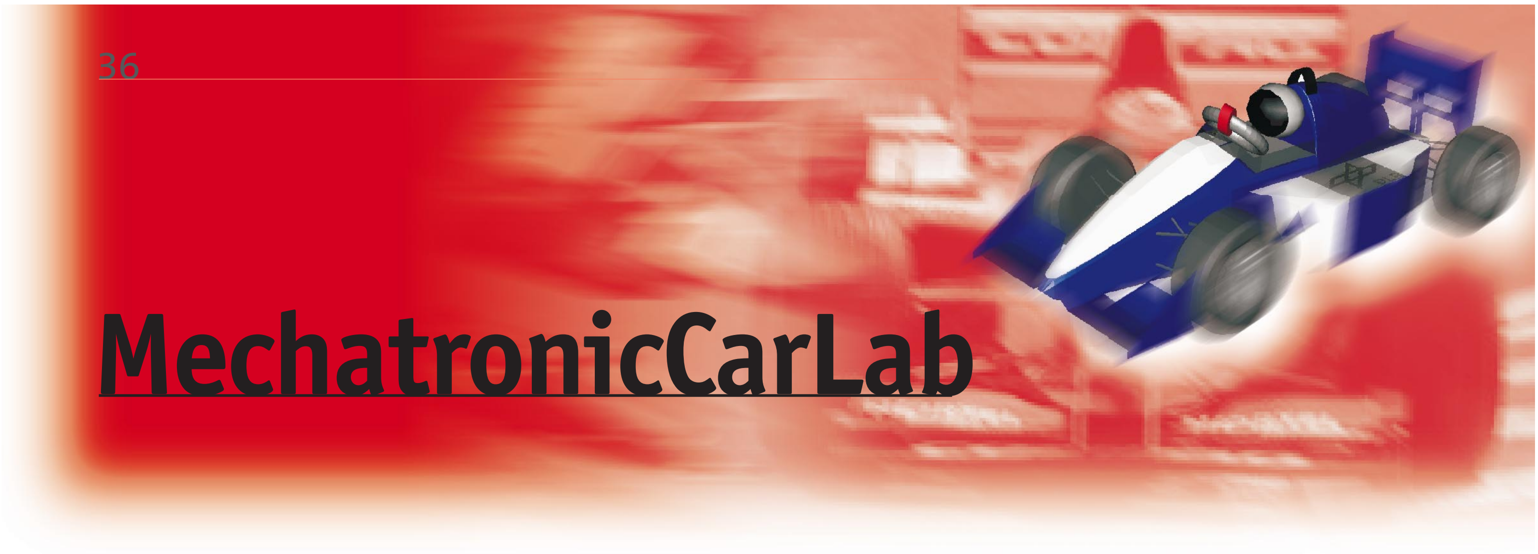


MechatronicCarLab

A System Development Environment with Real and Virtual Mechatronic Vehicle Components

Various engineering disciplines are involved in the development of mechatronic components: The know-how in the fields of mechanics, electronics and information technology is in demand when the most diverse functions become integrated into one product within a confined space. At the DLR in Oberpfaffenhofen this technology already has a tradition - in the meantime automotive engineering has become an extensive area of application.

In recent years the technical inner life of our motorcars has changed dramatically. Whereas formerly components such as carburettor or ignition distributor could still be recognized if the engine bonnet was opened, nowadays electronic control units have taken command. But this would not be practicable any other way when we consider what we as purchasers and drivers of the cars expect in terms of functions and attributes. These include, for instance, low fuel consumption and the reduction of exhaust gas, but also systems which raise the active and passive driving safety such as airbag, anti-lock braking system or vehicle dynamics control, to name only those which already rank among the standard systems today. Moreover, driver assistance systems and technical devices to increase comfort such as air conditioning, navigation systems or automatic seat adjustment play an important role. ■

The MechatronicCarLab as a driving simulator at the Hannover Fair 2002 ■

Aerospace Technology for Road Vehicles

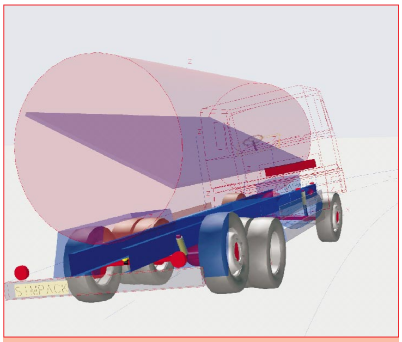
The prerequisite for the fact that such systems are marketable is a favourable proportion of many properties such as weight, designed space, performance requirement, easy replaceability and (much more important in the automobile branch, for example, than in aerospace) low costs. These requirements have contributed towards the fact that today mechanical, electrical and electronic parts are combined into highly integrated mechatronic components. In connection with information technology and software algorithms, to some extent they possess a very high degree of intelligence and autonomy. The fusion of sensors, control and actuators into compact units fully complies with the trend of modularisation in the vehicle industry. As a result of the bloom of mechatronics in vehicles and its commercial importance, this topic also plays an important role in the Oberpfaffenhofen Institute of Robotics and Mechatronics. The expertise in the field of integration of highly complex mechatronic systems was acquired from the development of components for aerospace robotics. Today the institute with its many-sided main pillars has become a much sought after partner in industry. The interest is not only centred on the mechatronic components themselves, but also on the methods for their development as well as the scientifically established methods and tools for control engineering.■

Flexible Boundary between Reality and Computer Worlds

Research and development are carried out within the scope of the „Bayerisches Kompetenznetzwerk Mechatronik“ (Bavarian Competence Network of Mechatronics). In addition there is commissioned work for the automobile industry and its suppliers. Vehicle system dynamics, dynamics analysis and the evaluation of vehicles have a long tradition which began with the analysis of maglev (magnetic levitation train) systems and the running behaviour of railway vehicles on tracks. The main focus of the work, which is also promoted by the Bavarian State Ministry of Economic Affairs, Transport and Technology, is the simulation of the dynamics of road and rail vehicles. In the course of time a laboratory infrastructure has thus developed in Oberpfaffenhofen which is composed of real hardware and virtual components. The virtual components consist of mathematical models. A mechatronic unit can thus be developed and analysed taking into consideration the interaction with the entire vehicle. For example, the not really existing sub-systems of the vehicle are simulated in real-time and connected with the real components via suitable interfaces (hardware-in-the-loop-simulation).

Depending on concrete questions and availability, real and virtual components can be exchanged for one another. The virtual components are scaled according to requirements, i.e. they are considered with exactly the level of detail and effort as is appropriate to the type of problem.

For the simulation of multibody systems the SIMPACK software programme was developed at the Institute of Robotics and Mechatronics. This programme is now marketed and further developed by the company INTEC GmbH. As a result of interfaces to a variety of CAE programmes, SIMPACK has outgrown pure multibody simulation. As a tool for the analysis and design of complex mechatronic systems, it is also adopted by many renowned companies in the automobile and railway industry both home and abroad. Among the investigations carried out at the

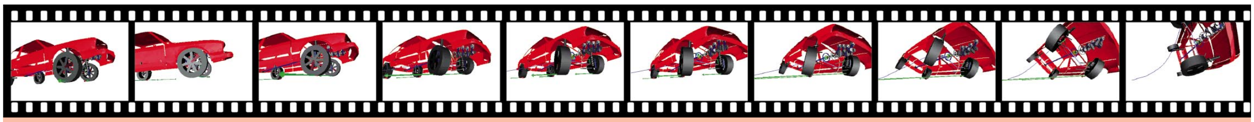


Tanker simulation model with sloshing fluid ■

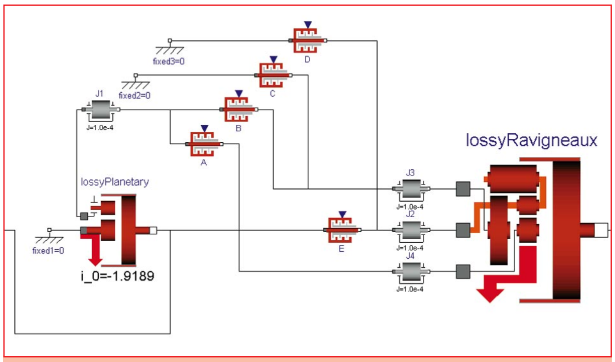
Institute of Robotics and Mechatronics are simulations of the roll-over stability of trucks and buses. Elastic deformation of the vehicle framework, the exact characteristics of the tyres, the reaction of the driver, sloshing fluid in the tanker as well as the interaction of vehicle and elastic roadway (e.g. when crossing a bridge) are examples of questions for which simulation models and new simulation methods are developed. ■

New Possibilities as a result of object-oriented Modelling

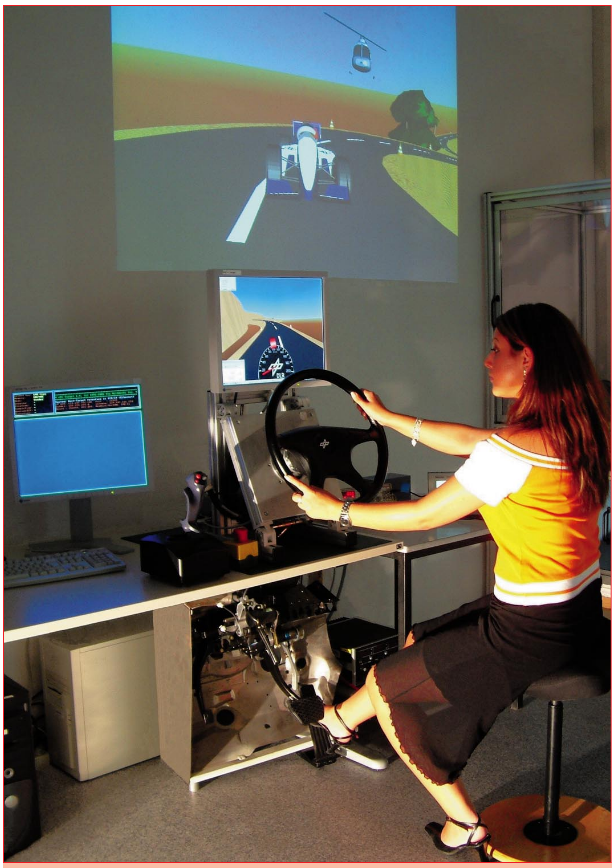
A project carried out jointly in 1996 by BMW and the Institute of Robotics and Mechatronics laid the foundation stone for the virtual drive train. When using the novel technology of the object-oriented modelling with Modelica® simple engine models and, if necessary, detailed gear models ranging from manual transmission to six-gear automatic transmission are simulated in combination with real electronic control units, i.e. in real-time. The modelling of vehicle drive trains is presently promoted within the scope of the project „Test and Optimisation of Vehicle Electronic Control Units with Hardware-in-the-Loop Simulation“ which is supported by the Bavarian State Ministry of Economic Affairs, Transport and Technology. This project is being dealt



Vehicle dynamics simulation with Modelica®/Dymola ■



Gear Simulation with Modelica®/Dymola ■



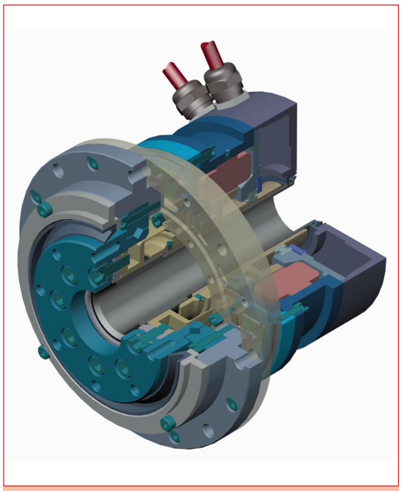
MechatronicCarLab with force-reflecting steering input devices (steering wheel, joystick) and force-reflecting accelerator pedal, real-time vehicle dynamics simulation and visualisation ■

with by the Institute of Robotics and Mechatronics together with BMW and Liebherr Aerospace. The results are incorporated in the commercially marketed drive train library PowerTrain which is used by several automotive manufacturers and suppliers.

Right from the start the Institute was significantly involved in the development of the modelling language Modelica® (as an open standard for the creation of multi-physical models of complex systems). Besides the development of this standard, the availability of comprehensive component libraries is of vital importance for the application of this technology. In this way base libraries for control-engineering and electrical components, drive trains, mechanical multi-body systems and heat conduction, as well as special libraries for robots, flight and vehicle dynamics etc. were developed at the Institute of Robotics and Mechatronics in cooperation with other members of the Modelica Association. ■

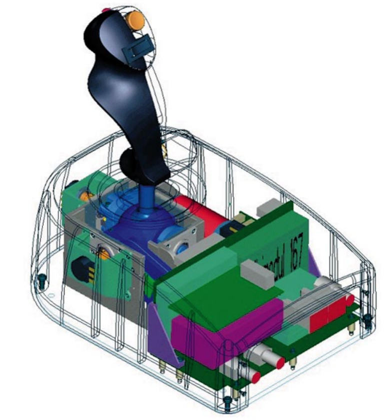
Descriptive and Tangible Development of Drive-by-Wire and Vehicle Dynamics Control Systems by „Virtual Reality“

The simulation of vehicle dynamics in the MechatronicCarLab can be performed in real-time with the aid of 3D-graphics, simultaneously in multiple projections, from the perspective of the driver or any other view. One of many applications of the MechatronicCarLab is therefore that of a driving simulator. The driver can be offered various interfaces for operating: A force-reflecting steering wheel is available which receives the driver's request and displays steering torques to the driver. The actuator for this is a compact electrical motor unit with Harmonic-Drive-Gears. The difference to conventional servo drives is an output shaft torque sensor which permits a swift and precise torque control. The drive unit was developed on the basis of the joint drive of the DLR lightweight robot and offers the foundation for the latest spin-off of the Institute. The company SENSODRIVE GmbH has made it its business to make use of innovative torque-controlled drives in the fields of industrial and service robotics, rehabilitation and training as well as in plant engineering and construction. A force-reflecting steering wheel was also delivered to the Braunschweig DLR Institute for Transportation Systems. With this steering wheel new assistance systems are analysed there in the driving simulator and drive-by-wire experimental vehicle which assist the driver also when steering. Furthermore, in the MechatronicCarLab a high-performance joystick with force feedback enables the analysis of novel control concepts alternatively to the conventional steering wheel. A force-reflecting accelerator pedal completes the configuration.



The mechatronic drive unit with torque sensor is suitable for generating torques on the Steer-by-Wire steering wheel ■

The DLR lightweight robot can be brought into the MechatronicCarLab for virtual analyses of the positioning and design of opera-



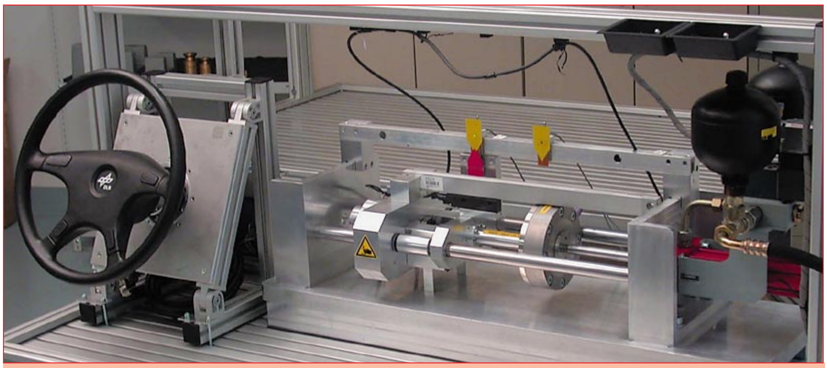
Force-reflecting joystick as an alternative to steering wheel and pedals ■

ting elements (e.g. a gearshift lever) in a vehicle. The handling of the operating element can be conveyed to a test person by mounting the control element on the tip of the robot. The lightweight robot, which is equipped with high-precision force- and torque-sensor technology, is controlled in such a way that it reflects the elasticity, stiffness and degrees of free-

Lightweight robot as force-reflecting interface for virtual operating elements ■

dom of the operating element. Besides the standard operating elements of present-day cars, with this universal force feedback device any novel (e.g. multifunctional) operating elements can be examined flexibly with regard to ergonomics and manageability. The MechatronicCarLab can also be operated as a test bench for mechatronic components or entire drive-by-wire systems. At present the work is concentrated on the torque control of the steering wheel actuator and the testing of a superordinate steer-by-wire control which restores the disconnected mechanical connection between steering wheel and front wheels by means of the mechatronic actuators. The control determines the steering feeling and the dynamics of the steer-by-wire steering system and was developed together with the company TRW Fahrwerksysteme.

Another field of application for the MechatronicCarLab is the virtual testing of vehicle dynamics control. With active additional steering or with steer-by-wire, for example, automatic steering intervention for the stabilisation of the vehicle state can be carried out. A distinct reduction of the risk of skidding or rollover can thus be achieved. The steering behaviour of the vehicle can also be completely redesigned by software in this way without additional constructive alterations to the suspension being necessary or a compromise at the expense of other vehicle dynamics criteria being called for. ■



Development of steer-by-wire algorithms and components on the steer-by-wire test bench ■

Mechatronic Component Development under Realistic Conditions

With a high-performance hydraulic linear actuator test bench another mechatronic steer-by-wire component can be brought from the model and simulation dimension into reality: The steering motor which shifts the tie rods of a vehicle and thus adjusts the steering angle to the front wheels. The load forces come from the vehicle dynamics simulation and are imposed onto the steering motor with the aid of a hydraulic piston. Either the hardware of a customer or one's own mechatronic linear actuator with positioning and force sensors can be used as a steering motor. The latter has its origins in the gripper for the world-wide first space robot ROTEX and is based on the patented DLR Planetary Rol-

The notion of drive-by-wire in vehicles generally indicates the replacement of mechanical (also hydraulic) connections by electro-mechanical components, sensors and control devices which only communicate with each other via signal transmission. Steer-by-wire and brake-by-wire are special terms for steering or braking systems respectively. The advantages lie in the considerably more flexible design possibilities; intervention in vehicle dynamics for the improvement of driving safety, for example, is in many cases only possible in this way. Drive-by-wire systems obviously demand high costs to safeguard against system failure, but in the long run they will substitute the conventional mechanical connections in vehicles.

Mechatronic linear actuator on the basis of the Planetary Roller Spindle Drive ■

ler Spindle Drive (PRSD). Due to its high power density and programmable dynamics the mechatronic linear actuator still offers multifaceted potential for use in vehicles, for example for active suspension. This can also be tested with the MechatronicCarLab.

The development of new concepts is also supported by further tests with the already mentioned hydraulic test bench, inter alia for the identification of mechatronic linear components. The aim of the experiments, for example with the PRSD and a semi-active, magneto-rheological damper, is in both cases to get to know the components over a wide operating domain and to derive realistic simulation models from the gained data. With this information conclusions can in turn be drawn on the effectiveness of new concepts. An important field of application is the road-friendly suspension design of trucks. So-called semi-active shock-absorbers can be used, the damping of which can be adjusted continuously and very quickly depending on the driving conditions. In this way the vertical vibrations can be reduced by up to 15 percent depending on the road conditions. Since it is above all these dynamic loads which damage the roadbed, such concepts can contribute towards limiting maintenance costs for the road network in Germany and Europe despite increasing truck traffic. ■

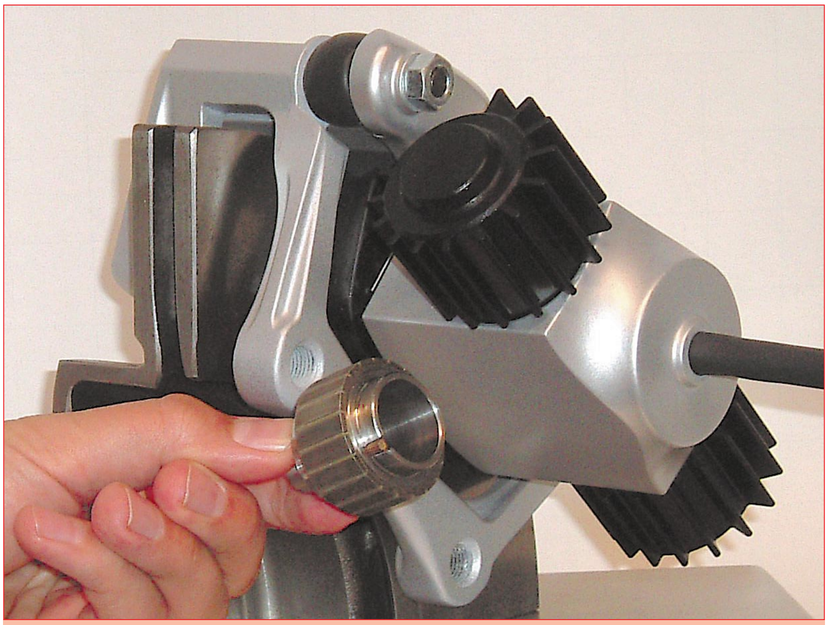
Mechatronic Brake-by-Wire

At the Institute of Robotics and Mechatronics components for Brake-by-Wire systems are also developed. The already mentioned Planetary Roller Spindle Drive (PRSD) with its low friction and high efficiency over 80 percent is predicted a great future for the application to Brake-by-Wire. The „classic“ Brake-by-Wire principle uses a motor-PRSD combination in order to actively compress the brake shoes. Normal forces in the range of 30 kN are not unusual. The company Narr in Kirchheim/Teck, a licensee, was the first to successfully establish methods for manufacturing the PRSD which allow production in a large series. With the first prototype of a brake for railway vehicles, built together with the company Knorr Bremse, the PRSD with a life span of far more than one million brake cycles recently proved to be far superior compared with all other spindles.

Yet another approach for a highly efficient mechatronic brake originated in the DLR Institute of Robotics and Mechatronics. In the meantime it is much discussed among experts as a possible brake concept for the future. Researchers have rediscovered the self-energising braking effect of a wedge from the times when there were still no virtual or mechatronic vehicles, but only coaches. In those days the coachman stuck a wedge between the wheel and wheel house and the wedge tightened itself. This very energy-efficient way of braking can also be applied to a modern brake unit. Mechatronic concepts with force sensors and swift control avoid (in contrast to the coach) a jamming of the wedge and

The Planetary Roller Spindle Drive as centre-piece of novel mechatronic brakes for railway vehicles has an unrivalled high life cycle. ■

blocking of the wheels. At the same time the energy demand compared with conventional brakes is reduced by up to 97 percent, for almost the entire power required is taken from the kinetic energy of the vehicle. At the



eBrake® - the self-energising mechatronic brake with RoboDrive propulsion unit ■

Presentation of the „HERMES AWARD – HANNOVER MESSE International Technology Prize" in April 2004 by Chancellor Gerhard Schröder to the company eStop for the mechatronic wedge brake „eBrake". This prize for outstanding scientific and technological developments was awarded for the first time this year and at 100.000 € is one of the world-wide highest endowed technology prizes. ■

same time the best possible braking effect remains. The development of a mechatronic brake of this second type (eBrake®) is in the meantime carried on by another spin-off of the Institute, the Seefeld company eStop. It can already demonstrate the first prototypes and for the wedge position control it has integrated both the PRSD spindle and the new, extremely low-loss DLR robot joint motor RoboDrive. This new, intelligent, torque-controlled and highly integrated lightweight drive is particularly optimized towards applications which demand a perpetually reversing operation with high dynamics and high torque, but low dead weight and low dissipation loss. Furthermore, this motor offers a quasi-linear (low-ripple) torque behaviour and is therefore also extremely well suited for applications where a human operator senses the resulting uniform revolution. Thus at present, besides the first test models of the eStop brake, several steering wheel prototypes are also equipped with this motor concept for steer-by-wire and driving simulators. ■

Mechatronics to tackle in the DLR_School_ Lab

The MechatronicCarLab of the Institute of Robotics and Mechatronics comprises the experimental infrastructure for testing mechatronic components for applications in vehicles as well as a multitude of already developed components themselves. It also includes the total methods and tools for the development and analysis of mechatronic systems. Working in the MechatronicCarLab, an inspiring building of virtual and real rooms, are „live" colleagues whose dedication, experience and knowledge also belong to this laboratory. It is therefore also the ideal for arousing and encouraging the scholars' interest in technical questions. The round tour of the laboratories which is covered in this article will end in the DLR_School_Lab in Oberpfaffenhofen. Here, for example, pupils can test the behaviour of self-built and self-programmed mobile mini robots. ASURO stands for „A Small and Unique Robot from Oberpfaffenhofen". The kit consisting of easily obtainable components has already been assembled several times by youngsters in the DLR_School_Lab and programmed with free software tools. By means of integrated sensors, for example, ASURO can follow a line or even spin lively pirouettes. If the robot is properly programmed it avoids obstacles autonomously or follows a preassigned track. Via infra-red even its most diverse functions can be commanded by a conventional TV remote control. Thanks to ASURO, many scholars have seen the light and in a playful way realized just how interesting mathematics and physics can be. Hopefully this enthusiasm over the knowledge gained will spur some of the young people on to come up with ideas of their own for the vehicles of the future or new paradigms for their development. ■

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