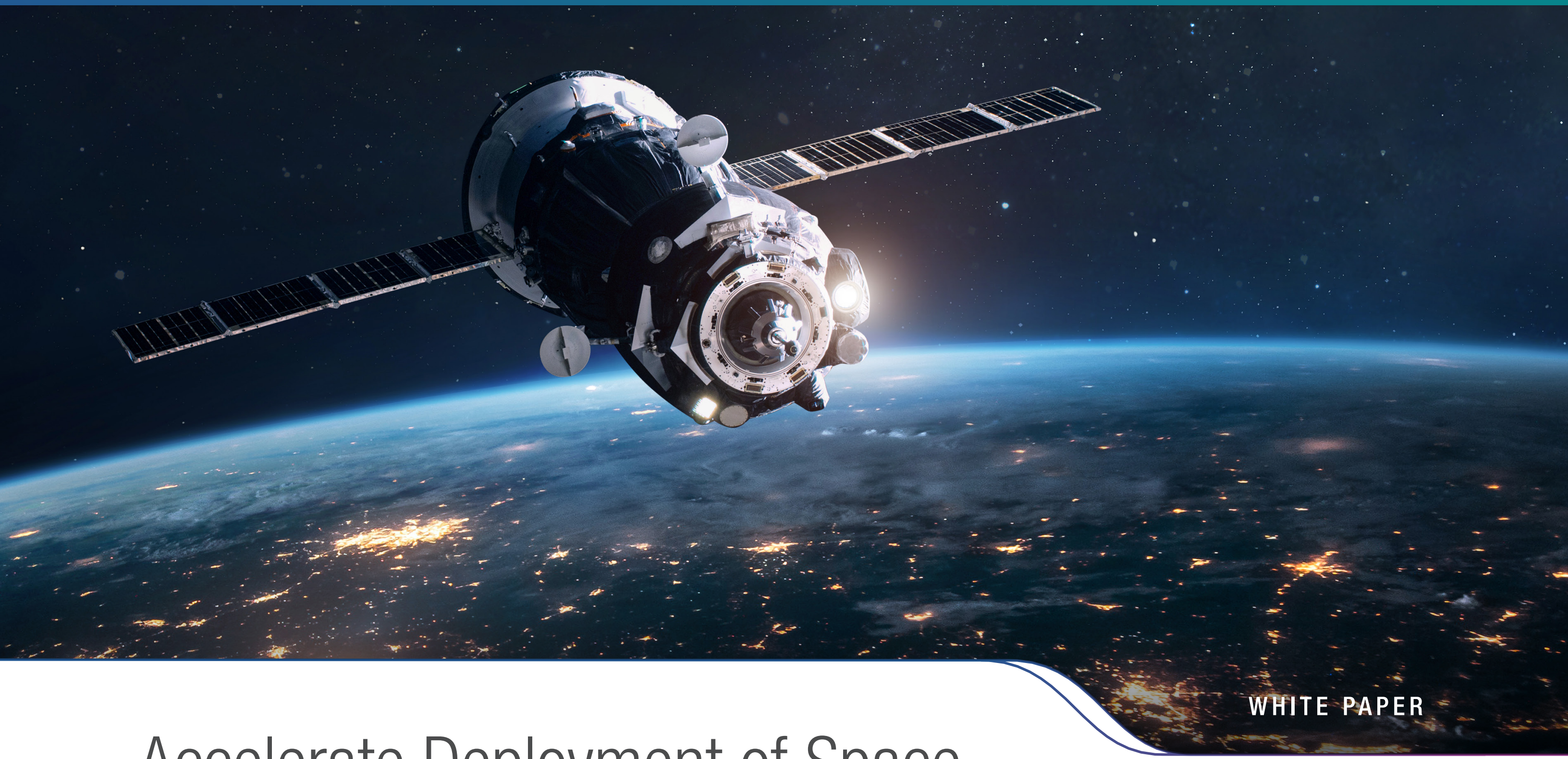

Accelerate Deployment of Space Missions Through Digitalization

Apply digital engineering techniques to reduce costs and increase operational confidence

Digital Engineering

The US Department of Defense defines digital engineering as an integrated digital approach that uses authoritative sources of system data and models as a continuum across disciplines to support life cycle activities from concept to disposal.

The Need for Speed

Huge paradigm shifts have occurred in the space industry over the last two decades. After the initial space race of the 1950s and ’60s, the investment in commercial space applications rested on the experiences of government agencies that put humans on the moon and satellites into orbit. Through the ’60s and into the mid-’70s, those agencies launched bent-pipe transceivers for television, telephone, and fax signals alongside the first weather satellites.

Through the 1980s and mid-’90s, commercial satellite operations were dominantly Global Navigation Satellite System, video broadcast, weather, telecommunications, and global imaging. The costs associated with the launch and deployment of such missions drove engineering choices that minimized risks, ensuring space durability for 15 to 20 years or more to provide maximum return on investment. The use of space-proven radiation-hard components was essential.

Large satellites with backup systems in medium Earth orbit and geosynchronous equatorial orbit provided global coverage. The largest of these satellites could weigh several tons on the Earth’s surface.

KEYSIGHT TECHNOLOGIES

In the early 2000s, a new space race began to drastically reduce the cost of access to space. Driven by the likes of SpaceX CEO Elon Musk, this trend merged with the ongoing densification of integrated circuit technologies to flip economies of space on their heads. The result is “NewSpace,” which comprises many smaller, more powerful satellites in less-costly low Earth orbits.

It is possible and economically viable to provide a space-based infrastructure for traditional space applications and emerging applications such as radar and quantum key distribution. This capability has kicked off a NewSpace race, or gold rush, to deploy commercial infrastructure in reserved orbits. The goal is to provide services and create new downstream industries leveraging the data generated or transferred through these satellite networks.

Meeting NewSpace Challenges Through Modeling

The changes in market dynamics brought about by this space gold rush have pushed manufacturers and system developers to accelerate design cycles while minimizing risks and development costs. Established manufacturers must accelerate or risk losing business to agile startups. The startups may need to balance their technological ambitions against limited capital resources.

In the past, engineering practices used radiation-hardened, space-proven components in service for potentially 10 to 15 years to minimize risk. Such methodologies cannot meet the requirements of quickly launching state-of-the-art technologies to compete with terrestrial applications. The answer may be digitalization and data-driven model-based engineering.

Evolution of engineering models

The use of models in engineering is not new. Mechanical development has used computer-aided design (CAD) since the mid-1960s. However, today’s computing power allows engineers to build complex models that may interact with one another in an entirely digital environment.

Digital models have reached the point that the term “digital twin” describes their operation. Ideally, a digital twin is interchangeable with the physical version, allowing teams to quickly develop, test, and improve designs without significant investment and costly design cycles.

The proper use of models within and across teams can accelerate development by enabling parallelism between groups. It also can inform decisions earlier in the development life cycle. This is particularly the case when the models are not static but evolve through the application of realistic data and increasing parameters to improve their realism.

Figure 1 shows a simple view of a product life cycle and its various stages alongside the processes. Generally, the generated data helps inform decisions or check models and assumptions made earlier in the life cycle. The illustration does not depict the number of iterations made in the development process. If a manufacturer finds a serious failure, it can take development back to design at the manufacturing or operation stage, resulting in higher costs and delayed deployment.

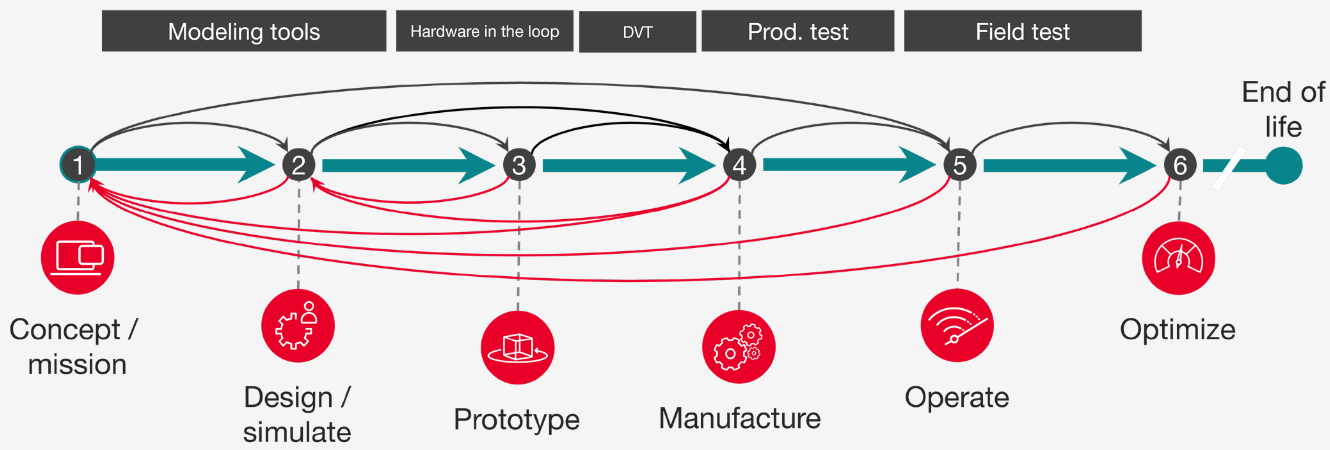

Figure 1. Processes and data through a simple product life cycle

Developers typically use modeling tools early in the process to define the mission and then design systems and components based on concept and objectives. Mission parameters will inform the operational goals and steer the design parameters for hardware and software. As we begin to build prototypes, we may test early runs via hardware-in-the-loop testing. Such testing validates the design and increases confidence that it meets requirements. Data from these tests gets fed back to check and improve the realism of our design.

As we shift from prototyping to manufacturing, we want to increase our operational confidence by performing a suite of measurements under design validation testing. Once in manufacturing, production tests quickly confirm that production units meet design standards and will match the expectations set out by the mission concept. Throughout this process, the generated data helps inform later discussions and allows us to check and control that we are on the correct path and meeting our objectives.

If we do not apply digitalization and model-based engineering methods, we may lose most of the data and experience obtained through this single life cycle. Individuals and teams that developed this system have the know-how and expertise. Without processes that accurately capture the data in a way that makes it accessible and usable in the future, that know-how may disappear over time as people change jobs or folders on individual hard drives get lost.

The Case for Digital Engineering

Figure 2 shows a simplified digital workflow that takes its lead from the product life cycle previously discussed. This workflow does not include an end-of-life stage, as this process looks to make data available throughout current and future product life cycles. It also leverages data acquired from previous developments. Such data accumulation and usage is a continuous cycle. It gathers and improves the quality of data used to model and simulate the decisions made in product life cycles.

But where do we start? There is no ideal point of departure for a digital engineering workflow. We accumulate relevant data that defines system and component performance throughout the product life cycle. We may embark on digitalization at the concept stage. Yet we can use measurement data from previous developments to improve our concept.

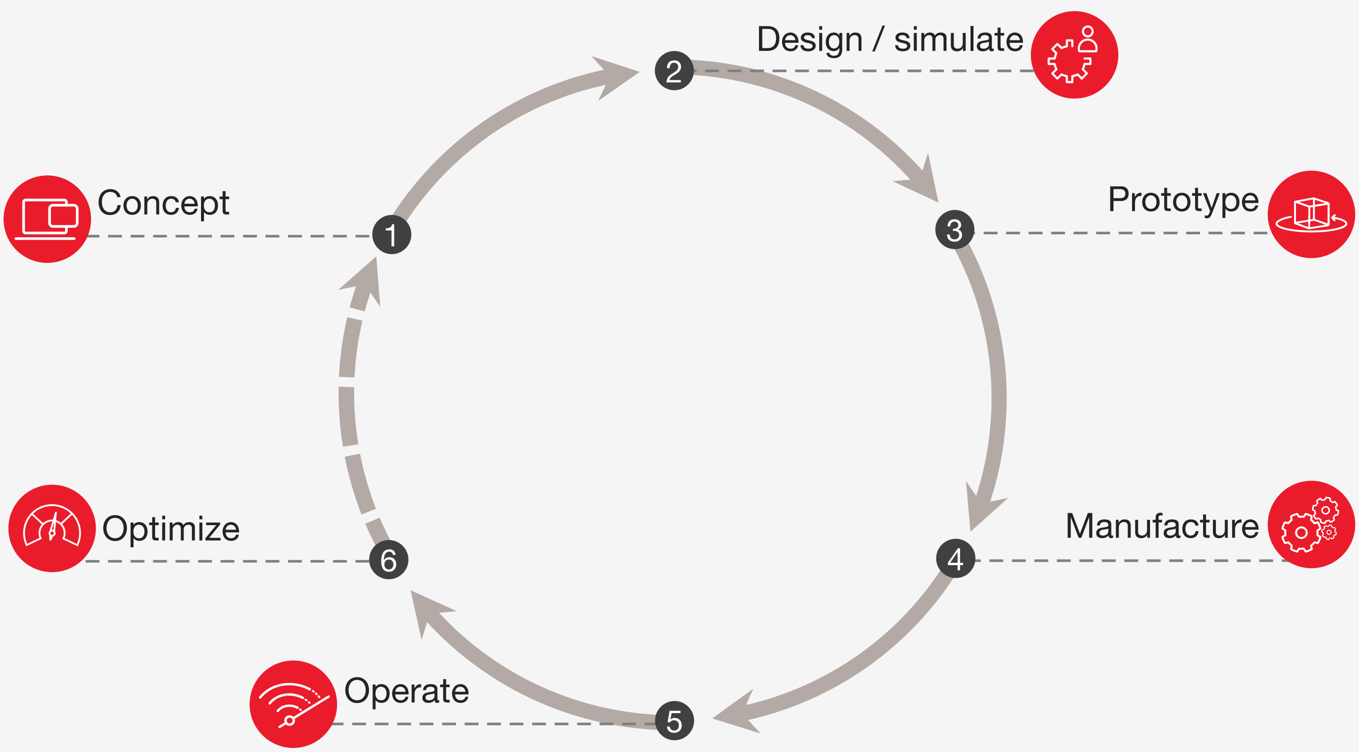

Figure 2. A digital workflow

An example with SSPA

Consider a manufacturer of high-power, solid-state power amplifiers (SSPA) making devices for satellite ground stations. Looking at Figure 2, it would be in stage 4 of the digital workflow. In the production of the SSPA, the manufacturer will test the devices to ensure that they meet specifications.

Typically, these measurements are optimized for speed of production and lower cost of test. The tests may be a superset of the entire device characterization. However, data acquired during the production of these SSPA devices go beyond the RF characteristics. It includes the cost of test, production yield, types of failure, and any other data that describes how the device performs in the production environment.

As the manufacturer moves to device operation (stage 5 of the digital workflow), data points of interest might include sales volume, customer satisfaction, and support costs. The manufacturer may have some data about how customers use the SSPA devices, including modulation bandwidth of the signals amplified, the modulation format and so peak-to-average ratio of the signal, output powers, and other RF requirements. For each customer use case, information such as purchase volume and geography of use can help inform later decisions.

The manufacturer may then look to optimize the system (stage 6). Customer requirements may drive such optimization: wider modulation bandwidths, higher output power, higher reliability, lower temperature operation for arctic deployment, and lower power consumption. It may be possible to meet these requirements with the existing solution, but some cases may warrant a new design or product. Optimization could also include internal optimization of the manufacturing processes, cost reduction, increased yield, and increased production volume.

A cyclical process

At some point, the manufacturer may identify a new opportunity or decide that it has acquired enough market requirements to justify the development of a new solution. The manufacturer moves into stage 1, building a new concept and pulling data from manufacturing, operation, and optimization. Using acquired data allows the new concept to closely match the reality of the current solution and know-how. Incremental improvements or technological reuse can leverage this data to build better models and simulations.

The informed concept can then move into stage 2, design and simulation. Using data from the concept stage, the design stage requirement parameters have higher accuracy. They facilitate an accelerated design process with a lower risk of redesign. They can reuse or build upon processes and designs that worked in the past.

Designers should test data acquired during this stage against assumptions made in the concept stage to ensure that design parameters meet the overall concept requirements. Similarly, parameters of operation as defined by the concept and design can help optimize other downstream development stages, such as the manufacturing and test processes.

As the manufacturer makes hardware components and initial prototypes, it passes to stage 3. Hardware tests observe the system's physical performance. The manufacturer has continually tested the concept and design data, leveraging acquired data. The resulting hardware performance should more closely resemble the objective performance to meet the mission concept. However, some differences could impact performance. To test them, the SSPA manufacturer simply needs to take the physical measurements of the system and feed that back to the conceptual model first defined.

Better data and models

Several loopbacks may exist in this process, specifically as the manufacturer develops designs and hardware and tests them against the requirements and concepts. In each iteration, the manufacturer obtains better information that reflects the reality of the system and how it operates in a physical environment. Improving the understanding of device performance builds better models that will improve this design cycle and inform future products and systems.

As the new SSPA moves into production, the manufacturer acquires new data and tests to verify that the system meets requirements and functions in its operation. The data workflow continues, informing future developments and allowing reuse and incremental improvements. It also provides long-term security to the manufacturer by capturing intellectual property in the organization's technology, methods, and processes.

The “Shift Left” in Risk Reduction

In the previous example, the process of acquiring and reusing data throughout a product’s life cycle and into the next clearly accelerates decision-making and overall development. More globally, this digital engineering process can reduce risks and provide maximum return on measurement investment.

Model-based engineering has a concept of “shift left.” Figure 3 shows this graphically. It charts confidence in system performance against the time and cost for corrective modifications over a product’s life cycle. The black line depicts a typical product development process. At the concept stage, confidence that the conceptualized system will operate at a given performance level is relatively low. Yet the costs of change are similarly low.

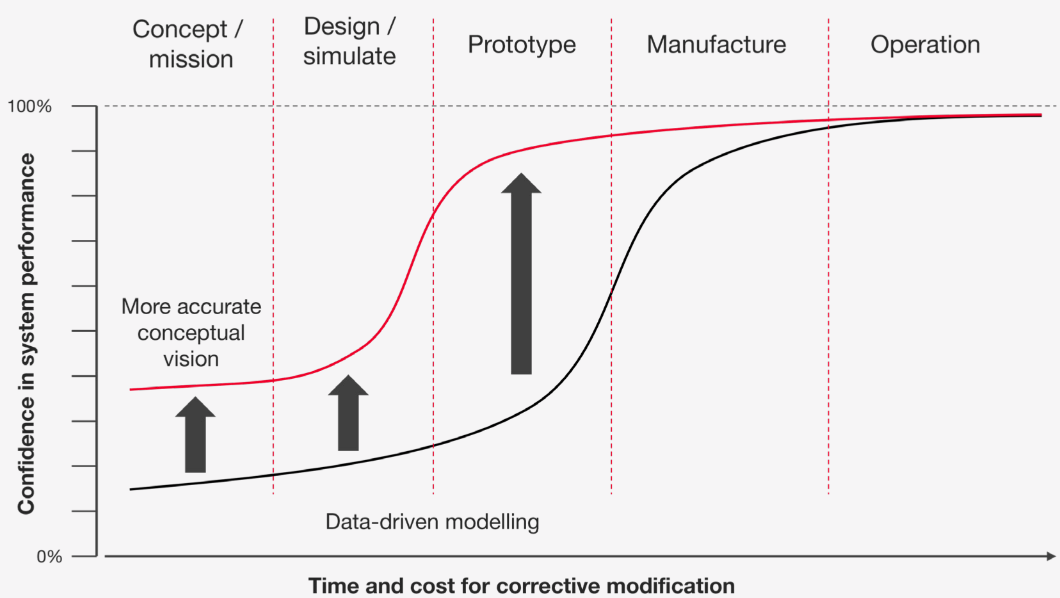

Figure 3. Increasing confidence through data-driven modeling (Source: Raymond M. Kolonay, Ph.D., Air Force Research Laboratory)

Engineers spend a lot of time defining what we will do during the concept stage because it is cheap and quick to make modifications. As we move through simulation and into prototyping, our confidence in system performance grows. Yet we are still far from 100% confidence.

As we move into hardware and manufacturing, our confidence begins to approach 100%. If we discover an issue at this late stage, however, correcting it can be costly and may even lead to redesign or reconceptualization. Our confidence rises when we reach the operation stage.

The red line shows a similar development based on data-driven modeling. At the concept stage, our data-based vision provides a better understanding of our capabilities and requirements. Our confidence in performance is higher as we build models based on real-life performance, so our confidence grows. As we build hardware based on those models, our ability to predict physical performance is nearly equivalent to a traditional life cycle moving into production. The “shift left” can be seen as a “shift up.”

The Tools of Digital Engineering Are Already Available

The acquisition and use of data enable increased confidence and quality, and reduce risk earlier in the digital engineering life cycle. Not all of this data links to electronic measurement. Production yields, cost of goods, supply chain requirements, and other information can help inform decision-making processes. However, many space applications — including communications, broadcast, intelligence gathering, and simple telemetry, tracking, and command — require radio-frequency communications and, therefore, an end-to-end signal chain.

The tools to enable us to adopt these methods are simple:

- measurements that allow us to obtain data that describes the system
- modeling that leverages this data to enable simulations of the system in a computer environment

Engineers can employ various hardware, software, and service products to enable these processes.

Conclusion

As the space industry enables new applications on orbital platforms and interplanetary missions, the race to deploy new technologies and systems has accelerated. The effort to reduce risk, accelerate development, and reduce costs has pulled the focus of engineering onto simulation and model-based engineering methods. These techniques require access to accurate physical descriptions of individual components that can only come from calibrated measurement.

By making such data accessible and usable throughout a development workflow, engineers can speed up development from the outset. Model-based engineering enables system development that does not depend on hardware availability. It allows parallelism in development across teams and immunizes development from supply chain issues.

Further Reading

For more information on the technologies enabling the satellite ecosystem, please visit the following resources:

Satellite Mission Assurance with Keysight Technologies
https://www.keysight.com/zz/en/assets/7120-1036/brochures/Satellite-Mission-Assurance-with-Keysight-Technologies.pdf

PathWave System Design: One environment for system architecture, design, and verification
https://www.keysight.com/zz/en/assets/3121-1074/technical-overviews/PathWave-System-Design.pdf

Engaging New SatCom Missions Hit aggressive goals with PathWave System Design
https://www.keysight.com/zz/en/assets/3121-1174/solution-briefs/Engaging-New-SatCom-Missions-Hit-aggressive-goals-with-PathWave-System-Design.pdf

Advantages System–Level Design Delivers for Phased–Array Development
https://www.keysight.com/zz/en/assets/7119-1049/white-papers/5992-4196.pdf

W4815B PathWave System Design and Satellite
https://www.keysight.com/zz/en/product/W4815B/pathwave-system-design-satellite.html

Satellite and Aerospace Channel Emulation Toolset
https://www.keysight.com/zz/en/assets/7018-05279/brochures/5992-1606.pdf

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