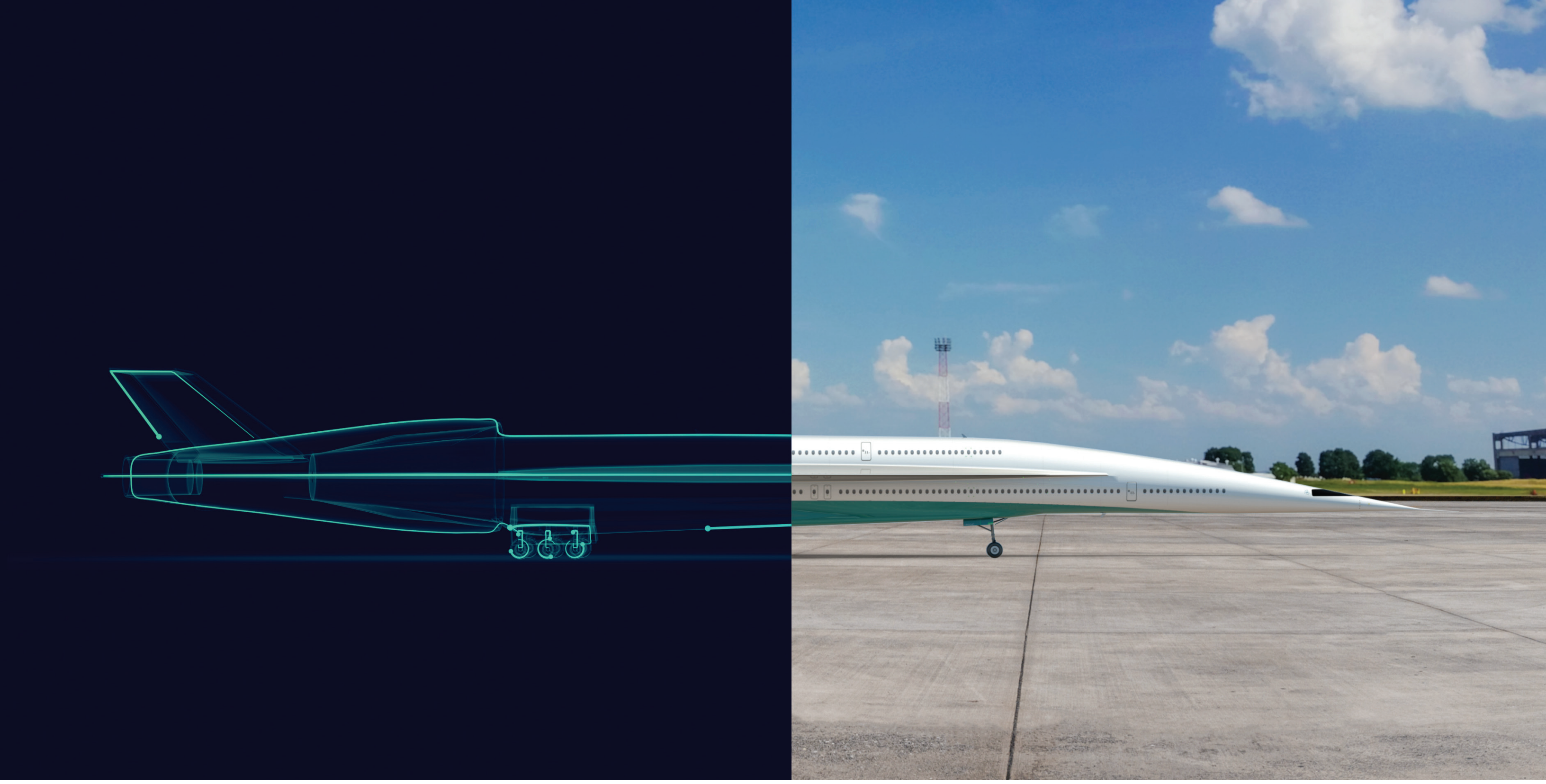

DIGITAL INDUSTRIES SOFTWARE

Digital transformation maturity

Integrating the digital twin and digital thread to overcome a shrinking workforce in aerospace and defense

Executive summary

Digital transformation can close the engineering workforce gap, but to date most aerospace and defense companies have seen only a limited return-on-investment (ROI) for their digital transformation investment. This is because most companies' digital transformations are still immature, and their vision for these transformations is limited. Siemens' "Five Levels of Digital Transformation Maturity" is a road map for closing the workforce gap and allowing aerospace and defense companies to build more optimized products faster with far fewer engineers.

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Introduction

This white paper focuses on digital transformation maturity as the largest issue facing the aerospace and defense industry in the next decade. Extra focus on hiring and educating new engineers will not close this gap. The industry must find a way to multiply the impact of their existing engineering workforce.

The aerospace and defense industry is in a place it has not been for more than 30 years. The commercial and defense sectors are projecting many years of continuous growth. This is outstanding news for the industry, but aerospace and defense is not on a path to spend their projected trillions of development and manufacturing dollars. There is a significant shortage of engineers to develop and manufacture these products. The gap between new engineering roles created and new engineers entering the U.S. market each year is stark, with about one-third of new roles unfilled.[1] The growth of the aerospace and defense industry and its ability to innovate is limited by its engineering workforce. There is plenty of money and a significant need. There are not enough skilled workers.

What is the answer? How do we correct this? We can train more engineers, but a 2022 U.S. National Science Foundation Report[2] said that while U.S. engineering graduation rates (bachelor's degrees) are increasing, the year-over-year (YOY) growth from 2018 to 2019 was just 3.9 percent, the smallest increase in a decade. We are not on a path to educate our way out of this problem.

The aerospace and defense industry must find a way to multiply the impact of their existing engineers. This can be done with digital transformation, but the pace and maturity of this transformation must be accelerated. Per a 2023 CIMdata research report:[3]

- Attempts to implement systems engineering and collaborative development are stymied by the lack of a road map for linking multiple product representations of the various disciplines
- Attempts to implement a digital thread often result in a series of false starts and frustration
- It is hard to see how a digital thread strategy can be planned and implemented incrementally with a predictable ROI

Digital transformation can help close the engineering workforce gap, but to date many aerospace and defense companies have not seen the expected ROI for their digital transformation investment. That's because many companies' digital transformations are still immature, and their vision for these transformations is limited. Siemens' Five Levels of Digital Transformation Maturity is a road map for closing the workforce gap and allowing aerospace and defense companies to build more optimized products faster with far fewer engineers.

Defining digital transformation maturity

Digital threads and digital transformation are not new topics for the aerospace and defense industry. Most aerospace and defense companies have been on a digital transformation journey for the past few decades. Mechanical and electrical components are designed digitally in computer-aided design (CAD) tools. These components have a digital twin that are analyzed virtually before they are built physically. What about the issues with the "road map for linking multiple product representations of the various disciplines" the CIMdata report describes? The Five Levels of Digital Transformation Maturity is the Siemens framework for linking multiple product representations and maturing digital transformation. Digital transformation is a journey. This framework explains how companies can understand where they are on their journey, and where they need to go next. The graphic below shows the five levels framework.

Most aerospace and defense companies are configuring their data so they can find and reuse it. Many are also connecting their data so they can trace requirements to analysis, design and test, and to evaluate the impact of changes. Although this is a good start, the CIMdata research report concluded that connected and integrated data is primarily what many companies expect from their digital transformations (or digital threads). For many companies, digital transformation is all about data connection and little about what can be accomplished once the data is connected. The result is their digital transformations have neither been fast enough, nor gone far enough.

As the CIMdata report concluded, "It is hard to see how a digital thread strategy can be planned and implemented incrementally with a predictable return-on-investment." Siemens believes the ROI for

digital transformation goes beyond just connected data. The payoff is when data is put to work and an integrated product is optimized virtually before it is built physically.

The next step is to automate. Automation has two parts: automating mundane tasks that humans do not want to do and automating complex tasks that we thought only humans could do.

This starts by automating mundane tasks involved in configuration and connection and then automating things such as report and requirement development. Siemens already has customers using rules-based algorithms to auto generate wiring diagrams and other electrical support material that is saving customers thousands of hours per aircraft. Once a company has automated the mundane, they are on their way to creating a better work environment that more engineers will want to be part of. More than just increasing efficiency, this can attract new talent and reduce attrition.

Once mundane engineering processes are automated, the next step is to automate complex engineering, development and manufacturing processes. This leads into the fourth step: generate. This is when the real payoff begins. This is where companies begin to see the multiplication of their existing engineering workforce. Generative development will eventually allow engineers to create complete integrated mechanical, electrical, electronic and software systems or product designs from just a set of input parameters.

The goal is not just a compliant design, but also an optimized design. The problem with current manual model-based design techniques is the design of complex, integrated aerospace and defense products require too much time and too many engineers. It takes far too long and far too many resources for a design to mature to the point that it can be evaluated and improved. Once the wings and fuselage are designed, we realize the aircraft is too heavy, or maybe the aero team decides the loads must change. This causes a second, third or fourth design iteration. Eventually it is time for the critical design review, and design teams are forced to accept the design they have been able to create in the time they were given. What results is a design that might meet most of its requirements but is not optimal.

The answer to this problem is not figuring out how to do the best design first. The answer is to find a way to do thousands of design iterations in the time it now takes to do five or 10. This is the promise of the fifth step: optimize.

Optimizing a complex aerospace and defense product requires complete integration and automation of mechanical, electrical, electronic and software design tools with a host of simulation tools. When this is combined with generative design, a closed-loop, optimized digital thread allows engineers to kick off thousands of design iterations that are then compared to a set of key performance indicators (KPIs). Then just the top few designs that best meet the KPIs are presented to engineers for consideration.

Companies can use the Five Levels of Digital Transformation Maturity framework to evaluate their progress toward maturity and determine the next step on their digital journey. Digital transformation maturity will help companies transition from a document-based company to a fully digitalized and optimized closed-loop enterprise, overcoming their workforce issues in the process.

The five levels of this framework are:

1 Configure

Configure is the initial transition from document-based to model-based workflows. This involves managing the creation, changing and archiving of all information related to a product, and storing data in a safe place so it can be found and reused at any point in the product lifecycle, also known as product data management (PDM).

2 Connect

Connect is the next stage, bridging multi-domain product data throughout the product lifecycle. This enables enhanced traceability from requirements to design, verification/certification, manufacturing, support and disposal. Connect also involves creating data models that enable the flow of product data across engineering domains, tools and databases, enabling an authoritative source of truth for a product. Many companies see this stage as the end of their digital transformation journey, but stopping here delivers only a limited ROI. To get the most from digital transformation maturity, companies must go further.

3 Automate

Automate is at the heart of digital transformation, freeing humans from costly, tedious tasks to focus on the work that matters. Automation enables computers or robots to reduce or eliminate the need for human interaction to accomplish a task. For development and design, this can include many of the tasks required to set up and maintain PDM and product lifecycle management (PLM) systems (the steps from configuration and connect). This automation extends to automatic movement of data across engineering domains, tools and databases. This allows generative tasks to be accomplished across a complex system or product. For product manufacturing, these automated tasks can also include movement of materials, build and assembly processes and inspection.

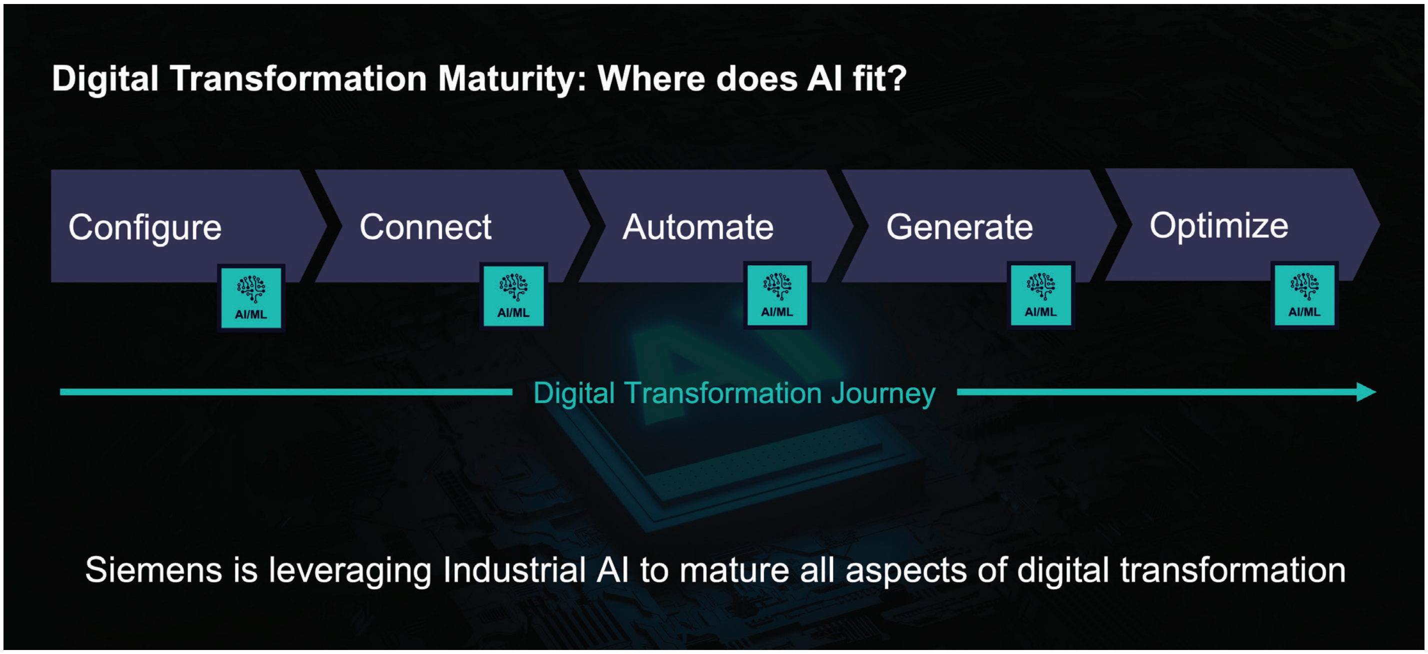
Automate can be divided into two phases; the first is automating the mundane (things humans don't want to do). The second phase is automating the complex (things we thought only humans could do). The goal isn't to replace engineers. Rather, the goal is to make the engineer's working environment easier and more productive. This allows them to dedicate their efforts to higher level tasks. This benefits current engineers and attracts new ones.

4 Generate

Generate is a multi-domain process to automatically create one or many design or artifact alternatives. The process begins with a set of parameters and results in a detailed design that can be evaluated, and then its performance parameters are measured. It'll be some time before generative design can be performed at the scale of an entire aircraft, but early inroads have already been made to generate individual parts and systems. Many aspects of a product's technical data package can also be auto generated. This includes test, manufacturing and support materials.

5 Optimize

Optimize is a closed-loop process to evaluate alternatives against key performance indicators, adjust goals and relaunch the generative process to create an improved artifact. If a design or artifact can be auto generated once, the results can be evaluated and optimized. This process is repeated by evaluating physics-based virtual prototypes (a digital twin) until the overall product is optimized at the highest level rather than having each individual system suboptimized in isolation. This can result in hundreds or even thousands of iterations, the best of which are presented to engineers for final validation. Optimization can find problems early in the digital world before a product, test lab or manufacturing facility is first built in the physical world.



Using industrial AI to achieve digital transformation maturity

Many people think that OpenAI invented artificial intelligence (AI) in November 2022 when they released ChatGPT. AI has been around for decades in many forms. ChatGPT is based on a specific type of AI called generative AI (Gen AI) that uses large language models (LLM) to deliver results in response to natural language prompts. ChatGPT and most LLMs that are trained with public data are great for many tasks, but they are not appropriate for designing complex aerospace products for several reasons, including:

Hallucinations: If ChatGPT does not know the answer, it sometimes just makes up an answer. Without detailed knowledge of the domain in question, many users cannot tell the difference between fact and fiction. The results cannot be trusted.

Data privacy/access: ChatGPT uses a public model trained with publicly available data. The prompts shared with ChatGPT are public. Using ChatGPT is not appropriate for trade secrets or proprietary product development. Therefore, public LLMs have limited access to the complex physics-based engineering data needed to develop an aircraft or a rocket. Expecting today's public LLMs to generatively design the next commercial aircraft is a bit like expecting a 16-year-old to be the chief engineer for the rocket program to reach Mars. Public LLMs have no access to private design data because aerospace companies do not trust them with their data.

Public Gen AIs are not trusted for aerospace design tasks because they hallucinate. They hallucinate because they lack all the data they need to make critical decisions. They lack this data because they are public and cannot be trusted to protect private data. It's a vicious circle. Companies need industrial-grade AI to break this circle.

Industrial AI is trusted, and it is physics based. AI and AI tools are much broader than just LLM-driven Gen AI tools. Although LLM-based Gen AI tools have driven unprecedented interest, the issues listed above have caused many companies to question the use of all types of AI for product development. AI must be industrial AI to be generally accepted by companies developing complex products.

Trust means AI can be trusted be used for product development. It must be reliable and always give correct answers. Trust also means that it protects any data it is given. This is critical when training an LLM. However, few aerospace companies have the resources to train LLMs from scratch.

The accepted standard for training an aerospace engineer today is:

Graduate high school: Eighteen years to gain general knowledge and skills and prepare for university. They learn how to be a person.

Graduate university: Four to 10 years to gain specific knowledge and skills in one or more engineering domains. They learn how to be an engineer.

Become an aerospace engineer: Many years working for aerospace companies to gain specific knowledge and skills needed to develop complex aerospace products. They learn how to be an aerospace engineer.

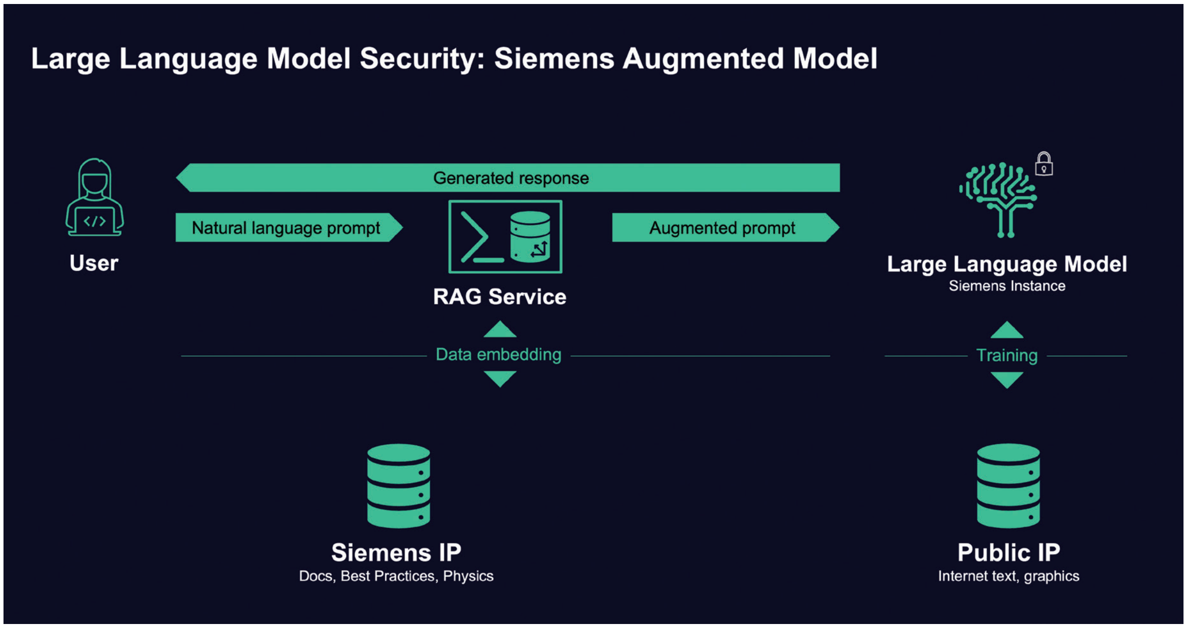
Training aerospace engineers require several steps and evaluations. Siemens believes the path to training an LLM to develop aerospace products also requires several steps and evaluations:

License a public model: The aerospace LLM will need to know how to understand thousands of basic things like communication via human language, geometry and how gravity works. Public LLMs can do all these things. This is a bit like a high school level education.

Augment the model with Siemens data: Public LLMs can create incredible and realistic images and videos that adhere to the basic laws of physics, but they lack the detailed understanding required to engineer physical things. The aerospace LLM needs detailed, physics-based knowledge of multiple engineering domains. It needs to be able to use a digital twin to evaluate results of multi-domain simulations. It needs to understand and apply multiple rules and standards for organizations like SAE, the Federal Aviation Administration (FAA) and European Union Aviation Safety

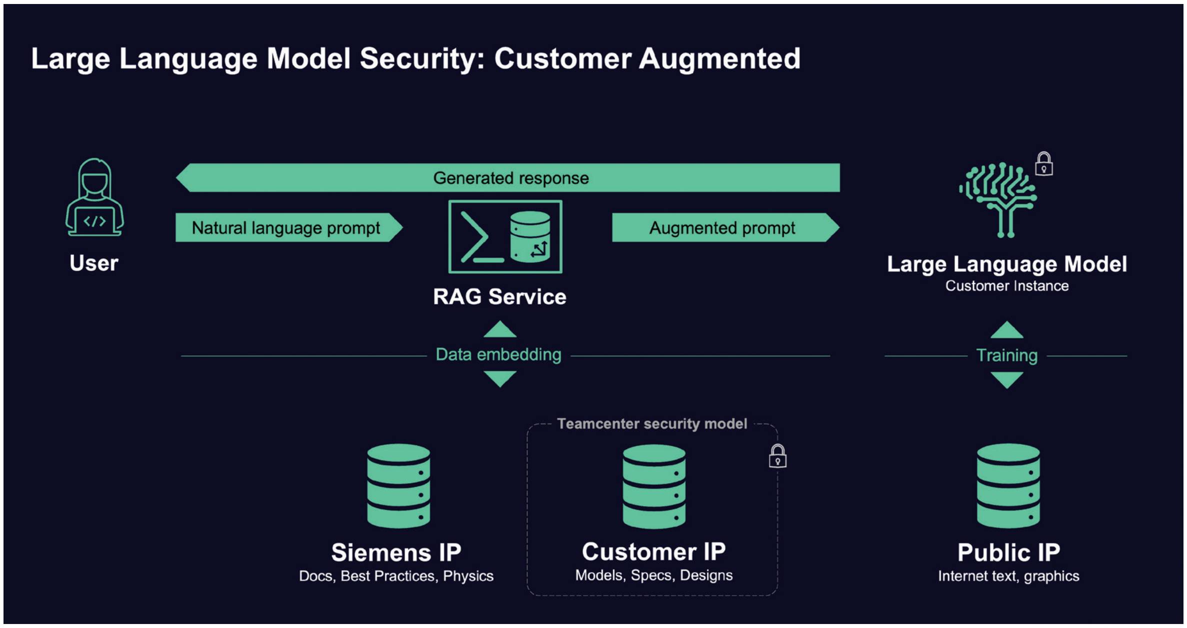
Agency (EASA). It also needs to have a detailed understanding of the Siemens Xcelerator business platform of software, hardware and services.

The public LLM becomes the Siemens LLM via a process called retrieval-augmented generation (RAG). RAG enhances LLMs with specific data to provide more accurate and reliable responses. This may be data that was not available when the LLM was originally trained, or in this case not available because it was behind a proprietary data wall. At this point our LLM has graduated college and is ready to begin working.



Augment the model with customer data: A Siemens LLM could do generic generative product development, but who just wants a generic aircraft or spaceship? Companies want their products developed with their proprietary technology and methods. It's the secret sauce that differentiates them from their competition. Doing that requires their proprietary data. Human engineers are only given access to proprietary data once they sign a nondisclosure agreement (NDA). LLMs cannot sign NDAs. How will LLMs ever be given access to proprietary data?

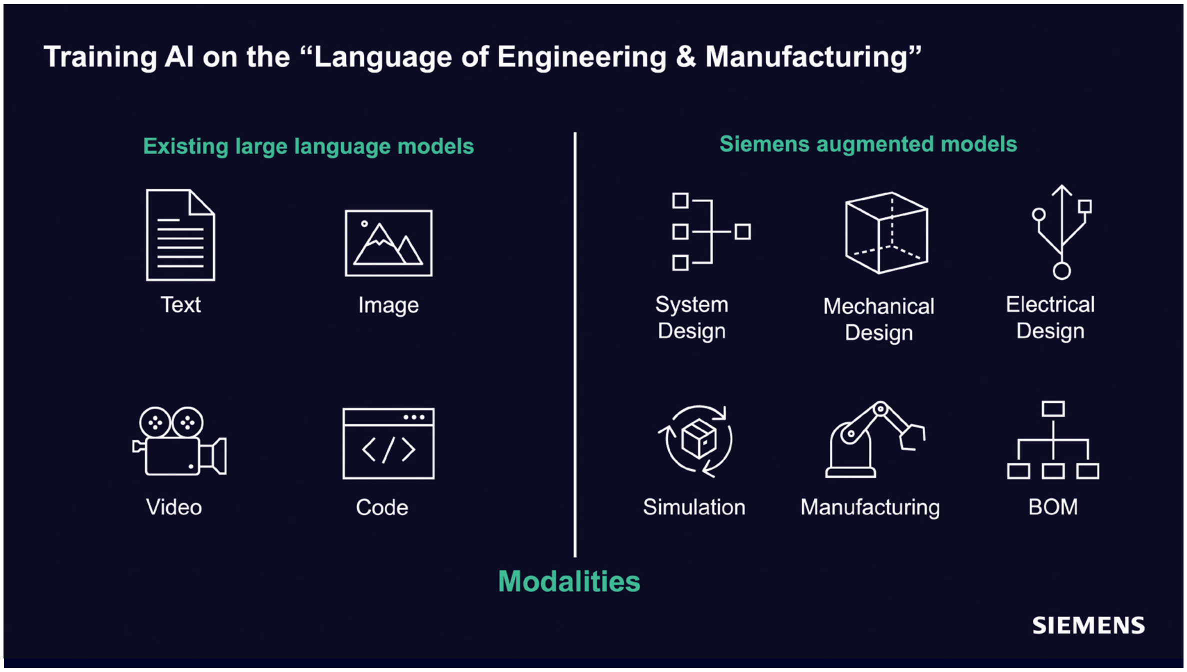
Customer-augmented LLMs will be trained with their proprietary data via RAG, much like the Siemens LLM was trained, but the customer LLMs will have a Teamcenter® software security layer. This may be done on premises or in a private cloud. In any case, the proprietary data never leaves the customer's possession. At this point, the LLM is trained and ready to do company-specific aerospace engineering.



It takes decades to train a person as an engineer. They eventually change companies or retire and take their knowledge and experience with them. Initially, aerospace LLMs may take months to train, but this is likely to shrink to weeks or even days as industrial AI-driven LLMs are more commonly deployed. Once LLMs are trained, they will never quit or retire. They will just grow smarter.

This does not mean Skynet will eventually take over and replace human engineers. Multiplying the effect of the workforce is the motivation behind supporting an industrial AI-enhanced digital transformation. However, AI will change the way engineers work, and it will add to the skill sets they need to do their jobs.

Engineers will always need a foundation of math, physics and domain-specific knowledge, just as they have for hundreds of years. Most engineers can be categorized as leaders or doers. Leaders decide WHY a product should exist and WHAT it should do. Doers perform the tasks involved in HOW to bring the product to life. In the future, the doers will also need to become leaders of AI-driven tools. Rather doing all the math and physics themselves, doers will translate their leaders' WHYs and WHATs into prompts for their LLMs to process. Then the human doers and leaders will ultimately certify the LLM results before designs are deemed ready to be built and trusted for use.



The state of the art for current LLMs is to generate text, images, videos and computer source code. That is what LLMs have been trained with. Those are the modalities shown on the left above. The physics-based LLMs for Siemens industrial-grade AI will need to understand the language of engineering and manufacturing. This requires adding the modalities on the right above. These are some of the next steps in developing Siemens industrial-grade AI.

Siemens industrial-grade AI is trusted, and physics based. This is important not just for LLM-based gen AI, but for all types of AI. AI is not a new technology at Siemens. We have been doing AI research and investing in AI for many decades. Siemens currently delivers solutions that incorporate industrial AI across Siemens Xcelerator. Here are a few examples:

- Generative* Mechanical Design
- Generative* Wiring Design
- Generative* Systems Architecture
- Automated PMI Generation
- Optimized ASIC/SoCs Design
- Optimized ASIC/SoCs Verification
- Optimized CFD Analysis
- Industrial Co-Pilots for multiple products
- Command Prediction for multiple products

*Note: As of September 2024, the shipping versions of these generative tools use AI, but they are not currently LLM based.

Conclusion

The Five Levels of Digital Transformation Maturity framework is not just a model for industry to follow. It is also a framework for how Siemens is incorporating industrial AI into our solutions. Siemens is leveraging industrial AI to mature all aspects of digital transformation.

Image a system that could optimize thousands of generative designs of an entire mechatronics product and simultaneously look at multiple KPIs to provide a complete product design package ready to manufacture, or an optimized factory design that is ready to build. That may sound crazy, but we believe it is possible. Think of how much faster aerospace and defense product designs can mature. Engineers will be able to focus their time on innovative ideas and critical decision-making, not putting the details of mechanical parts into a CAD tool or creating point-to-point wiring diagrams.

The Five Levels of Digital Transformation Maturity is the practical path to allow the aerospace and defense industry to overcome its workforce shortages. This framework will significantly multiply the impact of a company's engineers. As the CIMdata study asks for, this is how a "digital thread strategy can be planned and implemented incrementally with a predictable return-on-investment." This will allow aerospace and defense companies to build more optimized products faster at far less cost.

References

1. The US Needs More Engineers. What's the Solution? Boston Consulting Group report. December 2023. https://www.bcg.com/publications/2023/addressing-the-engineering-talent-shortage

2. "The State of U.S. Science and Engineering 2022" https://www.ncses.nsf.gov/pubs/nsb20221

3. "Promise and Reality of the Digital Thread – Results of Industry Research" https://www.cimdata.com/en/education/educational-webinars/webinar-the-promise-and-reality-of-the-digital-thread-results-of-industry-research
   Note: A summary eBook of data from this report will be jointly released by CIMdata and Siemens the week of June 5, 2023.

Note

This is the first in a series of white papers written by Siemens Digital Industries Software in support of a request for PLM vendor perspectives by the AIAA Digital Engineering Integration Committee (DEIC). The final AIAA white paper, "Digital thread and twin integration: Defining the problem space – OEM and vendor perspective on gaps" delves into the challenges and gaps identified by the industry while integrating a digital thread with a digital twin. The AIAA white paper builds on the past digital thread and twin position and realization papers published during 2021-22 and will be presented at AIAA SciTech 2025.

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