Special Report: Generative Design and Topology Optimization by Altair

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FOREWORD

This report by engineering.com has been modified for use by Altair and is specific to Altair products. It is based on Generative Design and Topology Optimization, available for download on the engineering.com website.

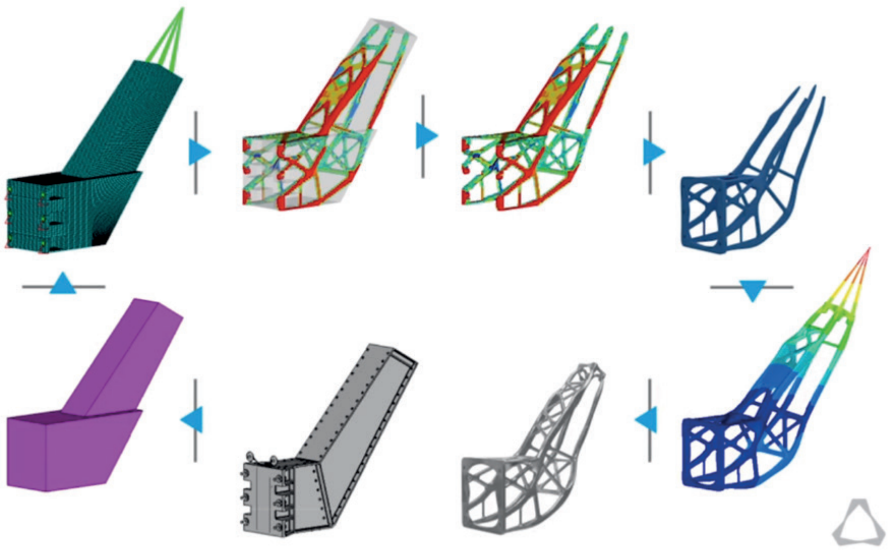
INTRODUCTION

In the world of computer-aided design (CAD), the loudest buzz is around two technologies: generative design and topology optimization.

Overused and inconsistently applied by various parties, and sometimes used interchangeably, the two terms have become ambiguous and confusing. What exactly is generative design? How is it different from topology optimization? Different engineers will have different responses.

To clear up this ambiguity, we'll begin this report with a discussion of what the terms generative design and topology optimization have come to mean to different players in the space. With a (hopefully) better understanding of generative design in hand, we'll delve into a case study for a practical picture of how generative design technology is being applied. We'll then discuss Altair's generative design software packages, OptiStruct and Inspire.

TOPOLOGY OPTIMIZATION



While generative design is a fairly recent term, the idea of topology optimization has been around for decades. Academic papers describing topology optimization stretch back to the early 1990s. In 1994, Altair received IndustryWeek's "Technology of the Year" award for OptiStruct, the first commercial implementation of topology optimization technology.

"Topology optimization is a methodology to derive an optimal material distribution for a design under given usage conditions," said Jeffrey Brennan, Altair chief marketing officer and senior vice president, Global Markets. "It gives the optimal shape of a part or system constrained only by the available design space."

In essence, topology optimization takes a model of a part and removes bits from it until a particular goal is satisfied. For example, the goal could be to find the stiffest possible design using the least material. Alongside topology optimization, you'll often hear terms like "shape optimization" and "structural optimization." There is less consensus on the distinction between these terms. We will dispense with them for this report.

Let us now cover the relationship between the 30-year-old idea of topology optimization and the much newer idea of generative design.

GENERATIVE DESIGN

Generative design differs from topology optimization in that it doesn't refer to a specific algorithmic process. Everyone seems to have their own idea of what generative design means. The definitions don't always overlap. Despite the lack of industry consensus on what exactly generative design should be, there seem to be two main ways of looking at it: either as a broad umbrella encompassing topology optimization or as a wholly distinct technology.

For the former case, many people take the view that generative design is something of a generic term for using computation to assist in the design process. In this view, topology optimization is simply a subset of generative design. Complementary to this view is the opinion that topology optimization, rather than being a subset of generative design, is an enabling technology for generative design. A third view is that topology optimization is entirely distinct from generative design.

Where does this leave us in regard to generative design and its relationship to topology optimization? Perhaps we can dispense with finding an exact definition and instead focus on the main theme: driving design through computation.

The rest of this report will adopt the view of generative design as an umbrella term encompassing or enabled by topology optimization. At its core, the software we'll discuss in the final section uses computation to actively assist in the design process in a way that would be difficult, if not impossible, for a human designer.

THE NEXT GENERATION OF CAD

Whatever definitional debates persist around generative design, everybody seems to agree on one point. Generative design will change the way engineers think about design.

But, why? If topology optimization has been around for nearly three decades, why has generative design only made waves recently? In part, it's a matter of computation. Processing abilities have advanced quite a bit since the 90s, so generative algorithms can run faster and with higher resolution. There's an even bigger reason for generative design's recent rise: additive manufacturing.

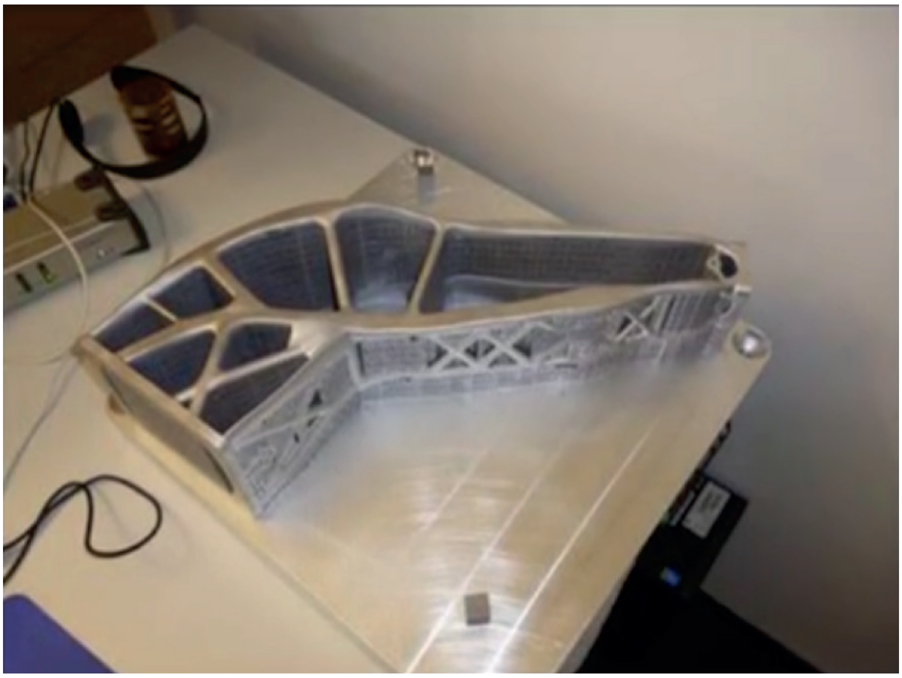
Additive manufacturing is an important development for generative design. Generative parts often have strange, organic shapes that would simply be impractical for traditional manufacturing methods. With the increasing popularity and capability of additive manufacturing, engineers now have a practical method for realizing the weird geometries of generative design. However, that's not to say generative design is incompatible with traditional manufacturing methods.

Perhaps the most well-known and useful advantage of generative design today is for lightweighting parts, which it does staggeringly well. In some cases, generative design can offer mass reductions of up to 70 percent.

It's easy to see the benefits of a drastic reduction in mass. In the aerospace and automotive industries, where mass is of utmost importance, lightweighting is crucial. Indeed, these industries are among the earliest and most eager adopters of generative design technology. Lighter weights are important in many other applications. Less mass results in lower manufacturing, shipping and material costs—and may even result in a more aesthetically pleasing product.

Another huge advantage of generative design is its ability to consolidate parts, making for less complex assemblies. These are easier and less costly to manufacture than their non-generative counterparts.

WHAT ARE THE DOWNSIDES OF GENERATIVE DESIGN?



The infancy of generative design also brings with it a drawback: there is still the need for human expertise or, at the very least, some understanding of the results you're trying to achieve. With efforts to democratize simulation, this drawback may become less pronounced as generative design develops.

Two more potential drawbacks of topology optimization and generative design are computational and manufacturing requirements. However, both of these drawbacks are also receding. With more and more computational power being offered in the cloud, it's no longer necessary to invest in expensive hardware to run intensive simulations. As for manufacturability, additive manufacturing is getting better by the day. Some generative design packages have started to generate parts that are directly manufacturable in both additive and subtractive ways.

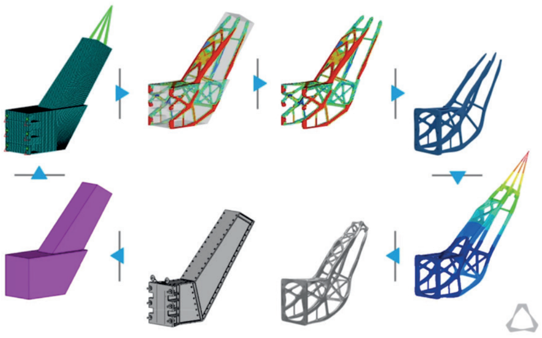
With the potential disadvantages of generative design on track to be addressed, generative design techniques appear to have a clear path to wider industry adoption. In the next section, we'll look at a case study of how generative design is being applied.

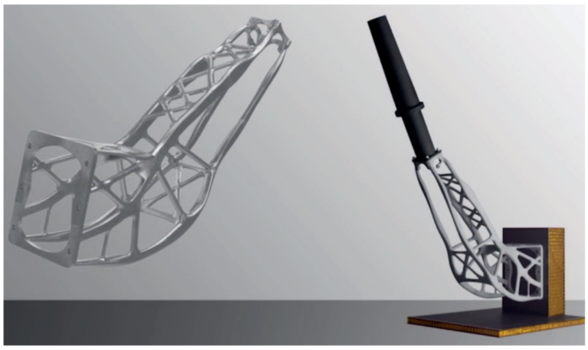
CASE STUDIES

RUAG SPACE: ANTENNA BRACKET

The antenna bracket (circled in red) on the Sentinel-1B Earth observation satellite. (Image courtesy of Altair.)

Space may be the final frontier, but it's served as an early proving ground for generative design. For example, consider the Sentinel-1, a four-satellite earth observation mission from the European Space Agency (ESA). Sentinel-1A was launched in 2014, followed by Sentinel-1B, pictured above, in 2016. Note the antenna bracket circled in red—for Sentinel-1C and Sentinel-1D, this bracket will be replaced by a new, optimized design from RUAG Space and Altair.



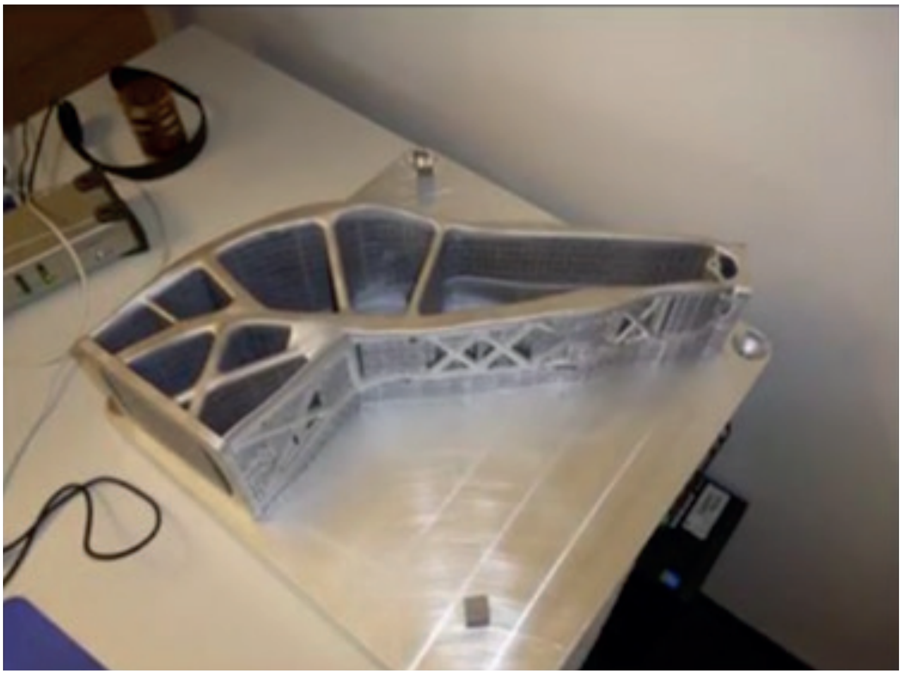


"We started the [Sentinel-1] program developing a conventional bracket," said Franck Mouriaux, RUAG Space chief engineer spacecrafts. "Then, in parallel, we started to enter into additive manufacturing, discovering the technology and learning about topology optimization."

Working together with Altair and 3D-printing company EOS, RUAG Space chose the antenna bracket as an experimental foray into generative design.

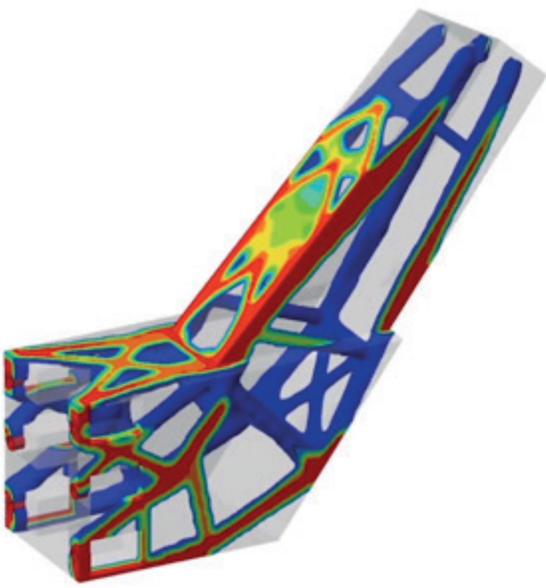
“We were looking for a good example to show the benefits of additive manufacturing and topology optimization,” Mouriaux said. “We tried to find a part that was relevant and could really show the potential, but was not too critical, in order to allow that part to fly.”

Using Altair OptiStruct, RUAG developed and printed an optimized version of the antenna bracket. The new bracket is only 0.94kg (2.1lbs), a 40 percent decrease from the original 1.6kg (3.5lbs). At the time, the bracket was the largest additive manufactured part made for space. When RUAG started development, no 3D printers big enough for the job existed yet.

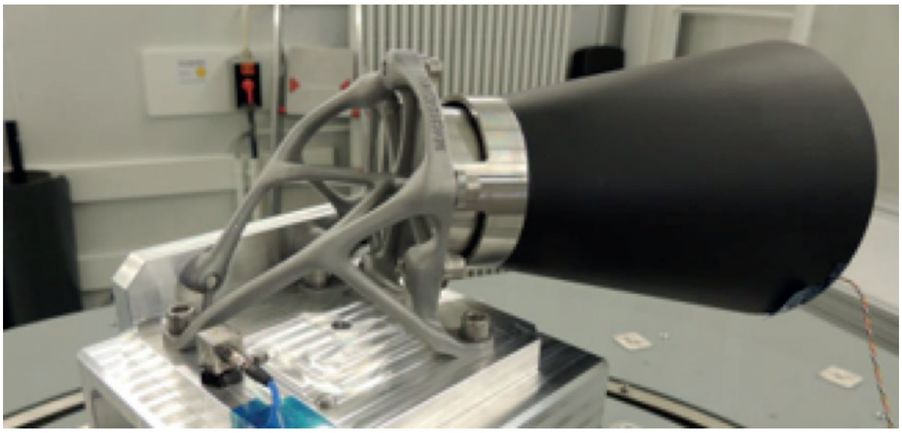


According to Mouriaux, the antenna bracket was a highly educational project for both RUAG Space and Altair alike.

“We realized that doing optimization is extremely complicated because in order to optimize, you first need to understand what you’re optimizing for,” he said.



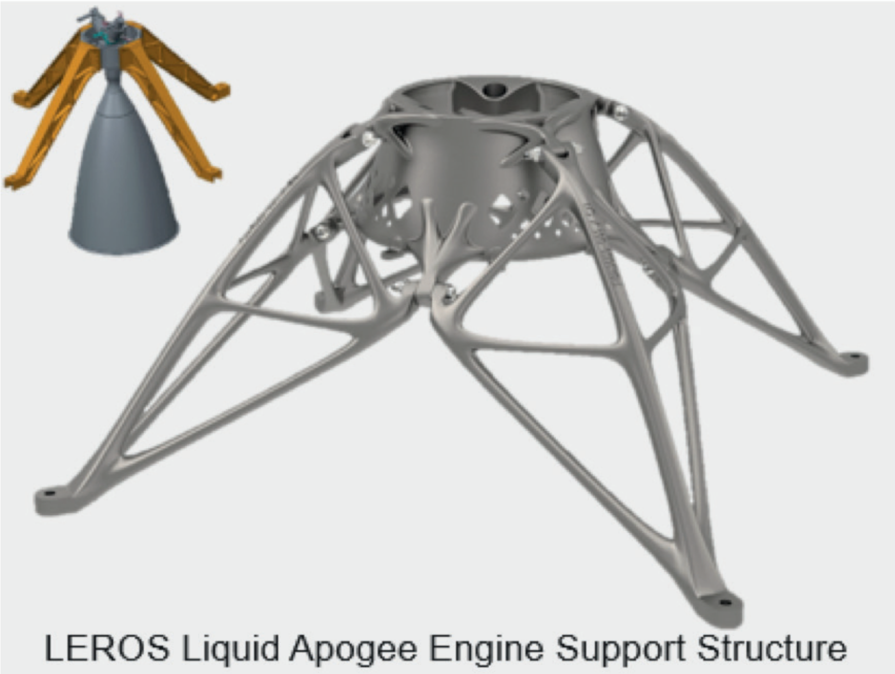
Clearly, the education paid off. RUAG Space has continued to use generative design for its aerospace projects. It developed optimized inserts and brackets for the RemoveDEBRIS satellite, a space debris removal satellite that launched in April 2018. The company also developed parts for the CARBONITE-2, an earth observation satellite that launched in January 2018. One of the parts RUAG Space developed was an optimized bracket for the star-tracking camera, a critical element used to position the satellite accurately in space.



The RUAG Space camera bracket. (Image courtesy of RUAG Space.)

"The star camera bracket that we manufactured—from the start of the project to delivery to the customer, fully qualified—was done in eight weeks, which was really a performance," Mouriaux said.

Finally, RUAG Space broke its own size record by designing an even bigger additive bracket for use in space. This bracket supports the main thruster engine for one of the teams competing in the Google Lunar XPRIZE competition. In contrast to the Sentinel-1 antenna bracket, this bracket is highly structural since it supports the main engine.

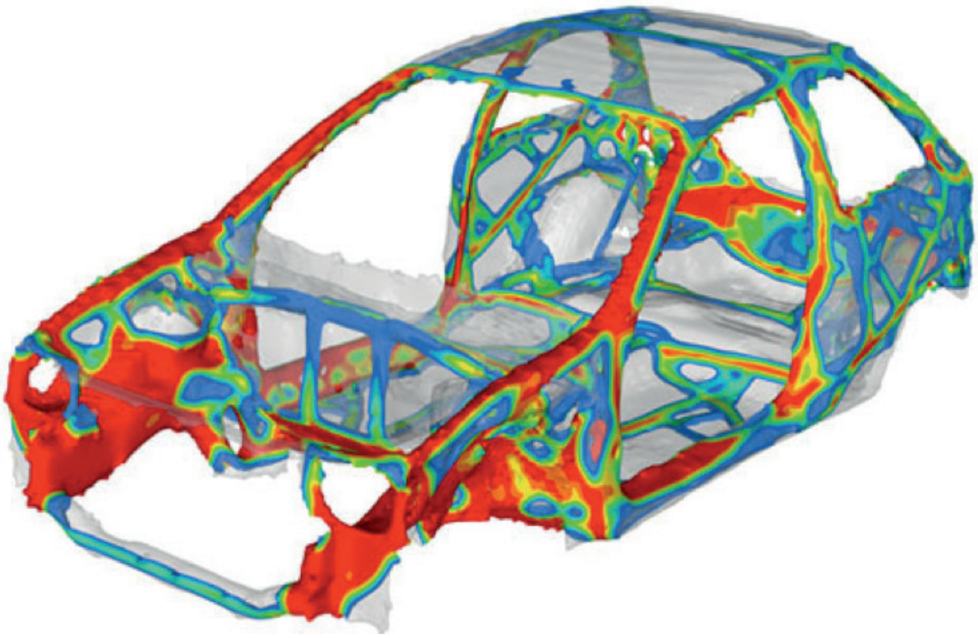


The engine support bracket optimized by RUAG Space. The part went from 4kg (8.82lbs) to 2.95kg (6.5lbs), a 25 percent reduction in mass. (Image courtesy of RUAG Space.)

"The part looks pretty good. It's a pretty nice design," Mouriaux said.

GENERATIVE DESIGN SOFTWARE

ALTAIR OPTISTRUCT AND INSPIRE



A car frame designed with OptiStruct topology optimization.

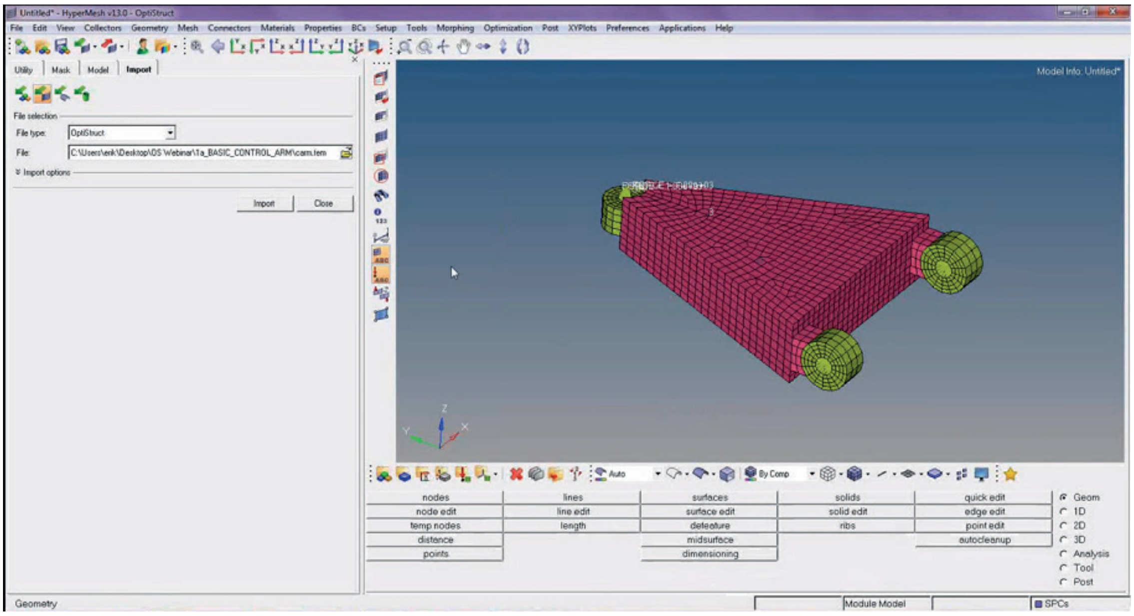
Altair has been in the topology optimization game from the very beginning and, as such, the company observed firsthand the developments in additive manufacturing and changes they spurred.

“In the early years of topology optimization, we put a lot of effort toward things like minimum member size and draw direction constraints,” Brennan said. “Many of the ‘best’ designs proposed by topology optimization were not possible to make at a reasonable cost in the past, whereas now we can unleash the full power of designs that are perfect for additive manufacturing.”

OptiStruct is one of Altair’s main optimization products and is a structural analysis solver for linear and nonlinear problems with static and dynamic loads. Another Altair product, HyperStudy, provides a design exploration tool for Design of Experiments (DoE) and trade-off studies.

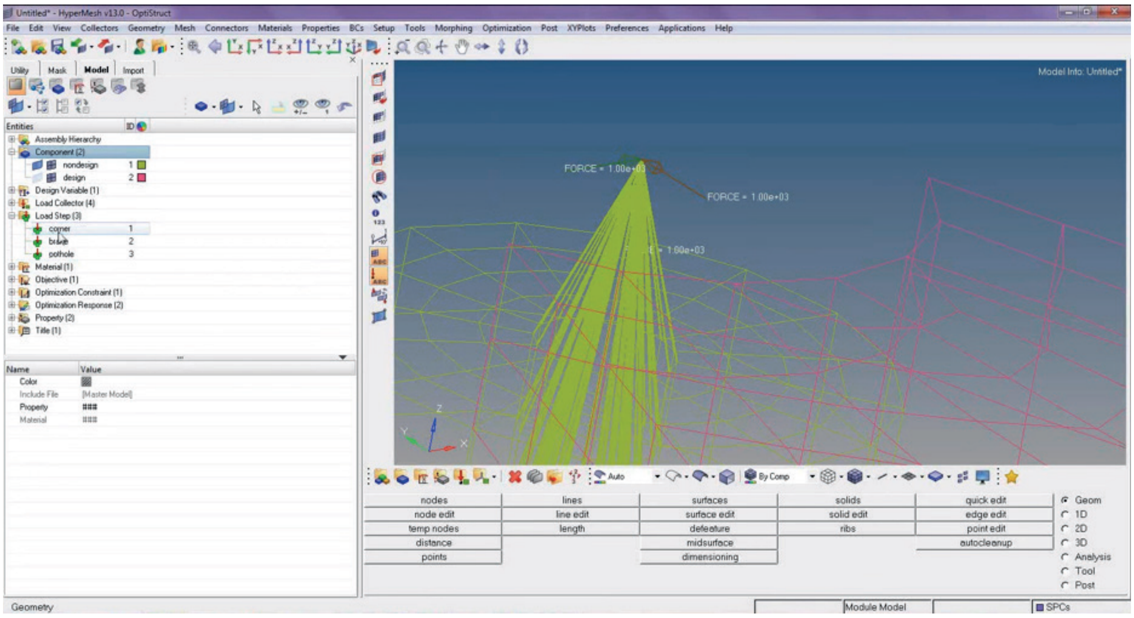
OptiStruct is a fairly full-featured solver and offers much in addition to structural optimization. Even in that category, Altair draws a distinction between different types of optimization: topology, topography, free-size, size, shape and free-shape. OptiStruct also allows for the design and optimization of lattice structures for additive manufacturing, as well as the design and optimization of laminate composites. For the sake of brevity, we’ll focus on OptiStruct’s topology optimization.

In a webinar on OptiStruct’s capabilities, Altair Training Manager Erik Larson presented an example of topology optimization for a simple control arm:



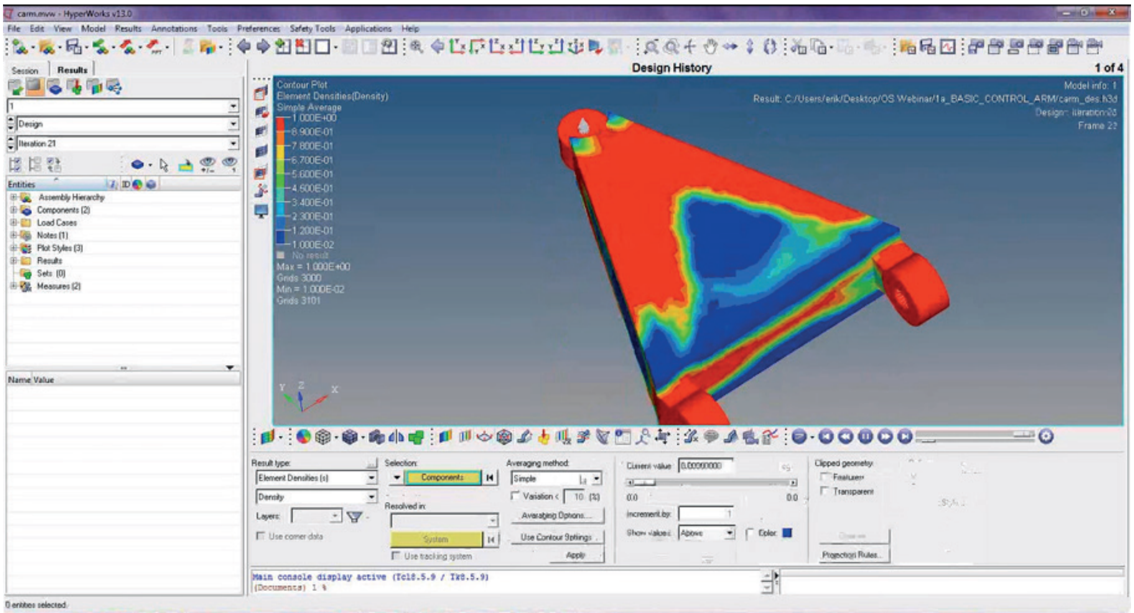
In the above model, the red area represents the design space—the volume in which the optimized structure will exist. To clarify this concept, Larson alluded to famed Italian artist Michelangelo, who would look at a block of marble and envision the sculpture hidden within. The design space is like a block of marble and must be sculpted away piece by piece until the optimal design is revealed.

The yellow areas are outside the design space and represent regions that you want preserved. With both the design and non-design spaces defined, you then add loads to the model.

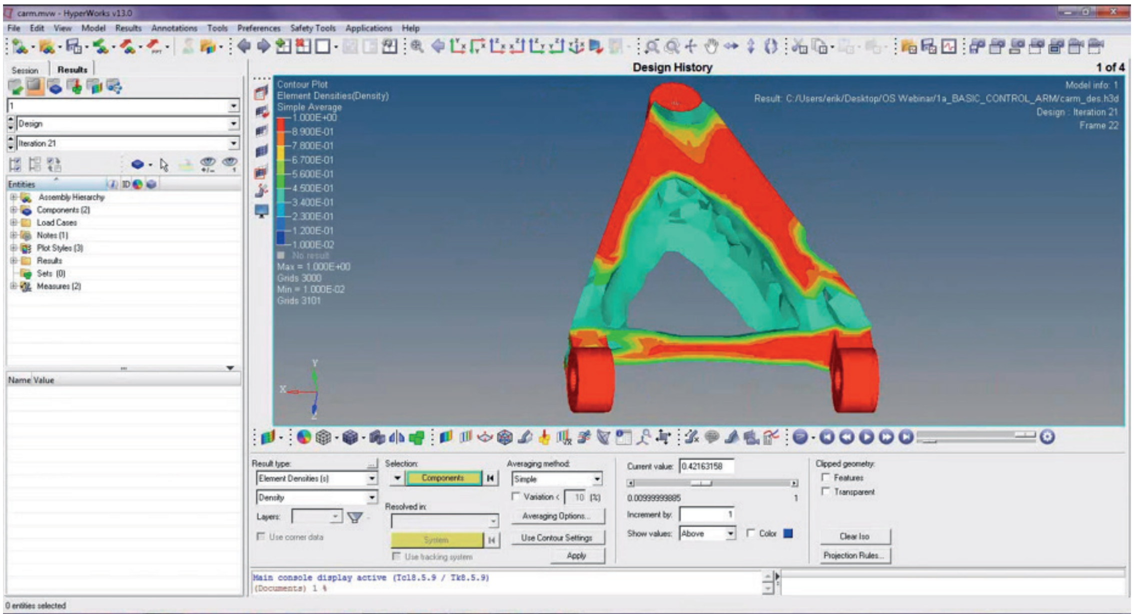


With loads defined, you can add constraints. In this example, Larson added an upper bound for the amount of material to remain in the design space: 30 percent. He also added an objective to minimize the compliance, which is the inverse of stiffness—to minimize compliance is to maximize the stiffness. According to Larson, optimization works better when you're trying to minimize rather than maximize a function.

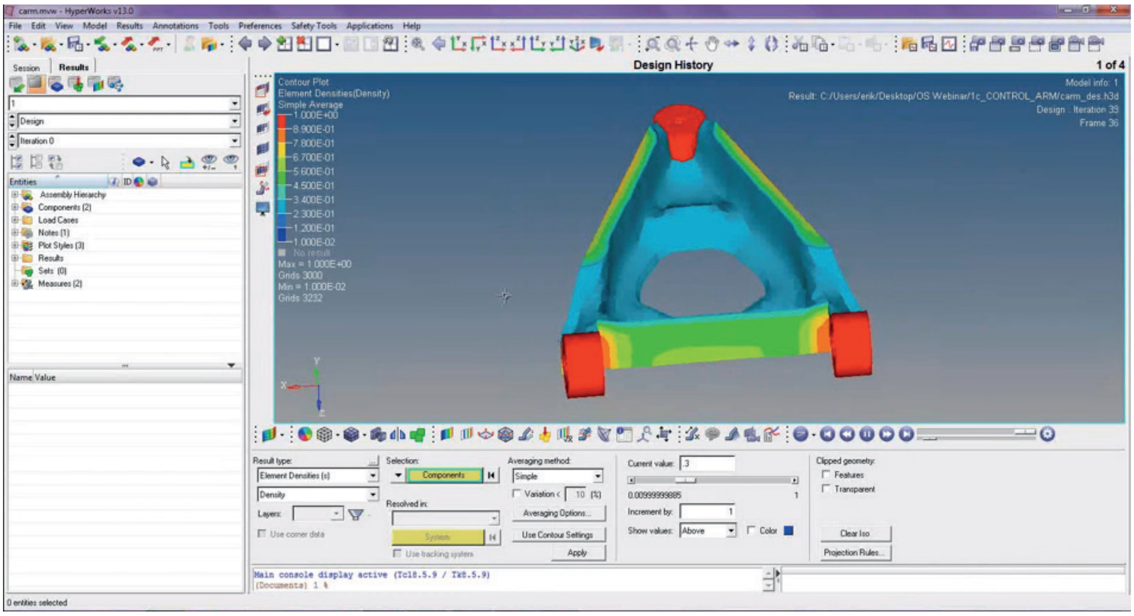
OptiStruct then analyzes each finite element and applies a density weighting between 0 and 1. The closer to 0 the weighting, the less critical the element. Here's a contour plot of that analysis:



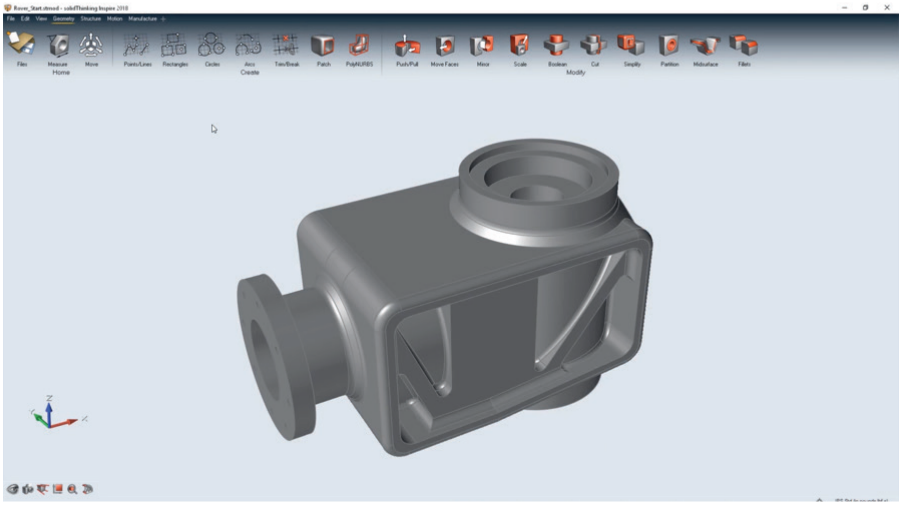
You can then filter out densities below a certain density value to go beyond the surface level contour:



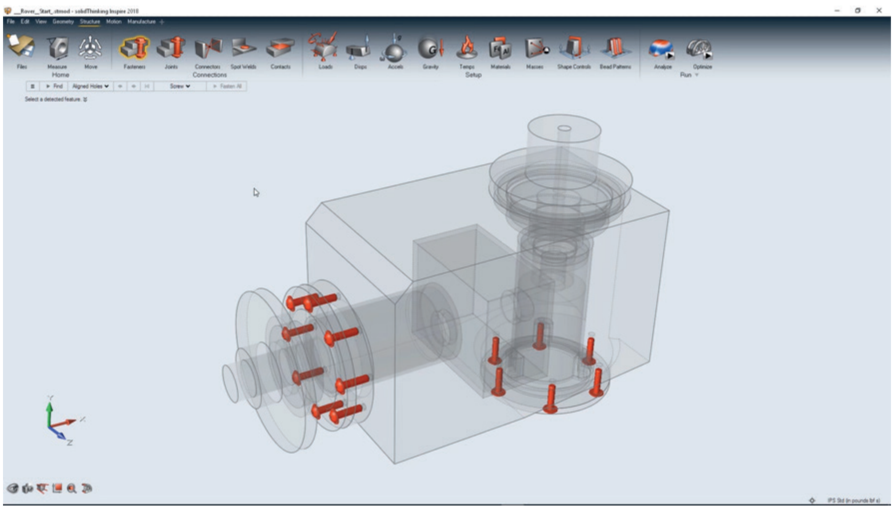
As Larson pointed out, this is a geometry that can only be manufactured additively. For other types of manufacture, OptiStruct allows you to impose manufacturing constraints to derive parts that can be made in other ways. Here's the result Larson got when he added a so-called draw direction constraint for a part suited to casting:



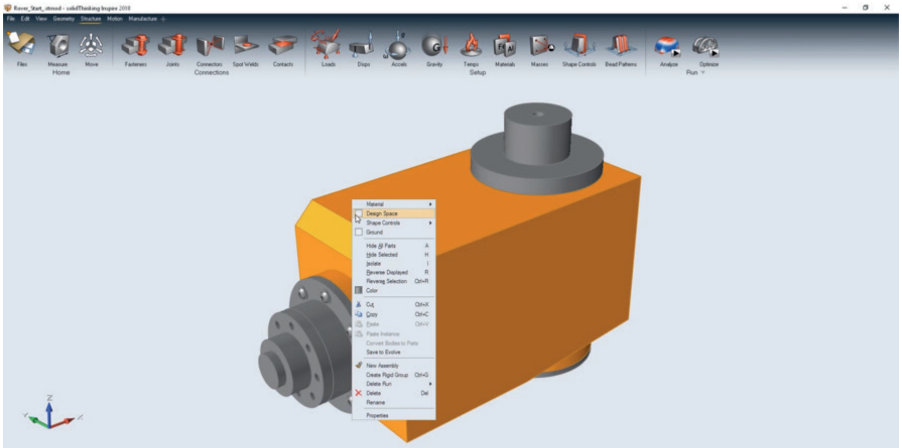
In addition to OptiStruct, Altair offers similar optimization capabilities in solidThinking Inspire. It allows users to both import existing CAD models as well as create models directly in the Inspire interface.



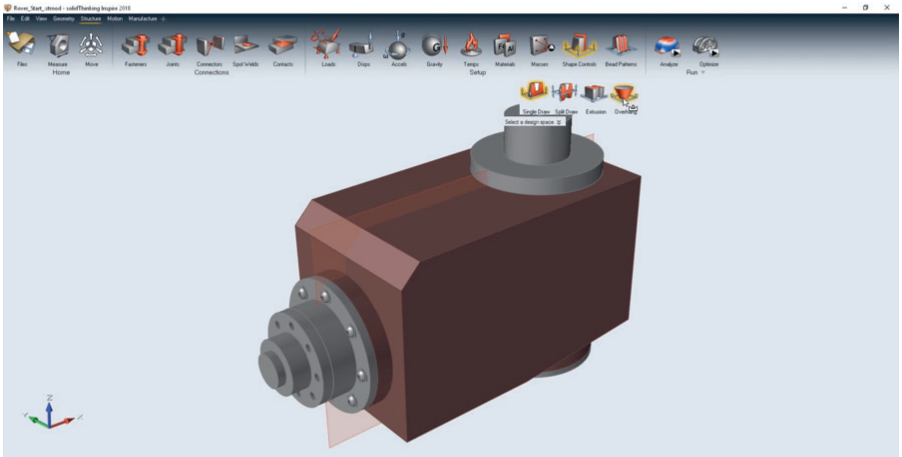
Just as in OptiStruct, the user then needs to define parameters like contacts, loads and materials.



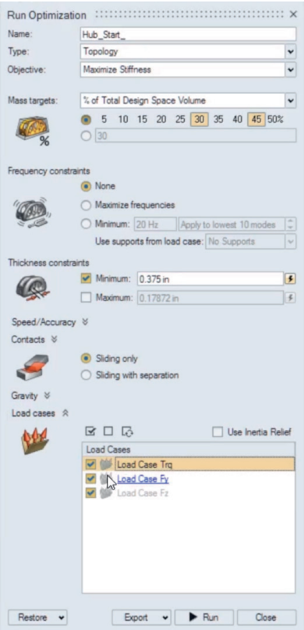
Inspire uses the same definition of design space as OptiStruct, i.e., the volume from which material can be removed. Below, the design space is colored in orange:



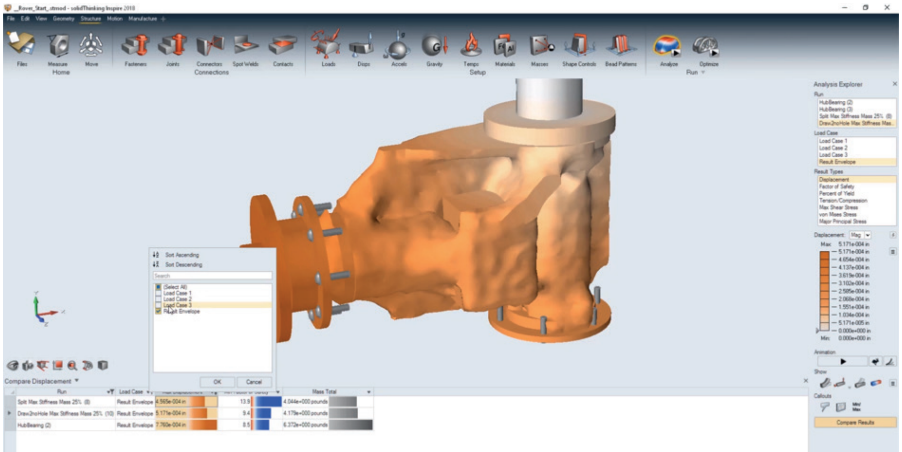
Constraints like draw direction and overhang can also be added:



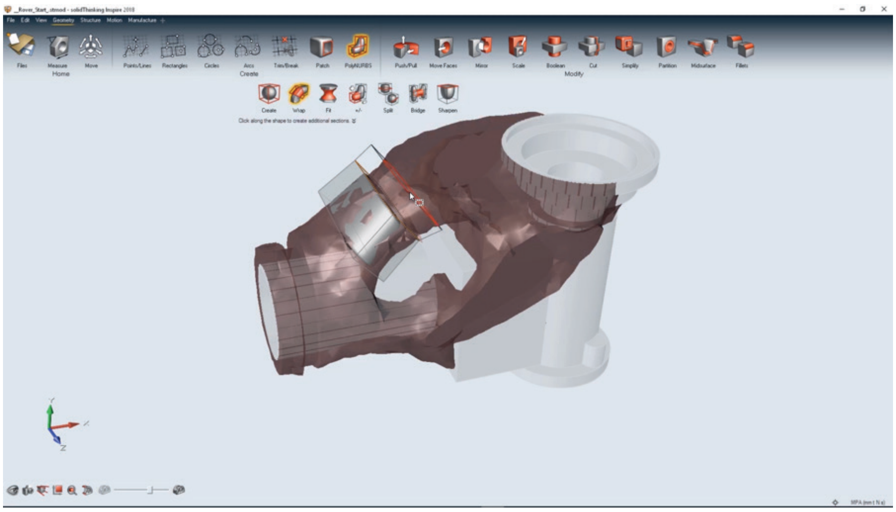
Finally, the optimization study can be run. The user has two choices for their objective: maximize stiffness or minimize mass. You can also tune the results with thickness and frequency constraints before running the study.

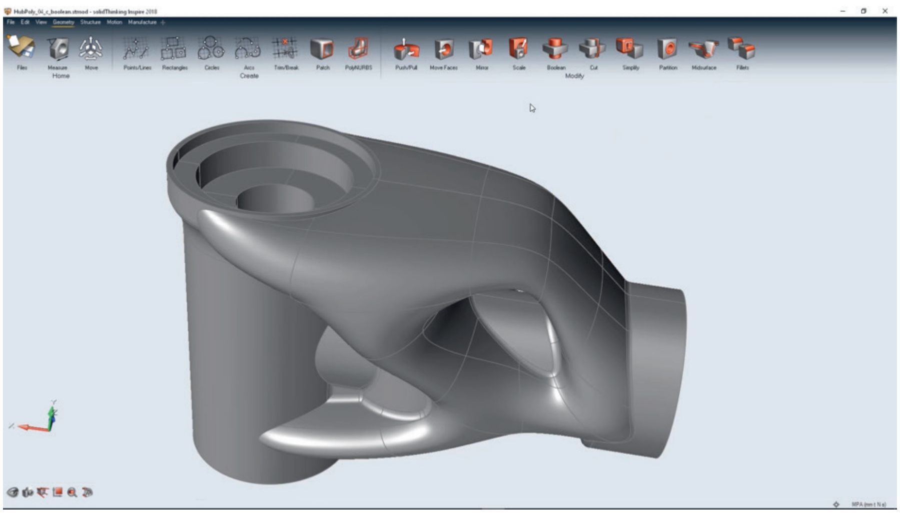


Once the study is run, users can further explore the design space by changing parameters in the shape explorer window. You can also compare different results by compliance and mass, and analyze the results for stress, displacement and factor of safety across different load cases.



Once you're happy with your design, you can export it as an STL mesh or use Inspire's geometry tools to build on top of the design. Users can use PolyNURBS to smooth out the generated shape.





"Topology optimization methods in OptiStruct and Inspire allow for multiple disciplines, objectives, constraints and variable types to solve real-world problems versus simple demo examples," Brennan said. "Literally decades of application support have increased the breadth and depth of our solver capabilities."

CONCLUSION

In this report, we've taken the view of generative design as a collaboration between human and computer. Generative design techniques use the computer as a designer to create shapes that would be impossible for a human engineer to devise.

Topology optimization is the most popular example of generative design technology being used today. This technology begins with a design space that designates a volume to work with. Topology optimization algorithms remove pieces of this volume until a desired fraction remains. The removed parts are determined by the load cases—forces and boundary conditions—applied by the engineer.

Generative design techniques, especially topology optimization, have only recently achieved real practicality. Though these techniques have been studied for decades, the results of topology optimization have been impractical to manufacture. With the recent boom in additive manufacturing, these optimized parts have become manufacturable at last.

We're still in the early stages of generative design. As algorithms, hardware and manufacturing techniques improve, generative design will undoubtedly play a larger role in the overall design process. Many people believe this technology signals a new generation of CAD. The early successes of generative design lend credence to this idea. The ability of topology optimization to significantly reduce part mass makes the technology extremely valuable to many industries. This may only be the tip of the iceberg of what generative design can eventually do.

All images courtesy of Altair unless stated otherwise.

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