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Aerospace and Defense Acquisition Strategy Recommendations from Current Mission Class Execution Experiences

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ABSTRACT

As a result of recent program experiences, Ball Aerospace has identified several areas that impact risk-based acquisition decisions. These lessons have been gleaned from current program execution, including customer interaction and internal developments. By leveraging these lessons, we can improve current program execution as well as better prepare for future architectures. We anticipate that future architectures will focus on shorter missions, company command media driven execution, advanced technology implementation, and, most importantly, achieving all the above at a much faster rate. Mission class definitions need to evolve in response to these demands and to enable future architectures. New architectures and programs mix mission class elements across program segments, enabling systems that can demonstrate heritage-like capabilities as well as significant new capabilities in an evolving execution and operation environment. This paper reviews examples of these developments from the perspective of three (3) groups of recent programs.

Ball's Mission Assurance (MA) framework starts with heritage MA disciplines (design assurance, quality assurance, and specialty engineering), and incorporates evolving assurance disciplines (e.g. cyber security and supply chain risk management). By implementing lessons learned from inside this framework, enhanced mission success is enabled through tailored MA approaches from concept to on-orbit operations that diverge from historical execution. This tailoring has evolved, and will evolve, as its applied to current and future acquisitions. Most importantly, the MA framework empowers contractors and acquisition organizations to work together to align requirements and develop an understanding of offerings prior to contract award, which ensures both parties understand expectations within the given resource constraints. Management approaches that only leverage heritage programs are insufficient to address the current acquisition landscape, given the level of evolution at desired speed of execution, incorporation of innovative technologies, and desire to leverage alternative development strategies. Future architectures will need to implement many of the indicated lessons to achieve their desired end goals.

INTRODUCTION

In recent years, government and commercial activity in near-Earth space has rapidly increased. Recent reports indicate more than 90 individual countries have assets in space. The rapid decline in development costs, rapid increase in launch opportunities and options, and addition of commercial ground entry point (GEP) operators have all allowed commercial and non-traditional space fairing countries to enter the arena and launch a significant number of vehicles – and all without the historical infrastructure costs. This is similar to the rapid expansion of the telecommunications systems in the 1990s, where inventors of telecom systems bore the brunt of infrastructure costs while late adopters could leap frog directly to cellular networks.

The result is a wide variety of satellites, from picosats to traditional large satellites, being put into orbit on a regular basis. With the increased access to space, the number of satellite launches and the total number of in-orbit (LEO, MEO, GEO, HEO, etc.) objects has grown exponentially (See figure 1). These satellites (both individual and constellations) are commercial and government, with some also being mixed use; increasingly, governments have leveraged commercial data along with their own hosted payloads.

The changing environment means typical program considerations of cost, schedule, and performance are insufficient to address the needs of the future architectures. All these activities represent opportunity and risk to developers of space systems.

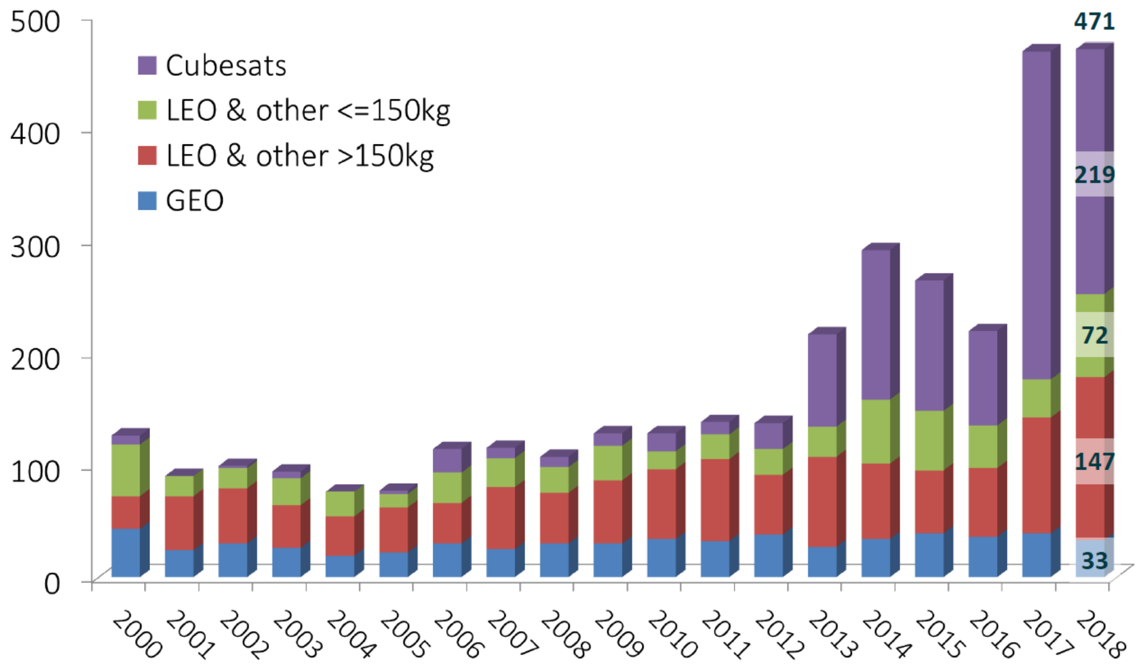

Figure 1: Satellites launched from 2000 to 2018 (Multiple orbits) (Courtesy of AXA XL)

There are continued opportunities to create highly-unique mission elements (payload, bus, etc.), and a growing demand to create low-cost options for commercial markets. As opportunities have increased, new market segments have emerged to meet this demand. There is a market that provides ground processing capabilities that range from basic to fully autonomous, leveraging data analytics to create real-time data visualization products. There are some space system developers who will leverage this new capability as an extension of their own sensor analysis algorithms for their own end-product services.

With an increase in opportunities, there is also an increase in risk and threats to the successful outcome of the customer's mission. Arguably, the most challenging to overcome is limited resources (monetary, physical, and personnel) to take advantage of these opportunities. There is also risk in choosing the wrong market to target, investing too heavily in physical inventory, or choosing the wrong staff. Any of these may result in incorrect positioning to take advantage of evolving opportunities, which in turn may hinder a company's ability to be appropriately positioned in this rapidly evolving environment.

There are other risks that are inherent to a crowded and evolving marketplace. Many space system suppliers claim to be able to discriminate between opportunities but have never fielded or operated a unit. This lack of experience to know what is or is not critical during development has resulted in many recent operational failures; some of these failures are threats to on-orbit systems as they become uncontrolled space debris. Availability of critical experience from key personnel across the industry is also changing as the baby-boomer generation continues to retire. Difficult decisions must be made to address the multitude of risks within the constrained option space. In the end, all of these risks must also take into account the potential repercussions to customer missions of nation states, including unintended effects, as a result of their actions.

Security and Mission assurance (SMA) at Ball Aerospace is tasked with both evaluating mission risk to programs and program trades that may conflict with customer or corporate goals. SMA fulfills customer requirements, takes advantage of opportunities, and manages risks by carefully constructing execution paradigms and risk management plans. Figure 2 shows a sample of items regularly considered when working with customers, programs, and industry when deciding what is possible to complete. The internal cycle of SMA trades is informed and constrained by the outer circle of program and mission constraints.

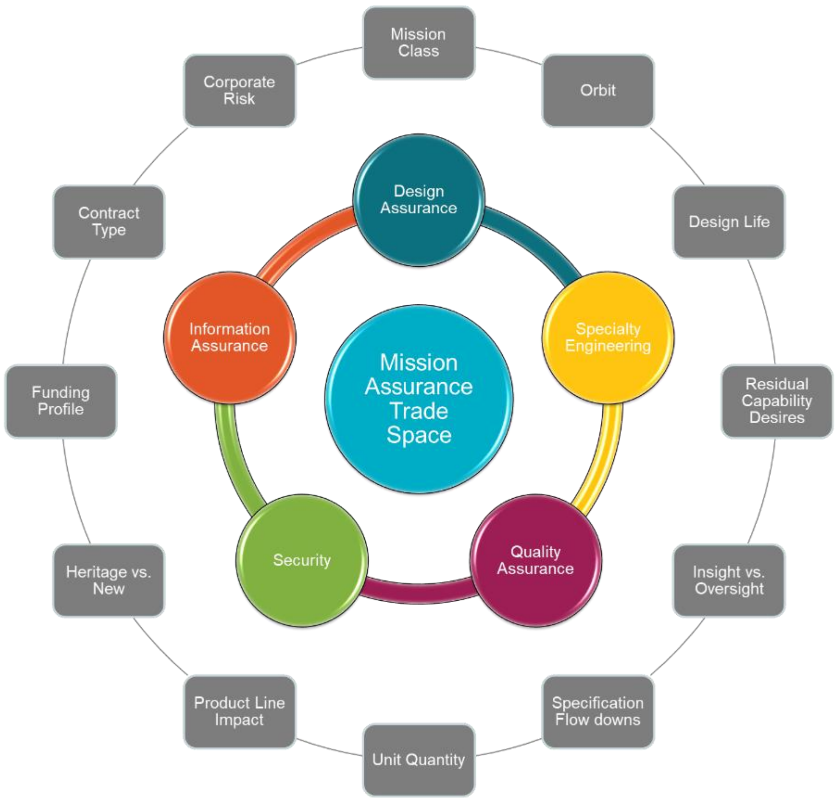

Figure 2: Mission Assurance trade space informed by program and system constraints

SMA at Ball Aerospace has responded to evolving customer demands by making structural and business changes to address them. SMA is built around a "mission class" framework, where customer needs are aligned to our capabilities in products and processes. Development and production are in the same framework, allowing the teams to leverage heritage products while still incorporating new technologies when necessary. This allows the company to use standardized command media for projects ranging from internally funded research and development (IRAD) to operational National Security Space (NSS) and human rated space flight programs. A key benefit of this framework is that it allows Ball to quickly and efficiently compare customer desires and requirements against mission analysis capability results. This reinforces customer collaboration, ensuring the program operates within the programmatic and technical constraints of the mission architecture. Ball Aerospace developed this unique MA framework a decade ago, anticipating the growth in the sector and work across multiple mission areas.

Five years ago, Ball Aerospace evaluated the market for threats and opportunities across our customer base and identified security as a key discriminator for future architectures. Ball has since incorporated security in the framework by fully integrating Ball Aerospace Security into the Mission Assurance organization. This new SMA organization structure ensures the delivery of the best-value products to our customers, especially considering the rise of security threats.

Today, security is more than traditional physical and classified security. Security threats of all types (physical, cyber, quality, etc.) impact all levels of supply chain and product development; thus, security must address all elements that are used to create the end deliverable. The updated MA framework does so, addressing security risks from all angles, from cradle to grave. It allows Ball to execute traditional Class A operational systems and "new space" opportunities, with multi-unit production and constellation level redundancies. Furthermore, this reinforces Ball's ability to holistically address opportunities and threats, especially when one area may be offset by threats in another.

This merger highlights the benefits of Ball's SMA team. Threats can be addressed, designed out, and/or mitigated early, thus reducing problems and better setting the mission up for success. This becomes clearer when you consider the breadth of threats a Mission Assurance Manager (MAM) and the assurance team must address to identify, quantify, and assess mission risks.

At Ball, the MAM, program manager, and chief system engineer form the program management triumvirate. MAMs are typically responsible for:

- Specialty engineering functions at a "Systems Assurance" level
  - Parts engineering support for screening and qualification identification and specification
  - Part and system radiation effects optimization
  - Materials and processes management for the space environments
  - Contamination control engineering for optical systems and related design impacts
  - Reliability engineering from product to architectural resiliency assurance
- Traditional quality engineering functions
  - Hardware and software quality patent/latent defect elimination
  - Non-conformance and anomaly management
- Safety and environment compliance
  - System safety to personnel and space segment assets
  - Support to launch activities through design trades
  - Environmental health and safety regulatory compliance
- Information Security and Information Assurance
  - Information assurance for enterprise infrastructure, program development environments, and all applicable mission segments
  - Supply chain risk management for trusted development
  - Program unique cyber assessments and compliance
  - Program unique anti-tamper and related requirement sets

Ball's framework merges these responsibilities with cross-company functions that address program security and business continuity. This allows Ball to be able to broadly address program specific needs within each program specific environment. This also supports addressing key supply chain risks and associated security requirements. Please see a top-level organization chart (Figure 3) below.

- IT execution system compliance
  - Physical information system management
  - Information security and system compliance
  - Non-program unique cyber threat assessments and management
- Business Process Management
  - Audits
  - System compliance
- Data management

- Cross business data management and metric leverage
- Data analytics

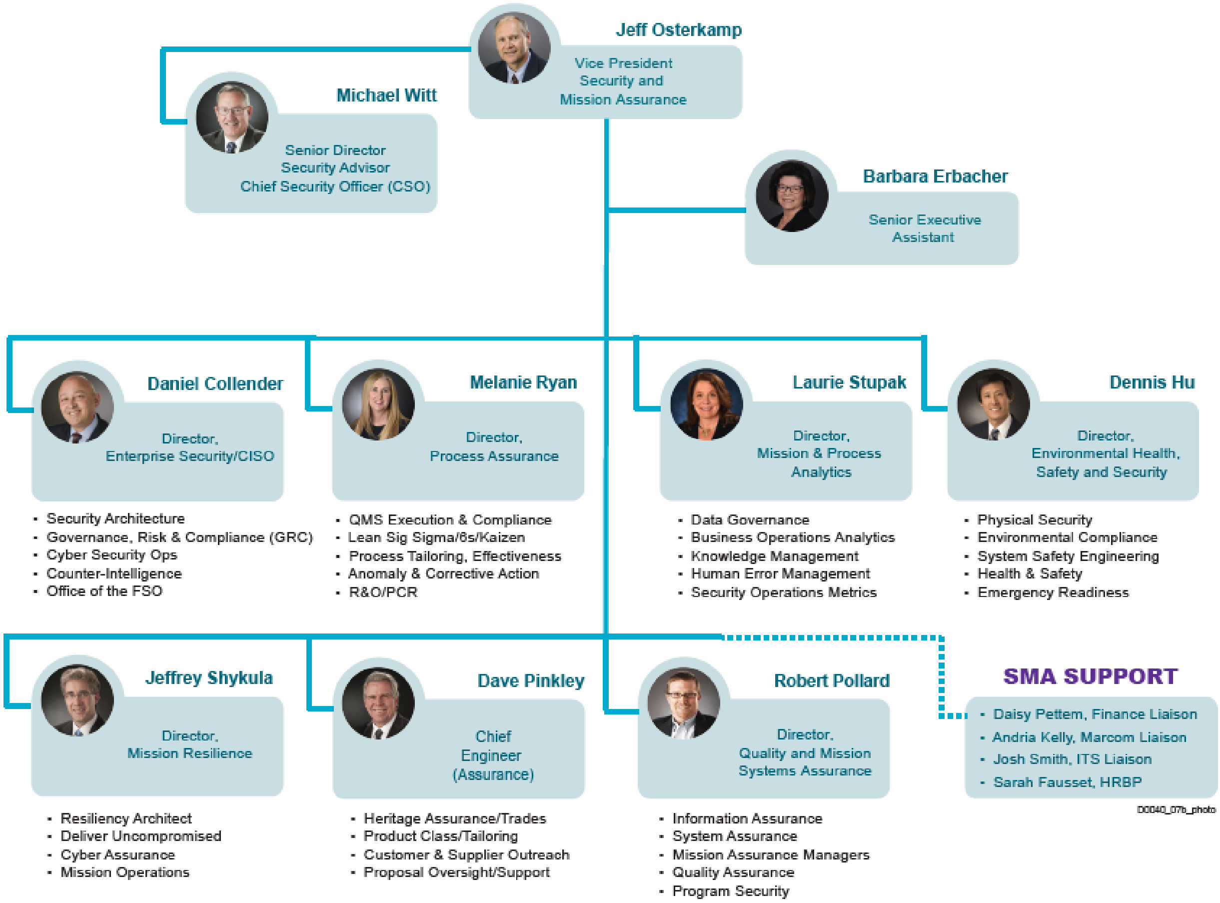

Figure 3: Ball Aerospace Security and Mission Assurance (SMA) Organization

Three recent program groups provide insight into how and why the SMA organization was formed. These three programs, ranging from Mission Class A through C (Figure 4), provide an idea of how Ball leverages our internal command media, experienced SMA personnel, and organizational constructs to develop frameworks for programs over a broad range of missions. A summary of the approach to each program is provided in Figure 5 with categorization of risk strategies.

Mission Risk Class	Class A	Class B	Class C	Class D
Ball Internal Product Baselines	Operational (Customer Driven)	Operational/Pathfinder (Capability Driven)	Operational/Demo (Streamlined Heritage)	Demos/Experiments (ALT* Margins, Safety)
Mission Success	Spec/STD Compliance	Equivalent Compliance	Best Practices Artifacts	Threshold Performance
Product Baseline Managed Risk	• >> Mission Length	• > Mission Length	• < Mission Length	• << Mission Length
	• Custom Developed	• Heritage Developed	• Heritage Developed	• Board Subsystems
	• Prescriptive "How To"	• Requirements Volatility	• MA* Surgical Focus	• ALT Based Assurance
	• >> Assurance Artifacts	• > Assurance Artifacts	• RE* Decision Authority	• << Empirical Data
	• Resource Balance	• Trusted Suppliers	• Audit Process Integrity	• Supplier Stability

* ALT: Accelerated Life Test, MA: Mission Assurance, NSS: National Security Space, RE: Responsible Engineer

Figure 4: Nominal Mission Class characteristics used to identify baseline program execution approach. Typical program is a mixture of multiple classes depending on deliverables and results of mission assurance trades within the program defined constraints.

Baselines	Class Alignment to Mission Class Risk Strategy			
Method	**Relationships**	**Level**	**Rigor**	**Governance**
Principles	**Verification/Validation** • Method Overlap • Standards/Capability • Inspection/Screening • Qualification/Margins	**Artifacts Scope** • Application Level • Isolation Bounds • Graceful Degradation **(Unknown-Unknowns)**	**Risk Exposure Align** • Methods/Depth • Standards • Accepted Risk **(Known-Unknowns)**	**Insight/Oversight** • External Oversight • Oversight/Insight • Risk Governance **(Unknown-Knowns)**
Mission Class A Example	• Program heritage modified to meet customer directives • Stringent adherence to program based standards	• Difficult mission driven orbit • Broad based standards application and qualification	• Minimum practical risk adjusted with schedule constraints • Highest rigor level for all products	• Extensive Oversight/Insight • Customer approval for all deliverables
Mission Class B Example	• Heritage based design and qualification profile • Define and refine acceptance criteria	• Heritage technical baseline acceptance • Workmanship and end deliverable driven	• Risk profile focus on new developments • Heritage Change management	• Complete insight with contractual oversight • Customer heritage vs. STD alignment
Mission Class C Example	• Demonstration driven reliability • Test vs. analysis focus	• Capability driven program decisions • Adjunct mission profile with highly tailored assurance profile	• Programmatic driven Acceptable risk • Constraint driven execution	• Leverage heritage product/processes • Key customer concerns drive oversight

Figure 5: Characteristics of mission examples.

MISSION CLASS A EXAMPLE

The first example is an operational class mission. These types of missions are characterized by a desire to reduce potential operational risk to an absolute minimum by requiring a maximum compliance to "industry best practice" documents. The principal is that these compliance documents represent the best-known possible execution standards for each of the technical elements making up a product. Therefore, enacting these requirements should result in the best possible product. The challenge with this approach is that these documents are written in a vacuum in relation to each other and to the program trade space. Additionally, they do not consider the ability for the supply chain to provide products that meet the indicated requirements within an acceptable time frame and cost. The result is that attempting to enact these requirements in totality typically results in misalignment with programmatic and technical constraints, which is further exacerbated when security is added.

Ball Aerospace has enabled mission partners and suppliers to establish equivalence to these "best practice" documents through: 1) leveraging our mission-class based command media to align capability with mission goals and 2) communicating with the customer as early in the acquisition phase as possible to identify and incorporate mission unique tailoring. This approach enables customers to make critical trades that align with mission goals, while maximizing return on investment (ROI) in a risk-balanced environment. Alignment of SMA trades early in the acquisition cycles enables pre-RFP decisions that significantly improve programmatic risk posture. A few key examples of lessons learned from these programs are provided in the following sections.

Specificity in component requirements

Suppliers should be flowed mission requirement documents that detail the scope of work early in order to support budgeting and alignment of supplier capabilities. It is critical to be as specific as possible as to the required capability of the components. Ambiguous requirements can, at worst, invalidate the product and process baseline of the component being procured. Ball works with our supply base to help maintain product lines, establish program requirements at a given Mission Class, and partner on increases and/or changes to the product. This supply-based product and process alignment continues from the mission to the component level, which enables execution within programmatic constraints, resulting in an overall lower risk level.

Security architecture and supplier flow down

In the rapidly evolving security threat environment, Ball evaluates its supply base's capabilities to determine whether the security requirements must be designed into the overarching system vs. should be flowed down to suppliers. The aerospace and defense (A&D) supply base is characterized by a significant number and frequency of mergers and acquisitions, but still relies on many small businesses for specialized components. Flowing security controls that are not aligned with a supplier's capabilities can result in non-compliances, no-bid situations, and waivers that must be mitigated by the system integrator. In these situations, the system integrator must perform the appropriate critical program information (CPI) assessment prior to supply base flow downs and identify methods to alleviate these requirements through the supply chain. These assessments and resulting mitigations need to be agreed upon early with end users to ensure mission-unique security is addressed appropriately.

Radiation Hardened Electronics

In the A&D market, there has been a reduction of radiation hardened and high reliability electronics. Electronics play a key part in virtually all A&D systems. As a result, some element of the electronics architecture is typically critical to the program. However, some of the current and envisioned security requirements are difficult, if not impossible, to meet without having A&D dedicated fabrication capabilities that do not widely exist. The result is that trades between security, acquisition, and architecture are required. This requires technical (performance, SWaP, etc.) and programmatic (cost, schedule, etc.) tradeoffs. An example is the availability of radiation hardened devices and high-performance processors. Current generations of high-performance processors are targeted to automotive and other consumer markets with no intent to become radiation hardened for the A&D market. As a result, programs need to design around reliability, life times, and radiation testing to enable the use of these devices, or design systems to perform without them. Additionally, issues arise with flowing DFAR specific requirements to commercial product suppliers and the ability and desire of these companies to be compliant to these requirements.

Technology Insertion

To meet desired preferences, “high end” Mission Class A programs require leveraging best-in-class electronics. Some performance demands are not possible in the current A&D electronics environment without program specific testing, resulting in cost and schedule risks. In these cases, customers and users need to come to an understanding that the historical EEE parts baseline construction, analysis, and testing procedures are not applicable. For example, some future architectures are enabled through using electronics that are packaged using stacked die and use highly integrated system-in-package configurations where current A&D testing for destructive physical analysis (DPA) is not directly applicable. This results in needing a detailed requirement evaluation for applicability, including identifying alternative approaches to avoid significant time and cost expenditures with questionable results during execution. To have more efficient execution, it’s imperative to understand when to tailor, what to tailor, and potential ripple effects through the program execution phase.

MISSION CLASS B EXAMPLE

The second example is a significant departure from Mission Class A execution because of its contractual baseline as fixed price vs. a cost-plus that is associated with using Mission Class B and C risk postures. A contractor must accept performance risk in a fixed price environment. This will drive the selection of capability-based and flight heritage designs that have proven less qualification and development risk for on-orbit performance. This results in customer mission level requirements needing to be aligned with product lines, as well as SMA products that manage mission risks, and given capabilities. The net result is working with customers to balance their need for insight to assess risk and the contractor’s need to manage residual risks on the product line.

Early phase studies that use cost plus contract vehicles are invaluable in these situations to provide the government insight into capability-based designs that achieve their mission objectives through alternative methods. The interaction also provides the contractor an ability to characterize the financial implications of executing a program in a fixed price environment given the mission constraints. This is especially true for development-type programs, where unknown technology hurdles may be experienced. Recently, a Ball Aerospace Mission Class B program without a preceding study phase required extensive post award discussions with customer representatives to reach alignment. The net result was extensive time and effort to educate the customer on the contractual baseline with minor adjustments to Ball’s execution approach. Lessons learned in this case are presented below.

Heritage

Heritage is a key element of fixed price programs. Well-characterized system elements help alleviate significant schedule and cost risk to new development programs. Both parties must agree on what is and what is not defined as heritage, as well as how to assess heritage risk. The definition of heritage is not exact; there are many industry definitions used across the range of government and commercial customers. All involved parties should agree upon a definition early in the process to ensure alignment of expectations and to reduce the potential for misalignment later in the program after key execution decisions have been made. Definitions must incorporate more than technical elements to fully characterize the heritage risk. These include programmatic (e.g. suppliers, delivery schedules, and contract deliverables), security (e.g. cyber considerations, information assurance implementation, and program specific classification guidelines), and other elements that may impact the ability of an element to be used by another program. Ensuring a holistic review of the component heritage baseline enables clear risk evaluation guidelines and agreement between all parties is efficient and effective.

Qualification

Component qualification is an integral element of evaluating heritage and its relation to development risk. Understanding this relationship requires an exact method and definition of “qualification.” There are many definitions within industry accepted documents as well as customer, , program, and contractor specific requirements. The disparity of requirements and breadth of qualification needs forces these issues to the forefront when considering usage of heritage elements in a fixed price environment. Nominal "best practice" is to qualify each element in environments identical to the anticipated flight environment, i.e. Test-Like-You-Fly (TLYF) with margins to address mission life, workmanship and environmental uncertainties. There are a multitude of underlying assumptions with the combination of these factors. For example, TLYF can have greater relevance in a multi-build environment versus a one-of-a-kind development. TLYF forces architectural design choices, in-situ measurement demands, test facilities, equipment, test bed requirement, etc. that negatively impact programmatic risk while having limited technical risk benefits. Additionally, when applied to product lines, minor changes that occur between block builds are either disregarded or not addressed at all.

The result is that leveraging heritage components between programs requires a deep knowledge of component qualification baselines that enable risk-based requirement trades, otherwise nonspecific qualification testing can increase component risk. Well-defined expectations and an understanding of heritage qualification approaches reduces potential execution risk by ensuring both parties fully understand what they are getting and why.

Reliability

The method used to trade capability-based architectural elements can be highly dependent on what practices are followed for reliability assessment. Ball follows the industry standard for reliability, MIL-HDBK-217. While it's well-known that this document is obsolete, as is the underlying data the empirical formulas are based on, it is still the method used for calculating reliability values by NASA, NOAA, virtually all national security space, and many other acquisition organizations. A consequence of using this document is that it places substantial importance on the Probability of Success (Ps) it calculates, without considering the ripple effects this may have through an architecture.

Fixed price programs can address this through bidding a specific product line along with its components, which characterize the reliability based on empirical on-orbit performance and conservative adjustments to reliability factors. When this is not accepted, contractors are forced to follow overly conservative design practices that result in products that are not optimized to meet mission objectives. This requires higher quality grade EEE parts, which in turn impact cost, schedule, and performance. Adding redundancy into a system impacts overall mass, schedule, cost, and, potentially, cycle time to orbit. Impacts of these decisions can be contrasted with historical performance of NSS systems that typically survive multiples of design life, with the ripple effects impacting: maintenance costs for out of date systems, ability to field new systems, and the effects of new technology insertion. Ball's own on-orbit history highlights the impact this can have, as our systems have been proven to survive well past their design lives, as shown in figure 6.

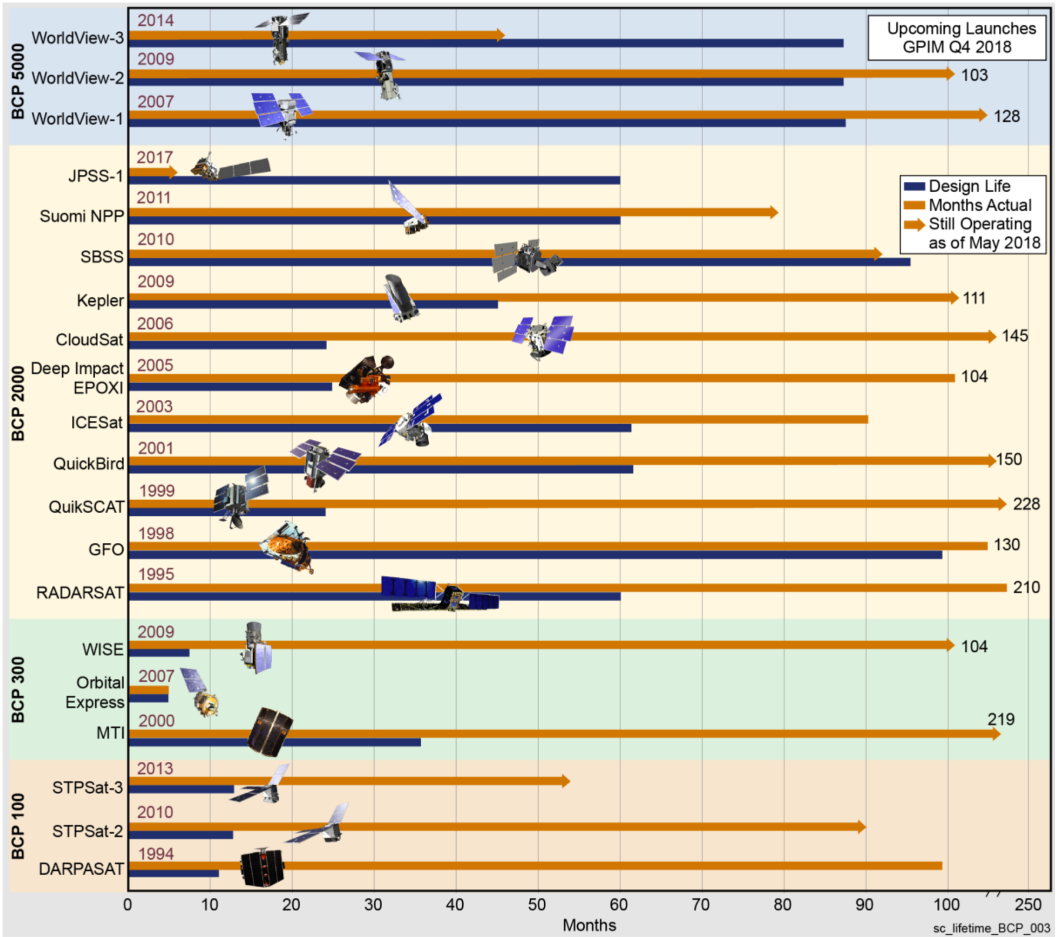

Figure 6: Flight history of Ball Aerospace Ball Configurable Product (BCP) missions. Demonstrating a mean-time-to-decommision of ~14 years based on missions with design lives between 1 and 7 years.

MISSION CLASS C EXAMPLE

The third and final example is based on Mission Class C developments. These developments leverage command media driven processes, focus on short cycle times to orbit, and address technology desires through tradeoffs of performance capabilities and execution risk. These programs often want to support a unique capability, have adjunct capabilities to operational systems, and/or are providing resilient capabilities. These programs can present significant security challenges because the desired capabilities are often sensitive but require leveraging recent high-performance technology developments without control by the heritage supply chain. SMA offerings that are capability-based are key for this class of program, as they require early and rapid alignment of capabilities, mission architecture objectives, and customer assurance requirements. Recently, Ball demonstrated alignment to a SMA required contractual baseline in 10 weeks, versus more than a year it took to complete in recent historical programs, despite having virtually the exact same set of requirements. Additionally, we have evaluated a similar set of requirements five (5) different ways to programs within the same customer community. Each of these instances exemplify efficiently providing the information that different programs are looking for to address their unique needs. The lessons learned from this activity, as identified in the sections below, are key elements that lead to greater mission success.

Staffing

Staff on both sides of the SMA tailoring discussion must be aligned to both the programmatic and technical performance goals of the program. If both sides are not fully aligned in the common goal, discussions can quickly become adversarial and derailed. This can lead to losing the opportunity to tailor the program informally, and instead requiring submittal of formal deviation and/or waivers.

To avoid further problems with tailoring, staff must be allowed to make decisions and changes, with the caveat that these decisions will be reviewed and approved by those responsible for executing the program. The staff should be experienced in the technical aspects that are being tailored, and the ripple effects these changes will make throughout the rest of the program. This process may run smoother by leveraging related Mission Class programs that are also capability-based architectures.

Supply Base

Because the supply base is instrumental in the success of the mission architecture, the subcontract management team must be a key element in architectural discussions and decision making. If the team understands the planned supply base for each element in the offering, it will be easier to conduct timely and appropriate trades that are necessary for the program to be executed smoothly. Suppliers have changing component availability, and often supplies are sourced from more than one supplier. Thus, to understand the risks to the program, all disciplines (including traditional assurance and evolving disciplines) must be evaluated across the supply base.

Personnel Experience

To efficiently accomplish the contracted assurance baseline, the program should create, maintain, and support on-boarding and staff changes. Decisions that are specifically tailored to the program should be written down and put into baseline requirements. However, these tailored decisions should be allowed to evolve as the program needs, and individuals working the program should be allowed to modify execution parameters as fits the situation. This creates a need for explicit program management that has a clear rationale behind the changes; this responsibility falls to the program leads. Without this leadership, the rationale based on heritage can be lost, and long-lived programs may change execution approaches without understand how this impacts previous baseline decisions and heritage products.

SUMMARY

Ball Aerospace's recent experiences on Mission Class A-C programs has produced insights into omptimizing mission architectures and the efficacy of Ball's SMA framework. In order to execute a risk-balanced program that is aligned with customer expectations, especially in the expanding and congested space market and environment, there must be multifaceted trades and solutions. SMA is a key discriminator in this rapidly expanding trade space, due to evolving threats and their ripple effects into other programmatic and engineering disciplines. The merging of traditional design assurance, specialty engineering, quality assurances, and now security engineering into a single cohesive organization enables these trades and solutions to take place. Each area receives the visibility needed to ensure customer expectations are met as market conditions evolve. SMA is becoming even more critical as risks to systems expand horizontally and vertically through supply chains and grow across multiple organizational and customer boundaries. Ball Aerospace's mandate is to provide a "certified uncompromised" product. The definition and content associated with this mandate is evolving rapidly in response to customer demands. SMA tackles this demand head on by leveraging Ball's mission partner approach to system development.