Approved for Public Release

GSAW 2014 – Session 11C
Current and Future Ground Systems for CubeSats Working Group

Summary Report

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Acknowledgements

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Forward

This document contains the panelist presentations, out-brief charts, and discussion notes from the GSAW 2014 Session 11C Working Group titled “Current and Future Ground Systems for CubeSats.”

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Outline

- Session Goals
- Presenters/Panelists
- Key Points
- Conclusions
- Way Forward
- Appendix A: Presentations & Notes
- Appendix B: Detailed Working Group Discussions

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Working Group Outbrief

Ground System Architectures Workshop

Session 11C

Current and Future Ground Systems for CubeSats

Catherine Venturini, The Aerospace Corporation

Thom McVittie, NASA Jet Propulsion Laboratory-CalTech

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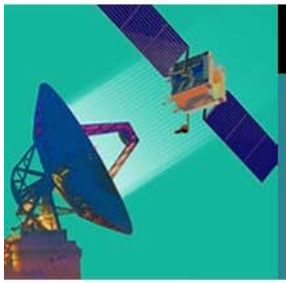
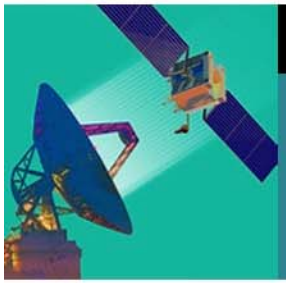


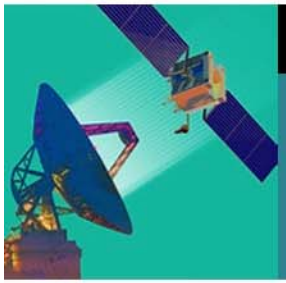
Session Goals

- Understand what makes a CubeSat Mission different from a ground system perspective?
- Identify key Misconceptions about CubeSats.
- What are the CubeSat issues that affect ground systems today?
- What are the ground system issues that would affect future CubeSat missions?



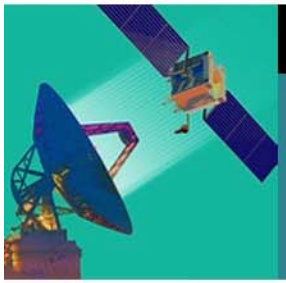
Presenters/Panelists

- Dr. Charles Norton – NASA JPL-CalTech (See Charts Appendix A)
  - Technology maturation mission in development
  - Constellation concepts, mission concepts for beyond LEO
- Mr. Bryan Klofas – SRI International (See Charts in Session 9)
  - Communications, RF issues
- Major Dave Illsley – NRO (No charts)
  - Government reference architecture
  - Acquisitions & ConOps (CubeSats as part of bigger mission architectures)
- Dr. Jamie Cutler – University of Michigan (See Charts Appendix A)
  - Bridging Student Education, Innovative Research & Entrepreneurial Vision
  - Future ground system needs



Key Points

- Large diverse & vocal community (we learned a lot)
- Real need for the community to come together to address key issues
  - CubeSat “unique” characteristics that drive Ground Systems
    - Number of CubeSats, bandwidth/power, development schedule
    - Mission ConOps Driven
  - Ground System Cost
    - Are CubeSat contact costs any cheaper than traditional sats?
  - New operations concepts
    - Keeping the ground system relevant from a technology and user-needs perspective
  - Where do standards make sense?
  - How do we share and leverage ground capabilities within the community? Are we at a tipping point?



Conclusions

- Definite interest in continuing the conversation
- CubeSats are rapidly increasing in complexity and capability
- Operational needs require us to think about 3 families of CubeSats
  - Government, Research/University, Commercial
- Certain aspects of ground systems are ripe for standardization
  - Ground Station Scheduling/planning
  - Ground Station to MOC interfaces
- Cost/Benefit for different ground system strategies isn't well understood
  - Federated support
  - Build your own
  - Commonality across the three families

Way Forward

- Present key points and conclusions at other venues to gather additional feedback e.g. Space Ops 2014, Cal Poly CubeSat Developer Workshop
- If there is enough interest, continue the working group conversation
  - *Establish focused topics for discussions*
  - *Identify action items or goals for the group*
- Don’t want to reinvent the wheel
  - *Support the Small Sat/CubeSat community*
  - *Integrate with ongoing efforts*

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Appendix A: Presentations & Notes

Charles Norton – JPL
Major Dave Illsley – NRO
Dr. Jamie Cutler – University of Michigan
Brian Klofas – SRI
Jonwa Kim – SMC/XR
Lyle Abramowitz – Aerospace Corp.
Lt Alan Frazier – SMC/XR
Paul Blanchard – L3 Communications

Presentation:
Current and Future Ground Systems for Cubesats

Dr. Charles Norton
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California Institute of Technology
Charles.D.Norton@jpl.nasa.gov

See charts at: http://gsaw.org/past-proceedings/2014-2/

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Notes: Dr. Charles Norton, NASA JPL-Caltech

- JPL Presentation
  - *IPEX: Produce near-real-time data products*
  - *Grifex: high frame-rate focal plane tech validation*
  - *RACE: Science observations flight test towards using constellations for atmospheric measurements*
  - *Isara: 100 Mbps Ka band downlink in LEO*
  - *LMRST: radio transponder for calibration of DSN*
  - *Inspire: Interplanetary test bed for science and stereo magnetometry*
  - *Luna Flashlight: Solar sail reflector concept*
  - *NEA Scout: Astroid characterisation concept*
  - *Relic: ~30 vehicle constellation concept*
  - *Sentinel: Earth-Sun L5 space weather constellation concept*

Notes: Major Dave Illsley, NRO (no charts)

- NRO CubeSat program office
- Cultural challenges
  - *CubeSats thought of as smaller versions of big satellites*
    - Big mistake, miss the potential
    - Need to use them properly
      - *Acquisition process*
      - *Technology: Physical differences*
      - *Ground systems: CONOPS*
        - How we use them
        - What's the best use
  - *Have to fight cultural issues*
- Short acquisition timeline
  - *Growing acquisition workforce*

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Notes: Major Dave Illsley, NRO cont.

- Next generation bus
  - *Government owned design*
  - *Lawrence Livermore National Laboratory (LLNL) is the lead for development*
  - *Modular, scalable*
  - *Ready to compete for build in 2015*
- Chicken-egg problem
  - *Need to show capability*
  - *Real capability (regardless of mission) is strength in numbers*
- CONOPS
  - *Need to approach very differently*
  - *Can't afford stove-pipe system*
  - *Have to look at differently*
    - Command and control
    - Where we locate ground stations

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Notes: Major Dave Illsley, NRO cont.

- Audience Questions:
  - *Is anyone keeping track of CONOPS and rhythm to put together CONOPS and structure"*
    - Their office is working with OSL to follow processes before/during/after launch
    - Keeping track of details to see what is applicable
  - *Colony 2 ground architecture and what is going to be different?*
    - Colony 2 uses MC3 ground station nodes.
    - Like Colony 2, next gen bus would use UHF and S-band to use MC3

Presentation:
Thoughts on Imagining the Future with CubeSats

Prof. James W. Cutler
University of Michigan
jwcutler@umich.edu,
http://exploration.engin.umich.edu

See charts at: http://gsaw.org/past-proceedings/2014-2/

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Notes: Dr. Jamie Cutler, University of Michigan

- Launch about 1 cubesat/year
- Peach Mountain retrofitting for tracking
  - *Upgrading 26 meter dish for deep space ops*
- CubeSat teams have to consider the end-to-end systems
- Need ground networks to support low-cost operations
- Modeling capacity and schedule of ground networks
- Federated networks using open source software
- Audience questions
  - *What is the orbital plan for launch?*
    - Yes, working with the launch provider. Must show deorbit plan.

Notes: Bryan Klofas, SRI International

- See briefing charts in Session 9
- Use the SRI Allen array in California

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Notes: Jonwa Kim, SMC/XR

- SENSE launch November 19, 2013
- Going through LEO on-orbit checkout
- Pathfinder for SMC operational CubeSats
- Using NRL Common Ground Architecture (CGA)
  - *Blossom point antenna*
  - *Manzano antenna*
  - *Some AFSCN contacts*
- 18 month contract award to delivery
  - *Rapid acquisition not usually seen*
- Spacecraft are complex vehicles compared to some educational systems
- 7-man crew doing ground ops for 2 vehicles, goal is to move to lights-out
- Lessons learned are being flowed into the NRO Colony 2 and next gen programs

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Notes: Lyle Abramowitz, Aerospace Corp.

- Some problems with ground
- ORS-3 mission deployed 30 objects
  - *Considerable difficult to get TLEs*
  - *Took a couple of weeks*
- Perhaps put corner reflectors and/or beacons?
- People who had low-frequencies had the quickest acquisition
- As missions progress low-latency will be more desired
- Frequency management is a difficult process
  - *FCC is taking an interest in the debris problem and must document*

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Notes: Lt. Alan Frazier, SMC/XR

- Using CGA
  - *Were able to change the ground software within one orbit pass*
  - *Very flexible system was beneficial*

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Notes: Paul Blanchard, L3 Communications

- COTS Package in-control for ground station
  - *GPS in factory*
  - *Inmarsat on-orbit*
- Ground system
  - *Cubesats could build*
  - *Pay too much*
- Developed a pricing model for APL that reduced costs
  - *Agreed to use the process as-is, no PDR, CDR*
- University of Colorado using their product
- COTS packages can do 92-95 percent of requirements

Appendix B: Detailed Working Group Discussions

Discussion Charts and Notes:
Common CubeSat Myths
What makes a CubeSat Unique?
What is the role of Standards?
Do we need a Ground Reference Architecture?
How about Federation?

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Common CubeSat Myths:

- Myth #1: “A CubeSat is a CubeSat is a CubeSat”
  - *Panel and audience discussion presented a wide variety of CubeSat designs and missions.*
  - *Significant differences in:*
    - Destinations (LEO, lunar, planetary?)
    - Configurations (singletons, constellations, swarms)
    - Capabilities (particularly in navigation/position, communications, propulsion)
    - Required Data Rates (1200 baud -> Mbits/sec)
    - Operational use (adhoc science -> time critical mission data)
      - *Impact on the number of passes and predictability of data completeness & latency*
    - Business Models (lowest possible individual cost -> sustained fleet operations)
  - *Conclusions:*
    - Operational needs require us to think about 3 families of CubeSats
      - *Government, Research/University, Commercial*
    - Need to understand which ‘market’ we are serving to size the capability to the different classes of mission
    - Mission Characteristics/ConOps has a major influence on determining which is the relevant family, e.g., flight qualifying an instrument might be classed as Research rather than government, regardless of the funding agency.

Common CubeSat Myths:

- Myth #2: “CubeSats are small things with low data rates that have little or no impact on our ground systems”
  - *The number of CubeSats being launch is increasing rapidly, so significantly more spacecraft to contact and command/control.*
  - *While CubeSat missions can be short, many continue to operate after several years.*
  - *CubeSats require as much effort to track as a larger mission*
  - *CubeSats may stress the Ground Stations more – lower power, smaller antennas*
  - *CubeSats have highly constrained processing power which may put more of the work on the ground system. (planning, system management, safing and fault diagnostics, etc.)*
  - *CubeSat development schedules can be very short (e.g. NRO 18 months from idea to operations) which significantly reduces the amount of time to develop/customize, test and integrate the ground system.*
  - *CubeSats would likely be as highly specialized as possible, which would require the ground systems to be as flexible as possible.*
  - *CubeSats have more limited “self position reporting” capabilities and many have limited propulsion, which means the ground will need to perform traffic control functions.*

Common CubeSat Myths:

- Myth #2 (cont.): “CubeSats are small things with low data rates that have little or no impact on our ground systems”
  - *Conclusions:*
    - CubeSats have a variety of characteristics that drive the capabilities/design of Ground Systems.
    - Potential areas where we need to rethink the Ground System’s role and capabilities:
      - *Approaches to providing cost-effective communication infrastructure*
        - Repurposing unused apertures and crowd-sourcing communications (particularly for receive-only)
        - Dealing with multiple CubeSats in the same beam
        - Opportunistic use of side-lobes and unused bandwidth. (second tier customer)
      - *Rethinking how we schedule/request aperture time*
        - Exchanges or market places
        - CubeSat Consortia
      - *Approaches interacting between multiple apertures and the mission ops center*
        - Commands via “pager-like” satcom, and downlink distributed via “bit torrent like” approach.
        - Rethinking the role of standards (Space Link Extension, Delay Tolerant Networking, etc.)
        - What are the security (confidentiality/integrity) needs?
      - *Ability to rapidly tailor and test Ground System to meet short development cycles.*
      - *Role of Ground Systems in providing innovative command/control to get more out of the CubeSat.*

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What makes CubeSats unique?

- NASA getting over the idea that CubeSats are university only
  - *Trying to plan for future post-TDRSS world*
  - *What are the capacities and data volumes for the future*
  - *Would take 15 years to build out the infrastructure*
  - *How can we commoditize sections of the ground to drive innovation and volume*
- Recap
  - *Relative cost of operations*
- Ground system driven by mission requirements
- Bandwidth and power are limiting factors for CubeSat missions and is a big consideration when selecting a ground system solution

Afternoon Discussion Topics*

- What are the key issues from a ground system perspective to better support current and future CubeSat missions?
  - *Security for future CubeSat missions*
  - *Communication licensing and spectrum allocation*
  - *Identify and track (e.g. lessons learned from recent launches)*
  - *Coverage, priority, & scheduling (e.g. spacecraft emergencies)*
  - *Information sharing & access*
  - *Usage of standards - interoperability and reuse*
  - *Proprietary vs. government reference architecture*
  - *Enabling development of new technology*
- How to “share” or leverage current ground capabilities within community?
  - *Federated vs. stand alone communications approaches*
  - *Scheduling and management of contacts*
  - *Buying shared contact time*
  - *Changes to support higher data rate communications*

*Topics highlighted were selected by audience vote.

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Topic: Usage of Standards

- Question:
  - *What are the areas where standards may be beneficial?*
    - Flight/ground?
    - Ground station to Mission Ops Center (MOC)?
    - Within the MOC?
    - Across Missions?

Flight/Ground Standards

- CCSDS standards (framing, packetization, on-board messaging, etc.) not usually picked for CubeSats
  - *Considered by some as being too "heavy weight"*
  - *CubeSats grew up in the "IP in space era" and CCSDS only recently starting to adapt its framing standards to supporting IP encapsulation.*
- As CubeSats need to access shared mission infrastructure (agency level communications resources, COTS tools, etc.) we may need to revisit the role of standardized interfaces
  - *CubeSats can't ask for a unique interface without incurring a large cost.*
  - *Need to revisit where standards exist, and whether there is a need/business case for making the transition.*
- *Universities may not have experience using CCSDS, both organizations could benefit from re-opening the discussion.*

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Ground Station to Mission Ops Standards

- Standards for how users:
  - *Schedule & configure contacts and aperture time*
    - University of Michigan has a proposed XML standard
    - CCSDS Service Management spec is also a possibility
      - *Also the CCSDS Orbital Ephemeris Message*
  - *Collect and transport command and data*
    - GENSO (focused on small UHF receivers)
    - CCSDS Space Link Extension – extending frame services from stations to MOC via IP
- Concerns:
  - *Standards need to be very lightweight and easy to adopt.*
    - Any potential for open source implementations?
  - *GENSO was a good start, but the standardization process made it difficult to use/adopt.*
- Seem to be several good candidates, but need to understand how the standards (and the standardization process) would interact with the faster and sometimes looser CubeSat development approaches.

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Within the MOC Standards

- Standards for how users:
  - *Connect various components of the MOC*
    - Messaging bus – such as GMSEC
  - *Configure the MOC for a mission*
    - XML telemetry and command dictionary formats
      - *CCSDS/OMG XTCE*
        - Tailoring for GovSat (several GSAW sessions)
        - ESA & JPL/GSFC also tailoring for their own needs
- Hope is to make COTS more readily adaptable for CubeSat missions

Cross Mission Standards

- Tracking/Position information
  - *Currently difficult to understand/predict location of your CubeSat and it's neighbors.*
  - *Large systems generate their own TLEs after launch*
    - Predicts from the launch vehicle or communications providers
    - CubeSats are often secondary payload and don't same same level of information from flight vehicle or primary mission.
  - *GPS/self-reporting can be difficult – problems with the Z-axis*
  - *Unique messages require more resources to handle, a standard scheduling format or message would be helpful*
  - *TLEs are a standard format, but there isn't a common standard for how to obtain them.*
    - Could benefit from JSPOC standardization
- 'Registry' of vehicles planned for launch
  - *Enables neighborhood predictive analysis*
  - *Space debris*
  - *"Air traffic control"-like capabilities*

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Cross Mission Standards (cont.)

- Standardized CubeSat mission information & common parameters
  - *Goal is to make information sharing and data mining/analysis across missions easier*
  - *Industry groups working to get GEO folks sharing data, also useful for LEO.*
    - Single event upset information
    - Communications/coverage gaps
    - Common definition & access to science data
  - *Lots of information being collected/maintained by individual organizations, but very difficult to share. No single group to coordinate making any of this happen.*
    - Aerospace Corp. doing internally
      - *Only so much data that can be collected*
      - *Keeping up with recent launches is a challenge*
    - SRI keeping a communication table
    - St Louis University has on-line database
  - *Concern: if we share out data – others will make money off of us or scoop our results.*
  - *Needs*
    - Define and prioritize the information that needs to be shared
      - *Look at the CubeSat standard definition (currently version 12)*
    - Identify an organization/consortia that can lead/champion the standardization activity
    - Develop/adopt a standard for data sharing
      - *Look at the Maritime AIS standard for data sharing and ID as an example*
        - Provides location and maneuver capability

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Standards Wrap-up

- Identified several areas which are ripe for standardization. Agreed that we should focus on the interfaces.
- Particularly interest in
  - *Ground-Station to MOC*
    - Contact scheduling, tracking and ephemeris exchange
    - Data exchange standards
  - *Cross-Mission areas.*
    - CubeSat mission registry
      - *What happened to the CubeSat Launch Portal?*
    - Sharing common interest data
- Need to work with community to further refine:
  - *Identify the high payoff points for standardization*
  - *Impediments to data sharing*
  - *Look at the lessons learned from previous standardization efforts*
  - *Determine the right forum to discuss*
    - Suggestion that this be brought up at the CubeSat Developer Conference in April

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Topic: Reference Architectures

- Questions:
  - *Do we need a reference architecture for CubeSat Ground Systems?*
  - *If so, who should lead?*
- A reference architecture gives a common set of capabilities across the family of vehicles
  - *Helps us understand the capabilities we need in common and where we diverge (boutique versus commodity)*
  - *May provide a basis for reusability and interoperability*
  - *Concerns:*
    - Risk is to attempt to cover too many customers with the standard
      - *Which families do we consider?*
    - Do we allow a marketplace to develop around a standard?
      - *Does this take away the ability of vendors to innovate?*
      - *Will proprietary information make evolution slower/more difficult?*
    - Will the speed of change in a reference architecture be able to keep pace with the rapid evolution of CubeSats?
      - *How rapidly should the standard evolve*
      - *Technology changes rapidly, CubeSats launch ~6 months*

Reference Architectures cont.

- How to go forward?
  - *Need to identify the interoperability points between ground station architectures*
    - This would allow different agencies to service each others missions (e.g., provide a federated architecture)
    - Need to address issues such as the wide variation in Security concerns.
  - *Look at existing efforts*
    - Openstack being worked by larger spacecraft
    - From the university perspective the ground system is released as open source
      - *The barrier to entry is fairly low*
      - *Objective is to get as many ground stations available*
  - *Who should lead?*
    - Observation that we need one group to lead this forward and the community will follow.
    - Government – current focus on next generation bus. Advantage is that it has the funding and organization to manage any changes. But may not be nimble enough.
    - "Build it and they will come" approach is attractive, but …
      - *GENSO built it, but once deployed it was out of date*
      - *Can you react fast enough to make it work out*
    - Potentially a good role for an independent agent (maybe the FFRDC community?)

Topic: Moving to a Federated Architecture

- CubeSats have a lot of common needs, but also some that are very unique.
- A federated architecture could allow a lot of flexibility in how missions use common infrastructure while supporting their mission unique needs
  - *Different networks may have different needs for information*
  - *Different operations tempos are supported*
  - *Different scheduling software in use*
  - *Even if schedule standards in place sharing could be difficult*
  - *A market for contacts may be helpful*
  - *Universities barter for time now*
  - *Currently assume the MOC handles the spacecraft details*
- Does the University want to run the ground system?
  - *Should be operated as a service*
  - *No dedicated funding to make this happen*
  - *Are groups that would support if funding were available*

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