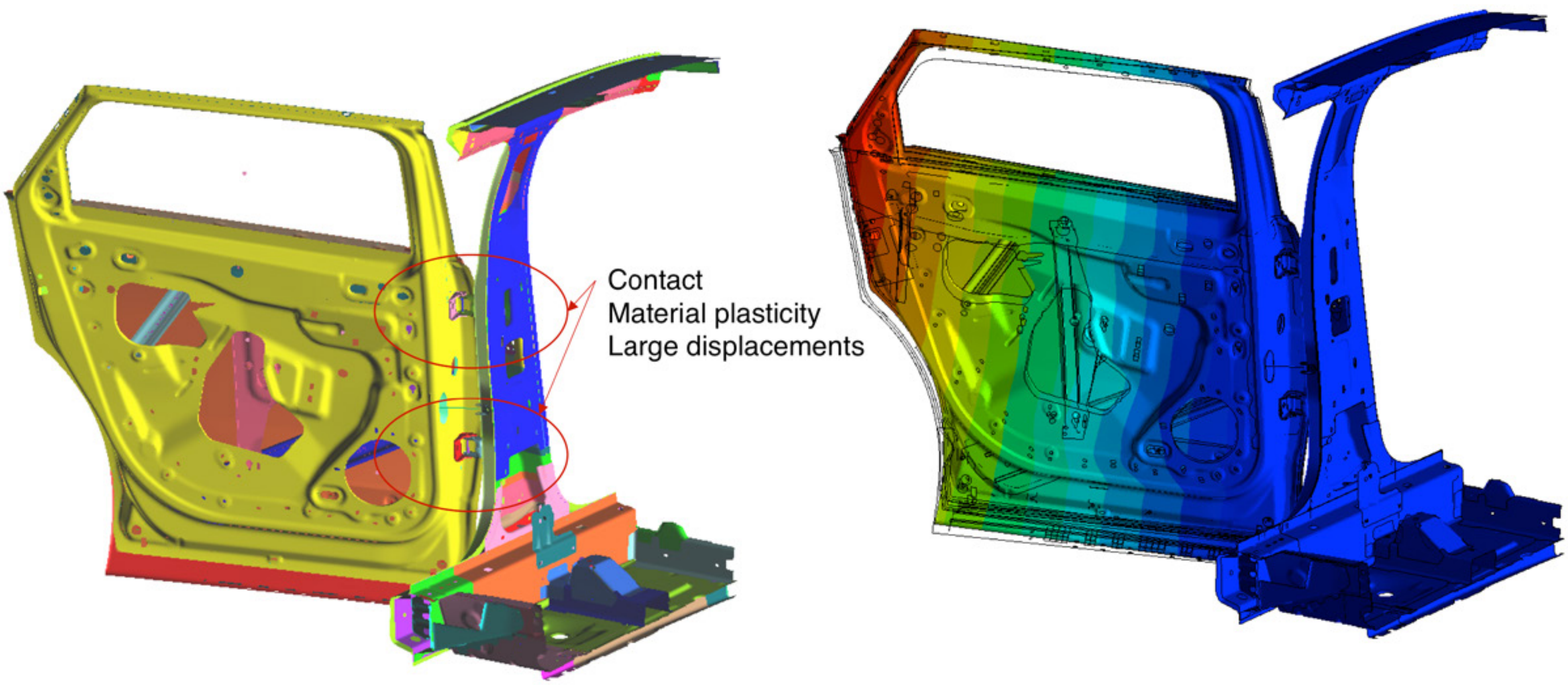
White paper

From linear to nonlinear simulations inside MSC Nastran

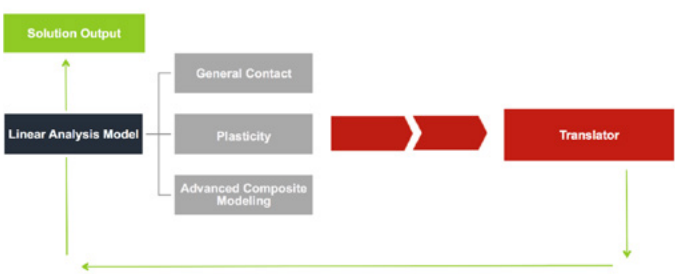
MSC Nastran Sol 400

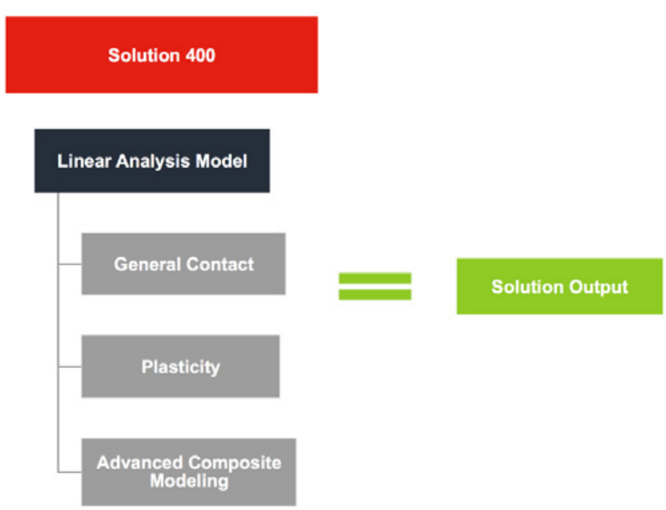


With 50+ years of development, MSC Nastran is the most trusted Finite Element Analysis tool on the market today. Its Nonlinear Analysis capability, SOL 400, has been used in the field for over 10 years. Its proven multidisciplinary approach to structural analysis at various points in the product development cycle yields the most accurate results time and time again.

MSC Nastran SOL 400 provides advanced nonlinear capabilities by merging the proven technology from Marc with MSC Nastran. It makes it possible for MSC Nastran users to add advanced nonlinear capabilities to their already existing linear models without leaving their familiar simulation platform. Structural analysts have successfully used Nastran nonlinear analysis to solve structural problems as large as an aircraft wing panel post buckling, and problems as small as a Printed Circuit Board (PCB) component leads.

Hundreds of companies who started in MSC Nastran for linear statics and dynamics have now added SOL 400 because it is saving them hundreds of hours in their design and engineering process. SOL 400 brings a lot of value to organizations with flexible, cost-effective access, and multiple licensing options through MSC one. Engineers will be able to spend more time on analysis work and less time on translation.





MSC Nastran workflow without SOL 400

The structural analysis nonlinearities that are covered in solution 400 include:

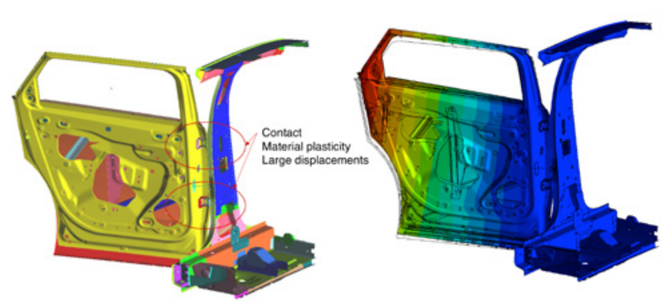
- Geometric Nonlinearity
- Material Nonlinearity
- Failure and Fracture Analysis
- Contact Analysis
- Coupled Analysis
- Chained Analysis

Geometric nonlinearity

Geometric nonlinearities manifest when the structure undergoes a large displacement or rotation (e.g. large rotation of cantilever beam and shell type structures, buckling, or snap through). This violates the small displacement assumptions that are inherent to the equations of linear analysis, which results from the relationship between strain and displacement. Geometric effects may be both sudden and unexpected, but without taking them into account any computational simulation may completely fail to predict the real structural behavior.

MSC Nastran SOL 400 uses advanced element technology with the ability to handle large deformations and rotations, while maintaining an accurate nonlinear strain-deformation relationship. Nonlinear analyses are performed with incremental loads, where each increment is solved iteratively to ensure equilibrium between the external and internal forces. SOL 400 uses advanced solver technology that is tuned for performance, as well as automatic stepping schemes that help reduce solution time without sacrificing accuracy. These schemes are designed to make MSC Nastran SOL 400 as robust, efficient, and user friendly as possible.

The smart default parameters are specifically adjusted based on the level of nonlinearity in the simulation model, for example if contact analysis is present or not.



SOL400 simulation of partial car body & rear door, image courtesy of PSA

Materials

In a linear analysis, stress is assumed to be linearly proportional to strain, which is a reasonable approximation when the deformations are very small. 30+ years ago, most structures were made out of metals, this was a well-accepted linear assumption for engineering designs (albeit no material exhibits a truly linear behavior). In today's world, much more advanced composite, plastic, and rubber materials require more and more nonlinear analyses to be performed in order to obtain real-world behavior and accurate results.

Elasto-plastic simulation of an automotive link arm

Users can model time-dependent and time-independent material response (including varied temperature). Complex material behaviors that can be modeled with SOL400 include:

- Linear elasticity (isotropic, orthotropic, anisotropic)
- Nonlinear elasticity
- Elasto-plasticity
- Viscoelasticity
- Creep
- Hyperelasticity
- Viscoplasticity
- Composites
- Shape memory alloys
- Gasket materials
- Cohesive material
- Custom, user defined materials

Failure and fracture analysis

When a certain failure criterion is met, the material fails and no longer sustains the load bearing capacity. In FEA, this means that the element, where the material reaches the failure limit, loses its ability to carry load. The element is flagged for failure, and essentially, is no longer part of the structure during the calculation.

Different materials experience different failure characteristics and therefore, SOL 400 provides multiple failure criteria including:

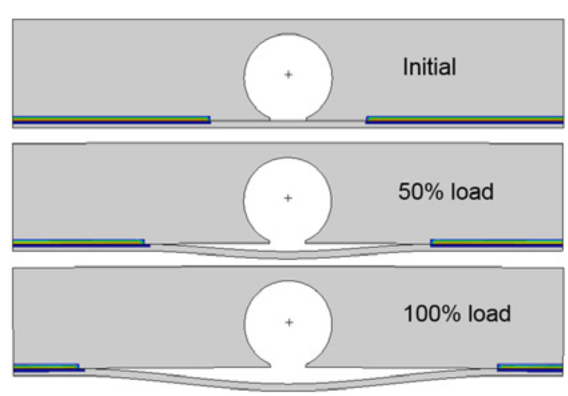
- Maximum Stress and Maximum Strain
- Tsai-Wu
- Hoffman
- Hill
- Hashin, Hashin Fabric, and Hashin Tape
- Puck
- User defined criteria through user subroutines.

Progressive failure behavior for various materials can be simulated so that the materials strength is degraded gradually depending on the load history. Additionally, SOL 400 integrates MSC's Digimat Material Modeling System, by providing the user with a holistic solution to compute the material properties of a composites on a component basis.

SOL 400 supports linear and nonlinear fracture mechanics in order to determine the conditions under which crack propagation occurs. By investigating stability of the crack propagation, speed of crack growth, and possibility of crack arrest with nonlinear fracture mechanics, users can then modify the designs to achieve longer product life. Simulation of delamination and crack propagation can be done using either Cohesive Zone Modeling

(CZM) or the Virtual Crack Closure Technique (VCCT). The implementation of CZM is based on a library of special elements called interface elements that are used to characterize the interface behavior of the structure. These interface elements in MSC Nastran, measure the relative displacements of a "top" and "bottom" region in terms of "tractions vs. displacement".

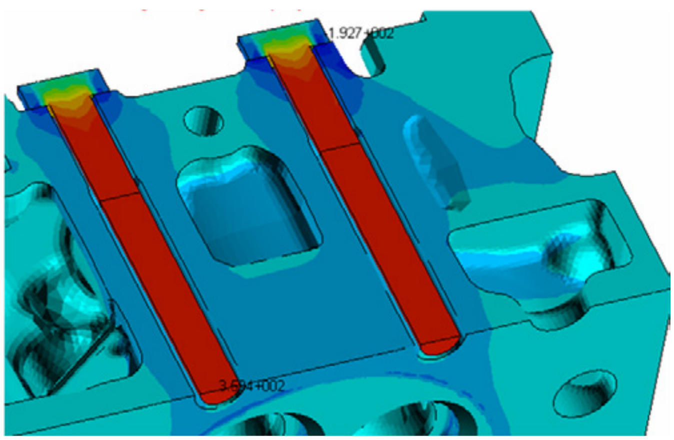
VCCT is a simple and robust method that evaluates the energy release rate during crack propagation (advancement in crack length). All three modes of crack extension are supported (I. crack Opening, II. Sliding and III. Tearing), which will help improve the overall performance of every component.



Crack propagation using VCCT

Contact analysis

In assembly models that interact with multiple parts, progressive displacement gives rise to the possibility of either self-contact or component-to-component contact. It varies depending on their load history. This characterizes a specific class of nonlinear effects, known as boundary condition or contact nonlinearity. In these situations, the stiffness of the structure or assembly may change when two or more parts either come into contact or separate from the initial contact (e.g. interference fit, bolted connections, gears, sealing, and closing mechanisms).



Bolt pre-tension simulation using body contact with friction

The analysis of contact behavior is complex because of the requirement to accurately track the motion of multiple geometric bodies, and the motion due to the interaction of these bodies after contact occurs. This includes representing the friction between surfaces and heat transfer between the bodies if required. The numerical objectives in this case are 1) to detect the motion of the bodies 2) apply a constraint to avoid penetration and 3) apply appropriate boundary conditions to simulate the frictional behavior.

The general contact methods implemented in MSC Nastran SOL 400 focus on ease of set up with the ability to handle simple to highly complex contact scenarios. SOL 400 can be used to solve a wide array of contact scenarios without the need for additional contact elements, accurately predicting the physical response of the structural assemblies.

- 1-D, 2-D, and 3-D contact
- Self-contact detection
- Touching or glued (stiff or flexible) contact
- Contact between deformable bodies
- Contact between deformable and rigid bodies
- Friction between bodies
- Small and finite sliding
- Over-closures and interference fits
- Friction generated heating

Coupled analysis

Thermal analysis is second only to structural analysis in terms of its usage because of the strong influence of temperature on structural performance. MSC Nastran provides a complete set of capabilities to solve nonlinear thermal problems that have temperature dependent properties. The thermal results often affect structural response and vice versa, requiring a coupled analysis for better understanding of the physics. For example, friction in brake systems generates heat and the temperature gradients may lead to warping, which in turn could be the source of unwanted noise.

MSC Nastran SOL 400 allows engineers to simultaneously simulate the interaction of structural and thermal loads with the following capabilities:

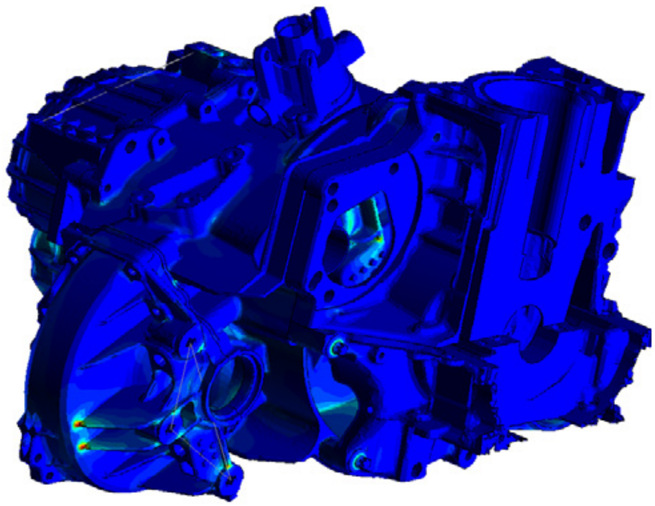
- Thermal analysis accounting for all modes of heat transfer (conduction, convection, and radiation)
- Efficient calculation of radiation view factors for higher productivity
- Steady state and transient heat transfer analysis
- Temperature dependent material properties
- Linear and nonlinear material properties for better representation of behavior
- Thermal contact to allow heat transfer across components
- Perform thermal stress analysis with temperatures as initial conditions
- Inclusion of friction and internal plastic heat generation

Chained analysis

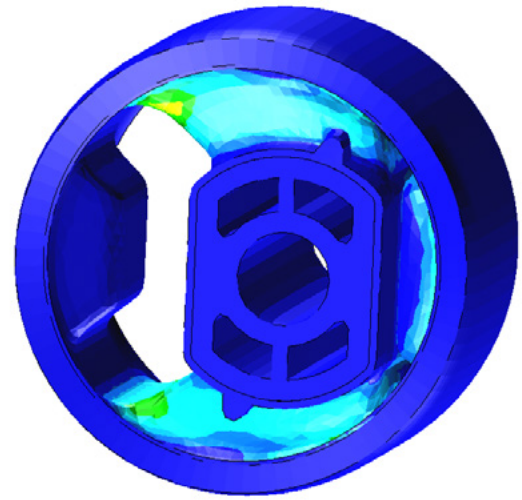
MSC Nastran, is a multidisciplinary solver that allows users to conduct chained analysis between disciplines. This provides users with the ability to tackle a multitude of FEA problems without the need for switching between software products.

Supported capabilities include:

- Perturbation analysis to perform a linear analysis based on the nonlinear equilibrium state of a structure
- Multiple options for perturbation analysis, including linear statics, normal modes, buckling, direct and modal frequency response, direct and modal complex eigenvalues, modal transient response, static aero-elastic response, and aerodynamic flutter
- Chained thermal-structural analysis (thermal analysis followed by a separate stress analysis).



Stress analysis of a powertrain model



Large strain simulation of a rubber bushing using the adaptive load stepping scheme

Summary

MSC Nastran SOL 400 enables significant time savings by allowing for an easy transition from linear to nonlinear analysis inside one tool, and more convenient model sharing between multiple groups eliminating error prone transition and duplicate work. SOL 400 set of capabilities is rich and covers non-linearity in form of geometric, material and contacts. It’s all packaged in a framework that allows for coupled analysis, perturbation, and chaining. SOL 400 is available in MSC One, allowing for flexible, cost-effective access with multiple licensing options.

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