SIMSOLID™
simulation reinvented

WHITEPAPER
SIMSOLID Technology Overview

Highlights

Abstract

Computer Aided Design (CAD) and Computer Aided Engineering (CAE) are intrinsic parts of modern engineering. CAE simulation tools are extremely important because they allow for performance validation and optimization of a product design before the product is physically created. Today this is typically done using software based on Finite Element Analysis (FEA).

The weak link in traditional FEA is the need to create an accurate and efficient finite element mesh. The meshing process would typically fail if done on original geometry, or produces excessive number of elements which would often make FEA impractical. In case of assemblies, incompatible meshes on adjacent parts make handling part connections extremely difficult. In practice, geometry model simplification is a must for a successful FEA. But the simplification is a non-trivial step which requires a highly skilled specialist in both FEA and CAD technologies.

SIMSOLID™ is intended to drastically streamline simulation process and increase engineering productivity by replacing the underlying FEA technology, rather than through improvements to user interface. New technology eliminates the most failure-prone and skills/labor consuming stages of analysis process.

This whitepaper was written to provide users of SIMSOLID simulation software with basic understanding of how the technology works. Technological foundations of SIMSOLID are discussed with respect to mathematical background, computer implementation, and positioning among other numerical methods.

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Product Summary

SIMSOLID is a simulation software application which performs statics, dynamics and thermal, analyses of structural systems. SIMSOLID always uses fully featured, not simplified, solid geometry models in the analysis and does not use a mesh.

The SIMSOLID computational engine is based on breakthrough extensions to the theory of external approximations. External approximations are a generalization of Finite Element Method (FEM) in terms that:

- absolutely arbitrary geometrical shapes can be used as "finite elements"

- basis functions which approximate field of interest in the "element" can be of arbitrary class and are independent of the "element" shape, alternatively to strictly structured polynomials used in conventional FEA

SIMSOLID controls solution accuracy using multi-pass adaptive analysis. Adaptivity can be defined on a global or part local basis and adaptivity is always active. SIMSOLID provides smart connections for bolts and welds to make assembly modeling easier and more robust. The SIMSOLID methodology is fast and efficient. It provides superior performance metrics for computational time and memory footprint that allow very large and/or complex assemblies to be solved quickly on desktop class PC's.

SIMSOLID Theoretical Background

In the following we will discuss the theoretical background of SIMSOLID and its software implementation workflow then compare it to methods used in traditional FEA.

OVERVIEW OF INITIAL RESEARCH

Ritz-Galerkin method invented at the beginning of 20th century for approximate solution of boundary value problems assumed that functions that approximate the solution are analytical functions defined on the whole domain of interest. In practical applications these functions were either trigonometric or polynomials which were infinitely smooth,

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i.e. they had infinite number of derivatives. There were two main problems with such functions. First, it was difficult or impossible to construct such functions that a priori meet essential boundary conditions on boundary of arbitrary domains (in structural analysis the conditions appear as displacement constraints). And second, the equation system built on such functions was ill-conditioned and numerically unstable which did not allow solving real life problems with sufficient accuracy.

Finite Element Method (FEM) appeared in 1950s was just a different implementation of the classic Ritz-Galerkin approach, but it succeeded in solving of both – constraints and numerical instability issues because it consistently used functions with local supports called finite elements. Though locally the basis functions of finite elements were infinitely differentiable standard polynomials, global basis functions assembled from local polynomials were not smooth at all – even their first derivatives were discontinuous. FEM success proved that requirements to continuity of the approximation functions should be met only to a certain degree - just enough to provide finite energy when they are substituted into energy functional of a boundary value problem. The spaces of such functions were introduced and investigated by Sobolev in 1930s.

The next step in the relaxation of continuity requirements to approximation functions was the introduction of the concept of external approximations [1]. The name "external" was used in the following context. When approximation functions belong to Sobolev space of functions with finite energy the approximation is called "internal" which means that while the approximation is refined and the solution is converging to the exact solution, the approximation functions are always inside the Sobolev space. Alternatively, in external approximations the approximation functions do not belong to Sobolev spaces at every refinement step (they have infinite energy), but in the limit, when number of degrees of freedom tends to infinity, the limit function must belong to the corresponded Sobolev space, i.e. it must recover the necessary smoothness properties. The abstract theory of external approximations was developed in work [2].

The technological foundations of SIMSOLID have been published in work [3]. In this work the abstract theory of external approximations developed in [2] was applied to a particular case of approximations by finite elements under the assumptions that the elements are of absolutely

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arbitrary shape. In result the necessary and sufficient condition of external approximations by finite elements has been established and convergence theorems proved. It was also shown that the theorems were constructive, i.e. they not only defined hallmarks of external approximations, but also provided a mechanism to build them.

Theoretical Background

An abstract boundary value problem is formulated as follows.

Find a function U which fulfils equations:

$$AU = f \quad inside\ a\ domain\ \Omega \qquad (1)$$

$$LU = g \quad at\ the\ domain\ boundary \quad (2),$$

Where A and L are differential operators.

Some boundary value problems can be equally formulated in variational form as: find a function U which provides a functional F(U) a minimum value, where the functional F(U) is usually an energy functional.

In 1908 W.Ritz proposed a method of finding an approximate solution of a boundary value problem by approximating it with a linear combination of some basis functions

$$U_h = \sum a_i p_i, \quad i=1, 2, \ldots n \quad (3)$$

Where a_i are unknown factors, p_i are basis approximation functions.

Factors a_i are found to provide minimum value of the energy functional

$$F(\sum a_i p_i) = min \quad (4)$$

If a boundary value problem is linear, then minimization problem (4) can be reduced to a linear algebraic equation system with respect to factors a_i

$$Ka = B \quad (5)$$

here K is a symmetric matrix, a is a vector of unknown factors, B is a right hand side of the system.

In FEM matrix K is called a stiffness matrix, vector B is called a load vector, and factors a_i are called degrees of freedom.

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In 1915 Galerkin proposed another approximate method of solving boundary value problem (1)-(2). According to Galerkin method unknown solution U is approximated as

$$Un = U_0 + \sum a_i p_i, \quad i=1, 2,... n \quad (6)$$

Where U_0 is some function which fulfills nonhomogeneous boundary conditions (2), p_i are analytical approximation functions which fulfill homogeneous boundary conditions, a_i are unknown factors.

Substitution of (6) into (1) results in residual

$$R = AU_0 + \sum a_i \, Ap_i - f \quad (7)$$

Unknown factors a_i are found from the equation system

$$\int_\Omega Rp_i \, d\Omega = 0, \quad i=1, 2,... n \quad (8)$$

If a boundary value problem is linear, then system (8) is a system of linear algebraic equations.

Galerkin method does not use a variational formulation of a boundary value problem, so its applicability is much wider.

Ritz and Galerkin methods proved to be effective means of solving problems in engineering and science. At the same time mathematical justification of the methods faced significant difficulties which were solved with the introduction of functional analysis as a mathematical discipline.

Modern theory of Ritz-Galerkin method is based on the concept of weak solution of a boundary value problem. Weak formulation of a boundary value problem consists in finding a function $u \epsilon V$ from corresponding Sobolev space which fulfils an abstract variational equation

$$a(u,v) = f(v) \text{ for any function } v \, \epsilon \, V \quad (9)$$

here V is some subspace of Sobolev space, a(u,v) is generally an unsymmetrical bilinear form which is continuous on the space product VxV, f(v) is some linear form on V.

In structural analysis Sobolev space is a space of functions with finite strain energy.

In Ritz-Galerking method space V is approximated with some finite-dimensional space X_h, and approximate solution is found in form (3)

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where functions p_i belong to the space X_h. Therefore the discretized formulation of a boundary value problem is:

Find a function $U_h \in X_h$ which fulfills the equation

$$a(U_h, V_h) = f(V_h) \ \text{ for any function } \ V_h \in X_h$$
$$(10).$$

Substitution of (3) into (10) results in linear algebraic equation system from which unknown factors a_i are found.

In classic Ritz-Galerkin method X_h is a space of analytical functions defined on the whole domain Ω, factors a_i have no physical meaning. In conventional Finite Element Method X_h is a space of piecewise polynomials and factors a_i are values of function U_h in nodes of finite elements. In structural analysis they are displacements of the nodes.

 Many modifications of Ritz-Galerkin methods have been invented. They differ by variational equations (9) and by classes of basis functions (3) used to approximate the solution. The same boundary value problem can have several equivalent formulations (9) which differ by spaces V.

External Approximations by Finite Elements

As it was already mentioned, internal finite element approximations are built on functions that belong to a corresponded Sobolev space. These functions must meet certain continuity conditions on inter-element boundaries. For instance, when 2D or 3D theory of elasticity problems are under consideration, the function need to be continuous between finite elements. For plate bending problems not only functions, but their first derivatives must be continuous as well.

The continuity conditions are quite restrictive. They can be met only for very simple shapes of finite elements through the use of standard interpolation polynomials as basis functions of finite elements. The polynomials are associated with element nodes. To provide inter-element compatibility the same interpolation functions are used to represent finite element shape. In case of curved boundaries mapping onto a canonical element is used to provide the compatibility. Geometry of finite elements and their approximation functions are tightly coupled.

In order to improve approximation qualities of finite elements researchers invented incompatible finite elements. The elements appear when interpolation basis functions of elements of standard shape are

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enriched by some other polynomials. The additional functions create discontinuity across inter-element boundaries, but incompatible finite elements often provided much better accuracy than the compatible ones. The problem was in difficulties of mathematical proof of convergence and in inconsistency of results.

A comprehensive theory of external approximations by finite elements was developed in work [3]. In the theory the word "finite element" was used to designate an arbitrary shaped sub-domain of the domain Ω, so the definition of finite elements was not restricted anymore to canonic shapes or other shapes obtained from canonic by mapping. The whole domain Ω could be considered as one finite element, and therefore, in case of assemblies a part of an assembly could be one "finite element" in FEM terminology. Another assumption was that approximation functions inside finite element could be absolutely arbitrary - not necessarily polynomials. The only requirement was that the functions belong to the corresponded Sobolev space, so they need to be sufficiently smooth inside element.

The task was to find conditions under which the approximations built according to the assumptions above would be external approximations, i.e. they would converge to the exact solution of a boundary value problem from "outside" of a Sobolev space. Necessary and sufficient condition which provides the external approximations was found. The condition happened to be constructive – its formulation also implied the way of building finite elements that meet the condition. Convergence theorems and error estimates also have been proved.

It was shown that the necessary and sufficient condition for a finite element approximation to be external is:

$$<\delta, \gamma U> = 0 \quad (11)$$

Here <,> is duality pairing in certain functional spaces of defined on inter-element boundaries, δ and γ are some operators, and U are approximation functions defined inside element.

As one can see, condition (11) does not relate neither to a Boundary Value Problem (BVP) formulation, nor to a method the BVP is solved (Galerkin, Ritz, Trefftz, etc.). It imposes constraints on basis functions of finite elements which just guarantee that the limit approximation function will belong to a corresponding Sobolev space, so it will possess necessary smoothness properties.

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Therefore, even before the solution method is chosen (Galerkin, Ritz, etc.), one may construct finite element spaces that possess important properties. These properties can be just "good to have", as, for instance, when solving elasticity problems it is not required to use functions that fulfill equilibrium in volume, but it might be useful because the use of such functions increases accuracy and reduces number of DOF. Other properties can be crucial, for instance, only divergence-free functions can provide unconditionally stable solutions for incompressible materials.

Condition (11) can be extended by continuity from duality pairing into inner product in other spaces of functions:

$$(g, \gamma U) = 0 \quad (12)$$

Here g are functions defined on inter-element boundaries, they are called boundary functions. Boundary functions are functions of surface parameters and they generate boundary DOF that are integrals of products of boundary functions onto finite element basis functions over finite element boundary:

$$\int_\gamma g_k \, \gamma U \, d\gamma, \quad k = 1, 2, \dots N \quad (13)$$

Here γ is boundary of finite element, g_i are functions defined on boundary of finite element, U is a function to be approximated on the element (for instance, displacements in structural analysis).

For comparison, degree of freedom in FEM is value of the function U in the node (i) of finite element:

$$U(x_i, y_i, z_i). \quad (14)$$

Functions g_i in the expression (13) are basis functions from finite-dimensional space G_h of functions defined on element's boundary. They can be arbitrary, the only requirement – spaces G_h must be dense in the space of boundary functions, i.e. they must be able to converge in the space of boundary functions. The latter is easily fulfilled in case g_i are polynomials or piecewise polynomials defined on element's boundary.

Functionals (13) are called boundary degrees of freedom. They do not have physical meaning and they make approximation functions from space of finite elements compatible in limit when number of boundary DOF tend to infinity. Boundary DOF are responsible for meeting inter-element continuity conditions and essential boundary conditions. In

adaptive solution the number of the boundary DOF is managed automatically to meet the convergence criteria.

Boundary DOF (13) are not the only DOF produced when external approximations are built. Other DOF are called internal DOF because they are associated with finite element volume. Internal DOF are defined automatically when the approximation of the solution within a finite element is being built. Final approximation of a function U on the element looks as follows:

$$U_h = \sum a_i(U)\, p_i + \sum \left(\int_\gamma g_k\, \gamma U\, d\gamma \right) p_k, \qquad (15)$$

Here a_i are internal DOF of the element (some factors), p_i are basis functions of the internal DOF,

$\int_\gamma g_i\, \gamma U\, d\gamma$ are boundary DOF, p_k are basis functions of the boundary DOF.

Basis functions p_i and p_k constitute a finite-dimensional space P of approximation functions of a finite element. It was proved that for convergence the space P must be complete, for instance, in case of polynomial space it should contain all polynomials up to a certain degree assigned to an adaptive iteration.

Basis functions of a finite element are not pre-defined because the element has an arbitrary shape. They are built on-the-fly during a solution run. What is pre-defined at an adaptive pass is the whole space P of approximation functions of the element. The algorithm of building basis functions of an element at an adaptive pass works as follows:

- A set of boundary functions g_k is defined
- A complete space P of approximation functions of the element is defined by choosing a complete set of generic basis functions. In case of polynomial spaces a complete space of polynomials of a certain degree is specified. For instance, generic second degree polynomials for 3D problems are:

$$\{1, x, y, z, x^2, xy, y^2, xz, z^2, yz\}$$

- Generic basis functions are generated automatically on-the-fly for every sub-domain during solution when stiffness matrix of a sub-domain is evaluated
- Basis functions p_i and p_k are found automatically by solving a certain system of linear algebraic equations

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After basis functions of element have been found, element's stiffness matrix and load vector are evaluated the same way as it is done in conventional FEM by integrating energy over the element volume and loads over the element boundary.

Geometry-Functions Decoupling

Geometry-functions decoupling is the core feature of the SIMSOLID technology. As one can see from the above, the basis functions of an arbitrary element are built from generic basis functions "on-the-fly" during solution. Neither element geometry representation is used in building the generic functions, nor the functions dictate the shape of the element. The only requirement to the space P of approximation functions of an element is that P must be a subspace of a corresponded Sobolev space associated with the formulation of boundary value problems. Therefore, any combination of generic basis functions is allowable provided they are linearly independent.

The geometry-functions decoupling proved to be the key feature which provides better performance, better accuracy, robustness, less computer resources, less modeling errors. The following substantial benefits can be realized when finding an accurate solution for a specific problem, or managing adaptive solutions:

1. It is possible to build special approximations that make approximate solutions of boundary value problems unconditionally stable. For instance, when parts made of incompressible materials are simulated, SIMSOLID uses divergence-free functions which exactly meet the incompressibility condition. Here is an example of some generic divergence-free 3D functions of degree 3 (here u,v,w are displacement components):

$$\text{Function 1:} \quad u = -xz^2, \quad v = yz^2, \quad w = 0$$

$$\text{Function 2:} \quad u = -3xz^2, \quad v = 0, \quad w = z^3$$

$$\text{Function 3:} \quad u = -2xyz, \quad v = y^2z, \quad w = 0$$

$$\text{Function 4:} \quad u = -2xyz, \quad v = 0, \quad w = yz^2$$

$$\text{Function 5:} \quad u = -xy^2, \quad v = 0, \quad w = y^2z$$

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2. Neighbor parts may have approximation functions of different classes. For instance, in case an assembly contains parts made of compressible and incompressible materials (rubber insertions, or cavities with liquid) the approximation functions for incompressible material are built as special divergence-free functions. On neighbor parts with compressible material regular functions like standard polynomials are used

3. It is always possible to use basis functions that a priori fulfill governing equations of boundary value problems which provides better accuracy and reduces number of DOF. For instance, thermo-elastic problems are solved using a complete polynomial solutions of the corresponded governing equations:

$$(\lambda + \mu)\frac{\partial \varepsilon}{\partial x} + \mu\Delta u = \frac{\alpha E}{1 - 2v}\frac{\partial T}{\partial x}$$

$$(\lambda + \mu)\frac{\partial \varepsilon}{\partial y} + \mu\Delta v = \frac{\alpha E}{1 - 2v}\frac{\partial T}{\partial y} \qquad (16)$$

$$(\lambda + \mu)\frac{\partial \varepsilon}{\partial z} + \mu\Delta w = \frac{\alpha E}{1 - 2v}\frac{\partial T}{\partial z}$$

here (u, v, w) are displacement components,

$$\varepsilon = \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z},$$

$$\lambda = \frac{Ev}{(1+v)(1-2v)}, \quad \mu = \frac{E}{2(1+v)},$$

$$\Delta = \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} + \frac{\partial^2}{\partial z^2},$$

α is a coefficient of thermal expansion; E is elasticity modulus, v is Poisson's ratio, T is temperature field.

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Equation system (16) is non-homogeneous. For instance, when $E = 1$, $\nu = 0.25$, $\alpha = 1$ and temperature field is described by a monomial $T = ax^m y^n z^p$ the solution of the non-homogeneous problem for a=1, m=0, n=2, p=3 is:

$$u=0,$$
$$v=0.1667yz^5,$$
$$w=0.4167y^2z^4 - 0.02778z^6$$
$$(17)$$

Here is an example of a polynomial solution of the homogeneous equations (14):

$$u = 20x^4z - 20x^2z^3,$$
$$v = 20x^3yz - 20xyz^3,$$
$$w = 8x^5 - 60x^3z^2$$
$$(18)$$

When solving a thermo-elastic problems polynomial approximation of temperature T are imported from thermal analysis, functions of type (17) are generated for every element, and generic functions of type (18) are used to build basis functions of elements.

For heat transfer problems harmonic polynomials are used as basis functions which precisely fulfill corresponded equation of heat transfer. Here are some generic harmonic functions of degree 3:

Function 1: $x^3 - 3xz^2$

Function 2: $x^2y - yz^2$

Function 3: $xy^2 - xz^2$

Function 4: $y^3 - 3yz^2$

Function 5: $3x^2z - z^3$

4. The approximations are always built in physical coordinate space without mapping onto a canonic shape. Therefore, properties of generic basis functions are preserved throughout solution which eliminates a substantial source of approximation errors

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5. A complete set of basis functions is always used to approximate solution on a sub-domain. Completeness means that no functions are missing from a space of a certain degree. For instance, if solution is approximated with harmonic polynomials of degree 5, then all harmonic generic polynomials of degree 5 are included into the approximation space of a sub-domain. This provides high accuracy, ease of building p-adaptive solutions globally and locally, and ease of implementation of new types of problem-specific basis functions

6. Geometry-functions decoupling allows effectively handle assemblies of parts with incomparable geometries in terms of size and shape (multi-scale assemblies)

7. Local effects like concentrated forces, cracks, stress concentration, etc., can be easily simulated by enriching approximation space of sub-domains with special functions that possess corresponded asymptotic associated with the feature

Stress concentration around small holes
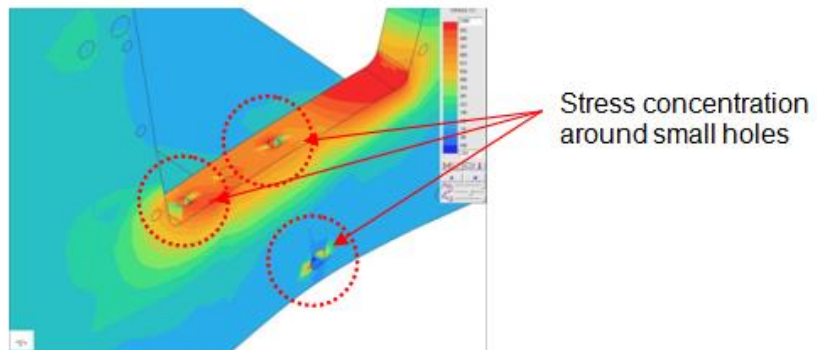
SIMSOLID Software Implementation

The SIMSOLID software implementation workflow is summarized in the following:

Step 1.   Process geometry. Raw part geometry is imported using either a direct CAD process, as in Onshape, or from a standard STL file. In either case the geometry is processed and stored internally in an efficient faceted form.

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SIMSOLID will create faces and volumes, insure the volumes are water-tight and identify special part geometry such as bolts, nuts and washers that can be used for pre-loading.
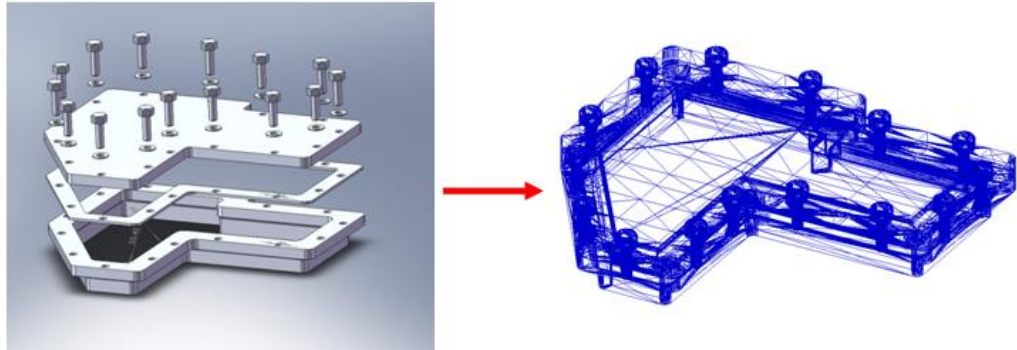

Step 2. <u>Create part connections.</u> Contact interfaces between parts of assembly are found automatically. Bonded and sliding contact is supported initially. More general non-linear contact is a possible extension.
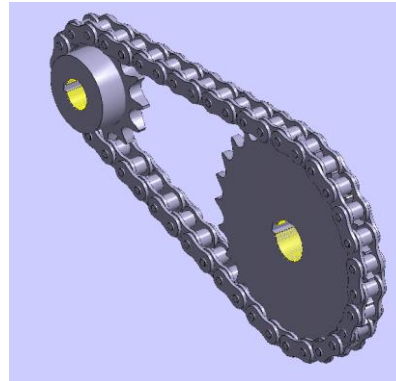

Step 3. <u>Analysis parameter specification.</u> An analysis type (static, modal, thermal) is selected and boundary conditions/ materials are applied to the model. At this point, the model is ready to analyze. No mesh creation steps are required by the user.

Step 4. <u>Adaptive solution is performed.</u> SIMSOLID employs a proprietary adaptive technology to automatically refine the solution in the areas where it is necessary to achieve the highest accuracy. The maximum number of adaptive iterations is set on either a global or local (part) basis. Adaptivity is always active in the solver methods.

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Step 5. <u>Response mesh is built over the geometry.</u> Response mesh is used to display result plots only and can be refined "on-the-fly".
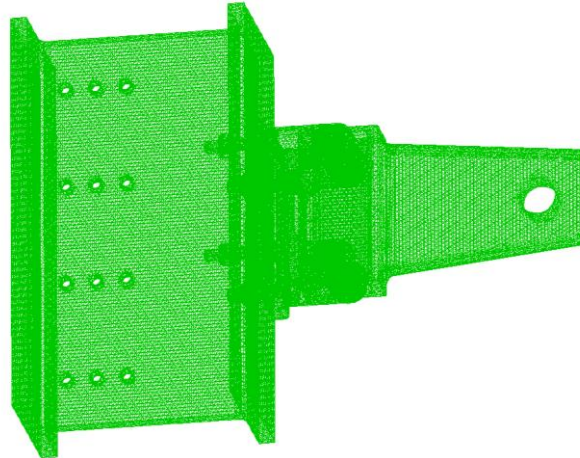
Step 6. <u>Evaluate quantities of interest.</u> Quantities of interest are evaluated in nodes of the response mesh and displayed. The evaluation is done "on-the-fly" when a post-processor window is launched. The nodal values are not saved, instead the analytical approximants of the field of interest are stored which provides significant savings in memory and disk space in particular for non-linear and dynamic response analyses. It also allows for effective coupled analyses when results of one analysis are directly used in analytical form in other analyses.
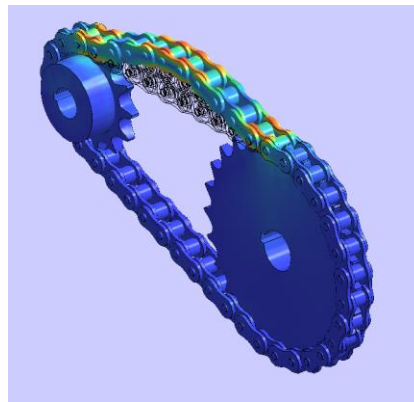
Step 7. <u>Re-analysis is fast.</u> SIMSOLID remembers the output response mesh. Additional load analysis types or load cases can be done quickly. Unique to SIMSOLID is the ability to incrementally increase the solution

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detail on a part or region basis. Simply select the part, right click and select part solution settings, then click the "Regenerate Project" button.

Comparing Traditional FEA and SIMSOLID Modeling Methods

Implementation of analysis in the design process means that analysis results are used to make design decisions. It is, therefore, important that analysis tools provide results with predictable accuracy. Analysis results validation is a complex problem because all numerical methods are approximate and there can be many sources of errors including the major ones: modeling errors and approximation errors.

SIMSOLID eliminates major sources of errors associated with conventional FEA. It also introduces a new approach to adaptive solution refinement based on exact measures of error on surface of a structure.

Sources of Modeling Error in Traditional FEA

Modeling errors occur when the CAD geometry model is being modified to make it suitable for traditional FEA meshing. The modification can include many steps such as assembly simplification, part de-featuring, surface idealization and geometry face clean up.

Successful meshing is pre-requisite to obtaining any results in FEA. Even if only global displacements are of interest, the geometry still has to be meshed to the smallest detail. Furthermore, meshing has to use the correct element type, show correct element shape (no degeneration or bad aspect ratio) and have enough elements to model the expected stress pattern. These quality requirements are quite difficult to satisfy for complex parts. Adaptive re-meshing to satisfy numerical convergence is possible but not practical in many situations and is not commonly performed in design analysis of assemblies.

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For assemblies the situation is getting even worse because meshes in contact areas of parts must be either compatible or good enough to provide meaningful results. The latter gets practically impossible in case of multi-scale assemblies when large parts are connected through small parts like bolts, nuts, rivets, pins, etc.
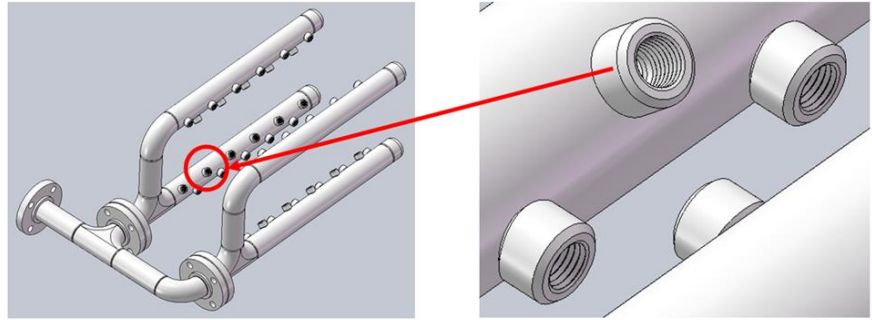
Assembly idealization is also dependent on the solution method. Pictured above is an example of small parts that can be simply removed in Statics analysis, but need to be replaced by mass points or artificial bodies with 6 inertia moments in Dynamics analysis in order not to change mass distribution in the structure.
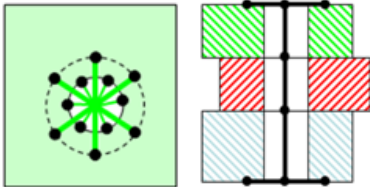
Other sources of error in traditional FEA include special element consideration for connections. Bolts and welds are problematic in that both special elements and special mesh patterns are required to model them adequately. To the left are examples of connection idealizations of a bolt replaced by beam and spider rods.
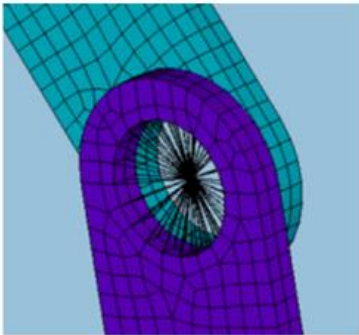
The final stumbling block is solving. Even if model has been successfully meshed, solution is still not assured. Having meshed complex geometry, the model is often found to be too large to be solved within a reasonable time or contains poorly shaped elements that cause instabilities in the numeric of traditional FEA solver methods.

Using the traditional FEA workflow to manage these potential error sources is complex. Training, and retraining, can be expensive and time consuming. Occasional (infrequent) use of simulation is especially problematic. Errors introduced by mis-application of a user interface workflow are far too common.

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SIMSOLID Approach

All the traditional complexities of geometry simplification and meshing are not present in SIMSOLID. The true geometry is processed directly. Assemblies can have parts with different scales (big/small or thick/thin). Connections between parts are more straightforward to apply. The time required to setup the simulation model is dramatically shorter and the reduction in the required process steps means there is much less possibility of user error.

Adaptive refinement is always activated during the solution process. Simple controls are available to increase the relative number of equations or to adjust the number of adaptive solution passes performed. This can be done on both a global (all parts) or part local basis. The degree of solution completeness can be easily managed by the user at a high level without the need to create and closely manage complex meshing patterns.
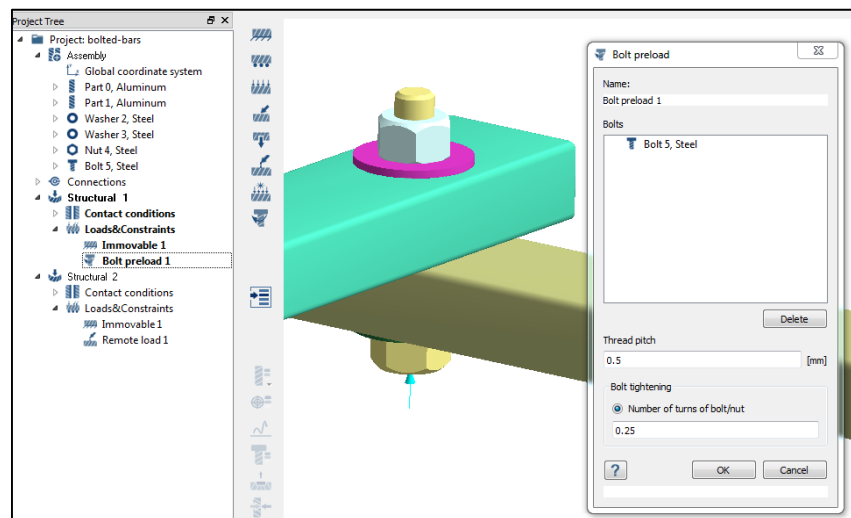
Application Examples

Included below are several representative SIMSOLID solution examples.

Access Platform

An assembly of 153 parts consisting of 10 small bolts, washers and nuts as well as 123 other parts including hollow tubular frames, solid ladder rungs and a single large complex floor grate was analyzed. 412

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connections were automatically generated. This model illustrates the ability of SIMSOLID to efficiently analysis a large assembly with parts of varying size scales (small to large) and varying geometric complexity. Typical modeling and solution time for a static analysis on an 8-core Intel i7 was 10-minutes.

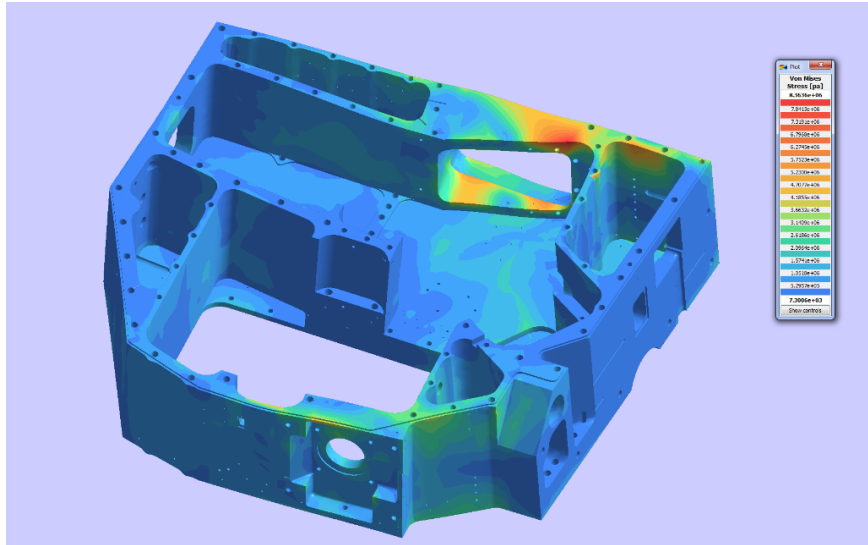*Close up detail of bolt, nut and washer geometry.*
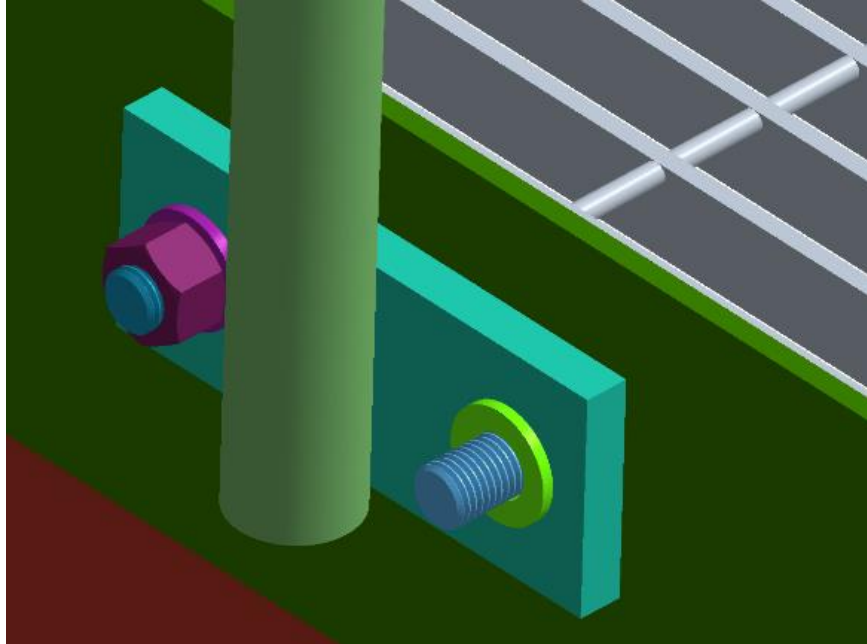
*SIMSOLID simulation solution.*

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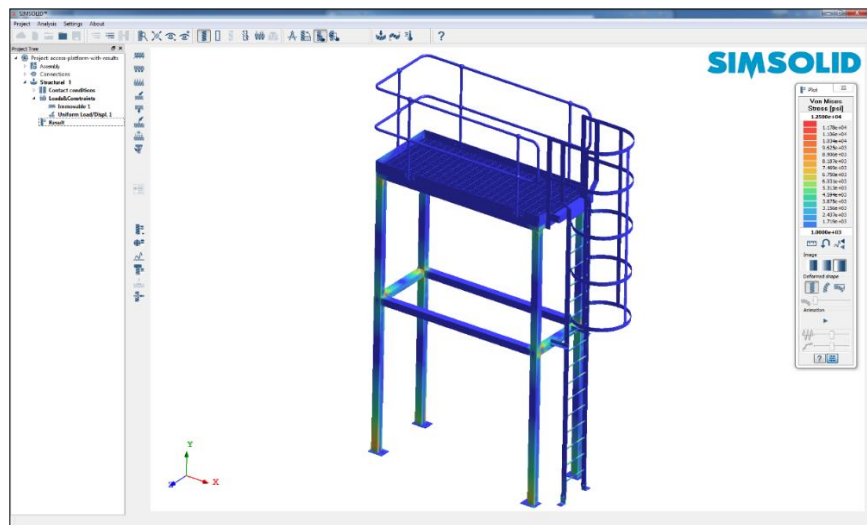
Complex Machined Plate

Static analysis of a complex machine plate consisting of 1,200+ faces and 150+ small holes. Typical solution time on an 8-core Intel i7 is 4-minutes. Reanalysis is faster, typical 45-seconds.

Modal Analysis of a Quad Copter Frame

Quad copter frame consisting of 48 parts and 986 connections. Unconstrained modal analysis to calculate the first 10 flexible modes. Typical solution time on an 8-core Intel i7 is 4-minutes.

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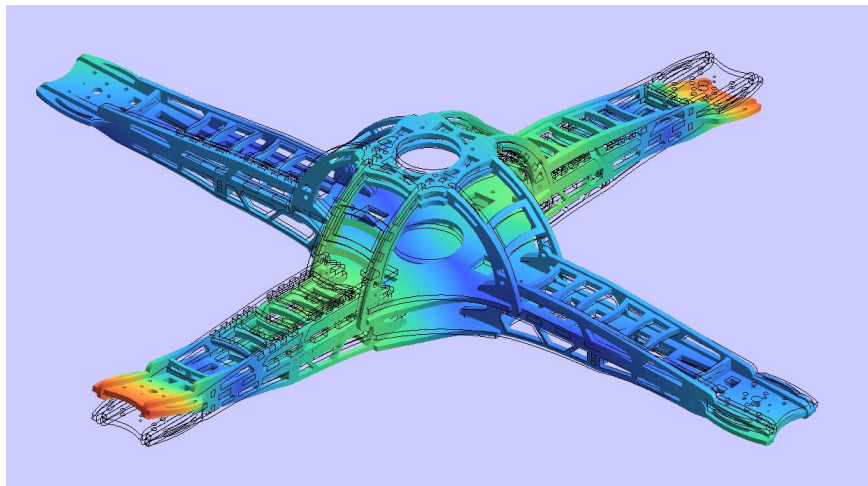
Conclusion

In order for simulation to truly drive the design process it needs to work lock step with each geometry concept and concept modification. The complexity of traditional FEA eliminates its use in all but the most trivial of design conditions. Simulation working directly on design geometry provides a path to quick meaningful answers that guide designers and engineers to more optimal design scenarios.

Only SIMSOLID can provide this by not only eliminating time consuming and expertise extensive geometry simplification techniques such as defeaturing and mid-planning but by also eliminating the mesh all together. The result is a simulation tool that is both:

- fast enough with respect to both model and solve time to be used every day
- simple enough to be used occasionally without the need for extensive training and monitoring.

Try SIMSOLID for yourself. We think you will agree it is how design-simulation should be done. For more information and to trial our product, please go to www.simsolid.com.

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