National Defense Industrial Association

Promoting National Security Since 1919

National Defense Industrial Association
Manufacturing Division
Advanced Manufacturing Engineering Capabilities (AMEC) Committee

21st Century Manufacturing Modeling & Simulation Research and Investment Needs

May 2011

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Preface

The origin of National Defense Industrial Association (NDIA) dates back to 1919 with the formation of the Army Ordnance Association, which was later renamed the American Defense Preparedness Association (ADPA). With the merger of the National Security Industrial Association (NSIA) in 1997, NDIA has become America's leading defense industrial association promoting national security. NDIA is a non-partisan, non-profit, international association located in Arlington, VA.

NDIA's mission is to advocate cutting-edge technology and superior weapons, equipment, training and support for the Warfighter and First Responder; promote a vigorous, responsive, Government-Industry National Security Team; and provide ethical forums for the exchange of information between industry and Government on National Security issues.

Currently, the association's membership base consists of individuals from the entire spectrum of the defense and national security industrial base and individual government employees. Included in the Association's membership are organizations selling goods and services to the various Departments of the Executive Branch of government.

The NDIA is comprised of 32 Divisions and 6 Industrial Working Groups, each focused on a specific Defense Industry topic important to the Defense Industry. One of these, the Manufacturing Division, is focused on enhancing the security of the United States by promoting communications and interaction between defense industry, government, and military in the area of manufacturing.

The NDIA Manufacturing Division facilitates industry/government interaction in technology areas directly related to manufacturing research, design, development, test, and production. Such interaction is intended to promote the development of advanced technology for the Warfighter and First Responder, and provide for an exchange of information between defense industry, government and military representatives. The effective cooperation between these groups is vital to our defense effort in the manufacturing area. Each group brings unique inputs to such interaction. No one group can function at maximum effectiveness without the others.

Specifically NDIA's Manufacturing Division:

- Advocates national support for defense manufacturing.
- Promotes defense manufacturing excellence.
- Supports promising technologies, processes, and implementation methodologies.
- Supports efforts to educate, recruit, and train a highly skilled defense manufacturing workforce.
- Conducts research and analysis on manufacturing trends and policies. Conducts government-industry forums focused on defense manufacturing.

NDIA's Manufacturing Division has prepared this document to inform U.S. leaders of the current military need for developing and implementing advanced modeling and simulation technology within the U.S. defense industrial base. Additional copies of this white paper can be found at:

http://publish.ndia.org/Divisions/Divisions/Manufacturing/Documents/NDIAAMECMS.pdf

Sincerely,

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Forward

America's manufacturing sector is the engine that powers the nation's economy and is vital to both our national and economic security. Today U.S. manufacturing companies face tremendous challenges to remain competitive in the global marketplace, with several initiatives underway to revitalize American manufacturing and address the declining state of scientific innovation. One of these initiatives is the development and use of advanced modeling and simulation (M&S) techniques and high performance computing (HPC) technologies as enablers for next-generation manufacturing. This paper identifies critical research and investment needs required to develop a new class of advanced M&S-based producibility analysis capabilities that would enable manufacturing risk to be designed-out and manufacturing efficiency to be designed-in to complex aerospace and defense products during early systems engineering activities. The target audience for this paper includes government, industry, and academic leaders responsible driving engineering and manufacturing innovation into the nation's aerospace and defense industrial base. The paper also provides use-inspired research guidance to universities, government laboratories, and modeling and simulation tool vendors for the development of new and novel M&S-based analysis tools and design methodologies that address many of the top manufacturing-driven affordability problems plaguing aerospace and defense system development.

Findings Summary

Summarized in this paper are the findings and recommendations of an 18-month study conducted by the NDIA Joint Committee for Systems Engineering and Manufacturing (JCSEM) Modeling and Simulation (M&S) sub-committee to define critical M&S-based analysis capabilities needed to address gaps in current manufacturing risk assessment practices for complex aerospace and defense systems. The committee was chartered in the fall of 2008 and consisted of a cross-functional team of subject matter experts from government and industry with a wide range of expertise in systems engineering, design engineering, manufacturing, and M&S analysis working across the mechanical and electronics product development sectors. The study revealed the following gaps in current systems engineering practices and design for manufacturing (DFM) analysis capabilities responsible for many of today's manufacturing and production rate issues encountered in complex aerospace and defense system development programs:

- **Producibility is one of the most neglected "ilities"** due to the lack of validated analytical tools to predict its impact on life cycle cost during early systems engineering and design activities.
- **Inadvertently designed-in producibility issues** drive significant "hidden factory" inefficiencies across the manufacturing enterprise that directly and indirectly impact life cycle production costs.
- **Current DFM tools are inadequate** to predict the fundamental physical mechanisms and design characteristics driving complex aerospace and defense system producibility problems.
- **Producibilty M&S is a critical research area** missing from current S&T portfolios with focused research and investments needed to develop new and novel M&S-based analysis capabilities.

It should be noted that M&S-based methods for engineering performance and functionality analysis have been in development for the past two decades, with these analyses routinely used to guide early design decisions and trade studies by providing key knowledge early in the design process. Unfortunately, comparable M&S-based analysis tools for manufacturing are severely lacking, with most producibility issues uncovered late in the development cycle as physical hardware is being built and tested for the first time at which point it is very costly and often impossible to design-out the problems. In order to change this paradigm, the following top six M&S focus areas were identified where advanced design and analysis capabilities are needed by industry to help address the top manufacturing-driven problems impacting complex aerospace and defense system affordability:

- **Systems engineering trade study and design decision methodologies** that allow rapid "ility" trade-offs to be performed during early conceptual and preliminary design activities.
- **System integration, assembly, and test analyses** that predict production rate, yield, and cycle time performance characteristics as a function of key system architecture and test parameters.
- **Electrical, mechanical, and assembly yield models** that allow the statistical prediction of manufacturing yield targets as a function of key design, process, and test method attributes.
- **Enterprise level supply chain design and analysis methods** that incorporate quality loss mechanisms and allow "what if" scenario analyses to pinpoint and understand global risks.
- **Quantitative DFM analyses including complexity characterization** that are non-rule based and characterize the cost and yield impact of deviating from established guidelines.
- **Should cost modeling and risk impact analyses** that enable design to cost target feasibility to be analyzed at each level in the system hierarchy including probabilistic uncertainty assessments.

Detailed research and investment roadmap development for each of these six focus areas is currently underway and being led by the newly formed NDIA Manufacturing Division Advanced Manufacturing Engineering Capabilities (AMEC) committee. These roadmaps will directly support ongoing multi-year DOD ManTech and Systems 2020 initiatives to develop the next-generation of advanced model-based approaches and systems engineering tools to mitigate manufacturing risks early in the acquisition process. The roadmaps will also provide a path-forward to develop a "virtual" simulation-based framework for manufacturing risk mitigation and efficiency optimization that has the potential to fundamentally transform the way complex aerospace and defense systems are designed and manufactured in the 21st century global marketplace.

Background and Motivation

Manufacturing has always been the catalyst for innovation, with the flattening of the world as globalization unfolded over the last two decades creating new challenges and paradigms for designing, developing, and manufacturing the next generation of complex aerospace and defense systems. For example, as U .S. companies off-shored manufacturing and moved into system integrator roles a tremendous reliance was placed on all elements of the global supply chain enterprise to efficiently and cost effectively produce and deliver products on time to the system integrators responsible for delivering the end products to the customers. Unintentional or not, this industrial base landscape shift has divorced design and manufacturing activities during system development, making it even more important to have advanced M&S-based analysis tools and systems engineering methodologies available so that manufacturing risks in the present day global marketplace are understood and mitigated early in the design process. Several aerospace and defense systems that include the F-35 Joint Strike Fighter, Airbus A400M, Airbus A380, and Boeing 787 launched at the beginning of the 21st century fell victim to the perils of these additional challenges, with billions of dollars in cost overruns and schedule slips on the order of years spent correcting unanticipated problems that resulted from the inability to effectively understand and plan for manufacturing risks when the programs were launched.

The severity of the affordability problem in the defense industry is highlighted by a recent Government Accountability Office (GAO) study which found current defense acquisition programs are experiencing on average 42% growth in research and development costs from original estimates, have an average delay in delivering initial capabilities 22 months behind schedule, with 42% of the programs also reporting a

25% or more increase in unit acquisition cost[1]. The GAO study also revealed that most programs still proceed past key milestones with far less technology, design, and manufacturing knowledge than best practices suggest. A good case in point is the Joint Strike Fighter (JSF), which entered system design and development in 2002 and is unarguably the most challenging system development program ever due to its sheer size, international scope, and competing objectives for performance, affordability, and commonality among the tri-services. Over the last three years, the acquisition costs of the JSF program have increased $46 billion and the development schedule extended two years compared to the baseline established in 2007, with life cycle costs over the next 30+ years now estimated to be approaching more than $1 trillion[2]. Several factors have contributed to the JSF affordability issues including the procurement of several aircraft being pushed out to later years, but a key finding in the GAO report was that continuing manufacturing inefficiencies, supply chain problems, design maturity, and engineering technical changes were also impeding the ability to efficiently produce aircraft at the planned rates.

Commercial aerospace system development programs have also experienced their share of design and manufacturing issues as well. For example, the Airbus A380 superjumbo jetliner launched in 2000 and the Airbus A400M military transport plane launched in 2003 were both years behind schedule and billions of dollars over budget, with Airbus attributing these overruns due to the inability to price "risk"[3]. Delays are also plaguing the Boeing 787 Dreamliner launched in 2004 which was expected to revolutionize the way airplanes are manufactured using new advanced materials and a daring global manufacturing network where nearly 80% of the airplane is fabricated by outside suppliers[4], with the first flight taking place nearly two years late[5]. Several articles have been published on the supply chain problems that have plagued the Boeing 787, with production problems associated with sub-tier suppliers having a ripple effect through the extended global supply chain enterprise, costing Boeing and its suppliers billions of dollars in penalty payments[6]. More than two years after the original supply chain problems were cited, Boeing is still struggling to get quality parts shipped from its suppliers and is having to do 10X more work than initially planned to assemble and test the aircraft[7].

Unanticipated design and manufacturing-driven risks such as these not only impact program development costs and schedules, but also erode profits of companies who are faced with bringing the products to market. In addition, millions of additional dollars are spent once the designs are finally transitioned to production trying to "value engineer" or "lean out" manufacturing problems that were inadvertently designed-in to the products and supply chains as a result of early decisions. In many cases, the fixes are usually nothing more than to implement additional quality controls and oversight on the supply base to ensure suppliers meet overly stringent design specifications that are on the ragged edge of producibility. These same companies then employ armies of quality engineers to ensure suppliers meet their quality and delivery targets, which only causes the factories building the systems to spend millions more each year in "hidden costs" associated with supporting the quality control and oversight activities. Suppliers often

[1] Government Accountability Office, "Defense Acquisitions: Assessments of Selected Weapon Programs", GAO-09-326SP, 2009.
[2] Government Accountability Office, "Joint Strike Fighter: Additional Costs and Delays Risk not Meeting Warfighter Requirements on Time", GAO-10-382, 2010.
[3] Michaels, D., "Airbus Officials Cite Challenges: Parent EADS Says Key Questions is how to put a Price Tag on Risks in Airplane Programs", the Wall Street Journal, pp. B3, June 10, 2010.
[4] "The 787 Encounters Turbulence: Technical Glitches and Manufacturing Woes could Delay Boeing's Breakthrough", Business Week Online, June 19, 2006.
[5] Ray, S., "Boeing's 787 finally takes Flight", Bloomberg Businessweek Online, December 15, 2009.
[6] Greising, D., and Johnsson, J., "Behind Boeing's 787 Delays: Problems at one of the Smallest Suppliers in Dreamliner Program Causing Ripple Effect", Chicago Tribune Web Edition, December 10, 2007.
[7] Ray, S., "Headaches Still from Boeing 787 Suppliers' Parts", The Seattle Times Online, May 21, 2010.

struggle with meeting these additional quality requirements imposed upon them by the primes, and routinely raise their prices during contract renegotiations to remain profitable due to the high unplanned cost of poor quality problems that are impacting their businesses. Clearly, ignoring manufacturing risk is a costly gamble with the inadvertently designed-in manufacturing inefficiencies probably costing the entire defense and aerospace industrial enterprise upwards of trillions of dollars in "hidden factory" operating and support costs for systems that must be produced and sustained over 30+ year life cycles.

Producibility and Early Systems Engineering

Even though producibility is commonly referenced as an important design characteristic to be considered in the systems engineering process to minimize manufacturing risks, it is usually neglected in the early conceptual and preliminary design activities because it is hard to quantify due to the lack of relevant validated analytical tools. And since producibility and manufacturing considerations are often neglected during these early systems engineering activities, a key customer input has not been included in the requirements definition process - the voice of the customer for manufacturing. The needs of this internal customer are equally as important as the external customer since they will be responsible for the long term production and profitability of the proposed system, including the design and development of a robust industrial base that must manufacture and sustain the product over life cycles spanning 30+ years. Producibility has thus been targeted as an "ility" of primary importance where focused research and investments are needed to develop advanced M&S-based approaches and systems engineering methodologies that can be used to identify and design-out producibility problems as early design and industrial engineering concepts are being refined and go-forward baselines established.

The aforementioned examples also illustrate how the significant industrial base landscape shifts driven by globalization combined with the exponential growth in aerospace and defense system complexity over the last two decades has created an environment where the effective application of systems engineering principles and advanced M&S-based producibility analysis approaches are being recognized as critical skills. However, "traditional" systems engineering methods and practices which were created to a large degree during the post-WWII cold war and Apollo space-race eras are not adequate to meet the emerging challenges of present day complex global system development needs[8]. In 2007 the International Council on Systems Engineering (INCOSE) went so far as to state that the future of systems engineering will be "model-based," with the key driver being the continued evolution of complex, intelligent, global systems that exceed the ability of the humans designing them to comprehend and control every single aspect[9]. A main conclusion of the report was that by 2020, the systems engineering discipline will be especially important for the systems being designed and developed by multi-national teams in order to be able to address the social, economic, and political challenges of the 21st century.

And since the outputs of the systems engineering process are the system, sub-system, and component architectures including specifications and baselines which ultimately constrain the design trade space, it is critical that producibility and manufacturing requirements be treated as inputs to the systems engineering process. In fact, many production issues can be traced back to early architecture decisions that placed a premium on size, weight, and functionality and resulted in designs that could not be efficiently produced due to overly complex manufacturing processes, excessive yield fallout, and scrap and rework levels that were not factored into the original "should cost" estimates. Figure 1 graphically illustrates this point and

[8] "Development of a 3-Year Roadmap to Transform the Discipline of Systems Engineering", Systems Engineering Research Center, Final Technical Report No. SERC-2010-TR-006, March, 2010.
[9] "Systems Engineering Vision 2020", International Council on Systems Engineering (INCOSE), Document No. INCOSE-TP-2004-004-02, September, 2007.

shows the results of a study that found 70% of the life cycle costs are locked in by the time conceptual design is completed when only 8% of actual development funds are spent[10]. Clearly the largest, and only, opportunity to make step change improvements in producibility and affordability is in the front-end of the systems engineering process as product and industrial base requirements are being analyzed and initial design and supply chain concepts are being developed and refined.

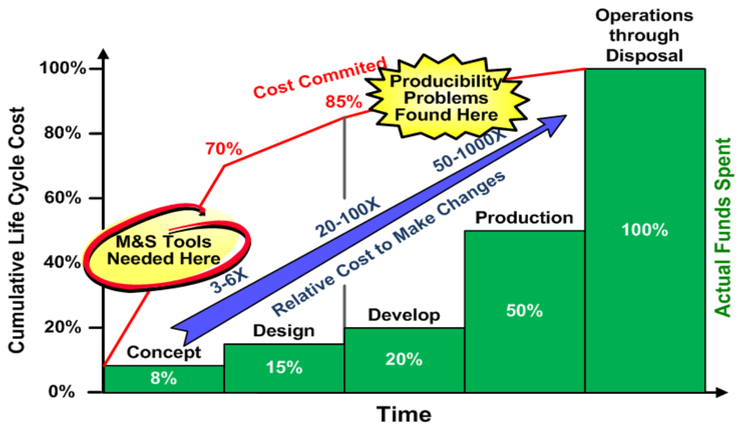

Figure 1: Life Cycle Cost Commitment as a Function of the System Life Cycle.

As aerospace and defense systems and the associated global industrial base continue to grow in size and complexity, so will the need for more advanced systems engineering approaches, design methodologies, and M&S-based analyses to guide early system design and supply chain decisions that have significant impacts on affordability. This includes the realization that new systems must be designed to not only deliver enhanced capabilities, but also be interoperable with numerous existing, partially developed, and yet to be designed systems, including the systems of systems of which it will be a constituent along with the manufacturing enterprises that must sustain them over 30+ year life cycles. It has also been realized that new methods are required to cope with the inherent uncertainty and risk associated with complex system development, the prediction of emergent system and industrial base behavior, understanding how requirements and capabilities evolve and can be managed over time, and the ability to design products for adaptability to changing threats and global supply chain dynamics. This has led to a push by government and industry to identify the next generation of advanced systems engineering methodologies and model-based analysis tools needed to help identify risks early in the design process and rapidly assess trade-offs between the ever increasing list of competing "ilities" that must be balanced in complex system design.

Current State-of-the-Art DFM Analyses

Current commercially available design for manufacturing (DFM) software analysis packages are largely based on relatively simple approaches where worksheets or automated analyses are used to analyze the impact of reducing part counts, minimizing assembly times, standardizing parts, and implementing modular design approaches. However, the majority of complex aerospace and defense system producibility issues are not being driven by simple part count issues, but rather the complexity associated with manufacturing the individual components where maximum functionality has been integrated into the smallest and lightest packages. Here producibility problems arise due to the intricate internal and external

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[10] INCOSE "Systems Engineering Handbook: A Guide for System Life Cycle Processes and Activities", version 3, edited by Haskins, C., INCOSE-TP-2003-002-03, June, 2006.

design features, highly complex three-dimensional shapes, the use of exotic and hard to machine/fabricate materials, unique special process requirements, and tightly controlled geometric dimensions and tolerances required to meet aggressive performance and weight requirements that are pushing current state-of-the-art capabilities that these simplified DFM analyses fail to address.

As a result, checklists and design rules based on best practices and lessons learned from previous designs the typical state-of-the-art tool available to aerospace and defense system design teams, with these techniques having limited success at influencing design decisions due to their inability to quantify the impact of potential producibility concerns. If more formal DFM evaluation criteria and analysis tools do exist, they are usually based on checklists that have been loaded into automated computer aided design (CAD) rule checkers used to determine if the designer has adhered to recommended best practices or not. The limitations of these approaches are threefold: first they are only as good as the rules that are captured in the checklists or software, second they are go/no-go and do not "quantify" the impact of not adhering to the rule, and third they are usually applied when the design is near final and enough information is available to answer all the checklist questions or run the CAD-based DFM analysis, at which point it is too costly to implement significant design changes as 95% of the cost has already been committed by earlier design decisions, e.g., Figure 1. For complex aerospace and defense systems where maximum functionality in the smallest and lightest package is a primary design driver, it is quite common for numerous DFM violations to occur as the design layout is being completed in order to meet competing performance, functionality, size, and weight objectives with the impact on producibility an afterthought.

Needed are the development of more advanced M&S-based analysis capabilities that can be used to quantitatively evaluate the producibility characteristics of proposed design concepts and allow potential problems to be designed-out of the product as requirements are being analyzed, designs are being conceived, and systems engineering "ility" trade-offs performed. These advanced M&S-based capabilities would enable design and industrial engineers to identify potential producibility concerns during the "fuzzy" front-end of the design process where the flexibility exists to pursue alternative design concepts that will satisfy both affordability and performance constraints. Currently M&S-based methods to predict system performance and functionality characteristics are routinely used to virtually prototype proposed design concepts and determine which alternatives are most viable early in the systems engineering process. These M&S-based approaches have been used within the engineering domain for the past two decades, with low and high fidelity numerical simulations replacing and/or reducing the amount of prototype testing required during the design and development effort. However, comparable M&S-based methods capable of predicting the underlying physical mechanisms driving complex aerospace and defense system producibility issues are severely lacking.

Producibility Modeling and Simulation Needs

It is thus no surprise that high performance computing (HPC) and simulation-based manufacturing have recently been identified as critical transformational technologies that can enable U.S. manufacturers to compete on innovation rather than cost alone[11,12]. This includes the development of advanced software and cloud computing platforms that would give small, medium, and large size manufacturing companies access to advanced analytical tools enabling virtual engineering and manufacturing simulations to replace many of the current costly and wasteful trial and error physical approaches used to bring new products to

[11] Council on Competitiveness, "High Performance Computing to Enable Next-Generation Manufacturing", White Paper, January, 2009.
[12] Council on Competitiveness, "U.S. Manufacturing – Global Leadership through Modeling and Simulation", White Paper, March, 2009.

the marketplace. These advanced M&S-based methods would not only allow U.S. manufacturers to reduce manufacturing risk and maximize the manufacturing efficiency of new and existing production operations, but also provide a means to strengthen and grow the U.S. manufacturing base using advanced analytics to identify future manufacturing technology needs. Missing however, has been a focused research and investment strategy aimed at developing new and novel M&S-based producibility analysis capabilities that can be used within the HPC framework to predict the top manufacturing-driven problems plaguing industry that impact complex aerospace and defense system development.

The need for developing more advanced M&S-based analysis capabilities and frameworks that integrate producibility and manufacturing considerations into early systems engineering activities was first recognized by NDIA in 2008, with a Joint Committee for Systems Engineering and Manufacturing (JCSEM) formed and chartered to identify current analysis capability gaps and define future analysis capability needs. A total of thirteen focus areas where advanced M&S-based analysis capabilities are needed to help address complex aerospace and defense system affordability were identified by the NDIA JCSEM M&S subcommittee that are described in detail in their final report[13]. The NDIA Manufacturing Division also recently added a fourth committee to its structure, the Advanced Manufacturing Engineering Capabilities (AMEC) committee, which will focus on identifying "engineering-based" approaches to enhance the affordability of weapon system development, production, and sustainment. The primary near term objective of the NDIA AMEC committee will be to bring together subject matter experts in industry, government, and academia to develop detailed research and investment roadmaps for the following top six high-impact focus areas identified by the JCSEM M&S sub-committee:

- **Systems engineering trade study and design decision methodologies** that allow rapid "ility" trade-offs to be performed during early conceptual and preliminary design activities.
- **System integration, assembly, and test analyses** that predict production rate, yield, and cycle time performance characteristics as a function of key system architecture and test parameters.
- **Electrical, mechanical, and assembly yield models** that allow the statistical prediction of manufacturing yield targets as a function of key design, process, and test method attributes.
- **Enterprise level supply chain design and analysis methods** that incorporate quality loss mechanisms and allow "what if" scenario analyses to pinpoint and understand global risks.
- **Quantitative DFM analyses including complexity characterization** that are non-rule based and characterize the cost and yield impact of deviating from established guidelines.
- **Should cost modeling and risk impact analyses** that enable design to cost target feasibility to be analyzed at each level in the system hierarchy including probabilistic uncertainty assessments.

Integrated computational materials engineering (ICME) is another emerging scientific discipline that is transforming research agendas across the country as government laboratories and universities grasp the significance of marrying computational power to the notion of designing materials for specific applications. At the core of ICME is an intrinsic focus on predicting the quantum to micro-scale behavior of materials including the integration of materials information, captured in computational tools along with engineering product performance analysis and manufacturing process simulations[14]. The true potential of

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[13] Sanders, A., "Modeling & Simulation Investment Needs for Producible Designs and Affordable Manufacturing: Systems Engineering Implications", NDIA JCSEM M&S Sub-Committee Final Report, February, 2010. http://www.ndia.org/Divisions/Divisions/SystemsEngineering/Documents/JCSEM%20MS%20Final%20Report.pdf
[14] Pollock, T. et al, "ICME: A Transformational Discipline for Improved Competitiveness and National Security", National Materials Advisory Board, National Academy of Sciences, 2008.

ICME will ultimately be realized when the systems engineering process invokes modeling of the transformation of materials into piece parts, and the assembly of these parts into subassemblies and functional systems. I t is here where modeling and understanding the yield of both individual transformational and higher-order assembly processes is absolutely essential to avoiding costly downstream quality and reliability issues. The research needs proposed herein fully complement ongoing ICME thrusts by addressing the manufacturing characteristics as part of the computational simulation.

Benefits to the DOD and Defense Industrial Base

The DOD ManTech program has clearly recognized and articulated the need for such approaches in two of the four strategic thrusts in its recently released (March 2009) DOD Manufacturing Technology Strategic Plan (see https://www.dodmantech.com). Strategic Thrust 3, "Active support for a strong institutional focus on manufacturability and manufacturing process maturity," supported by Enabling Goal 3.2, "Full integration of Design for Manufacturability," makes a strong case for fully leveraging the systems engineering process to move producibility and manufacturing considerations sufficiently "to the left" in the product realization process to not only reduce product life cycle costs, but also to enhance acquisition schedule and product performance objectives. Further, Strategic Thrust 2, "Active support for a highly connected and collaborative defense manufacturing enterprise," supported by Enabling Goal 2.1, "Innovative, enterprise level ManTech initiatives enabling collaborative and network centric manufacturing," specifically identifies the need to develop and leverage modeling and simulation tools within the Design for Manufacturing (DFM) construct.

An Assistant Secretary of Defense for Research and Engineering (ASD(R&E)) sponsored imperative is also underway to reduce the cost, acquisition time, and risk of Major Defense Acquisition Programs (MDAPs), with a focus within that imperative to champion systems engineering as a t ool to improve acquisition quality. As part of this imperative, the DOD Systems 2020 Initiative was launched to develop new system engineering foundations for the next decade and beyond to help cope with the exponential growth in system complexity and the associated affordability issues that have occurred. A key component of the Systems 2020 Initiative is the use of model-based engineering approaches that employ multi-scale, multi-physics M&S-based tools for use in virtual concurrent design, development, and manufacturing environments. The advanced M&S-based capabilities advocated in this paper are critical enablers that will allow producibility and manufacturing considerations to be integrated into early systems engineering trade studies and improve acquisition quality by helping ensure complex aerospace and defense system development programs are started right from the beginning with manufacturing risks actively mitigated.

The focused campaign to develop research and investment roadmaps for advanced M&S-based producibility analysis capabilities being led by the NDIA Manufacturing Division AMEC committee is therefore an important contribution to the aerospace and defense industrial base that has the potential to fundamentally transform the way complex aerospace and defense systems are designed, developed, manufactured, and sustained in the 21st century through advanced model-based approaches. Having these advanced M&S-based producibility analysis capabilities in the systems engineering toolkit will also enable "virtual prototyping" of both design and manufacturing characteristics early in the design process and address significant gaps in current Science and Technology (S&T) research and investment portfolios. In addition there are tremendous synergies between the roadmaps being developed by the NDIA Manufacturing Division AMEC committee that support both the ManTech strategic plan and the recently launched Systems 2020 initiative, with the development of these advanced M&S-based methods a critical enabler for improving aerospace and defense system affordability and acquisition efficiency.

Summary and Recommendations

Developing advanced systems engineering and M&S-based producibility analysis tools can play a big role in reducing manufacturing related cost overruns and schedule slips in complex aerospace and defense system development programs and are a key component of knowledge-based acquisition strategies. Despite this potential, M&S-based techniques for manufacturing and producibility have not been fully invested in, leveraged, or implemented into DOD programs, with significant gaps present that must be addressed for these producibility and manufacturing considerations to be integrated into early systems engineering activities. It is worth noting that M&S-based tools for engineering design and analysis have been maturing for over twenty years, with a unified research and investment strategy develop comparable manufacturing and producibility M&S-based analysis capabilities currently lacking.

This paper describes the findings of an 18-month study by the NDIA JCSEM M&S sub-committee chartered in the fall of 2008 to identify gaps in current M&S-based producibility and manufacturing analysis capabilities where focused research and investments are needed. Six high-impact focus areas have been identified with work underway by the newly formed NDIA AMEC committee to generate the research and investment roadmaps required to develop and mature advanced M&S-based producibility analysis tools and conceptual design trade study methods applicable to early systems engineering activities. Additionally, this paper also provides use-inspired research guidance to universities, government laboratories, and modeling and simulation tool vendors for the development of new and novel M&S-based producibility analysis capabilities and advanced systems engineering methodologies for up-front manufacturing risk prediction during complex aerospace and defense system development.

Recommendation 1: Complete development of a manufacturing M&S roadmap targeting complex aerospace and defense system producibility analysis and systems engineering design needs.

- Identify synergies with DOD ManTech Joint Defense Manufacturing Technology Panel (JDMTP) Advanced Manufacturing Enterprise (AME) Sub-Panel and ASD(R&E) Systems 2020 initiative.

Recommendation 2: Communicate the value proposition for focused research in producibility M&S and advanced systems engineering methodologies to government, industry, and academic leaders.

- Distribute paper to policy and technical leaders within the OSD ASD(R&E) and DASD(M&IBP) communities to advocate need for focused research and investments in manufacturing M&S.
- Distribute paper to the White House Office of Science and Technology Policy (OSTP) to identify synergy opportunities with their technology and innovation plan.
- Distribute paper to National Academy of Engineering (NAE) and Engineering Deans of leading research universities to help influence research agendas in manufacturing M&S.

Recommendation 3: Establish a national investment strategy to support the research needs identified in this paper and implement the manufacturing M&S roadmap being developed.

- S&T portfolios for federal agencies such as NSF, NIST, NASA, AFOSR, ONR, ARL, and DARPA should include basic and applied research in areas that address long-term roadmap gaps.
- SBIR/STTR solicitations should include targeted phase I & II programs aimed at developing and commercializing manufacturing M&S-based design tools that address shorter-term roadmap gaps.

Recommendation 4: Establish a government/university/industry (GUI) research consortium aimed at guiding the advancement of next-generation manufacturing M&S tools in critical research areas.

- Formulate GUI alliances to execute trans-disciplinary research agendas and develop industry technology transfer plans that address the top manufacturing M&S roadmap research gaps.

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