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ARCADE EXPERIMENT ON BOARD BEXUS 13 AND 17: DESIGN, INTEGRATION AND FLIGHT OF A TECHNOLOGY TEST PLATFORM WITHIN A STUDENT BALLOON PROGRAMME

1st Symposium on Space Educational Activities

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EXPERIMENT OBJECTIVES

Primary Objectives:

- To test innovative solutions for **proximity navigation**, **attitude control** and **docking** suited for **miniature autonomous space and aerial vehicles**
- To evaluate disturbances affecting operations at different altitudes on board a **stratospheric balloon offered by the REXUS/BEXUS programme**
- To relate performances to disturbances

Secondary Objectives:

- To collect environmental data (pressure/temperature profiles)
- To determine wind direction and speed

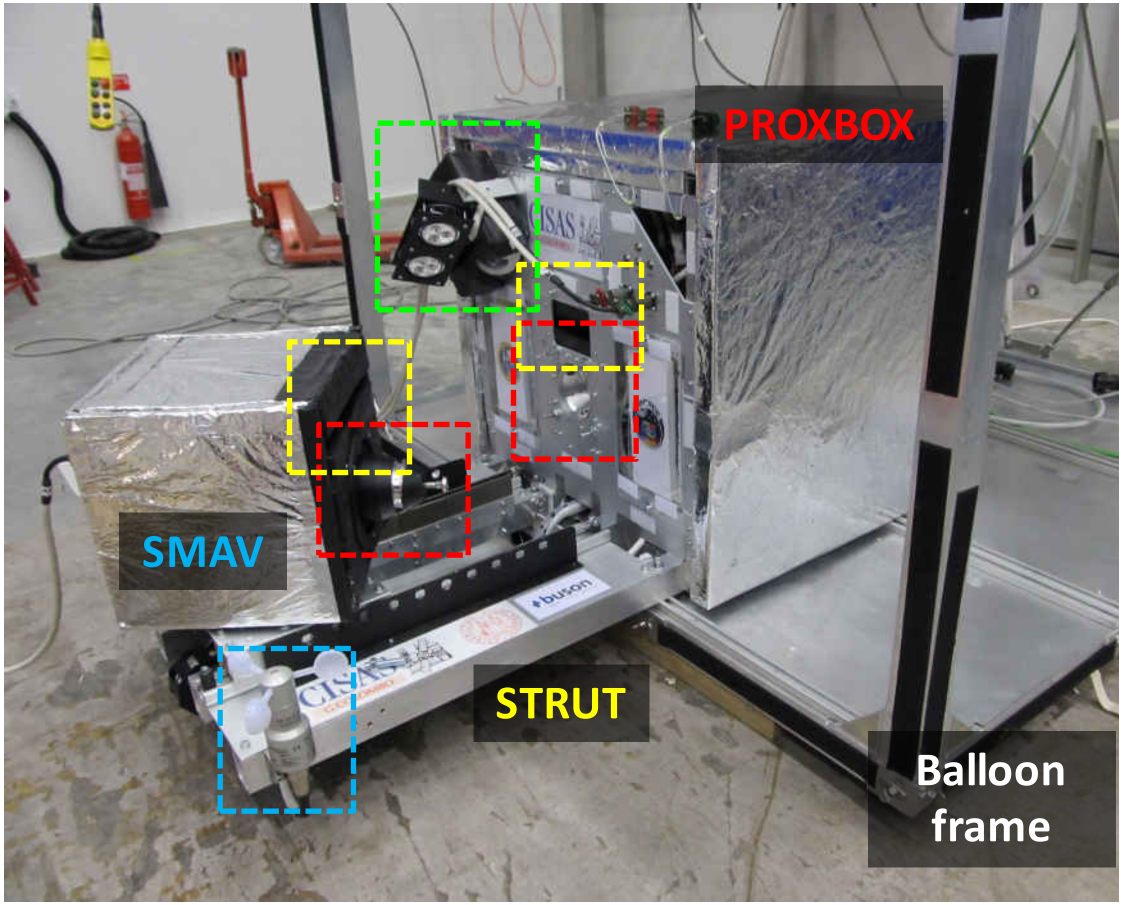
EXPERIMENT OVERVIEW (2013)

Main Elements:

- SMAV (SMAll Air Vehicle)
- PROXBOX (PROXimity BOX)
- STRUT (STRUcTure)

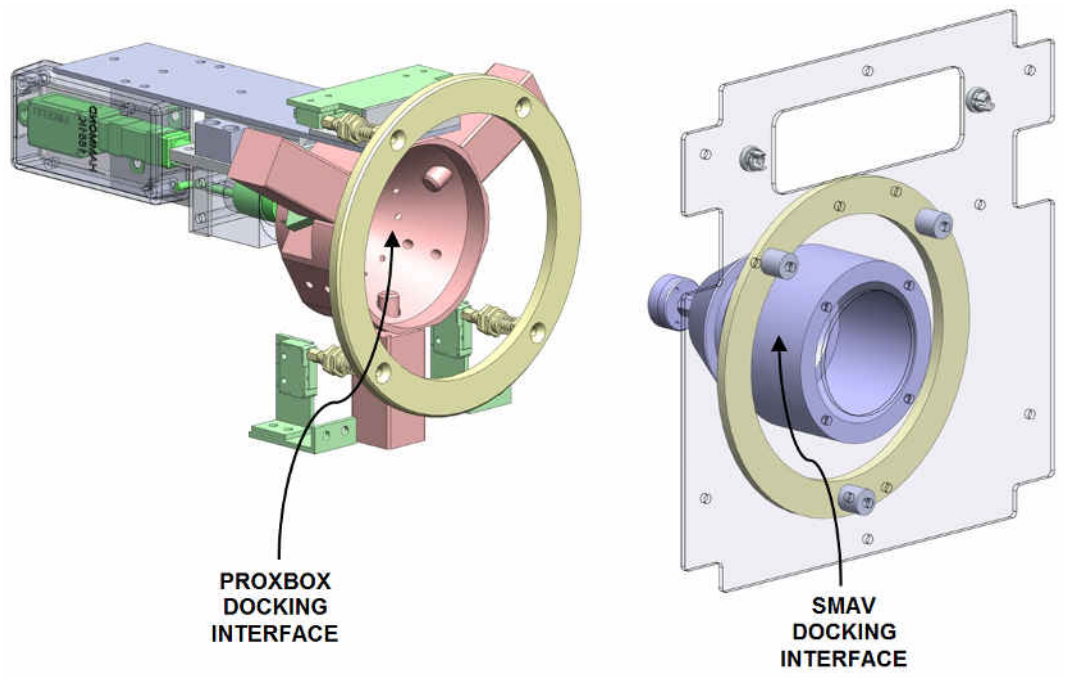
- Docking Subsystem
- Navigation Subsystem

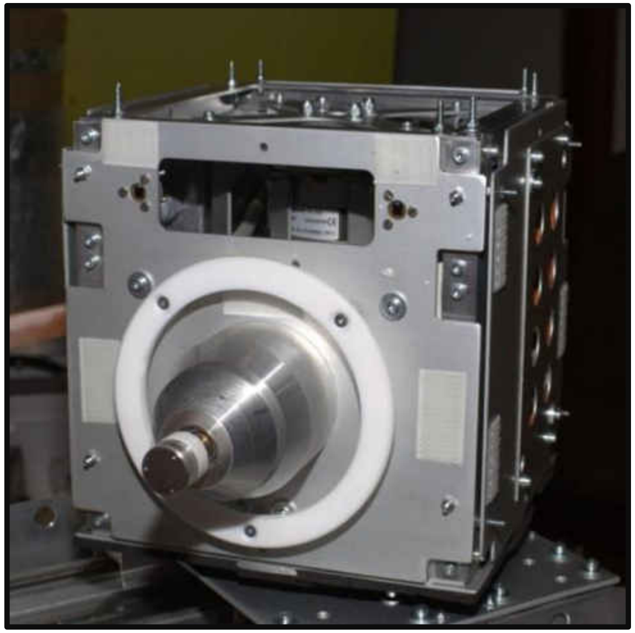
- Wind Sensors
- Webcam



DOCKING SUBSYSTEM

- Based on Soyuz and ATV probe-drogue configuration
- Probe length of 10 cm (SMAV size: 20x20x20 cm)
- Up to 10° of allowable misalignment





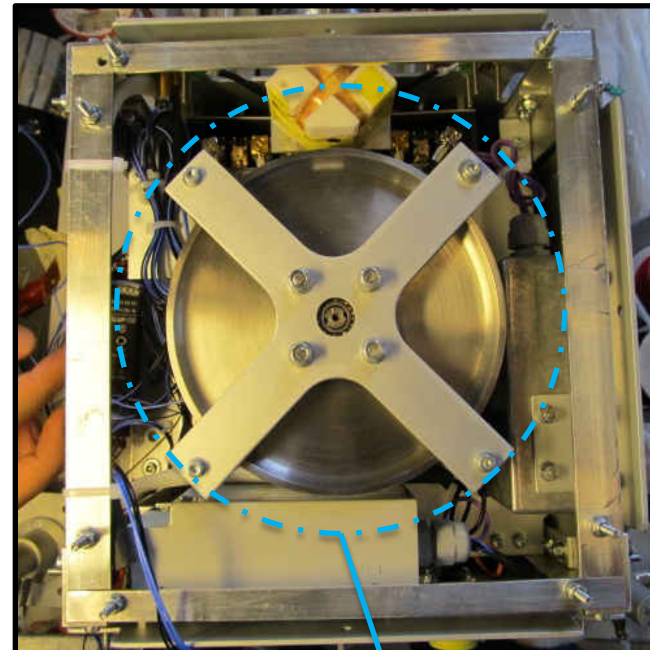
MOTION CONTROL SUBSYSTEM

Main Goal & Architecture:

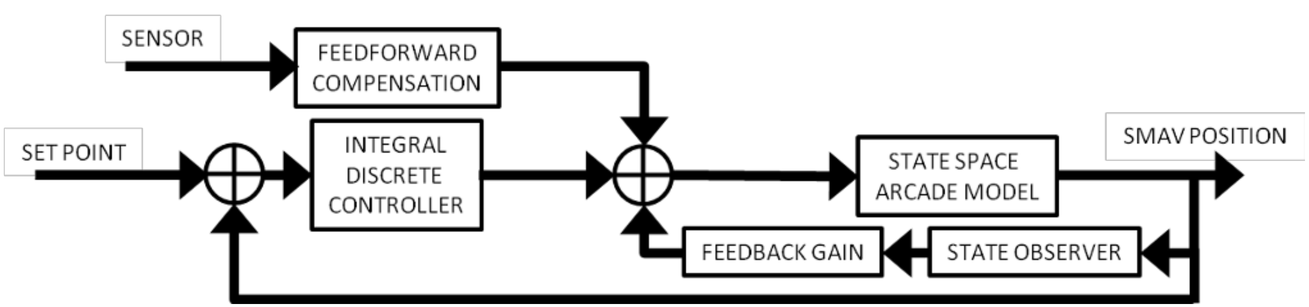
- Actively control SMAV yaw movements
- Main actuator: custom reaction wheel
- Backup solution: DC motor b/w SMAV and STRUT

State-Space Control

- State feedback + integral controller
- Disturbances rejected outside feedback loop
- Linear movements not influencing attitude
- Backup solution: manual-tuned PID controller



SMAV Reaction Wheel



PROXIMITY NAVIGATION SUBSYSTEM

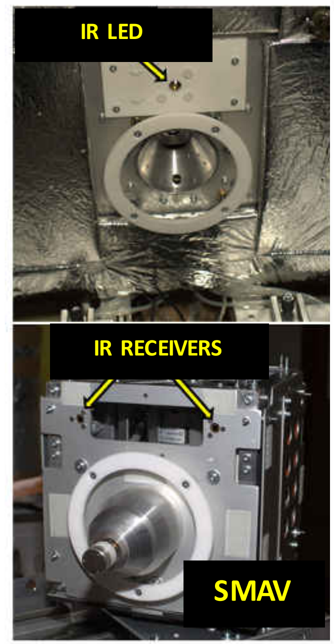
Sensor selection:

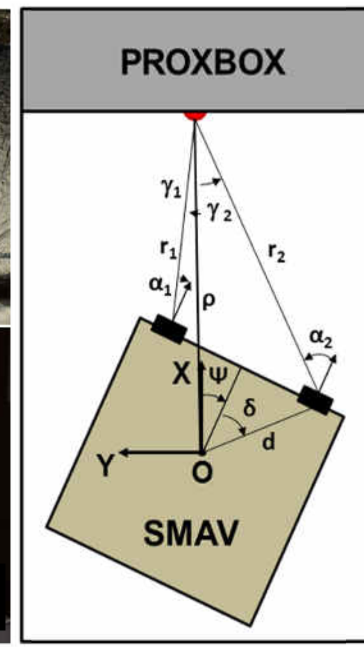
- Compactness (minor part of SMAV volume)
- Simplicity (hardware components & software computational burden)

custom relative navigation IR sensor based on radiation intensity measurement

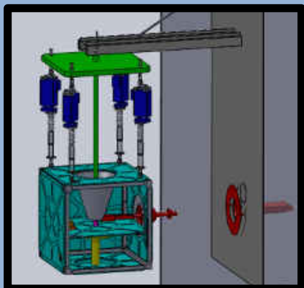
Sensor layout:

- IR LED emitter (pulsed at 10 kHz) on the PROXBOX
- Two IR receivers on the SMAV
- Reconstruction of relative range ρ and yaw angle ψ

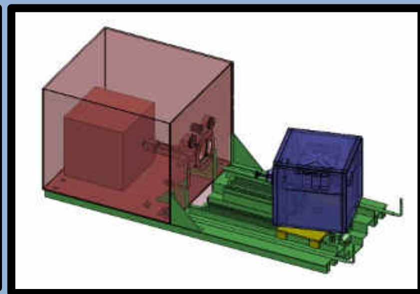




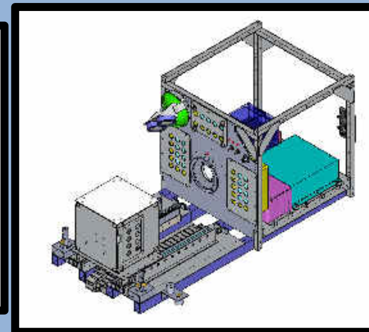
ARCADE EVOLUTION 2010 - 2013



1) Selection Workshop



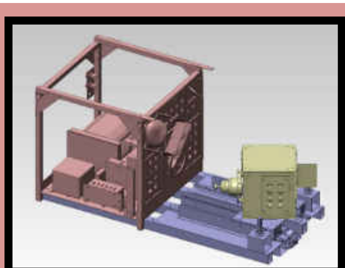
2) PDR



3) CDR

DESIGN PHASE
(10/2010 – 6/2011)

1) Concept definition
2) Baseline configuration selection
3) Detailed design



4) IPR & EAR

5) BEXUS 13 flight - 2011

INTEGRATION & TEST PHASE
(6/2011 – 9/2011)

4) Integration and acceptance
5) Launch Campaign
(October 2011)

Unsuccessful flight because of critical software failure

RE-FLIGHT
(11/2012 – 10/2013)

6) BEXUS 17 flight - 2013

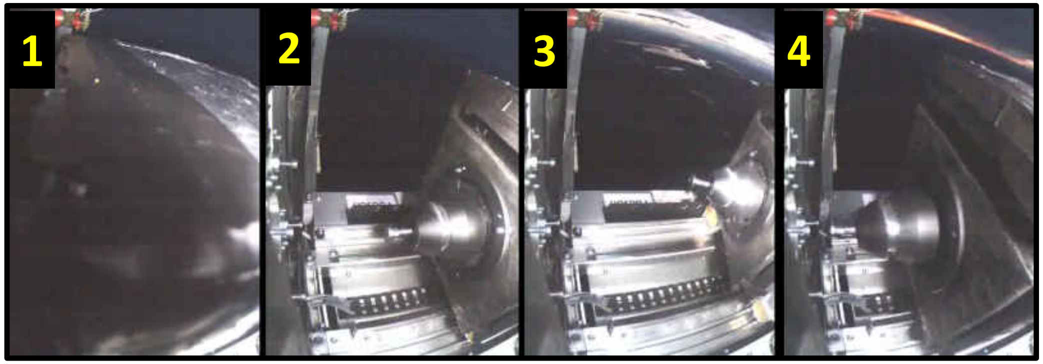
- Substitution of damaged or obsolete h/w
- **Complete re-writing of software**
- Other **design upgrades**
- Mass reduction

➡ ***Successful flight!!!***

FLIGHT RESULTS (1/2)

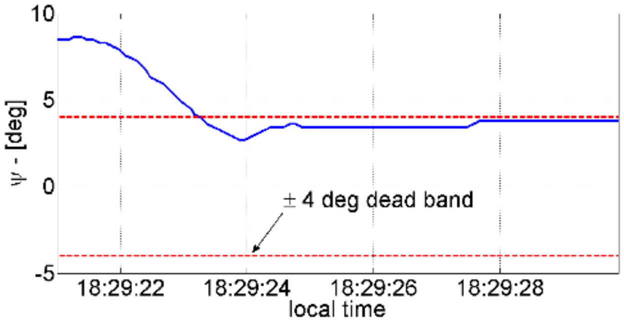
Docking system

- Successful release of the SMAV
- Thermal deformation: in-flight modification of actuators stroke
- Two complete docking and release procedures

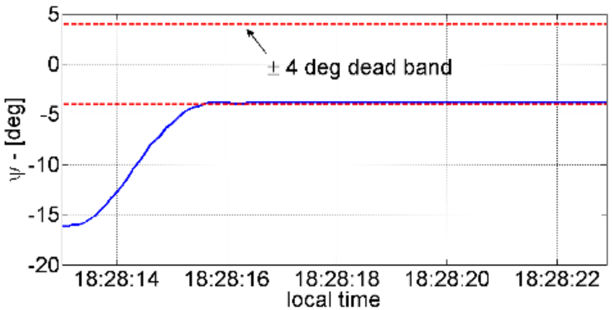


Motion control system

- Backup motor successfully pointing and moving the SMAV
- Reaction wheel successfully tested with **both PID and State-Space controls**

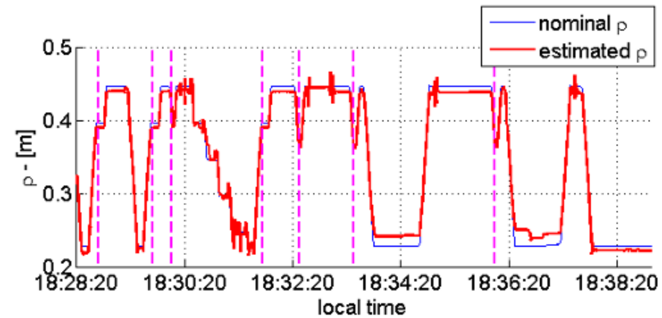


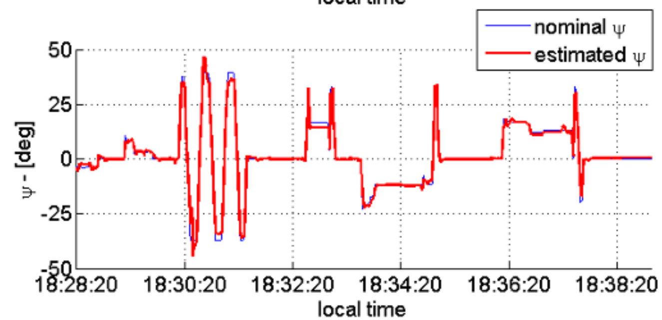
State-Space Controller Manoeuvre



PID Controller Manoeuvre

FLIGHT RESULTS (2/2)



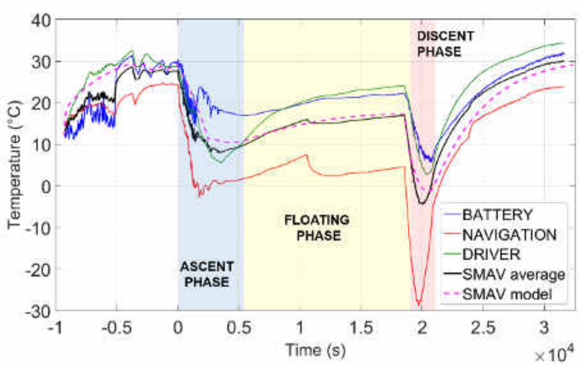


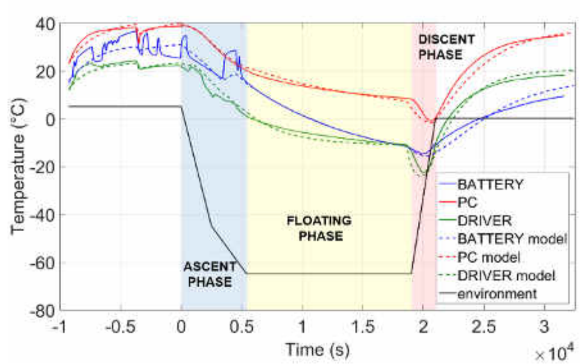
Proximity navigation system

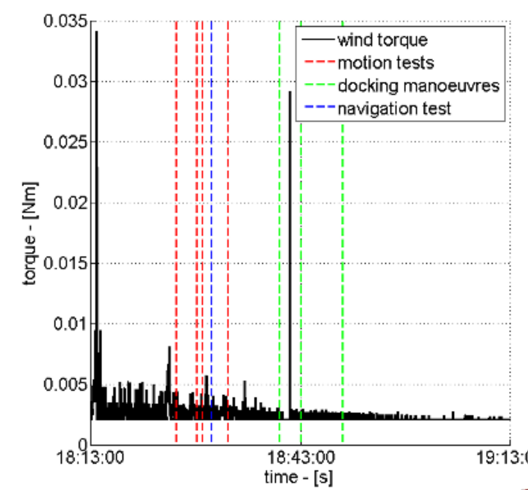
- Automatic calibration of photodiodes electronics (temperature-dependant)
- Real-time estimation with on-board software: accuracy of 17 mm – 2.7 deg
- Post processing: accuracy of 5 mm – 1.5 deg

Thermal control system and wind sensors

- Experiment temperature always within operational range
- Estimation of wind torques on the vehicle



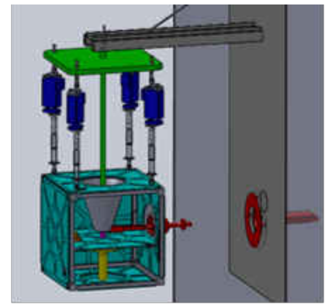




LESSONS LEARNED (1/3)

Experiment Design

- Don't fall in love with design ideas but ask to experts for what already exists
- The simpler the better: a simple solution, although less elegant, is preferable
- Always opt in favour of COTS against self-built components
- Don't underestimate time to allocate to software developing. Even in integration is incomplete



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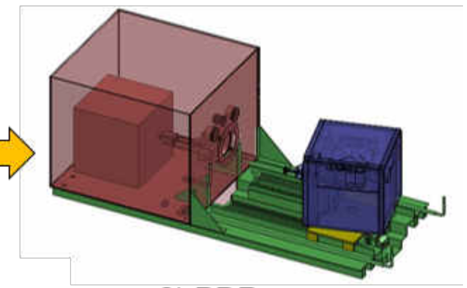

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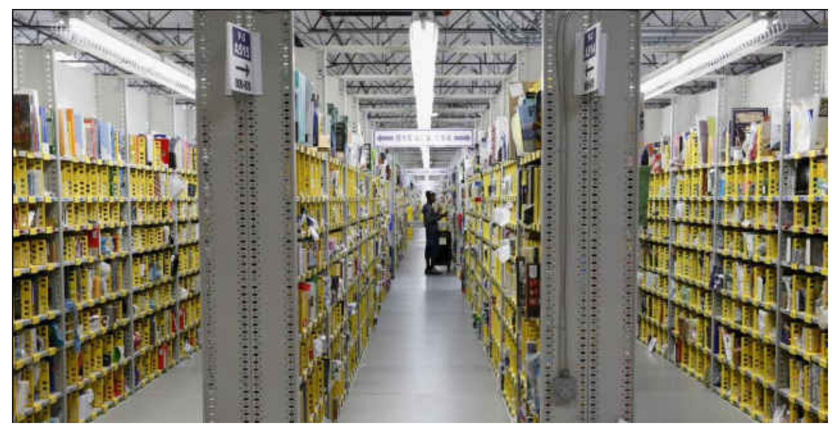
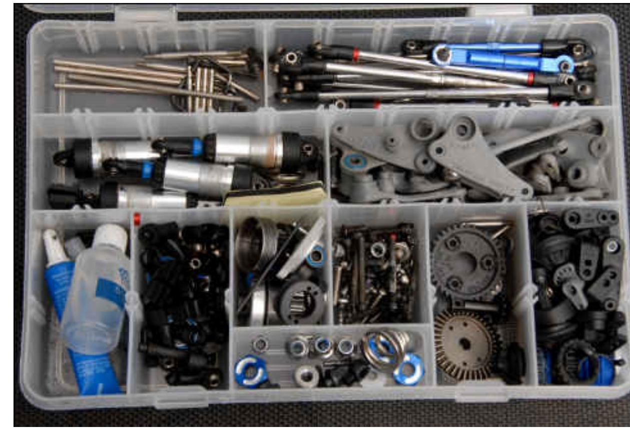
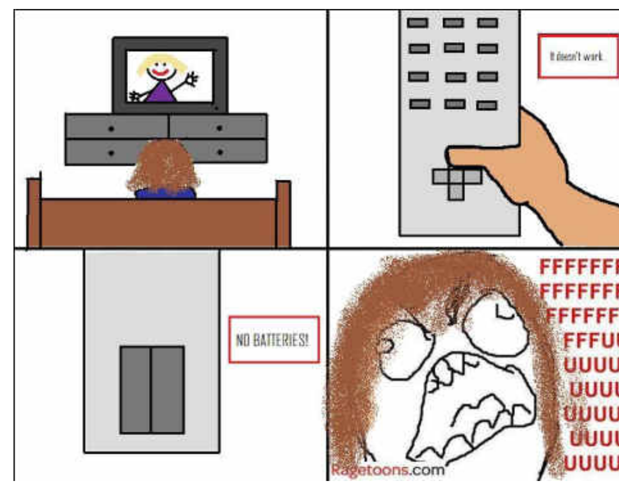


LESSONS LEARNED (2/3)

Launch Campaign

- Finalize as early as possible the integration. Worst problems happen at 99% of progress. Drop things if needed
- Don’t change software at last even if it’s soooo easy
- Have spare parts both for COTS and self-built components
- Make systems serviceable
- Don’t rely on telecommand for the success of the experiment





LESSONS LEARNED (3/3)

Procurement and Shipping

- Freeze long lead time components as early as possible
- Use components from big distributors
- Consider Li-SOCl2 battery shipping. Couriers are scared of hazmat!

Testing

- Test flight configuration in the most realistic way
- Give tests a priority. Test first things which are likely to have problems in your mind

Outreach and Funding

- Good outreach means funding
- Good outreach devotes a full-time person – or even more.

CONCLUSIONS

- Important **scientific** and **technologic** results
- Tested critical technologies for:
  - **Docking**
  - **Relative navigation**
  - **Attitude control**
- **Know-how** of the team seriously improved
- **Big experience** about space programs and deadline-driven teamwork

HOW MANY ERRORS BE AVOIDED THANKS TO THIS EXPERIENCE?

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THANK YOU FOR ATTENTION !

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