AEROSPACE
REPORT NO.
OTR-2019-01165

Small Satellite Industrial Base Study: Foundational Findings - Final Report

September 30, 2019

Allyson D. Yarbrough, Elizabeth Klein-Lebbink
Engineering and Technology Group
Space Systems Group

Prepared for:

Dr. Jonathan Pellish
NASA Electronic Parts Manager
Engineering and Technology Directorate
NASA Goddard Space Flight Center

Contract No. NNG11VH00B
Authorized by: Civil Systems Group

Abstract (Part 1 of 2)

This report documents findings from a Small Satellite (SmallSat) Industrial Base Study conducted by The Aerospace Corporation between November 2018 and September 2019. The primary objectives of this study were a) to gain a better understanding of the SmallSat community's technical practices, engineering approaches, requirements flow-downs, and common processes and b) identify insights and recommendations for how the government can further capitalize on the strengths and capabilities of SmallSat offerings.

In the context of this study, SmallSats are understood to weigh no more than 500 kg, as described in “State of the Art Small Spacecraft Technology, NASA/TP-2018-220027, December 2018. CubeSats were excluded from this study to avoid overlap and duplication of recently completed work or other studies already under way.

Abstract (Part 2 of 2)

The team also touched on differences between traditional space-grade and the emerging "mid-grade" and other non-space, alternate-grade EEEE (electrical, electronic, electromechanical, electro-optical) piece part categories. Finally, the participants sought to understand the potential effects of increased use of alternate-grade parts on the traditional space-grade industrial base.

The study team was keenly aware that there are missions for which non-space grade parts currently are infeasible for the foreseeable future. National security, long-duration and high-reliability missions intolerant of risk are a few examples. The team sought to identify benefits of alternative parts and approaches that can be harnessed by the government to achieve greater efficiencies and capabilities without impacting mission success.

Acknowledgments

The authors thank Dr. Jonathan Pellish of NASA for funding the study and Mr. Dave Davis of the Air Force Space and Missile Systems Center for his leadership. We also acknowledge Mr. Leo Cheatham for his document preparation and graphics assistance, and Kristal DaVoy and Lisa Falk for their library services research assistance.

Small Satellite Industrial Base Study: Foundational Findings

Allyson Yarbrough, PhD
Principal Engineer
Electronics and Sensors Division

Elizabeth J. Klein-Lebbink
Senior Project Engineer
Engineering and Integration Division

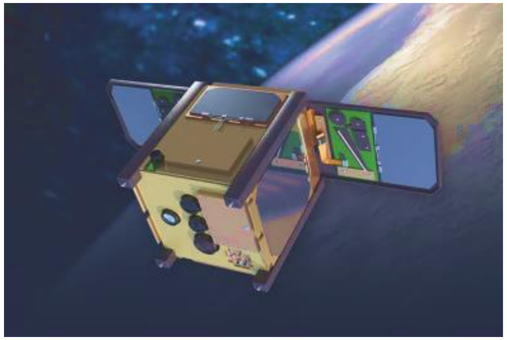
The Aerospace Corporation • El Segundo, CA

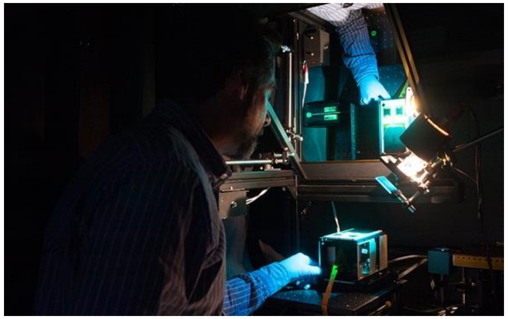
30 September 2019

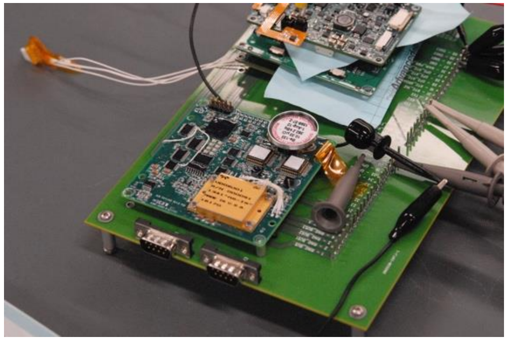
Executive Summary

(1 of 8)

- Study objective – What we were tasked to do
  - *Gain better understanding of the SmallSat community's*
    - Technical practices, engineering approaches and common processes
    - Requirements flow-downs
  - *Glean insights and recommendations for how the government can further capitalize on the strengths and capabilities of SmallSat offerings*



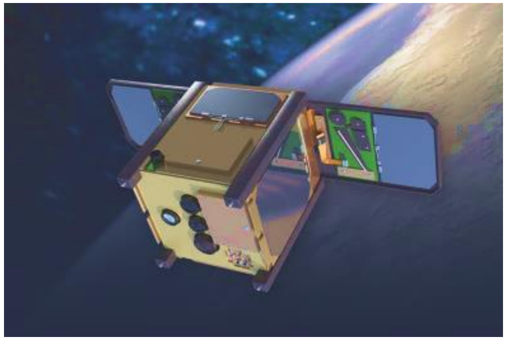


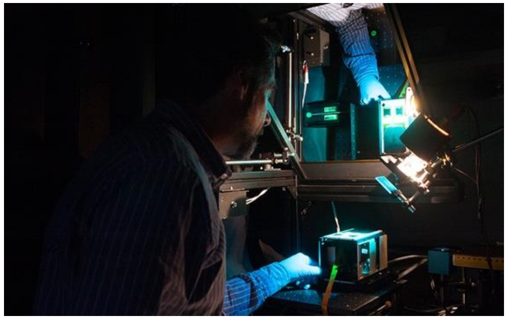


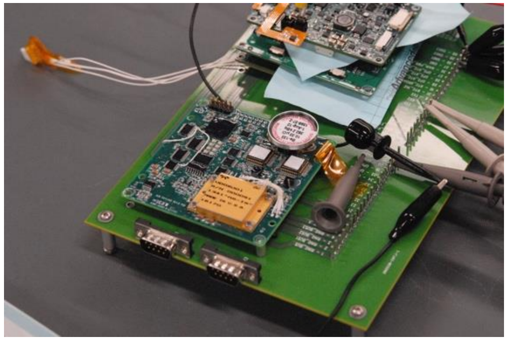
Executive Summary

(2 of 8)

- Study process – How we conducted the study
  - *Four stakeholder groups across the SmallSat ecosystem were interviewed, with responses captured on a non-attribution basis*
  - *In the context of this study, the SmallSat ecosystem consisted of entities that supply electronic a) piece-parts, b) subsystems or assemblies, and c) spacecraft, and/or launch vehicles for SmallSat missions.*
    - Focus was on those who produce non-space grade products. However, some stakeholders interviewed offer both non-space grade and space-grade products.
  - *The ecosystem also included a fourth stakeholder entity, those who procure and/or specify the requirements for SmallSat spacecraft, launch vehicles, or missions*



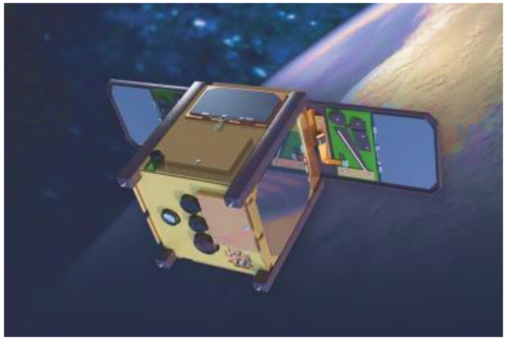


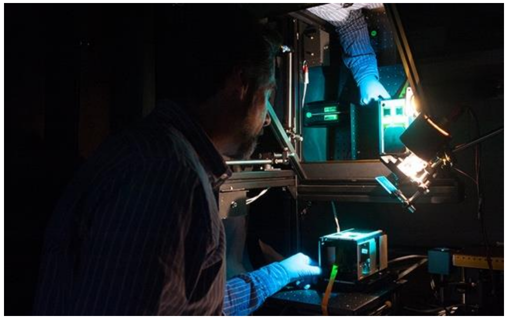


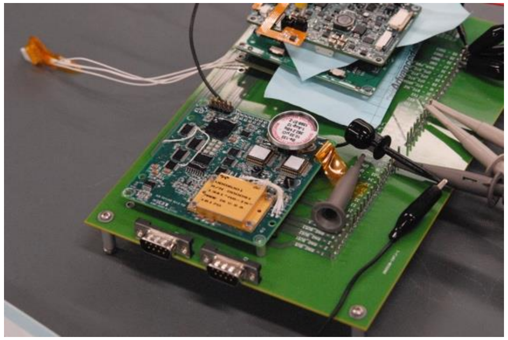
Executive Summary

(3 of 8)

- Study process – How we conducted the study
  - *Interview questions were grouped into topic areas within a stakeholder group for qualitative analysis*
  - *Samples of the diverse responses to each question were captured*
  - *Similar responses heard from multiple interviewees and selected candid comments were recorded as key messages*



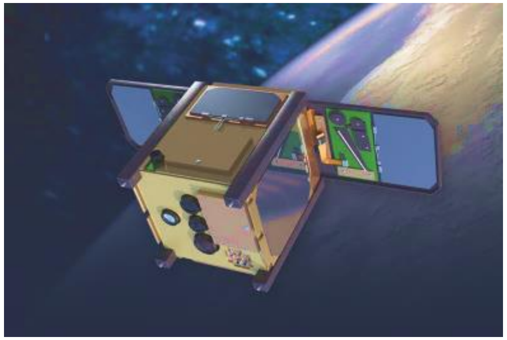


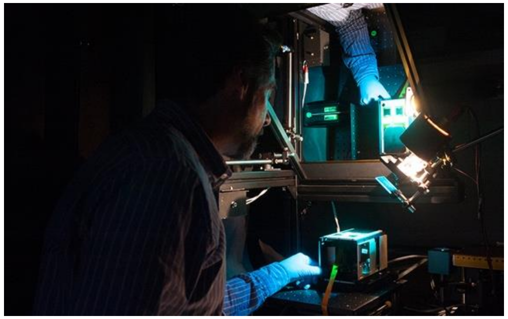


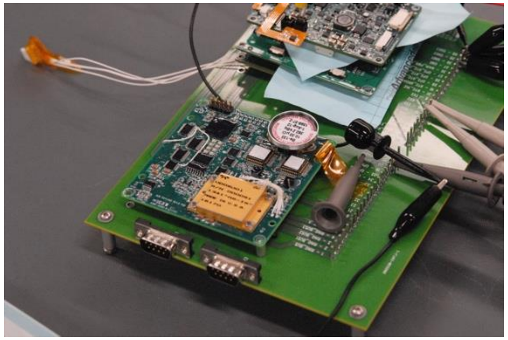
Executive Summary

(4 of 8)

- Findings – Top-level observations identified looking across the entire data set of interviewee responses
  - *In this period of burgeoning opportunity and transition, norms are being challenged*
  - *Requirements flowed to suppliers are fragmented and are not easily categorized*
    - Widely variable and dependent upon what suppliers and procurers at various levels are willing to agree to, rather than a codified set of standards adopted across the ecosystem.
- Study captured the rich diversity of perspectives and identified common themes in the hope that they sharpen insight as new norms are established
  - *Findings are foundational and will help inform future studies as the industry continues to evolves*



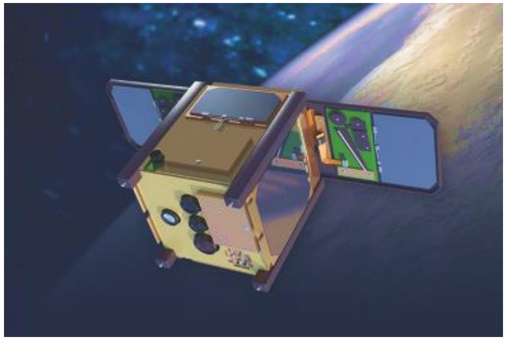


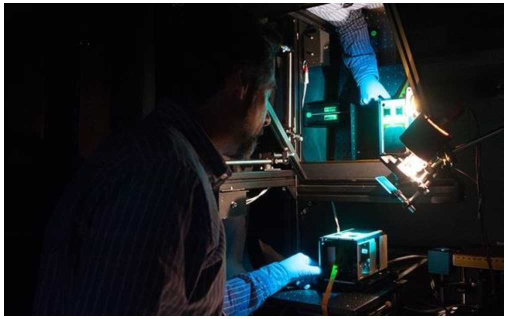


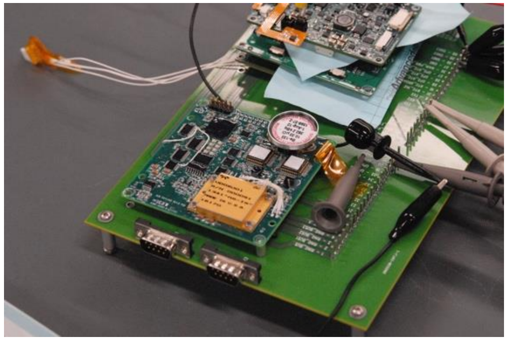
Executive Summary

(5 of 8)

- Repeated themes and observations, and selected candid comments:
  - *Members of the SmallSat ecosystem are willing to build – test – fly – learn, then repeat (i.e., frequently evolve designs based on what they learn on orbit)*
  - *Government acquisition practices and development approaches do not align well with those of many in the SmallSat ecosystem*
    - Achieving better alignment and synergies may require changes to federal laws or statutes OR
    - Government procurers must be willing to leverage the flexibility that already exists in current laws that would make SmallSat engagements simpler and quicker. However, “no one wants to be the first to step out and do that.”
  - *SmallSat projects are more frequently constraints-driven vs requirements-driven. Government projects are more frequently requirements-driven. This causes disconnects in communications and expectations.*





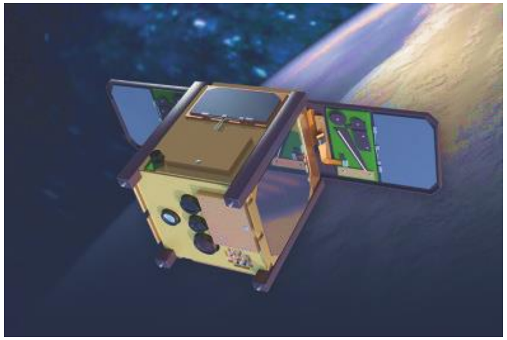


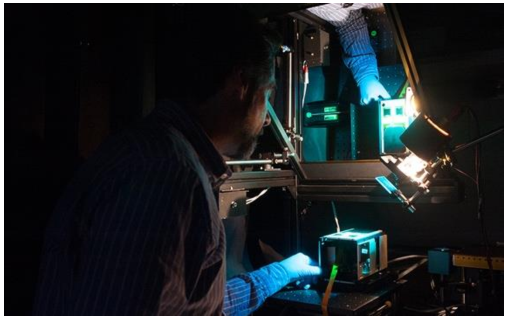
The comments expressed here are quotes from the Interviewees and do not represent the opinions of The Aerospace Corporation, NASA or the Air Force Space and Missile Systems Center

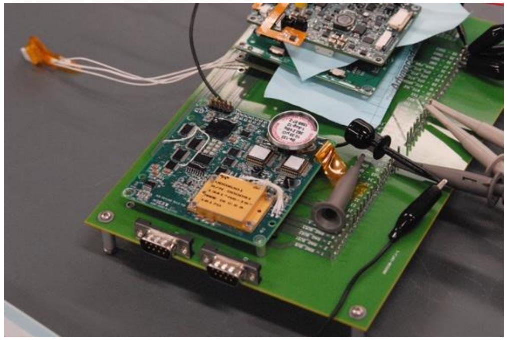
Executive Summary

(6 of 8)

- Repeated themes and observations, and selected candid comments:
  - *SmallSat providers are very concerned about and attuned to reliability and risk. They simply approach it differently.*
    - Detailed testing starts at card or assembly levels of integration vs at individual piece-part level
    - Manage risk at vehicle level or better yet, constellation level
  - *Government perceives some suppliers as holding data "close to the chest" and wants them to do more sharing. What suppliers don't realize is that access to data could actually help resolve misgivings the Government may have.*
  - *Some SmallSat ecosystem members don't trust certain Government entities or POCs enough to share data with them.*
    - Previous experience (or perceived fear) that information they shared with the Government made it to a competing entity
    - The value of building relationships cannot be over-stated





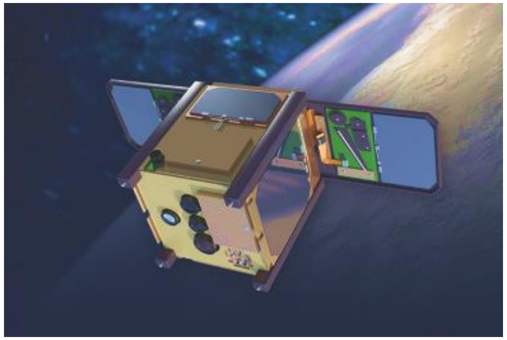


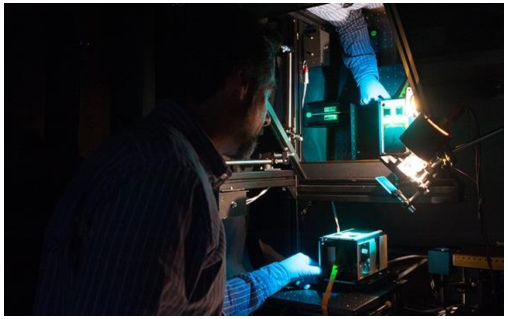
The comments expressed here are quotes from the Interviewees and do not represent the opinions of The Aerospace Corporation, NASA or the Air Force Space and Missile Systems Center

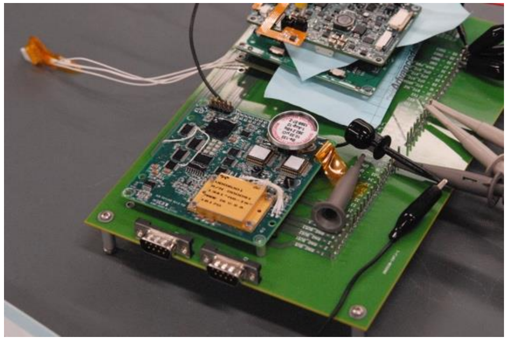
Executive Summary

(7 of 8)

- To accelerate progress, the SmallSat industry requests:
  - *Signal from the government that COTS can be considered*
  - *Publish guidelines for how COTS can be accepted for space applications*
  - *Produce a standard for what a "construction analysis" shall contain*
  - *Generate a standalone reliability document for automotive parts*
  - *Government to use any flexibility available to reduce the overhead burden on small space companies, associated with contracting and performance monitoring*
  - *Government to enter into engagements that more closely resemble collaborative, trusted partnerships vs strictly contractual engagements*





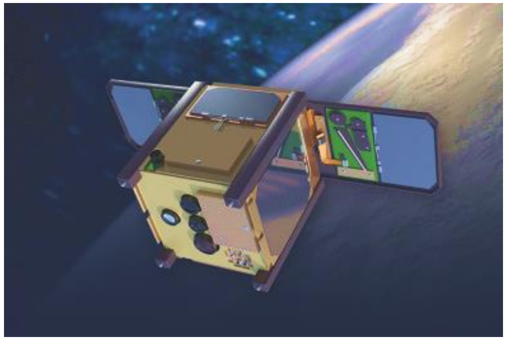


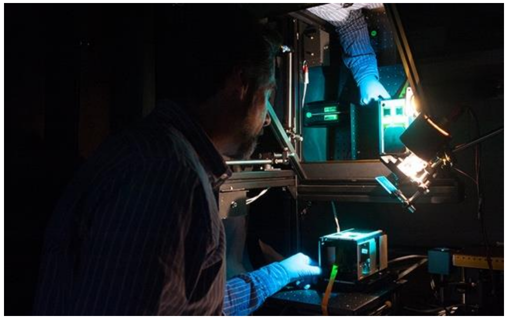
The comments expressed here are quotes from the Interviewees and do not represent the opinions of The Aerospace Corporation, NASA or the Air Force Space and Missile Systems Center

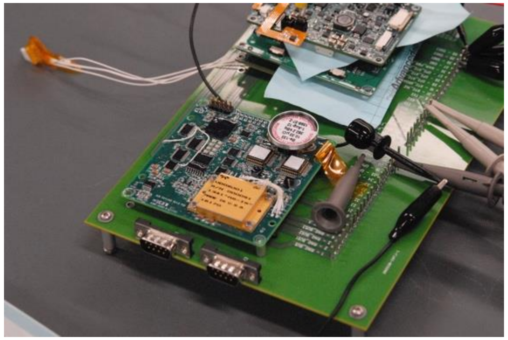
Executive Summary

(8 of 8)

- To accelerate progress, the SmallSat industry could:
  - *Create one giant catalog for COTS*
  - *Create a good Web site with specs and information*
  - *Attend conferences with Government in attendance*
  - *Deploy better key word searchability of Web sites and documents (e.g., use common terminology)*
  - *Support and work with the government to develop standards*
  - *Share more technical information/insight with the Government*







The comments expressed here are quotes from the Interviewees and do not represent the opinions of The Aerospace Corporation, NASA or the Air Force Space and Missile Systems Center

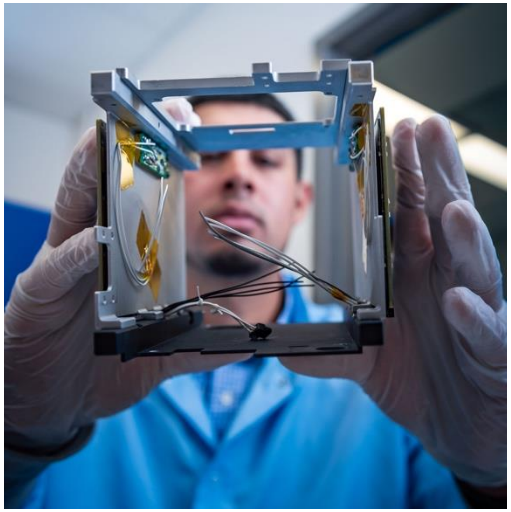
THE AEROSPACE CORPORATION

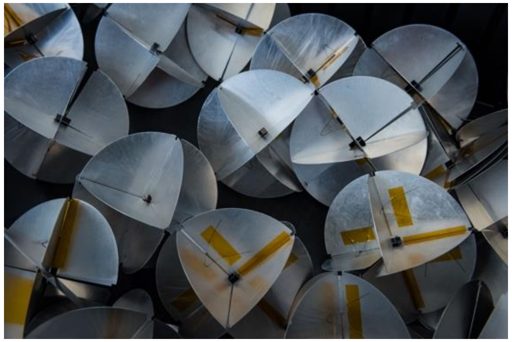
SmallSat Industrial Base Study

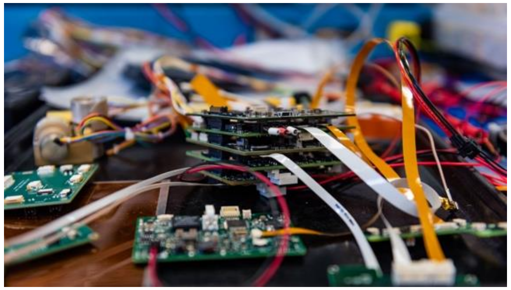
Objectives of the Study

(1 of 2)

- Gain better understanding of the SmallSat community's
  - *Technical practices, engineering approaches and common processes*
  - *Requirements flow-downs*
- Glean insight and recommendations for how the government can further capitalize on the strengths and capabilities of SmallSat offerings
- Understand the types of EEEE (electrical, electronic, electromechanical, electro-optical) part requirements that are flowed to sub-tier suppliers from small satellite programs
  - *Gather data through interviews and data reviews*
  - *Exclude CubeSats to avoid duplication of studies already under way*



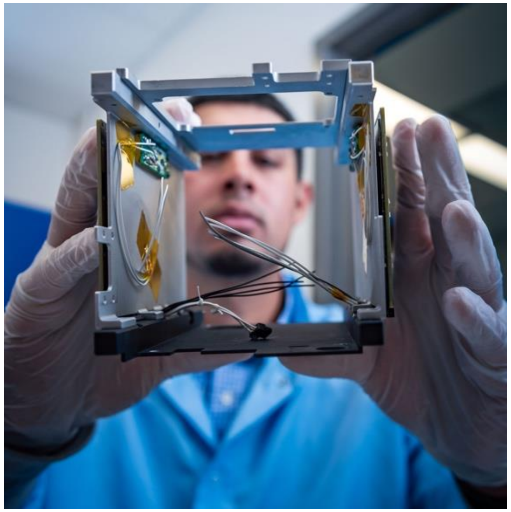


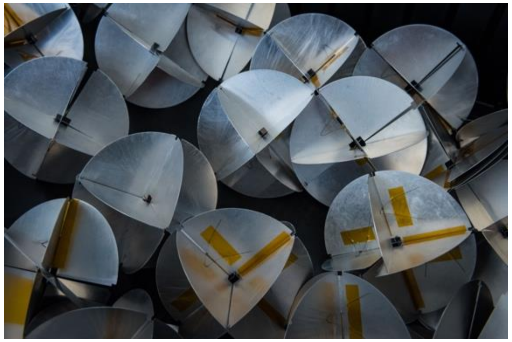


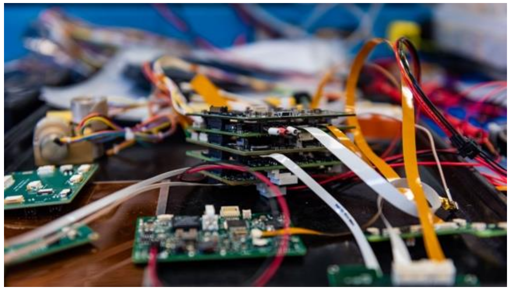
Objectives of the Study

(2 of 2)

- Touch on similarities and differences between part selection and testing practices for emerging “mid-space” parts vs traditional space-grade parts
- Where possible, determine potential effects on the larger space industrial base
  - *Enable use of alternate-grade parts without impacting the health of the space-grade supply chain*
  - *Reiterate that alternate-grade parts are not appropriate for some missions*





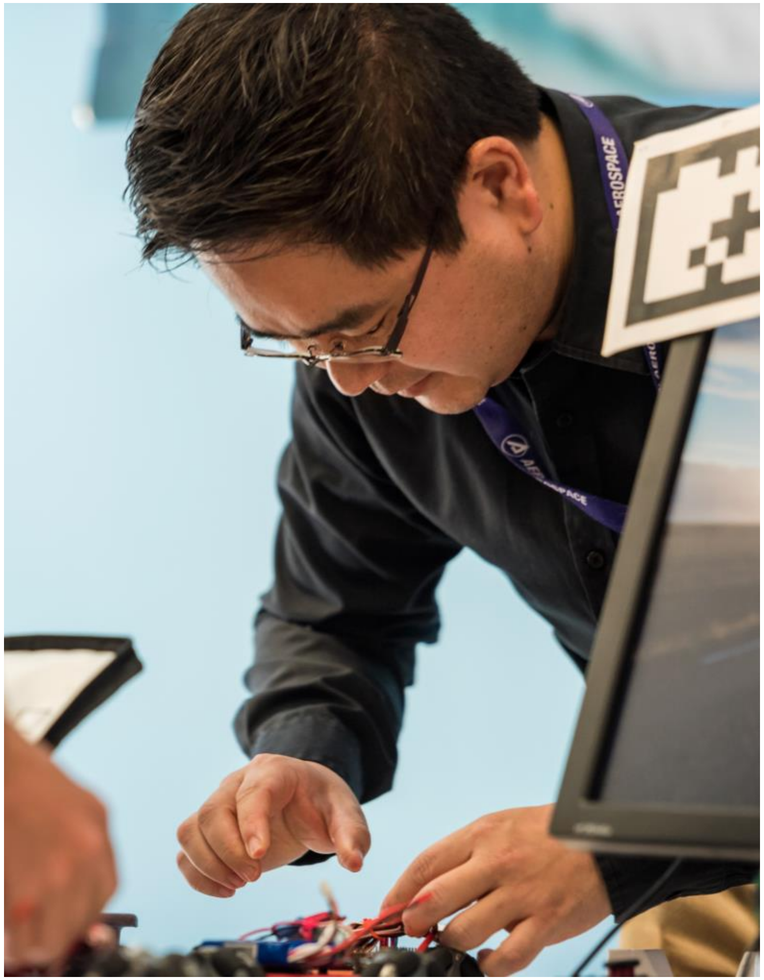


Study Approach

- Team reviewed conference and workshop proceedings, reports and recommendations from colleagues and the study's sponsors
- Prepared a list of four stakeholder groups representing the relevant SmallSat ecosystem
  - *Electronics Piece-Parts Suppliers*
  - *Card, Assembly and Subsystem Providers*
  - *Spacecraft Builders*
  - *Procurers of SmallSat vehicles or missions*
- Questions specific to each stakeholder group were prepared to support 30-minute interviews
  - *Due to scheduling constraints, some interviewees chose to respond by e-mail*
  - *All responses will be included on a non-attribution basis*
- Sincere thanks to stakeholder entities who agreed to participate in the study
- Coordinated with JPL, NASA/GSFC, Air Force Space and Missile Systems Center and leveraged knowledge of other concurrent initiatives
  - *NASA's Small Satellite Reliability Initiative*
  - *Collaborations with academia*
  - *February 2019 Small Satellite Symposium insights*
  - *August 2019 Small Satellite Conference*

Assumptions and Disclosures

- The study team committed to reporting participants' responses on a non-attribution basis
- To report particularly insightful responses in the report that will be distributed widely, and still protect anonymity, we have replaced specific references to names or products with a generic reference
  - *In cases where we have done so, we placed the generic text within [square brackets as shown here]*
- Besides the participants' comments, the team relied on open source, publicly available conference and workshop proceedings, reports and Internet sources



Report Layout

(1 of 2)

- Study team considered several options for representing the qualitative data gathered in the interviews and for identifying common themes
- One such approach is a heatmap, a depiction of data as a map or diagram in which data values are represented as colors
  - *Where needed, the heatmap concept was augmented by text that captured specific attributes of the interviewee or response*
- In the heatmap, each respondent is represented by a letter (see capital letters in the top row of the heatmap.)
- Key practices, criteria or themes important to the Government as a key procurer appear in the left-most column of the heatmap
- Based on responses to interview questions, heatmaps were prepared that qualitatively depict similarities and differences between the respondent's organization's practices and the Government's traditional practices
  - *Piece-part suppliers, circuit card/assembly/subsystem suppliers, spacecraft/launch vehicle builders*

Report Layout

(2 of 2)

- Colored cells of the heatmap express the degree of general alignment of a given respondent's practices with government specifications, standards, expectations or practices
- In no way are the colors meant to convey any type of value judgment or assessment of correctness. Rather, the intention is to highlight where similarities and differences in practices may exist, based on responses to interview questions
- The goal is to deepen understanding as entities across the space industry communicate and collaborate to serve their diverse stakeholders in this rapidly evolving environment
- Following heatmaps, the report documents selected responses to interview questions
  - *The comments captured are quotes from the interviewees and do not represent the opinions of The Aerospace Corporation, NASA or the Air Force Space and Missile Systems Center*
- Key messages for the Government and Industry to consider, gleaned from the interview responses, are reported
- Finally, selected references, standards and technical guidance documents mentioned by respondents, and an acronym list complete the report

Heatmap: Electronic Piece-Part Suppliers

General Alignment with Gov't Standards:	STRONG	MODERATE	WEAK	MINIMAL	NONE

Respondent / Practices Used	A	B	C	D	E
Amount of alternate-grade parts usage	COTS, Enhanced Product, Automotive, Military, Space	COTS, Medical, Aircraft Military, Space	COTS, Rad Tolerant, Automotive, Military, Space	COTS, Industrial, Automotive, Medical, Military, Space	COTS, used in Automotive, Medical, Military, Space applications
Data provided to customers	MODERATE	WEAK	WEAK	MINIMAL	MODERATE
Basic requirements flowed	MODERATE	MODERATE	MINIMAL	MODERATE	MINIMAL
Standards referenced	MODERATE	MODERATE	MODERATE	STRONG	MINIMAL
Estimating reliability or risk	STRONG	STRONG	STRONG	STRONG	NONE

Note: Not an assessment. Simply an indicator of similarities/differences between respondent's organization's practices and Government's traditional practices, based on responses to interview questions

Heatmap: Card, Assembly, Subsystem Suppliers

General Alignment with Gov't Standards:	STRONG	MODERATE	WEAK	MINIMAL	NONE

Respondent / Practices Used	A	B	C	D	E	F	G	H	I	J
Amount of alternate-grade parts usage	Very little. Space-grade parts preferred	COTS is most-used part grade	COTS ~50%, Auto/Indus ~25%, Space/Rad Hard ~25%	Industrial 90%, COTS 5%, Aviation/ Auto 5%	Avoid commercial, use some industrial, lot of JAN, lot of upscreening	Many COTS, the rest are a mixture of multiple grades	Many COTS	95% COTS	100% COTS	Small amount of non-Class-S
Data provided to customers	Depends on customer	Functional tests for custom parts	Determined by customer spec and Statement of Work		Temperature screening and burn-in, qualification, End Item Data Package	Not much different from flagship missions. Extensive testing etc. to ensure meeting requirements.	Depends on customer and mission	Depends on customer. Does more for a cost.	Parts traceability, wafer traceability when possible	Acceptance testing at supplier
Basic requirements flowed										
Standards referenced	Not available									
Estimating reliability or risk										

Note: Not an assessment. Simply an indicator of similarities/differences between respondent's organization's practices and Government's traditional practices, based on responses to interview questions

Heatmap: Spacecraft and Launch Vehicle Builders

General Alignment with Gov't Standards:	STRONG	MODERATE	WEAK	MINIMAL	NONE

Respondent / Practices Used	A	B	C	D	E	F	G	H	I	J	K	L
Standards referenced			Not Applicable									
Basic requirements flowed to subs			Not Applicable									
Tests and validation performed												

Note: Not an assessment. Simply an indicator of similarities/differences between respondent's organization's practices and Government's traditional practices, based on responses to interview questions

SmallSat Electronic Piece-Part Suppliers

SELECTED INTERVIEW QUESTIONS/RESPONSES

SmallSat Piece Part Suppliers:

Selected Interview Questions/Responses

- What data do you provide to customers for the various types of parts you supply and is there a cost for the data?
  - *COTS: No data.*
  - *Military grade: QCI (Quality Conformance Inspection) attributes data.*
  - *Aerospace grade: Expanded C of C (Certificate of Compliance-with wafer lot and wafer no. ID).*
  - *Automotive: PPAP (Production Part Approval Package).*
  - *No unit level or lot level data to any customer or market.*
  - *Aerospace product shipments receive an expanded C of C (with wafer lot & wafer no. ID) and a full data package is available for a purchase order upcharge.*
  - *If required by the automotive customer, a PPAP is generated documenting the product design, assembly and qualification (PPAP contents per AIAG – Automotive Industry Action Group – template).*

The comments expressed here are quotes from the Interviewees and do not represent the opinions of The Aerospace Corporation, NASA or the Air Force Space and Missile Systems Center

SmallSat Piece Part Suppliers:

Selected Interview Questions/Responses

- What data do you provide to customers for the various types of parts you supply and is there a cost for the data?
  - *Depending upon the flow down and specification requirements by the customer, we provide Technology Qualification reports, lot specific qualification reports, read and record electrical test data, attribute summaries, etc.*
  - *Depending upon the business engagement, [our company] may absorb the cost of acquiring and publishing this data or we may require the customer to fund the activity/datapack.*
  - *For [certain of our products destined for space use] a data pack is included with QML class V [products]. A data pack is an optional extra for [certain] QML class Q [products]. The data pack includes: C of C, group C data, group D data, assembly traveler, test traveler, TID (Total Ionizing Dose) report, and various other documents depending on the screening level ordered.*
  - *Automotive or commercial = Only C of C.*

The comments expressed here are quotes from the Interviewees and do not represent the opinions of The Aerospace Corporation, NASA or the Air Force Space and Missile Systems Center

SmallSat Piece Part Suppliers:

Selected Interview Questions/Responses

- What data do you provide to customers for the various types of parts you supply and is there a cost for the data?
  - *For Class V and Class Q products, lot summary information (tests performed) and QCI summaries.*
  - *For automotive, a PPAP can be requested. (Full PPAP requires an NDA). Lot specific data is not provided.*
  - *For commercial products, limited qualification, monitor, and reliability data is provided online. Lot specific data is not provided.*

The comments expressed here are quotes from the Interviewees and do not represent the opinions of The Aerospace Corporation, NASA or the Air Force Space and Missile Systems Center

SmallSat Piece Part Suppliers:

Selected Interview Questions/Responses

- What types of tests and validation do you perform for the various part types you provide?
  - *Commercial products = Most products 100% probed in wafer form, limited models are blind assembly (no probe). 100% ATE (Automated Test Equipment) @ +25C typical. Characterized over full temp range at release. Qualification at initial release and for process/product changes per JEDEC industry standards.*
  - *Automotive = Full APQP (Advanced Product Quality Planning) process employed from design conception to release. Special probe (good die/bad neighborhood, etc. per industry standards), 100% ATE with special defect detection such as SYL, SBL, PAT (statistical yield limits, statistical bin limits, part average testing) etc. Characterized over full temp range at release, burn-in typically performed in safe launch phase, IC (Integrated Circuit) qual per AEC-Q100, SIP (System in Package) qual per AEC-Q104.*
  - *Standard military per Class H MIL-PRF-38534 for hybrids or Class Q 38535 for ICs. 100% test over full temp range, Group A,B,C,D.*
  - *Aerospace per Class S MIL-PRF-38535. 100% test over full temp range -55/+125C, 240 hour burn in, Group A,B,C,D,E (for QMLR/QMLL)*

The comments expressed here are quotes from the Interviewees and do not represent the opinions of The Aerospace Corporation, NASA or the Air Force Space and Missile Systems Center

SmallSat Piece Part Suppliers:

Selected Interview Questions/Responses

- What types of tests and validation do you perform for the various part types you provide?
  - *Space, Military, and Aircraft (ICs MIL-PRF-38535 and MIL-STD-883, CCAs per Contract).*
  - *Medical and Commercial (JEDEC standards (e.g. JESD47) and as agreed per Contract).*
  - *Commercial [products] are qualified in conformance to JESD47. Commercial [products] offered as Automotive are qualified in conformance to AEC-Q100.*
  - *Radiation tolerant [products] are qualified in conformance to Mil-STD-883 class B, QML class Q, and in some cases to QML class V.*
  - *Radiation tolerant [product for] QML provides more prescriptive requirements in comparison to Automotive or Commercial.*
  - *MIL-PRF-38553 for QML Class Q, Class V, and Class N. Automotive grade per AEC-Q100. Commercial grade per JEDEC. Other product types have additional tests and validation.*

The comments expressed here are quotes from the Interviewees and do not represent the opinions of The Aerospace Corporation, NASA or the Air Force Space and Missile Systems Center

SmallSat Piece Part Suppliers:

Selected Interview Questions/Responses

- What basic requirements do you see flowed down to you from the contractor (technical and quality)?
  - *We produce COTS devices and rarely accept additional flow downs.*
  - *Depends on the customer and application. Includes full MIL-PRF-38535 QML Class V, NASA PEM-INST-001, standard automotive, and commercial*
  - *In some cases, radiation performance is specified.*
  - *We often see requirements for single lot date code, and date code no older than two years or three years.*

The comments expressed here are quotes from the Interviewees and do not represent the opinions of The Aerospace Corporation, NASA or the Air Force Space and Missile Systems Center

SmallSat Piece Part Suppliers:

Selected Interview Questions/Responses

- What basic requirements do you see flowed down to you from the contractor (technical and quality)?
  - *Space: QML, ISO-9001/AS9100, TOR-2006(8583)-5235, TOR-2006(8583)-5236, Counterfeit Controls, Prohibited Materials.*
  - *Military: QML, ISO-9001/AS9100, Counterfeit Controls, Prohibited Materials.*
  - *Aircraft: ISO-9001/AS9100, Counterfeit Controls, Prohibited Materials.*
  - *Medical: ISO-9001, ISO13485-Medical Devices, ROHS/REACH (Restriction of Hazardous Substances / Registration, Evaluation, Authorization of Chemicals)*.
  - *Commercial: ISO-9001, ROHS/REACH.*

The comments expressed here are quotes from the Interviewees and do not represent the opinions of The Aerospace Corporation, NASA or the Air Force Space and Missile Systems Center

SmallSat Piece Part Suppliers:

Selected Interview Questions/Responses

- What basic requirements do you see flowed down to you from the contractor (technical and quality)?
  - *For large volume customers (commercial or automotive), there is usually a general quality document.*
  - *For custom products, there is a full source control drawing with the datasheet parameters fully defined.*
  - *Customer requirements can vary widely – the typical requirements can include environmental, failure analysis, legal, logistics, packaging, quality, reliability, shipping/warehouse, wafer fab, assembly, test.*
  - *Depending on the end application, there is a wide variety of requirements and no two are alike. Automotive customers usually document whether AEC qual is required and which PPAP (Production Part Approval Process) Level (if any) is required.*
  - *For COTS and mil/aero SMD (surface mount device) products the goal is for customers to buy standard part numbers with well-defined requirements, thereby eliminating the need for customer drawings.*

The comments expressed here are quotes from the Interviewees and do not represent the opinions of The Aerospace Corporation, NASA or the Air Force Space and Missile Systems Center

SmallSat Piece Part Suppliers:

Selected Interview Questions/Responses

- What hurdles to you see in meeting requirements for traceability and homogeneity primarily for automotive and commercial?
  - *As packages continually decrease in size, the ability to provide full traceability through the package marking becomes more challenging.*
  - *We currently provide our customers with foundry, wafer lot, and assembly lot traceability for quality control and reliability tracking, should field failures occur.*
  - *Depending on the size of the device, the area for marking traceability information is limited. In some cases it may only be possible to identify a one-month window for a product assuming the customer can reasonably determine the year in which the part was purchased.*
  - *We see no hurdles. Homogeneity is an unnecessary requirement if unit level traceability is assured with device level serialization.*

The comments expressed here are quotes from the Interviewees and do not represent the opinions of The Aerospace Corporation, NASA or the Air Force Space and Missile Systems Center

SmallSat Piece Part Suppliers:

Selected Interview Questions/Responses

- What hurdles to you see in meeting requirements for traceability and homogeneity primarily for automotive and commercial?
  - *Automotive and commercial customers require component sameness versus homogeneous lots. To keep costs competitive, certain lot combination rules are allowed. Assembly date codes will not be combined prior to final pack. For catalog products, four date codes maximum, not more than 52 weeks apart may be combined into one intermediate manufacturing pack (bag/box/reel).*
    - In other words, after standard quantities are packed (e.g., full reel) the units left over from a given lot are set aside and combined with the next production lot to make a full reel.

The comments expressed here are quotes from the Interviewees and do not represent the opinions of The Aerospace Corporation, NASA or the Air Force Space and Missile Systems Center

SmallSat Piece Part Suppliers:

Selected Interview Questions/Responses

- What hurdles to you see in meeting requirements for traceability and homogeneity primarily for automotive and commercial?
  - *Commercial and automotive customers desire a multiple sourcing strategy to mitigate supply chain risk, so a specific device may originate from more than one wafer fabrication or assembly/test site. The sites cannot be specified by the customer.*
  - *Product is identified from raw materials through all stages of production and shipment to the customer.*
  - *Depending on the size of the device, the area for marking traceability information is limited. In some cases it may only be possible to identify a one-month window for a product, assuming the customer can reasonably determine the year in which he part was purchased.*
  - *In the event of an excursion, outward traceability to the end customer is not possible if the product was sourced through a non-authorized distributor/broker/reseller/test lab.*

The comments expressed here are quotes from the Interviewees and do not represent the opinions of The Aerospace Corporation, NASA or the Air Force Space and Missile Systems Center

SmallSat Piece Part Suppliers:

Selected Interview Questions/Responses

- What hurdles to you see in meeting requirements for traceability and homogeneity primarily for automotive and commercial?
  - *For our commercial products, we currently provide our customers with foundry, wafer lot, and assembly lot traceability for quality control and reliability tracking, should field failures occur. Some products have individual [specialized] device traceability.*
  - *Traceability is done with an internal tracking unique code, date code, and wafer lot number. Homogeneity for automotive or commercial products: Multiple date codes are shipped together – there is no limitation in processing a single lot date code (unless requested by customer). For Space/Military, there is a clear requirement in terms of definition of lot from a date code standpoint.*

SmallSat Sub-system Providers

SELECTED INTERVIEW QUESTIONS/RESPONSES

SmallSat Sub-system Providers:
Selected Interview Questions/Responses

- What available information and measures does your organization, subcontractors or vendors offer in lieu of the heritage management approach and military specifications?
  - *Relies on a detailed agreement between us and the customer*
  - *If the part is not available NOW for immediate delivery, we will likely not consider it, and strike it from our list of approved components.*

The comments expressed here are quotes from the Interviewees and do not represent the opinions of The Aerospace Corporation, NASA or the Air Force Space and Missile Systems Center

SmallSat Sub-system Providers:

Selected Interview Questions/Responses

- How does your organization quantify or estimate reliability or risk?
  - *Estimate reliability using MIL-HDBK-217 methods, for lack of a better option.*
  - *Identify technical and programmatic risks using traditional 5x5 Risk-Impact Matrix. Funding is allocated as appropriate to retire [risk] if possible.*
  - *We don't, apart from our selection process... Our 20+ years of flight heritage has shown that our approach yields very reliable and long-lived systems.*

The comments expressed here are quotes from the Interviewees and do not represent the opinions of The Aerospace Corporation, NASA or the Air Force Space and Missile Systems Center

SmallSat Sub-system Providers:

Selected Interview Questions/Responses

- Does your organization use a quality management system (QMS)?
  - *Yes, but it's still new.*
  - *Best practices are in place and executed, just not documented.*
    The quality management system procedures and processes are in the heads of the employees, most of whom have 20 – 35 yrs of space experience. Employees know what to do.
  - *Yes, AS9100 is the general QMS.*
  - *We have and occasionally use a QMS, such as when it is required by program requirements. For R&D projects especially, we do not use a QMS.*
  - *Not a formal one.*
  - *We use an internal quality management system.*

The comments expressed here are quotes from the Interviewees and do not represent the opinions of The Aerospace Corporation, NASA or the Air Force Space and Missile Systems Center

SmallSat Sub-system Providers:

Selected Interview Questions/Responses

- How frequently are COTS parts used in your space-bound systems?
  - *100% of the time.*
  - *It depends on the product line. They are very infrequent in traditional hi-reliability missions. For low-cost missions, they are used in several applications. One distinction is whether automotive grade passive devices are considered COTS. … We consider COTS to be an imprecise term.*
  - *Depends on complexity. None of our circuit boards are COTS – those are special. We hire an electronics shop to do those. [Some electromechanical components] are special order.*
  - *For the spacecraft, use almost all COTS parts. Occasionally buy a radio or an [other] receiver from a vendor, but it is an off the shelf item. We look for and pick something that has flown before. Often chose items that have been used in the aircraft industry for years.*
  - *Exclusively. Some critical modules use higher grade industrial parts.*
  - *Infrequently. Prefer Class-S.*

The comments expressed here are quotes from the Interviewees and do not represent the opinions of The Aerospace Corporation, NASA or the Air Force Space and Missile Systems Center

SmallSat Sub-system Providers:

Selected Interview Questions/Responses

- How frequently are COTS parts used in your space-bound systems?
  - *Company stocks Level 1 parts or Class S parts. Only when dictated by performance requirements that cannot be met by other Class S parts will we use COTS.*
  - *Usually, we prefer to start with Class S QML parts, but will procure other parts as necessary.*
  - *Going forward (in a perhaps a year or more), small satellites within our organization can expect to use more automobile COTS, but for now it is relatively rare.*
  - *Very frequently.*
  - *<75%.*

The comments expressed here are quotes from the Interviewees and do not represent the opinions of The Aerospace Corporation, NASA or the Air Force Space and Missile Systems Center

SmallSat Sub-system Providers:

Selected Interview Questions/Responses

- Estimate the percentage for each category of COTS parts used in your product-line (e.g., commercial, industrial, aviation, up-screened)?
  - *Very few COTS, where QML (Qualified Manufacturer's List) or otherwise space-grade parts are preferred.*
  - *Especially because of EEE parts, most of our parts are commercial grade.*
  - *Commercial ~50%, Automotive/Industrial ~25%, Space Qualified, RHA (Radiation Hardness Assurance) 25%.*
  - *Commercial: 5% Industrial: 90% Aviation/Automotive: 5% Up-screened: 0%.*
  - *Commercial: near zero; we avoid these as much as practical; industrial: some, particularly things like high-speed memory which have limited availability from other category sources. We use a lot of JAN-level components in our more commercial products which many be some combination of JAN/JANTX/JANTXV.*
    - If a customer requests a certain level for these parts, we can supply it (sometimes with an impact in cost/lead-time).
  - *Up-screened: we use a fair number of up-screened parts in some applications. The percentage of these really depends on the product and varies significantly across our product offerings.*

The comments expressed here are quotes from the Interviewees and do not represent the opinions of The Aerospace Corporation, NASA or the Air Force Space and Missile Systems Center

SmallSat Sub-system Providers:

Selected Interview Questions/Responses

- Estimate the percentage for each category of COTS parts used in your product-line (e.g., commercial, industrial, aviation, up-screened)?
  - *Very limited. In the future we will have a mixture.*
  - *We custom make the electronics boards – trying to design for an analog to the space rated part. Then the COTS part can survive. Outside LEO, we choose a rad hard part to survive.*
    - Definitely helps to save cost on developing flight-like system for [customers] to test on the ground. That opens up the major customers – form - fit - function replacement, should a customer request that.
  - *Use 95% COTS. Sometimes, as in the case of solar cells, they were space parts, but without the testing and pedigree (documentation) to prove it.*
  - *100%.*
  - *Small amount of non Class-S.*

The comments expressed here are quotes from the Interviewees and do not represent the opinions of The Aerospace Corporation, NASA or the Air Force Space and Missile Systems Center

SmallSat Sub-system Providers:

Selected Interview Questions/Responses

- Does your organization rely on redundancy to increase reliability?
  - *We do tour best to use redundancy to increase reliability or at least provide degraded functionality.*
  - *Redundancy is implemented in a couple of ways on critical functions:*
    - Redundancy at the system level (redundant spacecraft, for example)
    - Redundancy at the functional level (typically utilizing a different hardware/software design approach)
  - *In some cases, we do. Otherwise the systems are single-string.*
  - *In critical applications. As an example, events that are considered hazardous typically require single or dual fault tolerance for the generation of a hazard. This includes things such as separation inhibits for spacecraft, battery overcharge/discharge, propulsion systems, etc. We also consider redundancy when it is necessary to meet high-level availability requirements or if a customer wants it for an application.*
  - *We work with vendors to match expectations with respect to interfaces wanted for fault detection correction. It has saved our bacon for flight missions. We develop a shoulder-to-shoulder relationship with vendors. Some aren't as accommodating, so we find another vendor.*

The comments expressed here are quotes from the Interviewees and do not represent the opinions of The Aerospace Corporation, NASA or the Air Force Space and Missile Systems Center

SmallSat Sub-system Providers:

Selected Interview Questions/Responses

- Does your organization rely on redundancy to increase reliability?
  - *It depends. [One of our products has a critical enabling component]. We know there could be a lifetime issue with [that component], so we put four on there as a redundancy where we anticipate there could be a failure.*
  - *No. Where we could put functional redundancy in, we would. For example, we would put in the ability to upload a [particular parameter] should [a key component] fail. But we apply no block redundancy.*
  - *Recommend implementing redundancy at the system level*
  - *No.*

The comments expressed here are quotes from the Interviewees and do not represent the opinions of The Aerospace Corporation, NASA or the Air Force Space and Missile Systems Center

SmallSat Sub-system Providers:

Selected Interview Questions/Responses

- What are the most important technical requirements your organization provides to suppliers of subsystems, assemblies, and piece parts?
  - *Size, weight, power, interface details, functional performance specific to the item.*
  - *In the case of COTS, we cannot flow down a source-control-drawing or give definite requirements. Otherwise, it is the usual requirements depending on the specific subcomponent, application and environment.*
  - *We don't. We either build items that require this in-house, or we purchase COTS parts that come with sufficient documentation.*
  - *Radiation tolerance, electrical performance, life drift, temperature performance*
  - *If we are buying subsystems, we would require environmental stress screening or tests OR do it ourselves. We prefer to have items come to us already tested. We would do this for sub-assembly level items. No special requirements for piece parts. We purchased piece parts [online from an authorized distributor].*
  - *All parts for each [multi-unit] build are purchased from a single wafer lot when possible.*
  - *Source Control Drawings.*

The comments expressed here are quotes from the Interviewees and do not represent the opinions of The Aerospace Corporation, NASA or the Air Force Space and Missile Systems Center

SmallSat Sub-system Providers:
Selected Interview Questions/Responses

- Certain DoD and NASA standards or test methods are often referenced by the SmallSat community. Some standards need to be updated to reflect advanced technologies and mass production quality improvements achieved since the original documents were published. What approach would you take to do this?
  - *Military standards and many other existing standards are very recipe-oriented, so we wouldn't suggest updating them. A reliable system comes from deep understanding of the system, rather than following a recipe.*
  - *Need a better way to estimate reliability. Suggestion would be to utilize the methods of MIL-HDBK-217, but with the manufacturer's failure rate data. (Most COTS manufacturers develop failure rate estimates based upon life testing, and many of them publish the data.) This method needs to be coupled with thermal management requirements, derating, and radiation testing programs.*

The comments expressed here are quotes from the Interviewees and do not represent the opinions of The Aerospace Corporation, NASA or the Air Force Space and Missile Systems Center

SmallSat Sub-system Providers:

Selected Interview Questions/Responses

- Certain DoD and NASA standards or test methods are often referenced by the SmallSat community. Some standards need to be updated to reflect advanced technologies and mass production quality improvements achieved since the original documents were published. What approach would you take to do this?
  - *Quality does not stem from following standards and test methods -- quality stems inherently from good design, and there are a lot of terrible designs out there. The only mandatory judge of SmallSat-style quality should be whether the components and subsystems are passing or failing typical test (NASA GEVS - General Environmental Verification Standard for GSFC Flight Programs and Projects, etc.) and their on-orbit success.*
  - *The notion that NASA or the DoD can match the reliability of consumer devices (e.g. 25,000,000 iPhones per quarter) at a reasonable cost is simply laughable. Instead, a combination of good design and using the latest, mass-produced consumer parts in industrial and automotive grades is the key to minimizing cost while piggybacking on a much larger market, and the quality performance of the suppliers in that market.*

The comments expressed here are quotes from the Interviewees and do not represent the opinions of The Aerospace Corporation, NASA or the Air Force Space and Missile Systems Center

SmallSat Sub-system Providers:

Selected Interview Questions/Responses

- Certain DoD and NASA standards or test methods are often referenced by the SmallSat community. Some standards need to be updated to reflect advanced technologies and mass production quality improvements achieved since the original documents were published. What approach would you take to do this?

  – *We recognize that the single largest source of possible errors in the manufacturing of SmallSat components is human error; therefore procedures to be followed and inspections to be done are a very effective way to minimize quality errors, and (non-mandatory) NASA and DoD procedures are a very reasonable guide to follow. But at the volumes of the SmallSat industry, these are generally not cost-effective to implement, short of serious government subsidies to the manufacturers (which is how many SmallSat players are in business).*

The comments expressed here are quotes from the Interviewees and do not represent the opinions of The Aerospace Corporation, NASA or the Air Force Space and Missile Systems Center

SmallSat Sub-system Providers:

Selected Interview Questions/Responses

- Certain DoD and NASA standards or test methods are often referenced by the SmallSat community. Some standards need to be updated to reflect advanced technologies and mass production quality improvements achieved since the original documents were published. What approach would you take to do this?
  - *MIL-HDBK-217F comes to mind for reliability (though there are VITA (VME International Trade Association) standards that can be used to augment it which are much more modern).*
  - *EEE-INST-002 could use better definition on what constitutes a PEM (plastic-encapsulated micro-circuit) since there seem to be a lot of parts designed for higher reliability and extended temperature range using plastic encapsulation. The PEM section approaches these parts as being much more standard/commercial; it would probably be better to have a more specific definition in that document for these parts (and potentially have different classifications that recognize the difference between 0-70C rated plastic encapsulated parts and -55-125C rated plastic encapsulated parts which may also have a significant hi-rel screening flow).*
  - *No, all are ok.*

The comments expressed here are quotes from the Interviewees and do not represent the opinions of The Aerospace Corporation, NASA or the Air Force Space and Missile Systems Center

SmallSat Sub-system Providers:

Selected Interview Questions/Responses

- Certain DoD and NASA standards or test methods are often referenced by the SmallSat community. Some standards need to be updated to reflect advanced technologies and mass production quality improvements achieved since the original documents were published. What approach would you take to do this?
  - *Creating a standard that people can build to for Class D helps make it a reality.*
  - *Space parts are used in small quantities. Look...computer laptop batteries are used in SmallSats. Need to take advantage of the quality inherent in mass-produced parts. The types of quality standards commercial industry applies give you some inherent reliably just based on the volume in which they are produced. The mass-produced parts are sometimes more reliable than the small-batch space parts.*

The comments expressed here are quotes from the Interviewees and do not represent the opinions of The Aerospace Corporation, NASA or the Air Force Space and Missile Systems Center

SmallSat Sub-system Providers:

Selected Interview Questions/Responses

- What outside-the-box, agile measure can the government take to help the COTS community (i.e., manufacturers, providers and parts suppliers) adapt to new demands for satellite systems and services?
  - *The government can and should advocate for a comprehensive database that collates information collected in programs and allows accession by others. For example, radiation data are expensive and sorely needed in this market segment.*
  - *We have found that Class D is not well defined. We could use clarification on specific requirements for meeting Class D requirements. In another area, [certain types of] new entrants could use a streamlined process for navigating the bureaucracy, such as when and how to get FCC, NOAA or FAA, and similar approvals. Also, could use help with ensuring a streamlined process for range safety. The government should also invest in lower TRL (Technology Readiness Level) technologies.*
  - *Developing good standards that have several different levels so that end-users can procure systems to established standards would be helpful. Pushing these standards into use on government procurements to generate volume on them would also be helpful.*

The comments expressed here are quotes from the Interviewees and do not represent the opinions of The Aerospace Corporation, NASA or the Air Force Space and Missile Systems Center

SmallSat Sub-system Providers:

Selected Interview Questions/Responses

- What outside-the-box, agile measure can the government take to help the COTS community (i.e., manufacturers, providers and parts suppliers) adapt to new demands for satellite systems and services?

  – *A Class D specification/formal doc would be good. On our first [productized] system, we couldn't get a straight answer on doing the vibration test. And on another program we had requirements creep on the survival temp (55 deg C to 71 deg C) – What does it really need to be? Some reality measure is needed of "What do you realistically need?"*

  – *Some commercial new space companies don't even care if the government does business with therm. They're not interested in, say, building buses for the government. They want to build them for themselves, get assets on orbit and start generating revenue. The government needs to figure out which pieces of the "new space" industry want to become a government contractor. These companies want to sell data, not necessarily the hardware.*

  – *Recognize the value of better design, instead of basing decisions on paper trails and following procedures. Buy more COTS components and distribute them out to various users.*

The comments expressed here are quotes from the Interviewees and do not represent the opinions of The Aerospace Corporation, NASA or the Air Force Space and Missile Systems Center

SmallSat Sub-system Providers:

Selected Interview Questions/Responses

- What can the COTS community do to make it easier for the government to gain insight into the relative strength and challenges of COTS?

  – *Understand how to provide more information and contribute to databases.*

  – *Ideally, providers of subsystems and/or small satellite systems would contribute their successes and failures into a database, say their test results and bill of materials. Emphasize this especially for radiation-hardened devices. The government could encourage this by requiring it as part of the acquisition process. Also, whenever there are failures and they can pin-point the problem, then it would be helpful for them to share that in this database.*

SmallSat Sub-system Providers:

Selected Interview Questions/Responses

- What can the COTS community do to make it easier for the government to gain insight into the relative strength and challenges of COTS?
  - *Provide government access to derating analyses, standardized reliability predictions (assuming we're able to make headway on the problem of MIL-HDBK-217), and test results from part qualification programs.   Rather than ask the government to establish the requirements, my suggestion is that the providers establish processes which match the risk posture and capabilities of the provider, and that said providers convince the government that their methods and results are valid for each mission.*
  - *A spacecraft provider should be able to provide the government the following:*
    - *Visibility of the parts qualification plans and processes*
    - *Insight into parts derating and thermal analysis*
    - *Understanding of the qualification program, including radiation qualification*
    - *At the system level, a prediction of reliability and radiation tolerance for the application in each mission*

The comments expressed here are quotes from the Interviewees and do not represent the opinions of The Aerospace Corporation, NASA or the Air Force Space and Missile Systems Center

SmallSat Sub-system Providers:

Selected Interview Questions/Responses

- What can the COTS community do to make it easier for the government to gain insight into the relative strength and challenges of COTS?
  - *The COTS community (as opposed to the SmallSat community) probably couldn't care less about government usage, since it's such a tiny fraction of the total dollar volume, and unless you're a big company or big Prime, dealing with the government is time-consuming and costly, not worth doing unless a return is guaranteed. With sufficient lobbying, a return is guaranteed, of course.*
  - *Support and work with the government to develop standards.*
  - *Requirements creep falls into that last one. COTS parts – the more the requirements creep, the more you go outside the range of what COTS parts can do. Sometimes you can't get a straight answer, but you need to get clarity.*

The comments expressed here are quotes from the Interviewees and do not represent the opinions of The Aerospace Corporation, NASA or the Air Force Space and Missile Systems Center

SmallSat Spacecraft / Launch Vehicle Builders

SELECTED INTERVIEW QUESTIONS/RESPONSES

SmallSat Spacecraft / Launch Vehicle Builders:

Selected Interview Questions/Responses

- How have you incorporated COTS EEE parts in your vehicle design?
  - *Our designs are milestone and cost driven. Focus on EEE COTS hardware based on a) meeting performance requirements b) Cost c) heritage (where used). Not focused on space heritage.*

The comments expressed here are quotes from the Interviewees and do not represent the opinions of The Aerospace Corporation, NASA or the Air Force Space and Missile Systems Center

SmallSat Spacecraft / Launch Vehicle Builders:

Selected Interview Questions/Responses

- What outside-the-box, agile measures can the gov't take to help the COTS community adapt to new demands for satellite systems and services?
  - *Lots of luck on that. We have limited experience with COTS. Space is too small a buyer to have influence.*
  - *Develop a standard for what a "construction analysis" shall contain.*
  - *Develop a standalone reliability document for automotive parts.*
  - *First Thing: Make contracting much easier. Gov't wants to buy commercial but levies FAR (Federal Acquisition Regulations) and other requirements that don't match with commercial.*
  - *Need to buy more and buy more often. Like the [other mission-critical, high-reliability industries] do. They are buying different kinds of parts all the time.*
  - *Way too hung up on automotive. Need to take a closer look at [other mission-critical, high-reliability industries], which are very high tech.*

The comments expressed here are quotes from the Interviewees and do not represent the opinions of The Aerospace Corporation, NASA or the Air Force Space and Missile Systems Center

SmallSat Spacecraft / Launch Vehicle Builders:

Selected Interview Questions/Responses

- What outside-the-box, agile measures can the gov't take to help the COTS community adapt to new demands for satellite systems and services?
  - *In personal prior work experience:*
    - Worked in [the aviation market] – Specified and procured things like many types of O-rings. Bought from many different suppliers
    - In the case of SmallSats – Gov't could look for frequently-used commodities to buy in volume
  - *Use CFI (Customer Furnished Item) approach. Gov't could buy what components are needed and give to those they're contracting with.*

The comments expressed here are quotes from the Interviewees and do not represent the opinions of The Aerospace Corporation, NASA or the Air Force Space and Missile Systems Center

SmallSat Spacecraft / Launch Vehicle Builders:

Selected Interview Questions/Responses

- What outside-the-box, agile measures can the gov't take to help the COTS community adapt to new demands for satellite systems and services?
  - *Sometimes regulations would be good, but retrospectively regretting what would become a huge dollar figure.*
  - *We need to work on the efficiency of how the communication and communication methodology happens – e.g., a two-hour PowerPoint slide presentation. (Think of how many hours it took to create that briefing.)*
  - *If you have to ask your COTS supplier to demonstrate weekly, then why did you pick them in the first place?*
  - *Require providers to serialize boards so it is easier to identify specific bad actors when issues occur.*
  - *Hearing from the gov't about what tests are preferred e.g., Thermal Cycling, etc.*
  - *Use parts built on a QPL (Qualified Products List) line, but not tested.*
  - *Levy reliability requirements on the engineering design at the system level, not the part level.*

The comments expressed here are quotes from the Interviewees and do not represent the opinions of The Aerospace Corporation, NASA or the Air Force Space and Missile Systems Center

SmallSat Spacecraft / Launch Vehicle Builders:

Selected Interview Questions/Responses

- What outside-the-box, agile measures can the gov't take to help the COTS community adapt to new demands for satellite systems and services?
  - *Let vendors know what the Government is looking for. We need more engagements like [vendor events.] They help set expectations.*
  - *Invite vendors to come and talk about [specific products] for spaceflight.*
  - *Need to set forward guidelines. Get on the same page regarding guidelines and what we want to see in the hardware offerings. Our behavior or words say "Here's how we want you to build it. Go away and build that rock." And then when they come back with it, we beat them about the ears and tell them why we don't like it.*
  - *Government needs to get more up to date with its requirements and expectations.*

The comments expressed here are quotes from the Interviewees and do not represent the opinions of The Aerospace Corporation, NASA or the Air Force Space and Missile Systems Center

SmallSat Spacecraft / Launch Vehicle Builders:

Selected Interview Questions/Responses

- What unresolved concerns do you have regarding use of alternate-grade EEE parts in space?
  - *We're not using a lot of alt-grade parts. Our commercial customers are just like dealing with the government. Primary: Grade 1 parts. Secondary: Grade 2 parts.*
  - *One of our customer's program is using Grade 2 parts. The other is COTS. Without burn-in, pre cap inspection, hermetically sealed.*
  - *Selection of parts is done by the customer. We are "Build to print."*
  - *We're not using a lot of COTS parts as we are unsure about the reliability of COTS parts.*
  - *Procuring MIL-Spec parts with lower assurance levels.*
  - *Procuring NASA EEE-INST-002 Level 2 part and figuring out the trade offs.*
  - *In-house up-screening of a lot of parts.*
  - *Unresolved issues: understanding COTS performance in radiation for reliability.*
  - *Have to review suppliers of COTS parts, perform site visits and audits.*

The comments expressed here are quotes from the Interviewees and do not represent the opinions of The Aerospace Corporation, NASA or the Air Force Space and Missile Systems Center

SmallSat Spacecraft / Launch Vehicle Builders:

Selected Interview Questions/Responses

- What unresolved concerns do you have regarding use of alternate-grade EEE parts in space?
  - *The biggest concern is the automotive parts. Industrial is like COTS. Our [organization] seems very enamored to include automotive parts. What I need are detailed requirements on how to deal with ensuring the parts are properly qualified. Our guidelines for approving automotive parts [concern me].*
  - *I recognize "Manifest Destiny" at work in our organization. The message seems to be "Let's just do what we have to in order to justify use of automotive parts."*
  - *SEL (Single Event Latch-up), but we have no time, money or facility to perform such testing. Instead, we put in latch-up protection.*
  - *Temperature is a huge concern. We try to fly all the parts at the correct temperatures. No formal deratings.*
  - *Novel parts…there are concerns but there's not much we can do. There are preferences for heritage, but sometimes we get recommendations to use something besides the heritage part.*

The comments expressed here are quotes from the Interviewees and do not represent the opinions of The Aerospace Corporation, NASA or the Air Force Space and Missile Systems Center

SmallSat Spacecraft / Launch Vehicle Builders:

Selected Interview Questions/Responses

- What outside-the-box, agile measures can the gov’t take to help the COTS community (i.e., manufacturers, providers and parts suppliers) adapt to new demands for satellite systems and services?
  - *A Certified CAS (Cost Accounting Standard/System) is required, for example. Small suppliers don’t have this. Contracting with the Government favors the larger suppliers that have the resources to manage CAS and other requirements.*
  - *Be more realistic: If its COTS, then treat it as COTS. Government tends to over-analyze. Should focus on mission-critical issues.*
  - *Don’t try to control every single little thing. Use incentives instead! Or maybe disincentives work better. Look at things more realistically. These are not $B satellites. They’re cheap satellites. You need to scale the oversight accordingly.*

The comments expressed here are quotes from the Interviewees and do not represent the opinions of The Aerospace Corporation, NASA or the Air Force Space and Missile Systems Center

SmallSat Spacecraft / Launch Vehicle Builders:

Selected Interview Questions/Responses

- What unresolved concerns do you have regarding use of alternate-grade EEE parts in space?
  - *We focus rigorously on identifying infant mortality. Look for repeatability and trends. What we're doing requires a change in mind set. How do you see risk across the supply base? We probably over-cover on that front.*
  - *We have a human-critical or life-critical testing philosophy.*
  - *None – Mitigations are used to resolve any concerns.*
  - *We've had to realize that "Things, they are a-changing…"*
  - *"Do No Harm" is a concern.*
  - *"Arcing and sparking": This is one of our main concerns for our environments. We don't levy requirements.*
  - *Radiation: It's not that a lower grade part can't work. It's just that it has no pedigree and people have no confidence in it. Radiation is still a [gamble]. You can't predict space weather, after all.*

The comments expressed here are quotes from the Interviewees and do not represent the opinions of The Aerospace Corporation, NASA or the Air Force Space and Missile Systems Center

SmallSat Spacecraft / Launch Vehicle Builders:

Selected Interview Questions/Responses

- What are the most important technical requirements you flow to your suppliers of piece parts, assemblies or subsystems?
  - *NASA-INST-002 Grade 1, 2.*
  - *COTS specified by the customer.*
  - *Dependent on program and parts: performance requirements, reliability and mission assurance requirements.*
  - *Drawings, key parameters.*
  - *Performance specs (e.g., thermal models). Both [our organization] and our supplier produce models and then they are compared for consistency.*
  - *If we are buying subsystems, we require environmental stress screening or test OR do it ourselves. We prefer to have items come to us already tested. We would do this for sub-assembly level items. No special requirements for piece parts. We purchased piece parts [online from an authorized distributor].*
  - *TRL level, temperature, demonstrated performance, workmanship.*
  - *Functional. We focus on whether the part is doing what it is expected to do.*

The comments expressed here are quotes from the Interviewees and do not represent the opinions of The Aerospace Corporation, NASA or the Air Force Space and Missile Systems Center

SmallSat Spacecraft / Launch Vehicle Builders:

Selected Interview Questions/Responses

- What are the most important technical requirements you flow to your suppliers of piece parts, assemblies or subsystems?
  - *Attempt to buy single lot date codes or builds (lifetime buys if required).*
  - *We impose no requirements on piece part suppliers.*

The comments expressed here are quotes from the Interviewees and do not represent the opinions of The Aerospace Corporation, NASA or the Air Force Space and Missile Systems Center

SmallSat Spacecraft / Launch Vehicle Builders:

Selected Interview Questions/Responses

- What do you accept as proof of meeting any of the requirements you have levied, i.e. is it analysis or is it testing of parts or subsystems?
  - *We have many subcontractors and we audit them every ~2 yrs. We spot check documentation e.g., Travelers, quality paperwork.*
  - *We accept:*
    - C-of-C’s; Not buying data packages for parts
    - DPA or construction analysis from vendor, or perform DPA in-house
    - Verify vendor has a good quality and screening plan for parts
    - Buy from preferred vendors, reputable vendors; leverage more data from lesser known vendors
    - Quality audits of vendors
  - *We accept analysis and testing (preferred) and data packages.*
  - *Supplier must provide data for any required test at component level. Sub-components, too. There is a lot of information exchange and dialogue.*

The comments expressed here are quotes from the Interviewees and do not represent the opinions of The Aerospace Corporation, NASA or the Air Force Space and Missile Systems Center

SmallSat Spacecraft / Launch Vehicle Builders:
Selected Interview Questions/Responses

- What do you accept as proof of meeting any of the requirements you have levied, i.e. is it analysis or is it testing of parts or subsystems?
  - *Deliverables such as "as built" or "as designed" parts list,*
  - *If there's a technical requirement that we want demonstrated – both analysis and test are acceptable. Will accept analysis in lieu of test data.*
  - *Parts are procured without certifications. Each assembly is tested on a [test bed] specifically built to test that one assembly.*
  - *Qualification and Acceptance testing at the unit/module level.*

The comments expressed here are quotes from the Interviewees and do not represent the opinions of The Aerospace Corporation, NASA or the Air Force Space and Missile Systems Center

SmallSat Spacecraft / Launch Vehicle Builders:
Selected Interview Questions/Responses

- Certain DoD and NASA standards or test methods are often referenced by the SmallSat community. Some need to be updated to reflect advanced technologies and mass production quality improvements achieved since the original documents were published. What approach would you take to do this?
  - *Provide radiation data. There's nothing much on Low LEO or short duration missions.*
  - *Need more radiation data for long-lived missions (SEU, SEL, SEFI, SEGR,...)*
  - *First order of preference: NASA INST-002. "I love that document. It tells me what to do. I can flow it down to my subs. Fine, I'm done. I do not have time to go off and do a big experiment to figure out what to do."*
  - *Update MIL-STD-1547: does not contain new technologies like plastic parts.*
  - *Update MIL-STD-947 which some vendors are still using.*
  - *Our internal standards are changing. We plan to change them to a lower level (base system) and flow it up to the higher system. We'll have a base, minimum system document and will add requirements to it as needed, rather than take requirements from the highest level requirements documents.*

The comments expressed here are quotes from the Interviewees and do not represent the opinions of The Aerospace Corporation, NASA or the Air Force Space and Missile Systems Center

SmallSat Spacecraft / Launch Vehicle Builders:

Selected Interview Questions/Responses

- Certain DoD and NASA standards or test methods are often referenced by the SmallSat community. Some need to be updated to reflect advanced technologies and mass production quality improvements achieved since the original documents were published. What approach would you take to do this?
  - *We find that the Government's reliability assessments are way too conservative. They're applying things that don't really make sense. Would be better to conduct an empirical study; see how empirical data lines up. Need to look at trends. Reliability assessments are outdated.*
  - *We don't use DoD or NASA electronic parts standards. We do look at NASA GEVS for [certain projects] so we can be compatible with the launch provider and Do No Harm requirements.*
  - *We do impedance measurements of every point. This catches mis-populated parts, debris, faulty parts, wrong parts.*
  - *We decide on what tests are most important and whether we have the time, staff and facilities to do them.*

The comments expressed here are quotes from the Interviewees and do not represent the opinions of The Aerospace Corporation, NASA or the Air Force Space and Missile Systems Center

SmallSat Spacecraft / Launch Vehicle Builders:

Selected Interview Questions/Responses

- What can the COTS community do to make it easier for the gov't to gain objective insight into the relative strengths and challenges of COTS?
  - *Produce one giant catalog for COTS.*
  - *Prepare a good website with specs and information.*
  - *Attend conferences with Government in attendance.*
  - *Better key word searchability of websites and documents (common terminology)*
  - *Propose Aerospace to make a keyword search list.*
  - *Work on the efficiency of the communication and communication methodology.*
  - *Build trust. I won't share with some Government [organizations] because they may then go and share it elsewhere, e.g., with an [entity] I'm competing with.*
  - *Some vendors have been a little close to the chest with their data. We want them to be freer with their info. What they don't realize is, that could actually help resolve the problems.*

The comments expressed here are quotes from the Interviewees and do not represent the opinions of The Aerospace Corporation, NASA or the Air Force Space and Missile Systems Center

SmallSat Spacecraft / Launch Vehicle Builders:

Selected Interview Questions/Responses

- What measures do you employ to ensure the likelihood of a successful mission?
  - *Lots of up-screening.*
  - *Verify heritage.*
  - *In the future will pursue more redundancy in the designs.*
  - *Depending on application and mission.*
    - Functional redundancy in cameras
    - Upscreening
    - ATP (Acceptance Test Procedure)
    - Application specific characterization
    - Good FMECA – Failure Mode Effects and Criticality Analysis (identify key functional parts)
  - *Achieve redundancy by sending something to orbit more frequently. Spread the risk. Send up many that aren't expensive; tolerate a few failures. As opposed to redundancy WITHIN the satellite (Side A/B). Put more units in space.*
  - *You need a robust test plan – That's hard if you're just making one unit; testing applied might not even matter.*
  - *Build statistics based on numbers.*

The comments expressed here are quotes from the Interviewees and do not represent the opinions of The Aerospace Corporation, NASA or the Air Force Space and Missile Systems Center

SmallSat Spacecraft / Launch Vehicle Builders:

Selected Interview Questions/Responses

- What measures do you employ to ensure the likelihood of a successful mission?
  - *This is an important question. We employ parts screening. Environmental stress screening is hugely important at the sub-assembly level. Learned this the hard way at system level. We thoroughly test (thermal, vibe) units while powered. If the Government wants to assess likelihood of success, they should look at what type of testing a contractor does, e.g., the type of environmental screening, failure-free hours. We buy, but do not inspect piece parts. We use an outside house to build our boards and we inspect them when delivered. We do Burn-In, Thermal Cycling, Vibe testing.*
  - *If the Government wants to help industry, they should get lists of parts the SmallSat contactors use and offer to do the radiation testing.*
  - *For most of these (New Space/SmallSat-type) companies, radiation testing is out of reach. It would be a tremendous help just to get basic guidance about what might be naturally rad hard, based on the fabrication process, and suggestions about what to look for.*

The comments expressed here are quotes from the Interviewees and do not represent the opinions of The Aerospace Corporation, NASA or the Air Force Space and Missile Systems Center

SmallSat Spacecraft / Launch Vehicle Builders:

Selected Interview Questions/Responses

- What measures do you employ to ensure the likelihood of a successful mission?
  - *Redundant satellites in formation. Implement redundancy at the constellation level, rather than on board in each satellite. Use redundancy to make it easier to NOT lose the mission. But it is unique to that one mission.*
  - *When it makes sense, we implement redundancy, as in the cases of processors, solar cells, batteries. We leave crazy hooks in that can save us later. What kind of flexibility can you build in that doesn't cost you anything? Write code to RAM; Jump to RAM. Execute from there. That said, such mitigation work and measures introduce more complexity.*
  - *For us, it's less risky to fly one less risky radio than two risky radios.*
  - *Part upscreening: comes down to cost. High temp range parts aren't that much more expensive than the low range part. Buy the best part you can afford. Thermal cycling: we try to do that if we have time, but often we don't have the time. I really like thermal testing. It stresses the system in interesting ways. Be agile, and get the system working as fast as possible, even though you might have less functionality.*

SmallSat Spacecraft / Launch Vehicle Builders:

Selected Interview Questions/Responses

- What measures do you employ to ensure the likelihood of a successful mission?
  - *We build in redundancy to mitigate for SEU effects and test key components with high energy protons. FMEA analyses are performed to mitigate or eliminate any single point failure modes. Life tests on components such as reaction wheels and Li-Ion batteries are performed to enhance understanding of any life limiting issues. Board level radiation tests are also performed. Our process is an iterative design cycle.*
  - *Modeling and on-orbit experience is also used to determine part choices and level of acceptance tests needed.*
  - *Each satellite receives random vibration, sine vibration, TVAC and EMC/EMI testing. Generally Proto-qual and flight levels. In addition, burn-in at ambient is performed on all active parts, generally at the unit/subsystem level.*
  - *We have adopted vertical integration to mitigate supply chain risks.*
  - *Watch Dog timers help.*
  - *The requirement that "payloads have to be off at launch" is one way used to manage risk.*
  - *Avionics unit: do things to the design (e.g., de-rating) to make it more radiation tolerant.*
  - *Design it so you can't get a SEU or you design it so you can recover.*

The comments expressed here are quotes from the Interviewees and do not represent the opinions of The Aerospace Corporation, NASA or the Air Force Space and Missile Systems Center

SmallSat Spacecraft / Launch Vehicle Builders:

Selected Interview Questions/Responses

- When using commercial parts, how does your risk management approach differ from that for space grade parts?
  - *Conservative derating, lots of up-screening, performing radiation testing in-house.*
  - *The risk management approach does not differ. We identify mission critical parts. Use the same FMECA process.*
  - *We do use some space grade parts. We've negotiated better pricing with the suppliers of those parts based on quantity. Have a solid test plan. We buy things and buy them frequently, ... and learn. This lets you establish a baseline. It's easier to learn if you keep referencing that baseline as you work to improve.*
  - *Not applicable. We don't use space grade parts.*
  - *Risk management for commercial parts is about trying to get as much previous user data, QCI, and qualification data. It's not available. You have to beat the bushes. If important enough, I'll apply the standards (NASA-INST-002, etc.), and pay someone to figure out what the analysis and testing is to understand the complexities or the materials used. Through analysis or testing, we would try to fill in gaps for those parts – or perform in-house testing.*

The comments expressed here are quotes from the Interviewees and do not represent the opinions of The Aerospace Corporation, NASA or the Air Force Space and Missile Systems Center

SmallSat Spacecraft / Launch Vehicle Builders:

Selected Interview Questions/Responses

- When using commercial parts, how does your risk management approach differ from that for space grade parts?
  - *No one has ever specified space grade parts, but there have been times where we have been requested to use specific parts. We get the part they want, and then they deal with the code for that part. There is shared effort and risk in handling that aspect.*
  - *COTS components are used with substantial margins designed in. Industrial grade parts are used in critical applications. Only use space grade parts for solar arrays (testing is unknown).*
  - *We do radiation testing at the module level for COTS parts assemblies. Emphasis is on software testing for operational mode, safe mode and survival mode.*
  - *We apply fault tolerance. However, you can over-use it. You can put in so much fault tolerance that you start to wither under it. You took something tiny and turned it into something that now weighs 10 tons. Which is cheaper?: Use a better part or make it more fault tolerant?*
  - *LEO: COTS community needs to realize that now the Government wants to use these parts in a different environment (further out in space, e.g., GEO).*

The comments expressed here are quotes from the Interviewees and do not represent the opinions of The Aerospace Corporation, NASA or the Air Force Space and Missile Systems Center

SmallSat Spacecraft / Launch Vehicle Builders:

Selected Interview Questions/Responses

- How do you met government traceability standards for COTS parts?
  - *To be honest, other than consulting a military standard for a particular part, we don't consider government trackability standards as a requirement in our parts selection.*

The comments expressed here are quotes from the Interviewees and do not represent the opinions of The Aerospace Corporation, NASA or the Air Force Space and Missile Systems Center

SmallSat Spacecraft / Launch Vehicle Builders:

Selected Interview Questions/Responses

- What are the most important technical requirements you flow to your suppliers?
  - *We don't flow requirements to our suppliers. We study their data sheets which communicate the component's performance and determine if it meets our performance requirements. We only speak directly to the supplier when there is a particular performance characteristic that is not addressed in their data sheet.*

SmallSat Spacecraft / Launch Vehicle Builders:

Selected Interview Questions/Responses

- What lifetime requirement do you place on yourselves for in-house builds and your suppliers?
  - *We don't impose any life requirements on the components we fabricate in-house and our suppliers usually have listed life data.*

The comments expressed here are quotes from the Interviewees and do not represent the opinions of The Aerospace Corporation, NASA or the Air Force Space and Missile Systems Center

SmallSat Spacecraft / Launch Vehicle Builders:

Selected Interview Questions/Responses

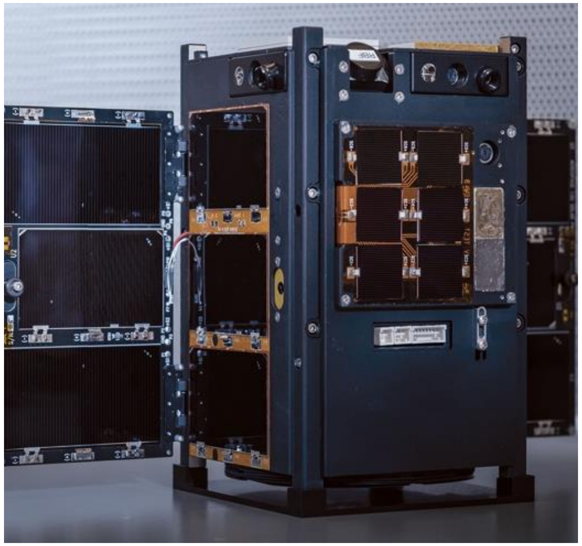
- What acceptance or quality test or documentation review do you often do for received components or subsystems to confirm that your levied requirements have been met?
  - *Our responsible design authority (RDA) engineers are responsible for the design, development and procurement of components and determine acceptable validation procedures for COTS hardware.*

SmallSat Procurers

SELECTED INTERVIEW QUESTIONS/RESPONSES

SmallSat Procurer Interviews

- Procurers' (largely Government entities) standards, specifications, expectations and practices are the baseline against which the piece-part suppliers,' subsystem providers' and spacecraft builders' responses were compared. Therefore, no heatmap for the Procurers' category was prepared.
  - *Instead, the questions and responses for the Procurers interviewed are summarized on the following charts.*



The comments expressed here are quotes from the Interviewees and do not represent the opinions of The Aerospace Corporation, NASA or the Air Force Space and Missile Systems Center

SmallSat Procurers:

Selected Interview Questions/Responses

- What design life (mission life?) are you targeting for your SmallSats?
  - *One year design life. That said, our vehicles last much longer. Five years is easy. Our experience is that if we get through infant mortality, our vehicles last a LOT longer. Some last 15 years. In most cases, they last until it's no longer possible to maintain the orbit OR [we] run out of funding to maintain operations.*
  - *[We use multiple approaches.] In one, we buy missions as a whole, sometimes with an overall development lead. Mission duration is six months to one year. In another approach, the mission is typically one – to two years for small spacecraft.*
  - *[With our particular type of teams], we don't understand any of these terms. The concept is too complex/exquisite. We shoot for 180 days mission duration. Our first mission was a SmallSat. All others have been CubeSats. In my program, I have a rough sense of the boundaries of what we can pull off. I can tailor scope to fit within the boundaries.*

The comments expressed here are quotes from the Interviewees and do not represent the opinions of The Aerospace Corporation, NASA or the Air Force Space and Missile Systems Center

SmallSat Procurers:

Selected Interview Questions/Responses

- What design life (mission life?) are you targeting for your SmallSats?
  - *Mission life depends. The target is 1 year. Sometimes in orbits longer. We won't do anything specific to last longer. No strict requirements on lifetime – it's for as long as it will last.*
  - *Design life is one - threes years, goal of 10 years (or beyond). Depends on what [the customer] is willing to pay.*
  - *One year stated. Design/Mission Life <= three years. GEO orbit.*

The comments expressed here are quotes from the Interviewees and do not represent the opinions of The Aerospace Corporation, NASA or the Air Force Space and Missile Systems Center

SmallSat Procurers:

Selected Interview Questions/Responses

- Do you flow down a system reliability target to your contractor or supplier? If so, what is it and how did you arrive at it?
  - *[Many of our systems] are not typically designed to a reliability target; rather, it's a product of the design. Typically low cost missions (single string, <$10M). Lowest reliability classification. They are cost and schedule-driven, not reliability--driven. Main aim is to raise the TRL for [certain types of] missions. In these cases, the hardware is not supposed to be the experiment. On some other programs, we would have a reliability target and do FMEAs, etc.*
  - *Reliability target is currently a hole in my project. There is no target. We have no FMEA/fault tree process. Don't have the language for it so we don't talk about it.*
  - *We use ad hoc rules: heritage, has it been used before or previously flown. We are driven by cost and schedule, which out-weighs any reliability target.*
  - *Requirements levied are objectives. Consists of a Pass/Fail requirement and some threshold. E.g., Be able to execute circumnavigation of a target at a range of 10 km, or a target of a certain brightness at a certain distance.*

The comments expressed here are quotes from the Interviewees and do not represent the opinions of The Aerospace Corporation, NASA or the Air Force Space and Missile Systems Center

SmallSat Procurers:

Selected Interview Questions/Responses

- Do you flow down a system reliability target to your contractor or supplier? If so, what is it and how did you arrive at it?
  - *On some of our programs, we do use requirements, usually by agreement between [parties]; flows down to mission for requirements and the actual vendors or contractors. But what does that mean, "constellation level?" I would expect a "swarm" to be typically below mission level.*
  - *With respect to suppliers, we're looking for a catalog of capabilities, selecting between a choice of three, from the most expensive to the cheapest option that most closely meets our needs. We flow technical requirements within our organization, but reliability is not in our vocabulary.*
  - *Requirement: provide the opportunity to take images. Time spent on target in percentage of time, for X number of days. That gets flowed down with power, pointing, processing that flow from that. Reliability is in there, but it comes down to FMECA and eliminating single point failures.*

The comments expressed here are quotes from the Interviewees and do not represent the opinions of The Aerospace Corporation, NASA or the Air Force Space and Missile Systems Center

SmallSat Procurers:

Selected Interview Questions/Responses

- Do you flow down a system reliability target to your contractor or supplier? If so, what is it and how did you arrive at it?
  - *We scope our mission based on what's already out there. We run constraints driven vs requirements driven projects. It's about what can you do with your spacecraft? We focus on functional requirements, which are derived from the mission. Reliability does not come into play. Thermal, Vacuum, Radiation (Great if there is data. If not, we'll take the risk.)*
  - *We don't flow down a reliability number. We flow down mission objectives. Example: 90% chance of success for the first year. We do not ask vendors to perform a reliability analysis. For one SmallSat, the goal was 0.85 probability of success at 1 year.*

The comments expressed here are quotes from the Interviewees and do not represent the opinions of The Aerospace Corporation, NASA or the Air Force Space and Missile Systems Center

SmallSat Procurers:

Selected Interview Questions/Responses

- What process do you use to define requirements for your program?
  - *We define top-level requirements or a baseline design. Then for that design we focus on: Does the design fit the program constraints? (What needs to be tweaked so that the design is not so scary and is do-able?*
  - *Design flexibility, money, [staff] that are available to perform the work.*
  - *We are empowered to unilaterally make trades among requirements as needed.*
  - *Interface Control Document – Based on compatibility with the spacecraft bus, and maybe the needs of other experimenters. A requirement may read something like "Achieve 10 data collections over the course of the mission."*

The comments expressed here are quotes from the Interviewees and do not represent the opinions of The Aerospace Corporation, NASA or the Air Force Space and Missile Systems Center

SmallSat Procurers:

Selected Interview Questions/Responses

- What process do you use to define requirements for your program?
  - *An Industry Day is held to determine "What are the drivers?" We gather feedback from suppliers. Changes are made even prior to Source Selection.*
  - *TRD (Technical Requirements Document) waivers are common. For us, Requirements = Program Objectives and Priorities. Constraints = Cost, Schedule.*

The comments expressed here are quotes from the Interviewees and do not represent the opinions of The Aerospace Corporation, NASA or the Air Force Space and Missile Systems Center

SmallSat Procurers:

Selected Interview Questions/Responses

- What is the same and what is different about how you specify and manage SmallSat programs vs traditional programs?
  - *[We have official documents] that govern risk management requirements for large projects. Small spacecraft projects may or may not have requirements.*
  - *There is very little that I can do, but run.*
  - *Not applicable. Everything we do is SmallSat….severely constrained and fixed budget We don't have the resources to do what any traditional programs do.*
  - *[Somewhat] similar from a discipline perspective. Documentation in general would be the same. Depends on whether project is in-house or not. For in-house [builds] interim deliverables and documentation are inter-linked. Audits for SmallSats are definitely minimal to nonexistent. Requirements verification: not that different between SmallSats and traditional programs. Just as vigorous. Pre-Ship Review is really important.*

The comments expressed here are quotes from the Interviewees and do not represent the opinions of The Aerospace Corporation, NASA or the Air Force Space and Missile Systems Center

SmallSat Procurers:

Selected Interview Questions/Responses

- What is the same and what is different about how you specify and manage SmallSat programs vs traditional programs?
  - *We hold reviews and have associated milestone payments. We act as more of a collaborator. Goal of program is to broaden the industrial base available to the Government. Bring in non-traditional offerors. We use Other Transactional Authority.*
  - *Insight stops at the Prime Contractor. Subcontractor management is the purview of the Prime. Government team only gets involved if the Prime encounters challenges. We have insight but no ability to direct or manage subs.*
  - *We never do audits. We do participate in System Level Design Reviews. The Aerospace Systems Engineering Handbook is heavily leveraged. There are not a lot of CDRLs (Contract Data Requirements List). ~20 (10 - 15 preferred).*

The comments expressed here are quotes from the Interviewees and do not represent the opinions of The Aerospace Corporation, NASA or the Air Force Space and Missile Systems Center

SmallSat Procurers:

Selected Interview Questions/Responses

- What is the same and what is different about how you specify and manage SmallSat programs vs traditional programs?
  - *As far as what is contained in the CDRLs and Requirements Verification, we ask: Did they give us an artifact? Industry standard is accepted to create the artifact.*
  - *Our Requirements Verification is focused on the ICD (Interface Control Document). We manage at the interface. We ask: Are we getting what was provided vs what was required? Our role is to focus on "Does the spacecraft work for the experiment?"*

SmallSat Procurers:

Selected Interview Questions/Responses

- Do you have the ability and authority to trade technical, cost, schedule, risk and resiliency priorities? If so, how do you typically go about trading these priorities?
  - *We hold reviews and have associated milestone payments. We act as more of a collaborator. Goal of program is to broaden the industrial base available to the government. Bring in non-traditional offerors. We use Other Transactional Authority.*
  - *Yes! In fact, not only de we have the ability and authority, we are expected to create trade studies. Have to plan for descoping of projects (usually for cost and schedule, not technical objectives).*
  - *Yes. We go about that aggressively and far too frequently.*
  - *Yes. We negotiate with the customer. The tradeoff may be operational.*
  - *As a program manager, yes, for ability and authority. And to make corrective actions.*

The comments expressed here are quotes from the Interviewees and do not represent the opinions of The Aerospace Corporation, NASA or the Air Force Space and Missile Systems Center

SmallSat Procurers:

Selected Interview Questions/Responses

- Do you have the ability and authority to trade technical, cost, schedule, risk and resiliency priorities? If so, how do you typically go about trading these priorities?
  - *Yes. We proceed until someone tells us to stop. We pursue things that are important to mission partners without being specific. Our goal is to be fast and cheap. We don't use low TRL (Technology Readiness Level) items. E.g. [a supplier] wants to sell into the commercial market. So they are willing to give [us their product] to fly, in exchange for receiving health and status telemetry.*
  - *Depends on the funding. We can adjust the Requirements and Risk "knobs" but not the Cost and Schedule knobs.*

The comments expressed here are quotes from the Interviewees and do not represent the opinions of The Aerospace Corporation, NASA or the Air Force Space and Missile Systems Center

SmallSat Procurers:

Selected Interview Questions/Responses

- What are the most important technical requirements and standards you flow to your contractors and suppliers?
  - *Technical requirements to raise TRL are the most important ones. Start with technical requirements and then go from there and put on contract.*
  - *We don't have any standards we push to contractors. NASA-INST-002 referenced, maybe? We just don't know those standards. That is our ignorance. We focus on functional and environmental [tests].*
  - *The ICD (Interface Control Document) is the law. For payload accommodation, we use [a number of] industry standards, e.g., RS-232, SpaceWire, and best practices.*

The comments expressed here are quotes from the Interviewees and do not represent the opinions of The Aerospace Corporation, NASA or the Air Force Space and Missile Systems Center

SmallSat Procurers:

Selected Interview Questions/Responses

- What are the most important technical requirements and standards you flow to your contractors and suppliers?
  - *We may reference GEVS (the NASA General Environmental Verification Standard) and Mil-Std-1580 (Test Method Standard: Destructive Physical Analysis for Electronic, Electromagnetic and Electromechanical (EEE) Parts), but only adhere to these specs broadly.*
  - *We reference Mil-Hdbk-1553 (Multiplex Applications Handbook).*
  - *We generally require no manufacturing or testing specs. If we do apply them, they are tailored.*
  - *We definitely adhere to the Air Force Space Command Manual 91-710 - Range Safety User Requirements Manual and Orbital Debris Mitigation Standard Practices 91217 documents. Also MIL-STD-882 System Safety Hazard and Mitigation Plan.*

The comments expressed here are quotes from the Interviewees and do not represent the opinions of The Aerospace Corporation, NASA or the Air Force Space and Missile Systems Center

SmallSat Procurers:

Selected Interview Questions/Responses

- What are the most important technical requirements and standards you flow to your contractors and suppliers?
  - *Typically ~four standards, related to range safety, ground support, standard interface spec for the launch vehicles, and security*
  - *We test to conditions 3dB above the max predicted environment.*
  - *Requirements are excerpted out of MIL-STD-1540 (Product Verification Requirements for Launch, Upper Stage and Space Vehicles) and put into the Technical Requirements Document.*
  - *Experiment Requirements Documents, Technical Requirements Documents. These contain high level requirements and are negotiable.*

The comments expressed here are quotes from the Interviewees and do not represent the opinions of The Aerospace Corporation, NASA or the Air Force Space and Missile Systems Center

SmallSat Procurers:

Selected Interview Questions/Responses

- What do you accept as proof of meeting any of the requirements you have levied (i.e. is it analysis or is it testing of parts or subsystems)?
  - *We love tests, but sometimes do inspection. Depends on what we're buying. If buying a system (spacecraft), we test at spacecraft level. If buying a board, we test at board level.*
    In the case of parts, we're moving away from buying those. We don't do as much in-house development as we did 30 years ago. We're buying systems and subsystems, rather than buying parts to build systems ourselves.
  - *Analysis is frequently done for integration purposes and for things that can't be tested (e.g., launch loads, etc. – use "test like you fly" approach, but it ends up being more implementing software tests where you look at sequences). You can't fully simulate on-orbit space environment in a test – only approximate. (how much testing can you afford?) Testing is more expensive than analysis, generally, but we do functional and environmental testing. We performance test our [hardware]. If you can't meet performance test in lab, you're unlikely to do so in space.*

The comments expressed here are quotes from the Interviewees and do not represent the opinions of The Aerospace Corporation, NASA or the Air Force Space and Missile Systems Center

SmallSat Procurers:

Selected Interview Questions/Responses

- What do you accept as proof of meeting any of the requirements you have levied (i.e. is it analysis or is it testing of parts or subsystems)?
  - *The catalog. We are dependent on the good faith of the sales contract. We are willing to stay with the same supplier for a number of procurements in order to develop a relationship.*
  - *We desire test data to demonstrate functionality. We ask the supplier to do the tests for those parts. How do we know the system is working? Check the relevant test data for that.*
  - *The data packages we expect are from Sell-Off, Pre-Ship Review, Pre-Storage Review. The ICD requires delivery of artifacts which vary from things like a thermal model for the payloads (hosted or free-flyers) to a hardware mass simulator used in tests. [We also use] a 'Giver-Receiver' list which spells out items [each side of the interface needs to deliver to the other]. Launch minus 9 months is a rough estimate of [required delivery date to the launch vehicle]. It is somewhat negotiable.*

The comments expressed here are quotes from the Interviewees and do not represent the opinions of The Aerospace Corporation, NASA or the Air Force Space and Missile Systems Center

SmallSat Procurers:

Selected Interview Questions/Responses

- What do you accept as proof of meeting any of the requirements you have levied (i.e. is it analysis or is it testing of parts or subsystems)?
  - *We take what artifacts we can get. These may be printouts of a response spectrum to random vibe test, for example. We extrapolate from little to no info to a risk assessment. We "reverse engineer" a risk assessment.*
  - *Focus is on a Robust Design up front. Our subject matter experts are embedded. We know Pass/Fail in real time.*
  - *We personally witness and participate in system test with the Contractor. Includes an Acceptance Level Random Vibe Acoustic Flow.*
  - *Goal: Don't break the hardware on the ground.*

The comments expressed here are quotes from the Interviewees and do not represent the opinions of The Aerospace Corporation, NASA or the Air Force Space and Missile Systems Center

SmallSat Procurers:

Selected Interview Questions/Responses

- How do you define, assess, monitor and mitigate risk?
  - *Not enough data to quantify risk. We’re usually only building a single spacecraft.*
  - *We look at “Who is the team?” Have they demonstrated capability? We try to develop an understanding and familiarity so that there’s a working relationship after [product delivery], in case we need to resolve an issue with [the supplier’s product].*
  - *We use the Risk Management Framework. But it is very cyber-centric. Can be labor-intensive. We take out things that don't make sense for [our situation]. Our programs have no operational impact so we have less concerns with Risk ("Big R" risk), and deal instead with risk ("little R" risk).*
  - *This is in mission assurance. Communicate risks to the mission assurance staff, who take responsibility and coordinate with system engineering staff.*

The comments expressed here are quotes from the Interviewees and do not represent the opinions of The Aerospace Corporation, NASA or the Air Force Space and Missile Systems Center

SmallSat Procurers:

Selected Interview Questions/Responses

- How do you define, assess, monitor and mitigate risk?
  - *We address risk empirically in the design process because [we] will aggressively get ahead of the mission requirements creep process and force a requirements rework process to ensure it is worked down. We get ahead of the mission definitions that will lead to simple spacecraft. Where possible, [we] avoid levying pointing requirements, and high data rate or time-critical events.*
  - *Primary risks are integration and workmanship issues.*
  - *Apply [Program Manager-developed] heuristics developed over time. We address risks on the back end, focus on functional performance. Software either works for 30 days or not.*
  - *Helps to get multiple eyes on the workflow – almost like an oversight committee. Use a checklist of activities and best practices.*

SmallSat Procurers:

Selected Interview Questions/Responses

- How do you define, assess, monitor and mitigate risk?
  - *Robust risk management process is in place, including a monthly Risk Management Board. By our definition an Issue = Risk realized.*
  - *30 – 40 risks are monitored during the life of the program.*
  - *Cannot mitigate all risks. We decide what we can/cannot live with.*
  - *Government owns the risk process across Ground, Spacecraft, Launch.*
  - *Risk is very well defined in [our organization's risk document]. We use a standard 5x5 matrix for probability and impact. Report our top five and revisit our risks, periodically. Try to mitigate the ones with the main issues and impacts. Very subjective.*

The comments expressed here are quotes from the Interviewees and do not represent the opinions of The Aerospace Corporation, NASA or the Air Force Space and Missile Systems Center

SmallSat Procurers:

Selected Interview Questions/Responses

- What are the primary drivers of your program and the mission assurance you apply? Are they your requirements? Constraints? Risk and probability of mission success? Something else?
  - *Mission assurance requirements or technology development activity, depending on the program.*
  - *Primary driver of program is: I want to do this for another 20 yrs. Tries to figure out how to make it sustainable. It is better to say we have a live satellite on orbit, rather than say we have flight hardware on orbit.*
  - *We scope missions to ensure they work. We ask "What mission performance requirements are you willing to throw overboard if that meant you will make the ride or delivery?"*
  - *Primary drivers: just about everything. We never have enough time or enough money. The budget is a constraint. Have to make it fit. Secondary drivers: you have to make changes to accommodate the primary mission's orbit inclination. In one case, that caused our system not to work so we had to redesign the whole payload.*

The comments expressed here are quotes from the Interviewees and do not represent the opinions of The Aerospace Corporation, NASA or the Air Force Space and Missile Systems Center

SmallSat Procurers:

Selected Interview Questions/Responses

- What are the primary drivers of your program and the mission assurance you apply? Are they your requirements? Constraints? Risk and probability of mission success? Something else?
  - *Performance and Cost. From there, figure out how much mission assurance is involved. (It's analogous to titration.)*
  - *Be fast and cheap. Meet the needs of the mission partners.*
  - *We focus on Constraints (Lane Dividers) and Mission Objectives (Vision).*
  - *What is good enough?*
  - *Is it still worth it to launch, despite the risk?*
  - *Sometimes 50/50 is chance of success is good enough.*

The comments expressed here are quotes from the Interviewees and do not represent the opinions of The Aerospace Corporation, NASA or the Air Force Space and Missile Systems Center

SmallSat Procurers:

Selected Interview Questions/Responses

- What contract types do you typically use?
  - *We love Fixed Price contracts. They are for more mature items (e.g., spacecraft is envisioned as a commodity).*
  - *Bigger projects use CPAF's (Cost Plus Award Fee). [Our organization] likes CPAF's more than Fixed Price contracts. There is also a desire to move away from award fees to incentive fees (fee earned of you get something done by a particular date).*
  - *Firm Fixed Price, and performance-based.*
  - *Non-FAR contract types.*
  - *Everything from Cost Plus Incentive Fee to Firm Fixed Price.*
  - *Other Transactional Authority.*
  - *Whatever the last contract type wasn't.*

The comments expressed here are quotes from the Interviewees and do not represent the opinions of The Aerospace Corporation, NASA or the Air Force Space and Missile Systems Center

SmallSat Procurers:

Selected Interview Questions/Responses

- In your context, how do you see the emergence of COTS assemblies and non space-grade hardware in space applications affecting the traditional space industrial base?
  - *We use COTS. But we'll be careful about what COTS means. They may not be as "off the shelf" for one as another technology.*
  - *We have no experience with anything but COTS. Everything I learn is from NEPP (NASA Electronic Parts and Packaging) program and related workshops. I'd be curious to know what would be the impact, but not sure how to handle it.*
  - *We do not procure from the traditional space industrial base. In my humble opinion, seems like we need to find a middle ground. There will be some tension. Both groups have pros/cons. Parts obsolescence is an issue.*
  - *Risk aversion must be dealt with. Is it faster to guarantee that something is going to work by minimizing risk OR just build another spacecraft?*

The comments expressed here are quotes from the Interviewees and do not represent the opinions of The Aerospace Corporation, NASA or the Air Force Space and Missile Systems Center

SmallSat Procurers:

Selected Interview Questions/Responses

- In your context, how do you see the emergence of COTS assemblies and non space-grade hardware in space applications affecting the traditional space industrial base?
  - *If there is broad embracement of COTS, would that be a threat to traditional? – I don't see how it couldn't. If you look at EEE parts, I could sprinkle pixie dust on [certain classes] and pretty soon we won't need QML parts anymore! (Be mindful so there are no unintended consequences). We can make higher risk decisions under the pretext that this is not the norm. After a while, there may become a new norm for lack of due diligence…Need to be smart about where we accept risk – what you're doing in high risk areas. Don't think that you can apply that high risk method/approach across the board. Need context and disclaimers, use proper disclosures – don't apply across the board. The benefit from this is becoming more prevalent, in situational training. What positive behaviors we are communicating when you get [seasoned] engineers, vs. the new [professionals] who don't know the lexicon? Everyone is driven by cost and schedule. Better communication drives better expectations and cost.*

The comments expressed here are quotes from the Interviewees and do not represent the opinions of The Aerospace Corporation, NASA or the Air Force Space and Missile Systems Center

SmallSat Procurers:

Selected Interview Questions/Responses

- In your context, how do you see the emergence of COTS assemblies and non space-grade hardware in space applications affecting the traditional space industrial base?
  - *For a [System Builder], it is easier to use all one type/category of part or supplier.*
    - When using two sets of suppliers, there's a risk of grabbing a part from the wrong bin. This is true with both space-rated or COTS parts.

The comments expressed here are quotes from the Interviewees and do not represent the opinions of The Aerospace Corporation, NASA or the Air Force Space and Missile Systems Center

Future Steps…

To accelerate progress, industry requests…

(1 of 3)

- Signal from the Government that COTS can be considered.
  - *General feeling that Customer and [their support] team will not buy off on COTS parts*
- Published guidelines for how COTS can be accepted for space applications.
  - *Minimum requirements, path to use in space applications*
- Keyword search list.
- Standard for what a "construction analysis" shall contain .
- Standalone reliability document for automotive parts.
- Make contracting much easier. Government wants to buy commercial but levies FAR (Federal Acquisition Regulation) and other requirements that do not match with commercial.
- Government needs to buy more and buy more often, like other high-reliability, mission-critical or high-volume industries do. Look for frequently-used commodities and buy in volume to gain price advantage.

The comments expressed here are quotes from the Interviewees and do not represent the opinions of The Aerospace Corporation, NASA or the Air Force Space and Missile Systems Center

To accelerate progress, industry requests…

(2 of 3)

- Update Mil-Std-1547 "Military Standard, Electronic Parts, Materials, and Processes for Space and Launch Vehicles," which does not address new technologies such as plastic encapsulated devices.

- Create an approach to utilize the methods of MIL-HDBK-217 "Military Handbook: Reliability Prediction of Electronic Equipment," but with manufacturer's failure rate data.

- Conduct an empirical study, see how performance/flight data aligns with predictions, and analyze the trends. Current reliability assessments are far too conservative, applying things that don't really make sense.

- Government is way too hung up on automotive grade parts. Need to take a closer look at [other high-volume, mission-critical, high-reliability application parts], which are very high tech.

- Government could buy needed components and provide them to their contractors.

The comments expressed here are quotes from the Interviewees and do not represent the opinions of The Aerospace Corporation, NASA or the Air Force Space and Missile Systems Center

To accelerate progress, industry requests…

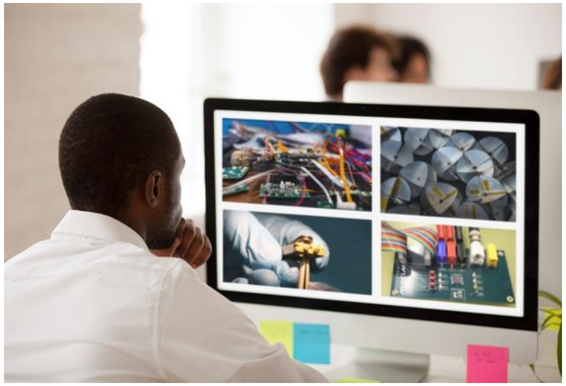
(3 of 3)

- Be more realistic: If an item is COTs, then treat it as COTS. Gov't tends to over-analyze. Instead, should focus on mission-critical issues.
- Do not try to control every single little thing. Use incentives instead or maybe make disincentives work better.
- SmallSats are not $B satellites, they are cheap. Gov't needs to scale the oversight accordingly.
- Create a base system document to which requirements could be added based on the mission objective, rather than starting with the highest level system requirements documents.

The comments expressed here are quotes from the Interviewees and do not represent the opinions of The Aerospace Corporation, NASA or the Air Force Space and Missile Systems Center

To accelerate progress, industry could …

- Create one giant catalog for COTS.
- Create a good Web site with specs and information.
- Attend conferences with Government in attendance.
- Deploy better key word searchability of Web sites and documents (e.g., use common terminology).
- Support and work with the Government to develop standards.
- Share more technical information/insight with the Government.



The comments expressed here are quotes from the Interviewees and do not represent the opinions of The Aerospace Corporation, NASA or the Air Force Space and Missile Systems Center

Study's Key Messages

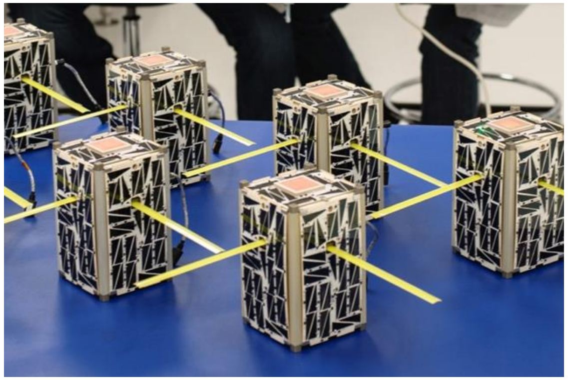
- In this period of burgeoning opportunity and transition, norms are being challenged.
- Requirements flowed to suppliers are fragmented and are not easily categorized.
  - *Widely variable and dependent upon what suppliers and procurers at various levels are willing to agree to, rather than a codified set of standards adopted across the ecosystem*
- Study captures the rich diversity of perspectives and identifies common themes in the hope that they sharpen insight as new norms are established.
  - *The findings are foundational and will help inform future work in this actively evolving area*

Recommended Follow-on Work

- No general concrete patterns across the SmallSat community were evident. Therefore, we recommend assembling these Small Satellite Industrial Base results with those of other studies.

- Doing so would
  - *Create a substantially larger data set amenable to applying data analytics and machine learning techniques.*
  - *Identify additional themes and trends of assistance to the Government in procuring Small Satellites.*

- Coordinate with
  - NASA's Small Satellite Reliability Initiative
  - University Small Satellite researchers
  - 2019 Small Satellite Symposium insights
  - 2019 Small Satellite Conference attendees
  - Industry working groups, task forces, councils, trade groups



Acknowledgments

- The authors and study team wish to thank the following for their collaboration, support and guidance.
  - *The Small Satellite piece-part suppliers, subsystem providers, spacecraft/launch vehicle builders, and small satellite procurers who generously contributed their time and candid insights*

Dr. Jonathan Pellish
NASA Electronic Parts Manager,
Goddard Space Flight Center

David E. Davis
Engineering Branch Chief,
Air Force Space and Missile Systems Center

Allen Compito
General Manager,
Electronics and Sensors Division,
The Aerospace Corporation

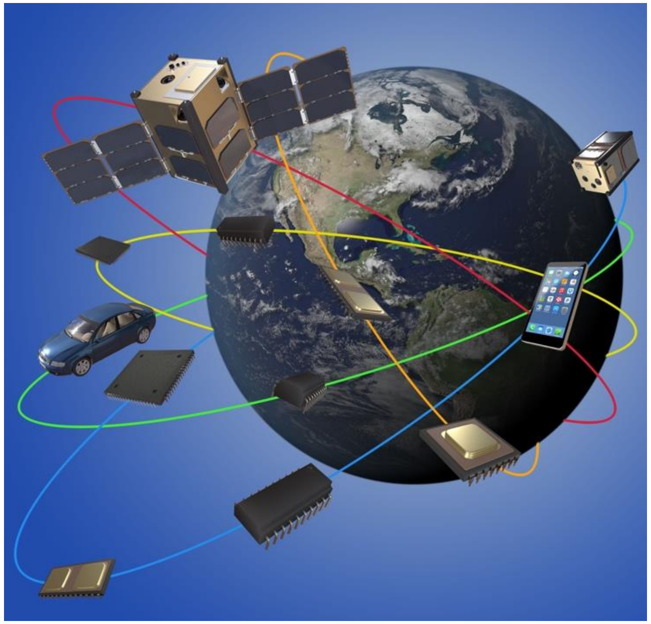
Supporting Information

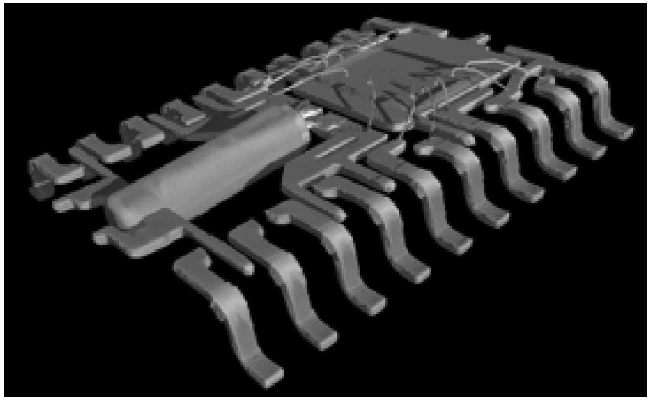
- The list of interview questions for each SmallSat stakeholder type are presented:
  - *Electronics Piece-Part Suppliers*
  - *Circuit Card, Assembly and Subsystem Suppliers*
  - *Spacecraft and Launch Vehicle Builders*
  - *Procurers*

SmallSat Electronics Piece-Part Suppliers

Interview Questions

1. What types of parts do you provide?
2. What hurdles do you see in meeting requirements for traceability and homogeneity primarily for automotive and commercial?
3. What basic requirements do you see flowed down to you from the contractor (technical and quality)?
4. What data do you provide to customers for the various types of parts you supply and is there a cost for the data?
5. What types of tests and validation do you perform for the various part types you provide?

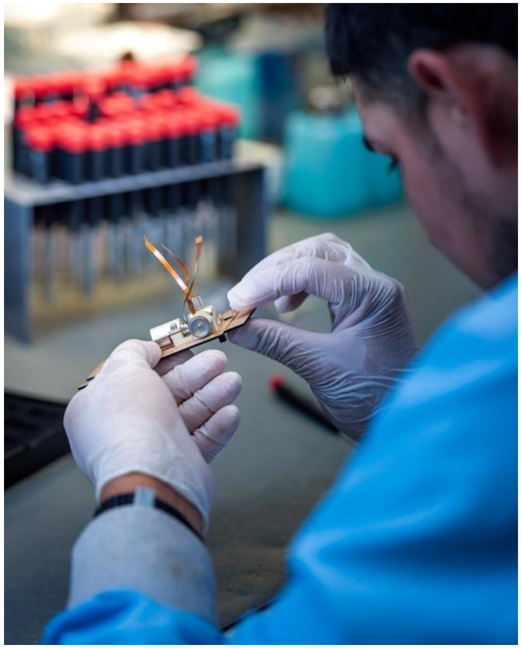




SmallSat Circuit Card, Assembly, and Subsystem Suppliers

Interview Questions (1 of 3)

1. Provide the level of the information at which you are responding.
2. Does your organization use a quality management system?
3. Indicate your organization's definition of "COTS" parts.
4. How frequently are COTS parts used in your space-bound systems?
5. Estimate the percentage for each category of COTS parts used in your product line.
6. What available information and measures does your organization or subcontractors or vendors offer in lieu of the heritage management approach and military specifications?
7. How does your organization quantify or estimate reliability or risk?



SmallSat Circuit Card, Assembly, and Subsystem Suppliers

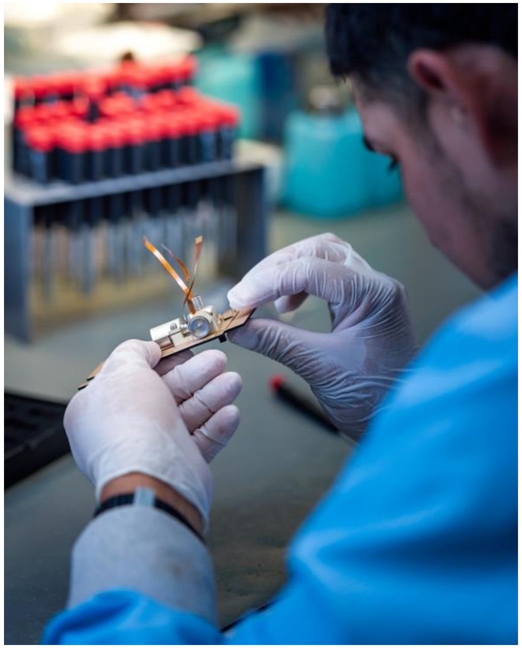
Interview Questions (2 of 3)

8. Does your organization rely on redundancy to increase reliability? If so, please explain.

9. What are the most important technical requirements your organization provides to suppliers of subsystems, assemblies and piece parts?

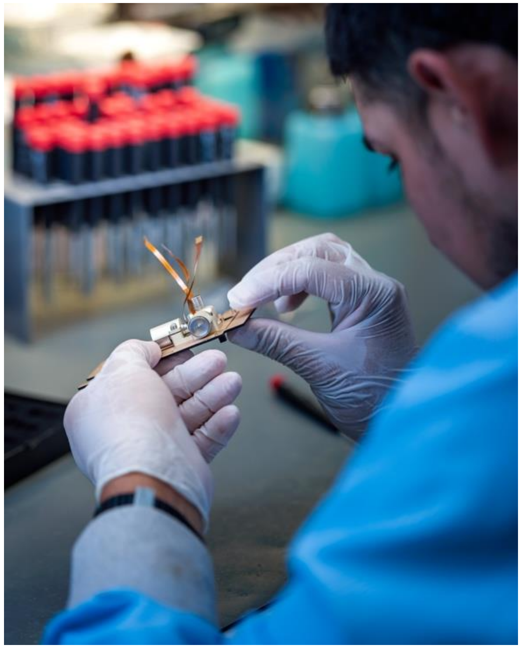
10. What percentage of your organization dollars go toward building (make %) versus purchasing products or services outside your organization (buy %)?

11. What standards do you often reference for in-house builds or suppliers?



SmallSat Circuit Card, Assembly, and Subsystem Suppliers

Interview Questions (3 of 3)



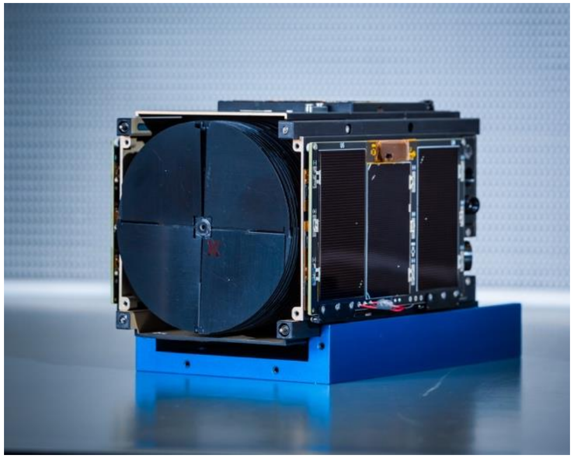
12. Certain DoD and NASA standards or test methods, e.g., those for electronic parts management and reliability assessments, are often referenced by the SmallSat community. Some standards need to be updated to reflect advanced technologies and mass production quality improvements achieved since the original documents where published. What approach would you take to do this?

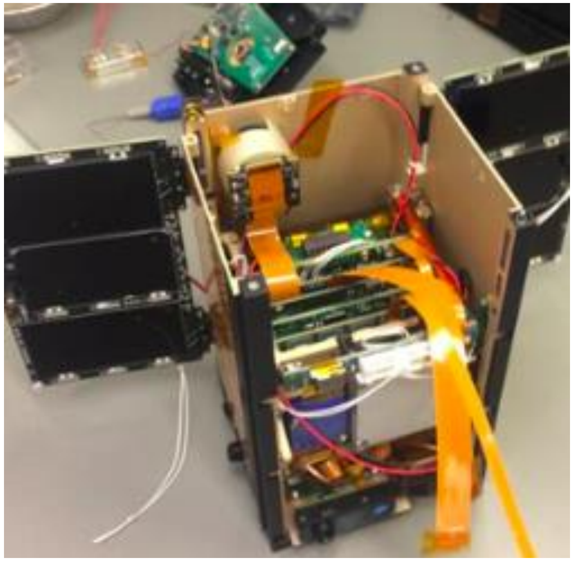
13. What outside-the-box, agile measures can the government take to help the COTS community adapt to new demands for satellite systems and services?

14. What can the COTS community do to make it easier for the government to gain insight into the relative strength and challenges of COTS?

SmallSat Spacecraft/ Launch Vehicle Builders

Interview Questions (1 of 3)





1. What unresolved concerns do you have regarding the use of alternate-grade EEE parts in space?

2. What standards do you often reference for in-house builds or suppliers?

3. What are the most important technical requirements you flow to your suppliers of piece parts, assemblies or subsystems?

4. What do you accept as proof of meeting any of the requirements you have levied?

5. Certain DoD and NASA standards or test methods are often referenced by the SmallSat community. Some standards need to be updated to reflect advanced technologies and mass production quality improvements achieved since the original documents where published. What approach would you take to do this?

SmallSat Spacecraft/ Launch Vehicle Builders

Interview Questions (2 of 3)

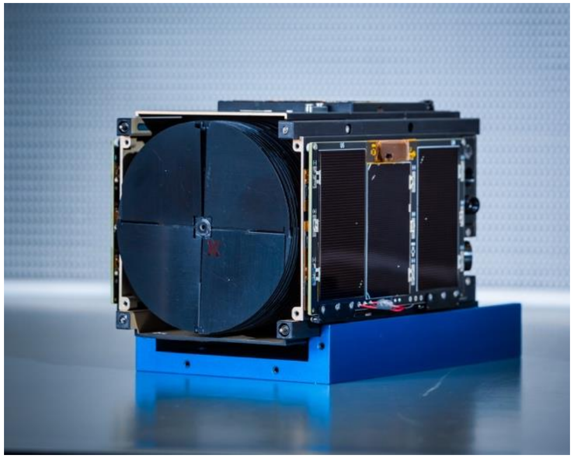
6. What outside-the-box, agile measures can the government take to help the COTS community adapt to new demands for satellite systems and services?

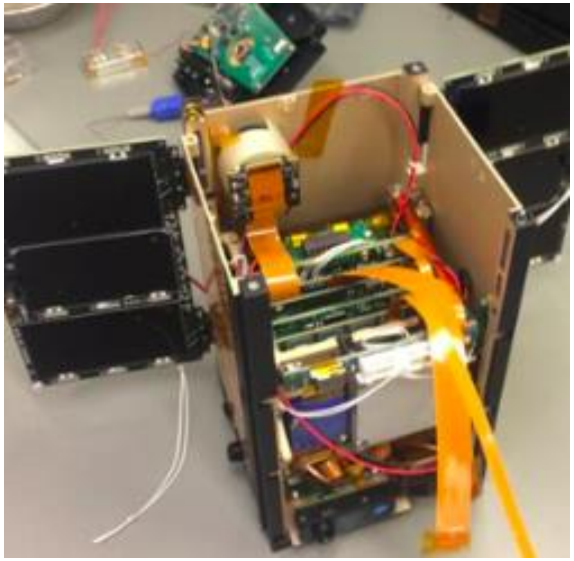
7. What can the COTS community do to make it easier for the gov't to gain objective insight into the relative strengths and challenges of COTS?

8. What measures do you employ to ensure the likelihood of a successful mission?

9. When using commercial parts, how does your risk management approach differ from that for space grade parts?

10. How have you incorporated COTS EEE parts in your launch vehicle design?





SmallSat Spacecraft/ Launch Vehicle Builders

Interview Questions (3 of 3)

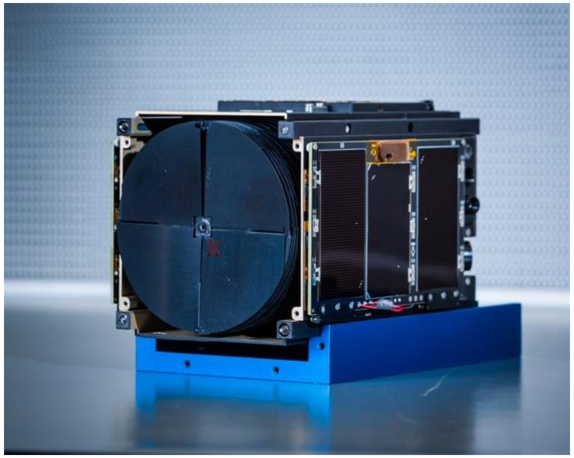
11. How do you meet government traceability standards for COTS parts?

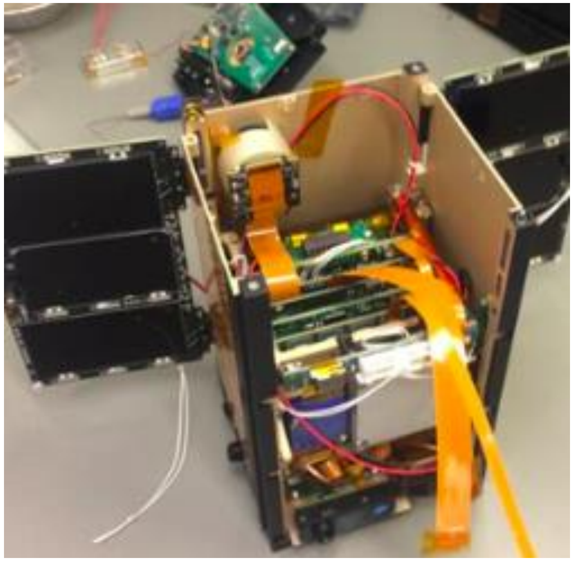
12. What are the most important technical requirements you flow to your suppliers?

13. What lifetime requirement do you place on yourselves for in-house builds and your suppliers?

14. What acceptance of quality, test or documentation review do you often do for received components or subsystems to confirm that your levied requirements have been met?

15. Is there anything we have not asked about that you would like to share?





SmallSat Procurers

Interview Questions (1 of 2)

1. What design life (or mission life) are you targeting for your SmallSats?

2. Do you flow down a system reliability target to your contractor or supplier? If so, what is it and how did you arrive at it?

3. What technical requirements do you flow to your contractor(s) or supplier(s)?

4. What process do you use to define requirements for your program?

5. What is the same and what is different about how you specify and manage SmallSat program vs traditional programs?

6. Do you have the ability and authority to trade technical, cost, schedule, risk and resiliency priorities? If so, how do you typically so about trading these priorities?

SmallSat Procurers

Interview Questions (2 of 2)

7. What are the most important technical requirements and standards you flow to your contractors and suppliers?
8. What do you accept as proof of meeting any of the requirements you have levied?
9. How do you define, assess, monitor and mitigate risk?
10. What are the primary drivers of your program and the mission assurance you apply? Are they your requirements? Constraints? Risk and probability of mission success? Something else?
11. What contract types do you typically use?
12. In your context, how do you see the emergence of COTS assemblies and non space grade hardware in space applications affecting the traditional space industrial base?
13. Is there anything we have not asked about that you would like to share?

References

- State of the Art Small Spacecraft Technology, NASA/TP-2018-220027, December 2018
- Mars Small Spacecraft Studies: Overview, Nathan Barba, Tom Komarek, Ryan Woolley, Lou Giersch, Vlada Stamenković, Mike Gallagher, and Charles D. Edwards Jet Propulsion Laboratory, 2019 IEEE Aerospace Conference
- Single Event Effect (SEE) Test Planning 101, Kenneth A. LaBel, Jonathan A. Pellish, NASA/GSFC and Melanie D. Berg, MEI Technologies, NASA/GSFC, 2011 RADECS (Radiation Effects on Component and Systems) Conference
- Electrical, Electronic and Electromechanical (EEE) Parts in the New Space Paradigm: When is Better the Enemy of Good Enough?, Kenneth A. LaBel, Michael J. Sampson, NASA/GSFC, International School on the Effects of Radiation on Embedded Systems for Space Applications, October 2017

References

- Utilization of Data and Models for Commercial off-the Shelf (COTS) Electronic Component Selection and Reliability Assessment, Elburn, E., Das, D., Pecht, M., Univ. of Maryland, Sood, B., NASA, Annual Reliability and Maintainability Symposium (RAMS), p 7 pp., 2019

- Use and Benefits of COTS Board Level Testing for Radiation Hardness Assurance, M. C. Rousselet, Philippe R. Adell, Douglas J. Sheldon, Jérôme Boch, H. Schone, F. Saigné, 16th European Conference on Radiation and Its Effects on Components and Systems (RADECS), 2016

- A Low-Thrust-Enabled SmallSat Heliophysics Mission to Sun-Earth L5, Natasha Bosanac University of Colorado Boulder, Farah Alibay and Jeffrey R. Stuart, Jet Propulsion Laboratory, 2018 IEEE Aerospace Conference

- Global Trends in Small Satellites, Bhavya Lal, Elena de la Rosa Blanco, Jonathan R. Behrens, Benjamin A. Corbin, E. K. Green, Alyssa J. Picard, Asha Balakrishnan, Science and Technology Policy Institute, Institute for Defense Analyses, July 2017

References

- Reliability of CubeSats – Statistical Data, Developers' Beliefs and the Way Forward, Martin Langer, Technical University of Munich, Jasper Bouwmeester Delft University of Technology, 30th Annual AIAA/USU Conference on Small Satellites
- EEE Parts Database of CubeSat Projects and Kits, Kathryn Beckwith, Jet Propulsion Laboratory, 2015, NASA WBS: 724297.40.49.11, JPL Project Number: 104593, Task Number: 40.49.01.26
- Traditional EEE Part Testing versus "Higher Assembly" Validation Tests Is Better the Enemy of Good Enough?, Henning Leidecker, NEPP Workshop: EEE Parts for Small Missions 2014
- Alternative Methods to Qualify EEE parts for Small Missions, Ed Wyrwas and Craig Hillman, DfR (Design for Reliability) Solutions, 2014 NASA Electronic Parts and Packaging Workshop

References

- A Small Company Approach to Space Mission Assurance, Abigail Davidson, Cubic Aerospace, NASA Electronic Parts and Packaging Program Electronics Technology Workshop, 2017
- Mission Assurance 2.0 - S&MA in the SmallSat Paradigm, D.J. Sheldon, Assurance Technology Program Office (ATPO) Office of Safety and Mission Success, Jet Propulsion Laboratory
- Jean-Francois Castet and Joseph H. Saleh. "Satellite Reliability: Statistical Data Analysis and Modeling", Journal of Spacecraft and Rockets, Vol. 46, No. 5, 2009
- Reliability of CubeSats – Statistical Data, Developers' Beliefs and the Way Forward, Martin Langer, SSC16-X-2 2016
- Reliability Prediction MIL-HDBK-217 Subsidiary Specification, ANSI/VITA 51.1 – 2008 (R2013)
- Reliability Prediction, ANSI/VITA 51.0 – 2008 (R2012)

References

- Qualification and Environmental Stress Screening in Support of Reliability Predictions, ANSI/VITA 51.3– 2010 (R2016)
- SpaceVPX System, ANSI/VITA 78.00 – 2015
- Requirements for Plastic Encapsulated Discrete Semiconductors in Space Applications, AS6294/3 (Revision in Process as of September 2019)
- 2018 The Aerospace Corporation Recommended Specifications and Standards List, Aerospace Report No. ATR-2017-00581-Rev A

References

- Improving Mission Success of CubeSats, Catherine Venturini, Barbara Braun, David Hinkley, The Aerospace Corporation, Greg Berg, Formerly at The Boeing Company, 32nd Annual AIAA/USU Conference on Small Satellites
- Balancing Capability and Cost on the STPSat-5 Microsatellite Mission, Clifford Graham, Mark Barrera, The Aerospace Corporation, Pat Remias, John Eterno Sierra Nevada Corporation, Linda Ettling, US Air Force
- The Challenges of PEM (Plastic Encapsulated Microcircuit), Integra Technologies, NASA Electronic Parts and Packaging Program Electronics Technology Workshop, 2014
- EEE Parts Guidelines for SmallSat Missions, Michael J. Campola, Miguel Moe, Christopher Green, NASA Electronic Parts and Packaging Program Electronics Technology Workshop, 2018

References

- Defining a New Mission Assurance Philosophy for Small Satellites, Lee Jasper Space Dynamics Laboratory, Lauren Hunt, David Voss, Charlene Jacka Air Force Research Laboratory, 32nd Annual AIAA/USU Conference on Small Satellites
- The NASA Electronic Parts and Packaging (NEPP) Program – An Overview, Kenneth A. LaBel, Michael J. Sampson, NASA/GSFC, NASA Electronic Parts and Packaging Program Electronics Technology Workshop, 2016
- Effective Small-Satellite Radiation Assurance for Non-Specialists, Rebekah Austin, Arthur Witulski, Brian Sierawski, Nag Mahadevan, Gabor Karsai, Robert Reed, Ron Schrimpf, Vanderbilt University, 33rd Annual AIAA/USU Conference on Small Satellites
- From COTS to Space Grade Electronics: Which is the Best for Your Mission? Robert Baumann, Radiosity Services, LLC, Conference on Radiation Effects on Components and Systems (RADECS), 2018

Standards and Technical Guidance Documents Mentioned by Respondents

- Reliability Prediction of Electronic Equipment, Military Handbook, MIL-HDBK-217F, 2 December 1991
- EEE-INST-002: Instructions for EEE Parts Selection, Screening, Qualification, and Derating, NASA/TP—2003–212242, April 2008
- PEM-INST-001: Instructions for Plastic Encapsulated Microcircuit (PEM) Selection, Screening, and Qualification, NASA/TP—2003–212244, June 2003
- System Safety, DoD Standard Practice, MIL-STD-882E, 11 May 2012
- DoD Test Method Standard Microcircuits, MIL-STD-883K, 3 May 2018
- Requirements for Soldered Electrical and Electronic Assemblies, IPC J-STD-001F, July 2014
- Quality Management Standard for Electrostatic Discharge, ANSI ESD S20.20
- The Acceptability of Electronic Assemblies, IPC-A-610

Standards and Technical Guidance Documents Mentioned by Respondents

- Qualification and Performance Specification for Rigid Printed Boards, IPC-6012D, September 2015
- IPC-6012DS: Space and Military Avionics Applications Addendum to IPC-6012D, Qualification and Performance Specification for Rigid Printed Boards, 22 September 2015
- IPC-WHMA-A-620C, Requirements and Acceptance for Cable and Wire Harness Assemblies, January 2017
- IPC-WHMA-A-620B-S: Space Applications Electronic Hardware Addendum to IPC-WHMA-A-620B, June 2013
- Generic Standard on Printed Board Design, ANSI-IPC-2221, February 1998
- General Environmental Verification Standard (GEVS) for GSFC Flight Programs and Projects, NASA - GSFC-STD-7000, April 2005

Standards and Technical Guidance Documents Mentioned by Respondents

- MIL-STD-1629A, Military Standard, Procedures for Performing a Failure Mode, Effects, and Criticality Analysis, 24 November 1980
- SMC-S-011 (2015), AFSC Space and Missile Systems Center Standard: Parts, Materials, and Processes (PMP) Control Program for Expendable Launch Vehicles (ELV), July 2015
- MIL-STD-1540D, Department of Defense Standard Practice: Product Verification Requirements for Launch, Upper Stage and Space Vehicles, January 1999 (Superseded by: SMC-S-016 (2008))
- SMC-S-016 5 Space and Missile Systems Center Standard: Test Requirements for Launch, Upper-Stage and Space Vehicles, September 2014, Supersedes: SMC-S-016 (2008)
- ISO 9001:2015, Quality Management Systems – Requirements
- AS9100: Rev D, Requirements for Aviation, Space, and Defense Organizations

Standards and Technical Guidance Documents Mentioned by Respondents

- Aerospace Report Number: TOR-2006(8583)-5236, Technical Requirements for Electronic Parts, Materials and Processes Used in Space and Launch Vehicles
- Aerospace Report Number: TOR-2006(8583)-5235, Parts, Materials and Processes Control Program for Space and Launch Vehicles
- ISO 13485 Medical Devices -- Quality Management Systems -- Requirements for Regulatory Purposes
- JEDEC JESD 47, Revision K, Stress-Test-Driven Qualification of Integrated Circuits, August 2018
- AEC-Q100 Failure Mechanism Based Stress Test Qualification For Integrated Circuits
- AEC-Q101 Failure Mechanism Based Stress Test Qualification For Discrete Semiconductors
- AEC-Q200 Stress Test Qualification For Passive Components

Standards and Technical Guidance Documents Mentioned by Respondents

- MIL-PRF-38535 Revision: L, General Specification for Integrated Circuits (Microcircuits) Manufacturing, December 2018
- ECSS-Q-ST-60C Rev.2 21 Space Product Assurance - Electrical, Electronic and Electromechanical (EEE) Components, ECSS-Q-ST-60C Rev.2 21, October 2013
- MIL-PRF-123: General Specification for Capacitors, Fixed, Ceramic Dielectric, (Temperature Stable and General Purpose), High Reliability, (w/Amendment 2), Revision D, September 2007
- MIL-PRF-55681: General Specification for Capacitor, Chip, Multiple Layer, Fixed, Ceramic Dielectric, Established Reliability and Non-Established Reliability, (w/Amendment 1), Revision G, September 2017
- MIL-PRF-55310: General Specification for Oscillator, Crystal Controlled, (w/Amendment 2), Revision F, November 2018

Standards and Technical Guidance Documents Mentioned by Respondents

- MSFC-STD-3012, Electrical, Electronic, Electromechanical (EEE) Parts Management and Control Requirements for MSFC Space Flight Hardware, Revision A, February 2012
- NPR 8705.4, Risk Classification for NASA Payloads, w/Change 3, June 2004
- SLS-RQMT-019, Space Launch System Program (SLSP) Electrical, Electronic, and Electromechanical (EEE) Parts Management and Control Requirements Document, Revision A, February 2013
- NPR 7120.8A, NASA Research and Technology Program and Project Management Requirements, September, 2018
- NPR 7120.5E, NASA Space Flight Program and Project Management Requirements, Updated w/Change 16, August 2014
- NASA NPR 7120.3, Data Management, Programs/Projects, Revision E, July 25, 2005

Standards and Technical Guidance Documents Mentioned by Respondents

- NPR 8000.4B, Agency Risk Management Procedural Requirements, December 06, 2017
- MIL-STD-1580B, Department of Defense, Test Method Standard: Destructive Physical Analysis (DPA) for Electronic, Electromagnetic, and Electromagnetic, and Electromechanical Parts, January 2003
- MIL-STD-1553B: Digital Time Division Command/Response Multiplex Data Bus, United States Department of Defense, September 1978.
- SAE AS15531: Digital Time Division Command/Response Multiplex Data Bus
- SAE AS15532: Data Word and Message Formats
- SAE AS4111: RT Validation Test Plan
- SAE AS4112: RT Production Test Plan
- AFSC MANUAL 91-710 (VOL 3), Range Safety User Requirements Manual Volume 3 – Launch Vehicles, Payloads and Ground Support Systems

Standards and Technical Guidance Documents Mentioned by Respondents

- NPR 8000.4B, Agency Risk Management Procedural Requirements, December 06, 2017
- MIL-STD-1580B, Department of Defense, Test Method Standard: Destructive Physical Analysis (DPA) for Electronic, Electromagnetic, and Electromagnetic, and Electromechanical Parts, January 2003
- MIL-STD-1553B: Digital Time Division Command/Response Multiplex Data Bus, United States Department of Defense, September 1978.
- SAE AS15531: Digital Time Division Command/Response Multiplex Data Bus
- SAE AS15532: Data Word and Message Formats
- SAE AS4111: RT Validation Test Plan
- SAE AS4112: RT Production Test Plan
- AFSC MANUAL 91-710 (VOL 3), Range Safety User Requirements Manual Volume 3 – Launch Vehicles, Payloads and Ground Support Systems

Acronyms

ADCS	Attitude Determination and Control System
AEC	Automotive Electroincs Council
AIAG	Automotive Industry Action Group
APQP	Advanced Product Quality Planning
ASME	American Society of Mechanical Engineers
ATE	Automated Test Equipment
BI	Burn-In
CADRE	Cost Analysis Requirements Document
CAS	Cost Accounting Standard/System
CDR	Critical Design Review
CDRL	Contract Deliverable Requirements List
COTS	Commercial Off the Shelf
CPAF	Cost Plus Award Fee
CPIF	Cost Plus Incentive Fee
CPK	Continuous Process Capability

Acronyms

DC	Date Code
DLA	Defense Logistics Agency
DPA	Destructive Physical Analysis
ECSS	European Cooperation for Space Standardization
EEE	Electrical, Electronic and Electromechanical
EIDP	End Item Data Package
EMI/EMC	Electromagnetic Interference/Compatibility
EP	Enhanced Plastic
ESPA	ESPA (EELV Secondary Payload Adapter)
FIT	Failures in Time
FMEA	Failure Modes Effects Analysis
FMECA	Failure Modes Effects and Criticality Analysis
FPGA	Field Programmable Gate Array
GEO	Geosynchronous
GFE	Government Furnished Equipment
GNC	Guidance Navigation and Control

Acronyms

ICD	Interface Control Document
ISO	International Organization for Standards
LDC	Lot Date Code
LEO	Low Earth Orbit
MAM	Mission Assurance Manager
MPE	Maximum Predicted Environment
MTF	Mean Time to Failure
NEPP	NASA Electronic Parts and Packaging
NPR	NASA Procedural Requirement
OTA	Other Transactional Authority
PAT	Part Average Testing
PDR	Preliminary Design Review
PMP	Parts, Materials and Processes
PPAP	Production Part Approval Process
PPK	Process Potential Capability

Acronyms

PSR	Program Status Review
QA	Quality Assurance
QCI	Quality Conformance Inspection
QFN	Quad Flat No Leads
QML	Qualified Manufacturing List
QMS	Quality Management System
QPL	Qualified
RDA	Responsible Design Authority
REACH	Registration, Evaluation, Authorization of Chemicals
RHA	Radiation Hardness Assurance
ROHS	Restriction of Hazardous Substances
RT	Radiation Tolerant
SBL	Statistical Bin Limits
SEE	Single Event Effects
SEL	Single Event Latch-up

Acronyms

SEU	Single Event Upset
SIP	System in Package
SIS	Standard Interface Specification
SNL	Statistical Yield Limits
SOW	Statement of Work
SRR	System Requirements Review
TID	Total Ionizing Dose
TRD	Technical Requirements Document
TRL	Technology Readiness Level
TRR	Test Readiness Review
Tvac	Thermal Vaccuum
UNP	University Nanosatellite Program
USG	US Government
VITA	VME (Virtual Machine Environment) International Trade Association