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Strengthening Simulation's Business Impact: Optimizing Product Development Through Faster Analysis Workflows

September 25, 2009

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Executive Summary

The world's best manufacturers rely on digital simulation and analysis to deliver better products faster and at lower cost than rivals. Best practice focuses on bringing simulation to bear early in a project or program, when performance, cost and other key product attributes are being decided and the cost of change is low, then using it pervasively throughout a program to guide and refine designers' choices as they work toward those targets. But manufacturers still suffer program-gating constraints on analysts' ability to work at the same pace and cadence as the design groups driving product development schedules. As a result, analysis is too often relegated to the role of late-stage validation, giving only a go/no-go decision. What are these constraints, and what are analysts and their organizations doing to overcome them?

To find out, we interviewed experts at leading manufacturers around the world. Based on that research, this report documents contemporary best practices for accelerating analysis workflows in key manufacturing industries, business drivers for development of these practices, and technological capabilities required to enable them. Our key findings – practitioners are working toward implementing integrated solutions that accelerate analysis workflows by (1) supporting multi-source geometry interchange, (2) providing broad multiphysics and multidiscipline analysis capabilities in a common environment, (3) enabling comprehensive management of simulation data and processes, and (4) letting organizations build simulation knowledge bases, together with applications that encapsulate best practices.

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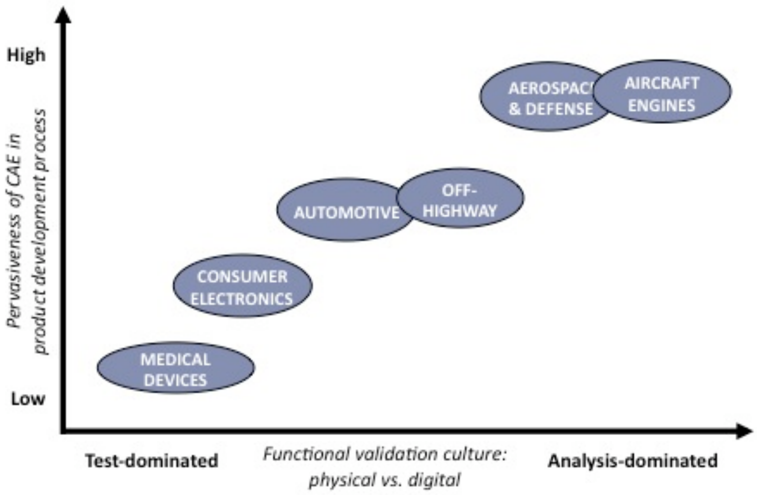
This report offers a summary of new directions and emerging best practices for accelerating analysis workflows. Analysts, discipline leads and program managers will find first-hand advice and lessons of experience for planning new and ongoing investments in simulation and related technologies, and for managing these tools to speed up analysis iterations and exploit their organizations' simulation competencies to the fullest.

Simulation Maturity Map: Current State of Analysis Practice in Key Industries



Simulation Maturity Map

In conducting research for our series of reports on *Strengthening Simulation's Business Impact,* of which this paper is one, we interviewed analysts, discipline leads and methods experts in six manufacturing industries around the world: aerospace and defense, aircraft engines, automotive, consumer electronics, medical devices, and off-highway (construction and agricultural) equipment. In part because different manufacturing industries first engaged with simulation technologies at differing times and for differing reasons, what practitioners are doing today to make their use of the technology more efficient, effective and productive varies from one industry to another. Too, each industry has its own requirements for competing and winning, and thus differing priorities in the business goals each seeks to advance through better use of simulation.

At the same time, we found some key business drivers for faster analysis workflows that are common across manufacturing industry. The "Simulation Maturity Map" above offers a snapshot of the current state of simulation practice in each industry – and a framework for the rest of this report, which seeks to understand what each industry's practice leaders are doing to advance their use of simulation to better address those business drivers.

At **aerospace/defense** firms and **aircraft engine** manufacturers – the industries mapped toward the upper right of this figure – product development is simulation-driven. For these companies, it's plainly not practical to build physical prototypes in order to find out if a design will fly. Thus, these industries have long used CAE early and continuously in product development. Their engineering cultures are heavily analysis-centric; digital simulation predominates over physical test during design excursions. For discipline leads and methods experts in these organizations, the focus now is on achieving tighter toolset integration, greater work-process automation, and institutionalization of solver overlay technologies such as for DOE (design of experiments), robust design and DFSS (design for Six Sigma). The goal is to bring higher-fidelity simulations earlier in the design process.

At industries in the middle of the map – **automotive** and **off-highway** – design validation was traditionally weighted toward prototype fabrication and testing. Today, however, leaders in both industries are working to move toward a culture of analysis-led design – environmental, fuel efficiency, and sustainability imperatives have added new urgency to this drive. At automotive as well as off-highway manufacturers, the challenges now center on making CAE usage more pervasive throughout product development, and advancing its use upstream to have greater impact on design exploration and refinement.

By contrast, in industries that fall toward the lower left of the map – **consumer electronics** and **medical devices** – CAE usage may be as often opportunistic as strategic or institutional. Engineering cultures tend to be more comfortable with physical models, breadboards and workbench mockups than with simulation. But within these industries we did find initiatives to do more with simulation; these may begin with a chief engineer introducing comparatively easy-to-use, CAD-integrated analysis solutions to the product development group.

Of course there are outliers. In the medical device industry, for instance, makers of diagnostic imaging equipment are some of the world's most sophisticated analysis users. But the many small and medium-size developers of insulin pumps, drug-delivery catheters, surgical equipment and the like tend, in our observation, to fit the characterizations above.

Similarly, among off-highway equipment manufacturers we found wide disparity between practice leaders and laggards. The least mature firms still rely heavily on handbook solutions and engineering sense checks for design exploration, and on physical prototypes for functional validation – predictably, the result is often over-engineered, materials-hungry products that barely keep pace with customer demand for greater fuel efficiency and performance, and with government-mandated emissions standards. But the most advanced are aggressively retooling their product development cultures to implement analysis-led design – leveraging simulation not just to make incremental improvements in existing products, but to deliver next-generation technologies that more than satisfy customer hot-button issues and regulatory requirements while leapfrogging their old-thinking competition.

Accelerating Analysis Workflows: Business Drivers

Common drivers across manufacturing industry Digital simulation and analysis is increasingly critical for manufacturing enterprises to meet program objectives for schedule, budget, and product performance and differentiation – the complexity, performance and efficiency demanded of today's products simply can't be achieved any other way. Today, best-practice leaders in many different manufacturing industries are working not just to use CAE on more projects, but to make its use pervasive throughout product development. This extends from early concept design, where good decision-making has the greatest leverage on lifecycle costs, all the way through manufacturing engineering where simulation helps shorten production ramp-up, control unit costs, and boost fit and finish.

Why the emphasis on up-front analysis? A manager at a major off-highway equipment manufacturer – it could be most any industry – describes the need this way: "Doing simulation and analysis up front before you finalize anything is definitely a big value proposition. I'm spending all my time working in the one-dollar-to-change region of the product development cycle, up front. You don't have a lot committed there except some engineers' time." This is the time when manufacturers have only incomplete product performance information, but must make decisions that drive big product lifecycle costs.

More broadly, practitioners we interviewed repeatedly described their search for solutions to the two most frequently cited constraints on getting more value from simulation and analysis: (1) not enough trained, knowledgeable professionals available in the global workforce, and (2) not enough time in the program schedule to do all the analysis they would like.

In this quest, accelerated analysis workflows and faster analysis iterations are key to simulation having greater impact on product development than ever before – and to analysts' initiatives to transform their professional role from one of late-stage validation to that of trusted advisor offering guidance and direction from the earliest stages of a project or program.

Aerospace and defense At the same time, each industry we studied has its own distinct business drivers as well. For example, developing a new aerospace product or defense system is a massively complex undertaking that can cost hundreds of millions if not billions of dollars, and can span a decade or more. By making it possible to meet program objectives on time and within budget, simulation and analysis confers competitive advantage out of all proportion to its direct cost.

As one discipline lead describes it, "The buzz phrase you hear being used is 'bring fidelity forward.' The idea is to bring in more and more detailed analysis of the structures, and to make that information available as early as possible in the design cycle." Another aerospace/defense executive elaborates on why: "The constraints [gating product development today] involve being able to develop product configurations and investigate them early in the cycle. The early, preliminary design and configuration of our products is a constraint in terms of schedule and cost. It's been that way for some time, this is nothing incredibly new, but that up-front rapid configuration assessment is quite complex – and of course, the more sophisticated our products become, the more in-depth, multiple technologies need to be accommodated."

Aircraft engines Similarly, in the aircraft engine industry, "What we're striving for is more robust designs," says a manager in charge of robust design at one of the world's leading engine makers. "And the only way to achieve that is by using simulation – you cannot examine all the possible variations using physical test alone."

Simulation and analysis technology holds the key to competitive advantage in other ways as well. With the commercial aviation industry under intense cost pressure even as fuel prices soar, every increment of improved engine efficiency translates into significant savings for airlines. As a result, these companies face unprecedented challenges to deliver products that are more efficient, better performing, and with a smaller carbon footprint – all while keeping development and production costs under control.

Automotive In today's automotive industry, the drive toward sustainable mobility – starting with greener, better-performing vehicles – requires rapid development of dramatically more fuel-efficient and lower-emission powertrains, alternate-fuel engines, as well as lighter-weight and more aerodynamically efficient vehicles – at costs that consumers will pay.

The role of simulation? Hybrid powertrain and electric powertrain control systems, as well as the many other mechatronic systems being introduced or extended in new auto models to improve vehicle performance and efficiency as well as driver experience – steer-by-wire, automatic stability control, intelligent braking, active all-wheel drive – require new levels of coordination between design of hardware, electrical and electronic subsystems, and software control systems. Critical to mastering these challenges is to move from slow, disjointed, sequentially bound, physical-prototype-based development processes to those grounded in digital simulation and functional modeling.

Consumer electronics In consumer electronics, the name of the game is cost, quality, and rapid innovation. At one company we studied, the prime focus used to be quality, but today is reducing product development costs; at this company, criteria for gauging CAE's success are, first, reduction in physical prototype counts and, second, standardization and capture of corporate knowledge. At another company we studied, emphasis has shifted the other way. The business driver for using CAE used to be reducing product cost to compete with low-cost manufacturing centers, especially China. But today the key driver is quality, to meet Quality Engineering (Six Sigma) goals.

With product styling and consumer appeal paramount, what simulation results are used for, and by whom, is also evolving inside consumer electronics firms. One company told how it has expanded its application of CAE beyond analyzing product performance to include visualization and virtual-reality presentations of material qualities and appearance to project participants outside the analysis group.

Medical devices Increasing the number of new product introductions is a central business driver for digital simulation and analysis usage in today's medical device industry. Improved clinical efficacy, increased product differentiation and shorter development schedules follow closely behind. Of course maintaining and enhancing quality – in many cases, effectively zero failure rates – is a baseline requirement for success. Beyond this, intensifying price competition, often driven by insurers and regulators pressing healthcare providers to rein in costs, is confronting growing numbers of manufacturers for whom price was formerly no object. And some, facing saturation in volume market segments, are seeking cost-effective ways to develop lower- volume product for more narrowly targeted disease classes and smaller patient populations.

Off-highway equipment Some of the world's best off-highway manufacturers are succeeding in driving their product development methodology toward an analysis-led, right-first-time, zero-prototypes process. Digital simulation is helping these companies move beyond traditional test-centric development – "design, build, test, break, fix, break, fix, sell" – to become leaner, faster, better able to innovate and to meet today's efficiency and environmental targets for their products. Also, developing a new off-highway product can take two years or more and cost tens of millions of dollars – simulation is key to shortening development schedules by as much as 50%. By substantially reducing errors and rework late in the design cycle, simulation allows for faster time to market and longer time *in* market – substantially increasing the profitability of new products.

Constraints on Accelerating Analysis Workflows

What constrains manufacturers and the analysts they employ from achieving faster analysis iterations? A central problem is the need for better data integration between CAD and CAE technologies, and also among CAE tools for different disciplines. As one automotive OEM told us, "A major constraint is how well the CAE tools integrate with one another and with the CAD tools…[even where vendors have integrated their software with one another] you may have trouble getting CAD geometry into the CAE mesh, then getting CAE results back to the CAD model…in the CAD-to-CAE links, there's a lot of manual intervention in the meshing process."

Consolidation or commonization of engineering software tools, and of solution providers, is a focus for many manufacturers. However, for digital simulation, large OEMs find they simply must have a multitude of software tools – auto makers have to use several dozen, while major aerospace companies use literally hundreds. Because of the requirement to transfer data from tool to tool, how well toolsets are – or can be – integrated is a key determinant of process efficiency. As one aircraft engine maker summed up for us, what's needed – but not always readily available – are "tools at each phase that we [can] connect."

Similarly, "we always need better tools that can work faster and better together," a corporate Six Sigma master at an aerospace/defense company told us. "That's what I do for a living – make tools work together at a system level, able to cycle through faster and more accurately, and bring higher fidelity further and further up to the front end of the design process."

Other aerospace/defense companies report much the same thing. "From a DFSS [Design for Six Sigma] perspective," said one, "the industry and we do a lot around performance modeling, cost modeling, defect modeling and other things – but are they all integrated together so you're trading off across these spaces?" Not only is it important that the tools be integrated; at the same time, the models being used should represent the same design state, otherwise tradeoff studies are meaningless and can lead to the wrong conclusions.

The need is not to be locked into a closed solution set, but instead to implement open simulation solutions that can readily be integrated with other commercial solvers and internally developed codes, as well as with collateral design, manufacturing and productivity applications. The benefits are clear – better tool integration yields more efficient and accurate work processes and data flows, while greater tool freedom-of-choice gives companies more control over technology cost and fitness for purpose, as well as training and maintenance costs.

Need for integrated design and simulation environment A perennial constraint has been the technological gaps that exist between product definition geometry on one hand, and simulation models on the other – and the resulting penalties in time and, sometimes, accuracy exacted by the need to prepare geometric and functional models for input to analysis.

For the automotive industry, a key need is to the ability to execute and iterate analyses quickly enough to give feedback to product development before the design team has already moved on. A CAE manager at a U.S. Tier 1 supplier sums up the problem this way: "When [our OEM] customers come to us, they have tight timing – they want prototypes quickly. But they are constantly changing their minds, the design is evolving daily; and at the same time, your CAD people are constantly trying to do the drawings and models, and keep them updated as the design constantly changes. And all those three things need to be dealt with in real time: CAD, design analysis, and customer requirements. In the heat of the moment, with the drastically reduced prototype delivery times we're being asked for now, [response to design changes] needs to be daily, even hourly. We're not a large organization, so we have analysts running around from desk to desk talking to the CAD guys. And talking to the customers. It would be easier if we had a design that didn't change. But even if we had that, the constraints remain CAD and analysis – the biggest bottleneck is the fact that those activities take time, because CAD and analysis are not tied together."

The same gaps exist in aerospace and defense organizations, where "CAD and CAE technologies…are two different cultures that don't communicate well with each other," comments Dr. Tom Hughes, Professor of Aerospace Engineering and Engineering Mechanics and Director of the Institute for Computational Engineering and Sciences at The University of Texas at Austin. "They basically communicate by 'encyclicals' that are thrown over the wall to each other. All the steps are optimal within each of the two domains, but it adds up to a very suboptimal overall process."

An executive at an aerospace/defense company details the problem: "Typically we receive the product definition geometry, then we massage that to create the geometry on which we build our analytical models. That is, we start with a model, then we use all kinds of high-powered math to optimize that model for analysis – which can be quite costly. Then once you have it optimized, you have to ask how the new geometry relates back to the product you have to build. Because you have optimized the model, but not the product. This is significant, because transferring the optimization of the geometry back into the product is not that simple. What would be great would be to optimize the product in its operational environment, rather than taking an abstract model and optimizing that. That would be a very great breakthrough that would alleviate a lot of the cost currently incurred in setting up our models."

Another aerospace/defense executive reiterates the point: "Among the constraints on ['bringing fidelity forward'] – doing more detailed analysis earlier, the biggest one is figuring out how to be able to construct the models quickly enough to be able to do the analysis quickly. So it isn't the threat of a 6-hour solver run that's holding you up; it's how you are going to produce the geometric and finite element models fast enough that the 6-hour run does become the gating factor. If it takes you 6 weeks to prepare the input, the 6-hour run time is irrelevant. But if you can get the models ready in 15 minutes, the run time becomes significant. We would like to get to the point where the run time of the solver code is what's holding us back."

Consumer electronics manufacturers face a somewhat less daunting problem – these companies we studied typically use on order of a half-dozen key simulation applications, compared with 30 or more in automotive powertrain alone, never mind the hundred-plus required for a major aerospace project. Nonetheless, the short product lives and highly compressed development cycles in consumer electronics means these companies too are seeking ways to accelerate data flows between their design and analysis tools.

Across manufacturing industry, companies invest millions of dollars in developing and documenting product designs, yet many simulation processes don't leverage these investments. In the absence of tools for intelligent model generation, valuable CAE experts spend inordinate amounts of their time re-creating geometry – time that would be better spent executing simulations and interpreting results.

Worse, simulation models based on discrete snapshots of the continuously evolving design model risk becoming outdated before analysis results are even delivered. The upshot? Design managers who can't hold up the program waiting for simulation results are forced to move ahead with scant information and risk expensive changes late in the program – or else make "safe" design decisions that too often stifle innovation and add cost. And analysts find themselves pushed into the background of a project or program, instead of helping to lead it.

Ability to derive simulation models automatically on an as-needed basis from the current design state will help simulation deliver more impact both early in product development, when its impact can be greatest, and throughout the cycle.

Need for multiphysics and multidiscipline analysis capabilities in a common environment Growing product complexity and performance demands, together with ever increasing schedule pressure, make both multiphysics and multidisciplinary simulation more important than ever before. But here, too, toolset gaps slow analysis iterations, often to the point of making such simulations not feasible within the program schedule.

This is a serious problem for the automotive industry, where a single program may employ dozens of different analysis applications. A CAE service provider to U.S. auto makers details this "lack of interdisciplinary integration… the vehicle dynamics [group], working on a suspension, take forever to make sure vehicle dynamics are okay. But they assume the chassis is rigid, not flexible – although in reality, it is flexible. Those two groups – vehicle dynamics and body-in-white – work independently. In turn, the body-in-white group doesn't see the real loads, the real driving cycle data, from the dynamics group, even though they need it to accurately estimate the fatigue life of the body-in-white. The challenge is to integrate multi-body dynamics and FEA: they should eventually be one. Practitioners should not have to choose between implicit FEA, explicit FEA, and multi-body dynamics codes; it should be all one code doing all three of those functions together. You talk to the dynamics group and say, 'You know, the frame there is actually flexible; you do all these fancy controls for vehicle dynamics, but you don't consider the fact that the chassis is flexible.' They answer, 'Well, the dynamics group isn't ready in time.' But vehicle dynamics, NVH and safety are the three areas that need to be brought together."

The problem is arguably even more pressing in aerospace and defense, where a project may easily use 100 or more analysis tools. Moreover, for these classes of product, simulation is especially critical "at the systems level, where interactions may not be obvious," as one major contractor told us. Another aerospace/defense contractor explains why: "Because computers have gotten faster, there are analyses we can do today that we couldn't five years ago. But doing a full-blown aeroelasticity problem, for example, still involves compromises. We still have not reached the point were we can take a CFD code and a structures code, and run them together efficiently. What will fix that? Increasing automation, especially in automatic mesh generation. The show-stopper has always been that when you try to couple together the very best codes you have, the primary model you're using has to be the computational grid for one or the other of those codes – and that prevents the other code from being an equal partner in the process. If the geometry representation can be made code-neutral, so that both codes are sharing equally in the modeling, that will improve the situation."

In some other industries, for example medical device manufacturers, the need exists but is a lower priority. This is due in part to the comparatively simpler products being designed – catheters, for example, or endoscopic surgical instruments – and the consequent ability to get by with little or no coupling between different analysis disciplines. As a manager at one such company said, "The flow of data from design into simulation is pretty good, mostly because we use [an integrated software suite] for both design and mechanical simulation. There could be better flow into some of the other tools such as thermal, but that's not a big loss."

Today, however, in a range of industries where rapid and accurate multiphysics and multidiscipline analyses are a top priority, many implementations still have only loose coupling of solutions, if any. Manual processes for retrieving results from one analysis discipline and re-entering them into another are all too common – this can exact a heavy toll on accuracy, efficiency and, ultimately, program schedules and product quality.

Need for better simulation data/process management Another chief constraint is the need for robust simulation-specific data management and process management tools. Indeed, many name simulation data and process management as the biggest technological challenge constraining the value available from analysis technologies today. Some of the most advanced thinking about this challenge and how best to address it is in the aerospace/defense and aircraft engine industries, with major automotive OEMs not far behind. Also, some – though by no means all – medical device, off-highway, and consumer electronics manufacturers are beginning to study the problem and map solutions.

What do practitioners see as the key challenges?

Find the right data faster; ensure it's the right version One problem is that simulation results required by concurrent and downstream project functions are too often unavailable, outdated, or captive to error-prone manual methods of dissemination and re-entry. Needed are capabilities to help users find the right data faster, and ensure that all disciplines are using the same version. Building on these base capabilities, many industries also need effective, secure data-sharing across groups globally, as well as tools for visualizing and interpreting simulation results.

These needs arise across all the industries we studied. "[There are] bottlenecks in data movement," an engineering manager at a German auto maker told us. "In some areas it's demanding…e.g., with body-in-white, spot welds are something you have to look at very carefully…is design aware of how the positions of the welds might influence the behavior of the overall structure, or will they adjust and finalize spot weld positions during the production process definition? You have to make sure that you get the correct data for simulation."

Improving the certification process As a manager at an aircraft engine maker told us, a major bottleneck on faster analysis iterations "is the data. The CAD data is all stored in one set of databases, whereas simulation data management is only just now picking up. Lack of a mature tool for simulation data management is still a big bottleneck on broader use of simulation. If you want to start moving CAE data around under version control, we need more of SDM." Another simulation manager in the aircraft engine industry said, "Current [CAE data management] processes can meet certification requirements, but improvements could benefit productivity and improve the development and certification process."

Version control; configuration control; secure, managed data-sharing "We need to be handling analysis data much better than we are" – that's how another manager at a jet engine maker put it. "Tools having an ability to hide or encrypt some portions of the simulation activity and not others is important" in order more easily to work with suppliers, subcontractors and joint-venture partners. A manager at another jet engine company reiterated this need, pointing to the importance of version and configuration control for simulation data, just as for design data: "Sometimes we'll contract out the engineering of pieces of the engine," he said. "In that work there are requirements to share the right version of analysis data."

Ability to re-run or re-validate analyses months or years later A manager at an aircraft engine maker details this need: "When someone runs an analysis, and a couple of years later wants to redo or update that analysis, we find it very hard to pull together all the data from that analysis. Or when something changes in the design, how do you make sure that analysis is re-run when the inputs are changed?" The twin needs are to make it easier to re-run analyses, and easier for occasional users to run analyses.

Why not use traditional CAD-centric PDM tools for this? A CAE service provider to the U.S. automotive industry explains the limitations: "[Traditional] PDM makes sense for CAD but not for simulation. You don't want to keep track of every simulation file you run; you need to keep the process, not the model – loads, boundary conditions, etc. … Who needs the solver file? Even better would be an automatic reporting capability for simulations in which you publish the inputs, outputs, assumptions, and lessons learned. That's all you need to keep from a simulation. You don't need these old files."

Long-term archiving of simulation results On the other hand, aerospace and defense manufacturers often have a requirement to archive results as well as to re-validate past simulations across the service lifetimes of their products, which can span many decades. Medical device manufacturers that use simulation results in the certification process have similar needs, as well as the ability to respond quickly in order to diagnose and remedy product problems in the field.

Global data sharing An engineering manager at a maker of medical diagnostic equipment observes: "[What constrains] the product development cycle? We do an extremely good job of expediting schedules and getting things done quickly. But what gets lost in the process is global data sharing." Most believe that working with commercial solution developers is the optimal way to attack the problem – this medical equipment maker is working on "global data sharing, including across different sites" with a commercial PDM provider. "Making that process more efficient and robust and less error-prone [by eliminating] manual intervention is a big opportunity for us." Inadequate capability for "data sharing and global collaboration is the biggest hit to productivity" in simulation activities because users too often "get data that's out of date, out of synch…That's why we are moving to a true global data vaulting tool" – something that should also aid "knowledge retention."

Need for simulation knowledge capture and reuse Better ability to capture and then reuse simulation knowledge is emerging as a key to helping manufacturers overcome the twin constraints examined earlier in this report – not enough trained, knowledgeable analysis professionals, and not enough time in the schedule to do all the analysis you want.

As a Japanese consumer electronics company reported to us, "One of the goals of the simulation group is to standardize the storage of know-how." In addition to making analysts and designers more productive, this activity is also designed to help secure corporate knowledge assets against generational turnover in the workforce. "One objective," the company explained, "is to transfer knowledge to younger engineers. The Japanese engineering workforce is graying. However, design engineers are very busy and the product lifecycles are very short – both of which make it difficult to transfer simulation know-how."

For aerospace and defense, a program manager at a major contractor puts it this way: "The only constraints [on CAE usage] are getting simulations set up and knowing how to do them" – she termed this "a matter of corporate knowledge."

Also needed are ways to capture and share best-practice work processes beyond the project where they originated. An aerospace/defense industry executive illustrates this point: "One of the underlying things needed is the ability to capture the implicit knowledge we have all around us, and turn that implicit knowledge into something more tangible, so it can be used to intelligently execute our product development activities. Today we really have hardly touched that. Sure, we have done some work with knowledge-based engineering. KBE technology lets you take some of the logic that a designer uses, and build that into software so that, when you have a similar case, you can replay that logic – a similar layout of stringers and spars, for example. This has given us some good breakthroughs. But they've been quite localized – we need to do it more universally."

Overcoming Constraints: New Directions, Emerging Best Practices

The good news – our research found that significant progress is now being made on all these fronts.

Toolset gaps arise from many causes – having to work in a multi-CAD world, OEMs and suppliers using different systems, one OEM acquiring another that had standardized on a different system from its new owner. Many manufacturers we interviewed believe the key to overcoming toolset gaps is to find a solution provider best able to help companies increase their permeability to new technologies and code streams – without requiring prohibitive new investments in integration, support or personnel. "If you get into the mode of picking point solutions, you're going to be changing your solutions every few years," one maker of off-highway equipment told us. "You don't want to do that. It's way too costly. Your models don't work anymore. We have to pick the best partner for the future, and stick with them. We'll make so much money from this strategy that it won't be worth our time to chase the best point solution at any given time."

The cost of integrating legacy applications with commercial simulation environments has traditionally been prohibitive. However, new applications that leverage SOA (service-oriented architectures), and those based on XML, can offer significantly lower integration costs, and provide an economical way to maintain investments in unique intellectual property.

Decision-makers need to understand the range of applications in daily use and the teams using them. What does it cost to maintain their user interface? Where do they get data from? More specifically, decision makers need to understand how well systems under consideration can access various data formats – STEP, IGES, STL, Parasolid, ACIS, Pro/ENGINEER, CATIA V4 and V5, SolidWorks, DXF, DGN, ANSYS, ABAQUS, Nastran, RecurDyn, MSC.Adams, more. They should also evaluate how well these systems are positioned to leverage SOA capabilities for integration and information exchange with other applications and data repositories.

Then they should ask: Is it possible to automate data flows and thus reduce the risk of errors while speeding up throughput? Should the point tools be integrated into a broader process? If so, what solution and service providers are best equipped to help with this?

Implementing an integrated design and simulation environment We found substantial progress in efforts to narrow the gaps between design and simulation models. Best practice here is about finding – or developing – tools and processes to better manage and automate the flow of data between CAE and CAD.

"Traditional software has exacerbated the [gaps between designers, analysts and their respective work processes], because the two started speaking different languages," explains Dr. Tom Hughes of the University of Texas at Austin. "To solve software problems, you need software solutions. The answer is to build CAD software such that a designer can do what a designer wants to do, and does the things he needs to do his job – but also to build the software so that what comes out is suitable for other processes beyond those of the designer.

The software has to be written with the right intent. That should not put a burden on the designer; the software should automatically put his work into a file format that is usable by other [disciplines and their software tools]… A software environment that facilitates the overall process [will make] both parties – designer and analyst – happier. It's a win/win, but it has to be embedded in the software."

A major gap results from inflexible, non-intelligent, point-to-point CAD model import. Most simulation tools can work with specific CAD input formats. However, the ability to access, create, revise and repair geometry is a core differentiator among simulation vendors – this is a key driver of user productivity in a multi-CAD world. It helps companies apply lean methodologies to analysis workflows and thus dramatically reduce overall development cycle time.

A clear demonstration comes from a benchmark at an American aircraft engine manufacturer. In a final presentation to management, the company reported, "We saved two weeks of translation effort, and a further four weeks from geometry healing and associative FEM on a single model." With 26 models involved in the project, this adds up to six-figure dollar savings per iteration.

Decision makers need to consider these potential barriers to moving simulation up-front – how well can their system create and change geometry? Then, throughout all of product development, what about advanced analysis requirements such as rapid geometry cleanup and repair, feature suppression and modification, and topology evaluation/abstraction, automation and control? Finally, what about change management and customization to re-use knowledge and best practices in more automated validation applications?

Implementing multiphysics and multidiscipline analysis capabilities in a common environment Similarly, we found substantial focus on integrating the tools used in the various analysis disciplines. "Multiphysics – multidisciplinary integration – is the next natural step from solvers," an automotive CAE service provider notes. "We should stop using specialized codes for specialized solutions just because that's how they grew. Some software companies started in structural, others in multibody dynamics, other still in crash and safety. Well, isn't it time to have one code for all this? The user should have one system, and be able to say: 'Here's my system; here are my performance requirements; give me a solution.'"

A CAE manager at a U.S. Tier 1 automotive supplier seconds this view: "It's definitely a trend that in multiphysics tools, it's getting easier to pass data around without two years of internal coding first. The commercial tools are more available and higher-fidelity, to allow people to start evolving away from individual analyses, toward multiphysics analyses."

"Multiphysics" has come to refer to any simulation that involves highly coupled systems, for example tightly integrating fluid mechanics with finite elements for coupled thermal-flow analysis of an electronics enclosure. It goes without saying that the more coupled the physical phenomena, the greater the need to use a coupled solution.

"Multidisciplinary" simulation commonly refers to the less coupled, but no less important, case where several disciplines are combined. For example, a simulation of an aircraft flap system to ensure a smooth flight transition may involve kinematics and rigid-body dynamics to look at loads in the system, a CFD analysis to calculate pressures, a structural analysis to estimate stresses, and a durability analysis to estimate the life of key components.

Besides ensuring that solution providers can deliver the capabilities described above, decision makers need to ensure that vendors are pursuing a two-pronged development strategy:

- Continuing to add capabilities aimed at the most advanced simulation practitioners.
- Making core solver technology available integrated with a suite of modeling, meshing, and results display and analysis tools in order to make simulation capabilities and results available as broadly as possible.

Decision makers should identify their internal needs for multiphysics simulation – which applications need this ability the most? They should also identify opportunities for multidisciplinary simulation, and exploit these opportunities by working with vendors that can support the use of common models and data to avoid needless translation and rework.

Implementing simulation data/process management In addition to tying existing design tools, preprocessors and solvers more closely together, best-practice initiatives to accelerate analysis workflows also focus on implementing data/process management technologies and methods.

How are industry leaders structuring and attacking the problem? A senior technologist at a leading aircraft engine maker details his team's approach: "[Our work to automate our simulation data and process management focuses on] three areas. The near-term focus is data management. If we manage our data well, it opens up so many opportunities for increased productivity. The key benefits are version verification – in handoffs, it's critical that you use the correct data – and data reuse: if you don't know what something is or you can't find it, you can't reuse it."

"Our mid-term focus," he continues, "is automated studies. Once you automate management of the handoffs between simulations and models, then you can more easily run sequences of models – an engineer can select a black-box model, and say: do that again."

"Finally," his group's "long-term focus is helping engineers with innovation – which requires that we first accomplish our data management and automated-studies goals. Look at how an engineer does his work with the models that make up a simulation – he has to run the models repeatedly until he gets the right answers. [With better data management and automated studies], engineers can much more readily carry out directed studies – exploring the design space much like a search-and-rescue operation. And they can do optimized studies – using algorithms in effect that tell you to look here and not there. Then the final opportunity, which from an engineering design standpoint is a kind of holy grail, is probabilistic studies – recognizing that reality is not deterministic, that all of the X values going in have some kind of variation with a distribution, and thus that all the results will have some kind of mathematical distribution. The result is that you can determine what confidence you're able to have in your deign results, and you can explore the whole space.

"Each one of those goals," he concludes, "depends on being able to manage the data, and to do it efficiently, in order to automate the design studies."

Another aerospace/defense company told us how its "PDM system is much more than CAD data management. It's a portal into our entire product development virtual environment. It enables collaboration across our design facilities around the world…it includes a lot of the data that is an input to simulation as well as the simulation results."

A related development is growing use of tools that automate the execution of analysis codes in order to more efficiently explore design spaces. These tools and the methods they support – multidisciplinary optimization (MDO), design of experiments (DOE), robust design, Design for Six Sigma (DFSS) – are becoming feasible through improved approaches to better managing problem setup and problem execution, as well as data interchange between different simulation and analysis tools, and between analysis codes and CAD systems.

Overall, we found that practitioner priorities are focused on capabilities to:

- Capture, archive and retrieve simulation models, input conditions and results, together with related assumptions and conclusions
- Have confidence that analysis was based on current, correct CAD configuration
- Easily retrieve data from one CAE discipline for use as input to another discipline
- Easily retrieve past analysis models, processes and results for re-execution or updating months or years later
- Automate data exchange between analysis disciplines, and between geometry modelers and mesh generators
- Ensure that design changes trigger re-analysis; ensure analysts receive correct inputs from modified design; ensure re-analysis results feed back to design

Balanced against these user-level requirements, what enterprise requirements should decision makers seek? Most manufacturers told us they would ask whether the solution under consideration makes it possible to embed simulation data and process management in the context of the following functions:

- Configuration management, product structure management?
    - To coordinate CAD geometry and CAE models and processes. This is needed for two kinds of new-product development work processes:
        - CAD-led
        - Analysis-led
    - To coordinate simulation models and results with corresponding matrices of product variants, such as in automotive and commercial vehicle development
- Change management, workflow management?
    - To ensure geometry changes trigger timely re-analysis
    - To ensure analysis results are fed back to product development, and acted on
- Requirements management?
    - To ensure system-level performance targets adhere to program requirements
    - To ensure adherence is maintained as system-level targets are "cascaded" down to component-level performance targets
- Project/program management?
    - To enable controlled data sharing as determined by partner trust levels
    - To achieve ITAR compliance
    - To ensure schedule adherence
- Document management?
    - To associate simulation data with, or incorporate it into, documents such as those mandated by regulatory agencies
- Management reporting?
- Process orchestration?

Implementing simulation knowledge capture and reuse We found many cases where manufacturers are working to implement technologies that automate the capture, classification, storage, retrieval and re-use of knowledge. The goal is a greatly enhanced capability to capture, archive and retrieve simulation models, input conditions and results, together with related assumptions and conclusions. Beyond simply securing information, it involves the collateral activities of classifying data and putting it in meaningful context, so that subsequent consumers will find the information both meaningful and trustworthy – transforming an organization's "implicit knowledge" into "explicit knowledge."

For example, a simulation manager at one aircraft engine maker told us, "Large data storage and data mining capability, taken in combination with simulation, has great potential. There is a lot of data that is not easy to use directly in our simulations. Being able to filter and understand this data and put it in a form that can help validate and improve analysis will have significant benefits in the future."

Most often, best practice is to seek technologies that enable a company's knowledge, methods and work processes to be captured in reusable process wizards and other tools that encapsulate knowledge and automate its application.

Technologies that support these initiatives to capture knowledge in standardized, easily accessible ways will make it easier for anyone in the organization to understand, trust and reuse others' data and processes. A related benefit of these activities is securing corporate knowledge assets against generational turnover in the workforce, as illustrated by the Japanese consumer electronics company that told us, "One objective [of our project to capture know-how] is to transfer knowledge to younger engineers." However, this company's follow-on remark – "design engineers are very busy and the product lifecycles are very short – both of which make it difficult to transfer simulation know-how" – highlights the requirement that, to be practical, knowledge-capture technology must not impose too great a burden on those tasked with building the knowledge bases. Success lies not just in the ability to build tools, but the ways users can capture knowledge – for example, selecting technology that lets users build one single application to capture knowledge and automate an activity that currently takes four separate applications to execute. Best practice involves capturing what users do, then building that into a repeatable automation tool.

The resulting capabilities will empower experts to capture, manage and reuse best practices throughout a given product development cycle as well as across different projects and programs. Making these best practices and key project learnings readily available for re-use through data mining will powerfully support organizations' continuous-improvement initiatives. Product quality is improved because performance data can then be delivered in time to positively impact design decisions.

Managers evaluating technologies should look at how solutions gather process and application know-how. How easy is it to capture and manage knowledge? Is corporate value driven through team efficiency, or instead via entire engineering, design, simulation and manufacturing processes that can be streamlined and automated with best practices? Has the solution provider established a track record of longevity in the marketplace, and reliable delivery on its promises?

Mapping the Way Forward

Driving change To drive change in an organization, a powerful call to action can be to benchmark the organization's maturity level against industry best practices. Using this report as a starting point, compare practices in your organization with those of your most successful rivals. Identify areas where accelerated analysis workflows and more impactful application of CAE throughout product development would put you in the lead.

One way to begin is to assemble a multidisciplinary team – include representatives from the analysis groups, design, test, and program management – to audit current practices, identify gaps and bottlenecks, and develop recommendations for improvement. First review the constraints identified by practitioners in this report:

CAD-CAE gaps
Cross-discipline analysis gaps
Need for better simulation data/process management
Need for simulation knowledge capture

Determine which of these is most severely gating progress in your organization today, then investigate sources of solutions.

Evaluating solutions and providers In evaluating solutions and providers, it's important that simulation/analysis purchase decisions be grounded in not only technical but also business criteria. Criteria for qualifying and selecting a solution provider, conditioned on what constraints you need to address first, include:

- *Functionality of solvers*
- *Functionality of meshers, gridders, other tools for problem setup and results execution*
- *Competence as integrator of diverse functionality – multi-CAD, multi-CAE, other product lifecycle functionality from requirements capture through manufacturing into service, support and sustainment*
- *Commitment to providing help with process change, people/cultural issues*
- *Commitment to providing:*
    - *Simulation data management framework*
    - *Process automation tools*
    - *Knowledge capture tools*
- *Reliability as long-term partner*

To begin with, look at the overall architecture of the solution environment being considered – first, is it proven to work? Then, is it built on infrastructure technologies that are familiar to the customer's internal support organization? Better, is it built on an infrastructure that's already installed and supported? Best of all, is it part of an existing installed infrastructure that is already generating or managing volumes of structured product data that simulation users will be able to leverage? All this will help gauge how well the long-term support costs are understood, and whether the technologies can be implemented as an extension of existing installed capability rather than a new, additional infrastructure.

Finally, consider the business issues: Does the vendor have a major market presence and market share in its field? Has it demonstrated a long-term commitment to, and expertise in, digital simulation? Will the vendor be compatible as a long-term partner?

In your organization's next procurement cycle, revisit your qualification and selection policies to ensure they address your requirements not just for superior point functionality but also for integrated multi-source geometry interchange, broad multiphysics and multidiscipline analysis capabilities, comprehensive management of simulation data and processes, and simulation knowledge capture. Factor in solution-provider stability, longevity and change management experience.

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