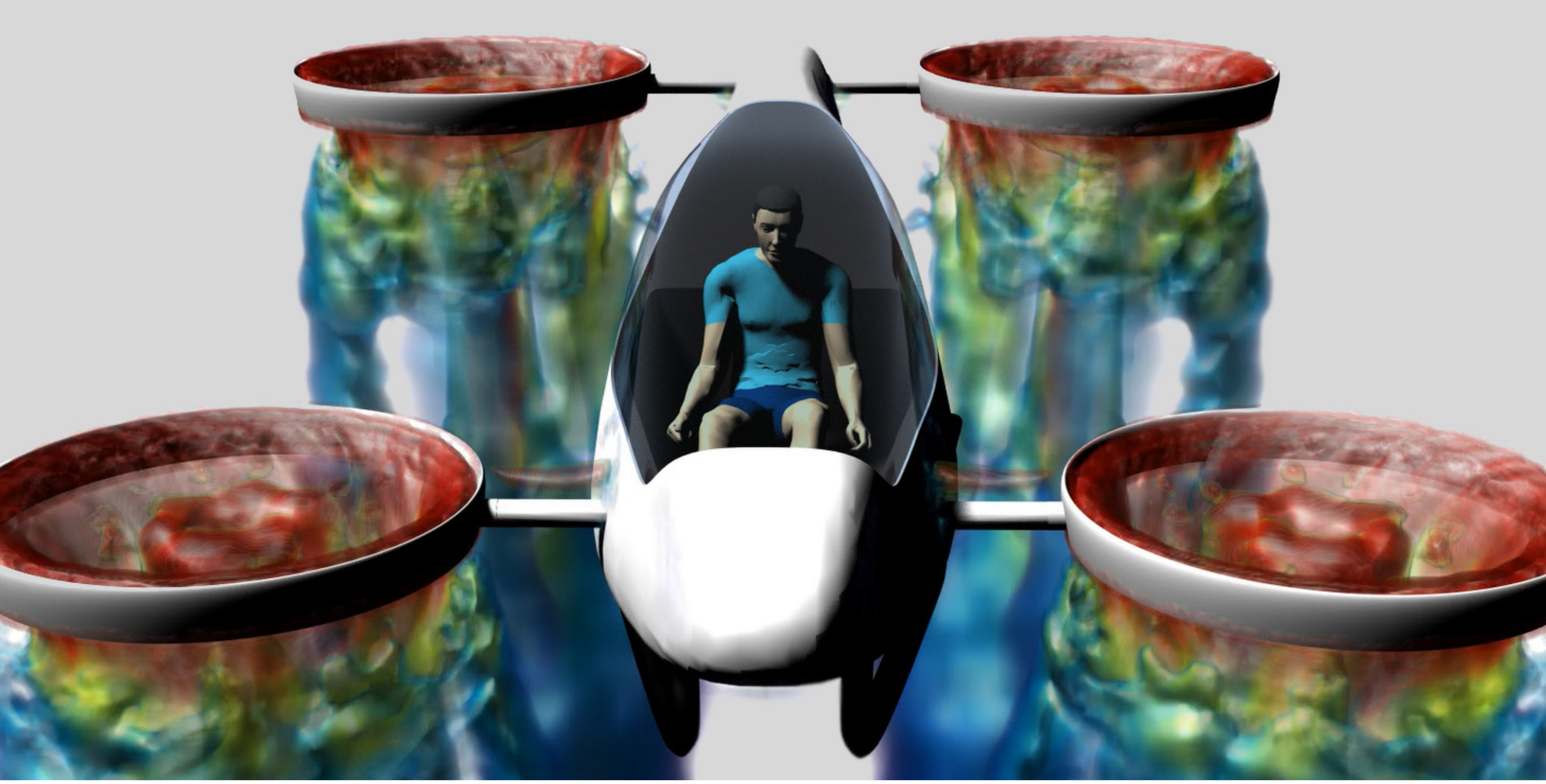

DIGITAL INDUSTRIES SOFTWARE

Designing the next generation of aircraft

Taking a new approach to aircraft engineering

Executive summary
Due to expected passenger growth, the aircraft industry will need to be transformed to avoid a dramatic increase in carbon dioxide (CO2) emissions so electrifying the propulsion system is a top priority. However, the power density this requires generates thermal concerns and electrical system integration challenges due to increased interactions between various physics. To handle these complexities, aircraft integrators will need to upgrade their development processes, which are often too siloed, from a static, document-based engineering approach to a dynamic, model-based engineering approach. The portfolio of Simcenter™ software and hardware offers a comprehensive set of scalable and collaborative tools for dynamic model-based performance engineering, from concept design to certification, all on one platform. This will enable consistent and accurate behavioral verification and validation throughout the design cycle.

SIEMENS

Contents

Abstract

The impact of fossil fuels on the environment sets the agenda across all transportation industries, making electrification one of the major areas of focus. Designing electrified aircraft will require innovative technologies and new development processes. In this white paper we describe specific challenges and explain how a model-based engineering approach can help aircraft manufacturers and their suppliers deploy a comprehensive digital twin for performance engineering. This methodology facilitates behavioral verification and validation by using realistic simulation to tackle design complexities more effectively by removing silos between disciplines and applications, resulting in shorter development time and reduced risk. Together with the deployment of a digital thread, this leads to program execution excellence.

Aviation in today's society

Aviation: a globalization cornerstone
It's always tricky to predict what changes an era will be most remembered for. Over the last 50 years, it's reasonable to state that globalization has been one of the most important trends. Today, most people, societies and companies worldwide are more and better connected than ever. This is because of advancements in many fields. For example, a vast number of countries enjoy increased stability, both internally and in their foreign relations, which has helped substantially improve education and public welfare. We've seen revolutionary innovations in communication technologies, many of them with roots in or affiliated with achievements in aviation and space industries.

But what undoubtedly has been one of the most important drivers of our globalized society is the increased ability of people around the world to meet in person. Air travel has allowed people (and goods) from anywhere around the globe to go to practically any continent. Just about 50 years ago, air travel was still only affordable for large international business corporations and for the happy few. Today, aircraft and airline industries fulfil the crucial role of connecting people and businesses.

Meanwhile, passenger travel volume continues growing steadily, whether it is for business travel or leisure. As spelled out in the Airbus Global Market Forecast[1] and Boeing Commercial Market Outlook,[2] the number of passengers traveling by air can be expected to double between 2017 and 2032.

Air travel has been a cornerstone for the globalization that took place over the last five decades, and it will continue playing this role in the future.

Environmental concerns
At the same time there is also criticism. Globalization, and by extension the industrialization that is largely driven by fossil fuels, has put enormous pressure on our planet. We've come to a point where there is scientific consensus that if no action is taken promptly, the damage will be irreparable. The problem of global warming has led to international agreements on man-made CO2 emissions, which has resulted in legislation in which all transportation industries are being targeted. Combined they are responsible for about 15 percent of the total greenhouse gas emissions worldwide.[3] And even though aviation's share in this is relatively small (around 2 percent of the total, or 12 percent of transportation),[4] the industry suffers from a negative perception in that respect.

The aircraft industry realizes its ecological footprint and troubled image urgently need to be addressed with new technologies that make air travel cleaner and more sustainable. In figure 1, the International Air Transport Association (IATA) describes how the emission of CO2 produced by the sector could evolve between 2010 and 2050 if the predicted passenger volume growth is maintained. Without any targeted action, the CO2 emission would simply double. So obviously aircraft and aircraft propulsion companies continuously look for solutions. In addition to the continuous quest for reducing weight, improvements should be pursued by further enhancing existing aircraft engines, or by optimizing operations and infrastructure. However no evolutionary updates to existing technology can help achieve any reductions. Radically new technologies will be required to reach the targeted reduction of 50 percent by 2050. In addition to biofuels and hydrogen fuel types, alternative airframe configurations and structural and material technologies such as morphing wing technology, electric and hybrid-electric aircraft propulsion systems show potential.

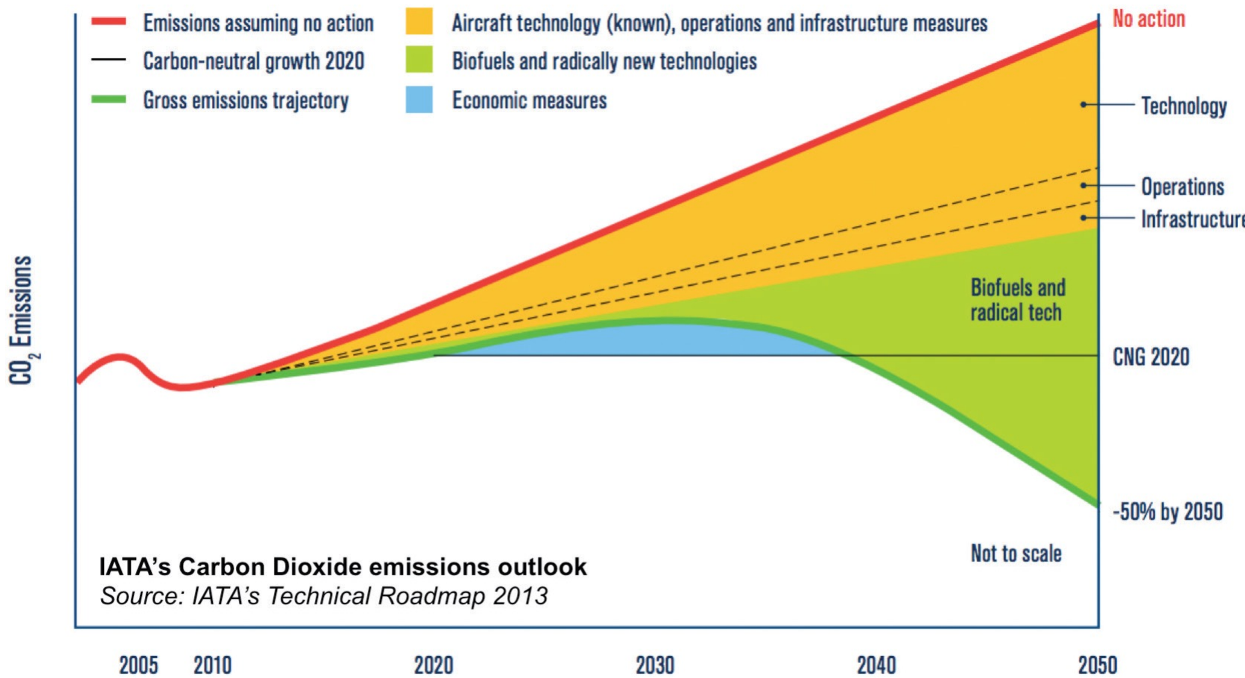

Figure 1. Evolution of CO2 emissions considering evolving technologies.[5]

Fuel consumption versus operational cost

Next to these environmental concerns, it's important to mention the aviation industry has an additional incentive to improve energy efficiency and decrease its dependency on fossil fuels, especially for commercial aircraft. Figure 2 shows the total cost of ownership (TCO) of a typical Boeing model 737-800. Over 50 percent is directly related to fuel. For aircraft operators, this is a huge financial burden and even a risk because fossil fuel prices are volatile due to issues such as geopolitical disputes. Any improvement in this area will have a positive impact on the financial side of air travel operations. So electrification provides an interesting path. IATA mentions that hybrid-electric technology could decrease the consumption of fossil fuels by 10 to 40 percent by 2030 for smaller aircraft (15-to-20 seats) and even with 40 to 80 percent for midsize aircraft (50-to-100 seats) by 2045. And that's only the intermediate step to full electrification.

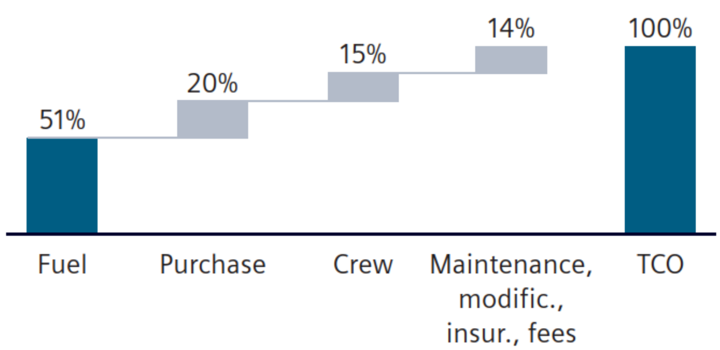

Figure 2. Total cost of ownership of a typical single aisle commercial aircraft.[6]

Airport operations

In addition to fuel consumption and emissions, noise and local air quality are part of the overall environmental impact of aviation. For example, noise is the reason for lots of local regulations on operations during evenings and early mornings. When existing airports are extended, or new ones are planned, it is often one of the main hurdles. To achieve sustainable growth in harmony with people living in proximity to airports, the aviation industry must consider this aspect. When radically new technologies are due to be implemented, whether they are accompanied by required infrastructural changes, aircraft manufacturers and airport operators must collaborate to bring environmental noise below acceptable levels.

Also, electrification can present advantages. Electrical drives could reduce the rotational speed of propellers and fans, while maintaining propulsion power. Further, they could enable the application of distributed propulsion. This will allow engineers to experiment with the aircraft architecture and design fans that are shielded by the aircraft structure to avoid direct noise propagation toward the environment.

A safe flight

Safety is the number one priority for all aircraft stakeholders. Increased electrification in the aviation domain brings an additional layer of complexity, which makes failure analysis and mitigation difficult. Furthermore, a large amount of engineering collaboration and effort is required to analyze the interconnections between the new electric systems. These systems often execute control functions that are automatically generated based on advanced logic and a large set of sensors. Thus, it is necessary to have a process that facilitates the exchange of design data throughout the aircraft lifecycle.

Automated systems are man-made and not immune to malfunction, and they can lead to a totally new dimension of complexity of the aircraft and its development process. In specific the deployment of electrification in aircraft will lead to an enormous number of new systems, which often combine diverse technologies. That will undoubtedly challenge the aircraft integration problem, especially when working with various stakeholders in a global organization.

Electrifying future aircraft

We are currently in a period of evolutionary developments on the classic tube-and-wing jet configurations, awaiting a new, more radical innovation wave by 2035 (provided the economic framework conditions are favorable). Today, we can see the first steps in aircraft electrification along with introducing other innovative structural and material technologies. But to be fair, there is still a lot of work to do before we can speak of a real industry transformation.

Even though propulsion systems that use electrical motors are promising and will gradually find their way to the market, to date they have not been implemented on other than small general aviation aircraft. There is of course the challenge that today's electrical motors are too heavy to be applied at large scale on an aircraft, and that electrical energy storage still has much lower power density than the traditional kerosene. In the next paragraphs, we highlight some more of the specific challenges.

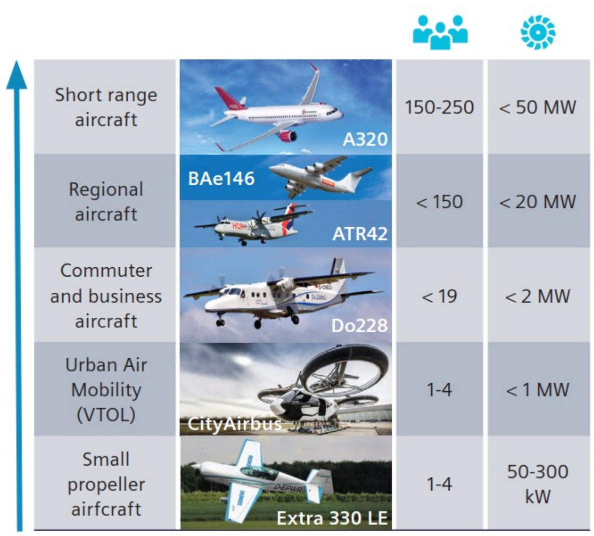

Figure 3. Required electrical power per aircraft type.

Undeniably, many things are moving. A new market segment that is being formed is urban air mobility (UAM). Electrical propulsion units allow entrepreneurs to develop new aircraft concepts that will be able to fly over congested areas. This market segment is accelerated by the booming drone business. Very soon, these will mature and be capable of transporting people. Their market presence can help some supplier businesses to grow and speed up the readiness of necessary technologies.

Technological engineering challenges

Integration of high-power electrical systems

The integration of medium- to high-power electrical systems in aircraft is relatively new to the industry. Indeed, some examples today, such as the Boeing 787, have already realized a certain degree of electrification. But these are merely applications such as electrical actuation systems replacing their classic hydraulic counterparts, or electrically driven pumps feeding the environmental control system (ECS) instead of the jet engine bleed air system. Still, such applications have gradually set the standard for on-board installed electrical power to 1 or 2 megawatts (MWs) for a long-range widebody aircraft.

Now a major scale increase will be required for implementing electrical propulsion. Figure 3 shows the necessary power to lift different categories of aircraft. A relatively simple UAM, transporting four to six people using a vertical take-off and landing (VTOL) configuration needs as much power as a long-range widebody aircraft, whereas a shortrange passenger aircraft already requires 10 to 100 times more. This has lots of implications. New technologies and solutions will have to dramatically increase voltage and current to levels that have never been implemented on aircraft. For example, that will require new electrical harnesses.

Power density

Every kilogram counts on an aircraft. Today's industrial electrical motors typically reach power densities of about 1 kilowatt per kilogram (kW/kg). That is simply insufficient. To successfully implement electric propulsion units (EPUs), this value would need to increase to at least 10 to 15 kW/kg. Apart from the motor, the same holds for subsystems such as inverters and more.

Weight reduction will be crucial. And the good news is current electrical motors and inverters can potentially become lighter. However, it will be a big challenge to accomplish this without affecting too many of the other design aspects, such as thermal behavior. In the industrial motors we know today, electromagnetic, electric, structural and thermal behavior are mildly coupled. This will change dramatically when removing mass.

For example, less structure will reduce the weight of the motor, but will impact its thermal capacity, heating the motor in less time. This can cause thermal deformations in the electromagnetic system, which in turn influences motor efficiency. Or it could set stricter requirements for heat rejection to prevent permanent magnets from demagnetization.

In summary, higher power density will always lead to a closer interaction between the involved physics and engineering domains.

Thermal management

Electrical systems require an entirely different approach to heat rejection than traditional power systems. In today's aircraft, the heat exchange between systems happens in a quasi-static manner, allowing for a maximum heat load development approach. In future aircraft, heat exchange will be much more complex, dynamic and with values that can be five to 10 times higher than today. Most current development approaches would lead to oversized systems and an overweight aircraft.

Therefore, the design of future thermal management systems will need to be smarter. It will need to be systematic and include all components that can play a role as a heat source or as heat sink, such as propulsion systems, environmental control systems, the powerplant, fuel and even the aircraft structure. This requires a system-level engineering approach that allows you to step away from the current siloed way to deal with heat and define the thermal management system architecture from the beginning of the development cycle to the finished aircraft level.

Challenges related to the development process

As we've noted, electrification will intensify the interaction between various physics and add complexity to aircraft development. And as mentioned, the application of new technologies such as systems automation, embedded software and more will also add to that.

Today, aircraft programs seldom deliver on time and on budget, exactly because of technical and organizational challenges. So, to keep development, certification and production affordable and predictable, current development processes will require a paradigm shift.

Below we describe how some of the weak aspects in typical aircraft development processes can obstruct or delay the introduction of innovative technologies.

Siloed organizations create blind spots in performance engineering

A major issue in current aircraft development is that scale and complexity have led to programs being split up between various partners around the world, and the division of work mostly happens as if an aircraft is an assembly of separable systems that can be integrated at a later stage. There is obviously a constant flow of communication between the various stakeholders, but often this is based on dead digital data, being flat documents that are shared throughout the organization. A good example could be the cooling budgets between electrical and ECS departments, which are usually described as flat numbers.

Such a siloed approach can never capture the dynamics of physical interactions between systems. Therefore, each department will have to implement safety margins in order to cover uncertainties at the interfaces, which then results in more weight than necessary. Finally, this will lead to poor integrated aircraft performance, increased integration testing and certification cost, a complex operational envelope and in the worst case, compromised missions. Below, we will describe this based on two examples.

Thermal management

One of the most striking cases that illustrate this problem is the way thermal verification is usually done today. Thermal engineers in all major divisions obviously make a great effort by using various tools, such as finite element analysis (FEA) and fluid dynamics simulation. But most of the time it's only the flight testing that reveals whether a structure, system or subsystem is running hot or not. And communication between division typically happens with PDF data (see figure 4), excluding the possibility to account for the energic interactions at the interfaces between systems, which are dynamic.

Such a blind spot can turn out to be highly problematic for the overall aircraft development program. It might lead to the need for late redesigns that will patch the problem, in the worst case requiring the creation of a new kind of iron bird, "the thermal iron bird." All this can cause major program disruptions, huge additional costs and poor program execution.

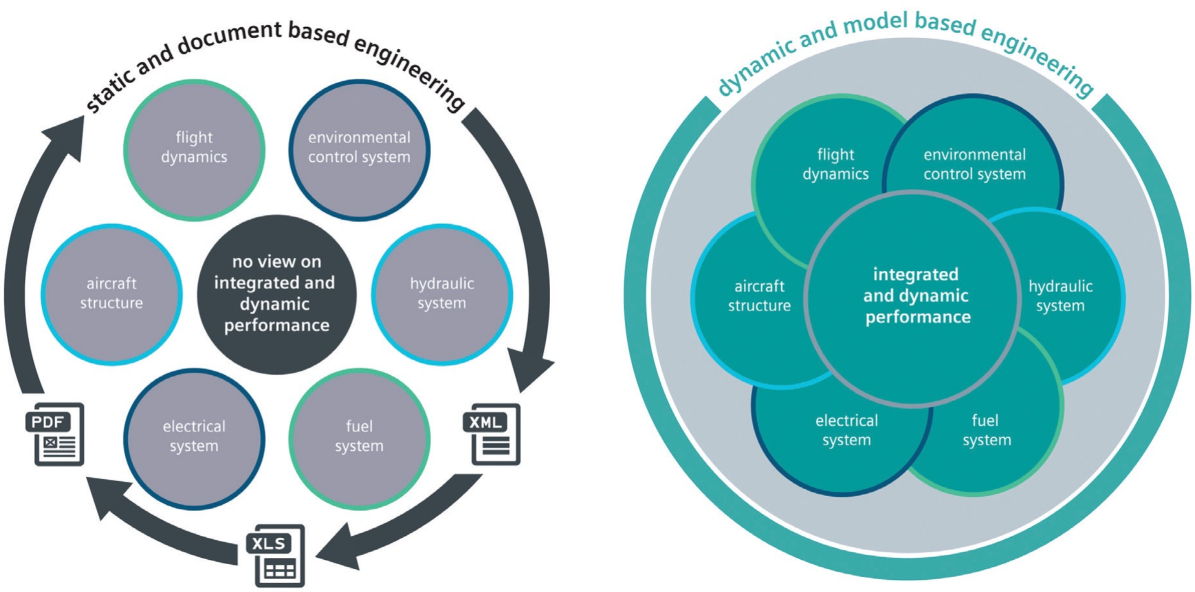

Figure 4. A siloed approach can never capture the dynamics and physical interactions between systems. A dynamic and model-based engineering approach supports an integrated view of performance.

Electrical system integration

A second example is related to the design of the various aspects of the electrical system, which as mentioned requires ever more power, voltage and current. Today, the electrical system design (mechanical), electrical harness design, the performance analysis and the electrical system integration tests such as electromagnetic interference/electromagnetic compatibility (EMI/EMC) testing happen in a siloed way. Program managers usually recognize this as a major risk. You know where you start, but you never know when it will be finished.

Indeed, EMI/EMC certification is typically costly and based on trial-and-error. When a certain design, already implemented on the prototype, does not comply with EMI/EMC standards, one typically reroutes branches of the harness. This requires changes in the electrical system design, which then requires changes in the mechanical design and hopefully leads to better EMI/EMC performance.
All too often, this results in a never-ending process (see figure 5).

Model-based reliability, availability, maintainability and safety

Current manual reliability, availability maintainability (RAMS) methodologies are siloed and cannot be used to keep up with the increasing complexity and interdependencies of the systems (see figure 6). This leads to design inconsistencies caused by differences in terminology and methodology. Furthermore, a manual approach is difficult to scale, making the combination of RAMS analysis a demanding task and the reporting a burden to maintain. For example, in this traditional approach, a safety engineer conducting a failure mode and effects analysis (FMEA) on an aircraft system would have to assemble engineers focusing on different aspects of the developed system (electrical, avionics, software, hardware, etc.). Starting the exercise using tabulation and gathering the same engineers several times to update and maintain the FMEA table are tedious tasks and imply inefficiency in the allocation of resources and slows down the overall development process. Model-based RAMS processes put the system model at the

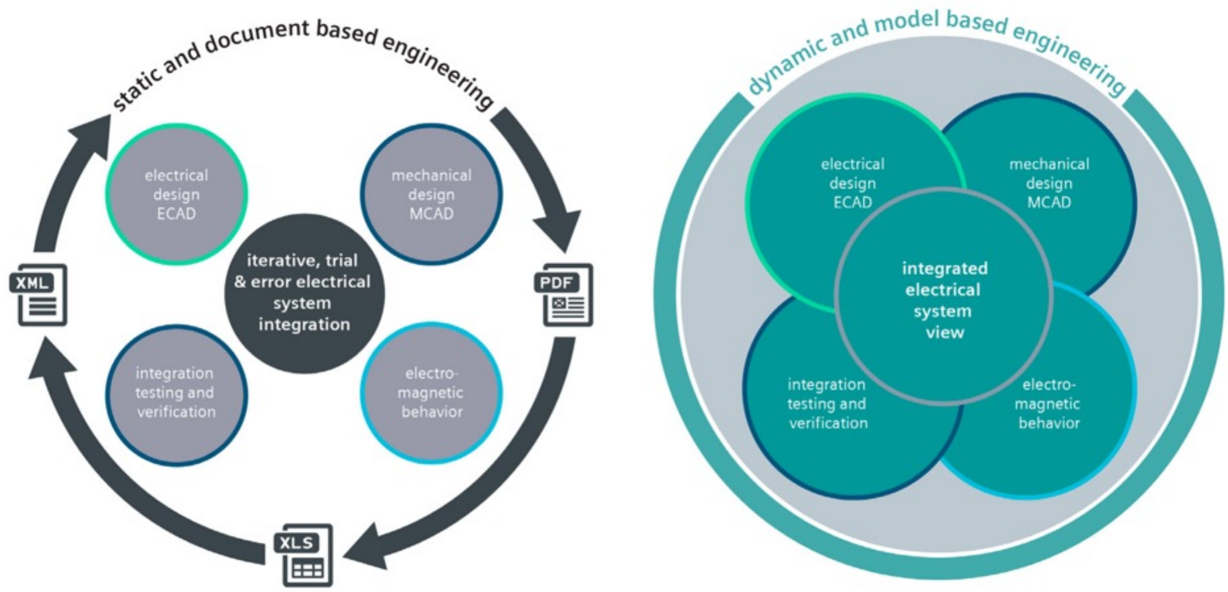

Figure 5. Today, electrical system design, electrical harness design, performance analysis and electrical system integration tests happen in a siloed way. All too often, this results in a never-ending process. A dynamic and model-based engineering approach allows for an integrated view of the performance.

center of the analysis by defining a common taxonomy understood by stakeholders. This leads to consistent, self-explanatory and efficient failure analysis.

Model-based RAMS analysis (the digital risk twin) allows engineers to collaborate better between disciplines and departments, automate and digitalize the RAMS analysis and reduce errors. This model consists of a functional and logical model of the product, a complete taxonomy describing the failures, their causes and mechanisms, their operational conditions and a model of how failures propagate. Based on this digital risk twin, a wide range of RAMS analyses can be performed from the early stage of design.

Therefore, the increasing aircraft complexity requires a leap towards model-based and automated methodologies, the so-called model-based digital risk twin.

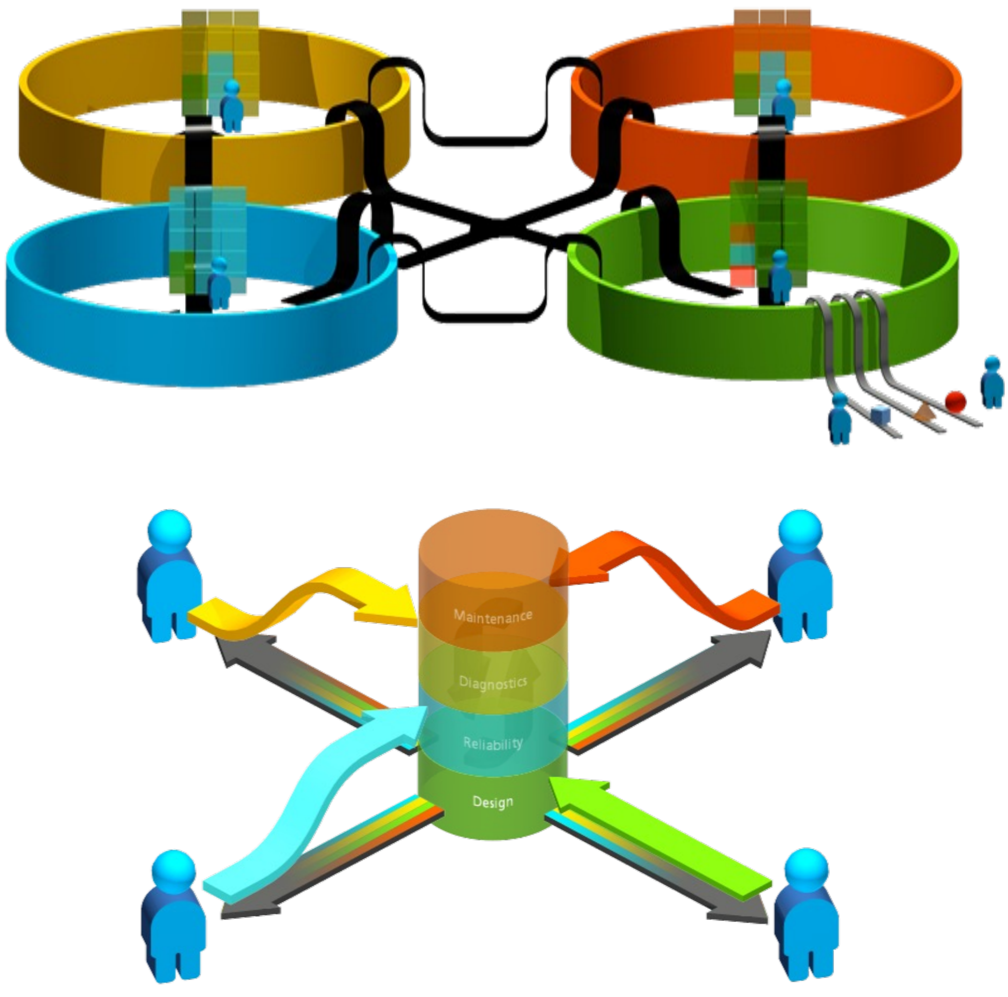

Figure 6. The digital risk twin streamlines collaboration between reliability, maintainability and safety engineers

A new approach to aircraft engineering

Technology and process challenges like the ones we describe are inherent to current aircraft development, and even more to future electrification. And they can only be tackled by pervasive digitalization on various levels.

On the technology side, it will require prediction-capable methodologies to achieve record-breaking power density, experimentation with new aircraft configurations and architectures, the ability to successfully deal with all thermal issues and address safety and reliability challenges related to the new technologies. On the process side, there needs to be a platform that integrates the various disciplines and physics involved, and at the same time keeps track of the development workflows, engineering decisions and verification actions taken. We speak about the comprehensive digital twin and the digital thread (see figure 7). In this section, we elaborate on how the Siemens Xcelerator portfolio, the comprehensive and integrated portfolio of software, hardware and services, can be instrumental in helping you deploy the necessary infrastructure and solutions.

The solutions in the Siemens Digital Industries Software portfolio for the digital twin and digital thread have a long, proven track record in significantly improving aerospace program execution. As a global industry leader and with a clear focus on innovation, Siemens strives to deliver solutions that will allow businesses in the entire transportation sector, including aviation, to take the next steps in digitalization. It has achieved this by making substantial investments in research and development (R&D) as well as by strategic partnering and acquiring technology pioneers that can provide decades of engineering expertise in the sector.

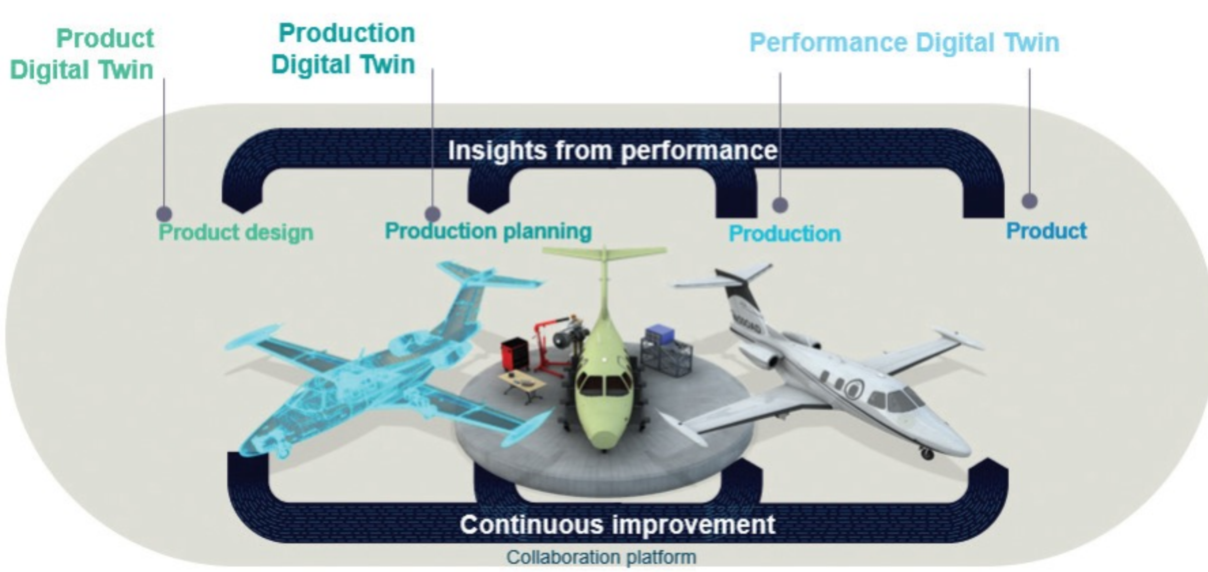

Figure 7. The Siemens digital twin and digital thread platform.

An important part of this offering is bundled in the Simcenter software and hardware solutions portfolio, a comprehensive platform that combines simulation with testing tools and services for performance engineering. Using Simcenter allows aviation engineers to model, gain insight into, understand and optimize the physical behavior of all elements of future aircraft, including structural development, fluid and heat transfer, systems development, thermal management, cabin comfort, electromagnetics and integration, verification, certification testing and more. The solutions integrated in the Simcenter environment facilitate a scalable modeling approach, from component level to integrated aircraft, and from low- to high-fidelity representations. Therefore, Simcenter can be used to support all development phases, from early concept, trade-off studies and detailed design to the verification phase, covering all physics and disciplines that are involved, and fully underpin the digital twin/digital thread paradigm.

Figure 8 shows what areas Simcenter is being used in. In the later sections we highlight its importance for future aircraft performance engineering.

Moreover, using Simcenter offers the possibility to connect to Xcelerator Share, an engineering-centric, cloud-based solution for ad hoc collaboration, which will allow teams of all sizes to collaborate securely with key stakeholders, including designers, managers, test engineers, suppliers and customers with appropriate access control. This enables scalable, project-based workspaces that support greater flexibility in product development. Project members can view and mark up designs, share simulation templates and review simulation results at any time using any device.

Removing silos with model-based system engineering

As demonstrated previously with examples of thermal management and electrical system integration, a siloed approach can seriously impact, and even endanger, the success of an entire program. The sooner the dynamic behavior of the integrated aircraft can be understood, the better, especially when considering the additional complexity and the increased multi-physics that come with electrification and other new technologies. Within current development processes, problems at the integration level are identified late, all too often during the flight test phase. To keep future aircraft development costs under control, this needs to change. It is necessary to have an integrated view of the aircraft from the concept phase onwards.

To achieve this, all former silos must contribute with behavioral models and closely collaborate with each other to align on how models are made, what they represent and how they interact with neighboring systems or other disciplines using well-defined interfaces. There are lots of submodels involved, including a multitude of physics and myriad mathematics, so it will be crucial to have the right tools and methods to come to an integrated synthesis. With Simcenter, Siemens offers a virtual integrated aircraft (VIA) and virtual iron bird (VIB) strategy exactly for this purpose. In the next paragraphs, we describe the nature and the scope of these solutions.

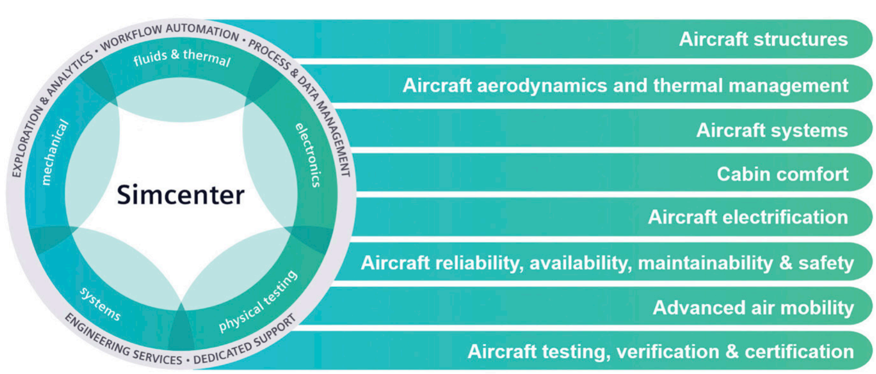

Figure 8. The Simcenter portfolio supports these areas of aircraft performance engineering.

Leverage ready-to-use aviation models

By itself, building a VIA is quite an extensive operation. Obviously, time that can be spent on analysis is more valuable than time spent on programming physical models of individual aircraft systems. When setting up simulations, all too often engineers lose time by reinventing the wheel, whereas they could just start from existing representations and make small adjustments. Within Simcenter, aviation engineers can find libraries for typical aircraft systems. These have been validated with major aircraft integrators, suppliers and academic partners. Well documented models exist for components such as the electrical system, pneumatic system, hydraulic system, flight control, landing gear and more, and readily address new aircraft configurations, like hybrid electrical propulsion systems.

The availability of such libraries allows aircraft engineers to focus on their product design rather than on a physical model programming. It allows you to perform more and better early trade-off studies and get a better view of what is the optimal structural and system architecture. The importance of this within the larger program cannot be underestimated. More, better and earlier insight into the integrated aircraft results in better choices, which significantly lowers the program risks and decimates the accumulated rework over the course of the program. It is important to add that Simcenter is an open platform, in which data from other industry-standard tools can be seamlessly included. This allows aviation engineers to easily combine the components in the standard libraries with their own legacy models.

Easily scale models according to engineering needs

Rather than being one single all-inclusive model, a VIA is a set of component models, data and parameters that come in various representations and continuously evolve over the development cycle. A good platform for VIA lets engineers pick and combine subsystems in a form or at a scale that best fits the application.

Simcenter provides a broad range of compatible solutions, which in many ways make it a scalable platform for VIA.

From coarse models to detailed development

During early architectural trade-off studies, engineers often miss detailed design parameters and have to use coarse models to make initial decisions. Later in the development cycle, when more details about the

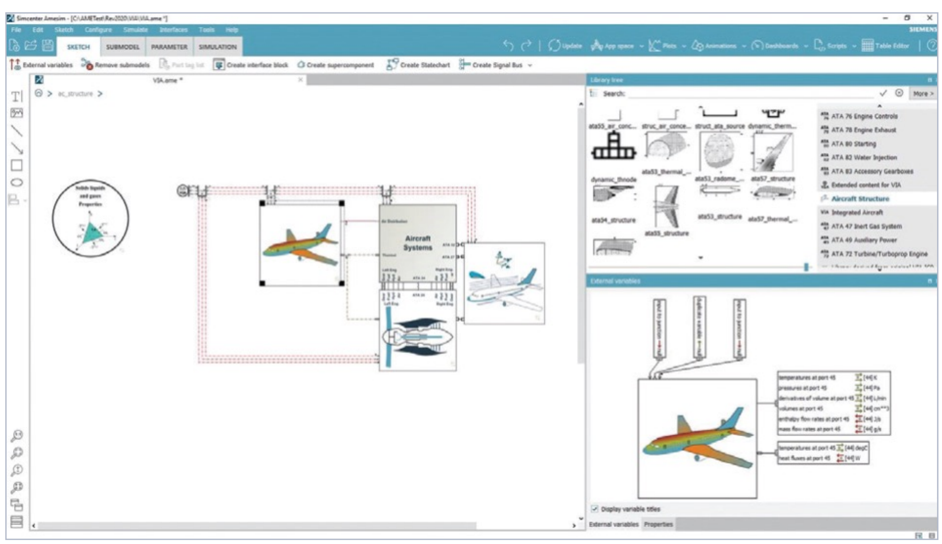

Figure 9. All former silos must contribute with behavioral models and closely collaborate with each other to align on how models are made, what they represent and how they interact with neighboring systems or other disciplines using well-defined interfaces. With Simcenter, Siemens offers a virtual integrated aircraft and virtual iron bird strategy exactly for this purpose.

physics become available, these decisions can be further elaborated with in-depth simulations.

But during these later stages as well, the application plays a role for the model selection. To provide sufficient accuracy when running calculations, the amount of detail in a model should neither be too large or too small to provide sufficient accuracy and correct granularity aligned with the modeling intent. The requirements in that respect can be application-dependent. Therefore, it's important to have tools that can easily adapt the level of detail according to the engineering needs, while consistently using the same base model. Simcenter is by nature flexible for this purpose.

From component to integrated aircraft level

Simulation capabilities and libraries are necessary to model the aircraft subsystems and their components by themselves, but also as a part of the integrated aircraft. This might require components and parameters to come in various forms, or levels of abstraction. For example, it is important to understand the detailed physical behavior of an aircraft brake servo-valve. But it will be equally important to take that model and integrate it one level up into the braking system; and then another level up into the landing gear. It is also essential to understand the system's reaction to a potential failure of its subsystems or components. That's where RAMS capabilities help the user discover failures in the early design stage. In the end, the goal is to understand how the servo-valve contributes to the success of a rejected take-off scenario at aircraft level.

Within Simcenter, engineers can find embedded application knowledge as well as industry expertise to help them pick the appropriate model representation for each application.

From early concept design to verification phase

The scope of simulation is not limited to aircraft development. It has been proven that when data continuity is guaranteed until the verification phase, simulation can also help to reduce the certification cost. This applies to both structural and systems certification, as well as control strategy and software verification scenarios, such as model-in-the-loop (MiL), software-in-the-loop (SiL), hardware-in-the-loop (HiL) and pilot-in-the-loop testing. To be applicable in this context, physical models, whether detailed or coarse, usually need to be adapted to fit

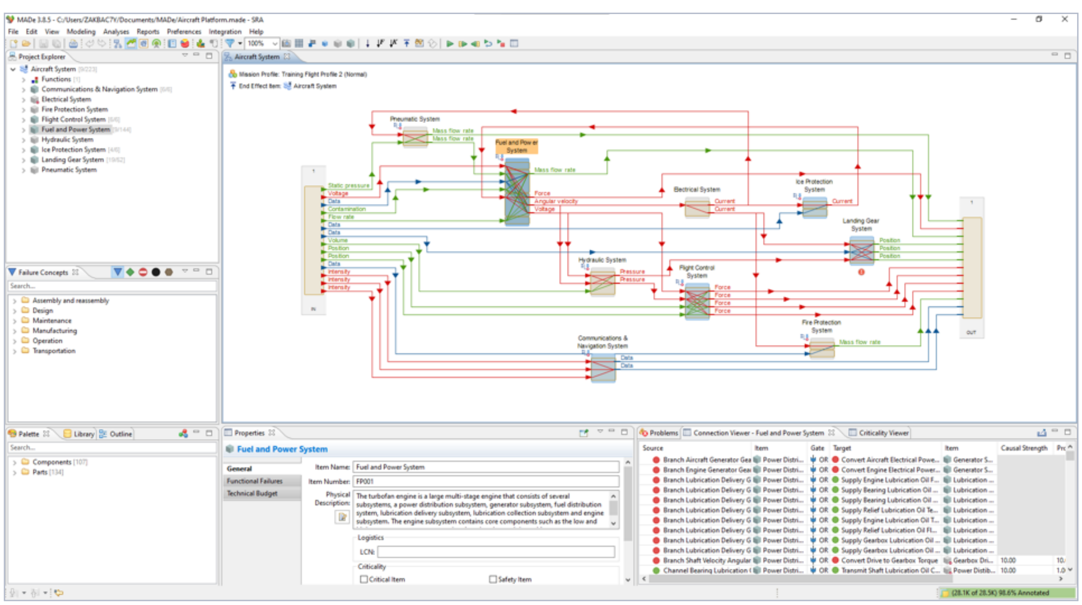

Figure 10. A model-based digital risk twin contains the system information embedded with a series of interrelated modeling perspectives to support the design RAMS process.

the test. Very often models have to be adapted to make them capable of running in real time to ensure model continuity along the V-cycle.

Being a platform that includes both simulation and testing capabilities, Simcenter includes lots of technologies and methods that allow engineers to consume models in the context of a verification phase. Obviously, having these models in exactly the same configuration as the to-be-certified design is of capital importance here. To that end, Simcenter also provides a verification process, including methods to accelerate the comparison between data sets in a managed environment in which traceability is assured by keeping a verification management digital thread.

The digital risk twin is a 1D representation of the system going from the aircraft to the component level. In this model, the risk is well understood in the early development stage since we can propagate failures in the system from an incipient state and trace the consequences of the risk.

The Simcenter model-based RAMS capability allows the creation of a digital risk twin. The user can focus on creating a sound model of the system and providing accurate operational conditions. The RAMS analysis, such as FMEA, fault tree analysis and reliability block diagrams are automatically done and can be easily exported in standard-based template documents. This helps cut development time and accelerate the overall design and verification process.

Covering a wide range of applications in-depth

As mentioned in previous sections, the technological challenges in future aircraft development will be great for aspects such as power density, thermal management and safety. To be a successful innovation partner, one cannot be a master of all disciplines. Quite the contrary, especially when the focus is on removing silos and comprehensive solutions, it is crucial to make sure state-of-the-art solutions are available for every individual discipline.

In order to do so, Siemens has been investing in technology companies that have all the necessary pre- and postprocessing capabilities as well as robust and high-performance solvers, for a wide range of applications, and bundled them in the Simcenter platform.

Getting the most out of simulation models

Setting up accurate simulation models is a huge effort. So once models are available, they can better be exploited to the maximum of their potential. All too often models are still just used to refine and validate specific preselected design options rather than instrumentally contributing to the decision-making.

With state-of-the-art technologies, however, engineers can define products in a completely parametrized way and easily associate simulation-based performance analysis to design, which enables a thorough form of design exploration. When adding new options for generative design to such a process, like topology optimization or methods for architecture or integrated system selection, enormous gains can be achieved in terms of concept design, pre and detailed sizing and more.

Simcenter includes tools for design exploration and provides a platform in which simulation methodologies can be coupled to generic design capabilities to help aviation engineers set up the most effective and high-performance design process.

Creating synergies between simulation and testing

Finally, electrification as well as the introduction of innovations that include software and electronics will dramatically increase the number of parameters and consequently the complexity of the aircraft that needs to be optimized, and later certified. Even though managing this will require ever more simulation, at the same time the workload for testing departments will continue increasing. That might sound contradictory, especially when talking in terminology like digital twin and digital thread, but it's not. Quite the contrary, testing is an essential part of the comprehensive digital twin, both during product design and certification. If anything, a tighter integration between simulation and testing is crucial for the success of the comprehensive digital twin as a predictive approach.

During the earlier development stages, the value of a digital twin approach is to a large extent defined by the degree of modeling realism that can be achieved. So, during this time, real measured data is vital to endorse modeling accuracy. Realistic simulation demands continuous testing work on components, materials, boundary conditions and more. This goes way beyond measuring accurate data for standard structural correlation analysis and model updating. Testing allows aviation engineers to explore uncharted design territories and build knowledge about new materials and all the additional parameters that come with mechatronic components. This often involves multiple physics and requires innovative testing methodologies.

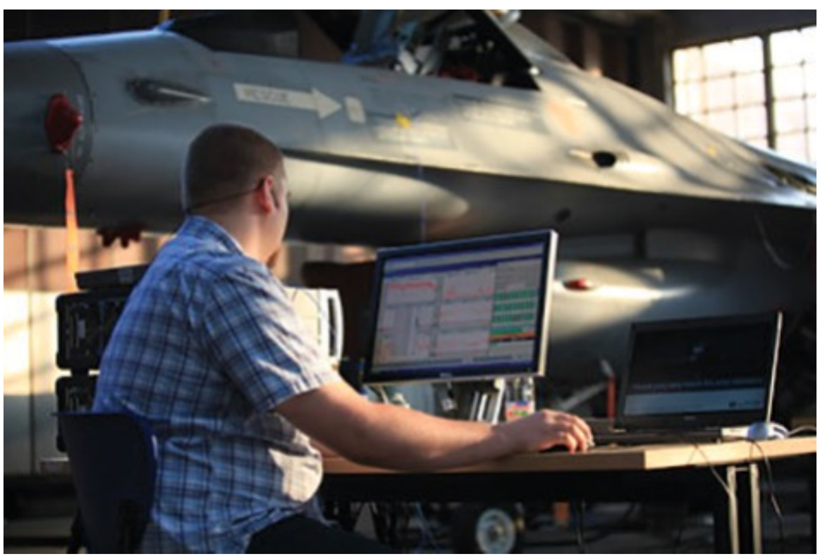

Figure 11. Simcenter is quite a unique environment as it is the only portfolio in the market that directly connects physical testing with system simulation, 3D computer-aided engineering and 3D computational fluid dynamics.

At the end of the development cycle, especially during certification, the situation is different, as typically testing is then at the center of events. At this time, the pressure is on. Prototypes and testing infrastructure are costly to use, and late discovery of defects can directly impact the aircraft's market entry. And with increasing aircraft complexity, including after-delivery updates, the share of work in this area can be expected to grow due to many more product variations, parameters, operating points, etc. At this stage, simulation can be a great addition and help to classic testing processes.

Indeed, virtual testing takes an increasingly prominent place in the certification process. But there are limits as in order to hand out airworthiness certificates, authorities will always require evidence from the integrators that proves the modeling assumptions in the simulations were right. Therefore, Siemens strongly believes that it is best to investigate approaches where physical and virtual testing go hand-in-hand, and where cheaper and better verification and certification processes can be achieved with synergies between both worlds. For example, simulation could help to define the best test configuration. There are often huge opportunities to simplify physical test benches and complement parts of the test with simulated elements. This can lead to cheaper test setups or reduce testing risks. That is just one example.

In that sense, Simcenter is quite a unique environment as it is the only portfolio in the market that directly connects physical testing with system simulation, 3D computer-aided engineering (CAE) and 3D computational fluid dynamics (CFD).

Conclusion

The Simcenter solutions portfolio, which is part of Siemens Xcelerator, offers aviation engineers a comprehensive set of scalable and collaborative tools for model-based performance engineering during aircraft development, from concept design to certification, all traceable and on one platform.

From the beginning of the development cycle, using Simcenter discourages working in silos by enabling the user to create a full aircraft comprehensive digital twin, or VIA. All models are scalable and can easily be further elaborated as data becomes available or adapted to specific simulation needs. During later stages, when development reaches the phase of detailed performance engineering and requirements validation, Simcenter offers state-of-the-art, application-specific solutions for all possible disciplines. These can be combined with high-performance testing solutions for model validation or to increase realism. Ultimately, the Simcenter simulation models can be the basis for virtual testing and assisting physical testing during aircraft certification and even beyond.

As all these solutions are in one platform that also connects to design, Simcenter can be used to create a digital thread that spans the entire development cycle. This facilitates deeper design exploration and provides applications such as topology optimization, generative methods for architecture and integrated system selection. As such, Simcenter can turn a classic verification-centric development process into a prediction-oriented comprehensive digital twin approach. With Simcenter, engineers can exploit simulation to the maximum.

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