AEROSPACE
& DEFENSE

OPTIMIZING PRODUCT DEVELOPMENT WITH **MODEL-BASED SYSTEMS ENGINEERING**

KEY VALUE CONSIDERATIONS

DASSAULT SYSTEMES

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"Model-based systems engineering (MBSE) is the formalized application of modeling to support systems requirements, design, analysis, verification and validation activities beginning in the conceptual design phase and continuing throughout development and later life cycle phases."

INCOSE Systems Engineering Vision 2020
(INCOSE-TP-2004-004-02, Sep. 2007)

EXECUTIVE SUMMARY

This white paper focuses on the application of Model-Based Systems Engineering (MBSE) in the aerospace and defense industry. The paper further elaborates on the industry transformations, business challenges, opportunities and advantages of using MBSE. The paper examples how MBSE can improve systems development processes, reduce costs, and ensure that complex systems are developed and deployed by improving communication among stakeholders, enabling early detection and resolution of issues, reducing rework, and ensuring compliance with industry standards.

The paper also discusses the challenges faced by the aerospace and defense industry and how MBSE can help address these challenges. The paper emphasizes the importance of using MBSE to create a model-driven environment that supports the integration of different system elements, including hardware, software, and human factors. The paper is divided into five main sections: our understanding, industry market overview, how Dassault Systemes can help, a case for change, an overview of the value engagement and additional resources around MBSE.

The **Our Understanding** section provides a contextual summary of what MBSE is and its relevance across various applications of system development processes and the perspective of how MBSE is defined and addressed from the Dassault Systemes perspective.

The **Industry Market Overview** section provides an analysis of the aerospace and defense industry, including key trends, challenges and initiatives. The section also discusses the role of MBSE in the industry and how it can be used to enhance the development process. It explains the transformations and challenges faced by the industry and how MBSE can help address these challenges.

The **How Dassault Systèmes Solutions Can Help** section explains how Dassault Systèmes' solutions can help organizations implement MBSE in their system development processes. The section highlights five domains of capabilities that focuses on the 'what', 'why' and 'how' the benefits of leveraging first class solutions will enable long term benefits.

The **Case for Change** section presents a compelling case for adopting Dassault Systemes solutions for MBSE to enable the larger value proposition. It elaborates on benefits realized across customer references from both an internal and external perspective. The section further details how certain A&D organizations have successfully implemented MBSE, how they measured the value and return on investment and how similar A&D businesses can benefit from similar approaches.

The paper concludes with an elaboration of the **Value Engagement** consulting framework and **Additional MBSE Resources** that enables Dassault Systèmes to provide comprehensive recommendations that align to our customers' business, organizational, and information strategies. Overall, this white paper provides a comprehensive overview of MBSE in the aerospace and defense industry. It highlights the benefits of adopting MBSE and how Dassault Systemes solutions and consulting services can help organizations achieve success in their system development processes.

VALUE PROPOSITION | KEY HIGHLIGHTS

Model-Based Systems Engineering

Drastically reduce lead-time
Reduce design time with true concurrent engineering on complex systems at all levels of abstraction.

Up-to-date and complete information, directly in models
Associate all the product information in the various model development, reducing manual disconnects leveraging in context design development and test.

Reuse and improve existing design
With a rich variety of standard and user-defined templates and components, the engineer is able to design faster than ever and to focus on added-value tasks.

Improve the design quality of your product
Create high-quality and complex mechanical shapes with a robust feature-based approach. Increase efficiency on tedious or repetitive manual tasks.

Easy collaboration and management of data
Collaborate with all the stakeholders. Manage your modeling data on the **3D**EXPERIENCE® platform without migrating data. Leverage centralized governance repositories, communities, in native digital tread for product development.

Access modeling artifacts anywhere, anytime
Build a dashboard for any type of user with the correct data available instantly. Immediate visualization of data increases understanding.

Validate your design
Digital prototyping, combined with Digital Mockup verification, allows product development teams to virtually create and analyze a mechanical product in its operating environment.

Secure data with managed lifecycle and controlled access
Perform lifecycle operations including revision, release and lock/unlock. Manage and protect your Intellectual Property by easily removing company know-how from any model prior to data exchange with multiple levels of security.

Compensate MFG deformation
Achieve real productivity gains by comparing and optimizing nominal shapes with predicted or real shapes, while preserving surface quality.

"Systems are much more complex today and there's a great demand for systems engineers from organizations such as department of defense, NASA and Department of Energy."

Gregory Harris,
Ph.DAssociate Professor Director
I&S Engineering at Auburn University

OUR UNDERSTANDING

MODEL-BASED SYSTEMS ENGINEERING

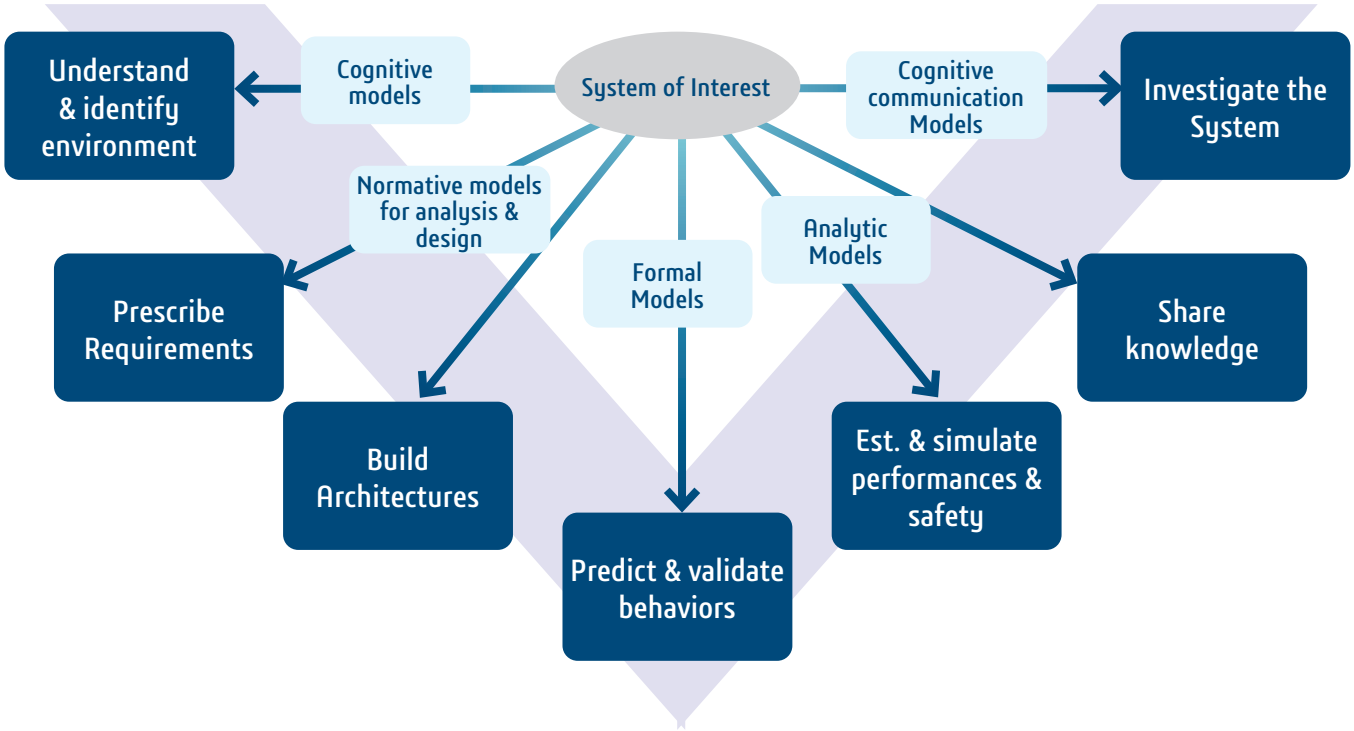
The Aerospace and Defense (A&D) industry is seeing an increased demand for **Model-Based Systems Engineering (MBSE)** capabilities across new, current and future programs. The technological complexities and challenges are growing at an exponential rate and the industry is experiencing an increased motivation to align opportunities that will help effectively manage these complexities effectively with improved efficiencies and robustness. With the growth and scale of these complexities, systems engineering processes are enabling approaches such as MBSE to facilitate a holistic development process to manage the development lifecycle, assure traceability and maintain consistency throughout the system development. Dassault Systèmes continues to advance methodologies, frameworks and enabling solutions to address the needs of MBSE capabilities in support of the rapidly changing industry.

According to the International Council of System Engineering (INCOSE), the definition of systems engineering "is a transdisciplinary and integrative approach to enable the successful realization, use and retirement of engineered systems, using systems principles and concepts, a scientific technological and management methods". Therefore, systems engineering supports a wide range of multi-disciplinary activities from concept through development, manufacturing and even operations and sustainment. As for MBSE, INCOSE defines it as an "execution of [SE] discipline using digital model principles of system-level modeling and simulation of physics and operational behavior through the system lifecycle."

MBSE is a part of the larger systems engineering (SE), focusing on the practice of utilizing models in support of the end-to-end development lifecycle. Digitally connecting development artifacts throughout the model value chain inherently aligns upstream and downstream development thinking, giving means to digital continuity. Leveraging today's state of the art solution are essential for business transformation and the **3D**EXPERIENCE platform has proven to enable the true value of MBSE and facilitate the technological capabilities that drive agility, quality and innovation.

"Systems engineering is more important- and more valued- due to rising complexity, increased interconnectivity, and societal impacts."

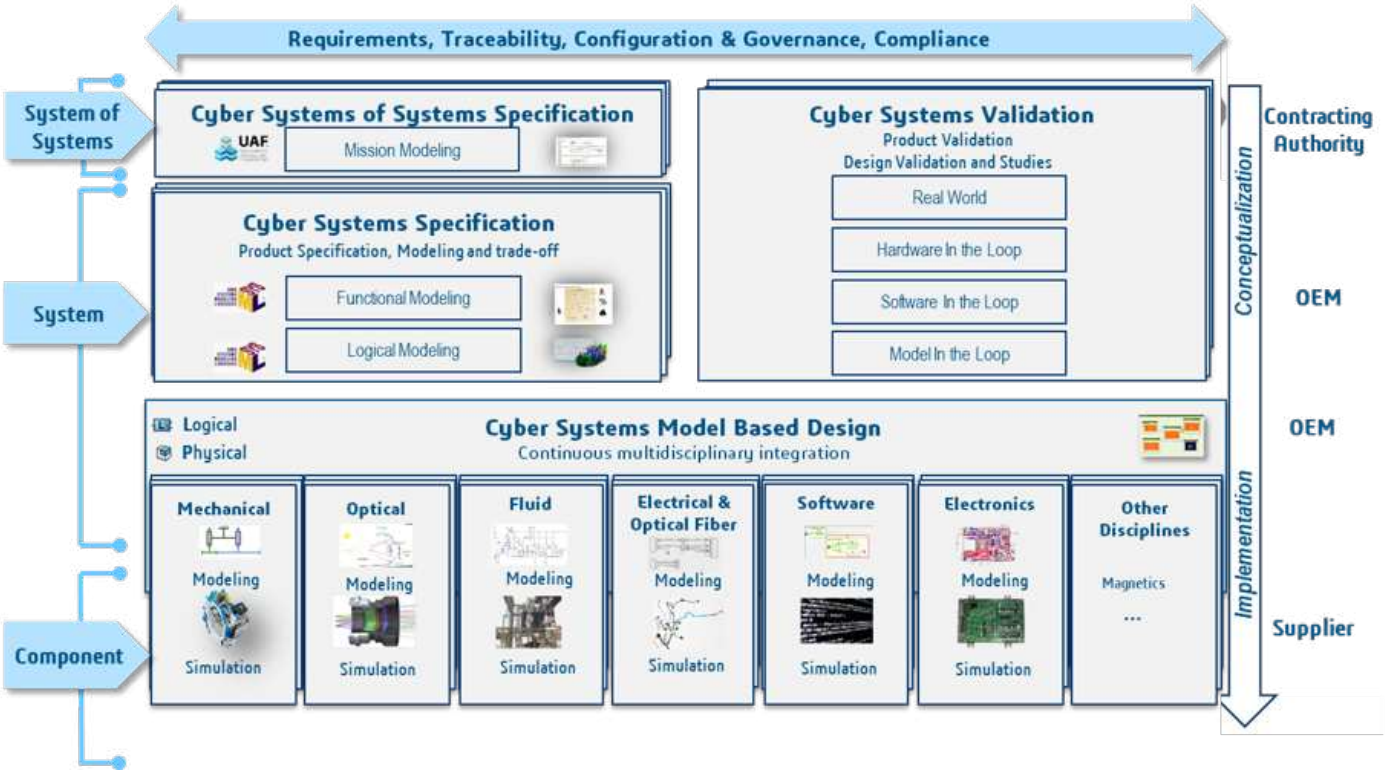
INCOSE Vision 2035



A HOLISTIC APPROACH

From the larger System of System (SoS) perspective down to the embedded systems and component of a product, MBSE methodologies can be applied to the many levels of abstraction throughout a product's development maturation. Understanding the breadths and depths of product and program development is an important consideration when aligning the context. Ensuring the alignment from the contractor authority through the OEM to the supplier is essential in ensuring the system(s) of interest is built as intended.

Managing the complex nature of the product development comes down to accurately defining requirements early on, ensuring traceability of artifacts, as well as consistent configuration management and governance, and ensuring continuous alignment and compliance across the development domains. Considering these complex layers, the intent is to address the value of the full end-to-end MBSE development. As such, these details are not limited to specific types of modeling as applications, but rather includes various engineering activities and domains driving the larger MBSE vision. This includes extending the modeling capability association across systems engineering development practices to include multi-disciplinary collaboration, product lifecycle management (PLM) as well as varying engineering domain needs such as system requirements, design, development, analysis, and verification and validation activities. Applying more systems thinking earlier in the lifecycle will proactively improve downstream alignment to supply chain and manufacturing execution.



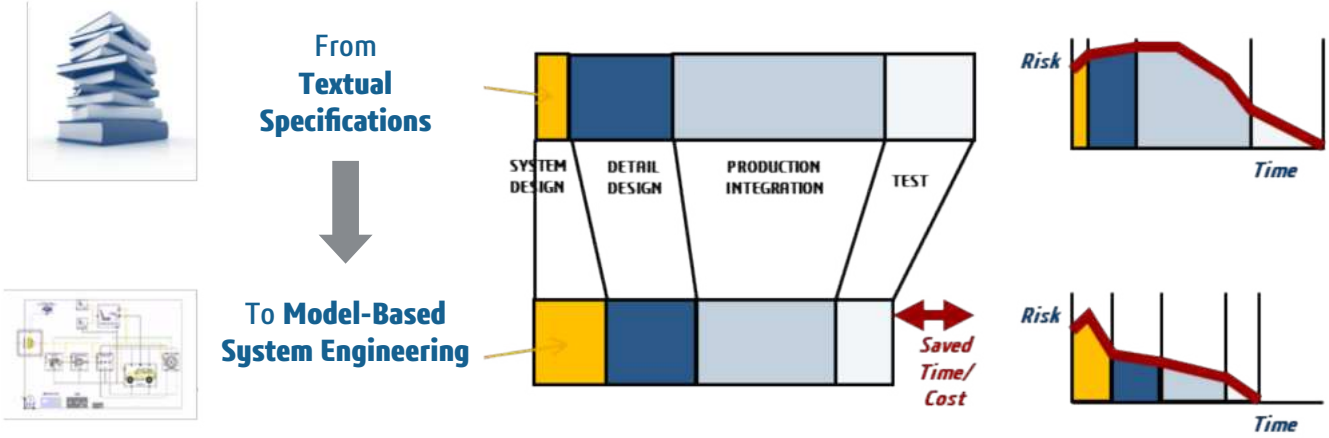
CURRENT CHALLENGES

There are many challenges associated with the product development lifecycle in the A&D industry, especially when it comes to the evolution of the world and the constraints imposed upon the product development process. With the ever increasing technological advances and complexities of products comes significant challenges. Some of those challenges include:

Increasing complexities	Technological advancements, system of systems, multiple subsystems, interfaces & interdependencies.
Integration of systems & data	Management of various data sources, interfaces, subsystems, & components causing significant downstream implications.
Cost management	Increased pressure to reduce costs to develop more complex systems.
Regulation, compliance & risk management	Managing & maintaining compliance to strict regulatory standards (safety & security) while managing & tracking risk implications.
Requirements management	A structured approach to capturing, tracking, managing & validating requirements throughout the product lifecycle.
Supply chain & data management	Manage the supply chain involving multiple suppliers & partners delivering on-time and to required specifications.
Time to market	A&D organizations are under pressure to reduce time it takes to bring new products to market in accelerated timelines.

A DIGITAL SOLUTION

Integrating a digital solution that uses authoritative sources of system data and models as a continuum across lifecycle activities will largely address many of these complex challenges. Traditional document-centric approaches will have to be abandoned in favor of connected and trusted models. Leveraging a digital platform with native MBSE capabilities will improve the efficiency and effectiveness of product development with clear, concise, and digitally connected solutions. The coupling of requirements, data, models and simulation activities are used to inform design decisions, improve collaboration and coordination among stakeholders and allow for comprehensive visibility into the development phases of the system(s) of interest and significantly reduce development time and cost, while simultaneously reducing risk.



Product Design using and MBSE brings significant gains in project performances (quality.cost.schedule)

"MBSE is a fundamental change in the way we think about systems engineering. It's not just a set of tools or a new way of documenting requirements; it's a paradigm shift that is transforming the entire engineering process. MBSE allows us to model and simulate complex systems, reducing risk and improving decision-making. It enables us to design and analyze systems in a more efficient and effective way, and ultimately, to deliver better systems to our customers."

Dr. William Roper
Former Director of Strategic Capabilities Office at the US DoD

INDUSTRY MARKET OVERVIEW

A&D INDUSTRY OUTLOOK

A new McKinsey research effort, in partnership with Aerospace Industries Association (AIA), found that advancing digital maturity of A&D opportunities could unlock $20 billion in annual earnings before interest, taxes, depreciation and amortization (EBITDA) (a 10% improvement based on a 2018 global sector EBITDA of $200B). [1] This value would come from both cost and growth opportunities across the value stream. Becoming a digital leader would mean doing away with paper-based processes, disconnected data systems, and tedious non-value manual tasks. The digital enablement for such value could require a transformation in business operations from digital strategy, talent, technology, implementation, process re-engineering and adoption. The value will come from both OEM and suppliers, from expanding revenue opportunities to reducing costs across the value streams of which include engineering, supply chain and procurement, manufacturing and aftermarket services and support functions.

A&D MARKET LANDSCAPE

Aircraft production and aftermarket services will need to be fundamentally reassessed to account for long-term demand shifts. Defense and Space industries need to be able to adapt to ever changing threats, dynamic market conditions, and new technologies

$3 Trillion+

Total global military expenditure is expected to surpass **$2 Trillion** by 2022 (forecast precedes the war between Ukraine and Russia). After March 2022, updated forecasts estimate that WW defense spending could reach $3 Trillion in less than a decade (by 2030). [2]

$100 Billion

Multiple armies are launching new Digitalization plans for their defense forces. The most recent and mediated one is the new **$100 Billion** defense plan announced by Germany in March 2022. [3]

$10 Billion

From 2015 to 2020, the investments into space companies have increased from **$1.4 billion** to **$5.2 billion**. The market should reach **$10 billion by 2030**. It is estimated that around **70,000 satellites** will enter space in the 2020s—far surpassing the **11,000 satellites** launched in the 64 years since Sputnik 1. [3]

DIGITAL ENABLEMENT

In efforts to reach new levels of innovation to improve engineering productivity, speed, cost and quality, an emphasis needs to be placed on enabling capabilities that drive analytic-driven productivity, development acceleration and scaling efforts. Since the engineering function is the basis of establishing end-to-end value through the development chain, digitizing engineering and MBSE have become a priority for almost every company in the A&D industry. The emphasis of the following points where mentioned in efforts to deliver on the potential value of digital engineering :

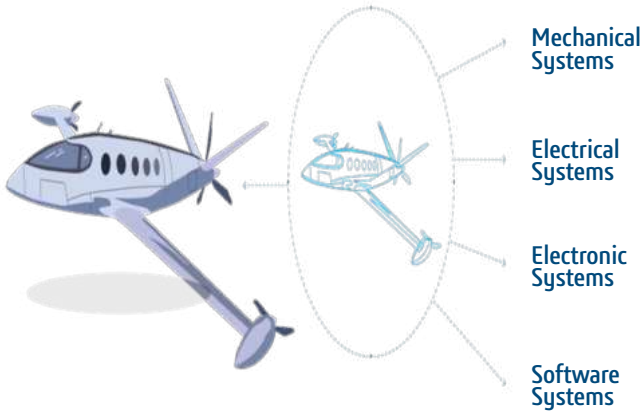
- Common standards, API's and data-sharing practices
- Having an authoritative source of truth; and
- Establishing a means to improve cross-functional communication and coordination

[1] McKinsey 2021 | Digital next horizon for global aerospace and defense
[2] SIPRI (2021)
[3] World Economic Forum (2022)

THE RISE OF MULTIDISCIPLINARY SYSTEMS

In today's hyperconnected world, virtually every product company has become a mechatronics company, combining mechanical, electrical, electronic and software systems into a single product. Designing so many fundamentally different systems to work together is a complex **systems engineering challenge**.

The A&D industry has demonstrated to be an early adopter of MBSE concepts due to the inherent complex nature of many aircraft and spacecraft in the market today. Due to the physical scale of such advanced systems, the integration of these systems have proven to be much too complex for traditional document-based systems engineering. Numerous interactions between subsystems and components across the development lifecycle would result in significant siloed, disconnected artifacts leading to costly implications in the end. Thus, the early adopters of MBSE in the A&D industry have paved the way for the industry to drive innovation and application in their means to develop new and emerging systems, driving strategic visions across A&D.



DOD DIGITAL ENGINEERING STRATEGIES

There are common objectives and goals across the industry that are influencing stakeholders to align to a **digital transformation initiative**. Some of these strategies are set forth by the DoD. From long standing Department of Defense (DoD) OEM's to start-up companies alike, the effects of change translates throughout all levels of the business. The figure to the left outlines a few official strategies deployed within the last five plus years in efforts to the set a vision aligning to the evolving world. The common objectives across the industry strategies is to achieve the state of digitization, modernization and security across aerospace businesses, product, programs and systems while improving cost, time and risk factors.

GOVERNMENT & DEFENSE

- DoD Modernization Strategy
- DoD Digital Engineering Strategy
- USSF Vision for Digital Service
- DoD Cyber Strategy
- National Defense Strategy

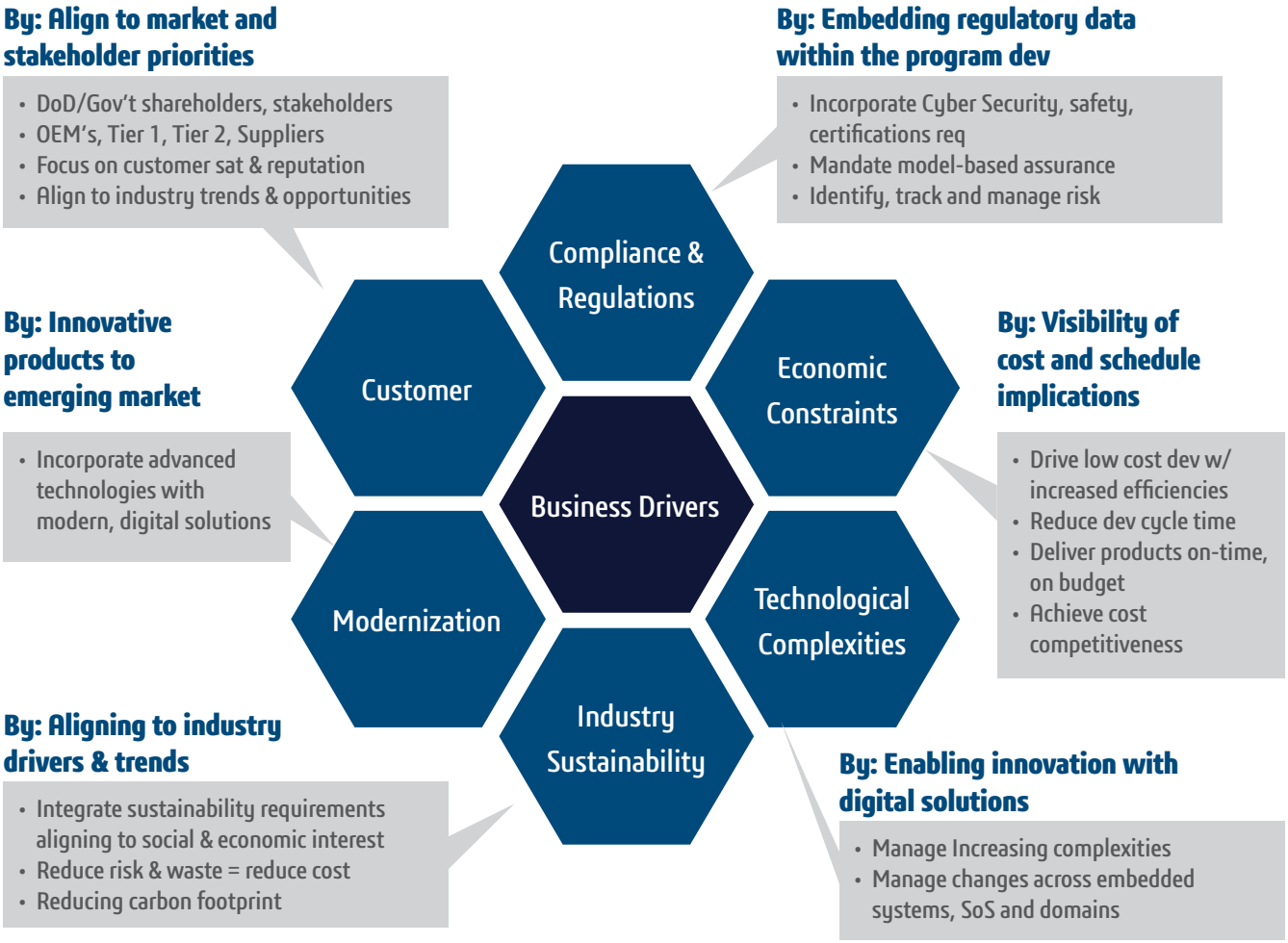
ADDITIONAL MARKET CONSIDERATIONS

The greater aerospace market is learning from their predecessors, recognizing the needs for establishing foundational development practices for their inherently complex products and aligning to the needs to leverage SE and MBSE practices. Commercial aerospace, space exploration, and innovative start-up companies have recognized the importance of MBSE development and the value it will bring to their business at large. Adopting MBSE will drive success across the commercial aerospace sector. The top drivers influencing companies in this sector include: competition, government regulations, customer demand, safety, supply chain volatility, technological advancements, and aligning to industry standards.

A&D BUSINESS DRIVERS AND OBJECTIVES

As aforementioned, technological capabilities are rapidly transforming and evolving and the A&D industry is experience a substantial shift in comparison to decades prior. Stakeholders are prioritizing safe, rapid, affordable and sustainable solutions that align to evolving needs. The trends that drive change across most A&D stakeholders are driving company initiatives to fundamentally transform their methods, processes, and technologies. Digital innovation and the need to standardize, modernize and digitize is becoming the common vision across the industry. This translates the need for A&D companies to explore the formalized applications of MBSE as a means to align their strategic goals and achieve their objectives.

The following are indicative of the business drivers influencing the A&D market. These drivers further define what objectives primary industry stakeholders will prioritize in to respond to the evolving business landscape.



"The **3D**EXPERIENCE platform will facilitate Lockheed Martin's digital engineering goals and help optimize their product engineering with an integrated platform approach"

David Ziegler
Vice President, Aerospace & Defense Industry,
Dassault Systèmes

HOW DASSAULT SYSTÈMES CAN HELP

MODEL-BASED ENTERPRISE FRAMEWORK

The Dassault Systèmes solutions that best align to the domain of interest are best contextualized within the Model-based Enterprise (MBE) framework. MBE is an approach, for people and disciplines of an extended organization, using enterprise infrastructure and applications to leverage lifecycle-managed, connected, descriptive and computational models through the program lifecycle to achieve organizational business objectives for process efficiencies, for user and organizational productivity. The MBE solutions are segmented into high level domains as a means to address the end-to-end development activities that are typical within the A&D industry. Each domain offers value-based solutions that enable the drivers for model-based development:

The high level domains for MBE include:

- Program & Configuration Management
- Model-Based Acquisitions
- Model-Based Systems Engineering
- Model-Based Engineering & Certification
- Model-Based Manufacturing
- Supply Chain
- Operations & Sustainment

MODEL-BASED SYSTEMS ENGINEERING FOCUS

From the end-to-end perspective, the domain of interest for solution enablement with Dassault Systèmes focuses specifically on the Model-Based Systems Engineering domain. The primary objective for MBSE solutions is to ensure the product development activities and processes are efficiently and accurately orchestrated throughout the development lifecycle, from as early as the conceptual development and design, simulation, and test down to manufacturing and operations. Core MBSE activities include requirements engineering, systems architecture, systems design and trade analysis, verification, validation and test. Additionally, as a means of supporting MBSE complexities, governance, collaboration and visibility are crucial to the process as well.

MBSE ENABLEMENT WITH 3DEXPERIENCE PLATFORM

At the heart of the Dassault Systèmes vision for MBSE is the **3D**EXPERIENCE platform. It enables the vision for digital transformation leveraging the development capabilities for MBSE. The following enablers have been proven capability solutions that align to the depths and breadths of the development lifecycle. As each capability is deployed, matured and utilized across the lifecycle, the greater the benefits are realized throughout the end-to-end value chain. The enabling capabilities are detailed as follows:

ENABLING SOLUTION DESCRIPTION	VALUE BENEFITS
1. Requirements Engineering Requirements management activities that enable product / program planning and definition throughout the development lifecycle. Enabling real-time traceability, continuous and iterative requirements management, development and visibility.	✓ Increase traceability & impact visibility to reduce downstream defects, risk & schedule delays by as much as ~30% ✓ Increase real-time health status & visibility reduce manual consolidation ✓ Reduce re-work with knowledge management systems ✓ Increase development efficiencies by reducing siloes between stakeholders
2. Systems Architecture Model development activities utilizing system modeling language (SysML) that follow methodologies and frameworks (such as RFLP, DoDAF, UAF, Cyber Magic Grid, etc.) to define and architect a system(s) of interest.	✓ Digital continuity enabling a comprehensive system definition ✓ Collaborative management of growing system complexity ✓ Reduction of systems development effort by managing in-configured architecture with variants and system assets reuse
3. Systems Design and Trade Analysis Development of systems design and optimization. Satisfaction of conflicting expectations & needs for an organized set of "ilities" through balanced architecture, real-time exploration and design considerations.	✓ Digitally integrate stakeholder needs ✓ Enable real-time design exploration, optimization & simulation ✓ Vertically integrate analytics & design ✓ Optimize efficiencies & improve flexibility ✓ Prevent costly late work/re-work
4. Verification and Validation Multi-disciplinary Analysis and Optimization (MDAO) co-simulation methodologies based on SysML models to integrate and execute multi-physical models. Enablement of V&V testing, tracking and monitoring across development	✓ Enable real-time tracking & monitoring of V&V activities ✓ Supporting costly certification process ✓ Expediting liability-related root-cause analysis investigations ✓ Benefiting from test execution tasks throughput & accountability
5. Governance and Collaboration Collaboration and management of development artifacts leveraging native, connected digital solutions. Enabling the 'invisible governance' with automatic updates. Multi-disciplinary collaboration via folders, discussions, and notifications ensures everyone working on the latest data in real-time.	✓ Increase interdisciplinary collaboration ✓ Improve time for decision making with real-time status, access & visibility ✓ Increase quality of artifact tracking ✓ Avoiding costly requirements coverage issues & physical re-test

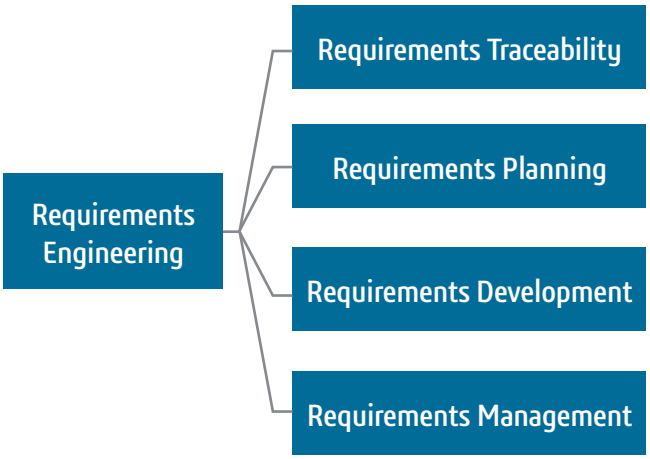
1 2 3 4 5

REQUIREMENTS ENGINEERING

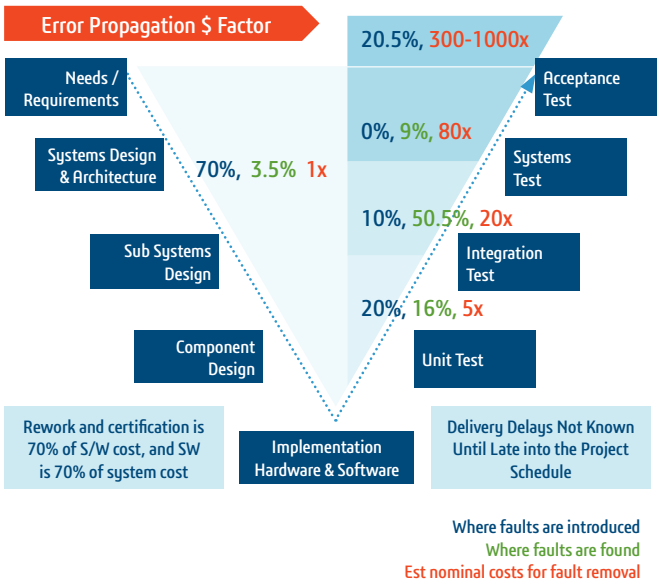
WHAT?

Requirements engineering involves the breadth of activities associated with defining and aligning stakeholder needs and requirements throughout the development lifecycle. The intent is to streamline the practice by leveraging technology and process to enable development capabilities along the program development maturation. Requirements engineering activities include:

- Collaborative requirements planning, development and management.
- Ensure full traceability of concept definition throughout lifecycle development through downstream development, test and V&V activities.
- Proactively assess full concept definition consistency and completeness prior to milestone review & approvals.
- Enable users to define and validate compliance parameters towards requirements.
- Incorporation impact analysis during fit/gap studies with proper planning, management & traceability.



Economic Impacts of Inadequate Infrastructure of SW Testing [1]



WHY?

Requirements engineering incorporated during the early lifecycle phases will significantly **mitigate down stream error** propagation resulting in significant time and cost savings. As errors are propagated through the lifecycle, the cost for fault removal exponentially increases.

- Estimated **70% of** requirements **& systems interactions errors** introduced in earlier phases.
- Estimated **80% of errors are discovered** in later phases, causing significant increase in costs downstream
- If requirements are integrated during the conceptual design phase, an estimated **40% of requirements are wrong**.

"Projects that expended the industry average of 2% to 3% of total project cost/effort on the requirements process experienced an 80% to 200% cost overrun. While projects that invested 8% to 14% of total project cost/effort in the requirements process had 0% to 50% overruns."

- U.S. National Aeronautics & Space Administration (NASA)

HOW?

- Traceability Requirements Manager (TRM)
- CATIA Stimulus
- Rectify
- CATIA Functional and Logical Design (RFLP)
- 3DDashbord Systems Review

[1] Source: NSIT Planning Report 2-3, The Economic Impacts of Inadequate Infrastructure of Software Testing, May 2002.
D.Galin, SW Quality Assurance: From Theory to Implementation, Person /Addison-Wesley (2004)

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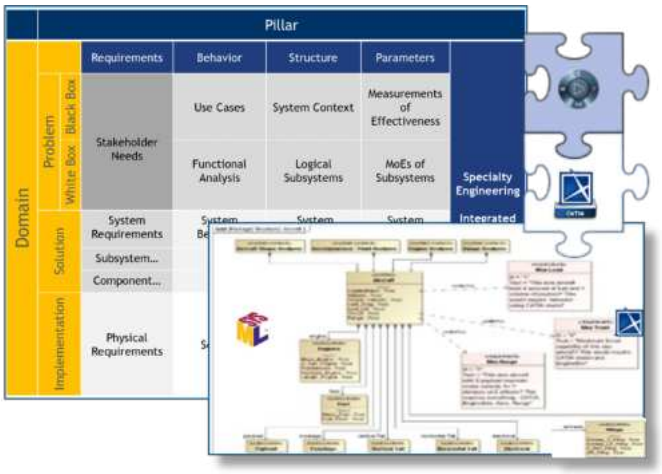
SYSTEMS ARCHITECTURE

WHAT?

Systems architecture are models that visually depict a systems concept through the use of a systems modeling language (such as SysML). The model views are developed using an architecture methodology to ensure consistency when modeling a system of interest. In A&D, the frameworks that could be used are those aligned to a defense architecture framework. A framework guides the systems development through various levels of abstraction – conceptual, functional and physical – in efforts to define a system of interest. The intent of architecture development is to:

- Detail and optimize systems architectures to accurately project product performance.
- Decompose the system into smaller to manage complexities; specify the interfaces and behaviors (requirements and models).
- Operational concept development, to systems development.
- Integrate the components, verify and validate the integrated solution against the systems specification.
- Transition stakeholder needs to systems requirements and design.towards requirements.
- Incorporation impact analysis during fit/gap studies with proper planning, management & traceability.



WHY?

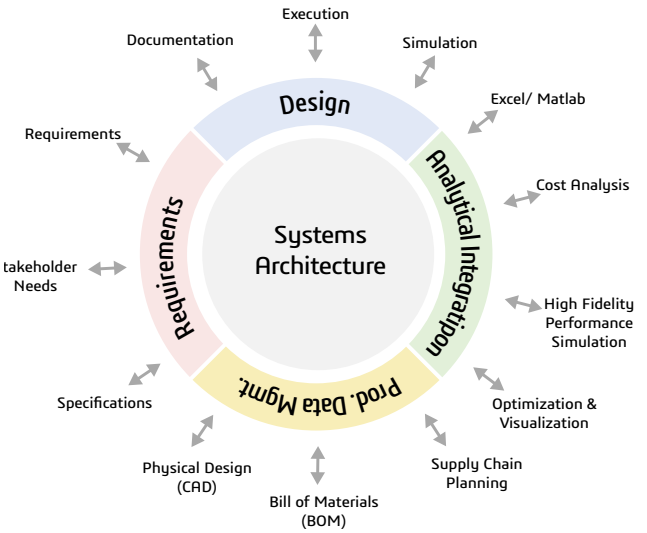
Systems architecture is an essential activity for MBSE. From integrating requirements to developing systems model views to incorporating important simulation analysis decisions, these integrated activities are key to architecture development. Multidisciplinary design development results in increased awareness of design decisions, understanding, visibility and accuracy of change impacts, and improving overall system quality. Having architectural views reduces ambiguities, accelerating collaboration across development teams resulting in many downstream productivity and efficiency gains throughout the lifecycle.

Key Differentiators and Benefits

- Includes the **systems safety & reliability** solutions (to include FHA, FTA, and FMEA capabilities).
- **Model transformation** enabling exchanging (consuming and providing) domain specific models (FLXML plugin).
- **Holistic view:** Systems perspective & stakeholder needs.
- **Quality**: Interface mastering & specification consistency.

25% Win rate ratio

50% Time to concept definition



HOW?

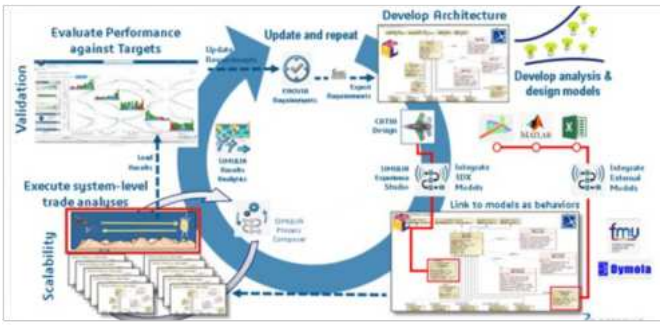
- CATIA Magic / NoMagic / Cameo
- Collaborative designer role (Power'by CATIA Magic)
- Magic Teamwork Cloud
- ENOVIA – Model Definition
- SIMULIA process composer
- Traceability (TRA)
- CATIA requirements management
- CATIA Systems Safety

1 2 3 4 5

SYSTEMS DESIGN AND TRADE ANALYSIS

WHAT?

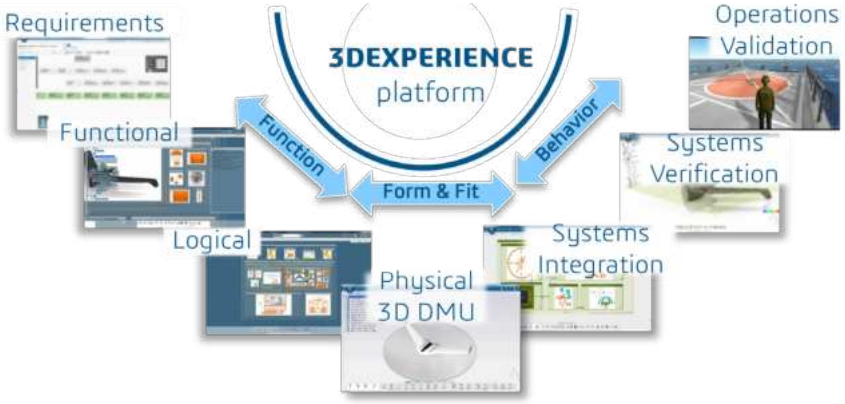
The design and analysis process starts with having a developed architecture based on the requirements of the system. The design if further refined through developmental analysis and models where the CATIA 3D design is integrated and linked to models as behaviors and trade studies are conducted there after. The results of the trade analysis are evaluated and validated against performance targets and updates to requirements are made, as needed.



Managing this product engineering process effectively requires digital management of the Requirements and how those link to the Functional Analysis as well as the Logical and Physical Design (RFLP) decomposition of systems. The benefits of this approach is that it enables product teams to analyse design elements independently, opening the possibility of reuse and natively providing the logical path for integration to gain a holistic view of the product definition. towards requirements.

WHY?

To address the need for improved efficiency, productivity and end-to-end connectivity the **3D**EXPERIENCE platform goes beyond the physical design to provide a Systems Digital Mockup (S-DMU) to include early validation of requirements and models. Furthermore, the platform is industry compliant (e.g., STEP AP 242 for managed model based 3D engineering) and delivers a common product definition for efficient collaboration and optimization of design efforts to drive down development and improve quality.



Value Benefits

- Improve productivity (reduce development time) by 40% to 60%.
- Accelerate product definition and delivery.
- Improve communication & decision making.
- Leverage MarketPlace on standard parts.
- Align compliance to A&D Standards.
- Provide an enduring, ASOT.

HOW?

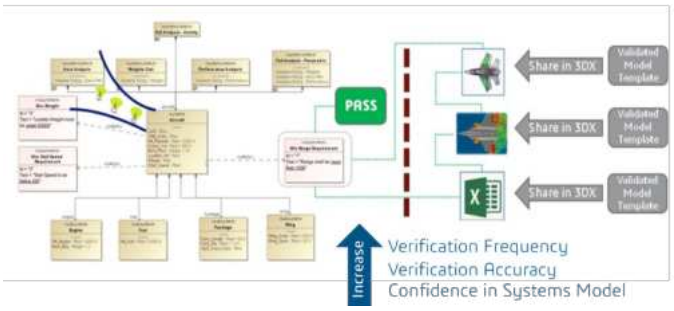
- CATIA Functional and Logical
- CATIA Dymola Behavior Modeling
- SIMULIA Digital
- ENOVIA Collaborative Lifecycle Management
- Stimulus
- SIMULIA Process Composer
- CATIA Magic / NoMagic / Cameo
- **3D**EXPERIENCE V+R Process Apps
- 3DS MarketPlace

1 2 3 4 5

VERIFICATION AND VALIDATION

WHAT?

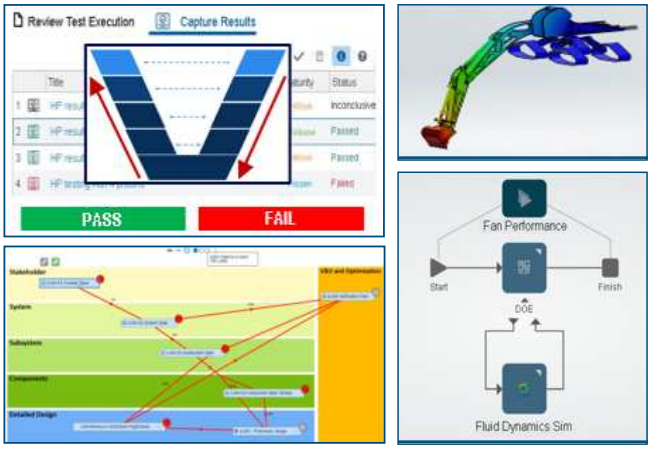
Verification and validation are critical activities that are executed continuously throughout the development process. During initial concept development, verification activities confirm that the operation and performance requirements and functional specifications are feasible. Requirements and specifications are driven by primary stakeholders defining the system(s) of interest (SOI) where they will use operational requirements for final validation. During engineering development, subsystems and components that make up the SOI must be verified, integrated and tested. Operational testing is the method that gathers data tovalidate the ultimate SOI to satisfy all operational capabilities. V&V are essential activities that confirm the 'contracted for' SOI provides the required operational capability. Leveraging



cyber-physical systems experience on the 3DEXPERIENCE platform will increase virtual V&V and testing capabilities early and often.

WHY?

Increased fidelity of models on a native, digitally connected platform enables the ability to verify and test frequently throughout development cycle ensuring design decisions, changes and impacts are identified early and often. Leveraging closed-loop simulation results on the platform decrease reliance on SMEs. Catch design discrepancies, issues, and defects as early as conceptual development as well a reducing the need for costly physical testing, all proven to significantly reduce downstream cost and schedule impacts.



Value Benefits

- Increase cross-domain productivity by ~30% with centralized tools & increased visibility.
- Increase quality through simultaneous modeling and design development (MODSIM).
- Cost reduction of up to ~40-50% with virtually testing earlier in dev.
- Evaluate requirements directly from architecture using SME-approved validation models.

HOW?

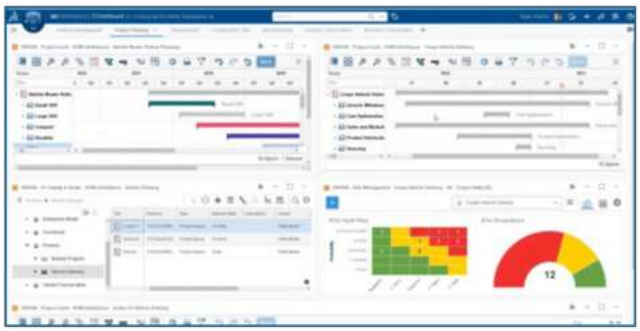
- ENOVIA Requirements manager
- CATIA Magic
- CATIA Design
- Functional & Logical Design
- MODSIM & MDO
- SIMULA
  - V+R Test Management
  - Results Analytics
  - Experience Studio
  - Process Composer

1 2 3 4 5

GOVERNANCE AND COLLABORATION

WHAT?

Establishing proper governance as a solution enabler is key to ensuring true process continuity. This capability incorporates visibility and management of data throughout the product development lifecycle. With large sets of data and artifacts, integrating and managing varying sources of data throughout the development activities largely improves cross-team/domain collaboration, quality, and configuration management. Project leaders have the ability to review live deliverable status. Stakeholders can collaboratively identify pending design decisions and issues, define and track corrective change actions and assess the end-to-end traceability to ease quality audit and certification activities. The **3DEXPERIENCE** platform enables the full end-to-end data and configuration management to support all key activities.



↑10-15%
Increased reusability
(Reduced rework)

↑~40%
Improved productivity
with upstream thinking

↓~70%
Time aggregating data

WHY?

The following benefits articulate the value propositions for leveraging the digital governance and collaboration capabilities throughout the MBSE development process:

- Improve quality, efficiency and governance management processes enabling authoritative models and data.
- Seamless change process across domains and organizations with end to end change management.
- Real-time status / health updates for a project– eliminating manual time for management review and data consolidation.
- Monitor systems engineering leading indicators.
- Actively assign, track and manage artifacts in real-time.
- Monitor the lifecycle processes, automatically updating plans.
- Improve team collaboration capabilities with folders, discussions, and notifications – ensures everyone is working on the latest data set(s).

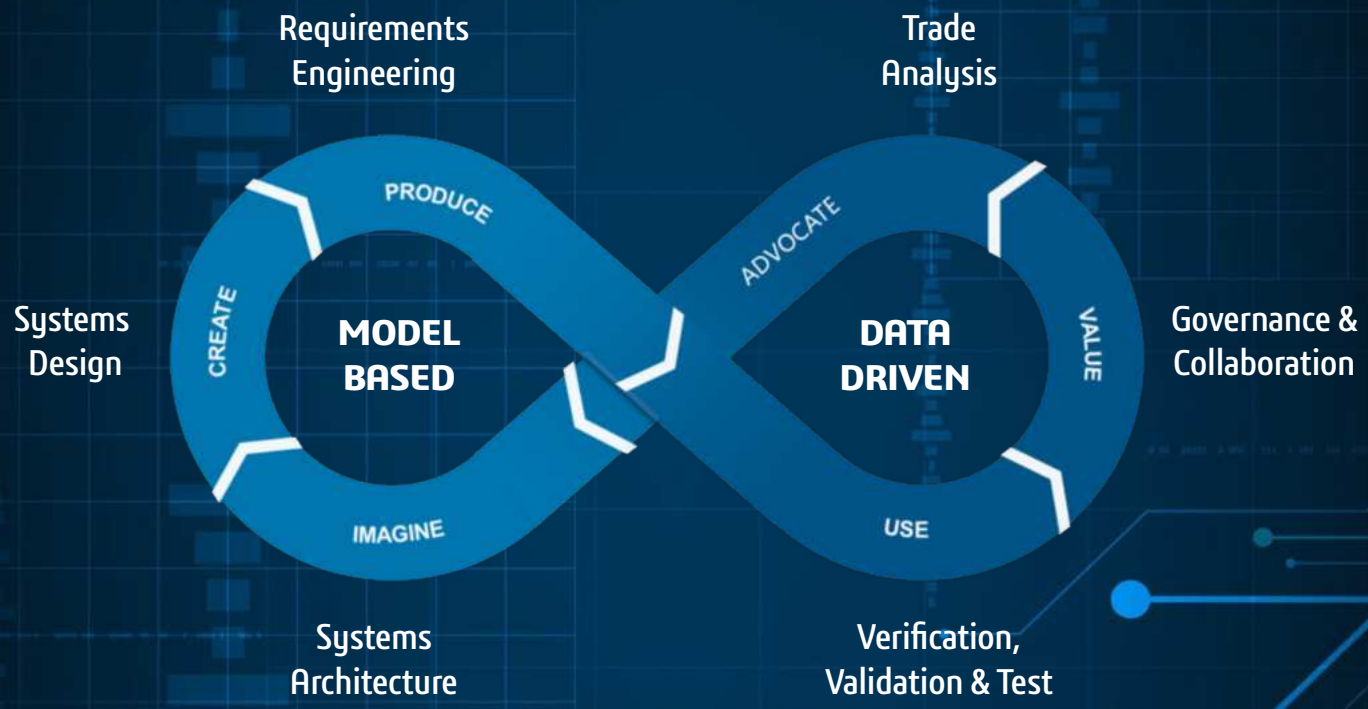
HOW?

Program Excellence (ISE)
- Continuous Product Development
- Collaborative Planning, Execution & Analytics
- Product Architecture
- End to End Change Management
- Know-How Capitalization and Automation
- Enterprise Systems Modeling & Simulation

- Extended Enterprise Collaboration
- Data Driven Business Performance
- ENOVIA Collaboration and Approvals
- ENOVIA Program and Contract Management
- ENOVIA Project Management
- Requirements Intelligence App

Model-Based Systems Engineering

IFWE Loop



Dassault Systèmes customers deploying **3DEXPERIENCE** MBSE solutions have seen improvements , such as:

- 18% reduction of development time
- Up to 60% quality issue reduction for early defect identification
- Up to 40% reduction of efficiency improvements time
- Increase product and execution quality with risk management and tracking
- Increase in downstream material cost savings through increased simulation & analysis earlier in the lifecycle

A CASE FOR CHANGE

A&D COMPLEXITIES AND CHALLENGES

The interconnections of products is ubiquitous and occurring across multiple domains, even with systems we use every day. This creates a complex web of interdependent systems where challenges inherently arise throughout the product development maturation. The challenges of such include:

Lack of global system def. & collaboration

Able to work with 10, 100, 1000 people across many teams.

Inconsistent silos of engineering disciplines

Able to share a unique system reference with domain-specific disciplines.

Increasing compliance complexity

Able to simulate and validate as soon as possible.

Costly compliance to regulatory standards

Able to trace and analyze engineering activities and generate reports.

The increasing complexity of Aerospace and Defense systems and the constant evolution of missions and threats require greater agility than before. Budgetary constraints will drive the need for predictable delivery and informed decision making, maximizing

United Technologies Corporation and Rockwell Collins

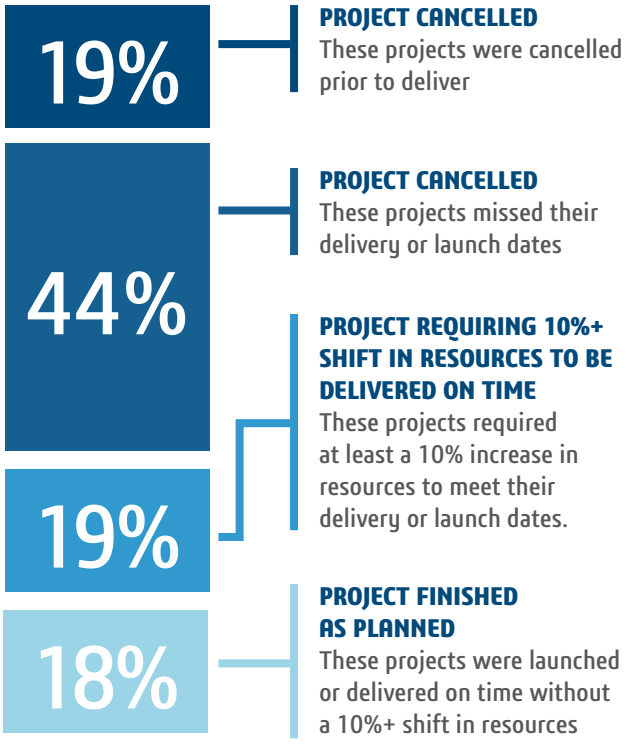
capability and availability within and affordability envelope. A transformation in the acquisition process and systems engineering towards a model-based approach is becoming inevitable. Evolving from the traditional document-centric approaches will improve the overall program performance.

A&D PROJECT DEVELOPMENT IMPLICATIONS

According to survey results from Lifecycle Insights, the analyst study states that only **18% of all A&D programs and projects are delivered on time** without disruptive shifts in resources. [1] Typically finding themselves in one of two states:

1. Consistently cancelling projects or missing their launch/ delivery dates; or
2. In a constant state of emergency as they shift resources between projects to stay on schedule.

The study also points out that there's a correlation between physical testing failures and poor product development performance where many additional implications can occur around cost, safety and risk. The conclusion was evident in the fact that companies are shifting their focus and efforts to find ways to capture their developing IP, streamline processes and related technologies to structure and successfully enable their organizations. From a program performance standpoint, integrating the right level of technology, strategies, simulation, design exploration and decision analytics earlier in the lifecycle will lead to a deeper understanding of the design space and further help organization make the right decisions, avoiding downstream implications. With over 80% of A&D programs at risk, the opportunities are significant.



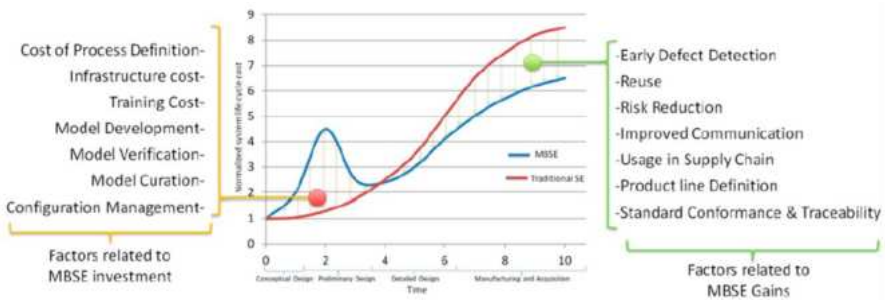
[1] Improve program execution with integrated simulation by Lifecycle Insights

DIGITAL CONTINUITY WITH MBSE

Dassault Systemes portfolio is becoming the standard for MBSE tools in new development programs, but that is only a small part of how we are able to support cost control within our customers' programs. Models are created to deal with complexity. A digital continuity platform enables MBSE and facilitates vertical and horizontal integration. Models allow us to understand an area, concern, or system of interest and provide unambiguous methods of communication and collaboration across multi-disciplinary domains.

MBSE VALUE CAPTURE

The end-to-end MBSE vision is enabled through a true holistic open platform. The concept of 'front loading' alludes to use of digital artifacts and models to do more of the heavy lifting earlier in the lifecycle. Allowing for earlier product definition, traceability, and virtual validation significantly reducing down stream time and cost implications. Integrating a MBSE methodology on the **3D**EXPERIENCE platform has proven to bring significant value to the development lifecycle, such as improved engineering productivity and reducing total development time while effectively managing the increasing complexities of product solutions Leveraging the **3D**EXPERIENCE platform with MBSE methodologies could ultimately facilitate a safer, faster and reliable product that meets the needs of its stakeholders.



BENEFITS OF MBSE WITH THE 3DEXPERIENCE PLATFORM

There are several benefits gained from implementing an MBSE approach with the **3D**EXPERIENCE platform. A few of the examples are notated below:

REDUCE COST with early systems thinking & integrated approach

DESIGN ERRORS DETECTED EARLIER with increased connectivity, traceability & visibility

REDUCE RISK with advanced sim & early, ongoing requirements & design V&V with early systems thinking & integrated approach

INCREASE PERFORMANCE & ALIGNMENT by avoiding rework, increasing collaboration & alignment to stakeholder needs

INCREASE QUALITY with enhanced design integrity & consistency

INCREASE % OF REUSE INSTEAD OF RE-DESIGN with collaborative, open & agile MBSE platform

INCREASED PRODUCTIVITY within impact analysis, cross team collaboration, reuse, & automated optimization

IMPROVED HOLISTIC DATA MANAGEMENT & GOVERNANCE with closed-loop, real-time, traceable data & model-based artifacts

3DEXPERIENCE **PLATFORM VALUES**

MULTI-DISCIPLINARY COLLABORATION	OPEN	OPTIMIZED	EXPERIENCE

MBSE ADOPTION VALUE

MBSE can realize significant value from adoption of the Dassault Systèmes **3D**EXPERIENCE platform along with packaged solutions that leverage the global digital continuum to accelerate innovation, improve collaboration and enhance productivity.

STRATEGIC BENEFITS

- Strong MBSE practice is core to digital engineering strategy.
- Goes beyond implementing technology. It require new ways of thinking, operating and organizational change.
- Align to stringent safety, quality and sustainability standards.

RISK MITIGATION

- Increase quality and accuracy of products with cross-domain collaborative, connected and integrated development.
- Monitor real-time program health and proactively mitigate downstream impacts.
- Increase understanding and visibility of root cause analysis and trade-off across alternative designs.

ECONOMIC BENEFITS

- Improve time to market for complex and competitive products / programs.
- Reduce costs with increase modeling, simulating, and validating systems.
- Reduce non-productive work, such as data aggregation, analysis and reporting.
- Drive costs down with accelerated program integration.

IT IMPACT

- Model product from concept to operations is digitized on the **3D**EXPERIENCE platform and simulate against a range of stakeholder conditions.
- Harmonization of the IT landscape with true, native connected solutions enabling end-to-end development.

"The decision to adopt Dassault Systèmes' **3D**EXPERIENCE platform is a key milestone in our digital transformation. This digital enabler provides global design and manufacturing capabilities that will fuel our second century"

Ted Colbert
CIO + Senior VP of IT & Data Analytics
Boeing.

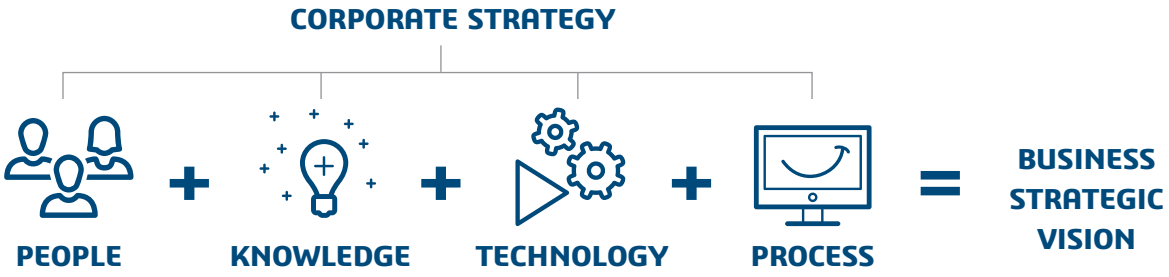
VALUE ENGAGEMENT OVERVIEW

DASSAULT SYSTÈMES CONSULTATIVE FRAMEWORK

At Dassault Systèmes, we believe our **3D**EXPERIENCE platform, applications, and ample industry expertise can give our customers and their partners an edge in their model-based systems engineering journey. In order to deliver true value, our efforts must align to our customers' vision from the beginning of our engagement.

Through our in-depth consultative Value Engagement framework, we seek to gain a deeper understanding of our customers' business needs and objectives. This strategic systems thinking and collaborative approach, allows Dassault Systèmes to provide comprehensive recommendations that align to our customers' business, organizational, and information strategies.

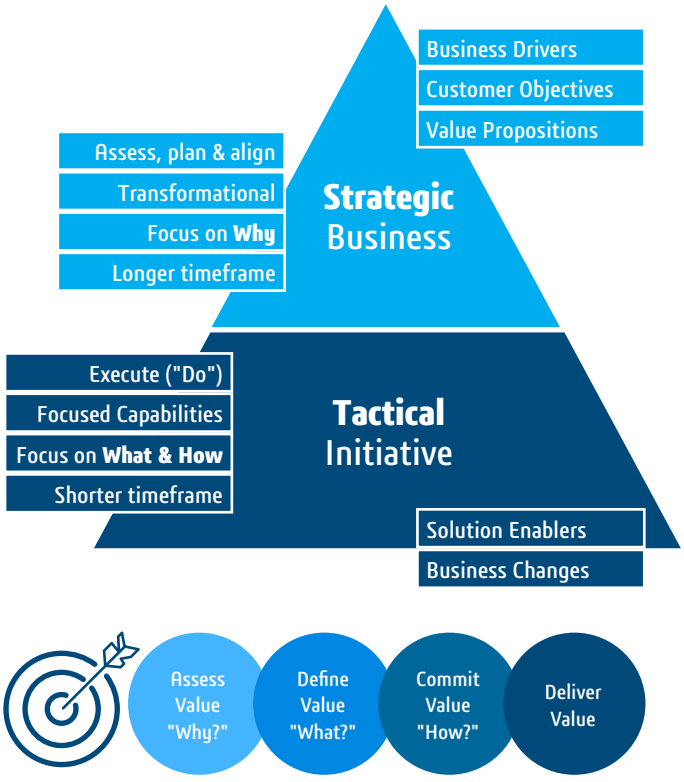
Our Value Engagement team ultimately synthesizes the findings throughout each phase into a set of comprehensive analyses and recommendations that align business drivers, enterprise objectives, and organizational and process changes with Dassault Systèmes solutions enablers. We believe a Value Engagement provides a solid end-to-end foundation of understanding and strategic planning that maximizes the benefit and success of our customers' digital transformation goals and objectives.



A Value Engagement has four progressive transformation phases:

- **VALUE ASSESSMENT**
- **VALUE DEFINITION**
- **VALUE COMMITMENT**
- **VALUE DELIVERY**

These phases leverage different analytical and consultative methods and frameworks to produce deliverables that address the business, solution architecture, and strategic aspects of a comprehensive digital transformation in partnership with Dassault Systèmes.



ADDITIONAL RESOURCES

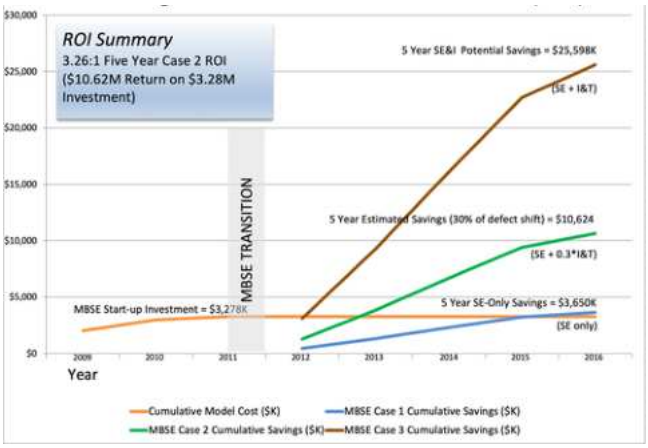
MBSE CASE STUDIES IN THE A&D INDUSTRY

An ample amount of studies conducted across the A&D industry show MBSE benefits and improvements that have significantly affected the schedule and budget performance of a variety of programs. It's important to note that specific benefits and measures of improvement for MBSE adoption can vary greatly depending on the organization, size and complexity of the system being developed and the baseline maturity of the organization's processes and tools.

A few well known A&D industry case studies programs that may detail additional insight are:

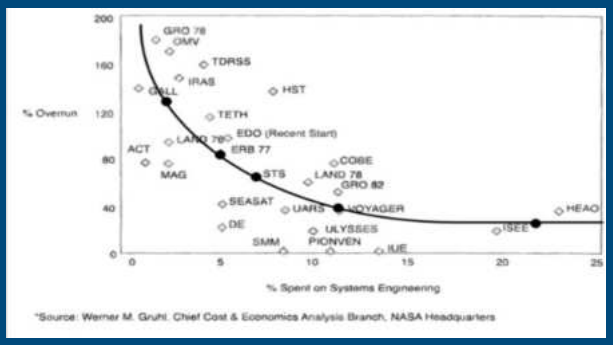
- Submarine Warfare Federated Tactical Systems (SWFTS) Program [1]
- Boeing 787 Dreamliner
- NASA's Space Launch System (SLS)
- Lockheed Martin F-35 Lightening II
- Northrop Grumman B-21 Raider

SWFTS PROGRAM MBSE ROI [2]



> "All our problems arise out of doing the wrong thing righter... The more efficient you are at doing the wrong thing, the wronger you become. It is much better to do the right thing wronger than the wrong thing righter. If you do the right thing wrong and correct it, you get better."
>
> Russel L. Ackoff

NASA PROGRAM PERFORMANCE VS. SE EFFORT [3]



[1] Systems Engineering, Volume: 24, Issue: 6, Pages: 385-408, First published: 21 July 2021
[2] MBSE delivers significant return on investment in evolutionary development of complex SoS
[3] Relations of SE Investments to NASA Programs Cost Overruns (Stutzke 2005). Released by NASA HDQRT/Gruhl

DEPLOYING MBSE | INDUSTRY KPIS

REALIZED VALUE

Some of the key, quantified actuals measured across the different MBSE Case studies within A&D industries
:

- Reduction of **18%** fewer SE labor hours.
- Reduction of issues by **9%**.
- Increase number of baselines developed by **30%**, improving quality and SE products
- **18%** reduction in cost requirements authoring with a **9%** reduction of overall interface defects, reducing downstream costs.
- Spending **7-12%** of program budget on Program management and systems engineering results a returns 10 times the investment.
- ROI ratio of over **3:1** over 5 year case study (**$3.28M** investment returned **$10.62M**).

INTERNAL MBSE CUSTOMER REFERENCES

Dassault Systèmes has deployed MBSE capability solutions across a wide-array of customers, in various industries such as Lockheed Martin, Sikorsky, EVOO electric, Airbus, Audi, thyssenkrupp Marine Systems, Audi, Bosch Car Multimedia, and many more.

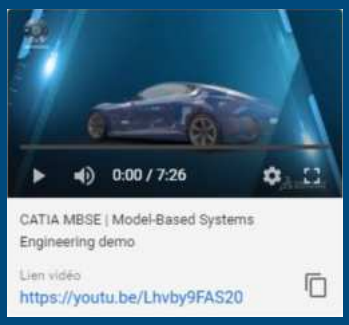
ADDITIONAL RESOURCES PROVIDED BY EXPERTS.

Note: some resources may require additional credentials to access the content.

MBSE No Magic Customer Case Study white paper (gated)

SMS ThinkTank Consultant white paper (gated)

CATIA Model-Based Systems Engineering demo (ungated)



New MBSE e-book (gated)

https://www.3ds.com/insights/model-based-systems-engineering

MEET THE AUTHOR

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Aligning the value of our MBSE technology enablement capabilities to empower our customers towards evolution, modernization and transformation.

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"Dassault Systèmes provides business & people with **3D**EXPERIENCE universes to imagine sustainable innovations capable of harmonizing product, nature and life."

Bernard Charlès
Vice Chairman, Chief Executive Officer

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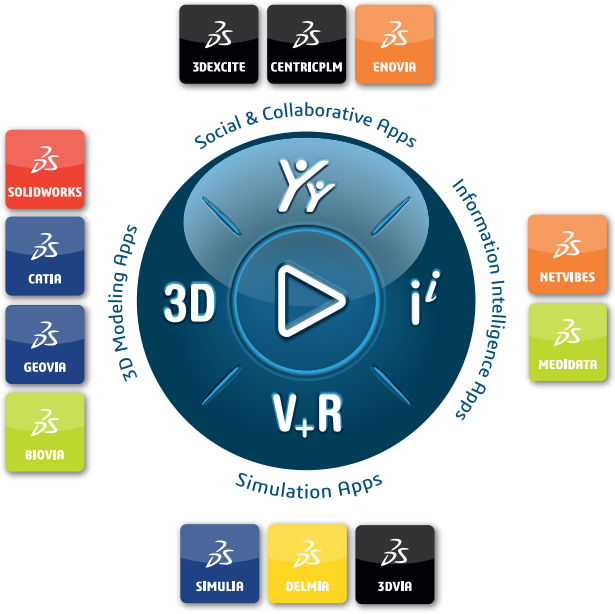
Our **3D**EXPERIENCE® platform powers our brand applications, serving 11 industries, and provides a rich portfolio of industry solution experiences.

Dassault Systèmes, the **3DEXPERIENCE** Company, is a catalyst for human progress. We provide business and people with collaborative virtual environments to imagine sustainable innovations. By creating 'virtual experience twins' of the real world with our **3DEXPERIENCE** platform and applications, our customers push the boundaries of innovation, learning and production.

Dassault Systèmes' 20,000 employees are bringing value to more than 270,000 customers of all sizes, in all industries, in more than 140 countries. For more information, visit **www.3ds.com**.



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