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Ingenuity for life



Siemens Digital Industries Software

Aircraft structural engineering and analysis

Leveraging an integrated simulation environment

Executive summary

By using end-to-end processes for aerostructures that take advantage of simulation throughout the product lifecycle, manufacturers have found they are able to deliver innovative products on time and with predictable performance. This has enabled them to reduce model preparation time, shorten design-analysis iterations, evaluate tradeoffs across multiple disciplines, streamline development for on-time delivery and improve the quality of designs.

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Executive summary

Most aircraft company engineering departments are facing fundamental challenges. This is most strongly felt in the structures areas due to the increased complexity of products and ever-increasing demands for safety and certifications. The main challenges in airframe structure analysis are automation, standardization, traceability and deployment.

The global simulation process means many engineering teams are working closely together; from computer-aided design (CAD) definitions to computer-aided engineering (CAE) model and stress analyses. Automating the process is key to speeding up and improving the efficiency of design-simulation iterations.

Also, aerostructure sizing that leads to aircraft certification requires computing thousands of structural analyses. A lack of consistency in the stress analysis process for getting the right data and using the right engineering methods, sharing work and publishing stress reports makes the certification difficult and long. Process standardization helps tackle this problem by improving process consistency and limiting the risk of errors.

Automating and standardizing the process are key challenges for airframe structural analysis, while maintaining visibility and traceability of specific data, models and process/methods from concept to end product is a constant struggle.

Lastly, to maintain a competitive edge, a global organization may share models with suppliers, which implies real challenges to data security.

How to implement a global aerostructure simulation process

Siemens Digital Industries Software offers a complete aerostructure simulation solution that enables traceable data and results while maintaining consistent global process control.

The Simcenter™ portfolio is a comprehensive collection of simulation (plus advanced methods) test and data management tools that streamlines the global simulation process, from facilitating CAD geometry definitions to providing a CAE environment.

In addition to a detailed finite element model (FEM) approach, end users can size aerostructure components using a library

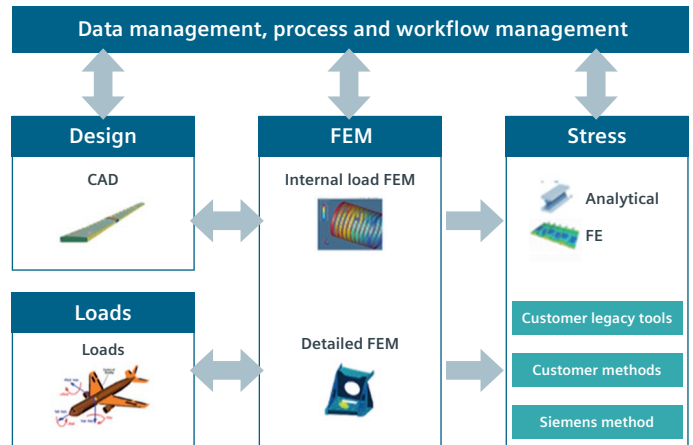


Figure 1: Siemens Digital Industries Software tools are used to streamline the global simulation.

of analytical engineering methods. With the capability of generating stress reports with data and results of the simulation, end users benefit from a consistent and integrated global process, resulting in saving time over the full design cycle.

An increasing amount of data and results to handle and share between global teams, models, simulation results and tools are managed and traced in Teamcenter® software for simulation.

Siemens Digital Industries Software solutions can be deployed across the globe so airplane original equipment manufacturers (OEMs) can outsource and create competition in the supply chain by providing an integrated environment for engineers with appropriate methods and tools.

In conclusion, automation and standardization challenges in airframe structure analysis are addressed by Siemens Digital Industries Software as it provides an integrated simulation environment covering the full simulation chain, with a strong focus on the capture and traceability of customer data, knowledge and processes.

Challenges in the aviation industry

Aerospace companies are faced with the challenge of containing development costs, improving program delivery performance and managing the introduction of innovation while facilitating product quality. For firms to achieve breakthroughs in efficiency, quality, compliance and cost, they must transform their model-based engineering processes. This is a complex and multi-dimensional problem that involves interdependencies among processes, tools and organizations. The objective is to make more accurate decisions, reach these decisions earlier in the program cycle, and increase linkage and traceability among key decision elements such as requirements, functions, test plans, verification and certification.

The first requirement is to support end-to-end digital connectivity and integration between teams, allowing them to perform seamless business work processes, and collaborate and manage access to information along the design cycle.

Another key aspect is to create a digital thread for disciplines and subjects, such as product architectures, design requirements, test plans and execution, simulation and verification, CAE data and process management.

Industry innovators and leading companies are building and initiating strategies that link business objectives with process improvement themes, and beyond that, developing specific initiatives that can deliver short-term value and lead to the target state.

Challenges in containing development costs that delay programs are strongly felt in the structures areas due to increased complexity in products and the ever-increasing demands for safety and certifications.

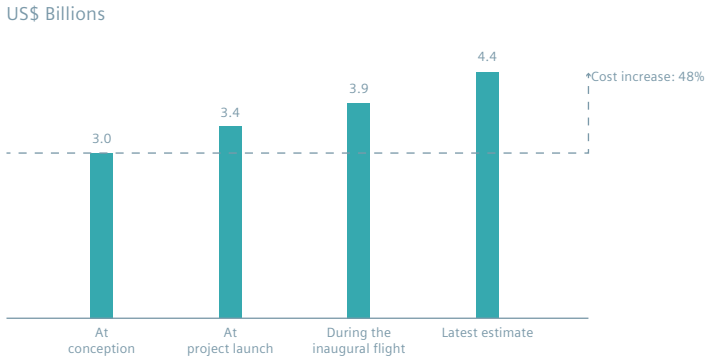
Increased pressure on costs

Aerospace companies face challenges in containing development costs, improving program delivery performance and managing the introduction of innovation while assuring product quality.

manufacturers significant additional engineering hours and hundreds of millions of dollars in cost overruns. The overrun costs are as high as 48 percent as shown in figure 3. In parallel, the contractual penalties that manufacturers must pay their customers is reaching billions of dollars (see figure 3).

Keeping the development and production planning of new products within budget and on schedule is a challenge for any aircraft manufacturer. Aircraft companies are experiencing delays on programs for as much as five years, costing

Exhibit 1: Recent aircraft program development costs, from preliminary design to 2014



Source: Company reports, Oliver Wyman analysis

Aircraft development project 1

Waiting clients > 50



Delay to date > 42 months



Penalties to date > \$4.5 billion



Aircraft development project 2

Waiting clients > 20



Delay to date > 36 months



Penalties to date > \$4.0 billion



Source: Company reports, Oliver Wyman analysis

Figure 2: Example of aircraft development costs and penalties.

Aircraft structure development program

At the feasibility stage, several potential aircraft configurations and matching airframe architecture and technologies are explored. For instance, you can assess the desirability of positioning the engine at the rear or on the wing box, or evaluate whether to use composites or metal for the structure.

Once a configuration has been selected, we move to the concept stage and the focus is on structural topology and design principles (for example, the number of frames). The complete aircraft is progressively defined using many tradeoff studies to evaluate the best compromise between several criteria.

Once the overall airframe has been defined, the final design with the definition of the structural details can begin. For instance, stacking sequences with ply drop-offs or

stringer-detailed profiles (for instance, web height, web and flange thicknesses) are considered.

After the detailed sizing of the aircraft, authorities assess the approval and certification of the aircraft based on key documents. This is the development stage.

In each one of these phases, iterations and rework with design and load updates are often needed in order to reach optimal design and certification requirements, which leads to an additional delay that impacts the entire development process.

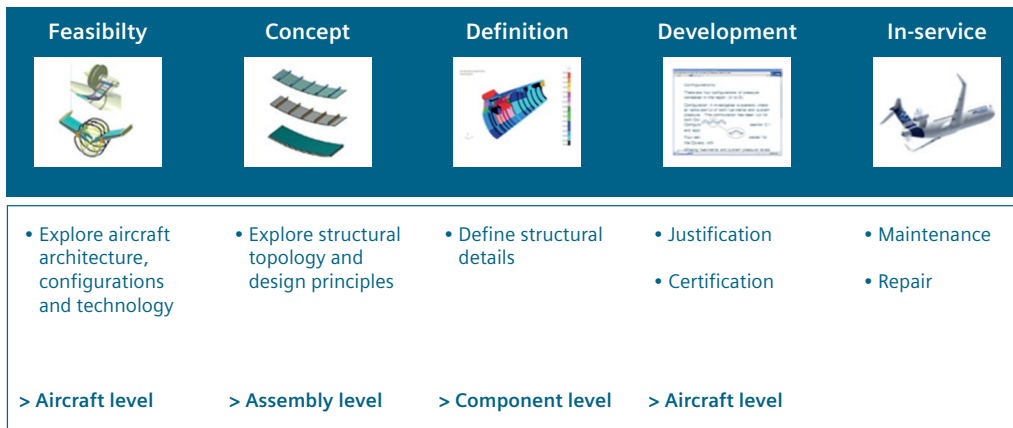


Figure 3: Typical phases of an aircraft structure development program.

Impact on the structural analysis process

Due to the increasing number of new and emerging aircraft manufacturers, there is more pressure to deliver with shorter lead times and at competitive costs.

Moreover, increasing material and design complexity drives an increase in structural analysis demand. The engineering ratio has grown from 5 designers for 1 stress engineer to 1 designer for 2 stress engineers.

In addition, environmental and safety standards for certification are becoming more restrictive.

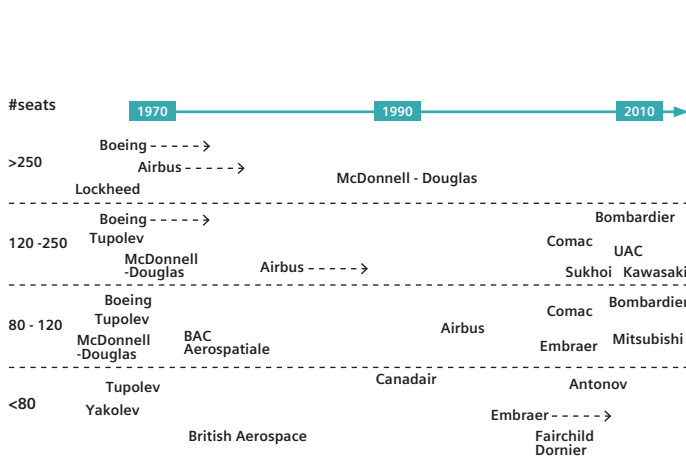
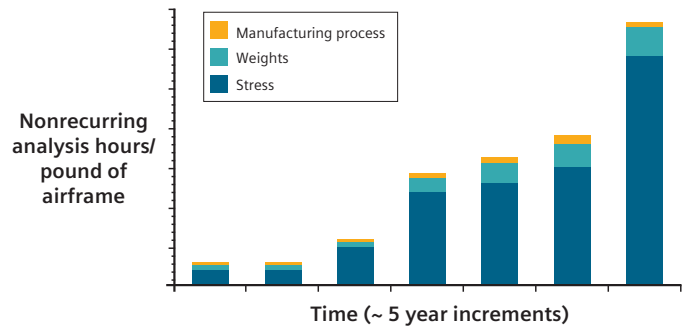


Figure 4: Competitive landscape for commercial jets by size (Cay-Bernhard Frank, partner, A.T. Kearney).



Engineering has gone from 5:1 designer-to-analyst ratio to 1:1 - 1:2 designer-to-analyst ratio

Figure 5: Complexity drives demand for analysis according to Keane Barthenheier, lead engineer and project manager at Boeing.

Challenges in aerostructure analysis

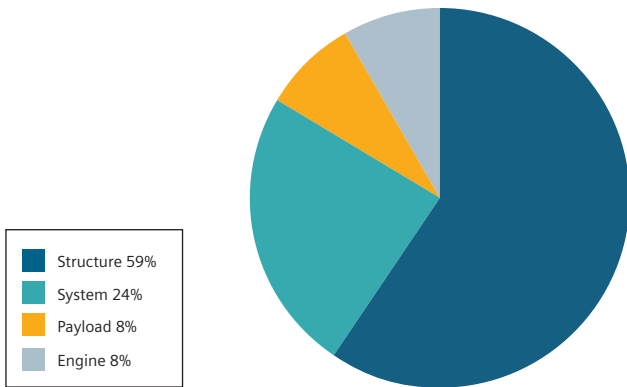


Figure 6: Commercial aircraft nonrecurring cost repartition (Jacob Markish).

Knowing that 60 percent of the nonrecurring costs (costs which are not likely to happen) of a commercial aircraft (30 percent for a military aircraft) is spent on the structure means that any improvement in the structure analysis process will have a key impact on reducing the delays and the cost overruns.

To highlight improvements that can be brought to the structure analysis process, let's look at a typical aircraft process.

Typical aircraft process and challenges

The pictures below show a streamlined process from a CAD-based base architecture, the internal load FE model (or global finite element model) generation, up to the stress and structural assessment analysis.

A typical aircraft process has mainly four different disciplines: Design/CAD, Loads, FEM with the FEM generation and FE analysis; margin of safety (MoS) calculation.

Design – The CAD model is updated by hand or is parametrized depending on company processes. However, CAD data is not primarily meant for simulation.

Preparing the geometry for simulation is very time consuming as it can take up to 20 percent of the analysis time. Also it is key to have a way to understand quickly the impact of any design change on the full process.

Being able to parametrize CAD geometry from the point of view of the simulation, which is independent of the designer intent, is a strong asset towards the reduction of geometry preparation time in the whole process.

External load calculations (flight sciences including aeroelasticity) – The external load FEM model is used for linear static, dynamic and flutter analysis of major structural stiffness and mass effects. It provides a way for mapping loads to the more detailed internal loads FEM.

Typically, these external loads are updated three to five times during an aircraft program. It is key to have a way to quickly understand the impact of load changes and the uncertainty on loads

The load FEM is also called global finite element model (GFEM). This FE model is either generated directly from the CAD model, or it is a modified FEM coming from a previous aircraft program. The internal loads FEM might be built in separate pieces, so when that is the case models are integrated into an assembly, meaning that a lot of models and data need to be managed.

This model is used for linear static analysis of every significant primary structural load path and also to provide free-body loads for detailed stress analysis of the primary structure.

The internal loads are used as input for FE calculation with a detailed finite element model (DFEM), or for analytical calculation (mainly with customer in-house tools or standard handbooks).

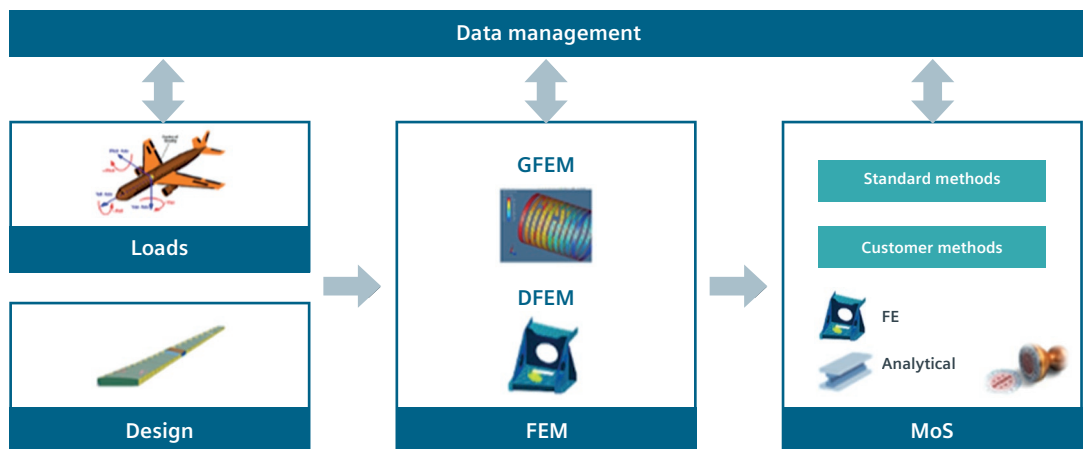


Figure 7: Typical aircraft process.

The challenge is to accelerate its creation through automation, assembly management of different submodels if necessary, and integrate company standards for mesh generation (for instance, meshing rules, quality checks, etc.).

Detailed FEM is usually generated for complex geometrical structures. Also, it is used to capture complex phenomena through nonlinear analysis.

The **margin of safety** calculation is performed for structural component analysis, which is primarily done with analytical methods (either from standard aircraft handbooks or from the company).

The internal load and geometry are extracted directly within the CAD or FE model and results, and the MoS calculations are performed with analytical methods from handbooks. It must ensure full traceability with the input data, the methods used and the MoS results.

The challenge is to accelerate data preparation (30 percent of the stress engineer's time is spent on preparing data), use the right methods and maintain traceability of the input and associated MoS for certification.

So integrating the different skills (load/CAD/CAE/MoS) is part of the challenge to improve program performance and break the development cost curve, setting the key requirements:

1. Streamline the structure analysis process → process automation
2. Deliver geometry access and design update → integrate design and simulation to increase productivity

3. Standardize methods and process → need openness to implement company process and methods

4. Need traceability → design configuration management material, load, FEM model management

On top of these activities, data management refers to a simulation data manager executing end-to-end simulation workflow. The challenge here is to:

- Capture and manage all simulation data (geometry, models, input decks, load cases, results, reports, etc.)
- Capture simulation files as well as their associated metadata
- Store and manage legacy, work-in-process (WIP) and released simulation data
- Manage large files in the database or optionally keep them outside the database and track them

The current approach to the structural analysis process is a mix of commercial-off-the-shelf (COTS) and company in-house methods and tools with specialized capabilities, with a need for:

- Geometry access and design update
- Load access and load loop iterations
- Standardized process and traceability

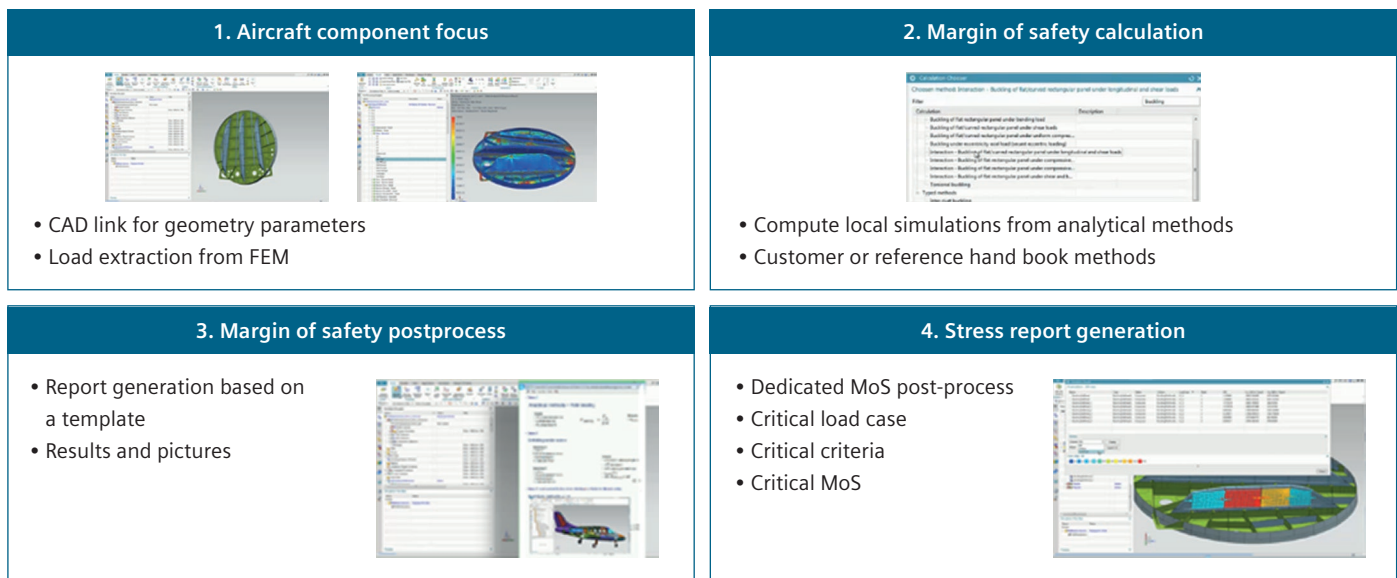


Figure 8: Margin of safety calculation.

Siemens solutions for aerostructures

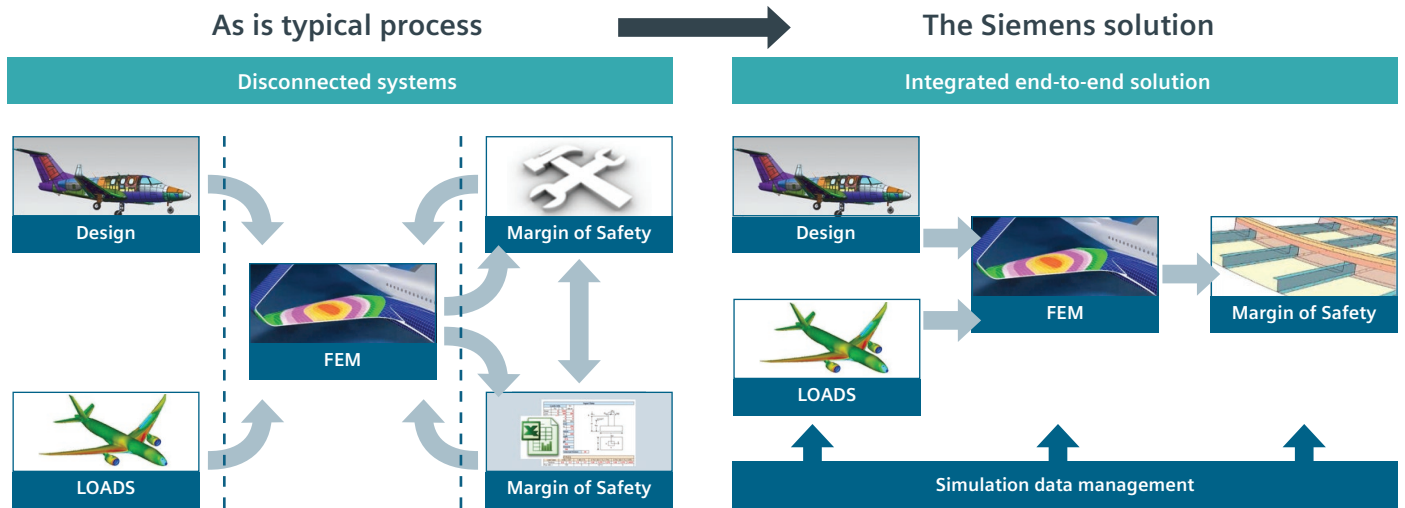


Figure 9: From disconnected systems to an integrated end-to-end solution.

Siemens Digital Industries Software offers an integrated end-to-end aerostructure solution covering the global aerostructure process, allowing you to:

- Close the CAD-to-CAE gap (design update, FEM assembly, etc.)
- Manage design change, load loop iteration
- Ensure traceability from conception to certification
- Streamline and standardize the stress analysis process (whether analytical or FEM calculation based)
- Tailor the process with the integration of customer methods, processes and best practices

Simcenter 3D (figure 9) is a comprehensive portfolio of simulation (plus advanced methods) and data management tools, which streamlines the global simulation process, from the CAD geometry definitions to a CAE environment.

With an increasing amount of data and results to share with teams on a global basis, models, simulation results and tools are managed and traced in Teamcenter for simulation (figure 9).

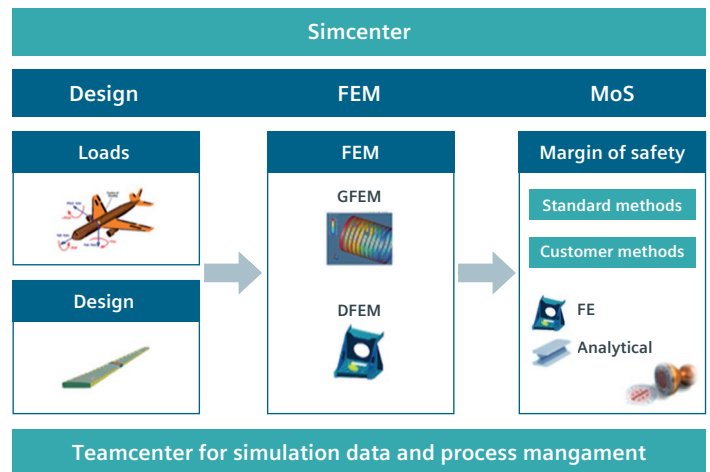


Figure 10: The Simcenter 3D integrated end-to-end solution.

Conclusion

The integrated end-to-end process for aerostructures leverages simulation throughout the product lifecycle to deliver innovative products on time and with predictable performance, such as:

- Reduce model preparation time by 70 percent
 - Eliminate bottlenecks by empowering CAE users to modify geometry for what-if analyses
 - Use application integration to increase productivity by 30 percent; 10:1 design cycle time improvements versus old software
 - Increase user productivity with a scalable interface and guided simulation (20 percent lower new user ramp-up time)
- Shorten design-analysis iterations
 - Analysis model to design geometry associativity allows analysts to rapidly update simulations when the design changes
- Evaluate different structural design tradeoffs (number of ribs, number of stringers...)
 - Integrated environment makes it easier to understand the impact of design decisions on multiple product performance aspects
- Streamline development for on-time delivery
 - Manage the simulation data from early design phases to in-service operations
 - Ensure simulations are based on correct data with a common data pipeline for design and simulation
 - Increase simulation speed and quality by implementing and automating best practices across the enterprise
- Improve the quality of nonrecurring charges
 - Traceability for certification through associative margin of safety, CAE models and CAD geometry
 - Maintain traceability by standardizing process and methods

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