# From Concept to Takeoff: Virtual Manufacturing in Aerospace

eBook

Why Simulation Technology is Essential for Next-Generation Aircraft Development

KEYSIGHT

# Beyond the Horizon: The Future of the Aerospace Industry

The aerospace industry is a significant global market, with a robust presence in both the commercial and defense sectors. Despite challenges like economic fluctuations, environmental regulations, and supply chain disruptions, the global aerospace manufacturing market is expected to grow steadily, driven by technological advancements and increased demand for next-generation aircraft and space systems. As of 2023, the U.S. aerospace and defense industry alone generated over $955 billion in sales. The industry has seen a strong recovery in air travel demand post-COVID-19, with global air passenger traffic expected to grow by 11.6% in 2024[1]. Recent advancements include the development of advanced air mobility (AAM) solutions and the integration of artificial intelligence (AI) in various aspects of aerospace operations[1].

## Key Trends in the Aerospace Sector

1. **Increasing Demand for Fuel-Efficient and Environmentally Friendly Aircraft** As global governments pile on the pressure for industries to work towards net zero emission targets, aircraft manufacturers are prioritizing innovations in sustainable propulsion technologies and the design of aircraft that produce lower emissions to achieve their sustainability goals.
2. **Advancements in Materials Science** There is a growing use of composites and lightweight alloys in aircraft manufacturing. These materials help reduce the weight of aircraft, leading to improved fuel efficiency and performance. The use of advanced materials also contributes to the durability and longevity of aerospace components[2].
3. **Growing Emphasis on Safety and Reliability** Companies are investing in advanced safety systems and rigorous testing protocols to ensure the highest standards are met. This focus is driven by both regulatory requirements and the need to maintain consumer trust[2].
4. **Rapid Technological Advancements** The industry is experiencing rapid technological advancements, including the digital transformation of operations and the adoption of innovative technologies. These advancements are enhancing manufacturing processes, improving supply chain management, and enabling predictive maintenance through AI and machine learning[1].
5. **Focus on Operational Efficiency and Cost Reduction** Aerospace companies are constantly exploring strategies to streamline processes and enhance financial sustainability. This includes optimizing production processes, streamlining supply chains, and leveraging digital tools to enhance productivity. The goal is to deliver high-quality products while maintaining competitive pricing[1].
6. **Space Exploration** A rapidly growing segment of the aerospace industry, space exploration has significant investments from both government and private sectors. The global space economy is projected to reach $1.8 trillion by 2035[1]. Key activities include the development of new rocket systems, satellite launches, and robotic exploration missions. Space exploration drives technological innovation and has applications across various industries, from telecommunications to climate monitoring[1][2]. Companies like SpaceX, Blue Origin, and NASA are at the forefront of these advancements, pushing the boundaries of what is possible in space travel and exploration[3].

The aerospace industry is poised for continued growth and transformation, driven by these key trends and the ongoing pursuit of technological excellence.

**References**
[1] Space: The $1.8 trillion opportunity for global economic growth
[2] Space industry worldwide - statistics & facts | Statista
[3] Space Manufacturing Technology Report - NASA

CHAPTER 1

# The Need for Innovation and Virtual Prototyping

Innovation is crucial for maintaining a competitive edge and meeting the ever-increasing demands for safety, efficiency, and performance.

However, the path to innovation never runs smoothly, and the aerospace industry faces several significant challenges that underscore the importance of adopting advanced methods, such as virtual prototyping, to streamline development, mitigate risks, and accelerate time-to-market. By leveraging these innovative solutions, the aerospace industry can overcome obstacles and achieve groundbreaking advancements.

## What are the Challenges?

**High Development and Production Costs** Developing and producing aerospace components and systems is incredibly expensive. The costs associated with materials, labor, and testing can be substantial, making it crucial to find ways to reduce expenses without compromising quality.

**Long Development Cycles and Time-to-Market Pressures** Aerospace projects often have lengthy development cycles due to the complexity and precision required. This extended timeline can delay the introduction of new products to the market, putting pressure on companies to accelerate their development processes while maintaining high standards.

**Stringent Regulatory Requirements and Compliance Standards** The aerospace industry is heavily regulated to ensure safety and reliability. Meeting these stringent requirements involves extensive testing, documentation, and validation, which can be time-consuming and costly.

**Complex Supply Chains and the Need for Coordination Among Multiple Stakeholders** Aerospace manufacturing involves a complex network of suppliers, manufacturers, and other stakeholders. Coordinating these various entities to ensure timely delivery and integration of components is a significant challenge that requires efficient communication and management.

### Table 1: Market Pressures Driving Product Innovation

| | |
|---|---|
| **39%** | Increasing pace of innovation |
| **38%** | Increased pressure to meet delivery deadlines |
| **38%** | Market demand for more feature-rich products |
| **34%** | Market demand for lower-cost products |
| **33%** | Market demand for more reliable products |
| **33%** | Need to address demand variability |

% of respondents rating each pressure as one of their top 3
n°203, Source: Aberdeen, December 2023

# Drivers for Innovation and Adoption of Virtual Prototyping

To address these challenges, the aerospace industry is increasingly shifting towards a virtual prototyping strategy. Let's look at some of the key drivers that are facilitating this new approach:

1. **Cost Reduction** Virtual prototyping helps identify and mitigate potential issues early in the design process. By simulating and testing designs in a virtual environment, companies can reduce the need for physical prototypes and costly rework. This approach not only lowers development costs but also minimizes waste and resource consumption.
2. **Time Efficiency** Virtual prototyping accelerates the development process by enabling rapid iterations and testing of designs. Engineers can quickly make adjustments and evaluate the impact of changes without the need for physical prototypes. This capability shortens development cycles and accelerates time-to-market, giving companies a competitive edge.
3. **Improved Product Quality** By simulating real-world conditions and performance, virtual prototyping enhances the accuracy and reliability of designs. Engineers can identify and address potential issues before they arise in physical prototypes, leading to higher quality and more reliable products. This proactive approach reduces the risk of defects and improves overall product performance.
4. **Regulatory Compliance** Virtual prototyping assists in meeting stringent regulatory requirements by providing detailed analysis and documentation. Engineers can simulate various scenarios and validate designs against industry standards, ensuring compliance with safety and performance regulations. This capability streamlines the certification process and reduces the risk of non-compliance.
5. **Sustainability** Virtual prototyping supports the development of more fuel-efficient and environmentally friendly aircraft. By optimizing designs for weight and performance, engineers can reduce fuel consumption and emissions, contributing to overall sustainability goals. And because of the reduction in the number of physical prototypes being produced, the amount of scrap material is also reduced. This approach aligns with the industry's commitment to reducing its environmental impact.
6. **Safety** Ensuring the safety and reliability of aerospace components and systems is paramount. Virtual prototyping enables rigorous testing and validation of designs, allowing engineers to identify and address potential safety issues early in the development process. This proactive approach enhances the safety and reliability of aerospace products.
7. **Competitive Success** Innovation and technological leadership are critical for competitive success in the aerospace industry. Virtual prototyping drives innovation by enabling the exploration of new ideas and concepts. Companies that adopt this technology can stay ahead in a competitive market, delivering cutting-edge products that meet the evolving needs of customers.

The adoption of virtual prototyping is becoming invaluable for addressing the challenges faced by the aerospace industry.

**Now, let's take a deeper look into the manufacturing processes that could really benefit from the virtual approach...**

# Virtual Manufacturing and the Role of Simulation

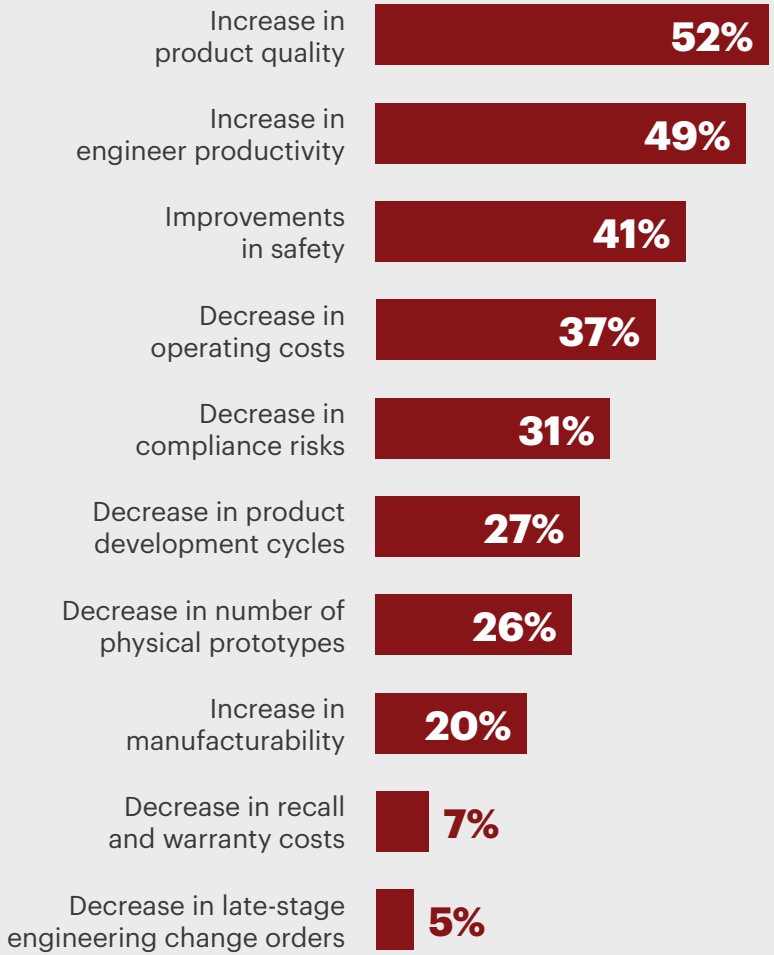
Simulation allows for the virtual testing and optimization of designs before physical production, reducing the risk of defects and material waste. By predicting potential issues and refining processes in a virtual environment, manufacturers can save time and costs associated with trial-and-error methods.

Additionally, simulation helps in understanding the behavior of advanced materials and complex geometries, ensuring that components meet stringent aerospace standards. This not only improves product quality and performance but also accelerates development cycles, giving manufacturers a competitive edge in the highly demanding aerospace industry.

Casting, composites, and sheet metal forming processes should all be leveraging the use of simulation software to enhance their efficiency and accuracy.

Keep reading for more specific insights into each process mentioned above, understand how the integration of simulation is changing the game, and learn more about the software that is the facilitator.

**Figure 4: Benefits of Using Virtual Prototyping or Simulation**




n°203, Source: Aberdeen, December 2023
% based on respondents feedback

# Casting

Casting is a cornerstone of modern aerospace manufacturing, enabling the creation of lightweight, high-precision components critical for aircraft performance and reliability, and is widely used to meet the industry's stringent tolerances and achieve optimal strength-to-weight ratios. From engine parts to landing gear and structural elements, casting combines advanced materials with precision engineering to produce parts capable of withstanding extreme conditions.

## Challenges in Casting for Aerospace

Casting for aerospace applications presents several significant challenges that must be addressed to ensure the production of premium-quality components.

**Occurrence of Defects:** These defects can range from porosity, cracks, and inclusions to issues with grain structures which can compromise the structural integrity and performance of the cast parts.

**Material Waste:** With some casting processes, the precision and high quality required for aerospace components can lead to a high amount of scrap material, which not only increases costs but also impacts sustainability efforts.

**High Costs:** These costs stem from the need for specialized materials, advanced manufacturing techniques, and stringent quality control measures.

These challenges highlight the complexities involved in casting aerospace parts and underscore the need for continuous innovation and improvement in casting technologies.

## Casting methods used by the aerospace industry

Investment and Sand Casting are the casting processes predominantly used by aerospace manufacturers.

Investment casting excels in creating components with exceptional surface finishes and precise dimensional control. The process begins with wax pattern creation, followed by ceramic shell formation and controlled metal pouring under strict atmospheric conditions.

Sand casting proves valuable for larger aerospace components, offering cost-effective solutions for parts exceeding traditional size limitations. Modern foundries enhance this traditional technique with computerized sand mixing and advanced binder systems.

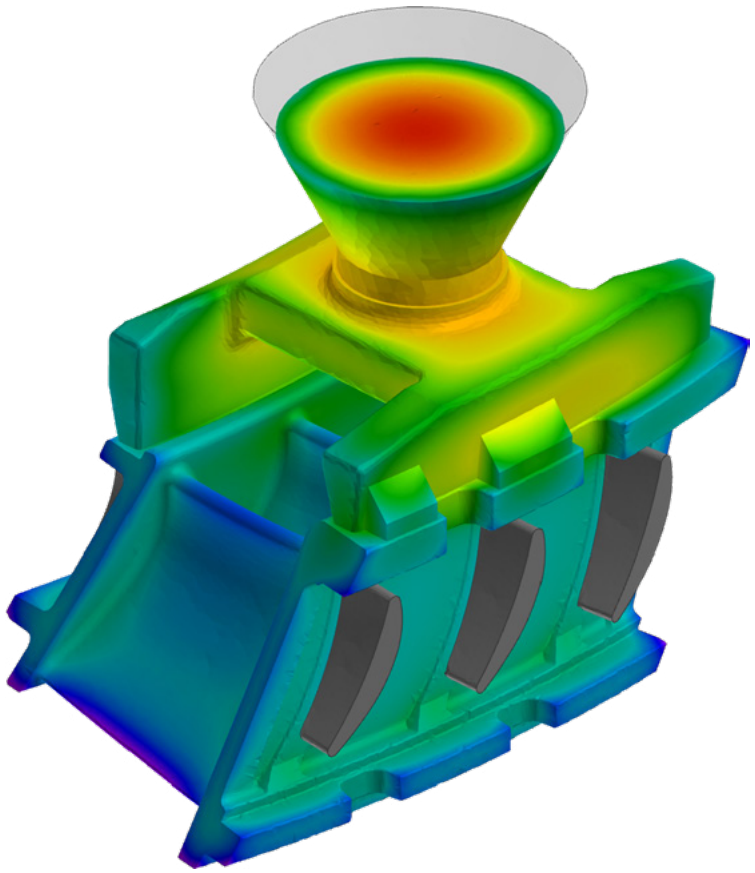
Using both of these methods allows manufacturers to meet diverse production needs. For example, turbine blades benefit from investment casting's ability to form complex cooling channels, while engine housings rely on sand casting's scalability and strength characteristics.

# The Dominance of Investment Casting

Although sand casting definitely has a place in the manufacture of aerospace parts, investment casting is the dominant process used due to several key advantages it offers:

1. **Precision and Complexity:** Investment casting allows for the production of highly complex and intricate shapes with tight tolerances. This is crucial for aerospace components, which often have complex geometries and require high precision to ensure proper fit and function.
2. **Material Versatility:** This process is compatible with a wide range of materials, including superalloys and other high-performance metals that are essential for aerospace applications. These materials provide the necessary strength, heat resistance, and durability required in the aerospace industry.
3. **Surface Finish and Quality:** Investment casting produces parts with excellent surface finish and minimal machining requirements. This reduces the need for additional finishing processes, saving time and cost while maintaining the high-quality standards needed for aerospace components.
4. **Reduced Material Waste:** This process is highly efficient in terms of material usage. The wax patterns used in investment casting can be reused, and the precision of the process minimizes excess material, leading to less waste and lower costs.
5. **Consistency and Repeatability:** Investment casting provides consistent and repeatable results, which is essential for producing large quantities of identical aerospace components. This reliability ensures that each part meets the stringent quality and performance standards required in the aerospace industry.

These advantages make investment casting an ideal choice for manufacturing aerospace components, where precision, material performance, and quality are paramount.



NGV Part (Nozzle Guide Vane)

## Benefits of Casting Process Simulation

Casting simulation software plays a crucial role in helping aerospace companies optimize their manufacturing processes and ensure the quality and reliability of critical components meet the strict regulations required.

ProCAST software uses accurate physics and finite element technology to help manufacturers produce high-quality cast parts on the first attempt. It supports various alloys like aluminum, titanium, magnesium and nickel-based superalloys, and casting processes like sand and investment casting, reducing scrap and minimizing late-stage redesigns.

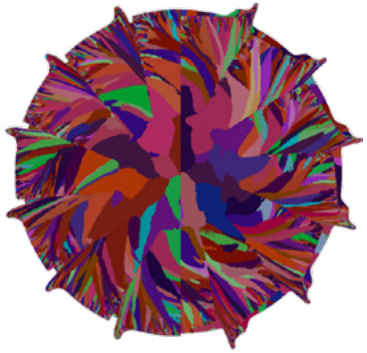
The software predicts key casting defects for the filling and solidification stages, like misruns, inclusion, air entrainment, shrinkage porosity and cracks and hot tear. Additionally, it simulates complex phenomena such as residual stresses and dimensional variations. ProCAST also provides insights into microstructure, grain structure, and mechanical properties, ensuring components meet performance and durability requirements.

In addition, specifically for investment casting, ProCAST includes functionality for accurate multi-layer, multi-thickness shell generation, realistic radiation considering view factors ensuring shadowing effects for multi-body shapes, and provides a 'shell bridge indicator' to identify manufacturing challenges during product design stages, making the solution extremely suitable for high-temperature and super alloy investment castings in Aero and other industries.

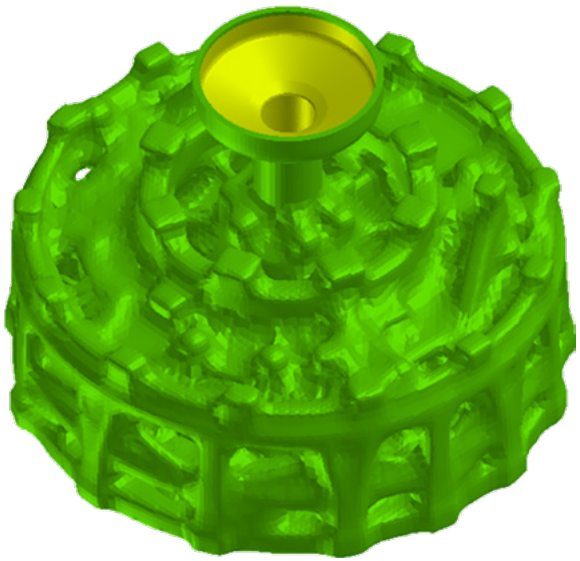
## ProCAST is the ideal solution for:

- Addressing challenges across different methodologies through predictive simulations
- Reducing casting defects
- Optimizing material yield
- Optimizing microstructure
- Minimizing cycle times
- Minimizing distortions/ensuring casted components within tolerances
- Optimizing gating design
- Achieving regulatory compliance

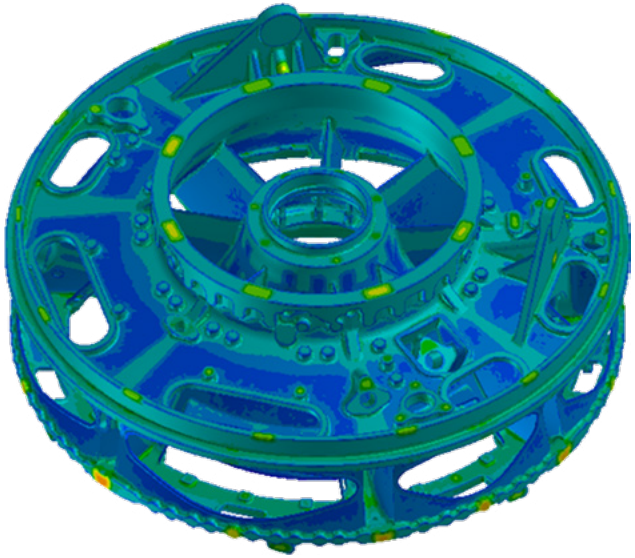
**To find out more, visit the ProCAST webpage.**



Turbocharger- Grain Growth Modeling



Engine Housing- Shelling View



Engine Housing-Niyama Criteria Results

# Composites

Composite materials are crucial in aerospace due to their lightweight and high-strength properties, which significantly enhance aircraft performance and fuel efficiency. These materials, typically composed of fibers like carbon, glass and aramid embedded in a resin matrix, offer superior strength-to-weight ratios compared to traditional metals. This makes them ideal for reducing the overall weight of aircraft while maintaining structural integrity.

Common applications of composites in aerospace include fuselage sections, wings, and engine parts. In fuselage sections, composites provide the necessary strength and durability while reducing weight, leading to improved fuel efficiency and payload capacity. For wings, composites allow for more aerodynamic designs and better resistance to fatigue and corrosion. In engine parts, the high-temperature resistance and strength of composites contribute to more efficient and reliable engine performance.

Overall, the use of composite materials is essential for advancing aerospace technology and achieving more sustainable and efficient aircraft designs.

## Challenges in Composite Manufacturing

Aerospace manufacturers face numerous challenges in composite material manufacturing due to the complexities involved in the process.

**Predicting Material Behavior:** Composite materials, composed of fibers and resins, exhibit complex behaviors that can be difficult to predict, especially under varying conditions such as temperature and stress. This unpredictability necessitates extensive testing to ensure reliability and performance.

**Process Optimization:** The manufacturing process for composites involves multiple stages, including layup, infusion, curing, and finishing, each requiring precise control to achieve the desired properties. Optimizing these processes to balance quality, efficiency, and cost is a continuous struggle, often requiring advanced technologies and methodologies.

**Variability in Material Properties:** Factors such as fiber orientation, resin distribution, and curing conditions can lead to inconsistencies in the final product. This variability can affect the structural integrity and performance of aerospace components, making it essential to implement stringent quality control measures.

**Predicting Material Performance:** The complex interactions between the composite constituents and the environment can lead to unexpected behaviors, making it difficult to ensure consistent performance across various applications. This unpredictability requires comprehensive testing and validation to meet the stringent standards of the aerospace industry.

**Expensive and Time-Consuming:** The need for specialized equipment, skilled labor, and extensive testing contributes to the overall expense. Additionally, processes such as autoclave curing are time-intensive, further increasing production times and costs. These factors make it crucial for aerospace manufacturers to continuously seek innovations and improvements to reduce costs and enhance efficiency.

The challenges in composite manufacturing for aerospace highlight the need for ongoing research, technological advancements, and process improvements to meet the demanding requirements of the industry.

**Simulation software is one solution that can solve some of these challenges - but how?**

## Benefits of Simulation for Composite Manufacturing

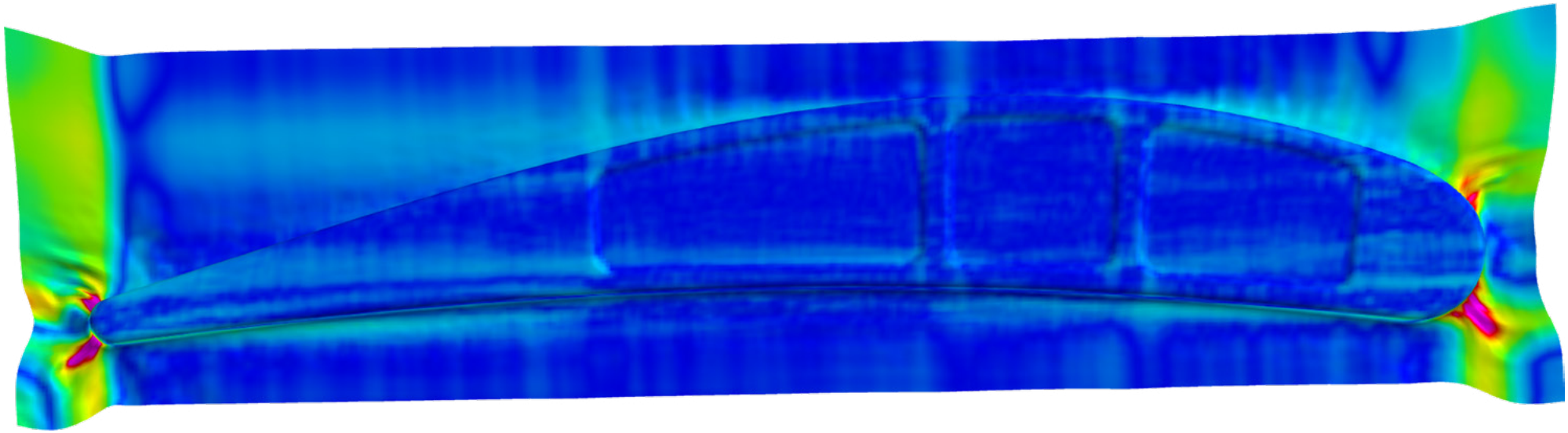
Composite simulation software is enabling engineers to optimize material behavior, reduce defects, and accelerate development cycles. By accurately predicting performance under real-world conditions, it ensures structural integrity while supporting lightweight and complex designs.

With PAM-COMPOSITES, you can study each step of the composites manufacturing chain through a process-oriented workflow. Material information and history (local shearing, local fiber content, and orientation, degree of cure, etc.), as well as geometrical properties (shape, thickness, etc.), are easily transferred from one stage of the manufacturing chain to the next. This ensures maximum feedback accuracy when adjusting the process parameters to correct defects and reduce production cycle time.

## Use PAM-COMPOSITES for:

- Predicting composite behavior accurately during the various manufacturing stages
- Detecting manufacturing issues at a stage where cost of changes is still low
- Optimizing manufacturing processes
- Seamless link to performance testing environment
- Reducing material waste
- Shortening development cycles
- Enhancing overall product quality
- Ensuring component manufacturability

**To find out more, visit the PAM-COMPOSITES webpage.**



Shear Angle Display on a Composite Rib

# Sheet Metal Forming

Sheet Metal Forming is a crucial process in the manufacturing of aerospace parts due to the ability to produce high-precision metal components efficiently and consistently. This level of precision is essential as even minor deviations can impact the performance and safety of aircraft. There are several different sheet metal forming processes, each suited to manufacturing particular parts of aircraft.

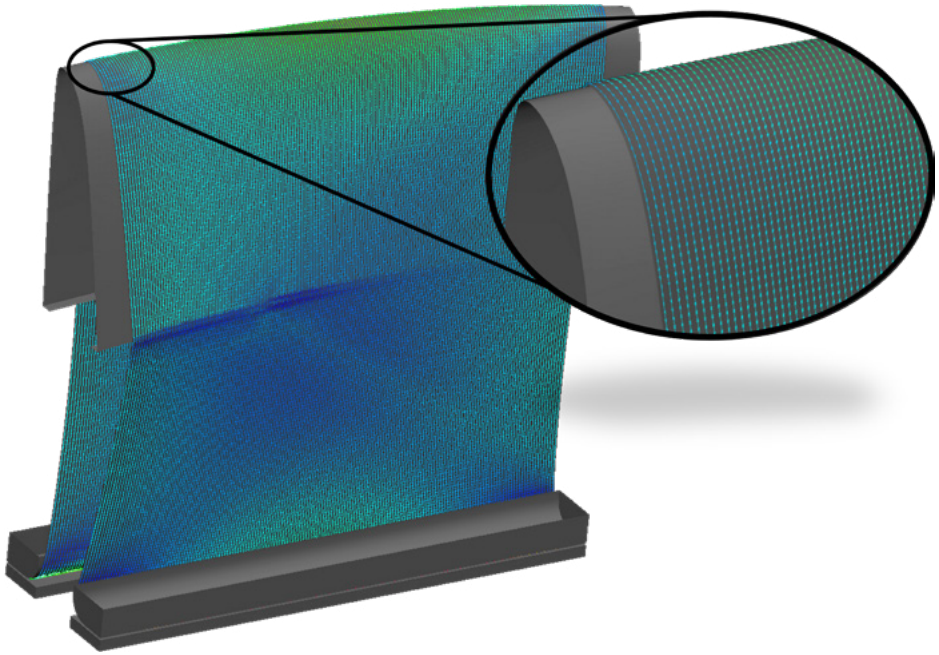
Superplastic forming (SPF) shapes materials like titanium and aluminum alloys at high temperatures and with very low strain rates, allowing them to deform without breaking. It's used to create lightweight, complex components with demanding specifications, for example in aero engines because titanium allows the production of strong and high-performance parts with excellent temperature resistance, and enhanced fatigue and corrosion resistance.

Stretch bending is best for creating large, contoured parts like fuselage panels, wing panels, and engine cowl panels. By simultaneously stretching and bending the metal over a die, it ensures excellent shape control, surface quality, and structural integrity.

Hydroforming is used to produce structural components, panels, and engine parts. It uses high-pressure hydroforming with a flexible rubber diaphragm, offering a gentle forming process that is ideal for low-volume production, and accommodates various materials like aluminum, titanium, and ultra-high-strength steels.

Another often applied sheet metal forming process in aerospace is solid rubber cushion forming. This is a sheet metal forming process where a solid rubber cushion is used to press and shape a metal sheet over a mold, providing uniform pressure during the forming process. It is used in aerospace for producing components like structural components and ribs in fuselage and wings.

Overall, sheet metal forming is indispensable in aerospace manufacturing, ensuring the production of reliable, high-quality components that meet the industry's stringent standards.



Stretchforming of Large Wing Panel

# Challenges in Sheet Metal Forming for Aerospace

Sheet metal forming processes in aerospace manufacturing face several significant challenges that can impact efficiency, quality, and cost-effectiveness.

**Material Deformation:** One of the primary difficulties in sheet metal forming is managing material deformation. This must be carefully controlled to avoid defects such as wrinkling, cracking, or excessive thinning of the material. Ensuring uniform deformation across complex shapes is particularly challenging and requires precise control of process parameters.

**Tool Wear:** The high pressures and repetitive nature of the process can cause significant wear and tear on the tools used. This wear can lead to dimensional inaccuracies and defects in the stamped parts. Regular maintenance and replacement of tools are necessary to maintain quality, but this adds to the overall production costs and downtime.

**Production Delays:** Production delays can occur due to various factors, including tool wear, material shortages, and unexpected equipment failures. These delays can disrupt the manufacturing schedule, leading to missed deadlines and increased costs. Effective planning and preventive maintenance are essential to minimize these disruptions.

**Achieving Consistent Quality:** Variations in material properties, tool wear, and process conditions can lead to inconsistencies in the final product. Implementing rigorous quality control measures and continuous monitoring are crucial to ensure that each part meets the required specifications.

**Managing Complex Geometries:** Forming complex geometries is particularly challenging due to the intricate shapes and tight tolerances required in aerospace components. Achieving uniform material flow and avoiding defects such as wrinkling or tearing in these complex shapes require advanced tooling and precise control of the process.

**High Costs Associated with Tooling and Rework:** The costs associated with tooling and rework are substantial in aerospace. High-quality, durable tools are expensive to produce and maintain. Additionally, any defects or inconsistencies in the parts often require rework, which further increases production costs and time.

Overall, addressing these challenges requires a combination of advanced technologies, rigorous quality control, and continuous process improvement to ensure the efficient and cost-effective production of high-quality aerospace components.

The adoption of simulation software is one such solution that can help solve some of these problems before any physical production starts...

### Benefits of Simulation for Sheet Metal Forming

Simulation capabilities enable manufacturers to precisely calculate springback effects and optimize tool geometries. This proves particularly valuable for producing large fuselage and wing sections, where even minor deviations can impact aerodynamic performance and assembly fit.

PAM-STAMP from ESI, part of Keysight enables the successful production of sheet metal formed parts for a wide range of sheet metal forming processes, whether working with simple or complex geometries, conventional, stainless or high strength steels, aluminium or titanium components.

The software's comprehensive analysis of material behavior under varying temperatures enables optimal forming strategies for critical aerospace parts.

## How PAM-STAMP addresses these challenges:

- Simulating almost all of the common aerospace sheet metal forming processes accurately thanks to the advanced physics-based solver
- Predicting potential manufacturing issues before production
- Optimizing tool design for highest part quality and in-tolerance parts
- Reducing material waste and rework
- Enhancing product quality and consistency
- Shortening development cycles and time-to-market
- Ensuring manufacturability

**To find out more, visit the PAM-STAMP webpage.**

Super Plastic Formed Nose Cowl

CHAPTER 5

# Integration and Synergy of ESI, part of Keysight Solutions

Integrating ESI, part of Keysight's simulation solutions offers a holistic approach to virtual prototyping, providing significant advantages for aerospace manufacturers. By leveraging ESI, part of Keysight's comprehensive suite of tools, aircraft manufacturers can create detailed and accurate virtual prototypes that encompass all aspects of the product lifecycle, from design and testing to manufacturing and maintenance.

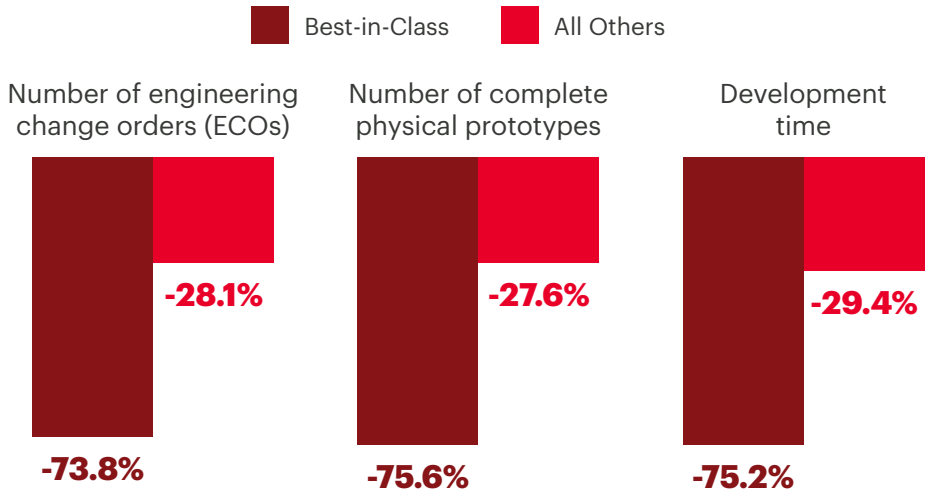
This integration allows for a seamless flow of information and insights across different stages, ensuring that potential issues are identified and addressed early in the development process. Additionally, the accuracy and predictive capabilities of integrated ESI, part of Keysight solutions result in higher product quality, as manufacturers can optimize designs and processes with greater confidence.

Using ESI, part of Keysight solutions enhances overall efficiency, and whilst these tools fit together under the Virtual Manufacturing umbrella, they also offer an attractive potential to link the manufacturing results to downstream processes like welding and assembly, and performance.

This collaborative use of ESI, part of Keysight solutions reduces time-to-market by minimizing the need for physical prototypes and iterative testing, leading to faster decision-making and implementation, maintaining a competitive edge in a rapidly evolving market.

**For more information on using ESI, part of Keysight's Virtual Manufacturing software portfolio in the aerospace industry, visit the dedicated webpage.**

**Figure 3: Simulation-Driven Design Boosts Performance**




% change over the past two years

n°203, Source: Aberdeen, December 2023

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Keysight is an S&P 500 company delivering market-leading design, emulation, and test solutions to help engineers develop and deploy faster, with less risk, throughout the entire product lifecycle.

For further information, go to: www.esi-group.com