Model-Based Systems Engineering (MBSE) Data Interoperability

Problem Statement, Assessment, and Go Forward Plan

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Model-Based Systems Engineering (MBSE) Data Interoperability

Executive Summary

The Aerospace and Defense Product Lifecycle Management Action Group (AD PAG) is an association of aerospace Original Equipment Manufacturers (OEMs) and aircraft engine providers within CIMdata's globally recognized PLM Community Program, which functions as a ***PLM advocacy group***. One of the key business issues identified by this industry group is that collaboration within a large, global, distributed supply chain of design and development partners is seriously hindered by relying on traditional, document-based development processes. As such, one of the key business challenges identified by this group is achieving OEM and supply chain collaboration through bi-directional exchange of technical data packages via digital tools and model-based processes.

In response, a project team of domain experts from the AD PAG member companies has been established to evaluate current data interoperability standards, enabling a Model-Based Systems Engineering (MBSE) conceptual design process. The activity was to assess the feasibility of exchanging digital requirements and systems architecture models instead of documents within a collaborative product development activity. To date, two project phases have been completed.

- Phase 1 identified a gap in the capability of SysML-based (Systems Modeling Language-based[1]) authoring tools to support data exchange out-of-the-box.
- Phase 2 considered options to address the Phase 1-identified issues in both the short and the long term.

The recommended short-term solution is to evaluate, validate, and employ the use of third-party MBSE interoperability software tools/adapters that supplement the basic capabilities present in the major SysML authoring tools, and/or the use of a translation service for more robust MBSE data exchange. In the longer term, the group strongly desires to see the data and model interoperability requirements be incorporated into the SysML2.0 modeling language standard and will advocate for the SysML2.0 standard to be fully implemented by all PLM/MBSE solution providers.

Introduction

In March 2016, executives from the AD PAG member companies – Airbus, Boeing, Embraer, Gulfstream, and Rolls-Royce – met with the intent that informal discussions of PLM-related issues would lead to agreement on common objectives, requirements, and plans for remediation of their common PLM pain points.

This discussion resulted in agreement of the member executives to jointly sponsor and staff a select set of projects, each chartered to define objectives, requirements, and roadmaps for eliminating or significantly reducing a key inhibitor to the value potential of PLM. The topic addressed by this

[1] SysML-based infers a provider application that implements a capability that compiles with OMG's SysML v1.4 or v1.5 specification.

particular special project, which was initiated in 2017, is **Model-Based Systems Engineering (MBSE) Data Interoperability.**

Since the initial members' agreement in 2016, AD PAG membership has increased from five to eleven OEMs, including Bombardier, Dassault Aviation, GE Aviation, Mitsubishi Regional Jet, Pratt & Whitney, and Safran, and this project team has added subject matter experts (SMEs) from many of them.

Motivation for Investment

The digitization of the product development process from the early conceptual design stage all the way through the entire product lifecycle is a major business goal across all manufacturing industries today. This is especially true in aerospace and defense programs due to the design complexities of cyber-physical systems with ever-increasing amounts of embedded software and electronics.

Many economic business drivers are cited for achieving this end-to-end digital and model-based strategy, which is often referred to as *the digital thread*:

1. Increased market share and profitability via faster time to market (shorter product design and development cycles)
2. Greater innovation leading to unique product features (design features directly linked to meeting end customer functional requirements)
3. Increased enterprise engineering productivity and supply chain collaboration through the use of robust digital models versus documents throughout the product development lifecycle
4. Reduction in total R&D (Research & Development) costs, fewer Engineering Change Orders (ECOs), and fewer physical prototype iterations
5. Improved product quality and reliability via continuous design validation versus document-based requirements (optimized designs via digital modeling and simulation of performance before commitment to physical prototypes and/or manufactured sytems)
6. Reduction in total lifecycle costs, including manufacturing, warranty, and in-service operations (digital models evolve to meet other domain requirements, a concept widely known as *digital twins*)
7. Compliance with global industry initiatives and regulations (safety, certification, re-use, green technologies, etc.)

Specific to these opportunities, the A&D OEMs recognize that collaboration within a large, global, distributed supply chain of design and development partners is being seriously hindered by reliance on traditional, document-based development processes. To address this challenge, OEMs are expanding their use of digital and model-based software tools to define and manage overall system requirements; associated system architectures; system simulations; product development, certification, sustainment, and safety; and regulatory/contractual obligations. To ensure comprehensive implementation, OEMs have engaged their supply chains to closely collaborate through the exchange of conceptual digital models — models that communicate the design intent

back and forth in a robust and iterative product development process that does not rely on traditional documents, singular artifacts, and/or drawings.

Goal and Approach

To influence future MBSE data interoperability solutions and best practices for model-based collaboration across the A&D industry, an AD PAG project team was formed to evaluate current data interoperability standards for enabling an MBSE conceptual design process based on digital models instead of documents. The goal of this project team is to evaluate the current capabilities of a typical aerospace supplier and an aerospace OEM to develop and communicate a set of system design requirements and a corresponding system architecture using digital data modeling standards, specifically the SysML systems modeling language combined with the ReqIF (Requirements Interchange Format) standard for requirements data interchange[2].

In Phase 1, the data exchange exercises evaluated the feasibility of producing, exchanging, and consuming a model-based system architecture defined in a SysML-based authoring tool along with a corresponding set of requirements for the new system design. A very simple subsystem example was used, namely, a light and its control system. The initial effort was focused on a conceptual design scenario in which the OEMs sent a request to suppliers to develop and design solutions to meet the stated OEM performance requirements for the new system design.

The conceptual design scenario mimicked how an OEM would solicit design proposals from suppliers with the intent of establishing a contractual relationship for design and development of a system/sub-systems. The digital deliverables were to resemble the system specification (SysML architecture diagrams) and the associated design requirements. The OEM had the option to specify the digital exchange format using any tool available to the team members for the digital data exchange.

This position paper provides an overview of the results of those Phase 1 MBSE data exchange exercises and subsequent conclusions about the industry's state of readiness.

For Phase 2 activities, which were conducted during 2018, the goal of the project team was to agree on the most promising strategies and best practices for digital data exchange across the A&D industry. Phase 2 was based on the current maturity level of the most suitable set of MBSE data standards and tools.

Purpose of This Document

The intent of this document is to convey the current state of data interoperability in the industry, to identify an interim solution, and to influence future solutions and best practices for MBSE model interchange that enable model-based collaboration across the A&D supply chain.

This position paper reviews the various alternatives considered by the group and makes initial recommendations on the most promising approaches to enable OEM–supply chain design collaboration based on both short- and long-term MBSE standards.

[2] The SysML and ReqIF standards were selected because each participating OEM had tools readily available.

Note on Authorship and Endorsement

This document represents the work of a project team staffed with SMEs from most AD PAG members. In total, the team has more than 20 contributors from these companies. As the result of an extensive review process, the content reflects consensus of all member companies. Regardless of their level of contribution, member endorsement indicates strong support and agreement with the main points in the problem description, objectives, and solution concepts.

Problem Statement

As introduced in the *Goal and Approach* section, Phase 1 of the project was intended to demonstrate a digital business process for producing, exchanging, and consuming a model-based system architecture and requirements applicable to a new system design. The simple example used was a light source and control system design.

Phase 1 expectations were to:

- Agree on the maturity of the industry's design capability needed to implement a digital business process
- Agree on suitable industry data standards and tools for a digital business process

The exercise focused on a business scenario that requested design proposals from the suppliers. Suppliers responded with a system concept using new or existing technologies.

In this business scenario, the OEM provided deliverables to solicit design proposals from suppliers with the intent of establishing a contract. The deliverables represented a Specification Control Definition, Drawing, or Document (SCD), a Document Requirements List (DRL), and associated business procedures. The OEM deliverables specified a system architecture, the format, and any tool or industry data standards required for the digital data exchange.

Context

The participating member companies were surveyed to understand their current work processes related to the systems engineering of new products and the associated MBSE software tools available to the AD PAG project members who would be participating in the Phase 1 data exchange experiments.

Software Tools Deployed by AD PAG Members as of 2018

Team participants were surveyed to understand which tools, versions, and adapters (translation tools) are currently in use by the team members. The results follow.

Table 1 - List of Software Tools Currently Deployed by AD PAG Members

	Modeling Software	Requirements Management Software	Data Exchange Plug-Ins Installed by the Company
Company 1	PTC Integrity Modeler v8.3.18 (main tool) Capella (trial) MagicDraw (pilot project) Sparx Systems Enterprise Architect	DOORS v9.5	Capella Artal to SysML bridge
Company 2	IBM Rational Rhapsody v8.2.1 Enterprise Architect Capella (trial)	DOORS v9.6x Some DOORS NG	
Company 3	IBM Rational Rhapsody v8.1.4	Requirements in SysML model	
Company 4	Magic Draw Cameo EA v18.1 IBM Rational Rhapsody v8.1.5 Eclipse Papyrus v1.1 (Eclipse Luna)	DOORS v9.6	IBM XMI (XML Metadata Interchange) toolkit (Sodius)
Company 5	Capella 1.2 (Trial)	Teamcenter 9.13	
Company 6	Observer in Phase 1		

Processes for Data Exchange Between OEMs and Suppliers

To capture the current process state, the team members were asked to define their historical process for how they collaborate with the supply chain during the preliminary design phase. These examples served as a basis for determining the business case for model-based data exchange going forward.

Company 1

- During the early design phase, communication is based on textual requirements and preliminary design descriptions in natural language augmented by drawings and diagrams; these are transferred via PDF, Word, and PowerPoint documents.
- The basis for the contracts is the Purchaser Technical Specification (PTS), a written document that contains textual requirements and, optionally, drawings and diagrams.
- The PTS can be augmented by annexes that contain more detailed information. In some cases, these annexes are extracted from formal (MBD) behavior models, such as Matlab/Simulink or SCADE.
- Additionally, DOORS modules containing requirements can be extracted and transferred to the supplier.
- 3D models are exported into STEP files.

Company 2

- Product Development and product procurement has relied on a traditional Specification Control Drawing (SCD) format to communicate text-based requirements as the primary communication/ collaboration mechanism.
- The SCD is augmented by images, tables, and graphs. The SCD may include a DOORS extract or module or allow a supplier direct DOORS access.
- In some cases, the definition of a behavior model is added as a supplement, but in most cases the collaboration occurs in the lab, SIL (Software In-the-Loop), or HIL (Hardware In-the-Loop).

Company 3

- The initial exchange of information with suppliers is through RFI (Request for Information). The requirements are in Teamcenter, without any access for the suppliers.

- The first formal exchange is with the standard SVCD (Specification Vendor Control Drawing) or SCD, and PCD (Procurement Control Data set for non-CAD data).
- The SVCD is composed of requirements, drawings, some 3D models, parts lists, attributes, and other non-CAD information.

Company 4

- Specification Control Document (SCD) format (often a DOORS module) is used to communicate text-based requirements as the primary collaboration mechanism.
- Often, behavioral models (simulations or Formal methods) are used to validate hard-to-understand requirements.
- The SCD is augmented by images, tables, and graphs.
- Requirements validation comes together during integration in a lab, SIL, or HIL.

Company 5

- **Textual Requirements:** The OEM receives a PDF file from the customer and enters the information contained in this PDF file into a DOORS module for internal work. Once completed, the results are transferred to the technical proposal in MS Word and MS Excel. The proposal is then converted to a PDF file and sent to the customer.
- **Drawings:** Pictures are pasted into a .ppt (PowerPoint) file. (However, this company is moving toward model-based definition.)
- **3D Information:** STEP files are provided as an attachment in PDF file format.

Company 6

- Text-based requirements are exchanged with suppliers using exported DOORS modules that contain the information needed by each supplier.
- Functional and architectural models developed in Simulink are used to augment the requirements.
- For Simulink models that capture intellectual property that suppliers or partners do not want to share, compiled code is requested as an alternative. These dlls (dynamic link libraries) are then used for simulation in virtual system integration activities/analysis.

Current State Assessment – Capability for Data Exchange Between a Supplier and an OEM

Using a common shared repository, the participants executed eight package exchanges with an average of three design items each. Assuming that member companies represented the higher end of the industry's capabilities, participants did not employ specialized tools or customizations and only used the tools already available within each company. A successful digital exchange translation occurred less than 50% of the time. Success in interpreting the design intent was roughly less than 20% of the time.

The team's overall conclusion determined that it is not yet feasible to exchange MBSE system architecture and requirements using current versions of the data standards as implemented in commercially available tools. Although each of the provider tools generally complied with the language specification standards, the implemented export and import formats were determined to be proprietary to each brand of tool. The following table shows the outcome of each round trip between providers' tools. Round trips between the same tool were possible but only by using native file formats.

Table 2 - Phase 1 Model Interchange Results

		To					
		Cameo Enterprise Architect 18.1	PTC Integrity Modeller	Capella	IBM Rhapsody 8.1.5 w/ XMI toolk	Eclipse Papyrus 1.1 (Eclipse Luna)	Eclipse Papyrus 2.0
From	Cameo Enterprise Architect 18.1				-1		
	PTC Integrity Modeller						
	Capella						
	IBM Rhapsody 8.1.5 w/ XMI toolkit (Sodius)						
	Eclipse Papyrus 1.1 (Eclipse Luna)	-2					

Partial (1) Cameo would import from Rhapsody if you applied the missing .xmi version attribute in the file header
Partial (2) Cameo would import .xmi from Papyrus, diagrams had to be manually recreated

Key:
Pass
Partial
Fail
Not Tested

A summary of the main tool-related findings is as follows:

- Out-of-the-box functionality in Commercial Off-the-Shelf (COTS) tools does not allow model export and import, even for the same tool.
- Commercially-available data exchange plug-ins were not readily available to facilitate data import/export between different COTS tools.
- Implementation of XMI does not seem to be consistent between COTS tools.
- XMI does not support system diagram (graphics) exchange.
- A system diagram standard (diagram interchange) is not supported between the COTS tools used in Phase 1.
- No industry standard or common modeling framework/ontology is natively implemented in the tools used.

Root Cause

Based on the results of the current state assessment, as well as on other similar research conducted by other industry research groups, it is clear that the current maturity of MBSE software tools and related standards for MBSE data interoperabilty are inadequate to enable a robust, bi-directional, and collaborative process for conceptual systems design between A&D OEMs and their suppliers.

Business Improvement Objectives

The expected outcome of this continuing project work is to agree on MBSE data interoperabilty strategies and initiatives to enable the business maturity level required for effective collabration between A&D OEMs and their suppliers based on a suitable set of MBSE data modeling standards.

As noted previously in the *Motivation for Investment* section, the ability to digitally exchange key conceptual design data such as requirements and system architecture models in digital form instead of as text documents is expected to provide significant business benefits to both A&D OEMS and their suppliers. The work performed focused on identifying solutions that can provide incremental business benefits versus current business processes, both in the short-term and longer-term timeframes.

Desired State

To develop a set of viable strategies and initiatives, the following activities were conducted:

- Examined different alternatives for data exchange (including using intermediaries for file conversion, paper-based methods), data format, business restrictions, tool combinations, and replacement data standards
- Identified scoring criteria, solution priorities, and solution practicalities
- Provided recommendations to solution providers/industry via this position paper

Alternative Solutions for MBSE Data Exchange

A wide range of solutions were considered to enable OEM–supply chain collaboration and exchange to address findings of the current state assessment.

The following list represents the feasible range of capabilities considered for a technical alternatives evaluation. The alternatives were ranked using a variety of scoring systems with three rounds of multi-voting. The basis of the alternatives evaluation was support for a data exchange capability that would apply to an Architecture Description Language (ADL), with SysML being the primary MBSE systems modeling standard.

(The numerical order of the following list does not indicate level of importance; numbers were used for easy reference.)

1. **The OEM requires the use of a pre-defined brand of tool (and versions).** The OEM would contractually identify a specific provider brand and version of a SysML-based language that all suppliers would use for their applicable work statement.

2. **Manually convert the design data to a specific format (using multiple provider licenses).** The OEM would translate the supplier's design into a form that could be integrated with other models.
3. **Purchase each tool provider's custom plug-in for data translation.** A provider's import/export plug-in appears to be designed for a point-to-point exchange in a limited context (in most cases, no diagrams or the alternative provider's license is required for translation). Multiple plug-in brands would also require at least one license of each translatable product. Some data loss would be expected and manually transcribed.
4. **Identify and use third-party software-based adapters (translation tools).** There are multiple brands of third-party translation tools that are generally designed for a point-to-point exchange of models. Risks are applicable to new software versions and/or proprietary data representations generated by specialized tool features.
5. **Support a provider-neutral industry research organization (e.g., NIST) or a university research program to provide a web-enabled MBSE data translation service that provides access to multiple third-party translation tools (adapters/MBSE tool plug-ins).** OEMs and suppliers would be able to use this service on a contract basis to convert MBSE models and data from one authoring tool format to another format(s) of their choice.
6. **Similar to alternative 5. Support a neutral, third-party, commercial, interoperability service that provides expertise in using MBSE provider plug-ins and multiple third-party translation tools (adapters)**. OEMs and suppliers could contract with an IT services organization to purchase the necessary variety of MBSE software licenses and plug-ins that support converting a variety of MBSE data between various provider formats. Translation providers could also provide the expertise needed to verify results and manually convert data if necessary. Increased reliability in the model translation results would likely come with added expense of the commercial services versus alternative 5. It may also be possible and desirable to include this as part of a collaborative IT environment for data sharing, model archiving, access control, and security to enable standard, as well as customized, workflows between OEMs and suppliers.
7. **Use a PDM/PLM integration system to merge the designs into a new format (e.g., RDF to MOF or other).** The PDM/PLM provider would combine the capability of alternative 5 with a data integration service and the potential to export all data into a common format. The capability may already be implemented in specific provider offerings.
8. **Use an alternative ADL standard format (ISO 42010).** Better results may be achieved with the use of a non-SysML/UML (Unified Modeling Language) language that has been implemented by specific tool providers. There are several proprietary or standardized languages to choose from. However, this option would involve potential new costs associated with training, IT infrastructure, and licenses for A&D suppliers

9. **Use an alternative proprietary format (e.g., Simulink, Modelica).** There are MBD tools that implement a block style modeling interface capable of creating functional and logical models. Limited support exists for allocating and decomposing integrated requirements, but SCXML (State Chart XML) translation options increase if the implementation is limited to state flow diagrams.
10. **Use a set of mixed export formats (e.g., XMI + SCXML/UMLDI, JSON).** Supplementing conventional XMI translations with customized language translators could increase success rates and provide a neutral representation. Several third-party tools already use these techniques with partial success.
11. **Use a brand of PLM system that can decompose and expose SysML product structure.** Similar to alternative 7, but PLM tool(s) would convert SysML brands to an industry data standard or proprietary format and benefit from additional license contracts with more OEMs.
12. **The industry recommends a Common Architecture Framework.** Similar to a unified SysML profile, a common architecture framework would simplify the integration of SysML models but provide limited support for exchanging multiple brands. This option would be combined with another alternative.
13. **The industry identifies a common meta-model and ontology for all architecture models.** Similar to alternative 7, but with reliance on a new or complementary standard versus reliance on a PDM or PLM provider. Many SysML providers are planning to or are already supporting the translation to a Web Ontology Language (OWL) format. There may be limits on the translation of diagrams, and some data loss may occur. This capability may already be implemented in specific provider offerings.
14. **Combine legacy process with existing XMI capabilities.** OEMs would need to agree on document enhancements to the SysML designs, but the combination of partial models and published diagrams may outperform the existing "all documentation" process. This option may be rationalized as the lowest cost alternative.

By establishing commercial out-of-the-box solution capability for MBSE data interoperability as the baseline, the following three alternatives were short-listed by the team at the conclusion of the voting process. Each choice was further analyzed, assuming the final recommendation would represent the most practical, acceptable, and expedient solution.

1. Use independent, tool-neutral, third-party service(s) for MBSE model translation and data exchange to enable a collaborative design process between OEMs and suppliers.
2. Require using a single brand of SysML-based authoring tool combined with systems modeling semantics and design rules to create system architecture models.
3. Invest in the manual conversion of paper-based documents.

Alternatives Analysis

Alternative 1: Use a Third-Party, Software-Based Adapter Tool and/or MBSE Data Interoperability Service

Solicit a provider-neutral MBSE data interoperability services organization and/or university research organization that would purchase each MBSE tool provider's application and selected custom plug-ins for data translation. The selected organization(s) would work with this project team to develop and demonstrate one or more solutions to the scope of requirements and SysML system architecture diagrams across heterogenous MBSE authoring tool environments. Some data loss would be expected in the short term (one to three years) due to the current state of the tools and industry standards.

Pros:

- Allows suppliers and OEMS to work with their own choice of provider software
- Prevents "lock-in" to a single MBSE software provider
- Promotes competition, which is good for continuous technology improvements – a single provider in a dominant position removes competition
- Reduces the cost per company if jointly employed by multiple industry OEMs and suppliers

Cons:

- Services organizations need to be willing to invest in the upfront costs of software licenses and IT infrastructure before there's a commitment to widespread use by the industry.
- It is untested on large-scale models, such as a complete aircraft.
- This option may not be readily available for every tool, and the tool's version may incur translation problems similar to the different brands.
- Each user of the service is responsible for change and configuration control.
- Providers might change the API (Application Program Interface) to stop or limit the effectiveness of the translation services after initial investment by the service provider.
- There exists the potential to be limited by XMI standard or proprietary product features.
- We know that we can generally exchange data within one tool, whereas any exchange tools, plug-ins, or services will need to be proven.

Alternative 2: Use a Single MBSE Authoring Tool

With this approach, each OEM would require the use of a pre-defined brand of ADL tool (and versions). The OEM would contractually identify a specific provider brand and version of SysML (or other suitable ADL) that all suppliers would use for their applicable work statement. OEMs would prescribe the specific design rules and profiles to be used by suppliers in authoring and/or modifying the system model diagrams and elements.

Pros:

- Available immediately - this approach could be implemented fairly quickly.
- In the short term, this option could be cheaper compared with acquiring/utilizing data exchange tools or service contract costs.
- From what we have seen, these types of enforced processes have historically been intended for data migration rather than for collaboration across heterogeneous tools.

Cons:

- Existing OEM tool investments and other business realities would conflict with having a common brand across the industry. Each OEM and supplier makes software choices based on their specific technologies, products, and competitive business strategies.
- This option would likely require suppliers to maintain multiple MBSE authoring software brands for multiple customers. Similar cost and inefficiency issues exist in the realm of multiple MCAD systems in use in the automotive and aerospace industries.

Alternative 3: Manually Convert Paper-Based Documents

This option would entail manually converting the design data to a specific format (using multiple provider licenses). The OEM would consume the cost of translating the supplier's design into a form that could be integrated with other models.

Pros:

- Does not require new technology or capability

Cons:

- Does not enable the promised business benefits of model-based processes and implementation of a digital thread across the lifecycle
- Combination of a document process with data exchange could be too complicated, removing the potential for any benefit
- Prone to legacy errors and alternative integration/verification tools/processes
- An additional step in the process, adding delay
- Disconnect from requirements that will change over the product development lifecycle
- Lack of change control and configuration control

Recommendations

With the understanding that the current state of standards for MBSE data interoperability are not yet mature enough to enable a completely digital and model-based systems engineering process for OEM–supply chain collaboration, the project team recommendations for future efforts were defined for both short-term and long-term timeframes. The project team concluded that the most promising and feasible solution alternative to focus on for the Phase 3 project activity is Alternative 1: Use a Third-Party, Software-Based Adapter Tool and/or MBSE Data Interoperability Service.

Short-Term Timeframe (One to Three Years)

The AD PAG team focused on the MBSE Data Interoperability project identified and recommends the following short-term goals that could be reached by the industry within one to three years:

- The A&D industry should promote the use of ISO 42010-compliant ADLs as the modeling baseline for implementing MBSE. Other types of modeling languages would supplement the baseline.
- The industry should define, solicit, and endorse a provider-neutral MBSE data interoperability services specification(s) that would provide coverage across each MBSE tool provider's application by enhancing or replacing available third-party adapters or plug-ins. The service(s) meeting these specifications would provide a commercially available solution for reproducing the required scope of MBSE requirements and ADL system architecture diagrams across the heterogenous MBSE authoring tool environments used across the A&D industry.

- It may also be possible and desirable for an external services organization to provide a collaborative IT environment for data sharing, model archiving, access control, and security to enable standard, as well as customized, MBSE workflows between OEMs and suppliers.

Long-Term Timeframe (Three to Five+ Years)

To achieve the goal of implementing both short- and long-term data interoperability standards for the exchange of digital MBSE models and related data, a three pronged strategy will be required and should be adopted within the AD PAG member companies.

- Influence and endorse the SysML 2.0 RFP content, including the non-mandatory features describing model interchange and formal semantics. Recommend the incorporation of the UMLDI (UML Diagram Interchange) specification or equivalent into future SysML specifications to support diagram exchange.
- Actively participate in the definition and promotion of a common architecture framework for systems modeling and simulation, including formal semantics and systems modeling rules/best practices for the A&D industry
- Encourage our MBSE tool providers to prioritize an industry-wide, open exchange strategy and to implement new industry standards (e.g., SysML 2.0) as soon as they become available.

Longer term, the group expects and believes that the current standards for MBSE data interoperability will evolve and mature to the level where the industry will have access to out-of-the-box software capabilities that meet our business requirements. However, when comparing this journey with the experience of the industry in achieving a reasonable level of 3D MCAD data interoperability, that time line of progress measured in decades is clearly not acceptable as it relates to achieving a robust level of MBSE data interoperability.

As a result, the group will continue to learn from and document the collective knowledge of this working group to accelerate the progress currently being made by both the standards organizations, such as OMG, OASIS, and Modelica, as well the industry groups, such as INCOSE, NAFEMS, Prostep ivip, Automotive Action Group (AAG), NIST, DoD, NASA, and the European Space Agency (ESA) that are actively working to evaluate and improve commercial solutions.

High-Level Requirements

In addition to the requirements for MBSE tool interoperability, the team identified a number of other long-term, top-level Model-Based Engineering (MBE) requirements prerequisites that need to be established and verified before an MBE approach can be adopted across the industry. These are listed in the following table.

Table 3 - Additional Prerequisites for Model-Based Engineering Collaboration

What we need for successful model-based collaboration across companies:
Software tool
Server (external)
Data exchange standards
File format
Graphical representation
Architecture Description Language (ADL)
Framework / Ontology - how to structure the model, diagrams, packages, how to apply the ADL to the product and processes
Scope of exchange / access - how much do we exchange with each other?
Model architecture (i.e., does each company incorporate a duplicate of the other's model?)
Other Requirements
Support change control
Support user permissions / intellectual property / export controls
Support simulation tool compatibility
Support requirements management tool compatibility
Support required data structures (e.g., multi-dimensional data arrays)
User interface / ease of use
Compatible with each company's network architecture (no. of users, low latency, etc.)
Compatible with regulations regarding in which region the data is physically stored

While the above list is certainly not intended to be sufficiently comprehensive at this point, the AD PAG MBSE project team will continue to work with industry standards organizations and MBSE initiatives to define and refine the minimum set of requirements to achieve a collaborative, model-enabled process for cross-domain systems engineeering that spans A&D OEMS and their global teaming partners and extended supply chains.

Go Forward Plan

The AD PAG will focus its efforts during 2019 on implementing the short-term timeframe recommendations (listed in the *Recommendations* section) and on influencing and helping to define the longer-term key MBSE solution elements outlined below.

- The A&D industry needs to understand its own MBSE data requirements in the context of high-priority use cases and what data it needs to exchange to enable effective conceptual design collaboration.
- A set of design representation/diagram-type priorities needs to be defined and addressed by the standard bodies and industry consortiums.
- The industry needs to define the business case and technical requirements for a common, neutral third-party MBSE model translation and collaboration service, based on commerically available software adapter tools that can be leveraged either as stand-alone solutions or as plug-ins to the major PLM/MBSE authoring software tools. These services would be endorsed and used by the AD PAG members, based on their specific business requirements and ROI (Return on Investment).

- The market for commercial software solutions should be monitored and influenced in the space of MBSE data interoperability and third-party adapter software and related IT collaboration services.

The AD PAG MBSE team intends to provide an update to this report covering 2019 activities, outcomes, and future plans by December 2019.

Requested Response from Industry

The AD PAG wrote this paper to demonstrate an understanding of the issues (i.e., problem statement) and to communicate the group's objectives, desired state strategy, and high-level requirements.

For readers of this position paper who represent manufacturing companies in the aerospace and defense industry as well as other industry segments, the AD PAG team welcomes your feedback and suggestions for future collaborative efforts. To submit comments click here!

For readers who represent a PLM and/or MBSE solution provider to the A&D industry, the AD PAG welcomes your feedback in support of this effort with the following actions:

- Provide comments and suggestions for improvement of the Problem Statement, Objectives, and Desired State as documented in this paper.
- State whether you accept the Conceptual Solution and Preliminary Requirements documented in this paper. For those points that you do not accept, provide an explanation for your position, and if appropriate suggest an alternative.
- Describe in what fashion and to what degree your current products and future product roadmaps comply with the Conceptual Solution and Preliminary Requirements documented in this paper.
- Recognizing that the content of this paper is directional and a work in progress, state whether you will support and participate in further refinement of the requirements and short-term solutions.

About AD PLM Action Group

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

- Set the direction for the aerospace and 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 PLM 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.

About CIMdata

CIMdata, a leading independent worldwide firm, provides strategic management consulting to maximize an enterprise's ability to design and deliver innovative products and services through the application of Product Lifecycle Management (PLM) solutions. Since its founding over thirty years ago, CIMdata has delivered world-class knowledge, expertise, and best-practice methods on PLM solutions. These solutions incorporate both business processes and a wide-ranging set of PLM-enabling technologies.

CIMdata works with both industrial organizations and providers of technologies and services seeking competitive advantage in the global economy. CIMdata helps industrial organizations establish effective PLM strategies, assists in the identification of requirements and selection of PLM technologies, helps organizations optimize their operational structure and processes to implement solutions, and assists in the deployment of these solutions. For PLM solution providers, CIMdata helps define business and market strategies, delivers worldwide market information and analyses, provides education and support for internal sales and marketing teams, as well as overall support at all stages of business and product programs to make them optimally effective in their markets.

In addition to consulting, CIMdata conducts research, provides PLM-focused subscription services, and produces several commercial publications. The company also provides industry education through PLM certification programs, seminars, and conferences worldwide. CIMdata serves clients around the world from offices in North America, Europe, and Asia-Pacific.

To learn more about CIMdata's services, visit our website at www.CIMdata.com or contact CIMdata at: 3909 Research Park Drive, Ann Arbor, MI 48108, USA. Tel: +1 734.668.9922. Fax: +1 734.668.1957; or at Oogststraat 20, 6004 CV Weert, The Netherlands. Tel: +31 (0) 495.533.666.

Appendix A: Glossary

The following glossary includes technical terms used throughout this position paper.

Term/Acronym	Definition
A&D	Aerospace and Defense industry segment.
ADL	Architecture Description Language.
Application Programming Interface (API)	A mechanism by which an external application can interact with a system through pre-defined hooks to the system's user interface, technical functions, and data model.
COTS	Commercial Off-the-Shelf.
DRL	Document Requirements List.
Engineering Change Order (ECO)	A document that identifies and describes a change to configuration(s), component(s), or document(s) in response to an ECP or ECR. ECOs identify all affected items and may also identify related items affected by the change. Additionally, metadata about the change are also defined, e.g., change class, requester, approver, program. An ECO is generally the defining document for a change or release package. (A change package is a group of documents defined by an ECO that must be modified as a group to effect a change.)
HIL	Hardware In-the-Loop.
IBM	International Business Machines.
Model-Based Engineering (MBE)	Model-Based Engineering is an approach to engineering that uses mathematical models (not only CAD models) as an integral part of the technical baseline definition that includes the requirements, analysis, design, implementation, and verification of a capability, system, or product throughout the acquisition lifecycle.[3] The design may be documented in associated drawings or as Model-Based Designs. Models are the authoritative definition of the system. Recent references to model-based engineering have focused on "Model-Based Systems Engineering."

[3] This Model-Based Engineering definition is based on: Final Report, Model-Based Engineering Subcommittee, NDIA, Feb. 2011.

Term/Acronym	Definition
Model-Based Systems Engineering (MBSE)	Model-based systems engineering is the formalized application of various levels of modeling (from 0D to 3D) to evaluate system requirements, design, analysis, verification, and validation activities beginning in the conceptual design phase and continuing throughout development and later lifecycle phases.[4] In its most direct form, MBSE applies a continuous modeling paradigm (0D, 1D, 2D, 3D...) to define systems, progressing from the most simple (0D) form to a fully defined 3D representation, and on to higher order models to understand temporal issues. This is done in addition to and in the context of written requirements and 2D and 3D CAD designs. The models are used to validate from very early stages that the system will function as conceived and defined by its requirements.
OEM	Original Equipment Manufacturer.
OWL	Web Ontology Language.
PAG	PLM Action Group
Product Lifecycle Management (PLM)	A strategic business approach that applies a consistent set of business solutions in support of the collaborative creation, management, dissemination, and use of product definition information across the extended enterprise, and spanning from product concept to end of life—integrating people, processes, business systems, and information.
PTC	Parametric Technology Corporation.
R&D	Research & Development.
SCD	Specification Control Drawing, Specification Control Document, Specification Control Definition.
SIL	Software In-the-Loop.
SysML	Systems Modeling Language.
UML	Unified Modeling Language.
UMLDI	UML Diagram Interchange Specification.
XMI	XML Metadata Interchange.

[4] INCOSE Systems Engineering Vision 2020. INCOSE-TP-2004-02. San Diego, CA. September, 2007.