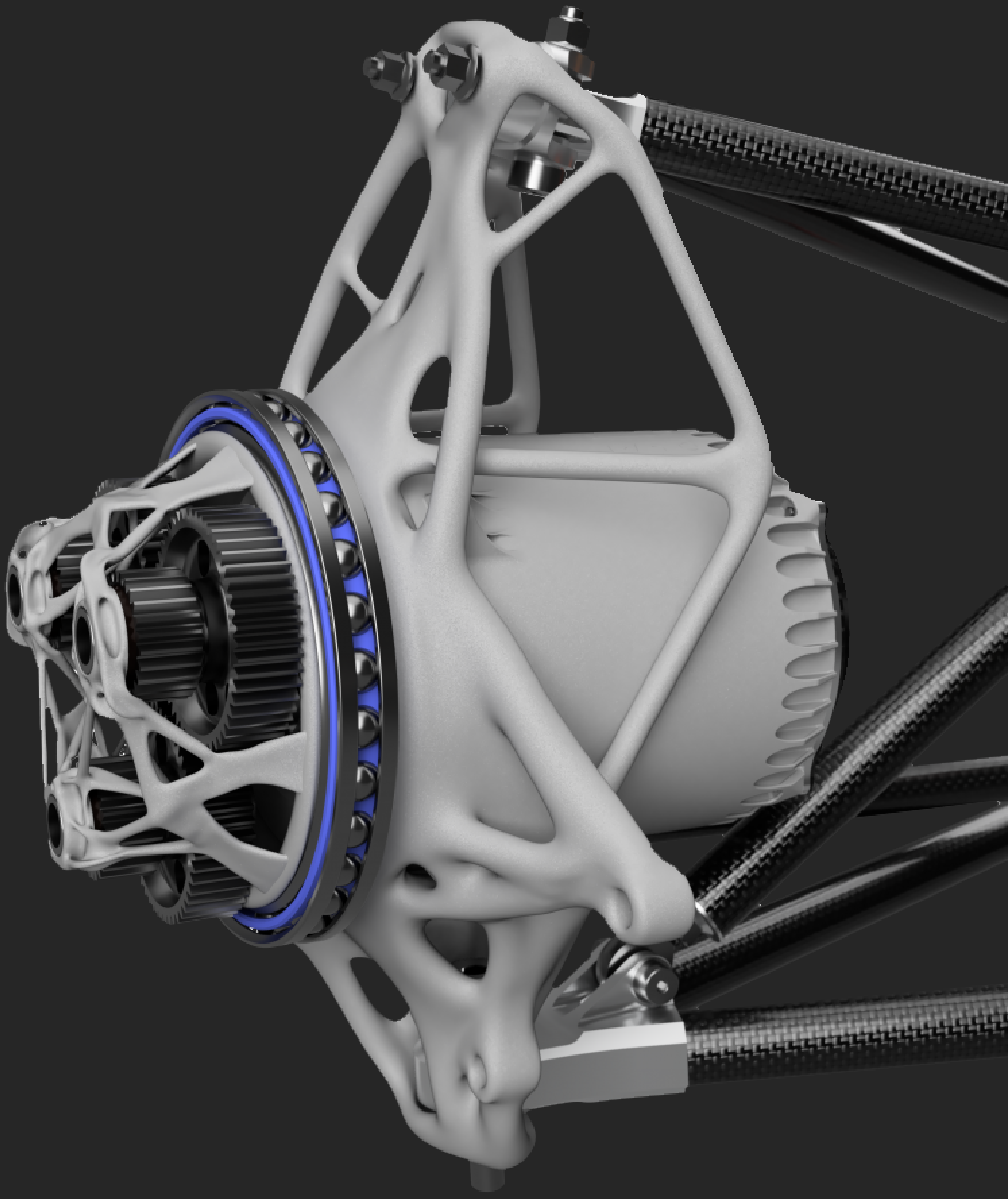
The Engineering Guide to **Lightweighting**



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Robot arm lightweighted using topology optimization

Introduction

Lightweighting means "doing more, with less" and has benefits beyond just material reduction. Depending on the application, a lighter design can improve product performance, reduce manufacturing costs, lessen energy consumption and emissions, or make a product more ergonomic and user-friendly. Lightweighting is also essential for creating "greener products" that minimize environmental impact.

What to expect from this guide

This guide will provide you with an in-depth understanding of the benefits, uses, and impact of lightweighting across the automotive, aerospace, medical, and consumer product industries. Most importantly, this guide will teach you how to apply lightweighting in your design process. You will learn when to use the most effective lightweighting design techniques and how to leverage cutting edge engineering design software to automate your lightweighting capabilities.

What is Lightweighting?

Lightweighting is the process of strategically removing material from a part or assembly to reduce its weight.

We can achieve this goal incrementally by replacing certain materials with lighter alternatives that maintain an appropriate strength-to-weight ratio or through fundamental design changes that achieve more radical performance gains.

The Importance of Lightweighting

Lightweighting is relevant whenever there is motion associated with the function of a product.

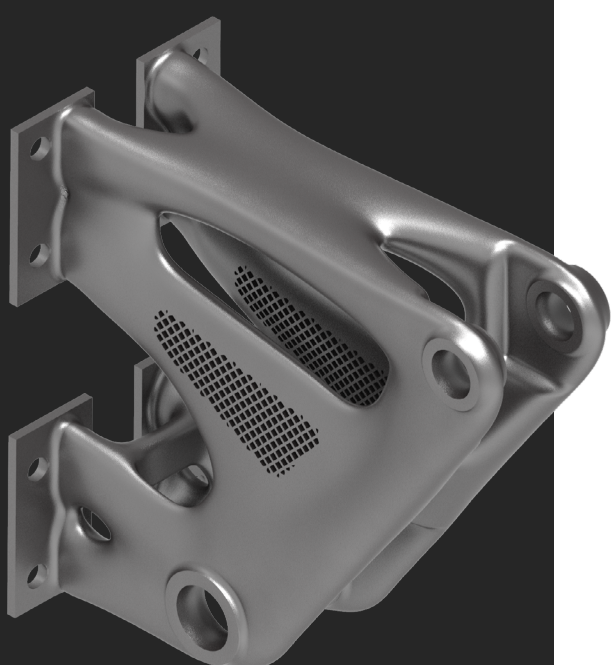
All motion requires energy, whether that energy is exerted by an actuator, an engine, or a person — the less energy needed to generate the desired motion, the more efficient the product.

This concept, of course, applies to automobiles, planes, trains, and rockets — arguably the most obvious use cases for lightweighting — but also to medical devices, consumer products, and many other products.

The relevance of lightweighting today is best demonstrated by the following:

- The European Commission recently unveiled proposals requiring manufacturers to achieve a 30% reduction in the emissions of new light commercial vehicles and passenger cars by 2030.
- Automakers in the US have agreed to the Corporate Average Fuel Efficiency (CAFE) targets, which require that fleetwide average fuel economy standards increase to 54.5 miles per gallon on light-duty trucks and cars.

These figures illustrate that lightweighting is in high demand by businesses and governments worldwide — a demand that will continue to increase as countries ramp up their sustainability efforts and the use of advanced manufacturing technologies (like additive manufacturing) becomes more pervasive.



PART:
Topology Optimized Trailing Bracket

Lightweighting by the Numbers

The power of lightweighting is that even the most negligible reduction during the design phase can have a remarkable impact.

3x power

3 times higher **wind turbine** generating capability when the weight of the turbine is reduced by 20-30%.

0.5 L/100km

0.5 liters reduction in fuel consumption per 100 kilometers when an internal combustion energy vehicle's **(ICEV's)** weight is reduced by 100 kilograms.

8% improvement

8% improvement in **battery life** when the weight of an electric vehicle is reduced by 10%.

10,000 L/year

10,000 liters of kerosene saved per year when the weight of an **A320** airplane is reduced by 100 kilograms.

10-12% fuel

10 - 12% improvement in **fuel efficiency** when the weight of the Boeing 787 was reduced by 20%.

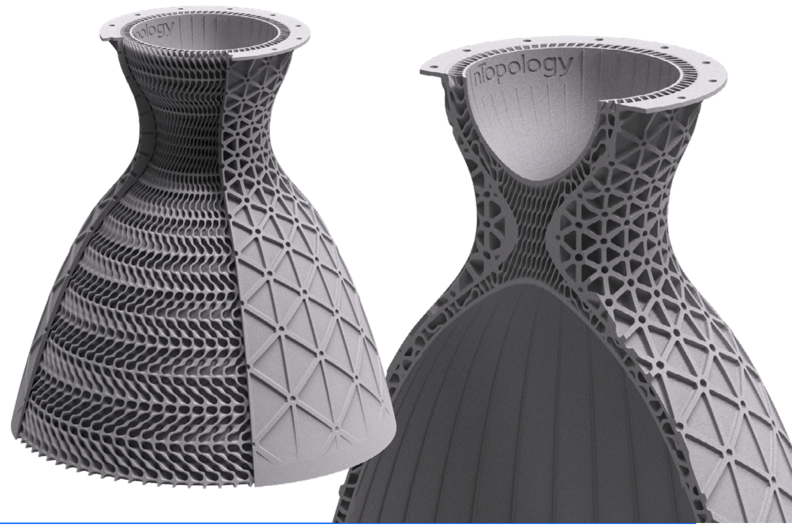
$10,000

$10,000 for every pound of weight reduction when sending material into a **low earth orbit.**

44.3%

44.3% of costs in the manufacturing sector are down to **materials**. This means that a 10% lighter design reduces the manufacturing cost on average by more than 4%.

Why is Lightweighting Relevant Today?



PART:
Rocket nozzle with conformal ribs and lattice

Additive Manufacturing

Lightweighting is both enabled by additive manufacturing and a requirement for additive production. Additive manufacturing allows engineers to design lightweight structures that are otherwise impossible to create with alternative processes. Lightweighting also plays an essential role in ensuring that additive production is cost-effective. The maturity of industrial additive manufacturing processes today unlocks many new opportunities for lightweighting.

Sustainability

Pressure to improve product sustainability affects all industries and continues to grow. Lightweighting plays an integral part in improving sustainability during the manufacturing process by reducing emissions, the use of finite natural resources, the amount of waste sent to landfills, and the energy associated with processing and mining materials.

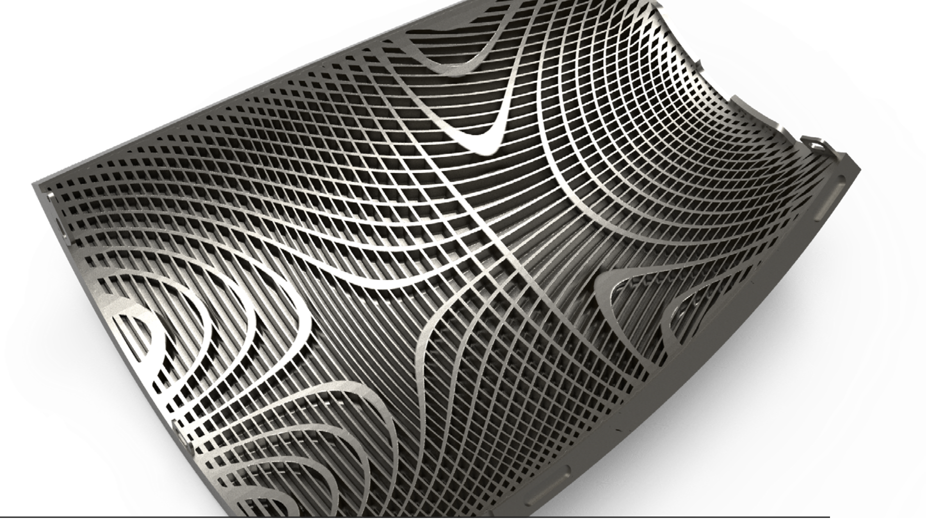
Electric Vehicles

It is predicted that there will be a considerable increase in electric vehicles in the automotive industry in the next decade. This year, the UK announced that it will require **all vehicles** to be "zero-emissions capable" by 2035. California has similar intentions and will require all light-duty **autonomous vehicles** to emit zero emissions from 2030.

However, the limited range of affordable electric vehicles discourages many potential buyers. That's where lightweighting comes in. Reducing the weight of electric vehicles can significantly impact their range.

Three Approaches to Lightweighting

From a "big-picture" perspective, there are three key lightweighting methods.



PART:
Conformal ribs on aerospace sandwich structure

01. Material Substitution

This method is the easiest to implement but delivers only incremental gains. It involves replacing the material of an existing part with a material that has a higher strength-to-weight ratio. For example, you might replace steel with plastics, aluminum, or composites.

It is a common misconception outside of the engineering industry that the stronger a material, the heavier it must be. But the strength-to-weight ratio of certain materials can often defy belief under the right circumstances. For example, graphene has 100-300 times the strength of steel while consisting only of a single layer of carbon atoms — if only there were an efficient manufacturing process to use it in lightweighting applications!

02. New Manufacturing Process

Material replacement often requires modification of the manufacturing process. Substituting the manufacturing process for another delivers average gains but requires more effort than material substitution. Doing so may also require the engineer to adjust the design to account for restrictions associated with the new process.

Typical manufacturing processes include additive manufacturing, forming, casting, molding, and machining. Advancements in these technologies can make the application of new lightweighting techniques more cost-effective and improve the strength-to-weight ratio of a material or object. For example, robotic Automated Fiber Placement technologies enable engineers to align the fibers of a composite along loading paths to reinforce the part's strength.

03. Advanced Design & Engineering

Material and manufacturing process substitution can only achieve so much. For substantial lightweighting gains, a complete redesign using the latest design tools and methodologies is often necessary.

By taking advantage of cutting-edge design approaches (some of which we will examine in the next section), engineers can develop new products that are both lighter and have enhanced functionality. This optimization method typically requires a simulation-driven approach to ensure the product operates within the necessary factor of safety once lightweighted.

Lightweighting Benefits

The benefits of lightweighting are numerous and vary between industries and use cases.

Improved Performance

Lightweight parts typically offer performance benefits. For example, a lightweighted car will provide better acceleration and braking performance than a heavier alternative.

Expanded Product Functionality

Lightweighting enables engineers to create products that maintain a certain weight but achieve more. For example, lightweighting allows vehicle cabin sizes to increase without the car getting heavier.

Reduced Manufacturing Costs

Lighter parts require less material, which means they often have lower material costs than their non-lightweighted counterparts. This can add up to considerable cost savings.

Reduced Transportation & Packaging Costs

The lighter an item, the less it costs to transport, and the fewer packaging materials are required to ensure its safe delivery.

Improved Sustainability

Reducing materials minimizes waste, the use of finite resources, and the amount of energy required to manufacture the parts — ultimately driving down carbon footprint.

Superior Products

Given that lightweighting can potentially deliver significant performance, ergonomic, and sustainability benefits, effective lightweighting can give your product a competitive edge.

Improved Ergonomics

In many industries, the lighter an item, the more ergonomic it is. A more lightweight tennis racket, for instance, reduces athlete fatigue and can improve their performance and comfort.

Reduced Energy to Manufacture

Reduced material also means less energy is required to manufacture parts, significantly reducing manufacturing costs and environmental impact.

Improved Fuel Efficiency

Improved fuel efficiency is a significant lightweighting benefit. In aerospace, removing 1 kilogram of material from an airplane can save 106 kilograms of jet fuel each year.

Lightweighting Design Techniques

Basic Lightweighting Techniques

PART:
Topology optimized motorbike footrest and latticed guard

Topology Optimization

Topology optimization is a simulation-driven structural optimization technique primarily used for engineering concept design.

In topology optimization, the designer defines a design space, the loading conditions, optimization target, and other non-technical requirements, such as manufacturing constraints. The software then removes material, through iterative simulations, from areas where stresses are low.

The resulting design has a reduced weight and high stiffness that can withstand the indicated loading conditions.

When Should You Use Topology Optimization?

- Early in the design process to generate concept design candidates
- To tackle structural optimization problems for parts that need high stiffness-to-weight

Lattice Structures

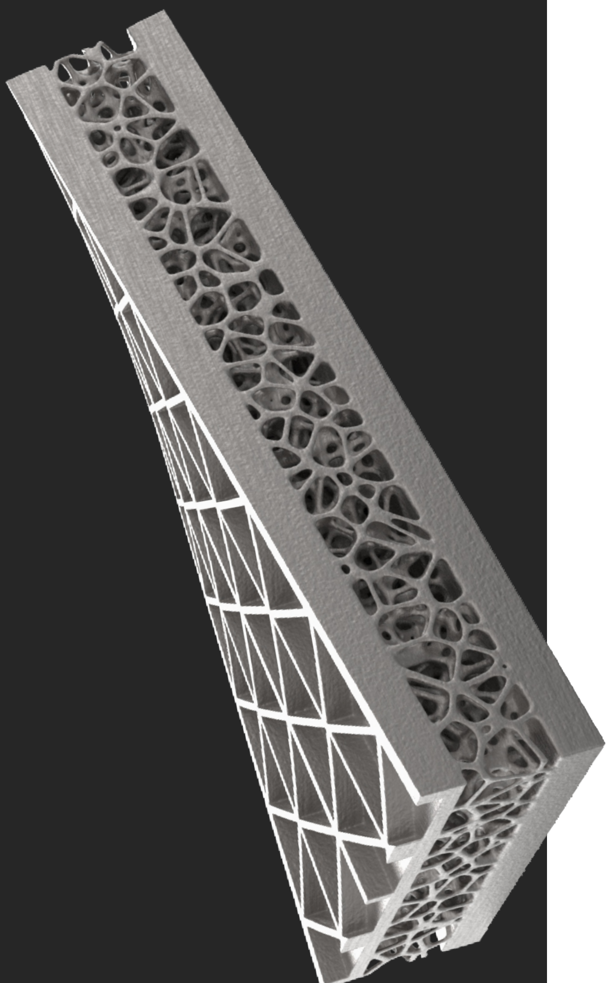
Lattice structures are 3D patterns that repeat in a volume or on a surface. Engineers primarily employ these structures to reduce the weight of a part while improving other properties, such as stiffness.

Each type of lattice structure has its benefits and characteristics. Common lattice types include beam lattices, honeycombs, foams, and gyroids. The most prevalent uses of lattice structures are as infills in a shelled volume and as ribs on a surface.

When Should You Use Lattice Structures?

- During optimization to reduce weight, material usage, and manufacturing time
- In the R&D phase, to create structures with tailored responses

Basic Lightweighting Techniques



PART:
Sandwich structure with isogrid rib and a Voronoi lattice infill

Shell and Infill

Parts with a hollow cross-section are prevalent as structural components in engineering applications — from the tubes of bike frames to electronic enclosures. These shells are typically extruded, cast, or molded and, due to manufacturing restrictions, have a constant wall thickness.

Additive manufacturing allows us to manufacture hollow parts with a variable wall thickness and a more complex geometry. Using field-driven design, the wall thickness can be informed by simulation data to increase stiffness where stresses are higher.

If we combine variable shelling with a lattice infill, we get a powerful yet easy lightweighting technique.

When Should You Use Shelling?

- For quick lightweighting gains in parts that require high impact resistance
- To preserve external shape in components with a large bounding box

Conformal Ribbing

Ribbing is a common lightweighting technique with applications ranging from aerospace to industrial and consumer products. Ribs are thin protrusions that extend perpendicular from a wall or surface to provide added stiffness and strength, and they are compatible with a variety of manufacturing processes.

A more advanced way to think about ribs is as lattice structures that conform to a surface. Rib grids can increase part stiffness isotropically or along a specific direction while keeping weight and material usage to a minimum.

When Should You Use Ribbing?

- To strategically reinforce thin-walled structures while using minimal material
- To improve stiffness and buckling resistance isotropically or along a specific direction

Basic Lightweighting Techniques

Perforation Patterns

Perforation patterns are prevalent in engineering. They have various uses, including thermal management, ventilation, decoration, and — of course — lightweighting.

Perforation patterns are holes with circular or other cross-sections that, in the case of lightweighting, eliminate unnecessary material from a component. Using a field-driven design approach, you can precisely control the position and orientation of each hole or use simulation results to drive their geometry.

When Should You Use Perforation Patterns?

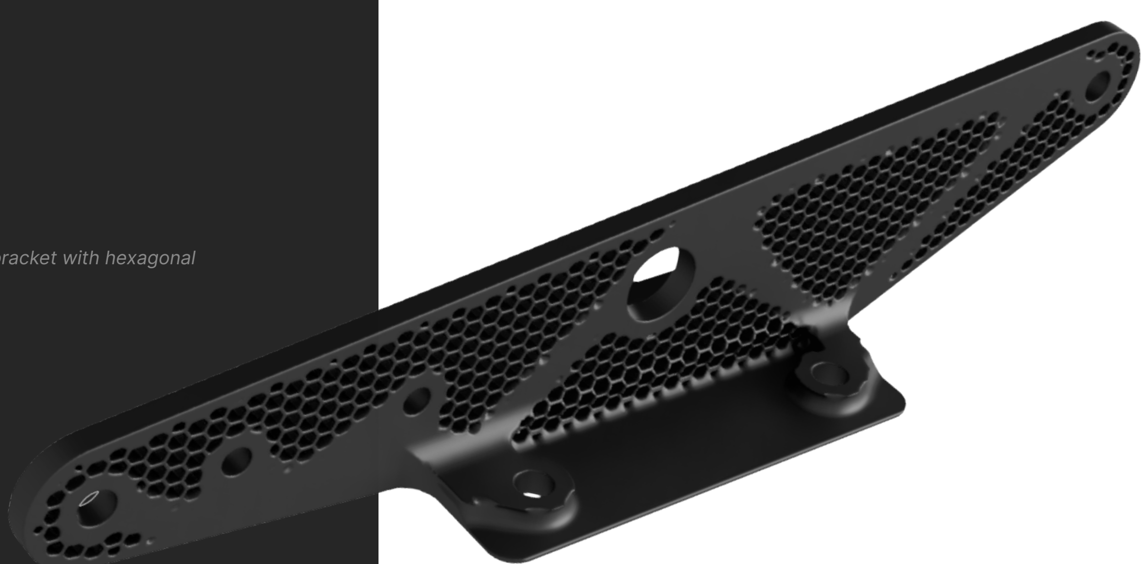
- To design parts that can be easily manufactured with traditional processes
- To combine lightweighting with thermal management, vibration dampening, or aesthetics

Combining Techniques

The trick to maximizing the benefits of lightweighting is combining various techniques. This approach enables you to overcome the potential weakness of one method with the strength of another.

Topology optimization, for example, is highly suitable for creating geometries that deliver high stiffness and low weight. However, the resulting structure may not meet other critical technical requirements, such as impact resistance, crashworthiness, and vibration resistance. By combining topology optimization with other lightweighting techniques, you can meet all technical requirements.

PART:
Aircraft elevator bracket with hexagonal perforations



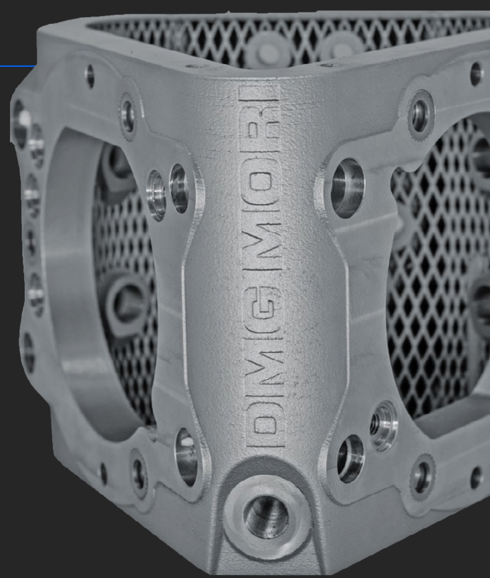
CASE STUDY

Robotic End-Effector Redesigned Using nTopology

DMG MORI is a leader in metal-cutting manufacturing equipment, producing high-quality CNC machines for over a century. The Robo2Go system is integral to the company's factory automation offering.

ADDITIVE INTELLIGENCE, DMG MORI's additive manufacturing design consultancy, was tasked with maximizing the stiffness-to-weight ratio of the head of the robotic end-effector while improving handling precision and reducing manufacturing costs.

A key design requirement was to keep the external form factor of the component unaltered. At the same time, the robot head had to house the embedded channels of the pneumatic system and the end effector's electrical components.



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With nTopology, we were able to create a powerful and unique additive design. It wouldn't be possible to create such a component with a traditional CAD system.

—

Martin Blanke

Additive Manufacturing Project Engineer at DMG MORI

Lightweighting
62% reduced weight

Assembly Consolidation
60% fewer components

Robot Handling
16x higher precision

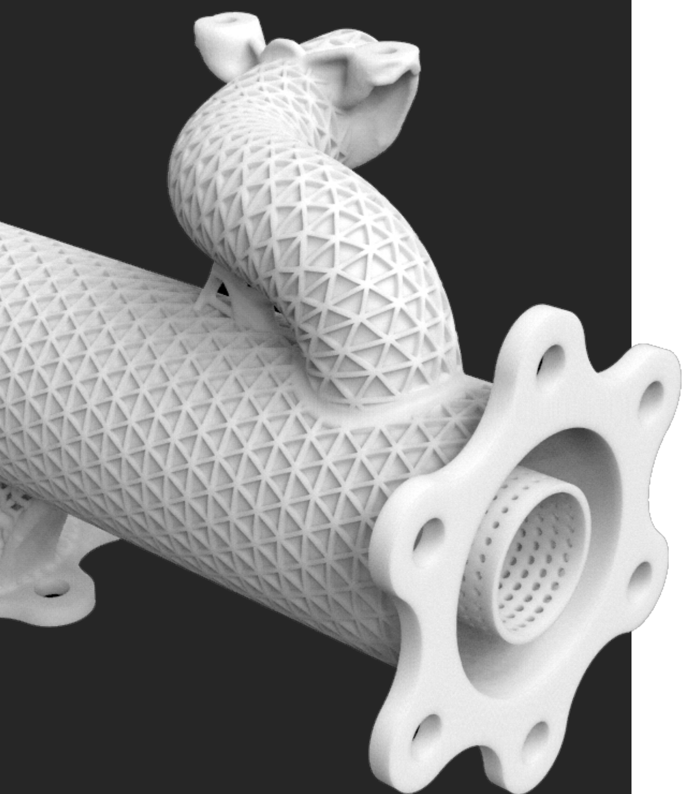
Pneumatic System
45% fewer sealing points

Material
Aluminum (AlSi10Mg)

Manufacturing
LASERTEC 30 Dual SLM

Lightweighting Design Techniques

Advanced Lightweighting Techniques



PART:
Airduct assembly consolidation

Assembly Consolidation

Many products are composed of various parts which are fastened together with bolts and nuts. These fastenings can significantly increase weight, assembly time, and cost.

Instead of reducing the weight of a single component, assembly consolidation involves combining the whole assembly into a single part. This method allows you to remove the bolts, nuts, flanges, and other unnecessary machine design elements contributing to the part's overall weight.

When Should You Use Assembly Consolidation?

- When redesigning an assembly for additive manufacturing
- When the original design includes more than 50 components

Multi-Functional Lightweighting

Multi-functional lightweighting takes the concept of assembly consolidation to the next level; in addition to combining structural components into a single part, you enhance it with additional functionality.

For instance, pneumatic and cooling channels can be embedded directly into the component, or a lattice structure can provide structural support and heat dissipation. Consolidating multiple functions into a single component makes separate subsystems and connectors unnecessary, thereby reducing weight.

When Should You Use Multi-Functional Lightweighting?

- During redesign as part of the holistic rethinking of a system's function
- To enhance the functionality of a component or system

Advanced Lightweighting Techniques

Architected Materials

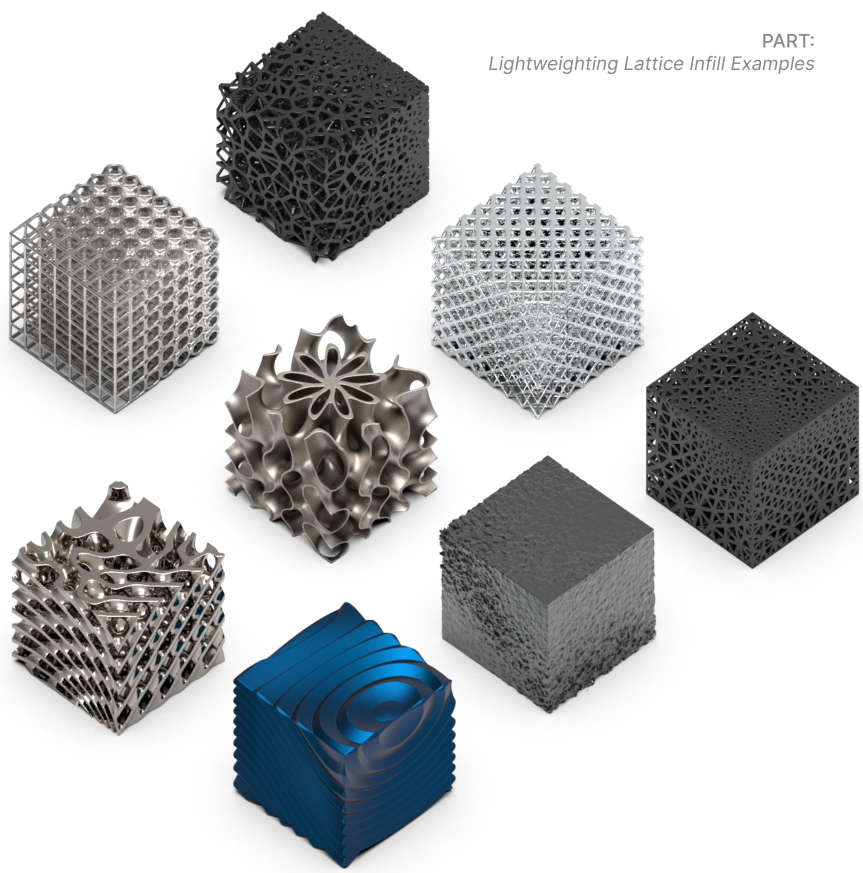
Architected materials build upon the concepts of lattice structures, material substitution, and function consolidation. They are advanced lattice structures with tunable performance characteristics. This means that you can design the response of a part by controlling its geometry instead of its material microstructure.

You can create architected materials to control stiffness, impact resistance, or vibration dampening characteristics — the most relevant applications for lightweighting — as well as thermal, electromagnetic, or biological behavior.

Once defined, you can apply the same architected material to multiple parts — the same way you would use any traditional material. Additionally, since these properties are connected primarily to the geometry and not the manufacturing material, they can be varied throughout the volume of the part.

When Should You Use Architected Materials?

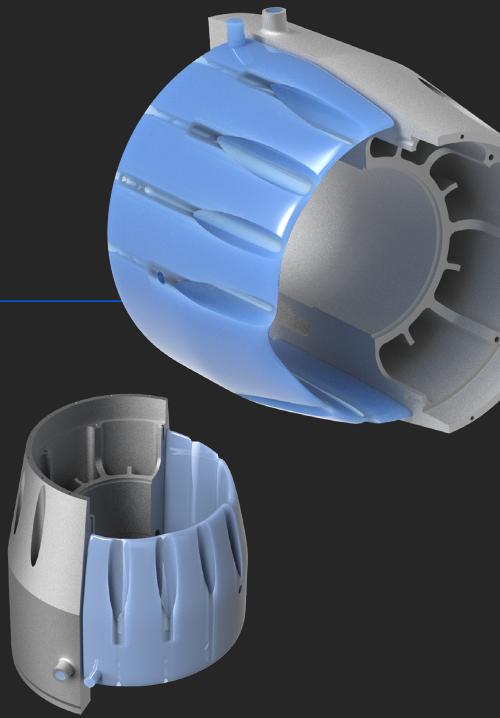
- Early in the development process to achieve radical performance gains
- To achieve property combinations that are not possible with traditional materials



PART:
Lightweighting Lattice Infill Examples

CASE STUDY

Microturbine Housing with Embedded Cooling Channels



KW Micro Power redesigned the housing of their aerospace-grade, high-power-density, compact turbogenerator for metal Additive Manufacturing. Using nTopology, the engineers converted an empty shell into a conformal cooling channel, improving the thermal management of their generator and reducing its weight by 44%.

- 44% weight reduction
- 33% temperature reduction
- 3 functions in a single part

Read More

PARTS:
Housing of Aircraft Auxiliary Power Unit

CASE STUDY

CubeSat Optimized Using Architected Materials

The U.S. Air Force Institute of Technology (AFIT) leveraged nTopology and architected materials to develop an additively manufactured CubeSat bus assembly from Inconel 718. Inconel is three times denser than aluminum, but the new design was 50% lighter and 20% stiffer than the original aluminum assembly.

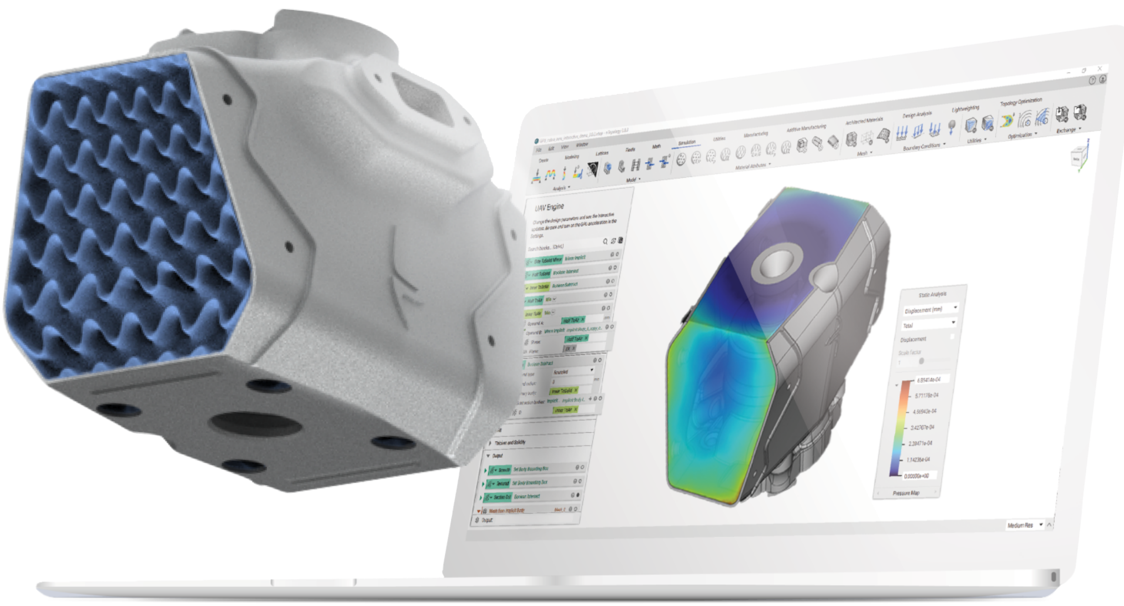
- 50% lighter
- 20% stiffer
- From 150 parts to 25

Read More

PART:
CubeSat bus assembly

Lightweighting with nTopology

nTopology is the only engineering design software that allows you to combine the techniques in this guide — which is critical to creating designs that fulfill all requirements — in a streamlined, efficient, and repeatable way.



Our approach is your competitive advantage.

Implicit Modeling

Generate parts at lightning speeds, no matter how complex, with modeling operations that never fail.

Field-Driven Design

Control design features at every point in space using simulation results, test data, and engineering formulas.

Codeless Automation

Create configurable and shareable processes that package knowledge and automate engineering tasks.

For lightweighting purposes, nTopology is quite simply unmatched. Leading companies worldwide depend on it to develop revolutionary products in the automotive, aerospace, medical, and consumer products industries.

Get a Demo

Reduce weight. Improve performance.
Expand Product Functionality.

Capability	nTopology	Traditional CAD
Latticing	Millions of unit cells in seconds. Advanced manipulations & control over design parameters.	Up to thousands of unit cells in minutes. Basic controls & post-processing. Basic filleting.
Topology optimization	Automated reconstruction. Immediately usable results. Scalable.	Manual reconstruction & post-processing. Not scalable.
Shelling, Ribbing & Perforation Patterns	Advanced control of design parameters.Thickness, size and orientation driven by fields, functions and simulation data.	Manual reconstruction & post-processing. Not scalable.
Part & Function Consolidation	Simple boolean operations that never fail. Automated fillets & smoothening.	Failures are expected.Troubleshooting is time-consuming & requires skill.

Ready for the next step?

See for yourself why leaders in aerospace, automotive, medical, and consumer industries depend on nTopology to develop revolutionary products.

Speak with our nTopology experts and application engineers today.

- Overcome design bottlenecks
- Accelerate engineering product development
- Unlock the potential of additive manufacturing

Contact Us

nTopology