PROFESSOR: Some funny things happened on the way to the moon, as a takeoff of *Funny Things Happened on the Way to the Forum.* And probably not too many people in this audience know that. Also, in particular, a thing that's happening this year is the 40th anniversary of the lunar landing. And we're going to talk a little bit about how MIT got involved. And let's see if we can move this along.

Sputnik was about the size of a large, maybe oversized beach ball, or a basketball. And it was launched in June, of 1957, or later, maybe not June. I thought I had it on the screen. But anyhow, if it hadn't been for Sputnik, I doubt if anything would have happened in terms of the United States getting interested in the space program. So we have to have a lot of gratitude for the Russians for doing this.

I remember Wernher von Braun in a meeting was asked, this was after maybe six months of the program, says, "Wouldn't we do a lot better if we collaborated with the Russians?" And he, without hesitation, said, "If there were collaboration with the Russians, there wouldn't be a program in either country." So it had all to do with the race, the race for the moon. It was October 4, I'm sorry, 1957.

Right after the lunar landing, Dave Hoag and I were invited to the Soviet Union as their guests, all expenses paid. It was really quite an experience. And they gave us a good show. Everywhere we went-- we had some movies of the lunar landing.

And as soon as they knew we had movies, they wanted to-- they took them and set up their screen. If the didn't have a screen, they'd put up a bed sheet. And they oohed and aahed in all of the right places for the landing. And it was really quite an experience.

And also they asked us, when will the Americans go to the moon again? Well that was Apollo 14. And the date was sometime in November. And I was always grateful that it went on time and on that date, because the Russians never gave any indication of what they were planning on doing until it was all over. And then they would take bows, or they would hide the results.

But anyhow, I happened to buy this little device. It's actually a music box. It plays the Russian national anthem. It used to, but it's all rusted out in there now. It's been around a long time.

And when we were in Moscow, we went to the GUM department store. And I saw this there and bought it. I'm so glad that I did. And I brought it home.

1957 is particularly interesting to me, it's because my son, my youngest son, was born in that year. And so he really became-- everything that happened in space, he was right there to watch it on TV, or whatever news there was. And he's still much like that today.

This the MIT Instrumentation Laboratory responded to-- we're going to go into space, so why don't we design a spacecraft which will indeed take us, not to the moon-- we aren't going to think about the moon-- but actually into interplanetary space. In 1957, when the Sputnik was flying, the MIT Instrumentation Laboratory was-- that building on the right is the Whittemore Shoe Polish factory. And the one on the left is the old Hood's Milk factory. And the railroad tracks there are the same tracks that cross Mass Avenue today. The buildings, of course, are gone. And Doc Draper's office is indicated as a little, the corner of these warehouses. So we didn't really have plush surroundings.

The thing we wanted to do was to build a Mars probe. We would like to launch this spacecraft. And it would coast to Mars and pass close by, take a picture, and then return to Earth so we could collect the photograph, not a whole series of photographs, just one picture, because we didn't want to have all that time and effort invested and find that the wheel which would change pictures was screwed up.

So it was just the simplest thing to do, would be to just have it open the shutter and close it. And that was the only thing that had to be done. And we'd do that at the point of closest approach to Mars.

The round trip from Earth to Mars and return, there it is. We were serious about this. We were thinking of launching it in December of 1962. And we would intercept Mars on February 15. And then we would pass by the planet.

It's not a two-dimensional problem. This is the relative motion of the spacecraft with respect to the planet during the planetary contact. Then after that, we have to get back to the earth. And unfortunately, we had to make two trips around the sun to get back. And so the total trip time was more than three years. That did not play very well with those who are interested in getting some attention for the work that the laboratory was doing. But they did get some.

This is a picture from the newspaper. And I'm on the right hand side, a younger version of me. And there's Hal Laning and Milt Trageser, all of whom were involved in this program. And it said, this project may solve the life on Mars mystery.

But it didn't. In fact, it did do a lot of things. But it never flew.

The Mars probe involved always a three year round trip to photograph the planet. And we had to have onboard, self-contained navigation. For three years, this little vehicle was going to be cruising and making measurements to determine where it was and when to make velocity corrections, all done on board the spacecraft -- unheard of at that time. And after the three-year trip, it would splash down in the Gulf of Mexico. And this little model, which is a good size, is hanging in the Draper Laboratory.

I used to know where it was, but then they moved it. But they said, it's somewhere in the building. So if you want to take a look at it, and you can get into the Draper Lab building, then you can see this.

The big red, that's the entry vehicle, which was, in it was the film of the picture that we took of Mars. The major problem was how to design a small computer and its memory in 1960 to survive a three year round trip to Mars, with no data uplink and no inflight service. That doesn't mean what you think. Inflight service means if something breaks, you can't fix it. It's got to be perfect.

But then came 1961. Alan Shepard was ready to fly the Mercury-Redstone on May 5 of 1961. It was the first American in space, not the first human being in space, the first American. The Russians had already capitalized on their Sputnik, and they had a man in space somewhat before we did.

And you look at the picture, there's the blockhouse. It looks like about the size of a garage. And the space vehicle, not very big, all it was going to do was just fly a 20-minute flight and land in the ocean and be fished out.

That was what we were going to do, when in fact, the Russians were already putting men in orbit. Now, I will never be as amazed that three weeks after Alan Shepard made his flight, that John F. Kennedy said that he believed that this nation should commit itself to achieve the goal, before this decade is out, of landing a man on the moon and returning him safely to Earth. Now, that's pretty gutsy to do when your only success is a 20-minute splashdown in the Atlantic with one person at the helm.

Now, 1961, let's look at some of the other things. Alan Shepard's flight on May 5; May 25, President Kennedy's message to the Congress and to the world. And then on August 10, MIT is awarded the first NASA Prime Contract for Apollo. NASA had just barely been created. And in response to President Kennedy's "we're going to go to the moon," they gave the job to MIT.

That's pretty amazing when you think about it. And we'll say a word more about that in a minute. The Mars probe never flew, but the onboard computer did evolve into becoming the Apollo guidance computer. There was a computer that we had to have in our little space probe, and that did evolve into the guidance computer, the Apollo onboard computer, for the lunar mission.

We moved into better quarters. This is the home of the Apollo project from 1962 on. That building no longer exists. It was originally a storage warehouse for underwear.

And we took over the whole building, refurbished it, and my office was on the other side of the building. And it was on the corner. It was a nice office. Here's what the place looks like today. This is the luxury waterfront condominiums that they made long after the space program ended. And the underwear factory or underwear warehouse was replaced by these condominiums.

Now, MIT was chosen for the GN&C. And quite a big question is "Why?" Well, Jim Webb, who was the administrator of NASA, knew Doc Draper. And this is Doc's version of what happened. Jim Webb called Doc Draper on the telephone, says, "Doc," he says, "Can you develop the guidance and navigation system for Apollo?"

What would you say if you were Doc Draper. You would say, "Yes, of course. We'll do that." "When will it be ready?" "Well, when you need it." (Laughter) That's a good schedule. "And how do I know it will work?" And you say, "I will go along and operate it for you."

Now that's the story that Doc always told. And I believe it, because he did know Jim Webb. Jim Webb was not a scientist. Jim Webb was good at getting money out of Congress. He was a lawyer. And his job was to make sure that the Apollo program was adequately funded.

Now, was it Doc Draper's phone call from Jim Webb, or was it Bob Chilton's memo? Bob Chilton worked for NASA all of his life. He's retired. He lives down in Texas, at Texas A&M. And I hear from him once a year.

And here's what Bob Chilton did. He wrote this memo to the Chief of the Flight Systems Division in November 7, 1960. He said, "Development of the onboard capability to determine position and velocity by optical means is important to the principle of onboard command for Apollo. The Instrumentation Laboratory of MIT has shown a strong interest in the problem of self-contained navigation. The position and velocity determination schemes proposed in the reference report by Battin and Laning called A Recoverable Interplanetary Space Probe in 1959 are alike in principle to that desired for Apollo."

At the time, Bob Chilton was the head of the Flight Dynamics Branch at Langley Field. Bob Chilton's memo, the memo was stamped Confidential. Everything was classified in those days, and Bob gave me his original carbon copy, which I still treasure. Here we are sending men to the moon, and we had not even invented a good copy machine.

Why was onboard navigation a basic requirement? Well, one of the reasons would be that the Russians might not play fair. They might jam the communication links and we would not be able to communicate with our spacecraft.

1961 was a long time ago. We had to use typewriters and carbon paper. Xerox had not been invented. You could watch TV, but not in color. There were just black and white TVs and not very good quality.

You could do calculations using electromechanical machines, no personal computers or even pocket calculators. These things would cost about $800 to $1,000, and all the would do is add and subtract and divide. If you spent $500 more, you could get one that did square root. And that was a pretty amazing thing, because every day, just about, the repairman would be there to fix it, because it was such a complicated piece of equipment.

When we'd go on business trips, no jets. We had propeller-driven aircraft. And the per diem rates were $12 a day. With that $12, I was supposed to pay for my hotel bill and buy three meals, and do it for $12 a day. And that was plenty good enough. In fact, if you just said, give me the $12, and then if you didn't spend it, you could keep the dollar or two which was left. Those were different days than they are today.

Now let's look at, this came about only relatively recently, the numerology of 1961. It's an invertible number. That is, if you turn it upside-down, it's still 1961. Earlier invertible years, 1001, 1111, 1691, 1881. When will the next invertible year take place? 6009. You've got a long wait for the next invertible year. OK, that's one thing. But there's more.

President Kennedy's Special Message to Congress was 5/25/61. 5 plus 25 plus 6 plus 1 is 37, which is a prime factor of 1961, which is only interesting. But if you take the prime factor, which is 37, there's only one other prime factor, and that's 53. So 53 times 37 is 1961. If you take 53, and you get the month of August, 5 plus 3 is 8, and the 10th, 3 plus 7 is 10, and it's all written there forever that MIT would get the Apollo contract on August 10 of 1961. Isn't that-- that's pretty amazing.

I was going to give a talk on Apollo. And I had it in the afternoon. And I was fiddling around, and I came up with this. And I was really impressed. And so were the audiences when they realized that this was, as I pointed out, this is not an accident. This is the way it was all planned ahead of time. Now also, Apollo is Greek mythology. Apollo is America's Program for Orbital and Lunar Landing Operations, so even the Greeks knew that we were going to do the job.

1961 was a vintage year. A lot of things happened then. There they are. In January 26, the first multiple fly-by orbit of the planets was determined, by going from Earth to Mars via Venus. You go from Earth to Venus to Mars and back to Earth, all in one launch. And that was discovered by me in January 26 of 1961.

I have to emphasize that that date is very important. Because there was a lawsuit by somebody whose name I must not mention, who brought suit against me, because he said he did it first. But he didn't really.

In the spring of that year, the first offering, that is the first class in Astronautical Guidance, is what my course used to be called until it was changed to Astrodynamics. On April 12, Yuri Gagarin flew three orbits of the earth. And then to respond to that, on May 5, Alan Shepard did a quarter-orbit flight. And then, three weeks later, President Kennedy commits us to going to the moon. And in August, Gherman Titov flies 16 orbits of the Earth. And MIT is awarded the first Apollo contract.

In October 13, the American Rocket Society had a meeting, because Kennedy said he wanted to know what progress had been made. And so we had a spaceflight report to the nation of all the stuff that we were doing. Later, on November 21, Draper, who had said to Jim Webb that yes, he would make sure it worked, because he'd fly it, he volunteered formally to be an astronaut.

And then, I thought of this much later, December 23 was Christina Shue's [?] 100th birthday. Who in the world was Christina Shue [?] ? My grandmother.

So in 1961, a lot of things happened. Here is the first round trip to Venus. We were a little discouraged by taking three years to get to Mars and back home. So we said, maybe we could go to Venus and return in less time. And as a matter of fact, you can.

If you see the launch, and you go past Venus, and then you're coming back to Earth. But look, you're almost out to the Martian border. And wouldn't it be nice if Mars were there? And that was what we did.

We had a Venus fly-by. And then following that is the return to Earth. And it is all done in just a little over a year. And we visit two planets for the price of one, first to Venus and then to Mars, and then back to Earth.

And this was the very first one of these that was ever done. We do that all the time today, using fly-bys of planets to change the velocity to get to another location to accomplish something else. But this was the first time it was ever done on a computer.

Now saying that the first offering of astronautical guidance, it's kind of interesting. Because there are the people who took that course, Buzz Aldrin, who flew in 1961, in Apollo 11, and then Dave Scott, who flew Apollo 15, in 1962, and Ed Mitchell, who was on Apollo 14 in 1963. Each of these gentlemen, and they're all still alive and well, they walked on the moon. And they took astronautical guidance.

Apollo 14, I always thought that Ed Mitchell, it had more people watching that launch than any time in the past or the future. Why? Why? It was Apollo 14. What was the flight before that? Apollo 13.

And that was pretty serious. We almost didn't get them home. And then to be a crew for the next flight, I think, took a little gutsy.

Here's the textbook for the graduate course in astronautical guidance. The book is *Astronautical Guidance.* The diagram, if you take my course, you'll find out how to navigate in space by making measurements of angles between stars and near bodies. And so that little diagram was on the flyleaf, and was also on the inside of the book in color.

Now when the book came out, we were having a heavy load of important visitors. And Doc, he took my book, and he said, "Battin," he says, "I want you to buy a lot of these. And I want you to autograph them. We're going to have important people here." And sure enough, let's see who the important people are.

Well, there's Doc. And then there's Kurt Debus. He was the head of the Space Center in Florida. Wernher von Braun needs no introduction. Bob Gilruth, who was the head of the NASA team in Texas, and then me, looking smug. And everybody, you see, has got a copy of the book in front of them. And I was pretty excited about that.

There was an unauthorized version of the book, *Astronautical Guidance,* in Russian. And this was about four years later. And everything is in Russian.

There is Battin in Russian. And the diagram is exactly the same diagram that appeared on-- but it's an unauthorized, that is, they didn't ask permission to do this or give us any royalties. But they did give us an all expenses paid, round trip visit to Moscow and Leningrad and Tbilisi after the Apollo 11 landing.

MIT awarded the first Apollo contract, and here was the team. We have Jim Webb, the one in the center. And to the left is Hugh Dryden. He was the deputy administrator, but he passed away in December of 1965.

And then there's Bob Seamans, the associate administrator. He was promoted to deputy administrator. And Bob Seamans, as you are well aware, passed away. I was very happy that when I give this talk at this time last year, Bob Seamans came.

He had not heard it before. But he came and listened. And I was so pleased that he was there. But he passed away shortly thereafter.

MIT was chosen. Why? Well, Bob Seaman's book, *Aiming at Targets,* says, it doesn't give you much information. It just says, "When the decision was made to go to the moon, the Draper Lab got the contract for the navigation system."

He really knew why, but he didn't want to put in print. Because after all, he was from MIT Instrumentation Laboratory. Doc headed the laboratory. And then all of a sudden, we get the job for the GN&C for Apollo.

But we deserved it. And we performed well. So was it Doc Draper's phone call, or was it Bob Chilton's memo?

I guess I got this in there twice. I shouldn't. I have to do a little surgery on this.

Doc Draper volunteers to be an astronaut. He really did. And he had a letter. This is part of his letter.

"I would like formally to volunteer as a crew member on the Apollo mission to the moon, and also for whatever sub-orbital and orbital flights that may be made in preparation for this lunar trip. I realize that my age of 60 years is a negative factor in considering my request, but General Flickinger tells me that this is no sure bar to my selection as a crew member."

And we had a system, a real system, put on the roof of one of the buildings on the river, where you could practice navigating. And there's Doc Draper making a navigational fix. And you can recognize the Boston skyline, or what the Boston skyline looked like in those days. Some buildings are missing.

And you could actually make measurements, and the computer would calculate where it was on the basis of that. And the result was always the particular spot on the roof of the building, even though you could start off with very bad guesses of where you were. And then by utilizing the navigation algorithm, you could to get a navigation fix.

The guidance navigation laboratory system, you could see that today, if you get somebody to take you through the Draper Lab. This is actual-- it's not a mock up. It's really the equipment. And you have the means of communicating with the computer on the right, that was the DSKY, the display and keyboard. where you could get information, and you could also call up different things that you wanted to do in flight.

For navigation purposes, we had a scanning telescope and a good sextant to make these measurements. You could get a view of the stars and the planets through the sextant and then make the actual measurements. You'd try to line them up, line up these two images, press a button to get information to the computer. In fact, what we have here does not show behind, where the ball for getting information with respect to attitude and velocity, all done on the back side of the-- but this is the front side, is this what the astronauts saw and used in their flights.

There's the Apollo guidance computer. The fact that it's approximately one cubic foot, it's a really interesting story. When the spacecraft contractor was chosen, you got a phone call from them, saying, "Oh, I understand that you're going to have a computer on board. How big is it?"

Well, we had no idea. All we could see was all this equipment that was on the wall. And somehow or other, we were going to have to package this down to something that would fit in the spacecraft. So they said, "Well, we've got to give him a number." And so I said, "Well, just tell him it's a cubic foot."

And it was. We were able to squeeze it. You couldn't make it two cubic feet, because that's all they had room for, planned for. It was a computer of that size. And it weighed about 70 pounds, consumed 55 watts, which, that's pretty good.

And then this up close is the display and keyboard. The core rope memory was a-- we're not going to spend much time dwelling on it. But it was an invention of Hal Laning, primarily Hal and others, that you could have a memory system which you would wire in place, so that if you lost electricity, you wouldn't lose your memory.

And there is the way it was done. Each core would store a word. In fact, we got it down to where a single core could store 12 words, and each word was 16 bits or 2 bytes. And to read, to get information out, all you have to do was select the core and switch it. And then all of the sense wires that went through the core would produce 1s, and those that did not go through the core would produce 0s. And lo and behold, this was our system.

The trouble is that you had to make these things. You had to manufacture them. And after you've made it, and if there was a mistake, you couldn't change it.

Here's the speed in kilobytes. For our Mars probe, it had eight read only memory kilobytes, and change, this would be Random Access Memory, is a half of a kilobyte. The Apollo Guidance Computer had 74 ROMs and 4 read and write memory, and it was actually a little slower in speed than the Mars probe. Now today, the kind of memory that we're talking about, you can carry around in your pocket. In fact, I do have it in my pocket for this talk.

And it's just absolutely amazing that first of all, that they had the idea that this was the way to do it, because in Apollo 12, the spacecraft was struck by lightning on the way up. And all of the read and write memory vanished. They had to put that back in by hand. But the read-only memory was fine. There was no trouble with it whatsoever.

Here's a photograph of the core rope memory up close. And how would you manufacture something like that? Well, we used the LOL method, the Little Old Lady method, which I'll show you in a second.

The computers and the memory were manufactured by Raytheon. The flight software was written and tested at the Instrumentation Laboratory. The core ropes required six weeks to build, and you couldn't make any last-minute changes.

And there's one of the women who's wiring this thing. It was set up to be like a weaving machine that the computer would tell you where you're supposed to put the next wire. In fact, it would set it up for you so that you could put the wire through the right core.

And all this was done at Raytheon. And it must have been very tedious for these women to do that kind of work. But they were always so proud when the astronauts would come and visit. Oh, it gave them the feeling that we can't screw up. We have to do this right, because we just met the men whose whole lives depend upon.

How many computers? Well, we wound up with one for the Command Module and one for the Lunar Module. And there would be no inflight repair. There would be no built-in redundancy. That is, if one of the circuits fails, that's it.

There would be no uplink from the ground. And there were many possible single-point failures, but none of them ever happened. The quality control people couldn't calculate the mean time between failures, because they never had any failure of the AGC at all.

Software, the early NASA manned flights. The first one was Mercury flight. There were 6 Mercury flights. And there were 10 Gemini flights. The first one was May 5. We've already seen Shepard's. And the last one of the Mercury group was May in 1963. Then there were Gemini flights, where there were two astronauts in a capsule, rather than just one. And there were 10 of those, from '65 to '66.

George Mueller was the Associate Administrator for Manned Spaceflight. And he was a NASA person. And he was very much concerned with the computer software. In fact, he was in charge of the software for the Mariner 1 spacecraft to Venus, which was launched in 1962. And it went off course due to a software error. There was a missing minus sign in the code. He had this minus sign framed and hanging in his office. Do not take for granted. That you've got to check everything to make sure that it's going to work.

The astronauts used to come and visit us. And in the fall of 1966, we had six astronauts. There were all sitting down there in the front row. And we had them autograph these. And then the people in the back were the ones that were working on the job. There is me. And there is Dave Hoag, and there's a whole bunch of other people all there to be photographed with the astronauts.

This is a very sad picture, because Virgil Grissom and Roger Chaffee and Ed White, who where in that picture, were in Apollo 1. What happened to Apollo 1? It burned up on the ground.

And so those guys, next to them was Dave Scott, who was one of my students, and Jim McDivitt and Russell Schweickart. Russell Schweickart was an MIT student, but he didn't take my course. And they flew on Apollo 9. Apollo 9 was the first flight using the Lunar Module.

Apollo 8. This was the round trip trajectory to the moon. And you notice you're going from Earth to moon, go around the moon and back. And of course, what you want to do is to go on an orbit which is going to arrive at the lunar orbit ahead of the moon, and then we'll go around and then be swept back to Earth. Instead, if you had gone behind the moon, then the energy exchange would have been such that you would go off into the solar system someplace. You had to do this just right in order to get on an orbit back to the Earth.

This picture is also in my book. And you can look at it. And they made a big deal out of the fact that it is a figure eight.

And Apollo 8 was the first manned flight away from the Earth. And so Apollo 8, which was the Christmas flight, you may remember that, maybe you don't know. You don't have to remember it. But it was the time when the astronauts were for the first time in orbit around the moon. And they were in this particular mission.

Of course, you always worry about, what if the engine doesn't work. You're going to stay there forever. You're not going to come back to the Earth. There's nothing the ground could do to help you out. And this design for the Apollo 8 is really a Earth around the moon, just as the real mission showed.

Here's the crew. Frank Borman was the commander. And Bill Landers was the Lunar Module pilot. Even though we didn't have a Lunar Module, they had work to do. And Jim Lovell was the Command Module pilot.

And he was the one that did the navigation. He did all the measurements to do the orbit determination, the navigation, for the first time, on a flight to the moon. And what he had to do, this is the navigator measuring an angle between a star and a landmark. And you would put a mark in the computer, which would register the time and the direction of each of these, and then it would calculate the angle, the shaft angle and trunnion angle, or two angles.

And you'd get one piece of information. But when you added all these different measurements together, separated in time and position, you were able to do a very credible job of navigating to the moon. As a matter of fact, it was so close that it was decided that we didn't need an update from the ground.

In the rule book, it said, before you make any velocity change, you have to get your state vector information from the ground. And Chris Kraft said, he couldn't see any difference. The onboard computer and the ground were almost identical. But they did have to follow the rules and make the correction. And Jim Lovell navigated all the way back. So he was the very first person to ever navigate a spacecraft by making telescopic measurements on board.

Jim Lovell, he trained at MIT using the Earth horizon simulator. He was calibrated. That is, he would tell you where he thought the horizon was, and it would be different than what the computer thought the horizon was. And so eventually, at least he was consistent.

And so he had demonstrated that his consistency was such that we would calibrate him. That is, when he looked at the horizon, and there was a little difference, that that particular offset would be Jim Lovell. And other astronauts would have their own. And it says here that Jim was the first to demonstrate that man could navigate in space without assistance from the ground.

He wrote a book called *Lost Moon.* This was the Apollo 13 book. And he was the Command Module navigator on Apollo 8. There he is when he was younger.

And that's just kind of sad, because on Apollo 8 navigational measurements, he said, "After leaving Earth orbit, the astronauts took a few rapturous sightings of the receding planet, and then turn their spacecraft around to fly in a proper, nose-forward attitude." That always, whenever I see that, it's sort of upsetting. We went to all kinds of trouble. And he was the navigator. And when he wrote the book, he didn't mention anything about how he did this. He just took some rapturous sightings of the receding planet. Oh, well.

Here are the flights. Apollo 1 was destroyed by the fire. Then there was Apollo 7, which was to try it out in Earth orbit. Apollo 8 went to the moon. Apollo 9 was a flight for that the first time, the lunar module flew in Earth orbit. Apollo 10 was a dress rehearsal to fly to the moon. You do everything except land. And then Apollo 11, you land.

Then there were a bunch of others, as you can see. 12, 13 was, it took a while before they were ready, over a year and a half, to go from Apollo 13 to 14. And at the very end, they had Apollo 17.

But there were 18, 19, and 20. The rockets were there. The spacecraft were there. They could have flown. But I think that probably the reason was that with all these successes, why don't we quit when we're ahead? And there's another reason why you might want to quit. And that is numerology, again, more numerology.

1 plus 9 plus 6 plus 1 is 17. And Alan Shepard's flight was on 5/5/61, which is 17. So Apollo 17 was going to be the last flight to the moon, all set by the very beginning.

But not only that, 17 is an important number. It's a Fermat number. It's a Fermat prime. Fermat numbers are 2 to the 2 to the, and so on up the line. And Fermat had suggested that all such numbers would be prime. And they're not. In fact, the only numbers which are known to be Fermat primes are the ones at the bottom 6, or 0, 1, 2, 3, and 4 are the only known primes, and F2, which is 2 to the 2 to the 2 plus 1 is seventeen. And so it is one of the only known primes generated by this formula. So obviously, 17 had to be the last flight to the moon.

Then Apollo 11. Here are the guys that flew Apollo 11. There's Neil Armstrong. And there's Buzz Aldrin. These pictures were taken when they were young. They don't look like that anymore. And Mike Collins stayed in orbit while Neil and Buzz landed on the moon.

And there is a picture of, this is the arm patch for Apollo 11. It's the Eagle. The spacecraft, the Lunar Module was the Eagle. And there it is, landing on the moon.

Now, in the aftermath of Apollo 11, this is Newton's tomb in Westminster Abbey. And I recently went to

Westminster Abbey to see, again, Newton's tomb. And they wouldn't let you go up to it. Before, you could walk up to it. And you could pat the-- but now you couldn't.

And I was talking to one of the guides there. And I told them what had happened in Apollo 11. I said, there was a message left on Newton's tomb with flowers. And it said, "The Eagle has landed."

And his eyes just lit up. He said, "I was here when that happened. This was my job. And I saw the symbol, the flowers. And I saw the note at that time." He said, "It really did happen." And there it is. There is Newton's tomb. It's a huge thing. If you stand in front of it, you're no taller than the base. And so that was the story about Westminster Abbey and "Sir Isaac, the Eagle has landed."

It was Howard Johnson who knew about this. Howard Johnson was president of MIT not too long ago. And a friend of his was killing time between flights. And he went to Westminster Abbey, and he saw this note. And he told Howard Johnson about it. And Howard Johnson told me.

And it's very, very-- brings tears to your eye when you think that they were able to actually do this. And I'm still pretty emotional. "Sir Isaac, the Eagle has landed." So thank you.

[APPLAUSE]

If you have any questions, fire away. If you don't have any questions, I had a good time. I hope you did, too.

AUDIENCE: First of all, on the numerology, was that all your personal touch? Or was that an active discussion topic?

PROFESSOR: No, that was just me talking to nobody. No, I was really struck by the factoring 1961 and getting the date out of that. That just didn't seem like it should be, unless somebody was moving the hands, and we were able to get the job. And the number 17, I was just fiddling around one day, and I said, oh, maybe that's why 17 was the last flight to the moon, because there's only one other prime Fermat number beyond 17. And if you used that number, it'd be much too big for having anything to do with the number of the flights.

AUDIENCE: I have a question about the orbital mechanics that you were looking at of that early period. I was in high school several weeks ago, and somewhere around 1951 or 1952, in an advanced math class, we were doing celestial orbital mechanics. And we were doing it from a small textbook imported from England. And it was written by somebody who I didn't recognize as a mathematician that year, Arthur C. Clarke.

PROFESSOR: Oh yes, of course. He just passed away recently.

AUDIENCE: Yeah, and now I've got to go home and find out if multiple body orbits were in it or not.

PROFESSOR: No, he didn't-- you mean the one I was showing you? No, he said he was not impressed at all by that. I didn't send it to him. Somebody else did. And he said, well, that's not a problem. Well, it's not a problem until you try to do it. So he was just not interested.

AUDIENCE: Work it on the blackboard for him. Thank you.

PROFESSOR: OK. Yes?

AUDIENCE: Where were you when Neil Armstrong walked on the moon?

PROFESSOR: I was in Houston. And I was in the center there. And we were all wringing our hands. The alarm that came off just before landing, none of us knew, except the one person who had to know, and that was the, what's his name. I can't think of his name. But he was the one who said, he knew what the alarms were. Forget it. They're OK.

Because everyone else, if he hadn't spoken up, they were ready to scrub it, because they didn't know what happened. And they would have just decided to play it safe and not land. But it was not a problem.

Actually, what was happening was that the computer had a lot of jobs to do simultaneously. It can only do one thing at a time. But it would do a piece of a job, and then it would switch to another one. And all the time, it had to be reading the accelerometer information and calculating what the x-acceleration was, lots of things to do. And it had more to do than it had time to do it.

And the reason was that somebody, and Buzz Aldrin has admitted to it now, that he put on the ascent radar, just in case they were told to not land but leave, they'd be all set with their radar. And by leaving that on, which the computer would do, if they were actually launching to the moon, it was just an additional task which was not supposed to be done at that time. And so fortunately, the guy who was in charge knew that that was what the problem was, and he just said forget it. Let's go.

It's one of those things that you don't want to be responsible for. You don't want to have to be the one who says, go ahead, and then have it smashed into the surface of the moon. You'd be very serious about what you would do with the rest of your life. Any other questions?

AUDIENCE: Dr. Battin? On your left. I worked at the lab on the guidance system. And I think the astronaut students, your old students, might be interested knowing, it wasn't just one program. But the Lunar Module and the Command Module were very different, because of the ascent and landing. And also, the lunar module was a very early digital autopilot. It worked on a phase plane to decide when to fire its jets. And for ascent, it didn't have a "gimbal-able" engine, so the whole scheme for controlling it was very different.

PROFESSOR: Well, the interesting thing about the LEM computer was that the people who were responsible for the LEM said, "OK, well, we'll put a computer in. We'll do our own." And we kept saying, and NASA kept saying, why do we want to do that? I mean, if the Command Module computer will functionally do the same things that the Lunar Module computer is supposed to do, then let's do it.

Let's just change the program. Let's don't reinvent a new computer for that job. And fortunately, the decision was that there would only be one computer. We had two sets of software to design, but we didn't do it for two different computers.

Actually, the Lunar Module had, I forget what it's called. But it was a little computer which could do basic things. And if you couldn't do anything with the big computer, at least with that, it could run the engine, for example. It may not calculate what the result's supposed to be. You'd just give it to the astronaut. And the simple jobs that you expected the computer to do, you would do.

And again, they never, ever had to do that. They never had to use it. But it was always there. And they were always trained for it. But it didn't ever have to be used. Yes?

AUDIENCE: I had hear about Draper attempting to be an astronaut. Whatever happened with that? Did they just decide--

PROFESSOR: Draper what?

AUDIENCE: Wanting to be an astronaut. Did they just determine--

PROFESSOR: Oh, well, I mean ha ha. Actually, Draper would have gone if they had picked him. The Instrumentation Laboratory existed before Apollo. And he personally designed instruments for aircraft. And then he would test-fly them in the plane, and he would be the pilot. So he was a test pilot in that sense.

But the fact that he was 60 years old, that's unheard of. I remember when I was 60 years old. It was a while ago. But no, I don't know whether he was actually serious about it. He did write a letter to Bob Seamans saying that he would like to be considered. And they could say, well, we considered you, but you couldn't do it, physically couldn't do it.

AUDIENCE: Also, in those days, all of the astronauts were military pilots.

PROFESSOR: And there weren't any women. There weren't any women, because there weren't any women test pilots. Had there been women test pilots, that'd be OK.

Janice Voss was the first female astronaut from MIT. And she helped me with my course. She was really a very good student. And when she graduated, she applied to be an astronaut. And she was turned down once, twice, and she was turned down three times. The fourth time, she was selected.

And so she says, don't ever give up. If you want to do something, make sure that you don't give up. It may not come right away, but it could come eventually.

So she was very excited about that. And she was actually the first female astronaut from MIT. We've had other-- well, you just saw some of the guys who went to the moon were all MIT students.

Incidentally, when Buzz Aldrin was a student, he did not have a label on saying I'm going to be flying to the moon. He was a military pilot. And he was interested in, I guess they had begun to talk about it. He was interested in doing some of the rendezvous calculations. But he was not representing NASA. He was just there to get a Master's degree.

And all the other astronauts, none of them arrived and said, I am an astronaut, and I want to [UNINTELLIGIBLE]. They were all just students. Mostly, they were from the military. They might be from the Air Force Academy, that sort of thing. But it was only afterwards that they got an assignment, actually being an astronaut. Yes?

AUDIENCE: Can I ask your opinion on the Constellation program? I imagine you think it's long overdue, but are they doing it the right way? Do we still have the skills to go back to the moon?

PROFESSOR: I don't know. I really don't know. They're doing so many things which are just unbelievable, the Messenger program of getting a spacecraft to Mercury. And they did that by at least a dozen or more fly-bys of Earth and/or Venus in order to get the energy lowered down to where you could actually contact Venus and maybe go around, orbit it, or take pictures of it, or what have you. But I don't know any more about that today than anybody who reads the paper. The Constellation is, I'm not sure. Is this is a new program or what?

AUDIENCE: No, that's the return to the moon, and then to continue on to Mars.

PROFESSOR: They got a name for it now, oh. Well, I think it's certainly a great idea to do what we did. And it would be wonderful to be able to do it again.

And I had a student, she was actually a freshman at the time. And she was Japanese. And I was a freshman advisor. We were going around to ask, what would you like to do? What would you like? And it got to her.

She said, I would like to be the first woman on Mars. And she was serious. I want to be an astronaut. The fact that I'm Japanese shouldn't have any problem. I said, well, that's great. I'll be there to cheer you on.

But the Japanese do seem to be getting more interested in space, as are the Chinese. And the only thing that's going to get us really interested is when it looks like they're going to do it, and we're going to be left in the dust. If as von Braun said, if you had tried to cooperate with the Russians, there wouldn't be a program.

What was I going to say? I've forgotten what I was going to say. But anyhow, there are so many opportunities that we hopefully will not ignore, just because there isn't any particular competition.

The whole business of Apollo, we learned how to make these computer chips. And the chips were manufactured by Raytheon for Apollo, and the largest number of computer chips that were being made were the ones for Apollo. There were very few applications. And so you might say that the Apollo computer really was the original device that we have here. And I think that that is true, that with an application, demand, you're going to learn how to do it better and cheaper. OK.

[APPLAUSE]

Thank you for coming.

[APPLAUSE]