ARC Class D Missions
Using COTS Parts

Kuok Ling
EEE Part LDE
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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

**Architectural 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

<table>
<thead>
<tr>
<th>Project</th>
<th>GeneSat</th>
<th>PharmaSat</th>
<th>SporeSat</th>
<th>O/OREOS</th>
<th>UV LED (P/L)</th>
<th>Eucropis (P/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Life-cycle cost</td>
<td>&lt; $10M</td>
<td>&lt; $10M</td>
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<td>&lt; $10M</td>
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<tr>
<td>Classification</td>
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<td>Sub-D</td>
<td>D (w/KACST)</td>
<td>D (w/DLR)</td>
</tr>
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<td>Mission Outcome</td>
<td>Fully Successful</td>
<td>Fully Successful</td>
<td>Failed/Partial Success</td>
<td>Fully Successful</td>
<td>Fully Successful</td>
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- **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
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

PowerCell Payload System w/ x2 Payload Assemblies

DLR EuCROPIS S/C
The Eucropis satellite established a variable, artificial gravity by controlling the rate of rotation about its axis; 1mx1m (DxH), 250 kg.


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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