Manufacturing Engineering for Collaborative Development

Problem Statement and Go-Forward Plan

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Abstract

The Aerospace and Defense (A&D) industry operates at the cutting edge of engineering and manufacturing innovation, where Zero-defect standards are not merely a goal but a nonnegotiable requirement. Meeting these standards for complex products and industrial systems demands integrated and synchronized processes across all lifecycle phases, where the production spans decades even after product decommissioning.

Persisting gaps in the industrial system lifecycle cause operational inefficiencies, budget overages, and program issues that extend beyond the factory floor. Considering the fact that the A&D supply chain is shared among Original Equipment Manufacturers (OEMs), the solution cannot be a single fix but a holistic, multi-faceted strategy that combines proven methodologies, a foundational digital infrastructure, and a cultural commitment to true, end-to-end collaboration suitable for all A&D manufacturers.

The ME4CoDev (Manufacturing Engineering for Co-Development) working group within the A&D PAG (Aerospace & Defense PLM Action Group) is addressing the gaps. Since January 2026, 18 A&D experts from 13 leading companies have worked together to define an industrial system-specific roadmap of processes, methods, tools, and standards that addresses the problems and provides real solutions. Phase 1 work presented here is a common view of the problems. This work is intended as an inflection point for creation of a strategic roadmap for operational excellence transformation, which will be addressed in future phases.

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Table of Contents

Revision Record 5
Introduction 6
Problem Statement 10
Context 10
Business Problem #1: Industrial System Architecture, Including SoS Integration 10
Business Problem #2: Multi-Tier Extended Enterprise Collaboration, Including Data Exchange and Integration 12
Business Problem #3: Translation of Engineering Definitions into Manufacturing Plans 13
Business Problem #4: Producibility Feedback Loops, Including Shop Floor Product Data Capture 13
Business Problem #5: Industrial V&V and Industrial System Lifecycle Digital Twin 14
Business Problem #6: Modernization of Core Digital Infrastructure 15
Current Way of Working 16
Use Case #1: Cross-Domain Architecture and Simulation Integration 16
Use Case #2: Extended Enterprise Collaboration and Digital Thread Lifecycle Traceability 17
Use Case #3: From Design Intent to Shop Floor Traceability 18
Use Case #4: As-Built Reconciliation and Conformity Validation 20
Use Case #5: Multi-Site Legacy System Retirements and Enterprise Data Migration 20
Business Consequences 21
Business Consequence #1: Industrial Performance Risks and Production Delays 21
Business Consequence #2: Impact on Efficiency and Operations 22
Business Consequence #3: Long Development Cycles 22
Business Consequence #4: Loss of Knowledge 22
Business Consequence #5: IT Costs and Vendor Lock-In 22
Business Consequence #6: Loss of Digital Thread 22
Business Consequence #7: Standards Gaps 22
Causal Analysis 23
Cause #1: Siloed Collaborative Development Methods for Product and Industrial Systems 23
Cause #2: Incompatible Platform for Collaborative Development Product and Industrial Systems 23
Cause #3: Immature Adoption of Systems Engineering (SE) and MBSE for Manufacturing Engineering 23
Cause #4: Inefficient Knowledge Management 23
Cause #5: Manual and Ad-Hoc Industrial Configuration Management 24

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Cause #6: Data Leverage Gap in the Industrial Digital Thread 24
Cause #7: Lack of Industrial Digital Standards 24
Go-Forward Plan 24
About A&D PLM Action Group 26
About CIMdata 26
References 27
Appendix A: Acronyms 28
Appendix B: Supporting Figures 30

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Revision Record

Release	Date	Description
1.0	September 2026	Phase 1 Report of the Problem Statement and Go-Forward Plan

To ensure AD PAG publications continue to address the most critical industry challenges, we invite your perspective on this publication. [Time to complete: < 60 seconds]

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Manufacturing Engineering for Collaborative Development

Introduction

The Aerospace and Defense (A&D) industry operates at the cutting edge of Engineering and Manufacturing innovation, where Zero-defect standards are not merely a goal but a non-negotiable requirement. Meeting these standards for complex products and industrial systems demands an integrated and synchronized process across all lifecycle phases for both product and industrial systems because the production lifecycle spans decades even after product decommissioning. Persistent gaps in this integration have historically caused operational inefficiencies, budget overages, and program issues that extend far beyond the factory floor, impacting the stability of the extended enterprise.

Although A&D leaders have conceptually adopted "concurrent engineering" and "collaborative frameworks," the actual deployment of supporting tools, technologies, and methodologies continues to be fragmented and underdeveloped. Also, considering the fact that the extended enterprise is shared among them, the solution cannot be a single fix but a holistic, multi-faceted strategy that combines proven methodologies, a foundational digital infrastructure, and a cultural commitment to true, end-to-end collaboration suitable for all A&D manufacturers.

Additionally, low production volumes trap industrial systems in an suboptimized state described as the "Aerospace Dead Zone," visible in Figure 1. In this environment, time and cost are primary performance drivers, yet the business cases for traditional high-volume automation and lean processes collapse because the cost of advanced automation cannot be amortized over such few units. This lack of a viable return on investment (ROI) starves factories of necessary funding, ultimately forcing a systemic reliance on manual, labor-intensive assembly methods.

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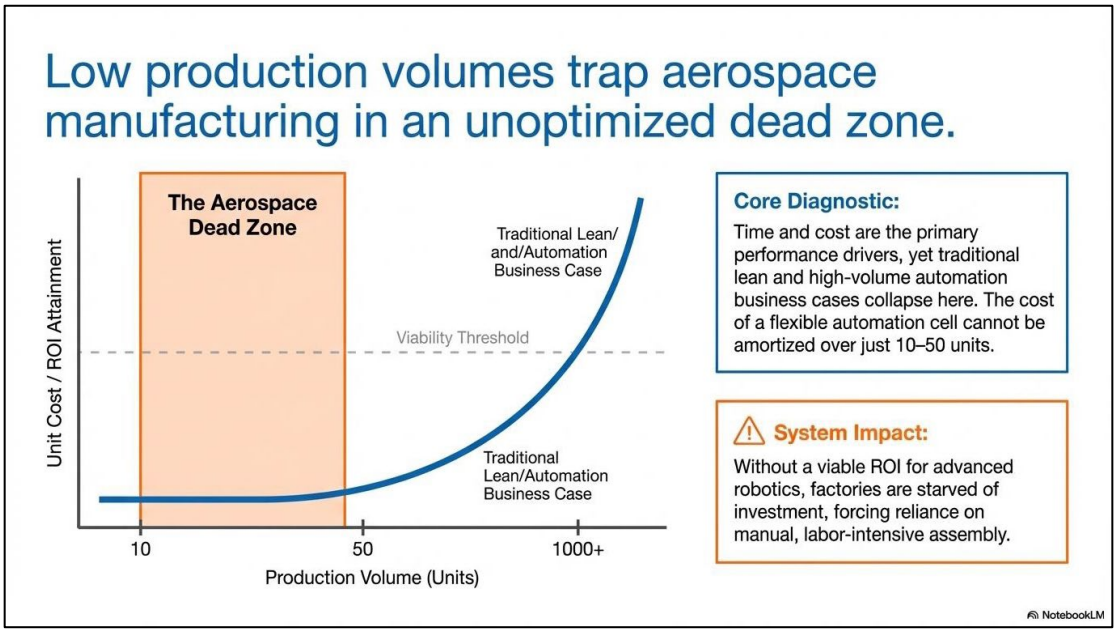


Figure 1 - Aerospace Dead Zone: Low Production Volumes Trap Aerospace Manufacturing in an Unoptimized Dead Zone[1]

The socio-economic scale of this challenge is unprecedented and extends across both civil and defense sectors. Industry backlogs now include more than 17,000 commercial aircraft awaiting production, equivalent to approximately 14 years of production at current output rates, and more than $747 billion in defense commitments. Meeting this demand while maintaining safety, compliance, affordability, and resilience will require the industry to move beyond flashy digital demonstrations and toward industrialized digital threads capable of operating reliably at production scale. [Oliver Wyman 2025; PWC 2025]

This position paper details the persisting business problems, consequences, and their root cause. It is intended as an inflection point to generate an up-to-date strategic roadmap for A&D transformation towards operational excellence, providing a unified voice on industrial system-specific gaps in terms of processes, methods, tools and standards that allow actionable solutions. The content of this report is based on the work and analysis of 18 A&D experts from Airbus, Airbus Atlantic, Boeing, Bombardier, CT Engineering, Eaton, Gulfstream, Lockheed Martin, Moog, Rolls-Royce, RTX, Pratt & Whitney, and Safran Group.

This paper presents concepts, processes, and role descriptions using terminology that reflects the collective contributions and perspectives of the authors and participating organizations. Readers should recognize that specific terms, organizational structures, responsibilities, and role titles may vary across industries, companies, and regions. While the terms and definitions used in this paper may differ from those employed within a particular organization, the underlying concepts, challenges, and objectives are intended to be broadly applicable. Readers are encouraged to review the following terms in Table 1 and interpret the terminology within the context of their own organizational frameworks and practices.

[1] Image in PDF generated by Airbus using NotebookLM, "Create slide based on document ADS Manufacturing Challenges and Issues" March 30, 2026.

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Table 1 – Terms, Definitions, and Context

Term	Aerospace Definition	Context
Industrial System	The overarching, multi-dimensional ecosystem that encompasses the entire lifecycle environment of an aerospace product, treating manufacturing as an engineering discipline rather than a downstream execution phase.	Under ISO 15288, it is designated as a System of Interest, functionally integrating Concurrent Architecture, Lifecycle Management, the Production System, and the Supply Chain Refer to Figure B1 in Appendix B.
Production System	The core physical and operational manufacturing hub nested within the broader Industrial System, responsible for the actual fabrication, assembly, and integration of aerospace components.	While the scientific community often uses "Manufacturing System" as a synonym, aerospace primes contextualize the physical boundaries differently: Airbus prefers viewing it as a canonical standard for a global Model-Based Enterprise, whereas Boeing historically limits the term geographically and physically to the immediate manufacturing facility or environment. Refer to Figure B1 in Appendix B.
CAD Features	Boundary representation (B-rep) items and geometric data elements generated within legacy CAD applications that are required solely to display a 3D model efficiently on a computer screen.	In the Digital Thread Ontology, these are classified as Digital Artifacts. Because they lack embedded manufacturing intent, they are non-manufacturable on their own and are strictly stripped from the authoritative Model-Based Enterprise definition to ensure data continuity. Refer to Figure B2 in Appendix B.
Logical Features	Conceptual, high-level functional and behavioral areas defined by systems engineers during the early product architecting phase.	Originating from frameworks used by primes like RTX, Logical Features belong to the Functional Architecting digital domain. They represent abstract concepts (e.g., power distribution logic or aerodynamic lift constraints) and are not directly manufacturable without physical mapping. Refer to Figure B2 in Appendix B.

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Term	Aerospace Definition	Context
Operational Features	Singular geometric identifiers embedded within a 3D model that capture the true mechanical design intent and explicit manufacturing constraints of an aerospace component.	Associated with the Mechanical Engineering digital domain (and frameworks defined by Lockheed Martin), Operational Features represent the authoritative, fully manufacturable geometry of the product. Refer to Figure B2 in Appendix B.
Supply Chain	The traditional, linear sequence of transactional steps, logistics, and tier-structured procurement operations focused primarily on cost reduction and component delivery.	In legacy aerospace operations, this model operates on a transactional paradigm where engineering data is sequentially passed along—or "thrown over the wall"—to discrete suppliers, often creating data silos. Refer to Figure B3 in Appendix B.
Extended Enterprise	A highly collaborative, interconnected "neural web" of risk-sharing partners, Tier-1 suppliers, regulatory bodies, and original equipment manufacturers (OEMs) operating under a unified governance structure across the full aircraft lifecycle.	The Extended Enterprise replaces linear logistics with continuous digital collaboration, though regional implementations vary: • United States of America Regional Nuance: Heavily prioritizes strict ITAR (International Traffic in Arms Regulations) compliance, high-security gateways, and complex risk-sharing partnerships. • European Union Regional Nuance: Focuses on consortium-driven "Digital Continuity" (e.g., Decade-X) and shared Software as a Service (SaaS) interoperability to establish a common technical language. Refer to Figure B3 in Appendix B.

Appendix A provides a list of acronyms, and Appendix B includes several figures that illustrate the specific terms noted above.

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Problem Statement

The following subsections describe the context of the current problem set by characterizing the operational environment, defining the current way of working, identifying the associated business consequences, and performing a causal analysis to diagnose root causes.

Context

The major business problems identified can be grouped into six problem areas, which are listed here and described in detail below:

- Industrial System Architecture, Including System-of-Systems (SoS) Integration
- Multi-Tier Extended Enterprise Collaboration, Including Data Exchange and Integration
- Translation of Engineering Definitions into Manufacturing Plans
- Producibility Feedback Loops, Including Shop Floor Product Data Capture
- Industrial Verification and Validation (V&V) and Industrial System Lifecycle Digital Twin
- Modernization of Core Digital Infrastructure

Business Problem #1: Industrial System Architecture, Including SoS Integration

There is a severe lack of a unified, 3D collaborative environment where multiple domains can concurrently review the product concepts and negotiate requirements efficiently, while having a consistent architecture per system and integration at the SoS level for multi-domain optimizations.

Pain Points

- **Industrial engineering is not treated as a primary discipline:** The structural undervaluation of industrial system design remains a critical bottleneck, where manufacturing is frequently relegated to a secondary afterthought compared to core product design (see Figure 2). While aircraft systems leverage high-fidelity simulations, digital twins, and formalized Model-Based Systems Engineering (MBSE) frameworks, industrial engineering lacks equivalent collaborative modeling capabilities. This systemic failure to elevate industrial architecture to a primary discipline forces a reliance on unoptimized assembly and production methods.

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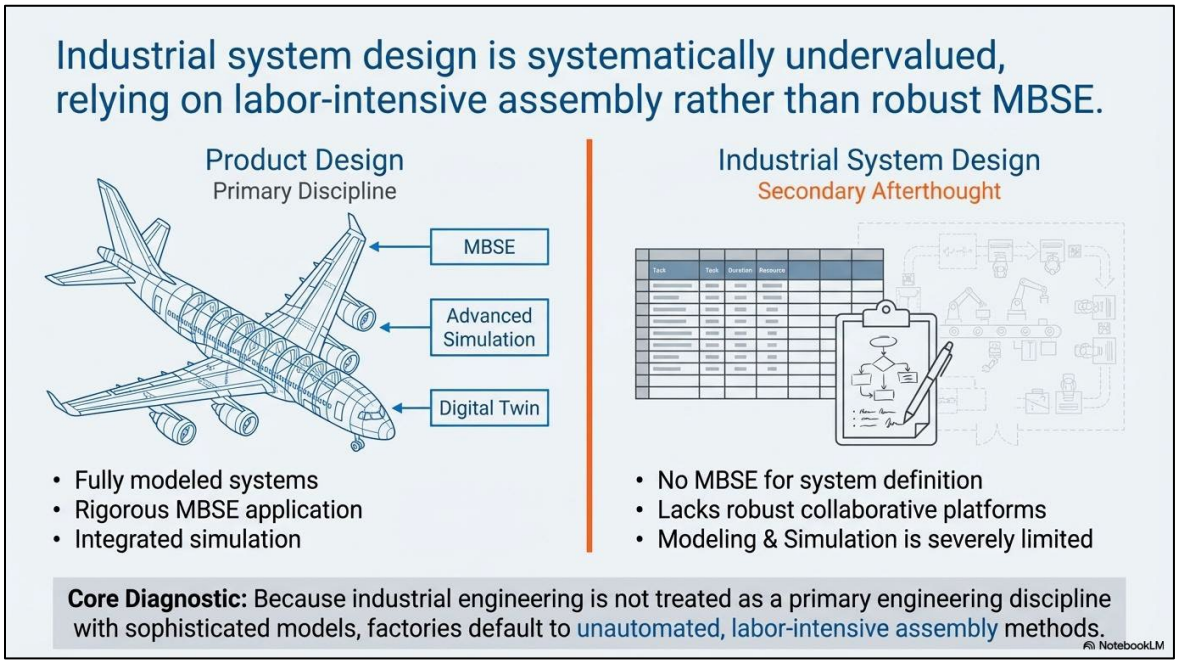


Figure 2 - Industrial Engineering Not Treated as a Primary Discipline[2]

- **Global process harmonization and culture:** The current industrialization and product design processes appear as concurrent events, happening at the same time but in separate silos, requiring administrative synchronization. Also, diverse needs across business units lead to localized solutions for each of them (e.g., Commercial Aviation, Space, etc.). A collaborative process, where people work together actively toward integrated multi-discipline collaborative engineering, will require a complete cultural change.
- **High manufacturing performance gaps due to fragmented early design:** Seventy percent (70%) of time, cost, and quality gaps are locked in or committed during the architectural phases [INCOSE 2015]. Also, early architectural and simulation models struggle to accurately represent high-level factory behaviors (e.g., thresholds and bottlenecks). Reliance on early stages of highly abstract MBSE tools and modelling languages like SysML creates a steep learning curve that distances and discourages practical manufacturing users.
- **Loss of business user buy-in due to methods and tools abstraction:** Introduction of methods like systems engineering to cope with these problems comes with standard MBSE/SysML tools that are still too complex and too far from the realities of manufacturing engineers, leading to a widening gap between architectural models and industrial reality.

[2] Image in PDF generated by Airbus using NotebookLM, "Create slide based on document ADS Manufacturing Challenges and Issues" March 30, 2026.

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Business Problem #2: Multi-Tier Extended Enterprise Collaboration, Including Data Exchange and Integration

From a company's external viewpoint, the industry's reliance on "throwing technical data packages (TDPs) over the wall" structurally limits the extended enterprise to a "build-to-print" role. OEMs as well as Tier-1 suppliers and below lack the digital frameworks to securely federate models or share executable behaviors without violating Intellectual Property (IP), leading to delayed discovery of manufacturability constraints.

Pain Points

- **High risk of part delivery and ramp-ups delays:** The unidirectional, top-down workflow prevents suppliers from providing early manufacturability feedback, causing critical assembly line shortages.
- **Stifled co-development due to IP and security boundaries:** The inability to safely share behavioral models or navigate multi-level sovereign security clearances prevents true risk-sharing co-development. Also, the need for establishing a continuous, federated digital thread across thousands of multi-tier suppliers requires development of a resilient cybersecurity framework and robust data governance.
- **Ecosystem lock-in and financial strain on supplier small/medium enterprises:** Mandating complex, proprietary software tools places severe financial burdens on small/medium enterprises, while locking OEMs into rigid platforms.
- **Wasted effort on manual push-and-pull document exchanges:** Without synchronized models, engineers lose significant time manually tracking modifications and exchanging data across disconnected partner platforms (illustrated in Figure 3).

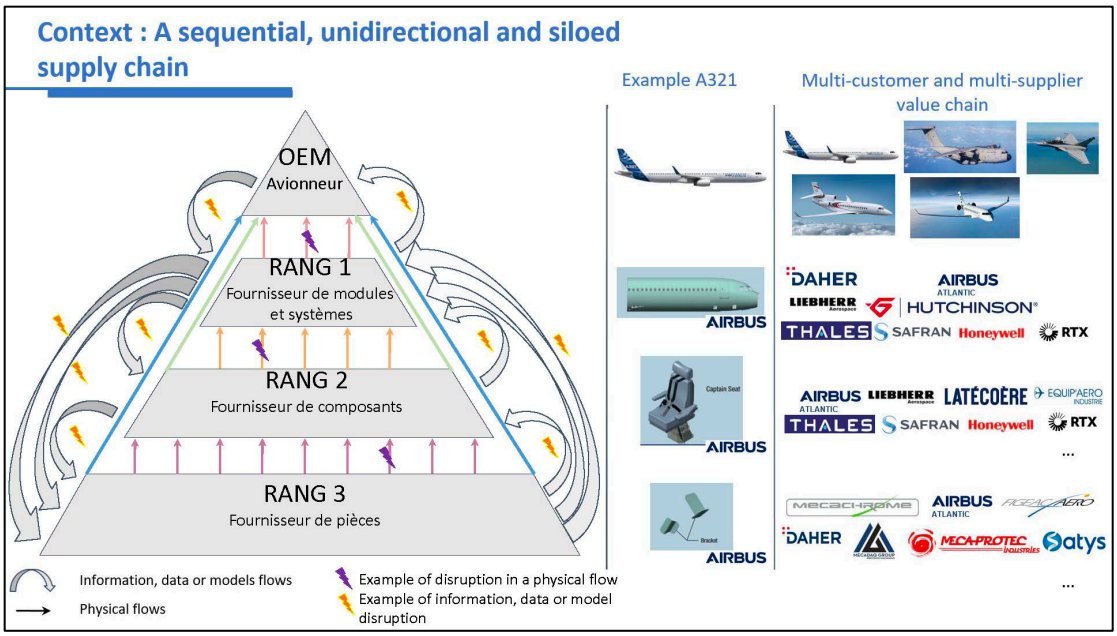


Figure 3 - Sequential, Unidirectional, and Siloed Supply Chain[3]

[3] DAUMAS, Julien, R&D - In charge of Digital Thread & Digital Twin, "ME4CoDev_AA", pdf presentation, April 29, 2026, Airbus Atlantic, www.airbus.com.

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Business Problem #3: Translation of Engineering Definitions into Manufacturing Plans

Companies consistently identify the Computer-Aided Design/Computer-Aided Manufacturing (CAD/CAM) transition as a structural one-way street that destroys traceability. The lack of machine-readable operational features forces manufacturing engineers to manually recreate design intent, stripping the digital thread of its core value before production even begins.

Pain Points

- **Irreparably broken digital threads and lost Model-Based Definition traceability:** Translating CAD visualization data (Boundary representation (B-rep)/topology data) into executable manufacturing instructions permanently drops traceability back to the authoritative model. Also, data schema used for model-based requirements is not usable for downstream consumption such as manufacturing, operations, and analytics.
- **Probability of errors and manual rework:** Reliance on manual human intervention to translate engineering definitions can lead to non-conformities, scrap, and costly rework loops on the factory floor.
- **Designs authored in isolation from factory capabilities:** A lack of robust manufacturing models leads product engineers to create geometries that are highly inefficient to manufacture.

Business Problem #4: Producibility Feedback Loops, Including Shop Floor Product Data Capture

Beyond producibility analysis performed at the design stage, such as Design for Manufacturing and Assembly (DFMA) assessments, a universal industry struggle to allow producibility feedback loops is the semantic disconnect between time-based manufacturing data, such as MTConnect[4], and geometry-based inspection data, such as Quality Information Frameworks (QIFs). Without persistent feature-level identifiers, mountains of data remain stranded in downstream silos, requiring immense manual effort to stitch data together for meaningful analytics.

Pain Points

- **Stranded and useless production data lacking context:** Massive volumes of collected routine production and quality data from the shop floor remain isolated and unusable because they lack the necessary metadata or feature-level identifiers to map back to the engineering models.
- **Inability to scale analytics due to point-to-point fragility:** Deploying new systems requires brittle, manual integrations or bespoke analytics that cannot scale to adjacent products without starting over.

[4] MTConnect is the open, royalty-free standard that gives manufacturing equipment a common language — making machine data universally accessible, real-time, and actionable. The MTConnect Institute is a 501(c)(6) not-for-profit standards development organization for the MTConnect standard (ANSI/MTC1.4-2018). Its membership is made up of over 400 companies and research organizations in discrete manufacturing including automotive, aerospace, medical, and other industries as well as software developers, system integrators, and research organizations supporting those industries. MTConnect.org

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- **Inefficient manual effort to stitch data for producibility:** Engineers waste substantial cycle time manually extracting and aligning datasets from siloed platforms—Product Lifecycle Management (PLM), Enterprise Resource Planning (ERP), Manufacturing Execution Systems (MES)—to run correlation analytics (illustrated in Figure 4).
- **Permanent loss of tribal knowledge:** Critical manufacturing context relies heavily on undocumented knowledge, which is permanently lost when veteran workers retire.

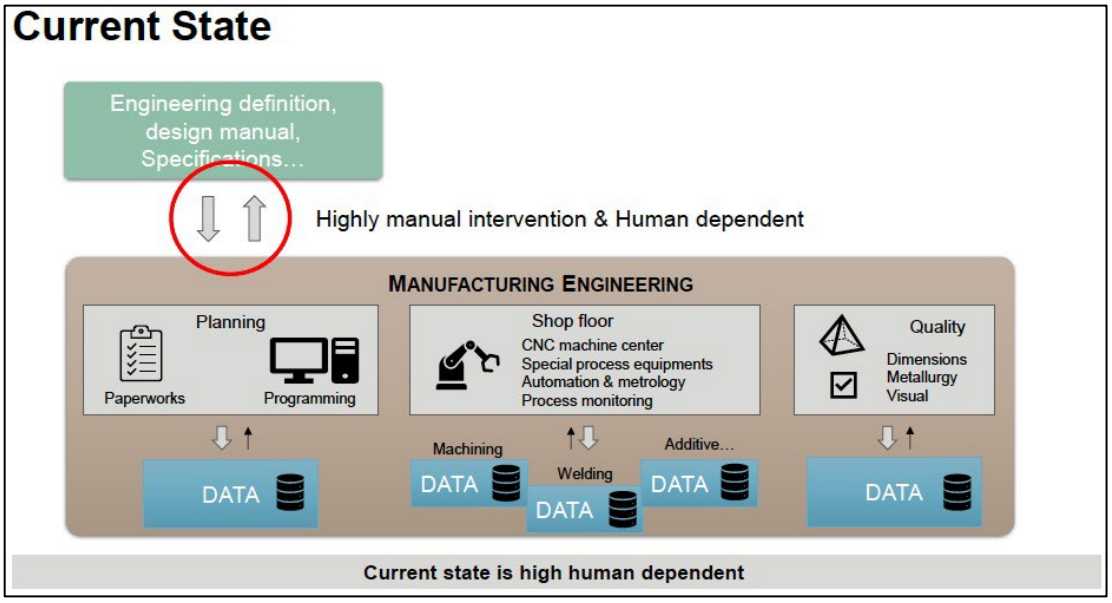


Figure 4 - Human Dependent Feedback Loop[5]

Business Problem #5: Industrial V&V and Industrial System Lifecycle Digital Twin

Current V&V processes for industrial requirements, architecture assumptions, and manufacturing plans are hampered by the absence of timely, high-quality data. Consequently, the industry operates in a reactive mode. Verification is deferred until operational issues trigger late-stage rework rather than being validated, verified, and monitored for predictive evaluation and prescriptive actions.

Pain Points

- **Inability to trace field failures back to root causes:** A systemic breakdown in traceability across the multi-tier extended enterprise prevents OEMs from effectively linking operational data or field failures to their root causes. This lack of continuity creates a blind spot, making it impossible to trace defects back to the specific design or manufacturing processes where they originated.
- **Costly manual engineering effort for conformity validation:** The current approach to conformity validation is highly manual, as illustrated in Figure 5. Legacy data

[5] Georges, T., "AD PAG ME4CoDev - Aerospace & Defense PLM Action Group – Manufacturing Engineering for Co-Development Working Group," 2026, Pratt & Whitney Canada Corp., PDF presentation. RTX.com.

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inconsistencies and duplicated master data records force reliance on highly manual processes to unequivocally align As-Built configurations with As-Designed requirements, further integrating sub-component/component models from parts delivered from the extended enterprise.

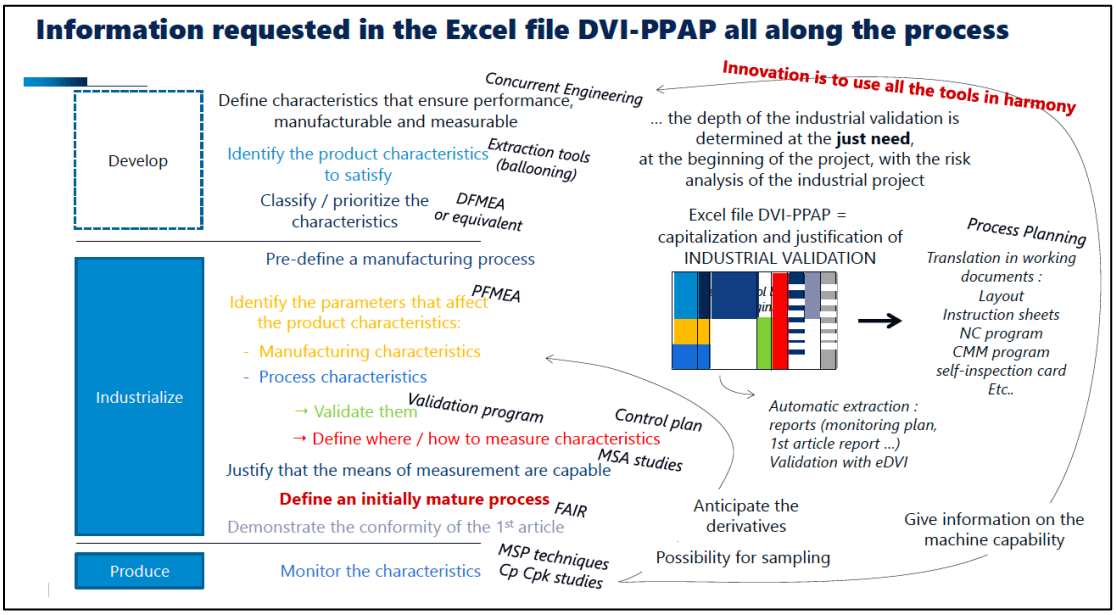


Figure 5 - Manual Engineering Effort for Conformity Validation[6]

- **Manual management of operational compliance and auditability:** Corporate operating environments must satisfy rigorous regulatory requirements. However, organizations often grapple with fragmented data sources that hinder their capacity to demonstrate compliance. An example is the case of personnel executing certified operations. Lack of integration makes it difficult to align with strict regulatory standards and preserve exhaustive audit trails.

Business Problem #6: Modernization of Core Digital Infrastructure

This last problem area is more of a technical than business problem. Even so, decades of unmanaged technical debt and over-customized legacy PLM/ERP/MOM (Manufacturing Operations Management) platforms force manufacturers to reverse-engineer past software modifications just to make legacy product data ingestible by modern baseline systems. Also, legacy systems struggle to natively manage the new data types required for advanced manufacturing.

Pain Points

- **Escalating operational costs and information technology (IT) technical debt:** Legacy platforms with extensive historical customizations act as massive bottlenecks. These platforms require continuous, costly development to maintain integration.

[6] Didelot C., "ME4CoDev – Safran," 2025, Safran, PDF presentation. Safran.com.

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- **Sluggish business responsiveness due to fragmented data:** Critical enterprise data fractured across multiple and disconnected legacy systems hampers access to data, information, and knowledge needed to support agile decision making and operational velocity (see Figure 6). Companies are forced into new platform applications to handle data types, thereby fragmenting the fabrication digital thread.
- **Severe bottlenecks when reverse-engineering legacy code:** Because the original software architects are no longer available, current IT teams must manually dig into legacy programming to understand undocumented change management rules before data can be migrated.

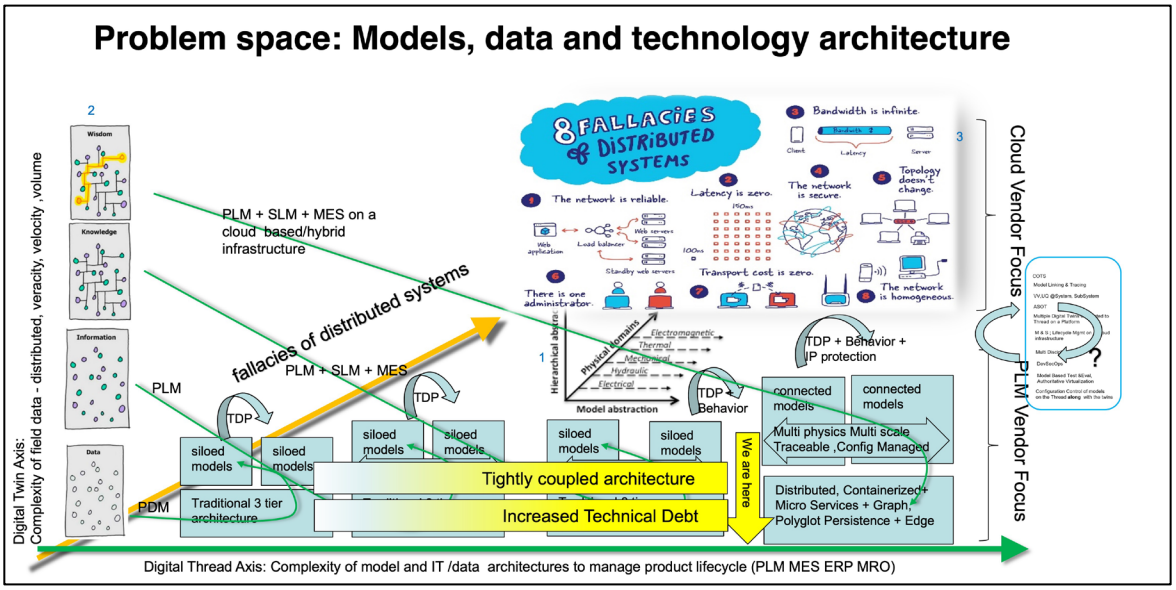


Figure 6 - Technical Data Packages Over the Wall Don't Carry All the Complexity for Thru-Lifecycle Collaboration[7]

Current Way of Working

In this section, narrative-driven examples of the business problems previously described are presented as use cases that characterize existing operational methodologies. Roles, procedural steps, technological ecosystems, and data transfer protocols are detailed. The specific friction/pain points and obstacles identified in the current workflows are emphasized.

Use Case #1: Cross-Domain Architecture and Simulation Integration

Roles: Program Architect, Aircraft System Architect, Industrial System Architect, and Wing Manufacturing Architect.

Sequence of Activities: To design an aircraft (like a new aerobatic plane), the Program Architect first sets high-level objectives (e.g., ROI, rate/ramp-up goals). Then, the Aircraft Architect works in their silo to define the physical shape and performance. Finally, this baseline is cascaded to the Industrial System and Wing Manufacturing Architects. Because their needs heavily impact one

[7] From AIAA Digital Thread and Twin Integration Working Group, "Problem Space: Models, Data and Technology Architecture," PowerPoint slide. 2026. AIAA.org.

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another, but they do not share a common technical environment, they are forced to express their manufacturing constraints sequentially rather than concurrently.

Systems and Tools Used: Highly fragmented tools. Product Architects use CATIA (3D Mockup), System Architects use Cameo (SysML), and Industrial Engineers use AnyLogic or Factory Flow for Discrete Event Simulation.

Information Shared or Transferred: Aircraft shape/split requirements, system functional block diagrams, simulation models, and Key Performance Indicators (KPIs), including cost, lead-time, and resource utilization.

Means of Communication and Collaboration: Data must be manually mapped or converted between the different domains because no native semantic interoperability or unified "cockpit" exists to view the holistic impacts.

Challenges Encountered:

- **Security Mazes:** True collaboration is actively blocked by a "Multi-Level Security Maze"—International Traffic in Arms Regulations (ITAR), Export Administration Regulations (EAR), and national restrictions—meaning external suppliers cannot easily view or co-develop architectural models.
- **Loss of Effectiveness:** Without a unified environment to connect abstract architecture to detailed design and simulation, the industry suffers from endless non-conformity loops when late design freezes conflict with manufacturing realities.

Use Case #2: Extended Enterprise Collaboration and Digital Thread Lifecycle Traceability

Roles: OEM, Tier-1 Aerostructure Supplier, and lower-tier elementary parts suppliers.

Sequence of Activities: The current extended enterprise operates as a "sequential, unidirectional and siloed" environment. An OEM Design Engineer creates a set of complex design and analysis models of an aircraft aerostructure assembly, accounting for critical performance requirements. The OEM completes the product design and generates the Engineering Bill of Materials (EBOM) and Manufacturing Bill of Materials (MBOM).

Product definition models are prepared, consisting of 3D geometry and product manufacturing info (PMI), which flows down the product acceptance criteria in a TDP. The TDP, containing these product specification data sets, is then pushed down in a top-down and "thrown over the wall" manner to the Tier-1. The Tier-1 receives these requirements and TDP files and must manually translate them to industrial processes and MBOM as required in preparation for production execution. In some cases, selected components are outsourced to sub-tier suppliers as Build to Print instructions.

The Tier-1 builds, integrates, and delivers the aerostructure assembly. The assembly gets installed by the OEM, and the aircraft goes into service. Years later, unexpected material defects are found in the aircraft. An engineer at the OEM attempts to trace the defect back through the lifecycle to figure out if it was a design flaw, a manufacturing defect, or an operational issue but encounters a tedious quest to collect and analyze information distributed across the supply chain in silos.

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Systems and Tools Used: The OEM works within its own proprietary PLM platform, while the Tier-1 works within an entirely separate PLM platform. Tools used include disconnected PLM, Product Data Management (PDM), and MES systems operating on traditional 3-tier architectures across multiple companies.

***Information Shared or Transferred*:** Disparate CAD, CAM, and inspection software. Reliance is on traditional 2D drawings or STEP files (AP242) for data exchange.

Means of Communication and Collaboration: Data exchange is heavily document-based and requires manual push-and-pull activities. Data is not seamless; Tier-1 engineers must log into the OEM's platform to view the primary engineering data. TDP exchange primarily consists of static geometry snapshots. Unidirectional "throwing" of TDPs across the extended enterprise boundaries is the means of collaboration. Models are siloed within their respective domains.

Challenges Encountered:

- **IP and Knowledge Lock-in:** Engineering data is continuously trapped on the customer's (OEM's) platform. When Tier-1 engineers apply their manufacturing knowledge to design a part, that IP and knowledge become locked in the customer's silo, making knowledge management and reuse extremely difficult.
- **Inability to Automate Rules:** Because the Tier-1 supplier operates in a separate environment, they cannot easily use their automated engineering design checkers that verify cost, manufacturing constraints, and weight. This prevents effective bottom-up co-design where manufacturing constraints could proactively influence the OEM's early design.
- **The Reverse Traceability Blind Spot:** Because there is no continuous context across the multi-tier extended enterprise, engineers face a messy challenge when trying to navigate backward from field data to find the root cause of a failure.
- **Missing Persistent Links:** The industry suffers from missing standard feature identifiers known as *Universally Unique Identifiers* (UUIDs), from software version conflicts, and from a lack of interoperability, which prevents the As-Built component data from seamlessly integrating back into the OEM's subsystem models.

Use Case #3: From Design Intent to Shop Floor Traceability

Roles: CAD/Systems Designers, Process/CAM Engineers, Quality Engineers, and Operational Data Analysts.

Sequence of Activities: A designer creates a functional "bore" feature with specific geometric dimensioning and tolerancing limits (i.e., design intent). The CAD system, prioritizing visualization, strips this semantic meaning and converts the feature into a complex, "dumb" B-rep topology (e.g., 12 separate construction surfaces and points). This fragmented data reaches the Process Engineer. Because the semantic link to the original "bore" intent is destroyed, the CAM software cannot automatically recognize the feature. The engineer is forced to manually recreate the machining program, effectively surmising what the designer intended, thereby introducing potential errors at the first point of manufacturing.

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As the part moves to production, critical design intent (i.e., why this tolerance is needed) is absent. The manufacturing team members work in a silo, often requesting concessions because they lack the context to understand the feature's criticality.

During post-production, data is collected in two silos: manufacturing sensors record machine telemetry in the time domain (e.g., in MTConnect), while Coordinate Measuring Machine (CMM) inspection reports record geometry in the geometry domain (e.g., in QIF). When a defect occurs, analysts attempt a root-cause investigation but hit a wall. They cannot correlate the sensor data (time) to the specific CAD feature (geometry) because the link to the authoritative digital model was not maintained. The manufacturing process effectively "forgot" the design intent.

Systems and Tools Used: Integrated CAD/CAM (Native systems), PLM, MES, ERP, MTConnect, QIF-compliant CMM systems, STEP AP242 files and manual correlation tools (spreadsheets).

Information Shared or Transferred: B-rep/topology data, product manufacturing information, cut planes, and construction points.

Means of Communication and Collaboration: Data is transferred via a one-way street translation process that relies heavily on static, document-based, or neutral file exchanges (e.g., STEP AP242). Communication is inherently unidirectional because the engineering definition (Design Intent) is decoupled from the execution definition (Process Intent) at the moment of authoring. Domains talk past each other. The CAD/CAM translation process forces the conversion of logical features into fragmented B-rep topology, stripping away the semantic identifiers necessary for comprehension of intent by downstream systems.

Consequently, stakeholders across the digital thread must rely on manual push-and-pull activities, extracting data from PLM/ERP silos, converting disparate formats, and manually "stitching" datasets together to reconcile engineering definitions with shop-floor reality. No persistent, machine-readable link connects the design intent to the operational or quality data. Therefore, collaboration is entirely dependent on verbal negotiation and tribal knowledge, not digital continuity.

Challenges Encountered:

- **Irreparable Loss of Digital Continuity:** The translation of intent into B-rep geometry-only visualization permanently severs the digital thread, making the PMI in the authoritative model useless for downstream consumption.
- **Manual Rework and Tribal Knowledge:** Because CAx (Computer-Aided technology) tools currently do not support persistent feature identifiers (UUIDs), manufacturing requires high-touch, manual data "stitching" to connect process data to CAM program and Computer-Aided Innovation (CAI) inspection results and to perform root-cause analysis.
- **Ineffective Feedback Loops**: The inability to map time-series manufacturing data back to specific design features renders advanced analytics non-actionable. The data remains stranded because it cannot be contextualized with the geometry.

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- **Regulatory and Audit Risk:** Reactive, manual reconciliation of As-Built versus As-Designed data is error-prone and creates significant bottlenecks at the end of the production cycle, jeopardizing certification.

Use Case #4: As-Built Reconciliation and Conformity Validation

Roles: Aircraft Designers, Manufacturing Engineers (Methods), Production Execution teams, extended enterprise partners, and Aftermarket/In-Service teams.

Sequence of Activities: During aircraft development, the engineering team establishes the Engineering BOM (EBOM). As production begins, a Manufacturing BOM (MBOM) and Build process is created to plan the assembly. Suppliers manufacture the parts and send them along with assembly workbooks. Currently, proving that the final, physical aircraft (As-Built) perfectly matches the As-Designed requirements is a massive, reactive effort. Engineers must manually cross-reference the fragmented documents at the end of the production line to reconcile configurations before the aircraft can be certified by regulators.

Systems and Tools Used: Highly complex and fragmented legacy systems, including CATIA V5, Teamcenter PLM, SAP ERP, and disconnected data warehouses.

Information Shared or Transferred: Engineering BOMs, product structures, part definitions, options, features, and As-Built configuration records.

Means of Communication and Collaboration: Manual data extraction and reconciliation across different domains. Data pulled from one system frequently fails to meet the input formatting requirements of the next, requiring manual data management and "scrubbing."

Challenges Encountered:

- **Costly Manual Effort:** Fragmented data and disconnected systems cause teams to manually trace legacy data inconsistencies.
- **End-of-Line Bottlenecks:** Waiting to reconcile the EBOM, MBOM, and As-Built configurations until the end of the process makes conformity validation a painfully slow manual process right before aircraft certification.
- **Audit Nightmares:** Because records are kept manually and validation is inconsistent, preparing for strict regulatory audits by the Federal Aviation Administration (FAA) and European Union Aviation Safety Agency (EASA) is time-consuming and reactive.

Use Case #5: Multi-Site Legacy System Retirements and Enterprise Data Migration

Roles: IT Teams, System Architects, Plant Managers, Operations Staff, Research and Development Engineers, Manufacturing Engineers, Data Managers, and Extended Enterprise Partners.

Sequence of Activities: Large aerospace manufacturers operate multiple plants, often acquired over decades, each running their own distinct, outdated software. Instead of a single global digital transformation, the current approach is highly fragmented. When the company decides to upgrade, it selects a single plant and executes a plant-by-plant migration. A team is sent to the site. The team maps the site's specific legacy architecture (e.g., an extremely old ERP from an acquired supplier) and slowly pulls the site onto the new baseline.

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Currently, an engineer authors the EBOM in an older PLM environment (like Enovia) or directly inside a heavily customized legacy ERP (like SAP ECC). To transition, the IT and engineering teams must extract the legacy data. However, they immediately hit a wall: the extraction does not match the input requirements of the new target systems. Because the original architects who wrote the custom SAP code have left the company, current IT teams must dig into the programming code manually to figure out the undocumented change management rules before successfully migrating the data.

Systems and Tools Used: A patchwork quilt of highly complex legacy platforms (e.g., SAP ECC, Enovia V5, Macpac) being migrated toward modern baselines (e.g., Teamcenter PLM, SAP HANA).

Information Shared or Transferred: Large volumes of historical product data, EBOMs, MBOMs, site-specific routing instructions, internal extended enterprise deliveries, historical workflows, and customized business rules.

Means of Communication and Collaboration: Fragmented and high friction. Data transitions rely heavily on manual intervention, debugging, and muddling through legacy configurations. When one plant migrates, it must maintain rigidity. A frequent experience is manual integrations with other plants still running legacy software. This creates a fragile environment where data consistency is constantly threatened.

Challenges Encountered:

- **Reverse-Engineering Bottlenecks:** Legacy systems were often "modified heavily for our own use," creating a massive bottleneck where current teams must painstakingly decipher undocumented change management rules just to make historical data ingestible.
- **Supply Chain Disruption Risk:** Because manufacturing plants are interdependent, an IT migration at one site risks breaking the supply chain for the entire network, making holistic transformation incredibly complex and prone to operational delays.
- **Inconsistent Global Data Structures:** Legacy data is structured differently across every version, program, and site, and is governed by outdated, site-specific business rules incompatible with modern, standardized global platforms.
- **Running Production Concurrently:** The requirement to maintain active production while performing an IT update creates immense operational risk and slows the pace of transformation, as the "new" and "old" systems must coexist in a state of precarious, manual integration.

Business Consequences

The main business consequences identified follow.

Business Consequence #1: Industrial Performance Risks and Production Delays

Massive performance gaps regarding time, cost, and quality exist because product architectural and design decisions are locked in prior to industrial evaluation and validation. Missing interfaces and missed requirements during physical factory commissioning occur due to a lack of complete, integrated system understanding, which causes delays in achieving desired first-pass quality.

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Business Consequence #2: Impact on Efficiency and Operations

Wasted engineering effort and loss of data traceability occur due to the manual "double entry" required to copy product characteristics from the PLM system into Excel validation files. There is a high risk of manufacturing engineers working from outdated engineering definitions because product design changes cannot be automatically synchronized with the manual validation files. Significant manual engineering effort for data transfer between systems increases the risk of introducing software bugs or errors in the loaded data. Extracted legacy data routinely fails to meet the strict input requirements of the new target systems. Operational costs escalate and system failure risk increases as legacy PLM and ERP systems near end-of-life.

Business Consequence #3: Long Development Cycles

Months of tedious, iterative negotiations between aircraft engineering and manufacturing engineering over requested compromise cause long development cycles. The risk of late-discovered manufacturability issues that prevent elementary part suppliers and every extended enterprise node from delivering on time heightens.

Business Consequence #4: Loss of Knowledge

Critical manufacturing process knowledge is often distributed across subject matter experts' (SMEs) tacit expertise, design documentation, manufacturing manuals, and operational data but much of it is not formally captured in a way that supports reuse or continuous updating. When SMEs retire or transition to new roles, the undocumented context required to interpret process data, troubleshoot issues, and understand process intent may be permanently lost.

Static knowledge artifacts, such as manuals and procedural documents, degrade over time if not routinely refreshed using analytics, process telemetry, and feedback from actual production performance. Lack of robust knowledge management capability to capture, maintain, and evolve the organization's accumulated knowledge causes risks of reduced decision quality, slower response to issues, inconsistent execution, and weakened long-term competitiveness and business continuity.

Business Consequence #5: IT Costs and Vendor Lock-In

High operational and IT costs driven by the need for continuous, specialized platform development and the reliance on SMEs to manually manage diverse, localized systems of record. Ecosystem lock-in to proprietary software providers and heavy customizations make it difficult to migrate systems or flexibly integrate diverse partners.

Business Consequence #6: Loss of Digital Thread

The inability to rapidly trace field failures back to their root cause (design, manufacturing, assembly, or maintenance) is the result of a complete breakdown of traceability across the multi-tier extended enterprise. Ability to scale analytics, machine learning, or continuous improvement efforts across the enterprise is not possible because manufacturing data cannot be reliably linked back to the engineering models.

Business Consequence #7: Standards Gaps

Expensive technical debt from building customized, tailored data models internally to compensate for the lack of interoperability across industry standards accumulates over time. This

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makes it difficult to scale the digital ecosystem because adding new tools, machines, or software providers requires manually re-engineering these complex, point-to-point software integrations.

Causal Analysis

The different causes that originate the six business problem areas described in the *Context* section are grouped into seven key topics. Each is described below.

Cause #1: Siloed Collaborative Development Methods for Product and Industrial Systems

Currently, the industry is operating under a legacy industrial engineering paradigm that creates severe bottlenecks across the product lifecycle. The primary pain point identified is that the product design, industrial system, and services are treated as isolated domains. Unlike a typical system provider that engineers and manufactures entirely within its own digital environment, Tier-1s frequently engineer their aerostructure products directly within the customer's (OEM's) PLM platform. However, the company designs its industrial systems (the process design and MBOM) within its own distinct PLM platform.

Cause #2: Incompatible Platform for Collaborative Development Product and Industrial Systems

A&D companies operate in a shared ecosystem where the extended enterprise serves multiple OEMs, meaning suppliers are routinely burdened with differing methods and tools imposed from different OEMs. The traditional technical environment expected to handle this data consists of core enterprise systems: ERP, PLM, and MES. Software providers for these core systems are frequently lagging in their support for this expanded scope of engineering artifacts. Another pain point is experienced within the access management processes for sensitive engineering tools and data where the authorization process bridging these systems is heavily reliant on manual validation.

Cause #3: Immature Adoption of Systems Engineering (SE) and MBSE for Manufacturing Engineering

In current trends, companies approach co-development through the lens of a highly complex SoS that integrates three distinct but tightly coupled domains: Product (Aircraft System), Manufacturing (Industrial System), and Services (Service System). MBSE is an emergent design method without widespread usage in the context of industrial systems, and existing approaches are often "homebrew."

Cause #4: Inefficient Knowledge Management

As the aerospace industry faces an aging, retiring workforce, companies are challenged by the loss of tacit knowledge. Without formal digital systems to capture the original design and manufacturing intent, the enterprise struggles to efficiently onboard entry-level engineers or maintain business continuity over its extended product lifecycles. Data lacking contextual metadata may appear merely as "a bunch of numbers on a spreadsheet" to users unaware of the complete use case context and data capture information. Furthermore, considering the human-in-the-loop, organizations do not pay enough attention to knowledge change management process and workforce upskilling initiatives to drive sustainable user adoption within these new digital processes.

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Cause #5: Manual and Ad-Hoc Industrial Configuration Management

A&D companies execute massive digital transformations spanning both their PLM and ERP platforms across multiple manufacturing sites. A critical requirement within this environment is the aerospace verification and certification process, which mandates that the As-Built production data seamlessly aligns with the As-Designed EBOM to prove that all parts were consumed, and all engineering requirements were unequivocally met. Companies rely on rigorous manual industrial validation frameworks, which are most often in-house developments, to ensure that production processes can consistently fulfill all requirements at the required customer demand rate.

Cause #6: Data Leverage Gap in the Industrial Digital Thread

A&D companies experience a severe "data leverage gap," as the percentage of manufacturing data that can be utilized at scale for analytics or continuous improvement is extremely limited. One of the main reasons is that it cannot be reliably linked back to the product Model-Based Definition (MBD). Also, the underlying architecture lacks persistent traceability of product data across domains (i.e., engineering, manufacturing, and quality) and lifecycle phases, relying heavily on brittle, point-to-point integrations between individual software providers and tools.

Cause #7: Lack of Industrial Digital Standards

Engineering uses ASME Y14 series standards to author product definitions, while downstream execution relies on a mix of 3D geometric models, interoperable data exchange standards, such as STEP AP242/238 and QIF, and executable programs, such as Numerical Control/Geometric Code (NC/G-code) and CMM programs. Differences in how software implements interoperable data exchange standards can cause a disconnect between the neutral file exported by one application and how another application imports it.

Even when data is accessible, the underlying architecture is missing persistent traceability to integrate product data across lifecycle domains (i.e., engineering, manufacturing, and quality). As noted above with respect to the data leverage gap, the same is true here—the architecture relies heavily on brittle, point-to-point integrations between individual software providers' tools, making deployment of new production systems tedious and unscalable.

Go-Forward Plan

The A&D PAG ME4CoDev working group will establish a strategic roadmap centered on clear, metric-driven business performance goals for remediating the identified pain points in each business problem area. This roadmap will include a desired state, which provides a contextual overview of the target future environment. An analysis will be made of the business benefits, including a list of requirements necessary for changes in people, processes, and technology to achieve the desired state, and details of intended performance improvement targets that would allow validation of the proposed change actions.

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About A&D PLM Action Group

The Aerospace & Defense PLM Action Group (www.ad-pag.com) is an association of aerospace and defense companies within CIMdata's globally recognized PLM Community Program, which functions as a ***PLM advocacy group*** to:

- Set the direction for the aerospace & defense industry on PLM-related topics that matter to members (*including promoting, not duplicating, the work of standards bodies*)
- Promote common industry PLM processes and practices
- Define requirements for common interest PLM-related capabilities
- Communicate with a unified voice to solution providers
- Sponsor collaborative PLM research on prioritized industry and technology topics

CIMdata administers Group operations, coordinates research, and manages the progression of policy formulation.

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CIMdata, a global strategic management consulting firm, provides services designed to maximize an enterprise's ability to design, deliver, and support innovative products and services. For more than forty years, CIMdata has provided industrial organizations, providers of digital technologies and services, and investment firms with world-class insight, expertise, and best-practice methods on a broad set of product lifecycle management (PLM) topics and the digital transformation they enable. CIMdata also offers research, subscription services, publications, and education through certificate programs and international conferences. To learn more, visit www.CIMdata.com or email info@CIMdata.com.

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Appendix A: Acronyms

Table A1 - Acronyms

Acronym	Acronym Expansion
A&D	Aerospace and Defense
A&D PAG	Aerospace and Defense PLM Action Group
AIAA	American Institute of Aeronautics and Astronautics
AS9100	Aerospace quality-management standard
ASME	American Society of Mechanical Engineers
ASME Y14	ASME Y14 standards series
BOM	Bill of Materials
B-rep	Boundary representation
CAD	Computer-Aided Design
CAI	Computer-Aided Inspection
CAM	Computer-Aided Manufacturing
CAx	Computer-Aided technologies
CMM	Coordinate Measuring Machine
EAR	Export Administration Regulations
EBOM	Engineering Bill of Materials
ERP	Enterprise Resource Planning
FAA	Federal Aviation Administration
INCOSE	International Council on Systems Engineering
IP	Intellectual Property
ISO	International Organization for Standardization
IT	Information Technology
ITAR	International Traffic in Arms Regulations
MBD	Model-Based Definition
MBOM	Manufacturing Bill of Materials
MBSE	Model-Based Systems Engineering

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Acronym	Acronym Expansion
ME4CoDev	Manufacturing Engineering for Collaborative Development working group
MES	Manufacturing Execution System
MOM	Manufacturing Operations Management
MRO	Maintenance, Repair, and Overhaul
OEM	Original Equipment Manufacturer
PDM	Product Data Management
PLM	Product Lifecycle Management
PMI	Product Manufacturing Information
QIF	Quality Information Framework
SaaS	Software as a Service
SE	Systems Engineering
STEP	Standard for the Exchange of Product model data
STEP AP238	Application Protocol 238
STEP AP242	Application Protocol 242
SysML	Systems Modeling Language
TDP(s)	Technical Data Package(s)
UUID(s)	Universally Unique Identifier(s)
V&V	Verification and Validation

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Appendix B: Supporting Figures

The following figures enhance specific terms noted in the *Introduction* section.

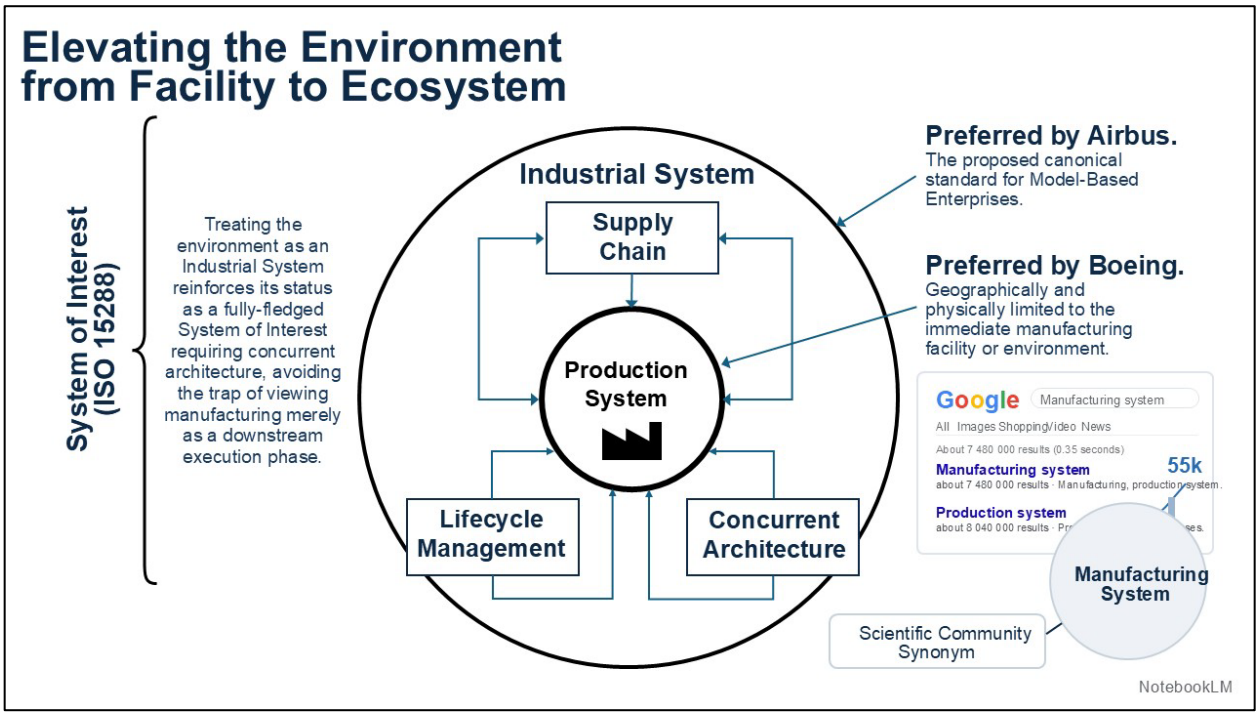


Figure B1 - Elevating the Environment from Facility to an Industrial Ecosystem[8]

[8] Image in PowerPoint generated by Fernando Mas/CT Engineering Group, using NotebookLM, prompt unavailable, June 10, 2026.

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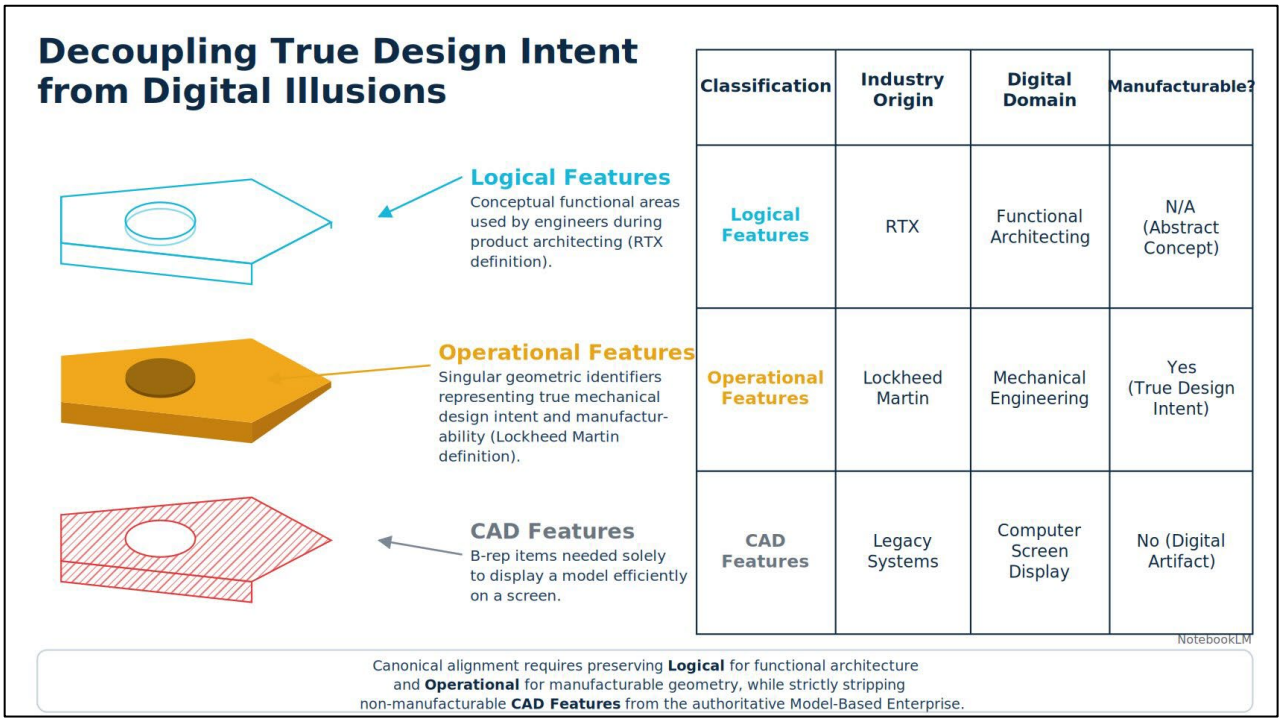


Figure B2 - Decoupling True Design Intent from Digital Illusions[9]

[9] Image in PowerPoint generated by Fernando Mas/CT Engineering Group, using NotebookLM, prompt unavailable, June 10, 2026.

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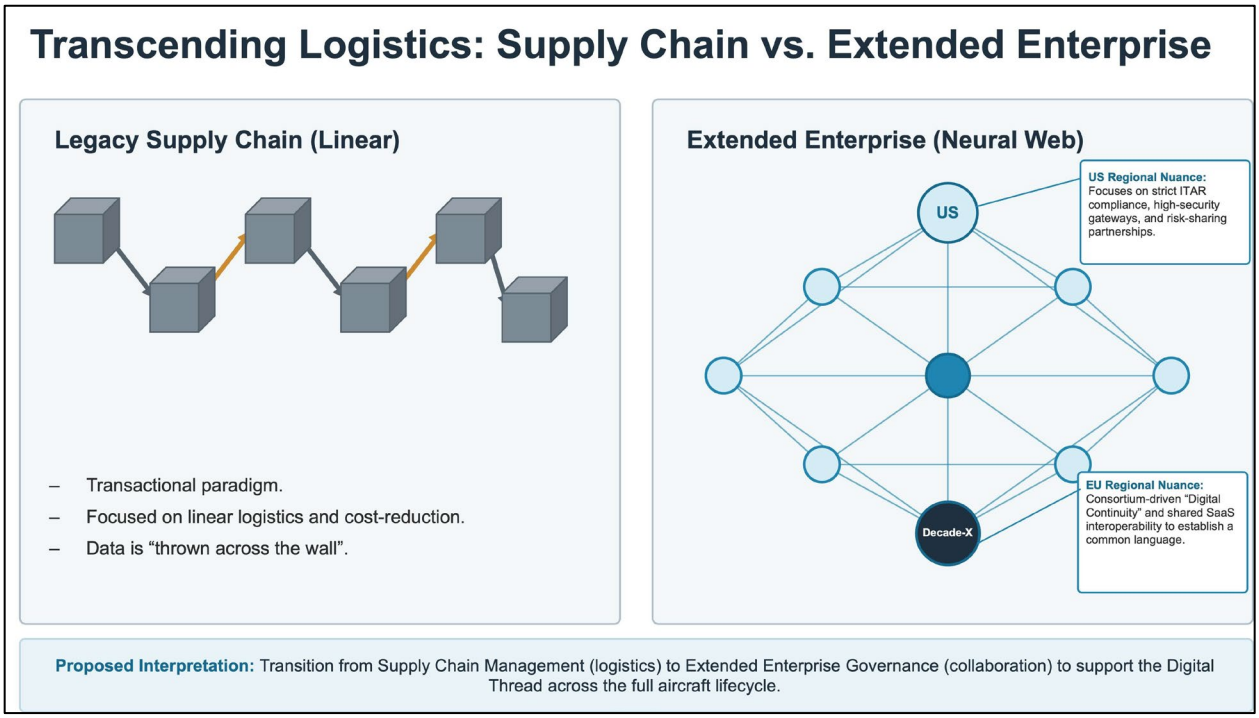


Figure B3 – Transcending Logistics: Supply Chain vs. Extended Enterprise[10]

[10] Image in PowerPoint generated by Fernando Mas/CT Engineering Group, using NotebookLM, prompt unavailable, June 10, 2026.

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