White Paper

Digitalization: Best Practices for Designing Smart, Connected Products and Driving Business Outcomes

Products are becoming smarter and more digital every day — creating consumer benefits, but also significant engineering challenges. Simulation offers the only solution for combining extreme innovation with product reliability, speed to market and profitability via cost control.

Today's product designs contain more functionality per square inch than ever before. We've all been impacted by the growth of smartphones and other consumer products, but digitalization has impacted every industry, from manufacturing and transportation to health care. Even traditional products are being reimagined with new smart capabilities. In the current fast-paced, highly competitive global marketplace, engineers in every industry are challenged to produce new functionality and extreme innovations, faster than ever. Yet they are also charged with reducing product size and weight, optimizing energy efficiency and delivering a host of other performance benefits. Many engineers are designing products for mission-critical applications or extreme operating conditions, which means they can't afford to overlook safety or reliability concerns. In this complex design environment, only engineering simulation enables product developers to visualize every aspect of performance, understand the trade-offs they are making, and arrive at design decisions that combine innovation with cost control, reliability and reduced time to market.

Smart Products Demand Smart Engineering Strategies

Digital technology is transforming the world around us. Digitalization has transformed entire industries, including retail, transportation and hospitality via consumers' ability to order products, summon an Uber driver or book rooms online in mere seconds. It has changed our personal lives by keeping us connected to our friends, family and jobs — and even our cars and homes — 24 hours a day.

Of course, for product development teams the biggest impact lies in the increasingly digital nature of products. Not only are there a host of new smartphones and other devices, but even common products like industrial pumps and consumer appliances are becoming smarter and featuring new functionality. Because engineers are charged with delivering this increased functionality — while keeping prices low, delivery windows short, energy efficiency high and packages small — digitalization has created significant challenges for product development organizations.

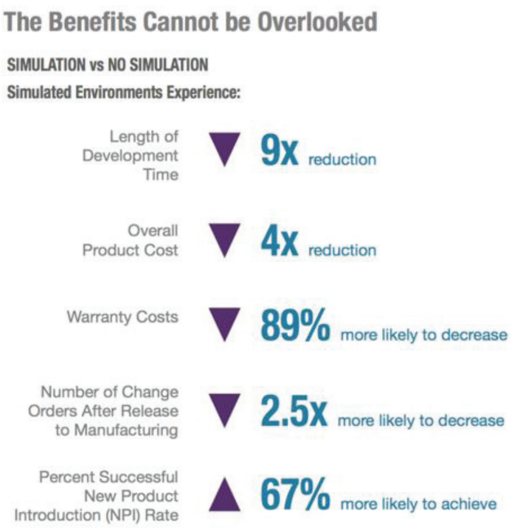

Figure 1. The Aberdeen Group reports that engineering simulation is critical to designing smart connected products

In achieving these goals, which often conflict with one another, product developers must make a series of complex trade-offs. For example, adding functionality may mean new electronic components — but will that make the product larger or heavier? Will it affect energy efficiency? Will thermal buildup become an issue?

Engineering simulation has emerged as the only means to manage these trade-offs quickly and cost-effectively, resulting in design decisions that optimize all-around product performance while also controlling costs to ensure profitability. With engineering simulation, engineers can simulate the performance of smart products, from the chip level up, to replicate the real-world conditions these products will be subjected to — without the enormous time and financial investments required by physical product testing.

With its full complement of industry-leading simulation software, ANSYS can help product development teams deliver the optimized designs they need to succeed in a crowded and competitive marketplace. Simulation software from ANSYS helps engineers address these critical smart product design challenges:

- **Size, weight, power and cooling (SWAP-C).** The addition of digital technologies creates a higher density of electronic components, leading to additional size, weight, energy and thermal challenges. Product developers must manage all these design aspects in a constrained space, while optimizing performance — using enough power to deliver reliable wireless connectivity, keeping the device cool, ensuring longer battery life, and minimizing device weight, size and interference.

- **Sensing and connectivity.** Today's products are considered "smart" because they can sense their environment, communicate with other electronics, and enable faster, more informed decisions and outcomes. This means engineers must master complex challenges such as minimizing electromagnetic interference, maximizing signal integrity and ensuring uninterrupted connectivity.

- **Reliability and safety.** Many smart products, such as those in the automotive, aerospace and medical industries, operate in safety-critical environments. The embedded control and display software underlying these products must meet high regulatory standards. In the most complex products, such as connected cars and aircraft systems, validating tens of millions of lines of safety-critical embedded software code is absolutely critical.

- **Integration.** As the complexity of products has increased over time, significant late-stage design issues can arise when individually engineered components are assembled to create an integrated system. System integration issues often lead to cost overruns and design flaws as engineers race to meet product release deadlines. The complexity of digital devices, their complex operating environment and the increased need for higher reliability mean that engineers' integration challenges have grown significantly.

- **Durability.** Smart products are expected to perform reliably under a wide range of conditions, including in extreme, harsh environments whose exact conditions are difficult to define in advance. Design scenarios are incredibly difficult to anticipate or explore using a physical test regime, yet the expectation is that the product must perform in these mission-critical environments. For example, consumer electronics must withstand minor drops and impacts. Exploring and ensuring performance in a variety of operating environments is a core engineering challenge.

In each of these areas, engineering simulation can help by replacing costly, time-consuming physical testing with smart, early-stage design in a risk-free, low-cost virtual environment. Recognizing the continuing growth of smart products, ANSYS has invested in developing a number of simulation capabilities that specifically address the digitalization trend.

ANSYS has developed seven digital engineering applications that are crucial to designing successful smart products. These applications include:

- Accurately predicting real-world antenna performance
- Making smart trade-offs in chip-package-system design
- Generating innovation in power management
- Delivering accuracy and reliability in sensors and MEMS performance
- Supporting mission-critical performance in embedded software
- Designing smart products for harsh environments
- Improving business outcomes with digital twins

Figure 2. Whether designing antennas, circuits, or printed-circuit-boards, engineering simulation can proide greater insights over build-and-test methods

By capitalizing on the capabilities of engineering simulation to make advancements in each of these areas, engineers focused on smart products can understand and intelligently manage trade-offs among product weight, energy efficiency, power and other key performance aspects. Following is a discussion of the role simulation can play in supporting product excellence in each of these six areas.

Accurately Predicting Real-World Antenna Performance

Antennas are central to the reliable, consistent performance of wireless systems. However, antennas can behave very differently in the real world when compared with the prototype testing environment of an anechoic chamber. Complex real-world structures, the movement of devices in which antennas are installed, and even human beings can cause a number of problems, ranging from multipath signal propagation to fading. To add even greater complexity, modern devices use multiple wireless technologies and frequency bands, requiring multiple antennas. The resulting antenna coupling and co-site issues can significantly degrade performance. Consider a scenario where a wireless sensor network is deployed in a factory. Each sensor uses a dipole antenna to communicate with other sensors. When a dipole antenna is deployed in an industrial setting, the complex structures and the interference from other antennas distort its radiation pattern — reducing antenna efficiency, increasing power consumption and leading to unreliable performance and even failure.

Fortunately, engineering simulation provides a reliable means for accurately predicting an antenna's behavior and connectivity under real-world conditions, whether the antenna is placed in an industrial setting, on a car, on a plane or inside a smartphone. Product development teams no longer have to rely on time-consuming, expensive build-and-test methodologies.

Using ANSYS solutions, engineers can perform a near-field analysis to predict the effects of an entire industrial environment — or other real-world surroundings — on the performance of antennas and wireless devices. By leveraging a range of simulation techniques, product development teams can quickly solve electrically large and complex full-wave electromagnetic problems.

By designing antenna systems via simulation, engineers can benefit from greater insight, improved accuracy, increased product reliability and higher performance levels — while also saving time and money. As an example, engineers at Synapse Product Development, a leader in wearable electronics, have used ANSYS tools to increase antenna range by a factor of five, while reducing the overall design cycle by 25 percent.

Making Smart Trade-Offs in Chip-Package-System Design

High-speed printed circuit boards (PCBs) and semiconductor integrated circuits (ICs) form the foundation for many smart products. Engineers are challenged to master the design complexity of these components, while answering market demand for lower operating voltages, reduced circuit density and faster data rates. In addition, engineers focusing on electronic devices also need to address size, weight, power and cooling considerations.

Whether designing a PCB or an IC, product developers must balance requirements in three broad areas that affect product reliability: electrical, thermal and mechanical performance. Engineering simulation is the best-practice method for making intelligent design trade-offs among these three areas — ensuring that a gain in one area does not degrade performance in another area. In addition to performing individual physics simulations, engineers must consider the interaction between physics disciplines, coupling signal integrity analysis with thermal simulations and connecting thermal simulations with structural analysis. This method provides a holistic view of the overall reliability of PCB design.

Simulation addresses the issue of thermal reliability by supporting an evaluation of the impact of temperature changes on the board and associated components, ensuring that the devices operate reliably over a specified temperature range. Simulation improves mechanical reliability by enabling engineers to evaluate thermal and mechanical stresses in the board, along with solder joints between the board and its components.

The chip-package-system workflow, unique to ANSYS, enables engineers to improve electronic system performance. This simulation workflow enables PCB designers to incorporate crucial information from IC and package models into their final designs. Conversely, the workflow also allows IC designers to include insights from the overall product package and the PCB when verifying their IC designs.

With all relevant system-level considerations modeled and simulated, engineers can reduce electromagnetic interference, increase electrostatic discharge protection and dramatically improve their electronic systems. Companies can also significantly reduce costs and launch their innovations faster. As one example, telecommunications leader Alcatel-Lucent leveraged ANSYS solutions to design high-speed networking technology, reducing costs by more than 67 percent.

Delivering Accuracy and Reliability in Sensors and MEMS performance

Sensor and microelectromechanical systems (MEMS) can mean the difference between the success and failure of smart products. Innovation is critical in this technology area, creating pressure on engineers to design high-performing products as quickly and cost-effectively as possible.

MEMS and sensors represent a complex product design challenge because of their special functions, challenging manufacturing processes and tiny size. MEMS are so small that performance measurement equipment can impact device function, making it difficult to obtain reliable performance data. Simulation provides accurate insight into the performance of these devices, gathering information far beyond that generated by physical prototyping — and at a lower cost.

ANSYS simulation solutions replicate the performance of a wide range of sensors, actuators and other MEMS devices — from RF sensors, dependent on electromagnetic fields, and gyroscopes, dependent on mechanical motion, to piezoelectric devices, dependent on both. Proven solvers and coupling solutions in ANSYS software enable the high-fidelity analysis of device designs. Once an initial design is created and simulated, ANSYS enables the entire device to be optimized, including the interaction of the components, before building begins. For example, an initial design may be optimized to minimize power use and temperature spikes by varying the product's physical size and examining performance trade-offs.

Supporting Mission-Critical Performance in Embedded Software

While invisible, embedded software code lies at the heart of every digital product system — adding functionality, controlling component interactions and safeguarding against failure. The importance of this software cannot be overstated, making it critical for engineers to develop high-integrity code that supports flawless system performance.

The average new car may contain 50 million to 100 million lines of code — and, with autonomous vehicles on the way, software content will only increase. But embedded software is not just for cars; it also adds smart functionality and control to industrial equipment, robots, planes and drones. Because many of these products and systems are safety- or mission-critical — for example, braking systems on cars and planes — the control software must operate flawlessly. And, when systems do fail, they must fail in a predictable way that minimizes damage.

Software development is no longer just about writing the code; it is also about verification and validation. Typically, there are industry regulations, certifications and qualifications that govern the reliability and performance of software. For each line of executable code, software engineers may need to write 10 or more lines of verification code.

To accelerate this process, improve productivity and increase accuracy, ANSYS has created a model-based embedded software development and simulation environment with a built-in automatic code generator. Engineers can use ANSYS solutions to model complex systems, understand the interaction of subsystems and generate high-integrity code that complies with tough industry standards.

Piaggio, an Italian manufacturer of motor scooters, has been using ANSYS simulation software for automatic code generation, allowing the product development team to express design specifications in a formal manner. As a result, Piaggio can produce software quickly, remove functional bugs and reduce the number of expensive test demonstrations. Software modeling and simulation have accelerated Piaggio's development process by a factor of three.

Designing Smart Products for Harsh Environments

Whether they're employed in industrial, aerospace or consumer applications, highly digital devices can be subjected to harsh environmental conditions that include vibration, impact and fatigue. In these challenging conditions, smart products must operate robustly for extended periods and across great distances, often without maintenance. In extreme environments, a product malfunction can result in significant costs to repair or replace the system. Critical missions can fail, and human lives can be lost. For example, NASA has demonstrated that 45 percent of first-day spacecraft electronics failures were caused by vibration during launch.

With so much at stake, engineers must consider potentially harsh environmental conditions very early in the development process, when design choices can be made at the lowest cost — and with the least impact on the project schedule.

Physical prototyping is simply not a viable option. Not only is it difficult to create all the possible test scenarios given the constraints of time, budget, location and resources — but, in addition, measurement results can vary greatly and lack the necessary level of fidelity. Simulation provides the answer, empowering engineers to apply a wide range of physical forces and temperatures to their designs in a risk-free, cost-effective virtual design environment. The results are a higher degree of product confidence, a shorter launch cycle and significant cost savings.

As just one example, a leading aerospace and defense firm leveraged ANSYS software to simulate harsh environmental conditions, including vibration, to eliminate expensive and time-consuming physical testing. As a result, the company was able to save over $1 million by reducing the development time, eliminating consultant fees and cutting physical testing costs.

Figure 3. Simulation enabled digital twins can deliver business value through predictive maintenance, lifing, and future product innovation

Improving Business Outcomes with Digital Twins

Engineering simulation is a key component of one of the most exciting innovations that can improve industrial operations and services: the digital twin. A digital twin is a physics-based model of a physical product, mirroring its real-world operating conditions and enabling engineers to predict the product's life, performance and failure modes with the aim of maximizing reliable uptime.

A digital twin is the combination of all the organization's digital information on a specific product with operating data streaming live from the product as it is being used in operation. Merging a physics-based understanding of product performance with analytics delivers the insights that unlock the true value of the digital twin. Using these insights, engineers can understand the operational failure modes of the product, prevent unplanned downtime, improve product performance and seed the next product generation.

The digital twin leverages multifidelity simulations from detailed 3-D physics models of a physical asset to create reduced-order models (ROMs). The ROMs, synthesized representations of the physical asset, compress simulation times and demonstrate key product performance aspects. For example, a digital twin of a gas turbine installed in a power plant might be designed to highlight energy efficiency, emissions, turbine blade wear or other factors of importance to the customer and thus the product development team. When deployed in the field with the physical asset, the digital twin can utilize virtual sensors that augment physical sensors to provide in-depth analysis of the asset's performance. Defying physical constraints, virtual sensors can be embedded in digital twins with no limitations.

By studying the digital twin, engineers can determine the root cause of any performance problems, improve output, schedule predictive maintenance, evaluate different control strategies and otherwise work to optimize product performance — and minimize operating expenses — in near real time. This is becoming increasingly important as customers shift from buying a product to buying an outcome, with the performance risk passed on to the product developer.

"One of the most exciting aspects of digital twins is that we can now look at an individual product system — such as a wind turbine — and isolate just that one product," notes Marc-Thomas Schmidt, chief architect of the Predix® analytics platform for GE Digital. "We're not talking about a general class of turbines, but that one turbine. We can study the weather patterns that affect it, the angle of its blades, its energy output, and optimize that one piece of machinery. If we do this across all our product systems in the field, imagine the impact on overall product performance. This clearly represents a revolution in product engineering."

ANSYS is partnering with GE Digital and PTC ThingWorx™ to maximize the contribution of engineering simulation in supporting digital twins. Simulation is a critical capability for creating an accurate model of the operating product under study and providing the greatest level of insights to the product development team. Chris MacDonald, senior director of ThingWorx Analytics at PTC, emphasizes that "the technologies that underpin the IoT make it possible to integrate simulation with products as they exist and operate in the real world."

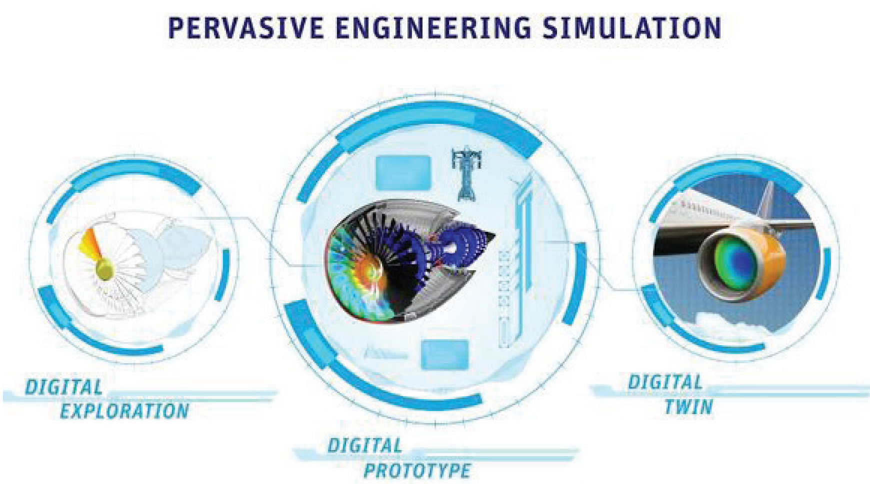

Figure 4. Engineering simulation can improve the entire product lifecycle

Seizing Leadership in Today's Digital Landscape

The digital revolution is characterized by extreme product innovation, placing incredible pressure on product development teams to incorporate more and more functionality into their designs, while also optimizing costs, profits, time-to-market and productivity. Since many smart products perform mission-critical sensing and control tasks, engineers can't afford to sacrifice reliability or safety in their race to product launch.

Engineering simulation has emerged as a critical capability that separates the leaders from the followers in the fast-paced, highly competitive world of smart product design. Via simulation, product development teams can understand the implications of various design decisions at a very early stage, enabling them to make strategic decisions that support overall business success. Already, companies in virtually every industry are leveraging the power and speed of engineering simulation to establish themselves as leaders in today's digital world.

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