# Physics-Based Modeling in Design & Development for U.S. Defense

# Virtual Prototyping and Product Development

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**Traditional product development, upgrades, and anomaly investigations require design, analysis, and testing that are time-consuming and expensive with sluggish response to changes in market conditions and technology demands. Iterative analysis and testing are often the primary vehicle for product development, operational assessment and business campaigns. This type of approach serially focuses on the physical product, the physics involved, or the product's functional characteristics. This time-consuming and cyclic process involves geometric modeling and a series of analyses, each focusing on a different physical discipline. This requires extensive interfacing and handshaking with intermediate files and transfers and altering the configuration requires new analyses. On the other hand, the integrated multidisciplinary technology that we utilize relies on a common design and modeling environment. This allows rapid conceptualization and design, coupled with precision analysis encompassing multiple fields. We have successfully integrated design with mechanical, thermal, and fluid response. Furthermore, we have extended this technology and successfully developed and implemented virtual design and prototyping, which simultaneously and associatively links the geometric design, physics, and functional performance in a seamless technique. This ground-breaking approach allows us to streamline design, analysis, innovation, product development, and performance evaluations to meet the affordability requirements dictated by the current and future business environment.**

## I. Introduction

Virtual product development is a process of design, analysis, performance evaluation, and visualization in a virtual environment based on mechanistic physical principles, accurate analysis, and reliable performance predictions. Recognizing the need for this capability, our team has over the past decade created a path toward virtual product development by maturing an integrated modeling capability which uses commercially available and in-house-developed design and analysis tools. The next generation of lifecycle simulation tools are revolutionary in their role in accurately and precisely building assemblies digitally so that they can be virtually built before they are physically built. This increases agility while reducing the lifecycle cost as well as labor, time, and testing. Our team is adept with not only the use of these emerging technologies, but also the development of such tools. We have continually added new phenomena that are required to meet business needs and as a result, we have developed a robust physics-based integrated modeling capability for a wide range of disciplines including design, thermal analysis, thermal deformation, structural analysis, and fluid dynamics. Furthermore, we have successfully used this technology for spacecraft, aircraft, missiles, and other products and business campaigns. Each development and enhancement of this digital tapestry creates a framework for virtual product development which streamlines design and analysis and lowers cost, while aligning seamlessly with model based engineering initiatives to integrate systems engineering requirements with design, multidisciplinary simulation, testing, performance prediction, and digital manufacturing. This capability has matured and has been verified on numerous programs and proposals, and leads ultimately to the development of high fidelity virtual prototyping to meet affordability requirements, support operational excellence, and meet the next generation of business imperatives. Due to the use of a variety of tools and processes, development of an open-architecture virtual prototyping capability is essential in the context of model-based engineering for agile product development, operational excellence, affordability and sustainment.

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## II. Technology Maturity

Innovation and technology development should start with the identification of a need. Once a solution has been proposed, the definitions of the technical path as well as the business path are required. The realization of these plans may rely on internal company resources or may benefit from partnerships. Once a solution is in hand, maturation is the natural next step. Maturation may not mean "making it better", but may instead mean understanding the product's behavior under different conditions than originally posed. Maturation is the key to minimizing failures.

Different approaches can be utilized during the development of technology and products. A methodology that depends mostly on testing will require the most resources but will take the longest amount of time to mature the design. To decrease the time to market, a combination of testing and analysis can be invoked. These approaches are depicted in Figure 1. There are a variety of approaches to the analysis component. Reliance on handbooks, a common practice in industry, is the lowest on the resource curve, but is also the least versatile. More complex analysis approaches increase versatility and agility while increasing the resources required. These steps toward agility include closed-form solutions, numerical solutions, and multidisciplinary processes. Hand-in-hand with testing, these reduce time to market. On the other hand, virtual prototyping and testing requires the least amount of resources and has the shortest time to market. This ability to "build before you build" allows analysts to design and virtually test a product from cradle to grave, significantly reducing testing and time to market. This increases maturation capabilities as well, as the product can quickly be analyzed in different environments and boundary conditions. Virtual prototyping in this way is similar to a digital lab.

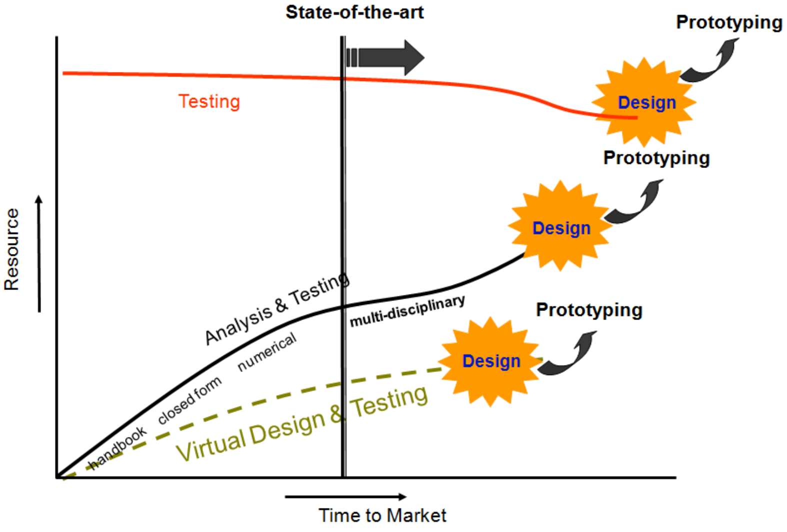

**Figure 1. Product Evolution Development**

The affordability is related to the level of resource required, and while virtual design and prototyping may have high up-front costs, the cost over the life cycle is greatly reduced. Technology is approaching a level in which the capability to create virtual products exists. However, the understanding of that technology must grow as well. As that understanding grows, the usefulness of the technology also increases. This allows users to put it to better use in the incorporation of the design of a product.

It is clear that there are currently different levels of virtual prototyping efforts being pursued by government and industry. Some approaches are limited to certain fields. However, the more a company or that company's capabilities grow, the more complexity should be added to virtual product development. The largest companies should develop and maintain virtual prototyping that encompasses all disciplines and life-cycle stages. This is the approach we have taken, so that we can have the capability to virtually design and analyze any product, from payloads and other subsystems to full systems such as aircraft, satellites, or terrestrial systems. In that situation, there will be many pockets where simpler software and methods are employed, but the grander virtual prototyping architecture should be planned to allow for those to merge into the virtual prototyping highway down the road. Additionally, the more extensive the virtual prototyping capability, the more difficult simple problems become for untrained staff to solve. Thus training becomes an imperative part of virtual product development.

A best practice used in the commercial world and identified by GAO is to separate technology maturation from product development. In an ideal case, a research organization matures developing technologies in a laboratory environment. In a laboratory, risk of failure is acceptable. The lab conducts experiments and naturally experiences some failures along the high road to knowledge. This IRAD phase of development is needed to mature and develop the knowledge of the technology until it can be incorporated into proposals. A product developer should use a specific new technology only after it has achieved a reasonable level of maturity in the research environment.

## III. Product Life Cycle Development Architecture

Our team has made the most out of our past accomplishments in integrated modeling by continuing the path forward with the leap to virtual product development. In this way, engineers can efficiently and affordably investigate geometry, physics, and function in high fidelity and real time. We have carried out IRAD projects, which have led to pilot projects and program support. Our goal has been to provide a unique capability for affordable virtual prototyping of new products, maintenance of existing assets and archiving of retiring designs. As the technology becomes more wide-spread, there are issues to address involving the variety of tools available and methodologies employed. For example, large companies may have tool preferences that vary from program to program. A parallel issue is the development of system architecture models to tie into product performance specifications. While translators are available between various environments/domains, the resulting loss of associativity of native parts and breakdown in interdependence of analytical logic prevents effective virtual prototyping and causes affordability issues. To mitigate this limitation, a Teamcenter environment was employed with proven success in providing an environment for various integrated and heritage tools. This minimizes the amount of handshaking and file translations. The goal has been an associative modeling environment that will be available to propagate any design changes through all disciplines in real time.

In this associative modeling environment, the virtual prototyping approach is used to analyze individual components as well as a system that integrates those components and therefore fosters platform-based engineering. For example, current technology in Siemens NX software allows a user to model a design within the built-in CAD, create a finite element model, perform integrated thermal/fluid/mechanical/electro-optical analyses, and then easily swap one part for another without recreating the project. This integrated and modular nature of the NX toolset, as well as collaboration with NX software engineers, makes this an ideal platform for cradle-to-grave simulation and rapid what-if scenarios. Although we have defined one preferred integrated modeling and virtual prototyping architecture, it is important to support other currently accepted industry standard techniques and methodologies. We have worked to provide suitable entrances to the virtual prototyping highway, while also providing exits for isolated tools. In this way, a wider range of analysts can join the next generation of modeling technology with minimum investment in training and cost.

## IV. Managing Product Development

Using a mature technology is one pillar of successful virtual product development. Another important aspect is a positive team dynamic, which is made up of effective leadership, a motivated and trained workforce, and a cohesive team environment. This is required to determine the appropriate tool development needs and path forward based on the overall payoff as opposed to short-term costs. The more integrated the tools, the more agile these capabilities will be. It is imperative to cultivate and sustain a knowledge base by developing and maintaining subject matter experts as well as the implementation of a robust training program. The analysts must not only be adept with the tool set, but also have problem-solving expertise based on fundamental physics. The subject matter experts must identify discriminators for affordability and agility, and with the support of management

Figure 2. Managing Product Development

identify best practices and paths forward. This creates a cycle of agility (Figure 2) and facilitates state- of- the- art product development.

Traditional processes tend to assume that systems are fully specifiable, predictable, and can be built through meticulous and extensive planning. Traditional management style is typically command-and-control, with explicit knowledge management and specialized role assignments. Communication in a traditional setting is formal; the lifecycle model is a waterfall, spiral, or similar, while the organizational structure is mechanistic and bureaucratic. On the other hand, agile processes allow high-quality, adaptive products which can be developed by small teams using the principles of continuous design improvement and testing based on rapid feedback and change. Management style in that setting is based on collaboration, while knowledge transfer imparts tacit knowledge as well as explicit knowledge. In an agile setting, teams are self-organizing which encourages role interchangeability. With more informal communication and a product feature-based product cycle, agile processes lead to an organic, flexible, and cooperative organizational structure and evolutionary product delivery.

In the context of product lifecycle, traditional product management focuses on processes and tools, anticipates limited changes and requires comprehensive documentation, emphasizes the importance of contract negotiation and tasks delineated in the contract, and follows the plan to the end. On the other hand, agile product management focuses on team communication and interaction, places priority on developing products and/or solutions that will be progressively modified and improved, emphasizes the importance of the customer with project team collaboration and daily communication, and features flexibility, response to change, and object-oriented technology.

## V. Product Lifecycle Affordability

Affordability, as a requirement, is based on the expected budgets for a product over its life cycle and provides a design constraint on the product that will be built, procured, and sustained. The “should-cost” approach challenges us to do our best to find specific ways to beat the affordability requirements and other cost projections funded in our budgets (i.e., "will-cost"), when we find sensible opportunities to do so. The overall product lifecycle cost is imperative to consider as opposed to one or a few phases of the lifecycle. As seen in Figure 3, the affordability is related to the integral of the whole cost curve from conceptual design to proof of concept, to prototyping and production, to operation, sustainability, and maintenance. This total must be less the “must cost.” Virtual prototyping (purple curve) can cost more in the beginning phases, but will run into fewer problems later on. An important factor is the time spent in the operation, sustainability, and maintenance phase. The virtual prototyping curve is lower in this phase, and if this time spans decades, the overall cost integral is greatly reduced.

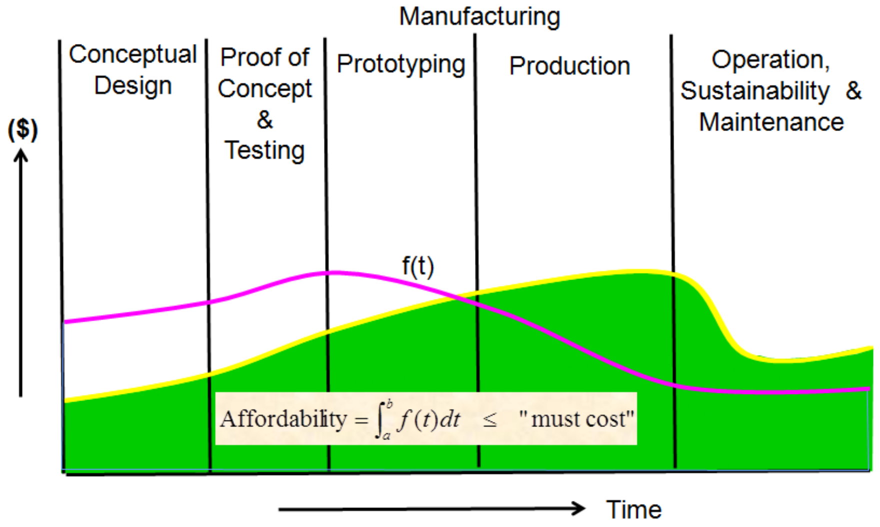

**Figure 3. Product Lifecycle Affordability**

## VI. Approach

Our goal was to use an architecture and process in which product developers can continue operating without any changes in their tools with the ability to take advantage of added capabilities and change over on an as-needed basis. Multi-CAD and -CAE users need to be able to seamlessly and associatively collaborate within a common environment. The approach is compatible with model-based engineering and accommodates progressive additions of capability and enablers for all users with minimum impact to their ongoing operation. This open architecture capability takes advantage of collaboration with COTS vendors and the latest innovations while it leads to an affordable, agile, and compatible full virtual product development. The process relies on heritage capabilities and avoids directive standardization of tools while relying on evolution of best practices in collaboration with vendors, universities, research institutions, and customer's expectations.

Our initial focus was on simulation-driven design. This consists of CAD/CAE data management and storage, process, and workflows in Siemens Teamcenter for Simulation; multidisciplinary optimization, design of experiments, response surface modeling, and reliability studies in Phoenix ModelCenter; and a large suite of potential CAD and CAE tools for parametric design, associative modeling, advanced simulation, and test correlation. Using the tightly-integrated Siemens CAD and CAE allows for bi-directional associativity between CAD and CAE files, while uni-directional associativity with CATIA and Creo CADs can be achieved through the use of JT files.

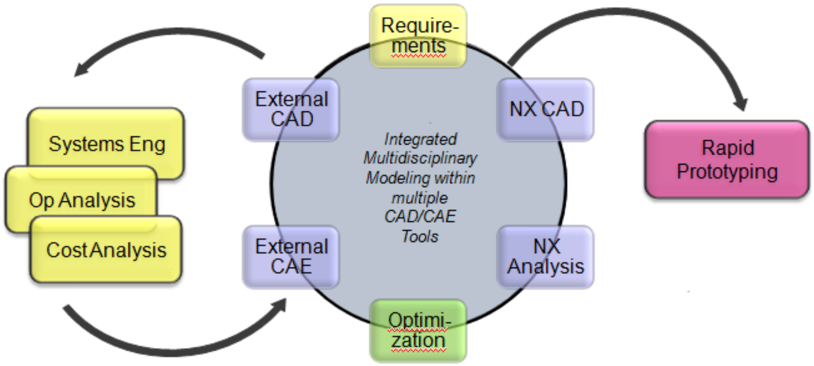

**Figure 4. Integrated modeling with Teamcenter for Simulation Product Lifecycle Management**

There are various scenarios for the use of this architecture. The Siemens NX CAD and CAE analysis suite allows an ideal associative virtual prototyping environment. Using NX CAD and CAE with non-NX CAD origins is a solution for an associative virtual prototyping environment with multi-CAD via synchronous technology. Another option is to use NX CAD with non-NX CAE, which involves interfacing any CAE including homegrown tools resulting in downstream propagation through the analysis, with data model linkage. Additionally, non-NX CAD and non-NX CAE can be used with modular launching and interfacing of all tools with downstream propagation with data model linkage. These approaches are summarized in Figure 4. Regardless of the usage scenario, the overarching benefits within a multi-tool environment for migration into Teamcenter are linkage to other modules (i.e. requirements, manufacturing), simulation files, data management, revision control, and collaboration. Integration between analysis and manufacturing requires additional modules beyond the Teamcenter for Simulation module.

## VII. Results

Our team has demonstrated the simulation module, which has comprised of integrated multidisciplinary modeling with multiple CAD and CAE tools, both internal and external. The work has been completed on proprietary and sensitive programs, but an illustrative example of some of the associative features of the method is shown here.

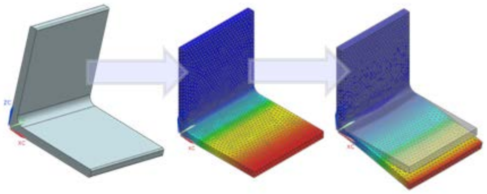

**Figure 5. Example of NX analysis.**

In this example, a solid model of a part representing a bracket was created in NX CAD (left, Figure 5.) An idealized part was created, which allows an analyst to remove unnecessary features of the solid model, while retaining a connection with the original solid model so that changes made by the designer are propagated to the idealized part.

Once the part has been meshed, a multidisciplinary and coupled analysis can be carried out. For example, temperature results from an example analysis are shown in the center of Figure 5, while a combined thermal deformation and structural response is shown in the right of Figure 5.

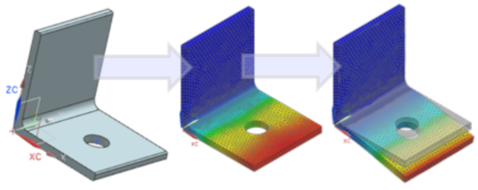

**Figure 6. Changes in the original part propagate associatively through the rest of the analysis.**

The associative nature of the process is illustrated in Figure 6. A new feature is introduced by the designer in the original solid model (left, Figure 6), and this change is pushed through to the rest of the analysis. After being updated, the previous simplifications performed by the analysts in the ideal part are preserved. Finite element models and simulation models update associatively. The thermal results update without having to redo the analysis (center, Figure 6). The structural/thermal deformation response also updates associatively (right, Figure 6.)

This simple illustration demonstrates the power of associativity. The role associativity plays in virtual prototyping cannot be underestimated, as this is the key to quick turn-around changes and trade studies.

## VIII. Conclusion

We have successfully developed a customized simulation-based virtual prototyping architecture which is robust, affordable, accommodates current and future needs, and takes advantage of existing capabilities. The architecture relies on Siemens products, which we acquired, installed, configured, and tested. We identified and demonstrated virtual prototyping processes within NX in the Teamcenter environment and compared to the native NX model. Then we demonstrated importing I-DEAS CAD into the Teamcenter environment and compared to the native I-DEAS model. We defined processes to integrate other prevalent industry modeling and simulation methodologies and demonstrated Pro-E and Catia model conversion and analysis within Teamcenter and NX. Furthermore, we demonstrated associative thermal/structural analysis for non-NX CAE.

This fully associative physics-based integrated and modular modeling and virtual prototyping capability has been developed for performance evaluation, anomaly investigation, and product development. The modular characteristics and virtual environment of this approach allow addition and implementation of more advanced physics and technology. As the technology matures, progression is made from integrated multidisciplinary modeling and modular experimental facilities to virtual prototyping, digital and agile manufacturing, and seamless and automated quality control.

The progression to virtual product development produces high-fidelity and innovative design and analysis capabilities perfectly suited for cost savings, aggressive time-to-market demands, geographically dispersed development teams, and global design and manufacturing collaborative processes. Additionally, this technology is ideal for integrated holistic conception, design, modeling, simulation, and production support encompassing the full life-cycle.

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