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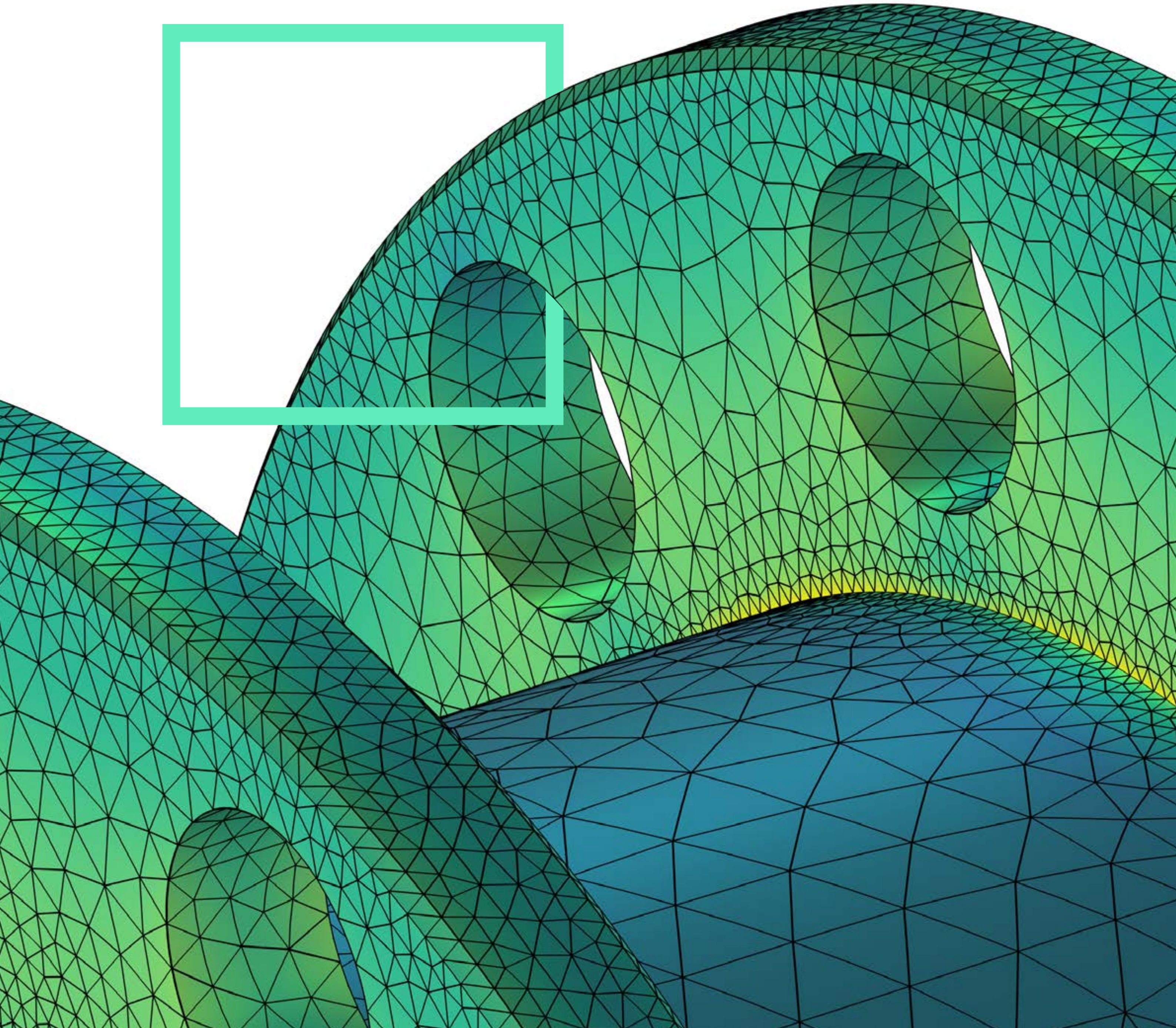
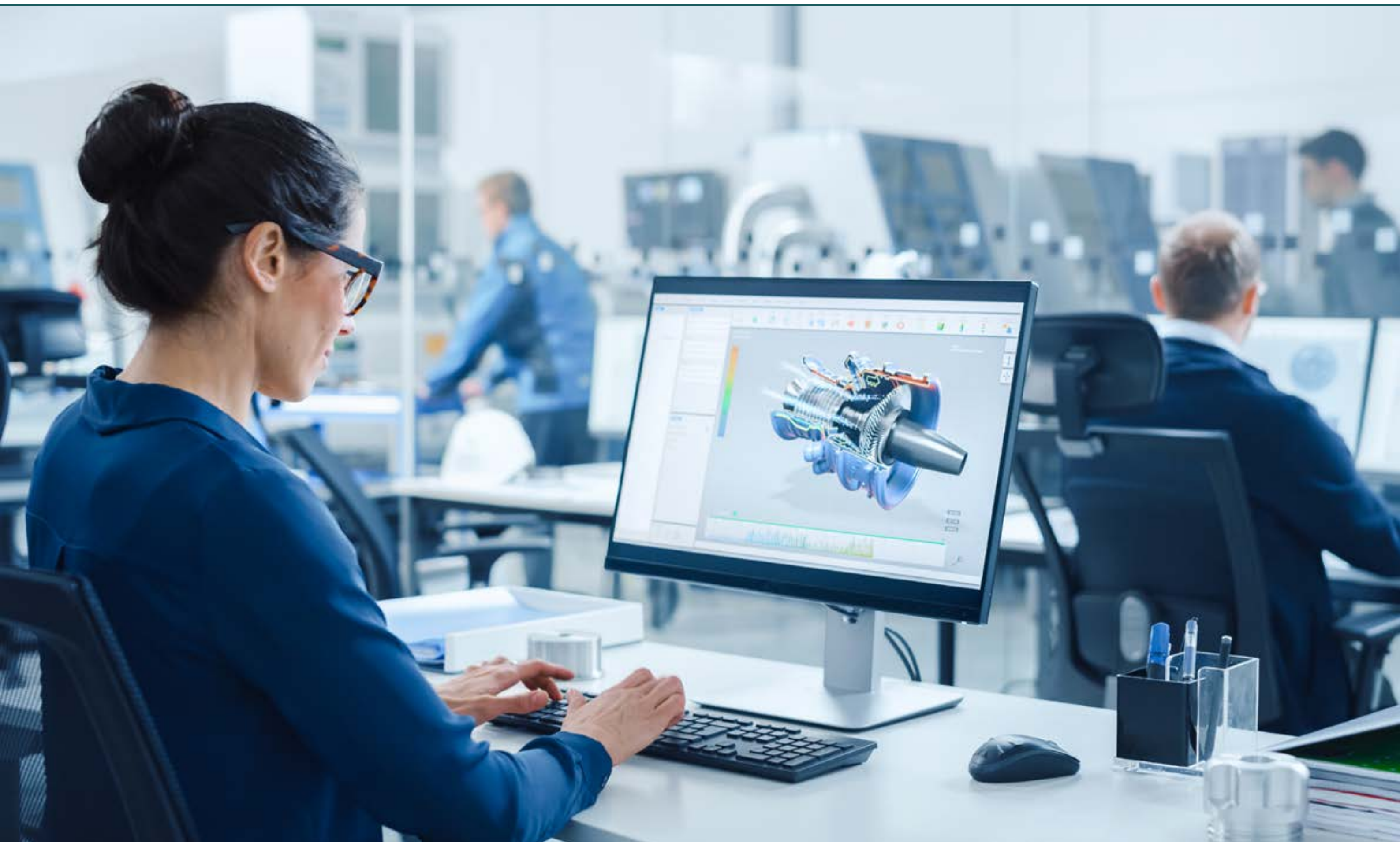
WHITEPAPER

How to devise effective simulations that improve R&D performance

Author: Dan Spencer - Consultant, Applied Science



Simulations enable R&D teams to explore, optimise, test, and troubleshoot products and processes throughout the development cycle. Yet, there are common pitfalls that can reduce simulations' effectiveness or incur unnecessary time and expense. This whitepaper examines two high-level approaches to simulation: finite element analysis and simplified analytical modelling. We consider how to select and implement the most appropriate method for the task in hand, sharing real-world examples.



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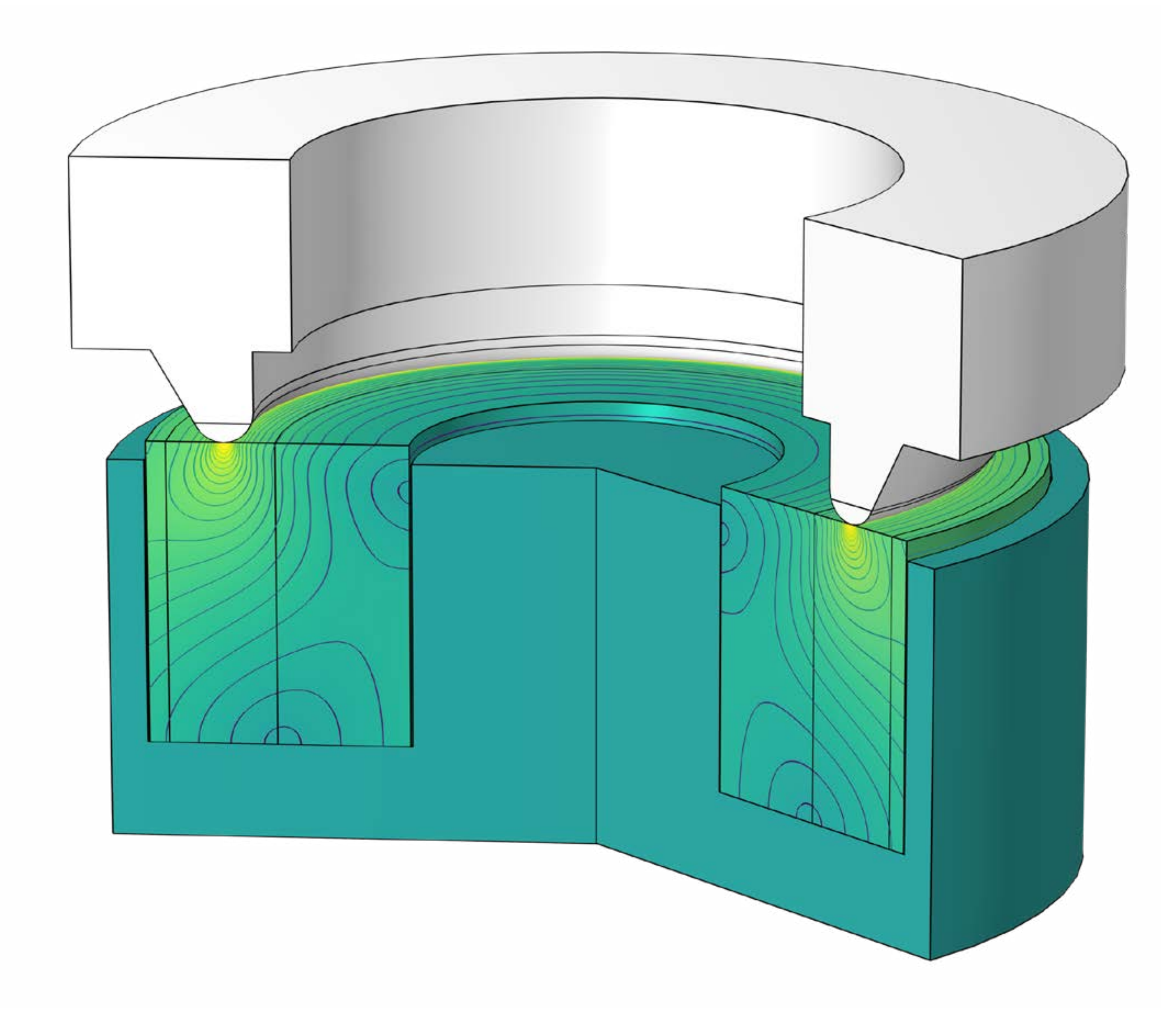
Computer representations of a product or process – known as simulations – offer a powerful way to understand and develop technologies. Applied well, they enhance the entire product development lifecycle, reducing risk and enabling innovation to deliver better outcomes sooner. In short, simulations predict how a new or adapted product or process will behave in the real world. They allow R&D teams to rapidly explore front-end concepts, inexpensively optimise designs, and rigorously test prototypes, whilst enabling product managers to control back-end manufacturing processes and troubleshoot market issues.

Nevertheless, certain pitfalls can hinder simulation efforts. For instance, it is common for R&D teams to dive straight into detailed finite element analysis (FEA) without considering whether simplified, targeted models might provide more illuminating results on a shorter timescale. FEA is undoubtedly a valuable tool, and used correctly it can transform product development. However, it's wrong to assume it's always the best option.

Getting simulations right

Advancements in the provision of computational power and the proliferation of approaches like digital twins and machine learning in edge devices unlock new opportunities for simulation. The possibilities have never been greater, but it's important to get it right. A key driver of simulations is their ability to save time and money, but they don't always deliver the intended outcome.

This paper looks at how to carry out effective R&D simulations using targeted approaches to save time and costs. We present simulation as an important part of a holistic approach to product design, which combines technical performance with consideration of the end user through human-centred design (an area often considered at odds with the mathematics and physics of simulation). Finally, we consider how R&D simulations can be leveraged outside the technical sphere, providing benefits in education, sales, marketing, and beyond.



A comprehensive simulation strategy

Figure 1 indicates some of the ways simulations can be applied throughout product development to enhance technical performance.

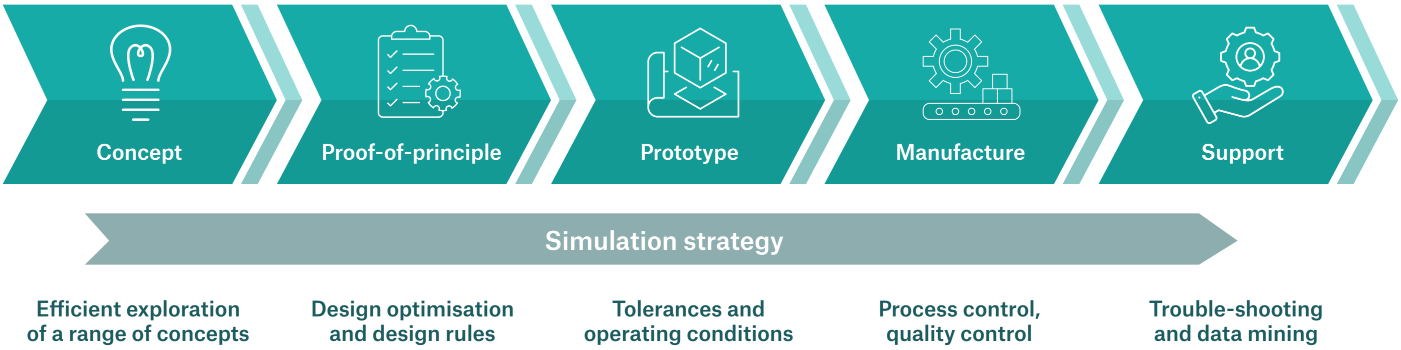


Figure 1: Key points where simulation can bring value throughout the product development lifecycle

Simulations provide a fast and inexpensive way to assess competing concepts from the earliest stages of product development. During front-end innovation they can de-risk exploratory work concerning ground-breaking approaches or new technologies as R&D teams look to gain competitive edge. Once a concept has been established, a process is needed to ensure the design is as strong as it can be. Prototyping large numbers of designs is expensive and time consuming, but simulations can help pinpoint optimal configurations.

Simulations can also enhance process and quality control, prescribing tolerances and pre-empting problems that might otherwise be encountered due to manufacturing variations. Similarly, they can investigate how products behave in different operating conditions without the need for expensive, time-consuming, and potentially dangerous experimental programmes. Once products are in manufacture or on the market, any problems that arise can be diagnosed and fixed using simulations as part of root cause analysis.

Aside from the technical advantages, it is important that simulation sits within a strategy that retains a focus on the end-user. Simulations can be used to assess usability alongside performance in various use case environments, complementing human centred design. Simulations can focus on factors such as user interaction and parameters that affect users, as well as troubleshooting and data mining if issues surface during manufacture or after launch. A joint consideration of human-centred design and simulations can help product development teams achieve a better balance between technical performance and user experience.

Two simulation methods

Various techniques can be used for simulation, but to demonstrate how R&D teams can select the best method on a case-by-case basis, we're focusing on two.

FEA is the first option that comes to mind for many people when they think about simulation. This modelling approach typically uses high-end software to perform detailed simulations of a product or device. It produces highly detailed outputs and generates impressive graphics to showcase results, but it can be slow to run, and software can be expensive.

Another common approach is streamlined analytical or simplified numerical models. The results are less detailed than with FEA, but they are often obtained faster and can be interpreted easily. As Figure 2 indicates, it's also possible to take a hybrid approach, leveraging the advantages of FEA and simplified modelling.

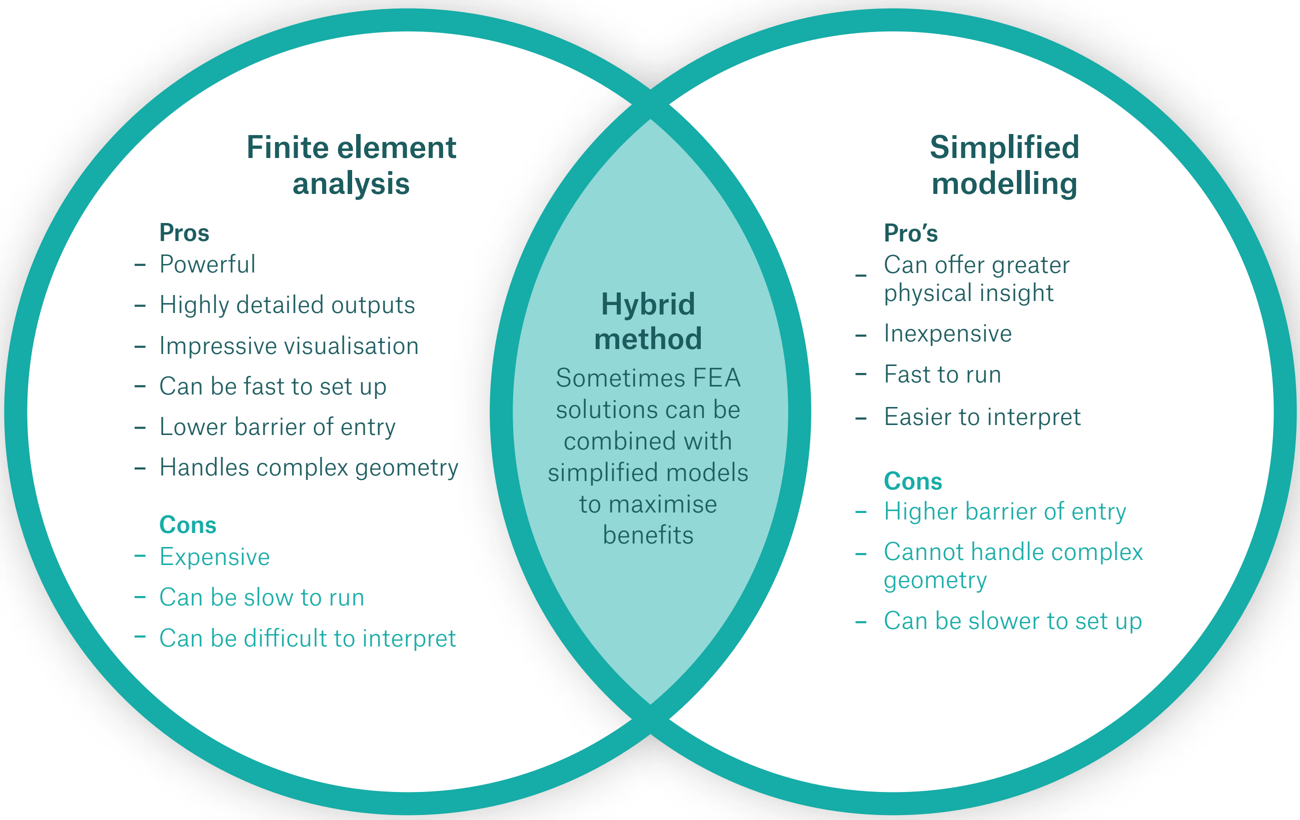


Figure 2: High-level examples of simulation

Why am I simulating? Devising an effective strategy

Discussions about simulation should always start by defining what needs to be discovered and why. Once this has been established, a few key questions can aid the planning and refinement of an effective simulation strategy. Figure 3 sets out a framework for these early conversations.

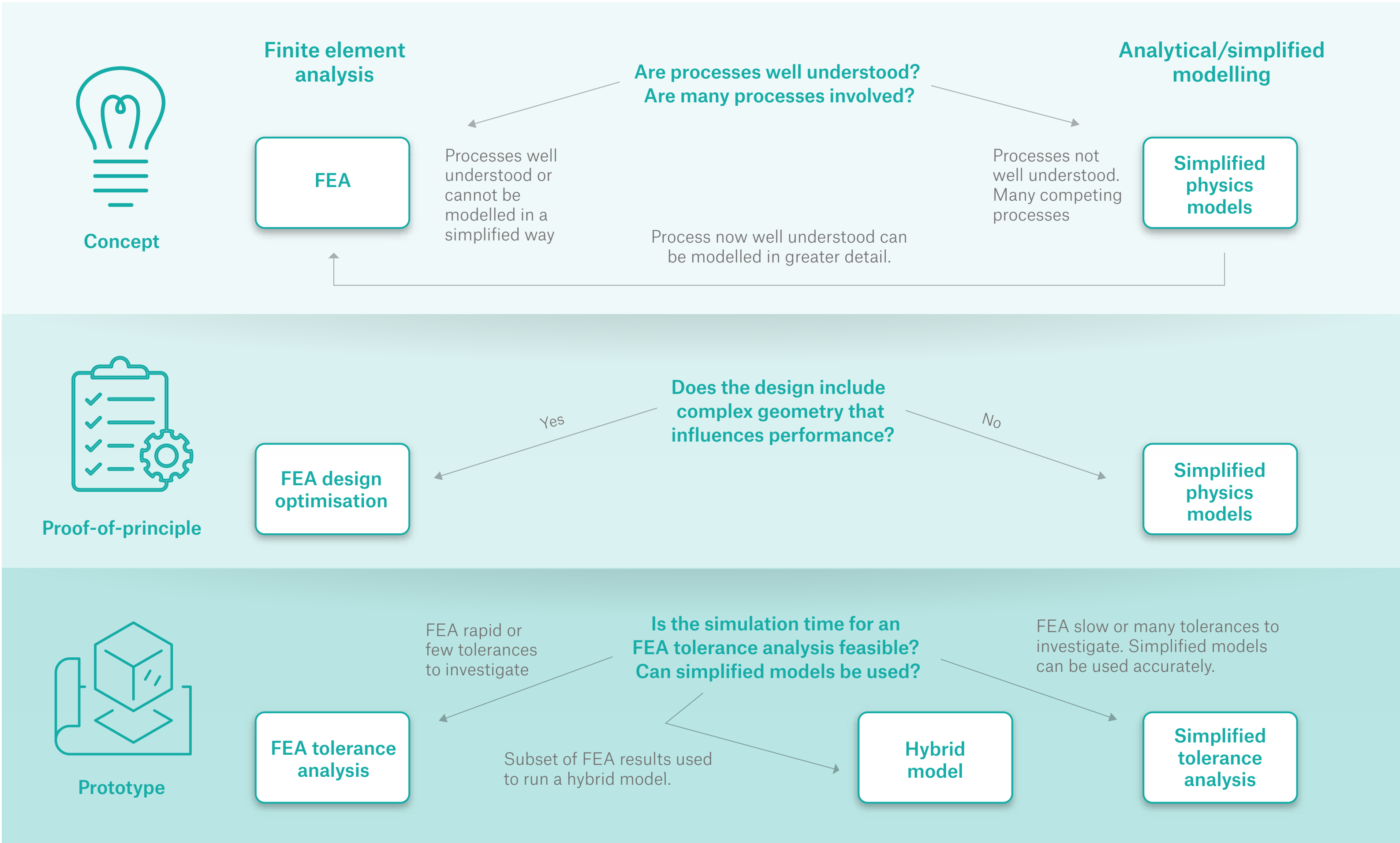


Figure 3: Asking the right questions can frame simulation strategies to maximise the benefits

Concept

In the earliest stages of R&D, teams typically want to understand the different processes at play in a product or system. Fundamentally, they want to know if their new ideas will work.

A vital question to ask during concepting is **"are all the processes in my system well understood?"** If the answer is no, the first stage of modelling should involve the creation of simplified analytical models for individual processes. These will illustrate whether a given process is likely to be important. It's much better to spend a small amount of time investigating process relevance upfront than having to fix unexpected process-related problems later.

In some cases, simplified models are sufficient to prove whether a concept is workable. For instance, sensor systems typically need a certain level of accuracy or fidelity to perform their desired function. A parking sensor on a car doesn't need to be millimetre accurate, but meter accurate isn't going to cut it. Similarly, a mathematical model of an ultrasound proximity sensor may demonstrate that it can't detect objects of a certain size which, depending on the application, may render the concept unworkable. Probing concepts with simplified analytical models, and discarding those that don't meet requirements, can significantly reduce costly and time-consuming down-selection processes that rely on prototypes or detailed FEA.

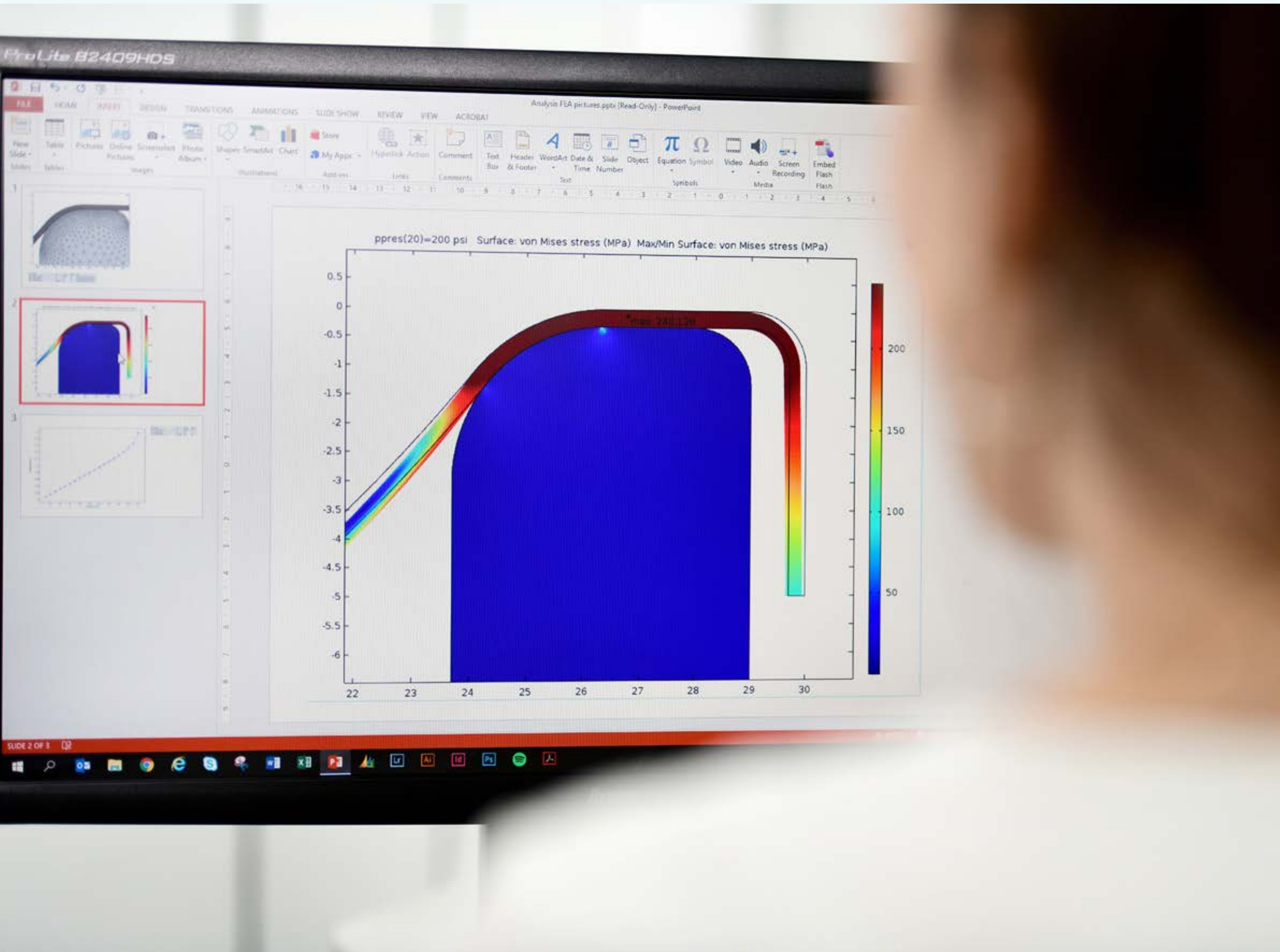
Of course, it isn't always possible to unpick complex interrelated processes with simplified models. In these cases, FEA may be the best route, but proceed with caution and always define the scope of a simulation with care. Early-stage FEA should focus on certain key questions to filter out unworkable concepts, without trying to understand all aspects of how an individual concept will operate. If there are concerns about heat dissipation in a fluid system, modelling the thermal problem may be enough, without focusing on the fluidics. A disciplined 'just enough' approach helps avoid scope-creep and the associated waste of time and money.

Try asking questions about technical feasibility, such as "can enough heat be generated for my application?", or "can an object of a given size be sensed?". Alongside this, consider how end-users will interact with the concept. A powerful electromagnet may have the required ability to actuate a metal component, but if the electromagnetic field is unsafe for humans, the concept shouldn't be taken forward. Framing simulations to tackle both technical and human feasibility enables unworkable concepts to be identified and discarded earlier.

Real-world examples of concept simulation

An agricultural company engaged us to assess different sensing concepts. Using simplified models, we quickly demonstrated that ultrasonic techniques would not have sufficient accuracy in the target application, whereas a camera system would provide a workable solution. Detailed modelling and prototyping of these concepts would have been expensive and time-consuming, but with our support the down-selection process took just a few weeks.

Another concepting project we undertook related to ablation cancer therapy. Many interconnected effects were involved, which couldn't be separated into smaller, simpler models. On this occasion we devised an FEA simulation incorporating all the effects, carefully designing it to target specific client questions about expected performance.



Proof-of-principle

Once a concept has been chosen, R&D typically turns its attention to creating a proof-of-principle device. At this stage, the aim is to optimise a preferred design, and to understand design rules.

To frame the simulation strategy, ask **"does my design include complex geometries that influence how the device operates?"** If the answer is yes, FEA is a good way to go, since it excels at modelling process behaviour in complicated geometries.

An important aspect of finite element modelling is the production of the 'mesh' - the network of points where the equations of your system are to be solved. Intricate geometries require a very fine mesh, and the model may fail if it is not designed carefully. Whilst advanced FEA software can help with this, very complex geometries often require careful tuning by the user. Where possible, unimportant aspects of the geometry should be simplified into basic shapes, with only the most critical areas afforded a high level of detail.

When geometries are not complex, or have little bearing on device performance, design optimisations can sometimes be investigated with simplified models. Devices that create or leverage electromagnetic fields are a case in point. Analytical solutions for electromagnetic fields around simple shapes like spheres, cylinders, and plates are well established. Complex shapes can also be broken down into simpler shape combinations, allowing a design to be simulated in a fraction of a second whereas FEA would take much longer.

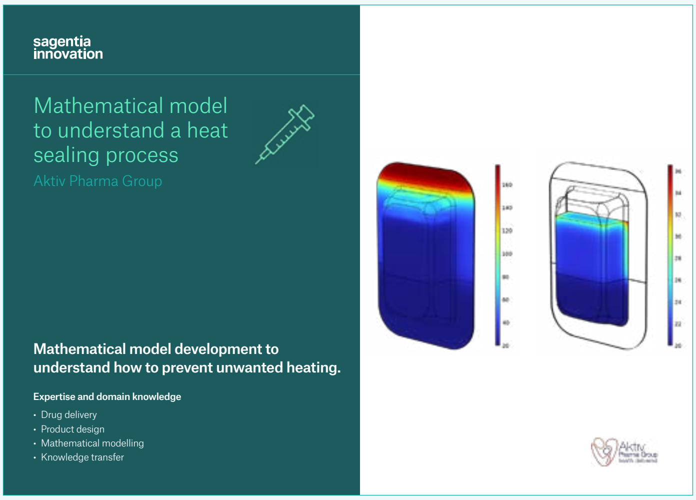
Design optimisation is a powerful function of simulation, but care must be taken not to 'optimise into a corner', where optimising one aspect of a design has a negative effect on another aspect. Otherwise, altering design parameters for improved technical performance may have a detrimental impact on user experience.

Take the design of a heat-sink for a hand-held device. Modelling may show that a metal heat-sink with a large surface area facing away from the heat source gives the greatest cooling capacity. However, this is also where a handle is likely to be located. Placing a large heat-sink in this area may make the device unbalanced or heavy, posing increased risk of burns to the user. Such considerations might not be raised until much later in the design process, at which point the handle may have to be moved to an awkward or unwieldy location to avoid redesigning the heat-sink.

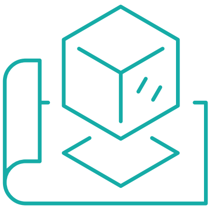
To prevent situations of this type, parameters affecting user experience – such as size, geometries, weight, temperature – should be optimised in the same way as those for any other design parameter. Accounting for both technical and human-centred design parameters ensures simulations don't have a negative impact on usability.

Proof-of-principle simulation examples

In a project for Aktiv Pharma Group, we conducted a simulation to investigate how a heat-seal packaging process affected temperature-sensitive drugs. The packaging's complicated curved surfaces influenced the flow of energy through the system, meaning geometry was exerting an important control on operation. We developed a thermal model using FEA to demonstrate heat transfer in these complex geometries in a way that would not have been possible with analytical approaches. (Read the full case study here).



On the other hand, our proof-of-principle simulations to support the development of Sensopad™, an inductive sensor technology, involved analytical models. The sensor coils had intricate geometries, but the field from each coil segment had a simple mathematical form. This allowed a design to be simulated in a fraction of a second. With an optimised FEA model it would have taken much longer. (Access the case study here).



Prototype

During prototyping, simulations can benefit two core areas of understanding:

- How manufacturing tolerances affect performance,
- How devices will operate under a wide range of conditions.

In both cases it's important to ask, **"is the simulation time for an FEA investigation feasible?"** Tolerance analyses and investigations into operating conditions can require a high number of simulations. This may prove problematic if the simulations are time consuming, as is likely when modelling complex geometries or non-linear processes like fluid flow or contact mechanics.

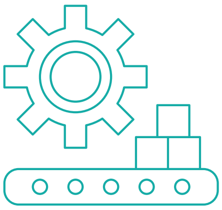
When simulation time transitions from hours into days and weeks it may become infeasible. However, in many cases, particularly in systems that leverage electromagnetic fields or solid-state heat transfer, simplified models can be used. Considered alongside key physics concepts, such as linearity (i.e., double the voltage, double the field), these approaches can reduce simulation time to minutes.

If simplified models cannot accurately depict a system but FEA is too slow, a hybrid approach combining finite element simulations with mathematical principles might help. FEA is used to understand the detail of a few key aspects of the system, and simplified models use these results to understand behaviour over a wide range of scenarios.

An example of prototyping simulation

A prototyping simulation project we undertook for a multinational healthcare services company involved tolerancing the performance of a positioning system that used an array of Hall-effect sensors. A wide range of manufacturing tolerances could affect performance, and performance in each case had to be investigated in a variety of configurations. Exploring these tolerances in FEA would have required weeks of simulation time. Instead, magnetic fields were modelled in a simplified analytical model, and the full range of tolerancing was conducted in a matter of hours.

Closing the circle: manufacture and beyond



The advantages of simulation, and approaches for devising a simulation strategy, remain applicable as products progress to market. However, from the point of manufacture, work often becomes reactive. If problems arise on the production line or on the market, solutions need to be found quickly.

In time-sensitive situations the power of simple analytical models comes to the fore. Unlikely root causes can quickly be discarded, just as unworkable concepts are at the front-end phase. Perhaps a component is overheating, and one hypothesis is that it's being inductively heated by a nearby electromagnet. A simple analytical calculation can determine how much power the electromagnet could deliver, affirming or discarding it as a potential root cause.

When things go wrong during manufacture, competing ideas about root causes can lead to a stalemate. Simple analytical models focus the troubleshooting process, so a path forward can be identified.

Throughout product development, simulations provide an effective means of extrapolating from known behaviour into different scenarios. However, extrapolation requires a level of confidence in the information provided. Once prototypes or products exist, real world data can be used to provide anchor-points for simulations that lend confidence to their results.

This process of benchmarking and extrapolation can be used during prototyping to help optimise designs, as well as during or after manufacture to aid root cause analyses. It's common, especially when troubleshooting, for teams to gather large quantities of data, but without simulation tools for comparison, that data is difficult to understand.

Our team is frequently engaged to help clients diagnose complex or subtle issues with products on the market. A common theme is that product development is not accompanied with a comprehensive simulation strategy. This poses a problem in that important processes or pieces of physics may not be identified or well understood prior to manufacture, making reactive problem solving very difficult.

Combining a well thought out simulation campaign with product development will not pre-empt all possible issues. But it does improve the likelihood of identifying critical, unexpected factors at an earlier stage. Incorporating simulation alongside human-centred design also ensures any end-user problems are more likely to be noted early on too. It's much easier to design around issues when they're identified upfront. And while further problems will almost inevitably arise during manufacture, resolving them is more straightforward if simulations already exist.

Rapid root cause analysis at point of manufacture

A consumer electronics company engaged us to help diagnose a screen defect in a product that had just gone to manufacture. Using simple analytical models, we discounted an explanation provided by the original design manufacturer, presenting and evidencing a competing hypothesis. The simple and rapid nature of the modelling allowed the root cause to be identified in just a few days, allowing manufacture to resume with no delay to the product's release timeline.

Beyond technical matters

Simulation can provide far reaching benefits outside of product development too. When used correctly, it has a powerful ability to convey design rules or illustrate device functionalities. These outputs are useful to those directly involved in product development, but they can also add value to non-technical colleagues.

Where technical excellence is central to a product proposition, the ability to evidence this to customers is of critical importance. Simulations can produce graphics and visualisations that allow non-technical individuals to understand complex technical ideas. This unlocks a new tool for presenting concepts to internal stakeholders or to clients and customers via sales and marketing.

For instance, design rules or device functions might be conveyed via interactive applications where users vary design parameters and see the effects on device performance in real-time. Simulations typically have a high bar of entry, but simplified models can be packaged into applications with relatively little uplift, producing engaging, interactive widgets. These tools can be used to help sales, marketing, or executive teams understand the benefits of designs and why certain choices have been made. This in turn enables them to communicate product strengths and benefits to customers more effectively.

How Sagentia Innovation can help

We have extensive experience leveraging simplified analytical models and FEA in tailored simulation strategies throughout the product development cycle.

Talk to us if:

You can't work out what simulations will complement your product development.
We can help determine what simulation strategy best suits your needs, and if necessary, design simulation approaches.

Your simulation work is unproductive or slow.
At many of the junctures discussed in this article, simulation can become bogged down or even stall. With our wide range of experience in simulation techniques we can help unpick these problems and get things back on track.

You're struggling to interpret simulation results.
Results from simulations, especially FEA, can interweave complex effects that make it hard to distil important lessons or design rules. This can often be remedied with simplified modelling to understand the individual processes operating in the system.

You want to leverage simulations as a learning tool or in sales and marketing.
Simulations can communicate concepts to non-technical individuals in a powerful way. We can help package them up as intuitive real-time widgets for sales and marketing or executive teams.

If you'd like to hear more from our experts on how modelling and simulation can accelerate product development you can watch this webinar presented by Ross Jones and Barry Dobson: **https://www.sagentiainnovation.com/insights/how-modelling-and-simulation-can-accelerate-product-development-webinar/**

For further information visit us at:
sagentiainnovation.com or
email info@sagentiainnovation.com

Sagentia Ltd
Harston Mill
Harston
Cambridge
CB22 7GG
UK

Sagentia Ltd
First Floor
17 Waterloo Place
London
SW1Y 4AR
UK

Sagentia Inc
1150 18th Street
Suite 475
Washington
D.C. 20036
USA