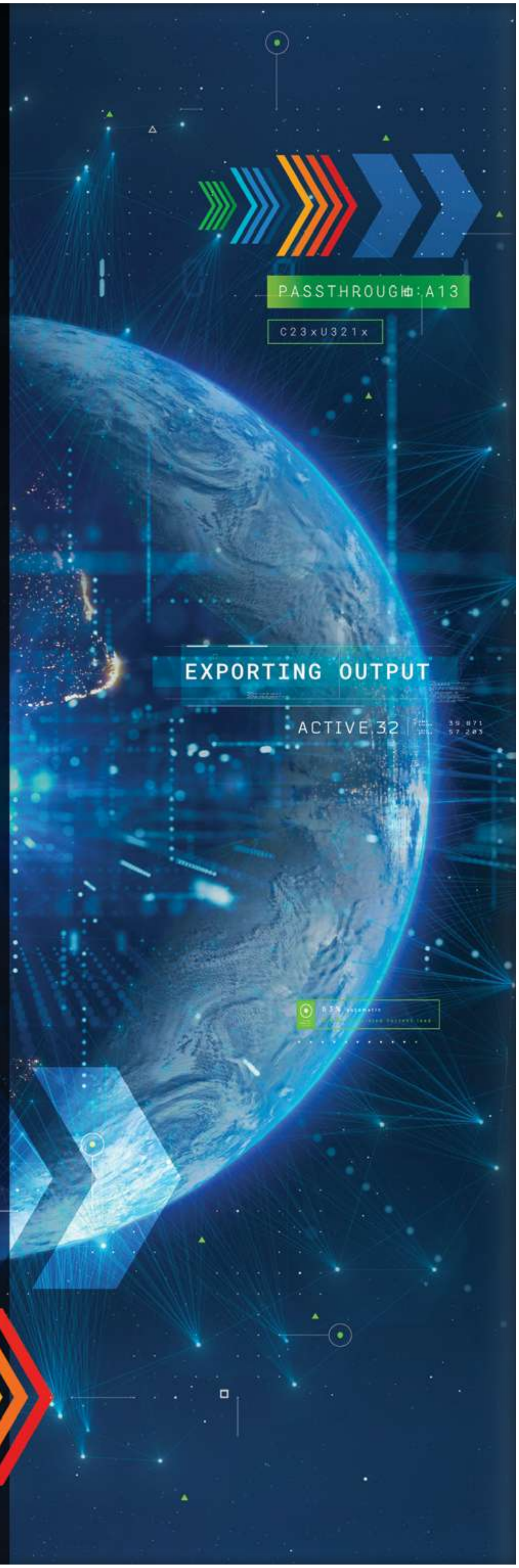
WHITEPAPER

ENGINEERING SPACE AT SCALE: COMPLEXITY ACROSS MODERN SPACE PROGRAMS



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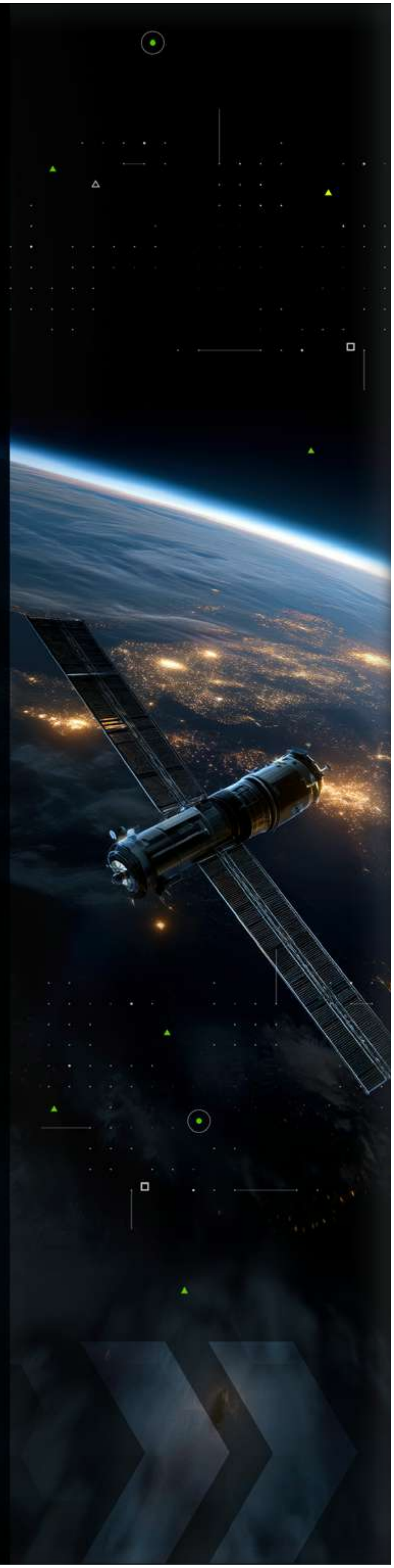


EXECUTIVE SUMMARY

Space programs are entering a new era of complexity. Larger satellite constellations, software-defined spacecraft, autonomous systems, distributed supplier networks, and accelerated launch schedules have increased the number of engineering decisions that must stay synchronized throughout development.

The challenge is no longer simply designing sophisticated systems. It is maintaining control as every requirement change, software update, supplier modification, and engineering decision creates downstream impacts across the program.

In a zero-repair environment where launch opportunities are limited and failures can have significant mission, schedule, and cost implications, understanding these relationships becomes as important as managing the technology itself. Organizations that can understand how decisions affect requirements, software, hardware, suppliers, verification, manufacturing, and configurations can identify risk earlier and respond with greater confidence.

Leading space organizations address this challenge through a connected digital engineering environment.

THE NEW ERA OF SPACE ENGINEERING

Modern space programs are fundamentally different from previous generations. Satellites have evolved into software-defined platforms. Mission capabilities can continue expanding after launch through software updates. Commercial operators are deploying hundreds or thousands of spacecraft instead of individual missions. Defense programs are integrating autonomy, AI, and advanced communications. Suppliers are contributing larger portions of complete subsystems, not just individual components.

Each trend increases the number of engineering relationships that must remain coordinated throughout development. Requirements, systems engineering, software, mechanical design, electrical systems, manufacturing, suppliers, testing, and certification can no longer be managed as separate workstreams.

As programs become more software-defined and mission requirements continue to evolve, decisions made in one area increasingly affect work happening elsewhere. That makes coordination more difficult as programs move from concept to launch and makes connected engineering data essential to maintaining control.

EVERY CHANGE CREATES A DOWNSTREAM IMPACT

Space programs are built on thousands of interconnected engineering decisions. A mission requirement influences system architecture. System architecture shapes hardware and software development. Design decisions affect manufacturing plans, supplier deliverables, verification activities, certification evidence, and approved configurations.

That interconnectedness is what makes modern space programs both powerful and difficult to control.

Consider the impact of a change to a mission requirement. What appears to be a localized update may require software modifications, mechanical redesigns, interface updates, additional verification, supplier changes, manufacturing revisions, and new compliance documentation. A single decision can quickly ripple across the program.

The challenge is rarely the change itself. It is understanding the downstream impact of changes before work begins to diverge across engineering teams, suppliers, and production.

As programs scale, these relationships multiply. New software capabilities, additional suppliers, more mission variants, and compressed development schedules increase the dependencies that must remain synchronized. Without visibility into those relationships, teams often spend more time assessing the impact of change than executing it.

Issues that originate early in development often remain hidden until integration, testing, or launch preparation, when they are far more costly to resolve. The organizations that consistently deliver complex space systems are not those that avoid change. They are the ones that understand its downstream impact early enough to respond with confidence.

HOW LEADING SPACE ORGANIZATIONS MAINTAIN CONTROL AT SCALE

As programs become more software-defined, interconnected, and supplier-dependent, control is most often maintained across four critical stages of the lifecycle.

STAGE 1: ADAPTING TO EVOLVING MISSION REQUIREMENTS

Every space program begins with changing requirements. Missions evolve. Threats change. Payloads mature. Regulations shift. Customer priorities change.

Successful organizations expect this. The real challenge is understanding the downstream impact before engineering work begins to diverge.

A requirement update can create new software work, affect system interfaces, change verification plans, trigger design revisions, or require updates from suppliers and manufacturing teams. When those relationships are connected and visible, teams can assess impacts sooner, make better decisions, and avoid unnecessary rework later in the lifecycle.

Why it matters: Prevent late-stage redesigns, protect program schedules, and maintain system integrity.

INDUSTRY PERSPECTIVE: NASA

NASA's engineering transformation reinforces the importance of understanding change impacts early. As missions become more ambitious, connected engineering data helps teams assess requirements, configurations, and mission variants with greater speed and confidence.

"The things that NASA are asked to do are not going to get any easier. They're only going to get harder and more complex. So to manage the complexity we have to take on digital engineering."

Terri Hill, Senior Leader for Engineering Transformation, NASA

<15 MINUTES

Time required to identify the root cause of an Apollo 13-style failure scenario using a digital twin of the Artemis I electrical power system. Traditional investigation methods could take hours.

STAGE 2: COORDINATING HARDWARE & SOFTWARE DEVELOPMENT

As programs mature, coordination becomes the next challenge. Hardware, software, systems engineering, manufacturing, suppliers, and verification teams begin making decisions at the same time, often across distributed organizations.

When disciplines operate in disconnected environments, changes may not be visible across teams until integration or testing begins. By that point, resolving issues becomes more expensive and disruptive.

A shared engineering baseline helps every team work from the same authoritative source of data. This improves coordination across disciplines and helps identify potential issues before they surface during integration and verification.

Why it matters: Improve cross-functional coordination from a shared engineering baseline.

INDUSTRY PERSPECTIVE: D-ORBIT

As D-Orbit scales production of its ION Satellite Carrier, engineers must rapidly adapt each spacecraft to unique customer missions while managing increasingly complex assemblies. By using a connected digital engineering approach, the team can efficiently model, visualize, and validate designs in 3D, helping engineers assess manufacturability, maintain confidence in large-scale assemblies, and accelerate delivery of customized orbital transportation missions.

STAGE 3: BRINGING COMPLEX SYSTEMS TOGETHER

Integration is where hidden complexity becomes visible. Problems discovered here rarely originate here.

Hardware, software, electronics, and autonomous capabilities must function together under demanding operating conditions. Interface mismatches, incomplete requirements coverage, unexpected software behavior, and validation gaps may often emerge during integration, even when their root causes originated much earlier in the development cycle.

Organizations that connect requirements, engineering data, software development, and test activities can identify many of these issues earlier. This improves change visibility, reduces rework, and helps teams move toward critical program milestones with greater readiness.

Why it matters: Detect issues earlier, reduce costly rework, and increase confidence before launch.

INDUSTRY PERSPECTIVE: ARCA DYNAMICS

As ARCA Dynamics prepared to scale its FALCO-X nanosatellite constellation, the company needed to accelerate development while maintaining precision across increasingly complex satellite designs. A connected digital engineering approach enabled engineers to digitally validate designs, rapidly prototype new concepts, and manage intricate assemblies before production, helping reduce integration risk and accelerate development.

"Creo gives us speed, but also precision. That's what our customers expect from us. Solutions that are fast, reliable and built for the future."

Daniele Luchena, CEO and Co-founder, ARCA Dynamics

STAGE 4: SCALING ACROSS CONFIGURATIONS & PROGRAMS

Complexity accelerates once organizations move beyond a single spacecraft. Programs become product families. Configurations multiply. Suppliers expand. Engineering changes increase.

Without strong governance, teams struggle to answer basic questions: Which version is approved? What changed? Which systems are affected? Are suppliers working from the correct baseline?

As organizations scale from prototype development to repeated delivery, multiple variants, supplier contributions, manufacturing builds, and approved baselines must remain synchronized. Strong configuration control helps ensure every delivered system reflects the intended design.

Why it matters: Prevent configuration drift and maintain approved baselines across programs.

INDUSTRY PERSPECTIVE: INTUITIVE MACHINES

As Intuitive Machines scaled from a single lunar mission to multiple concurrent programs, the company needed stronger configuration control and a more scalable engineering foundation. A connected digital engineering approach helped reduce mission design time by 50%, improve configuration management, and enable parallel development of multiple vehicles, allowing engineers to maintain control as program complexity continued to grow.

"Creo and Windchill gave us the scalability we needed to handle larger assemblies, improve reporting, and manage configuration as we grew."

Marc Granson, Structures & Environments Lead, Intuitive Machines

WHY THESE CHALLENGES COMPOUND

The four control points do not exist in isolation. Decisions made in one area frequently create impacts across the rest of the program.

Complexity rarely increases in a straight line. Every new requirement creates additional engineering relationships. Every supplier introduces additional interfaces. Every software release creates new verification activities. Every product variant increases configuration management effort.

Individually, these changes may appear manageable. Collectively, they create thousands of dependencies that become increasingly difficult to coordinate without connected engineering data.

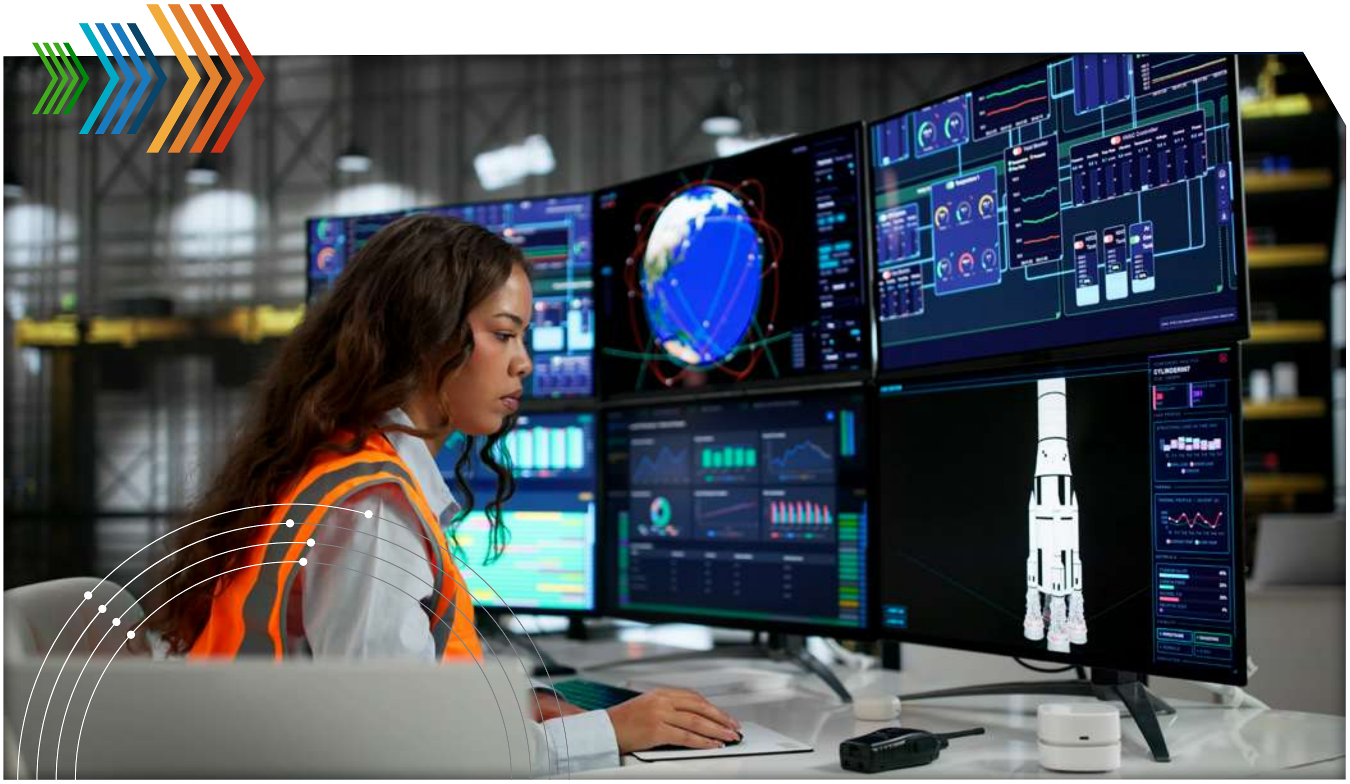
The challenge is rarely the change itself. It is understanding the downstream consequences before they affect schedule, integration, compliance, or mission readiness.

PROGRAM GOVERNANCE, COMPLIANCE, & TRACEABILITY

Governance, compliance, and traceability span the entire lifecycle. Mission success depends on maintaining a clear record of how requirements, engineering decisions, verification evidence, manufacturing records, and program documentation connect from concept through launch.

When this information is scattered across disconnected systems, teams are forced to reconstruct decisions and gather evidence manually. When traceability is built into the engineering environment, those relationships already exist.

Teams can follow the connections between requirements, designs, software, tests, and configurations without recreating them after the fact. The result is stronger audit readiness, improved mission assurance, faster certification activities, and greater confidence as launch readiness reviews approach.



HOW LEADING SPACE ORGANIZATIONS STAY IN CONTROL

High-performing space organizations recognize that complexity is inevitable. Their advantage comes from maintaining control as programs grow in scale, sophistication, and interdependence.

Rather than treating requirements, engineering, software development, manufacturing, verification, and configuration management as separate activities, they connect them through a shared digital engineering foundation. This gives teams the visibility to understand how decisions made in one area affect work across the rest of the program.

While every mission is different, leading organizations share a common approach. They evaluate the impact of change before it creates program risk, maintain alignment across hardware and software development, preserve configuration integrity as programs scale, and rely on connected engineering data to make faster, more informed decisions.

Organizations that establish these capabilities are better positioned to adapt to changing mission requirements, reduce integration risk, and scale increasingly complex space programs with greater confidence.

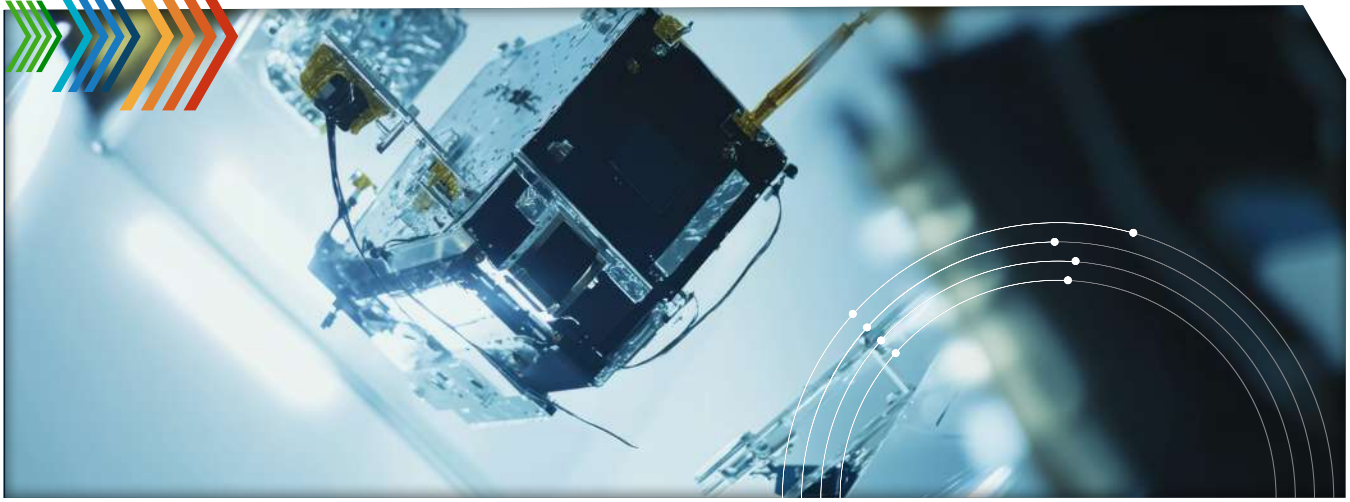
THE ROLE OF DIGITAL ENGINEERING INFRASTRUCTURE

Digital engineering is often described as connecting engineering tools. In practice, its greater value is connecting engineering decisions.

Requirements, designs, software, manufacturing plans, supplier contributions, verification evidence, and configuration baselines become part of a continuous engineering record. That record helps organizations understand downstream impacts before they become downstream problems.

No single engineering tool can provide the program-wide insight needed to manage today's space programs. Organizations need a connected digital engineering foundation that brings together requirements, design data, software development, verification, configurations, supplier collaboration, and lifecycle information within a shared operating environment.

When data remains connected, teams can better understand the impact of change, maintain alignment across disciplines, and make decisions using current, authoritative information. For leadership teams, the outcome is straightforward: stronger program control, fewer downstream surprises, and greater confidence in mission readiness.



HOW PTC HELPS

PTC enables space organizations to establish a connected engineering foundation that preserves visibility, traceability, and configuration control as programs scale.

By connecting Application Lifecycle Management (ALM), Product Lifecycle Management (PLM), Computer-Aided Design (CAD), and manufacturing data, organizations gain earlier visibility into change impacts while improving coordination across engineering disciplines and suppliers.

With solutions including Codebeamer for ALM, Windchill for PLM, and Creo for CAD, teams can connect software development, hardware design, requirements, changes, configurations, and product lifecycle data within a shared digital thread.

This helps space organizations connect requirements to execution, align hardware and software development, maintain configuration control, improve visibility into change impacts, preserve lifecycle traceability, and support secure collaboration across teams and suppliers.

The result is stronger visibility into change impacts, improved configuration control, and greater confidence as programs scale.

CONTROL COMPLEXITY BEFORE IT CONTROLS THE PROGRAM

Space programs will continue becoming larger, faster, more autonomous, and increasingly software-defined. Complexity will continue growing.

The advantage will belong to organizations that can understand the downstream impact of every engineering decision before it becomes program risk.

In modern space development, controlling complexity is no longer an operational improvement. It is the foundation of mission success.

CONTACT A PTC DIGITAL ENGINEERING EXPERT

Need more information? **Solutions for A&D**

1417750 [Whitepaper] Space Systems - Executive Brief Engineering Space at Scale