The Democratization of Simulation with Intelligent Templates

Realizing the Full Benefits of Simulation

DESIGN/SIMULATION COUNCIL
SIMULATION & ANALYSIS

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PRODUCT LIFECYCLE MANAGEMENT ROAD MAP™

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The Democratization of Simulation with Intelligent Templates

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"Intelligent Templates" present an extremely innovative concept in product development that focuses on a reusable framework for managing product information and simulations of product performance. Simulation is made available to a wider audience of product developers in a reliable way that does not require them to be experts in specific simulation applications. The core enabler for intelligent templates is the idea of an "abstract model." This functional model of the product and of the associated simulations remains independent of a particular instance of the product design, and independent of the physics or fidelity of a particular performance simulation. A definition of all the data required supports the abstract model. The templates then define "best practice" workflows that can be executed using information contained in the abstract model and its associated product and process data. Experts must create the templates, but non-experts can use them reliably.

The concept of intelligent templates is not simply an evolutionary improvement in the way most companies approach product design and simulation; it represents an entirely different paradigm. It is, in fact, a systems engineering approach to model-driven design that demands, but also fosters, systems thinking and collaboration.

Intelligent templates also require that companies document their intellectual property (IP), and define their workflows and best practices. This is an exercise in knowledge engineering. The templates and abstract model now contain the IP and can deliver it to a far wider audience than was possible before. Templates can be used across project teams and product families and can be reused for the next product generation.

Intelligent templates can be a huge enabler for the product development system, enabling the delivery of higher quality products in much less time. Comet's technology finally enables the effective implementation of intelligent templates. But the issues are not just technical; companies will face significant cultural and organizational issues as they attempt to implement changes in the way they develop their products.

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This publication is derived from the keynote presentation by Malcolm Panthaki of Comet Solutions at the CIMdata annual conference, PLM Road Map™ 2011. Comet Solutions can be reached via www.cometsolutions.com or at 513-295-3641.

Introduction – The Full Promise of Simulation

Many advances in simulation and CAE represent exciting breakthroughs that may herald new ways that CAE can change approaches and processes for design. But there are hundreds of thousands of companies whose entire revenues would be dwarfed by the CAE budgets of the giant companies. What about them? How do we provide effective simulation capabilities to realize the full promise of simulation for companies of all sizes, including those with five engineers, as well as for those with thousands? This presentation focuses on meeting those challenges.

In the spirit of democratization, let us celebrate for a moment the spread of democracy throughout the world. In my visits to China, it was obvious that the new freedoms have brought a new level of energy to the country. Closer to home, the Internet supports the ability to democratize information and to reach out to people. Software solutions have now become available inexpensively—and sometimes even free—that serve as enterprise solutions working bottom-up rather than top-down.

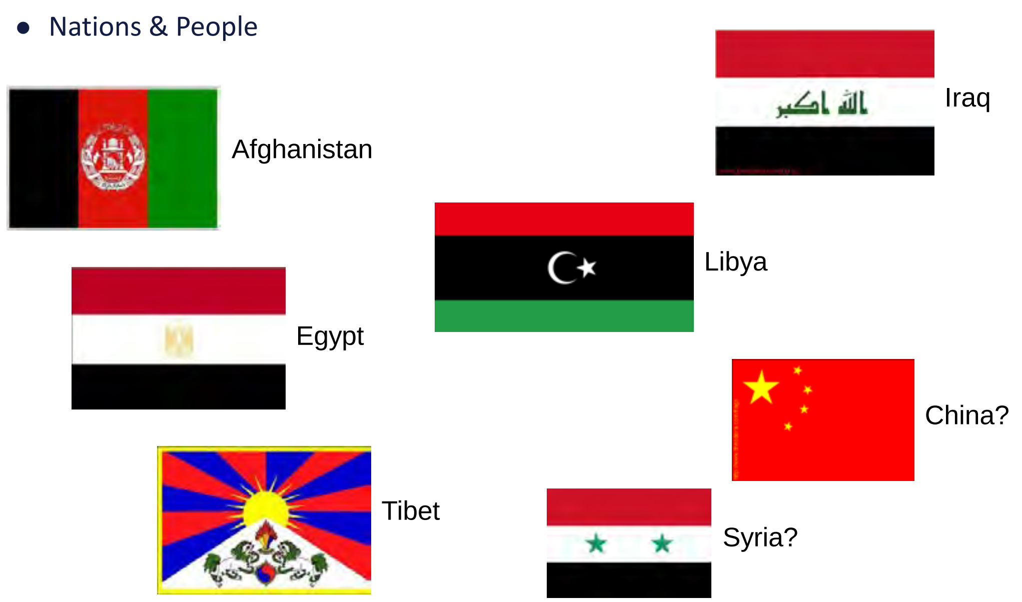


Figure 1: Democratization Is Everywhere

The Current Reality in Simulation

So where do we stand when it comes to simulation? Not in such a good place, unfortunately. Many large companies have clearly made dramatic progress, and yet the power of simulation could be utilized with a much larger number of people from smaller companies, with smaller groups. Anyone asking performance questions about a product and its design should be able to access hundreds of great CAE tools. How will it perform; what's the cheapest way to get that product to market? A host of questions about performance can clearly be addressed before cutting any metal. The solutions cover a wide range of different physics, and different levels of fidelity.

What About the State of Simulation?

- "CAD is King" and in its own silo
  - Not engineering performance
- Great CAE tools in silos
  - Each is limited to a particular physics and level of fidelity
  - Integrated tools from single vendors – "Use only *my* CAE tools"
- Tool and domain experts in silos
  - Create dependencies and bottlenecks
  - Drive ineffective workflows for design of complex systems
  - Create experts in the use of particular tools – tool experts
- Huge amounts of data in silos
  - Little reuse of data or processes
  - Poor design decision support – *where's the key data for decision-making?*
  - No integrated view of the engineering models/data – disparate data

The challenge has always related to addressing the questions that come up in design. CAD brought great capability to the whole simulation world and, at the same time, many shackles. Simulation had to wait for CAD. Analysts constantly had to revise analyses based on changes in the CAD, and then rerun their calculations. CAD became a bottleneck as well as a separate silo. In simulation, the sophisticated tools created their own sets of experts, yet such experts are rare, and expensive. Those tools cannot be used by a large number of engineers and designers simply looking for performance information. Again and again we hear about the huge amounts of data. How do we manage it; how do we mine it to extract the key pieces of information required to make design decisions?

These are issues faced by companies with thousands of engineers as well as by those with only five. The question comes up once again; what's missing? What can we add to this set of tools that will allow many more people to get the information they need using simulation. With a search on Google, no one cares about the amount of data that exists, the searching, the caching, or the databases available. They simply ask a question, and expect an answer. It is time now for simulation to achieve that promise as well.

So what is that promise? At the top of the list are more effective work flows. Most often, designers and engineers are not using one tool, but multiple tools at different levels of fidelity. Everything grinds to a halt when they go from one tool to the next. The promise of simulation-driven design has not been achieved. It is exciting to learn about situations where simulation can truly start to drive design, but today that solution represents a complex environment requiring a major investment.

The Promise of Democratization of Simulation

- Much more effective workflows
  - Model-based systems engineering
  - Simulation-driven design
- Empowered designers, engineers, and systems engineers
  - Expertise, tools, and data available outside the silos
  - *Engineers free to use (multi-vendor) best-of-breed CAE tools*
- Information to support design decisions
  - Integrated simulation data from early concept through detailed design phases
  - Single systems-view of engineering data
  - Product performance data available throughout the design process
- Simulation achieves (its long-promised) business results
  - Early detection of problems means lower cost of development, higher quality
  - Drive product innovation

The Payoff from Democratization

Empowering more people in the use of simulation represents a top objective. The number of people using simulation today accounts for a small fraction of the potential market. Large numbers of people have performance questions and need to use simulation to find the solutions. Very often, simulations provide information about the behavior of the design. Is the key data easily accessible—and accessible when it is needed? Most often, it is not. When these problems are solved, simulation will achieve its ultimate and dramatic contribution to business results—not only for the large organizations, but for the small ones as well.

Several items have been missing from the simulation world that would ensure these issues could be resolved. Today at this conference we heard about templates, which represent nothing more than a script, or a program, that automates a few tasks. But templates can do much more. They should be able to capture the knowledge of the experts for safe and broad reuse. The key concept is *safely;* by anybody who wants to ask the relevant questions.

We need to get away from single-point tools that solve individual problems. We must be able, in a continuous design process, to rely on tools at different levels of fidelity and physics to answer the appropriate questions at appropriate levels of accuracy.

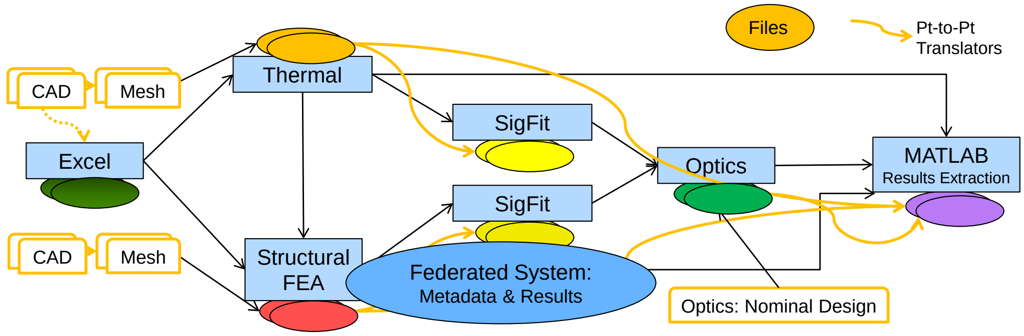
Roots of the Next Revolution in Simulation

- Intelligent templates
  - *Anyone* can easily and *safely* perform analysis to answer performance questions
- Direct modeling tools
  - Geometry tools for engineers; shift away from CAD-driven/-centric design
- Multi-physics/multi-fidelity environments
  - Boundaries of physics and fidelity no longer dictate analysis workflows
- Abstract (functional) CAE modeling
  - Templates independent of geometry or topology (configuration) are a game-changer for reusability and breaking the CAD dependency
- *Low overhead*, work-in-progress simulation process and data management
  - Changes the rules for project data tracking, design/simulation configuration management and team collaboration
  - Higher overhead, enterprise-level PLM software used when appropriate (e.g., archiving key analysis data at project milestones)

We need to move away from working directly with geometry, which has been a bottleneck. Engineers constantly wrestle with it, wasting a tremendous amount of time, in preparation for simulation. We need to do better. In consideration of the bottom line, the designer must be able to set up templates that capture changes both in the geometry and in the fundamental configuration. Also, even small engineering workgroups need data management. True, simulation data management may involve difficult and nebulous problems with massive files, and thousands of people may rely on the data that needs to be mined. But that does not address the issues facing the small engineering workgroup. Small groups of systems engineers who work through a conceptual design process to come up with the initial platform represent an important step, not involving thousands of engineers, or tremendous amounts of data, but still needing data management. I call this process, "low-overhead work-in-progress" simulation process and data management. The iterative data for the engineers should be embedded inside their tools daily. The engineers should barely be aware of it, but it should be available when they need it.

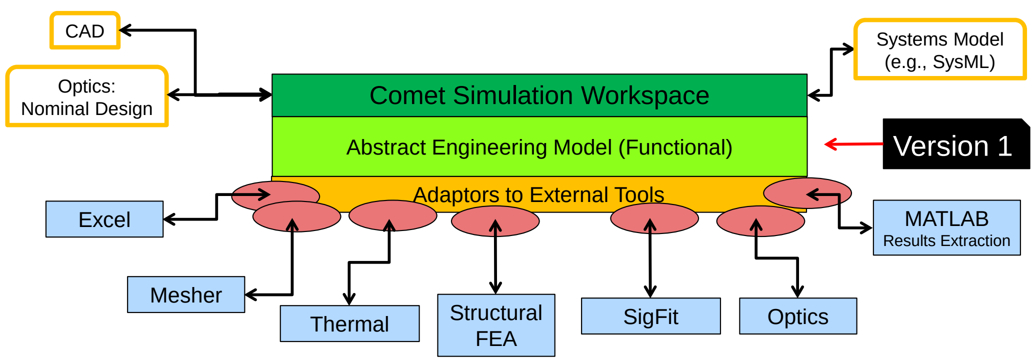
The major CAD tools are now starting to create hybrid systems with parametric and direct modeling to leverage their benefits, which is wonderful. Ultimately, engineering CAD or geometry will be automatically updated as the primary CAD representation changes, but that is not yet the case. The direct modeling tools are having a major impact, with particularly rapid progress over the last year. But they have not gone as far as we need. With CAD, it must be possible to bring the geometry into the direct modeling tool, and rapidly and easily change it, simplify it, tag it, and get it ready for analysis. But there is still a discontinuity in the process when sending these engineering changes back to the primary CAD system. Even so, the progress has been a major improvement compared to the past, with engineers often recreating the geometry to represent modifications. Most of all, the geometry-independent templates that we have reviewed provide the key in allowing engineers to deal effectively with changing CAD.

Figure 2: Federated Systems



Various tools need to run in a kind of tool chain, where the engineers have to create inputs for each of the tools. That process creates disparate clusters of information. Very often, because the information is not consistent, point-to-point translators are needed to move information from one code to the next. When the model changes, the effort starts all over, involving a rerun of the processes. So the engineer recreates the files one by one, puts the system together, and re-runs the process. That is certainly better than doing it manually, and certainly helpful. But many issues arise with this approach for bringing tools together in order to answer performance questions.

Figure 3: Unified Data and Process



Let's turn that approach on its head and see what happens. With all the information together in one space, organized consistently, the data can be maintained independently of all the tools. In this mode, consider the expert, the engineer who understands how to run the tools, creating a functional description of what is required to arrive at good answers. Functional descriptions must capture the essence of what the engineer wishes to do, without actually worrying about the product structure or the geometry. Then, that functional information must be entered into into the process. Many different approaches define the product structure; it could be a systems-level model or an optics design; it could be a CAD description. The system should support all the various ways to describe a particular system, and through the use of adapters, communicate all necessary information to the analysis tools. These adapters now take the information out of the common representation to create the inputs to each of the codes automatically.

The difference in approaches involves a fundamental shift in thinking of how these codes will be run. Once they run, the relevant results must then support an environment in which the basic description represents an analysis of the central data. The files required to run these analyses are then available when necessary. The system now deals with variability in the model and runs the calculations easily.

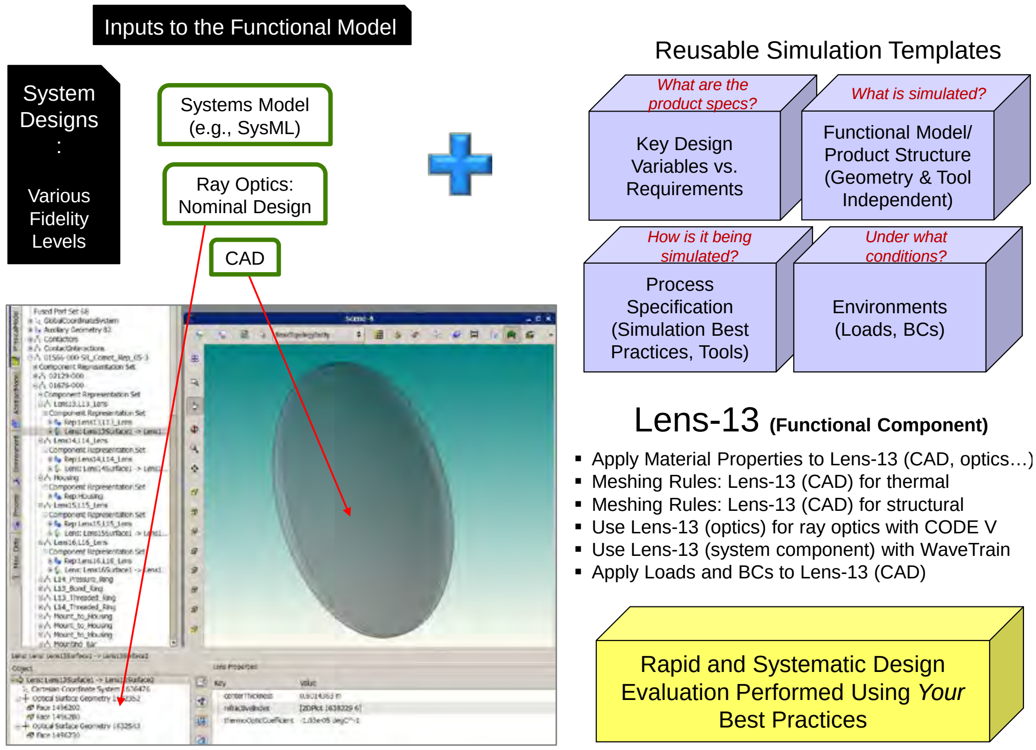
Intelligent Templates

To make this a bit less abstract, the templates describe exactly what it is that should be done. What are the requirements and key design inputs? What is being simulated? What is the functional product structure? If it is for an excavator, there is a bucket, there is a load arm, and there is a boom. These functional parts need to be represented in the product family. How is it going to be simulated; what tools will be used, and at what level of fidelity? What are the rules that the experts know that will be embedded in that tool? And finally, what are all of the environmental conditions? All of that information goes into the creation of the "intelligent" template as reflected in Figure 4 below.

Nowhere in the templates do you see geometry, or CAD, or a particular product structure. But part of the description does involve setting up the process, which describes what is analyzed, and how. A lot of the expertise goes into the process. The templates also involve dashboards, which define the key data accessed. What are the key inputs? What are the key metrics, and how do the metrics compare to requirements? The simulation environment is set up to run the processes quickly as the geometry changes, and to access the data quickly for the key inputs and the key outputs. Of course none of this is static. It can keep changing as engineers learn more about the behavior of the product. The templates need to evolve just as the design does.

Ultimately, the inputs must define what product version will be analyzed. The inputs can come in different forms such as a systems-level description, a CAD-level description, or an optics description. With enough information available, the templates can tie it all together. Once such a description is imported into the template, the system will often end up with multiple representations of the same component. For example, a component might be described as Lens-13 (see Figure 4 below). It is a functional component in the sense that it could be a single part, or it could be a group of parts. The designer knows that the component represents specific functionality from an engineering perspective. They set up a set of rules to apply boundary conditions, and to add material properties to the component; they add the different meshing rules. The description maps out the required functionality, and defines how to view this object, whatever it is, and perform different tasks on it. These are tasks that the engineers do manually all the time. Each time the design changes, they do it again. But in the template environment, the engineer can easily rerun their processes because they have already set up the rules. Once the information about the product structure has been entered, the models are prepared for analysis automatically. For example, consider two representations of the component. One of them is the CAD representation; the other one happens to be an optics representation suitable for doing ray-traced optics. Both share data and yet that data is quite different in its form.

Figure 4: "Intelligent" Templates and Abstract Models



There is nothing magical about the approach. These templates are not going to be perfect up front, and will evolve over time as the designers add more expertise into them. They are highly reusable once they have evolved. They can save tremendous amounts of time, because all of the work is done automatically that would usually be done by hand as the design changes. For example, it becomes relatively simple to create a coarse thermal mesh and a very fine structural mesh for a component. Each involves a different set of rules, different subsets of the assembly, and different experts involved in the automated process. Finally, the engineers can run a whole host of different tools. The adapters know what information to grab out of the central system, how to create the files, and how to run the different tools.

A few case studies of the actual use of templates provide more detail and context on the process and the payoff. What does this really look like; how has it been used in different contexts; and how can this environment be applied to rapidly and systematically evaluate designs, and make much better use of the expertise available? How can it empower others, such as systems engineers and designers with simulation capabilities? In terms of the bottom line, who would use these templates? Ultimately anyone asking performance questions should be able to safely rely on fairly sophisticated simulations to get the answers.

General Dynamics Land Systems

Our first case study reviews the design of an off-road army vehicle at General Dynamics Land Systems, or GDLS. The fundamental problems addressed were quite common and represent familiar challenges—multiple tools, tools at different levels of fidelity, and moving data from one level of fidelity to the next. In particular, GDLS wanted to transfer information from a 3-D CAD system to a MATLAB-based dynamics program. That process accesses the data from a higher fidelity representation, lumps the information together, and then transfers it. Previously, it took them from three to ten days to create a single model to be run by the MATLAB code. That involved manually pulling information out of the CAD model without being sure, ultimately, of its accuracy. Then they would take that data upstream to run a code like ADAMS, and from there go to an FEA code. It was a highly manual process and the information was not managed well—again, a common thread across most U.S. companies.

Military Vehicle Concept Design: CAD→MATLAB Tool→Adams→FEA

Customer: General Dynamics Land Systems

Simulation Problems

- Inefficient, error-prone, manual process – CAD model to MATLAB tool (3-10 days for a single model, single analysis)
- Changes to the CAD model required recreating the simulation models
- Not integrated with downstream tools such as ADAMS and NASTRAN
- No configuration management of CAE data

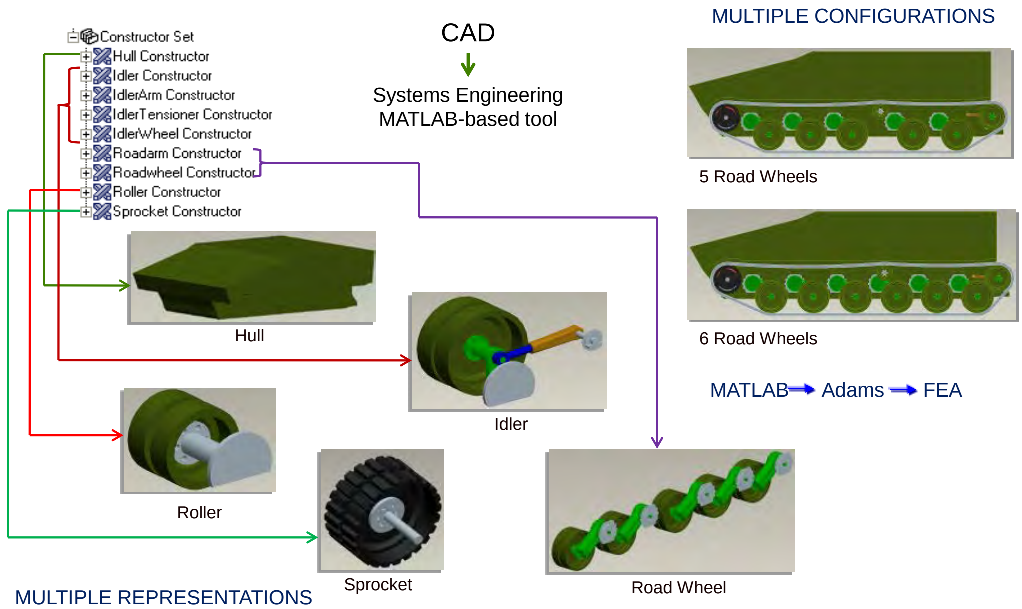
Goals

- Single integrated environment from systems engineering to detailed design, *accessible to systems engineers and expert analysts*
- Rapid (re)analysis using in-house MATLAB tool when CAD changes
- Efficient and accurate data transfer between the tools, better process management, enforce best practices
- Single consistent view of the engineering models/data

The engineers started out with their complex representation contained in the CAD data—none of which was directly suitable for analysis. They had to add information to convert it to an engineering model, and the additional data was required for importing the CAD representation into the engineering work space.

Many types of components were involved, but the initial data covered just the raw geometry. With the additional information that was added to the geometry, they were able to automatically construct multiple CAD representations. They could construct low-fidelity representations by grabbing the relevant information out of CAD, and feeding various configurations rapidly because the adapter automatically created the low-fidelity representations. For example, a change from a five-wheel configuration to a six-wheel configuration was automatically processed. It was fully automated. The engineers could swap out the suspension system and rerun the analysis. The template automatically reruns those calculations all the way from MATLAB to ADAMS to FEA with a code like NASTRAN.

Figure 5: Military Vehicle Program Saves R&D Cycle Time



A lengthy, tedious, and error-prone process was reduced tremendously. Various engineers, including systems engineers, were able to use this multi-fidelity environment to run the calculations once the experts defined the appropriate rules. As a result, they are happy enough with the environment to want to use it from scratch on a new Army program, all the way from systems engineering to the more detailed calculations.

Enabling Rapid Vehicle Concept Design Studies

Results

- Compress 3-10 week design evaluation per vehicle by 80%
- Various engineers including systems engineers use complex multi-fidelity, multi-tool analysis process
- Drive various tools using single integrated engineering model
    - High-fidelity CAD to low-fidelity MATLAB systems model to high-fidelity FEA model
    - Multiple representations of various system components managed seamlessly
- Major new Army program will use Comet from concept to delivery

The Evolution of Templates

In an earlier presentation at this conference, Chris Paredis from Georgia Tech talked about the move from documents to systems models as a fundamental step required to facilitate model-based systems engineering. The key is to move from document-driven and file-driven systems to systems with a centralized notion of all the information, in a form that is independent of the underlying tools. The workspace relies on a centralized systems model that can run various analyses, and communicate with CAD as and when required. Yet the data remains independent of the underlying tools used. If an engineer can run a particular analysis with NASTRAN, they should be able to replace NASTRAN with a different tool that does the same thing and requires similar data.

Let's consider templates once again from a slightly different angle. What's the current status quo with templates, besides the fact that they do not represent a magic bullet? Many of them are vertical applications. They have existed for a while, but are usually expensive to create, and time-consuming to run. They are also brittle. That is, if things are not exactly right with the models, they are not going to work. In going from one configuration to the next, even in the same product family, they too often break and someone then has to reprogram them. That is why their use has been fairly limited in the past to a very narrow scope. They did not really deliver the benefits that they potentially could have provided.

Simulation Templates: Before and After

Status Quo

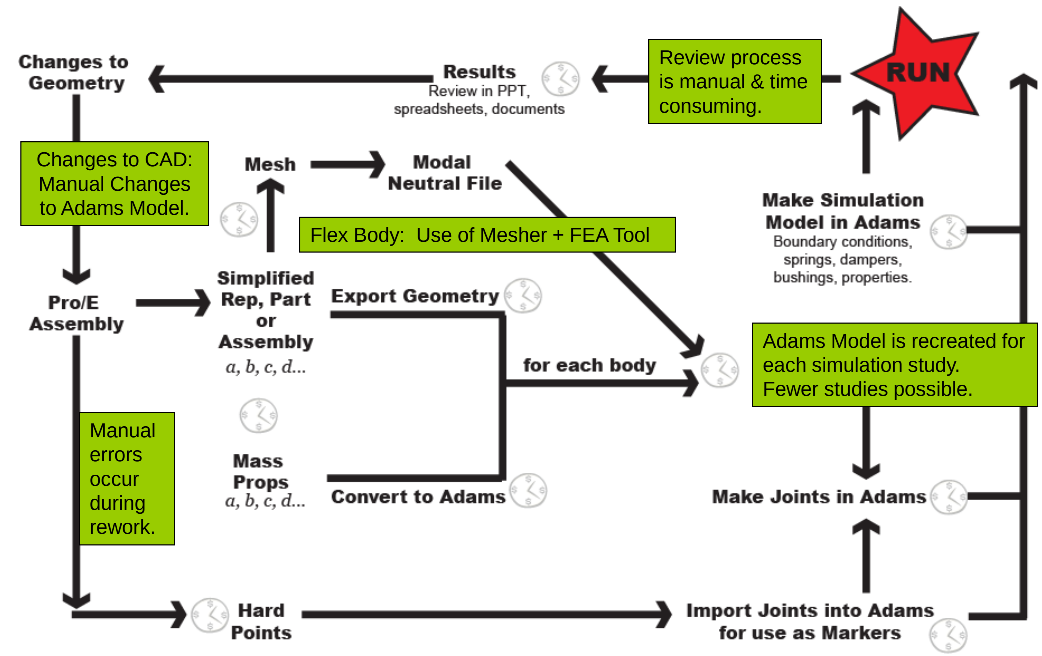
- Many "vertical applications" (product-specific analysis templates) exist
- Custom developed – *expensive (>$200K) and time-consuming (months to create)*
- Usually quite brittle – built for specific cases and specific topologies
  - Geometry changes, template breaks
- Usually created by services organizations, IT groups, and vendors, not by the end-users
- Cannot be easily extended by the end-user

"Intelligent" Templates

- Intelligence and expertise are embedded in these templates
- Customer creates their own templates graphically and rapidly
  - Complex templates are created and tested in days
- Templates are geometry/topology-independent
- Easily evolved/enhanced by the customer as knowledge/best-practices change

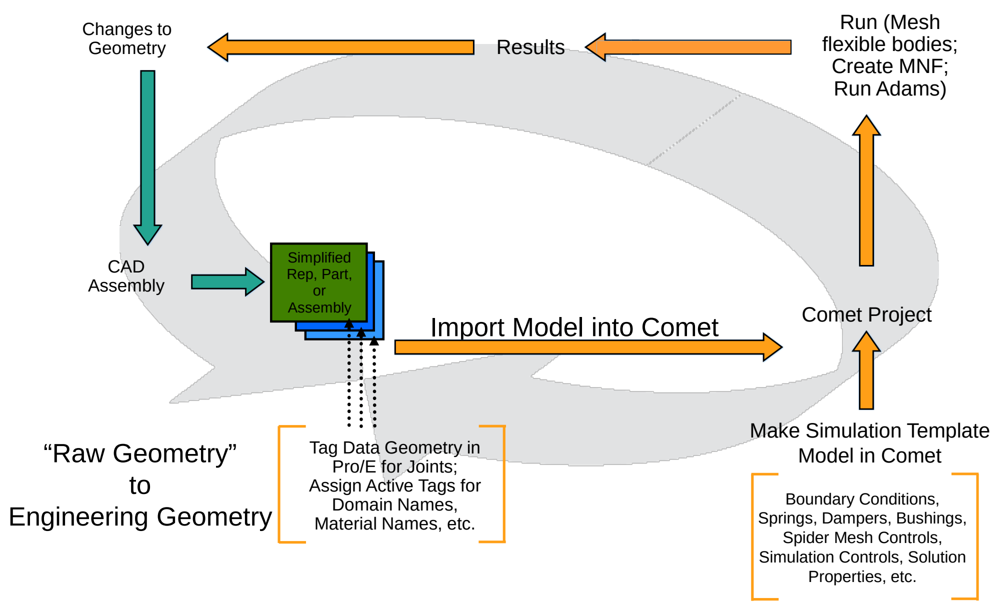
What is missing from today's approach to templates that would deliver their full potential? First and foremost, the templates should embed the available expertise easily and rapidly. However, that is a problem if the effort involves almost any programming at all. The experts should be able to manipulate the system graphically to embed their own rules. It should be easily changeable, because templates change almost as often as the model and design change—as the designers and engineers continue to learn they will enrich their templates. Most important of all, the templates must be independent of the geometry and the underlying topology or configuration. The experts should be able to create a template that runs a fairly complicated set of analyses even when a new configuration that is topologically quite different is analyzed. The functionality remains consistent, but the details from an engineering perspective change. Unless the users are able accomplish these objectives, they are not going to safely put these templates in the hands of a large number of people, which is critical.

Figure 6: Current Dynamics Analysis Process – Manual Steps



Transformations to Support a Wide Range of Activities with Consistent Information

Figure 7: Comet Process – Geometry-Independent Automation

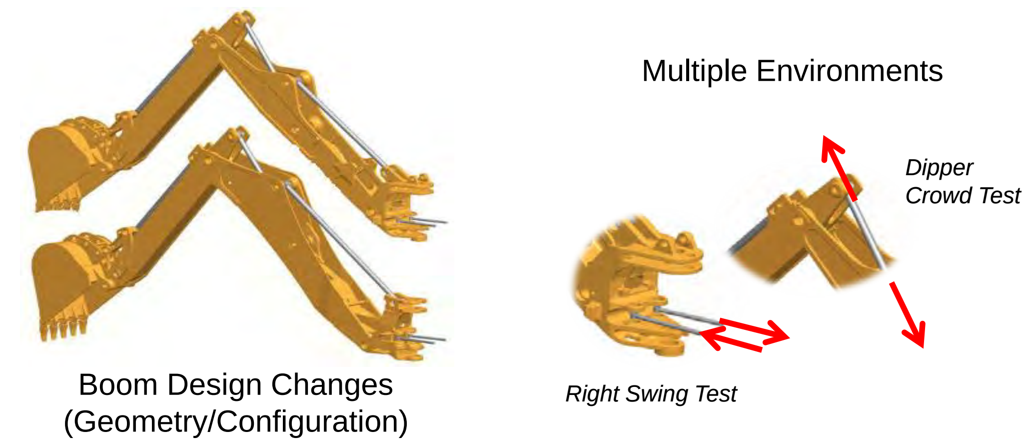


The common process concerning dynamics can be flipped on its head by creating a template that is independent of a particular configuration, and still contains a lot of the engineering information. The process starts out with raw geometry and converts it to engineering geometry by adding tags and information that labels items, such as a joint or a spring. By inputting that model into a template, 90% to 100% of the work is completely done. The process is then ready to run the simulations, whether they are rigid-body or flex-body calculations. The process drives downstream all the way to the final analysis. Upfront effort in creating the geometry for the independent templates provides the capability to run the process rapidly as the geometry or configuration changes.

Figure 8: Engineering Challenge

Calculate performance specifications for all configuration combinations/variations across a product family (web interface)

- There are 12 models in the product family
- Each model has 15 major subassemblies
- Each subassembly has 5-15 attributes required to build and analyze the model plus a number of custom attachments chosen by a buyer
- There are >35 separate calculations to be done for each configuration



Consider the case where the manufacturer has a product family. There may be two different configurations that behave similarly, although one may be half the size of the other, and they may have different sets of mechanisms to perform the same tasks. From an analysis perspective, and from a functional engineering perspective, the two are close to identical in behavior. The designers want to subject both to simulations involving a large number of environmental variables. In this case there might be twelve models in the product family. Each model involves major subsystems that occur in each example, and has various attributes that need to change. Customizations and custom attachments that a buyer might choose could be added. The experts want to create templates easily so they can run all of the simulations inexpensively and automatically, with zero user input, to rapidly extract valuable performance data.

That is possible in the Comet environment, and several clients accomplish that now. Figure 9 below presents the actual user interface, and what we call the project appears on the left. The project includes a tree of stages where each stage records the state of the entire project at any given time. Going back to a certain state is as simple as pointing to it and telling the system to move there.

Figure 9: Integrated Rigid/Flex Body MBD→FEA Process

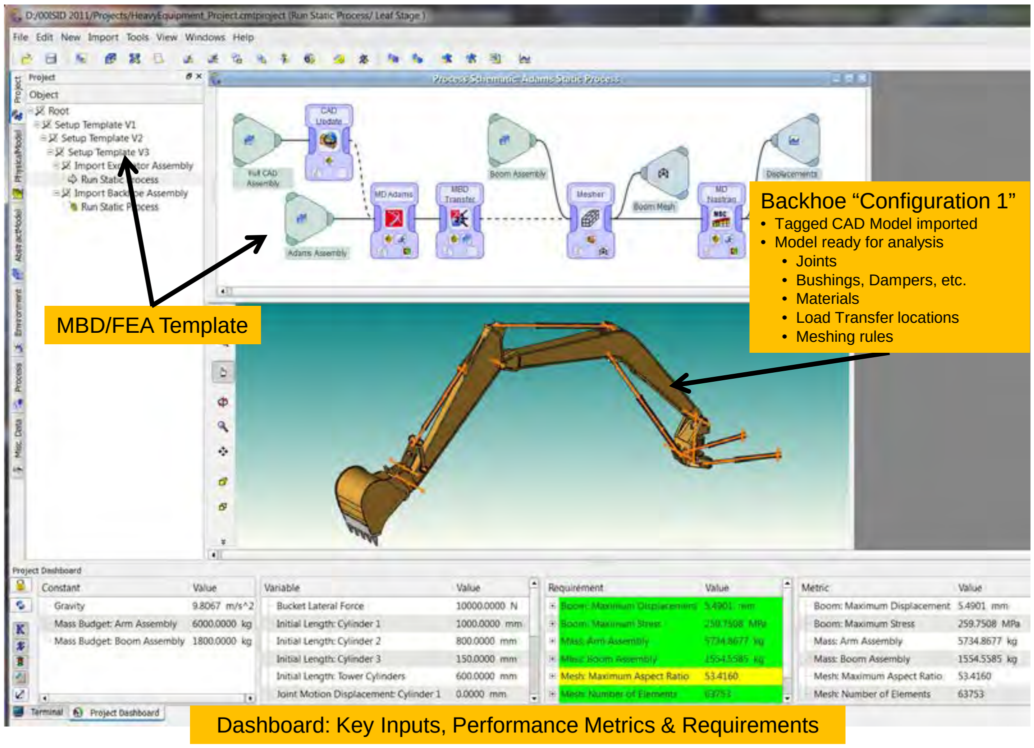
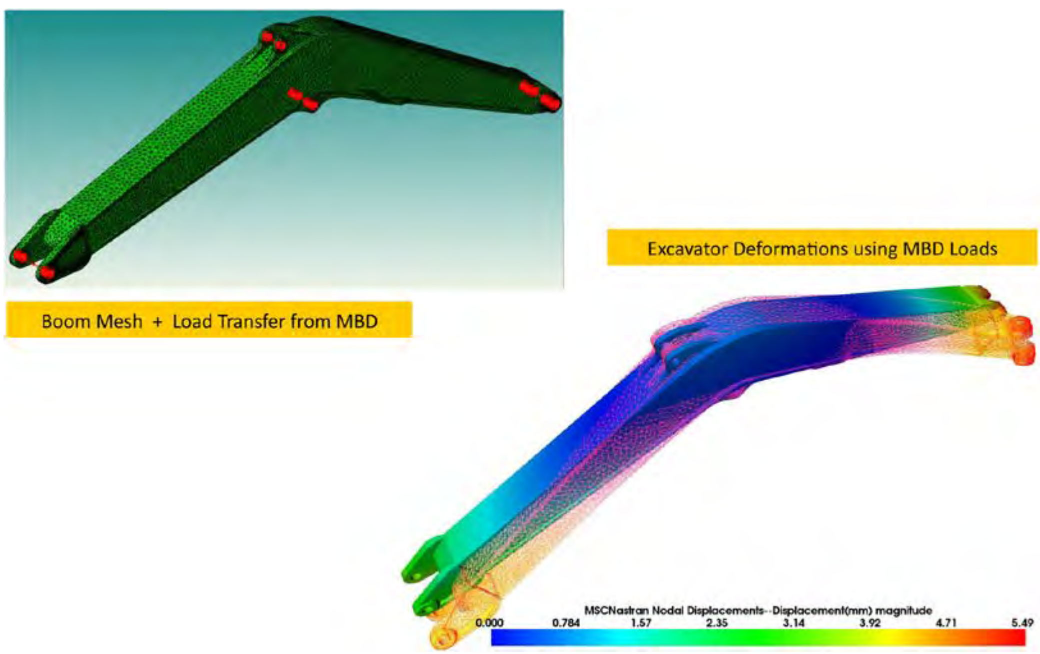


Figure 10: Running a Multi-Body Dynamics Simulation



Consider the payoff of managing all of the configurations. Multiple engineers can work simultaneously in the system—independent experts can work in their silos when needed. When it's time for the team to work together, the team can come together both from a data perspective, and from a collaborative perspective. That simple project mechanism serves many purposes in terms of maintaining the configuration, archiving it, allowing the system to share data rapidly and easily, and allowing users to collaborate. The users create a process that grabs the particular representation of the CAD model, or at least some subset of it, updates the CAD if changes have been made, and runs a multi-body dynamics calculation. The approach automatically picks up the forces and loads around a certain subset of the model when a more detailed calculation on that subset is needed, transfers those loads, meshes that subset, and runs the finite element calculations. The mesh on that subset happens to be in this case a reasonably complex assembly. The red areas in figure 10 above are the sections where the loads were automatically transferred. The system knew exactly where to do the transfer, how to run the finite element calculation, and where to get the key results at a detailed level on a critical subsystem.

Consider several configurations that may be similar from an engineering perspective, but with different types joints that are in different locations. The assembly structures and geometry are different as well as the size, but it does not matter. The designers can run the new configuration through the exact same template. All the rules that were applied to the first configuration are applied to the second as well. The idea is that once the template is set up, additional configurations can be imported and analyzed easily and automatically. The results appear right on the dashboard to compare one version to the next (bottom of Figure 9).

What are some of the key conclusions? It is critical for experts to be able to set up a template in a few days at most. A lot of the time initially needed to come up to speed derives from the lack of familiarity with the environment. Over time as the templates evolve the experts are better able to add new information to them. The templates become more accessible, more powerful, and more easily used by both experts and non-experts. The systems engineer as well may start out with a CAD model, bring it into the environment, run it, and quickly and easily get results to compare with requirements.

Looking again at model-based systems engineering, the process starts with a system-level model at various levels of detail. It is critically important that a wide range of activities can be accomplished through transformations with consistent information. For example, the Young's Modulus of steel may be defined once and only once, and then sent out to many different codes. If the engineer wants to represent a joint, it is created once, and sent out to ADAMS, to NASTRAN, or to Abaqus. The transformations to each code represent that exact same set of joint data in different representations, ensuring consistency—a critical contribution of the integrated data model.

Leveraging the Experts for Broad Use of Simulation

Figure 11: "Democratization of CAE" in China

Tangshan Railway Vehicle Co., Ltd.

CRH3 350 km/hr train

Location makes it difficult to get–and keep–top talent

Customer Goal:

> "Use Comet as the integration platform across all engineering work because template-based analysis processes mean much higher engineering productivity and confidence in simulation results, with fewer staff and lower CAE expertise required."
>
> *– Chief Engineer*

Another example of using intelligent templates comes from Tangshan Locomotive in China. Their engineers eagerly embrace change, preferring the latest and the best tools and technology. Moreover, they have money to spend. In this particular case, this high-speed rail manufacturer faced a major problem due to its location. Situated a few hundred miles from the coast, it was difficult for them to attract and keep talent because engineers did not want to live there. The company was introduced to the template system, which captured expertise and effectively helped address the problem by making the location less of an issue. The quote in the figure above comes from their chief engineer, who concluded that the integration platform allows a large number of their design engineers to utilize the expertise from very few experts, including consultants, and from their own in-house talent. Tangshan Locomotive is now in the process of developing web-based front-ends that drive fairly complex templates. As an interesting side benefit, templates that can run successfully across different configurations also support simple, vertical applications that work well with significant design changes.

In the web-based vertical application, the user changes geometric parameters. The system updates the CAD automatically behind the covers and then automatically generates a complex mesh of 1-D, 2-D, and 3-D elements created for analysis. FEA analysis is performed to determine the key results and make design decisions.

Results

- Consistent process enabling rapid analysis of all configurations
  Intelligent templates handle large geometry/configuration changes
- Less-experienced people perform complex simulations
  Use the same tools that the experts use
- Auto-generated performance spec sheets
  Predict performance against requirements without a Ph.D.
- Same concepts/processes can be applied across all product lines
  Standard way to safely provide complex simulations to anyone asking performance questions

The benefits of this approach include consistent processes that enable the rapid analysis of all configurations. The best practices may be encoded in these templates in an executable form, rather than in documents. That is the key; the analysis managers do not deliver a document to a group with orders to "follow it or else." They ask the users to run the templates, with best practices and rules embedded in them. The experts can put in rules to make it safe for use in exploring a large area of the design space, and these less-experienced people safely perform complex simulations.

None of this removes the need for the experts. Those analysis tools are still difficult to use, and the expertise of those designing the process must be deep enough to make the templates safe for non-experts to use. Even more importantly, it is difficult to assess the accuracy of a result, often provided to the n^{th} decimal place. What does it mean? Is it 5% off? Is it 150% off? The experts know the answer because they have coaxed the code for years. It remains critical to keep the experts in the loop, creating the templates and monitoring, testing, and evolving them. With the intelligent templates, many processes can then be applied across various product lines to unleash a much larger number of engineers using these processes.

Supporting Efforts at Multiple Levels of Fidelity

Another use case concerning a refrigerator company substantiates the ability of templates to support work at multiple levels of fidelity. Simulations often start out with fairly low-fidelity systems-level calculations and then progress to more detailed calculations. The key is to manage all the information consistently, from the start to the end of the process.

The refrigerator manufacturer initiated a pilot project with us addressing a common problem. They are global, with a number of different manufacturing locations. Each plant had, over time, created its own systems tools, everything from highly complex Excel tools to FORTRAN programs. They wanted to take that information, run various configurations, export the results, send the results downstream, drive CAD, run thermal finite element calculations, and loop back.

Refrigerator: System Thermal Performance
Excel → Meshing → FEA → Optimization

Customer: Large U.S. Appliance Manufacturer

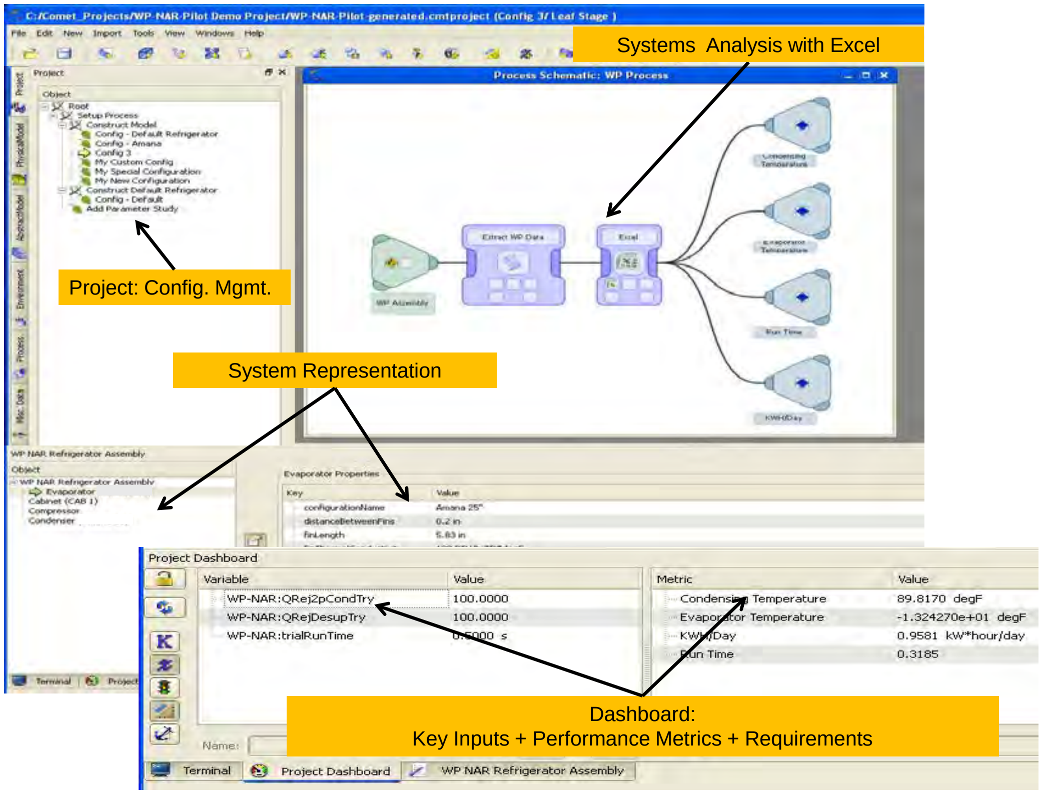
Simulation Problems
- Many (4) ad hoc Excel systems tools worldwide for the same calculations
- Not integrated with FEA or optimization tools; inefficient, error-prone manual process
- Changes to the CAD design required recreating the simulation models (Excel, Ansys)
- No single view of the engineering models
- CAE configuration management issues – including the thermal systems spreadsheets

Goals
- Single integrated environment from systems engineering to detailed design, easily and safely accessible to systems engineers, designers, and expert analysts
- Rapid (re)analysis using in-house Excel tool when CAD changes
- Efficient and accurate data transfer between the tools; better process management; enforce best practices; manage configurations of the systems spreadsheets
- Single consistent view of the engineering models/data

Of course, they can already do this work, but manually, with no way to manage the information well. With Excel spreadsheets, not only can certain inputs change to force a rerun of the spreadsheet, but the spreadsheet itself may change. They often end up with many different versions of the spreadsheet. Both versions of the tool and versions of the data need to be managed—which is a logistical nightmare. At least a dozen highly complex sheets are involved. Not only are the calculations captured on the spreadsheet, but all the various off-the-shelf components, such as condensers—including multiple versions—are included as well. To swap out a component, the user pastes a number of cells from one area of the spreadsheet into another area, and reruns it. That is how things are done today.

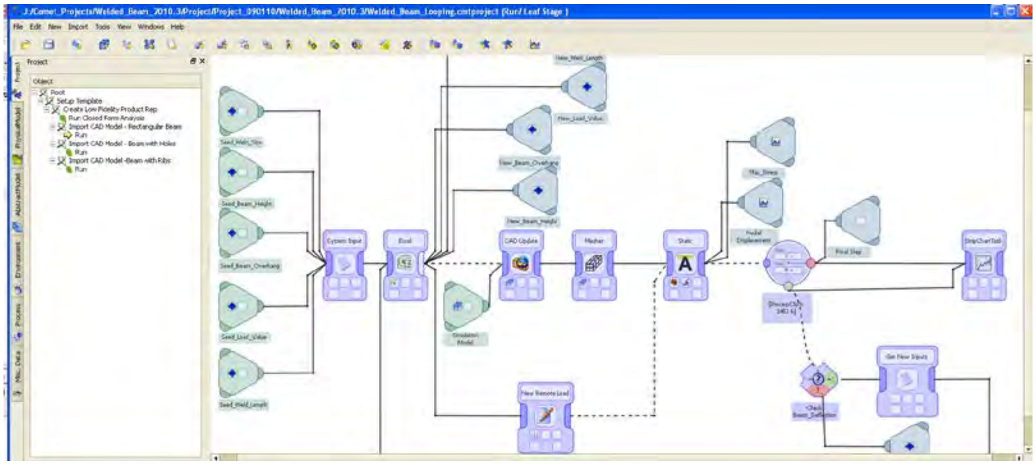
The pilot relied on a common template, which provided several benefits. First, the process is simple. It involves extracting data from a systems model of the refrigerator and running Excel—that's it. The system representations are rather simple in terms of representing an evaporator, a cabinet, a compressor, or a condenser. That is all that is required to run the fairly sophisticated thermal use and management calculations. Each of the components has a set of properties associated with it. The same component hierarchy appears in the old approach and in the pilot, but now the pilot has a simple system representation that dramatically reduces the complexity. Creating a new stage in the project is as simple as requesting a new one, which provides all the information from the previous stage, and involves making some changes to rerun the calculations. Full management of the configuration, the spreadsheets, and the data is supported as a natural part of the environment.

Figure 12: Comet – Mixed Fidelity Modeling – Excel to CAD/FEA



With intelligent templates, the next step in a project typically concentrates on enhancing the level of fidelity. A more complex process may involve systems-level calculations feeding into a CAD model, which takes recommendations from the systems tool to update the CAD model. From there it meshes the relevant portions of the CAD model and performs a thermal calculation on the high-fidelity model using an FEA code such as Ansys. The process sends the relevant performance information back to the systems model with all the information managed in one place. That supports a CAD representation of the components alongside the systems representations. The systems representation of the components provides common parameters that drive materials data as well. Multiple engineers may work simultaneously in their own silos. Moreover, all the information goes back out to a dashboard to provide a quick summary view of the status of the design at any given point.

Figure 13: Mixed-Fidelity Looping Process



A "Visual CAE Program": Excel (Systems Analysis); Pro/Engineer; Ansys FEA (3-D, High-Fidelity Analysis)

While we would like to claim that this revolution with intelligent templates is benign, it is not completely so. There are changes needed in the way the engineers and designers think, and in how they approach the process. However, when it comes to groups working together to achieve a goal using simulation, they achieve such a radical improvement in their effectiveness that we have found they will often embrace the change.

This Revolution Does Not Lead to Anarchy

- Robust templates, dealing rapidly with design and configuration changes
  "Raw geometry" is turned into "Engineering geometry"
- *Safe* CAE for all – *not "dumbed-down"; use the experts' tools*
- Breaking down silo boundaries without eliminating the silos
- Model-based systems engineering across any levels of fidelity – *using the same analysis tools that the experts use*
- Single view of the systems model capturing the functional aspects of the system ("SysML" - to CAD - to mesh)
  - Multiple component representations managed seamlessly

Several critical components support this solution. Robust templates allow designers to keep the design and analysis up to date despite rapid changes. Experts are certainly in the loop, and they use the same tools. When problems arise, the experts can easily take over where the designers leave off, precisely because they do use the same tools. The approach breaks down the silo boundaries while fully acknowledging that these organizational silos will not change any time soon. Allowing groups to work together and then return to their silos for their silo-related work helps. The ability to come back together as a team to collaborate, and to support model-based systems engineering across any level of fidelity, provides a major payoff. A systems-level representation may coexist with a CAD representation to answer a particular question and create a feedback loop. Most importantly, a single view of the system, with all of its different representations and multiple levels of fidelity, drives the different tools.

Direct Modeling at NASA's Jet Propulsion Laboratory

Consider an example from NASA's Jet Propulsion Laboratory (JPL) that starts with complex CAD, which is rapidly simplified into an engineering model of surfaces and solids within a direct modeling tool—SpaceClaim. The next step relies on a Comet application to turn the raw geometry into functional or engineering geometry, by adding joints and tags in different locations, to abstract the model so it can be analyzed. The engineering geometry is then imported into a template to be run. The template creates a surface mesh for thermal analysis or more complicated solid meshes on the simplified geometry, and gets the results. A different version of that same model from SpaceClaim may come along, and it can be run through the same template with little or no user input.

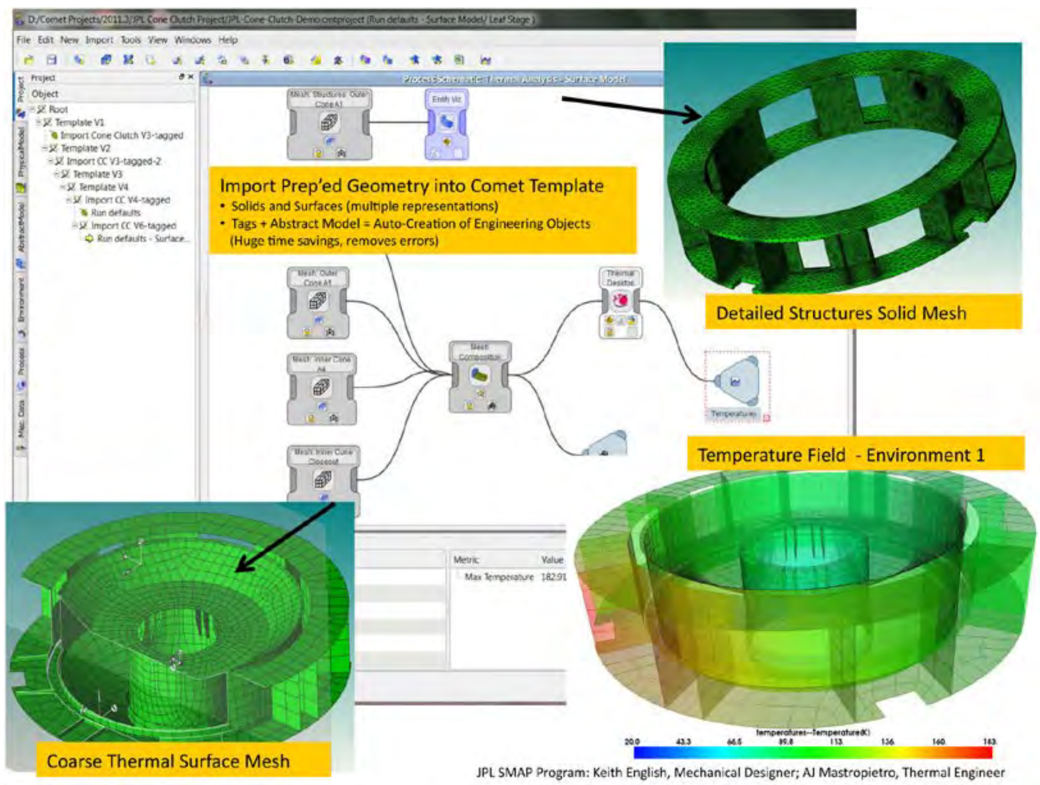


Figure 14: Rapid CAD Prep for Thermal and Structural Analysis

This approach breaks down the barriers between concept analysis and detailed analysis. For too long, those have been separate areas, involving distinctly different silos and different types of people, each with unique tools and data. Conceptual analysis is completely separate from the detailed review. Both may now be drawn together in a consistent data model to capture the engineering data, from the coarse, systems-level models, down to the details, with all their complexity and richness. The combined model can now run integrated analyses with mixed fidelity, not just low- or high-, but anything in-between. Ultimately, with that capability, the promise of model-based system engineering becomes a reality, allowing systems engineers to explore various concepts rapidly at any desired level of model fidelity.

Potential for the Near Future

Given the capabilities already supported, what is the potential for the near future? First, sophisticated simulation may be used safely by anyone asking performance questions. Many of the pieces have already been assembled. The intelligent templates that capture the expertise are easier to create and easier to modify than they have ever been. They support the ability to create vertical applications that can drive the process. These intelligent templates can be accessed from the web, which is the next step. Mobile tablet interfaces to these applications will become available, including on iPads accessing sophisticated calculations. They will not run the calculations, but serve as a portal that will launch either a simple or an extremely complex calculation in the background. If the enormous portal capabilities of the Cloud are added, then the may access all the computing power needed. Combining templates with web access from portable devices and huge computer resources in the background, with the ability to extract key performance data, supports sophisticated calculations to answer performance questions from practically anywhere.

What to Expect in the (*Very Near*) Future (1)

Sophisticated simulation *used safely* by anyone asking product performance questions

- Intelligent templates capture expertise and make it available, safely
  (Heavy equipment, Figures 8, 9, and 10)
- Vertical applications (desktop or web-based) drive these templates across geometry and configuration/topology changes
  (Locomotive cabin, Figure 11)
- Ubiquitous access to simulation
  - Mobile tablet device interface to complex analyses
  - Increased throughput by running compute-intensive analyses in the Cloud

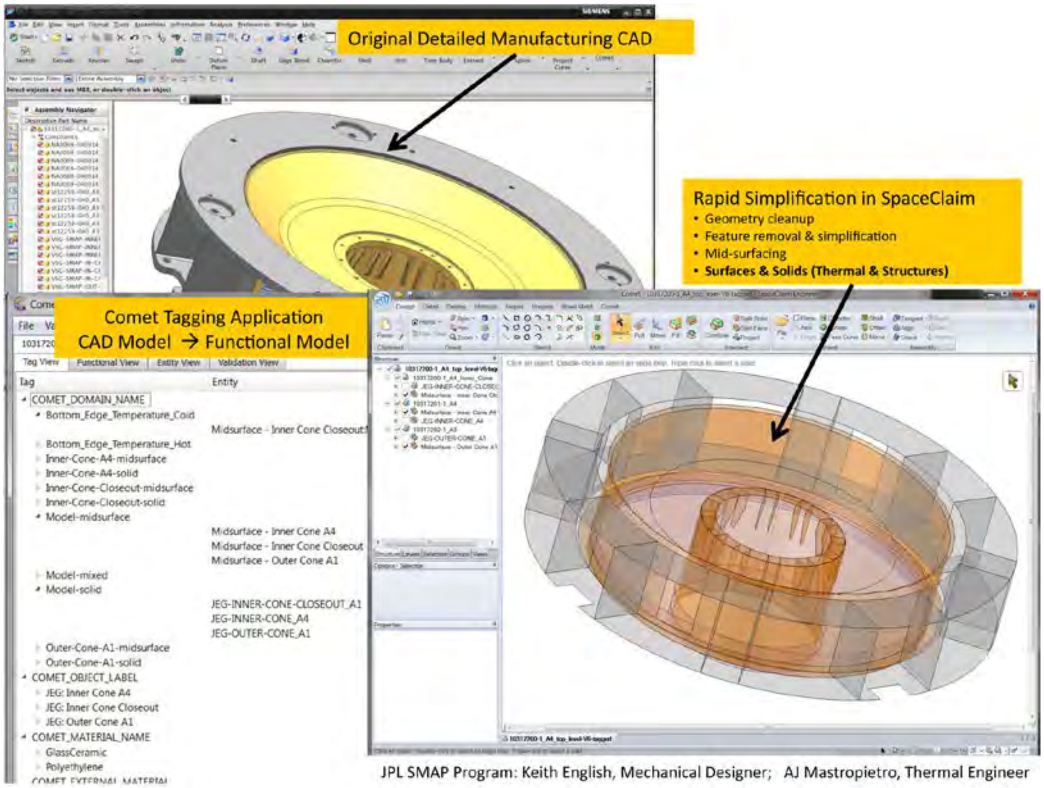
Parametric 3-D CAD has been a great boon to simulation while at the same time its limitations have created major drawbacks. The geometry-centric approach has to be retired. Geometry represents just one design input, like material data; it does not need to be the central piece of data to which everything else is attached. The moment that happens, inevitable changes and modifications force designers back to the beginning to restart the CAD process. That has been a huge bottleneck, preventing simulation from responding rapidly to design changes.

What to Expect in the (*Very Near*) Future (2)

Engineers better able to deal with CAD's shackles

- CAD tools creating hybrid systems *(combining parametric modeling and direct modeling has some technical challenges)*
- Direct modeling for engineers *(gathering steam)*
  [Oct 3, 2011: Comet announced direct connection to SpaceClaim]
- Geometry-independent intelligent templates *(now)*
  - Abstract modeling deals with large geometry & topology changes
  - Assemble systems from subsystems defined with multiple geometry sources

Figure 15: JPL: Rapid CAD Prep for Thermal & Structural Analysis



What to Expect in the (Very Near) Future (3)

Breaking down the barriers between concept analysis *(with or without CAD)* and CAD-based detailed analysis

- Single integrated representation of the engineering models, *spanning all physics, tools from all vendors, and all design phases*
- **Model-based systems engineering**
  - o *At any mixed levels of fidelity*
  - o *Using the same tools that the experts use in detailed design*
  - o *Available to answer systems performance questions during any phase of the design process*

The systems representation should not stay at a coarse level that would then constrain the approach to be all that could be run off the model. It should directly support higher fidelity calculations from the same centralized data model that the Comet approach provides. The ability to run systems-level calculations at any mixed level of fidelity realizes the full potential of simulation to answer performance questions at various levels of accuracy throughout the design process, starting from the early stages and going all the way through system validation.

Conclusion

In conclusion, several significant direct benefits are realized with this environment and with this approach—using a single, integrated data model to represent all the engineering data. It can capture and reuse best practices in an executable form. Once the experts create the intelligent templates, they can hand them over to others without the same deep expertise and training, to increase simulation capacity and effectiveness. The number of users relying on sophisticated analyses will likely increase dramatically—a many-fold increase. The system supports full data access and traceability without incurring the overhead of a heavyweight and expensive PLM system. The approach does not replace the PLM system, but adds to that environment. Workgroups need to be able to manage their highly iterative, work-in-progress data, and at certain points, upload the key simulation data into a PLM backbone. To give you an idea of the IT footprint involved in installing Comet, the workspace can be installed and connected to the required CAD and calculation tools in less than thirty minutes. When was the last time anyone had a PLM system up and running in less than thirty minutes?

Direct Benefits of Simulation Democratization

- Capture and reuse best practices and tools ("intelligent" templates)
    - Better utilization of scarce expert CAE analyst resources
    - Significantly reduce/eliminate model re-work per simulation iteration
    - Use best-of-breed tools – *not locked into using analysis tools from a single vendor*
- Increase simulation capacity and effectiveness (experts bottleneck)
    - Many more design alternatives evaluated earlier in the design process
    - Engineers and systems engineers can access *all physics tools at all fidelities*
- Have full data access and results traceability (project tree)
    - Workgroup/project-level WIP configuration control and data capture/sharing
    - Milestone upload of key project data to enterprise PLM/SDM backbones *[Comet Workspace installed and running with all tools in <30 minutes.]*
    - Collaborate across organizational silos & project teams (project tree)
- Make design decisions based on key design variables and performance metrics (project dashboard)

The intelligent template approach directly targets the simulation needs of experts, engineers, and designers. The idea is to use the right tool in the right place for the right reasons, and combine the tools in ways that provide the best return on the investment, providing performance data rapidly, and having a strong impact on the design. The approach enables the engineers of any company, large or small, to collaborate in simulations across organizational silos and to work together. It extracts the key information rapidly and easily to help drive the design—realizing the promise of simulation-driven design.

About CIMdata

CIMdata, a leading independent worldwide firm, provides strategic consulting to maximize an enterprise's ability to design and deliver innovative products and services through the application of Product Lifecycle Management (PLM) solutions. Since its founding more than twenty-five years ago, CIMdata has delivered world-class knowledge, expertise, and best-practice methods on PLM solutions. These solutions incorporate both business processes and a wide-ranging set of PLM enabling technologies.

CIMdata works with both industrial organizations and suppliers of technologies and services seeking competitive advantage in the global economy. CIMdata helps industrial organizations establish effective PLM strategies, assists in the identification of requirements and selection of PLM solutions, helps organizations optimize their operational structure and processes to implement solutions, and assists in the deployment of these solutions. For PLM solution suppliers, CIMdata helps define business and market strategies, delivers worldwide market information and analyses, provides education and support for internal sales and marketing teams, as well as overall support at all stages of business and product programs to make them optimally effective in their markets.

In addition to consulting, CIMdata conducts research, provides PLM-focused subscription services, and produces several commercial publications. The company also provides industry education through PLM certificate programs, seminars, and conferences worldwide. CIMdata serves clients around the world from offices in North America, Europe, and Asia-Pacific.

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