MAKING THE FULL POWER OF SIMULATION AVAILABLE TO EVERYONE – AT THE CONFLUENCE OF SOLUTION-SPECIFIC WEB APPS, "LIGHTS-OUT" AUTOMATION, DESIGN OPTIMIZATION TOOLS, AND "INFINITE, ELASTIC COMPUTING" ON THE CLOUD

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1. Introduction

Imagine a saleswoman at a customer's site, entering new customer specifications on her iPad, selecting an appropriate base product from a company catalogue, adjusting design variables, and then clicking a button that launches complex simulations and, perhaps, even a design optimization that runs on a large cluster in The Cloud [1]. Within a short while, she has a response, indicating whether the selected design meets the specifications and, if so, what the unit price of the product would be at various volumes and for various manufacturing parameters. Of course, the customer then wants to know how the unit cost can be lowered, maintaining the original delivery schedule and certain design specifications, while allowing other specifications to be "loosened". Again, within a short while, the saleswoman has a modified design that meets the latest set of customer criteria, while knowing, with relatively high confidence, the range of potential profit margins for her company.

This scenario is one that occurs, perhaps only occasionally, in cases where the underlying calculations are either "pre-canned" or are simple and able to be performed on a mobile device. Allowing a saleswoman to access complex simulations still seems implausible and, especially to experts in the use of CAE software, even dangerous. This is because most CAE tool experts continue to believe that simulation cannot and should not be performed except by those who have *deep* expertise in the esoteric and arcane art of extracting reasonable results from today's simulation software. Hence, unfortunately, simulation has been the exclusive domain of too few (the "experts") for too long, ever since its inception in the earliest days of computing.

In this paper, we will demonstrate the ingredients of a solution that aims to put simulation, simple and complex, *safely* in the hands of those that need it, and in particular, those that do not have any expertise in the underlying CAE tools. We will demonstrate how the intricate confluence of simple-to-use, solution-specific web applications that speak the language of the user, called SimApps™* [2]) automated design space exploration tools [3], and "lights-out" automation that works across all design changes, bolstered by the "elastic and infinite" computing capabilities now available on The Cloud, facilitate the global and safe deployment of complex simulations to anyone who needs it.

We will show how these tools and methodologies are already being used at global manufacturing companies such as Intel® [4], American Axle & Manufacturing (AAM) [5], and Magna [6], to automate simulation processes and extend the use of simulation beyond a small number of CAE experts, while globally enforcing CAE best practices and significantly increasing the impact of CAE investments on their businesses. In these use cases, the full power of simulation becomes available to everyone who needs it, from a systems engineer who wishes to accurately compare the relative trade-offs of various architectures, to design engineers who need accurate and rapid assessments of the change in performance of a design variation, to junior engineers who are still learning the intricacies of CAE codes.

These simulations are deployed to users on the Web using simple, solution-specific Web applications – SimApps. SimApps are targeted, simple-to-use applications that speak the language of the user/engineer and are often customized to the needs of a particular company. The "real work" is done by simulation templates that automate the use of calculation tools, from Excel, Matlab and Mathematica, to more complex 3-D tools such as Abaqus, Nastran, Adams, ANSYS and LS-DYNA [7], and mesh generation tools such as Simmetrix and ANSA [8. We believe that this confluence of methodologies, software, automation templates, and computing hardware, aided by the advent of mobile devices with ubiquitous high-bandwidth access to the Internet, has the potential to significantly increase the number of users of simulation tools over the next decade, *making the full power of simulation available to everyone who needs it.*

2. Motivation

Engineers have used calculation software of all kinds since the 1960's. These calculators have ranged from programmable calculators and spreadsheets, to the complex, physics-based simulators and PDE solvers.

Complex engineering software is rarely user-friendly. Numerical algorithms are inherently complex and hide details from the casual user. They are *not* fool-proof – small changes to inputs can result in large changes in results and the validation of results is difficult and painstaking. Geometric models need to be carefully simplified for analysis and also, simplifications of the numerical model are often carefully made by experts to minimize computational expense, while obtaining the desired results at the desired level of accuracy. This makes the process of model set-up complex, manual and error-prone – the danger is pretty-looking results that might be wrong.

The automation of engineering analysis, using home-grown scripts to targeted vertical applications, has existed for decades. Over the last decade, the GUI's of simulation tools have improved dramatically, making them more accessible. However, many of the complexities are *inherent complexities of the underlying mathematical algorithms*. To get good results from such a tool and to really comprehend these results (what's useful and what the limitations are of the inputs and hence, of the results) requires people who are experts in the related physics domain as well as experts in using the particular tool. **Automation templates need to capture this CAE expertise and best practices in an executable form that is then safely put in the hands of non-experts – i.e., even when the user is not an expert in the underlying tools, the results can be trusted. Without this, the automation technique is only useful to the experts who can interpret the results safely.**

Automation templates have also suffered from their limited ability to work robustly across a large portion of the design space. These templates are often brittle – i.e., significant geometry and topology changes cause the template to fail. In addition, what is needed are templates that are also robust across configuration changes (swapping components) and across a family of products. Today's templates do not work across such significantly different product designs and are hence, limited in their utility.

Designers and systems engineers search for designs that best meet specifications, while minimizing cost and time-to-market – hence, the need for automated Design Space Exploration (DSE) tools. However, for these tools to be truly effective, the underlying simulation automation techniques need to work across design geometry, topology and configuration changes, allowing the DSE algorithms to explore a much larger portion of the design space. Also, non-expert users need to be able to use these DSE tools.

Commonly, CAD models are created mainly for visualization, marketing and manufacturing, *not for simulation*. Hence, expert analysts spend huge amounts of time preparing geometry for analysis. Also, the CAD geometry is rarely parameterized with simulation in mind. Hence, each geometry change that is suggested by analysis is often manually inserted back into the CAD model. This is highly inefficient, and worse, it turns into a roadblock to "lights-out" automation.

Almost always, companies use CAE tools from a variety of vendors. This is not likely to change in the foreseeable future, despite attempts by large vendors to create ever growing suites of tools and integrated environments around their tools. Hence, an automation solution needs to be vendor/tool-agnostic and highly extensible, so it can easily include tools from a variety of vendors and also, home-grown tools.

These roadblocks and deficiencies have resulted in:

- **Highly inefficient simulation workflows** – it can take many hours and often many days or weeks to set up a complex assembly model for a *single* analysis.

- **Manual model building steps that are error-prone**, resulting in inefficient use of expensive and limited CAE experts.

- **Islands of expertise, tools and data.**

- **Lack of a simple, rapid technique to capture CAE expertise** and deploy and enforce it globally using "executable" templates that are accessible on the Web.

- And, most importantly, **simulation being limited to CAE experts**.

3. "Lights-Out" Simulation Automation across a Product Family

Simulation automation is, by definition, bounded – "vertical applications" that perform a limited set of simulation tasks automatically, over a limited set of product designs. The broader the scope of the design space that can be analyzed, the more useful it becomes. **Templates that can answer product performance questions across design**

geometry, topology, and configuration changes, and also across an entire family of products, are most useful.

"Lights-Out" automation minimizes the required user input, while providing answers to the user's product design questions, at the required level of accuracy – enter key geometric and non-geometric inputs and hit the "Calculate" button to obtain a report. Templates need to capture the expertise of the experts to make it safe for non-experts. Lights-out automation is a key ingredient of useful "vertical applications", allowing non-experts to safely perform and leverage sophisticated simulations.

We believe that these targeted, solution-specific vertical applications, which we call SimApps [2], are a necessary and useful complement to general-purpose integrated simulation environments that the major CAE vendors have been developing over the last two decades. While the general-purpose tools are essential for what the experts need to do, and while their GUI's have become much more user-friendly, they will never be able to fully-automate specific calculations on specific product families without special-purpose scripting (see Section 5). Hence, vertical applications are required, as they are the most effective way to put sophisticated simulations safely in the hands of non-experts. This has been clearly validated by users of Comet Solutions® SimApps and templates (see Section 6).

We have demonstrated, with the Comet Platform for template creation ([9], [10], [11]) and the related vertical applications that make sophisticated simulation accessible on the Web to non-experts using SimApps [2], the key ingredients in the recipe to make the full power of simulation available to everyone. These key ingredients are:

- A single Extensible Integrated Data Model (Comet's Abstract Engineering Model - AEM™)
    - Across levels of model fidelity and physics
    - Data as functional Engineering Objects rather than "numerical objects"; >95% of the data are independent of CAE tools
- Product Architecture captured as an abstract component hierarchy with support for multiple component representations per component, including non-physics representations such as on-board software
- Abstract modelling techniques and data abstractions – this allows the rules in the template to be defined based on functional architecture rather than on geometry; this is what enables the

templates to work robustly across geometry, topology and configuration changes, and across families of products that share a similar functional architecture – this is how engineers think about their products

- Ability to rapidly and automatically create and assemble mixed-fidelity models for analysis – use of parameterized libraries of component representations at mixed levels of fidelity and a highly extensible connector architecture enable the easy swapping of components at different levels of fidelity

- Process specification and automation

    - Capture expertise using rules that are based on the functional architecture, independent of the geometry format, and topology and configuration changes

    - Create graphically, minimizing the need for scripting, which makes these automation processes easy to create and modify; Comet's Process Schematics are a visual programming language for CAE and can be created in days

    - Auto-generate model files for each tool in the process translating Engineering Objects into the language of the underlying tool – supports templates that work across a family of products

- From "Manufacturing CAD" to "Analysis CAD" (ACAD), ready for auto-meshing and analysis, and parameterized for analysis – create libraries of reusable, parameterized ACAD for components

    - Geometry simplification and clean-up is *not* required, removing a roadblock to automation

    - ACAD codifies the "functional architecture" and "engineering intent" in a persistent form

        - "Engineering intent" enables the template to automatically create Engineering Objects for analysis – joints, bushings, rigid point masses, bolts, welds, contact conditions, meshing rules, environments

        - Enables templates to deal with variability between different designs

  - ACAD has "analysis parameters" to modify geometry and topology – SimApps and DSE tools have direct access to analysis parameters via the templates

- Automatic mixed-fidelity assembly meshing
  - Manual assembly mesh generation, taking hours or days to complete for a single mesh, is a roadblock to automation
  - ACAD, containing "engineering intent", supports fully-automatic meshing, including low-fidelity connectors between parts
- Tool-Agnostic Templates – adaptors access CAD, CAE and Systems Analysis tools from various vendors, supporting customers' choices of tools, including their home-grown tools
- Configuration management, data mining and automated report generation
  - Manage configurations of all the CAE data, across the workgroup – access to project state at any checkpoint
  - Template can automatically extract and post-process results, and generate reports of key data for decisions
- A scripting API for process customization – while template creation is predominantly visual/graphical, there is a need to enable functionality not directly supported in the GUI
  - Full access to the underlying data model, including the process, model data and simulation results
  - Use of Python provides access to an extensive set of commercial and free libraries for extended functionality

The Comet Template Authoring Workspace [12] has implemented the key ingredients for lights-out automation. The significant benefits realized by users are described in Sections 6 and 7.

4. SimApps™ – Providing Safe Global Access to Tool-Agnostic Product Development Calculators on the Web

The fundamental technologies for deploying web-based applications on the Cloud have been around for some time. From an engineering perspective, we are in an enviable position with respect to technology – advances and innovations in software, hardware and networking are occurring faster than we can capitalize on them. Furthermore, with the commercial acceptance of Cloud computing in various other domains, we now have access to infinite and elastic computational resources, *without the need to bear the large fixed costs.*

While the infrastructure is evolving rapidly, the end-user markets in the engineering space are not well-defined and business models have not matured. Vendors have yet to figure out how to leverage all of these capabilities and user demand has not reached a level that demands a solution. The first companies that offer working, affordable and elastic engineering analysis tools on the Web will be the big winners in the next wave of growth in engineering software – Autodesk, at present, appears to be one of the front-runners [13].

Current attempts to bring simulation capabilities to the Web are focused on making the existing simulation tools available via a Web interface [1]. While this begins to provide customizable computing resources cheaply, all of the same issues remain regarding the use of these tools by non-experts.

Not until we begin seeing simple-to-use and safe Web-deployed simulation applications such as Comet's SimApps will the market for simulation in the Cloud explode. We need one or two orders of magnitude more users for the model to make business sense to the ISV's who are reluctant to license their software on the Cloud. The SimApps will bring higher-volume non-experts to the table, cracking open this new market and thereby increasing usage of the CAD and CAE tools to a business-feasible level.

In addition, we need to motivate a large, growing ecosystem of Simulation App developers – *note that these developers must be experts in the products and the tools*. This needs a platform for easily and rapidly authoring these Apps. There have been numerous examples of this – Microsoft's Windows OS, the Apple hardware and OSX platform for App development, and in our domain, the AutoCAD platform that sparked the development of thousands of "plugins" developed over the last 25 years, and the highly-successful SolidWorks CAD platform for Add-In application development. The Comet Platform for authoring vendor-agnostic templates and SimApps follows in these footsteps.

A thriving ecosystem of content providers, "expert" App developers, Cloud infrastructure providers and a much broader base of simulation consumers is required to make this business model work – we need "Amazon, Google, and Apple App Stores of Simulation" (Figure 4.1). The authors believe that the key market and technology ingredients now exist for this market to ignite in the next couple of years [1, 2, 14].

For example, an interesting experiment on "CAE in the Cloud" has been generating promising results over the last couple of years [15]. This conversation is not new – the following link on HPC Wire describes a September 2012 discussion, "*Why Are CAE Software Vendors Moving to the Cloud?*" [16].

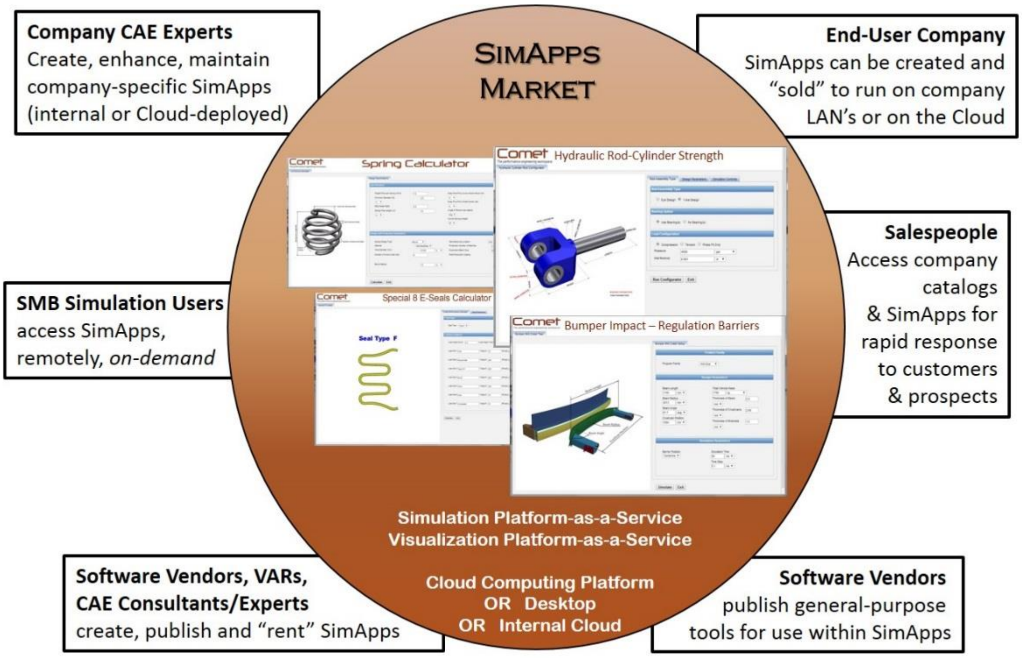


Figure 4.1: The SimApps Marketplace

We believe that there are 3 potential categories of users of solution-specific Apps deployed on the Web:

1. *Companies that are already heavy users of CAE.*
   These have experts in-house and are capable of developing their own Apps given the right framework such as the Comet Workspace [12] and COMSOL's App Builder [14]. These Apps capture and enforce their internal best practices. The Apps are deployed on their internal network or on private, password-protected portals of public Cloud providers.

2. *Companies that currently use CAE, but outsource all of it.*
   These do not have internal CAE expertise or licenses to the tools. Apps for these companies are created by CAE service providers or vendors like Comet Solutions, and are deployed on private, password-protected portals of public Cloud providers. These SimApps capture and enforce the best practices that are dictated by the company. With Apps that speak the language of engineering instead of the language of CAE, the designers and

engineers in these companies, *not* CAE experts, are able to run sophisticated calculations themselves.

3. *Companies that do not currently use CAE.*
There are a large number of companies that could benefit from using CAE in their design process, but do not – the cost and time barriers to entry have been too high. With the creation of SimApps by CAE service providers and vendors and the option of "paying by the drink" on the Cloud, the financial and technical barriers are eliminated. This allows these companies to *finally* begin leveraging the power of CAE and design optimization.

We believe that this segment of the Simulation Apps market on the Web is the largest untapped set of simulation users. There are many companies, Comet Solutions and Autodesk included, who are betting on this being a huge growth segment for simulation software vendors and expert services.

Figure 4.2 shows some examples of Comet's SimApps ([2], [12]). Also, in Section 6, we describe how prominent manufacturing companies such as Intel®, American Axle and Magna Cosma, use Comet's simulation templates and SimApps in their product development process, and the benefits that they have realized.

5. The Case for *Both* General-Purpose CAE Tools and SimApps

There is a strong market need for *both* general-purpose CAE environments (e.g., Siemens' NX Simulation, ANSYS Workbench, MSC's SimXpert/SimManager, DS SIMULIA's SLM environment, and Autodesk's Sim360 [7], [13]) as well as targeted, solution-specific applications such as Comet's SimApps [2] and COMSOL's Apps [14]. We believe that both are required if we are to be successful in bringing simulation to a much wider audience of non-experts.

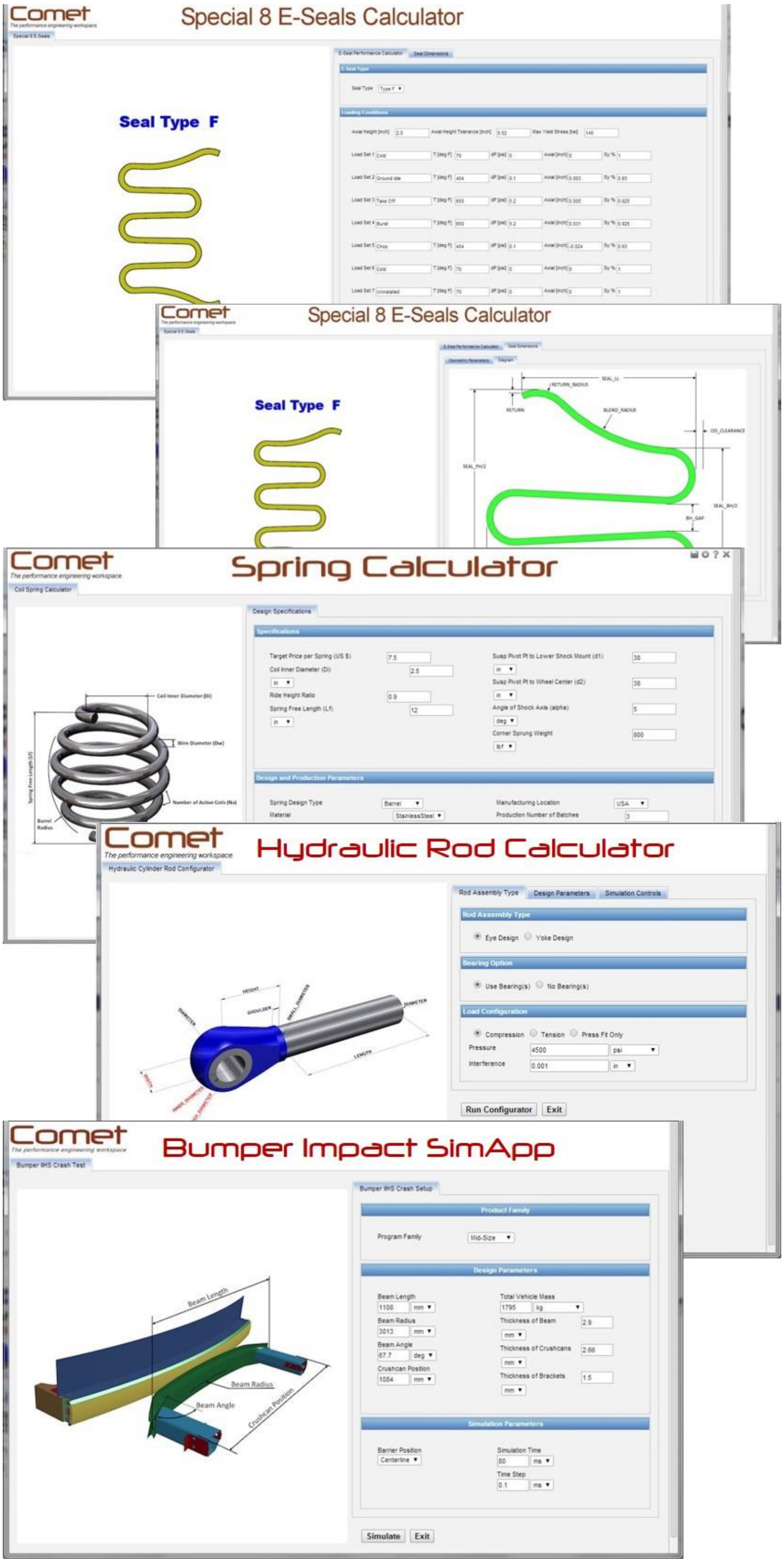
General Purpose Simulation Environments

These environments have been getting easier to use and more powerful – i.e., support an ever-widening scope of simulation capabilities, *using tools supplied by the same vendor*.

With these improvements, CAE expert analysts will continue to use these environments to more effectively achieve the following:

- Support product development by running "routine" simulations – this often becomes their main responsibility, unless they are part of a dedicated "methods team"

Making the Full Power of Simulation Available to Everyone



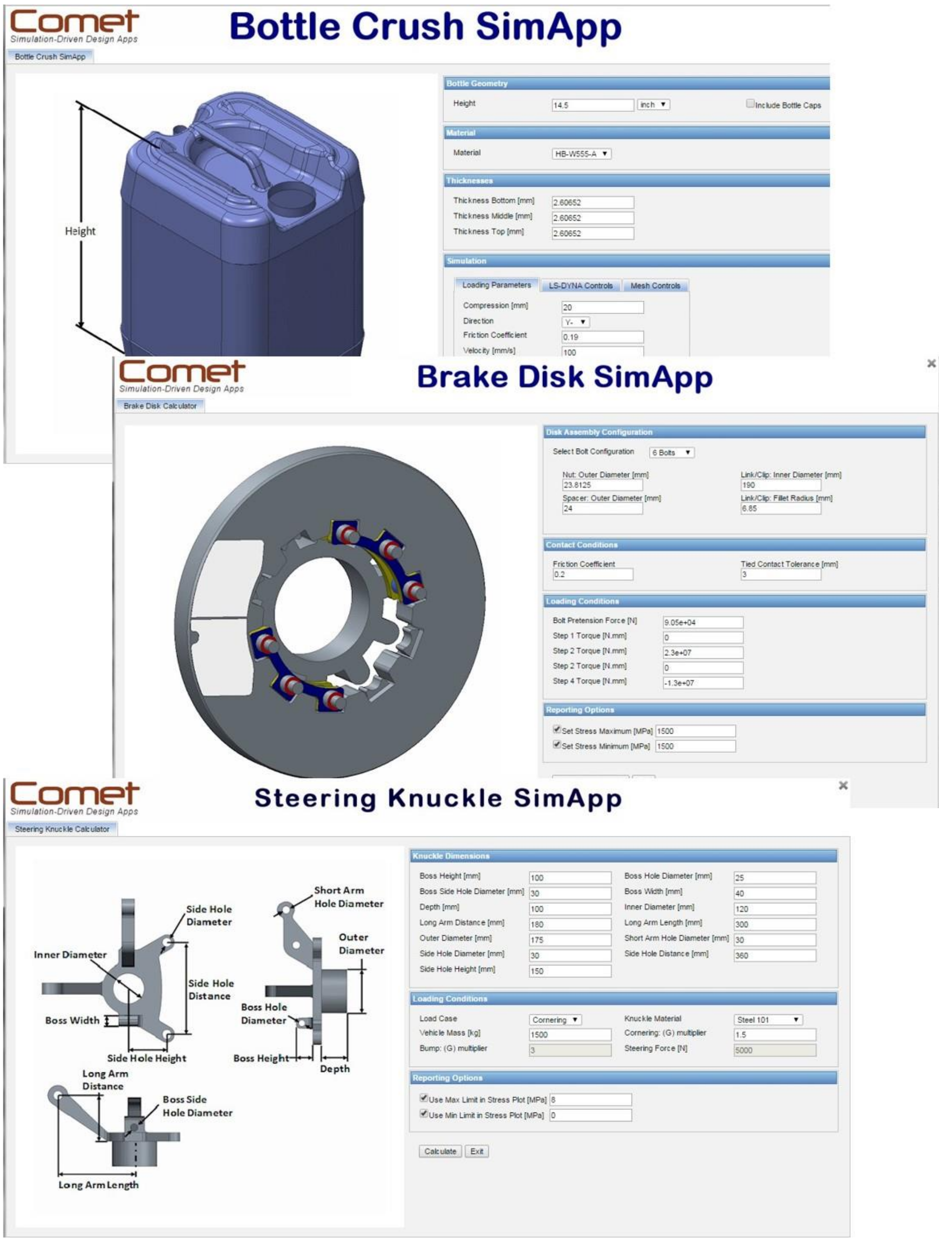


Figure 4.2: Examples of SimApps powered by Comet Automation Templates. Using abstract modelling, each template works robustly across geometry, topology and configuration changes, and across a Product Family that shares a common functional architecture.

- Explore how best to analyze a design that is (significantly) new
- Validate models against theory and test results
- Improve simulation best practices of the company – better results, faster turnaround, testing new numerical techniques and capabilities, adding new physics
- Debug issues in models run by non-experts

CAE non-experts such as designers, systems engineers and junior analysts can also use these environments for simulation. However, we believe that regardless of how simple these general-purpose tools are made and how much "intelligence" is baked into them to guide non-experts, the types of simulations that can be safely performed are usually the simplest ones – e.g., component-level linear statics, modal, and steady-state thermal analyses. This has been amply proven over the last 15-20 years. Non-experts cannot be expected to correctly and rapidly set up assembly-level models, even as these general-purpose tools become easier to use.

Solution-Specific Vertical Applications such as SimApps

Almost by definition, solution-specific SimApps are much simpler and more efficient to use, and also, narrowly-scoped – each SimApp is limited to answering particular product development questions for particular products, at a particular level of model fidelity. *However, as SimApps have captured the expert rules and best practices, non-experts are able to run sophisticated calculations rapidly and safely, across a wide range of the design space, including across an entire product family*. SimApps require minimal input from the user and use the language of the user, not that of the underlying CAE tools.

Also, the experts themselves are now able to run "routine" calculations much more rapidly and accurately. For example, in the Intel® (Section 6.2) and the AAM (Section 6.1) cases, experts using Comet's SimApps are seeing significant efficiency and accuracy gains – at Intel®, going from months/weeks of expert time to days/hours or less of non-expert time for highly complex socket stack calculations, deployed on the Web for broad global access to Intel engineers and to their customers.

Comet Solutions is demonstrating, without doubt, that there is a strong appetite for their SimApps, and that this is the way to bring simulation to large numbers of non-experts in a safe and useful way (see examples in Section 6). Adding ubiquitous, mobile access to SimApps on the Cloud, increases their appeal and utility.

<u>The case for both types of simulation tools is clear and strong.</u>

6. Cases Studies – Demonstrating the ROI for SimApps and "Lights-Out" Simulation Automation

Let's review a few production case studies that demonstrate how lights-out automation and the related SimApps are being used, and describe the benefits that have been experienced, so far.

6.1 American Axle & Manufacturing (AAM)

AAM is a global tier 1 supplier of integrated driveline products. One of their major competitive advantages is the proven capability of integrating driveline components to ensure optimal dynamic performance for quiet and anonymous operation. This normally requires extensive computer simulation and experimental validation by Noise-Vibration-Harshness (NVH) professionals. The simulation effort is further complicated by the fact that on a typical light truck platform it may be necessary to evaluate over 100 combinations of propeller shaft and axle designs to cover the broad range of body styles and powertrain combinations. The NVH specialists at AAM have refined their simulation models and have demonstrated excellent correlation to test data up to the 800 Hz frequency range. The models will typically include several variations of axle models coupled with a large number of variations (>30) in propeller shaft design. Furthermore, it is common for the engineering teams to request design studies on the propeller shaft or interface design features. This results in numerous requests between various engineering teams to perform the studies. Additionally, the models have been historically defined in a manual entry fashion that lends itself to data entry errors or misinterpretation of design requests, and a lack of traceability to design revision levels.

This type of application is a perfect opportunity for simulation automation and forward deployment of simulation tools. AAM and Comet Solutions cooperated to develop a simulation template that captured the topology of simulation driveline models using model definition templates that are graphical and readily incorporate historical databases for critical component properties. This driveline model template enables the NVH expert to define the sophisticated dynamics model of the axle centre-section, and then use the fully automated process to perform the simulation to the defined standard, creating a standardized results summary (Figure 6.1.1). The template accesses the component parameters through standard data sheets managed within the engineering PLM software, ensuring model integrity and traceability.

The advantages of this usage scenario are numerous:

1. Use of databases of modelling parameters/properties for the numerous simulation iterations that are performed, ensuring repeatability and accuracy of the simulation models.

2. Forward deployment of the simulation tool to propeller shaft application engineers to be used in consultation with customer integration teams.

3. Improved quality through globally enforced standards and practices, removing human error.

4. *Average 75% time reduction for each iteration.* This allows us to run many more NVH iterations, leading to more design decisions, earlier. The experts are no longer a bottleneck in the process.

AAM has also utilized this approach to automate upstream detailed component models used in architectural studies early in a program. One of the more critical aspects of axle design is the selection of bearing architecture and the requisite analysis to ensure bearing durability, acceptable stiffness for NVH performance and protecting against degradation from build variation and thermal extremes.

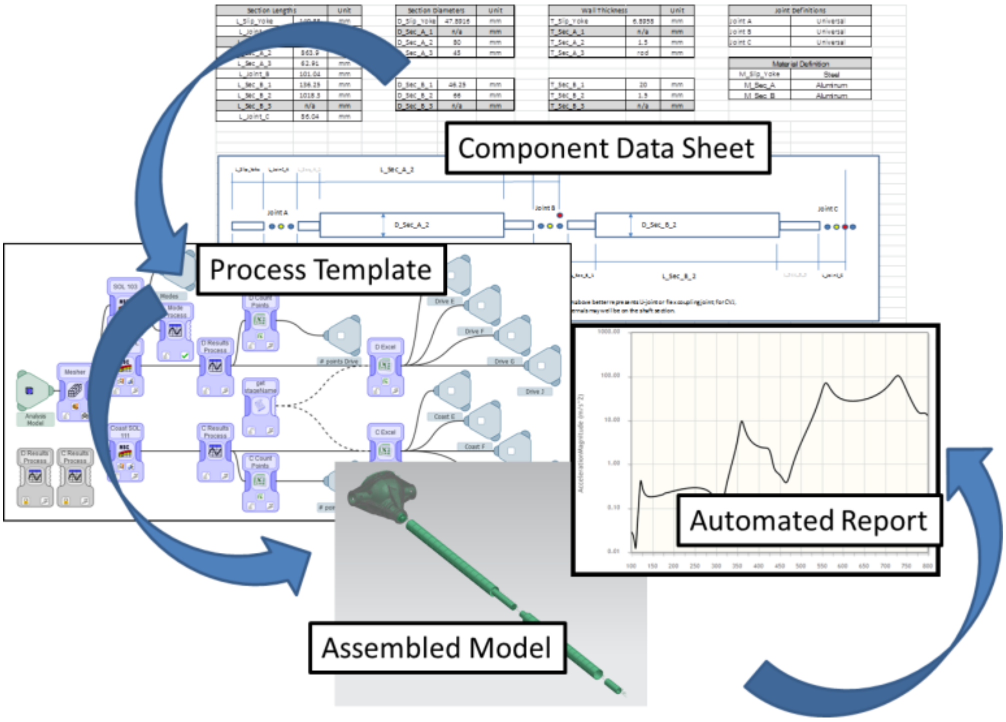


Figure 6.1.1: Use of a Comet SimApp to fully automate the assembly and analysis of a driveline model, including automated report generation.

Detailed models for bearings and gear assemblies are required to perform durability assessments early in the concept stage. These models rely on spreadsheet and generic calculations to develop the input. Human error and interpretation of sign conventions, coordinate systems and values can be even more challenging in a global collaborative engineering environment. Process automation using Comet SimApps alleviates many of these hurdles, removes human errors, and helps standardize the process. Gear deflection and bearing force calculations were automated, with data imported from drawings.

Process automation using Comet SimApps has enabled standardization of accurate, consistent and repeatable CAE processes, executed globally (Figure 6.1.2). Full traceability of CAE input and output data ensures problem solving and rapid response to design changes. Our CAE engineers can now run multiple iterations in a single day, thus allowing for statistical comparison and understanding variation better.

The savings in time and improved productivity will pay back the investment within a couple of years. The business case for deploying such tools does exist and, with the right partnerships in the industry, it is possible to make greater strides in “virtual reality” as a suitable, feasible and less expensive complement to physical testing.

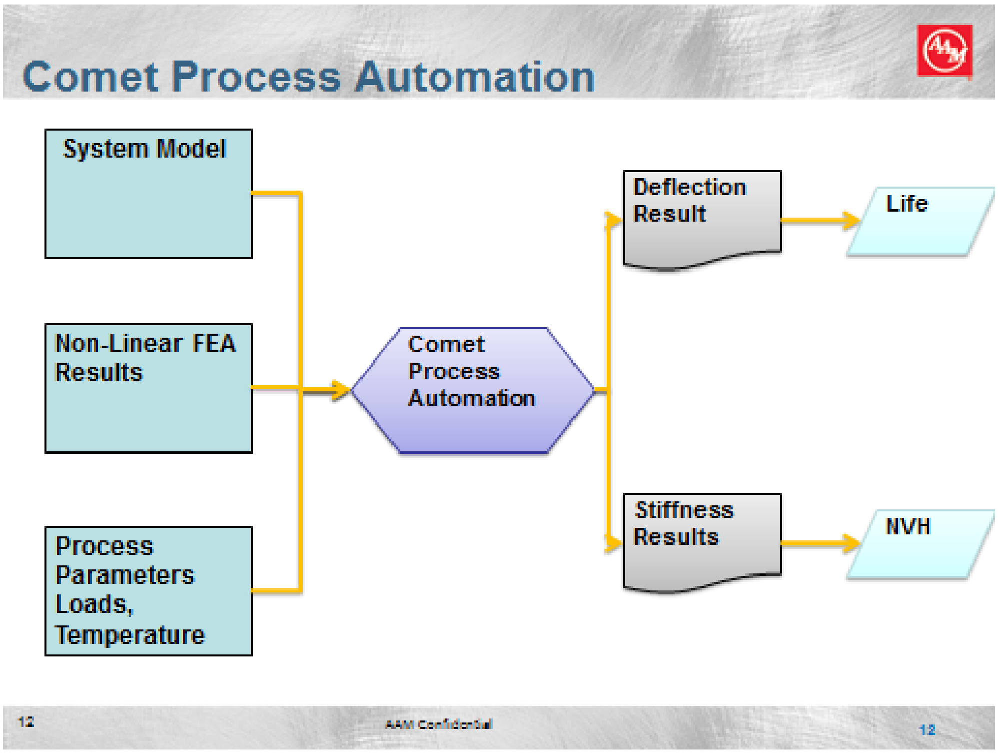


Figure 6.1.2: Automation of best practices from System Models of varying fidelity to product performance.

6.2 Intel® Corporation

Intel® utilizes structural analysis technology to optimize both component and system level designs. The purpose is to reduce the number of design cycles while improving the durability and function of the design for a variety of end user applications. Intel® expects complex analyses to be completed quickly (usually <1 week) which requires a high level of standardization and expertise. The business environment also requires the ability to communicate and enforce Best Known Methods (BKM's) between engineers. Both of these goals are difficult for the typical structural analysis engineer to achieve and thus only select designs are fully analyzed due to time constraints.

Comet Solutions has provided a simulation automation environment with depth and adaptability. Using this environment, we have been able to create automation templates that support Intel®'s complex, large, heterogeneous and multi-physics problems. In this section, we will illustrate this capability via two examples:

1) The component level analysis of a simple leaf spring with difficult design requirements.

2) System integration of the complex structural components that are required to analyze the thousands of electrical connections of a Xeon socket stack on a PC system motherboard, which need to perform flawlessly under adverse conditions.

6.2.1 Component analysis – keep a simple leaf spring simple

Component level modelling is a fundamental approach to rapid design optimization. The designer produces CAD and hands it off to the structural analyst who then creates the engineering analysis model and meshes it using *engineering judgment*. Next the structural model is executed to determine its static, transient, modal, and frequency response, and possibly nonlinear responses, depending on the expected worst case scenario, using *engineering judgment*. Finally, the results are interpreted, again using *engineering judgement* to produce various key metrics calculated from the results. Despite the relative ease of doing component level analysis, the turn-around time is typically between 1 day and 1 week because of resource availability issues.

Although the actual component level analysis is quite easy to construct and execute, it is good "engineering judgement" that is critical to getting high levels of returns on the time and money invested in the structural analyses. This has often been observed in our design teams at Intel® –

the designers would like rapid results but lack the experience and confidence to perform the analyses themselves.

Intel® has worked with Comet Solutions to achieve two objectives related to component level analysis: (1) Capture *expert engineering judgement* in an executable, knowledge-based format that survives the experts, and (2) Automate the analyses so that non-experts can *easily, rapidly and safely* perform them with minimal, intuitive inputs that are familiar to someone like the typical designer (geometry, dimensions, input force levels, and bolt locations) using engineering language and not the language of structural analysis. These two objectives have been successfully achieved.

The leaf spring model and results

This model is a leaf spring that provides the forces needed to press a heatsink against a CPU Package as shown in Figure 6.2.1. The spring geometry envelope is highly constrained, but there are high loads expected while maintaining low stiffness, a very common scenario for heatsink loading systems in the presence or real world tolerances.

In Figure 6.2.2, the BC and Loads are applied along with the contact simulation data. Despite the simplicity of this modelling, it took several hours to properly create the contact parameters to be satisfactory.

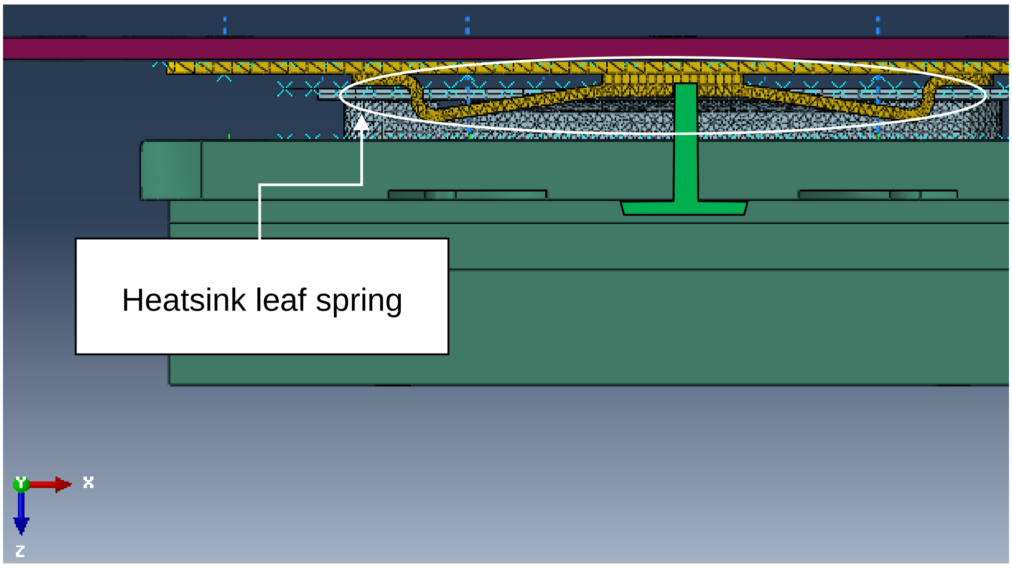


Figure 6.2.1: Heatsink Leaf Spring as Part of a Larger Assembly

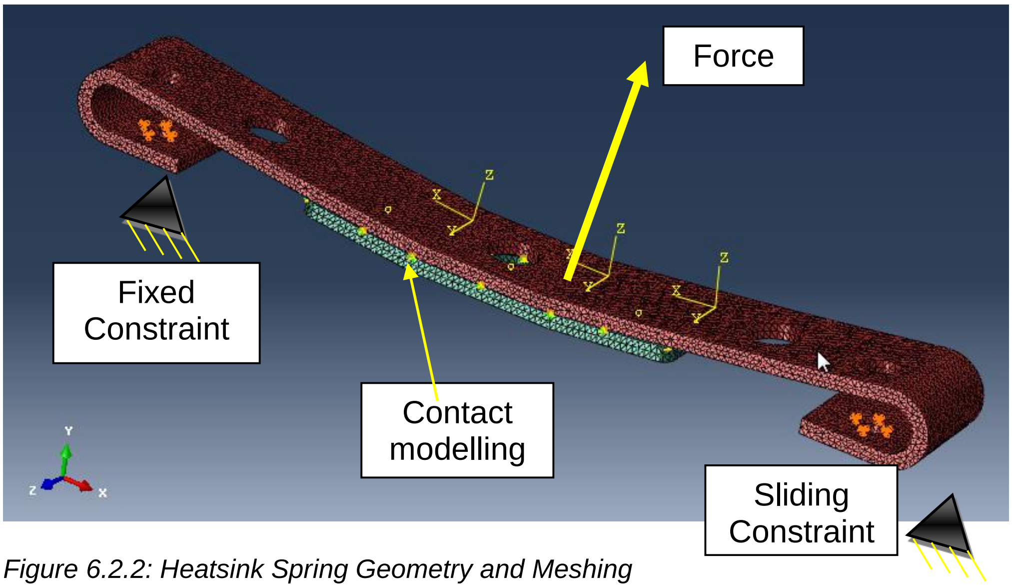


Figure 6.2.2: Heatsink Spring Geometry and Meshing

Figure 6.2.3 shows a typical fringe plot from the Abaqus post processing environment that an analyst might use to assess design pass-fail.

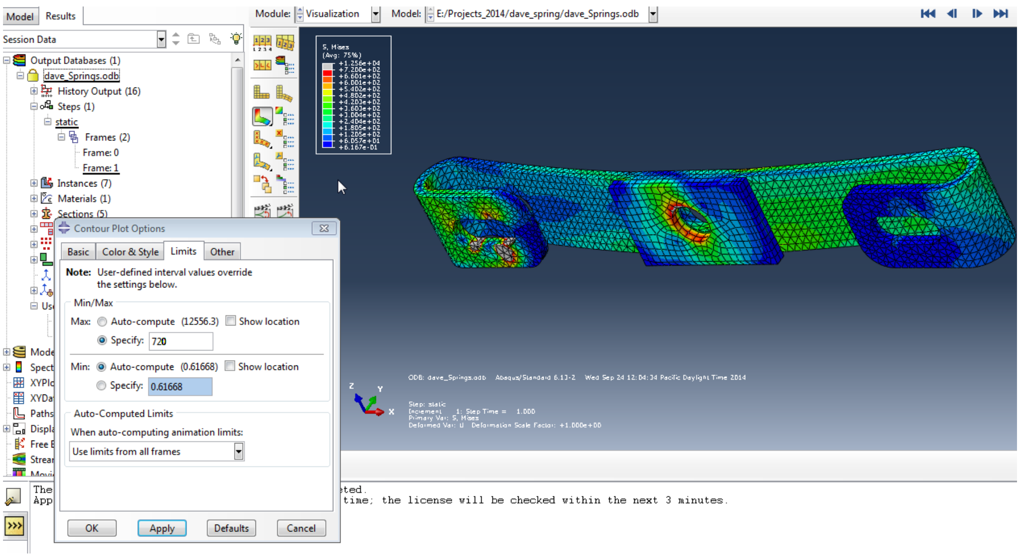


Figure 6.2.3: Heatsink Leaf Spring Von Mises Stress

This model has several opportunities for over-constraining and misinterpreting results for the engineer new to structural analysis. More importantly, the contact requirement introduces many opportunities for non-convergence. Thus in the next section, we will show how Comet Templates and SimApps were used to eliminate these potential errors and shield the non-expert user from analysis errors.

Heatsink Leaf Spring FEA Template and a web-deployed SimApp

After the FEA model is validated and "made safe" across multiple designs of the leaf spring and multiple scenarios, a Comet Template and a web-deployed SimApp are created, capturing this expertise for reuse. First, the model expertise/knowledge is incorporated into a template using Comet's authoring environment (Figure 6.2.4) – in this case, it took no more than a few hours. What is important to note is that the template can be used across multiple spring designs and is independent of the type of input CAD – Creo, SolidWorks, NX, etc.

Next, a web-deployable SimApp is created (Figure 6.2.5). This is a GUI front-end that creates a simple access point for the leaf spring calculations. The platform currently used by Comet Solutions for the creation and deployment of these SimApps is EASA [17].

The designer and analyst work together to decide what the key input variables (geometric and non-geometric) are going to be and these are built into the SimApp. The geometric parameters work regardless of the type of CAD that is supplied as an input to the SimApp. In the next version of the SimApp, the user will also be allowed to set up an optimization run using tools such as Isight and HEEDS.

Next, the metrics that are key to making design decisions and providing results reports are determined. Most often, these are fringe plots, peak deflection and Von Mises stress. The Comet Template automates the extraction of this data (scalars, tables, plots, fields, and images) and the generation of an HTML report that is easily shared within the team.

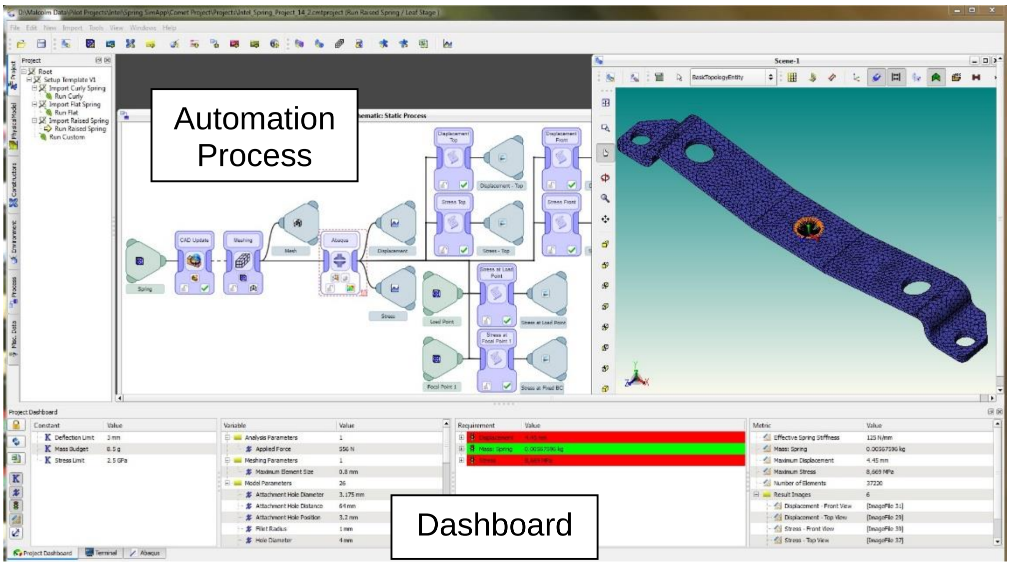


Figure 6.2.4: Heatsink Leaf Spring Template shown in Comet's Authoring Tool

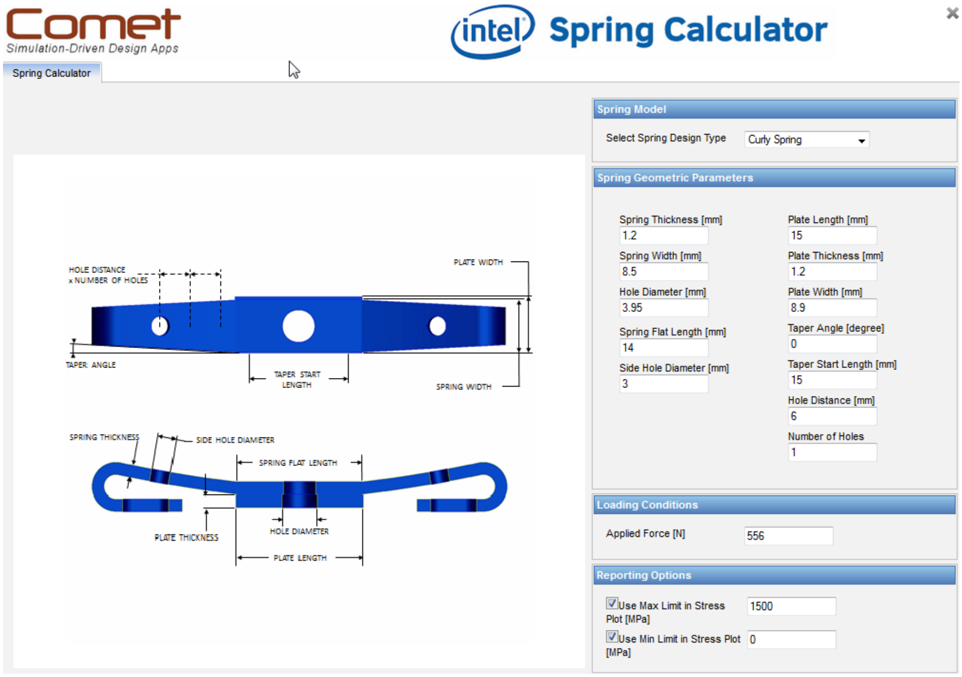


Figure 6.2.5: Spring Calculator SimApp showing geometry, force and report generation input parameters – “speaking the language of the engineer”, not CAE

Figure 6.2.6 shows the metrics of maximum displacement, mass, and maximum stress used to make spring design decisions. These are compared to the design requirements and coloured green for low risk, yellow for medium risk and red for high risk.

Now, a designer is able to log in to a SimApps portal at Intel®, select this SimApp and conduct multiple analysis of their spring design without any additional input from an expert analyst. Further, the designer can not only use existing spring designs from a library, but can upload a new CAD design that is then analysed. The Comet Template is smart enough to constrain and load the new geometry appropriately. This simple but intuitive interface puts powerful simulation directly in the hands of designers, requiring little or no input from expert analysts.

6.2.2 Assembly Modelling – complex Socket Stack nonlinear structural analysis

One of the more difficult structural modelling problems in electronics is the detailed Ball Grid Array (BGA) attachment scheme used to connect small silicon chips and packages to a motherboard (MB). As shown in Figure 6.2.7, the solder balls are quite small (~1mm in diameter). There are many of these simultaneously reflowed (melted) to cause the interconnects to a matching set of copper pads on the MB, resulting in a reliable electrical connection that must survive adverse conditions.

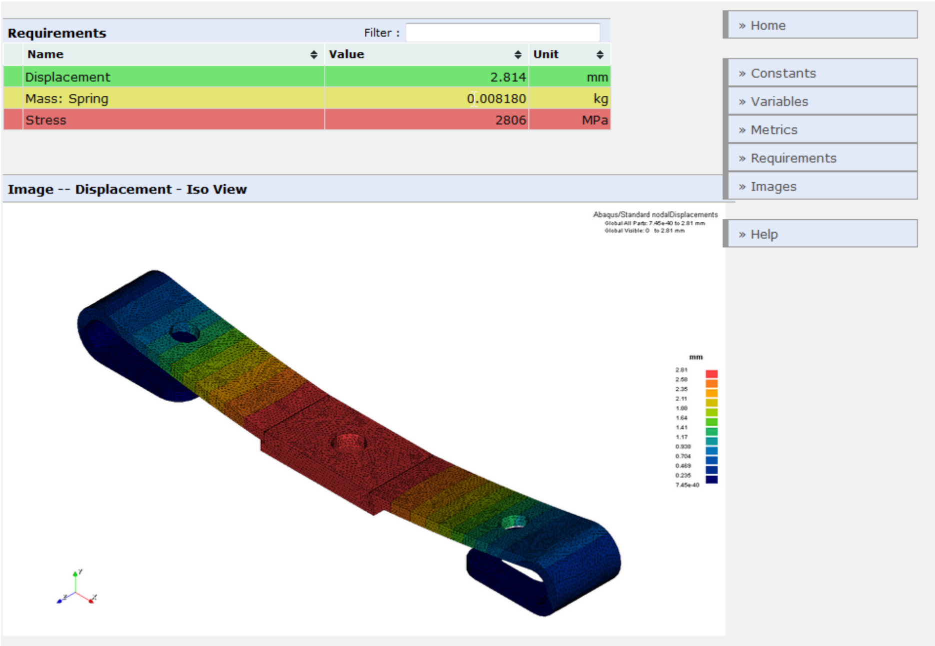


Figure 6.2.6: Metrics, requirements and images in the auto-generated report

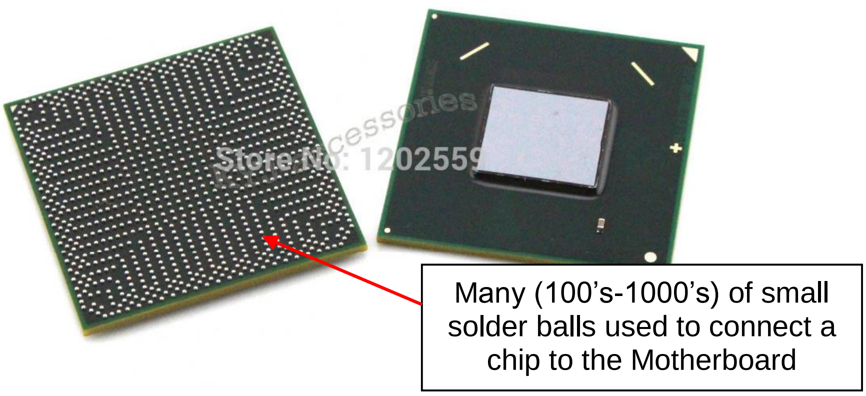


Figure 6.2.7: Typical BGA pattern

Another BGA based structure frequently used for CPU integration to MB systems is referred to as a socket, of which there are several varieties. Sockets provide a means to easily install and replace CPU's without the need to do any soldering. For this report, we will focus on the LGA socket approach which has become common for Intel® integrations. Figure 6.2.8 shows a typical installation to a MB with a mounting structure designed to trap and seat the CPU with a clamping force. Figure 6.2.9 shows a top view of the "springy bed of nails" and a bottom view with the BGA pattern that gets soldered to the MB.

It should be noted that these small BGA solder balls are susceptible to cracking and complete debonding in the presence of dynamic shock and fatigue events. Thus, there is a strong impetus to numerically

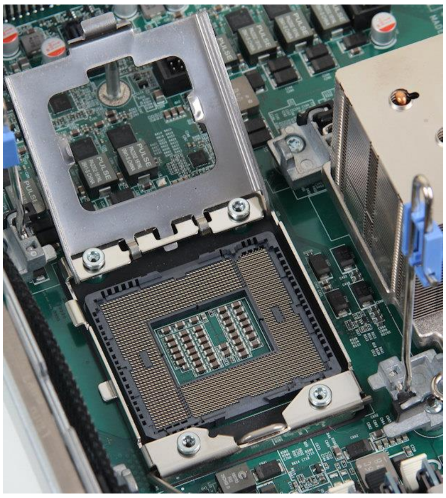


Figure 6.2.8: Typical Socket Installation on a MB

predict solder ball stress and predict failures. This is accomplished at Intel® using nonlinear FEA modelling of the socket stack assembly using Abaqus. The model captures all of the connections so that failures, at the individual connection level, can be predicted.

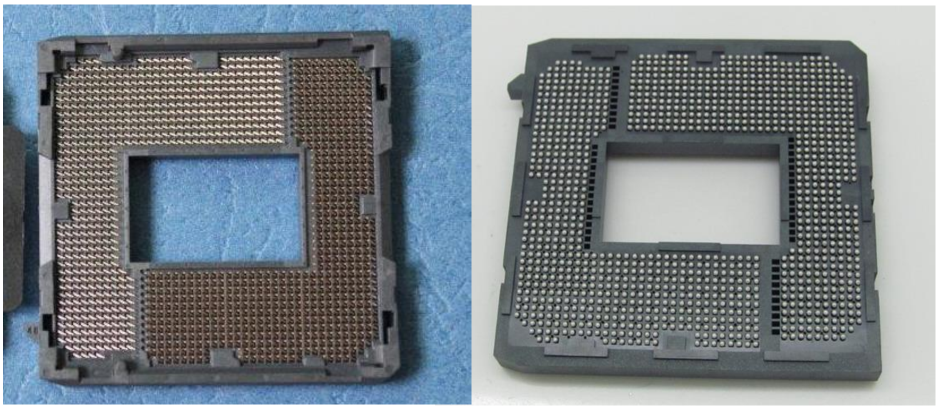


Figure 6.2.9: Socket LGA and BGA Patterns

Unfortunately, with the 1000's of solder balls, each being a complex stress problem, the FEA model is huge and can overwhelm even computers with the highest memory and best CPUs. Thus, the model uses various engineering approximations and idealizations. More recently, Intel® has started using substructures (or super-elements) in Abaqus to maintain stiffness and stress accuracy via Guyan Reduction. Sometimes, Component Mode Synthesis is utilized if the component has significant low frequency constrained modes. A further complexity that occurs in modelling a socket system is the number of supporting structural elements that play a significant role in solder joint loads.

We will refer to the system this comprises as a “Socket Stack”.

FEA Model of the Socket Stack Integrated to a Testboard

The purpose of this analysis is to simulate shock, vibration and modal response to guide design decisions for CPU clamping, socket design, and retention bolt design. The primary metric for decisions is the solder joint force and a secondary metric for decisions is the MB strain.

This first and most complex part of this model is the socket stack itself. Figure 6.2.10 is the exploded view of the socket stack DEA model. There are many types and numbers of interconnects and contact abstractions required in this model and any change to the geometry of a component requires redoing the interconnects. *This is the most error-prone and time-consuming activity that is eliminated by using Comet Templates.*

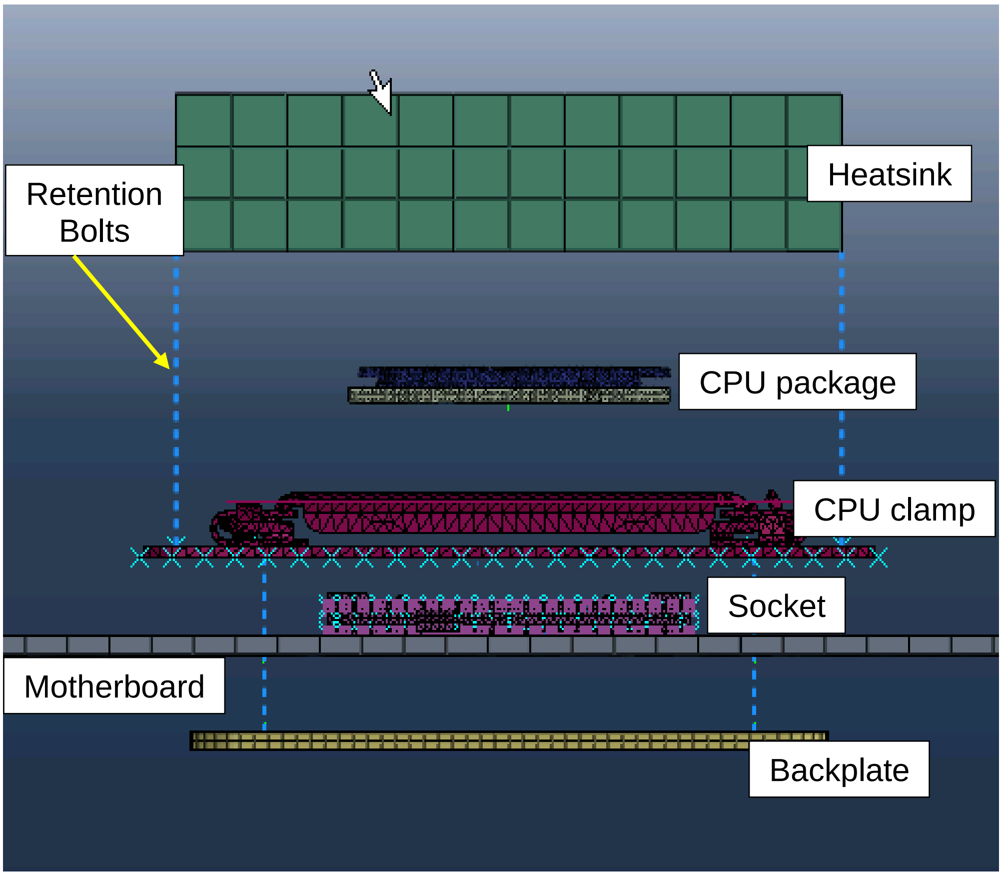


Figure 6.2.10: Exploded Socket Stack FEA Model

Figure 6.2.11 shows an exploded view of some of the socket body, solder joint, and critical contact point idealizations involved in an accurate simulation of the socket. These features are very complex to setup and frequently cause mysterious instabilities in solutions, when not set up correctly. When done manually, this is a highly error-prone process. ***A Comet Socket Stack Template fully automates the creation of all of these interconnects, even as the geometry of the components changes.***

Finally, Figure 6.2.12 shows the various components assembled to the system model, a shock testboard. Some of these components have been converted to substuctures for computational efficiency. There are additional interconnects, representing tying components together and contact simulation. All of these are manual steps that the Comet Template fully automates.

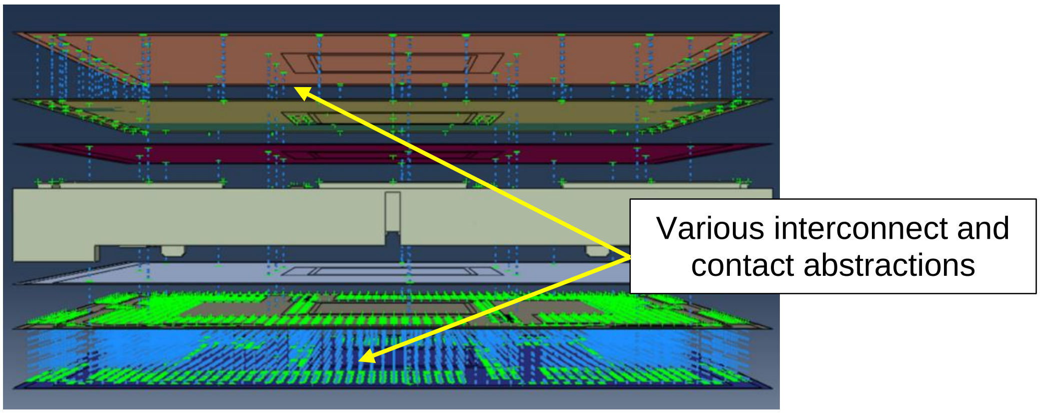


Figure 6.2.11: Exploded Socket Body and Joint Integration (large complex patterns of solder joints and bolts)

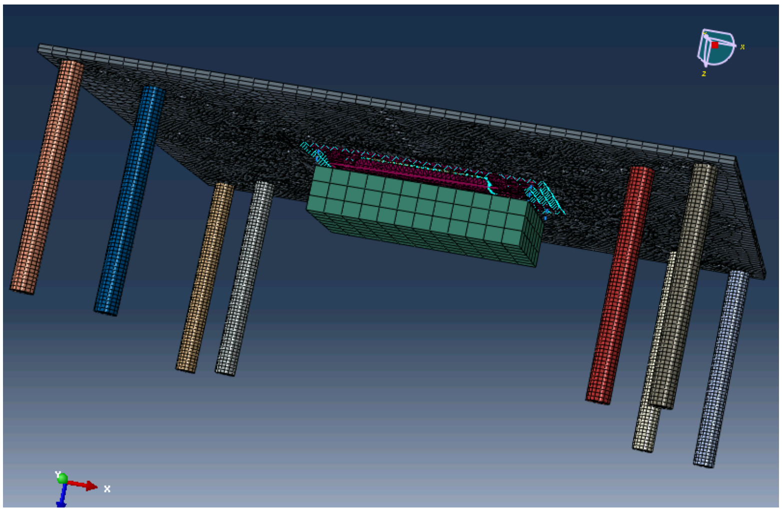


Figure 6.2.12: Integrated Testboard with a Socket Stack

The Comet Socket Stack Template and Web-Deployed SimApp

The construction and debugging of a socket stack model typically takes an expert 3 months. Integration of the stack to different MB systems requires an additional 4 weeks for each new MB. Further, it is not possible to speed up either step by adding more expert analysts. This is too slow to meet time-to-market requirements. Model simplifications and engineering judgment are used to guide design decisions until the integrated system shock models are completed. Thus, there was strong interest in automating/standardizing methods of socket stack modelling.

After assessing different tools, Comet was selected as the platform for expertise capture and automation of socket stack simulation. Besides a need to greatly reduce errors and time, inherent to manual model building, the primary reasons are (1) ability to automate processes that require multiple, multi-vendor tools, (2) the technical capability of the Comet staff, and (3) the demonstrated ability to fully automate a highly complex, manual process and deploy it on the web as a SimApp.

Figure 6.2.13 shows the workflow that needed to be captured in a Comet Template and deployed on the Web using a SimApp. The blue blocks are portions that represent the expertise of the analysis experts and are made accessible to the end user via the automation template. The green blocks are the selected variables the non-expert user is allowed to modify and the outputs that can be examined. The Comet Template allows creating new geometry in the designers' CAD software (e.g., PTC/Creo, SolidWorks, NX or SpaceClaim) and automatically regenerates the required Abaqus super-elements and model files.

The SimApp provides a simple interface to the user for the input of the various components of a Socket Stack. For each component, the user has the option to supply new CAD or an existing super-element, and can modify parameters associated with the component. **The template fully automates the following tasks:** (1) Create super-elements, if needed, (2) Assemble all the components into a single coordinate system, (3) Create the required connections between them (1000's), (4) Generate the Abaqus input files for the model, (5) Run Abaqus on a local or remote cluster machine, (6) Perform post-processing operations on the results data from Abaqus, and generate a report with the key results associated with the solder joint performance.

Figure 6.2.14 shows the Comet SimApp that drives the templates, enabling the engineer to change any part of the stack and have the model be reliably regenerated, automatically. ***What had taken weeks/ months of expert time can now be done accurately and safely in minutes/hours by an engineer who is not an expert analyst.***

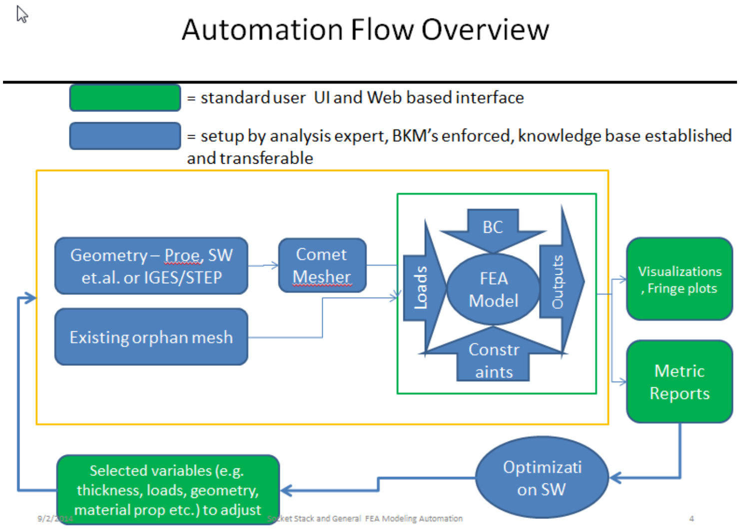


Figure 6.2.13 Flowchart for Codification into a Comet Template

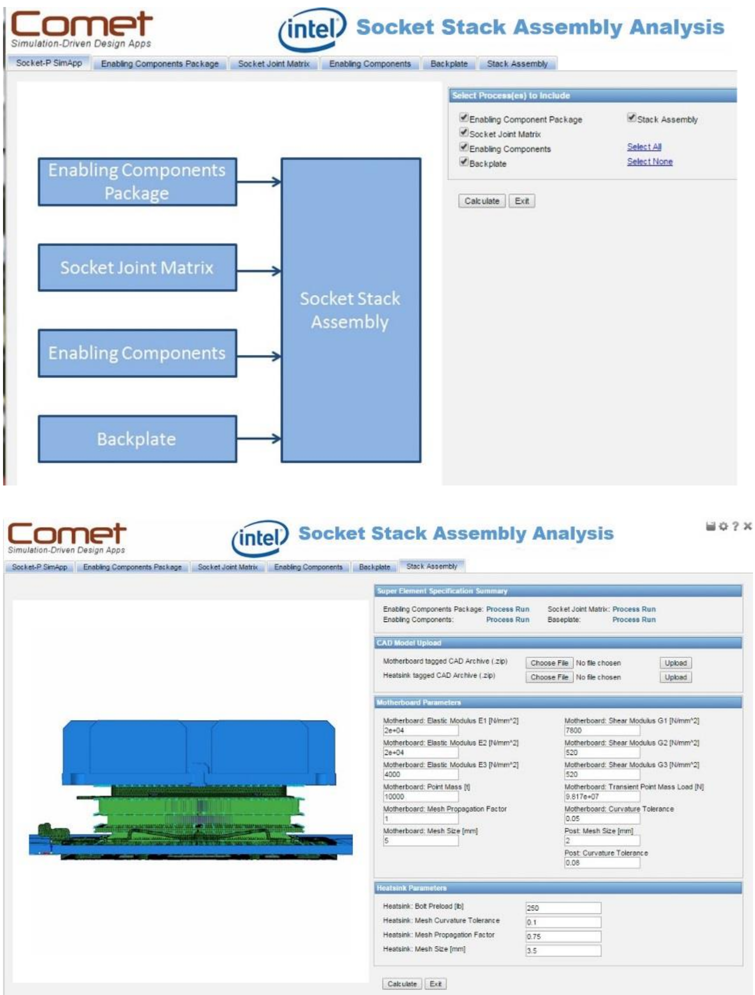


Figure 6.2.14: The Socket Stack SimApp for fully-automated nonlinear analysis

6.2.3 Benefits of Using Comet SimApps and Templates

The following benefits have been realized at Intel®:

- Capture and enforce expertise in executable Templates
  - Capture Best Known Methods (BKM's), analyst expertise and Intel® best practices
  - Enforce these standards when running Templates – this provides global process and data consistency and avoids non-convergence issues which are quite common
  - Provide standard global metrics for the assessment of the robustness of the designs
  - Avoid disruption by using existing software (such as Abaqus) and licenses – minimal IT footprint
- ***Order of magnitude efficiency gains for socket stack analyses, while maintaining accuracy and enforcing BKM's***
  - Reduce 1-3 months to 1-3 days per iteration
- Better leverage design and CAE personnel
  - Ability of non-expert designers to run trade studies on expert-developed models, even for complex analyses
  - Utilize best-known/validated models from different divisions across the global organization using SimApps
- Enable external customers (PC system designers) to perform socket stack calculations without the need for Intel® experts
  - These customers can run complex socket stack calculations, using Intel®-generated super-element models
  - Metrics obtained are standardized and easier to interpret
- Easily extend current templates and SimApps
  - Support multiple socket stacks for MB and MTB analyses
  - Create an ever-expanding set of analysis automation templates, such as the Leaf Spring SimApp, for designers

Given the significant benefits already realized, Intel® will continue to utilize Comet Solutions' automation templates to better leverage its CAE investments to achieve Simulation Driven Design.

6.3 Magna Cosma Engineering

Meeting all of the customer’s requirements while accommodating manufacturing limitations with a tight constraint on timing has always been a challenge. This challenge has been no different at Cosma International, a wholly-owned operating unit of Magna International, one of the leading automotive suppliers for body and chassis systems.

The traditional work flow from the conception of an idea, design, CAD generation and analysis quite often leaves the simulation group at the end of the chain and with very limited time. Yet, the list of analysis requirements and the expectation for CAE to drive design is becoming more demanding. CAE is no more just a “service group” responsible for analyzing and reporting results but is integral to proposing design changes and making sure that performance, weight and cost targets are met. This paradigm shift in the role of CAE engineers has exponentially increased the type and volume of simulations that are required.

This exponential increase has required the creation of standard ways to automate various tasks from pre-processing and modelling through post-processing. Standardization and automation help in decreasing the human errors and also reduce fatigue in the engineers performing the same repetitive jobs. Automation also helps in reducing the cycle time for each of these simulations and the accuracy of setting up the models. Cosma was actively working towards these goals of standardization and automation when we decided to collaborate with Comet Solutions.

The Comet Workspace is a simulation template authoring tool that was implemented to unify the CAD and analysis groups and their processes. A fully parametric model developed by the design team is used as the starting point. Our simulation best practices are rapidly captured in a Comet template and then the meshing and assembly tools within Comet are used to automatically generate the analysis model files, even as the design changes significantly. Once the analysis is complete, the template automatically post-processes the results, places key values in a dashboard and generates reports. These results are easily reviewed by the analysts and their team of engineers to make further changes to the design via the parametric model, directly within Comet.

Since the CAE analyst can now make section changes in few minutes, without the need to request updated CAD from the CAD department, the overall turnover improved along with accuracy and repeatability. This process is capable of being applied to an optimization process either through a DOE based or gradient based analysis loop.

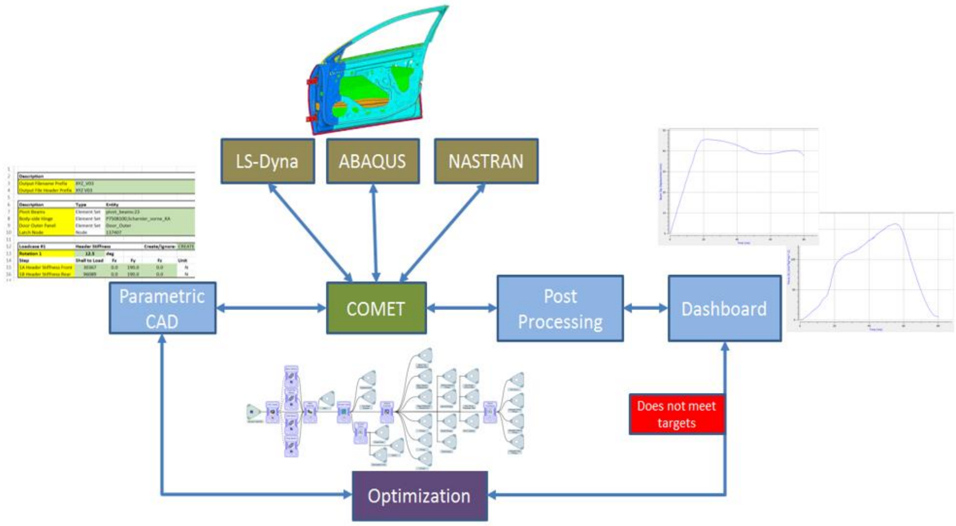


Figure 6.3.1: Comet automation templates – inputs to report generation

The project demonstrated the powerful capabilities of Comet within the Cosma environment (Figure 6.3.1) when used in a production project. As a result, Comet has now been chosen to be used across the CAE department for simulation automation and optimization.

The CAE group has seen tremendous increase in process and timing efficiencies when using Comet's templates for automation. Also there has been a significant decrease in user errors. This efficiency in cycle time has freed the engineers to perform other value-added functions such as optimization and to innovate on the design. Comet has replaced numerous home-grown macros that were previously created and used by engineers. This makes it easy for centralized creation and enforcement of CAE standards. Ease of distribution and installation is also achieved. The biggest advantage Cosma has realized is the amount of time available for the engineers to perform other engineering activities that add more value than spending time on repetitive pre- and post-processing tasks. The increased iterations and different types of simulations able to be performed in a short period of time have led to better engineering decisions, and hence, better designs more rapidly.

Comet has the potential to be an integral and enabling part of all simulation activities at Magna Cosma, globally. We believe that it will play a vital role in the automation of engineering processes at Cosma and at other similar manufacturing organizations.

7. Bringing it all together – *Simulation for Everyone!*

In this paper, we have demonstrated how the Comet Automation Platform enables users to rapidly create automation templates and SimApps to achieve the following:

1. Lights-out automation that works robustly across geometry, topology and configuration changes to a design, and across a product family – from *"Parametric Analysis CAD to reports in a single click!"*

2. Capture/enforce simulation best practices in an *executable* form

3. Empower salespeople, designers and system engineers (CAE non-experts) to *safely* perform sophisticated simulation

   - Enforce engineering analysis data and process consistency globally, even with non-experts

   - Provide consistent, accurate and traceable simulation data transport into/out-of global enterprise PLM

4. More effectively use DSE tools (optimization, DOE, Robust Design) by using Comet's templates for design assessment

   - Automated DSE is a key requirement – this is the ultimate goal of users performing product simulation – Simulation Driven Design

   - DSE tools, using Comet's templates, can now explore a much wider range of the design space, parametrically making geometry and topology changes, and even automatically swapping entire components

5. Provide global access to SimApps deployed on the Web – solution-specific simulation applications that drive templates (see Section 6) and use the language of the non-expert product development user

6. Provide access to infinite/elastic computing hardware in "the Cloud" – either inside or outside a company's network – via the SimApps

   - Increased, elastic, on-demand computing – access larger numbers of computational cores, only when needed

   - *With the lights-out automation of SimApps, businesses locked out of leveraging simulation due to the fixed high cost of ownership, can now access simulation tools and expertise (captured in the templates), as and when they need it and can afford it*

The time has come – all of the ingredients now exist for making simulation available to everyone who needs it, on a wide scale. We must stop believing that simulation tools can and should only be used by those that have a deep understanding of how they work. There is tremendous value embedded within these tools – we are already unlocking this value for a broader user base that can immediately benefit from it.

Ultimately, and most importantly, we have demonstrated that the long and torturous learning curve associated with CAE tools is *not* required to safely leverage their power. *Bringing the full power of simulation to everyone is achievable.*

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