MITMECHE

Spring/Summer 2014

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MIT Massachusetts Institute of Technology

MechEConnects

News from the MIT
Department of Mechanical Engineering

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MITMECHE

Unlocking the Oceans' Mysteries

Dear Alumni and Friends,

Ocean engineering is a major area of focus in the Department of Mechanical Engineering. In fact, it is one that is almost as old as the Department itself.

Ship design and construction has been a beacon of departmental excellence dating back to 1893, when Nathanael Herreshoff, MechE class of 1870, won the America's Cup race with the Vigilant, a boat he designed, built, and helmed; the Herreshoff Yard proceeded to build every winning America's Cup yacht for the next 40 years. It was that same year that Course 13, the Department of Naval Architecture, was created.

The number of ocean-related accomplishments that have flowed out of the department since then are abundant. From one of the most highly regarded Naval Construction and Marine Engineering programs in the country to one of the first autonomous underwater vehicle (AUV) labs, our ocean engineering faculty, alumni, and students have established a reputation as the leading problem-solvers in ship design and construction, naval construction, ocean engineering, robotics, control, communications, modeling, biology, mechanics, and biomimetics, – and the many interfaces thereof.

Today we move forward to areas of the ocean deeper and more inaccessible, seeking to uncover the mysteries they hide through the technology we develop together.

In the pages that follow, you will read about the many creative ways our faculty, alumni, and students are bringing their characteristic passion to the exploration of our oceans. You will read about the journeys of some of our ocean engineering alumni, including graduates who earned the titles of Vice Admiral in the US Navy and managing director of ExxonMobil Norway; faculty members exploring currents that are occurring under the ocean's surface, studying the natural sensors of seals for submarine applications, and developing sophisticated algorithms for optimizing the paths of AUVs; and students teaching high school classes from underneath the sea and building novel oil-well blowout protectors inspired by everyday life.

As engineers, the untapped potential of the ocean calls to us and we feel a duty to develop technology capable of taking advantage of opportunities in areas such as oil drilling, gem mining, and underwater navigation. But we also feel responsible for protecting the oceans. We create technologies that not only extract oil but also follow oil plumes created by well blowouts; technologies that not only map the unknown but track marine life and enable its protection.

Our goal is to improve and help better manage the way we interact with our oceans, which are so vital to the well-being of our planet.

As always, thank you for your ongoing support and friendship.

Sincerely,

Gang Chen, Carl Richard Soderberg Professor of Power Engineering and Mechanical 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 science and technology**

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

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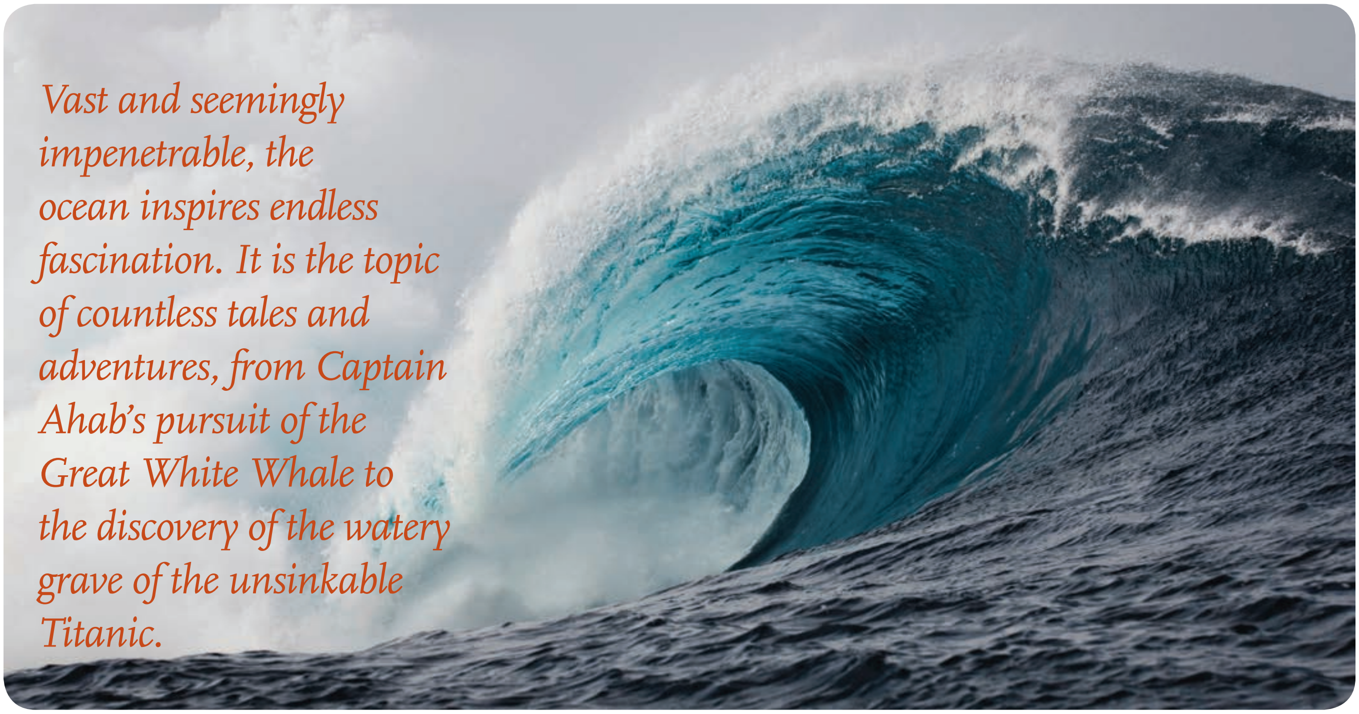
The Power and Potential of Oceans Unknown

Engineering and the Ocean Environment: Challenge and Opportunity

by Alissa Mallinson



Vast and seemingly impenetrable, the ocean inspires endless fascination. It is the topic of countless tales and adventures, from Captain Ahab's pursuit of the Great White Whale to the discovery of the watery grave of the unsinkable Titanic.

The mysteries of the oceans' depths and what lies beneath offer exciting challenges for engineers, who strive to develop new means to explore and utilize its resources.

But why does the ocean generate such fascination and yet remain so unexplored?

"The ocean is very large," says the William I. Koch Professor of Marine Technology and Director of the Center for Ocean Engineering Professor Michael Triantafyllou. "You can see that when you go looking for a crashed plane and can't find it, and don't even know where to look. There are parts of the Pacific Ocean that have never even been crossed scientifically since Captain Cook.

"And some people don't recognize the ocean as interesting," he continues. "For example, back in the '60s when the Alvin submersible was first dispatched, they wanted to go down and look at the deep parts of the Atlantic. But there were a lot of negative reactions around it. People asked, "What are you going to find? Why look at the bottom?" Well, they went there and they found the Mid-Atlantic Ridge, and all of a sudden Wegener's tectonic plate theory was confirmed and changed the view of the planet."

Indeed, it is only in the past few decades that researchers have really been able to inspect, investigate, and utilize the ocean environment. Its extent, depth, and extreme temperatures and pressure all present significant challenges to exploration technology.

At MIT, ocean engineering has always been a major element of our curriculum – notably the naval construction and engineering program 2N, which has produced many of the Navy's top-ranking technical naval officers, and the naval architecture program, which produced several America's Cup winners. The Department of Naval Architecture was established in 1893, and in 1976, it began a fruitful partnership with the Woods Hole Oceanographic Institution, creating a joint MIT-WHOI program in oceanographic engineering. In 1989, the MIT Sea Grant Autonomous Underwater Vehicle (AUV) Laboratory was established, producing some of the first functional AUVs to become commercially successful. Several areas of mechanical engineering – such as mechanics, controls, design, optics, and robotics – play a large part in modern ocean engineering, and they all interface as we navigate the idea of responsible exploitation and protection of the ocean.

Many ocean engineering faculty in MechE have been at the forefront of ocean discovery and achievement, such as the program on Arctic acoustics that led to such fundamental discoveries as the first proof of Arctic Ocean warming; the Heard Island experiment, during which Professor Emeritus Arthur Baggeroer was part of a team that became the first to find, identify, and calculate average ocean temperature measurements; the introduction of data-driven ship design by Professor Jerry Milgram, leading to an America's Cup win (see page 20); the first marine biomimetic robot co-developed by Professor Triantafyllou; and ocean acoustic waveguide remote sensing (OAWRS), co-developed by Professor Nicholas Makris, which enables the observation and tracking of massive fish populations in their natural habitat and migratory patterns.

The oceans are utilized for everything from transportation (approximately 90% of the world's transportation takes place by sea) and defense, to oil production, fishing, and entertainment. At MIT, we are keenly aware of our duty to utilize them as a resource while also understanding the impacts of that utilization.

"The ocean is a global system that needs to be thought of as a whole piece, not just parts," says Professor Alexandra Techet. "There is so much of the ocean that we were not able to get to until technology allowed it. It is great that we are able to utilize our oceans, but at the same time, if we don't protect them, there will be no more ocean to utilize."

"The ideas of utilization and protection of the oceans go hand in hand," adds Professor Henrik Schmidt, Director of the Lab for Marine Sensing Systems (LAMSS). "Whenever you start using or trying to exploit the oceans' resources, you have to make sure you know what the impact will be. So we need to put the infrastructure in place that allows us to monitor what's happening and take action if needed. Since 95% of the ocean is still unexplored, there's still a lot we don't understand."

"The fair breeze blew, The white foam flew, And the furrow followed free. We were the first to ever burst into the silent sea."

-Samuel Taylor Coleridge
The Rime of the Ancient Mariner

Professor Nicholas Makris' acoustic imaging breakthrough in 2006 enabled a new means to look into the oceans. His OAWRS technique allowed researchers to take images of areas about 100 kilometers in diameter every 75 seconds. Compared to previous techniques, it used low-frequency sound waves that can travel far distances, providing a new way to track marine life and its migrations, and set the foundation for the use of acoustics as a means for gathering ocean data.

Researchers at MIT have also played key roles in developing underwater vehicles for ocean exploration. At first, they were large, expensive, and could only follow very simple directions, but the ability they offered to start exploring the deeper, less hospitable parts of the ocean was the foundation for all the investigation, responsible exploitation, and protection that came after. They were, among other things, an efficient way of reaching extreme ocean depths to gather samples and information that could be sent back to the surface.

Today, researchers are working on ways to send multiple AUVs out for exploration as a fleet, to gather data collaboratively and send it back immediately. But communications underwater have traditionally been a great challenge because electromagnetic signals only travel well underwater at very low frequencies, light attenuates rapidly, and the amount of information that can be transferred over acoustic channels is low.

Professor Franz Hover is looking at ways to give AUV fleets more sophisticated directions to allow them to communicate effectively with each other, something he likens to storm chasing.

"Here in the terrestrial zone," he says, "we're watching the weather very carefully: its winds and clouds, and physical properties. All those things are going on underwater too, through moving water masses with different temperatures, chemistries, and critters.

"On land, we have ubiquitous connectivity of agents; you can have wireless connectivity across miles and get very high coverage and good rates of information transfer. We'd like to have that underwater as well to monitor the oceans and go where things are exciting. There are important science, policy, offshore industry, and defense questions that you'd be able to answer if you had these observing capabilities."

Hover envisions a group of mobile underwater vehicles that can communicate with each other, but more importantly, can develop and act on a global model of the situation at large, individually and collectively, reporting back to a dynamic control system that receives the data in real time and distributes commands based on a full understanding of the situation.

"Underwater we're going to pay for every single bit of information that passes acoustically between these vehicles," says Professor Hover. "Agents don't really have the ability to share all their information with each other or update each other very frequently. So what if the vehicles could exchange less information yet still follow the event they're studying?"

One of the kayaks Professor Hover is using in his robotic control systems research.

Where Professor Hover's solution to underwater observing systems is based on sophisticated controls communicated acoustically, Professor Henrik Schmidt is developing onboard intelligence and autonomy of AUVs based on data they gather acoustically.

He's developing the infrastructure to observe and study the oceans by commanding his AUVs to map the ocean and track acoustic events one specific directive at a time, then training them to make an intelligent decision in real time about what to do with the data they gather.

Students learn to program autonomous marine vehicles to collaboratively and adaptively explore the marine environment, a core mission of Professor Schmidt's lab.

For example, in the case of a missing airplane, says Professor Schmidt, normally a robot would be sent down to map areas using a lawnmower path. But because acoustic communications can't transfer large amounts of information, the robot has to come up to the surface to send back its data, then wait for an above-water operator to analyze it and respond with instructions on where to hone in. Schmidt's robots, on the other hand, are able to analyze sound underwater and make their own intelligent decisions about what to do with it.

"The underwater robots being sent to the bottom of the ocean – down to 5,000 meters in depth in some cases – have to be able to complete the mission of finding something, identifying what it is, and locating where it is accurately enough to pick it up or follow it, and that requires significantly more onboard intelligence," he says.

"That's where the artificial intelligence becomes such a key technology. We are essentially trying to clone expert understanding of underwater sound and put that into the robots, so that if they're using sound for mapping or location purposes, they know when they see something abnormal, and can say, 'Let me go look at it' without waiting for an external command."

But in oceans so vast, how do researchers choose the best routes for their robots? To answer that question, Professor Pierre Lermusiaux conducts ocean modeling research, particularly the characterization and prediction of uncertainty in ocean dynamics, to help optimize the paths of AUVs. In turn, data from these AUVs can be assimilated into Professor Lermusiaux's model to help constrain his calculations, providing a greater degree of confidence in predicting data for regions where AUVs haven't visited yet (see page 15 for more on Professor Lermusiaux's research).

With these technological advancements in imaging, communications, and modeling, we are developing the tools we need to better explore and understand the oceans. Alongside exploratory tools, there is also a need for engineering technology that improves our operations in the ocean environment, addressing key societal needs such as transportation, defense, oil extraction, fishing, and disaster response.

With motivations such as this in mind, Professor Alexandra Techet has looked to biomimicry to investigate ways to improve the performance of underwater and air-sea vehicles. Professor Techet develops 3D imaging technology to study the physics behind the propulsive performance of accomplished sea swimmers and jumpers, which are able to gracefully maneuver in and out of the water.

"Salmon swim upstream and jump out of the water, whales breach, and archer fish can jump from a dead stop," says Professor Techet. "They're looking at their prey above the surface, and they go from zero velocity to shooting out of the water just by flipping their tail back and forth. How?

"We want to understand their propulsive performance, jumping capability, and maneuverability, and apply that knowledge to a vehicle underwater. We're not necessarily going to build a mechanical fish because it would likely be too heavy to get out of the water, but we can understand the hydrodynamics required to propel something from either a slow speed or zero velocity out of the water."

First she needs the tools to observe the hydrodynamic behavior of locomotion in water.

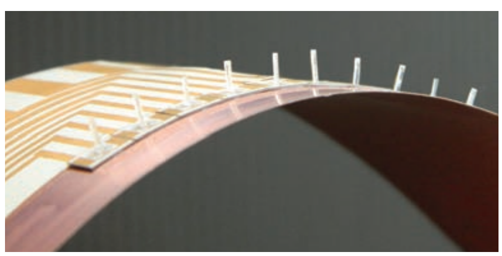
"Fully temporally and spatially resolved volumetric flow measurements are the next frontier in fluid mechanics," says Professor Techet. "So the question is, 'How can you do that experimentally?' In my lab, we have developed a 3D particle image velocimetry (PIV) measurement tool that allows us to study higher speed flows and more unsteady problems."

Professor Triantafyllou's research on underwater vehicles has also been inspired by the mechanics and biology of marine creatures, particularly fish and seals, but his focus is on their ability to map the environment around them, the flows and eddies, by sensing changes in water pressure.

"The difference between fish and submarines," he says, "is that a submarine does not sense what's happening around the propeller or the rudder. This is not a capability we would even think about if we hadn't noticed it in marine life."

Using micro-electro-mechanical systems (MEMS), Professor Triantafyllou is able to emulate the sensing capabilities he's observed in fish and seals in lightweight and cost-efficient ways.

"We were working on underwater robotic vehicles that looked like fish, and one of the things we wanted to explore was a way for such vehicles to extract energy from surrounding flows. We discovered that trout actually do this – they hide behind rock formations, using minute motions and taking energy from the rocks. We wondered how the trout knew where these wakes are, and it turns out it's because of what we call a 'lateral line.'"



An array of 10 MEMS velocity sensors emulating the lateral line of fish.

This "lateral line" is comprised of hundreds of tiny sensors on the side of a fish through which they can sense that an object is near, like when a truck passes by you on a highway and you sense a blast of pressure.

Professor Triantafyllou has been similarly inspired by the whiskers of seals. After conducting research on how they work, he discovered that they don't shake unless they are affected by a change in pressure, but when they do, the seal knows that a fish has swum by and starts to pursue it.

Such underwater sensing capabilities could allow ships to detect an eddy forming under its hull from the drag of a sharp turn, slowing down the ship, and counteract it with opposing forces, or sense a current in the path of an AUV, giving it a chance to change course and avoid expending energy to fight it. This technology could also be used to locate objects or other transient events in the oceans, such as an oil plume.

The foreseeable future of the ocean presents a rich frontier of ocean engineering challenges to improve our ability to investigate, understand, and operate in this relatively unexplored system. But the more we are able to utilize the resources and opportunities the oceans have to offer, the more we are responsible for protecting them.

Alumni Spotlight

Dr. Dana Yoerger (SB '77, SM '79, PhD '83)

By Alissa Mallinson

Dr. Dana Yoerger standing in front of the AUV SENTRY on the vessel Atlantis.

Everything he'd learned up until that point, every study he'd conducted, every time out at sea, had led him to this day.

"The night before we got there," says Dr. Dana Yoerger (SB '77, SM '79, PhD '83), senior scientist at the Woods Hole Oceanographic Institution (WHOI), "we could see the sky glowing red from the flares' flames. I'll never forget that feeling. I thought, 'We've got all the right equipment, we've got all the right people, we're on a good ship; I'm not sure how this is going to turn out, but everything we've done has been leading us to this point."

It was the notorious 2010 Deepwater Horizon oil spill, and Dana Yoerger and the SENTRY team had come in to do detailed mapping of the deep plume.

"The oil was still flowing," he continues. "The next day we drove right into the middle of the exclusion zone because we were dropping off some team members to sample the flow. We drove right into the middle of it. There were more than 50 ships and helicopters, flames were shooting out. It was unbelievable."

Yoerger and his team showed that it was indeed a deep plume and that it originated from a wellhead that was at 1,100 meters. They utilized an AUV, SENTRY, equipped with a mass spectrometer, to gather and transmit a limited subset of data that gave them the information they needed to drop samplers into the water at the right locations. From there, they characterized the plume and calculated its chemical flux, as well as determined which directions the currents were taking it.

As an MIT student, Yoerger studied under Professor Tom Sheridan, who was researching human-machine interactions.

"One of Tom's strengths was being able to see all of the possibilities for human-machine interactions – not just falling into some obvious kind of configuration but contemplating all of the possibilities for it. He wanted to consider the dimensional space of who is in charge. And we think about all of those things all of the time now. It's not just that the automation is working and people are directing it – there's a lot of richness to it now, and the trick is to put those pieces together in the best possible way."

One day during his job hunt, he got a call from his advisor saying a guest was coming in. Dr. Yoerger was intrigued, and went to meet him. After 20 minutes with the guest, he looked at the clock and thought to himself, "I think I know what I want to do with my life." The guest was award-winning oceanographer Professor Robert Ballard, who would later discover wreckage from the Titanic.

"Sometimes I think to myself," muses Yoerger, "what if I had slept in that day?

"I don't think I would have had the same kind of success elsewhere as I have had at WHOI. It turned out to be a great match to my skills and abilities. I like going to sea and solving problems at sea by producing engineering and scientific results."

Yoerger, in addition to being a major part of the team that identified the Deepwater Horizon oil spill characteristics and tendencies, has also been a key contributor to major AUV research throughout the past few decades. He was part of the research team for the remotely operated vehicle JASON; the Autonomous Benthic Explorer known as ABE; the hybrid remotely operated vehicle NEREUS, which reached the bottom of the Mariana Trench in 2009; and most recently the autonomous underwater vehicle SENTRY. He has gone to sea on more than 70 oceanographic expeditions exploring the Mid-Ocean Ridge, mapping underwater seamounts and volcanoes, and surveying ancient and modern shipwrecks.

Today, Yoerger spends more of his time onshore, setting up the Center for Marine Robotics at WHOI to support the proliferation of robotics in ocean science and engineering. As an educator, Dr. Yoerger also supervises the research and academic program of graduate students studying oceanographic engineering through the MIT/WHOI Joint Program in the areas of control, robotics, and design. He's also the 2009 recipient of the Lockheed Award for Ocean Science and Engineering.

"To deliver the kind of operational product that we need, you've got to push boundaries," he says. "But there's also a strong element of engineering involved. If you work at Woods Hole, there's no point in just generating engineering theory that can't be implemented at some point. Even the researchers that are typically highly theoretical in signal-processing or acoustic communication, for example, are tied to people who allow them to execute experiments and verify those theories with practice."

Alumni Spotlight: VADM (ret) Paul Sullivan (SM '80)

Former Associate Professor of Naval Architecture and Marine Engineering

By Alissa Mallinson

For Vice Admiral Paul Sullivan, USN (Retired) (SM '80), a graduate and later an Associate Professor of Naval Architecture of what is today MechE's 2N program in naval architecture and marine engineering, the crafts of naval architecture and ship design are as important now as they ever were.

With 283 ships in the Navy, several classes of ships currently under construction, and some new designs on the way, there is plenty to do.

"I love the process of starting a ship design from scratch, but those opportunities are rare. More often we're taking a class of ships and trying to convert it to a new mission. That's pretty challenging too," he says.

According to Vice Admiral Sullivan, the Navy is always looking for ways to improve its ships and submarines – stronger materials, more powerful engines, more powerful mission systems, and reduced costs.

"There is always new technology to add to our ship designs," he says. "The new aircraft carrier is a great example. We shifted from steam catapults to electromagnetic catapults so that we're now launching the aircraft using a linear induction motor. The physics are simple, but the engineering of actually getting it into the ship and getting it to work time after time as we throw these 20-ton aircrafts off the deck at 150 knots is no small chore."

Vice Admiral Sullivan is well acquainted with large chores. Turning an interest in boats and ships – which started at a young age when his mother bought a Sunfish sailboat – into a passion, and then turning his passion into an education and a career, he's worked hard to get to where he is.

"As a teenager, I read magazines associated with sailing and that got me interested in performance sailing, which got me interested in designing sailboats for performance sailing," he says. "At that time the Navy was experimenting with hydrofoils. Anything that went fast in the water, I was interested in it. And that got me on an engineering bent. I thought, 'Wow, you mean people can actually design and build these wild things?'"

As an undergraduate, Vice Admiral Sullivan was accepted to both MIT and the Naval Academy, and decided to attend the Naval Academy to study mathematics.

After he graduated, he went out to sea, as all Academy graduates do. One day, a notice about graduate curriculum came across his desk. He had regretted his decision to major in mathematics instead of naval architecture as an undergraduate, so he lunged at a second chance.

"As a graduate student in MechE's 2N program (formerly Course 13A), I had a very difficult time my first year because my undergraduate math major was too theoretical. I found that the average sophomore undergraduate at MIT knew more engineering calculus than I did, even as a math major from the Naval Academy. I showed up with a very deficient education to go into a really heavy-duty engineering program, and my first year was awful. But by the second year I had caught up, and in the third year I was as good as anybody. That's not unheard of for Course 2N students."

After graduation, Admiral Sullivan became an Engineering Duty Officer at a shipyard, overhauling aircraft carriers, surface ships, and submarines. Because of his ship design background and recent experience with submarines, his next assignment was as Deputy Ship Design Manager on the SEAWOLF program.

The assignment that followed, though, was quite a surprise.

"I got a call from the Admiral, and he said, 'Do you still want to go to MIT and teach?' And I said, 'Yes, sir, I'd love to do that some day.' And he said, 'I'm not talking about some day.'

Vice Admiral Sullivan moved from Washington, DC., to Cambridge, Mass., that year and became an Associate Professor of Naval Architecture in MechE's 2N program. He taught for three years.

"I had a wonderful time," he says. "I had learned my trade well executing on the SEAWOLF design, but I learned it even better teaching it to very bright Navy students. You need to know twice as much to teach it because you have to be able to answer all the hard questions. You need to be able to demonstrate a deep understanding of the material."

Vice Admiral Sullivan – who later sat on the MechE visiting committee from 2003-2005, leaving his chair when he was nominated for his third star – left his post as associate professor in 1989 and headed to the waterfront in Groton, Conn., to build OHIO class submarines, then transferred to LOS ANGELES class submarines. His final move was to the Naval Sea Systems Command in 1992, where he stayed for many years.

One of the jobs he performed at the Naval Sea Systems Command brought him back to the SEAWOLF program as the Program Manager, this time delivering the first ship of the class. "It's very instructive to design a ship early in your career, then have to correct all your design mistakes and deliver on the final product," says Sullivan, who adds that the most difficult part of the delivery was certifying the submarine for her initial sea trials.

"It's the same thing as certifying a space shuttle," he explains. "It was more exciting because it was the first ship of a class. When you're on the 58th LOS ANGELES class submarine, you more or less know how that sea trial is going to go. But with the SEAWOLF, there were many new things on the ship. You needed to go back to first principles, and you needed to think through each new problem."

His next assignment was working on another first class submarine, VIRGINIA. By this time, he was in his third assignment as a Navy Captain, and worked as the Program Manager of the VIRGINIA's design and construction.

After VIRGINIA, Vice Admiral Sullivan was selected to flag rank and assigned as the Chief Engineer of the Naval Sea Systems Command and later as the Commander, retiring in 2008.

"The 2N program set me up for success," he says. "Some people ask why we send our Navy officers to MIT and not somewhere else. It's because MIT teaches you how to think. When you're designing the next Destroyer, you can't just go look at the last one for your inspiration. We want to be on the cutting edge of technology, from electronics to materials to physics, and to do that you're required to think through problems that no one has ever thought through before, and that's why you send people to MIT. That is its strength."

2N: Graduate Program in Naval Architecture and Marine Engineering

by Alissa Mallinson

MechE's 2N program in Naval Architecture and Marine Engineering is almost as old as the department's main Course 2 program in mechanical engineering.

The graduate program, which started in 1901 under the direction of Professor William Hovgaard and in cooperation with the US Navy, prepares Navy, Coast Guard, and foreign naval active duty officers, as well as other graduate students, for careers in ship design and construction.

Influential in the field of ship design and as a professor of marine engineering at MIT, Professor Hovgaard was a commander in the Danish Navy when he came to the 2N program. He taught several hundred Navy officers during his time at MIT and was the author of several leading textbooks on the subject, including *Structural Design of Warships*, *General Design of Warships*, and *Modern History of Warships*.

At the time, many ship designs were built by engineers who didn't have experience with life on a boat or at war. Professor Hovgaard developed 2N with the idea that a prerequisite of knowledge in these areas would lead to more effective and well-built warships. Similarly, the program's instructors have always been commissioned US Navy officers as well.

Those principles on which the program was based are still important elements of the course of study today.

"The average 2N student is coming from the fleet," says the program's director, Captain Mark Thomas. "They've gotten their commission at the Naval Academy, ROTC, or Officer

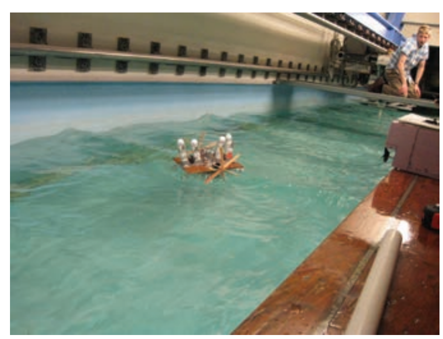
2N students presenting their final ship designs.

Candidate School. They've gone to sea for four to five years, either on a surface ship or a submarine. And then they apply for this program and come back here as graduate students."

Most post-graduate naval students attend the Navy's own graduate school in Monterrey, Calif., but the school doesn't have a naval architecture program, so all the naval architects go to MIT. They have all earned a technical undergraduate degree, although not necessarily in naval architecture, and they all want to become engineering duty officers, not to command at sea.

"Our graduates aspire to command shipyards, warfare centers, and major acquisition programs," says Thomas. "Their careers involve the design, acquisition, construction, testing, and maintenance of surface ships and submarines."

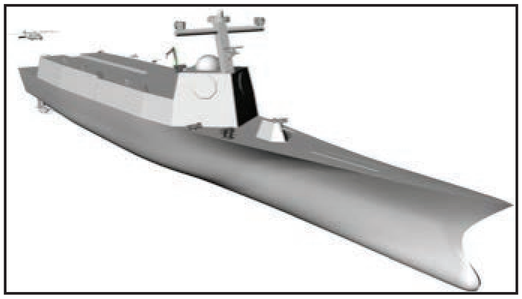
The program, which is competitive, with only about nine spots offered to more than 30 applicants per year, is comprised almost entirely of already existing MechE courses open to any student at MIT – with only one catch:

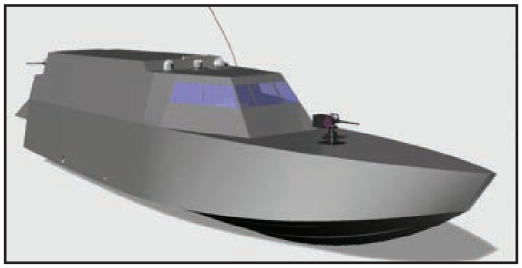


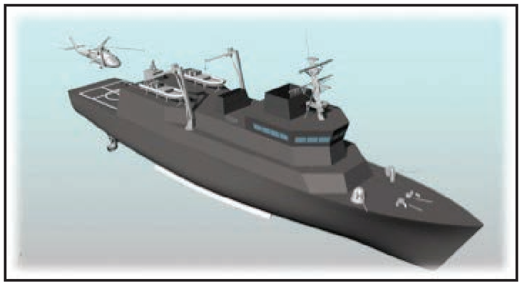
the Navy-specific courses are held off campus at Draper Labs. It involves lessons in submarine combat systems, surface ship combat systems, weapons effects and vulnerability, and submarine concept design. The rest of the courses focus on hydrodynamics, power and propulsion, autonomous underwater vehicle control, and structural dynamics, among other things. There is a specific series of five courses that are required to earn the naval architecture master's degree – Naval Architecture, Systems Engineering and Naval Ship Design, Naval Ship Conversion, and a capstone project – but outside of that the students are free to hone in on their individual interests.

Because of the overlap with Mechanical Engineering requirements, most students only have to take a few extra classes to graduate with dual degrees in both naval architecture and mechanical engineering.

And many students now are also pursuing the Systems Design Management degree in conjunction with the Sloan School of Management.







Student renderings of their ship designs.

Since many graduates of the 2N program go on to become commanding officers and program managers, they are interested in gaining some business savvy as well the standard technical degrees they are required to earn.

"From the Navy's perspective, the 2N program is a crown jewel of Navy graduate education," says Thomas. "It has produced more than its share of officers who go on to very senior ranks, including the current Assistant Secretary of the Navy (RDA), the Honorable Sean Stackley. There is a long history of success."

Professor of the Practice in Naval Architecture and Engineering Captain Mark Thomas earned his BS in electrical engineering from Oklahoma State University, his SM in electrical engineering from MIT, his NE in naval engineering from MIT, and his PhD in hydrodynamics from MIT. He is the US Navy's senior uniformed Naval Architect. His technical contributions encompass a wide range of naval engineering challenges, from keeping today's ships at sea and designing ships for the future to evaluating technology advancements for both today and tomorrow's Navy.

Alumni Spotlight

Meg O'Neill (SB '93, SM '94)

By Alissa Mallinson

It sounds too simple to be true, but Meg O'Neill credits much of her career success – and personal satisfaction – to her willingness to say one three-letter word.

Yes.

"I think the ability to say 'yes' is very important," she starts. "If ExxonMobil asks me to take on a new project or move somewhere I've never lived, I have the philosophy that I ought to try to say 'yes.' It gives me a chance to see new things, and I know I won't be asked to do anything I'm not ready for. Saying 'yes' keeps doors open."

Having started at ExxonMobil as an engineer in 1994, O'Neill is currently the managing director of ExxonMobil companies in Norway. She's held several other positions along the way, moving to new countries every few years with each new promotion.

When O'Neill first started with ExxonMobil at its Upstream Research Company, the oil industry was just starting to develop fields in more than 1,000 meters of water. Her job was to conduct modeling testing and computational analyses to begin to answer questions about how to design structures for such water depths. After a few years, she transferred within the company to work as a reservoir engineer, producing models about how oil and gas flow through the subsurface and developing plans to optimize value from the fields.

Her next move to New Orleans as a reservoir engineering supervisor placed her much closer to the business side of the company, something she prepared for as an ocean engineering student taking courses at the Sloan School of Management.

"It was very helpful to understand the business context of the technical work I was doing," she says. "When I started at ExxonMobil, I was doing hardcore technical work – very cutting-edge applied research. Moving into the production environment put all that engineering in a business context.

"One of the best things about an MIT education is the emphasis on problem solving. It's been very helpful for me as I've gone through my career and worked on problems that weren't immediately relevant to my technical education. But MIT taught me how to define and tackle a problem, figure out what I need to solve it, and determine what the remaining uncertainty is. It gave me the framework for how to address a wide range of questions and gave me a good amount of flexibility."

O'Neill was asked to move to the company's fields in Indonesia, and she replied with her trademark response. She worked there for several years, first in engineering management, then in field operations.

"That was a very fun time because I really had to have my hands on the business," she says.

From there, O'Neill returned to Houston to work as a global reservoir engineering manager, looking after all the reservoir engineers around the world, then moved to Canada after she was promoted to President of ExxonMobil Canada. She transitioned into her current position in Norway in 2012.

"I've lived in four different countries doing everything from hardcore engineering and operations to business and management, so there's been a tremendous amount of variety, a different challenge every day.

"It's been great to be able to enjoy so much variety within the same company, to come up through the system and encounter different challenges in the workplace everywhere around the world."

As for next steps?

"We'll see what ExxonMobil asks me to do," says O'Neill. "I'm confident that I will say 'yes.'"

Faculty Research: Professor Pierre Lermusiaux

New Methods and Software Can Predict Optimal Paths for Automated Underwater Vehicles

By David Chandler, MIT News Office

Sometimes the fastest pathway from point A to point B is not a straight line: for example, if you're underwater and contending with strong and shifting currents. But figuring out the best route in such settings is a monumentally complex problem — especially if you're trying to do it not just for one underwater vehicle, but for a swarm of them moving all at once toward separate destinations.

But that's just what a team of engineers led by Professor Pierre Lermusiaux has figured out how to do. They have developed a mathematical procedure that can optimize path planning for automated underwater vehicles (AUVs), even in regions with complex shorelines and strong shifting currents. The system can provide paths optimized either for the shortest travel time or for the minimum use of energy, or to maximize the collection of data that is considered most important.

Collections of propelled AUVs and gliding AUVs (also called gliders) are now often used for mapping and oceanographic research, for military reconnaissance and harbor protection, or for deep-sea oil-well maintenance and emergency response. So far, fleets of up to 20 such AUVs have been deployed, but in the coming years far larger fleets could come into service, Lermusiaux says, making the computational task of planning optimal paths much more complex.

He adds that earlier attempts to find optimal paths for underwater vehicles were either imprecise, unable to cope with changing currents and complex topography, or required so much computational power that they couldn't be applied to real-time control of swarms of robotic vehicles.

While researchers have studied such systems for many years, "what was missing were the methodology and algorithm," he says — the mathematics allowing a computer to solve such path-planning riddles rigorously but quickly enough to be useful in real-world deployments. "Because ocean environments are so complex," he says, "what was missing was the integration of ocean prediction, ocean estimation, control and optimization" for planning paths for multiple vehicles in a constantly changing situation. That's what MIT's Multidisciplinary Simulation, Estimation, and Assimilation Systems (MSEAS) group, led by Lermusiaux, has now developed.

The team's simulations have successfully tested the new algorithms in models of very complex environments — including an area of the Philippines amid thousands of islands with convoluted shorelines, shallows, and multiple shifting currents. They simulated a virtual fleet of 1,000 AUVs, deployed from one or more ships and seeking different targets. Adding to the complication, the system they devised can even account for "forbid-

Continued on page 19

Faculty Research: Professor Thomas Peacock

Large-Scale Tests in the Lab and the South China Sea Reveal the Origins of Underwater Waves that Can Tower Hundreds of Feet

By David Chandler, MIT News Office

Their effect on the surface of the ocean is negligible, producing a rise of just inches that is virtually imperceptible on a turbulent sea. But internal waves, which are hidden entirely within the ocean, can tower hundreds of feet, with profound effects on the Earth's climate and on ocean ecosystems.

Now new research, both in the ocean and in the largest-ever laboratory experiments to investigate internal waves, has solved a longstanding mystery about exactly how the largest known internal waves, in the South China Sea, are produced. The new findings come from a team effort involving MIT and several other institutions, and coordinated by the Office of Naval Research (ONR).

(From left to right) Matthieu Mercier, Henri Didelle, Samuel Viboud, Louis Gostiaux, and Thomas Peacock inside the 50-foot rotating tank used for their tests, with a replica of the seafloor topography of the South China Sea inside it.

Seen in cross-section, these waves resemble surface waves in shape. The only difference between an underwater wave and the water around it is its density, due to temperature or salinity differences that cause ocean water to become stratified.

Though invisible to the eye, the boundary between colder, saltier water below and warmer, less-salty water above can be detected instrumentally. That boundary layer can resemble the ocean's surface, producing waves that reach towering heights, travel vast distances, and can play a key role in the mixing of ocean waters, helping drive warm surface waters downward and drawing heat from the atmosphere.

Because these internal waves are hard to detect, it is often a challenge to study them directly in the ocean. But now Associate Professor Thomas Peacock has teamed with researchers from the Ecole Centrale de Lyon, the Ecole Normale Superieure de Lyon, and the University of Grenoble Alpes, all in France, as well as the Woods Hole Oceanographic Institution, to carry out the largest laboratory experiment ever to study such waves. Their results have been published in the journal *Geophysical Research Letters*.

The team performed laboratory experiments to study the production of internal waves in the Luzon Strait, between Taiwan and the Philippines. "These are the most powerful internal waves discovered thus far in the ocean," Peacock says. "These are skyscraper-scale waves."

These solitary waves have been observed to reach heights of 170 meters (more than 550 feet) and can travel at a leisurely pace of a few centimeters per second. "They are the lumbering giants of the ocean," Peacock says.

The team's large-scale laboratory experiments on the generation of such waves used a detailed topographic model of the Luzon Strait's seafloor, mounted in a 50-foot-diameter rotating tank in Grenoble, France, the largest such facility in the world. The experiments showed that these waves are generated by the entire ridge system on that area of seafloor, and not a localized hotspot within the ridge.

The last major field program of research on internal-wave generation took place off the coast of Hawaii in

Continued on page 19

Faculty Research: Professor Franz Hover

Mission TULiP: A Robotic Pursuit on the Charles River

By Genevieve Wanucha, Oceans at MIT

If you take a stroll past the MIT Sailing Pavilion on Memorial Drive, you may see, among the usual glut of sailboats on the Charles River, two red child-sized kayaks riding the waves. Instead of the 80-pound human they are each designed to hold, the kayaks carry an array of electronics and pull along a string of plastic flags that flutter in the wind. One is named "Silvana," the other "Nostromo," and together they are following close behind "Icarus," a motorboat. It is a mission of pursuit.

These baby kayaks star in robotic control systems research led by Franz Hover, Associate Professor of Mechanical Engineering at MIT, graduate student Brooks Reed and colleagues. In the Hover Group's workspace in the sailing pavilion, Reed is monitoring real-time data streaming in from the GPS mounted on the kayaks. He only has to glance to his right to see Silvana and Nostromo at work on the river.

Each of the kayaks tow an acoustic WHOI Micro-Modem, at a depth of about 1.5 meters. Icarus, the target vehicle, sends out a pulse of sound, called a "ranging ping." Silvana and Nostromo receive it and calculate the ping's travel time. By dividing that number by the speed of sound in water, they can compute their own distances from Icarus. Then, they

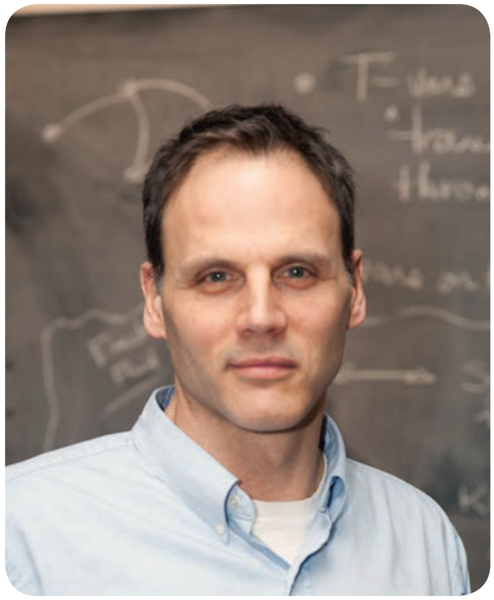
One of the Hover Group's kayaks gets adjusted.

coordinate. Each swap their own location measurements and control actions by sending data packets to each other using the modems. And voila, the pursuers know where to go next. The pair achieves its joint goal of maintaining a tight triangular formation relative to the position of Icarus, tracking their target even as it turns in unpredictable loops.

This shallow-water pursuit scenario is a simple one, but it's an experimental platform for a highly complex engineering endeavor of which scientists can only dream — using autonomous underwater vehicles (AUVs) to track fast or ephemeral undersea phenomena whose boundaries and trajectories shift in time and space – for example, an oil spill as it meanders downstream, a toxic algae bloom as it forms, a swirling school of fish, a salinity front, or the waters near the edge of a calving glacier.

"Imagine having vehicles that can operate in these kinds of dynamic environments," says Hover. "That's what we are after."

Capturing the details of quickly evolving ocean features is not a job for which individual AUVs qualify. On their own, AUVs get partial or long outdated information if the target is moving faster than the tracking robot. So, the Hover Group's long-



Professor Franz Hover

term vision hinges on designing control systems for fast vehicles that work together by communicating via acoustics.

But communicating underwater is a challenge, especially in the shallow waters of the Charles.

When sound propagates through the water, it bounces off the surface, river bottom, and Memorial Drive's sea walls, creating echoes in the signal. Many times, data packets get lost along the way. So Hover must design a control system that knows it won't be dealing with very precise information. "Part of why we choose to do tests here in the Charles River is that it is one of the most difficult communication environments you can find," says Reed. "If we can make a system work here, it's much more likely it will work in a place that has better acoustic communications performance."

Because Hover and his team are not specialists in the fine arts of acoustics, they collaborate with Milica Stojanovic, Professor at Northeastern University in the Department of Electrical and Computer Engineering, a leader in digital communication networks. She's a key contributor to the ongoing development of the acoustic modem used on the Hover kayaks, the WHOI Micro-Modem, which grew out of her PhD research 20 years ago. In her work with the Hover Group, Stojanovic helps improve the speed and reliability of signal processing between the vehicles. "That's where we come together," she says, "in closing the control loop in the presence of unreliable communications. That's the beauty of the interdisciplinary project."

Following on the successful mission with the autonomous kayaks, Hover is now leveraging established numerical ocean models to better design controllers. Ultimately, feeding an ocean model's forecasting of circulation patterns into a vehicle control system would help guide the vehicles to the most useful or advantageous position for monitoring an ocean feature, such as the boundary of an algal bloom.

Lermusiaux, continued from page 15

den" zones that the craft must avoid and fixed obstacles that affect both the underwater craft and the flow of the currents, and even moving obstacles, such as passing ships.

Taking advantage of the "free ride" offered by the currents, the craft often follows startlingly indirect pathways, meandering around in loops and whorls that sometimes resemble a random walk. That's because it can be much quicker to drift with a current and then double back than to try to cut straight across, fighting the flow the whole time. In other cases, the AUV may find a quicker or more energy-efficient path by rising over, or diving under, jets, currents, eddies or other ocean features. Uncertainties in ocean predictions — and how they affect the optimal paths — can also be accounted for.

In addition to finding paths that are quickest or most efficient, the system also allows swarms of data-collection vehicles to collect the most useful data in the fastest time, Lermusiaux says. These data-optimizing approaches could be useful for monitoring fisheries or for biological or environmental studies — such as a new National Science Foundation effort to characterize the New England Shelf Break, an area important to the region's fisheries as well as for climate research.

While the methodology and algorithms were developed for an underwater environment, Lermusiaux explains that similar computational systems could be used to guide automated vehicles through any kind of obstacles and flows — such as aerial vehicles coping with winds and mountains. Such systems could even potentially help miniature medical robots navigate through the circulatory system, he says.

The algorithm allows for real-time control and adjustments — such as to track a plume of pollution to its source, or to determine how it is spreading. The system can also incorporate obstacle-avoidance functions to protect the AUVs.

The team included mechanical engineering graduate students Tapovan Lolla and Mattheus Ueckermann SM '09, Konuralp Yigit SM '11, and research scientists Patrick Haley and Wayne Leslie. The work was funded by the Office of Naval Research and by the MIT Sea Grant College.

Peacock, continued from page 16

1999. In the years since, scientists have come to a greater appreciation of the significance of these giant waves in the mixing of ocean water — and therefore in global climate.

"It's an important missing piece of the puzzle in climate modeling," Peacock says. "Right now, global climate models are not able to capture these processes," he says, but it is clearly important to do so: "You get a different answer ... if you don't account for these waves." To help incorporate the new findings into these models, the researchers met in January with a climate-modeling team as part of an effort sponsored by the National Science Foundation to improve climate modeling.

These waves are potentially "the key mechanism for transferring heat from the upper ocean to the depths," Peacock says, so the focus of the research was to determine exactly how the largest of these waves, as revealed through satellite imagery of the Luzon Strait region, are generated.

Beyond their effects on climate, internal waves can play a significant role in sustaining coral-reef ecosystems, which are considered vulnerable to climate change and to other environmental effects: Internal waves can bring nutrients up from ocean depths, Peacock says.

Matthew Alford, an associate professor of oceanography at the University of Washington who was involved in the related field studies for this project, says, "The strong forcing and ridge geometry at Luzon Strait result in some of the strongest internal waves in the world's oceans. They are important for a variety of reasons, including the region's biology, the mixing and turbulence they produce, and marine navigation in the region." This team's research, he says, "contributed to a massive advance in our understanding of how these waves get generated and dissipated."

The research, carried out by Peacock and a team of eight other researchers, was funded by the ONR, the Centre Nationale de Recherche Scientifique and the Agence Nationale de la Recherche in France, and the MIT-France Program.

Lifetime Achievement: Professor Emeritus Jerome Milgram

The Sherlock Holmes of the Seas

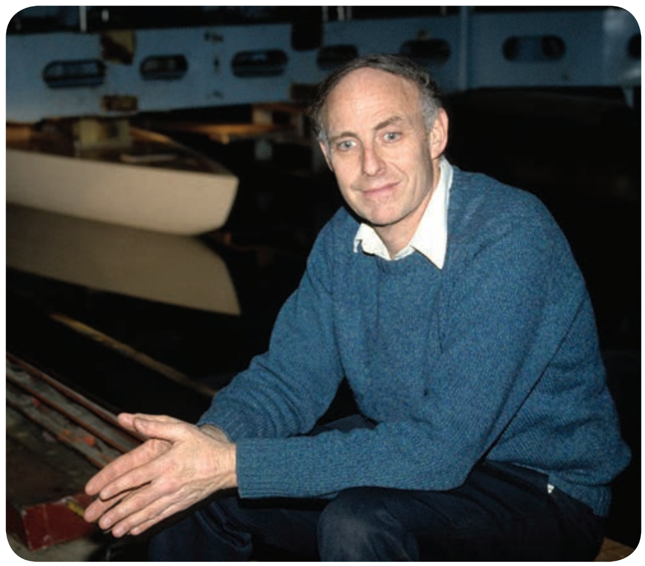
By Alissa Mallinson

He refers to himself as a seagoing Sherlock Holmes.

Known for many things, not least of which is his expert understanding of hydrodynamics, fluid mechanics, and oceanography, Professor Emeritus Jerome Milgram is perhaps most highly regarded for his work as an ocean investigator, an unrelenting seeker of the most precise ocean science and engineering truths. He was a member of the MIT team that produced the leading research on how oil escapes from a boom, and a frontrunner in oil containment research and technology, both of which helped to establish him as a leading expert in marine accident investigation.

"Professor Jerry Milgram takes a very careful, and scientific, data-driven approach to things," says Penn Edmonds ('83), a naval architect on the 1993 winning America's Cup team, of which Milgram played an integral part with his cutting-edge, analytical ship designs.

Milgram started out as an undergraduate in the Department of Electrical Engineering and Computer Science at MIT, adding naval architecture and ocean engineering to his list of majors as he became increasingly interested in the aerodynamics of sails. After graduation he continued on at MIT, becoming captain of the Sailing Team and earning a PhD in ocean engineering. His thesis laid the foundation for the analytical method of designing sails that is standard today. Shortly



thereafter, Professor Milgram became a member of the faculty at MIT, and was asked by Professor James Faye to join a study about how oil spreads on the oceans and booms. As a result of this research, he was one of the early developers of oil spill cleanup equipment, for which he holds 12 patents.

In addition to teaching naval architecture, ocean engineering, theoretical hydrodynamics, system dynamics, and numerical marine hydrodynamics in the MIT Department of Ocean Engineering, he has also taught fluid mechanics in the Department of Mechanical Engineering, as well as signals and systems, and modern optics in the Department of Electrical Engineering.

"Professor Milgram has this remarkable breadth of coverage of the disciplines that make up ocean engineering," says John Leonard, Associate Head of Research in MechE and Professor of Ocean Engineering.

"He has an approach that's uniquely MIT," adds Professor Michael Triantafyllou, the William I. Koch Professor of Ocean Engineering, and the Director of the Center of Ocean Engineering. "He doesn't know just design; he knows naval architecture, hydrodynamics in particular, as well as electrical engineering."

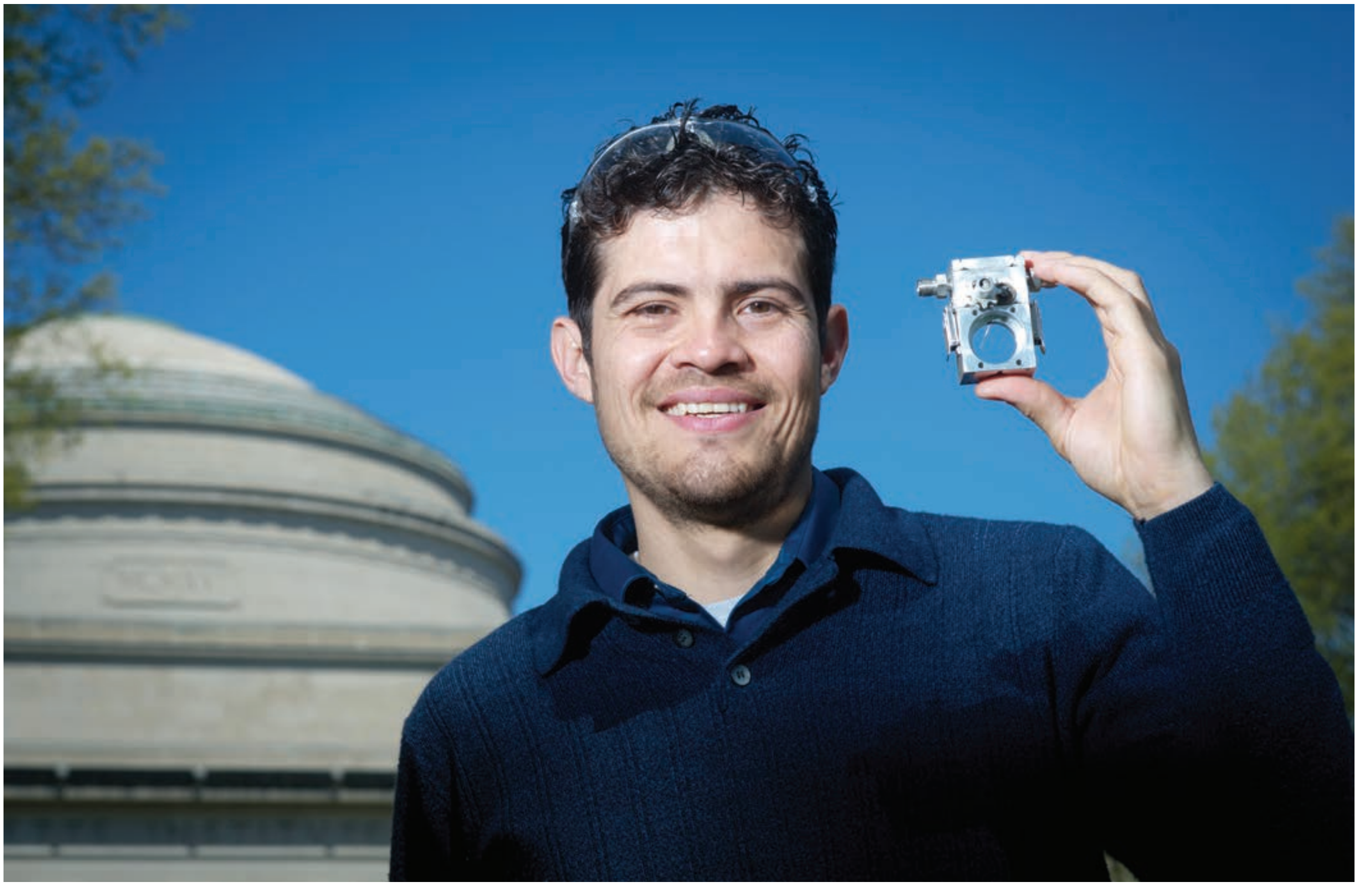
Professor Milgram's research areas have included ship development, the behavior of oil spills on the ocean, the behavior of sea waves and of natural surfactants on the surface of the ocean, and the dynamics of underwater vehicles, among many other topics.

He's authored more than 100 publications, and is a Life Fellow of the Society of Naval Architects and Marine Engineers, as well as a Life Member of the National Academy of Engineering.

Student Spotlight: Folkers Rojas (SB '09, SM '11, PhD '14)

The Case of the Welcome "Hairball"

By Alissa Mallinson



What do a bathtub hairball and a MechE-developed blowout preventer tool have in common?

They both cause blockages.

In the case of a hairball, the blockage is caused by an unwelcome natural buildup of hair in the drain. The blowout preventer tool, on the other hand, is a system built by PhD student Folkers Rojas (SB '09, SM '11, PhD '14) to prevent oil from unintentionally spilling into the ocean, a purposefully engineered blockage. But the mechanics behind each of them are essentially the same.

It is the specific mechanics behind this idea that for the past few years has been at the forefront of the mind of Rojas, who is graduating this year – a challenge posed to him by his advisor Professor Alex Slocum.

"I wanted to pick a PhD focus that kept me up at night," he says. "This problem had breadth; it had depth; it was a great engineering challenge. You're looking at about 1.5 kilometers of water depth (which was the case for the Deepwater Horizon oil spill), but you're also looking at approximately 3.5 kilometers for ultra-deep wells. And all of this is happening at a water temperature of 5° Celsius, and the temperature coming out of the well can be as high as 150° Celsius, so it is happening at extreme environmental conditions. The well diameter is about 0.5 meters, and you have to take into account the pressure as well, which is the equivalent of hanging 6 [Honda] Accords on each square inch of the wellbore cross-section. You also have to be able to remove the plug after you've closed the well."

With all the government-imposed regulations and inspections on oil rigs these days, blowouts aren't very likely to occur – and in fact often don't – but sometimes there is a series of unfortunate events and no effective countermeasures in place, as happened with the Deepwater Horizon oil spill in 2010. According to Rojas, who recently won second place in this year's DeFlorez Competition for his technology, it is an engineer's duty to acknowledge and prepare for inevitable breaks and errors that can eventually lead to what could have been a preventable catastrophe.

"The technologies that are in place right now take anywhere from one to four weeks for the temporary solutions to arrive on site. For the permanent solutions, it can take between four to 10 weeks. Meanwhile, every second that the well is leaking, a bathtub's worth of oil can be leaking into the ocean. It has a phenomenal negative effect on the environment but also on the oil company's finances. The Deepwater Horizon oil spill cost BP more than $40 billion. So there is a need for a better solution."

Rojas investigated several variables as he researched the solution that would be both efficient and effective considering all the concrete limitations, many of which are based on strict industry standards that exist to protect people, the environment, and company assets. The first aspect he looked at was the dynamics of the wire entanglements (i.e., the generation of the "hairball"). He had to find the right material and size so that the wire was neither too flimsy nor too stiff. Too flimsy and the wire will simply be swept away by the drag force of the flow; too stiff and the wire doesn't entangle to create a blockage. The ideal solution ended up being a hybrid of the two, a stiff entanglement inside a free-flowing medium that gets anchored against the existing obstructions (that were designed to close the well but failed to fully close in the first place). The last stage is a sealing material that allows compression of the entanglement against the obstruction and is packed by the pressure inside the well to create a cohesive mechanical plug.

Rojas also looked at the mechanics behind generating just the right type of entanglement. He researched varying angles, tilts, rotations, and velocities until he found an effective one – it starts as a little ball that moves forward as it grows bigger and longer until it creates a plug that will anchor in the pipe despite the drag force. In other words, a continuous feeding mechanism that creates a mechanical plug. His last step was to prove that the solution was scalable and ready for the next development phase.

"This is a technology that we need," says Rojas. "Someone invented airbags, and I am inventing the equivalent for oil production, an industry that isn't going to be discontinued anytime soon. Until then, we need to do it more safely."

Student Spotlight: Grace Young (SB '14)

Under the Sea

By Jessica Fujimara, MIT News Office

A house by the sea isn't uncommon, but it takes a true love of the ocean to want to live beneath the sea.

When ocean explorer Fabien Cousteau asked MIT senior Grace Young to join his team of aquanauts in living underwater for a month, Young didn't hesitate.

"I said 'Yes!' right away," she says. "It's great outreach, plus really interesting research."

Beginning in June, the expedition, known as Mission 31, will consist of 31 days living in an underwater capsule called Aquarius, 63 feet below the surface in the Florida Keys National Marine Sanctuary.

Young, a mechanical and ocean engineering major who was recently awarded a prestigious Marshall Scholarship, will take charge of marine robots on the mission and run daily Skype sessions with K-12 classrooms all over the world.

Young says that her path to robots and the ocean floor began years ago in the small Ohio town where she spent her early childhood. On weekends she would often sail at the lake near her house, and the family spent every summer in Michigan, sailing on the Great Lakes.

Her family operated a chocolate factory that her great-grandfather had opened; Young spent every day after school playing there with her cousins, watching her uncle tinker with the machines that made the chocolate, fascinated by the robotic arms that stirred, molded, and packaged the candies.

When she was 12, Young's family sold the factory and moved to Washington, D.C., where she took up ballet and began training with a pre-professional company, dreaming of becoming a professional dancer — that is, until she joined the robotics team.

"My school started a robotics team, and I joined as soon as I heard about it," Young recounts. "I honestly had no idea what it was, but I was hooked almost immediately. For a while, I was the only girl on the team, but it didn't really matter."

While she continued ballet training, Young also threw herself into robotics. It was a different sort of challenge than she faced in dance.

"I liked problem-solving. That feeling when you get something working, even just an arm on a robot or a motor turning the right way. It's exhilarating. I love it," she says. Her hard work paid off: Young's team made it to the VEX and First Robotics 2008, 2009, and 2010 world championships.

She also excelled in her science and math classes, conducting physics research at Johns Hopkins University and the University of Maryland during her summer vacations and taking advanced math classes at the University of Maryland during the school year. With her college counselor's support, Young took the unusual step of applying to college as a high school junior — and was accepted at MIT.

"Amazingly, MIT worked out," Young says.

Young joined the sailing team during her first week at MIT, and has been racing on the varsity team ever since.

"I love the wind in my face and being on the water," she says. Being under-

water has also been a favorite pastime since high school, when Young participated in scuba-diving excursions in the Florida Keys.

"It's as if you're in a new world. It's really peaceful; sometimes all you hear is the sound of your breathing and water moving around you," Young says. "In some ways I feel big, because I'm usually much larger than the fish, but at the same time I feel incredibly small, because the ocean is so huge and powerful."

But as Young has come to realize, this vast and mysterious world is in serious danger: In addition to damage to ecosystems from global warming and ocean acidification, overfishing is estimated to have depleted as much as 90 percent of the ocean's fish stocks since 1950.

Over this past summer, Young worked in Hawaii with the National Oceanic and Atmospheric Administration (NOAA) on an underwater robot called BotCam, which she hopes will help prevent overfishing. "It's basically a camera monitoring system that tracks the number and size of fish in different locations," Young explains. "The idea is that NOAA can use accurate data to set annual catch limits or mark some zones as no-fishing zones."

After graduating in June, Young plans to go on to graduate study in ocean engineering and hopes to continue her work on marine robotics to help protect the oceans. "I'm especially interested in how humans can sustainably harvest the oceans' resources in energy, food, and minerals, while conserving their fragile ecosystems. I'll likely focus my graduate research on mineral extraction — seabed mining — and how that affects ocean ecosystems," Young says. "It's going to happen in the next five to 10 years, and I want to help develop technology that makes sure it happens cleanly."

Find out more ►

Read the MIT News Office article:
http://bit.ly/1ljZlSV

Faculty Awards

Lallit Anand

Professor Lallit Anand will receive the 2014 ASME Drucker Medal.

Rohit Karnik

Associate Professor Rohit Karnik was honored recently by his alma mater IIT Bombay with the Young Alumni Achiever Award. It was bestowed upon him as recognition by the institute of his outstanding achievements in mechanical engineering as an alum below the age of 40. He was one of four alumni to receive the award.

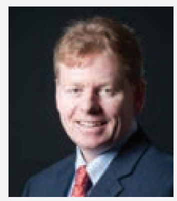
Sangbae Kim

Associate Professor Sangbae Kim was recently bestowed with a CAREER Award from the National Science Foundation (NSF) to pursue his research on gait transition principles in quadruped robots.

Hermano Igo Krebs

Dr. Hermano Igo Krebs has been named fellow of IEEE for contributions to rehabilitation robotics and the understanding of neuro-rehabilitation.

John Leonard



Associate Head of Research and Professor John Leonard has been named a fellow of IEEE for his contributions to navigation and mapping for mobile robots and autonomous underwater vehicles.

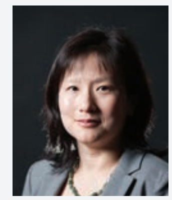
Pedro Reis

Associate Professor Pedro Reis recently received a CAREER Award from the NSF for his project, "Smart Morphable Surfaces for Aerodynamic Drag Control." *Popular Science* magazine recently named Reis to its 2013 Brilliant 10 list of young stars in science and technology.

Alexander Slocum

Professor Alexander Slocum was recently selected for the 2014 ASME Thar Energy Design Award.

Maria Yang



Associate Professor Maria Yang has been selected for the 2014 Capers & Marion McDonald Award for Excellence in Mentoring and Advising, as well as the 2014 Ruth and Joel Spira Excellence in Teaching Award. She was recently elected to be an ASME fellow and was selected for the 2014 ASEE Fred Merryfield Design Award.

Faculty Snapshots

From top to bottom: Professors Sangbae Kim and Amos Winter carry around Clare Zhang after she won the 2.007 robot competition; Professor Mathias Kolle checks out Stephanie Scott and Jeff Mekler's entry to the de Florez competition (they won second place).

Student Awards

Undergraduate

Alfred A. H. Keil Ocean Engineering Development Award (For Excellence in Broad-Based Research in Ocean Engineering)
Beckett Colson, Lampros Tsontzos

AMP Inc. Award (Outstanding Performance in Course 2.002)
Antonia Warner

MIT-Lincoln Lab Beaver Works Barbara P. James Memorial Award (Excellence in Project-Based Engineering)
Lucille Hosford, Jacqueline Sly, Katelyn Wolfenberger

Carl G. Sontheimer Prize (Creativity and Innovation in Design)
Jonathan Slocum

Department Service Award (Outstanding Service to the Department of Mechanical Engineering)
Jad El Khoury, Rohun Kulkarni, Jacqueline Sly, Katherine Spies

BP Women of Academic Excellence
Hannah Barrett, Emma Nelson

BP Women of Research Innovation
Kirsten Lim, Georgia Van De Zande

Ernest Cravalho Award (Outstanding Performance in Thermal Fluids Engineering)
David Bian

International Design Competition (Outstanding Performance in Course 2.007)
Clare Zhang

John C. and Elizabeth J. Chato Award (Excellence in Bioengineering)
Shirley Mao, Jonathan Rea

Lauren Tsai Memorial Award (Academic Excellence by a Graduating Senior)
Erin Meyer

Lockheed Martin Prize (Outstanding Sophomore in Mechanical and Systems Engineering)
Nicholas Kwok

Louis N. Tuomala Award (Outstanding Performance in Thermal Fluids Engineering)
Sarah Fay

Luis de Florez Award (Outstanding Ingenuity and Creativity)
Michael Farid

Park Award (Outstanding Performance in Manufacturing)
Josh Queeney, Yasmin Inam

2014 Phi Beta Kappa Inductees

Bruce Arensen
Sean Cockey
Grace Young

continued on page 27

Student Awards, cont. from page 26

Peter Griffith Prize (Outstanding Experimental Project)
Marta Krason, Rashed Al-Rashed

Robert Bruce Wallace Academic Prize
Jaya Narain

Society of Naval Architecture and Marine Engineering Award (Outstanding Undergraduate Student in the Marine Field)
Sarah Brennan, Priyanka Chatterjee, and Rosalind Lesh

Thomas Sheridan Prize (Creativity in Man-Machine Integration)
Kristine Bunker

Whitelaw Prize (Originality in 2.007 Design and Contest)
Joshua Born, Michael Cheung, Emma Steinhardt, Jacob Wachlin

Wunsch Foundation Silent Hoist and Crane Awards
David Christoff, Brian Foley, Julia Hsu, Manuel Romero, Hazel Zengeni

Graduate

Carl G. Sontheimer Prize (Creativity and Innovation in Design)
Michael Stern

Department Service Award (Outstanding Service to the Department of Mechanical Engineering)
Daniel S. Dorsch, Joseph Sandt

Clement F. Burnap Award (Outstanding Masters of Science in the Marine Field)
Brian Heberley

Luis de Florez Award (Outstanding Ingenuity and Creativity)
Yi Chen, Jiahui Liang, Luke Mooney, James Schulmeister

Martin A. Abkowitz Travel Award
Derya Akkwaynak, Audren Cloitre, Barry Scharfman, Yu Zhang

Meredith Kamm Memorial Award (Excellence in a Woman Graduate Student)
Leah Mendelson

Rabinowicz Tribology Award (Outstanding Research in Tribology)
Adam Paxson

Wunsch Foundation Silent Hoist and Crane Awards
Athanasios Athanassiadis, Eric Heubel, Seung-Hyuck Hong, Bavand Keshavarz, Matthew Klug, Andrej Lenert, Tapovan Lolla, Nikhil Padhye, Jean-Phillippe Peraud, Douglas Powell, Stephanie Scott, Nicholas Sondej, Brooks Reed, Zhiting Tian

Student Snapshots

From top to bottom: Students of 2.S998: Additive Manufacturing show off their 3D structures; students of 2.014: Engineering Systems Development pose with their final project; a student of 2.739: Product Design & Development presents his market-ready prototype; 2.680: Marine Autonomous Vehicles' students stand in front of the Charles River.

Department News

RoboClam Inspired by Efficient Razor Clam

The Atlantic razor clam uses very little energy to burrow into undersea soil at high speed. Now a detailed insight into how the animal digs has led to the development of a robotic clam that can perform the same trick. The device, known as "RoboClam," could be used to dig itself into the ground to bury anchors or destroy underwater mines, according to its developer, Amos Winter, the Robert N. Noyce Career Development Assistant Professor of Mechanical Engineering. Winter and his co-developer,

Professor Anette Hosoi, investigated how the clam's movement causes the soil to liquefy around its shell, and then applied the same techniques to the RoboClam. To develop this low-energy anchoring system, the researchers built a mechanical puppet clamshell, consisting of two halves that can move together and apart in a similar way to an accordion. In addition to anchoring underwater vehicles and detonating mines, the RoboClam could also be used to lay underwater cables, Winter says. –Helen Knight, MIT News Office

Ben Peters

MechE Students Win Both "Use it!" Category Lemelson-MIT Prizes

MechE students won both the undergraduate and graduate student prizes in this year's Lemelson-MIT Program "Use it!" categories, which recognize students working on technology-based inventions that can improve consumer devices and tools. Graduate student Ben Peters won for his invention of critical technology that enables the production of a new breed of machine tool: a high resolution, reconfigurable molding surface. Similar to a desktop pin-impression toy, Peters' reconfigurable molding surface combines the high production rate of injection molding with the custom reconfigurability of a 3-D printer. This "digital mold" has a technological potential to be a fast and flexible industrial fabrication tool used in commercial manufacturing, prototyping, and the emerging market of do-it-yourself personalized fabrication. An undergraduate team, led by Christopher Haid, won for its do-it-yourself personalized fabrication tool, a 3-D printer designed for the classroom. The automated, easy-to-use cloud interface and remote monitoring capabilities allow teachers and high school students to print continuously from any device. The team's invention, commercialized by their company NVBots, gives students the ability to turn their virtual designs into physical objects. Additional team members include Mateo Pena Doll, AJ Perez and Forrest Pieper. –Stephanie Martinovich, Lemelson-MIT Program

STE@M Day Welcomes Companies and Celebrates Technology in Sports

This past April, an MIT tech group started by MechE Professor Anette "Peko" Hosoi welcomed several engineering-focused sports companies to campus for the first ever STE@M Day. The group, also called STE@M (Sports Technology and Education @ MIT), was created for students who

are interested in "advancing technology at the interface of sports and engineering." Several MechE faculty gave tours of their labs and presentations about their recent research to representatives from companies such as Eastman, Nemo Equipment, Nike, Okuma, Patagonia, Polartec, and Red Bull. After the lab tours, it was the companies' turn to present their sport-related technology to MechE faculty and students for an engineering version of show and tell called the "Engineering Petting Zoo." Okuma discussed their advanced fishing reels; NEMO displayed their inflatable tents and sleeping bags; and Red Bull brought a wingsuit donned by faculty and student attendees, among many others.

MechE Students Part of Winning Team in DoE Better Buildings Competition

A team of eight MIT undergraduate and graduate students – including two MechE students, senior Cheetiri Smith (SB '14) and graduate student Julia Sokol – won two awards in this year's US Department of Energy (DoE) Better Buildings Case Competition, out of more than 150 students from across the country. The Case Competition engages the next generation of engineers, entrepreneurs, and policymakers to develop creative solutions to real-world energy efficiency problems for businesses and other organizations. The MIT team, First Fuel, led by two urban studies and planning graduate students, won in two of the six real-world case studies. They won Best Proposal for Experimenting with Efficiency: Greening the grant process for research institutions, and Most Innovative for Electri-City: Energy Management in Public Buildings. For Experimenting with Efficiency, the team recommended a three-pronged strategy to change the financial incentives and disseminate information to research labs, including establishing efficiency standards for the most energy intensive lab equipment; changing the indirect cost recovery calculation to reduce the amount of energy expenses that can be claimed; and mandating that a best-energy-practices training be required for all lab staff. For Energy Management in Public Buildings, the students recommended that the city establish a revolving loan fund, which allows energy efficiency projects to pay for themselves through avoided utility costs. –Victoria Ekstrom, MIT Energy Initiative

MechE Graduate Program Ranked #1 in US News

US News & World Report recently awarded MIT a score of 100 among graduate programs in engineering, followed by No. 2 Stanford University (93), No. 3 University of California at Berkeley (87), and No. 4 California Institute of Technology (80). As was the case last year, MIT's graduate programs led *US News* lists in seven engineering disciplines, including mechanical engineering (which tied with Stanford). Other top-ranked engineering programs at MIT this year are aerospace engineering; chemical engineering; materials engineering; computer engineering; electrical engineering (tied with Stanford and Berkeley); and nuclear engineering (tied with the University of Michigan). MIT's graduate program in biomedical engineering was also a top-five finisher, tying for third with the University of California at San Diego. *US News* bases its rankings of graduate schools of engineering on two types of data: reputational surveys of deans and other academic officials, and statistical indicators that measure the quality of a school's faculty, research, and students. –MIT News Office

Talking Shop: Professor Themis Sapsis

Predicting Extreme Ocean Events

Professor Sapsis' research focuses on the area of stochastic dynamical systems in ocean engineering, including uncertainty quantification of turbulent fluid flows, passive protection configurations for vibration mitigation in structural systems, and energy harvesting from ambient vibrations. One particular focus is on the characterization of the ocean conditions that cause extreme wave events (rogue waves) (Fig. 1), which have been responsible for many ship accidents. Since these monstrous waves, often reaching 80 feet or higher, had no obvious pattern of occurrence, Professor Sapsis and his group have been working toward the development of short-term predictive schemes that are able to quickly predict the times and locations where there is a high probability for an extreme wave to occur, before it even starts to form.

Fig 1: Rogue waves are isolated events of extreme magnitude that show up without prior indication.

MC: If these events are seemingly random, how do you gather enough data to know when to look for them or where to find them?

TS: We are utilizing information for the current state of the system that is available from radars of a ship or an off-shore platform. Using the current wave field we are able to spot locations of high probability for an extreme event. This is possible by identifying low-energy patterns that "trigger" the formation of the extreme wave; ironically, the challenge with identifying these triggers is their low energy, which makes it particularly hard to distinguish them from the complex background of waves. But we have shown that with careful analysis one can formulate ways to identify those triggers very efficiently.

What have you discovered about what is causing these events?

The mechanism we have discovered is related to a critical length-scale associated with important energy transfers – and when I say critical length-scale, it also goes with a critical amount of energy. We have seen that when we happen to have a sufficiently strong localization of energy as a result of the dispersive propagation of waves, then there is a high probability that this situation will trigger the formation of an extreme event.

Why is this happening? The reason is because this scale is the most sensitive to instabilities. Thus, if we exceed a certain amount of energy on this critical length-scale, instability occurs in which energy starts flowing into smaller and smaller scales, and that gives higher wave elevation. We analyze this mechanism by using localized basis elements that help us to understand and visualize these energy fluxes. Next, we apply statistical analysis to see how these energy fluxes are associated with the eventual formation of an extreme event. Then we use this statistical knowledge and apply it to a prediction framework where we are able to see and analyze the spectral content – in other words, how energy is distributed over space and frequencies or wave numbers. By looking at that, we are able to say that in this location there is enough energy to trigger this instability, which we have seen before and will most likely lead to an extreme event.

We are utilizing rigorous mathematical analysis and concepts in order to obtain inexpensive and practical methods that we will be able to run on real time and give useful predictions (Fig. 2).

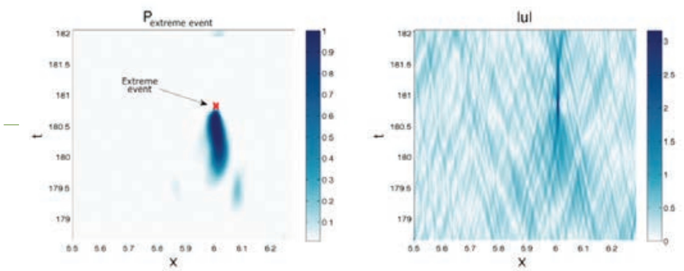


Fig 2: a) Probability for the occurrence of an extreme event (left). Actual wave field as computed through a prototype nonlinear dispersive wave equation (right).

If a crew were out on a ship, would this information help them avoid a problematic location?

Yes. We cannot control these events – this is nature, and the amount of energy associated with these events is huge – but we can avoid them. An immediate application of this information would be ship navigation – especially autonomous ship navigation. We could know where the high-risk areas are and navigate away from them.

American Bureau of Shipping Career Development Assistant Professor Themis Sapsis graduated from the National Technical University of Athens where he earned his diploma in naval architecture and marine engineering in 2005. He began his graduate studies at MIT in 2006, earning his PhD in mechanical engineering in 2011. He then spent two years as a Research Scientist in Courant Institute of Mathematical Sciences at NYU. As an MIT student, he was named the George and Marie Vergottis MIT Presidential Fellow. Professor Sapsis has also twice received the European Union's Marie Curie Fellowship, as well as the Best Paper Award for Young Scientists at the Chaotic Modeling and Simulation Conference in 2009.

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Coming in the next issue:

► Mechanical engineering for global change

Associate Professor Thomas Peacock (right) and collaborators (Thierry Dauxois, Sylvain Joubaud, Guilhem Bordes) from ENS de Lyon, France, sponsored by the MIT-France program, test their survival suits on board the R/V Kilo Moana. This research cruise was part of the NSF Experimental study of Internal Tide Scattering (EXITS) program, which took place at the Line Islands Ridge, about 1,000 miles south of the Hawaiian Island Chain. The study was focused on better understanding the location and impact of vertical mixing in the ocean.