MITMECHE

Fall/Winter 2015

Vol. 6, No. 2 Published twice a year

Massachusetts Institute of Technology

MechEConnects

News from the MIT
Department of Mechanical Engineering

Propelling Transportation Forward: Toward a Cleaner, More Efficient Future

MechE faculty are urgently investigating solutions to the global reliance on fossil fuels for transportation, including engine efficiency, alternative fuels, and battery improvements.

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MITMECHE

The transportation industry is on the brink of yet another major change.

Dear Alumni, Students, and Friends,

Along with many members of our community, I believe that the transportation industry is on the brink of yet another major change. We've recently seen many history-making transformations begin unfolding before us – such as commercial space flights – and many more are just around the bend.

For example, the possibility – and indeed request by global leaders – of providing consumers with desirable clean-energy transportation is more tangible now than ever and will transform the industry on every level, from design and engineering to economics and policy. Similarly, the progressive implementation of controls and robotics in transportation is leading the path toward a safer – and likely more autonomous – experience.

In the MIT Department of Mechanical Engineering, our faculty, post-docs, and graduate students have been working on how to solve these issues – and many others – for years, and in many different ways, each tackling it from their own unique area of expertise.

For example, Professor Wai Cheng is working on ways to increase the efficiency of engines and reduce the emission of toxic particulates; Professor Chryssostomos Chryssostomidis is developing ways to wirelessly charge batteries for underwater autonomous vehicles (AUVs); Professor Ahmed Ghoniem is investigating the best ways to produce zero-carbon biomass as a clean fuel alternative; Professor John Leonard is developing a Level 2 autonomous car that will never crash; Professor Yang Shao-Horn is working to advance energy storage for electric vehicles; and Professor Wierzbicki is researching ways to design fracture-resistant batteries for electric vehicles.

We feel so strongly about the importance of this type of research in the future of transportation that we are investing heavily in the renovation of MIT's Building 31, home to key laboratories for the Center for 21st Century Energy (http://web.mit.edu/c21ce/), including the Sloan Automotive Lab, led by Professor Cheng; the Electrochemical Energy Lab, led by Professor Shao-Horn; and the Reacting Gas Dynamics Lab, led by Professor Ghoniem.

A passion for safe, innovative, and energy-efficient transportation and propulsion drove many of us to pursue mechanical engineering in the first place, and I am very pleased to present an issue that illustrates how important it is to progress the technology of this industry for the greater good and how many members of our MechE community are propelling that progress forward.

With gratitude for your ongoing support,

Sincerely

Gang Chen, Carl Richard Soderberg Professor of Power Engineering and Department Head

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About MechE

Mechanical engineering was one of the original courses of study offered when classes began at the Massachusetts Institute of Technology in 1865. Today, the Department of Mechanical Engineering (MechE) comprises seven principal research areas:

- **Mechanics: modeling, experimentation, and computation**
- **Design, manufacturing, and product development**
- **Controls, instrumentation, and robotics**
- **Energy science and engineering**
- **Ocean science and engineering**
- **Bioengineering**
- **Micro and nano engineering**

Each of these disciplines encompasses several laboratories and academic programs that foster modeling, analysis, computation, and experimentation. MechE educational programs remain leading-edge by providing in-depth instruction in engineering principles and unparalleled opportunities for students to apply their knowledge.

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Contact MechE

Department of Mechanical Engineering
Massachusetts Institute of Technology
77 Massachusetts Avenue, Room 3-174
Cambridge, MA 02139

E-mail: mecheconnects@mit.edu

mecheconnects.mit.edu
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Newsletter Staff:

Alissa Mallinson
Managing Editor

Professor Thomas Peacock
Media Moghul

B. Harris Crist
Webmaster

Wing Ngan
Designer

Tony Pulsone, Felice Frankel, John Freidah, Bryce Vickmark
Photography Credit

Propelling Transportation Forward:

Toward a Cleaner, Safer Future

by Alissa Mallinson

A joyride. A cruise. A flight to your next vacation or a drive to see your family. Or just simply getting from point A to point B.

Whatever the reason, there are few people who don't appreciate a good ride. But aside from those times when something goes wrong – your car won't start, or your plane is delayed, for example – most people take transportation, and the engineering that enables it, for granted.

It makes sense. Ground, sea, and air travel are well established and very reliable. To the naked eye, there's not much left to do but add a few luxury options and call it complete.

But more and more, people across the globe are increasingly concerned about the state of transportation: specifically, our reliance on fossil fuels for propulsion and perhaps more importantly their effect on the environment.

According to the EPA's web site, the burning of fossil fuels to power the transportation of people and goods is responsible for 31% of total carbon dioxide emissions in the US, the second-highest cause after only electricity. It was also the source of 26% of greenhouse gas emissions in the US in 2013. Globally, greenhouse gas emissions from transportation made up 14% of the total greenhouse gases in 2010.

"The most pressing need in energy production now – on the ground, in the air, or at sea – is not supply or cost of the fuel; it's how to reduce CO2 emissions," says Ronald C. Crane Professor Ahmed Ghoniem, director of the Center for Energy and Propulsion Research and the Reacting Gas Dynamics Lab. "With COP21, everyone agrees that we are producing lots of CO2 and not enough clean energy. We have our marching orders."

Judging by the number of research projects related to these emissions, the urgency is abundantly clear, and many engineers foresee a major disruption on the horizon for the transportation industry as new solutions bubble up – some quickly and some gradually – to the consumer level.

In the MIT Department of Mechanical Engineering, faculty are researching solutions from almost every angle. Some, like Professor Wai Cheng, are focused on improving the efficiency of the engine; while others, like Professor Tomasz Wierzbicki and Professor Chryssostomos Chryssostomidis, are working on ways to improve implementation of battery-powered propulsion. Some are working on drag reduction to improve efficiency; some are finding new sources of renewable energy.

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For his part, Professor Ghoniem is focused on producing fuels that enable near-zero-carbon renewable sources to replace CO_2-heavy fossil fuels. These include biofuels – fuels made from nonedible biomass and waste, such as grasses, woods, and fast-growing plants – or hydrogen/synthetic gas from water/carbon dioxide mixtures.

Biofuels are an attractive option because they produce liquid fuels at the end of the process – which works out well in transportation because liquid fuels have the highest energy density, thereby allowing for longer drives without having to refuel. Synthetic gas, produced by reducing water or carbon dioxide emitted in power plants or other industrial processes, essentially "recycles" these products back into fuels using "renewable heat" such as solar heat. The syngas, as it's commonly called, can be converted into liquid fuels for transportation applications using well established (Fischer Tropsch) processes.

"The implementation of electric cars is slow because they are still expensive," says Professor Ghoniem, "and refueling requires an infrastructure that doesn't currently exist at scale. So for now, we have to continue to rely on combustion-driven engines while still reducing CO_2 emissions. One way to do that is to expand the use of fuels produced using renewable sources. The question is: How do you expand the production of these fuels?"

There are a few different processes that produce biofuels from "waste" biomass, but an efficient and economically sound one, says Professor Ghoniem, is a thermochemical process that turns it into synthetic gas first, then liquid fuel.

"It's nearly a carbon-neutral process," says Professor Ghoniem, "because the carbon from the material is turned into fuel; the fuel is burned and produces CO_2; and the CO_2 is ingested back by the plants. It's a closed cycle where the carbon moves from the plant to the fuel and then back to the plant."

But it's not as easy as it may sound. It is a complicated, multi-step process with variables that must be analyzed and balanced to achieve the optimal, most energy-rich outcome. But, if done optimally with the right knowledge, he says, it can be the most promising method of producing biofuel, as well as fuels from other waste.

"It's very difficult to measure things inside these systems because of

Driving on Sand

Assistant Professor Ken Kamrin has been working on large-scale models of sand flow for most of his career. Granular materials, which have the odd characteristic of behaving like a solid and a liquid without actually changing phase, have not been understood to nearly the same extent as water or elastic solids. When he and graduate student Jake Slonaker '15 looked at a recent empirical model that was able to predict the resistive force of sand against arbitrarily shaped objects, they found to their surprise an invariance in the system that tipped them off to the idea that a general scaling law could exist that relates different granular locomotion problems to each other. Scaling relations are commonly used in fluids contexts such as aerodynamics and ocean engineering but have not been available for granular materials due to their complexity. Along with undergraduate student Carrington Motley (read more about Carrington on page 21), and with aid of equipment in MIT's Robotic Mobility Group, Professor Kamrin's team has verified their scaling relation in many experiments that used their newly created scaling law to successfully relate the performance of different wheels. They are now developing models that can optimize tire designs for ideal driving in sand. Their scaling relation, through an ability to scale gravity, could potentially allow NASA to simulate how a tire will behave on Mars and then optimize a design specifically for that environment.

A Clutchless, Hybrid Supercar

Assistant Professor Amos Winter and MIT alum Franco Cimatti SM ’82, Technical Director of Vehicle Concepts and Predevelopment Manager at Ferrari, partnered up last year around an idea that could have a profound effect on the engineering of supercars: What if you could decrease their weight and increase their performance by hybridizing the vehicle and packaging the electric drivetrain components directly into the transmission? Professor Winter posed the question to his students in 2.76: Global Engineering, with the following requirements: Maintain the weight and size of the existing transmission and take advantage of the functionality of two electric motors in as many ways as possible. The students proposed an innovative concept that no one, especially Ferrari, had expected: Remove the clutch from the transmission entirely by using the electric motors to control the engagement of the engine to the drivetrain instead. The students built a prototype that demonstrated all the core functionality and showed through simulation that the concept could maintain all the features consumers want from a hybrid supercar – a quick launch, stationary charging, mobile charging, and an option to switch to electric only. PhD candidate Daniel Dorsch, SB ’12, SM ’14, who has mentored the Ferrari team in 2.76 for the past two years, is continuing the project for his PhD research.

the very hostile environment,” says Professor Ghoniem. “There are lots of things cooking and flying all over the place. People have been trying to operate these systems, but with mixed success. It is important to develop detailed predictive models that use supercomputers to make up for the lack of measurements to help designers and operators.”

Professor Ghoniem and his research team are developing such computational models to codify the fluid mechanics and chemistry of the process at many scales, to understand how to achieve the desired energy outcome for any types of biomass or waste, and to maximize the production of useful fuels and minimize the formation of undesirable products.

His group is also working on several innovative approaches of utilizing heat to produce fuel from water or carbon dioxide. This requires energy such as electricity or heat to break up the strong chemical bonds between oxygen and carbon monoxide or oxygen and hydrogen.

“The process is like reverse combustion: We put heat in to get a chemical fuel out, instead of burning a fuel to get heat out as we do in combustion,” says Professor Ghoniem. “And to make it renewable, the heat source must be solar energy collected using large collectors or concentrators. This reduction (or dissociation) process produces fuel and oxygen, and both can be stored for later use.”

Given the relatively low temperature of solar heat, enablers such as ceramic membranes are used to promote the processes.

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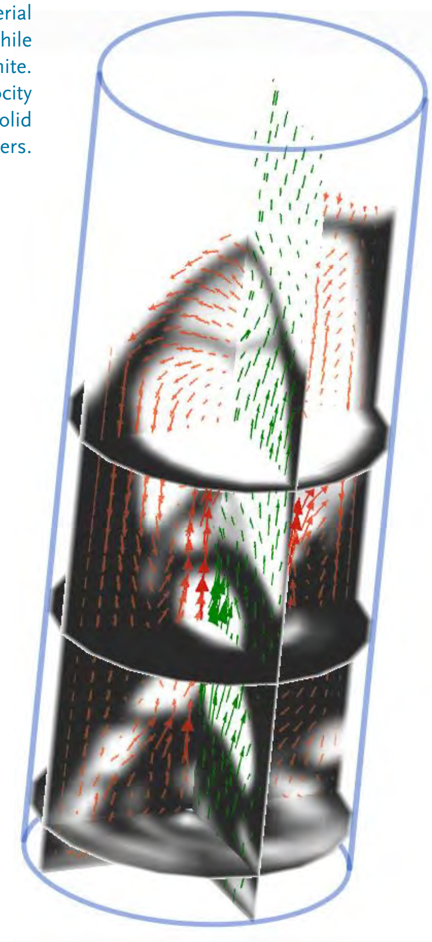
Computational results for a fluidized bed gasifier. The flowing bed material (emulsion) is shown in dark grey while the gas flow (bubbles) are shown in white. The green vectors show the gas velocity and the red vectors show the solid velocity. Image courtesy of researchers.



Professor Tomasz Wierzbicki, the director of the Impact and Crashworthiness Lab, is also developing computational models to reduce CO_2 emissions. His goal is to develop tools that can predict how materials, components, and structures will react to extreme loading, including everyday automobile crashes as well as other extreme conditions such as explosions.

On the surface, that may not sound like it’s related to reducing carbon dioxide emissions, but his experience in modeling and predicting fractures also puts him in a good position to design a lighter material and structure, which can significantly reduce vehicle weight and in turn save energy, as well as to model the deformation and fracture of lithium-ion batteries in electric vehicles.

"I realized several years ago that we could help predict and prevent batteries from catching on fire and exploding in collisions involving electric cars," says Professor Wierzbicki. "We knew that under a certain type of loading, such as hitting road debris or a side collision, an electric short circuit can develop inside a battery pack and cause a fire or explosion in a fraction of a second. So we wanted to understand the physics of that and provide the battery industry with the tools to predict what type of loading is safe and what type of battery is safe."

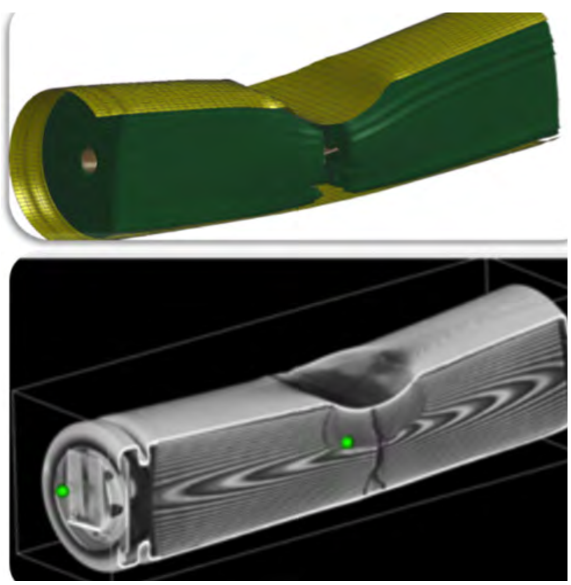
Professor Wierzbicki is the coordinator of several consortia of industry leaders in automobile and battery manufacturing. Through the consortia, he shares his research with companies that want to find answers to questions about how automobiles and other vehicles will behave in certain impact scenarios, and how to design and manufacture vehicles that can provide better protection to the occupants and at the same time weigh less.

He is also working to develop another set of computational tools that will predict how to use additive-layer manufacturing to create structures as light as titanium and magnesium but much less expensive than those made from conventional stainless steel. "We are developing computational models now," he says, "to prove that components made through the additive-layer manufacturing technique can be used as load-bearing elements and pieces with complicated shapes."

But Professor Wierzbicki doesn't ask his industry partners just to take his word on the reliability of his models. He and his research team have also designed and built their own testing machines along with specially designed specimens in order to validate their mathematical and computational models and prove that their predictions are accurate. In fact, the Impact and Crashworthiness Lab sets a high standard for itself by using wisely chosen constitutive models to predict material and structure behaviors with so far unattainable accuracy.

"We took part in the Sandia Challenge One and Two," he says, "which invited labs around the world to make blind predictions about fracture. The Sandia provided the labs with some limited information about a material and asked participants to predict what would happen next under a prescribed loading.

The Sandia researchers conducted their own physical test and later on compared it to each lab's predictions to see how accurate they were."



Li-ion batteries can develop fracture of jelly roll under certain abuse loading. The ICL team predicted, numerically, a dramatic through-thickness fracture inside the cell leading to electric short-circuit. The CT scan of a damaged battery confirms the numerical prediction.

In the Sandia Challenge Two, Professor Wierzbicki's lab came in first ahead of 13 competing labs.

"Looking into the future," he says, "we are confident that we can predict fracture under impact and crash loads of more complex materials and structural systems, such as welded pipes for risers and linepipes; fragment-impact containment structures of exploding airplane turbofan engines; and burst containment of turbo chargers of racing and passenger cars, as well as low- and high-cycle fatigue loads. These ambitious tasks will be accomplished in close cooperation with top European universities and worldwide industries."

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Professor Wai Cheng has been a member of the Sloan Automotive Lab since 1980, and has been serving as the Lab's director since 2008. He and his team of researchers are focused primarily on improving engine efficiency to reduce carbon dioxide emissions. It's a much more delicate balance of requirements and constraints than it may seem on the surface, and what's interesting, he says, is that in many ways he's solving problems he's already solved once before – but this time it's for different reasons.

"A lot of the old topics become new again," he says.

For example, one way to decrease CO_2 emissions in automobiles is to make the engines smaller so that they operate more efficiently in situations such as cruising – but by doing so, you also decrease the power output when you need it for power-heavy situations such as climbing hills.

To make up for that, you add a turbo charger, which boosts more air into the engine, and thus, burns more fuel and produces more energy.

But then suddenly you are presented with a problem that has already been solved, well, many times actually, going back to the 1930s: knocking, which is essentially a mini-explosion in the engine caused by the air and the fuel igniting very quickly. The increased temperature and pressure of the turbo-charged engine induces knocking once again.

Lightweight Lithium-Air Batteries

Professor Yang Shao-Horn leads the Electrochemical Energy Lab (EEL), which, among other things, is working to develop efficient lithium-air (Li-O2) batteries for electric cars. Because Li-O2 batteries utilize oxygen for energy storage instead of the heavier transition metal-based materials in today's batteries, they represent the potential to create a lightweight battery with up to three times the energy density of standard lithium-ion batteries. Professor Shao-Horn's research group has pursued a strategy that combines fundamental characterization and electrode materials design to help address the efficiency challenges. In one project, the group developed a vertical carbon-fiber-based electrode, increasing the amount of void space – essential for maximizing the amount of discharge product and energy that can be stored – up to roughly 90% compared with approximately 60% in more conventional electrodes. The electrode structure enabled one of the highest gravimetric energy densities, 2400 Wh/kg electrode, to be realized to date.

Cheng and his team are focused on researching variables that induce or reduce knocking – such as the fuel effects (including the use of alcohols and other alternative fuels) and the way it is introduced into the engine – in context of the modern constraints imposed by small engines and turbo-chargers.

At the same time, he is also working on addressing another old problem: particulate emissions. Although they were a problem in the 1970s and 1980s in engines generally, spark ignition emissions were never much of a concern because they were so low. Today, however, scientists understand that they contain small particles that can cause significant health effects despite a low mass emission. To make matters worse, direct fuel injection, which is a method used to suppress knock, leaves a residual liquid fuel on the cylinder walls that is a major source of particulate emissions.

Cheng and his team are researching ways to minimize these startup emissions. The catalytic converter was a very effective invention that reduces tailpipe emissions by several orders of magnitude – but only after the catalyst reaches a certain temperature (referred to as "light-off"). For a typical trip, more than 90 percent of the emissions come from the first 10 or 20 seconds of operation while the catalyst is still warming up. Professor Cheng's team is working on engine strategies to reduce both the catalyst light-off time and the level of emissions during that time.

Professor Wai Cheng

The delicate domino effect manifests thusly: Increase the efficiency, lose power. Maintain power, introduce knocking. Fix knocking, decrease efficiency, increase emissions.

"It is always a balancing act.," says Professor Cheng. "The hope is that you can push on all fronts so that you get a better car and a better engine. Everything interacts."

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As challenging as it is to engineer within seemingly contradictory constraints, it is even more difficult deep underwater, where there are a whole slew of additional issues. MIT Sea Grant graduate students and researchers, led by Professor Chryssostomos Chryssostomidis, want to be able to command autonomous underwater vehicles (AUVs) from their office, sending them down into the ocean to collect data, predict hot spots, deploy sensors, identify environmental issues, and send back information to the on-land operator.

But underwater, refueling is currently impossible without bringing AUVs back to the surface, a costly and time-consuming process. And along with this limited energy storage also comes a limited radius for data collection – and therefore limited data.

"Imagine if we had 'gas stations' in the ocean," says Professor Chryssostomidis, "and I could take my vehicle there to refuel and then just continue on with my work. Right now, I'm forced to work within a radius. No matter how efficient I make my propulsion, I will always run out of juice at some point. There is no way I can invent the perpetual machine."

One way Professor Chryssostomidis is solving for that problem is by developing wireless underwater battery recharging. Professor Chathan Cooke, Principal Research Engineer at MIT Research Laboratory of Electronics, and Michael Defilippo, Research Engineer at MIT Sea Grant College Program, have conducted research that shows that a four-coil wireless recharging station using low series resistance minimizes energy losses within the circuit and maximizes the transferred power. The high resonant factor of this system can make up for a minor misalignment or large separation between the transmitter and receiver coils, enabling more than 90% efficiency of power transfer. Now, Michael Defilippo is working on how to overcome the effects of saltwater on the system.

"The related technology that goes very much into the heart of underwater autonomous transportation is that of electric cars," says Professor Chryssostomidis, "because electric cars could also recharge the same way. But trying to accomplish that same thing in the ocean is even more complicated because the salt environment causes a lot of parasitic effects."

The electric ship is another mode of transportation that Professor Chryssostomidis and his research group at MIT Sea Grant are working on. The power demands of a military ship are forever increasing, especially as power-heavy electrical modern weapons like lasers and ray guns are added. Meanwhile, the ships still need to move ahead at moderately high speeds, requiring power at the cube of the speed. Traditionally, ships have been powered mechanically, but Professor Chryssostomidis's idea is to make everything electrical.

"The power demands we have are just phenomenal," he says. "The Empire State Building requires 10 megawatts. The ship we are designing right now requires 100 megawatts. And it's similar for cruise ships as well. The ship is 150 meters long, so it becomes important that the power cables are precisely positioned."

Researcher Julie Chafant and Postdoctoral Associate Hessam Babaee are developing models to help optimize the design of the power cables using a variety of criteria, not least of which is the cooling system for all this power transfer, which generates an incredible amount of heat.

Professor Chryssostomos Chryssostomidis

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Many of us do appreciate our modes of transportation, as well as the engineering that enables them and perhaps because of that we expect so many things: quickness, reliability, comfort, exhilaration, safety. And yet we know we need to do this in a clean, responsible way that doesn't cause more damage to our environment. As it stands, our desires and our needs are in conflict, and it's up to us to find a way to reconcile them.

Wrinkling for Drag Reduction

Associate Professor Pedro Reis and his team have studied how wrinkling occurs on curved surfaces and found regular dimpled patterns similar to the topography on golf balls. Their rough surface allows them to fly farther compared to a ball with a smooth surface. This occurs because the dimpled pattern holds the airflow close to the ball for longer, thus reducing the size of the downstream turbulent wake that is the major source of aerodynamic drag. The advantage of the mechanism developed by Professor Reis's group is that the depth of the dimples of their morphable surfaces – and consequently the effect for reducing the aerodynamic drag – can be switched and tuned on-demand by reducing the pressure of inner cavities. This discovery could be used to reduce drag on automobiles at certain speeds and improve fuel efficiency.

2.013: Engineering Systems Design

Breakthrough Fuel Alternative May Allow Electric Vehicle Charging on Demand

by Alissa Mallinson

With the unstable cost of petroleum perpetually threatening to shoot upwards, and its potentially devastating effects on the environment waiting anxiously in the wings, many people are hopeful that electric vehicles will provide a cleaner, cheaper option to diesel- or gasoline-powered vehicles.

But there are still several problems that engineers are working to solve before this hope can become a reality, the most major of which is recharging. For many consumers, it's currently a deal-breaker: You have to recharge too often and it takes too long. And that's assuming that recharging stations exist at the necessary distances in the first place.

Undergraduate students in Professor Doug Hart's 2.013/2.014: Engineering Systems Design/Development capstone sequence are developing a promising solution: aluminum fuel.

"Relative to batteries," says student Nicholas Fine, "the amount of energy you can store with aluminum fuel relative to the amount of mass you can carry with you is significantly higher – which means your mission duration is significantly longer."

2.013/2.014 started back in 2011 in response to a challenge by MIT Lincoln Laboratories: Develop an energy source for underwater systems that can increase endurance tenfold.

The first year's class of students – who worked together under a CEO like a real-world design team – discovered that aluminum can react with seawater in a particular way to generate hydrogen gas. The resulting fuel is created by stripping the passivation layer from aluminum using a gallium-based eutectic, then reacting the aluminum with water to generate hydrogen gas and heat.

A student rendering of the aluminum-fueled electric vehicle being designed by undergraduate students in 2.013.

When this reaction occurs, student David D'Achiardi explains, about half the energy goes into the heat and half goes into the hydrogen. Since hydrogen can be converted to electricity at higher efficiencies than fossil fuels using a fuel cell, and since aluminum is nearly four times as energy dense as diesel, aluminum provides a very safe and efficient energy source without the need to store compressed hydrogen.

"But," says D'Achiardi, one of the class's CEOs, "if you are able to recover a portion of the heat energy, your fuel consumption is dramatically decreased, and that is where the fuel becomes extremely interesting as a very high-energy-density fuel."

The discovery, originally made by Jonathan Slocum when he was a student in 2.013, led to several progressive underwater autonomous vehicle (UAV) power systems in subsequent years of class that could monitor the oceans at depth for weeks at a time.

This year's 2.013 class is pursuing other possible applications for the technology, including electric cars. Students have organized themselves into four separate teams, each with their own CEO and their own potential application.

One team, led by Laura Jarin-Lipschitz, is designing a way to use the aluminum fuel to power a submersible power station that rises to the surface to recharge drones for search and rescue missions; another, led by Alexander Klein, is looking at how to automate the production of aluminum fuel and lower its cost; yet another is designing a portable emergency charging device for military situations, led by Fine.

The fourth team, led by D'Achiardi, is designing a way to extend the range of electric cars using an onboard aluminum-fueled generator.

(continued on page 20...)

Alumni Spotlight: John Wall, SB, SM ’75, ScD ’78, and Jennifer Rumsey, SM ’98

The Cummins Connection

by Alissa Mallinson

It’s 1991.

The first-ever web site was just published, gas costs an average of $1.12 per gallon, and Jennifer Rumsey, SM ’98, walks into the office of John Wall, SB, SM ‘75, ScD ‘78, then Vice President of Advanced Heavy Duty Engine Development at engine design and manufacturing company Cummins.

It was Rumsey’s first day as an intern, and she was 18 years old. Wall was – as he continued to be up until his retirement from Cummins just this past October – the MIT educational counselor for local high school students.

“My first exposure to engines happened when I worked for Cummins as an intern the summer before I went to college, and every summer while I was getting my undergraduate degree,” says Rumsey, who recently succeeded Wall as Cummin’s chief technical officer. “I was fascinated by complex systems, especially those that combined mechanical, electrical, and chemical engineering.”

Wall had been at the company for five years, a point in his career trajectory that connected back to 1972, when he had met Leroy Besone, SM ‘72, his new roommate and a master’s student in mechanical engineering at MIT.

“After he graduated, Leroy returned to his job at Chevron Research in San Francisco,” remembers Wall. “One day he called me up and asked if I wanted to be an intern there that summer. I said, ‘Give me about 2 seconds to think about this’ and then went out to work in the engine lab at Chevron for two summers. It was the first time that I had been working around engines and really getting into the research side of things, looking at engine lubrication and friction.”

Wall earned bachelor’s and master’s degrees simultaneously from MechE’s Honors Program, then joined the Sloan Automotive Lab under Professor John Heywood for his ScD – as a Cummins Fellow. It was the 1970s, and John Heywood was in the middle of researching the mechanics of engine pollution (read more about Professor Heywood on page 14). The EPA had just been formed, and many people were interested in solving this newly identified emissions problem.

Wall earned his ScD in 1978, then went back to work at Chevron.

“With that group,” he says, “we discovered the effect of fuel sulfur on diesel particulate emissions. It really helped us begin to build that bridge between engine technology, fuel technology, and atmospheric particulate emissions.”

In 1986, he got a call from Cummins.

“At Cummins, I got the opportunity to work on emissions from an engine technology standpoint, and that’s pretty much what I’ve been doing ever since. The fuel sulfur content turned out to be a big deal. In early emissions meetings with the EPA and fuel companies to negotiate future diesel fuel sulfur limits, I had the funny situation where I had done the research at Chevron, and the data that the oil companies were bringing in to talk to us engine companies about was actually my data.”

Wall’s first major challenge was controlling NOx emissions by reducing

(continued on page 13...)

Alumni Spotlight: Thomas Ober, SM '10, PhD '13

The Fluid Dynamics of Motorsports

by Alissa Mallinson

Thomas Ober, SM '10, PhD '13, was a post-doctoral associate at Harvard University when the application of Gene Haas, founder of Haas Automation and co-owner of the Stewart-Haas NASCAR racing team, was accepted into the Formula 1 championship with his newly created Haas Formula 1 racing team.

A motorsports fan in high school and a member of the FSAE team at Cornell University, Ober has always been interested in racing. In fact, during his time as a PhD candidate with Professor Gareth McKinley's group, Ober had interned at Lotus Renault GP, another Formula 1 team in the United Kingdom, working in their aerodynamics department. So when he came across a job opening for a computational fluid dynamics engineer at Haas Formula 1 during his job search, it quickly rose to the top of his list.

He got the job.

As a computational fluid dynamics engineer on a racing team, Ober combines his physical knowledge with computer software to analyze the flow field around the race car to improve downforce and reduce drag. The Reynolds numbers he's working with now are much higher than when he was studying viscous fluid flows in MechE's Hatsopoulos Microfluidics Lab, but, he says, "The overarching fluid mechanics concepts I learned throughout my master's and PhD coursework relates very well to what I'm doing now, even though it's not directly related to what I was doing with my PhD."

In a lot of ways, says Ober, the startup atmosphere of the Haas Formula 1 racing team is very similar to working in a research group: It's a small, passionate team working together closely to solve a particular set of problems.

"In a research group, everyone is an expert in their own sub-area," says Ober, "and you get the chance to learn from everyone else as a result. Because the Haas F1 team is a startup, I'm getting that same type of experience here. I work in a fairly small group of eight or 10 engineers. We are all working on our own small projects, but at the end of the day, we're using the same types of tools and helping each other develop new solutions and learn more about the performance of our car."

Since Haas Formula 1 is a brand new team, they haven't yet built any cars and in fact aren't even officially racing for the first time until later in 2016. It is also the only United States-based racing team in Formula 1. All of which provides Ober with a pretty unique opportunity.

"Every team makes a new car every year, but for us it's different, because it's all so brand new. We haven't built a car at all yet. It's going to be really neat to see this car roll out, representing not just Haas Automation but also on many levels the

United States as a global player in the motorsports field."

Designing a race car, he says, is at once both an innovative and iterative process, one that requires engineers to incrementally improve their car each race to keep up with their competitors but also to outfox them in a groundbreaking way to speed ahead.

"Right now, as we develop our first car," says Ober, "we've really been looking at all areas of possibility because we're designing from scratch. Historically, as a season moves on and you start to see all the designs of the other teams, you notice the areas of the car that teams are focusing on and try to keep up.

"On the other hand," he continues, "if you want to get ahead of the grid, you have to innovate. I think a lot of that is organic. You try a few things that you think are going to work and find it doesn't do at all what you wanted – but you discover something new that might have an application for another part of the car. So you have a direction, but a lot of the big successes you have are kind of by accident. Quite a bit like research, in a way."

In terms of timing, though, race car engineering is a far cry from research. Between each race, the engineering teams have to conduct analysis on previous races and develop, in a few weeks' time, an incremental technical advancement to improve the car for the next race. They don't have time to explore all the possibilities as thoroughly as they'd like and yet have to uncover the best possible options in the shortest amount of time.

"We are in a much more short-term-application, goal-driven kind of environment than a typical academic setting, where you could have a project that goes on for many years and ultimately leads to a single publication," says Ober.

"In my new environment, the time frames are about two weeks to a month, at most. And then at that point, you have to move on to the next thing."

Personally, Ober has no intentions of moving onto the next thing any time soon. He's quite content working his dream job.

(Cummins, continued from page 11...)

the temperature of combustion, and the solution he and his team developed was a significant innovation. Later, in the early 1990s, he and his team applied new electronic fuel systems that allowed unprecedented flexibility on system design, as well as computer models that provided a better view of the fluid mechanics going on inside the engine.

It was around that time that Wall, in his role as MIT educational counselor, first saw Rumsey's technical capability and interest.

"It has been interesting to watch Jennifer's career develop," he says. "I am very excited to have someone coming into this role of CTO who is so experienced with engines and exhaust aftertreatment systems but also so knowledgeable about new technologies that will help lead to a cleaner environment and new sources of energy. Someone who is as passionate about people and team development as she is about technology development."

After receiving her bachelor's degree in mechanical engineering from Purdue University and her master's degree from MIT MechE, Rumsey went to work in Cambridge, Mass., for Nuvera, a company that specializes in fuel processing and fuel cells. In 2000, she moved to Cummins, working in a variety of engineering roles across Cummins' engine and components business units, including advanced technology development, new product development, and current product engineering.

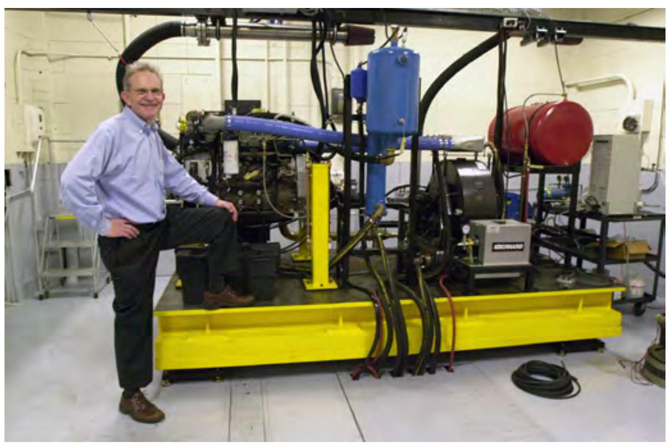
"I found a passion for research and development as an intern at Cummins," says Rumsey. "Here, I can see how my work is going to matter for the environment and for our customers. I like solving problems, but I really like developing solutions that will have an immediate positive and large-scale impact. I also really enjoy upstream research and working on projects that demonstrate a technology's impact.

"John Wall had a major role in transforming Cummins products and emission technology in our industry," she continues. "I intend to build on his legacy and develop that next generation of breakthrough innovations. We have a big focus on creating an environment where our global technical organization can work together to solve some of the world's biggest challenges."

Lifetime Achievement: Professor John Heywood

From Identifying the Source of Emissions to Analyzing the Future of Automotive Engineering

by Alissa Mallinson



Professor John Heywood is one of the most recognizable and highly regarded names in internal combustion engines. His work with Professor James Fay and Professor James Keck in the MIT Sloan Automotive Laboratory in the 1960s and 1970s led to seminal contributions to the science of automotive and aircraft engines – and in particular to the understanding of emissions. He literally wrote the book on internal combustion engines, one that continues to be referred to today.

Following in the footsteps of his father, a mechanical engineer, and his mother, a chemist and metallurgist, Professor Heywood began his career at Cambridge University, earning a BA in mechanical engineering.

“I grew up in an academic family,” says the Englishman. “I did well in math and science, and I liked the idea of being practical. My dad did a lot of projects at home, and in fact he built early solar-water-heaters way back in the 1940s.

“I wasn’t really a tinkerer, but I loved hands-on projects and understanding things.”

Professor Heywood also enjoyed research and, after graduating in 1960, decided to move to Cambridge, Mass., to attend MIT for a master’s degree, and then a PhD, in mechanical engineering.

“I loved MIT,” he says. “People’s investment in what they did here and the intensity of their commitment to doing useful things was very apparent. Coming from a more restrained English culture, it was so refreshing.”

It was around that time that Professor Heywood met his future wife Peggy, who attended Radcliffe College to study history. The two eventually married and moved to England, where Professor Heywood worked on plasma dynamics for the Central Electricity Generation Board, looking at new ways to generate electricity. But by 1968, they were back in Cambridge, Mass.

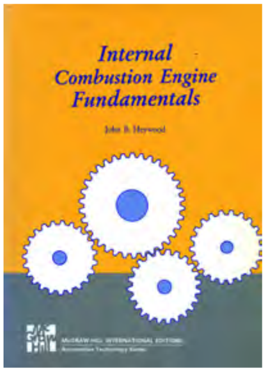
Professor Heywood was offered a job as an assistant professor in the Sloan Automotive Lab, soon after Arie Jan Haagen-Smit had proven that automotive exhaust was a major contributor to Los Angeles smog, though no one yet knew how these emissions were produced.

“It was right at the point when we got involved in the question of why cars emit these significant amounts of air pollutants. By that time, people were convinced that air pollution from automobiles was indeed a major problem that impacted their health, and they really cared about it.”

The oxides of nitrogen that form inside the flame in the engine and the hydrocarbons that come out of the exhaust are the two ingredients that reacted in the atmosphere to form this smog, he explains. At the time, automobiles were the source of 50% to 60% of these emissions.

“Nitrogen was expected to go through combustion as a molecule (N_2) and stay that way all the way through the process, even as it comes out of the exhaust,” he says, “and most of it did.

"But we discovered that some of it gets oxidized. So in those early days, we laid out the mechanism by which we got these NO molecules, and also the reasons why all of the fuel doesn't burn inside the cylinder. There proved to be a pretty complicated set of reasons for the hydrocarbon emissions, and I think that's where we made some important contributions."



By 1972, Professor Heywood was the director of the MIT Sloan Automotive Lab, and the group's research focus expanded to include a wider range of problems that arise out of the engine combustion process, including engine operation, fuel behavior, and engine performance and efficiency. He was joined by new young colleagues who today are faculty members and senior research scientists in the Lab, such as Professor Wai Cheng, Dr. Victor Wong, and Dr. Tian Tian.

"We really liked what we were doing, and it was very stimulating, because there were fresh problems that hadn't been solved yet," says Professor Heywood. "We discovered quite a lot and eventually were recognized as a major engines and fuels research lab in the United States."

As part of this epicenter of engine research at such an important time of discovery, Professor Heywood gathered up a considerable amount of new fundamental knowledge that had yet to be codified. In fact, there hadn't been a new textbook on internal combustion engines since C. Fayette Taylor's two-volume text *Internal Combustion Engine* in 1961. So Professor Heywood decided to write one, and in 1988 he published *Internal Combustion Engine Fundamentals*, which has sold approximately 130,000 copies and is widely considered a field-defining publication.

"It was time," says Professor Heywood about his decision to write an updated book on engines. "There was a lot of new knowledge and material – such as how air pollutants form inside engines and how to use computer simulations for analysis – but the book also covered engines more broadly. We had learned a lot at the engineering-science level, and I felt that it was worth the time and effort to organize these new materials and make them accessible."

(Professor Heywood has recently completed a major revision of his text to bring it up to date.)

After spending a good part of two decades helping to develop fundamental solutions to the emissions problem, Professor Heywood began to broaden his purview even further to include a systems-level perspective. He started to ask himself what the future of automotive engineering would look like.

"I asked myself: 'How much better can we make engines? What else can we do to match the fuel with the engine? What fuels will we have available when we want to seriously start reducing greenhouse emissions? How quickly can new technologies be developed and sold? What's going to happen to passenger cars 30 years from now?'"

In 2000, Professor Heywood and a team of colleagues and students answered some of these questions with the report "On the Road To 2020." Then in 2008, his team published another report titled "On the Road To 2035," and he has just published a third report called "On the Road Toward 2050." For each report, his team has developed methodologies for scenario analysis and identified rates of change for vehicle technology and use. He has also made predictions about what problems – such as fuel consumption, greenhouse gases, or engine efficiency – will need to be addressed and possible solutions that will be available to meet these demands.

One of his new predictions is that we will see a steady increase in sales for hybrids as their prices decrease. According to Professor Heywood, they can achieve significant improvements in their fuel economy through regenerative breaking – which is when the kinetic energy of breaking is used to recharge the batteries – and as these improvements occur, the price will drop.

Faculty Research: Professor Michael Triantyfallou

Artificial Whisker Reveals Source of Harbor Seal's Uncanny Prey-Sensing Ability

by Jennifer Chu, MIT News Office

Harbor seals have an amazingly fine-tuned sense for detecting prey, as marine biologists have noted for years. Even when blindfolded, trained seals are able to chase the precise path of an object that swam by 30 seconds earlier. Scientists have suspected that the seal's laser-like tracking ability is due in part to its antennae-like whiskers.

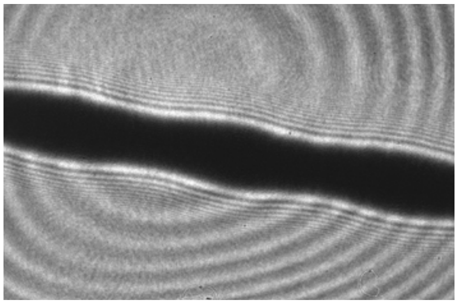
Now Professor Michael Triantyfallou and his team have fabricated and tested a large-scale model of a harbor seal's whisker, and identified a mechanism that may explain how seals sense their environment and track their prey.

The team found that a seal's whiskers serve two main functions in sensing the environment: first remaining still in response to a seal's own movements through the water, and then oscillating in a "slaloming" motion in response to the turbulence left by a moving object.

In their experiments, the researchers observed that once the fabricated whisker enters the wake left by a passing object, it starts vibrating at the same frequency as the wake's passing vortices. Careful visualizations show that the whisker "slaloms" among the vortices, like a skier zigzagging between flags.

The research shows that this slaloming allows the whisker to extract energy from the wake, causing it to vibrate at the precise frequency of the wake – a mechanism that may give seals a clue to an object's path, its size, and even its shape.

Professor Triantafyllou, the William I. Koch Professor, says that biologically inspired sensors, modeled after



the harbor seal's whiskers, may aid underwater vehicles in tracking schools of fish, as well as sources of pollution – a goal that he is currently working toward.

He and former graduate student Heather Beem, whose PhD thesis formed the basis of the work, have published their results in the *Journal of Fluid Mechanics*.

A "Quieting Effect"

The harbor seal's whiskers are unique in shape: Even to the naked eye, an individual whisker appears not uniform, but wavy. Under a magnifying glass, the pattern is more intricate, with an elliptical cross-section that varies in size along its span.

"It's marvelous to see this intricate pattern; it's not just a straight antenna – it's a perfect sinusoid," Triantafyllou says.

He and Beem proposed that a whisker's curiously geometric morphology may play a part in a seal's exceptional sensitivity.

Using 3-D printing techniques, Beem reproduced the seal's wavy morphology at a much larger scale, in order to accurately measure its response to various wakes. She tested the whisker's vibration properties in a 30-meter-long tank of water with a moving track suspended above the water.

In her experiments, Beem first attached the artificial whisker to the moving track, allowing the whisker to freely vibrate in the water as it moved down the length of the tank.

While most long, thin rods tend to create large vortices, or eddies, as they move through water, forming a pattern that's well known in fluid mechanics, Beem found that the wavy pattern of the whisker's geometry created much weaker vortices, enabling the whisker to move silently, with very little vibration, through the water.

(continued on page 20...)

Find out more >

Read the full MIT News article: http://bit.ly/1JU2v1j

! Watch a video about Professor Triantyfallou's research: http://bit.ly/1KSDOwT

Faculty Research: Associate Professor Xuanhe Zhao

New "Water Adhesive" is Tougher than Natural Adhesives

by Jennifer Chu, MIT News Office

Nature has developed innovative ways to solve a sticky challenge: Mussels and barnacles stubbornly glue themselves to cliff faces, ship hulls, and even the skin of whales. Likewise, tendons and cartilage stick to bone with incredible robustness, giving animals flexibility and agility.

The natural adhesive in all these cases is hydrogel – a sticky mix of water and gummy material that creates a tough and durable bond.

Now Associate Professor Xuanhe Zhao and his team have developed a method to make synthetic, sticky hydrogel that is more than 90 percent water. The hydrogel, which is a transparent, rubber-like material, can adhere to surfaces such as glass, silicon, ceramics, aluminum, and titanium with a toughness comparable to the bond between tendon and cartilage on bone.

In experiments to demonstrate its robustness, the researchers applied a small square of their hydrogel between two plates of glass, from which they then suspended a 55-pound weight. They also glued the hydrogel to a silicon wafer, which they then smashed with a hammer. While the silicon shattered, its pieces remained stuck in place.

Such durability makes the hydrogel an ideal candidate for protective coatings on underwater surfaces such as boats and submarines. As the hydrogel is biocompatible, it may also be suitable for a range of health-related

Find out more >

Read the full MIT News article:
http://bit.ly/1HulAWd

applications, such as biomedical coatings for catheters and sensors implanted in the body.

"You can imagine new applications with this very robust, adhesive, yet soft material," says Zhao, the Robert N. Noyce Career Development Associate Professor. For example, Zhao's group is currently exploring uses for the hydrogel in soft robotics, where the material may serve as synthetic tendon and cartilage, or in flexible joints.

"It's a pretty tough and adhesive gel that's mostly water," Hyunwoo Yuk, a graduate student in mechanical engineering and the lead author of a paper on the work, says. "Basically, it's tough, bonding water."

Zhao and his students recently published their results in the journal *Nature Materials*.

A tough, flexible hydrogel that bonds strongly requires two characteristics, Zhao found: energy dissipation and chemical anchorage. A hydrogel that dissipates energy is essentially able to stretch significantly without retaining all the energy used to stretch it. A chemically anchored hydrogel adheres to a surface by covalently bonding its polymer network to that surface.

"Chemical anchorage plus bulk dissipation leads to tough bonding," Zhao says. "Tendons and cartilage harness these, so we're really learning this principle from nature."

In developing the hydrogel, Yuk mixed a solution of water with a dissipative ingredient to create a stretchy, rubbery material. He then placed the hydrogel atop various surfaces, such as aluminum, ceramic, glass, and titanium, each modified with functional silanes – molecules that created chemical links between each surface and its hydrogel.

The researchers then tested the hydrogel's bond using a standard peeling test, in which they measured the force required to peel the hydrogel from a surface. On average, they found the hydrogel's bond was as tough as 1,000 joules per square meter – about the same level as tendon and cartilage on bone.

Zhao's group compared these results with existing hydrogels, as well as elastomers, tissue adhesives, and nanoparticle gels, and found that the new hydrogel adhesive has both higher water content and a much stronger bonding ability.

"We basically broke a world record in bonding toughness of hydrogels, and it was inspired by nature," Yuk says.

Sticky Robotics

In addition to testing the hydrogel's toughness with a hammer and a weight, Zhao and his colleagues explored its use in robotic joints, using small spheres of hydrogel to connect short pipes to simulate robotic limbs.

"Hydrogels can act as actuators," Zhao says. "Instead of using conventional hinges, you can use this soft material with strong bonding to rigid materials, and it can give a robot many more degrees of freedom."

The researchers also looked into its application as an electrical conductor. Yuk and other students added salts to a hydrogel sample and attached the hydrogel to two metal plates connected via electrodes to an LED light. They found that the hydrogel enabled the flow of salt ions within the electrical loop, ultimately lighting up the LED.

"We create extremely robust interfaces for hydrogel-metal hybrid conductors," Yuk adds.

Zhao's group is currently most interested in exploring the hydrogel's use in soft robotics, as well as in bioelectronics.

"Since the hydrogel contains more than 90 percent water, the bonding may be regarded as a water adhesive, which is tougher than natural glues, such as in barnacles and mussels, and bio-inspired underwater glues," Zhao says. "The work has significant implications in understanding bio-adhesion, as well as practical applications such as in hydrogel coatings, biomedical devices, tissue engineering, water treatment, and underwater glues."

This research was supported in part by the Office of Naval Research and the National Science Foundation.

Student Spotlight: Yamile Pariente, SB '16

When You Wish Upon a Car

By Alissa Mallinson

Senior Yamile Pariente first arrived at Porsche for her internship the week of June 8, 2015.

She walked into a building that was practically empty, and there was an almost eerie silence.

Her supervisor wasn't there to greet her, and she was being introduced to her new position by another engineer who oversees engine design and construction.

Everyone was at the 83rd 24-Hours at Le Mans race in Le Mans, France. It was the second time Porsche had competed in the famous 24-hour endurance race since 1998, which was also the last time they had won.

"Porsche won the Le Mans that weekend only a year after a 17-year hiatus," Pariente remembers, still in awe of her team's win. "It was incredible. Everyone was so happy. They came back the next week with the car and we had a party. Everyone was there, celebrating and taking pictures with the trophy and the car. That was my first week at Porsche."

Not too shabby for an undergraduate who never dreamed she'd be an intern at Porsche in the first place, never mind in the motorsports division.

When coordinators at MISTI (MIT International Science and Technology Initiatives), which organized her internship, asked her what she'd want to do at Porsche, she told them motorsports and powertrain engineering, because, she says, "I assumed they'd say no to my request, so I figured I might as well aim high. I never thought it'd be considered seriously."

But a couple of days later, Alexander Hitzinger, technical director of Porsche's 919 Hybrid racing team, emailed her directly to discuss the details of her upcoming internship. Pariente, who won second place in last year's 2.007 robot competition, packed up her bags without a moment's hesitation, took a leave of absence from MIT, and flew to Germany. "It wasn't even a question," she says. "This was my dream job."

The oldest of two daughters, Pariente's love for cars began as a young child – a passion passed down to her from her father, a sports car fanatic, according to Pariente.

"I was very good at math and science, and I loved art, but I wasn't sure what I wanted to do," she says. "I thought about going to art school for transportation design, but I really wanted to work with cars, so I chose to become a mechanical engineer.

"Of all the 'manly' hobbies my father tried to instill in me, cars is the one that stuck," she jokes.

But being one of only two women engineers on Porsche's motorsports team doesn't bother Pariente. "People are often shocked when they meet me for the first time," she says. "On paper, my name doesn't obviously reflect a specific gender, and people often aren't expecting me. I've gotten some pretty hilarious reactions from people when I tell them I go to MIT and I'm a mechanical engineer working at Porsche for their racing team. But being a woman in motorsports has never hindered me, and the engineers at Porsche are very nice and inclusive."

At Porsche, where she worked for six months from June to November, Pariente focused on engineering development for race cars. One of her first projects was to analyze telemetry data from previous races, and her main project was to run a dynamometer test on a single-cylinder engine and develop combustion models and optimization techniques.

"It's been a great learning experience," she says. "Usually only practicing

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(...Pariente, continued from previous page)

engineers get to do that. I got the chance to see a lot of new ideas that were being tested."

Pariente also took a lead role in connecting Porsche to MIT faculty and students. She helped to plan a Porsche visit to MIT in September in which Hitzinger gave a lecture to a packed room as part of MechE's Inspiring Engineering Lecture Series. He spoke about the Porsche racing team and their 919 Hybrid, the winning car in this year's Le Mans. Pariente and Hitzinger also met with several faculty members whose work is connected to automotive engineering.

Pariente will return to MIT in the spring semester to finish up her senior year in mechanical engineering, and she hopes to return to Porsche after graduation in 2017. I didn't have to ask her if it was all worth it.

(...Whiskers, continued from page 16)

The whisker's morphology, the researchers found, may help the seal block out its own disturbance as it moves through water.

"It's like having the ability to stick your head out of a car window, and have there be no noise, so that your ears don't ring: It's a quieting effect," Triantafyllou says.

A Whisker Sensor

To test how a whisker reacts to external stimuli, Beem conducted a second set of experiments in which she attached a large, long circular cylinder ahead of the whisker. As the cylinder moved down the tank, it created large eddies, similar to the patterns generated by a passing fish.

In response, she found that the whisker, when following the cylinder, vibrated significantly, moving in a slaloming pattern among the wake vortices. As she varied the speed of the moving track, the whisker quickly adapted, vibrating at precisely the frequency of the cylinder's changing vortices.

"The geometry of the whisker allows for this phenomenon of being able to move very silently through the water if the water's calm, and extract energy from the fish's wake in order to vibrate a lot," Beem says. "Now we have an idea of how it's possible that seals can find fish that they can't see."

Triantafyllou says artificial whiskers may be useful as low-power sensors for underwater vehicles.

"We already have a few sensors that can detect velocity, but now that we know better what they can do, we can use them to track sources of pollution and the like," Triantafyllou says. "By having several whiskers on a vehicle, like the seal, you can, for example, detect a faraway plume, and track it all the way to the end."

This research was supported in part by the Office of Naval Research, the Singapore-MIT Alliance for Research and Technology, and the MIT Sea Grant program.

(...2.013, continued from page 10)

"We want to show that this technology could be comparable, competitive, or possibly even surpass what a gas or diesel vehicle would look like in terms of cost, volume of the fuel, and mass of the fuel," says D'Achiardi. "These are all metrics we are using to shift and propose designs."

His team is working to design a heat-recovery system to take advantage of the heat energy generated, while also trying to devise a way to draw power from the fuel into the battery very quickly, so that electric vehicles can get the same range as fossil-fueled vehicles – all without modifying current electric vehicles.

"It's tricky," he says, "because we are trying to generate power *inside* the vehicle, using this clean technology."

Many of the students – some of whom are taking 2.013 for the second time now – plan to continue on with the development of their designs in the spring semester with sister class 2.014.

Student Spotlight: Carrington Motley, SB '16

Sand, Sand Everywhere

By Catherine Curro Caruso, MIT News Correspondent

Senior Carrington Motley spends a lot of his time at MIT surrounded by sand.

"Yeah, sand is everywhere," he admits with a laugh. "It was already in all of my clothes, and now it's in my backpack."

Motley is captain of MIT's men's track and field team – and when he isn't launching himself into a sand pit during triple-jump practice, he conducts research on how tires move through sand.

Finding a Balance

Motley didn't always know he would end up at MIT, nor did he expect to enter his senior year less than a foot away from MIT's varsity triple-jump record. As a sophomore at Sewickley Academy in Pennsylvania, after a long basketball season, a teammate of his persuaded him to try track and field. Motley developed into a competitive triple jumper, and when he began to look at colleges, he knew he needed to find a place where he could excel as both a student and an athlete without sacrificing either. A visit to MIT made it clear that this was a place where his interests could coexist.

"People are on the team, they're in engineering, they're in fraternities, they are in running clubs, they are doing everything," he explains. "And there is no compromise to be made by being an athlete and studying STEM [science, technology, engineering, and mathematics]."

By the end of the fall of his senior year in high school, MIT was at the top of Motley's list.

Into the Lab

Once on campus, Motley joined the research group of Ken Kamrin after taking an introductory mechanics course taught by the assistant professor of mechanical engineering. His work in the lab involves testing a model that's based on linear superposition and designed to optimize the mechanics of tires moving through sand. The goal is to design, for example, tires that achieve maximum velocity output for minimum power input; Motley describes far-reaching applications that range from dune buggies or rovers for use on a beach, or in space, to military vehicles that drive in the desert.

Mars or moon rovers that drive on a granular surface present a unique challenge: "They've had a lot of issues with tires getting stuck, or a robot not being able to move because it's stuck in sand," Motley says. "You can't do anything and you just have to wait because it's really far away."

Motley works with Jake Slonaker, SB '15, a graduate student in Kamrin's lab who has used the MATLAB computing environment to develop a computer model that can predict the forces that will act on a tire moving through sand. This simplistic model runs simulations in order to optimize the shape of a tire tread to drive in sand, which is much more efficient and generalizable than many of the models currently used by the military and NASA.

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(...Motley, continued from previous page)

"Right now the process for determining what wheel to use is to try wheels in sand and figure out what works," Motley says. "Our model allows you to build and test a bunch of different wheels on your computer and figure out the one that's best." Motley first ran verification tests to ensure that the real-world results match up with the model.

Motley conducts his tests in a basement lab that contains a pair of 3-foot-by-8-foot glass containers filled with 2 feet of sand. Each container is outfitted with a motor and a chassis on a system of rods, which allows a tire to move forward and backward, and up and down through the sand. The setup has sensors that record the torque and velocity of a tire as it travels, which can then be compared to the results of the model. Motley uses computer-assisted design (CAD) software to design the tires, and 3-D prints them in the lab.

Motley is currently completing tests on tires of different sizes; the results of the physical tests have been very close to the model's predictions. The next step will likely involve testing tires of different shapes.

Motley particularly enjoys the technical nature of his research at MIT: "Here you have to think a little bit more, because you have no previous attempts to guide your way," he says. After graduating from the Institute this June, Motley expects to pursue an advanced degree.

"I feel that my time at MIT has made me aware of: One, how much I know, but two, that I really don't know anything," he says. "There's just so much more that you could learn, and I think that knowledge is super powerful."

Giving Back

When Motley isn't shaking sand out of his possessions, he is involved in a number of other activities at MIT. As a freshman he participated in the Freshman Urban Program, a pre-orientation program that focuses on service in the surrounding community in Boston and Cambridge. The program also incorporates discussions of sexual and gender identity, privilege, life after college, and how to remain involved in service.

"It's just a really nice period, before coming to school, to reflect on who you are and what you believe in and how that interfaces with other people's beliefs," Motley says.

Motley enjoyed the program so much that he returned as a counselor for the following two years; last year, he served as co-coordinator with classmate Annie Kuan. He and Kuan were given free rein in their decisions about the program. "Every last detail was left entirely up to us," he says.

Pushing the Limits

Motley currently holds MIT's freshman indoor triple-jump record and was recently named to the NCAA Academic All-American team. He credits his athletic success to the support of those around him, particularly the dedicated MIT coaching staff. But he says he owes his success in the classroom to the love and unwavering support of his family.

That said, Motley is not quite satisfied yet, pointing out a scoreboard with names on the indoor track in MIT's Johnson Athletic Center: "When you get a [varsity] record, you get your name up there, and everyone gets to look at it every day of the year," he says. "Every time I see it, it's motivation to find a little bit extra somewhere to hopefully get my name up there."

MechE Snapshots

From top to bottom: 2.008 Design and Manufacturing II Yo-Yo Expo; 2.74 Bio-Inspired Robotics Robotic Zoo Festival; 2.76 Global Engineering Final Presentations; Professor John Leonard's lecture on the Science of Deflategate.

New Faculty

We are pleased to introduce five new faculty members to the Department: Assistant Professor Irmgard Bischofberger, Assistant Professor Betar Gallant, Assistant Professor Ming Guo, Assistant Professor Jeewhan Kim, and Assistant Professor Ellen Roche.

Irmgard Bischofberger, Assistant Professor

Irmgard Bischofberger received her BSc and MSc in 2006 and her PhD in 2011, all in physics, from the University of Fribourg, Switzerland. She worked as a postdoctoral researcher at the University of Chicago in the research group of Sidney Nagel. She is the recipient of a Kadanoff-Rice Postdoctoral Fellowship at the University of Chicago and a Swiss National Science Foundation Postdoctoral Fellowship. Irmgard works in the area of fluid dynamics and soft matter physics, with a focus on formation of patterns from instabilities in fluid and technological systems. In her graduate work, she studied the phase behavior and solvation properties of thermosensitive polymers. As a postdoc working for Sidney Nagel at the University of Chicago, she discovered proportional growth – a new growth pattern that was not observed in physical systems, despite its common occurrence in biological systems. Irmgard is also an enthusiastic champion for science education.

Betar Gallant, Assistant Professor

Betar Gallant received her SB, SM, and PhD degrees in 2008, 2010, and 2013, respectively, from the MIT Department of Mechanical Engineering, where she conducted her PhD research in the Electrochemical Energy Lab with Professor Yang Shao-Horn. She worked as a Kavli Nanoscience Institute Postdoctoral Fellow at the California Institute of Technology. Betar has performed research on a range of electrochemical energy technologies and materials, worked at the US Department of Energy on energy program development, and was involved in a number of entrepreneurial energy-related activities while at MIT, including serving as a managing director of the MIT Clean Energy Prize. Her research interests include using electrochemistry as a tool to manipulate energy conversion pathways, explore spaces for new materials synthesis, and enable fabrication of efficient and scalable devices.

Ming Guo, Assistant Professor

Ming Guo received his BE and ME degrees in 2004 and 2007, respectively, in engineering mechanics from Tsinghua University, and an MS and PhD in 2012 and 2014 from Harvard University. His PhD research investigated the mechanical and dynamic properties of living mammalian cells, with an emphasis on intracellular mechanics and forces, the mechanics of cytoskeletal polymers, the equation of state of living cells, and the effect of cell volume and intracellular crowding on cell mechanics and gene expression. Through this research, Ming discovered that there is a direct relationship between cell stiffness and volume; by varying the cell volume through a number of different techniques, Ming showed that the volume of cells is a much better predictor of their stiffness than any other cue. He developed a method to measure the mechanical properties and overall motor forces inside living cells by monitoring the fluctuation of microbeads inside the cells and delineating the timescales under which the contribution of active cellular processes could be distinguished from passive mechanical properties.

Jeewhan Kim, Assistant Professor

Jeehwan Kim received his BS in material science from Hongik University in 1997, his MS in material science from Seoul National University in 1999, and his PhD in material science from UCLA in 2008. Since 2008 he has been a research staff member at IBM T.J. Watson Research Center in Yorktown Heights, New York, conducting research in photovoltaics, 2D materials, graphene, and advanced CMOS devices. Jeehwan has been named a master inventor at IBM for his prolific creativity, filing more than 100 patents in five years. He has made several breakthrough contributions, including a demonstration of the ability to peel large-area single-crystal graphene grown from a SiC substrate, enabling reuse of the expensive substrate; the successful growth of GaN on graphene with 25% lattice mismatch, demonstrating that GaN films grown from the process function well as LEDs, and pointing to a new principle for growing common semiconductors for flexible electronics; and achieving high efficiency in Si/polymer tandem solar cells and 3D solar cells.

Ellen Roche, Assistant Professor

Ellen Roche received her BE in biomedical engineering from the National University of Ireland Galway in 2004 and her MSc in bioengineering from Trinity College Dublin in 2011. In between, Ellen also spent five years working on medical device design in industry for Mednova Ltd., Abbot Vascular, and Medtronic. She recently earned her PhD in bioengineering from Harvard University. At Harvard, Ellen performed research on the design, modeling, experimentation, and pre-clinical evaluation of a novel soft robotic device that helps patients with heart failure. Her invention, called the Harvard Ventricular Assist Device (HarVAD), is a soft-robotic sleeve device that goes around the heart, squeezing and twisting it to maintain the heart's functionality. The device has no contact with blood, dramatically reducing the risk of infection or blood clotting as compared to current devices. Additionally, she worked on the incorporation of biomaterials into the device to deliver regenerative therapy to help the heart to heal.

Department News

Second Annual Research Exhibition Brings Community Together and Recognizes Graduate Students

On a hot fall day this past September, MechE students and post-docs carefully hung up posters along the perimeter of Walker Memorial's main room. The first presentation session for the second annual Mechanical Engineering Research Exhibition (MERE) was about to begin. The event, which was held for the first time last fall, is organized by the Graduate Association for Mechanical Engineers (GAME) and sponsored by the Department of Mechanical Engineering. Its purpose is to offer the entire MechE community a chance to learn about current research in the department and network with alumni, faculty, students, and staff. Just as importantly, it also gives graduate students a chance to practice communicating their research to various audiences and receive feedback on their presentation. This year, more than 80 MechE graduate students presented their research, and more than 450 members of the MechE community attended the event. MechE alum Eric Wilhelm, SB '99, MS '01, PhD '04, founder of the popular company Instructables, an online community where makers can share their projects and connect with each other, gave the keynote address. Jerry Wang, a graduate student working in Professor Nicolas Hadjiconstantinou's Nanoscale Transport and Multiscale Simulation Group, won the highest honor, the Da Vinci Award for Outstanding Presentation for presentation of his work on nanofluidics.

First Joint Entrepreneurship and Innovation Mini-Hackathon with Sloan School MBA Students

This past October, the Department of Mechanical Engineering partnered with the MIT Sloan School of Management to host a mini hackathon around entrepreneurship. Six engineering faculty from a range of departments presented an innovative project from their lab and challenged students to develop entrepreneurial ideas for each technology. Approximately 105 first-year MBA students on the Entrepreneurship and Innovation track and 40 students and post-docs from the School of Engineering split into 14 mixed groups to discuss the projects and brainstorm commercial applications. When the 90-minute brainstorming sessions ended, each group presented a one-minute pitch of their idea. Professor Douglas Hart, who organized the joint event with Sloan Professor Edward Roberts, presented his lab's work on an aluminum fuel alternative. Assistant Professor Cullen Buie presented his work on the development of new bacterial biofactories. Professor Peko Hosoi presented her work on squishy robots. Professor Bruce Tidor, of the Department of Biological Engineering and the Department of Electrical Engineering and Computer Science, presented his work on target identification in biochemical pathways. Associate Professor Evelyn Wang presented her work with Department Head Gang Chen on a solar thermal aerogel receiver. Assistant Professor Amos Winter presented his work on single cylinder turbocharged engines. "It takes many different skill sets to come together for successful entrepreneurship and innovation," says Professor Hart about the collaborative nature of the event.

Alum Hock Tan Gives Professorship; Professor Seth Lloyd Appointed Inaugural Chairholder

The Department of Mechanical Engineering is pleased to announce a generous gift of $4 million for the endowment of a new full professorship from alumnus Hock E. Tan, '75, SM '75. The new professorship will be named in honor of Ralph E. and Eloise F. Cross Professor Emeritus Nam P. Suh, '59, SM '61, a celebrated mechanical engineer and leader. Suh served as

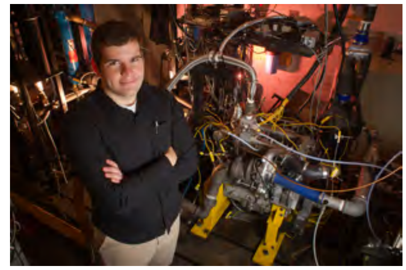
head of the department from 1991 to 2001, and founded the Laboratory of Manufacturing and Productivity (LMP) and the MIT-Industry Polymer Processing Program. He was also an influential and supportive mentor to Tan. Professor Seth Lloyd, who is internationally renowned for his work in quantum computation, physics of information, and complex systems, has been appointed the first Nam P. Suh Professor. "It is a great honor to be awarded the Nam P. Suh Professorship," Lloyd says. "Professor Emeritus Suh was a visionary department head of the mechanical engineering department. I am grateful to Hock Tan, whose support will allow me to develop novel teaching tools and enhance undergraduate research opportunities."

MIT MechE Recognized at International Desalination Association 2015 World Congress

Three MIT-affiliated researchers received awards at this year's International Desalination Association 2015 World Congress on Desalination and Water Reuse. PhD student Jaichander Swaminathan won the Best Presenter Award for his paper "High efficiency single-stage membrane distillation configurations: experimental investigation" (J. Swaminathan, H.W. Chung, D.E.M. Warsinger, and J.H. Lienhard V), from a project sponsored by the MMIP program operated by MASDAR and the Deshpande Center. Postdoc Dr. David Warsinger, PhD '15, received the Best Poster Award for his paper "The effect of filtration on membrane distillation fouling" (D.E.M. Warsinger, J. Swaminathan, H.W. Chung, S. Jeong, and J.H. Lienhard V), sponsored by the MIT and MASDAR Institute Cooperative Program. Finally, Dr. Prakash Narayan Govindan, PhD '12, CTO of MIT spinoff company Gradiant Corporation, was recognized with the prestigious 2015 IDA Emerging Leaders Achievement Award.

MechE Spinoff's Resuscitator Device Wins First Place in Boston Children's Hospital Innovation Competition

Alum Kevin Cedrone SM '10, PhD '13, CEO of Augmented Infant Resuscitator (AIR), came in first place in Boston Children's Hospital's second annual Innovation Tank competition, which took place this past November during the hospital's Global Pediatric Innovation Summit + Awards. Three inventors were invited to pitch their medical invention to a panel of venture capitalists and industry leaders, and Cedrone's augmented infant resuscitator won unanimously after only five minutes of debate among the judges. The device is a universal add-on to infant resuscitators that uses sensors to detect ventilation problems and send feedback to a nurse's laptop,



giving them actionable cues about what is happening and how to solve it. It also improves training and skill maintenance by providing feedback to users. According to Cedrone, studies have shown that AIR could reduce infant ventilation problems by 26-48%. AIR was awarded $30,000 for first place.

APS 68th Annual Division of Fluid Dynamics Meeting Hosted by MIT

This past November, MIT hosted this year's annual American Physical Society (APS) 68th Annual Division of Fluid Dynamics Meeting at Hynes Convention Center. The event, chaired by MIT Department of Mechanical Engineering Professors Triantaphyllos Akylas and Thomas Peacock, marks the first time in almost 50 years that the meeting was held in Boston, Mass. This year, a record-breaking 3,500 attendees presented new research, and approximately 40 lectures took place concurrently throughout the event. Several accompanying mini-events also were held during the meeting, including networking lunches, workshops, and award ceremonies. The Gallery of Fluid Motion (http://gfm.aps.org/), another highlight of the meeting, provided an opportunity for scientists to display their latest eye-catching images and videos of striking fluid flow phenomena.

Talking Shop: Professor John Leonard

A Mechanical Engineer's Obsession with Self-Driving Cars

What's your interest in autonomous cars?

I've worked on mobile robots my whole life, and a self-driving car has been the dream of robot navigation researchers, including myself, for more than 50 years. I've been obsessed with the developing story of self-driving cars, and I try to talk to everyone I can.

Why has it suddenly heated up after all this time?

One thing is that Uber has shown there might be a new way to think about mobility on-demand. It currently uses human drivers, but if there were fully autonomous vehicles, then this would be a real transformation of the economy. I have mixed emotions. I don't think we're as close to this fully driverless future as some others do. I worry about the impact upon employment and the legal consequences, as well as many other big policy questions.

Are there just logistical problems, or do you have technological reservations too?

With self-driving vehicles, there's a big distinction between levels of autonomy. A Level 2 vehicle has multiple active safety systems (like adaptive cruise control, anti-lock brakes, or lane-keeping assistance), but the driver has to pay attention at all times. That's what you can buy now. A Level 3 autonomous vehicle would be one in which you could surrender control to the car for sustained periods of time and, hopefully with some warning, the car would ask you to take control when it needed you back.

The Level 3 vehicles could provide benefits like reducing stress and preventing accidents, but studies have shown that humans are bad at monitoring an autonomous system. So suppose someone is working on their laptop and the car suddenly needs to give them control – are they going to be ready? Or what if the driver falls asleep? So this hand-off issue is a big challenge. Google was working on a Level 3 product a few years back, but they gave up on it for this reason and decided to go up to Level 4, in which there's no steering wheel and no brakes. You would just press a start button, and the car does all of the work. This is a lot more difficult technically than a Level 3 system.

AT MIT, we're really lucky because CSAIL just partnered with Toyota for a new major research project to work on highly automated driving. We're going to go back to the Level 2 system, where the human pays attention at all times, but we will also take advantage of recent advances in robotic perception and planning to try to prevent a broader class of accidents. I refer to this as "Level 2.99." The idea is to go as far as you can with active safety systems so that the car might be constantly scanning the environment for obstacles, pedestrians, cyclists, and other cars, and be ready to jump in to prevent an accident if the car determines that the human driver might be making a mistake. The ultimate goal of such a project would be to create a car that would never crash. That could make an enormous impact on safety: Currently, more than 30,000 people are killed every year in traffic accidents in the US and a million every year worldwide, so it's a tremendous societal problem.

I'm cheering from the sidelines for Google's Level 4 project, but I do want to give a balanced view to the public about challenges that will be difficult to solve, like driving in the snow and interacting with people such as traffic cops or crossing guards. It's important to me to do what I can to inform the policy debate and ground things in how real sensors work and how the algorithms work, how cars navigate, and how they detect things. I think that's part of our job at MIT.

John J. Leonard is the Samuel C. Collins Professor of Mechanical and Ocean Engineering and Associate Department Head for Research in the MIT Department of Mechanical Engineering. His research focuses on navigation and mapping for autonomous mobile robots, and he was one of the first researchers to work on the problem of simultaneous localization and mapping (SLAM), answering the question of how to deal with uncertainties in robotic navigation so that a robot can locate and navigate itself on a map that it's still in the process of building. He holds the degrees of B.S.E.E. in electrical engineering and science from the University of Pennsylvania (1987) and D.Phil. in engineering science from the University of Oxford (1994). http://marinerobotics.mit.edu/

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Department of Mechanical Engineering
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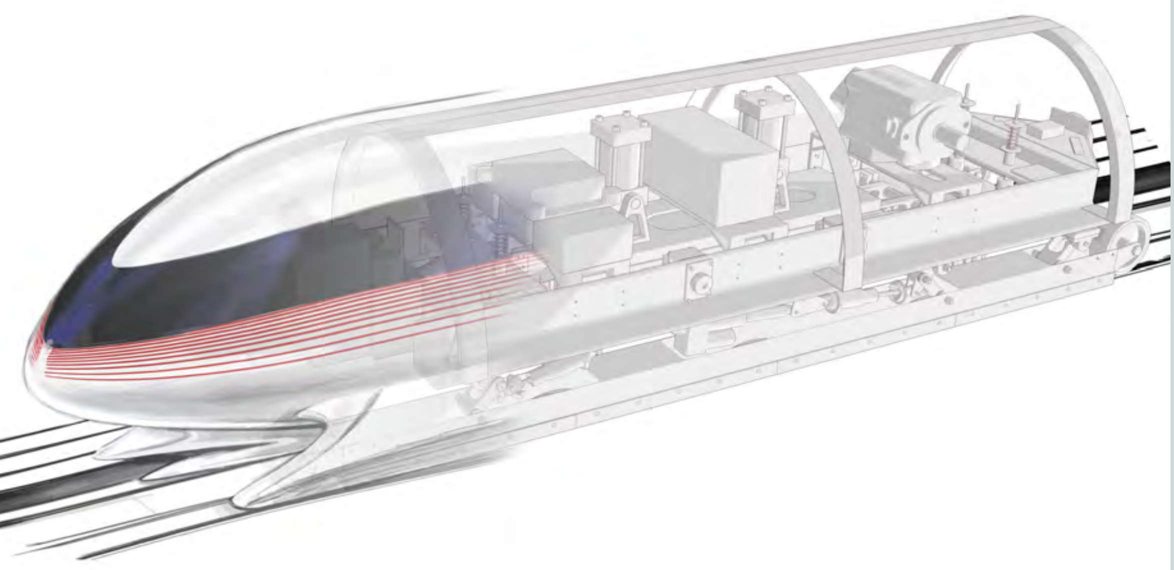
Coming in the next issue:

> Water technology advancements



The MIT Hyperloop team, including several MechE students, won the top spot in the first round of the SpaceX Hyperloop contest this past January, beating out more than 100 international entries. The team earned a chance to build and test their design on the first Hyperloop test track.