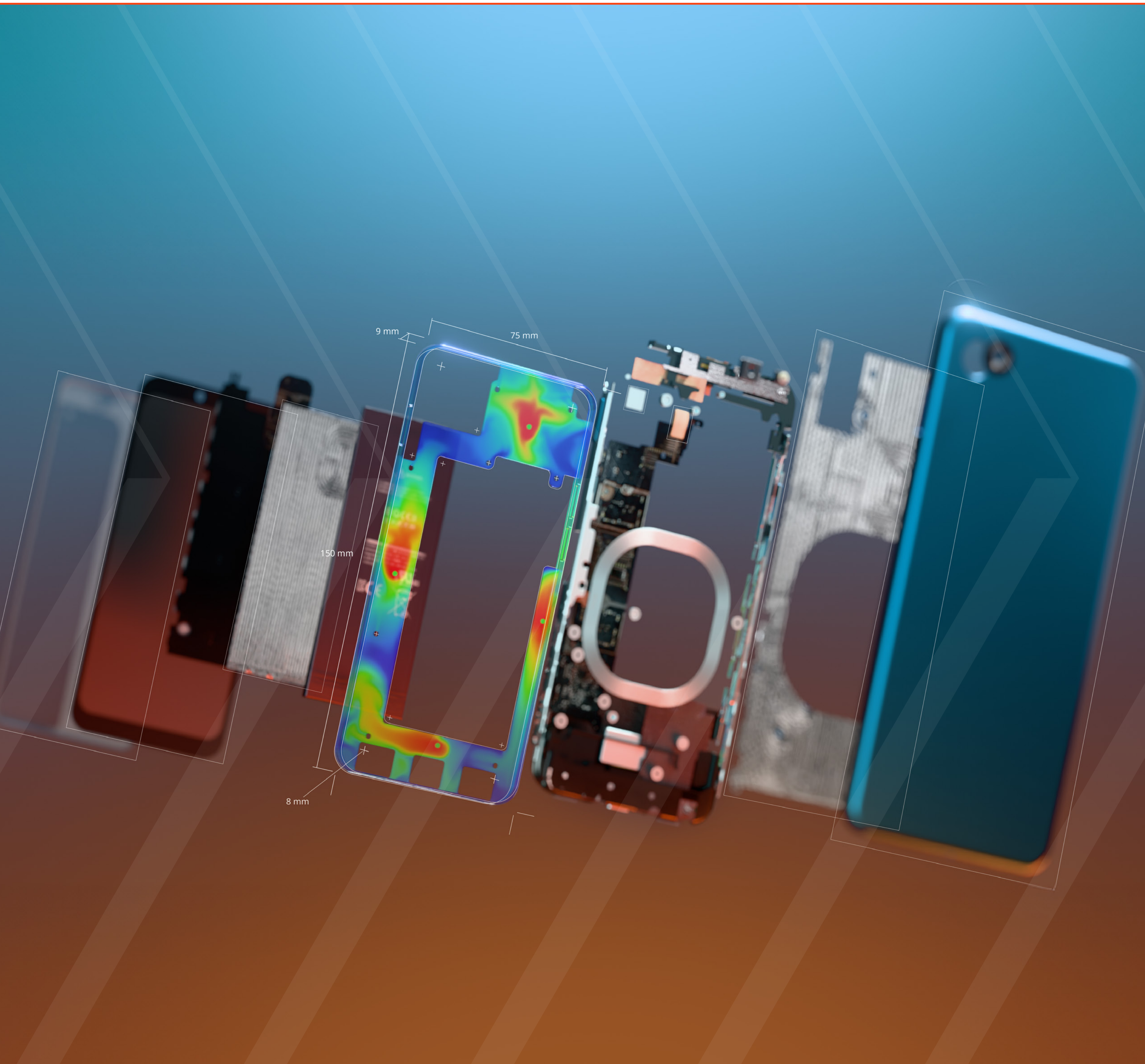
GUIDE TO SIMULATION-DRIVEN DESIGN: FROM GEOMETRY MODELING TO MANUFACTURING SIMULATION



INTRODUCTION

Bringing innovative, high-performance products to market requires more than just great ideas—it demands a smarter, more efficient approach to design. Traditional development methods often rely on late-stage testing, leading to costly redesigns and delays. Simulation-driven design transforms this process by integrating computational physics, validation, and geometry optimization from the start.

In this eGuide, you'll learn how simulation-driven design enhances product performance, streamlines workflows, and ensures manufacturability from concept through production. Backed by decades of expertise in engineering simulation, Altair provides the knowledge and tools that help designers reduce waste, accelerate development, and bring production-ready products to market faster.

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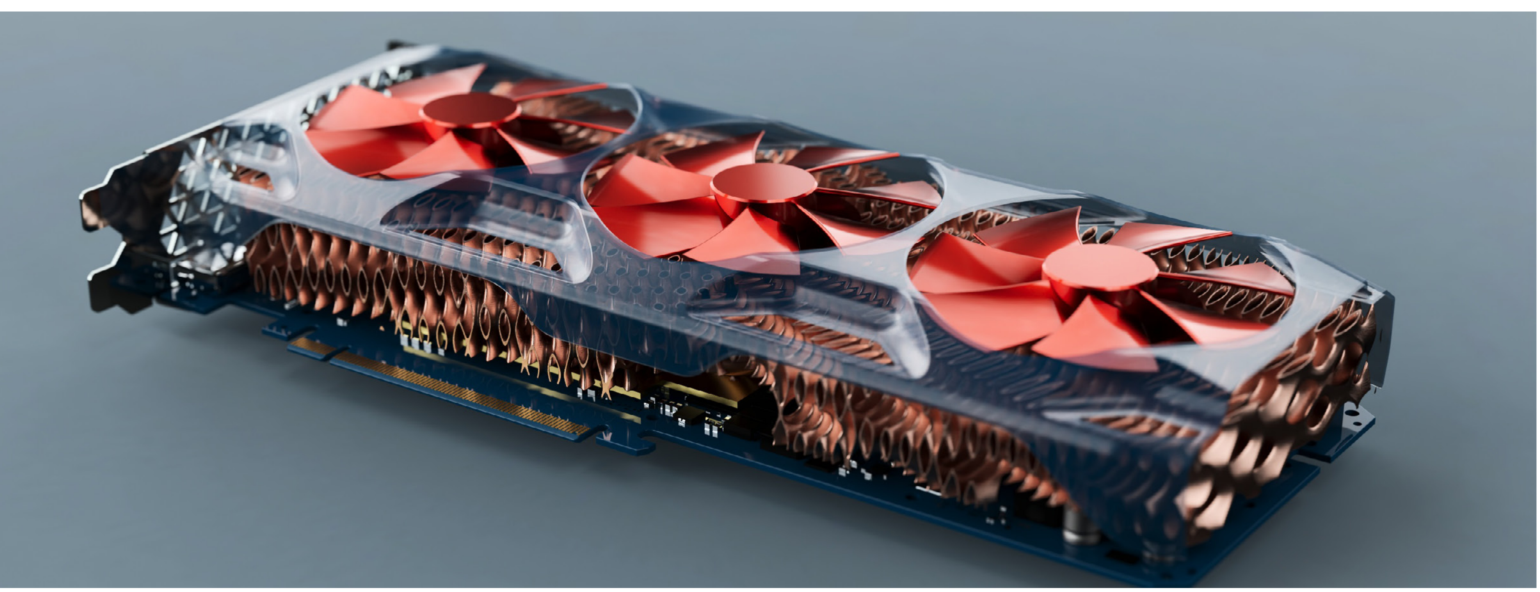
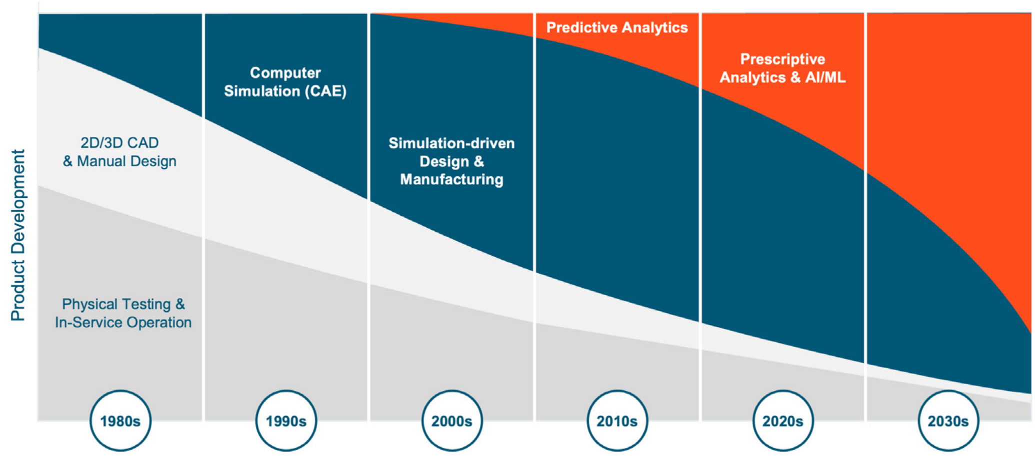


THE ENGINEERING DIGITAL REVOLUTION



When design offices replaced their drawing boards with workstations, the screen became the blank page, and at first, the tools mimicked the pencil. As computer technology advanced, capabilities and accessibility exploded, giving birth to computer-aided design (CAD).

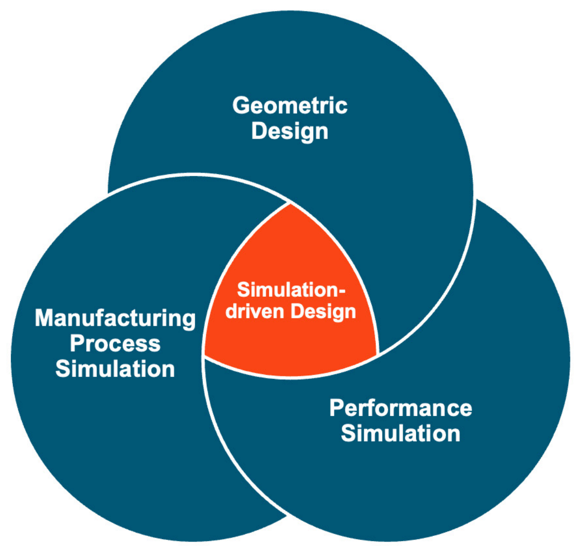
On the factory floor, machinery was equipped with computer numerical control (CNC) systems – initially punch-tape, then electronics – lathes, milling, and other machinery, providing greater precision and speed. The ability to produce complex shapes, otherwise impossible by skilled machinists, evolved further to become computer-aided manufacturing (CAM).

Elsewhere, hardware and software development meant numerical analytical software tools – previously the domain of applied mathematicians and confined to mainframes – made computer-aided engineering (CAE) accessible locally to engineers on commercial personal computers. The finite element method (FEM) brought finite element analysis (FEA), which became popular among the engineering community seeking a versatile, powerful, accessible methodology. Today, numerical methods are the workhorses of engineering and the foundation of modern artificial intelligence (AI)-driven, generative design.

But not all analysis of complex engineering models requires meshing. Today, a meshless approach eliminates traditional FEA pitfalls, enabling non-experts and experts alike to rapidly iterate designs on fully featured CAD assemblies locally and in the cloud. Facing structural analysis problems that are difficult to model with a mesh – e.g. complex 3D objects, multipart assemblies, non-linear problems, or designs with complex heterogeneous properties – no longer needs to be a bottleneck.

Understanding the Complete Picture

Much is said about "silos" and the negative effects of task compartmentalization. Created to provide a complete picture for product designers, modern tools address the problems of the manufacturing process being divorced from geometric design. Simulating industrial manufacturing processes for metals and plastics ensures understanding, prediction, and resolution of design problems early in the product development process. With the invention and adoption of 3D printing in mainstream engineering, success now hinges on the consolidation of design, calculation, and manufacturing processes.



In addition, the miniaturization and power of complex electronics means that today, practically every industrial process is instrumented and capable of generating a tsunami of data which, when properly exploited, future-proofs organizations.

WHAT IS SIMULATION-DRIVEN DESIGN?

The simulation technology previously deployed towards the middle or late stage of product design is now being used at the start of it. The more that can be known or predicted at the start, the more teams can reduce the risk of errors or costs later. Simulation-driven design has reinvented the traditional serial tasks of the development process of "concept – prototype – test – detail design – manufacture" into parallel activities, known as concurrent engineering. Together, the expertise of designers, analysts, and manufacturing engineers all contribute from their domain-specific simulation technology to create a design and validate it instead of using simulation to analyze it later. This unified approach removes the endless iterations between detailed design and validation. Simulation-driven design is an established, proven way to slash the time it takes to develop products and moves product engineering towards a world of prevalidated design.

Benefits of a Simulation-Driven Design Approach

As simulation has become more adept at modeling real-world product behavior, companies have embraced the benefits of simulation-driven design for manufacturing, optimization, and virtual testing. To increase innovation, cut costs, and streamline design and production, the implementation of simulation-driven design practices throughout the product development cycle has proven vital in the race to stay ahead of the competition.

What is Simulation-Driven Design for Manufacturing?

One often overlooked aspect of product design and simulation is part manufacturability. A simulation-driven design on a computer screen might not match what ends up being manufactured (or even be possible) if part details can't be executed by a particular manufacturing method. Discrepancies between virtual and physical prototypes can be a major burden at such a late stage in the product development process. For example, correcting defects during a mold trial can add an additional 25% to the mold's total cost. The choice of manufacturing process, materials used, and machine tolerances can affect what designs can be produced and how well that part performs compared to its virtual counterpart.

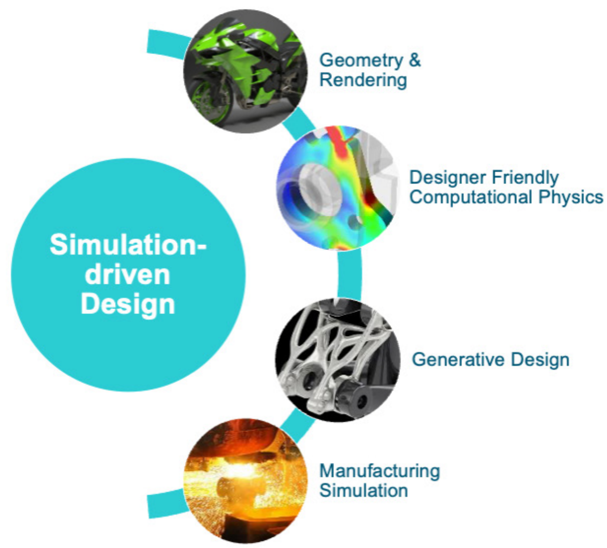
Trial-and-error approaches can make it difficult to anticipate manufacturing issues and know how to correct them. This often results in engineering teams committing time and resources to modify designs and physically retest new prototypes; as a result, parts run the risk of being over-engineered, adding cost and hampering performance.

By contrast, a simulation-driven design for manufacturing (SDfM) approach delivers manufacturability insights directly into product designers' hands. Design flaws can be detected and corrected early, allowing users to confidently design for their chosen manufacturing method. Designing for production right the first time brings products to market faster and enables the exploration of more cost-effective workflows for traditional manufacturing processes and more recent processes, like additive manufacturing.

For more on SDfM, visit altair.com/manufacturing-applications.

WHAT DOES AN IDEAL SOLUTION LOOK LIKE?

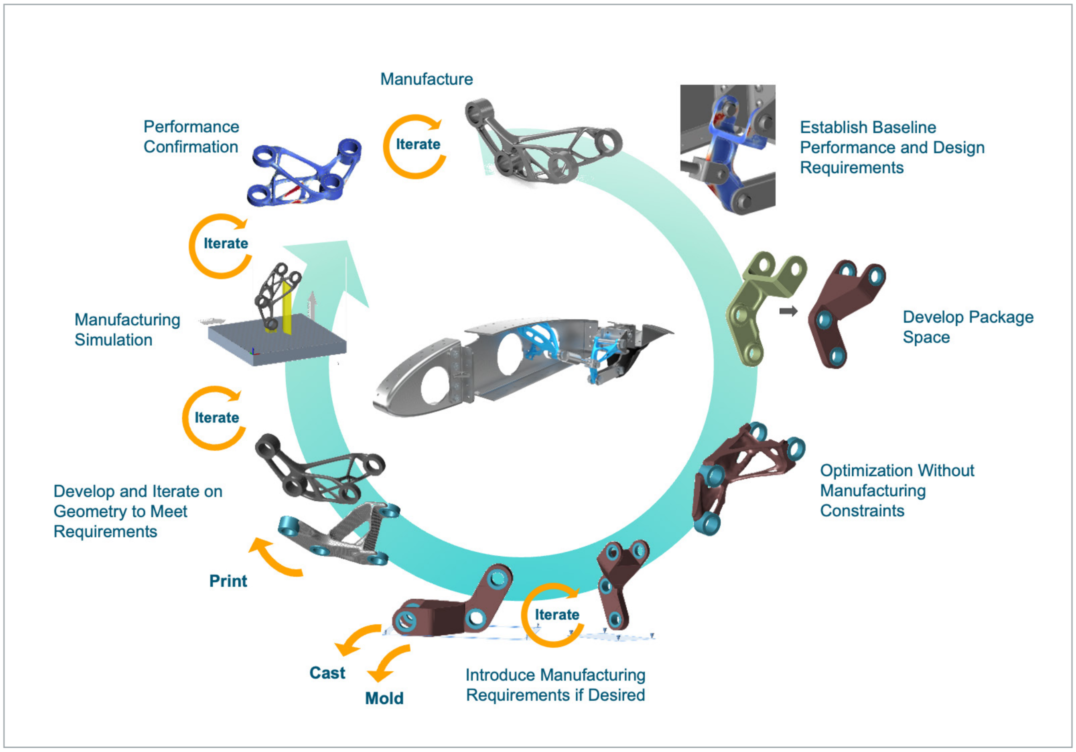
An ideal simulation-driven design solution provides an intuitive, integrated software environment that accelerates the design process from concept to final product. By emphasizing product performance and manufacturability early in development, designers can confidently create high-performance products in a single, unified workspace.



Developed with product designers in mind, this ideal solution provides accessible simulation tools and workflows that enable users to explore the performance and manufacturability of designs without requiring specialized expertise, such as the knowledge of an FEA analyst. Key capabilities include:

- **Geometry and Rendering:** Creation or modification of geometry. Supports use of parametric surfaces, solids, polyNURBS, facets, and implicit modeling within the same model.
- **Designer-Friendly Computational Physics:** For rapid exploration of complex physics simulations. Accessible to non-experts for fast, accurate analysis of structural, fluid flow, and motion dynamics.
- **Generative Design:** Creates optimized products by extending beyond traditional topology optimization, utilizing AI-driven generative design techniques to develop practical, sustainable, production-ready designs.
- **Manufacturing Simulation:** Evaluate casting, metal forming, injection molding, metal and polymer extrusion, polyurethane foaming, and additive manufacturing early to prevent defects and costly retooling.

Explore a real-world application of a simulation-driven workflow here.



An example of a typical optimization workflow, involving the consideration of manufacturing methods to produce a final product.

Additionally, the ideal solution includes flexible, guided workflows that enable users to efficiently address various design challenges. Customization and extensibility through APIs further allows users to automate and adapt the platform in numerous ways (run macros and batch modes, edit the toolbar, launch another product, etc.), and adapt core functionalities (objects, boundary conditions, geometry and graphics).

Learn more about Altair's solutions using Python API.

To Learn More:
Watch On-Demand

This holistic approach combines simulation, AI, and high-performance computing (HPC) to help organizations deliver validated, optimized, manufacturing-ready products.

CHALLENGES OF DESIGNING INNOVATIVE PRODUCTS

To successfully achieve rapid time to market, products must be designed with the following considerations:

- **Performance:** Ensuring optimal strength, weight, speed, and quality.
- **Sustainability:** Adopting new materials and processes, prioritizing material efficiency, emphasizing design for repairability, and encouraging reuse and recycling.
- **Affordability:** Managing product costs, ongoing maintenance, warranty coverage, and ease of repair.

By effectively balancing these often conflicting requirements from the earliest stages of the design process, Altair's simulation-driven design solution proactively identifies and resolves potential issues using an innovative approach.

GEOMETRY AND RENDERING

Begin your design with a simple sketch or seamlessly import CAD files from major commercial software. Using the same model, designers gain access to an extensive, continuously evolving set of modeling tools to build geometries, including:

- Parametric surfaces and solids
- Boundary representation (BRep)
- Facets
- PolyNURBS
- Implicit modeling

Those familiar with CAD tools will have encountered the limitations of designing organic-like forms which have become of growing interest in a world adopting generative design. With PolyNURBS, designers can create smooth, complex shapes—much like modeling with digital clay— but with the benefit of having a defined parasolid geometry for use in any manufacturing process simulation. Furthermore, implicit modeling tools enable the creation of even more detailed, intricate geometries such as lattice structures.

Next-Generation Graphics and Rendering – Discover how advanced visualization and rendering technologies enhance the simulation-driven design process for more realistic and detailed simulations.

What is Implicit Modeling?

Traditional geometry is modeled by construction of explicit surface patches bounded by curves between vertices. In contrast, implicit modeling represents geometry through implicit functions—essentially, a 3D field of scalar values indicating notional distances to the surface of a volume. While implicit modeling has traditionally been complex, modern tools and workflows have simplified its use, making it accessible for designers of all skill levels.

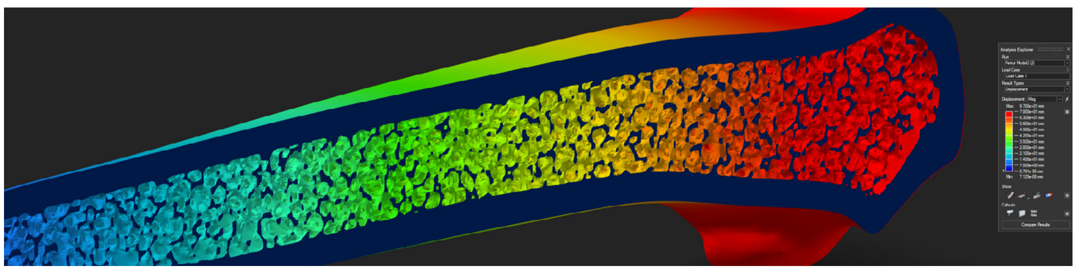
Advantages of implicit modeling include:

- **Fully Parametric:** Offers construction history and variable-driven, CAD-like operations to accelerate design cycles of typically difficult geometry with clear, editable operations and end-to-end history control.
- **Geometry Agnostic:** Seamlessly integrates implicit geometry with other geometry types (e.g., BRep, mesh, PolyNURBS), allowing flexible cross-representation workflows.
- **GPU Acceleration:** Ensures fast geometry creation and real-time rendering, as most implicit functions run directly on the GPU.
- **Integrated Simulation:** Links seamlessly with structural and CFD simulation tools, providing immediate feedback for design exploration and optimization.
- **Automated and Extensible:** Offers powerful scripting capabilities through APIs for automation, customization, and extension of design workflows.

The capabilities can be summarized as:

- **Latticing:** Create regular, stochastic, conformal, or customizable lattice structures driven by variable, field, or simulation data for creation of complex mathematical structures.
- **Offsets:** Robust Boolean operations and shelling and blending of geometry, offering efficient, unbreakable distance-based operations between surfaces.
- **Freeform:** Reconstruct, sculpt, surface, or repair complex geometry by converting any geometry type to implicit and perform targeted modifications to global and local regions.
- **Textures:** Apply regular and non-regular surface modifications, patterns, or perforations to any object along surfaces or curves.
- **Smoothing:** Apply global fillets and noise reduction using a range of smoothing algorithms and controls, as well as global filleting for controlled edge rounding.
- **Field-Driven Design:** Control geometric parameters at every spatial point. Create gradient effects for lattice geometry, create complex fillets, offsets, shell thicknesses, and map non-geometry data such as simulation results to the properties of geometry.

To Learn More:
Watch On-Demand

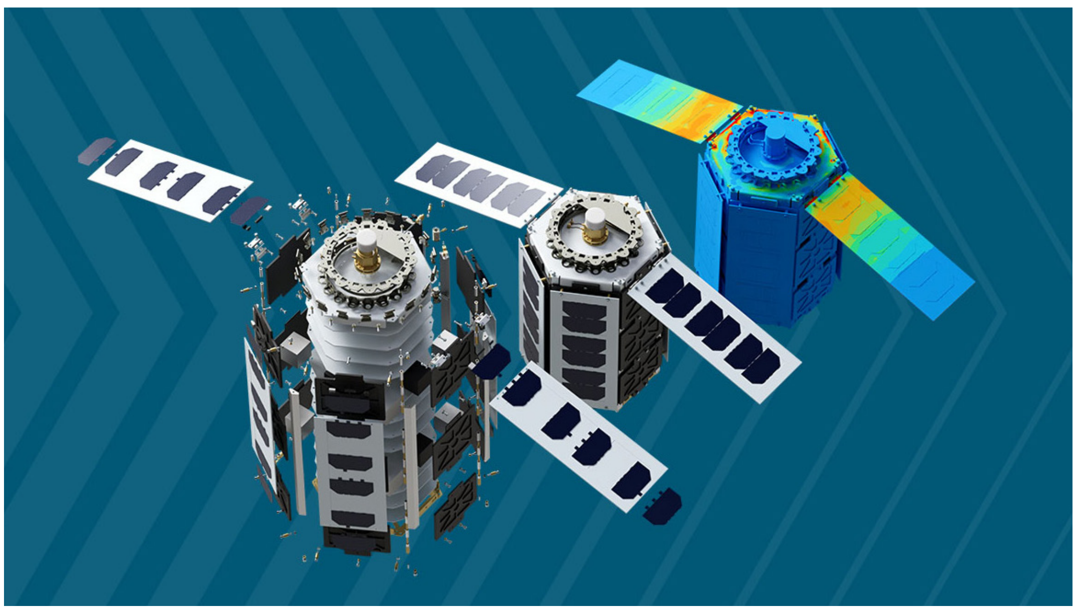


DESIGNER-FRIENDLY COMPUTATIONAL PHYSICS

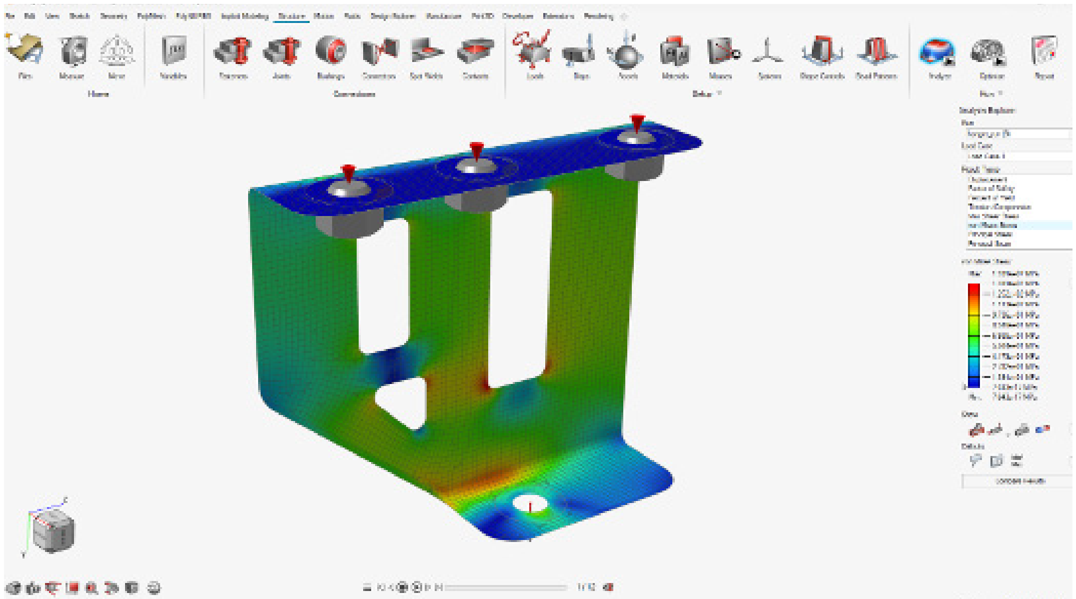
Complex physics simulations become intuitive and accessible, enabling rapid and accurate exploration – even for designers without specialized expertise. Users can efficiently analyze structural behavior, fluid dynamics, and motion dynamics to accelerate the design process and quickly iterate.

Structures

For rapid analysis of large, complex parts, use structural simulation to work directly on an original CAD assembly without the need to mesh, simplify, defeature, or midplane. Global and local controls make the simulation adaptable to attain the required level of accuracy. Well-suited for large assemblies and complex parts, advanced techniques provide solution times of seconds to minutes. Use for design exploration, design of experiments (DOEs), and optimization using geometry-driven parametric models.



For analysis of traditional FEM-based parts, product designers and design engineers can quickly and easily create and investigate structurally efficient concepts. Use FEA to ensure a design will support loads, and optimize via various optimization methods (topology, topography, gauge) — ideal for smaller assemblies, surface models, and motion-integrated loads.



Motion

From heavy equipment assemblies to simple latch mechanisms, and all mechanical and mechatronic assemblies between, motion simulation tools simplify the process of analyzing and optimizing the functional and structural behavior of systems. With intuitive tools, mechanizing models becomes quick and efficient.

Discovering optimal part shapes using dynamic motion loads ensures component integrity, while DOE and optimization studies enable mechanical performance to be optimized. Integrated capabilities include creating and modifying geometry, for example, to meet lightweighting objectives and reduce material specifications. Create flexible bodies, solve flexible body contact problems, and detect and remove part interference.

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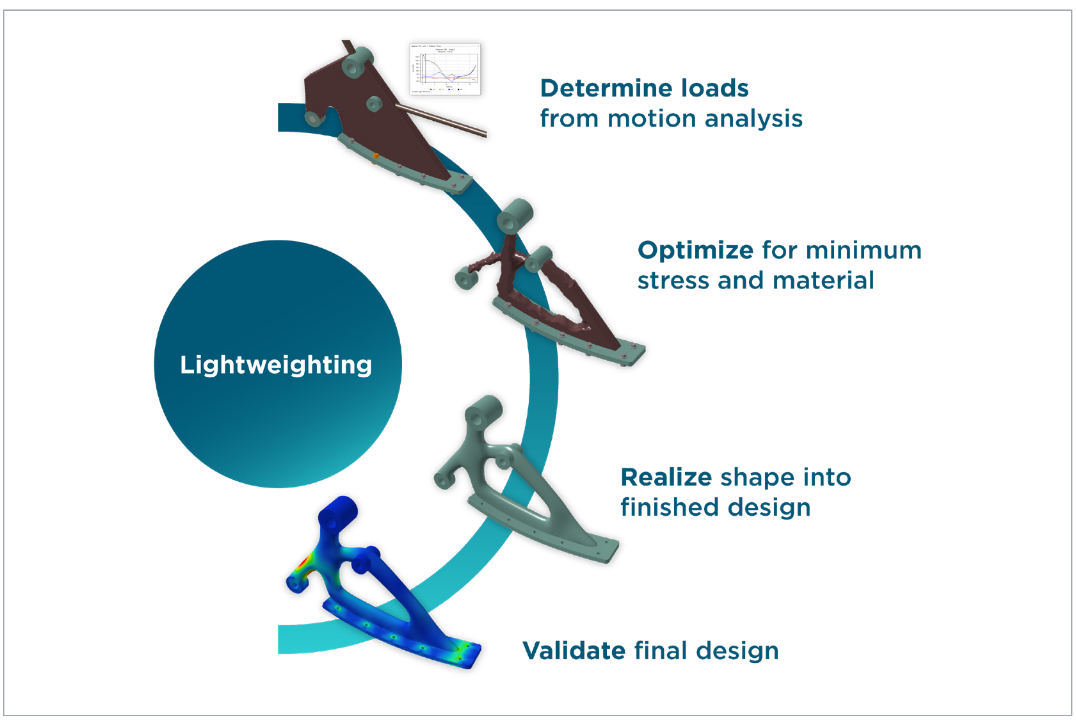
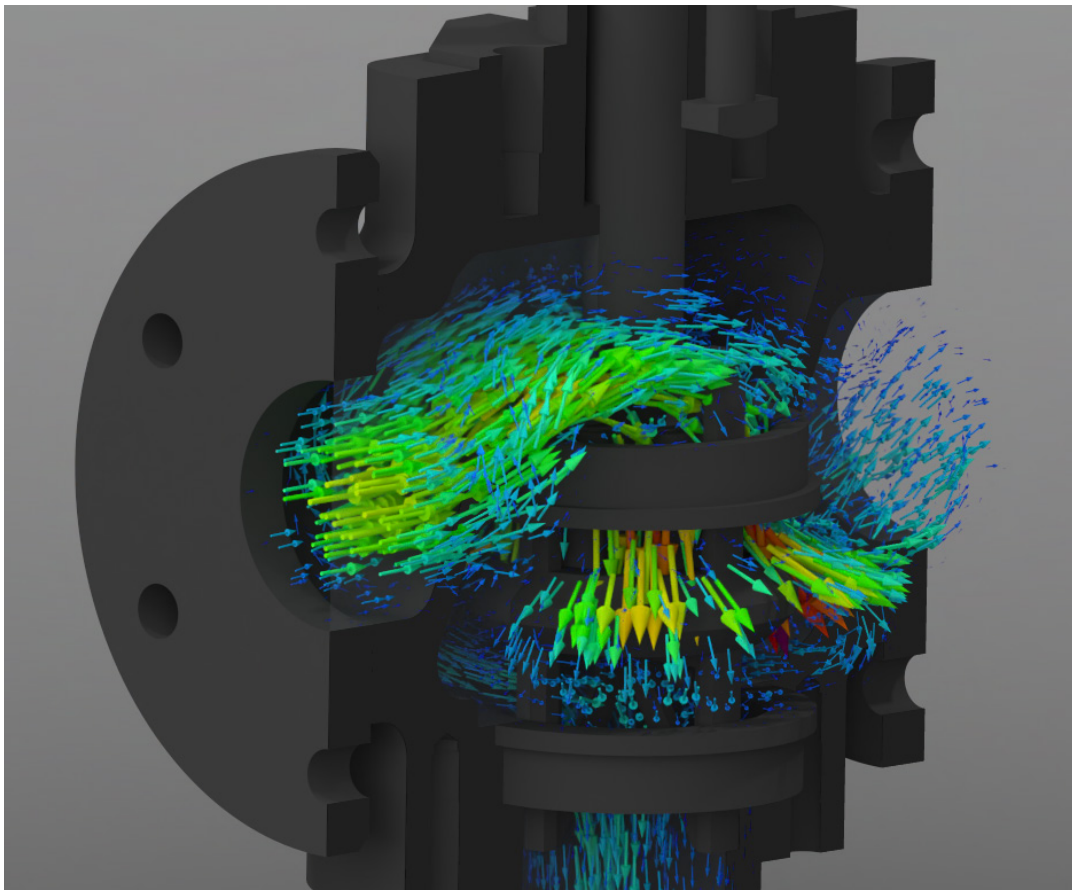


Fluids

When designing components for fluid transport or thermal cooling performance, it's essential to explore how a simple design modification can impact key system performance metrics. Designers require rapid exploration tools with parametric modeling and full construction history to efficiently evaluate computational fluid dynamics (CFD) early in the design process.

Using a CAD-based workflow without the complexities of traditional CFD meshing, these intuitive tools can streamline geometry creation, DOE, and reporting. Simplified workflows and GPU accelerated simulations quickly reveal performance trends, providing designers with clear, powerful visualization of fluids results to support informed decisions.

Watch to Learn More



GENERATIVE DESIGN

A generative design approach creates multiple design alternatives based on input from the user – such as performance requirements, materials, and manufacturing processes – in the aim to generate an optimized design. It has become a recent buzzword with the rise of AI in engineering, whereby it's an attractive approach for complex, resource-intensive design issues with numerous, often conflicting inputs. Recent programming environments or scripting, such as Python API, have simplified the task such that designers having little programming experience can readily explore ideas.

Design Optimization

Designers can readily access the industry's best optimization methods with embedded simulation for topology, topography, gauge, implicit (lattice) and polyNURBS, while ensuring manufacturability.

Design Exploration

A comprehensive, end-to-end workflow helps designers to quickly and easily set up, execute, and interpret multi-run studies such as optimizations and DOE. An intuitive environment provides access to an array of geometry and physics-based variables, complete with visual previews, making setup straightforward. Gain insight into a product's performance by identifying key attributes that influence behavior. With simulation support for structures, motion, and fluids, evaluate trade-offs without additional solver runs and compare results from multiple runs to reach an optimal design.

MANUFACTURING PROCESS SIMULATION

Effective product design requires close consideration of manufacturing processes. Simulation-driven approaches help designers ensure products can be manufactured by predicting and resolving potential process-related design problems before handing designs over to the factory floor.

Unlike traditional tools with limited capabilities, advanced simulation tools support both traditional and more recent polymer and metal manufacturing processes that can be simulated within the same environment and same model:

- Casting
- Injection molding
- Sheet metal forming
- Extrusion (metals and plastics)
- Polyurethane foaming
- 3D printing

This comprehensive approach allows designers to thoroughly explore manufacturing scenarios, explore the effects of process parameters, predict defects, and resolve issues long before actual production tooling is created.

Casting

Advanced casting simulation environments support various casting methods for metal parts, including gravity casting, high- or low-pressure die casting, investment casting, and tilt-pour. Benefits include:

- Comprehensive simulation of metal castings from filling to solidification.
- A fast, user-friendly framework for early casting feasibility and process development.
- Guided workflows for creating gates and runner system geometries.

Intuitive geometry creation tools enable rapid creation of essential rigging components, such as runners, risers, gates, cooling lines, overflows, and vents, and automatic generation of cores, molds, and dies. Automated riser creation provides designers with complete control over size adjustments.

Injection Molding

Injection molding simulation addresses one of the most widely used polymer manufacturing methods across all industry sectors, enabling users to quickly achieve accurate, robust results. Integrated material databases ensure access to properties of the wide range of commercially available injection molding polymer grades necessary to ensure an accurate process simulation.

Tools include geometry creation, parametric runner systems, and advanced workflows for gate optimization (hot and cold runners, sprues, vents), mold inserts, and cooling design, ensuring optimal filling and high-quality molded parts.

Sheet Metal Forming

Although a traditional process for creating shaped components from sheet metal, to achieve lightweight designs, thinner gauges, and different alloys are finding wider engineering uses. As a result, these materials may need more complex shapes to meet their exact performance requirements and modifications to processing to retain quality.

A robust stamping simulation workflow assesses product feasibility, material utilization, and die face design. This comprehensive process simulation covers both transfer and progressive die forming, accurately predicting forming issues and surface defects (such as splits and wrinkles), as well as springback. Additionally, it provides virtual tryout capabilities through an integrated nonlinear solver, enabling multistage incremental analysis.

Learn More at: altair.com/resource/understanding-scalability-in-altair-inspire-form-an-enhanced-springback-benchmark-study

Extrusion

Extrusion is a widely used manufacturing process where material is forced through a shaped die to produce continuous lengths of metal or plastic products with a consistent cross-sectional profile. Extruded products serve numerous industries, ranging from simple tubes to complex structural sections for automotive, architectural glazing systems, finned heat sinks, cable trunking, and more.

Advanced simulation tools for metal and polymer extrusion enable comprehensive analysis of dies and extrusion process conditions, helping designers predict and resolve common challenges, such as:

- **Metal extrusions:** Profile distortion, unbalanced wear, die wear, backend contamination, charge weld defects, poor seam welds, inconsistent grain structure, overheating, poor surface and profile quality, and quench-related issues.
- **Plastic extrusions:** Profile distortion, die swell, die deformation, (e.g. “clam shelling”), and issues related to the coextrusion of multiple polymers through the same die (with and without metal inserts).

Polyurethane Foaming

From home furnishings and car interiors to insulated panels in home appliances such as refrigerators and freezers, all aspects of our lives are cushioned, supported, and insulated by polyurethane foams (PU). With rigid, flexible, and semirigid variations, PU foams enable a range of inherently sustainable, lightweight, and adaptable strength products. Transitioning from traditional CAD-and-prototype approaches to PU foaming simulation allows manufacturers to reduce time, costs, and risks, resulting in substantial returns on investment.

Accurately simulating PU foaming processes is challenging due to the critical role of material behavior during filling, foaming, and curing. Comprehensive simulation capabilities enable designers to predict and optimize these processes early, identifying and preventing defects like incomplete filling and uneven densities well before tooling creation.

Leveraging an extensive database of material properties, advanced PU foaming tools accurately predict polyurethane reaction behaviors during the foaming process, simultaneously analyzing fluid dynamics, chemical reactions, and heat transfer. Key capabilities include:

- Precision tools for defining material properties, injection, flow, and foaming stages for various types of polyurethane foams.
- Quick characterization of material behaviors through simplified pouring cup tests, applicable to standard cavity shapes such as cones, cubes, and cylinders.
- Detailed process simulations that identify potential issues during material pouring, filling, expansion, and formation.

3D Printing

No longer limited to prototyping or research applications, 3D printing—also known as additive manufacturing (AM)—has become a mainstream manufacturing solution in industries that require custom components or shorter production runs. It has seen widespread adoption, particularly within healthcare, where it enables the creation of precise prosthetics and implants.

Learn More at: altair.com/resource/revolutionize-medical-device-and-implant-design-with-implicit-modeling

For manufacturers, the rise of 3D printing means a rapid transition into generative design to attain functional, optimized, intricate, organically shaped components previously impossible through traditional methods. Additionally, 3D printing is invaluable for creating complex forms to be used as patterns and cores for cast molds.

Advanced 3D printing simulation solutions provide an intuitive, process-oriented environment to enhance product printability, specifically tailored for key metal printing techniques such as metal binder jetting and powder bed fusion (also known as selective laser melting or SLM). A simplified workflow guides users through process-related part orientation, support structure optimization, and results visualization. The tool's speed and accuracy enable rapid printing, springback, and compensation analyses to help predict and correct common issues, such as cracking and deformation, before the printing process begins.

- **Powder Bed Fusion:** Optimizes part orientation in relation to support structures, print time, and minimizes deformation. Offers multiple options to configure, optimize, and generate supports as well as detailed simulations to analyze inherent strains during layer-by-layer printing.
- **Metal Binder Jetting:** Optimizes orientation during sintering to reduce sagging, assesses setter and deformation to reduce deformation and compensation, and provides process simulation to predict deformation and shrinkage during sintering. Shape compensation analysis ensures post-sintered parts precisely match as-designed geometry.

Our Customers Say It Best:
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ADDITIONAL INFORMATION ON SIMULATION-DRIVEN DESIGN

By shifting from a test-fail-fix approach to a simulate-optimize-validate approach, designers can accelerate development cycles, improve product reliability, and minimize costly iterations. The most effective simulation-driven design solutions integrate accurate physics-based analysis with AI-driven generative design, optimization, and seamless collaboration, enabling teams to assess performance, manufacturability, and real-world behavior early in the process.

To leverage this approach, the right tool should offer:

- **Seamless integration** with existing design tools and workflows.
- **Fast, efficient solvers** that minimize time-intensive meshing and preprocessing.
- **Automation capabilities** to explore more design possibilities in less time.
- **Manufacturing process simulation** to ensure designs are production ready.
- **Scalability and accessibility** to support designers across all industries.

For those looking to take the next step in implementing simulation-driven design and exploring Altair's solutions, learn more at altair.com/simulation-driven-design.

Altair is a global leader in computational intelligence that provides software and cloud solutions in simulation, high-performance computing (HPC), data analytics and AI. Altair enables organizations across all industries to compete more effectively and drive smarter decisions in an increasingly connected world – all while creating a greener, more sustainable future.

To learn more, please visit www.altair.com