simulating REALITY

MSC Software Magazine

Volume II | Winter 2012

Making Better Aircraft Everyday

TLG Aerospace, LLC

New Methods for Simulation Automation

Breakthrough Results for Fokker Aerostructures

Optimizing Engine Performance

Simulation saves auto supplier millions per year by getting design right the first time

Leading the Way in Composites

Paving the way with the most advanced material modeling technology

MSC SOFTWARE TECH TIP

Utilize CAD Defeaturing in SimXpert

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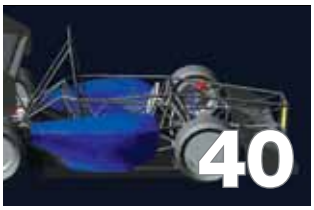

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Simulation Matters

I am reminded daily of the significance that engineering simulation brings to our customers. In this special issue of Simulating Reality, we bring to you new, intriguing stories from people who rely on computer-aided engineering technology to develop safer, more reliable products.

It is the passion of our customers, researchers, partners, and student users, and their relentless pursuit to innovate that keeps us at MSC Software inspired to continuously seek new ways of bringing better engineering simulation software and methods to the world of manufacturing.

In our feature story, TLG Aerospace, LLC, an aerospace engineering services company in Seattle, Washington shares their business critical experience in the world of aircraft certification. This impressive group of engineers is helping the aerospace industry bring aircraft to the marketplace and into service as efficiently as possible. Find out how on page 10.

Our Customer Spotlights this issue showcase significant momentum in the Automotive Industry with regard to the criticality of simulation during product development. On page 14, Steve Jia of Litens Automotive Group shares how simulation has saved the company millions per year by getting the design right the first time.

Polestar Racing's achievements result in top standings. Since they began using Adams for multibody dynamics simulations, 80%-90% of the ideas that they try on the track succeed. Find out how on page 16.

Of course, we always like to have some fun too. Check out the MSC Software Soccer team on page 25, and the progress this group of engineers has made as they kick their way into competitive rankings with soaring team spirit.

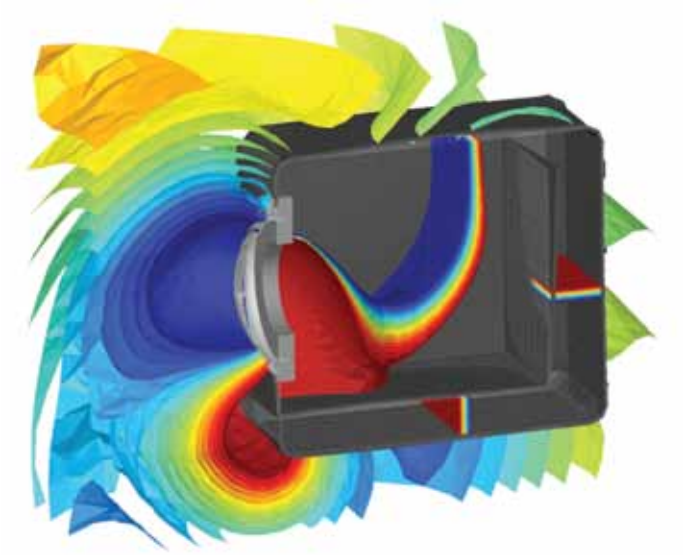
These are only a few exceptional articles you will find in this issue. We thank our customers, partners, and university connections for all their wonderful contributions.

We hope you enjoy.

Sincerely,

Leslie

NAFEMS TRAINING



In today's world, corporations and employees are re-engineering themselves to keep up with an ever changing economic and market environment. Training has become one of the top issues faced by all organizations.

E-learning from NAFEMS gives you access to best-in-class NAFEMS training courses direct from your desktop. Training from world-class tutors split into bite-sized chunks in interactive study groups, available when you need it, without the cost and inconvenience of travelling to a physical event.

Composite FE Analysis

e-learning course, online

23 February 2012

Basic Dynamic FE Analysis

e-learning course, online

28 February 2012

Essentials of Fluid Mechanics for CFD

e-learning course, online

13 March 2012

Fatigue & Fracture Mechanics in FE Analysis

e-learning course, online

22 March 2012

Non-Linear Analysis

e-learning course, online

5 April 2012

Advanced Dynamic FE Analysis

e-learning course, online

10 April 2012

Elements of Turbulence Modeling

e-learning course, online

1 May 2012

New courses and dates are announced regularly – visit

www.nafems.org/e-learning

for full details

New User Interfaces Accelerated Performance

We listened to our customers, and we delivered results.

Over the past couple months, users around the world experienced a series of new 2012 product releases. New user interfaces brought renewed interest in the technology and the long awaited MSC and MD brand consolidation took place, leading to one MSC Nastran product, one Adams product, and one MSC token system, making it easier for companies of any size to do business with MSC.

Marc®

Smarter Nonlinear Simulations

The latest release of Marc 2011 offers an all-new user interface with extended features for nonlinear contact, fracture mechanics, composites, and electromagnetic simulations.

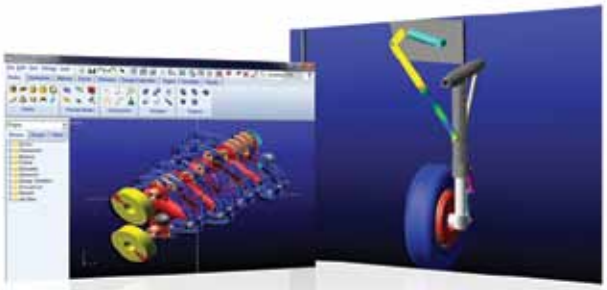
Marc's new user interface combined with improved CAD interoperability and meshing features makes it easier for engineers to create Finite Element Analysis (FEA) models and quickly learn the software program.

Marc 2011 also enables smarter setup of nonlinear contact problems including expanded segment-to-segment contact for large deformation analysis, along with other contact enhancements.

Watch New Videos at:
www.mscsoftware.com/marc

Benefits:

- Easier model navigation
- Easy to use menu organization
- Native CAD import and faster, improved meshing
- Easily Customizable



Adams™

Improves User Experience

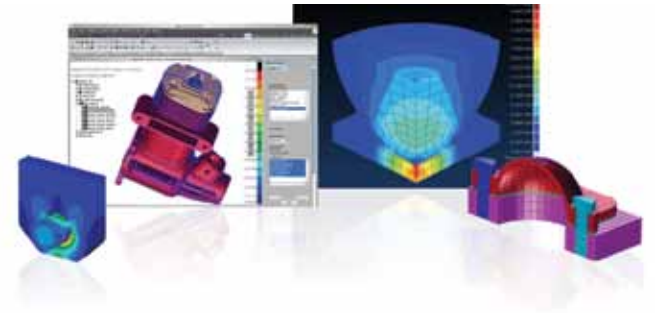
The latest Adams 2012 release benefits engineers with the consolidation of MD Adams and MSC Adams into one single Adams brand. Customers no longer need to decide which product brand they should be using, installing, and managing on their systems.

The all-new user interface and new model browser in Adams 2012 simplifies model setup; new automatic flexible body generation supports efficient, high-fidelity system modeling; and an innovative tire model complements the improved selection of standard events and road profile formats available for vehicle simulations.

Watch New Videos at:
www.mscsoftware.com/adams

Benefits:

- New user interface
- New ribbon-style format and intuitive layout
- Easier, more user-friendly model construction
- Create flexible bodies without leaving the Adams environment and without the dependence on external finite element analysis (FEA) software
- Access new tire and road enhancements in Adams/Car where higher-fidelity road simulations can be performed



MSC Nastran™

Expands Real World Behaviors

The latest MSC Nastran 2012 release consolidates MSC Nastran and MD Nastran into a single solution for all MD & MSC Nastran customers. This simplifies the product offering and provides customers a single MSC Nastran platform for the future.

With this release, users also experience significantly expanded real world behaviors for performing a wider range of event simulations.

To learn more, visit:
www.mscsoftware.com/nastran

Benefits:

- Simulate implicit nonlinear problems
- Perform explicit nonlinear simulations
- Improve results for composites analysis
- Simplify aeroelasticity calculations
- Enhance acoustics analyses
- Optimization enhancements
- New high performance computing capabilities
- 2-3x performance improvement

Patran® | MSC Fatigue™

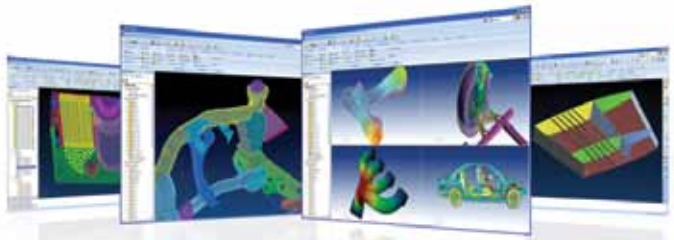
Delivers Modeling Efficiency

The new 2012 releases of Patran and MSC Fatigue provide engineers with significant modeling productivity, extended nonlinear and failure event simulations, and improved capabilities for predicting product fatigue life.

Watch new videos at:
www.mscsoftware.com/patran

Benefits:

- Navigate models with ease
- Reduce learning curve
- Quickly assembly and modify models
- Analyze more nonlinear problems
- Study failure more accurately
- Access more tools to analyze complex problems
- Estimate life-to-failure
- Perform fatigue simulations in Patran
- Move durability studies earlier in process



SimXpert®

Simplifies Multidiscipline Analysis

The latest release of SimXpert 2012 delivers significant improvements in geometry and meshing making import and modeling actions easier for users. Usability improvements as well as a series of new capabilities across Structures, Aeroelasticity, and Motion will help users assemble models and simulate a greater number of multidiscipline problems.

To learn more, visit:
www.mscsoftware.com/simxpert

Benefits:

- Spend less time preparing geometry for meshing
- Access new geometry editing tools
- Simplify preparation of mesh for analysis
- Increase modeling efficiency with new model browser
- Experience easier model navigation
- Speed assembly modeling and analysis
- Perform random analysis with new features
- Utilize easier explicit simulation capabilities
- Access new aeroelasticity modeling

SimManager™

Increases CAE Throughput

The latest release of SimManager 2012 provides dramatically faster CAE throughput with new CAE process automation and collaboration features that make it easier for engineers to use, install and implement simulation data and process management across the company.

SimManager delivers unmatched computer-aided engineering (CAE) process automation and reporting functions to increase the efficiency of engineers performing analysis, leading to orders of magnitude improvement over manual methods.

To learn more, visit:
www.mscsoftware.com/simmanager

Benefits:

- Create, execute, manage more simulations
- Assemble more simulation configurations
- Fully automate the generation of reports
- Generate reports on-the-fly
- Promote traceable collaboration across teams
- Manage huge amounts of simulation data
- Extend into new CAE domains with improved usability
- Easily deploy across enterprise

Way Beyond Products

Partnering in Engineering Methods Development

Dominic Gallello
President & CEO
MSC Software

Perhaps the thing we are most proud of at MSC is our deep knowledge of domain specific engineering methods and assisting our customers to reliably expand their simulations horizons.
New engineering methods mean moving into the unknown. The key is how to rapidly turn the unknown into a known and reliable engineering process that can be trusted within an engineering department to deliver certainty of results through the future development process.

With MSC's long history in aerospace and automotive, we have accumulated a broad knowledge of methods and a solid foundation to develop new methods.
Over the years, MSC has helped aerospace companies develop methods for; loads & dynamics, internal loads, rotor dynamics, acoustics, composites & space applications.
New methods being developed include; high fidelity maneuver loads, high fidelity structures, sizing optimization composites & metals, shape, sizing, & ply layup fractions and handoff to detail.
In the automotive field our expertise runs deep in ride & handling, NVH, powertrain and fatigue with new methods being developed in the areas of mechatronics, advanced suspensions and flow generated noise to name a few.

> "Sometimes new methods can be applied to take a look back and to move forward"

Sometimes new methods can be applied to take a look back and to move forward. In Japan, following the March, 2011 natural disasters and the Fukushima nuclear crises, MSC Japan has assisted private nuclear engineering companies and the Japanese government to take a fresh look the engineering methods for their reactors. This includes the development of a control rod insertion test system for earthquakes in simulation and full 3D simulations of an entire nuclear power plant moving from a traditional spring mass model to millions of elements to get accurate prediction of behaviors. These methods are intended to have more certainty in the behaviors of the structures under severe conditions.

Of course, engineering methods go beyond aero, auto and nuclear and are a must for any manufactured product where performance, safety and reliability are a must. If you have challenges in developing methods that can enable simulation to improve your engineering effectiveness, please contact me at: dominic.gallello@mscsoftware.com.
We hope that we can provide assistance.

Sincerely,
Dominic Gallello

MSC Software

NEWS

Building World-Class Connections

MSC AMERICAS

2011 Users Conference

The 3 day event that took place October 4-6, 2011 in Costa Mesa, CA was a smashing success:

- Over 270 Attendees
- 3 Customer Keynote Presentations (Boeing, Litens Automotive, & Lockheed Martin).
- 6 Technical Presentation Tracks covering 54 Technical Presentations.
- 7 Product Forums provided customers direct access to product managers & developers.
- 5 Training Tracks in Advanced Topics (Composites & Fatigue, Automation, Motion, Manufacturing, and Automotive Suspensions).
- 1 Training Track was broadcast World-Wide live from the conference.
- 5 Media Sponsors provided great real-time coverage of the event.
- 12 Partner Sponsors
- A visit from MSC Software Founding Member, Dr. Richard McNeal via video, who was provided a plaque for creating one of the 10 original software companies in existence today (MSC).

Please make plans now to attend the Americas Users Conference taking place in October 2012.

MSC Supports a Growing Economy in Mexico

New developments, airplanes, windmills, and automobiles makes Mexico an exciting and vibrant economy where MSC Software's solutions help local engineers solve tough problems. MSC is developing a strong alliance with local resellers to provide "on the ground" technical support in several analytical areas. To find local support in your area, please follow this link: www.mscsoftware.com/resellers

MSC JAPAN

Keio University Develops U*Toolkit for MSC Nastran

The MSC Japan team recently teamed up with Keio University to develop MSC Nastran U*Toolkit, a plugin compatible with MSC Nastran, that makes it possible to comprehend the entire load transfer path and degree of connection in structural analysis. Kunihiro Takahashi, a professor emeritus at Keio University, developed the new algorithm and introduced the new index U* for the load transfer path while taking advantage of the high speed analysis of MSC Nastran to save a substantial amount of time and optimize the design cycle. By allowing the user to analyze the load transfer path and the degree of connection of the structure in its entirety, U*Toolkit for MSC Nastran enables weight saving and higher rigidity solutions to be more quickly and easily developed.

Monthly Web Seminar Program

The MSC Japan team held monthly web seminar programs throughout 2011. The total number of registrants for the year exceeded 1500! These seminars focused on improving usability for existing customers, promoting new features and introducing product solutions to potential new customers. The series covered a broad range of topics including optimization design, fatigue analysis and acoustics analysis. The monthly web seminar won a favorable reputation for providing customers the latest and most useful information to improve their product design, while making it accessible without constraints on time and location. To register for web seminars in 2012, visit: www.mscsoftware.co.jp

MSC INDIA

VPD Conference 2011

MSC India's VPD Conference was one of the most anticipated conferences of 2011 and was conducted on September 8 and 9 in Bangalore. The conference received an overwhelming response with nearly 700 participants from a wide spectrum of industries. It kicked off with a presentation by Dominic Gallello, CEO & President of MSC Software and set the tone for the conference with a key message on MSC Product Strategies. In addition, multiple customer meetings took place with MSC products & domain experts to address the challenges faced by our customers in product development and design engineering.

MSC – ISRO Day

The Indian Space Research Organization (ISRO) is the leading space program organization in India. An MSC-ISRO Day was conducted in August of 2011 to share MSC Software user experiences. The event attracted 86 participants from different divisions of ISRO. Dr. Shiva Padmanaban, Director of MSC Software India, was the key speaker from MSC and talked about the latest updates on Marc and Dytran. The MSC India Pre-Sales Team supported the event by showcasing MSC products such as SimXpert and SimManager to create awareness and interest.

MSC CHINA

7th CAE Annual Conference

The China CAE Annual Conference is the most influential and highest ranked professional and technical conference in the domestic CAE field. The meeting, held in July in Kunming, was attended by more than 300 participants from national defense, auto manufacturing, marine, university and research institutes. MSC joined this conference as a Platinum sponsor and gave a presentation on MSC's Astro and Aero solutions at the conference for the Defense Science & Technology Industry branch.

SimManager Seminar

When MSC China successfully implemented the SimManager project in First Automobile Works (FAW) in 2010, it gained significant recognition and interest in the market. To share experiences from FAW, Audi and others with the auto industry, MSC conducted a 3-day seminar and invited Oliver Gaiser, project manager of SimManager in Germany, who worked directly with FAW, Audi and others, to be the event's key speaker.

Roadshow 2011

MSC China's Roadshow 2011 kicked off in August and was held through November. These events were conducted at 16 different locations in mainland China and included some of Taiwan's most important cities, Chengdu, Xi An, Shanghai, Beijing, Wuhand, Changsha, NanJing and TaiPei. The conferences received an overwhelming response with over 1500 attendees from various industries participating. The event offered a chance for partners to showcase their solutions as they related to MSC products for more specialized offerings. Over 50 technical papers were collected during this period and two were awarded "Best Paper."

MSC Sponsors Local University at Formula SAE

The Formula SAE competition has a 30 year history encouraging and motivating college students majoring in automotive engineering to draw up and build an innovative Formula car design in a team environment. The Southern Taiwan University (STUT) team participates in this event and has placed twice in recent years.

They were awarded 3rd for their "Gas Saving" vehicle in 2006 and took 2nd place in 2008 for "Design". In December, MSC Taiwan sponsored STUT for the 2012 Formula SAE competition, helping them to design their entry by providing related training and assistance. Using Adams, the entry car's performance was optimized to achieve goals and win the competition.

MSC KOREA

C&G TV: MDO and FSI Seminars

MSC Korea and C&G TV, a magazine for the CAD/CAM/CAE community in Korea, joined forces in July and October of 2011 to offer two online seminars. The seminars were conducted through C&G TV and discussed the subjects, MDO (Multi Design Optimization) and FSI (Fluid-Structure Integration). Over 90 attendees from 60 companies participated in each seminar to learn about these topics and were introduced to MSC Software's advanced technology. It was such a success that more seminars in both specialized and expert topics are in the works for 2012.

MSC EMEA

User Meetings were held in several countries and were attended by hundreds of participants. These meetings focused on presenting the new features of MSC's major products Adams, Marc and Nastran, but also gave an introduction to MSC's simulation data management solution, SimManager 2012, and the new CFD solution, XFlow. The user events were further enhanced by reputable industry sponsors, NAFEMS, IBM and BULL.

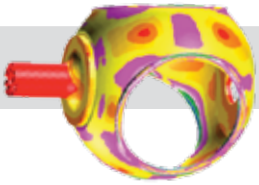
This year's program included major contributions from MSC Software customers, including Alenia, Fiat Research Centre and Cetena, as well as universities, research centers and MSC partner companies. Participants of these events provided exceptionally positive feedback, expressing their appreciation for seeing the new functionalities of the MSC solutions and the opportunity to collaborate with other users as well as with MSC experts.

Students Learn and Win in Germany

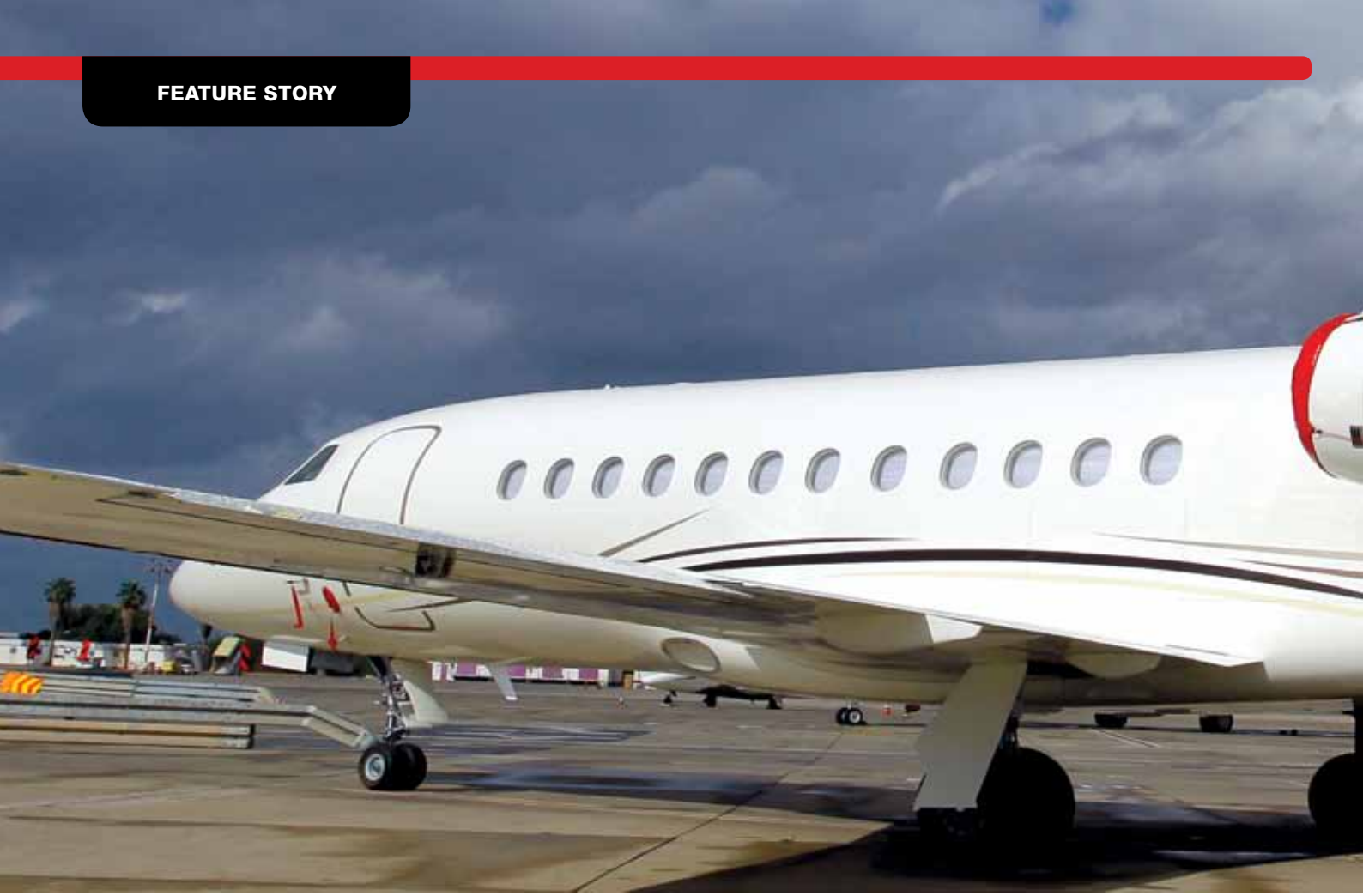
Right now, German students are downloading MSC's Student Edition to participate in the "Enlarge Your CAE Knowledge" student contest. Students must complete at least one tutorial and answer a question to qualify for prizes. First place is an iPad 2! The deadline to enter is March 31, 2012. To find out more about the contest visit & download of contest tutorials, go to: **www.mscsoftware.com/studenten**

Registration & download of MSC Student Editions: **www.mscsoftware.com/student-center**

MSC Fatigue: Bringing Knowledge and Expertise to Users Worldwide



Through the last half of 2011, Dr. Neil Bishop, author of the NAFEMS book, "Finite Element Based Fatigue Calculations", led a series of effective and compelling one and three-day seminars and workshops to hundreds of MSC Fatigue users and potential customers across the world. The events highlighted recent MSC Fatigue product updates, references and experiences and focused on "Modern Engineering Techniques for Fatigue, Durability & Damage Tolerance." Participants from different industries, including auto, machinery and wind energy acquired valuable knowledge in product algorithms and the direction of product development. Feedback from these events was overwhelmingly positive with attendees finding tremendous value and saying it exceeded expectations. Find out more about the recent release of MSC Fatigue 2012 at: **www.mscsoftware.com.**



Making Better Aircraft Everyday

TLG Aerospace, LLC | By Robert Lind

TLG Aerospace, LLC (TLG) is an aerospace engineering services company founded in 2008 in Seattle, Washington. TLG, 'The Loads Group' specializes in full vehicle analysis and optimization including static and dynamic loads, flutter, stability and control, aerodynamic design, Computational Fluid Dynamics (CFD) analysis, FAA certification and aircraft performance and handling qualities. TLG provides design, analysis and certification for new and modified aircraft and related aerospace products.

TLG's primary customers are OEMs, third-party modifiers, and other companies who design, analyze, build and sell aircraft, aircraft modifications, and related products. TLG's focus is on helping these customers get those products to the marketplace and in service as efficiently as possible. TLG routinely works with hardware-related groups such as manufacturing and test organizations. TLG engineers specify flight test instrumentation requirements and test conditions, act as engineering test crew for test flights, and prepare flight test reports within their disciplines. TLG also provides overflow capability for OEMs needing extra capacity, and helps new aircraft companies develop and validate their own loads and dynamics capabilities. TLG engineers have analytical and hands-on experience with over 100 aircraft models from more than 40 different manufacturers.

State of the Art Technology

TLG uses state of the art technology to provide its customers with advanced engineering solutions. TLG's core business is in airframe certification loads, dynamics, and flutter analyses. Working to rigorous FAA and foreign airworthiness specifications, TLG engineers participate in all levels of design, analysis, test, and certification of flight vehicles. TLG uses

MSC Software's products including MSC Nastran and Patran as the core model development and analysis engines for aircraft certification. MSC Nastran provides industry-leading coupled aeroelastic calculations which are advanced and flexible enough to handle modern transonic aerodynamic vehicles, but also fast and efficient enough to be usable for loads and flutter, which can require tens of thousands of individual solutions.

Aircraft Loads Analysis

Aircraft loads are the forces and moments applied to the airplane structural components to establish the required strength level of the complete airplane. These loadings may be caused by air pressure, inertia forces or ground reactions during take offs and landings. Determining design loads involves a full aircraft analysis of the air pressure and inertia forces during prescribed maneuvers, either in the air or on the ground. Aircraft loads are needed at all design phases, from day one through certification and product lifecycle support. Early in preliminary design, structural designers need initial loads to size the preliminary structure. As the design iterations progress, the detail and fidelity of the loads increases. The final step for an aircraft is a full set of certification loads for submission to governmental agencies such as the FAA and European Aviation Safety Agency (EASA).

The loads analysis needs to cover all possible combinations of speed, altitude, flap angle, airplane gross weight, airplane center of gravity, passenger and payload distribution, fuel quantities, engine thrust and airbrake positions for each of the required maneuver and load cases for each part of the airplane. Static loads are calculated for conditions in which the aircraft is assumed to be at steady state and range from high speed dives to low

Sample static aeroelastic load condition. Certification loads surveys require accurate representation of the cases to be analyzed.

> "TLG is proud to use MSC Nastran to drive their industry-leading capability in aircraft design, analysis and certification for loads, dynamics, and flutter."

speed stalls. The dynamic loads are how the airplane responds to gusts and bumps, including landing.

The input data to the loads analyses are accurate airplane geometry, aerodynamic data, weight (inertia) data, design speeds, stiffness data, miscellaneous systems data, operational data and regulations and requirements. This makes loads a multidisciplinary process. Early in a design program, these parameters can be estimated from various methods. As the design becomes more detailed and defined, the inputs will be more refined, and for the final certification level, verified by test.

TLG has developed an extensive set of tools to facilitate quickly setting up and running a large number of static and dynamic loads cases and then rapidly post-processing to obtain the most critical load cases, and then providing "loads envelopes" to the stress and structural engineers. TLG utilizes MSC Nastran as the core aeroelastic solver for both static and dynamic loads for these surveys.

MSC Nastran SOL144 and SOL145 are very suitable for these calculations, which require both structural and aerodynamic capabilities. Specific features, recent enhancements and upgrades have increased its utility:

Aerodynamic data can be input directly on aerodynamic or structural meshes

Aerodynamic pressures may be calculated from the built-in doublet lattice solver or alternatively input directly as pressures or forces on structural grid points. All of these aerodynamic variables may be linked to control variables and used in the airplane force balance for flight maneuver conditions. This capability allows TLG to input real-world data directly into the model, even if the results are difficult to calculate with the industry standard doublet lattice model. Examples include engine thrust, aerodynamic effects of deployed spoilers, and high trailing edge flap deflections.

User-defined input variables

MSC Nastran allows arbitrary combinations of user-defined inputs to be used as part of the balanced airplane calculations. These inputs can control arbitrary pressure inputs as mentioned above, or existing MSC Nastran trim variables, or combinations of existing

TLG customer aircraft modification. TLG performed the complete static & dynamic loads, and flutter certification analyses using MSC Nastran.

variables. This functionality allows TLG to perform such tasks as balancing the airplane in any way needed for particular calculations, defining control surface relationships such as control wheel to aileron gearing, or linking any set of balance variables together.

Separate rigid and flexible mesh

A single aeroelastic trim calculation can be performed using one aerodynamic mesh for the rigid aerodynamics and second aerodynamic mesh for the flexible increment. TLG uses this capability to maintain total control over the aerodynamic data.

Monitor points

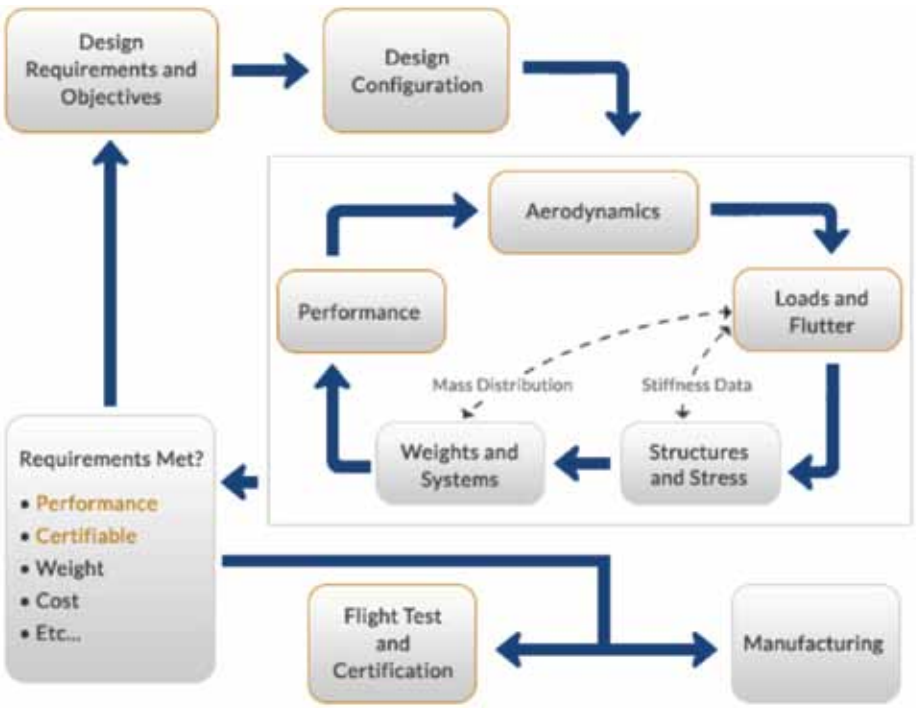
Loads calculations require complete user control over how the aerodynamic and inertial loads are tracked and accounted for in the downstream output. Structural FEM and aerodynamic mesh elements do not inherently provide this level of control. The aerodynamic and structural monitor point capability in MSC Nastran allows TLG to define engineering-level loads summations to sort for critical conditions and to provide loads to stress engineers.

Flutter

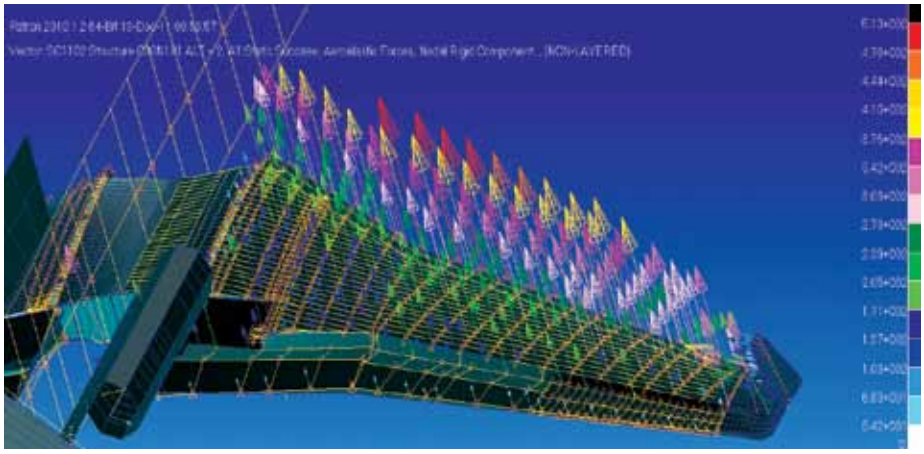
Flutter is an aeroservoelastic phenomenon in which unsteady aerodynamic forces combine with structural vibrations to produce a self-feeding oscillation which, if unstable, usually leads to airplane damage! Flutter analysis is done to ensure that the aircraft is safe and free from flutter at all points in the flight envelope. The interaction between structural vibrations and unsteady aerodynamics are modeled to show whether an airplane will respond in a stable or unstable fashion to atmospheric or other disturbances.

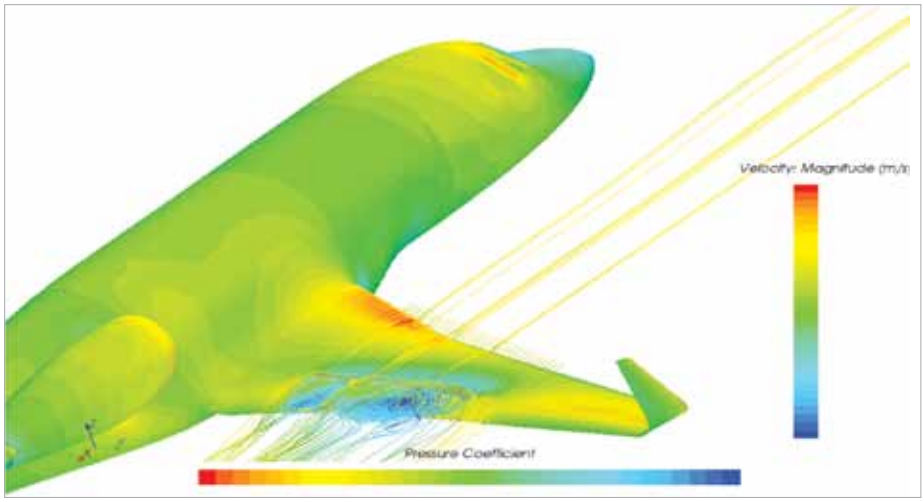
The FAA, EASA and other agencies require that the aircraft is shown to be free from flutter for all nominal flight conditions and for critical combinations of failed systems and structures. All possible combinations of fuel, payload and operating conditions must be considered. Flight flutter tests must be performed for some of the conditions to demonstrate the accuracy of the analysis and to prove the airplane is safe to operate.

TLG uses MSC Nastran SOL145 for flutter analysis. The results show which airplane types of vibration result in flutter and at what airspeeds the flutter occurs. Variations in the analysis model can show which design changes can be used to improve flutter behavior.



Aircraft Design Cycle





MSC Nastran allows the user to define & import complex aerodynamic data such as the effects of deflected spoilers. The spoiler effect is calculated with a CFD code & used in the MSC Nastran calculations.

Aircraft Design Cycle

TLG's areas of expertise form core parts of the aircraft optimization design cycle. Aircraft design is an iterative process; early in the design phase, a loop around the design cycle may take only a few days or weeks. As the design matures and the detail increases, each additional loop may take months. When all the requirements are met, it's time to build an airplane!

The design starts with Design Requirements and Objectives (DRO). Along with size, performance and weights, the DRO includes cost objectives and certification requirements. Engineers work from the DRO to create the initial airplane configuration.

Once an initial configuration is defined, the first design cycle begins. Estimates and approximations for input data are required - the aerodynamic analysis needs structure and weights design data, structural design requires loads data, and the loads analysis uses aerodynamic, structural, and weight data. After the initial design process, the results are compared against the objectives, assumptions and data are revisited, and an updated design is created. This process continues throughout the design, development, and certification process. Initial design phases involve numerous, relatively short design cycles as the configuration evolves to meet requirements. Later design phases are longer and involve higher fidelity data and more complicated analyses. The cycle continues through the project certification, as the certification loads depend on ground and flight test validation of the final dataset.

TLG is proud to use MSC Nastran to drive their industry-leading capability in aircraft design, analysis and certification for loads, dynamics, and flutter. TLG's capabilities in vehicle analysis and optimization make efficient use of MSC Nastran capabilities for aeroelastic analysis. These analyses are used in all parts of the design process, from conceptual design through to final certification and fleet support. TLG customers - including OEMs, modifiers, and new aircraft companies - benefit from more efficient designs and faster design cycles.

Please visit www.tlgaerospace.com or email us at info@tlgaerospace.com for more information on how we can support your aircraft design, analysis and certification projects. ◆

Optimizing Engine Performance

Simulation Saves Millions per year by Getting Design Right the First Time

Litens Automotive Group | Based on an interview with Steve Jia

Litens Automotive Group's patented TorqFiltr crankshaft vibration control technology uses an arc spring isolator mechanism to decouple the accessory drive system inertia from the engine torsional vibrations. The product is dimensionally rather small but incorporates a complex mechanism consisting of a series of components that transmit power to each other through complicated frictional contacts rather than fixed connections. The product must frequently be customized to deliver optimal performance for a specific automotive engine. In the past, this involved a time-consuming and expensive trial and error process.

Recently, Litens has developed the ability to accurately simulate the operation of the TorqFiltr, making it possible to accurately evaluate performance of design alternatives and iterate to the optimal design before building the first prototype. "MSC Software's Marc nonlinear finite element analysis (FEA) software has been used to accurately predict how the design behaves, how components move and react against each other and what happens under dynamic loading conditions," said Dr. Steve Jia, Chief Engineer, CAE Technologies and Materials Engineering, for Litens. "It is difficult to accurately estimate the cost savings we have obtained through virtual product development (VPD) but we are certain that it amounts to millions of dollars per year across our complete product line."

> "Marc not only substantially reduces development time and cost, but also is the only tool that enables us to investigate how the proposed design works"

Dynamic Tension Control

High static and dynamic accessory belt tensions reduce belt life, reduce accessory component bearing life, increase noise, waste fuel and add weight and cost through coping strategies. Litens specializes in delivering engineered control of pre-set (static) and running (dynamic) belt tension, resulting in accessory drive systems that are efficient, quiet and transmit maximum power under all conditions.

Litens TorqFiltr controls the system resonant frequency by tuning the spring stiffness to the system inertia. Because the spring stiffness is softer than traditional rubber isolators, vibrations from the engine are mostly absorbed before being transmitted to the accessory drive belt. This results in isolation of all components in the accessory drive, and any accessory drive system resonance has very small peak amplitudes since there is little excitation. TorqFiltr springs are made of steel and do not deteriorate like rubber. Additionally, the built-in automatic clutch system eliminates belt squeal associated with resonance of rubber dampers so no separate one-way clutch is needed.

The TorqFiltr device connects to the engine crankshaft through four bolts that connect to the holes in the driver shaft shown in the top half of Figure 1. The driver shaft has two wing tabs that compress the arc springs shown in red on the drawing. The arc springs connect to two shells shown in black in the drawing. Half of the shells have been removed for display purposes. The shells in turn connect to the clutch springs which are shown in gray in the drawing. The clutch springs have a frictional engagement with the pulley that drives the accessory belt.

Very complex engine vibration loading drives the device. The arc springs absorb most of the angular vibration energy of the engine and the clutch transmits power in only one direction, serving to decouple the engine from the accessory drive system. It's interesting to note that none of the components in the load path have a fixed connection each other and torque is transmitted only through frictional contacts rather than fixed connections. In addition, the contact conditions including the magnitude, location and direction of the contact forces are continually changing as torque varies or the device rotates.

Design Challenge

"This device provides an enormous design challenge," Dr. Jia said. "We need to fully understand the behavior of the design under dynamic loading conditions in order to ensure that we will deliver the right products the first time. We need to determine the magnitude, location and direction of the action-reaction forces and stress and deformation/deflection on each component and to investigate the contact mechanism

Figure 1: TorqFilter geometry

Figure 2: TorqFiltr mesh

Figure 3: Maximum principal stresses

in order to achieve an optimal design. Moreover, the automotive industry is very cost-competitive and weight-conscious so we also need to remove unnecessary material in the design in order to minimize the weight."

"We can determine the overall dynamic performance of a crankshaft decoupler though physical experiments but the information that can be gained from physical experiments is limited because there are no sensors available at a reasonable cost that can tell us what is going on inside that small assembly," Dr. Jia continued. "We are still left guessing as to what is happening inside such as contact locations and forces and stresses and deflections of the individual components."

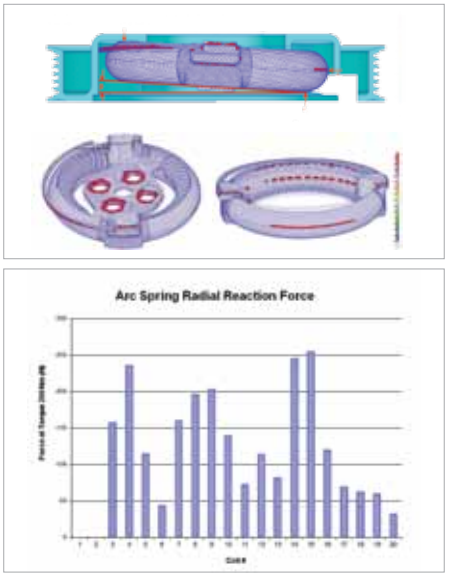


Figure 4: Marc highlights contact locations and forces

Picking the Right Simulation Technology

Litens has evaluated a number of different simulation technologies. Large displacement dynamic simulation systems such as MSC's Adams software do a great job of simulating complex mechanisms, however, they are not designed to handle the elastoplastic nonlinearities seen in this application. There are a number of finite element analysis software programs on the market but most are limited to solving within the limits of linear material properties and displacements, small strains and small rotations. Some software packages claim to have nonlinear capabilities but are not able to consistently and reliably solve problems involving continually changing contact conditions between components, large rotational sliding frictional contacts and elastoplastic material behaviors.

On the other hand, Marc was built from the ground up to consistently obtain converged solutions for highly nonlinear problems involving nonlinear materials, large strain and displacement and contacts. Marc also provides multiphysics capabilities, enabling engineers to simulate coupling between structures, thermal, fluid, acoustics, electrical and magnetics.

Litens analysts receive a detailed computer aided design model from the company's design engineers. They import the geometry into Patran, the company's pre-processor of choice. The biggest challenge in pre-processing is to reconcile the detailed meshing required in areas such as where the clutch inserts into a slot in the lower spring shell with fillets of 0.2 mm with the need to keep mesh size as large as possible in areas with smaller transients to reduce solution times. Patran gives Litens analysts complete control over the mesh distribution. Analysts typically manually create a surface mesh in critical areas and use the automesher to fill in the less critical areas. The model is then sent to a high performance computing computer with 32 CPU/cores and 256 gigabytes of RAM for solution.

Understanding How the Design Behaves

The simulation results enable Litens to understand how the design behaves, how the components affect each other and what happens as the product rotates through large angles of displacement. "We can see how every component moves and reacts against other components as the product rotates through its full range of motion," Dr. Jia said. "We can determine contact locations, contact forces, stresses and deflections, many things we need to know to optimize the design of the product. For example, our clutch was originally designed in an S-shape based on previous experience, but the FEA results showed us that a C-shape provided much better performance at no increase in cost. Simulation results with Marc are consistently within 5% to 10% of physical testing results, and even less than 5% in some cases, giving us confidence to use simulation to drive the design process."

Figure 3 shows the maximum principal stresses at one point in the rotation. The figure shows that the highest stress is in the arc springs. The ability to view stress on each location of each component makes it possible to identify hot spots so they can be corrected to avoid premature failures. At the same time, areas where stresses are low present the opportunity to remove material to save costs. By the way, for this plot the scale was set to 900 Megapascals in order to easily view stresses in the arc spring in relation to other components. Litens analysts lower the scale in order to distinguish differences in stresses among the components with stresses that are so close to each other that they all show up as green in Figure 3.

Figure 4 highlights the ability of Marc to determine the contact locations and forces. The colored areas show the location of the contact and the magnitude of the contact forces. Analysts can determine these values at any point in the rotation or can generate an animation that visually shows the contact locations and forces changing as the device rotates. "It's not practical to obtain this type of information using physical testing," Dr. Jia said.

"Marc has been widely used in our everyday VPD to simulate the complete mechanism and to virtually measure everything we need to optimize the designs. Marc not only substantially reduces development time and cost, but also is the only tool that enables us to investigate how the proposed design works and how the product behaves when a physical part is not available during conceptual development stage or a physical experiment is not practical or cost-prohibitive," Dr. Jia said. "Over the years, we have developed great confidence in both the Marc software platform as well as our own ability to apply the tools in an accurate and consistent method. Obviously this approach saves money and time and has become such an embedded part of our engineering process that I cannot see us developing any new product without this capability." ◆

Racing to Win

Polestar's Achievements Result in Top Standings

Polestar Racing | Based on an interview with Per Blomberg, Manager, Chassis Development

> "Since we began using Adams/Car, 80% to 90% of the ideas that we try on the track succeed."

Polestar Racing is a Swedish motorsport team, affiliated with Volvo Car Corp., currently competing in the Scandinavian Touring Car Championship and World Touring Car Championship. In this highly competitive environment, Polestar engineers spend months over the winter offseason struggling to squeeze a few extra tenths of a second per lap out of their cars. One of their most valuable tools is MSC Software's Adams/Car which they use to evaluate different vehicle designs in critical areas of the track such as the corners.

"With Adams/Car we can very accurately simulate the performance of any particular vehicle configuration in a corner and by simulating many configurations we can determine which one is the best for a particular track," said Per Blomberg, Manager Chassis Development at Polestar Racing. "We have one of the most advanced simulation capabilities on the racing circuit and this is one of the factors that helped us win the team championships twice the last three years and finish second the third year."

Polestar was founded in 1996 in collaboration with Volvo Car Corporation in order to drive forward Volvo´s investment in racing. Since then, Polestar has competed with the 850, S40, S60 and now the C30 Volvo models. The Scandinavian Touring Car Championship car was totally designed and developed in-house by Polestar in accordance with FIA S2000 regulations. The engine runs on Bioethanol (E85) and components from Volvo's DRIVe line of stock vehicles play a vital role. Polestar has had a stellar record, winning the Swedish Touring Car Championship team championship in 2009 and 2010 and placing second in its successor, the Scandinavian Touring Car Championship, in 2011.

Preparing for the Next Season

Blomberg said that the race team's greatest use of Adams/Car is during the winter months when it is preparing its cars for the next season. "We have many different ideas to improve race performance," Blomberg said. "But we can only spend four or five days every six weeks at the test track in southern Spain. We have a very intense schedule and the number of vehicle configurations that we are able to test is strictly limited." The team performs around 3,000 kilometers of track testing each winter with the new car compared to the 150 kilometers or so that each driver covers in the course of a normal race weekend. Polestar also uses Adams/Car during the race season to analyze events that have occurred in earlier events and evaluate small-scale improvements that are implemented during the racing season.

In the past Polestar used hand calculations and spreadsheets to perform some very rough estimates of vehicle performance to attempt to select the best designs for testing. "These tools provide some value in sharing knowledge but contribute little towards predicting the performance of a prospective design," Blomberg said. "We have long used simulation at the component level to, for example,

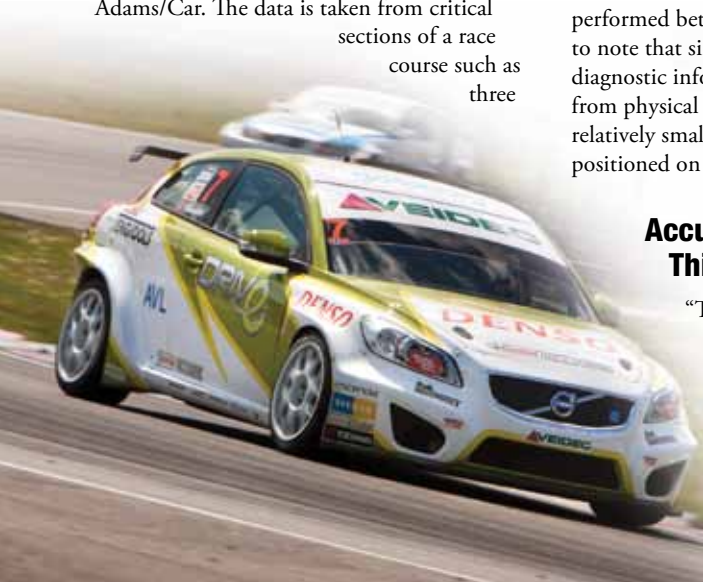
evaluate stress and deformation in suspension components, but we were not aware of the possibility of predicting the performance of the complete vehicle until the MSC representative introduced us to Adams/Car."

Adams/Car is designed to enable engineering teams to quickly build and test functional virtual prototypes of complete vehicles and vehicle subsystems. Working in the Adams/Car environment, automotive engineering teams can exercise their vehicle designs under road conditions, performing the same tests they normally run in a test lab or on a test track, but in a fraction of the time. "With front wheel drive cars the front tires are responsible for steering, breaking and powering the vehicle while the rear tires simply follow," Blomberg said. "It's a continuous struggle to find enough friction with the front tires and this is the area where Adams/Car makes its greatest contribution."

Modeling the Vehicle Configuration

Engineers create a model of the vehicle in Adams/Car to match a configuration that they are interested in evaluating. One of the key aspects of the vehicle is the pickup points in the suspension, the points where the suspension link arms attach to the chassis. The front end of Polestar's current vehicle has a Macpherson strut with a damper that attaches to the body under the hood and a lower link arm that attaches to the hub. The rear end uses a multilink suspension. The locations of the pickup points are limited by the rules of the racing series. Polestar sometimes simulates vehicles outside these limits in order to get a better understanding of the sensitivity of the vehicle performance with respect to certain design parameters. Other parameters whose impact is evaluated during simulation include the spring thickness, anti-roll bar thickness, camber angles, tire properties and weight distribution in the vehicle.

Polestar obtains data on the mechanical properties of the tires from the tire manufacturers and incorporates them into the Adams/Tire module that models the forces and torques that act on the tire. Polestar engineers take data recordings from measurement systems in the car such as the steering, breaks, and accelerator and export these channels to Adams/Car. The data is taken from critical sections of a race course such as three different types of 180 degree turns. The slow turn is normally taken at 60 kmh, the medium turn is taken at 100 kmh and the fast turn is taken at 170 kmh. This data is used to generate the driver control file that Adams /Car uses to simulate the input of driver. In most cases the driver provides little active control during the turn – the car goes through the turn so quickly that there is no time to react.



Adams/Car then simulates the vehicle traveling through the turn. The driver enters the turn at the outer edge of the track, steers into the corner to the inside edge of the track at the center of the turn, then exits the turn at the outside of the track. The margin, the distance between the vehicle and the outer edge of the turn, is one of the most critical outputs of the simulation because the existence of margin indicates that the driver can increase the speed of the vehicle through the turn. Polestar engineers often run the simulation several times at different speeds in order to find the speed where the margin is zero. This is the maximum speed that the vehicle configuration under consideration can be driven through the corner.

The simulation also provides detailed information on the behavior of every aspect of the car that is included in the model. This information is often used by engineers to understand the reasons why one design performed better than another. It's important to note that simulation provides much more diagnostic information than can be obtained from physical testing which is limited by the relatively small number of sensors that can be positioned on the vehicle.

Accuracy to Second or Third Decimal Place

"The correlation between Adams/Car simulation and physical testing is very good," Blomberg said. "When we compare simulated to measured roll angle or lateral or longitudinal acceleration the results match up to the second or third decimal place. Our biggest challenge in making further improvements in simulation accuracy is getting accurate material information from the tire manufacturers.

"Adams/Car helps us decide which ideas we should go to the test track with and which ones we should forget about," Blomberg said. "Before we used Adams/Car we found that only 40% to 50% of what we tried at the test track turned out to be effective. Since we began using Adams/Car, 80% to 90% of the ideas that we try on the track succeed. By enabling us to try out our ideas on the computer first, we can evaluate many more ideas than in the past and spend our scarce time at the track just on ideas that we are nearly certain will work."

As an example, the Swedish Touring Car Championship changed tire suppliers a few years ago. All of the teams scrambled to better understand the behavior of the new tires. Polestar used Adams/Car to explore the effect of variables that influence the behavior of the tire on the full vehicle performance. Polestar discovered that vehicle performance was optimized at two very different combinations of tire pressure and camber. Both of these combinations were equally fast but there were major differences in the way the vehicle handled, particularly in the degree of over-steering and under-steering. After noticing this phenomenon in simulation, Polestar engineers tested it out on the track and found that it was accurate. They used this knowledge to select one set of conditions or the other depending on which type of behavior was best suited for a particular track. On several conditions they even changed the conditions in midrace.

Blomberg concluded that Polestar's experience with and intensive use of Adams/Car provides a significant competitive advantage and has played a significant role in the team's success. "To win a race, you must understand the car," Blomberg said. "Adams/Car supports our success by enabling us to simulate the car for every vehicle configuration and track condition we can imagine." ◆

High Performance Seals

Nonlinear Simulation Helps Design Longer Lasting CV Boots

Race-Tec Sealing Limited | Based on an interview with Richard Kennison

> "We selected Marc because it was built from the ground up to consistently obtain converged solutions for such highly nonlinear problems"

Race-Tec Sealing Limited is a leading supplier of high performance seals and precision elastomeric products such as constant velocity (CV) joint boots and gaskets. CV boots used in racing, military and off-road vehicles undergo large amounts of deformation as the vehicle is steered and the suspension moves up and down. Boots must be designed to withstand the deformation without damage while keeping the size of the boot as small as possible to present a reduced area for flying object strikes. Virtually any geometry can be made out of rubber but the cost of building a prototype of and testing a proposed boot design is high.

Race-Tec engineers overcome these challenges by simulating the performance of CV boots with MSC Software's Marc nonlinear finite element analysis software. Marc enables them to very quickly evaluate alternative designs and iterate to an optimal solution. "In a recent typical example, we reduced the height of a boot for a military vehicle from 180 mm to 32 mm while maintaining stress under maximum deformation at constant levels," said Richard Kennison, Senior Design Engineer for Race-Tec. "The new boot lasts much longer than the previous design because its lower profile makes it less vulnerable to object strikes and significantly reduces self-contact."

Race-Tec has been supplying high performance sealing solutions to the racing industry for over a decade and has utilized its sealing expertise to enter other markets including high performance production vehicles, military vehicles and all terrain vehicles. The company specializes in compact designs that can be integrally mounted to the differential assembly, reducing drag and offering a substantial space savings for adjacent components.

CV Boot Design Challenges

The function of the CV boot is to cover and protect the mechanical components in the CV joint from humidity, dust and mud. while ensuring that lubricant does not leak out. The boot may be mounted to the hub or transmission using an interference press fit, mechanical retention with a custom designed circlip, cable tie or clamp or chemically bonded into the housing. The most common boot materials used are hydrogenated nitrile, silicone and fluoroelastomers. CV boot performance is critical even though the boot itself is not expensive to replace because the failure of a boot can cause lubricant to leak out and abrasive particles to enter, leading to the failure of the CV joint itself.

The greatest challenge in designing a CV boot is ensuring that the boot will be able to withstand articulation angles without excessive stress, deformation or contact. Physical testing can provide a good understanding of a proposed design, however, the cost and time involved in building and testing a prototype is considerable. Not long after the company began operation, Race-Tec engineers began looking for a way to simulate the performance of a boot under real-world operating conditions.

"CV boots present one of the most difficult analysis challenges because they exhibit large displacements, large strains, incompressible material behavior, susceptibility to local buckling and varying boundary conditions caused by the 3D contact between various parts of the boot," Kennison said. The boot undergoes complex nonlinear deformation during the combined rotation and bending of the CV joint. During bending and axial movements in normal operation, contact between the boot and itself

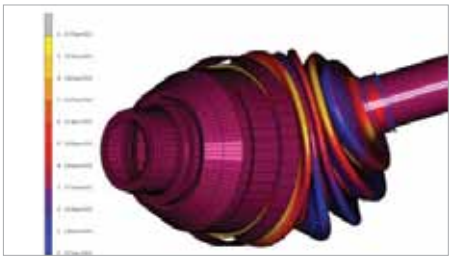


Figure 1: Marc simulation results for initial CV boot design

Figure 2: Marc simulation results for final CV boot design

or with other vehicle components should be minimized to avoid abrasive wear. Simulation needs to be able to predict and determine the effects of contact during boot operation.

"Traditional finite element analysis tools are limited to solving within the limits of linear material properties, small strains and small rotations," Kennison continued. "Some software packages claim to have nonlinear capabilities but are not able to consistently and reliably solve problems involving highly complex frictional contact, large deformation, large strain and hyperelastic material behavior."

"We selected Marc because it was built from the ground up to consistently obtain converged solutions for such highly nonlinear problems," Kennison said. Marc represents elastomeric material behavior with tried and tested material models including Generalized Mooney-Rivlin, Boyce-Arruda, Gent and Ogden using a built-in graphical curve fitting capability to establish appropriate material coefficients from experimental stress/strain data. Smart contact and load incrementation algorithms ensure accurate and robust nonlinear analyses while simplifying model setup.

In the presence of large deformations, elements can distort to such a degree that they are unable to adequately capture an accurate strain distribution. Marc automatically remeshes, mapping all the element state variables and contact conditions to ensure that the analysis can proceed to the desired final loading condition. Marc also offers a local adaptive remeshing capability in which an existing mesh is repeatedly refined until one of several user-defined error criteria are satisfied.

Simulating a CV Boot

Race-Tec engineers prepare for simulation by creating a computer aided design model of the proposed boot design. Then they import the model into Marc. They define the mesh manually in the most critical areas and use the preprocessor's automeshing capabilities to define the remainder of the mesh. Race-Tec engineers apply centrifugal forces to the boot to account for the fact that it is rotating. Further boundary conditions are applied using rigid contact bodies. In this way, very complex translational and rotational deformations can be readily applied to the boot to simulate shaft loading behavior identical to that experienced in the real world.

The boot is made from a hyperelastic material that exhibits a nonlinear elastic response up to a very large strain. Such materials are challenging to represent mathematically because their behavior depends on a large number of variables. Race-Tec uses its on-site facilities for tensile and compression testing of hyperelastic materials at large strains at temperatures ranging from -30°C to 175°C as shown in Figure 4.

The Marc solver performs the nonlinear analysis in load steps called increments. The user defines acceptable tolerances for force, displacement, strain energy and other parameters in seeking equilibrium for each increment. Within each increment, the program seeks a solution by iterating until equilibrium is achieved before proceeding to the next increment. Depending on the level of nonlinearity experienced at each increment, Marc automatically modifies the step size in order to achieve a converged solution using the minimum number of increments.

The simulation typically begins with the shaft at a zero angle of rotation and ends with the shaft at the maximum angle. In the case of the CV boot for the off-road vehicle, Race-Tec engineers simulated the existing design at worst case conditions consisting of 37 degrees of steering, 19 degrees of suspension travel and 3 degrees of camber for a combined 3D angle of 42 degrees. The design objective was to withstand these extreme conditions without any contact and while minimizing the size of the boot. With CV boots used on racing cars, which are typically tri-lobe joints, Race-Tec engineers normally take a somewhat different approach by simulating both ends of a plunge condition with the suspension at maximum and minimum vertical height.

Iterating to an Optimized Design

The Marc analysis predicted the displacement, stress levels, strains and the points where the CV boot contacts itself and where it contacts the steel shaft. The initial design case helped Race-Tec engineers understand how the boot was deforming in response to the movement of the CV joint as shown in Figure 1. They created and evaluated a series of design iterations with the goal of continually reducing the size of the boot while minimizing stresses and contact.

Over a series of 60 design iterations, the engineers succeeded in dramatically improving the boot design as shown in Figure 2. Figure 3 shows the height was reduced by 82% from 180 mm to 32 mm. The reduction in height ensured the boot presents a substantially reduced area for impact strikes from road debris and reduced self contact. Somewhat different benefits are typically seen in CV boots for racing applications. The accurate prediction of buckled shapes and levels of strain allows the boots to be run closer to the tri-lobe joint, reducing the size and mass of the boots while improving the aerodynamic profile of vehicle.

"Nonlinear analysis with Marc helps us dramatically improve the design of CV boots and other products," Kennison concluded. "The smaller we can make the boot, the longer it will last. Our simulation capabilities enable us to design boots that substantially outlast competitive designs. The result is that we have been able to increase our market share in our traditional markets and successfully enter new markets." ◆

Figure 3: Height comparison of initial and final design

Figure 4: Race-Tec tensile test machine

Tribal & Tribulations

Becoming an MSC Business Partner from scratch Part 1: Working Together

Tribal Engineering | By Dan Abir

June 8th, 2009, the laser toner has just finished fusing on the countersigned MSC Software reseller agreement #1234, and Tribal Engineering, LLC is officially a new MSC business partner in North America. It is a bit of a surreal experience for a variety of reasons. The first being that if you had asked me a year before if that was my plan, the answer would've been no. The second is that technically other than being an MSC Business partner with a business plan, I was still trying to define what that meant. And the third is that unlike many other resellers in the world, Tribal was created specifically for this purpose. Yes, we were the first test tube reseller.

January 1st, 1999. A little bit more than ten years earlier, I had just started a sales position for a Computer Aided Engineering (CAE) reseller in Southern California.

This company was created by a void created by MSC acquiring Silverado Software, little beknownst to me, destiny was being written. This was my introduction into the world of CAE, while also laying the foundation for my understanding of what a successful reseller OEM relationship needs to look like. This, like many things I have done before and since have all seemed to propel me towards Tribal, or so I thought.

January 2, 2002. I joined MSC Software a mere three years later in January 2002. My first position was as a Western Regional Overlay for MSC.visualNastran for windows (N4W), an entry level CAE tool designed for the SMB (Small-Medium size Business) allowing some compatibility with what then was commonly known as "Full Blown" MSC Nastran.

This experience introduced me to three concurrent new challenges:

1. How do you create a product that small businesses can afford, while not giving away the full version's value for an increment of the price?
2. How do you manage a product that is a combination of your technology coupled with a third parties solution from a logistics perspective?
3. How do you sell a low cost software cost effectively throughout a large territory?

On a side note, check out MSC's new MSC Nastran Desktop package (www.mscsoftware.com/scnastrandesktop), it is the latest and best revision on the challenging issue posed on question #1 above.

Following a successful period of focusing on promoting N4W in the entire Western region of the United Sates and Canada, I was offered an opportunity to offer all of MSC's solutions in Southern California.

Going from promoting a single product in a very large territory to promoting many products in a much smaller geography, presented yet another set of challenges and opportunities.

4. How do you become an expert in many products? (This was easy, you don't)
5. How do you educate and help add value to your customers, by uncovering new areas that you can contribute?
6. How do you work within a multi-member team complex solution-selling environment?

These challenges coupled with the ones from my experience with N4W, summarize what a new MSC reseller must address to be successful. While the list may seem daunting, I felt that by creating a company from scratch, they could be properly addressed yielding great rewards for all parties involved.

October 1, 2008. MSC combines its direct and indirect sales channels into a single organization. In an effort to create better synergy between its regional sales people and its budding reseller channel in "The

Americas", MSC unified the two groups into a single entity and asked that we start working together. It took us about three months to figure what this would look like, but by January 2009 a new Channel/ Regional Sales Director was hired and his message was clear:

7. The reseller channel is here to stay
8. You will be compensated for Reseller business
9. Go help them be successful

The writing was on the wall, MSC is fully committed to a hybrid-reseller business model in "The Americas", it plans to grow the Channel, and changes will be made to make that happen. From my interactions with the then current MSC Resellers in the Western region, my prior experience at MSC and working as a reseller for a competing solution, an opportunity was being presented. Why not create a company that will become a "model" reseller and work with customers and MSC to figure out what exactly it should look like.

June 8, 2010. Happy Anniversary. Tribal is one year old. It is hard to believe that one year had already past, and even harder to believe that the recession was still lingering. According to all reports, the recession had ended about a year ago, but according to my experience the economy was far from picking up and growing Tribal was getting harder. Also after having a stellar first year, the expectations were high and the pressure to perform was even higher. In effort to exceed expectations and continue to grow I began looking for complimentary products to the MSC suite of tools. At the time that Tribal started there were quite a few resellers that represented both MSC Software and competing solutions. That never made sense to me and seemed to be unfair to the customers and to MSC. The reason being is that a customer deserves to get good advice and great support when choosing a product. In the case of offering competing solutions a reseller is rarely in the position to provide both, and in many cases cannot do either properly. I decided that what Tribal should do is look to see what MSC customers could use that perhaps wasn't a primary focus of MSC's at the time as a way to truly add value to both relationships. While at the same time see if there is a good way to create synergy between the solutions. The analogy I used was creating the mortar between the two bricks. If Tribal could properly integrate the solutions in a way that would make the customers more productive it would be a win-win-win situation. We haven't mastered this area yet, but are constantly looking for ways to make this happen. One of our first attempts is integrating MSC's Adams multibody dynamics solution with National Instruments LabVIEW®, and a product we fondly call ALVI (Adams LabView Integration), allowing people to manipulate the Adams model from

within the LabVIEW® GUI. We are still in the process of looking for funding sources to continue development. If you are interested, please let us know.

Tribal Engineering LLC, is constantly growing and adapting to market challenges, and adding value to its customers and business partners. ◆

MSC Software TECH TIPS

Adams™ Numbers Behind the Plots

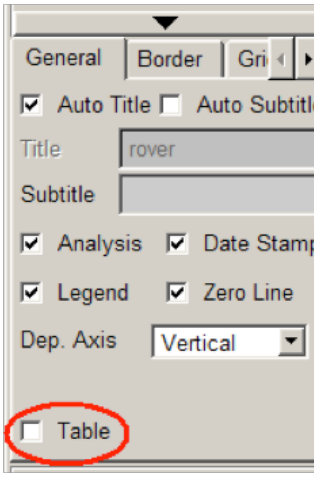
By Walt Daniel
Sr. Technical Representative,
MSC Software

Did you know that you can view an Adams/Post Processor plot as a table of values?

Sometimes you just have to see the numbers! Additionally, you can export as a file the numbers behind a specific plot. In other words, you can use plots to sort and create custom output files.

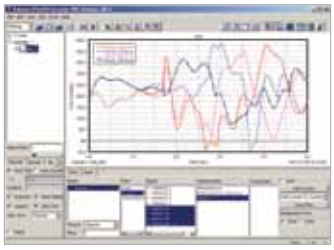
Here is how:

Select a plot by left-clicking inside it but do not select a curve, legend, or axis. Alternatively, you can select a plot in the Treeview at the left side of the Adams/Post Processor window. You may need to click on the + by a page in order to expose the plot. When a plot is selected, note the Table check box in the Property Editor at the lower left of the window.



Check the Table box and the Property Editor will change to controls for viewing a table. The plot will now be shown as an HTML table in the Viewport. Here is an example that shows the first few lines of shock forces in a rover model.

rover				
Time	shock_LF.force	shock_LR.force	shock_RF.force	shock_RR.force
0.0	180.0	200.0	180.0	200.0
0.02	186.4221	206.8221	186.4221	206.8221
0.04	192.0529	213.5846	192.0529	213.5846
0.06	198.0159	221.5991	198.0159	221.5991



There are three options for exporting data from Adams/Post Processor: Numeric Data, Spreadsheet, and Table. Numeric Data and Spreadsheet export entire results sets (large files with loads of data). Fortunately the Table option exports numeric data only for the curves on a plot that you specify.

Go to File -> Export -> Table and fill in the dialog box. The text in the File Name field will have ".tab" appended to create the name of the file. The Plot field specifies which set of data to write; you can type the name of the plot or use the Pick/Browse/Guess tools find select one. There are two choices for Format: spreadsheet and HMTL. In the spreadsheet format the columns are separated by Tab characters. The model name and column labels are included as text strings in quotes. Most spreadsheets should be able to read this file directly. You may need to edit or remove the lines with labels if importing the file is an issue.

"rover"

"Time" "shock_LF.force" "shock_LR.force" "shock_RF.force" "shock_RR.force"

0.000000e+000 1.800000e+002 2.000000e+002 1.800000e+002 2.000000e+002

2.000000e-002 1.864221e+002 2.068221e+002 1.864221e+002 2.068221e+002

4.000000e-002 1.920529e+002 2.135846e+002 1.920529e+002 2.135846e+002

6.000000e-002 1.980159e+002 2.215991e+002 1.980159e+002 2.215991e+002

For further details see KB8020137 and KB8020138 on SimCompanion: http://simcompanion.mscsoftware.com

Patran® Build Your Own Toolbar Using PCL

By Jeff Bugayong
Supervisor, Global Services
MSC Software

Access your Most Common Tasks With the Click of a Button

Although Patran comes with a whole set of toolbars, ready to simplify your user experience, there are some tasks that could still benefit from a custom toolbar.

Repetitive tasks would be a prime example for the need to create such a toolbar. This would eliminate the need to sift through multiple menus or mouse clicks. Since Patran records your work session by writing PCL (Patran Command Language) from your events in a session file, it is fairly simple to capture and reuse these steps through a toolbar.

In this example, we will create a toolbar that will automatically create an image of your viewport and save it to a file. Normally, this would be done through the File/Images menu, but we will turn this into a one-click icon.

To do this, we will perform the following 5 steps:

1. Record the session
2. Turn the session into a PCL "Function"
3. Create your icon
4. Modify the toolbar definition file (p3toolbar.def)
5. Make sure Patran can see your custom function (p3epilog.pcl)

1. Record your Patran session

- Fire up Patran, open your database and select "File/Images".
- Set the "Image Format" to JPEG and click the "Increment" radio button.
- Before you hit "Apply", record the session by going back to the Main menu and select File/Session/Record. Call the file "snapshot.ses"
- Now hit "Apply" in your "Images" form to create your .jpg image
- Stop your recording by selecting "File/Session/Record" and click "Stop"
- Quit Patran.

2. Turn the Session into a PCL Function.

- Open the file "snapshot.ses.01" in "notepad"
- You can safely remove the comment lines that start with "$#" so that all you see is:
  gm_write_image ("JPEG", "Snapshot.jpg", "Increment", 0., 0., 1., 1., 75, @ "Viewport")
- To turn this into a PCL Function, simply add a "FUNCTION name()" and "END FUNCTION" line so that the file looks like:
  FUNCTION snapshot()
  gm_write_image("JPEG", "Snapshot.jpg", "Increment", 0., 0., 1., 1., 75, @ "Viewport")
  END FUNCTION
- Save the file in your home directory as "snapshot.pcl"

3. Create your icon

- Use any picture you want. You can even create your own image provided:
  a. It is 16 x 16 pixels (standard size for toolbar icons)
  b. It is saved as a bitmap (.bmp) file
- Save your picture file in your home directory as "snapshot.bmp"

4. Modify the toolbar definition file (p3toolbar.def)

- Copy the current p3toolbar.def file from Patran's installation directory (C:\MSC.Software\Patran_x64\20111\p3toolbar.def) to your home directory.
- Open the p3toolbar.def file (in your home directory) in a text editor and add the following lines at the bottom of the document:

```
*START TOOLBAR   = Custom
   *ICON         = snapshot.bmp
   *CLASS        =
   *FUNCTION     = snapshot
   *HELP         = Create a JPEG image (snapshot_#.jpg)
*LOAD ITEM
*END TOOLBAR
```

5. Make sure Patran can see your custom function (p3epilog.pcl)

- Create (using a text editor) a file, in your home directory, called "p3epilog.pcl"
- In this file, add the following line: !!input snapshot.pcl
- Save and close the file

You should now be able to fire up Patran and see your new "Custom" icon in its own toolbar

Once a database is open, clicking on this toolbar will create .jpg images (in your working directory).

You can use this template to create toolbars for other tasks. This will also work with more complex Patran sessions (additional PCL editing may be required).

For additional information on this topic (including the complete set of required files), please login to: http://simcompanion.mscsoftware.com and search for article KB8019455.

Or register for a PAT304 training class to get the most out of your PCL customization experience: http://www.mscsoftware.com/Services/Training/Default.aspx

SimXpert® Utilize CAD Defeaturing

By Edwin Goei
Technical Representative,
MSC Software

Utilize New Cleanup Tools in SimXpert to Reduce Time

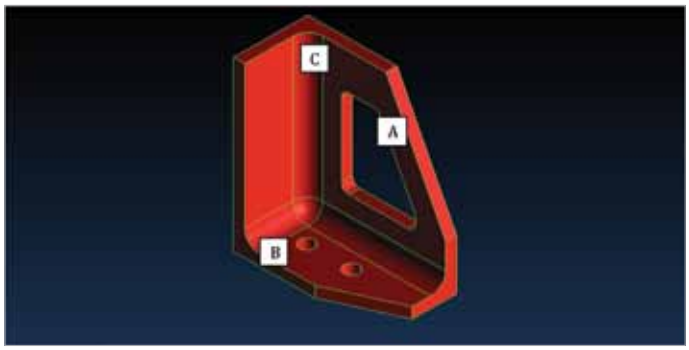
In SimXpert's 2011 version, an all new CAD defeaturing functionality was introduced to make it easier for solid geometry editing. These are powerful Parasolid-based CAD cleanup tools that can decrease the design cycle. With these tools you can do geometry editing in SimXpert without having to send your model back to your designer to change a minor feature. You can now simply do it yourself in SimXpert. Some of the functionality's most useful tools allow you to:

1. Change the size of features
2. Move the size of features
3. Delete features

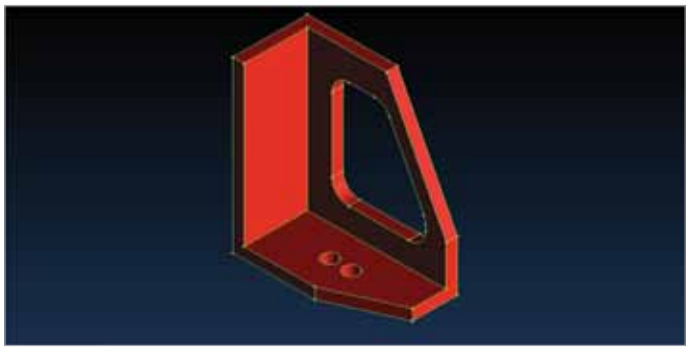
For example, the following part below can be changed within SimXpert to reflect design changes that require an:

A. Increase of size of the slot hole
B. The movement of the drilled hole
C. The elimination of the fillets on corners

The image below represents the part before editing.

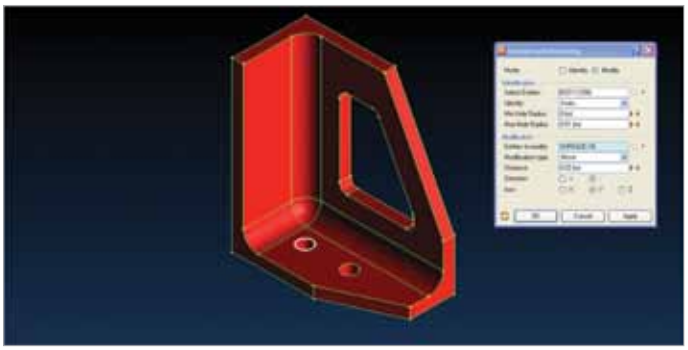


This image shows the part after it has been edited.



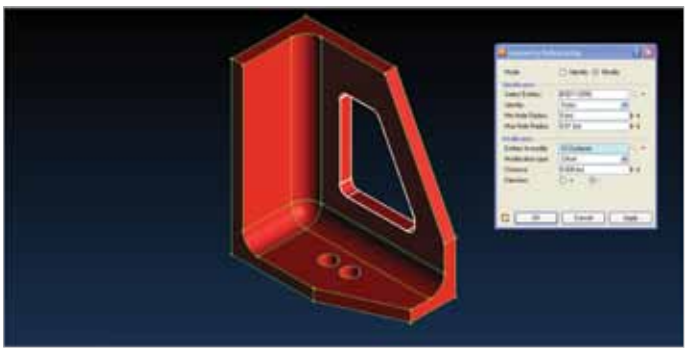
The following simple steps are taken to accomplish this:

To move the hole from one location to another, we go to Geometry/Tools area and select Defeature. A menu box will appear that allows you to begin editing your solid. Click on the Modify button, then pick your solid under Select Entities. We first select "Hole" under the Identify dropdown and then pick "Move" for Modification type. Then mouse click on the face that represents the hole you want to move. Enter the distance value you want to move the feature and also, the direction and axis.



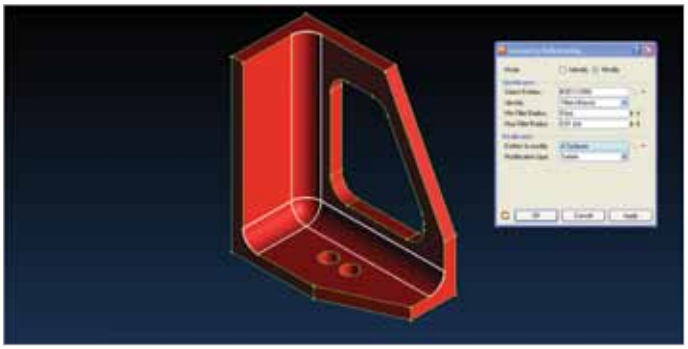
Once you click OK, you will see the hole feature being moved to the desired distance you specified.

To resize the slotted hole, we remain in this menu, and change the Modification type to "Offset". In this case, you want to select all the faces that represent the slotted hole. Finally enter the distance you want to increase the hole in the Distance box as well as the direction.



Once OK is clicked, you should see the hole is resized to your desired specifications.

Deleting or removing features is the simplest and easiest kind of feature editing one can do. Here we can do it with the fillets on the part. Simply choose "Fillets/Blends" under Identify, and then select the surfaces on the part that represents the fillet. Choose the Modification type "Delete."



This will remove the fillets, which will in some cases, simplify the geometry for meshing purposes.

To learn more, visit: http://simcompanion.mscsoftware.com

Team Spirit

ENGINEERS HAVING FUN

MSC Software is the sponsor of a soccer team in Michigan. The sponsorship proudly promotes MSC products, since; during the course of the season the MSC team will meet and correspond with many other players from other companies and industries. There are currently nine teams in this category playing in the Wide World Center located in Ann Arbor.

The team, before this sponsorship with MSC, has been around for approximately 10 years. It consists of a mix of engineers, managers and IT people from different OEMs and suppliers. It has competed with other leagues and previously won the tournament trophy.

MSC takes pride in supporting this team, which wears the respected MSC Software business logo on the front of the players' uniform shirts and the names of different software brands, such as Marc, MSC Nastran, and Adams on the back.

The MSC Software soccer team is aware of the importance of this sponsorship and how necessary MSC participation is to its success. It is committed to the overall well-being of each athlete and promotes positive principles in both training and competition. The team is extremely dedicated and gives 100% each time on the field.

New Methods for Simulation Automation

Breakthrough Results for Fokker Aerostructures

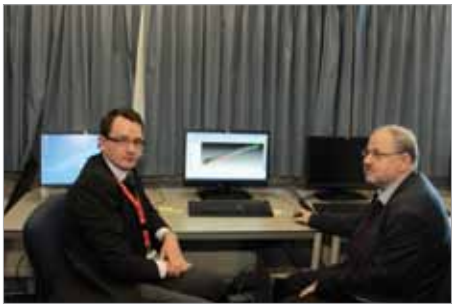
In Summa Innovation & Fokker Aerostructures | By Johan Morsink

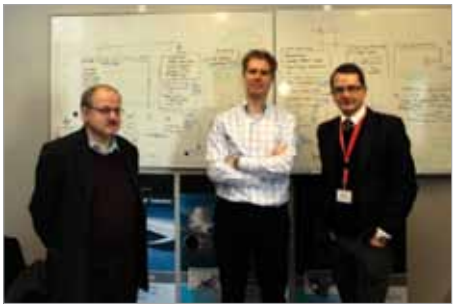
In May 2011, MSC Software, In Summa Innovation, and Fokker Aerostructures entered into a close partnership. In the so-called "Fokker Virtual Lab" the three companies started to do serious research with MSC Software products SimXpert and MSC Nastran. MSC Software and In Summa Innovation provided training and technical support to the partnership while Fokker invested in manpower to execute the specific research activities. The main goal was the investigation of new simulation technologies for (possible) future use. Together the companies developed a detailed plan for the execution of the research which was guided by a steering committee in which Fokker's engineering management participated as well as a representative from In Summa Innovation. All together some 900 man hours have been invested.

The goal of this first project was twofold, 1) familiarization and testing of MSC Nastran, and 2) familiarization with SimXpert to create a prototype for a process to automate the creation of a QA-sheet, the quality assurance of FEM models.

During the project many positive aspects of both tested programs have been found which lead to a positive recommendation to adopt both programs for production work at Fokker.

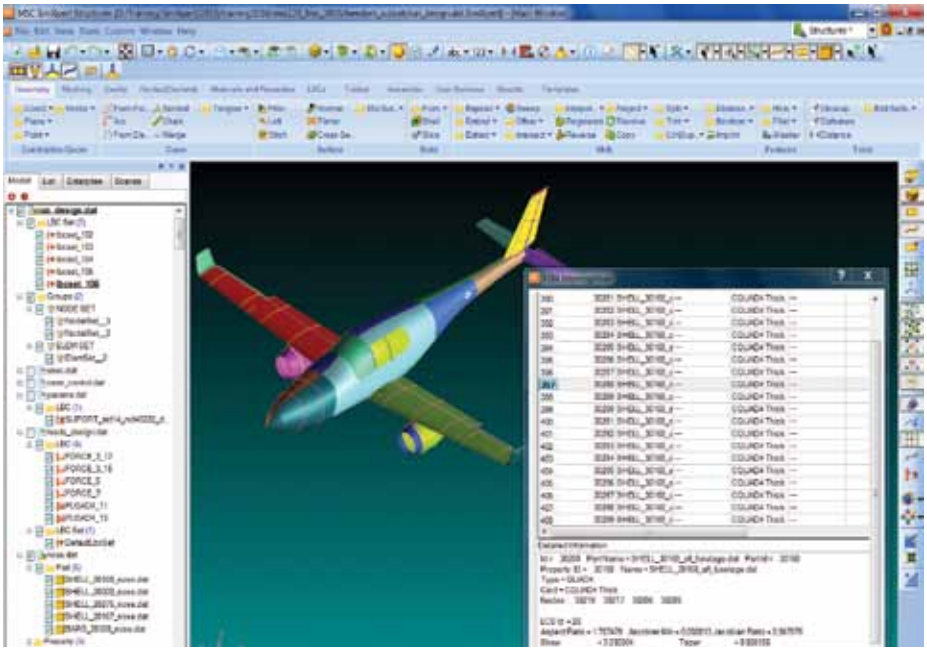
In Fokker's Virtual Lab, nine benchmarks have been done with MSC Nastran SOL400 which is the fully nonlinear solution integrated in MSC Nastran. Eight of these benchmarks are the standard Fokker certification benchmarks and benchmark number nine was defined to test element offsets. Fokker immediately noticed that only 2 small changes were needed to make an existing MSC Nastran input file (bdf) running with SOL400, and this is a great advantage because converting input decks is usually labor intensive and error prone. The results were very good and because SOL400 supports element offsets, accurate results at correct locations were produced.





Also larger models were analyzed with good results. Besides SOL400 fully supporting nonlinear analysis with element offsets, it offers support for large rotations (also for rigid elements), full 3D contact, different material properties for tension and compression, VCCT (Virtual Cracks), Acoustic Analysis, Advanced Thermal Analysis, Analysis Coupling (chaining) like Thermo/Mechanical, all within the well accepted MSC Nastran solver solution.

The Multidisciplinary Simulation Solution, SimXpert (supporting Pre and Post Processing for MSC Nastran SOL400), has especially been researched in the domain of process automation using the Template Builder Workspace. A SimXpert Template has been created to automate the creation of Quality-Assurance Sheets. The template comprises of existing built-in library actions which were Marco recorded and Fokker specific script actions. Each User Interface (UI) window that will prompt the user for input was easily generated from within the Template Builder Workspace. Here both the inputs and outputs are defined and necessary data connections are made between actions. Input of the one action is sent downstream to the next. This SimXpert Template gathers information and data from different sources, whether it be direct user input, existing files or from other applications. The user simply defines a project directory and the template then



> Fokker sees SimXpert as the next generation pre- and post-processor and wants to introduce MSC Nastran's Advanced Nonlinear capability as the prime nonlinear solver

searches and reports back a list of analysis solutions and associated loadcases found. It is then up to the user to define the model from a selectable list for which a QA sheet will be generated. User selectable quality checks, such as: Groundcheck and Element Quality Check, have also been built into this Template, allowing the user to do a complete model verification. The user is free to decide if the quality check results already exist or if an analysis still needs to be performed. The gathered data, including images, is processed and then inserted into a (MS-Word) document with the pre-defined QA sheet layout and formatting. It is entirely up to the user to execute the SimXpert Template completely with pre-defined input or interactively step-wise. This process automation allows Fokker to improve quality and make data integrity easier and faster to achieve. The template can be customized.

Based on our experience, the time needed to develop a QA report (from 25 to more than 100 pages) can be reduced with 50% or more. This delivers an interesting ROI for Fokker. And it provides an improvement in quality through the reduction of errors.

The overall conclusion of this project is that it is worthwhile to research new technologies in a joint effort between suppliers and users. For all parties involved the conclusion is that Fokker sees SimXpert as the next generation pre- and post-processor and wants to introduce MSC Nastran's Advanced Nonlinear SOL400 capability as the prime nonlinear solver.

Based on the results of this project we can expect that new projects can be developed for joint execution in the "Fokker Virtual Lab," an environment intended for the Tools & Methods department of Fokker Aerostructures to not only test software but also develop the process of how to use the software in the complete design process outside the production environment. Fokker and software vendors work closely together on real use cases, positioning of the software, acceptance in the engineering community and the final business case.

About In Summa Innovation

In Summa Innovation is the exclusive agent in Benelux for MSC Software. We deliver CAE applications like SimXpert, SimDesigner, MSC Nastran, Adams, Patran, Marc, Actran and XFlow. In addition to this software we provide our clients support, training, consultancy and engineering services. In Benelux we have more than 150 well respected clients. For more information, please visit: www.Insumma.nl/innovation

About Fokker Aerostructures

Fokker Aerostructures is a company of Fokker Technologies. Fokker Technologies is the group name for four specialized Fokker Business Units: Fokker Aerostructures, Fokker Elmo, Fokker Landing Gear and Fokker Services. Fokker Technologies develops and produces advanced structures and electrical systems for the aerospace and defense industry, and supplies integrated services and products to aircraft owners and operators. The group achieved a turnover of € 616 million in 2010 with 3,700 employees. ◆

Stimulating Nerve Paths to the Brain

Simulation of a Molded Elastomeric Helical Anchor Nerve Clamp

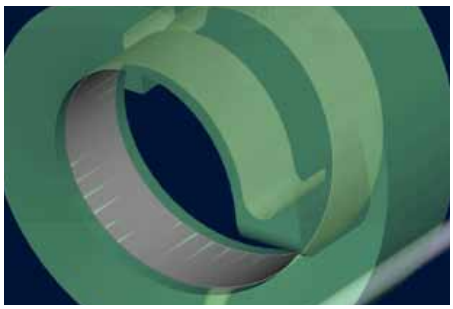
BioSimulations, LLC | By Svenn Borgersen

Human Anatomy Nervous System

The human anatomy nervous system transmits signals to and from the brain for various voluntary and involuntary muscles. Nerve receptors also transmit data to the brain for heat, cold, pain and other sensations. The nerve fibers are protected by a covering or sheath.

The ability to control, modify or block the signals from the receptors to the brain may be accomplished through selective electrical stimulation of a specific nerve path.

A baseline concept to provide control assumes an external, battery operated, signal generating controller with electrical lead wires attached to the nerve sheath surface. The attachment design must allow installation, use and removal of the electrical lead wires without damaging the nerve sheath.



A segment of proposed concept is illustrated above and discussed here.

Design Objective

The objective of this study was to evaluate a proposed design concept for an electro-mechanical contact device which would provide the following characteristics:

- Suitable contact interface with the nerve sheath, allowing necessary electrical stimulation
- Device geometry and materials allows leads to be positioned on nerve sheath without damage to sheath
- Allow repositioning or removal, as required, without incurring nerve sheath damage.

Design Material Selection

Biocompatible materials must be used for leads, contact device body and the electrical contact surface. Materials selected for evaluation were:

- Injection molded Silicon for lead and contact device body
- Stainless steel lead wires
- Platinum Iridium foil electrical contact surfaces

Analysis Software Selection

The analysis to be performed necessitated the following software capabilities:

- Complex geometry meshing
- Highly non-linear materials

> "The Marc post-processing features make results plotting easy"

- Complex 3-D contact surfaces
- Large displacement
- Sliding friction between contact bodies
- Calculation of contact forces and stresses
- Display analysis results

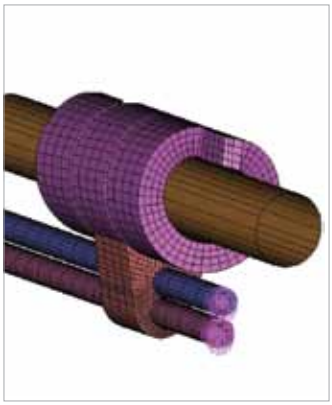
Based on these requirements, MSC Software's Marc nonlinear simulation solution was selected to generate the model, perform the analysis and post-process the results.

FEA Model:

Materials

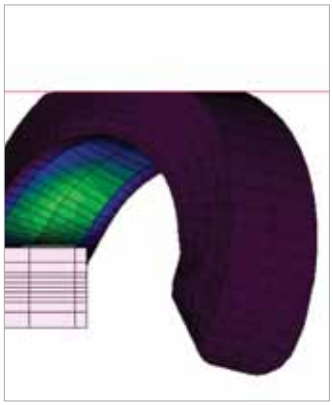
Molded Silicon was represented by the Mooney material library model available in the Marc materials library.

The very thin Platinum Iridium foil was represented by a non-linear, stress-strain curve generated by material tensile test data.



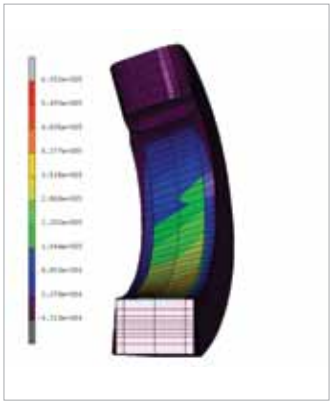
Model Total Assembly

Finger sub-assembly Compression

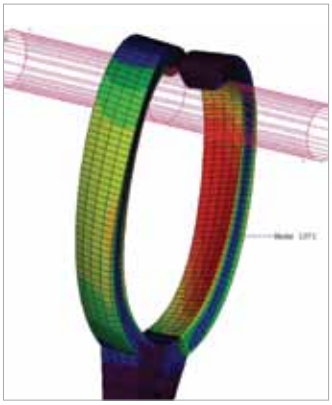


Finger sub-assembly in Compression Von Mises Stresses & Displacement

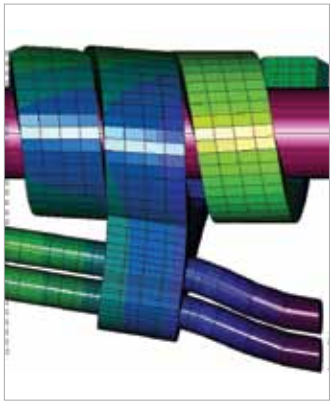
Finger sub-assembly Surface Pressure Load generating Tension & Bending



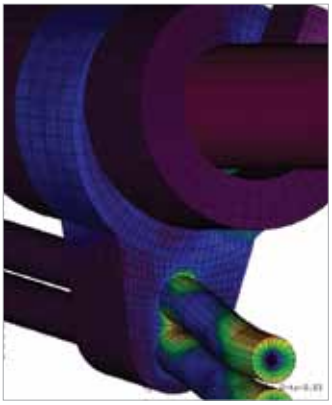
Finger sub-assembly Von Mises Stress & Tension & Bending Displacement



Finger Set Pull Off Contact with Simulated Nerve sheath



Full Model Assembly Pull Off Loading



Displacement Increment 200 Clamp Pulling Away From Sheath Finger Tip Sliding on Sheath Surface

Geometry

An initial study was based on model geometry consisting of a rigid cylindrical contact surface simulating the nerve sheath; a molded Silicon central body containing the electrical leads; molded Silicon contact "fingers" wound helically around the rigid nerve sheath.

The inner surfaces of the helical "fingers" were bonded to the very thin Platinum Iridium foil which, in turn, was connected to the electrical leads within the central body. The FEA model consisted of approximately 1,300 nodes and 8,200 Hexahedral 8-node solid brick elements.

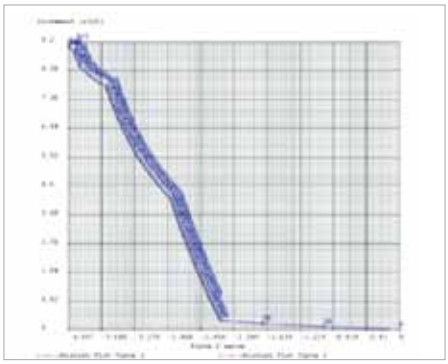
Modeling Procedure

The same model sub-assembly was also checked in tension using a distributed pressure loading incrementally applied to the inner foil surfaces.

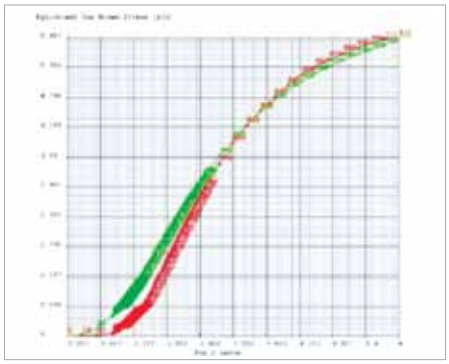
A final check used a single set of "fingers" and the simulated nerve sheath to verify functioning of the sliding friction contact mechanism between the 3-D contact sets and the simulated rigid nerve sheath.

After successfully checking the model components, a final assembly of the model was generated, consisting of: a set of three "fingers"; foil contact surfaces; central body; and simulated nerve sheath. The model was loaded by an incrementally applied large displacement of the simulated nerve sheath.

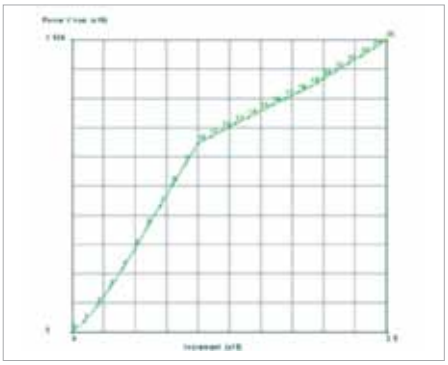
Model pull-off loading was performed using incrementally applied large displacements, moving the clamp assembly away from the simulated nerve sheath.The Marc software post-processing features make results plotting easy. ◆



Nodal Displacement v. Applied Displacement Increment



Nodal Stress v. Vertical Displacement



Pull-off Force v. Vertical Displacement

MSC Nastran Best-Practices

Networking, MPI and CPU Effect on Nastran Performance

Mellanox Technologies | By Gilad Shainer

Introduction

High-performance computing (HPC) is a crucial tool for manufacturing designs. It is used for computer-aided engineering (CAE) from component-level to full product analyses in the aerospace and defense, automotive and transportation, agricultural equipment, heavy machinery, medical devices, oil and gas, nuclear, renewable energy, consumer products, packaging, electronics, shipbuilding industries and more. HPC simulations, throughout the product design cycle, help drive faster time to market, significant cost reductions, and tremendous flexibility. The strength in HPC is the ability to achieve best sustained performance by driving the CPU performance towards its limits. The motivation for high-performance computing in the manufacturing industry has long been its tremendous cost savings and product improvements - the cost of a high-performance compute cluster can be just a fraction of the price of real prototype testing, while providing a system that can be used for every test simulation going forward.

HPC Clusters

MSC Nastran simulations are typically carried out on high-performance computing (HPC) clusters based on industry-standard hardware connected by a private high-speed network. The main benefits of clusters are affordability, flexibility, availability, high-performance and scalability. A cluster uses the aggregated power of compute server nodes to form a high-performance solution for parallel applications such as MSC Nastran. When more compute power is needed, it can sometimes be achieved simply by adding more server nodes to the cluster.

The manner in which HPC clusters are architected has a huge influence on the overall application performance and productivity – number of CPUs, usage of GPUs, the storage solution and the cluster interconnect. By providing low-latency, high-bandwidth and extremely low CPU overhead, InfiniBand has become the most deployed high-speed interconnect for HPC clusters, replacing proprietary or low-performance solutions. The InfiniBand Architecture (IBA) is an industry-standard fabric designed to provide high-bandwidth, low-latency computing, scalability for ten-thousand nodes and multiple CPU cores per server platform and efficient utilization of compute processing resources.

High-performance cluster productivity, sometimes not measured by just how fast an application runs, is the most important factor for cluster hardware and software configuration. Achieving the maximum number of jobs executed per day is of higher importance than the wall clock time of a single job. Maximizing productivity in today's cluster platforms requires using enhanced messaging techniques even on a single server platform. These techniques also help with parallel simulations by using efficient cluster interconnects.

This study was conducted at the HPC Advisory Council systems center (www.hpcadvisorycouncil.com) using the Dell™ PowerEdge™ R815 11-node (528-core) "Vesta" cluster. The cluster includes AMD™ Opteron™ 6174 (code name "Magny-Cours") 12-cores @ 2.2 GHz CPUs, 4 CPU sockets per server node.

The Importance of the Cluster Interconnect

The cluster interconnect is very critical for efficiency and performance of the application in the multi-core era. When more CPU cores are present, the overall cluster productivity increases only in the presence of a high-speed interconnect. We have compared the productivity of MSC Nastran using 40Gb/s InfiniBand, 10 Gigabit Ethernet and 1 Gigabit Ethernet. Figure 1 shows the jobs per day for these interconnects for a range of core/node counts for the xl0tdf1 benchmark case.

InfiniBand delivered superior scalability in performance, resulting in faster run time, providing the ability to run more jobs per day. The 40Gb/s InfiniBand-based simulation performance measured as ranking (number of jobs per day) was 14% higher compared to 10GbE and 42% higher compared to GbE at 11 nodes. MSC Nastran uses MPI for the interface between the application and the networking layer, and as such, requires scalable and efficient send-receive semantics, as well as good scalable collective operations. While InfiniBand provides an effective way for those operations, the Ethernet TCP stack which leads to CPU overheads that translate to higher network latency, reduces the cluster efficiency and scalability.

> MSC Nastran delivers scalable performance when using InfiniBand and therefore an efficient tool for manufacturing vendors

MSC Nastran MPI Profiling

Profiling the application is essential for understanding its performance dependency on the various cluster subsystems. In particular, application communication profiling can help in choosing the most efficient interconnect and MPI library, and in identifying the critical communication sensitivity points that greatly influence the application's performance, scalability and productivity.

MSC Nastran MPI profiling data (Figures 2 and 3), show the breakdown of MPI calls, the MPI message sizes being used and the time spent by MPI calls in several cluster configurations.
MPI_Ssend and MPI_Recv are the most used MPI calls with the MSC Nastran xl0tdf1 case (MPI_Ssend is a blocking synchronized send). Each of these MPI functions accounts for nearly half of all MPI functions. The xl0tdf1 shows some data communication as well, but not as large as the synchronization calls. From Figure 3 we learn that the majority of MPI messages are small messages, and mostly fall in the range between 0 and 64 bytes. Small message sizes are typically used for synchronization and large message sizes are typically used for data communication (Send/Recv). The MSC Nastran xl0tdf1 case spends the majority of the time on computation and less on communications. Still, the interconnect influence is noticeable and can greatly influence the application and the cluster productivity.

MPI Library Comparisons

We have compared the performance of two MPI libraries – Open MPI and HP MPI. The results are presented in figure 4.

HP MPI shows slightly higher performance on larger number of nodes compared to Open MPI, while Open MPI performs better on smaller number of nodes. In order to achieve the best performance with Open MPI, we have modified Open MPI to allow InfiniBand support - the openib BTL was not built with the Open MPI that is being shipped with MSC Nastran. Processor binding was also used to enhance performance with the Open MPI MCA using "mpi_paffinity_alone 1".

Conclusions

From concept to engineering and from design to test and manufacturing, engineering relies on powerful virtual development solutions. Finite Element Analysis (FEA) and Computational Fluid Dynamics (CFD) are used in an effort to secure quality and speed up the development process. Cluster solutions maximize the total value of ownership for FEA and CFD environments and extend innovation in virtual product development.

HPC cluster environments impose high demands for cluster connectivity throughput, low-latency, low CPU overhead, network flexibility and high-efficiency in order to maintain a balanced system and to achieve high application performance and scaling. Low-performance interconnect solutions, or lack of interconnect hardware capabilities will result in degraded system and application performance.

MSC Nastran software was investigated in this paper. In all InfiniBand-based cases, MSC Nastran demonstrated high parallelism and scalability, which enabled it to take full advantage of multi-core HPC clusters. Moreover, according to the results, a lower-speed interconnect, such as Ethernet becomes ineffective on large cluster sizes, and can cause a reduction in performance.

We have profiled the communication over the network of MSC Nastran software to determine its sensitivity points, which is essential in order to estimate the influence of the various cluster components, both hardware and software. We have provided the key points on how to configure the MPI in order to achieve optimum performance and scalability.

We would like to thank the HPC Advisory Council for providing the resources for completing this research and testing. We would like to thank MSC for the tight collaborations and for providing the licenses for the software. The testing results demonstrated the MSC Nastran delivers scalable performance when using InfiniBand and therefore an efficient tool for manufacturing vendors. ◆

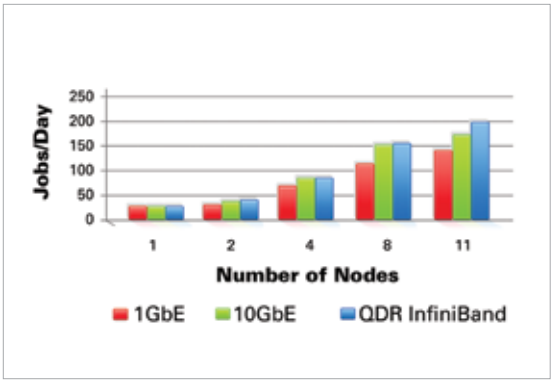


Figure 1: Interconnect comparison with xl0tdf1

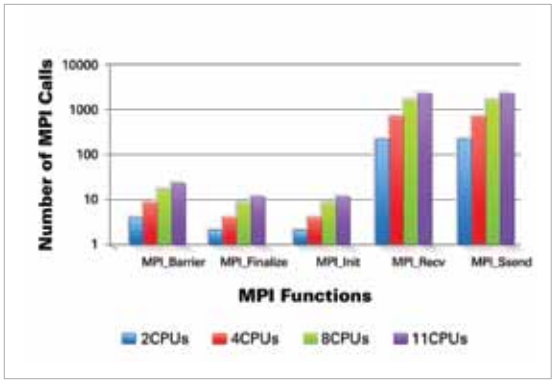


Figure 2: MSC Nastran Profiling – Number of MPI Calls

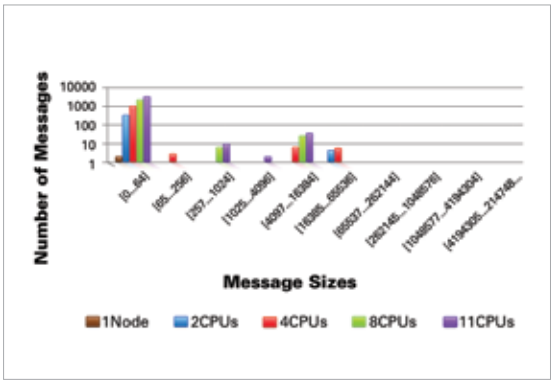


Figure 3: MSC Nastran Profiling – Number of MPI Calls

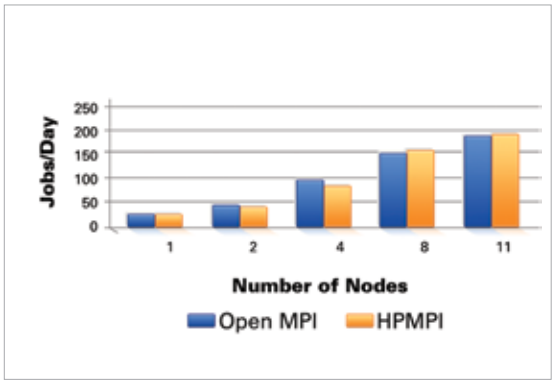


Figure 4: Time Spent by MPI

Changing The Game

Optimization Technology is finding solutions to challenges in design, manufacturing, distribution, and finance

Red Cedar Technology | By JoAnne L. Catlin

Red Cedar Technology is an MSC Software Community Partner that develops optimization software to help engineers design innovative products and find solutions to challenges in design, manufacturing, distribution & finance. The company's software solutions integrate with all MSC Software products including MSC Nastran™, Marc®, Adams™ and Adams/Car.

Many software companies offer optimization methods that have been "added on" to math models to resolve design, engineering, distribution and financial problems. These add-ons often require expertise in optimization, because the user must first have enough knowledge to select an appropriate optimization approach (i.e., gradient based, genetic algorithm, particle swarm), and then to enter the tuning parameters that will correctly direct the search method's exploration of the design space. There is another challenge here, as well: as the optimization study progresses, the problem may require a different search method to resolve a set of conditions that arise. In this situation, the analysis typically either fails or yields erroneous results.

For over a decade, Red Cedar Technology has focused on helping companies solve problems through the application of optimization techniques. By overcoming the technological barriers presented by other optimization tools, Red Cedar Technology has developed game-changing optimization software that is not only powerful, but requires no optimization expertise to use and allows human interaction with the optimization process.

HEEDS MDO multidisciplinary design optimization software is at the center of this technology. With the revolutionary search strategies available only in HEEDS MDO, engineers can uncover new design concepts that improve products and significantly reduce development costs. HEEDS MDO benefits users in two key ways: design space exploration (including parameter optimization, DOE, and robustness and reliability) and process automation.

Fast, Robust Optimization with SHERPA

HEEDS MDO's proprietary optimization method, SHERPA, is the most efficient and robust available, shortening design time significantly – often from weeks to days. Shorter design time translates into reduced product development costs. SHERPA is a hybrid, adaptive strategy that performs global and local searches simultaneously. It also learns as it progresses. At the same time, SHERPA provides a more thorough search for design possibilities (feasible and infeasible designs) with the potential to yield truly innovative designs that satisfy multiple, often conflicting, criteria. No tuning parameters are required for SHERPA. The user simply defines the objective of the study, and the parameters and constraints, and then tells HEEDS MDO how many evaluations to conduct.

Automated Integration with MSC Software products

HEEDS MDO process automation allows the user to set up, and then automatically repeat, a multidisciplinary study integrating HEEDS MDO with MSC Software products. The process automation component requires little effort. The desired process is manually set up once, and then it is automated by HEEDS MDO.

Industry Example: Pratt & Miller Uses HEEDS MDO with Adams/Car

Pratt & Miller Engineering has evolved from a small business focused on designing and building race cars into an international engineering powerhouse. Today Pratt & Miller is recognized around the world as a formidable force in both motorsports and high-level engineering and small volume manufacturing. After evaluating multiple optimization tools, Pratt & Miller concluded that HEEDS MDO, and its proprietary SHERPA algorithm, is the only optimization technology that can solve their highly constrained models. According to Pratt and Miller's Jesper Slattengren, "The SHERPA algorithm is currently superior to anything else that exists on the commercial market." For many of their optimization studies, they integrate HEEDS MDO with Adams and Adams/Car.

Pratt & Miller's typical optimization studies are set up as nearly over-constrained problems. They usually need to minimize or maximize only one or two objectives, but there can be up to 50 constraints that need to be satisfied. Examples of common constraints include gradient, overshoot and damping of roll displacement, yaw rate, lateral accelerations, maximum allowed steering wheel torque, limited lateral acceleration and various ride criteria.

Prior to using HEEDS MDO, Pratt and Miller would plan for 4 to 12 man-weeks to find an acceptable solution for their typical optimization problem. This was in addition to the time required to generate the baseline model using a combination of engineering intelligence and DOE methods. Using HEEDS MDO and parallel processing, this time has been reduced to one to two weeks.

Integration of HEEDS MDO with Adams and Adams/Car

For Pratt & Miller, a typical problem requires their engineers to meet all of the explicit requirements for a military vehicle (HMMWV) while maintaining good ride and handling performance.

In this example situation, the problem statement is to find the optimal spring and damper settings for a 2-axle vehicle under two different loading conditions: curb vehicle weight (12,000 lbs) and gross vehicle weight (16, 000 lbs). It is difficult to find springs and dampers that perform well in this context. The best solution must provide optimal ride characteristics, meet all military-mandated requirements for ride and handling, and meet or exceed a number of secondary ride and mobility requirements. With four people working for over three weeks manually using Adams, a solution was not found.

Study Setup

The HMMWV's springs, bump stops and dampers were parameterized in Adams. Adams/Car was used to set up several different runs:

- Drop-off test (at both loading conditions: curb vehicle weight and gross vehicle weight)
- Ramp steer (at constant velocity at gross vehicle weight)
- Constant radius cornering (at gross vehicle weight)
- Half round obstacle crossing (at curb vehicle weight)
- RMS road (at curb vehicle weight)

Using zero crossing detection and peak identification in Adams, Pratt & Miller calculated actual damped frequencies and damping based on logarithmic decrement.

Adams and HEEDS MDO were integrated through the use of a .cmd file and the Adams command language. In this study, 200 evaluations were run. Only 61 of them satisfied all constraints, and the optimum was found after 123 runs.

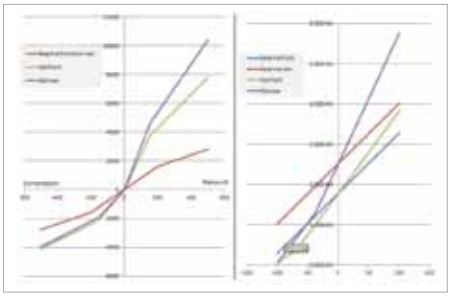
Results

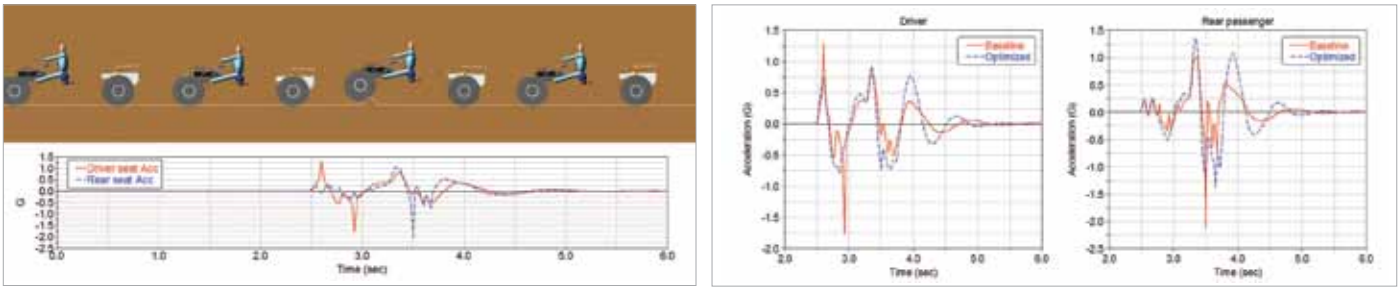
The heave and pitch frequency needed to be around 1Hz, with pitch greater than heave. This was satisfied by the optimized design. The lateral acceleration needed to be maximized, and it went from 0.60 to almost 0.70G, which is a significant change for such a heavy vehicle. The roll gradient needed to be below 14.00 degrees per G, and the optimized design had a roll gradient of 13.20 degrees per G. The yaw rate overshoot needed to be below 8.00 and started at 16.00. The optimized design had a yaw rate overshoot of 2.00. Finally, the roll overshoot needed to be below 8.00. It started at 20.00 and ended up at 5.40. The tables below summarizes the results.

> "HEEDS MDO and Adams make a powerful combination & are easily integrated"

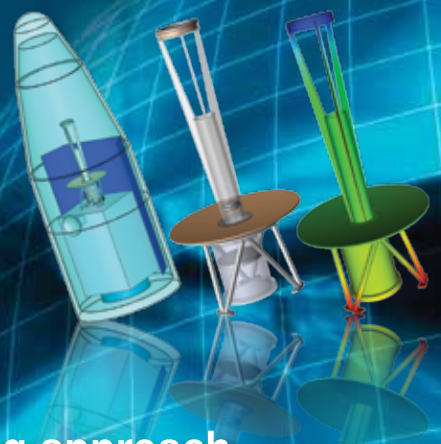
Pratt & Miller has discovered that HEEDS MDO works well with over-constrained or nearly over-constrained systems. Additionally, HEEDS MDO and Adams make a powerful combination and are easily integrated.

For more information about Red Cedar Technology's optimization software, please visit: www.redcedartech.com. ◆





Passing a half-round obstacle at specified speed (baseline). Vertical acceleration at all occupant locations < 2.5G.



Rapid Concept Engineering

Comet and MSC Nastran use a functional modeling approach to unify multiple engineering disciplines and physics domains

Comet Solutions | By Don Tolle

Comet Solutions Inc., an MSC Software Community Partner, develops and implements Comet®, an integrated modeling and simulation process automation environment that enables rapid conceptual engineering. Comet provides robust integrations with the MSC Nastran™ and Adams™ solutions, as well as other commercial 3-D CAD and CAE software tools.

The long desired goal of simulation-driven design has been to enable engineering analysts to focus on achieving the product's functional requirements starting early in the R&D cycle. By putting simulation analysts in control of the "engineering geometry" starting at the conceptual design stage, reusing CAE best practices, and automating highly manual and repetitive design simulation tasks, performance simulation results can finally drive critical new product development decisions.

Do More Early Conceptual Analysis at Higher Quality, Faster

Developing a new infrared (IR) telescope design required the collective experience and technical knowledge of multiple engineering teams working collaboratively in The Aerospace Corporation's Concept Design Center (CDC)– the Electro-Optical Payload Team (EOPT) and the Space Segment Team (SST). The EOPT, an interdisciplinary team of engineers (mechanical, structural, thermal, optical, and controls) is dedicated to the detailed design of Electro-Optical (EO) sensor payloads. The SST focuses on the space vehicle (satellite bus) design.

The IR sensor engineering activity began with the development of a concept design for the telescope optics (Figure 1). The sensor design is typically done separately by an optics system engineer in an optics design tool such as CODE V, which creates a non-geometric description of the sequential optical path that light travels within the telescope as it reacts with the various optics components– mirrors, beam splitters, collectors, etc.

A second source of conceptual design data is the 3-D geometry, which is imported into Comet from the CAD system in the form of a functionally "tagged" 3-D geometric description containing the various telescope components (Figure 2).

These two elements of the telescope design are "married" within the unique Comet Abstract Engineering Model® into a single, multi-fidelity functional model of the telescope, which captures all of the properties required to predict the overall performance of the optics system as attached to the satellite bus operating in various environments or duty cycle conditions (such as mechanical/structural loads due to launch, thermally induced deformations and stresses while the satellite is operating in space).

Comet's "Intelligent Templates," which specify how the overall optics system performance is to be evaluated, enabled the Aerospace team to rapidly create and refine multiple simulation processes in each of the individual domains (such as structural, thermal, optics, controls), as well as for the integrated multi-disciplinary analysis of the overall optics system.

With a traditional non-integrated and serial process, doing only a single iteration of the analysis to make changes of this nature could take weeks. With the fully defined Comet templates, the Aerospace team performed complete analysis iterations within a single day. They spent less time on manual rework, and could look at more options early in the design process.

The Structural/Thermal/Optics Performance (STOP) simulation process (Figure 3) was defined in the Comet Workspace to evaluate the effects of the various duty cycle environments on the optical performance of the IR telescope (such as image quality). In the overall process schematic, there are tasks dealing with automating the meshing of components for both the structural and thermal models; the thermal analysis is then performed with Thermal Desktop using the orbital temperature profile, and thermal results are transferred automatically to the structural model where various structural analyses are performed using MSC Nastran.

The Sigmadyne SigFit software is used as a bridge between the thermal finite element calculations and the structural finite element calculations and the Synopsys CODE V optics model. Because these templates are defined in functional terms, not specific to any one geometric instance of the design, engineers can use the Comet templates to evaluate substantially different geometric and topological design concept alternatives.

Once the Simulation Process for STOP analysis is set up, the effects of concept design changes or different thermal environments on optical performance can be re-evaluated in one day or less, even for complex opto-mechanical

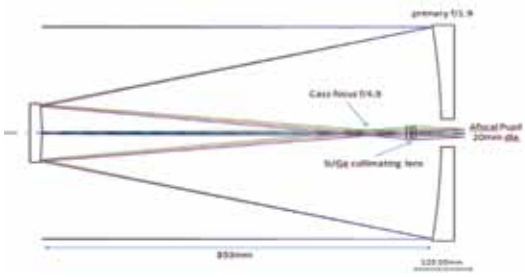


Figure 1: IR Telescope CODE V Optics Design

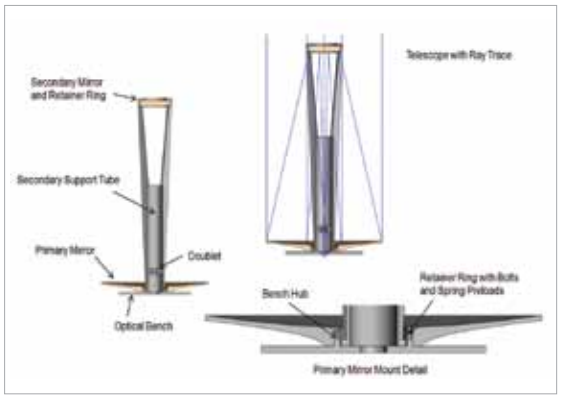


Figure 2: IR Telescope 3-D CAD Design Concept

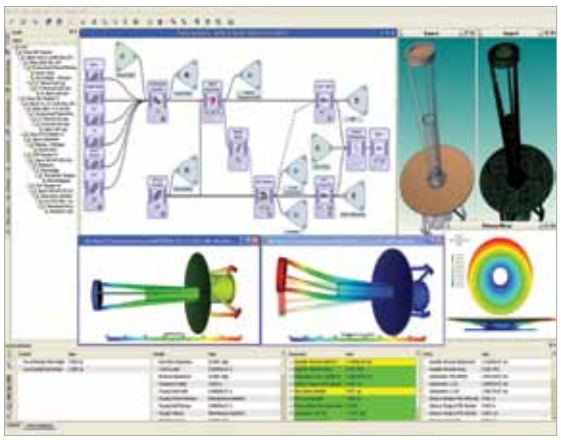


Figure 3: IR Telescope Project Results in the Comet Engineering Workspace

designs—with far less delays and human errors at the points where information is exchanged manually between the various disciplines.

As Dr. David Thomas (Engineering Team Lead, The Aerospace Corporation) commented, "The Comet-enabled integrated STOP process allowed our interdisciplinary engineering team to conduct an analysis that normally takes several days or weeks to perform to be completed in a single day. These savings are realized for each design cycle in the iterative process needed to converge to a satisfactory overall design for the IR telescope."

The Comet Project Dashboard (shown in Figure 3) provides a summary view of the key inputs (variables) and key outputs (metrics) compared to the required performance specs of the product (requirements).

Project data is always up to date and readily accessible from the workspace interface– replacing what are typically static data presentations using Word, PowerPoint, etc. Working from the Project Dashboard, analysts can modify the values of the key system variables to perform design trade studies and easily rerun "approved" simulation templates across one or more application domains – and the Dashboard is automatically updated with the new results.

Engineering/Program managers and systems engineers can also review the state of the design and compare designs easily across different variations of the model–with a complete history of all the design configurations and variants that have been performed within the Comet Project (also shown in Figure 3).

Summary

Using Comet, combined with MSC Software tools to perform integrated modeling and process automation for standard, well-defined and repeatable design simulation activities, engineering analysts and project teams can accelerate the design and analysis of complex, high-performance systems by being able to:

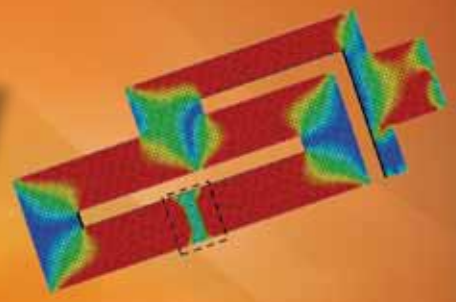
- Capture/reuse engineering best practices of domain analysts

> "The same integrated model was iterated to correct detailed design problems while easily assessing the impacts of those design changes on all aspects of systems performance."
>
> - Dr. David Thomas, The Aerospace Corporation

- Perform more robust mixed-fidelity trade studies starting early in the design cycle
- Reduce manual rework and errors
- Collaborate across the project team
- Make decisions based on consistent design data and simulation results (i.e., all disciplines work off the same pedigreed data)
- Produce an audit trail of project processes, assumptions, models, and results

For additional information on the Comet software and other industry applications, or to download a SPIE technical paper and conference presentation on this Aerospace Corporation project, visit www.cometsolutions.com. ◆

Leading the Way in Composites



Paving the way with the most advanced material modeling technology

e-Xstream engineering | By Dr. Bernard Alsteens

e-Xstream engineering is an MSC Software Community Partner who offers DIGIMAT, the unique nonlinear multi-scale material and structure modeling platform that addresses composite material suppliers and end user's needs. DIGIMAT enables the design of innovative and optimal materials and structures while reducing the related development time and costs needed to manufacture them.

Introduction

Environmental issues have been a key topic within R&D strategies for the main technological industries (e.g. aeronautic and automotive industries) for more than 10 years. These industries must find a new solution to meet the demands of increasingly stringent environmental norms while also reducing the development cost and the time to the market for their product. Switching to composite materials, which provide the greatest performance properties compared to density, are the most interesting solution to consider tackling these new challenges. These materials provide outstanding properties in mechanical, thermal and electrical fields. The word composite is a generic term where different types of composites can be distinguished: unidirectional composite, short fiber reinforced plastic, nano composite, ceramics.

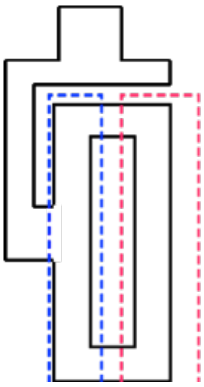


Figure 1: Mold geometry. The thickness of the mold is 2mm. In blue square is the Sample B, Sample A is in red square.

Introducing composite material in a part that was traditionally made of metals is a new challenge for engineers. Composite materials exhibit nonlinear anisotropic material properties that are much more complex to model than the properties of good old steel. The question arising is then how to accurately model the complex behavior of a composite material in an industrial part?

DIGIMAT Technology

With that target in mind, e-Xstream engineering has developed the DIGIMAT software suite. DIGIMAT provides the most advanced material modeling technology using a micromechanical multi-scale approach to account for the nonlinear, anisotropic, strain rate- and temperature-dependent behavior of composite materials. It is best suited to handle material modeling in the frame of global simulation processes in order to improve the accuracy of FEA.

Material modeling would be incomplete if it did not to include failure modeling. This is a great challenge for part producers, especially in the field of composite materials. DIGIMAT perfectly addresses such a challenge.

Accurate material computation with DIGIMAT can be performed on a Representative Volume Element (RVE) by the means of Digimat-MF. This is a way to study the material itself and the microstructure that constitutes it. It can also be done in the frame of FEA on structural parts by the means of DIGIMAT interfaces to CAE codes. DIGIMAT is interfaced with the most important FE codes available on the market, both implicit as well as explicit, and Marc is an important part of this. In the case of FEA, the DIGIMAT material computation is performed at each integration point of the FE mesh. This is done at every time step such that the continuously evolving material state is dynamically updated during the analysis.

DIGIMAT Coupling to Marc

DIGIMAT's interface to Marc has been used by the Kanazawa Institute of technology and UES Software Asia, Inc. to evaluate the effect of a weldline on the failure of a hexahedral beam during a bending test. The beam is made of PP reinforced by short glass fibers (PPGF). The specific mold has been designed to create in one injection process two beams: one with a weldline (Sample A) and one without (Sample B). Figure 1 shows a sketch of this mold. This process has been simulated in 3D TIMON (Toray Engineering). The fibers are randomly oriented in the weldline as visible in the Sample A. DIGIMAT is used to model the elasto-plastic behavior of the PPGF material. The inputs for DIGIMAT material model are the mechanical properties of

the polypropylene material and glass fiber. The microstructure must be also described by the mass fraction of fiber, their aspect ratio and the fiber orientation tensors.

This process has been simulated in 3D TIMON. The fibers are randomly oriented in the weldline as visible in the Sample A (area in the dotted line). Sample B shows a diffused orientation in the gate area. The fibers in the area around the weldline and around the diffuse area are quite highly oriented along the sample. This orientation will change progressively from the skin to the core of the sample. In the core the fibers will be randomly oriented.

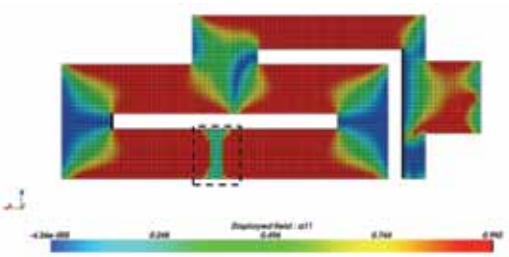


Figure 2: Weldline location in the Sample A

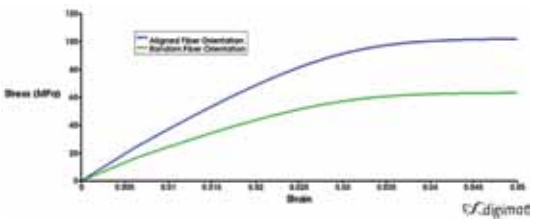


Figure 3: Composite behavior as function of the fiber orientation

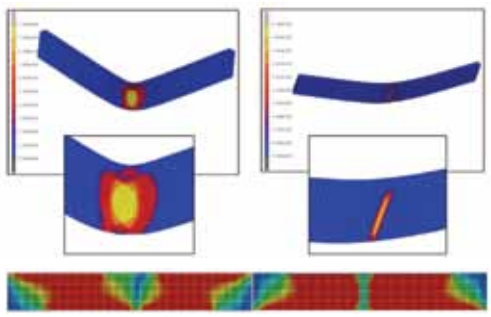


Figure 4: Failure pattern in the sample A (right) and sample B (left).

> The DIGIMAT to Marc solution bridges the gap between the composite microstructure, as induced by the manufacturing process, and the end-performance of the composite structure

DIGIMAT is used to model the elasto-plastic behavior of the PPGF material. The inputs for DIGIMAT material model are the mechanical properties of the polypropylene material and glass fiber. The microstructure must be also described by the mass fraction of fiber, their aspect ratio and the fiber orientation tensors. Figure 3 illustrates the effect of the fiber orientation on the composite behavior. The composite is much stiffer when the fibers are aligned with the tensile direction than with a random fiber orientation.

The local nonlinear anisotropic behavior of the composite material in the beam is captured by using the DIGIMAT Micro method. In this method, DIGIMAT is strongly coupled with Marc. In every integration point of the beam, DIGIMAT is called by Marc to predict the behavior of the composite as function of the fiber orientation observed in this point. This procedure is repeated in every integration point of the beam and for all time increment. To predict the failure pattern of the beam, the First Pseudo Grain Failure (FPGF) model is used. FPGF is the only known failure model specifically dedicated to model failure of short fiber-reinforced plastics. The FPGF model offers the great advantage of enabling to use the mere maximum stress limits of the composite which are most easy to measure experimentally.

The results of the DIGIMAT to the Marc analysis show a big difference in the failure pattern between the Sample A and Sample B (see Figure 4). This difference can be captured because DIGIMAT is predicting the right material behavior in every point of the part by taking into account the local microstructure of the material. In Sample A, the failure line is concentrated around the weldline. The strength of the composite is lower in this area due to the random orientation of the fibers. In Sample B, the failure pattern is not a line anymore but an area. This is due to the diffused orientation of the fibers in the center of the beam. This diffused orientation is due to the specific polymer flow at the gate of the mold.

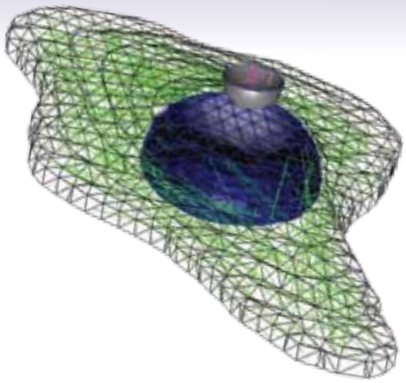
Conclusion

DIGIMAT is a unique software platform for the nonlinear multi-scale modeling of a large variety of materials. The DIGIMAT to Marc solution bridges the gap between the composite microstructure, as induced by the manufacturing process, and the end-performance of the composite structure. In this study, DIGIMAT to Marc has been able to accurately capture the local nonlinear anisotropic behavior of composite material and the effect on the failure pattern.

DIGIMAT is the standard solution used across many industries to model the behavior of composites as a function of their underlying microstructure. ◆

Pictures Courtesy of UES Software

Ground Breaking Cellular Research



Intriguing study on cellular mechanic properties

Clemson University | By Dr. Scott T. Wood

Patran and Marc were integral in the new intriguing study on cellular mechanic properties at the Multiscale Bioelectromechanics Lab based in Clemson University. This study presents a simulation of the nonlinear mechanical behavior of biological cells under dynamic loading using the FEM capabilities of MSC Software's Marc. The goal of this study is to construct a representative 3D finite element model of a biological cell based on the sub-cellular structures that provide the cell with its mechanical properties.

> "We chose Marc because it is such a robust nonlinear mechanics platform and is capable of modeling the highly nonlinear behaviors exhibited by biological materials"

The geometries for the model are constructed from 3D microscope images of cells using proprietary analytical algorithms, imported into Patran for pre-processing, and submitted to Marc for analysis. Vascular smooth muscle cells (VSMCs) are chosen for the study due to the strong correlation of the geometric arrangement of their structural components on their mechanical behavior and the implications of that behavior on diseases such as atherosclerosis.

The ability to model the mechanical responses of cells to physical stimuli presents many opportunities to the world of medical research. Chief among these is the ability to further our understanding of the etiology of many diseases. There are a wide variety of diseases whose etiology or clinical presentation are either known or suspected to be related to abnormal cellular mechanics, alteration of the cellular processes that regulate transmission of mechanical stimuli into biochemical responses, or changes in tissue structure. Because physical distortion can affect cell how cells grow, specialize themselves for specific tasks, move, and whether they live or die, the ability to predict the mechanical behavior of cells in response to pathological conditions and medical treatments may be critical to prevention and treatment of many of these diseases.

VSMCs are modeled using a linear elastic material model together with truss elements in Marc which simulate the cytoskeletal fiber network that provides the cells with much of their internal structural support. Geometric characterization of single VSMCs in 2D cell culture is achieved using confocal microscopy in conjunction with novel image processing techniques. These techniques allow for the creation of representative 3D model structures consisting of the cell nucleus, cytoplasm, and actin stress fiber network of each cell, which are then imported into Patran for structural analysis with Marc. Mechanical characterization is achieved using atomic force microscopy (AFM) indentation and stress relaxation techniques. Material properties for each VSMC model are input based on values individually obtained through experimentation, and the results of each model are compared against those experimental values.

This study is believed to be a significant step forward towards the viability of finite element models in the field of cellular mechanics because the geometries of the cells in the model are based on confocal microscopy images of actual cells with mechanical data obtained immediately prior to imaging and thus, the results of the model can be compared against experimental data for those same cells. These types of models could one day be used to decrease the cost and speed the development of new drug discovery and regenerative medicine therapies, as well as increase our understanding of the relationship between the structure and function of biological cells.

Researcher Dr. Scott T. Wood of the Multiscale Bioelectromechanics Lab at Clemson University said: "We chose to use Marc for this project because it is such a robust nonlinear mechanics platform and is capable of modeling the highly nonlinear behaviors exhibited by biological materials. In addition, pairing Marc with Patran allowed us the capability to easily integrate and optimize the complex meshes we generated from our cellular imaging data."

About the Multiscale Bioelectromechanics Lab - Clemson University

Headed by bioengineering Professor Delphine Dean, the Multiscale Bioelectromechanics Lab at Clemson University is a research laboratory which has conducted revolutionary research in topics such as single cell structure-function relationship, nanoparticles and cell function, dental materials and dental cells, radiation and cartilage tissue, and nanoparticle-modified hydrogels for improved electrical conductive properties. The lab has also produced over 20 journal publications in well-known journals such as Journal of Biomechanical Engineering and Biotechnology and Bioengineering, over 20 peer-reviewed Conference Proceedings across the country, and even has two patents pending.

The Multiscale Bioelectromechanics Lab - Clemson University :

http://www.clemson.edu/ces/mbem/DeanHome.html ◆

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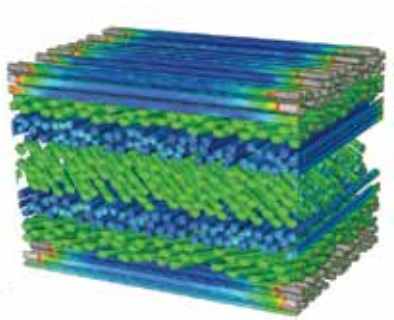

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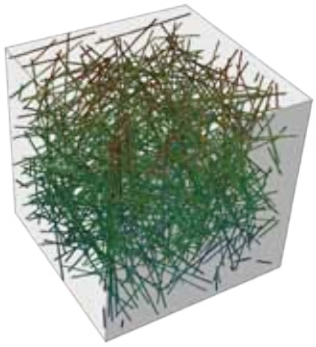

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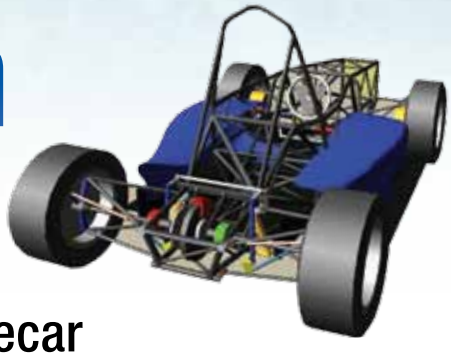


Modeling the award-winning Formula SAE Racecar

University of Texas - Arlington | By Justin Strempke and Dr. Bob Woods of UTA FSAE

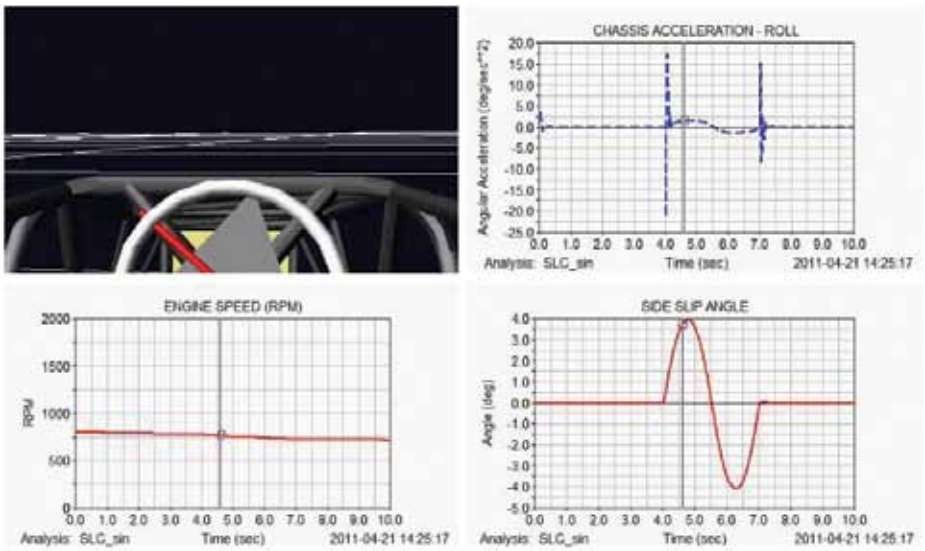
The use of MSC Software's Adams in 2010-2011 at the University of Texas at Arlington began with a design project to model the award-winning 2010 FormulaSAE racecar.

Combining pre-built templates with customized configurations and settings, the virtual model is able to simulate the real vehicle operating under most race conditions. Maneuvers such as a fishhook, straight-line acceleration and braking, and single lane change were used. There was also experimentation in creating full tracks, and using the SmartDriver built into Adams/Car. Such virtual testing will be validated against real-time data when available, and the model altered accordingly.

Portions of the car were also tested using the half-car analysis. The front suspension kinematic analysis concurred with previous design studies and goals, and was able to go above and beyond to include dynamic elements such as braking and cornering forces. This provides valuable feedback on included part forces, and will become essential to proper design.

The next step was to develop the HybridSAE model. This was based on the FormulaSAE model, but included applied torques and weights from the new hybrid powertrain. Electric motor property files can be changed to utilize different motors, as well as controlled individually for torque biasing. Ultimately the goal is to co-simulate with MATLAB/Simulink and use the actual code to be run in the hybrid control computer. This will give huge advantages in being able to develop and debug the controls code before the vehicle even hits the pavement, aiding in concurrent engineering efforts between design departments.

Top UTA's award-winning 2010 Formula SAE



Full-vehicle single lane change maneuver, displaying various model characteristics.

In the future, having both legacy models ready for modification will be extremely helpful. The majority of this year's time with Adams was purely focused on model development and validation. For both the Formula and Hybrid racecars, dynamic simulation will be a great way to evaluate a design before the construction, and possibly show many flaws before a single part is built. This will greatly increase efficiencies, reduce build time and cost, and be a tremendous asset to our design procedure! ◆

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