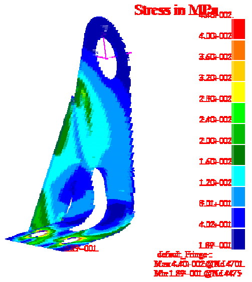
MSC.Acumen Expert System
Accelerates Truck Structure Design Process

By:
Les Grundman
Navistar International Transportation Corp.,
Navistar Technology and Engineering Center

David Bremmer, MSC.Software
Geetha Bharatram, MSC.Software
Sue Rice, MSC.Software
Thomas Phillips, MSC.Software

INTERNATIONAL®
DELIVERING. BEYOND THE EXPECTED.℠



MSC SOFTWARE
SIMULATING REALITY

Abstract

The Navistar Technology & Engineering Center (NTEC) has teamed with MSC to exploit a new technology with the goal of significantly enhancing the impact of concurrent simulation on the truck structure design process. MSC.Acumen was used to build an expert system of designer tools. Design Engineers use these tools to perform up-front concurrent simulation, yielding the same quality of results that the dedicated simulation experts produce. The specific best practices and methods for simulating particular design categories were captured from the experts at the NTEC structural analysis group and cast into customized and automated applications.

By using this system, component structural performance takes place on the same day that the design form is first rendered in CAD, as opposed to waiting in a queue for 4-to-6 weeks. In fact,

design iteration for changes of material, dimension, shape, or structural reinforcements is now supported by high quality simulation on the same day.

The custom MSC.Acumen applications are unique because they drive a Navistar specific process. They serve the collaboration and review process through automatic output of supporting data and simulation results in the form of web page HTML reports.

Navistar has selected two “work flow categories” for the first application set. They consist of eleven different “simulation templates” for structural brackets. These categories were chosen as very common and frequently designed structural components. The “simulation templates” will therefore see a high usage rate and yield the maximum impact to the design process. An additional benefit is that the structural analysis group experts are freed to pursue more complex and challenging tasks.

Introduction

Navistar International Corporation (http://www.internationaldelivers.com/) manufactures and markets medium and heavy trucks, school bus chassis and mid-range diesel engines in North America and selected export markets. Navistar has led the North American industry in sales of medium and heavy trucks for 18 consecutive years and is the leading supplier of mid-range diesel engines in the 160 to 300 horsepower range. Consolidated sales and revenues were $7.9 billion for the 1998 fiscal year.

The Navistar Technology and Engineering Center in Fort Wayne, Indiana is the largest engineering facility in North America dedicated exclusively to the design, development and testing of trucks and truck components. The Technical Center has recently expanded to over 1400 people and has started a new Technology Development initiative called Model Based Product Development (MBPD). The mission of MBPD is to simulate the key performance attributes and physical behavior of full vehicles using advanced computer analyses. This effort is required up front in the Product Development process and well in advance of prototype availability. Additional goals are to achieve optimized validation testing, higher product quality and reduced time to market.

One of the core simulation attributes of MBPD is durability assessment at the component, subsystem, system and vehicle levels. Expanded product development efforts are increasing the demand for component modeling while the core Structural Analysis Group (STAG) increasingly needs to focus on more advanced analyses. Therein lies the purpose for this specific MBPD development effort; creation of a system that allows design engineers to quickly and correctly model components while the members of STAG focus on advanced, higher complexity analyses.

Background of Design & Analysis at NTEC

Currently NTEC has a dedicated analysis group supporting the design community. Analysis requests are brought to the Structural Analysis Group and then "passed off". Dedicated analysts work closely with the engineers in design, but the backlog queue can sometimes stretch to several weeks.

Starting over ten years ago at NTEC, attempts were made to train design engineers on analysis tools. A three month rotation through the Structural Analysis Group succeeded in familiarizing these engineers with the people, process and capabilities of Finite Element Analysis but did not succeed in increasing Structural Analysis throughput. Previous technology (10+ years ago) required a learning curve of around three months to just get to the point of making reasonable analysis attempts with "good" mistakes.

Current Technology has reduced the learning curve to roughly one-month through user friendly GUI's and dedicated high performance workstations. It must be reemphasized that this training was, and still is, just enough to get to the point of making "good" mistakes. Although this 3x learning curve reduction is significant, it is not sufficient to increase the throughput to the point needed at NTEC. Moreover, the real need is for correct results as opposed to good attempts.

Background of the Solution Developed for NTEC

Four years ago the NTEC Structural Analysis Group worked with Chuck Bernitt from MSC to prototype an “Analysis Checklist”. This grocery-shopping list was a Patran PCL form that showed the required steps for a generic analysis. See Figure 1 below. The form had some limited hooks into Patran functions, but was still just a guide that did not control the analysis process. The checklist provided significant help, but did not offer the order-of-magnitude improvement needed. The checklist was not developed further.

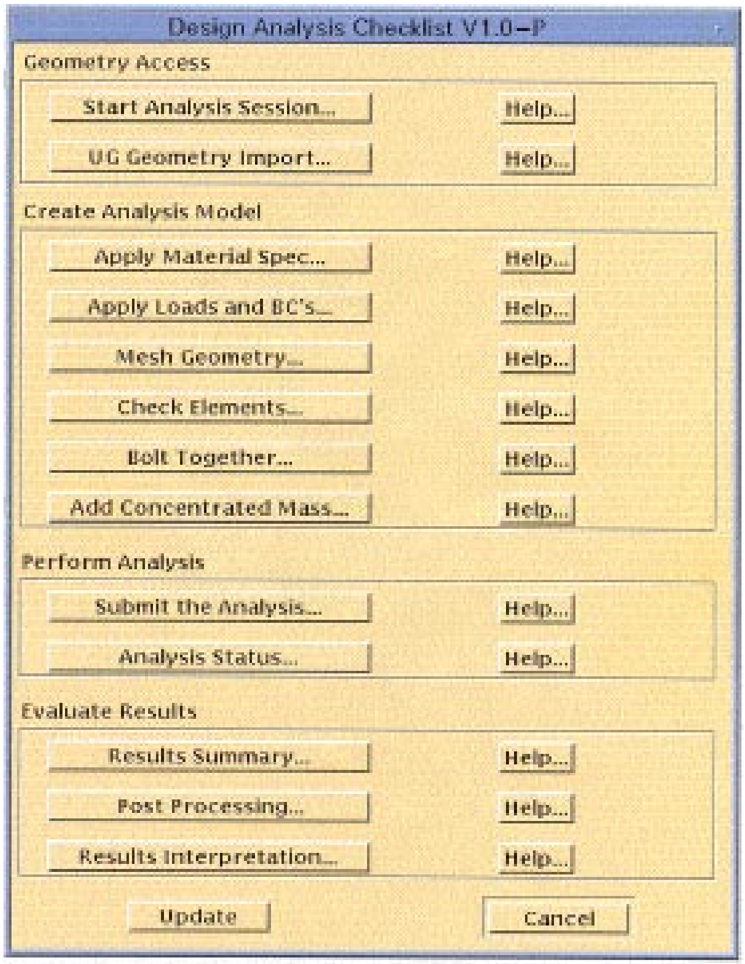


Figure 1. Early Prototype of a Checklist Help System

At this same time, MSC participated in the “Analysis Advisor” project, sponsored by the RRM (Rapid Response Manufacturing) consortium. The consortia members guiding and funding the effort were GM Delphi Systems, Eastman Kodak Company, and Pratt & Whitney. A government funding component was also received through NIST.

The concept of the exploratory development was to produce a “Microsoft Wizards” type guide to doing analysis. The stated goal guiding the endeavor was to find a way to: “Make MSC.Patran usable by the novice or occasional user”. A “novice” user was defined as one who is educated in engineering, and is familiar with the concepts of static equilibrium, stress, strain, and mechanical principles. The novice was also defined as not experienced with the specialized finite-element analysis method, or with CAE software.

The study revealed that CAE simulation complexity required more than simple “wizards” to enable success by novice users. It was concluded that some form of expert system that actively captures and enforces sophisticated methods was required. A breakthrough was achieved by considering how information is coded and logic is processed in a decentralized fashion on the Internet. A flexible and scalable solution was achieved by inventing the concept of “page driven software”, and by writing “drive pages” to control the simulation process to those scenarios scripted by experts.

The prototype software from the MSC Analysis Advisor Project was commercialized to produce MSC.Acumen. A version of MSC.Acumen was demonstrated at the Technical Center early in October of 1998. It was immediately apparent that a development project using MSC.Acumen could provide the needed solution. MSC.Acumen promised to increase analysis throughput by providing an efficient tool suitable for casual use.

After the initial demonstration, hands-on sessions were held with individuals from design, analysis and information technology. The response was overwhelmingly favorable. Another meeting was held in late October of 1998 to gather information for proposal generation by MSC. Again, individuals from design, analysis and information technology were included. In this proposal generation meeting, the technical aspects and capabilities of Acumen were discussed. Common, high use parts suggested by the design and analysis community were selected. The types of analyses were broken into three categories or workflows: a single bracket resisting a force or moment along a vector (radiator stay rod brackets, shock mount brackets, axle stop brackets and suspensions brackets), a single mass attached to a stamped bracket(s), (air dryer brackets, mud flaps, ECU control units, QualComm communications units), and a third category of a rigid object supported by two or more hangers, (air tanks, battery boxes and fuel tanks).

NTEC and MSC Software agreed to start by developing applications in the first two defined workflows; force on a bracket and mass on a bracket. These two workflows were to contain 11 templates; radiator stay rod brackets, shock mounting brackets, axle stops, two types of suspension brackets, air dryers, mud flaps, electronic control unit brackets, Qualcomm mounting brackets, oil reservoir brackets and oil filter mounting brackets. Later in the development process, three generic templates were substituted for specific templates to allow for more flexibility.

Development officially started in March of 1999 with a kickoff meeting at NTEC. Members of STAG met with David Bremmer and Sue Rice from MSC to begin gathering the NTEC STAG specific best modeling practices and methods. Working relationships were formed for the upcoming long distance development effort. After this meeting weekly teleconferences were held with Paul Conti (MSC office in Southfield Michigan), Bob Staas (MSC office in Dayton

Ohio), Geetha Bhartran (MSC office in Chicago), Tom Philips (now with the MSC Southfield office), David Bremmer and Sue Rice (MSC office in Costa Mesa) and Les Grundman from Navistar in Fort Wayne. A key part of this meeting was recording issues in a shared Word document that grew over time, listing commitment dates, issues, resolution, and assignments.

Deployment Issues

The deployment of this expert system is scheduled for the end of September 1999. The main deployment issues are:

- Roll out of process
  - Selection of 1st wave design engineers
  - Hardware upgrades
  - Software install
- Training
- Process implementation
- Long term maintenance and support

  (Additions to templates, corrections, training, integration with PDM…)

NTEC's computing environment lends itself to easy hardware and software deployment. NTEC began standardizing on NT workstations for UG in 1997 with the Structural Analysis Group converting to NT Workstations in 1998. Currently all UG and Patran CAE work is done on NT workstations. Although MSC.Nastran jobs are solved on a cluster of SGI Origin^{TM} Unix supercomputers, the integration with NT is seamless and will be transparent to the Acumen user.

This homogeneous workstation environment will greatly assist in the deployment of MSC.Acumen. The MSC.Acumen custom templates will be loaded on a single network location for one-point maintenance, though MSC.Patran will be loaded locally for best performance. An additional hard drive will be added to each design engineers workstation running Acumen. This hardware upgrade will be simplified by creating a master disk with the required Patran and local Acumen files and then cloning this drive. Cloned drives will be stored until needed and Acumen installation will simply require the addition of the drive with a short software setup. Future MSC.Patran updates will be handled through remote installation using VCN.

Training is critical so that this system is not used as a black box. A set of four 1 to 2 hours classes are planned. This training will initially focus on mechanics of materials and statics as applied to specific Truck components. Training will not focus on using Acumen until the later sessions. Training and process information will also be duplicated on NTEC's Intranet.

Benefits

Benefits are yet to be realized since the package has not yet been deployed. The costs without deploying the MSC.Acumen solution however, are known. Training new users now requires a month to get to the point of making good mistakes. This month of training time plus the required support costs approximately $10,000 per user. This traditional method of training and software deployment will not create acceptable throughput, and will only bring the design engineers to the point of making good analysis attempts.

Initial results from Acumen beta testing give a good indication of what to expect with the expert system:

- Improvements in the Finite Element Structural Analysis Process
  - Elimination of “bad” mistakes
  - Elimination or most “good” mistakes
- 4-8 hour learning curve
- Analysis iterations in minutes
- Closest coupling possible between analysis and design

Summary

In all things, you live and die by the process that exists. Incremental process improvements yield incremental result improvements. Structural analysis software has been continuously, incrementally improving for over 20 years. These incremental improvements have been significant, but have not been sufficient to allow CAE to be applied in all situations.

MSC.Acumen is a process change that offers dramatic, order-of-magnitude process improvement. These improvements will allow CAE to be applied in situations where it was not feasible to do so before.

Description of the Navistar Expert System Developed

MSC.Acumen was used as a basis to construct the required Navistar expert system of tools. The MSC.Acumen system enables an efficient knowledge capture, documentation, and active user guidance through the specific industry established methods and best practices for product simulation. The particular methods that a company’s simulation experts develop are cast into custom MSC.Acumen vertical applications. The applications guide and assist the user to a controlled quality of simulation with a resultant extreme ease-of-use. The non-expert user therefore produces simulation with the same quality and fidelity that the expert author has established.

MSC.Acumen uses XML as a medium for capturing expert knowledge, and for manifesting it in terms of custom vertical applications. The XML (Extensible Markup Language) standard was established in 1998 for conveying information over the world-wide-web with an increased power and efficiency. Reference: http://www.w3.org/Press/1998/XML10-REC.html. The use of XML for the documentation and work-flow management of CAE simulation is the invention that drives MSC.Acumen.

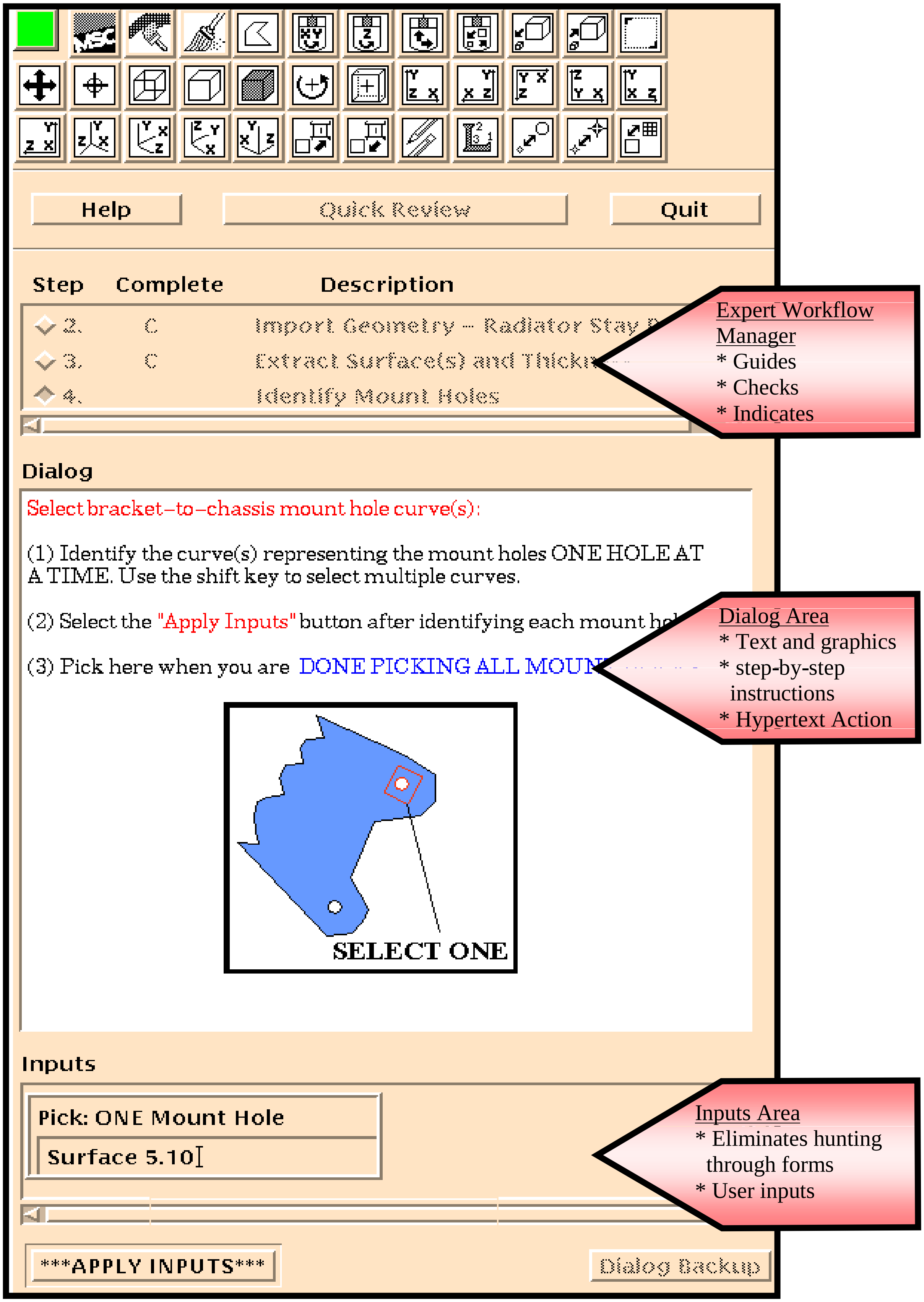
The simulation work-flow is divided into steps and dialogs. Each dialog contains an HTML packet that communicates to the user as a mini web page, displaying text and graphics. Figure 2 below shows the graphic user interface while displaying a particular dialog. The dialog area in the center of the form shows the web page like display. Icons on the top of the form are for graphics screen display manipulations. The three functional zones of the user interface are 1) the work flow manager area, 2) the dialog area, and 3) the inputs area. These functional areas effectively handle any work flow scenario without need for multiple forms. This image also shows that the application templates are highly customized for a particular process use. The interface adapts to fit and enhance a particular design process.

The XML design allows for several mechanisms to accomplish modeling actions through automation function calls. One powerful mechanism is the invocation of function calls directly from hypertext links. Hypertext images or text displayed in the dialog area can therefore initiate CAE modeling actions when selected.

An image of the user interface form plus the modeling graphics screen is shown in Figure 3. During a modeling session, the user receives graphic feedback from both of these sources. The state of the model plus clear instructions for what to do next are always displayed.

The Navistar vertical applications are implemented with MSC.Acumen directly driving MSC.Patran as CAE middleware. PCL automation functions are invoked from the XML “drive pages”. PCL is the general purpose programming language available within MSC.Patran. Customers who already have substantial investments in PCL automation functions can now leverage them further in MSC.Acumen applications. Because MSC.Patran and the MSC.Patran database are used, the files resulting from a MSC.Acumen session performed by a non-expert user can be passed to the expert analysis staff for examination or further work with full featured MSC.Patran.

A suite of eleven bracket simulation templates were developed for Navistar and organized into two separate workflow categories. Figures 4 and 5 below show selected dialogs from the leadoff page that allows the user to pick a simulation template to use. Note that the text is always speaking to the user about the particular task at hand. The dialog always results in an unambiguous action for the user to take. All problems associated with understanding the terminology and with searching through interface forms to find required capability are eliminated. Custom applications speak the language of the designer-user. They present all required options on the single-form interface in the logical sequence as scripted by the expert author.



Step	Complete	Description
◇ 2.	C	Import Geometry – Radiator Stay
◇ 3.	C	Extract Surface(s) and Thickn
◆ 4.		Identify Mount Holes

Select bracket–to–chassis mount hole curve(s):

(1) Identify the curve(s) representing the mount holes ONE HOLE AT A TIME. Use the shift key to select multiple curves.

(2) Select the "Apply Inputs" button after identifying each mount ho

(3) Pick here when you are DONE PICKING ALL MOUN

Pick: ONE Mount Hole

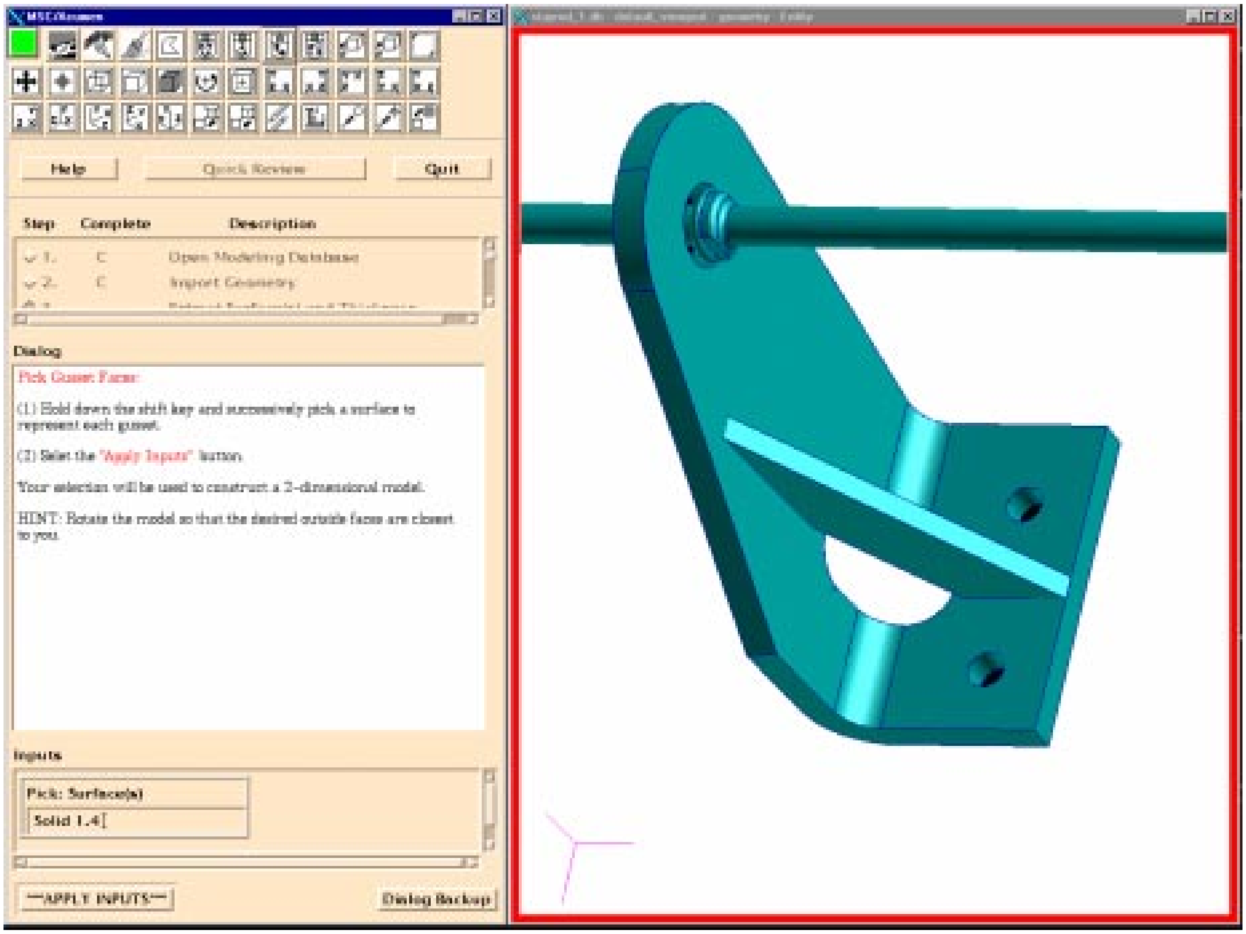
Surface 5.10

Expert Workflow Manager
* Guides
* Checks
* Indicates

Dialog Area
* Text and graphics
* step-by-step instructions
* Hypertext Action

Inputs Area
* Eliminates hunting through forms
* User inputs

Figure 2. MSC.Acumen Single User Interface Form Shown Displaying a Dialog



Step	Complete	Description
✓ 1.	C	Open Modeling Database
✓ 2.	C	Import Geometry

Pick Gusset Faces:

(1) Hold down the shift key and successively pick a surface to represent each gusset.

(2) Select the "Apply Inputs" button.

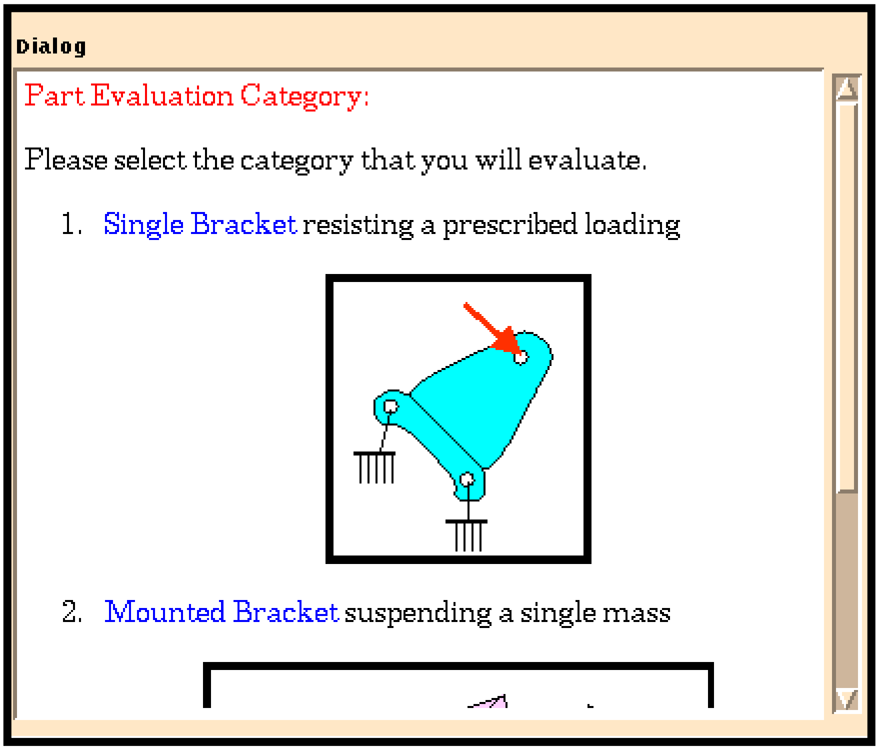
Your selection will be used to construct a 2-dimensional model.

HINT: Rotate the model so that the desired outside faces are closest to you.

Pick: Surface(s)

Solid 1.4

Figure 3. View of the Modeling Graphics Screen Along With the User Interface Form

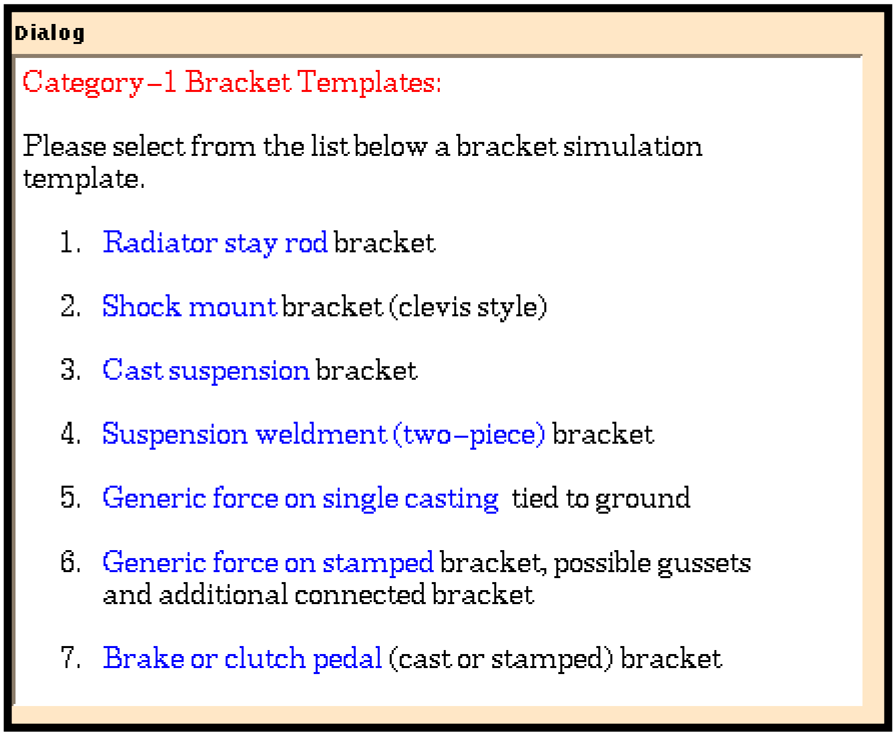


Part Evaluation Category:

Please select the category that you will evaluate.

1. Single Bracket resisting a prescribed loading
2. Mounted Bracket suspending a single mass

Figure 4. Dialog for Selecting the Category for Simulation



Category–1 Bracket Templates:

Please select from the list below a bracket simulation template.

1. Radiator stay rod bracket
2. Shock mount bracket (clevis style)
3. Cast suspension bracket
4. Suspension weldment (two–piece) bracket
5. Generic force on single casting tied to ground
6. Generic force on stamped bracket, possible gussets and additional connected bracket
7. Brake or clutch pedal (cast or stamped) bracket

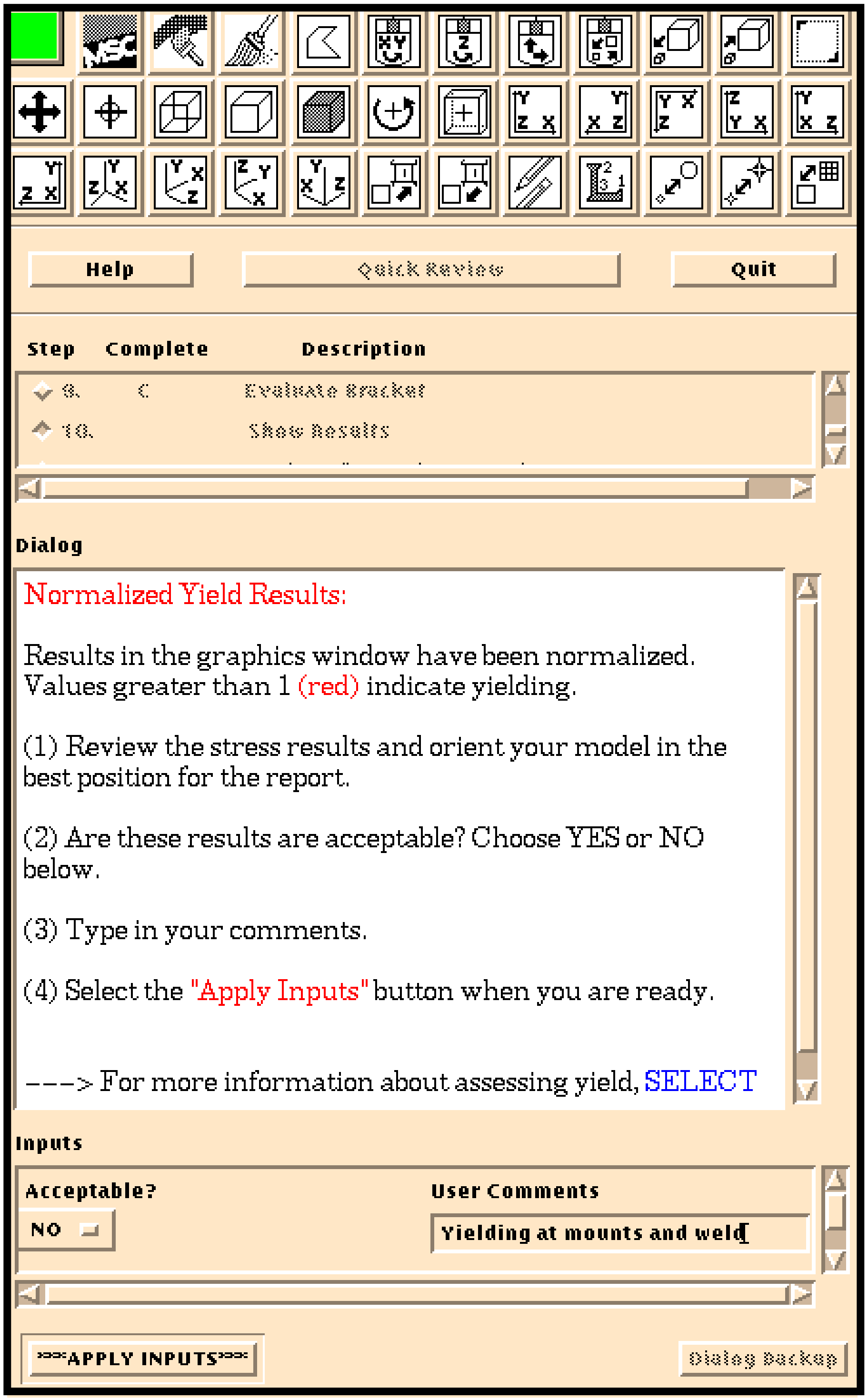
Figure 5. Dialog to Select the Bracket Type Within Category-1

The user of the Navistar developed system will select one of eleven different bracket types to simulate. Seven bracket types associated with workflow category-1 involve loading the bracket with known forces along pre-determined directions. Two-dimensional shell element models or three-dimensional tetrahedral element models are constructed automatically depending upon the bracket type. The expert author's methods are enforced, relieving the user of making finite-element model decisions.

To allow a wide range of applicability, two of the workflow category-1 applications (casting 3-D models, and stamped 2-D models) are written for generic bracket designs. Many different bracket designs can use these generic templates for simulation. The remainder simulation templates for specific bracket types benefit by automatically reading in standard known loading cases, and by producing web page reports specific to the designs. The specific design templates offer the greatest automation impact to the design process.

Four of the eleven bracket types are associated with workflow category-2. They involve a bracket suspending a single concentrated mass object, and subjected to vibration and G-force loading. One of the category-2 applications is written for a generic bracket design suspending a mass, while the other three are for specific bracket types.

After the user has selected the bracket type for simulation, an XML "home drive page" for that simulation is assigned. Subsequent simulation steps 2-through-n come from that assigned "drive page". Figures 6 and 7 show example user-interface images from subsequent steps of the truck-radiator stay-rod bracket simulation. These figures indicate how the user is guided by the expert system through the process. The workflow manager at the top of the interface form indicates which steps are successfully completed and which step the user is currently working on.



Normalized Yield Results:

Results in the graphics window have been normalized. Values greater than 1 (red) indicate yielding.

(1) Review the stress results and orient your model in the best position for the report.

(2) Are these results are acceptable? Choose YES or NO below.

(3) Type in your comments.

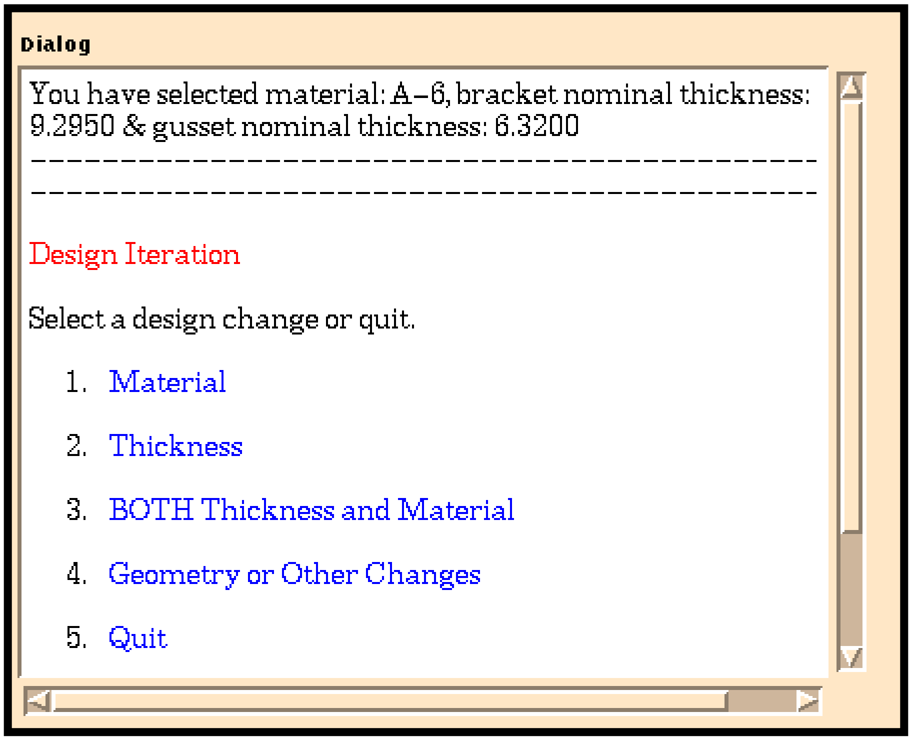
(4) Select the "Apply Inputs" button when you are ready.

---> For more information about assessing yield, SELECT

Acceptable? NO

User Comments: Yielding at mounts and weld

Figure 6. Example Dialog Displayed During the Post-Processing Step



You have selected material: A–6, bracket nominal thickness: 9.2950 & gusset nominal thickness: 6.3200

Design Iteration

Select a design change or quit.

1. Material
2. Thickness
3. BOTH Thickness and Material
4. Geometry or Other Changes
5. Quit

Figure 7. Dialog Displaying the Options for Design Iteration

The final steps of the simulation process are the post processing of MSC.NASTRAN analysis results followed by options for design iteration. During the post processing step, a web page report complete with GIF image screen captures is automatically output. The Navistar design engineer users will deposit the web page reports in a designated location for the Navistar intranet site. The structural analysis group STAG staff will later review the reports before the design is released for production. The web page reports plus databases and MSC.NASTRAN bulk data files constitute an effective means for collaboration and review. The expert analysis staff can quickly review results from the web page reports and then investigate further or perform more work with the same model if required, by taking advantage of full compatibility with MSC.Patran. Copied below is an example web page report from the radiator stay-rod bracket simulation.

- Example Web Page Report -

Radiator Stay Rod Bracket Assessment

22-Aug-99 / 17:05:58 / bremmer / CAD File: D:\Navistar\stay_rod_3.prt/Part #pn2074

Material	Load
A-6	Load Origin = Radiator
E = 207000. MPa	Front Axle Rating = 12k
ρ = 7.8599E–9 tonnes/mm**3	User Defined Load Info: NO
υ = 0.2899	User Defined Load Description: N/A
$\sigma_{\text{allowable}}$ = 397. MPa	Peak Force (Newtons) = 3000.
Bracket Thickness (Nominal) = 9.5 mm	Fatigue Equivalent (Newtons) = 1500.
Bracket Thickness (Minimum) = 9.2950 mm	Fatigue # of Cycles = 10000
Gusset Thickness (Nominal) = 6.4000 mm	
Gusset Thickness (Minimum) = 6.3200 mm	
Weld Knockdown Factor = 0.8999	

Mount Bolt Reaction Forces (Newtons):

X	Y	Z	Fx	Fy	Fz
-136.926	70.75266	38.76638	-356.986	-710.125	-461.268
-136.926	20.75265	38.76638	356.9869	710.1256	3461.268

- Example Web Page Report -

Radiator Stay Rod Bracket Exaggerated Deformed Plot

22-Aug-99 / 17:05:58 / bremmer / CAD File: D:\Navistar\stay_rod_3.prt/Part #pn2074

User Comment = Asymmetric deformation is evident.

- Example Web Page Report -

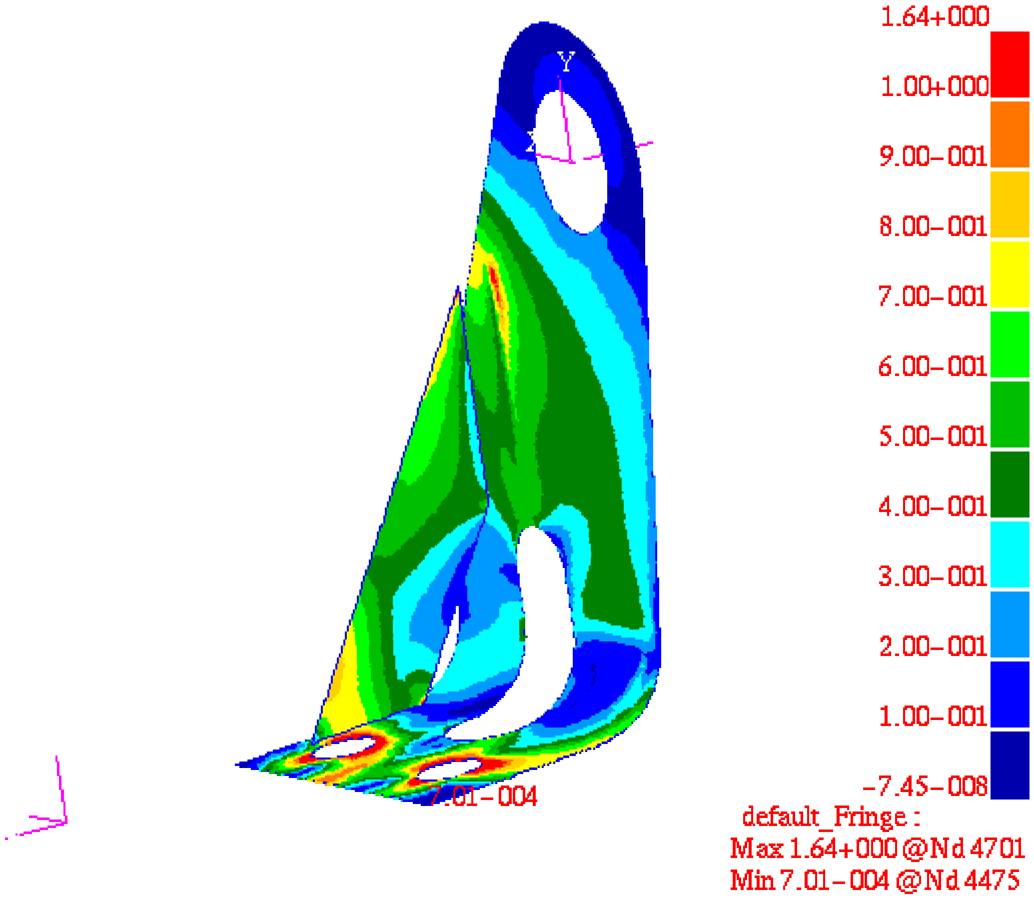
Radiator Stay Rod Bracket Normalized Yield Assessment

22-Aug-99 / 17:05:58 / bremmer / CAD File: D:\Navistar\stay_rod_3.prt/Part #pn2074

__Normalized Yield Assessment:__

Normalized σ max = 1.6351
Acceptable Stress (User Response) = NO
User Comment = Yielding at mounts and weld

Normalized Yield



- Example Web Page Report -

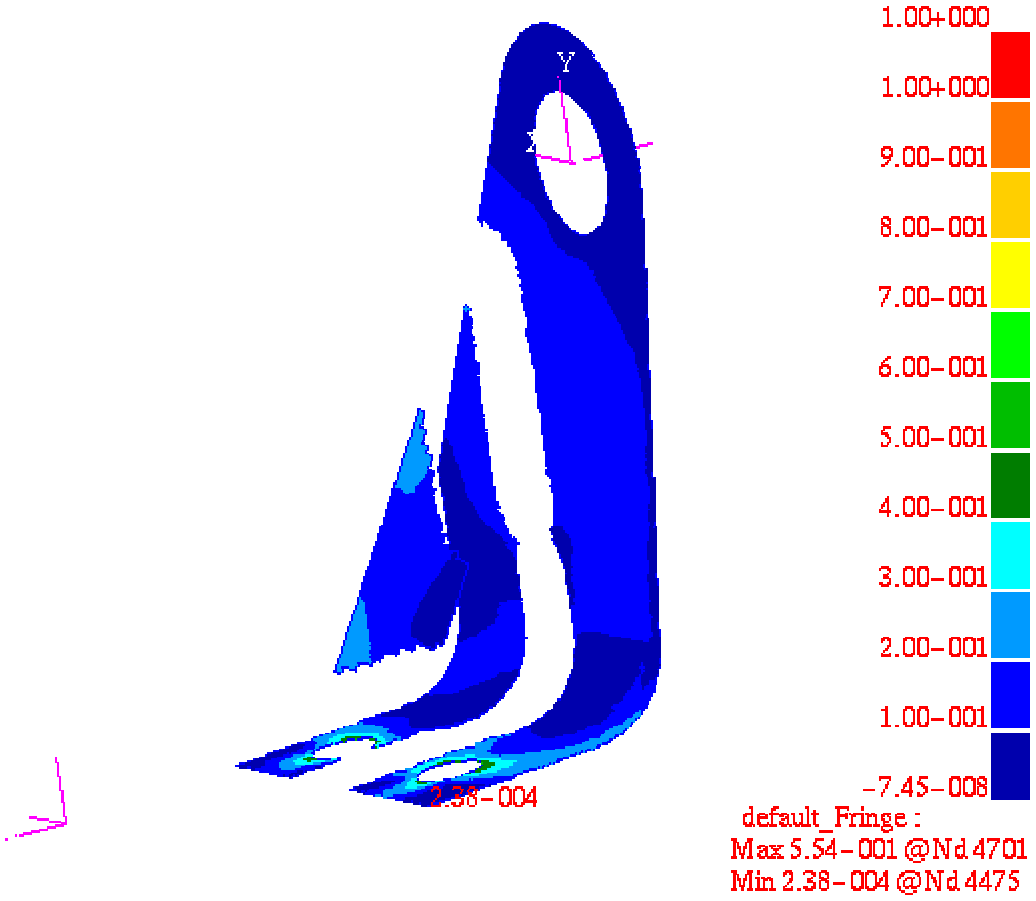
Radiator Stay Rod Bracket Normalized Fatigue Assessment

22-Aug-99 / 17:05:58 / bremmer / CAD File: D:\Navistar\stay_rod_3.prt/Part #pn2074

Normalized Fatigue Assessment:

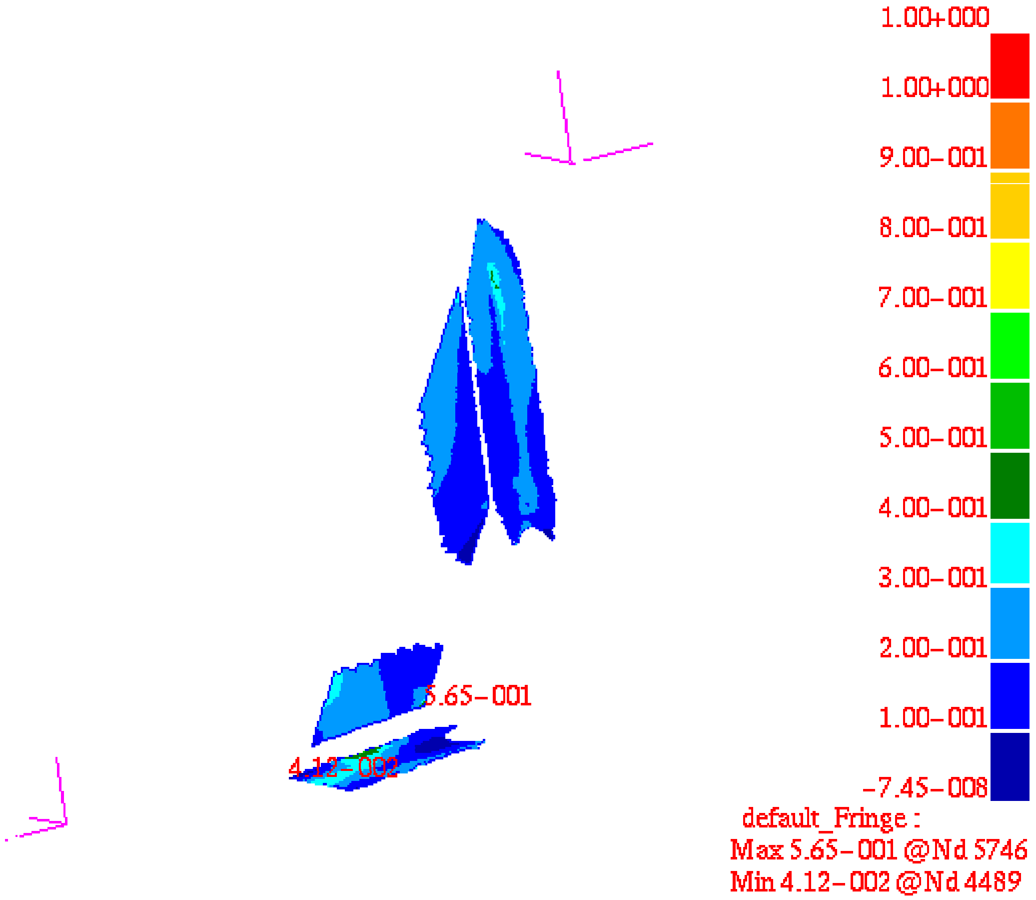
Normalized σ max (Parent Material) = 0.5539
Normalized σ max (Weld Material) = 0.5650
Acceptable Stress (Parent; User Response) = YES
User Comment = No fatigue in Parent
Acceptable Stress (Weld; User Response) = YES
User Comment = No fatigue in the weld

Normalized Fatigue (Parent Material)



- Example Web Page Report -

Normalized Fatigue (Weld Material)



- Example Web Page Report -

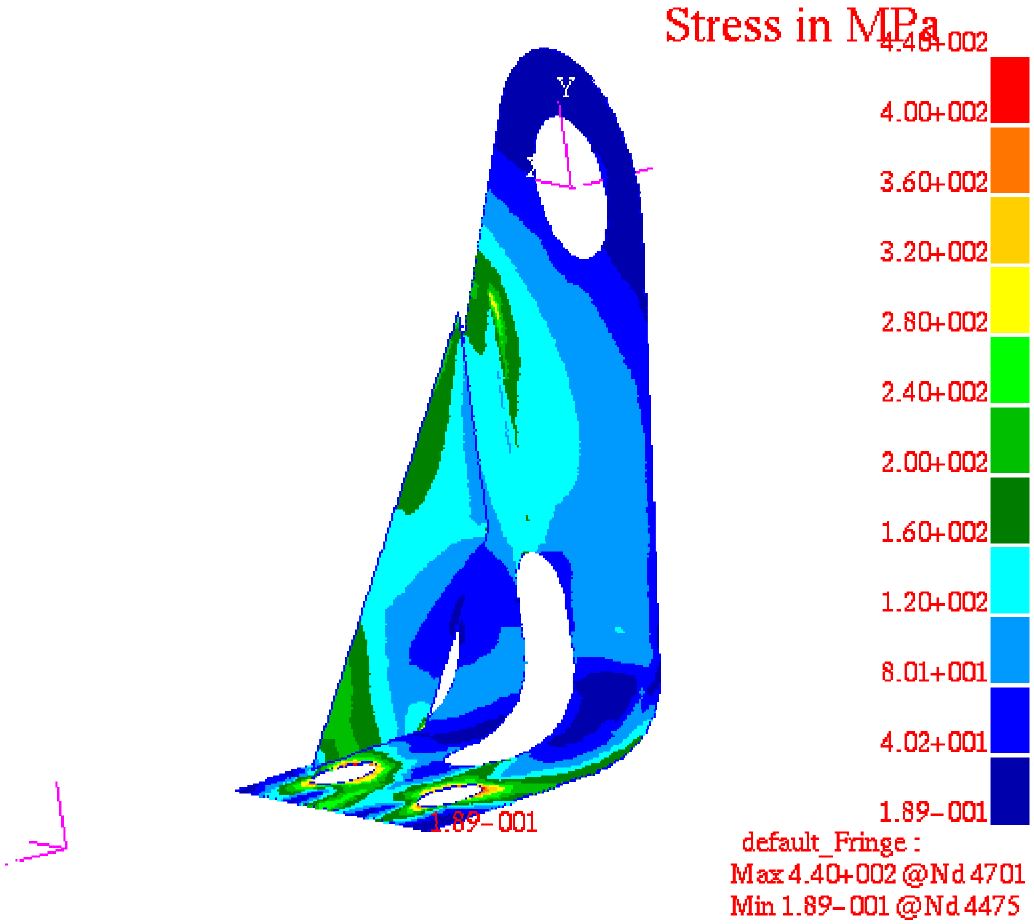
Radiator Stay Rod Bracket Absolute Stress Assessment

22-Aug-99 / 17:05:58 / bremmer / CAD File: D:\Navistar\stay_rod_3.prt/Part #pn2074

Absolute Stress Assessment:

Absolute σmax = 439.85 MPa
User Comment = More mount load spreading and direct gusset load path required.

Absolute Stress (MPa)



- Example Web Page Report -

Total Number of Elements in Model = 6089

Elements Failing Quality Test
Aspect Ratio = 0
Warp = 0
Skew = 0
Taper = 7

Corresponding Files
Nastran input file name: radiator.bdf
Database name: D:\Navistar/stayrod1.db

References

1. G. Allen, RRM final report on the Analysis Advisor project, MSC contract report to the RRM consortium, Mr. Bill Waddell-Chairman, November 1997.

2. Nishiura H., Bremmer D., Satoh E., "PVC Sewer System Seismic Analysis Made Practical" 1998 MSC Americas Users Conference Proceedings, Volume 1.

3. Soeiro, A., "Snecma Blade and Disk Meshing methodology", 1999 MSC Worldwide Aerospace Conference Proceedings, Volume I.

4. Jones J.W., Li J., Yamazaki Y., Yang J., Shiratori M., Yu Q., "Reliability Analysis of BGA Packages - A Tool for Design Engineers", 1999 MSC Worldwide Aerospace Conference Proceedings, Volume II.

5. Collaborative R&D Manufacturing's New Tool, Gene Allen and Rick Jarman, John Wiley & Sons Inc. N.Y., 1999.