ARC Class D Missions Using COTS Parts

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Outlines

- ARC's Spaceflight Project Niche/Specialty
- ARC's COTS Use Strategy/Methodology
- Examples ARC Missions
- Conclusions

ARC EEE Parts Management Program

- Controlling Document: APR 8730.2 Ames EEE Parts Control Requirements, created in 2009 per NPD 8730.2C
- Unique to Ames: ***Center focus is on Class D & Sub-D missions***
  - APR 8730.2 sets quality control policy w/o undue burden on numerous small and “low-budget” *(heavy tailoring <$25M LCC*) spaceflight projects (NPR 7120.8) at the Center
- Project Structures:
  - In-house spaceflight h/w development
  - Academia partners (Stanford, Santa Clara, MIT, Purdue, etc.)
  - International partners (DLR, Saudi KACST, etc.)
  - Partnerships with other NASA centers (e.g. LADEE w/GSFC, JPL; ACS3 w/LaRC, etc.)

ARC’s Niche/Specialty

Focus and expertise are in small spacecrafts and nano-satellites:

- Small S/C (\$100M < LCC < \$250M): Class D LADEE, IRIS, LCROSS, & Kepler
- Nano-Sats: Class D- (NPR 7120.8)
  - Low-cost (LCC <\$25M)
  - Quick turn (2-3 years)
  - Short mission life (few hours to < 30 days)
  - High risk/high reward – tech demos, short-duration science, proving concepts, etc.

ARC COTS Use Philosophy

- EEE part selection emphasizes educated & calculated risks
- ARC Chief Engineer's Office, SM&A and PMs agree to take on risks that are too great in traditional NASA sense; but, with our tiny budgets & huge potential scientific gains, near 100% COTS use is what defines ARC
- Our payload designs sometimes require advanced components that are even ahead of state-of-the-art COTS offerings (e.g. Ultra-Violet LED)

COTS Selection Strategy

- Typical ARC spaceflight missions' EEE parts are:
  - Commercial grade, plastic components (PEMs), not radiation tolerant
  - Available in-stock at major electronics distributors, free samples from manufacturers
- Selection and Screening :
  - No part level screening except best-effort visual inspection
  - Buy from electronics industry leaders w/good quality control & high-volume production
  - Select widely used parts w/good DPPM numbers
  - Pick highest available grade of parts; wider temp range, tighter spec
  - Avoid bleeding edge parts – takes time & volume to prove reliability
  - Reuse parts after flight heritage has been established
- Counterfeit control: buy from OCMs & authorized distributors only

ARC’s COTS Design Approach

Ruggedize at circuit level rather than part level:

- COTS use requires more analysis and thoughts in circuit design
- Thoroughly review part datasheets to ensure specifications meet project requirements under environmental and operational conditions over entire mission duration
- Thoroughly simulate circuit design & diligently prototype key circuits before PCB-level implementation
- Peer review circuit design informally often & share lessons learned
- Look to use COTS version of radiation tolerant parts
- Strategically using space rated parts and/or effective redundancy for mission critical single-point failures
- Improve reliability through h/w & s/w mitigations & limit faults locally

  => do no harm to other subsystems

COTS Design Approach - cont'd

Architectual Approach:

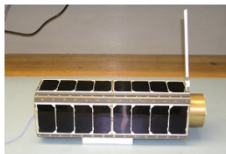
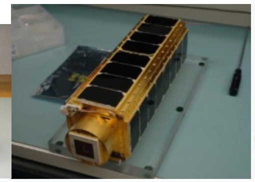
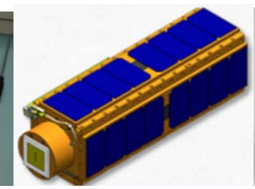
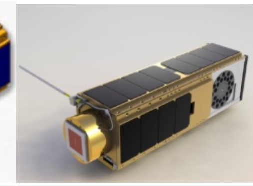
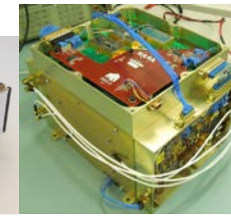
- Modularize subsystems: separate power feeds => damages can be quarantined & minimized so partial mission success is possible
- Monitor currents going into subsystems and/or critical circuits: shut down and reset via h/w & s/w
- Software protections: s/w TMR, creating saved system states
- Usually reuse avionic designs after successful missions; flight legacy a strong/prime consideration

Near-100% COTS use allows multi-revision engineering units to be built cheaply and quickly, so we can test early & often, especially in S/W, interface, form & fit (3D-printed models), etc. => reduces risk at I&T phase and shortens development cycle times significantly.

Radiation Strategy Using COTS

- Class D/D-: radiation hardness is overkill & over budget
- No radiation testing at any level! Too much cost & schedule hits
- Design for radiation tolerance at ***board/subsystem*** level, not part level, w/ effective redundancy, monitoring circuits & mitigation techniques
- TID: typically not an issue for short mission life; shielding w/Al (66-100 mil)
- Use commercial grade of rad-hard parts => cost, lead-time, some assurance
- SEE approaches:
  - Soft errors (SEU, SEFI): watchdog timer, EDAC, s/w TMR, MRAM
  - Hard errors:
    - -SEL: need to prevent destructive damages
      - » Over-current/voltage sense-and-reset capability in h/w & under s/w command & control
    - -SEB, SEGR: effective redundancy, minimize on time

Examples of ARC Spaceflight Projects: Near-100% COTS Parts


	GeneSat	PharmaSat	SporeSat	O/OREOS	UV LED (P/L)	Eucropis (P/L)
Life-cycle cost	< $10M	< $10M	< $10M	< $10M	<$5M	<$5M
Classification	Sub-D	Sub-D	Sub-D	Sub-D	D (w/KACST)	D (w/DLR)
EEE parts procurement	PO/credit card	PO/credit card	PO/credit card	PO/credit card	PO/credit card	PO/credit card
Avionics HW	Built at ARC	Built at ARC	Built at ARC	Built at ARC	Built at ARC	Built at ARC
Radio	Vendors	Vendors	Vendors	Vendors	N/A	N/A
Project Part Control Plan	No	No	Yes	No	Yes	Yes
Mission Outcome	Fully Successful	Fully Successful	Failed/Partial Success	Fully Successful	Fully Successful	Fully Successful

-SporeSat: OLED package trimming done in water (against datasheet!) at student's lab led to payload failure

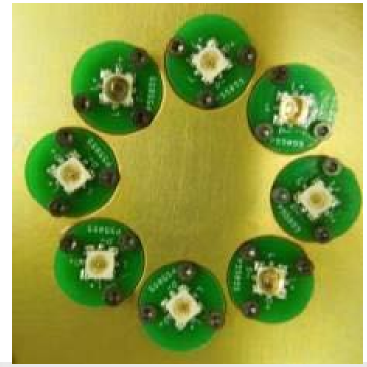
-Eucropis: Exceeded max success criteria; but one part suffered TID damage while executing last stretch goal

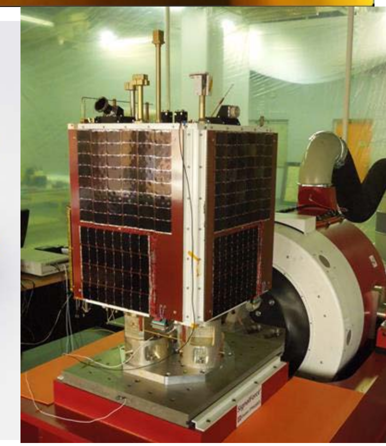
O/OREOS Nano-Satellite

- Organism/Organic Exposure to Orbital Stresses
- Utilized 100% COTS components, including free vendor samples
- 'Test early & often' philosophy – verify by test
- Fault recovery (reset w/current sensing) incorporated at subsystem level
- S/W protections: TMR, saved system states
- Launched late 2010, operated > 3 yrs (640km orbit)
- There were several system resets: related to power, thermal, and radiation
- No destructive damages

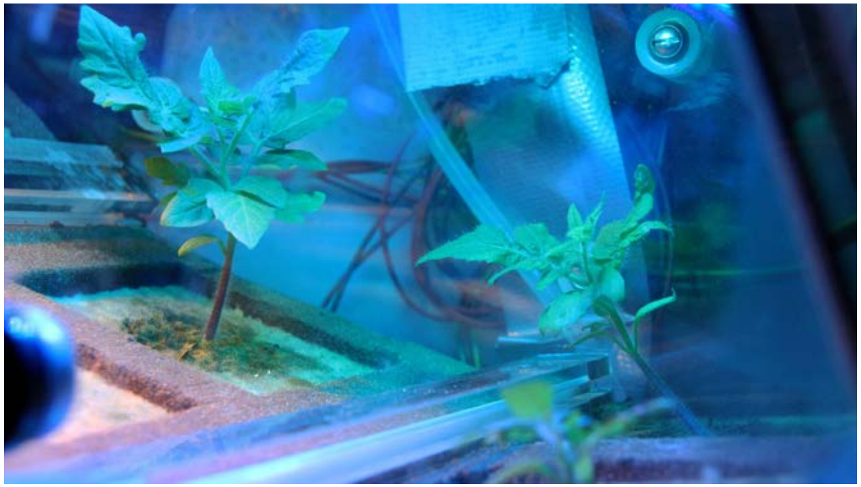
UV-LED Payload

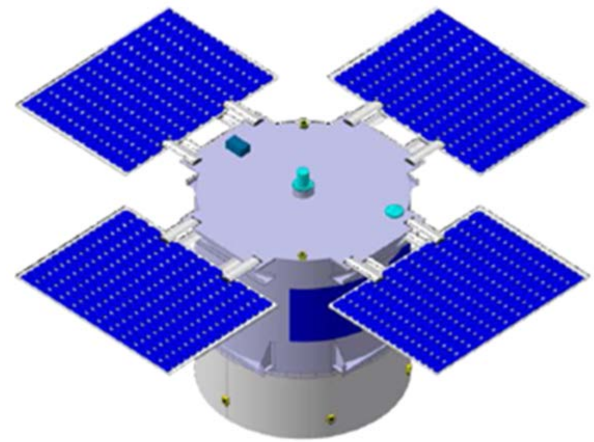
- Charge management tech demo for LISA and BBO; ARC, Stanford & Saudi KACST joint project
- Non-contacting charge control of floating mass using new solid-state ultra-violet (255nm) LEDs
- Goals: Space qualify UV LED (TRL8), demo non-contact AC charge management in space (TRL7)
- Payload for Saudisat-4 S/C, launched 6/19/14 onboard Russian Dnepr rocket
- All COTS except space rated DC-DC converters for mission critical power & comm box
  - Main board: 4.5”x6.5”, 900 parts, 19 layers
  - 2 sets of expt.: 16 LEDs, 4 bias plates, 9.5W, 2 charge amps using 0201 passives
  - Mission can be completed in 5 hours: 1 set of V-I-P curves generated & downloaded
  - 6.3kg, 23x27x18.5cm
- *Paper published in Physics journal: Classical and Quantum Gravity, 11/15/2016*



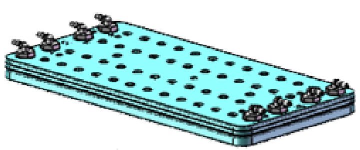

Eucropis Science Goals



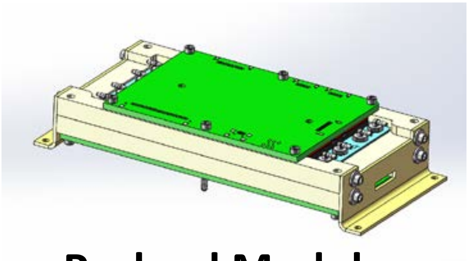


- Main DLR Payload (PL1): Demonstrate simple life support system with food output (tomatoes) under reduced gravity during space flight
- ARC PowerCell (PL2): Do changes in gravity affect the basic metabolic rate and metabolism of living systems (cyanobacteria and algae function as "plants")?
- Payload 3 is the Radiation Measurement in Space Instrument (DLR)

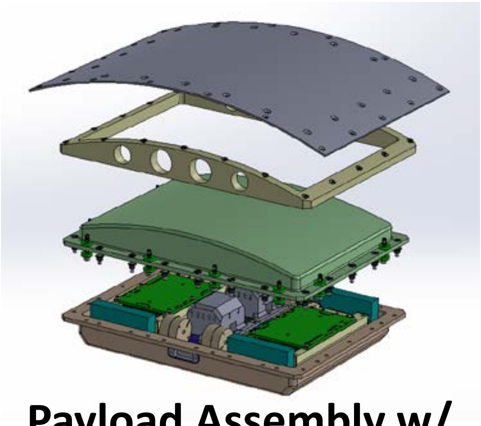
ARC PowerCell Payload



PowerCell
Fluidics Card



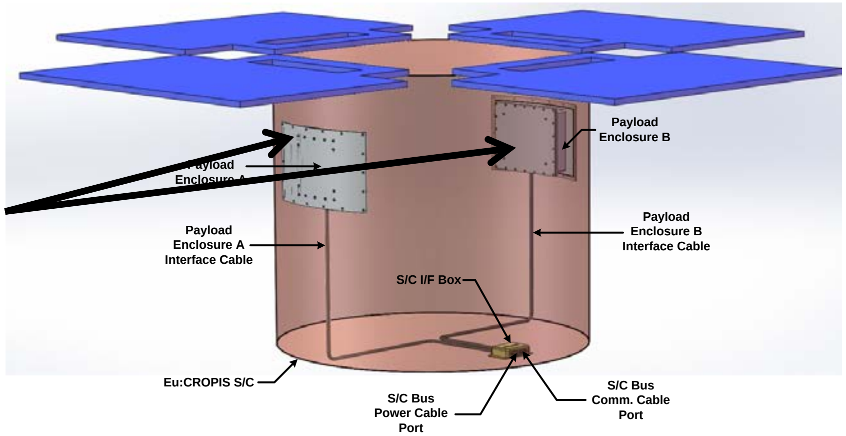
Payload Module



Payload Assembly w/
x2 Payload Modules

DLR EuCROPIS S/C

PowerCell
Payload System w/
x2 Payload
Assemblies



ARC Powercell PL2 Payloads (x2)

- The Eucropis satellite established a variable, artificial gravity by controlling the rate of rotation about its axis; 1mx1m (DxH), 250 kg.
- One-year mission lifetime, launched Dec. 2018: 6-month duration at each of two gravity levels, Lunar & Martian.
- Orbit: ~600 km, Sun Synchronous Orbit. Two experiments in each PL2 unit.
- Eucropis S/C provides NASA PL2 systems unregulated power and current monitoring along with an RS-422 communication interface.
- Exceeded max mission success criteria; encountered RS-422 failure while trying to run last extra experiment with one of the PL2 units.
- Comm. failure traced to radiation damage (TID) to the RS-422 chip w/o local over-current protection; S/C shut unit down when current limit exceeded. Would work after annealing; but hit current limit quicker each repower on.
- *Only ARC spaceflight h/w with a part failure in orbit due to missed local over-current protection. The current monitoring by the S/C was not sensitive or real-time enough to shut down and protect against radiation damage.*

Sample NanoSat Mission SEE Data

- ***GeneSat***: launched on 12/16/2006, 440km orbit, 7-day mission, functional for more than a year before re-entry, no SEL (i.e. no h/w reset due to over current) detected; SEUs probable but not data-logged. http://www.nasa.gov/centers/ames/missions/2007/genesat1.html
- ***PharmaSat***: launched on 5/19/2009, 440km orbit, 4-day mission, functional for more than 2 years before re-entry, no SEL (i.e. over current) detected; SEUs probable but not data-logged. http://www.nasa.gov/centers/ames/news/features/2009/pharmasat-update_0612.html
- ***O/OREOS***: launched on 11/19/2010, 640km orbit, 6-month mission, operated 3+ yrs in space, 1 system reset due to SEL (i.e. over current) on 12/27/2010, 4 beacon radio failures that required a reset (sensing over current & shutting down) on 12/19/10, 3/21, 7/7 & 8/10/11. Likely due to SEE; SEUs probable but not data-logged. http://www.nasa.gov/centers/ames/news/releases/2010/10-109AR.html

Conclusions

- COTS use requires more risk & value assessment:
  - Rely on part datasheets: maybe insufficient for space apps
  - Risk awareness and mitigation highly important
  - Where are limited resources & schedule best spent?
  - SWaP & performance often dictate use of COTS parts
- Identify risk -> document approach -> get stakeholder buy-ins
- Work to NASA & Center guidelines & project requirements
- *ARC COTS use methodology seems to be working well: 30+ small/nanosats operated successfully; S/W (usually Class B) bugs most common issue*
- *Can work for higher mission classes too w/proper care, analysis, testing & judicious design choices w/mitigation*

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