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EPISODE OPEN

ANNOUNCER In the battle for the ball, which strategy is on target. Come join the excitement on Scientific American Frontiers. Also, scientists compete with nature to grow the rare black truffle. Find out why this fan is pointed at this fire. And meet two champions of the deep. All coming up next on Scientific American Frontiers.

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TOTAL TENNIS AT MIT

WOODIE FLOWERS Hi. My name is Woody Flowers. It really is. In addition to be host of this new Science Magazine program I'm at least partially responsible for this bedlam you see here behind me. I'm a professor here at MIT. Years ago I helped dream up a contest for engineering students that's now become an annual battle. Tonight we're going to find out who wins and how.

NARRATION This is the hottest ticket at MIT--a contest that packs the largest hall on campus. For the spectators, it's a battle of ingenious machines. But for MIT's engineering design students, it's the grand finale to a semester of hard work. And this year there's more at stake than grades and glory--the best designers will go on to Japan for an international tournament. This is the challenge: Build a machine that can capture tennis balls from the pyramid atop this mesa. At the start, the machine must fit within a one-foot cube on the starting square. What makes the task more daunting is that it's a race--another machine starts here, and both students have 30 seconds to get as many balls as possible into their troughs on the far side of the table. If you end up with more balls in your trough, you win. The red ball? It's there to break ties. Six weeks before the big night, every student receives an identical kit of materials and motors. Then it's into the shop, to tackle the toughest part of the course--transforming the box of parts into a machine that actually works. We're going to meet four of these eager engineers in training-Erin, Susie, Charlie, and Anton--and find out some of what they've learned. But now--on with the contest. Erin's up early--and right away he runs into trouble. The metal loop is supposed to lasso the balls. It misfires, and flips his machine onto its back. A quick recovery, and he's upright again. But now he's got to drive up to the tennis balls, and knock as many as he can down to his side of the table. His machine's not working the way he designed it--but all that matters is getting balls into the trough.

ERIN I was going to catch the stack and then pull so that they would land in here. And I built this fine container with its fine door and it didn't work. And I flopped upside down, and I turned myself over. Aw, I got lucky. I got really lucky. But it was fun. God it was the most fun!

NARRATION The last seconds before a match are nerve-wracking-after all, it's a final exam on stage in front of 500 people. Susie started planning for this moment weeks ago, when she got together with some classmates to brainstorm ideas.

SUSIE I mean if you could get two machines that could detach and like attack two different areas at the same time, it would be ideal.

NARRATION Susie's vision of two machines may be brilliant--or foolhardy--when there's only six weeks to turn design dreams into reality. And building complex machines takes more than screwdrivers and hammers. But through it all, Susie hangs onto her scheme for two machines: She's built a bulldozer to tackle the offense--now she's struggling with a spring-released wall that she'll use for defense.

SUSIE It's going to go into the trough of the other person, and hopefully these rubber bands will trigger it out.

NARRATION The trigger is sticky. But it works. In the contest, Susie's bulldozer gets off to a fast start. Then it rocks back and forth to deploy her wall in front of her opponent's trough. Now she can race the bulldozer around to collect tennis balls--and anything else that gets in her way. Just one ball reaches her trough, but that's all it takes.

SUSIE The trigger works! I'm happy. I'll do better next time. I'm excited to make the second round.

NARRATION To pull down that imposing stack, a net seems like an effective strategy--and there are many varieties of nets in competition. But nets have a problem: They can get tangled. Charlie recognized that flaw in the shop and came up with a more streamlined approach.

CHARLIE As soon as the power is turned on, I'll pull the switch and it will fire this thing out. And this will open up like this, and go over the pile of balls and I'll just drag the whole thing with my car. And I was testing this and I found that I don't even need a net. This will do it by itself. So, you know, the net would just get all tangled up with the balls. So, I was really psyched about that. I mean, it will cut down on my work by a lot.

NARRATION In this match against a net, we can see why Charlie's design is better. His heavy projectile pulls down the pyramid more effectively than a net--but right here is his most important innovation: He releases a string and leaves the projectile behind. That means it won't get in his way, and it makes his vehicle lighter and faster. While the net machine pushes around its useless front end, Charlie's more maneuverable tractor is pushing balls into the trough--and demonstrating its contempt for nets! Anton has also designed a wall for defense. He built it quickly-then ran into some surprises in the testing room, when he dared a classmate to try to overcome his wall.

CLASSMATE Nice job.

ANTON Geez, small problem. The center of gravity doesn't look like it's inside the trough there, does it.

NARRATION Anton starts to gloat. But then ....

CLASSMATE You have to redesign it, Anton! Have to redesign it. Oh my God!

NARRATION Exposing design flaws is the reason testing's so important--and Anton hasn't finished learning yet.

ANTON My screws are a bit too long on the side, which means that you can push these balls over the edge and into the, top of the wall.

CLASSMATE I like that.

ANTON Another problem is they push it out of the way.

NARRATION In fact, for most machines, testing means struggle-and failure.

STUDENT That didn't work.

INSTRUCTOR You have a traction problem, not enough weight.

NARRATION But on the positive side--when the machines are this far along, students can get helpful suggestions from the instructors.

INSTRUCTOR What we have to do is widen that about two inches, and then you can win. OK? It's going to work.

NARRATION And the pace accelerates: Redesign, rebuild, test again--and try to keep learning from all your mistakes.

ANTON Well I've improved the wall, two sort of basic things. I increased the weight of the ball by just putting this heavy metal piece in the back. It just weighs five pounds so it's very hard to push. And I've also put square wheels on it. So, in essence, if you are trying to push it, you are pushing square wheels, turning square wheels, which is really had to do. And I've also flattened the sides off a bit so we can just bounce the balls off the side onto the top. And hopefully it will work really well.

NARRATION In the contest, Anton's extended the wall--but he triggered it too early, and it's not in the trough. That forces him to fight a battle in the trenches--and he pulls off a narrow victory.

ANTON We did it! I'm happy!

NARRATION Some matches are classic duels. But in other matches, the machines aren't quite on target. And just climbing the hill is too much for this pair. These tennis balls are frustrating a lot of students, and one rogue entry sums up their feelings eloquently. As the contest moves into the next round, some of the designs are emerging as strong contenders. This wall unfolds smoothly, and the speedy tractor wedges it solidly in the trench. With perfect placement, it takes just one ball to win--but pinning the opponent's vehicle is a more impressive victory flourish. Here's another strong starter: As this machine pulls down balls, it gobbles them up. Then it trundles toward the ditch--and this feeding machine doesn't even have to unload. It just parks right in the trough. A slick design that could win it all. Watch the machine on the right. It pulls down the balls with a belt. Then the tractor's front end flicks the balls into the ditch. This belt machine is another strong threat. Meanwhile, Erin's machine is forging ahead, even though it's never worked the way he designed it.

ERIN The secret of my success is that it's slow and powerful, so I can drive it well. I dismantled the arm because, you know, it doesn't work, and so I am beating people that, their machines mess up I can't screw this up now. It is literally a tank now, that is all it is.

NARRATION Now that he's abandoned the erratic metal ring, his tank just racks up balls to clinch the victory. In round after round, the pattern is the same. Erin nudges home another winner and keeps on advancing.

STARTER Are you ready? Go!

NARRATION Anton's up again. He heads directly for the other player's trough, and unfolds his wall in just the right spot. Now he drives over to knock down some balls. And then bad luck strikes. The red ball rolls right into the opponent's corner. That really rattles Anton, and he loses control. Fierce competition is taking its toll.

ANTON I was just too nervous, I just drove off the table. I couldn't handle the pressure, you know. Nerves, yeah.

CAMERON He just forgot how to drive.

NARRATION Charlie is winning one match after another. His V-shaped projectile consistently pulls down most of the stack. And that's not his only weapon. He's also got the speed to clean up balls all over the table. We're into the late rounds now. All the machines still running are strong, and every match from here on figures to be a fight to the finish. Case in point: This wall is perfectly played yet again, and its designer is already starting to celebrate. But even when you do everything right, things can go wrong. The stubborn wedge machine drives two balls under the wall. Last-minute victory is a thrill for the winner--and a stunning disappointment for the loser. Erin's up, against a cute and tricky penguin machine. This time the tank is too_ slow and steady--the penguin beats him to the top and snags some balls, including the red one. Then Erin bumps a few balls to his side. After a heart-stopping roll, only two wind up in his trough. That makes it two all. But the tie-breaking red ball is on the upper side, and Erin is knocked out of the contest. Susie's turn now, against a projectile machine. The smiley-face design is camouflage. This projectile is taking very serious aim. Meanwhile, Susie's gotten herself stuck in the ditch. And when she works her way out, she jams her wall right up around the red ball--on her opponent's side.

SUSIE My driving drove me to the ditch. I really wish I hadn't because I really think I could have won that round. But I got lucky last round. Those are the breaks. So let the best man will win.

NARRATION The best man will be Chris, Pat, Pete, or Charlie-the only one of our original group still in the running. These four have made it this far because they designed take-charge machines that can attack the stack, collect balls on the table, and deliver them to the trough. In the first semi-final match, Charlie, with his detachable projectile, faces Chris and the belt machine. One emphatic push, and Charlie's headed for the finals. The other semi-final pits Pete and his feeding machine against Pat and the penguin. Right from the start, the penguin is hopelessly outclassed. Pete's feeding machine swallows up a cartload of balls and then plows into the trough. That sets up the final match of the contest. Six weeks of frantic work, of designing and building and testing, has come down to this moment. The projectiles collide, and just three balls roll Charlie's way. He decides his only hope is speed: maybe he can block the feeding machine. What Charlie can't see is that Pete's jaw has jammed, and the feeding machine rolls away empty. Pete can still win by bulldozing the balls on his side of the table. But Charlie's machine is full of surprises. We know he's got a clever projectile and a fast tractor--now, in a nose-to-nose shoving match, Charlie shows he's also got raw strength. Thanks to this triple-threat design, the pride of the championship belongs to Charlie. He'll be leading MIT's contingent to Japan. And Frontiers will be there with him, for the world series of engineering design.

WOODIE FLOWERS The question that I'm often asked about these contests at MIT is "Why?" Sure, they are a blast, but each one requires months of planning. The companies donate thousands of dollars in bits and pieces to use in building the machines. Two hundred students spend about a hundred hours each. They are a big deal. Why do we do it? To give the students the experience in the engineering process. You see, knowing the facts and figures is not enough. We all have to learn how to apply them. Now, tackling a real, live engineering problem is not like competing in the contest, but building one of these machines is real engineering. That it happens to be fun is just lucky, I guess. Maybe that says something about engineering.

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DESIGNING DELICACIES

NARRATION A foggy January morning in the south of France. Farmer Boisset is trying to sniff out one of the world's most mysterious crops. They are hunting the black truffle. Not a chocolate, but an exotic species of subterranean mushroom prized for its unique, musky flavor. The truffle's humble appearance--much like a small potato-is deceptive.

M. BOISSET That smells good.

NARRATION But these days truffle harvesters face a crisis.

M. BOISSET You used to find them everywhere. But now there are not so many. Out of thirty oak trees, only two will have them underneath.

NARRATION That's bad news for farmer Boisset. And for his pig. To understand the problem, you first have to understand how the truffle grows underground. Every year thousands of truffles are harvested, but some remain underground, releasing spores from which tiny filaments emerge. These filaments--called mycelia-grow around tree roots, eventually forming a special type of growth, part tree, part truffle, which helps both feed each other. Seven years after the spores are first released the mycelia mysteriously knit together to form a truffle that will be ready for harvest. And that harvest goes on sale here in Lalbenque, 400 miles south of Paris. This historic market is devoted exclusively to truffle trading.

FRENCH MAN Would you like to buy some? Truffles are still available, but only in very small quantities.

WOMAN I don't know if you realize just how few truffles there are.

NARRATION The annual French harvest has dropped from 1000 tons to 50, and that sent prices through the roof. At 2000 francs per kilo, that's $175 a pound. There is hard bargaining...and careful weighing.

MAN Look, 800 grams

2ND MAN No, one kilo!

NARRATION So for anyone who can dream up a way of improving the truffle harvest, there is money to be made. Six thousand miles west of Lalbenque, just outside Davis, California, these two researchers may have perfected the world's first artificial truffle. Dr. Moishe Shifrine, the project's director, has to solve one key problem: How to mimic the truffle's natural life cycle in the laboratory. This tiny piece of real truffle contains spores which will, if left for several weeks, produce mycelia. In nature, tree roots provide this delicate growth with nutrition, but here in California the mycelia don't need trees. They flourish on a top secret liquid medium prepared by Dr. Shifrine and his colleague, Randy Dorian. As the truffles reach maturity, temperature, light level, and humidity are all strictly controlled. The result is a biological breakthrough. Not a truffle as we know it, but a carpet of truffle-like material.

RANDY DORIAN In nature, truffles grow exclusively in association with the rootlets of oak trees. Most people have assumed that there is an absolute requirement for that association. But we have found that in fact if the right conditions are simulated in the laboratory, that the truffles will develop quite nicely in the absence of oak trees.

NARRATION Of course, with this method there is no danger of a truffle shortage. But these sheets of growth are too delicate to be sold on the mass market. So instead, they are dried and then ground up into a fine powder, or mixed with olive oil. But there's one crucial question left. Does this product have the unique flavor of the true French black truffle? Dr. Shifrine chooses to sample a mix of artificial truffles...

DR SHIFRINE Boy does that look good.

NARRATION And vanilla ice cream.

DR SHIFRINE It's very good.

NARRATION Still, Frontiers wanted a second opinion, and so we took the California powder back to France.

CHEF Pure black truffle …qu'est ce que c'est?

NARRATION Chef Pierre Corre is skeptical. He is going to make two omelets, the first with artificial truffles.

CHEF I am putting the eggs into the pan. runny omelet. Here is the American omelet. I am going to make a Now I will make an omelet with French truffles. I am going to cook it runny. Omelets are supposed to be runny. I'll turn it out on the plate. Now I'll garnish the plate.

NARRATION It's all preparation for Frontier's first blind-fold taste test. How will the artificial California truffle perform? It's a tense moment.

WOMAN It has a bland flavor.

MAN It tastes like a plain omelet. I can't detect that special truffle flavor.

NARRATION Our tasters claim that the artificial truffle is totally tasteless. How about the real thing?

MAN This is a totally different flavor. You can really taste the truffle.

NARRATION Now with the blindfolds removed, what's the verdict? MAN There's no comparison. One omelet has a real taste; the other doesn't.

NARRATION But why doesn't the artificial truffle taste like its French cousin? Jean Marc Olivier leads truffle research for France's Department of Agriculture.

OLIVIER It is not a truffle smell.

NARRATION But it's hard to make an exact judgment on the basis of scent alone, so Dr. Olivier's team decides to take a closer look at the artificial truffle. Is there any visible clue which could explain the lack of the authentic taste and smell? Here's how the powder looks through the microscope--thin strands and clumps of loosely-scattered material. To an untrained eye, it's hard to make a quick analysis. But Dr. Olivier can tell at a glance that there's a crucial element missing.

DR. OLIVIER No spore, no sign of spores. That means that it is sure it's not a true, mature fruit body. If we have a mature fruit body, it's necessary to find spores and here is nothing.

NARRATION Under the microscope, the difference is clear. The California powder appears to be composed of chopped up mycelia, but real truffle--what Dr. Olivier calls the "mature fruit bodies"--contain tiny bags filled with spores, the seeds that produce mycelia that will themselves eventually form more new truffles. So the California truffle mimics part of the natural process by producing mycelia. But it doesn't appear to copy that mysterious final stage of development which produces the mature truffle. And that means one thing is for sure.

M. AVERSENG So far, despite all the research all around the world, nobody reached to get truffles with host tree.

NARRATION At this nursery outside Bordeaux, Pierre Averseng grows thousands of oak and nut trees, just the species with which truffles grow well. He and Jean Marc Olivier have developed a simple way to help nature along and thus restore the French truffle industry. They try to guarantee a bumper truffle crop by spreading a special mix of truffle spores and nutrients onto the medium that will hold the young tree's roots. If the bond between tree and truffle can develop at this nursery stage, then it should be well established when the tree is planted. It's a fragile union that depends on two key elements. The potency of the truffle spores and the health of the tree's root system. Now Dr. Olivier's group has come up with a way to marry tree and truffle even earlier. Every tree in this laboratory forest is genetically identical, cloned from a hybrid chosen for its hardiness and elaborate root system. The clones are a perfect match for this priceless raw material. Thousands of spores of the black truffle which could eventually restock France's truffle grounds. In a controlled environment, the natural process is copied precisely as each tree receives a carefully delivered dose of truffle spores. Early in 1998, these infant trees will have grown up, and best of all, their rich harvest of natural truffles will be ready to eat.

M. AVERSENG We like truffles very much in France. For dinner, it's a delicacy. It's a wonderful thing. Truffles.

WOODIE FLOWERS So in comparison to California's artificial truffle project, the French approach stays very close to nature. And this natural approach will produce powerfully flavored truffles that should keep farmer Boisset and his pig happy--years to come. Truffles are not a major part of my diet, but I do enjoy them. And I'm an even bigger fan of American innovation. So I think the California truffle deserves a second shot. That taste testing in Bordeaux--come on guys! A French chef, two French taste testers--not exactly what I'd call an unbiased test. So we're going to do it again. This time, in a traditional American institution. One of the problems that I had with the French taste test was that the blindfolds couldn't hide the texture difference between the California powder and the natural truffle. So we've gotten a new sample of the cultured truffle which looks and feels a lot more like the real thing. Our master chef Pat chopped them both up and added the same amount to each omelet. I don't know which one is which. But here goes. Well, this one has a fairly strong flavor that's not particularly pleasant--pretty heavy. Mushroom aftertaste. This has a nice complex musty flavor. So it looks like I agree with the French judges. But hey, California wines were a little rough around the edges at first too. Keep trying guys!

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DEEP DIVERS

NARRATION Ano Nuevo State Park is a nature reserve near Santa Cruz, California. And home--some of the time--to one of nature's most remarkable animals. These elephant seals, lounging in the shallows now, will spend much of their year far out in the Pacific, and most of their time far below its surface. It's mid-March right now, and this year's pups have been weaned and left behind by their mothers, who are already back at sea. Also left behind for the moment are the adult males, engaged in a few noisy but half-hearted brawls--the real fights were earlier, during the mating season. It's the males--which can weigh up to two tons--that have brought these biologists here today. Because soon the males too will be heading out to see--and before they go, the research team from the University of California, Santa Cruz, hopes to equip some of them with their own personal computers. But first the seal must be sedated--and when trying to put a twoton animal to sleep, it helps to know what to expect. Biologist Dan Costa.

DAN COSTA That was very typical that they rear up and sort of look at you and wonder what you are doing, and then go back to sleep and ignore you.

NARRATION Before he gets his computer, the seal will be measured.

DAN COSTA I don't think it's ready yet.

NARRATION It takes fifteen minutes for the seal to doze peacefully enough for its computer to be installed. That involves at patch of marine epoxy pasted on its hide. The tiny computer itself is part of an instrument package that also includes a depth recorder. For up to three months the device will record information about when and how deep the seal dives. When he returns to Ano Nuevo beach to moult, the recorder will be removed. Dr. Burney LeBoeuf.

BURNEY LeBOEUF It gives us a lot of data into the animal's diving behavior, its foraging behavior, and it tells us something about this black box called the sea which the animal enters into and then comes out of two months later.

NARRATION Until now, what happens once the seal disappears into the black box of the sea has been an almost total mystery. But the data the seals are now bringing back with them is revealing an astonishing picture.

BURNEY LeBOEUF In about twelve hours, he goes to sea and at first he is simply swimming about on the surface. Three o'clock in the morning, he gets very serious about it. He starts to dive to a depth of about a hundred meters. And this continues for about a day. And then he heads to deep water at five o'clock in the afternoon two days later, and he starts to dive rather deeply. This means he dives about three, four hundred meters.

NARRATION We've converted these data from the seals' computers into profiles of what Burney LeBoeuf has found are typical dives. After just two or three minutes of rest on the surface, the seal again dives to some four hundred meters--over thirteen hundred feet. The dive lasts about twenty minutes or so, and then the process repeats itself, over and over. LeBoeuf guesses that dives like these are how the seal travels. Other dives go to five hundred meters, over sixteen hundred feet, with the seal spending eight to ten minutes--probably feeding-at the bottom of the dive, before returning to the surface for another three minutes or so to breathe. Some dives go beyond the limit of the depth recorder to over one thousand meters--that's more than three times the height of the Empire State Building. But it's not just the astonishing depths of his dives that make the elephant seal so extraordinary.

BURNEY LeBOEUF They are spending 90 percent of their time at sea under water which is fantastic. No other marine mammal, even the whales, appear to spend that much time under water.

NARRATION The lengths and depths of the elephant seal's dives make it the clear world champion of diving. As to how it does it, we turned to another world champion to help us find out. This is Enzo Majorca. Taking a deep breath, he is about to plunge into the Mediterranean Sea off the coat of his native Sicily. He has no oxygen other than the air in his lungs. A weight carries him on this dive to a record depth of ninety-four meters, over three hundred feet. At the bottom the weight is released. Before he reaches the surface again, he will have held his breath for two and a half minutes. This unusual sport is called breath-hold diving. Majorca's daughter, Patrizia. She has inherited her father's love of the sport, and shares his feelings toward the sea.

PATRIZIA The sea is not our adversary.

ENZO MAJORCA The adversary we struggle against is ourselves.

PATRIZIA Against our own limits.

ENZO MAJORCA And our own fears. Because we go into the sea as typical people. We're absolutely normal people, and we go down there with normal fears.

NARRATION Daughter Rosanna completes the family team, favoring a head-first technique which on this dive will take her to seventy-eight meters--over two hundred and fifty feet. While the Majorca's dives aren't impressive by elephant seal standards, by human standards they're extraordinary. But even more remarkable is that both seals and humans cope with prolonged submersion by the same mechanisms. Seals may be much better divers--but humans are easier to study. The Majorca family has been invited to this facility at the State University of New York in Buffalo. The Center for Research in Special Environments is set up to look at how the human body copes with extreme conditions. Its director is Dr. Claes Lundgren.

CLAES LUNDGREN If you are at all interested in how the body reacts to severe stress, whether it be encountered at great depths or at high altitudes or from heavy exercise, what have you, it's very useful to push the body to its limit. It is as if you were looking at how the body reacts through a magnifying glass.

NARRATION Today the magnifying glass of Patrizia's particular abilities will be used to examine a universal reaction, one shared by all mammals--humans and seals included--to going underwater. It's called the diving response.

ENZO Patrizia, your eyes will have to get used to the water. Otherwise, they'll burn and you will be crying. So do an immersion first with your eyes open. Patrizia enters a pressure chamber that will be set to simulate a dive of forty meters--over one hundred and thirty feet. That's not extreme by the Majorca standards, but every deep dive has its risks. Of the several measurements to be made of the diving response, a key one will be the pressure on this band around her calf. When a blood pressure cuff around her thigh is inflated, it will prevent blood flowing out of her leg through the veins. Blood will still flow into her leg through the more deeply buried arteries.

ASSISTANT Placing the cuff now. Cuff is placed.

NARRATION Here's what happens when Patrizia is simply standing at the surface. The pressure on the calf band--the lower line--slowly increases as blood flowing into her leg is trapped by the blood pressure cuff, and her calf swells. When the cuff is released, the pressure falls as the blood escapes. But what will happen when Patrizia dives? As she submerges, pressure in the chamber is rapidly increased, creating the same effect as going deeper and deeper underwater. At the equivalent of forty meters down, she signals she's o.k., and the blood pressure cuff on her thigh is inflated. This time the lower line stays flat, showing there's almost no blood being trapped in her leg. The only explanation is that little or none is entering. In fact, this is what's happening. One of the first things that occurs when humans or animals go underwater is that the arteries supplying the outer parts of the body like legs and arms narrow sharply. This preserves the precious, dwindling store of oxygen-rich blood for the organs that need it most--mainly the heart and brain.

CLAES LUNDGREN So this is a way to stretch the oxygen supply and delay the onset of loss of consciousness--hopefully until you have been able to return to the surface where you can start breathing again.

NARRATION Patrizia has been under water for almost two minutes now. The mechanism her body is using to preserve oxygen supplies to her heart and brain is shared by us all. What Patrizia adds is training and a steely nerve. A second key part of the diving response is about to be measured in Enzo Majorca, as he prepares for the deepest dive ever attempted at the Buffalo facility.

CLAES LUNDGREN It's the dive which will put the greatest stress on the diver of all the experimental dives we have done in the series--because of the low water temperature and certainly because of the great depth.

NARRATION The diving response is more extreme in colder water. This dive is in water almost twenty degrees cooler than the other dives in the experiment, and is planned to go to seventy meters-well over two hundred feet. As the pressure is increased in the chamber, Enzo has to compensate for the growing pressure on his ear drums by forcing air into his ears.

MAN Forty meters.

NARRATION At forty meters his heart rate slows drastically, to one beat every five or six seconds. This is the second major feature of the diving response. As blood flow to rest of the body is cut, demand on the heart is lessened. That means it can beat more slowly, reducing its own need for oxygen, and reserving the diminishing stores for the most important organ of all--the brain. Enzo's diving ability--he once held his breath underwater for five minutes--is a dramatic exhibition of the diving response. But even Enzo has his limits. At fifty meters he begins to lose control of balancing the pressure in his ears--and he signals to come to the surface.

CLAES LUNDGREN He had ear problems at fifty meters. But otherwise it went well. There was a considerable slowing of the heart and we will have to look at the details before we say any more than that. Quite a lot of slowing of the heart. Which we expected.

NARRATION Enzo Majorca and his daughters are providing new data to understand how humans as well as seals cope with being underwater. The experiment is over and the scientists are pleased, but Enzo, like all champions, does not like to accept limits.

ENZO MAJORCA At fifty meters I, I will, I will be forced to stop myself because my compensation was bad. I even tried about ten seconds, but I have seen that I was not able to make the compensation, and I suffered the effects.

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SAFER FIRE FIGHTING

WOODIE FLOWERS When I was growing up in Louisiana, I learned how to keep a campfire alive. As everybody knows, when the campfire begins to fade, you carefully add a little fuel, and then you lean over and you blow, and try not to inhale too much smoke. Now here in New England where that same process is very important on a cold morning, this thing, which is called a blow poker, is a real big help. You see, it lets you direct a stream of air and its oxygen right on the glowing embers. Suppose I were a fire fighter, and my job was to put out a fire. The last thing I'd do is blow on it, right? Well, the next story is about a North Carolina fireman who's shown that sometimes blowing on a fire can make it easier to fight--and help save lives.

NARRATION At the fire training school in western North Carolina, fire fighters find out what it's like to confront one thousand degree flames from a few feet away. Protective clothing saves them from instant incineration. But in a real fire, heat is only half the danger they face.

INSTRUCTOR Once we get you in there, we are going to do what we can to get you lost. And we want you to find your way out doing that. Now we will be there with you, o.k.? So if you, if you panic, don't drop and run like a scared puppy, o.k.?

NARRATION This is the smokehouse, a sealed building filled with dense smoke. The carbon monoxide in the smoke is deadly, and fire fighters can only enter the building wearing breathing equipment. Today's drill: What to do when hot, lost in the impenetrable smoke, and out of air. The fire fighters are taught that a glove works as a temporary filter. The danger now is panic.

INSTRUCTOR What I want you now to do is I want you to find your way back out of the building. Using one of the techniques that we told you about. O.K.

NARRATION Closer to the floor the smoke is less dense and deadly, so fire fighters learn to move around on their knees. Smoke, deadly gases, heat--these are what kill fire fighters. And this, a powerful fan, is what now may help save them. The idea is simple on the surface: Blow the smoke and heat away through an open door or window. Instructor Larry Hughes.

LARRY HUGHES You can see how the air currents start to move and flow toward the exits, and within a matter of seconds, the visibility really increases.

NARRATION Larry Hughes has spent several years trying to prove to a skeptical fire fighting community that sometimes blowing on a fire can help fire fighters put it out.

LARRY HUGHES We have a lot of chiefs that basically are set in their ways, and when something innovative comes along, they like to read about it. But they are real slow about putting it into the fire service. Especially when you have been taught for hundreds of years that you don't add air into a fire room. And this goes against every principle that instructors for years have taught. Okay. Six and a half.

NARRATION So Larry Hughes has planned an experiment to prove his point. He and his colleagues are setting up smoke and heat sensors around what's called a burn building, a structure in which fires can be deliberately set and fought. This one monitors carbon monoxide levels--a measure of how deadly the smoke is. And this sensor monitors temperature.

LARRY HUGHES These are just heat probes. And what we'll be measuring here is at six and half feet when we'll run this one up from inside and give it three feet. So we're say like at bed level.

NARRATION With the burn building wired, it's the fire fighters' turn. Coast Guard Lt. David Eley is studying how fire fighters get in their protecting clothing. It's not just the fire they're fighting that heats them up.

DAVID ELEY You literally got a fire going on inside your body. When you're contracting muscles, exercising, even the beating of your heart is generating heat. Every one of those cells are burning little bitty fires. They are all, they're all generating heat, waste heat. It's got to be gotten rid of. It's got to be dissipated.

NARRATION Sweat evaporating from the skin is the main way the body rids itself of heat. Mike Calhoun, one of the fire fighters who'll be tested in the fan experiment, has a skin temperature at first of a normal 91 degrees. But it won't stay that way once he puts on his protective clothing. The suit helps keep flames away--but it also prevents the evaporation of sweat that cools his body. So in a hot fire, he can bake both from the outside in and from the inside out.

FIRE FIGHTER Fire is ignited. Fire is ignited.

NARRATION The control experiment--fire without the fan.

FIRE FIGHTER Four hundred fifty.

NARRATION Immediately the temperature in the building climbs to levels that can't be survived without protective clothing.

FIRE FIGHTER Four hundred ninety five. Mark, five hundred degrees.

NARRATION The five hundred degree mark is the fire fighter's signal to enter the building. But they wait until the fire is even hotter before attacking it.

FIRE FIGHTER Six seventy five, we're hanging right around there.

NARRATION The fire is quickly extinguished. But the fire fighter's job has only begun. Through the still dense smoke they must search the building. If this dummy were real, the high carbon monoxide levels would already have killed him. And the lingering deadly fumes continue to trigger alarms outside for minutes after the fire is out. Temperatures inside the building also remain high. After ten minutes in this deadly environment, the fire fighters emerge. For all this time, their exertions and the heavy protective gear--as well as the heat in the building--have been pushing their temperatures higher and higher.

FIRE FIGHTER 100.3 Fahrenheit.

DAVID ELEY We had high skin temperature readings of a hundred degrees. And that's above his core temperature. What that means is that, as the blood, the hot blood comes out to the skin, it's not cooling off. It goes back to the body, still hot, picks up more heat, and his body temperature begins to heat up. And it will creep up, creep up, creep up. And at some point it's just going to take off. And that's when you have heat stroke.

NARRATION Heat stroke could cause a fire fighter to pass out-potentially fatal in a fire--a fact Larry Hughes knows well. It's one of the risks to fire fighters he hopes his fan will reduce. The fire in the burn building is lit again. The fan forces air into the building, creating higher pressure inside than outside. Hughes opens a window next to the fire. At once, visibility improves as the heat and smoke generated by the fire are pushed out of the building. Inside, carbon monoxide drops rapidly--to levels that would have allowed this dummy's life to have been saved. And temperatures in the building drop rapidly, too. Inside his suit, Mike Calhoun's skin temperature measures a much healthier 94.8--and dropping. So in this test, the fan does its job. But Larry Hughes knows it will take more than a controlled experiment to convince fire chiefs to change their ways. What he needs is a real fire, in a real house. March 24, 1990. Outside an abandoned house in Marion, North Carolina, fire captains from around the state are preparing to see for themselves what Larry Hughes's fan can do. This time there will be gasoline to make a really big fire in the house-donated by its owner for the test. Within seconds, thick black smoke fills the house. Correct placement of the fan is critical. It's on the other side of the house from the room with the fire, so as the pressure in the house builds--and the fire fighters enter--the smoke and heat are pushed away from them. As an escape route for the smoke is created, the air clears more rapidly. And within moments not just the smoke and heat but also the fire itself is pushed outside. Had the powerful fan been pointed from the outside into the fire room, the fire might have spread over the attacking fire fighters and through the rest of the house. But in this fire, the fan helps the fire fighters douse the flames quickly--and by clearing the smoke, makes the search of the house much easier. The fan stays on even when the fire is out, helping clear the remaining smoke and heat. It's time for Larry Hughes to get the fire fighters' verdicts.

LARRY HUGHES Let's get together right over here. How much heat did you feel?

FIRE FIGHTER There wasn't any heat. A little bit around your legs, I mean along the floor coming out.

ANOTHER FIRE FIGHTER But you could see plenty of fire around all around you, yeah, fire all around.

ANOTHER FIRE FIGHTER But it was not hot.

LARRY HUGHES How quickly did that room ventilate itself and how quickly could you see every aspect of the room? How quickly could we go into the rest of the house and search for victims after we knocked it down?

ANOTHER FIRE FIGHTER Within thirty seconds. We had complete visibility in there so you could stand up and walk around in less than a minute.

NARRATION And the temperature monitors backed up the experience. The building started cooling down even before the fire was out. Larry Hughes has proved his point. Sometimes fanning the flames can help kill the fire.

WOODIE FLOWERS What I like about this story is that it proves you don't have to have a bunch of fancy degrees to think like a scientist. Larry Hughes proved his theory by paying attention to his own curiosity, being persistent, and understanding how to do a good experiment. And that's what counts out on the frontiers of science. See you there next time.

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