- 9600 baud
- 2-FSK

AX.25 is mainly used for telecommands & telemetry (CCSDS format)

• Structure of a AX.25 frame

<table>
<thead>
<tr>
<th>Flag</th>
<th>Address</th>
<th>Control</th>
<th>PID</th>
<th>Info</th>
<th>FCS</th>
<th>Flag</th>
</tr>
</thead>
<tbody>
<tr>
<td>01111110</td>
<td>112/224 Bits</td>
<td>8/16 Bits</td>
<td>8 Bits</td>
<td>N*8 Bits</td>
<td>16 Bits</td>
<td>01111110</td>
</tr>
</tbody>
</table>

Bit stuffing - NRZ-I encoding - scrambling
8. COM: D-STAR

- Simultaneous data and voice digital transmission
- Data: 1200 bps - Voice: 3600 bps (AMBE encoding)
- GMSK modulation
- Structure of a D-STAR frame

<table>
<thead>
<tr>
<th>Sync</th>
<th>Pattern</th>
<th>Header</th>
<th>Voice</th>
<th>Data</th>
<th>...</th>
<th>Voice</th>
<th>Data</th>
<th>End of frame</th>
</tr>
</thead>
<tbody>
<tr>
<td>64bits</td>
<td>15bits</td>
<td>660bits</td>
<td>72bits</td>
<td>24bits</td>
<td></td>
<td>72bits</td>
<td>24bits</td>
<td>48bits</td>
</tr>
</tbody>
</table>

- Basic communication
8. COM: link with D-STAR network
8. COM system overview

Diagram:
- **Rx antenna**
  - **Front-end RF chain (Rx)**
    - GMSK (area A)
    - GMSK (area B)
    - D-STAR Rx
      - D-STAR decoder
  - AX.25 Rx
    - FSK demodulator
    - AX.25 decoder
  - AX.25 Tx
    - FSK modulator
    - AX.25 encoder
  - D-STAR Tx
    - GMSK modulator
    - D-STAR encoder
  - Beacon

- **Tx antenna**
  - Power RF chain (Tx)
8. COM: Beacon
8. COM: Prototype
8. COM: Further works

1. Input RF stage (LNA, splitter)
2. Output RF Stage (RF amplifier, combiner)
3. OBC-COM Interface
4. Master clock system
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C. Concluding remarks
9. MECH: functions

Antennas + deployment system design and realization

- Main features:
  - 2 antennas: 170 mm and 500 mm
  - Mass budget: 53 g
  - Available volume: about 80 x 70 x 6 mm
  - Deployment 15 minutes after P-POD ejection
9. MECH: system configuration

- Retention wire
- Antennas
- Support

- COM
- ADCS
- Thermal knife
- EPS
- OBC
- STRU
- THER
9. MECH: work carried out

- Design of the main parts of the system: support, antennas, thermal knife, retention wire.

- Realizations: 2 prototypes

- Tests: vacuum thermal tests (-20°C / +60°C)
9. MECH: future work

• Design:
  • Assembly to define precisely
  • Connection of hardware with other subsystems to define precisely
  • Determination of the torque produced by deployment

• Tests:
  • Vibrations
  • Chocs
  • Integration (with COM, EPS, OBC, STRU)

• Realizations:
  • Protoflight model
  • Flight model
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C. Concluding remarks
10. GND: ground facilities

- Four main parts

  ![Diagram of Ground Segment and User Segment]

  - Ground Segment → control and monitoring of OUFTI-1, by satellite operators
  - User Segment → operations with OUFTI-1 main payload (D-Star relay), by ham community
10. GND: ground segment architecture

Mission Control Center

Ground Station

- Mission Control Center
- GS computer
- TCP/IP
- Tracking card
- Rotators controller
- Phasing line
- UHF/VHF Transceiver
- CI-V
- TNC
- UHF Antenna
- VHF Antenna
- Phasing line
- Control
- AX.25
- Serial Data
- GND: ground segment architecture
10. GND: ground station (GS)

- Comply with Amateur radio requirements
  - TM / TC exchanged in AX.25 frames (using TNC)
  - Satellite-capable transceiver in amateur bands (VHF / UHF)

- X-Quad antennas $\rightarrow$ circular polarization
  - Elevation (180°) and azimuth (360°) rotators
  - Tracking card developed by ham operator (EA4TX)

- GS computers runs software for:
  - Automatic tracking (Orbitron + WispDDE + ARSWIN)
  - Automatic Doppler compensation (Orbitron + WispDDE)
  - TCP server listening to Mission Control Center
10. GND: GS ham softwares

- Orbitron (developed by S. Stoff)
- WispDDE (developed by F. Mederos, CX6DD)
- ARSWIN (developed by J. Pablo Garcia, EA4TX)

→ Free softwares developed by the ham community!
10. GND: Mission control center (MCC)

- Protocol based on ECSS *Packet Utilization Standard* (PUS), which in turns relies on the CCSDS *Space Packet Protocol*
  - OUFTI-1 mission control software will implement a simplified subset of these standards
  - E.g., base services such as telecommand verification, function performing, housekeeping reporting, On-board storage, ...

- OS-independent and largely deployed technologies to allow for maximum portability
  - Java SE programming language
  - MySQL databases
10. Mission control software overview

- Try to be as generic as possible (not tied to OUFTI-1)
  - Mission-specific data defined in MIB (Mission Information Base)
    - TM/TC general configuration
    - Parameters description, format, housekeeping calibration
    - Function IDs
  - Modular code, Object-Oriented programming to ease future extensions and plug-ins for mission-specific services
10. GND: user segment

- « Terrestrial » D-Star repeater
  - Callsign ON0ULG
- Extended to allow satellite communication with OUFTI-1

- Any ham operator will be able to use the relay to communicate with OUFTI-1
- Also possible through internet!
10. GND: D-STAR repeater + extension

- Gateway
- Controller
- VHF module
- UHF module
- Duplexer
- D-Star Repeater
- Frequency Converter
- Tracking System
- VHF or UHF module
- Satellite extension
- Internet

OUFTI-1

10. GND: D-STAR repeater + extension

- Gateway
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OUFTI-1
Outline

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B. Technical overview

C. Concluding remarks
   1. Next year…
   2. Timeline
   3. Demonstrations
1. Next year...

- **Vacations!!!**
  - July 2009

- **Beginning of internship/MS thesis**
  - August 2009

- **End of MS thesis**
  - September 2009

- **Documentation time**
  - October 2009

- **Writing of documents**
  - November-December 2009

- **Next year...**
  - January 2010

- **End of MS thesis**
  - May-June 2010
2. Timeline

Phase A: Feasibility study
   May 2009

Phase B: Preliminary definition
   September 2009

Phase C: Detailed definition
   January 2010

Phase D: Qualification & production
   May 2010

Launch
   June 2010

Phase E: Operations
   June 2010

Launch
   June 2010
3. Demonstrations

- 2 groups

1st group:
  - On-board computer
  - D-STAR
  - AX.25
  - Electrical power system

2nd group:
  - CubeSat
  - Simulator
  - Antenna deployment
  - Educational model
www.oufti.ulg.ac.be

Thank you for your attention!