PROFESSOR: As it turns out, not by coincidence, the Apollo program that started after Kennedy's speech was made up of a few different elements of things that had been sort of percolating in the background. And one of them was studies at MIT on guidance, not so much to the Moon, but to Mars, and coming out of Draper's laboratories. So I wanted to say a little bit about that story, because it's an interesting story. And it's one you may not have seen quite in this way. So what we've talked about before and the inertial guidance and all that sort of stuff. This is the sort of very clearly posed paradigmatic picture of him.

And during the Second World War, they started making these gun sights. And one of them was called Doc's Shoebox. And then I think we talked about that too, which allowed him to sort of lead the target. You can actually see, if you go into the front door of Draper Laboratories, they have this prototype that he built in his garage, sitting there.

And then during the war, as we talked about-- sorry, during the Cold War, they built a lot of different kinds of-- I'm going to skip through these-- inertial guidance and stuff, particularly for ballistic missiles. And a bunch of these guys, including this guy here, Dick Batten, really did some fundamental work in the theory of inertia guidance. It was pretty much literally how do I get a nuclear missile to land on a Russian city, given the gravity field of the Earth is not uniform, and there's a lot of calculations, and we don't have a lot of different things?

And then this group-- the guy on the left, his name is Hal Laning and he was a computer guy from the Whirlwind group. Milt Trageser is the guy in the back there and Dick Batten is on the right. Batten actually still teaches a course in Core 16 on astronomical guidance. Actually, he may not have taught it this year. That's more or less a course he's been teaching continuously since 1945 or so, 1946.

And if you've ever seen when they send a probe-- actually they just did this with the Messenger probe to Mercury-- and then they sort of swing it around another planet as a way to get it accelerated toward its goal, as opposed to just sending it directly there, that's actually an idea that Batten invented. It is now used commonly in all these different space probes.

And they made this Mars probe. And the idea behind this probe was to go to Mars, take one picture, and come back to the Earth and reenter and drop the film. And this thing, which looks just like the Mercury capsule, is the film canister.

And they had also in the '50s, they built the guidance system for the Polaris missile. And the important thing about the Polaris missile is it was the first missile that could be launched out of a submarine, out of the Polaris submarine. And was a major US, huge project during the '50s.

And basically they wrote a very short proposal, proposing to use that guidance system to go to the Moon. And they were awarded a contract August 4, I believe it was, 1961. It was the first contract of the entire Apollo program and it came to MIT. Which is some indicator a, of how important they considered the guidance. Like how do you get there and how you keep from smashing into the Moon, and how do you get home and keep from smashing into the Earth when you get home? And b, it was the only major contract of the entire program that was awarded to a university, and not to a company.

And of course, the president was from Massachusetts. One of the very senior technical people, Bob Siemens, was an MIT guy, a student of Draper's. He was essentially the chief engineer at this point. And a little bit like the Radiation Lab, there's no question that those influences helped steer this contract, which was a lot of money. Although it was less significant for the money in some sense, than for the prestige that went along with it.

And it was sole source. There was no competition. There was no proposals. It just came straight MIT. And all kinds of companies protested it to Congress. And it turned out it was fully legal, so they never changed it.

But it was not for a computer, actually. It was just for this guidance unit and it was over the course of the project. And remember, this is 1961 and all they thought about was how do we get there and back? And they begin working on this problem in seven years or so. And the idea was that the astronaut would sit inside the capsule. And if you looked at the stars with the telescope, you could basically align yourself and align the inertia platform.

Remember the inertial platform navigates with accelerometers, which can be very accurate. But what's problem with doing that? It drifts. So it loses its absolute accuracy over time. So every once in while, you have to realign it and retell it where it is.

And you could align yourself by just pointing at the stars and knowing which way is up, in what's called an inertial frame. But if you wanted to actually navigate, you had to do things or closer to the planet. So you could look at particular points on the Earth.

The obvious one, the easiest one is measure the size of the Earth, because as you go further away, it get's smaller. It turns out that's not a very accurate measurement. But it is one way to measure where you are.

The most accurate way to measure it is star occultation. So that if there's a star that passes by the horizon, you note the timing of that star and that gives you a very good sense of where you are. So there's a whole variety of things-- is anybody into astronomy here? I never was particularly. But last year, my brother brought me a telescope that has one of these motorized mounts on it, where you can sort of tell it what star it is and it'll go there.

That's basically what the Apollo guidance computer was, where it would point out different stars. It had a little database. And the database of stars that was used in the entire Apollo program was, I forget, something like 100 stars long. And it was one junior engineer in 1962, came to the MIT libraries and looked up all the star coordinates and put them in the computer. And that's the one they used all the way through.

And astronauts were then trained to know which stars, and they each had a number on them, and they could align themselves with the catalog and make sure they were getting there. And eventually, they ended up putting a digital computer in it, which was a pretty radical step at the time. Because again, computers were room-size things. And this was a computer that was briefcase size.

And for those of you who are into computers, it looked a lot more like a microcontroller than a full-up, general purpose computer. It was modest numerical capability, but lots of I/O and interrupts and things going in and out, 16 bits. And it wasn't actually a single chip thing, like a microcontroller today, but it had a lot of those characteristics, including this interface for the crew. And it tied into the inertial system.

So you have this combination of the gyroscopes, the telescopes, the computer itself, and this display keyboard unit. And this is-- actually I forget who this is. I think it's Jim Lovell. No, Jim Lovell's the next one. One of the Apollo astronauts operating this system.

And there would have been a display keyboard like that, up on the main console, which he's looking at, you can see at the top. I don't know if you're familiar. Has anybody seen the Apollo capsules down in the Smithsonian Air and Space Museum?

They looked very awkward on Earth. But they were easier in space, where when they're launching, this guy, he would be in the launch position, and have his back on the ground, looking at this control panel. And then when they get into space, he actually can move up here. And this is actually 90 degrees from that position. And there's a whole station where they navigate from.

And what they would do would be navigate by-- again, they're not flying the spaceship doing this. They're just aligning the inertial system. And then once the inertial system knows where it's going, they type in where they want to go on the keyboard. And so every few hours or so, the inertial system would need to be realigned.

So it would point at where it thinks the star was. The astronaut would look through these telescopes. One was a sort of low power, for getting the thing in the field of view. And one was a high power, for the precision pointing. And then he had these two little sets of toggle switches here. One of them would just move the mirror in one axis and the other would actually rotate the spacecraft around.

And between those two things, they would realign the star. It would usually be off center, just a little bit. And they would say no, that's not where it should be. It should be here. And then enter it into the computer and say that's centered.

And the computer would take those error corrections, in what today we call a common filter-- Batten was one of the inventors of the common filter-- and then update its guidance solution. It turned out you could do that very accurately in getting to the Moon.

And in Apollo 8, this is Jim Lovell, who is probably best known for his commanding of Apollo 13, a few years later. But this is Apollo 8, where they first flew to the Moon. And here you can see him doing it. And there's the keyboard unit up there.

And there was essentially no real hands-on of the joystick, flying to the Moon. It was much more OK, we've got our unit aligned. He did this 200 times over the course of the trip to and from the Moon on Apollo 8. This is where they orbited, but they never landed. And he realigned it 200 times. It had very, very accurate navigation.

And the rest of it would be OK, here's where we want to go, here's the velocity we want to achieve. And the computer would just orient the spacecraft, set up the big thruster to fire, fire it, and then have the big velocity change. A bit change in how the astronauts expected to fly to the Moon.

Yeah, Sarah?

AUDIENCE: Is that a picture of the Command Module or the [INAUDIBLE]?

PROFESSOR: This is in the Command Module, actually.

AUDIENCE: So there was a DSKY in both?

PROFESSOR: There was a DSKY in both, yes. So there were two identical copies of the computer, one was in the Lunar Module and one was in the Command Module. They had different software running on them though.

And in Apollo 13, that turned out to be a huge benefit because they could shut the entire Command Module down and transfer the coordinates from one to the other and keep the inertial solution of where they were in the Lunar Module, while they powered down. So they had a redundant system without really what being aware of it, in a certain way, without planning it, although they did sort of plan it.

And the interesting thing is these were two separate spacecrafts. How would you do that today? Well, you'd have some network and you just say, copy the coordinates over. And all they could do there was read it off the LED display and yell it down the tunnel. And the other guy would type it in. There was no electrical connection between two computers.

This is actually-- the picture in the MIT Museum, behind the prototype of the computer that's sitting there. It's Davey Hoag, one of the engineers on it, just another view of it.

Although it's a very interesting thing here, this was the original block 1 version of the computer. And the idea was the astronauts would be able to repair the computer in flight. And it's sort of like, anybody ever have an old IBM PC where you could pull-- I guess PCs are still this way. You can pull the cards out and put new cards in them and stuff. That was the idea here. You'd be able to pull the cards out.

And they actually talked about the astronauts having tools and soldering irons and things to repair the computer in flight. That turned out to be a bad idea because on a space flight, and this is still true today, the physical environment becomes completely contaminated with all of the exhalations from the human bodies. And on one of the Mercury flights, one of the electronics boxes shorted out. And it turned out there were urine crystals from the astronaut that had-- it was vapor I guess, that had crystallized on the circuits and shorted them out.

And so after this, they ended up going away from this in-flight repair and just building one sealed box that was completely hermetically sealed, no possibility of repairing it. And how did they have redundancy you might ask? And the answer is they didn't. They just tried to engineer it really well, to make it really reliable.

Anybody know how many on the Space Shuttle to control it? Five. Five parallel redundant computers. There's one in the Apollo system. It never failed in flight.

This is another view of that process. Here's where the astronaut in the Command Module can look at the Lunar Module and they can navigate relative to each other. So you could think in your mind about all the different possible combinations of looking at the Command Module, looking at the Lunar Module, looking at the Earth, a million different things you can do. And it was an supremely flexible program that they could use.

Here's another view. I probably just like the way they make these drawings and stuff. And you can see in all of them, made by the computer engineers at Draper, with computers in the center of the system and the astronaut is like this minor peripheral that contributes something here and there.

Here's another one, yet another one. This is actually a view that's kind of interesting to look at, of the position error at the critical moment where they left the Earth's gravitational field and they entered the Moon's gravitational field. And when they're sighting on the Earth's horizon as they get that far away, the error is just rising and rising and rising. And then at this critical moment, they switched and they sight on the lunar horizon with these three stars.

And you can see the error just goes down almost to nothing, compared to the later calculated accurate value. So they plotted this stuff obsessively and were extremely clear. Actually, this is the actual error. That's the position of where their orbit is and depending on where you are.

And that was part of the common filter problem is you only want to take the sightings to update the solution when it's going to really be better than the noise in the process to do it. And Batten was very good at figuring out when that would be.

Another view of it. Here's the one in the Lunar Module. Remember, the crews are standing up. You can see them here. Here's the astronaut right there. Again sort of considering obviously this human and machine computing thing that I've been talking about all semester. Another view of the landing.

So I wanted to show you one little clip about the software for this, because it's actually really interesting. The entire work statement for MIT's role in the Apollo program is 10 pages long. This is before it became $140 million program.

And one line says, of course MIT will provide the programs that are required to run them the computer. And it doesn't use the word "software." The word software hadn't been invented. And I'll show a graph in a little bit. By the end of the program, they were worried they may not make the landing on the Moon because the software wouldn't be ready.

So the transition I would say between people bragging about how big their computers are and Apollo, was the beginning of people bragging about how small they are. And then also the transition from idea that hardware was really unreliable. But one of the things this computer used was really the first silicon chips, integrated circuits. They bought 60% of the entire US production of semiconductor chips in 1964. It gave a huge boost to this budding, very uncertain technology.

And that made the hardware actually really reliable. And like I said, they never really had a hardware failure in fight. But there were all kinds of funky software bugs that they kind of uncover and the beginning of that software could kill you too.

AUDIENCE: What was the percentage again?

PROFESSOR: 60%. So I'll play this little clip, which is from a video that we made a couple years ago.

[VIDEO PLAYBACK]

PROFESSOR: So one of things interesting about that is that they wove this core-rope memory. And we started this class talking about the relationship of industry in New England, and typically the textile industry to the foundation of MIT and how many of the people who had founded that industry were MIT's early trustees. And here we are a hundred years later, and the textile industry which is essentially dying or dead by that time in New England, these workers are still very much using those same kinds of skills. Literally, that software was manufactured in an old textile plant in Waltham, Massachusetts, which still exists today.

And also we probably mentioned Digital Equipment Corporation. They started in old textile plants. If you go today to Manchester, New Hampshire or even Lowell, you'll find high-tech software companies and stuff in these old textile factories. So there is this sort of site all of industrial decline and renewal.

This is one model. You can see, those of you familiar with microcontrollers, it looks very similar to what you might see today, all the different inputs, radars, and sensors, and things, and the outputs for the Lunar Module Another view of the system.

Totally fly-by-wife, so every time any commands from a joystick, which weren't used very commonly anyway, they always went through the digital computer before going out to any of the thrusters. At first, the astronauts wanted direct wires, physical wires, to control the solenoids for the thrusters. But there are 16 attitude thrusters on the Lunar Module. And you can imagine trying to, in these clusters of four, imagine trying to control each one of those individually. It was just not possible to do.

Here's one view that I like to show from the Draper-- the instrumentation lab, of no automation in the cockpit, no software. The crew is completely busy, overwhelmed, doing all these different jobs. And then full automation. They're sleeping and smoking cigars and playing cards. And all they have to do is look at the abort button.

It's pretty much how the launch happened. And still happens in the shuttle today. There's no manual control for the first part of the launch. And the astronauts were convinced they could fly the Saturn V rocket by hand, off the launch pad, which turned out not to be the case. And they tried to find a kind of middle ground between these two positions.

Another view of that navigation flow. This one is a little bit later and much more sophisticated than the earlier ones. I'll skip over a lot of this. That's the DSKY, the display keyboard. Another view of it.

This type of digit, anybody seen those before? There's sort of a standard-- you can still see them today in some places. They're called 7-segment displays, because it's seven segments of a number. They're a little bit obsolete today. But they're sort of part of calculators and stuff. As near as I can tell, that display was invented for the Apollo computer.

There's one guy on the team who claims that he did it. And I've never found anybody who claims that they did it before that. So this kind of numerical output, which became an icon of the digital age for a long time, was created for Apollo.

Just beginning to see touch-tone telephones. Anybody ever see a touchdown telephone? Probably before your time, mainly. But. Instead of dial tones. And this was the layout of the touch-tone telephone. And although in the end, AT&T flipped it upside down.

And the astronauts had a lot of resistance to typing things in. Because again, typing was not something that highly-trained test pilots were used to doing. They'd consider that office work and mostly women's work. And now of course, everybody types all the time. But at the time, that sort of work was not their idea of fun.

This guy is the guy you saw in that slide show, Don Eyles. Here he is with Don Draper. And I like this picture because-- and it actually relates us to some of the readings for today. It captures the sense that this Apollo project was partly a product of what was really the '50s, kind of Cold War mentality.

And by the time it came to fruition in the late '60s, was a whole different world. In fact, if you look at the naming of the Apollo capsules, the first ones are called Eagle and Colombia and these kind of super high-brow, patriotic names. And then by the later Apollo programs, the capsules are called Snoopy and Aquarius, and much more kind of reflecting '60s hippies culture.

And this guy Don Eyles, he graduated from BU with a degree in mathematics in 1967, so two years before the landing. The Apollo program was already beginning to wind down on the engineering. He got a job at Draper Labs and he started working there.

And within a few months, he was writing the code that controlled the landing on the Moon. And most of the code was written by him and a few other people for the actual landing. And he was 24 years old when Apollo 11 landed on the Moon.

And he was basically a hippie. He had long hair. And he talks about, during his lunch breaks, he would go out in Cambridge to protest the Vietnam War. And then come back to this super-secret facility that was working on nuclear guidance and other things and work on the Apollo program.

And he's this great example. And he's still around. And he's friend of mine these days. And he comes to speak in my Apollo class. And he's actually a visual artist. He does photography downtown.

And of the way that, on the campus you have this mixture of different kinds of cultures and different sorts of politics, mixing very freely on the campus. And he never found any problem with that. And he did his job just fine. And he worked at Draper Labs for another 25 years until he retired about 10 years ago.

This is an interesting one because it also shows you how-- this thing right here is a paper tape. And they would literally take the code from the computer, and very much in the same spirit of the numerically controlled machine tools that we talked about, feed the code into this paper tape, into this big machine. And it would automatically position this frame over the hole, where she's putting her needle through. So they did manage to automate it somewhat, where all the worker had to do was thread the needle, wait for the thing to move, and thread it. She didn't have to look up a binary chart and then find it there. So that work was becoming increasingly automated.

These are some of the people who were involved in the thing, some of who you saw in the video. This guy Joe Gavin was at MIT grad. He just died, I think less than a year ago. And he was vice president of Grumman when they made the Lunar Lander and then became president of Grumman later. And these other guys are mostly programmers of various kinds. And they mentioned Margaret Hamilton, one of the very few women engineers on the program.

Here's the manpower for hardware, which peaks in '65 and goes down. And then the software manpower just goes right up and almost swamps them by the end.

I'll just say a little bit more about the landing. The landing was the most challenging part of the entire mission. And up until this point right here, at about 50,000 feet, it was entirely controlled by this computer. So all these programmers down in Cambridge are sitting there, watching it on the big screen. And there's a room full of people like this size. And each one of them has a little piece of that program that's written in. And they're all sort of contributing in real time.

While the astronauts are standing there monitoring, until about 500 feet. And they have this very clever thing where the computer would spit out a number, which you could see down here, like 43. And then the commander, this would be Neil Armstrong, would look through his window at this number, minus 43, and he could look out and see where the target point was. And the idea was then he could change the target point if he didn't like where it was.

And this is another view of what he might see. So there would be that the landing site there, just sort of a passive heads-up display. And he could actually jog his joystick and just say, I don't like that landing site. I want to kick it over there. It would move by a degree. And then the computer would recalculate the entire trajectory and bring them that way.

And he could do that laterally and fore and aft, as many times as he wanted in the course of the landing. And in some of the landings, they actually did it up to 18 or 20 times. And the idea was it would gradually converge on a perfect spot.

And the interesting thing about that, which is sort of the topic of another story, is that on all six landings, they turned that system off at about 500 feet and they flew it in a more semi-automatic mode, still very much fly by wire. But then the story of the Apollo landings became, the astronaut intervenes, turns off this sort of balky technology, which is landing him in a crater, and saves the day by finding the perfect spot and bringing it down.

And it was not really an accurate story because the whole system was designed to interact with the operator to allow them to select the right kind of spot. But they all turned it off anyway. They just wanted to fly. Actually Dave Scott, who is an MIT graduate-- it's about a third of the people who walked on the Moon had degrees from MIT.

And I teach a graduate course in AeroAstro with Larry Young on this whole story. And we often have the Apollo astronauts in to speak to the students. And they'll tell you, they were either Larry's office mates or a few of them were his master's students when they were here in the early '60s.

And actually tomorrow, Dave Scott is going to come. He was the commander of Apollo 15. And he's the only one who I think gave a really accurate description of what happened in these last seconds. He said, you can say that you wanted to be in the loop if anything went wrong. But you knew that if something went wrong with a computer, you were dead anyway. But I came away that whole way and darn it, I just wanted to fly. And so they all ended up flying it the last 500 feet or so.

And then NASA and the public and the press could all say that sort of traditional American values were confirmed by these sort of cowboy astronauts landing on the Moon by themselves. But actually there was this MIT-designed computer there.

And it's an interesting story too about MIT educations, because the earlier crews-- Aldren had a Ph.D. from MIT. And the earlier astronauts were not very academic engineers. But gradually over time, they became much more highly educated.

And MIT, with the exception of West Point and the Naval Academy and Air Force Academy, the service academies, MIT has trained more astronauts than any other school. And it became increasingly sort of de rigeur to have a master's or a Ph.D in engineering. And those crews were much more accepting of these advanced techniques for the guidance and much less interested in just flying it on in by themselves.

Alan Shepard, and we mentioned his flight, he commanded Apollo 14. And he said, aah, if the computer failed, I could have just taken over and landed by myself on the Moon. Which is physically impossible, because you're looking at a terrain landscape that has zero indicators of how far away from it you are. You could actually be six inches or six miles and you wouldn't be able to tell the difference because there's no trees, there's no trucks, there are no highways, anything to give you a sense of scale.

And he had a problem with his landing radar. It didn't come in until the last few minutes. But if the landing radar had never come in, he said he would have landed it anyway. And he probably would have crashed, if he had tried to do that.

They're actually using this-- anybody want to guess what this is, what this diagram portrays? It's actually a model of the lunar terrain.

So if you've ever programmed a control system-- we used to have this problem building underwater robots all time-- and you want to hold a fixed altitude. If you're cruising along the bottom of the ocean in a robot that's programmed to hold a fixed altitude, so it's sending a sonar beam off the bottom and trying to hold an altitude, and then you go over a hole, the vehicle is going to dive down like this and smash into the side of the hole.

And same thing here. If you're trying to fly over a mountain range-- it's not a coincidence that the site for the Apollo 11 landing was called the Sea of Tranquility. They found the flattest, most even terrain they could find. But the geologists who were running the science experiments, really wanted to go into places where there was a lot of geological activity, so the terrain was a lot more crazy.

And on the later flights, they really did land very much high up in the mountains. And this is just a way, where with five line segments, in a very, very simple computer model, all it takes is these five line segments and like six numbers, you could model that there were mountains here. And then you expected the terrain to go like that. And the computer model could eat all that stuff for lunch and it would keep a very stable trajectory and allow you to go over the mountains, and then land right at the edge, which is what they did on Apollo 15, and 16, and 17, a very clever thing.

That's the view out the window, of Aldrin's side.

AUDIENCE: When do you begin to see the sort of the decline in the pilot-orientedness of the astronauts wanting to control more? Because the thing that your lecture brings to my mind is the book, *The Right Stuff,* in which that's a big issue. But clearly what you're saying is over time, that declines.

PROFESSOR: Hopefully, we're seeing it now. After the Moon landing, what did they do? They started sending an airplane into orbit. It wasn't the wisest choice. But it was because the astronauts wanted to fly something that had wings on it. And it's not a very efficient way to go to and from space.

AUDIENCE: So was Alex Roland right all along?

PROFESSOR: Yeah, in some way. But from MIT's point of view, again building into the Bill Leslie piece from today, the Apollo program ends in 1972. It has this huge triumph in 1969.

And that's right when all these protests end up happening and the Draper Labs gets spun out. They were extremely offended and insulted by that move. And there is still hard feelings about it today.

A lot of the people who worked at the Instrumentation Lab were happy to work on a civilian project. And one of the reasons they liked working on Apollo was that it was a non-weapons kind of project. And then they felt like they got the bad end of the rap during a lot of the protests anyway. There was still a lot of military funding and a lot of weapons work going on there.

But it's sort of this irony of this moment when this part of MIT has this world shattering technological triumph in a way, and then also becomes the brunt of it. And it just shows you again the ways that all these things on this campus and in the country were conflicted at the time.

And somebody wrote recently that at the time it seemed like the hippies and the Moon landings were the furthest thing apart. One of them was the military industrial complex and one of them was this kind of Utopian vision of the world. But looking back 30 years later, you can see they have a lot in common. They were both sort of Utopian, futuristic visions that never quite succeeded in the promise that they held. And yet they both influenced the world in different ways that people hadn't really expected. And that was true on campus.

So mentioned in their response paper, I'm forgetting who, about how it was really the one moment there was major political activism on campus. There were other places too. But in this entire story, we were teaching you the history of Yale University or NYU or Columbia.

It's a very political story the way the students are responding to the currents in the outside world and how those things played out on campus. And it's a much more muted story here for reasons that might be worth discussing. And in the discussion, it's really remarkable and notable this one moment in the '70s, when it happened.

And whereas, I went to college at Yale in the '80s and there were students being arrested all the time for protests and occupying the president's office and things. It became almost a kind of a cartoon of itself, it happened so often.

Well, if you noticed in the 150th Exhibit, one of the 150 objects is a tape of the Grateful Dead playing on the front steps of the student center. And I think it was April 1970, was that when Kent State was?

And the thing they write about it, it was within a week after Kent State. And the campus was extremely tense. Everybody was very unsure what was going to happen. And when they played their music, they were very aware of that and really tried to make it be a sort of soothing, calming moment as opposed to a fractious, contentious, potentially violent moment. And that's one of the reasons Debbie chose it as part of the 150 objects.

AUDIENCE: Very interesting.

PROFESSOR: So that takes us up to 1970 or so. And then there's four more decades to deal with, between now and then, some of which we read about. The Cambridge recombinant DNA story is in some ways very much a continuation of this sort of story.

Cambridge was, I'm not sure how much it still is, it still is a little bit, a very left-leaning community outside of the university, very activist, very concerned about these big, potentially scary technologies. That was very much the mood of the time, was what is this big nasty force of technology doing to our world? And MIT, it was pretty easy for to become the center of that. And John Durant's piece shows you how that played out, arguably in a constructive way, a very interesting one.

And then in '80s, the military-- we talked about this a little bit last time-- got very much going again under Reagan. And a lot of money came into computer science and other engineering disciplines. But also the economics of technology and the challenge from Japan became a big issue. That had a lot of influence on campus. All the while, biotech and biology is sort of creeping up in importance and dollar value.

And then the Cold War ends. Chuck Vest becomes president in the late either '89 or

'90, '91 I think. He became president right about when I came here as a grad student. And the big question on everybody's mind was what at that point? MIT is dependent on government funding for so long. Now that the Cold War is over, are we going to just shrivel up and die?

And the pendulum goes again. Where do they go? Back towards industry. And the '90s is very much-- I mean the government research support is always there, but very much industry.

I remember Chuck Vest saying-- it was probably pretty late in his presidency, soon before he stepped down, in a faculty meeting, I've spent so many years cultivating industrial sponsors, it's very difficult. It's very time consuming. I would be very happy for the government to start up again and support-- I mean it didn't go down ever, as much as people feared it did. But it became less of a percentage of MIT's income.

Then the financial crisis in '08 happens and the stimulus package comes in, more government. And the government runs out of money, less government. So this pendulum keeps swinging.

AUDIENCE: The periods are shorter.

PROFESSOR: The periods are maybe shorter. It could be true.