Ora Research LLC
P.O. Box 391227
Cambridge, MA 02139-0013
USA
tel. +1 617 875 9598
www.oraresearch.com

Strengthening Simulation's Business Impact: New Strategies in Aerospace & Defense

March 26, 2009

By Bruce Jenkins, Principal Analyst, Ora Research LLC

Executive Summary

Aerospace and defense companies, together with aircraft engine manufacturers, are among the world's most mature and sophisticated users of digital simulation and analysis – bringing the technology to bear earlier and more pervasively in product development than most any other industry. Nevertheless, these companies still experience program-gating constraints on getting the value they need from these technologies and the work processes that employ them. What are they doing about it? To find out, we interviewed discipline leads and methods experts at major aerospace and defense manufacturers around the world. We investigated business drivers for investing in simulation, current state of industry practice, chief constraints on maximizing simulation's value, and new strategies for overcoming these constraints.

This report summarizes our findings:

Ora Research LLC
P.O. Box 391227
Cambridge, MA 02139-0013
USA
tel. +1 617 875 9598
www.oraresearch.com

This report offers a practical, action-oriented analysis of new directions and emerging best practices for getting more value than ever before from digital simulation and analysis. We thank the interviewees – most of whom, partly in the interest of greater frankness, chose not to be identified – for sharing their insights and initiatives. Thanks to them, program managers, methods experts, discipline leads, and practitioners will find this report a source of first-hand advice and lessons of experience for planning new and ongoing investments in simulation technology, and for managing these tools to exploit their organizations' simulation competencies to the fullest.

Digital Simulation and Analysis Investments: Business Drivers

Aerospace and defense manufacturers are among the industrial world's most advanced and sophisticated users of digital simulation and analysis. Why? What drives investment in these tools and in the methods and work processes around them?

One reason is that products of today's complexity, performance and efficiency simply can't be developed any other way:

> *"…we have to [use simulation] to meet our goals. We simply couldn't design our products without doing modeling and simulation…" – Aerospace/defense company A*

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.

Commercial aviation business crisis In commercial aviation, major airlines are struggling with high fuel and other operating costs, competition from low-cost carriers, and travel volumes affected by the economic downturn. With all this, airlines are seeking more flexible, cost-efficient aircraft that are cheaper to operate and maintain:

> *"…How can I assure myself the aircraft can meet range requirements without refueling? You have to use simulation to do that. In our industry we can't throw something together with limited simulation and then fly it to find out…" – Aerospace/defense company B*

Another critical driver of simulation and analysis usage is the nature of aircraft industry sales cycles – order-taking begins long before the first prototype flies:

> *"Our marketing department frequently goes into customer meetings with answers based on modeling and simulation. When they have discussions about new aircraft we haven't*

Ora Research LLC
P.O. Box 391227
Cambridge, MA 02139-0013
USA
tel. +1 617 875 9598
www.oraresearch.com

built yet, the information in their sales pitches has to be derived from simulation." – Aerospace/defense company A

Major aircraft manufacturers also face growing competition from regional jet makers now developing larger and more capable planes. As a result, these companies face unprecedented challenges to deliver products that are more efficient, better performing, higher quality, better differentiated and more appealing to the flying public – all while keeping development and production costs under control:

"One thing that had been holding us back [from making more advanced use of simulation] is that we are a very big company that has been very successful for a long time, and that creates inertia that can make it difficult to do things in new and better ways. But now, one thing proving remarkably effective [in driving adoption of new simulation tools and methods] is losing market share. That's doing as much as anything else to help us crack through some of this resistance – there's increasing awareness that we can't keep doing things the 1955 way and expect to be successful." – Aerospace/defense company A

Defense systems: unprecedented complexity, capability, reliability demands In defense markets, the U.S. Department of Defense – which accounts for almost half the world's aggregate defense budget – is focusing on long-range strike capability, unmanned air combat and reconnaissance vehicles, precision guided weapons, joint operations, interoperability among weapons systems, and better integrated capabilities for the various branches of the armed forces. All this means defense contractors are having to cope with unprecedented complexity, capability and reliability requirements:

"…[one of our aircraft models has] been in production for nearly 25 years. In its infancy in the 1970s, it was a much less complicated product. The amount of simulation required was minimal compared with today, where many complex subsystems are interoperating and multiple sensors are collecting loads of information. You have to rely on simulation tools to validate performance. We're constantly pushing the edge of the envelope in simulating physics…" – Aerospace/defense company B

In addition to this increased product complexity, what it takes to win business has also gotten more demanding:

"We begin by asking: what is mission success for our customer? We're heavily involved in how we're going to assure mission success for our military customers – how can we get even better at that? A big thrust for us is getting closer to our customer, getting into the 'soft spaces' [of up-front requirements definition]. They write a requirement, but what problems are they really trying to solve? Maybe we can help them with tradeoffs. Getting closer to the customer is key – getting into their up-front design space to understand their real needs.

"As you move up that food chain – as you start to ask where the leverage is – simulation and modeling become increasingly significant… We've created a [group dedicated to] the pre-contract award period, even before a proposal is put out. [That group is focusing] on using modeling and simulation as a huge lever to leapfrog us forward, by helping us get into that up-front pre-award space with the customer." – Aerospace/defense company D

Space systems: cost and schedule overruns, mission failures An urgent, newly identified need is to alleviate perennial – and worsening – cost and schedule overruns in space-systems programs:

Ora Research LLC
P.O. Box 391227
Cambridge, MA 02139-0013
USA
tel. +1 617 875 9598
www.oraresearch.com

> *"The chief problem that has affected both the defense space community and the civil space program is that a quarter of all space flight electro-optical sensor programs are overrunning their schedule and budget allocations by 100% or more. At the same time, there have been increases in mission-critical failures with these payloads. Of course the systems themselves are becoming much more complex, but nevertheless these resource overruns are coming to be seen as unacceptable. Programs typically have a 20% overrun contingency; that is what is seen as acceptable. So [100% overruns mean] the industry has a factor-of-five problem today.*
>
> *"Several recent studies, such as the NASA Instrument Capability Study,[1] have explored a number of underlying causes for these large overruns. One of the clearest conclusions, cited by a task force headed by Thomas Young,[2] is the need to focus on reliability from beginning to end during flight program execution – that is, to perform simulation and test at each stage of development in order to catch problems at their earliest possible stage when they are far cheaper and quicker to fix." – Aerospace/defense company E*

Global project execution In all sectors of aerospace/defense, project execution has gone global:

> *"In the past, [products were developed mostly] inside a single company, versus the global participation common today – that in itself is a challenge." – Aerospace/defense company F*

This has spurred the search for ways to virtualize the various product development and validation workflows that, for most of the industry's history, were carried out by physically co-located teams:

> *"...our 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..." – Aerospace/defense company B*

Flight certification A perennial driver of technology investments in aerospace and defense is the requirement to certify products for flightworthiness. While physical test remains the predominant method, analysis results are increasingly provided and accepted as part of the certification process, perhaps most notably in aircraft propulsion systems.

In-service support Finally, both commercial and defense aircraft manufacturers are among the many industrial firms looking to in-service support and sustainment of their products as increasingly vital revenue and profit centers. On average, after-sales services and parts typically yield 25% of revenues and nearly 50% of profits for industrial companies, according to a study by Accenture Ltd. recently cited in *The Wall Street Journal*.[3] In addition to aiding urgent diagnosis of unanticipated performance problems as well as routine MRO (maintenance, repair and overhaul), ownership of simulation and analysis results can also help manufacturers fend off competition from third-party after-market service providers.

---

[1] Leon, John, Chair and Rivera, Jaun, Co-Chair, "NASA Instrument Capability Study Final Report", NASA Office of the Chief Engineer, NASA Headquarters, Washington, DC, December 2008.

[2] Young, Thomas A., Chairman, "Report of the Defense Science Board/Air Force Scientific Advisory Board Joint Task Force on Acquisition of National Security Space Programs," Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics, May 2003.

[3] "GE's Focus on Services Faces Test," *The Wall Street Journal*, March 3, 2009.

Ora Research LLC
P.O. Box 391227
Cambridge, MA 02139-0013
USA
tel. +1 617 875 9598
www.oraresearch.com

Simulation: Current State of Industry Practice in Aerospace and Defense

Against this background, we interviewed experts at industry leaders around the world to find out what best practices they have developed for using simulation and analysis to achieve the business objectives that they and all manufacturers face – to boost product quality, performance, efficiency and innovation, shorten program schedules, improve engineering productivity, and reduce development costs.

Pervasive and early… What we found is that use of simulation and analysis is pervasive throughout the product development process. In contrast to many industries, best-practice aerospace and defense manufacturers bring digital technologies to bear in the early stages of customer engagement to capture product requirements – more, to aid the customer with the process of requirements definition. Even before contract award, these companies begin using simulation and analysis for system- and product-level performance characterization, then continue using it post-award for product development and refinement into detail design.

> *"…to create sustainable growth, we're addressing five drivers around product development: customer integration, architecture, developing the capabilities of our people, knowledge sharing, and reuse. Customer integration involves issues such as: how do we get systems engineering into closer relation with business development and the business as a whole?… As you move up the value chain and start to ask where the leverage is, simulation and modeling become increasingly significant. There's a much increased focus today on modeling and simulation throughout our company…" – Aerospace/defense company D*

Maximizing the technology's business impact involves far more than simply buying today's best point functionality and handing it off to the analyst or discipline lead. Instead, contemporary best practices focus on making more efficient use of existing resources – both software and engineering staff. No one we interviewed named software budgets as a constraint on product development's ability to contribute to corporate business objectives – all identified time and human resources as limiting factors. New demands on product performance, mission complexity, product efficiency, total cost of ownership (TCO), new product cycle time and product development costs are driving companies to wring more value and output from their engineering resources.

…but working to achieve still more: "Bring fidelity forward" Notwithstanding the aerospace/defense industry's leadership position in early and pervasive use of simulation, current initiatives to increase its business impact focus most often on enabling even faster and more revealing investigation of early product configurations and design alternatives:

> *"…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." – Aerospace/defense company A*

> *"…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." – Aerospace/defense company F*

Ora Research LLC
P.O. Box 391227
Cambridge, MA 02139-0013
USA
tel. +1 617 875 9598
www.oraresearch.com

Constraints on Maximizing Simulation's Value

What constrains aerospace and defense companies from achieving the goals laid out above? We found that constraints fall into two primary categories: (1) technology constraints and (2) organizational and work-process constraints.

Technology constraints

CAD-CAE gaps 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:

> *"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." – Aerospace/defense company F*

> *"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." – Aerospace/defense company A*

Cross-discipline analysis gaps Similar barriers impede sharing of results between analysis tools in different disciplines:

> *"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." – Aerospace/defense company A*

Advanced-materials characterization needs At the same time, today's growing use of composites and other advanced materials is making the need to characterize materials properties a constraint on the value simulation can deliver:

> *"The biggest thing holding us back is the time it takes to integrate new and advanced materials – to qualify and analyze new materials, basically structures technology. If there's a weak link in the chain, that's it. It has as much to do with the difficulty of*

Ora Research LLC
P.O. Box 391227
Cambridge, MA 02139-0013
USA
tel. +1 617 875 9598
www.oraresearch.com

performing advanced analysis of composite materials as anything else." – Aerospace/defense company A

Need for better simulation data/process management Another chief constraint is the need, seen by many as yet unmet, for robust, capable simulation-specific data management and process management tools:

"We've done a very good job of automating geometry data management, as well as change and configuration management. My focus now is simulation data management. The challenge is to ensure that design studies, and the models and simulations used in them, are kept coordinated. We've developed processes and methods to do that, but it's less efficient than we would like because today it's all done essentially manually. The consequences are lost productivity, missed opportunities for innovation, reduced quality, greater difficulty obtaining certification, and inefficient knowledge management." – Mark E. Miller, Senior Technologist, GE Aviation

"PDM for CAE really isn't solved yet. There's lots of work to do. The commercial codes are simultaneously helpful and show-stoppers in making real progress – both solvers and data management tools. Commercial data management codes have tremendous capability, but also impose on you a situation where the engineering data and product data are held captive by a proprietary system. And when you're putting together a system that integrates many different codes, having your data held hostage by any vendor's PDM system is a problem. SOA approaches and ProSTEP help a lot, but I think the real solution has probably not been conceived of yet. The solution is going to come in finding the right mix of dealing with commercial software. There has tended to be this all-or-nothing approach – we either roll our own, or buy a whole system from some vendor. I think the final answer will be a mix of internal software and external solvers, capabilities and packages." – Aerospace/defense company A

Need for more highly automated model preparation/problem setup However, some feel that until the lack of fast, efficient model creation and problem setup capabilities is solved, this constraint will limit the benefits that could be had from better data/process management:

"It's not my perception that we're being held back by a lack of formalized and capable PDM tools; it isn't our lack of ability to keep track of the data that is holding us back today. It gets back to the 6-hour solver run time. If it were the case that the 6-hour solver run were the thing holding us back, then keeping track of the results of that run would be a big deal. But if it takes 6 weeks to set up the problem, that makes the analysis results disposable, because you're only 6 hours away from reproducing the results, in a 6-week process. But if we were dealing with a 6-hour cycle time, and it took a full 6 hours to retrieve your results, then storing that data better would be important. But that is just not what is holding up the process at this point." – Aerospace/defense company A

Organizational and work-process constraints

Human resource constraints Perhaps most striking was that no one we interviewed named simulation software budgets as a constraint on product development's ability to contribute to corporate business objectives. Instead, all identified a chief limiting factor as availability of trained human resources – coupled with not enough time in program schedules to do all the simulation they would like.

Methods development, work-process integration requirements One constraint is the requirement to integrate the tools, intelligently and with forethought, into an organization's work processes:

Ora Research LLC
P.O. Box 391227
Cambridge, MA 02139-0013
USA
tel. +1 617 875 9598
www.oraresearch.com

"It's not the cost of developing or acquiring the tools that is the major expense. The major expense is figuring out your process for using the tools, and integrating them into your process. That includes training as a significant cost; process modeling, process construction; calibrating the results of the process so you know how to interpret the results relative to what your old codes did, understanding how those calibration operations need to take place, qualifying the tools, characterizing the error in the tools, understanding the envelope of inputs under which the codes are reliable and meaningful. Getting a handle on all of that is the vast majority of the expense and time involved in using these codes." – Aerospace/defense company A

Organizational stovepipes A related constraint is how well – or poorly – organizational structures accommodate optimal usage of the tools:

"The stovepiped nature of the organization and how the work is executed is the main impediment to making more effective use of simulation earlier in the design process. We already have individual tools that are, for the most part, very capable in producing the design and analytical results we need. But these analyses are being done to fit fixed sets of requirements, and are being done in isolation – because of the way the job is defined, and the way it is organized and managed. And if you want to look at conflicts between those areas, that is still done mostly on an ad hoc basis: you form a cross-discipline group to look at the problem, but the people still do that work in the old ways. That is not robust, and it does not incent frequent use. There still have not been good approaches taken to integrating this work." – Aerospace/defense company E

Overcoming Constraints: New Directions, Emerging Best Practices

Fortunately, our research identified significant progress now being made on all these fronts.

"The movement of simulation and analysis to the front end of product development is definitely happening. To my eyes it's been quite slow; I had hoped it would move faster. But there's a definite movement in that direction, even though much more still needs to be done." – Aerospace/defense company F

Overcoming technology constraints

Toolset integration: cross-discipline and CAD-CAE We found substantial progress in narrowing the gaps between design and simulation models, and between analysis disciplines:

"Within the last 5 to 10 years, the data standards for file exchange across different engineering disciplines have become more advanced and robust, and it's now possible to share not just some thin abstraction of the geometry, but the whole CAD geometry across structures, thermal and optical. So you can work to a single CAD definition, or separate ones if you want to do trade studies; so that enables this to happen. Then, too, if you can share all the engineering data across the disciplines, you can bring up not just a snapshot of the performance, but also bring up the CAD data in real time and have a team of engineers responsible for the success of the product, all viewing the project interactively, solving problems in real time.

"The technical enablers of this are better data exchange than before, and also more capable and faster solvers, which make this more feasible now than even five years ago. These integrated environments are just now becoming feasible for doing detail design of products in real time. Of course you also still have the old-line offline analysis as before; but you ought to be able to do that on the same CAD model that you're working on collaboratively. That way, you don't get disconnects, you have version control, and you

Ora Research LLC
P.O. Box 391227
Cambridge, MA 02139-0013
USA
tel. +1 617 875 9598
www.oraresearch.com

avoid what often happens today, namely that different groups think they are working on the same model when they are not." – Aerospace/defense company E

"[In traditional practice], as a design proceeds, there are monthly management reviews on any project lasting a couple of years or more. Every month the different work-breakdown-structure cognizants and principals will give a short presentation on current status and issues in PowerPoint format to a program management group – both program manager and representatives from the customer. Issues will be brought up and cost estimates presented, and program managers will decide what we will and won't do going forward.

"The problems are that you are revisiting these issues only on a monthly time center, you're basing decisions on just a thin representation of all that's going on technically, and the key people involved are non-technical, really just trying to make a business decision of risk versus expense. If you wait until the monthly meeting, it's often too late – if you want to keep your budget and schedule under control, you have to make decisions much more frequently than that.

"Our solution – going to a single environment [unifying CAD and CAE, and unifying different analysis disciplines] – lets you make these briefings right out of the environment at any time; you don't have to go to the PowerPoint step, which is just wasted motion. You can bring management right into your working environment, and thus have a more frequent and rich dialog about the problem." – Aerospace/defense company E

Overcoming materials-related constraints We also found progress in addressing materials issues through both in-house development activities and partnerships with commercial solution providers:

"What are we doing about [the challenge of integrating new and advanced materials into our analysis process]? Company-wide, there are two main avenues of attack. One is new analysis methods and tools, some of which are internally developed, and some of which are in partnership with external tool vendors. The other avenue is changing our design processes to take advantage of the capabilities offered by modern materials. In the past, there has been a tendency to design with composites, but to treat composite materials as if they were black aluminum – that is, to arrange these materials to make them appear to be isotropic. Now we're working to change our design methods so that we have the design capabilities to take advantage of the anisotropic nature of the materials. There are both internal tools and commercial tools that begin to address this, and we're marching along on both fronts. We have a fairly sizable partnership with one of the structural analysis software vendors, to be able to do fairly rapid finite element analysis at a significant level of detail. [This is another example of an initiative to] 'bring fidelity forward'…" – Aerospace/defense company A

Simulation data management; process automation and integration Practitioners repeatedly described activities aimed at breaking through the two most frequently cited constraints on getting more value from simulation and analysis: (1) availability of trained, knowledgeable professionals and (2) time in the program schedule to do all the analysis they would like. Best-practice initiatives aimed at overcoming these constraints focus on tying existing design tools, preprocessors and solvers more closely together, and on using knowledge capture and data management aids to increase work throughput:

"[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.

Ora Research LLC
P.O. Box 391227
Cambridge, MA 02139-0013
USA
tel. +1 617 875 9598
www.oraresearch.com

"Our mid-term focus 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, our 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 depends on being able to manage the data, and to do it efficiently, in order to automate the design studies." – Mark E. Miller, Senior Technologist, GE Aviation

"My wish list for our managed environment? Ideally it will accommodate the processes that the company is pulling together, and once you know the processes that are needed in support of the product throughout its lifecycle – and we definitely need to address the lifecycle of the product; we have to do analysis and simulation up front in envisioning what the product is, right through support and disposal – the idea is to accommodate whatever the envisioned product requirements are. And then the workflows necessary to execute the development process. Of course this will have to accommodate multiple technologies to have it all make sense." – Aerospace/defense company F

Flight certification is one critical area where data management is crucial to having simulation results accepted as a trustworthy adjunct to physical test data:

"There is a clear requirement for long-term [simulation] data management. Without proper control (versioning, archiving, etc.), the certification authorities will not accept any CAE results for certification. And we need this to be integrated with the rest of the toolset." – Aerospace/defense company G

After-market service and sustainment, increasingly crucial to the business success of both commercial and defense aircraft manufacturers, is another area where capability and competitiveness increasingly require simulation data and knowledge management:

"There's no question that there is a need, especially in the aerospace industry, for better long-term management of CAE data… It would definitely help in support of effective and efficient maintenance of an operational fleet of airplanes." – Aerospace/defense company F

One notable area of innovation contributing to improved process automation and integration, we found, is the accelerating implementation of tools and techniques for automating and speeding up the execution of simulation and analysis codes in order to more efficiently explore "design spaces":

"There are some very interesting activities going on in design optimization right now. In particular areas such as design under uncertainty and robust design, there is steady progress being made. In MDO [multidisciplinary design optimization], much of the

Ora Research LLC
P.O. Box 391227
Cambridge, MA 02139-0013
USA
tel. +1 617 875 9598
www.oraresearch.com

progress has been in becoming able to handle many more design variables than before. And also progress in being able to integrate categorical variables into the process.

"There are three kinds of variables: (1) Continuous variable – for example, the length of wing. (2) Integer variable – say, the number of tires on a set of landing gear. I will not have 8.6 tires, but it may be that if I specify 8.6 tires, part of my analysis capability will probably still function – I can compute the weight or load capacity of 8.6 tires. (3) Categorical variable – here you can't interpolate the results, as you can with an integer variable. For example, I am going to design this piece using either aluminum or graphite – it has to be one or the other.

"Being able to handle categorical variables is becoming easier due to enhanced search algorithms, and better ways to examine design spaces that contain those kinds of variables. It's not a solved problem yet, but it is possible to do things with those variables today that were not possible before." – Aerospace/defense company A

These new methods – multidisciplinary optimization (MDO), design of experiments (DOE), robust design, Design for Six Sigma (DFSS) – require 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:

- Automate data exchange between analysis disciplines, and between geometry modelers and mesh generators
- Ensure that CAD-CAE data exchange capabilities are multi-CAD – partner/supplier collaboration requires this
- Readily re-run or update analyses months or years later
- Ensure that design changes trigger re-analysis; ensure analysts receive correct inputs from modified design; ensure re-analysis results feed back to design
- Manage intellectual property exchange and ITAR compliance issues when sharing data with subcontractors and partners

Knowledge capture and management Contemporary best practice further centers on the ability to capture, archive and retrieve simulation models, input conditions and results, together with related assumptions and conclusions:

"…The only constraints [on usage] are getting simulations set up and knowing how to do them. It's a matter of corporate knowledge…" – Aerospace/defense company C

Indeed, knowledge capture and management is a capability sought by many. Beyond simply securing information, it also 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":

"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. " – Aerospace/defense company F

Ora Research LLC
P.O. Box 391227
Cambridge, MA 02139-0013
USA
tel. +1 617 875 9598
www.oraresearch.com

Global project execution support Given the increasingly distributed nature of aerospace/defense program execution, best practice also includes the capability to manage simulation/analysis data in ways that support global organizational process requirements:

The challenges, impossible to meet without digital tools and infrastructure, begin with supporting and coordinating participation in globally dispersed programs…

> *"Our PDM environment provides configuration control to our multiple design facilities across the world. It includes much of the data that serves as input to simulation, and the PDM system may also have links to the simulation results, whether or not they reside in the PDM system itself." – Aerospace/defense company B*

…and extend to managing compliance with International Trafficking in Arms Regulations (ITAR) requirements:

> *"ITAR issues can be a constraint [in product development. Challenges include the need to] verify performance of subsystems from partners that are foreign suppliers, and [use that information to help] integrate those subsystems with other systems in the end product. Absolutely we need more tools for simulation data management [to support this activity]." – Aerospace/defense company B*

Simulation/test correlation The relationship between digital simulation and physical test can be used as a lever to drive change in how each is used in product development. Less true in space systems, this is a substantial benefit of analysis in developing commercial and defense aircraft:

> *"Is simulation displacing physical test? It varies depending on the product. In space vehicles, where you build one of a kind, the amount of physical prototyping and test required is already minimal because of the cost. At the other end of the spectrum, for example transport aircraft, there are still considerable amounts of test required – especially related to materials certification and reliability of the product. Here it's been seen that test has been reduced relative to some of the aerodynamic performance areas, because many CFD and aerodynamics codes are becoming more sophisticated." – Aerospace/defense company F*

> *"In some literature there is emphasis on early use of simulation as a means to eliminate hardware prototype testing. That applies in volume production environment, where once you get a certain amount of experience, you can know that your simulation models are pretty good. But in spaceborne systems, the details of hardware implementation in each new project bring their own problems that you'll never be able to simulate with confidence. Where we want higher-fidelity simulations is earlier in the process." – Aerospace/defense company E*

In the aircraft industry, however, we found that best-practice leaders are pursuing a goal of carrying out as much design exploration and refinement as possible with simulation/analysis, and driving physical test toward a role of final design validation only. While none feel this goal is fully practicable – for example, use of new materials not yet characterized in software will continue to require physical testing – all identified this as an ideal and an aim point.

> *"…in the future it's crystal clear that modeling and simulation will become more and more important, [and] physical test less important. You can only get rid of so much of it – people are constantly coming up with new physical materials [which] have to be tested to be understood. But given how expensive [physical] tests are, modeling and simulation will be used in their place whenever possible…" – Aerospace/defense company A*

Ora Research LLC
P.O. Box 391227
Cambridge, MA 02139-0013
USA
tel. +1 617 875 9598
www.oraresearch.com

> *"…we use simulation first, then physical test to validate…" – Aerospace/defense company B*

Overcoming organizational and work-process constraints

Of course, with even the most optimal technology implementations, much of the challenge in optimizing use of simulation and analysis and maximizing its impact has to do with organizational considerations and people factors.

Process capture, methods definition, toolset commonization In concert with the technology initiatives described above, a critical focus at some large enterprises is to document, understand and optimize – *in order to* automate and integrate – mission-critical, value-creating activity chains that utilize simulation and analysis.

One practitioner described his company's initiative to rationalize and better integrate its use of simulation and analysis. The first phase of this work was to capture the organization's existing processes for executing simulation and analysis:

> *"In the aerospace industry – certainly in our company – there is a move to capture our processes for analysis and simulation at the high level, then work down into the depths of it. Because how you do certain high levels of analysis is common regardless of the end product; but once you get down into the weeds, there will be some variation in the processes depending on what specific product is being analyzed. Capturing the processes is germane to improving the mess we're in." – Aerospace/defense company F*

The next step for this company was methods definition, together with identifying enabling technologies:

> *"The next question is: what methods and what tools are to be used? The methods relative to doing our analyses are changing slowly, [but could change more rapidly with the advent of] new techniques on the horizon… And as we move into multiscale modeling, spanning from atoms to parts to whole airplanes, this is introducing another level of complexity to the methodology required. So the methods will play a role." – Aerospace/defense company F*

Closely tied to defining current and future methods is the activity of qualifying, implementing and integrating supporting/enabling technologies:

> *"And then finally the tools: as we map common processes, the next step is to identify which tools are providing the methods best needed as we move forward on a new product. This is where companies like ours can reduce the number of tools in their toolbox. Everybody does have his/her favorite tool, and that presents a problem. But I think that if we agree on the processes and methods, we can then provide sufficient training on the tools in doing our specific job. We still do not have a unified infrastructure where the different analysts and partners can all use their own tools, and then still play with sufficient accuracy for our industry. But because of the high demand for accuracy in our industry, it's quite important that [we move toward] using a select set of tools." – Aerospace/defense company F*

In turn, the activity of capturing simulation processes and defining best-practice methods can be aided by – and at the same time can be used to foster – movement toward common toolsets across the enterprise. As a tactic for advancing this change, we heard that funding and procurement mechanisms – in concert with process capture and methods definition activities – can in fact help drive toolset commonization:

Ora Research LLC
P.O. Box 391227
Cambridge, MA 02139-0013
USA
tel. +1 617 875 9598
www.oraresearch.com

"If we capture the processes for doing structural analysis of our aerospace vehicles, for example, and then we look at the sub-processes involved, they would consist of things such as capturing requirements, doing the loads, doing detailed strength checking, doing margin-of-safety calculations, and so on – having those in hand, then striving to identify the preferred tools to use, and having an agreement across the company that these are the tools that we will be using, and we will be sharing the licenses across the enterprise – that helps identify how some of the acquisitions of these licenses are done. The objective, of course, is to get the most value out of these software licenses – in contrast to how it's been done in the past, where we had isolated sites or organizations that each bought their own licenses, and the cost was high. So cost-sharing of software is underway." – Aerospace/defense company F

"In the past, the company has standardized on a common CAD system, say. Is a similar path being followed for analysis and simulation? The answer is basically, yes, steps are being taken in that direction, and that is part of the path in which processes, tools and methods are being identified. I definitely see a similar path being taken in the control and oversight of which tools are used. And that allows for easier sharing of knowledge and information." – Aerospace/defense company F

"How do you [implement the recommendations of the Young panel to focus on end-to-end reliability]? You want to discover problems very early, when they're easy to fix. The secret is not only to use the tools early, but to share the results early across disciplines. We have a pyramidal hierarchy of system goals, flowed down to specifications for assemblies and subassemblies. The work in each discipline and across the partners responsible for building the components of these products happens in a fairly stovepiped manner: they try to flow results up the stovepipe, using document management methods. This is not very effective at catching design errors, especially ones that cross discipline boundaries. This has been my effort – to try to develop a new way of working these new kinds of problems earlier and more effectively." – Aerospace/defense company E

People factors In dealing with people factors, our research found that best practice focuses on two objectives:

- Garner executive sponsorship
- Create incentives for discipline leads, analysts, engineers to take ownership of the new tools and processes

"…we are attacking the problem at two ends, where people are most receptive…One is senior management of the company…senior managers and people with oversight over programs are very receptive to the idea of doing things differently and better. At the other end, individual engineers are also receptive and eager – they want to design a great product, and to use the latest innovative tools to design better, neater things than they can now…" – Aerospace/defense company A

Garner executive sponsorship Why is executive sponsorship important? Because optimizing use of simulation and analysis is an investment. It requires budget. It requires process change. And progress is not always smooth, so when things hit a bump, it requires commitment to stay the course. If improvement initiatives cause short-term hits to productivity, C-level understanding and backing can be invaluable.

"…[the president of our operating division] will have seen information firsthand pertaining to predicted performance of [our upcoming new product]. He's going to have firsthand knowledge of what that [product] can do on the basis of simulation and analysis…" – Aerospace/defense company A

Ora Research LLC
P.O. Box 391227
Cambridge, MA 02139-0013
USA
tel. +1 617 875 9598
www.oraresearch.com

Here's how to get it: Tie simulation process improvement to corporate business objectives, and to C-level initiatives and budgets such as Six Sigma, quality and efficiency programs.

> *"…[being] a very big company that has been very successful for a very long time…creates inertia that can make it difficult to do things in new and better ways…[strong] competition is doing as much as anything to help us crack through some of this [resistance]…senior managers…are very receptive to the idea of doing things differently and better…" – Aerospace/defense company A*

Create incentives for discipline leads, analysts, engineers to take ownership Of course, winning C-level buy-in is no guarantee of success. Alienating the head thermal analyst by forcing him or her to use a tool he/she doesn't like or trust is not the best way to deliver product on schedule. How can managers create incentives for these individuals to take ownership of new processes and enabling technologies?

We found the answer often comes down to best practices for change management. What will motivate these individuals to change the way they work? One key, we found, lies in individual engineers' professional motivation to excel, and their consequent receptiveness to new processes and technologies:

> *"… individual engineers…are also receptive and eager. They want to design a great product, and to use the latest innovative tools that let them design better and neater things…senior and mid-level managers are focused on having the company design really great products…the individual engineers have that same focus…" – Aerospace/defense company A*

Best practices also focus on introducing new processes and techniques in ways that mitigate resistance and risk:

> *"…lower levels of management [resist change]…lower-level managers have the focus of 'stick to the schedule, stick to the old way of doing things.' They're the ones being asked to assume the schedule risk, the program risk, all the risk that comes with doing things a different way…They are the configuration manager [and others] responsible for drawing out the best candidate designs…Throwing MDO [multidisciplinary optimization] at them disrupts everything they've done for 40 years, asks them to think about the configuration process a whole new way…[to win them over] we got the configuration manager and the chief engineer on [a new program] to agree to run the old and new processes in parallel – so if the new way doesn't work, the old way is there to mitigate the risk…" – Aerospace/defense company A*

A related best practice is to implement simulation and analysis process change in ways that minimize disruption in engineers' day-to-day work habits:

> *"…in our MDO [multidisciplinary optimization] initiative, we don't make any predetermination for the preferred tool…bringing MDO to fruition in a big company is a social battle…one thing we're doing to break down resistance is to make no* a priori *decisions about analysis tools. We say, 'What tools do you currently use to perform this analysis?' And we will integrate them into an MDO process…" – Aerospace/defense company A*

Next Steps

To drive change in an organization, a powerful spur to action can be to benchmark the organization's maturity level against industry best practices. Using this report as a starting

Ora Research LLC
P.O. Box 391227
Cambridge, MA 02139-0013
USA
tel. +1 617 875 9598
www.oraresearch.com

point, compare practices in your organization with those of your most successful rivals. Identify areas where more effective use of simulation and analysis 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 paper. Determine which of these is most severely gating progress in your organization today:

Technology constraints
- *CAD-CAE gaps*
- *Cross-discipline analysis gaps*
- *Advanced-materials characterization*
- *Need for better simulation data/process management*
- *Need for more highly automated model preparation/setup*

Organizational and work-process constraints
- *Human resource constraints*
- *Methods development, work-process integration requirements*
- *Organizational stovepipes*

Then investigate sources of solutions for both classes of constraints.

Technology solutions Although in-house development of CAE codes was long widespread, today practitioners tell us they are largely working to get out of this business, choosing commercial solutions wherever feasible. 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*

In your organization's next procurement cycle, revisit your qualification and selection policies for simulation solutions to ensure they address your requirements not just for superior point functionality but also for simulation data management, tool integration and process optimization. Factor in solution-provider stability, longevity and change management experience.

Organizational and work-process solutions Solutions to organizational and work-process constraints may come from commercial software and service providers, as discussed above. In addition, engineering and manufacturing companies abound with internal resources – often buried deep inside the organization and thus providing only limited, localized value. A corporate Six Sigma lead at a major defense contractor told us what he's doing to liberate this talent and get it into play on behalf of the entire enterprise:

> *"The problem is the silo-ing of talent [within the organization]. When you look at particular groups within the company, such as simulation and modeling, you'll often find clusters of people connected to one another, but not networked out to other groups. Why? The*

Ora Research LLC
P.O. Box 391227
Cambridge, MA 02139-0013
USA
tel. +1 617 875 9598
www.oraresearch.com

people with the greatest technical skills often have less capability as social entrepreneurs – you have a great statistics guy, say, but nobody knows he's even there.

"Our answer is to approach this as a 'social network' problem. In evaluating your firm's social networks, look for two fundamental behaviors. One is the 'skinner' – the isolated expert. The other is the 'trapper' – the expert who goes outside his or her own group and finds opportunities to contribute, as well as the program managers who go out and find modeling and simulation experts, and bring them into the projects.

"We're trying to promote those networks. We're using social-network approaches to try and get the skinners out of their silos and into play. In our case, we hold leadership programs [using principles developed by] Professor Ron Burt at the University of Chicago.[4] *[We train our people in how to] locate and develop those who are not only skinners but also trappers – who will go and find opportunities to apply best practices." – Aerospace/defense company D*

These internal experts can be a rich source of what this Six Sigma lead calls "found best practices" – solutions that have been developed and tested on a specific project, and await being discovered, communicated and made part of the organization's institutional knowledge.

[4] See, for example, "Structural Holes and Good Ideas," Ronald S. Burt, University of Chicago: http://faculty.chicagobooth.edu/ronald.burt/research/SHGI.pdf