Maplesoft Software Used in
Advanced Engineering Research

Engineering researchers must not only develop models quickly, but they also require in-depth analytical tools to help them understand on a fundamental level the intricacies of their models. Fortunately, tools like MapleSim™ and Maple™, from Maplesoft, are available to researchers to aid in their model development and analysis. With MapleSim, researchers can quickly develop their models and can gain insight into their systems' behaviours. Researchers at many academic institutions have adopted MapleSim, advanced physical modeling software from Maplesoft, as a key tool in their engineering research activities. This article illustrates how engineering researchers are making significant strides in their work with the help of Maplesoft technology. It highlights the work of six researchers from around the world, and discusses such diverse projects as space rovers, humanoid robots, parallel manipulators, golf clubs, and electric and hybrid-electric vehicle batteries.

Maple™
The Essential Tool for Mathematics and Modeling
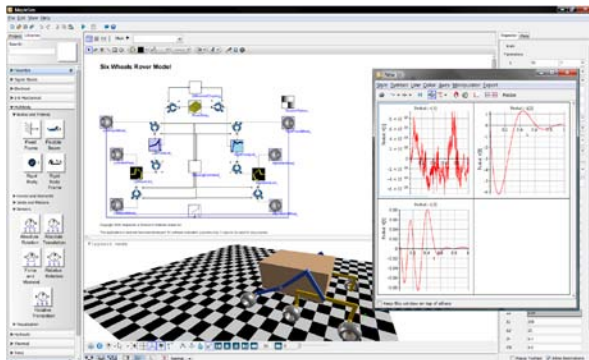
MapleSim™
High-Performance Physical Modeling and Simulation

Dr. Amir Khajepour

Professor of Engineering at the University of Waterloo, and
Canada Research Chair in Mechatronic Vehicle Systems

> **Research projects with the Canadian Space Agency,
> AEMK Systems, and General Motors**

Dr. Amir Khajepour, Professor of Engineering in the Mechanical
and Mechatronics Engineering Department at the University of
Waterloo, has used Maplesoft technology in all of his research
projects over the past 10 years. Recently, Dr. Khajepour used
MapleSim as part of an ongoing project with the Canada Space
Agency, to develop a full solution for the power management
system of autonomous rovers. "The benefits of MapleSim
compared to traditional tools are significant. We now have the
mathematical model of the 6 wheeled rover without writing
down a single equation," said Dr. Khajepour. "MapleSim
was able to generate an optimum set of equations for the
rover system automatically which is essential in the
optimization phase."

While researching delta robots as part of another research
project at the University of Waterloo, Dr. Khajepour first chose
Maple, Maplesoft's advanced technical computing software,
to develop and solve the equations of motion for a standard
delta robot. Dr. Khajepour developed the DeltaBot™, a robot
based on an innovative cable-actuated delta-style design.
All subsequent design improvements and enhancements to
the DeltaBot system were developed using both Maple and
MapleSim. The DeltaBot robots use cables instead of rigid
arms to reduce moving inertia and mechanical equipment costs
and are capable of handling up to 20 kg. Based on commercial
demand Dr. Khajepour established AEMK Systems, a company
specializing in the design and distribution of high-speed,
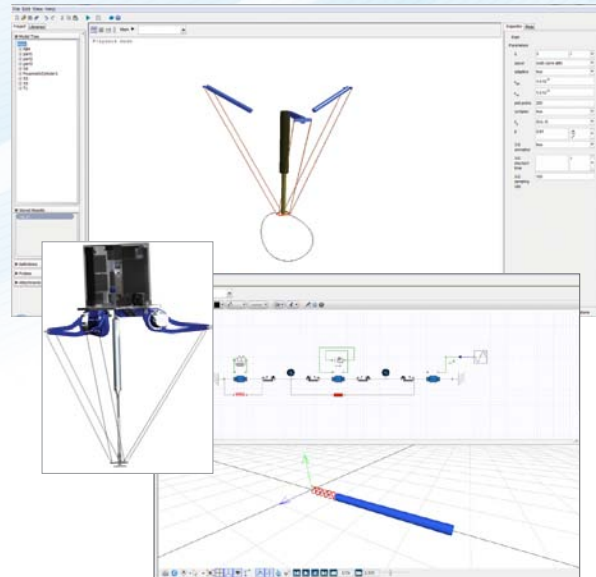
cable and vision-based robotics systems for use in a variety of
industrial applications. "With the use of Maplesoft technology,
the initial development time for the robot was significantly
reduced, and we continue to benefit from shorter development
cycles as we make enhancements," says Khajepour.

As part of a five-year, $10.5-million partnership between
General Motors of Canada, Waterloo-based Maplesoft
Inc., and the University of Waterloo, Dr. Khajepour and his
multidisciplinary research team are now tackling the challenges
of next generation electric vehicles. Through model-based
design and prototype testing, the team is investigating crucial
technologies for achieving more widespread use of
electric vehicles.

The development and validation of key enabling technologies
such as vehicle stability control, power management systems,
and battery monitoring and charging devices are important
focus areas for Dr. Khajepour's research team.

"Vehicle electrification is a key pillar of our energy
diversification strategy," said Kevin Williams, president and
managing director of GM Canada. "Building on our leading
R&D commitments in Canada, this project better positions
us to exceed customers' expectations with respect to the
performance, safety, and sustainability of our electric vehicle
technologies."

Dr. Venkat Krovi

Professor of Engineering, University of SUNY Buffalo and Director of the Automation, Robotics and Mechatronics Laboratory (ARM Lab)

> *Research projects conducted in cooperation with Quanser Consulting Inc. and the ARM Lab*

The Automation, Robotics and Mechatronics (ARM) Lab is an engineering research laboratory at the State University of New York (SUNY) at Buffalo. Ongoing research initiatives at this lab include robotics research, haptic user-interface design, and real-time simulation and control of engineering systems. As Director of the ARM Lab, Dr. Venkat Krovi is involved with all of the labs ongoing research activities.

One of Dr. Venkat Krovi's research projects at the ARM Lab

involved the study of kinematic and dynamic simulations of 6 degree of freedom Prismatic-Universal-Spherical (P-U-S) type manipulators. A parallel manipulator combines a platform that moves and a fixed base, interconnected by several legs. In his

research, Dr. Krovi and his research team analyzed a general 6 DOF P-U-S manipulator and conducted a kinematic analysis. He and his team then worked with Quanser Consulting Inc., a world leader in the design and manufacture of advanced systems for real-time control design and implementation, to create a specialized version of a parallel manipulator with the primary goal of optimizing the link geometries and parameters. Maple and MapleSim were used to create the system model. The key benefit to using MapleSim to create the model was that it provided the kinematic symbolic equations for the system automatically. Dr. Krovi and his team were able to obtain the optimal geometrical parameters for the specialized 6 DOF P-U-S system and the final device, termed the Hexapod, was created by Quanser.

Another of Dr. Krovi's research projects at the ARM Lab, also completed in cooperation with Quanser Consulting Inc, involved the design and analysis of in-parallel haptic devices. As part of this research, Dr. Krovi and his team, and Paul Karam, Director of Engineering at Quanser, developed the system-level kinematic model of an in-parallel haptic device, using the symbolic computing techniques in Maple and MapleSim. Using this approach they were able to generate the relevant symbolic equations for the system, and a combined symbolic and numeric analysis of the system performance. "The resulting symbolic equations helped to identify singularities, perform parametric design refinements and improve the real-time model-based control strategies," said Dr. Krovi.

Dr. John McPhee

Professor of Systems Design Engineering, University of Waterloo, Executive Director of the Waterloo Centre for Automotive Research (WatCAR), and NSERC/Toyota/Maplesoft Industrial Research Chair for Mathematics-based Modeling and Design

> *Research projects with Cleveland Golf, as well as Toyota and the Natural Sciences and Engineering Research Council (NSERC)*

As NSERC/Toyota/Maplesoft Industrial Research Chair for Mathematics-based Modeling and Design, Dr. John McPhee is responsible for research efforts focused on producing new methods for modeling physical systems. Current engineering practices create computer models that are numerical in

nature, to explore different design concepts and evaluate their performance. A more natural way to model a system is to use mathematics, and the main goal of this research is to develop the theory and computer algorithms necessary to automatically create engineering models in a mathematical form. This will speed up the model-based development approach for new products, an approach that is being pioneered by Maplesoft, and embraced by the automotive industry as it strives to become more efficient and responsive to consumer demands.

Dr. John McPhee and his team are collaborating with experts at Maplesoft and Toyota to develop these math-based models and computer simulations, with a focus on automotive applications such as vehicle dynamics, powertrains, and hybrid electric vehicles.

"Using MapleSim's simulation tools we can generate custom swing calculations based on every equipment variable, leaving nothing to speculation."

Dr. John McPhee together with Dr. Thanh-Son Dao and Mr. Aden Seaman also conducted research involving batteries for hybrid-electric vehicles. In recent years, the demand for electric vehicles has increased enormously. The development of such vehicles is a significantly more complex task than designing conventional cars because they incorporate many different engineering domains into a single system. One of the most important components of an electric vehicle is the
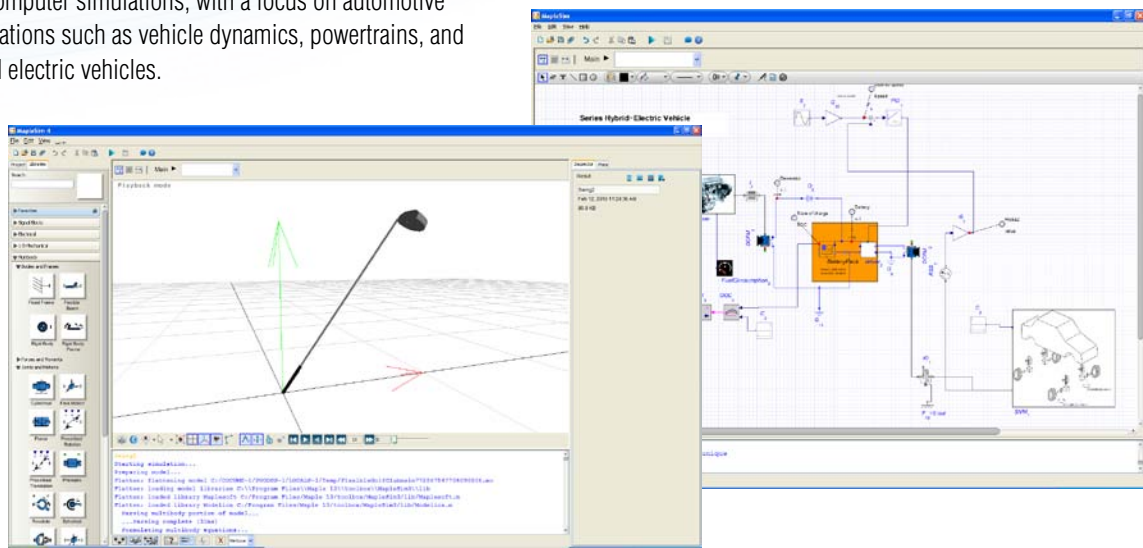
Dr. McPhee, as part of ongoing research projects at the University of Waterloo, has used Maplesoft technology in a wide range of research including a research project involving Cleveland Golf drivers. Cleveland Golf, an internationally recognized maker of golf clubs with a strong tradition of innovation, wanted to explore ways to increase the performance of their drivers. With the help of Dr. McPhee and his colleagues Dr. Matt Millard and Mr. Sukhpreet Sandhu, Cleveland Golf used MapleSim to create models of a driver. When the models were validated against experimental data, the MapleSim models were found to run significantly faster than similar models based on finite-element techniques. Cleveland Golf was impressed with both the accuracy of the model and the flexibility and performance MapleSim gave them. "The MapleSim models we're running allow us to predict head delivery conditions with more variables, higher precision, and faster run times," said John Rae, Research Manager, R&D, Cleveland Golf.

battery itself. Dr. Thanh-Son Dao and Mr. Aden Seaman are working with Dr. John McPhee to develop high-fidelity models of hybrid-electric and electric vehicles, including the batteries. They chose MapleSim because they have found the symbolic approach in MapleSim to be an effective way to develop models that accurately represent the physics of the physical system.

For battery electric vehicles, they designed a math-based model of a complete battery pack in MapleSim, along with a simple power controller, motor/generator, terrain, and drive-cycle. The resulting differential equations were simplified symbolically and then simulated numerically with physically consistent results. For hybrid-electric vehicles (HEV), they developed a multi-domain model of a series HEV using MapleSim, including an automatically generated optimized set of governing equations. The HEV model consists of a mean-

value internal combustion engine, DC motors driven by a chemistry-based NiMH battery pack, and a multibody vehicle model. As a result of MapleSim's lossless symbolic techniques for automatically producing an optimal set of equations, the number of governing equations in both models was significantly reduced, resulting in computationally efficient systems.

"With the use of MapleSim, the development time of these models is significantly reduced, and the system representations are much closer to the physics of the actual systems," said Dr. John McPhee. "We firmly believe that a math-based approach is the best and quite possibly the only feasible approach for tackling the design problems associated with complex systems."

Dr. Martin Brown and
Dr. Gustavo Medrano-Cerda

School of Electrical and Electronics Engineering,
University of Manchester

Dr. Darwin Caldwell

Italian Institute of Technology

A project using MapleSim at the University of Manchester's new center, the Centre for Interdisciplinary Compuational and Dynamic Analysis (CICADA), is helping to perfect the process of humanoid walking in robots. The Manchester team, lead by Dr. Martin Brown and Dr. Gustavo

Medrano-Cerda, and including Ph.D. student Mr. Houman Dallali, has been working with Professor Darwin Caldwell at the Italian Institute of Technology, Genova, who has been developing a novel compliant humanoid robot (CCub) based on the previously developed humanoid robot iCub at IIT.

Part of CICADA's research looks at walking characteristics and other locomotive actions using a hybrid model. The model uses spring dampers to simulate ground reaction force, actuator dynamics and compliant elements to capture the robot's full dynamic response.

One of the challenges facing the Manchester team is visualising experiments quickly and effectively to avoid slowing down the process and to ensure that experimentation is valid and relevant. "The ability to visualise in MapleSim, without having to write our own programs, has been invaluable," says Mr. Dallali. "What's more, we can directly generate C++ code to interface with the hardware and speed up the controller implementation/debugging process."

With a comprehensive and advanced library of models online – in one place – it was possible for the team to construct complex simulations easily using the 'drag and drop' modeling environment, and then edit existing models with little effort due to MapleSim's intuitive interface. The inclusion of linearization techniques in the MapleSim offering is also important for robotic modeling. "We are building models faster and completing experiments with better data thanks to MapleSim's accuracy and kinematics capabilities," says Mr. Dallali.

The speed and success of the MapleSim-aided research means that the CICADA team will quickly move on to projects for dynamic walking with full body control and extended range of gaits. In the future, they will be adding logic and learning approaches to their code and looking to develop applications from the research, such as better prosthetics and walking aids.

These are just a few examples of how MapleSim and Maple are being used in advanced engineering research projects.

For more detailed information about each of the examples described in this article please refer to the following:

MapleSim Used to Rapidly Develop a High Fidelity
Multi-Domain Model of a Robotic Space Rover:
http://www.maplesoft.com/company/publications/articles/view.aspx?SID=87670

High-speed robot, DeltaBot™, designed using Maplesoft™ technology:
http://www.maplesoft.com/company/publications/articles/view.aspx?SID=100216

GM and Maplesoft to Collaborate on Electric Vehicle Technologies at the
University of Waterloo:
http://www.maplesoft.com/company/publications/articles/view.aspx?SID=97845

MapleSim and Maple Used in Advanced Research Projects at the
Automation, Robotics, and Mechatronics Lab at SUNY Buffalo:
http://www.maplesoft.com/company/publications/articles/view.aspx?SID=100838

MapleSim Helps Improve Your Golf Game:
http://www.maplesoft.com/company/publications/articles/view.aspx?SID=94609

MapleSim Used to Create High Fidelity Physical Models of Hybrid and
Electric Vehicle Batteries:
http://www.maplesoft.com/company/publications/articles/view.aspx?SID=98868

Learning to walk faster with high performance modelling:
http://www.maplesoft.com/company/publications/articles/view.aspx?SID=102134

NSERC-Toyota-Maplesoft Industrial Research Chair in Mathematics-
Based Modeling and Design announced:
http://www.maplesoft.com/company/publications/articles/view.aspx?SID=33164

For more Maplesoft user case studies go to:

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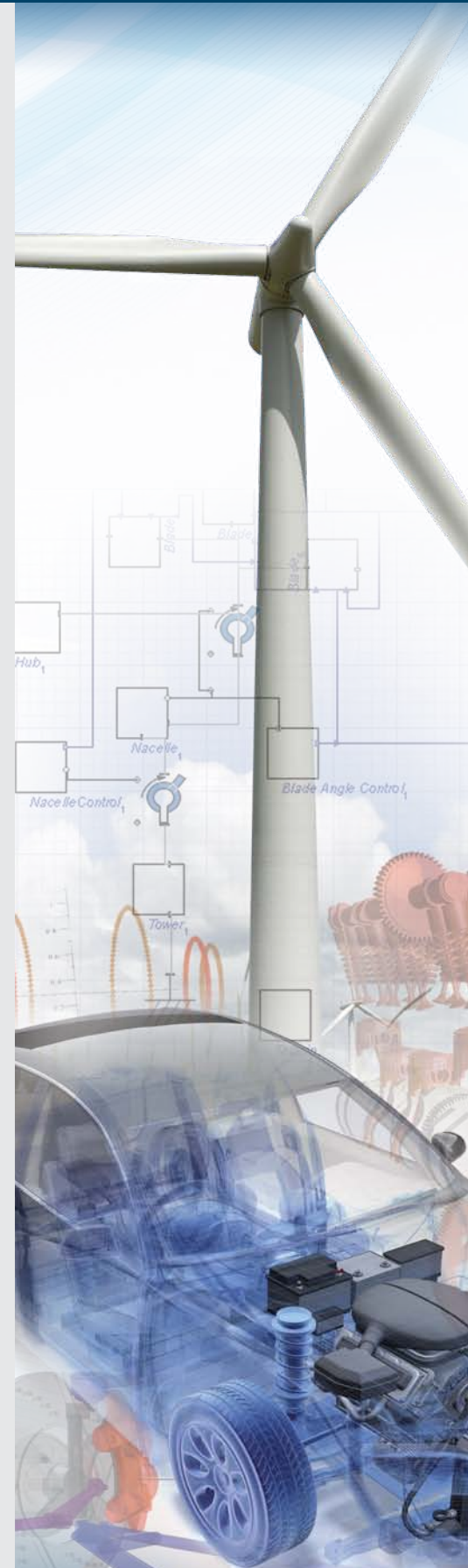
MapleSim™

High-Performance Physical Modeling and Simulation

MapleSim is a professional physical modeling and simulation tool adopted by engineering research and education institutions throughout the world. Built on the legendary Maple symbolic computation engine that revolutionized mathematics research and education, MapleSim provides unique technology that offers greater insight into system behavior, accelerating your research and enriching your teaching.

For researchers, MapleSim reduces model development time from months to days while producing high-fidelity, high-performance models. For education, instructors can use MapleSim to quickly demonstrate the connection between theory and physical behavior, and students can spend more time working with design concepts rather than the mechanics of mathematical derivations.

Maple™

The Essential Tool for Mathematics and Modeling

Maple is the essential technical computing software for today's mathematicians, engineers, and scientists. Whether you need to do quick calculations, develop design sheets, teach fundamental concepts, or produce sophisticated high-fidelity simulation models, the world-leading Maple computation engine offers the breadth, depth, and performance to handle every type of mathematics.

Maple's intuitive interface supports multiple styles of interaction, from Clickable Math tools to a sophisticated programming language. Using the smart document environment provided by Maple, you can automatically capture all of your technical knowledge in an electronic form that combines calculations, explanatory text and math, graphics, images, sound, and diagrams.

Extensive connectivity features ensure Maple can be integrated seamlessly with your other tools. Maple also provides the mathematical engine for MapleSim, a high-performance physical modeling and simulation tool, and Maple T.A.™, a web-based testing and assessment system.

Maple is supported by a dynamic user community and a vast collection of resources. MaplePrimes™ is a web community dedicated to sharing experiences, techniques, and opinions about Maple. The Application Center and the MapleCloud™ Document Exchange feature thousands of examples and applications contributed by the Maple community. Complementary products include specialized toolboxes, reference and self-study e-books, and more.

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