

A 3D CAD model of a mechanical assembly, possibly a turbine or pump, is shown. The model is rendered in a semi-transparent green color, revealing internal components like a central shaft and blades. Numerous green streamlines flow over and around the model, representing a fluid dynamics simulation. The background is a solid blue color.

FOUR WAYS EVERY ENGINEER SHOULD USE SIMULATION

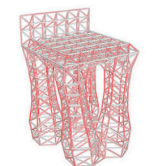
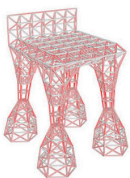
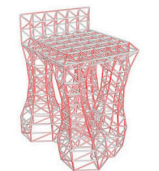
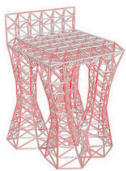
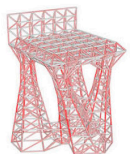
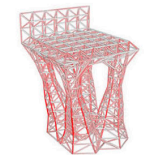
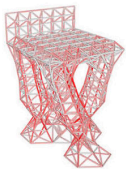
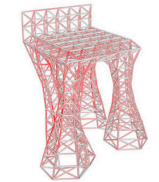
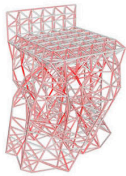
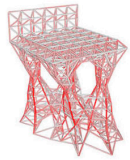
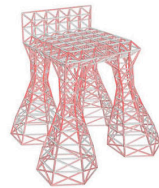
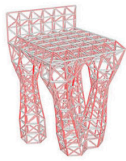
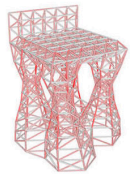
Introduction

20 pieces of uncooked spaghetti. Masking tape. String. And a marshmallow. You have 18 minutes to build the tallest structure you can that will support the marshmallow on top.¹

It's a fun exercise that reveals some interesting tendencies about how different types of people solve problems. And, surprisingly, kids do far better than most adults. The most telling difference is that adults spend a lot of time planning in an attempt to build the structure to perfection, putting the marshmallow on at the very last moment hoping it doesn't all come crashing down. Kids, on the other hand, start with the marshmallow and go to work building the structure underneath until it fails, making many successive attempts that gradually get better and better.

Early decision making is often done in a vacuum of information. But starting with an initial concept and testing as you go is a great way to collect data about what's working and what isn't that will ultimately get you to a better outcome.





INTRODUCTION

ESSENTIAL TOOLS OF ENGINEERING

While CAD software is widely viewed as the ultimate tool for engineers, design work is the equivalent to the planning and building steps in the process. You should also be equipped with tools that let you put the marshmallow on the top, so to speak, so you can test your design and learn how it will really work.

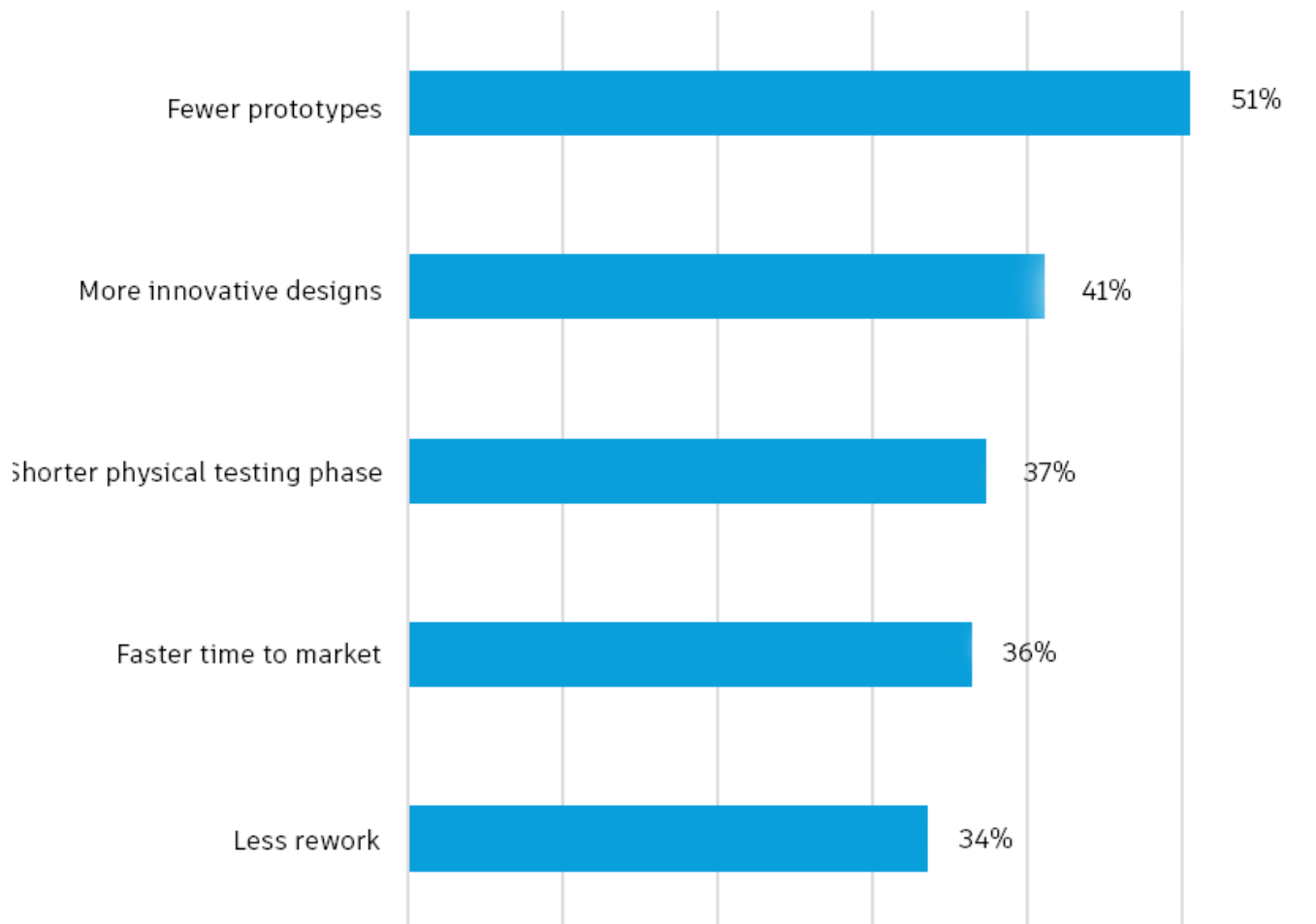
After all, the goal of any individual task in engineering should be answering the question, “what is the fastest way to design, test, and improve on an idea?” If you are limited in your ability to test, then you are not really able to engineer the product to its full potential.

This is where simulation comes in. Instead of waiting on prototypes and physical testing, simulation can be used from the outset of the design work being carried out. Individual decisions can be tested as you make them, giving you confidence that you made the right call or the necessary insight to see something has to be changed.

INTRODUCTION

THE BENEFITS OF SIMULATION

This is supported by more than just anecdotes. In a survey conducted by Tech-Clarity², engineers reported several benefits of adding simulation as a tool used in development, including more innovative designs, fewer prototypes, and faster time to market.



INTRODUCTION

EVERY ENGINEER CAN USE SIMULATION

The longstanding hang-up on simulation is that it takes too long and it's difficult to use. Simulation requires engineering expertise so the appropriate conditions are evaluated and results are interpreted and applied to design changes correctly. It has also required a certain level of specialization to properly operate the software—knowing what buttons to push, what options to select, and all the preparation needed to set up the model.

There is not much that can (or should) be done to mitigate the need for engineering expertise, but the user experience for many simulation offerings has now improved so one does not need to be an expert in the software to use it. Add in the fact that many analyses are now multi-threaded to take advantage of newer hardware and cloud computing, and the traditional barriers begin to dissipate.

This all leads to an ability to perform many more tests throughout the development process with minimal disruption to the flow of design.

There are also differing use cases for simulation. Early in the design process, simulation can be used to provide directional guidance that flags potential issues or confirms you are headed down the right path. As you progress further, specialized analysts may need to setup more complex simulations of complete assemblies with the aim of getting precise, definitive results that confirm requirements are securely met and the product will perform to spec.

There are many types of analyses that will help you collect data to inform your decision making processes as you engineer your product. The following sections discuss four of these, the results you can expect from them, and how they can help inform your design.

LINEAR STATIC STRESS

Linear static stress is the quintessential type of simulation—it evaluates the strength of the part based on how it will be loaded and constrained in use. It can be used in most scenarios where the material will experience small displacement that is linear and proportional to the loads being applied, and then return to its original shape.

LINEAR STATIC STRESS

How to use it

All types of analyses start by preparing the model. For linear static stress, this involves assigning materials, establishing contacts if multiple parts are being evaluated, and meshing the components in the model. It's right here that many engineers get stuck when they first begin using simulation. In many modern simulation environments, however, much of the manual effort has been removed: materials are carried over from the CAD model, contacts are automatically detected and can be easily modified, and meshing happens automatically with little refinement required.

The other step in setting up the model is assigning the loads and constraints the product will experience in use. The process of defining these is easy—knowing the location and size of the loads along with the exact way the product will be supported is where your engineering expertise comes into play. Setting these to match the real-world use of the product is essential to getting results that provide accurate information to base your decisions on.

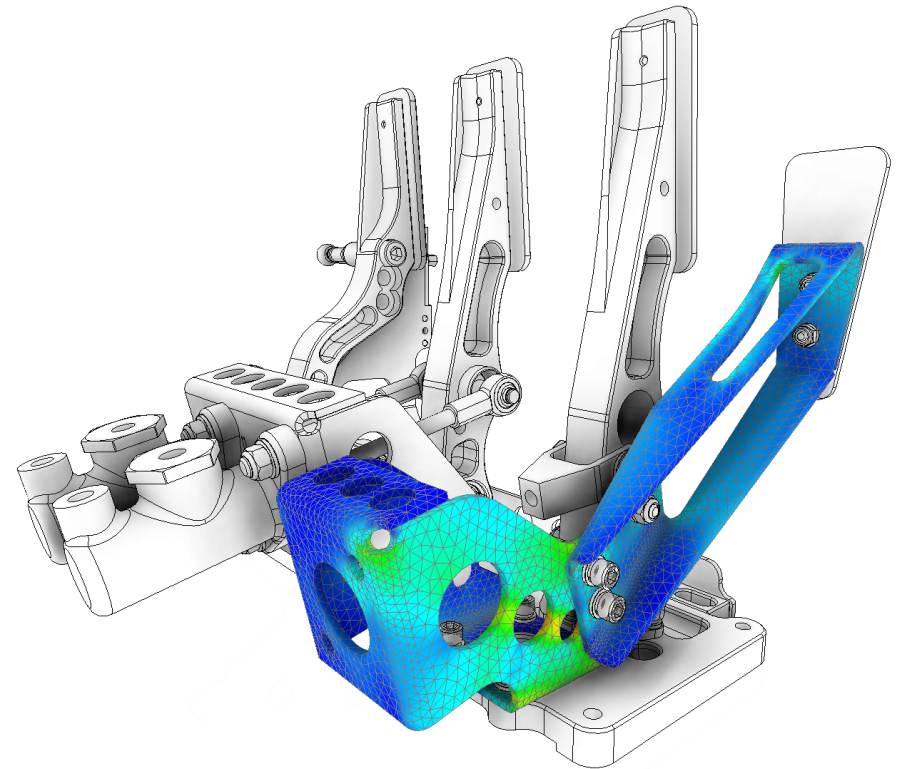


Image courtesy of Briggs Automotive Company, Ltd.

LINEAR STATIC STRESS

Applications

The output of a linear static stress analysis includes the resulting stress, strain, deformation, and safety factors based on the loads applied. In practice, these results can be used to make your designs better in a variety of ways:



EVALUATING DESIGN ALTERNATIVES

Early in the design process, you can quickly evaluate the performance characteristics of many different design possibilities to identify those that show the most promise. You can also assess different loading or constraint options to identify how it will perform in a variety of use cases.



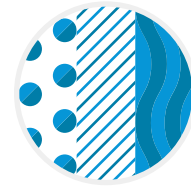
OPTIMIZING STRENGTH

Knowing where the highest concentrations of stresses and displacements in the part will be, you can modify the geometry or add structural reinforcements in these areas to increase strength and improve performance.



LIGHTWEIGHTING

Locations of the part that do not contribute to the strength or stiffness of the design can also be identified. In these areas, material can potentially be eliminated to reduce costs and avoid over-engineering while still maintaining the appropriate factor of safety.



MATERIAL SELECTION

You can also look at how the product will perform with different materials. With guidance on material performance, you can select the best option for your design, giving consideration to both quality and cost.

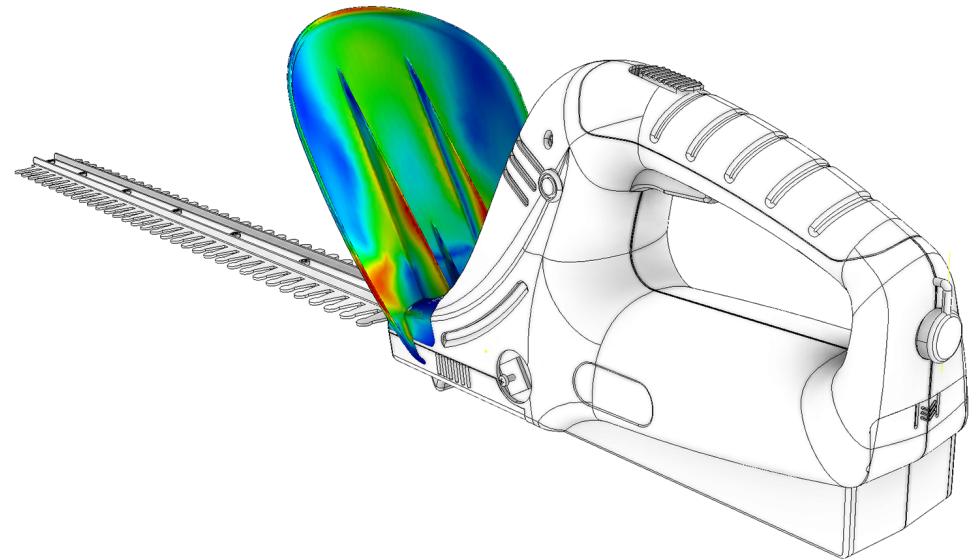
LINEAR STATIC STRESS

Going further

As mentioned before, the linear static stress analysis is appropriate for scenarios where small displacements will be linear and proportional to the loads applied. For many materials, such as cast iron, aluminum, and nylon, the working range extends well beyond the linear region of the stress/strain curve. And if components move in operation or if there is a large displacement, the dynamics of the event need to be accounted for.

For these cases, non-linear analysis uses models that better predict how materials respond beyond their linear range, so decisions on whether the design is acceptable or needs to be strengthened further can be made off accurate information. And mechanical event simulation helps you evaluate the performance of the design while it is moving, so the results reflect how it responds through the entire range of motion, rather than assuming it is static throughout.

Drop testing is a common application of non-linear, event-based simulation. By virtually dropping your product, you can identify how the product absorbs the impact. For example, if the product lands on an edge, you can evaluate different options for chamfering or rounding the corner to best survive multiple impacts.



MODAL ANALYSIS

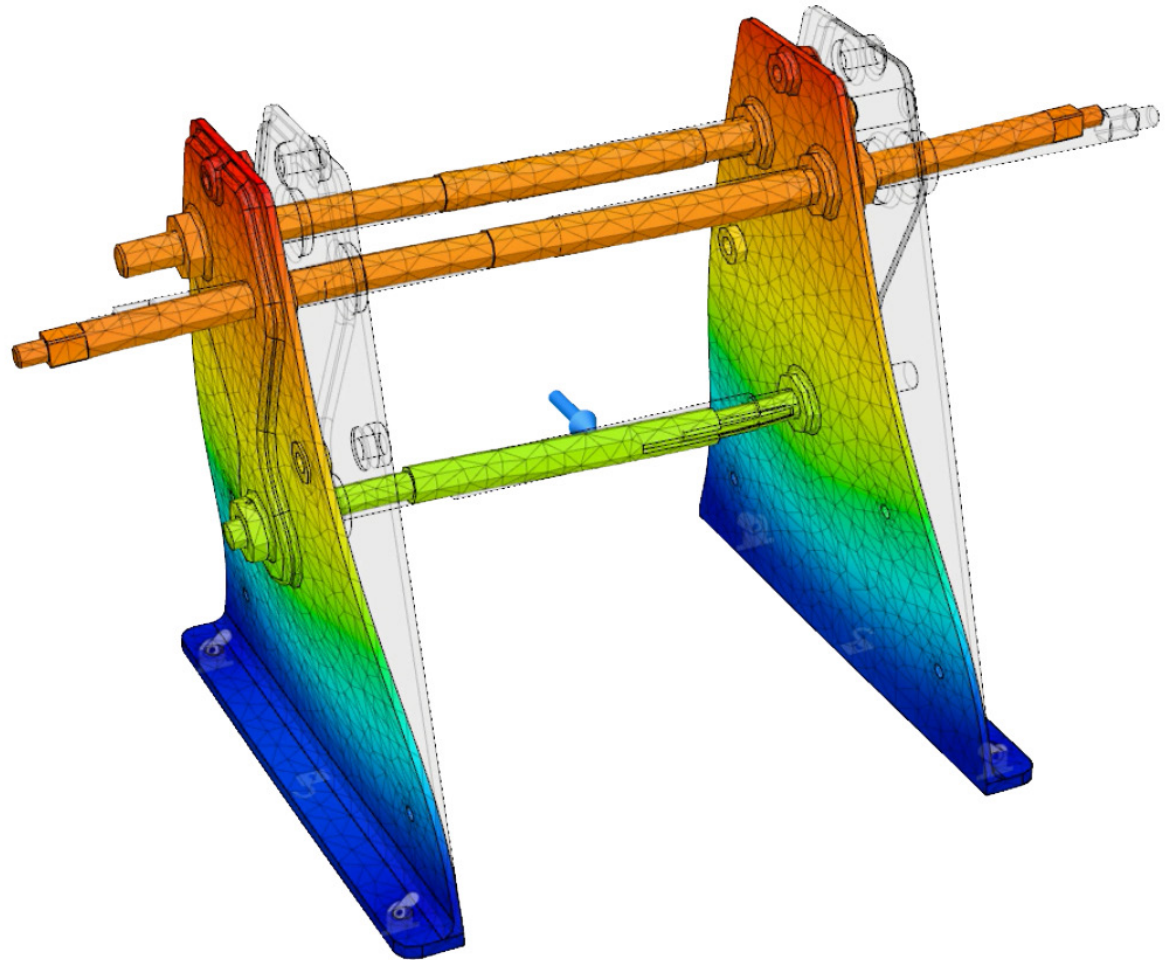
All things have natural frequencies at which they vibrate. In product design, the most concerning issue is when a power-driven device, such as a motor, causes a component within the assembly to resonate because it produces a frequency at which the part naturally vibrates. When resonance happens, the part will be destroyed, much like a wine glass shattering to a high-note produced by an opera singers voice.

MODAL ANALYSIS

How to use it

Much like linear static stress, the setup consists of assigning materials, defining contacts (if analyzing an assembly), and meshing the model. Again, much of this can be carried over or automatically completed based on information from the CAD model.

Following this, the main difference from linear static stress is that only the constraints defining how the product will be supported are needed, since external loads do not play a role in determining the natural frequencies of the object.



MODAL ANALYSIS

Applications

The primary function of a modal analysis is to identify the natural frequencies and mode shapes (i.e. shape of structure during vibration) of the part or assembly. This information can be used for:



VALIDATING DESIGNS

You can identify the frequency ranges at which motors or other power-driven devices operate from the manufacturer or through physical testing. Comparing these with the natural frequencies of the product validates they will not resonate in service. Ideally, the first mode will have a frequency higher than any potential driving frequency, with higher mode shapes having higher frequencies yet.



LIGHTWEIGHTING

Removing or relocating mass in a part can significantly change its natural frequency, so an important check as you make successive attempts at lightweighting is to validate the natural frequency has not slipped into the operating range of the product.



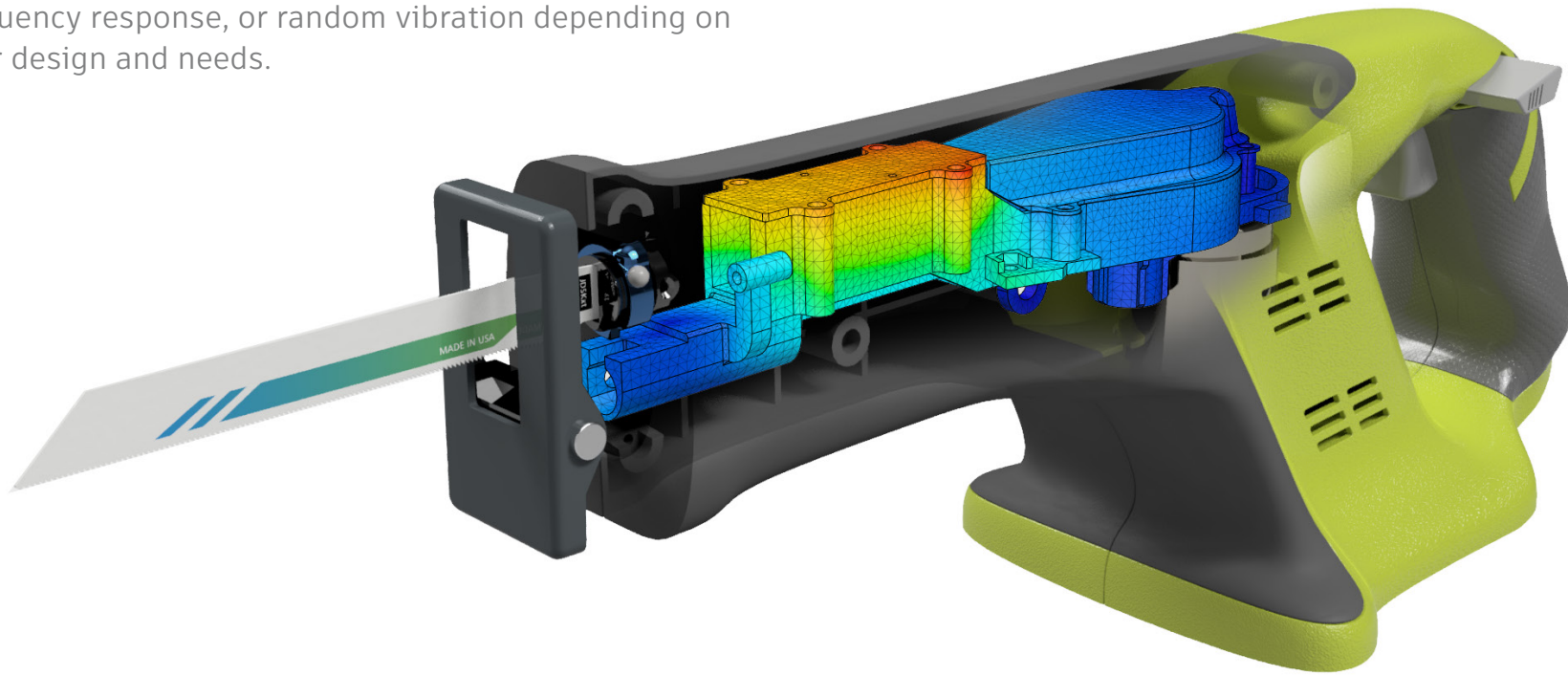
SHOCK TESTING

If it's possible that your product will be subjected to shock loads—an explosion or hitting a pothole—the results of a modal analysis can be used as input to further analyses aimed at helping understand whether the product will experience excessive stresses.

MODAL ANALYSIS

Going further

Answering the questions of what happens when a motor causes part vibration, even when not in line with a natural frequency, is always needed. While designing for natural frequencies is an essential step, understanding the resulting stress and displacement values from further analysis is crucial. Using the natural frequencies and mode shapes calculated here, you can perform additional simulations such response spectrum, frequency response, or random vibration depending on your design and needs.



THERMAL ANALYSIS AND CFD

Thermal analysis and Computational Fluid Dynamics (CFD) are separate disciplines of simulation and often employed on their own to evaluate heat distribution through a model and fluid flow in and around objects. When paired together, they can predict complex interrelationships between the two, such as how airflow inside an electronics housing will affect the temperature of the microchips on a PCB.

THERMAL ANALYSIS AND CFD

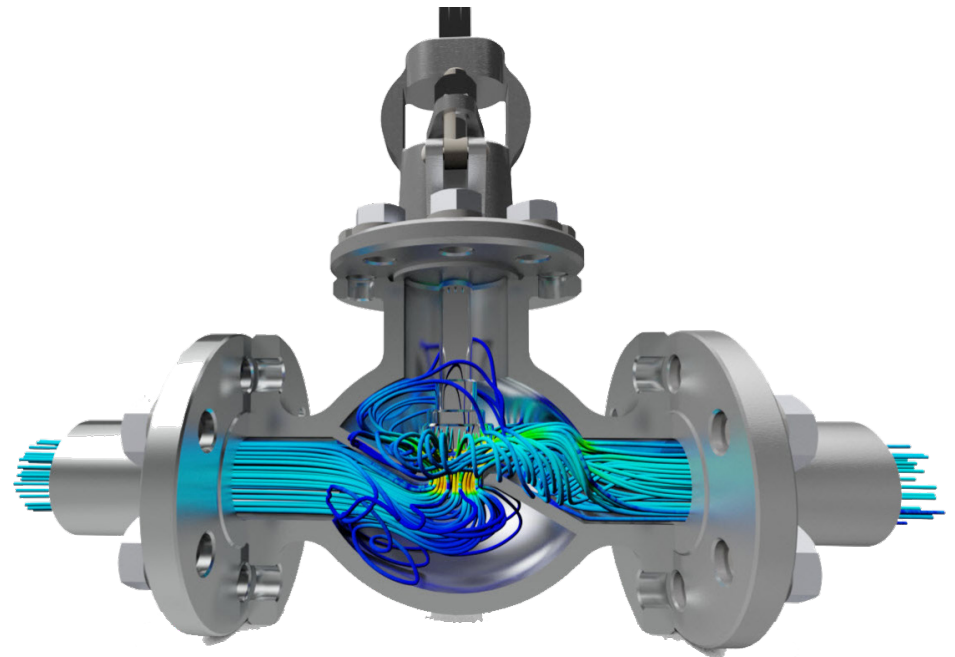
How to use it

Both thermal and CFD analyses require the same types of inputs as other types of simulation, but the actual material properties that are most crucial to the analysis are different than that of linear stress or modal, as are the loads and boundary conditions.

For materials, instead of modulus of elasticity and yield stress, values for thermal coefficient of expansion, thermal conductivity, fluid density, and viscosity are key parameters. Again, these are often provided within the software or can be easily identified through your material supplier or online resources.

Contact settings also play a different role in thermal and CFD. Rather than defining how parts interact with respect to motion, this contact can be used to define how heat passes between components in the assembly.

The most significant change to the loads and constraints is that many of them will be applied to the fluid volume (either the internal or external fluid, such as air) of the model. Each of these loads will define how the fluids interact with their solid surroundings and how temperature will change this behavior.



THERMAL ANALYSIS AND CFD

Applications

Thermal and CFD simulation results include visualizations of the temperature and fluid flows in or around your product. These can be used for:



CONTROLLING COMPONENT TEMPERATURE

Especially useful for electronic devices, visualizing the temperature profile of components and how air will flow through the enclosure helps you make design decisions that improve cooling. This can lead to smaller product sizes, improved performance, lower material costs, or reduced risk of failure in operation.



FLOW DISTRIBUTION AND PRESSURE DROP

By predicting fluid flow rates, pressure drops, and turbulence early in the design process, you can iteratively improve the design of pumps, valves, heat exchangers, and nozzles. These can then be tested under a variety of conditions to ensure they will perform to spec.



THERMAL STRESS

Changes in temperature can also induce stresses into the part. Pairing thermal and linear static stress analysis together can help you evaluate the stress, strain, and deformations that result from these scenarios.

THERMAL ANALYSIS AND CFD

Going further

For more advanced work, you may need to apply thermal and CFD analysis to look at transient behavior. This would be essential when evaluating components, such as microprocessors, that heat up and cool down based on different operating conditions. It is also necessary when airflow may be intermittent, such as a fan starting, stopping, or changing speeds.

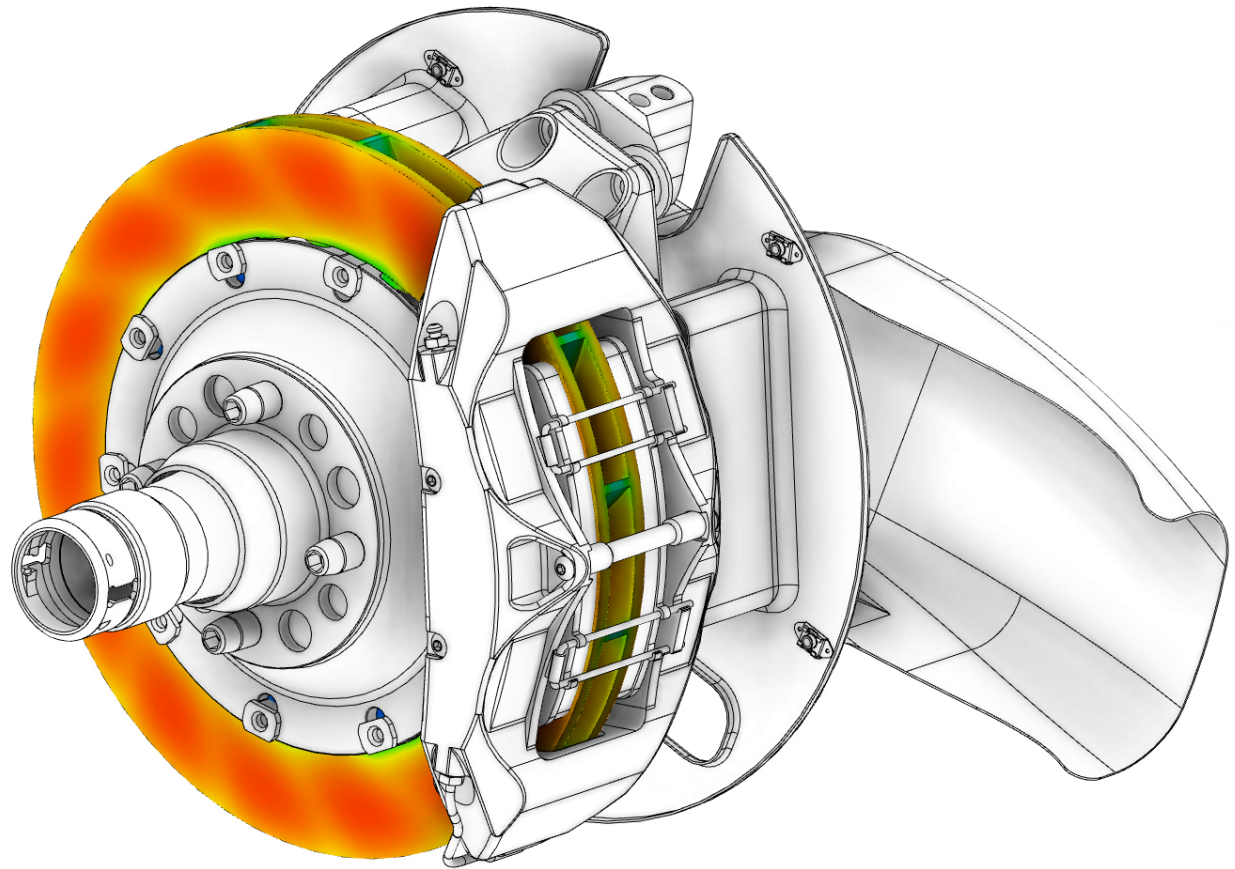


Image courtesy of Briggs Automotive Company, Ltd.

FATIGUE

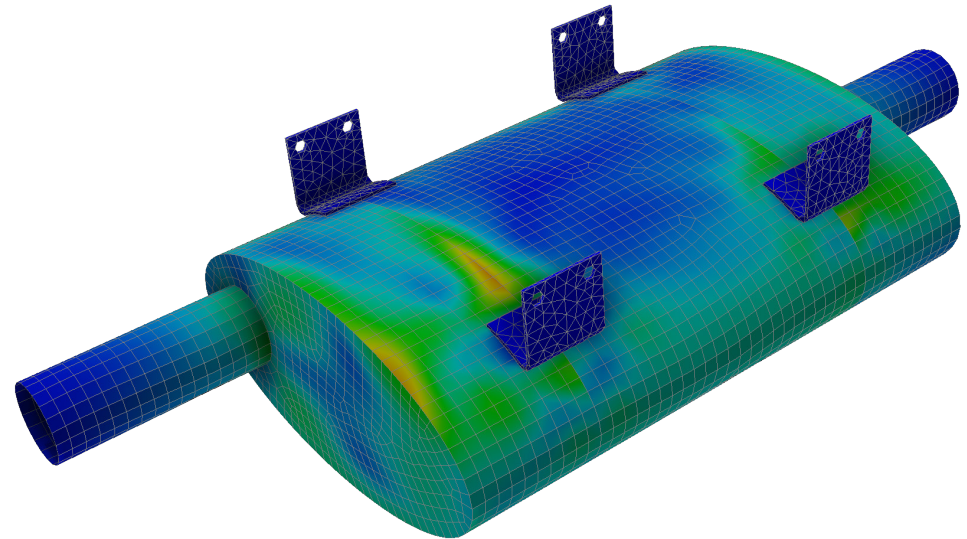
While stress analysis provides useful information on the maximum stress, strain, and deformations your parts will experience in use, it is not a good predictor of how well the part will hold up to repeated loads over time. Knowing the lifespan of your product also requires that you understand the long-term damage caused by thousands, or millions, of loading cycles, which can be done with a fatigue analysis.

FATIGUE

How to use it

Setup is similar to a linear static stress analysis, with a few additional inputs unique to characterizing fatigue. When assigning materials, there is an option to provide values for the stress life (S-N) curve for high-cycle or low-cycle fatigue. These values are identified using standard material testing methods for fatigue, and are often included in the software or available in material databases online.

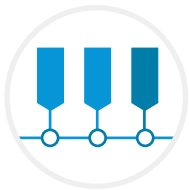
One additional step is needed to define how the load will be cycled on the model. You can set the forces to be fully reversed, higher in one direction, or simply loaded and unloaded.



FATIGUE

Applications

The primary result from a fatigue analysis is the number of cycles until failure along with the locations where the points of failure will occur. These can be used for:



DETERMINING PRODUCT LIFESPAN

While fatigue is typically used as a check at the end of the development process, it can also be applied earlier to identify areas of the design that may fail prematurely, shortening the lifespan of the product. Similar to a stress analysis, you can then make informed decisions on how to strengthen the part by modifying the geometry or evaluating materials that are less prone to fatigue failure.



FAIL-SAFE DESIGN

Avoiding failure entirely is not typically possible as components can be maintained or replaced for long service life products. Designing so that there is no single point of failure by staggering component lifespans and designing to mitigate inevitable problems can be done to prevent catastrophic failure of the entire system.



Image courtesy of Astro Studios

Summary

You need more than just design software to engineer your products to their fullest potential. Equipping yourself with tools that help you test your design decisions as you make them quickens the development process and results in better products.

Linear static stress, modal, thermal, CFD, and fatigue analyses are core simulation disciplines that cover the vast majority of applications. As you become more familiar with these, more advanced methods, such as evaluating non-linear or transient behaviors, will be easier to pick-up, broadening your toolset further.

All of this leads to you being able to design, test, and iterate on your ideas, giving you more opportunities to iterate and achieve better outcomes.



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1 Marshmallow Challenge, Tom Wujec. <http://www.tomwujec.com/design-projects/marshmallow-challenge/>

2 2016 Simulation Survey, Tech-Clarity.