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目　录

本期继续刊登美国科技教育系列片《寻求解答》后四集。

《星期日英语》每周星期日14:00—15:00由中央电视台播送。

TRIAL & ERROR

DAROLD CUMMINGS: You have a flying start or you go 200 meters and anything that's human powered is legal.

KEACH: No speed limits here. Just limits of muscle and invention. When you're after the speed record for human powered vehicles, you have to experiment, tangle with the gears, modify the stream-lining. Vary the position of the human engine, and try again. New hunches, and new combinations...

PAUL MAC CREADY: It's pedaled like a bicycle. It's got a 96-foot wingspan. You have to pedal fairly hard, but then you're able to keep it up in the air. It takes a really good bicyclist to keep it up for a long time.

DAVID GORDON WILSON: Well I've done about a third of a million miles, and I happened to have designed what I think is an improved bicycle. And I don't know whether it's really going to be better than the past one or not. But I'm going to try it. I think it's important to try it. Ideas are cheap actually. If you get into the procedure of problem-solving, you can come up very easily with ideas. But developing them to the point at which they are really practical is a great deal of trouble. It's why the Gossamer Condor experience is such a beautiful example, because that was the only plane that could be tried, could crash, they could mend it, and try it again next day. And so I think they tried thirty-five times, before it would perform as designed.

KEACH: You try something new. So it doesn't work. At least you know what not to do. Some call it trial and error. But it's more like trial and learn. If it's never been done before, how else can you figure it out? So you keep plugging. Who knows? Maybe you'll get something that flies.

WILSON: Trial and error shouldn't be simply trying something at random, and then seeing if it works. They should have some sort of a plan, and learn from the mistakes of the previous one.

MAC CREADY: Others tended to follow the same route, so, one person would make a plane, and the next one make one that was just a little better but had the same general philosophy, and that didn't permit any great leaps forward. Just slow evolutionary progress with a huge amount of work.

The big difference with the Gossamer Condor, it was simple to build, easy to repair. The whole plane is just about getting ready to break all the time. If any part is so strong that it'll never break, that part is too strong and too heavy. It's all aluminum tubing, piano wire, a little bit of wood, glue, mylar sheet, half mil, and quarter mil, lots of tape. We broke some of the tubes in the fuselage, we might be flying thirty minutes later just by putting in some splints. And we did a huge development job in a one year period, and it was feasible to do that because construction was so easy. I've just been doing some studies on the horsepower that it takes for a hand glider to fly. A really good hand glider only takes about one horsepower to keep in the air, then it dawned on me that if you tripled all the dimensions of a hand glider, just made it three times as big, but made it so that it didn't weigh any more, why then it would only sink a third as fast. And the horsepower to keep it aloft, would only be a third as much. So suddenly that's in the range that a human can put out. We now call it a human powered airplane because women fly it as well as men, and boys and girls as well as adults. It's probably the easiest to fly airplane that's ever been made, and if you catch thermals and go up to the clouds, but it wouldn't be safe.

KEACH: Some clouds are unsafe for any kind of plane. Clouds filled with water below the freezing point, are called supercooled. The water is just waiting for an excuse to turn into ice. An airplane can be the trigger. Ice coats the wings, they lose their lift. The plane becomes an instant rock.

VINCENT J. SCHAEFER: In 1946, I was trying to find material that could be used to seed clouds, because we were very much interested in preventing the icing of airplanes. And I had the idea that if I could eliminate supercooling, that would eliminate the icing problem. So I searched for various materials, or just ordinary off-the-shelf chemicals that might be used including various soils, quartz particles, and so on. . . but never had very effective results. Until one day in July of '46, when my chamber was not operating cold enough, I got a chunk of dry ice to see if I could cool it down more. And of course, the instant the dry ice went into the chamber, I found I had the answer I'd been searching for for a couple of years. Then I took the piece of dry ice out of the chamber, used a smaller piece and then still a smaller piece and finally found that the tiniest fragment was all I needed to completely saturate the supercool cloud with ice crystals.

KEACH: So it doesn't take much to drop the cloud on the ground, to snow, or rain. A pellet of dry ice, the size of a pea, shot into a supercooled cloud, can release hundreds of thousands of pounds of snow.

SCHAEFER: To be actually realistic about it, I was searching very hard to find something that would produce ice crystals. That was, I'd been working on that for over two years, but by a very fortunate accident, which we call serendipity, I found that the dry ice was the thing I was looking for.

KEACH: The Tour de France, a brutal test. 2,500 miles in 20 days. The riders are almost equal. The bikes almost exactly alike, so you have to work hard for small advantages. Champion Bernard Hinault pedals with a circular motion. Easy on the metal. So he can use a lighter bike. You try almost anything. To cut wind resistance, some riders are experimenting with shirts made of slick material. In terms of the energy you put in, and the speed you get out, bikes are already the most efficient transportation ever invented. But you can't stop there. There's always next year's race. Sometimes pioneers set out with nothing but a hunch. Back in 1901, an immunologist named Paul Ehrlich had the idea that man-made chemicals might search out specific germs in the body, and kill them. A magic bullet, he called it. Doctors called him crazy. In this laboratory, Professor Ehrlich, tried chemicals compounds one by one on diseased animals. A laborious process. He tried ten. He tried fifty, one hundred, three hundred. Finally, years later, number 418 gave him his first positive answer. It killed the infection. It also killed the mouse. But now Ehrlich could narrow his search. He started trying all the chemical variations related to compound 418. Then at try 606, a compound he called Salvarsan, it killed the infection, and spared the mouse. Salvarsan became the first real cure for syphilis. Other man-made chemicals would be identified as disease fighters. Medicine had a new arsenal. Chemotherapy was born. Ehrlich's approach was to test everything — a kind of brute force technique, still used by some researchers. Others use a deductive method. Like Dr. Phillip Crews who was looking to see if nature has evolved answers of its own. Some organisms in the sea are shunned by other living things. They may contain chemicals that can be used to fight diseases.

DR. PHILLIP CREWS: We go out and we look for plants and animals that seem to be being avoided by, by other species. Now this suggests to us, a clue. A source for, for interesting new chemistry. There are a number of compounds we're isolating from the ocean that have never been seen before. And in fact, we're asking ourselves: "Can they be active perhaps against insects? Not only insects, but disease? This is a really neat tide pool because it has a lot of different specimens. And, this one here is really different — this long one right here. Or in fact the eel grass right here. And in fact, at this spot, there's lot of different specimens of seaweeds, probably a 100, and we're just interested in two of them at this spot. More or less by a trial and error type process we found that the one we collected earlier, and then this one down here by the starfish, are the ones that are chemically interesting to us. Once the investigator's fully convinced that this is the particular specimen that wants to be investigated and it's all clean and homogeneous, it's . . it's next packed in this apparatus for the actual extraction. And the extraction process is very much like, essentially, extracting coffee from coffee beans. Next, a small disc is impregnated with the crude extract that we've just won from the apparatus to the right here. And then the next, they inspect for a zone of activity. And you can see that this spot on the lower foreground, certainly shows a nice ring of, of area where the bacteria did not grow. It's a trial and kind of revision, of. . . of, of our thought process. Or a kind of a trial-and-error process. It really never stops. In fact, the information that we put together today by means of perhaps new techniques that come tomorrow may be proven invalid. Or be shown to be slightly lacking in one or another different propositions. This is really kind of a common experience that all scientists have, and, and learn to, to live with and in fact, that's what makes science really so exciting because it's an ever evolving kind of field.

KEACH: Looking is as much fun as finding. It's deciding where to start looking that's tough.

WILSON: The art of framing the question is often as important as the solution. I started thinking about this bike for a number of reasons, but one of the main reasons was the continual reports of horrible accidents that people had. There are three main sorts of accidents, but the worst sort is the one where you go over the handlebars. Your hands tend to be grabbing hold of the brakes in an emergency as I've done many times, gripping a hold of them like mad. . . and your hands therefore get trapped under the handlebars and you go forward and you lead with your head. Now this bike you lead with your feet. Putting a full support seat brought about an enormous sense of comfort and, and attachment to the machine. Suddenly you felt as if you were in the machine and not just on it. And I often feel like singing. It's always easy to look back and say, and why didn't I go straight to this design? But I think that's one of the beauties of design engineering, rather than pure analysis — you can't analyze exactly what the human frame is going to like.

RACE: Turn it this way. You set it on the asphalt. Put the kickstand down. We're the only person that got a kickstand here today.

Ladies and gentlemen, once again the IHPVA wishes to welcome you to the Fourth Annual Human Powered Championships being held here in Ontario Motor Speedway.

KEACH: Trying a new idea, or tuning an old one, means using Trial and Error. It seems inefficient, but it isn't. It you're after something new or better, it can work when nothing else will.

ANNOUNCER: The magic time is 5.94 seconds, 50.04 miles per hour. That is the barrier. No human has ever achieved that speed.

CUMMINGS: If you were to take a regular street bike up to fifty-five miles an hour, you couldn't even pedal that fast. It'd be physically impossible. You know, you'd be turning probably on the order of 400 rpm. See the size of the sprocket it takes to make the thing go the speeds we're talking about. It's mostly trial and error. There's no supermarket that carries these bikes. You can't go down and, say, put in an order. Give me one with a low frontal area but easy to pedal . . . and structurally sound.

BRADFORD NUSBAUM: Most people, you know, they put a lot of money in their bearings and ours is inexpensive. Ours, our whole thing··· we spent forty dollars on the whole, whole bike.

NUSBAUM: We named it Go For Broke and we had a couple of crashes, so it's broken.

CUMMINGS: The richest guy in the world couldn't go buy one of these things and win. For instance, you could go out and buy the best (foreign-made) car there is, but they're pretty darn good, you know. Finish in the top ten percent without an extremely high level of skill. But in the bike race, it requires a completely unique design, but it's, nothing's been done. There's no standard, there's no criteria for what, what is a winner, you know, what is a loser.

NUSBAUM: We just picked up old bicycle parts from you, you know, a bunch of different bicycle stores and just found some used, old, old frames. And then we cut 'em up, welded them all together, came up with a, the bike.

ANNOUNCER: Fantastic. The first people to ever go over fifty miles an hour in a human powered vehicle. A 50.21 miles per hour, 8.51.

DRIVER: Yeah, oh, that's great. I love this thing, man. You ready?

NUSBAUM: I'm planning to be an engineer. It gives you a chance to put your ideas, you know, out on paper, and then when you see your finished product, you can look at that and say, Wow, I did that, you know. It's really something interesting. You know, you can be proud of what you've done.

试验与失误

达罗尔德·卡明斯： 人力发动的东西能飞起来，跑出两百米远，就是合格的了。

基奇： 这里没有速度限制。只有体力和发明的限制。如果你想打破人力车的速度记录，你得进行试验，解决传动装置，改进流线形状。变动人的位置，再次试验。新的设想，新的组合……

保罗·麦克·克里迪： 这就象骑自行车一样。它的翼展是九十六英尺。你必须相当使劲地蹬踏板，只有这样才能使它保持在空中。要想使它在空中飞行很长时间，非得一个优秀的自行车运动员不可。

戴维·戈登·威尔逊： 我大约飞了三十多万英里，我碰巧设计了这架在我看来是一辆经过改进的自行车。我不知道它是否真比过去的那一架要好。但我要拿它试验一下。我觉得拿它试验一下是很重要的。想主意实际上是不用化钱的。你一旦动手去解决问题，就会很容易地想出主意来。但是，要使这些主意变得切实可行，却颇费周折。怪不得《轻飘的秃鹰》的经验成了这样好的一个例子，因为只有那架飞机既经得起试飞，又经得起摔跌，他们可以修补一下，第二天又拿去做试验。所以我想他们恐怕试飞了三十五次，方才达到设计要求。

基奇： 试验新的东西，但是没有成功。至少你知道了哪些要不得。有人说这叫做试验和失误。但它更象是试验和学习。如果从来没有试验，你怎能找到答案？所以你要不停地钻研。谁晓得？说不定你能得到某种会飞的东西。

威尔逊： 试验和失误的过程不应当只是随随便便地试验一下，然后看它是否行得通。试验应当有某种计划，并且要从前次的错误中吸取教训。

麦克·克里迪：有的人趋向于沿老路走，所以有人造出了一架飞机，第二个人就造出一架稍微好一点的，但总的原理是一样的，不会有巨大的飞跃，只有缓慢的进展伴随着大量的工作。

《轻飘的秃鹰》的重大差别在于它制造简单，容易修理。整架飞机差不多就是随时准备摔碎的。如果某一部分坚固得永远不会摔坏，那就嫌太牢固了，太重了。它用的都是些铝管，钢琴弦，少量的木头，胶水，聚脂薄板，有半密耳厚的，也有四分之一密耳厚的，还有大量的胶布。我们如果把机身上的部分管子摔坏了，只要换上些细木条，半小时后我们可能又飞起来了。我们在一年内做了大量的改进工作。能够做到那样是因为制造非常容易。我一直在研究，要使一架手操纵滑翔机飞起来，需要多大马力。一架真正好的手操纵滑翔机大约只需要一个马力就能够保持在空中；于是，我得到了启发，如果把一架手操纵滑翔机的整个尺寸放大三倍，使它大了三倍，但重量不增加，这样它的下降速度只是原来的三分之一。维持它飞行的马力将只需要原来的三分之一，这么一来，就达到人力可及的范围了。我们现在称它是人力飞机，因为无论男人还是女人，成年人还是小孩，都能驾驶它飞行。恐怕这是至今制成的最容易驾驶飞行的飞机了。如果你遇上了上升的暖气流，可以进入云层，但不安全。

基　奇：有些云层对任何飞机都是不安全的。充满了低凝固点的水的云，称为过冷云。这些水正伺机变成冰。飞机可成为引起这个变化的刺激因素。机翼上裹了一层冰，就会失去升力。飞机霎时变成一块大石头。

文森特·谢弗：一九四六年，我曾想方设法寻找可用来摧云降雨的东西，因为当时我们对防止飞机结冰很感兴趣。我有一个想法，如果我能消除过冷云，就能消除结冰的问题。因此我寻找各种各样可用的材料，以及架上随手取得到的普通化学品，包括各种各样的泥土、石英砂及其它等等。可是都没有什么很有效的结果。到一九四六年七月，有一天，我的试验柜里不够凉，我弄来一块干冰，看看它能不能把温度再降低点。当然罗，这块干冰一进柜子，我就找到了两三年来一直在寻找的答案。后来我把这块干冰拿出来，用了一块小一点的，然后再用一块更小一点的，最后，我发现我要使过冷云完全饱和为冰晶体所需要的就是这一小小的部分。

基　奇：因此，要使云变成雪，变成雨，降到地面上来，并不需要很大的代价。将豆粒一样大的一颗干冰射到过冷云中，就能降下成千上万磅的雪。

谢　弗：事实确实如此，我曾费尽心机寻找能够产生冰晶体的东西，我为此一直工作了多年，可是由于一种非常侥幸的事情，俗话说碰上了运气，我发现了干冰就是我所寻找的东西。

基　奇：法国自行车赛是一次严峻的考验。二十天骑两千五百英里。骑车者的才能都差不多，自行车也差不多是完全一样的。因此你得拼老命才能占点上风。冠军伯纳德·希诺踩车用这样的圆周动作，对金属的要求就可低一些，所以他能使用一辆比较轻的自行车。你什么东西都得试一试。为了减少风的阻力，有些骑车人试穿光滑衣料做的衬衫。从付出的能量和获得的速度来看，自行车已是所有已经发明的交通工具中效果最好的了。但你不能就此止步。总是还有明年的比赛。有时候，探索者起步时仅仅只有一种预感。还是在一九〇一年的时候，一位名叫保罗·埃利希的免疫学家认为人造化学药品有可能找到人体内的特种细菌，并把它们杀死。他称这种化学药品为魔术子弹。医生们说他发疯。就在这间实验室里，埃利希教授一次又一次地用化学复合物在有病的动物身上做试验。试验

的过程是辛苦的。他试验了十次。他试验了五十次，一百次，三百次。若干年以后，第四百一十八次试验才给了他第一个肯定的答案。这次试验杀死了传染病菌，可也杀死了老鼠。但埃利希可以缩小探索范围了。他开始试验同四一八号化合物有关联的各种化合物。在第六百零六次试验中，一种被他称作洒尔弗散的化合物，是它杀死了传染病菌，但没有伤害老鼠。洒尔弗散成为治疗梅毒的第一种真正有效的药物。其他人工化学物品也会被用来治疗疾病。医药有了个新的武器库。化学疗法诞生了。埃利希的办法是拿各种各样的东西做试验——这是一种凭着蛮力苦干的办法，至今仍为某些研究工作者所采用。另外一些人使用演绎法。比如菲利普·克鲁斯博士，他正在探讨自然界的发展是否提供了自己的答案。海洋里有一些有机体，其它生物都躲避它。它可能含有某种可用来治疗疾病的化学物质。

菲利普·克鲁斯博士：我们外出寻找其他生物见了似乎就躲避的植物和动物。这给我们提供了一个线索，一个有趣的新化学的泉源。我们正在从海洋中提取的若干化合物是我们从来没有见过的。事实上，我们自己也在提出问题，他们是否能杀虫？不仅杀虫；还可治病？这是一个很好的潮水坑，里面有许多不同种类的生物标本。这个家伙确实有点特别——就是这个长家伙。事实上，我说的是这根大叶藻。其实，在这个水坑里，有许多不同种类的海藻，恐怕有一百种，而我们只对其中的两种感兴趣。我们大致经过了一个试验——失误的过程，发现了我们早些时候采集的那一根，以及底下这个靠近星鱼的这一根，它们体内有我们感兴趣的化学物质。调查者一旦完全相信这就是需要调查的特殊标本，就是这些干净的同类生物，下一步就是把它放在这个装置里进行实际提炼。提炼过程本质上象从咖啡豆里提炼咖啡一样。接着，我们把刚刚从右边这个装置里初步提炼出来的物质倒进一个小圆盘内。然后他们观察它的活动范围。你可以看到最前面靠下的这个小点，清楚地显示了一圈细菌不能生长的区域。这是一个经过试验然后修正我们的想法的过程。或者是一种试验——失误的过程。这个过程永远不会完结。说实在的，我们采用可能是明天的新技术来收集今天的情报是很可能站不住脚的，或者在这方面或那方面还是不完善的。这实在是一切科学家都有的共同经验，也是学会接受的共同经验。其实这正是科学使人倍感振奋的地方，因为科学是一个无限发展的领域。

基　奇：探讨和发现同样地有趣。探讨的难处是决定从何着手。

威尔逊：提出问题的艺术常常和解决一样地重要。我开始设想这辆自行车是出于若干原因的，但主要原因之一是不断听说人们发生了可怕的事故。有三种主要事故，但是最糟糕的一种是从车把上面翻了过去。遇到紧急情况，手往往总要去抓闸，我就多次这么做过，象发疯似的拼命抓闸……你的双手被困在车把下面，于是你就头朝前冲。现在这辆自行车是脚朝前。安装一个靠身座，给人带来了极舒服的感觉并对这辆车产生好感，顿时你觉得好象是坐进了车里，而不是骑在车上。我常常想唱歌，人们总是很容易地回想过去，责问自己为什么没有一下子就搞出这样的设计。但我认为这正是机械设计的妙处之一，这不是单纯的分析——你无法确切地分析什么东西是最适合人的体材的。

比　赛：由此转弯。把它立在柏油马路上。放下撑脚架。今天这儿只有我们带了一个撑脚架。

女士们！先生们！国际人力车协会再次热烈欢迎诸位参加安大略赛车道上举行的第四届年度人力车锦标赛。

基　奇：试验一个新的设想，或者调整一个旧的设想，就要经历试验——失误的过程。这似乎缺乏效率，其实不然。如果你要追求新的或更好的东西，别无它法，只有这个办法是能奏效的。

广播讲解员：真神，五点九四秒，合每小时五十点零四英里。这是一道关。从来没有人达到过这个速度。

卡明斯：如果要一辆普通自行车的速度达到每小时五十五英里，你就不可能蹬得那么快，从体力上讲是不可能的。你知道，那样，你每分钟大概要蹬四百转。要达到上面所讲的那种速度，你想扣链齿轮要多大！这多半是一个试验——失误的过程。没有一个超级市场出售这样的自行车。你不能走到一个超级市场去，递上一个定货单说，请给我一辆自行车吧，车头要矮的，但要好骑的……车子要结实。

布雷德福·努斯鲍姆：你们知道，多数人为他们的轴承花了很多的钱，而我们的这辆车是不贵的。整个一辆车只花了四十美元。

努斯鲍姆：我们把这辆车叫做"让它摔"，我们已经摔了好几次，所以它已经摔坏了。

卡明斯：世界上最有钱的家伙，不可能去买这样的东西来取胜。比方说，你可以去买一辆最好的（外国造的）小汽车，它们可都是好漂亮的。没有很高超的驾驶本领，也能名列前茅。但是在自行车比赛中，需要十分独特的设计。可是还没有这样的设计。没有标准，没有规定怎样的车能赢，怎样的车会输。

努斯鲍姆：你们知道，我们只是从一连串自行车商店那儿收集了旧的自行车零件，只是发现了一些用过的旧车架子，我们把它们切断，重新焊接，装成了这辆自行车。

广播讲解员：真是难以相信，人力车首次超过每小时五十英里的速度，每小时五十点二一英里，八点五一。

司机：喔，对，真了不起，我喜欢这东西，伙计，你准备好了吗？

努斯鲍姆：我打算当一名工程师。你知道它使你有机会把自己的想法画在纸上。当你看到你的制成的产品时，可以看着它说：看，这是我搞的。这实在是有趣的事。你可以为自己所做的事感到自豪。

（夏平文译　章　雄校）

MODELING

KEACH: At the speed of sound, mistakes can mean disaster.

MAN: Landing check list complete. Landing check list complete.

KEACH: An illusion of flight created by a television camera and a computer to train pilots. Experience without risk.

MAN: The airplane is in excellent position for the approach to this runway. We're leading 500 feet above the ground. Again we're on course. Our speed is reference plus ten. Sync is 700.

KEACH: This is a rehearsal for reality.

MAN: 100 feet. There's 30, 20, 10 touchdown. And you pull the power off. Exercise the speed brake. And we···just a little left rudder.

. . . . . .

MAN: When you're in here and strapped in the seat, this is an airplane. There's no other way to explain it. And that's really the essence of the simulation.

KEACH: A model is always less than reality. It's a problem reduced to match our ability to solve it. The massive sculptures of Henry Moore begin the size of toys.

HENRY MOORE: I usually make my original idea in very small, so that I can turn it over, and look at it like one's own hand, and see it from inside and outside. And then when I think that that idea is good enough, then it comes here. This is what I made before making this big sculpture. But in my mind as I made this, which I could turn overe and look, this was the size I meant it to be. So if you're working in that size, you can't turn it over and look. You see, this view is for me interesting. That view is interesting. That is. That is. And so on. But with the big one you can't do that. So now I work from little maquettes this size and I can imagine them any size I like.

KEACH: The small statues give Henry Moore freedom to explore his ideas before they are cast in bronze. Edward Allen needs only the bare bones of a structure to test his ideas. He can build and tear down a house within minutes.

EDWARD ALLEN: I've constructed here out of plastic strips a model of a floor plan of a very simple, one room house. And this house has a door in the one side of it, and it has a window in the other side. And I'm going to experiment with this one room, to see if I can work out ways of getting better cross ventilation through the rooms, so that all the parts of the room are swept by the moving air that's blowing through the room. I could, for example, move the window to one corner of the room, rather than in the center of the room. And you'll notice from the dye stream that this has two effects — it causes the main stream of air to be deflected diagonally through the room, and it also causes a little bit of a swirl to occur in the other corner of the room. There's a different kind of arrangement we could try: it's very easy with this, it's very fast, to start making incremental changes in it. And if something doesn't work, you just put it back and you try something else instead, until you get a pattern that works. It's a good analogue for air flow. That low velocity, such as the velocity of wind around buildings, water and air act essentially the same.

KEACH: A few pieces of plastic aren't a house. They don't have to be. A model doesn't have to look like the real thing. It just has to act like it. Air, water, or blood. To Dr. Joe Cannon, an engineer, they all behave the same way. He uses fluid dynamics to understand a problem in medicine.

DR. JOE CANNON: When you approach a very complicated problem, you generally break it up into smaller pieces that are much easier to study and interpret the results. Then you build from there and you make it progressively more complicated and study it pretty much in stages. We have here a rubber cast of the arterial system of a dog. You can see how complicated the system is, the tremendous number of branches, regions of sharp curvature. It would be virtually impossible to study fluid flow behavior in a system as complicated as that and ever hope to interpret the results.

KEACH: Cannon pulls out relevant features from a tangle of detail. In a few branches of glass tubing — an imitation of life.

CANNON: First we're going to use a dye injection into the flowing fluid to tag some of the fluid elements, to show the path that they take as we change the velocities and flow rates through the main portion of the artery and through the branches. We may be able to visually see separation if it occurs, or swirling motion if it occurs. We feel by studying the blood flow patterns in this particular section, that we will gain useful information about the blood flow patterns in the human body.

KEACH: Arteriosclerosis could be a plumbing problem. The fatty plaques that clog arteries tend to collect where the flow of blood is irregular. A map is also a model. The Inland Sea, where Japan catches much of its food, and dumps much of its industrial wastes. Keeping the wastes away from the food is a problem. Three thousand islands, 300 miles of water, reduced to the size of a football field. This model is more than a map. It shrinks time as well as distance. Plastic disks trace a 24-hour path of industrial pollution in nine minutes. There's no way to put a monsoon in a room, but Dr. Warren Washington has put one in a computer.

DR. WARREN WASHINGTON: If the Indian monsoon fails, there's a great deal of food shortage in India and in Southeast Asia. The present state of computer models is that they are able to simulate the Indian monsoon quite well. Okay, what you're seeing here is the wind at two levels in the atmosphere simulated by a computer. And we've got two sets of arrows here, there are yellow arrows, which are the low level flow, and the blue arrows are the upper level flow. We're trying to carry out sensitivity experiments, such as changing temperatures, the solar flux from the sun, things of this sort, to see what sort of effect they have on the Indian monsoon. If we're able to prove that the models are capable of simulating either a January or a July, a typical month, then we will know that the models are good. And that they can be used for testing various hypotheseis.

KEACH: The immense complexity of a monsoon can only be defined by numbers. Equations become moving arrows that replay the weather.

WASHINGTON: If we're able to understand on the climate system, then that's going to feedback to the common man on the street, because he'll be able to predict his future better if he knows what the climate's going to do.

KEACH: In Japan, where heavy storms threaten fields, homes, and lives, researchers are working in the rain. What does a cloudburst do to the soil? What about three weeks of rain? In real life it might take decades to collect enough information. In this rain room, earth scientists can make artificial storms, varying the size of raindrops, the consistency of the soil, the duration of the rain. They can run through several seasons of weather in a short time. Models can predict effects, and suggest precautions. Dr. William Trager is trying to find a vaccine for malaria, which affects more people in the world than any other disease. His colleague, Dr. Robert T. Reese . . . He tests vaccines on owl monkeys. Vaccines trigger immunity — the body's own defenses. So a monkey's health is a model for our own.

REESE: All except about three animals in this room are immune now.

KEACH: Models are tricky. We need to be sure that the information we get from them doesn't lead us astray.

REESE: What you want is homogeinity within your animal model. When you're trying to do any kind of science, what you want to do is to be able to change only one component at a time. If you had too many variables in your system, you can't determine what has caused the change. In other words, what you're trying to do is, we're trying to immunize. We want to know if we inject a particular thing, will it induce immunity? But let's say some of those animals have the capacity to respond very well on their own. We could be misled in thinking we had induced immunity, and indeed, it had nothing to do with what we did.

DR. LINUS PAULING: When one builds a model, it's difficult to build a model if one's ideas are fuzzy. Because the model is necessarily precise.

KEACH: Dr. Linus Pauling made the structure of a protein visible. This rough map led him to the first of his two Nobel prizes.

PAULING: In 1948 I was in bed with a cold. And after reading detective stories or science fiction for a while, I thought: why don't I think about the structure of proteins? And I took the sheet of paper and made this drawing of a polypeptide chain. I had known the dimensions since the 1930s, more than 10 years earlier. So I made it rather more carefully than this. And then I folded it along a line, not this line, but another line the first time. And I repeated that fold in parallel to the first one several times and finally found how to fold it so that the hydrogen atom attached to nitrogen just points toward the oxygen atom on the carbonyl group. Then I made some calculations and the other metrical properties of the Alpha Helix came out from the calculations. Later my associate, Dr. Cory, and I, built a large number of different molecular models, space filling molecular models, and this is the molecular model of the Alpha Helix.

KEACH: His laboratory is his mind. The tools of his mind — models.

PAULING: Well, these models are helpful in carrying on research. The models themselves permit you to throw out a large number of structures that might otherwise be thought possible. But then I think that the greatest value of models is their contribution to the process of originating new ideas, developing the imagination.

KEACH: Models break the barriers of time and space. A million gallons of water let astronauts practice working in the weightlessness of space. If you don't hold on, you'll drift off. In space, an astronaut can easily move a nine ton beam. New pounds, but new problems.

HARALD ROBINSON: Minimal surface research, or playing with soap bubbles, can solve some of those problems for us, and suggest new shapes that most of us haven't seen before.

KEACH: Harald Robinson is NASA's smallest contractor. He works with soap bubbles, finding new shapes for model homes in space.

ROBINSON: A film of soap wants to be very small, wants to be as small as it can be. And to show that it actually has a force that wants to pull it smaller, I'm going to break out that little window. The loop is round and wants to stay round, because the soap has surface tension. We can use that to solve all sorts of problems. This little piece of the model I'm going to build represents a room of a building in outer space. It might be a workshop, it might be a bedroom, or a dining facility. And I'm going to show you now how this shape was derived.

KEACH: Models are where you find them. A building is discovered in a bubble.

ROBINSON: Okay, that's more like the bubble. And then that turns out to look like this eventually. And then that piece, if we make a lot of them, we can make these little units with little housing modules. Fits on anywhere in any direction. And then we can use those in combination. Like you see here. It's important that these individual units can stack up, so that you can get a great number of them into the nose cone of a rocket and take them up into outer space.

KEACH: James Blinn explores the solar system without ever leaving the ground.

JAMES BLINN: A lot of the simulations and the modeling that goes on with a computer has to do with models of objects in space, things that are real or simulated as being potentially real. Making images of what we expect the satellite to see as it goes past a system. Like the image that the Voyager spacecraft is going to see, looking at Jupiter and looking at the moons of Jupiter as we go past.

KEACH: Jupiter, the largest planet. A cloud covered giant in the company of its moons. The computer showed how it would look to the Voyager spacecraft one year before the encounter. A trip in a time machine. A journey hundreds of millions of miles. Everything had to be right the first time. Voyager needed to know what to expect. Where our models go, we can follow.

模　拟

基　奇：处于音速时，错误就意味着灾难。

男　人：降落检查全部完毕。降落检查全部完毕。

基　奇：这是一次假设飞行，用电视摄像机和计算机训练飞行员。不用冒险即可取得经验。

男　人：飞机正处于进入跑道的最佳位置，我们正下到离地面的五百英呎处。我们又进入轨道了。我们的速度是参考数加十。同步器是七百。

基　奇：这是一次为真实飞行而进行的排练。

男　人：一百英呎。还有三十、二十、十呎着陆。关掉发动机。开动速度制动器。而我们方向舵稍稍偏左了点。

……

男　人：当你在这里，绑在座位上，这就是在飞机里了。没有别的解释。模拟的实质就在这里。

基　奇：模型总比真实的要差些。这是一个问题，迫使我们以相应的能力来解决它。亨利·摩尔的大量雕刻作品开始时只有玩具那样的大小。

利亨·摩尔：我通常是把我最初的设想做得很小，这样我可以把它翻来覆去，就象看自己的手一样地来看它，从里看，从外看。当我认为那个设想够好了，就把它弄到这里来了。这就是我在作大雕刻前做的。但在我做这个能转过来看的这个的时候，我脑中想要的就是这样的大小。如果你做那么大的，你就无法转来转去地看。你瞧，这么看我感到有趣，那么看也有趣。这么看，那么看，等等等等。但是那些大的雕刻，你就不能这样做。所以，我现在把初步设计的模型都做成这样大小，我将来可以想要多大就做成多大。

基　奇：这些小型雕塑使亨利·摩尔在把它们铸成铜像前能自由地去探索他的设想。爱德华·阿伦只需要一个光秃秃的结构骨架来测定他的设想。他能在几分钟内建成或推倒一所房子。

爱德华·阿伦：这里我用塑料条搭成了一所非常简单的单间房屋平面图式样。这房子的一面是一扇门，另一面是一扇窗。我将用这间屋子做实验，看我是否能设法使这房间获得较好的通风，要使屋内的各处都能得到吹进来的流动空气。比如，我可以把窗挪到屋的一角，而不放在屋子的中间。你将从这个染了色的气流看到这么一来有两个效果，它使得主要气流成对角线地斜穿过房间，又在房间的另一角引起一小股涡流。我们还可能试