

GETTING IT RIGHT

COLLABORATING FOR MISSION SUCCESS

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OUTPACING THE THREAT



By STEVE ISAKOWITZ
The Aerospace Corporation President/CEO

In this dynamic era of change—where our adversaries are working intensely to undermine our leadership in national security space—it is not enough to meet the challenges they pose, but to anticipate and confront them with greater speed, innovation, and resiliency.

Last spring, then-Deputy Secretary of Defense Patrick Shanahan issued a challenge to The Aerospace Corporation (Aerospace) to provide an actionable plan to outpace the threat and project lethality that aligns with the National Defense Strategy. We met that challenge by issuing a plan with four key components that called for:

- 1) The adoption of a concept called “Continuous Production Agility” (CPA)
- 2) An integrated architecture where our space assets are managed as an enterprise
- 3) The advancement of this architecture through prototypes and partnerships
- 4) The streamlining of decisionmaking to achieve speed

On February 12, Aerospace convened a forum for members of government and industry on ways to outpace the threat. One of the critical issues discussed was CPA, an approach which recognizes that resiliency does not come from picking one optimal future architecture now, but rather by adapting the architecture to future needs and threats. Through its simple—but vital—perspectives and prescriptions, CPA is quickly gaining recognition as a crucial foundation for revitalizing acquisition.

In essence, CPA calls for more production, flexibility, and competition through specific measures. Increased production is obtained through frequent constellation turnover/replacement (e.g., 5-year generations, not 15-year); production and launch “on schedule,” as opposed to “on need”;

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PANELISTS AND SPEAKERS FROM LEFT: Kevin Bell, Aerospace; John Daegele, Northrop Grumman; Steve Isakowitz, Aerospace; Enrico Attanacio, Boeing; Kay Sears, Lockheed Martin; Frank Doyle, Ball Aerospace; and from SMC: Lt. Gen. John Thompson, Col. Timothy Sejba, Col. Wallace Turnbull III, Col. Edward Byrne, and Col. Dennis Bythewood.



The James Webb Space Telescope

Courtesy of NASA, used with permission

WEIGHT WATCHERS: KEEPING TRACK OF VEHICLE MASS PROPERTIES

By PHILLIP HEAD and YI-LING TAM
The Aerospace Corporation

Losing weight is never easy—even for space systems. Recent guidance will help analysts predict mass growth and prevent painful mass reduction efforts.

In 2012, the James Webb Space Telescope exceeded its target launch mass by more than 12 percent. An intense, 13-month effort eventually brought the vehicle mass back within allocations, but not before adding almost \$1B to the price tag and two years to the schedule.¹

Mass growth can be costly, as this example clearly shows. Well-managed programs continuously track vehicle mass status, expenditures, and critical paths. Failure to do so invariably leads to rework, resulting in budget overruns and schedule slips. Rigorous control of mass properties must

be maintained during all stages of acquisition, design, manufacture, and test.

For example, during the acquisition phase, mass and mass growth are not only primary factors in selecting a suitable launch vehicle but are also among the best indicators of initial cost and sizing requirements. To support this phase, Aerospace developed the Satellite Weight Growth Database, containing mass property details and trends for more than 65 vehicles. This data supports critical decisions, particularly with regard to rapid procurement of space vehicles in a dynamic launch market.

Recently, evolving threats have prompted changes to known space vehicles. Programs are incorporating new hosted payloads, technology insertions, and rad-hard designs, each contributing to mass growth uncertainty. The database enables

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AEROSPACE APPOINTS TECHNOLOGY CHIEF



Aerospace has selected Dr. David W. Miller as a vice president and its first-ever chief

technology officer (CTO).

“David’s passion for new space, innovation, and experience with our most senior customers are critical as we work to outpace the threat in space,” said Steve Isakowitz, Aerospace President and CEO. “His experience developing agile space solutions—including rapid prototyping and new space demonstrations—across the academic, civil, commercial, and national security space enterprise are a perfect match.”

Miller joins Aerospace from the Massachusetts Institute of Technology (MIT), where he most recently held the position of director of the Space Systems Laboratory and the Jerome C. Hunsaker Professor in the Department of Aeronautics and Astronautics.

Miller’s work at MIT focused on developing ideas for spacecraft that can repair and upgrade satellites with multimission functions through space operations and docking using standard interfaces. He also helped develop a technique to control satellite movement without propellant using high temperature superconducting electromagnets.

As CTO, Miller will provide vital leadership for the company’s growing prototyping efforts through his supervision of Aerospace’s Experiments Lab, or xLab. He will also oversee Aerospace’s Innovation Lab (iLab) and the company’s Science and Technology Hubs.

MAKING THE CONNECTION: COPPER BOND WIRE

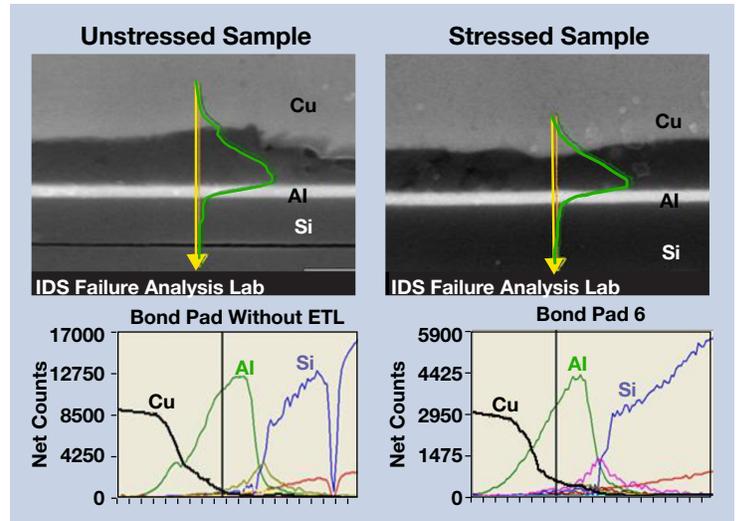
By AARON M. LECOMTE and AARON C. DERMARDEROSIAN Jr. Raytheon Company

Historically, semiconductor manufacturers have used gold wire to connect the semiconductor die to the lead frames and external pins. However, rising gold prices are driving manufacturers toward less-expensive alternative materials such as copper for use in high-volume commercial plastic package devices.

Military standards such as MIL-STD-883 do not define requirements for copper bond wires, and therefore manufacturers are using qualification and process monitoring developed for gold wire to qualify the copper bond wire technology. Although copper bond wire designs are moving forward for commercial applications, there are concerns with quality and reliability when using copper bond wires in high-reliability military electronics with a long mission life.

Potential failure modes of copper bond wires include corrosion, intermetallic growth, oxidation, susceptibility to cleaning process chemicals, and changes in electrical performance. Limited reliability data is available in plastic encapsulated microcircuits (PEMs). Some field failure reports have indicated failures associated with ball bond and crescent bond fractures.

Per J-STD-020, copper PEMs were subjected to bake-out, humidity



SEM analysis indicated negligible differences in stressed PEMs.

testing, temperature cycling, and surface mount technology reflow. Cross-sectioned samples of environmentally stressed PEMs were compared to cross-sectioned samples of unstressed PEMs in a scanning electron microscope (SEM), and the effect of the environmental stress was found to be negligible.

The diffusion between the copper bond wire and aluminum bond pad results in an intermetallic phase between the two materials. In both the stressed and unstressed samples, aluminum layers were identified that exhibited signs of cracking and voiding.

Several component manufacturers are transitioning from gold bond wires to

copper bond wires without reflecting changes in part numbers or without communicating these changes with a part change notification.

Since there is currently no official qualification procedure for the use of copper bond wires, an update to military specifications should be considered and should include increased stress levels during qualification, extended life testing to determine long-term reliability, and wire pull and ball shear specifications for copper bond wires.

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DISRUPTIVE MANUFACTURING TECHNIQUES ARE ADDING UP

By GAIL JOHNSON-ROTH
The Aerospace Corporation

Additive manufacturing is a rapidly advancing technology that promises process agility along with cost and schedule savings. The technique is well suited for forming complex shapes with near net volume for low production runs. Additively manufactured parts are already flying on some space systems. Implementation challenges include process-sensitive variability, knowledge gaps in defects and

nondestructive testing, and a lack of published processes and characterization results.

Aerospace recently partnered with the Space and Missile Systems Center to host a series of workshops focused on additive manufacturing. The events provided platforms to highlight progress, share lessons learned, address needs for future planning, and identify challenges and unknowns.

Highlights included a meeting of the “Manufacturing Problem Prevention Program” under the theme *Quality*

Strategies for Additive Manufacturing. Technical presentations discussed materials for space structures, with an emphasis on ensuring material quality. Contributors from government and industry described advances involving in-line monitoring and control with automated tools to predict product quality. Exhibitors showcased new developments in nondestructive and precision imaging techniques.

The “Space System Additive Manufacturing” workshop engaged the community to collaborate on comprehensive additive manufacturing guidelines. (Proceedings can be viewed at <http://aerospace.org/events/technical-workshops>.)

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ENTERPRISING SYSTEMS ENGINEERING

By AL HOHEB and GAIL JOHNSON-ROTH
The Aerospace Corporation

Model-based systems engineering (MBSE) is a necessary entry point in our ability to go faster in defining, acquiring, and operating as an enterprise. Rapid change for the space community—with greater international competition, enhanced threat to our space-based systems, and continued focus on how to become better at providing capabilities at the speed of need with a price that is nice—is driving an enterprise solution. MBSE is a strong contributor to meeting these needs and is viewed as a necessary evolution to conduct systems engineering.

“Leveraging Model-Based Systems Engineering (MBSE) Across the Enterprise” was the theme of the Systems Engineering Forum hosted by Aerospace. Close to 300 participants from more than 65 organizations—DOD, the Intelligence Community, civil and commercial space, tool vendors, and academia—attended.

The forum included tutorial fundamentals and basic research to lessons shared through panels, technical presentations, and collaborative workshops on implementation strategies and successful outcomes.

Aerospace’s roadmap for advancing the practice of MBSE provided a framework of near-term and end-state



Michael Orr, top, National Reconnaissance Office, and James Horejsi, Space and Missile Systems Center, challenged the community to address the “speed of need” at the “speed of thought” with data-focused systems engineering.



approaches to enable the enterprise, improve acquisition execution, institutionalize evolved systems engineering, and advance MBSE tools.

Government keynotes highlighted that the collaboration progress has advanced MBSE from a talking point at a similar forum four years ago to program and enterprise level implementation subsequently. Greater international competition and enhanced threat to space-based systems require rapid space community change. Focusing on enhancing model-based capabilities will increase missions success fulfilling the digital engineering vision.

Community leadership outcomes included the following:



“MBSE Strategies for Cyber Security” workshop was led by Karen Sharp of Aerospace.

LESSONS LEARNED

CONTAMINATION CONUNDRUM

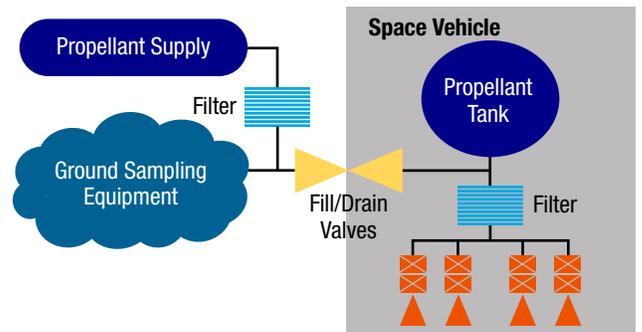
By THANH TRAN
The Aerospace Corporation

Propellants loaded into a space vehicle must meet contamination and debris tolerance requirements to avoid potential mission impacts. Samples of the propellant prior to satellite loading are tested to ensure the quality and cleanliness. A recent program failed the particulate check, but it was later determined that the ground equipment—not the

propellant—may be the source of contamination. Sampling procedures unfortunately do not differentiate from external contamination introduced by test equipment.

Failure of the process to properly sample underlines the need to carefully control testing and implement cleanliness controls. Potential impacts from introduced contamination may lead to launch delay, increased satellite internal contamination, and/or leakage of fill valves.

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Contamination most likely occurred in ground sampling equipment.

- MBSE Tool Vendor Exposition and use case presentations strengthened the relationship to government and industry. During the industry panel, one panel member stated that vendor participation in the government/industry discussions provided unprecedented insight into user needs.
- Government presentations showcased enterprise and program level plans, progress, and tool implementation that can be used as exemplars across the space organizations.
- Transformation talks showcased how digital data lives across the product lifecycle and is used from project formulation through a smart factory and beyond for operations and maintenance.
- The Aerospace “MBSE Fundamentals Tutorial” for newcomers provided language, concepts, and examples. A separate Aerospace “MBSE

- Problem Framing Tutorial” based on real-program applications provided a method to determine enterprise and program objectives.
- Trade groups, professional societies, and research centers connected for the first time to expose attendees to the emerging standards, committees, working groups, and products to apply MBSE to their domains.
- Collaborative workshops tackled the tough topics of “MBSE Utility in Cyber Security” and “MBSE to Streamline Testing.” Another workshop, “Model-based Capabilities Matrix,” provided an assessment framework to define and build organization capabilities development plans. (Proceedings can be viewed at <http://aerospace.org/events/technical-workshops>.)

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OUTPACING THE THREAT

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shorter design life (e.g., Class C satellites); and a stable, higher-rate production profile.

We can achieve greater flexibility through contracting for multiple buses and payloads, not programs or missions; the modularization of bus-payload interfaces when it's advantageous; and the establishment of modular interfaces with industry, federally funded research and development centers (FFRDCs), and the Air Force. We can fuel competition by dual-sourcing for select contracts with continuous product improvement.

Implementation of CPA offers a compelling opportunity to address the challenges before us. The recent forum that Aerospace hosted was the first in a series to promote collaborative discourse among members of government and industry to define solutions that address the escalating threats posed by our adversaries. While the demands are great, by working together, we are taking historic steps to shaping—and securing—the future.

2019 SPRING/ SUMMER EVENTS

March 2–9 IEEE Aerospace Conference, Big Sky, Montana

March 20–22 53rd Annual Conference on Information Sciences and Systems, Baltimore, MD

March 25–28 Spacecraft Thermal Control Workshop, Torrance, CA

April 1–4 Space Power Workshop, Torrance, CA

April 23–25 16th Annual CubeSat Developers Workshop, San Luis Obispo, CA

April 30–May 1 Space Parts Working Group, Torrance, CA

May 1–2 Space Parts Working Group (SPWG), Torrance, CA

June 5–7 Spacecraft and Launch Vehicle Dynamic Environments Workshop, El Segundo, CA

June 26–27 MiSatCom USA 2019, Arlington, VA

July 24–26 Malware Technical Exchange Meeting, El Segundo, CA

August 19–22 AIAA Propulsion and Energy Forum, Indianapolis, IN

KEEPING TRACK OF VEHICLE MASS PROPERTIES

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analysts to forecast weight growth resulting from such changes late in the design phase.

Program managers often overlook the wide-ranging impact of mass properties at the subsystem level. Mass properties affect calculations of coupled loads, jitter, motor alignments, stress analyses, and trajectory. They also influence the sizing of structural, propulsion, and control subsystems. Inadequate control of mass properties during development can severely degrade mission performance.

Accurate trajectory insertion demands extremely tight apogee motor alignments. In fact, in some cases, vehicle level center of gravity uncertainties must be as low as 0.02 inches. To achieve such tolerances, it is important to verify and validate all shortages and overages while ensuring ground-support and measurement equipment is properly configured and calibrated.

Accurate mass properties are critical for planning nearly all space maneuvers, including rocket stage separations, satellite deployments, orbital transfers, on-orbit station-keeping, and final deorbiting. Inaccurate data can result in severe mission shortcomings. For example, misalignment of an apogee motor's thrust vector due to center of mass

DISRUPTIVE MANUFACTURING TECHNIQUES ADD UP

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This activity followed up on a 2017 effort that resulted in a detailed framework for a guidance document. The resulting document covers more than 200 technical topics in 19 chapters published as TOR-2018-02676.

Four working groups addressed recognized knowledge gaps in the areas of qualification, outsourcing, defect detection, and production lifecycles. Each group was tasked to identify challenges, solutions, and specific actions for industry, government, and researchers. Each group provided a summary of findings that will be made available.

uncertainties could degrade stability control margins, while excess dry mass could reduce allowable propellant loading, thereby limiting life on orbit.

Recently published tailoring guidance for the industry standard for mass properties control includes a compliance table to provide applicability cases based on mission risk class.² Coupled with historical data, the guidance can help analysts forecast growth and risks, determine optimal sizing of vehicle subsystems, and minimize the likelihood of painful and costly mass reduction efforts.

REFERENCE

- 1 James Webb Space Telescope: Actions Needed to Improve Cost Estimate and Oversight of Test and Integration, U.S. Government Accountability Office (Washington, D.C., 2012).
- 2 TR-2018-01203, Tailoring for ANSI/AIAA S-120A-2015, Mass Properties Control for Space Systems: Space Vehicles, The Aerospace Corporation (El Segundo, CA, 2018).

For more information, contact Phillip Head, 310.336.3133, phillip.c.head@aero.org, or Yi-Ling Tam, 310.336.0823, yi-ling.c.tam@aero.org.

Overall, the workshops underscored how far additive manufacturing has progressed, and how much remains to be done before it becomes a routine part of space system development. Significant engagement with experts from the space community will be critical to ensure that further adoption is not hindered by overly rigid requirements, knowledge gaps, or misunderstandings between partners in the space enterprise. Findings were published in ATR-2019-00163.

For more information about the guidelines, contact Michael O'Brien, 310.336.2878, michael.j.obrien@aero.org and Alvar Kabe, 310.336.7489, alvar.m.kabe@aero.org.

RECENT GUIDANCE AND RELATED MEDIA

Model-Based Systems Engineering (MBSE) Tool Selection Framework by M. Zetilyan; TOR-2018-02532; USGC

Risk for Additive Manufacturing by M. O'Brien; TOR-2018-01161; USGC

Disposal Options 101: Space System Design Options for End-of-Life by A. Jenkin; TOR-2018-02911; USGC

Overview of Government and Industry Specifications and Standards for Additive Manufacturing by D. Witkin; TOR-2018-02545; USG

Space Domain Mission Assurance Ontology by E. Ryan; TOR-2018-01409; PR

Guidance for the Development and Qualification of Additive Manufacturing by M. O'Brien and A. Kabe; TOR-2018-02676; USGC

Space Power Heritage Study Final Results by M. Hayhurst et al.; ATR-2018-02688; PR

2018 Space System Additive Manufacturing Technical Workshop by A. Hoheb et al.; ATR-2019-00163; USGC

PR = Approved for public release
USG = Approved for release to U.S. Gov't Agencies
USGC = Approved for release to U.S. Gov't Agencies and their Contractors

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