Rockets and Space Research

Lecture by Dr. Frederick C. Harshbarger
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Transcribed by: Sherry Yin

Time	Transcription
00:00	Ms. Longstreth: It’s always a pleasure to welcome the students who come here to learn from the scientists who are making the seemingly impossible possible. Today’s lecture is the final one on the series *The Physics of Space* which the Theatre and Arts Foundation of San Diego County, Convair, General Atomics, and the Scripps Institution of Oceanography have presented for you. We hope that you have enjoyed them and that you are more aware of the study and research that has gone on before the spectacular advances of science which we have read so much about in the newspapers have taken place and we are sure that you have enjoyed meeting some of the scientists who have made these advances possible. Today's speaker, when he was just a high school student, was a member of the American Rocket Society and worked one summer for, for General Electric at the Rockets Test Station. He obtained his master's degree in science and his Ph.D. at the California Institute of Technology. He was awarded the Guggenheim Fellowship for two years graduate study in jet propulsion. He was also a Fulbright Scholar at the University of Oslo in Norway; he worked there on electron diffraction. Since coming to this country a year ago, he has been at Convair directing their advanced projects, particularly in the field of anti-missile research. He will talk to us now about rockets and space research. I take great pleasure in presenting to you Doctor Frederick C. Harshbarger.
01:55	[Audience Clapping]
02:03	Dr. Harshbarger: Thank you so much.
02:04	Ms. Longstreth: Do you know how to put these things on? [Audience Clapping]
02:15	Dr. Harshbarger: The interesting thing to me is that that movie was taken about ten years ago and they said in the movie that this was the highest altitude from which any pictures had ever been taken of the Earth and that was 76 miles; and just about a week ago, we all read in the newspaper that the Army had sent a rocket towards the Moon, which obtained an altitude of 66,000 miles, about a thousand times farther away from the Earth and I think you’re probably looking forward as much as I am to the day on which we can start seeing movies similar to this one but taken from that altitude. Today, I don't think, I think my plan is to just try and have a lot of fun. I brought some movies along of various rocket flights and I think what I, my main plan will be to tell you something about the history of rockets, a little bit about the principle upon which rockets work, and perhaps a little bit about the research which we can do with rockets. Interestingly enough the first interest in rockets, although they didn't know about it, started back in the time of the Greeks when a book was written about a trip to the Moon and since that time there have been many books written about a trip to the moon. One of the more interesting things that have been written about a trip to the Moon was written sometime in the 1800s when a series of articles started appearing in *The New York Times*, I don’t think it was *The New York Times* but it was some New York newspaper as a daily series and in this account, a man

described how he had set up a very high-powered telescope and he was examining the surface of the Earth, of the Moon and he saw the most curious things on the surface of the Moon.

04:10 Dr. Harshbarger: He saw one-eyed unicorns, he saw strange men walking around but finally it all turned out that this was just a big joke. It was a hoax and it wasn't really true but I think it does show that it went, his story ran for several weeks, so I think it does show that people even back in the 1800s were still very interested in space flight and in rockets. Now, it’s interesting that actually rocket history when they started, actually started using rockets dates back to the time of the Chinese around 1200 AD and the way in which rockets got started I think is quite interesting. If we could have the first slide. The Chinese, in defending against the Mongols, can we have the lights out, please? The Chinese in defending against the Mongols, of course, used ordinary arrows but then in defending their, in their battles against the Mongolian towns, they decided to be nice to add a section to their arrows which would burn and they would fire these arrows at the town and they landed in the towns and then this powder which was burning would help start the town on fire. Well after a while, they began to turn this charge around and it helped the rocket go forward and it still set the town on fire and finally, we have a final development, which is the normal skyrocket, which I think we're all used to which performs on the 4th of July. So this then is rather an interesting sequence of developments of how the rocket came into use I think; however, people had wild and various schemes by which they were going to use rockets. One of these is shown in the next slide.

06:02 Dr. Harshbarger: Here’s some enterprising man who thought that he would make some sort of a steam rocket. He had a little boiler going up here and he sent the steam down inside here. He rode on top of it, back out here comes exhaust. He goes riding through the sky. But most of these ideas really didn’t progress very far; in fact, they were lucky to get into printed paper. But there could I have the lights again, please? The, could I have the lights, please? The, the idea of the fire rocket, a rocket to set towns on fire and so forth, did gain wide acceptance in Europe. It turned out that the guns which had been developed were very poor in accuracy and you’d fire in one direction and the bullet would go someplace else and so for a long time rockets did seem to be more accurate than guns. And so, for this reason around the 1800s, Sir William Congreve developed a fairly accurate solid-propellant rocket which he used in salvos against enemy towns, and in so doing, he gained a great deal of notoriety. However, shortly thereafter, the guns became much more accurate by putting rifling into the barrels. So very quickly guns became much more accurate than rockets and so rockets for warfare dropped out of the picture. However, rockets were still important for doing certain duties of saving people, and so forth. For example, one of the primary missions of the Congreve solid-propellant rocket was used in saving ships. If a ship was floundering off the coast of England, they would fire a rocket from England shores out over the ship carrying rope with it which the people on the ship would try and secure to the boat and thereby try to get back safely to land. So this was the main use then of the rocket during the 1800s.

08:02 Dr. Harshbarger: About 1920 or so, the, a new interest in rockets was awakened. Several people, both the United States, Russia, and Germany, presented mathematical treaties which explained how rockets might be used to go to the Moon and even further into space. And so, the German Rocket Society was typical of the many societies which started up in an attempt to scientifically design rockets, which might be used for space research and space travel. I think it's very interesting what happened in Germany in particular. There were a group of people who started off in their rocket society working together and they were fairly successful but not very successful and so a couple of the people were very interested in sort of making a big name for themselves and they apparently weren't as interested in furthering the art of rocketry and as a result, they went, these people who were interested in building up their own name, went to the German car manufacturer by the name of Opel, somewhat synonymous to Ford in the United States and talked him into a big propaganda spiel about how great and wonderful Opel was, the Opel car. And so what they did was they took solid-propellant rockets, the most crude solid-propellant rockets, and put them behind cars. I mean this was no trouble at all. And they put these, had a big demonstration, crowds of people and they fired this rocket car down the middle of these people. Everybody thought it was really wonderful but it was no scientific achievement; it just made a big splash in the newspaper and Mr. Opel had his name written across the car. They also made trips in airplanes for very short distances and some people tried to put these rockets on their backs and then on ice skates, they tried to go across the ice.

09:57 Dr. Harshbarger: So this was good for laughs but it wasn't very helpful and the German Rocket Society continued on by themselves with their meager funds trying to build a successful liquid-propellant rocket. They were finally successful and in the process, Hitler came into power and Hitler was building an army and he was looking for new and advanced weapons. So several of the people from the German Rocket Society left the German Rocket Society, went into the army, and their hope was that they'd be able to build rockets funded by the German army that could reach the Moon and that was their whole goal. And so, they went on to Peenemünde and built the V-1, which was this subsonic Putt-Putt rocket, and the V-2, which was a 300-mile missile, ballistic missile which would reach from the German shores over to England. And now, I'd like to show you a little movie selection which shows you a little bit about this history. It starts off with the Congreve rocket and then ends up with some selections of the V-2 rocket. Now the thing that is going to be interesting, I think, is when you notice the V-2 rocket in its development as it leaves the ground and staggers and falls repeatedly and the reason for this is it's not so easy to build rockets. Let's have this movie.

11:17 [Movie Audio]

11:20 Dr. Harshbarger: The last picture, which you just saw was a scene of the, some of the captured German V-2 Rockets, which were brought over to the United States right after the war. In 1952, they were still testing these V-2 rockets that had been captured and they were still firing them in an attempt to learn more about the operation of rockets because the United States at that time was greatly behind Germany in the development of liquid-propellant rockets. At that time, 1952, I spent a little bit of time at the General Electric Company and our job at General Electric at the time was to develop an American version of the V-2. We called it the A-3 and at that time we were working on a new motor which was much smaller than the German motor, which had about the same thrust. But the point I want to make is that even in 1952, many years after the war, the United States was still essentially quite a ways behind the German development.

12:27 Dr. Harshbarger: It does take a lot of effort and a lot of experience before a person can develop a rocket which works smoothly and well. Now, there are two types of rockets which I'm sure you're all familiar with, there's a solid-propellant rocket and a liquid-propellant rocket. Perhaps I should just briefly describe the difference between these. Could I have the first slide or the next slide? This is a liquid or a solid-propellant rocket slide. This is, the red is the casing for the rocket, the yellow represents the fuel, which is a solid. This represents the combustion chamber, the chamber in which the fuel is burned and is finally exhausted out the end of the rocket and this green represents a clay structure, which is used as the nozzle of the solid-propellant rocket. Could I please have the lights? This rocket here is also a solid-propellant rocket, which is a homebrew. The rocket when, when loaded has propellant throughout the entire length with a nozzle back here. When initially ignited, it burns in a small area back here and the exhaust gases come out the rear. As the propellant burns, propellant burns in this manner up the length of the rocket. This is called an end-on burning rocket; it burns like a cigarette. It’s very simple.

14:09 Dr. Harshbarger: There’s another type of rocket, which if you look at the propellant backwards like that, if you look down the axis of the rocket, looks something like this. We're looking down the circle, at the back, and the propellant may, may have a design something like a star in the back, and this, you don’t like my star? [Audience Laughing]. And so if you were looking down this tube, you can see down the whole length and you’d see this same formation all the way down. And in this way, the burning takes place along this surface like this and then the surface slowly is burned backwards like that. And the idea is it keeps, the star is designed in such a way that there's a constant area burning. That is another type of solid-propellant rocket. Solid-propellant rockets are very simple but they have certain inherent disadvantages with them which we'll discuss later. A more complicated type of rocket is a liquid-propellant rocket, which is a type of rocket which most high-performance rockets, which you're familiar with, are built. If this is a, the total rocket, in a solid-propellant rocket, there is burning along the entire length of the propellant. In a liquid-propellant rocket, there's a small motor at the end. The combustion takes place in here and the gases go out the end.

16:01 Dr. Harshbarger: Above the motor, there's fuel and there's oxidizer in a liquid form and the fuel and the oxidizer are taken by plumbing, by pipes, from their respective tanks to the rocket motor and burned in the rocket motor. So the rocket motor is essentially small and the fuel is taken from the other tanks, put in the rocket motor chamber, and burned. Now, you can see that this type of rocket motor is essentially more complicated than a solid rocket motor. This requires plumbing, it requires valves that start and stop very quickly, which have to handle large amounts of liquid; and then it requires very sensitive timing and very finicky motors. Now, in the United States, the history of rockets somewhat paralleled that of the history in Germany. There was one lone man who was working on liquid-propellant rockets in the United States whereas there were some twenty or thirty in Germany. It just so happens that this one man in the United States happened to get his off the ground several years earlier than the Germans. But still, from that time on, the Germans went far ahead of the Americans and during the war, the Americans concentrated on solid-propellant rockets, which were used for assisting planes and their takeoff. These, even these solid-propellant rockets required quite a bit of development work. We said the liquid-propellants were difficult to develop, the solid-propellants were just as difficult to develop and now I'd like to show you some of the early American attempts at some of their solid-propellant rockets. [Audience sound]

18:02 Dr. Harshbarger: I'm always surprised at the number of people who think that it’s not possible for a rocket to operate outside the atmosphere where there's no air. So, I thought I'd just spend a moment discussing the principle of rocket flight, which is essentially embodied in Newton's Third Law of Motion, which says for each action there’s an equal and opposite reaction. Or essentially, it says that if I'm pushing against this wall with a certain force, then the wall is pushing back at me for the same force. Well, we can translate this to the problem of the rocket by several manners and perhaps I can show you the next slide. You visualize a frog sitting in a pond on a block of wood and the frog sees a fly flying by. This frog decides he wants to jump at the fly so he jumps and when he jumps, he goes one direction and a block of wood goes in the other direction. For each force, there’s an equal and opposite reaction. I think we can carry this a little further if you’d like to give me the lights, please. If we envision the fact that we are standing on a canoe or perhaps a light boat, row boat, very near land and you're standing there at the bow of the boat and you decide to jump ashore. I think if you’ve been on the water, you know you want to be pretty careful because if you jump too hard or too fast, you are likely to go right in the water. Well, here again, is the problem of equal and opposite reaction. If you're standing in this boat and you have a rock and you throw it as hard as you can, then I think you can understand that the rock will go in one direction but you and the boat are going to go in the opposite direction by Newton’s Third Law. And I think also the harder you throw this rock, the faster you're going to go in the opposite direction. So if you're sitting inside a rocket motor and you got hold of lots of air molecules and you throw them out the aft end, the faster you throw them out of course, the faster you're going to go with your rocket.

20:24 Dr. Harshbarger: So if you're going to design a rocket then, on the principle of equal and opposite reaction, you want to throw these particles, these molecules, these small stones out the back of the rocket as fast as possible to give you the highest thrust, the largest force. And I think you can also understand that this does not depend at all upon whether you're inside the atmosphere where there's air or outside the atmosphere. If we could have the next slide, we can demonstrate this in a second way. Here we have a box and this has a high pressure inside and it's such that the gas molecules are pushing on the sides of this box with equal force in all directions. Now, if we should suddenly remove one end of the box, then there's a portion of the box of which no pressure is being applied and therefore, there is an unequal balance of pressure and therefore, the box will tend to go up by the law of the Third Law of Motion. Now, if we have the next slide, we can see how we might progress from this to a rocket. Here we have our same box, the same high pressure in it, and the same ga. And here we have the same box again as we had before with a bottom removed. However, now we're feeding fuel from an injector in one side and we're feeding oxidizer in an injector for the opposite side and we're sustaining combustion in this chamber in the center and therefore, we're able to sustain this pressure, and therefore, sustain a force, a net force, up on this box. If we could have the following slide. We take this one step further from our box to a normal liquid propellant rocket configuration. In this particular case, can you, is it possible to focus that anymore? I guess not.

22:24 Dr. Harshbarger: Well, in a typical rocket motor, it gets very hot, particularly liquid-propellant. That's much better. It gets very, very hot and therefore, one thing you can do is work on the regenerative principle, that is to say, you feed the fuel which is relatively cool in around the rocket throat and let it circulate around this throat and through the walls of the rocket chamber itself. Now, there's combustion being sustained in the center of the rocket combustion chamber and this then heats the fuel, which goes through the outside wall. But it prevents the wall material from melting and then this heated fuel is finally injected into the combustion chamber at a higher temperature. So this then is one method of heating the fuel before it gets into the rocket chamber and also keeping the walls of the chamber cool. Perhaps we might show this next slide. This is a gadget, which is called Heron's Aeo, Aeolipile, which works as follows: there's a flame down here which heats water in this kettle, and then the steam which is generated comes up through these pipes and goes into this yellow spinner, which is capable of going round and round and this then spins. Now, I think you can see that if this gadget were placed outside of the atmosphere, out where there's no air, and if this would burn, which it wouldn't but if it would burn, then by the principle of Newton's Third Law this would spin around and it doesn't require there be any atmosphere. Well, I think that's probably enough about Newton's Third Law.

24:26 Dr. Harshbarger: And now, I'd like to show you another developmental picture, a movie, of a rocket which is called a Terrier. Now, the Terrier is a rocket which is used from, from surface up to air. In other words, it’s used to shoot down airplanes and before we go on to that, perhaps I should discuss for a moment something that you're going to see in the movie which is quite interesting. The Terrier is a two-stage missile, solid-propellant. I don't know exactly how it looks, something like this. It’s got some fins out here and then it's got another stage back here with some more fins. So this is the booster and then this is the second stage. Now, in the development of this rocket apparently, they've been having some peculiar troubles. You see what happens is this rocket fires first. The booster fires first and gets the rocket started on its way and then the booster falls off and then the second stage continues on to intercept the airplane. Now, just about the time of separation or shortly thereafter, the missile would start to wobble and all sorts of crazy things would happen. So they didn't know what was happening, so they mounted a movie camera up here. It's not that big. [Audience Laughing] And which they looked out and so they fired this, this gadget off the booster fired and the camera was on the booster and they kept looking forward and then they watched the missile when it separated and, you'll see in the movie, you'll be looking forward. You can't see what you're sitting on but you can see ahead of this thing and you'll be looking ahead like this and just as it separates, you will see this thing go like this and then it's gone.

26:22 Dr. Harshbarger: So they knew something was a matter right of separation and so they found their problem and then, so another picture and just a beautiful shot. You see this thing separate from you just as clean and nice and just drifts away right in front of you and then several seconds after, it’s ahead of you. Actually, what's happening is you're in the booster and the drag from the air is carrying you back but this thing looks like it’s way ahead of you and then you see the, it ignites and go on. Then finally, there are two scenes in this short film showing this rocket used, actually trying to intercept an airplane, which I think is quite interesting. So it starts off then with the scenes of the separation problem.

27:30 Dr. Harshbarger: I'd like to spend just a few minutes trying to describe why it's useful to have more than one stage on a rocket. We’ve already discussed the fact that it's useful to have a very high exhaust velocity from the rocket. That is to say, the velocity at which the gas is emitted from the nozzle of the rocket. The faster it comes out, the more thrust the rocket will have. Now, if we say that the velocity of the exhaust is VE, then it turns out, well, I guess I’m getting ahead of myself. Let’s start off with the rocket again. Here we got a rocket. Now, if this rocket weighs before it's launched some mass, let’s say 1,000 pounds - and we’ll call this mass initial - and if after it's been flown and burned out so it's empty if it weighs 200 pounds, that will be the final mass. Then we can say we can talk about a mass ratio. That is the mass of the final rocket after it's burned out to the mass initially before it has been fired. In this case, we have an initial, a final mass weight of 200 pounds, and the final or initial mass weight of 1,000 pounds, and therefore, we have a mass ratio of five.

29:11 Dr. Harshbarger: Now, I think you can understand that the rate of this mass ratio, the greater the velocity of the rocket will be. Something very interesting takes place that if the velocity of the gas coming out of the back of the rocket is the exhaust velocity, then approximately if the mass ratio is 2.7, then the velocity of the rocket at burnout, if there's no friction, will be the velocity of the exhaust. So if the mass ratio is 2.7, then the velocity of the rocket at burnout will be approximately the same as the exhaust velocity. That is to say, if the velocity of this gas is 10,000 feet per second at burnout, the rocket will be going 10,000 feet per second. If you want to, if you have - and this exhaust velocity is directly dependent upon what sort of fuel, what sort of oxidizer you have in here. The more energetic oxidizer and fuel combination that you have, of course, the greater exhaust velocity that you will have. But it's interesting, sort of the maximum velocities that you can expect out of fuels may be on the, they are, it's difficult to say what the maximum really will be but one maximum, theoretical maximum might be something like 5,000 meters per second. So this means then that if we have a mass ratio of 2.7, the magic number 2.7, then as the rocket burns out we'll be going 5,000 meters a second if there's no friction. But actually, we're not that lucky because even though this is a theoretical velocity which we can attain, actually you can't, you aren't that good, you're not that lucky and so, therefore, make him out to be half that or let's say 3,000 meters per second. But now what does 3,000 meters a second do for you? Well, not much.

31:10 Dr. Harshbarger: If it were 5,000 meters a second, you know how high you'd go? About 12,000 or beg your pardon, 1,200 miles, a thousand two hundred miles. That's not anywhere near the Moon, is it? It's not very good at all and this and we said that that was 5,000 feet a second, this is only 3,000 feet a second so let's see if we can have a burnout velocity that's a little faster. Now, the way you do that is you make a better mass ratio, have a better final mass to a better initial mass, and certainly let's, let's, to double the velocity after burnout you have to square this. So you want to square this and this comes out to be something like seven, 7.4 for a mass ratio and now you want, at burnout, you want to have a mass which is 7.4 divided into the initial mass. Okay, in this case then we get up to 6,000 feet per second if we had this situation of a mass ratio of 7.4. Well, 6,000 meters a second doesn't really get us very far either, that certainly doesn't get us to the Moon and maybe we want to get to the Moon. Now, if we start doubling this again, then we have to or if we go, if we want three times the exhaust velocity, then that will be 9,000 meters per second and then we have to have a ratio here which is equal to about 20, a mass ratio of 20. And it doesn't seem likely we're going to be able to design any rocket which can hold together, which has that sort of high-mass ratio. So the problem is we're limited to our exhaust velocity to a certain value, I just say 3,000 feet per second and we are also limited to the sort of mass ratios we can get. Actually, the sort of mass ratios we can get might be let's say in the order of ten, which means then that we might be able to get 2.3 times the exhaust velocity whichever that happens to be.

33:14 Dr. Harshbarger: So if we want to get to the Moon then we're going to have to do something because we seem sort of limited and so what we do is we use two or more stages to the rocket. Now, how does this work? Well, let's take this case over here. What we'll do is we'll build, here we had a mass ratio of five but let's change this and we will make two rockets. We will put one rocket here and I'll put another rocket down below and we'll say the total weight again, the total initial weight is 1,000 pounds. We will make this one weigh 800 pounds and this one weighs 200 pounds and we'll say that we said that about the maximum mass ratio we could get is 10. So if we make each one of these rockets, give each one of these rockets a mass ratio of 10, then what we have is an initial weight here of 800 pounds and a final weight of 80 pounds. Here we have an initial weight of 200 pounds and a final weight of 20 pounds. Now, if we fire this the following interesting thing happens.

34:15 Dr. Harshbarger: After the first stage burns out, we have a velocity of about 1.3 times our initial velocity, or 1.3 times 3,000 meters per second. Then we drop off the second stage and we fire this. Well now, the interesting thing is that we said we had a mass ratio of ten, didn't we? Well now, after burnout of this rocket, we burned all the fuel here but we have to include this weight in the burnout weight so we don't really have a mass ratio of, of ten for this first stage. We have something much less than ten and that's why we only get 1.3 times the exhaust velocity. But now when the second stage goes off, we are not worried about this stage anymore and therefore, we have a mass ratio of ten and we add the velocity so then we have an additional velocity of 2.3 times the exhaust velocity. And when you add these up, you have something like 3.6 times the exhaust velocity, which is getting up to be around 10,000 meters a second and we only need 11,000 meters a second or slightly more to get to the Moon. And so by this method then of putting stages on, you can gradually build up a superior rocket, which is capable of getting into outer space.

35:33 Dr. Harshbarger: If you only had one stage to this rocket originally, you'd have to have a mass ratio of something like 30 to do the same thing. So you can see we've gained a great deal then by having stages to the rocket. So the reason then that you want stages is to be able to carry your payload to a higher and higher altitude at a higher and higher velocity. Now, the next movie I'm going to show involves the launching of the first American satellite, the Explorer 1, and I'd like to describe just to remind you what the configuration of that rocket was. It was a Jupiter booster rocket and then on top of it as you'll remember, there was some sort of a funny thing up here with stripes on it and this thing was connected to the main booster by one rod and this thing up here spun around. And in this stage, there were three stages of solid propellant rockets, and up at the very top was the satellite. So what they did then, if this was the Earth, is they fired the booster. This is the Earth, they fired the booster up like that, carrying this, spinning third or second, third, and fourth stages with the satellite in it, and then they tilted - as this thing went up in the air - they started to tilt the whole business like this until it was aimed parallel to the Earth. And then they fired the second, third, and fourth stages and the rocket went like this and the satellite went like this also and went around the Earth. The satellite then stayed in orbit and it was a balance of forces between the velocity which gave us the, these are the centrifugal force, and the Earth's gravitational force which holds it in.

37:25 Dr. Harshbarger: This rocket was spinning because this made it possible to greatly reduce the weight on the second, third, and fourth stages. If this second, third, and fourth stage had to carry guidance in it - if there had been complicated electronics, all sorts of veins which had to move and wiggle - and it would have weighed a great deal more. And you can understand from our previous discussion that it's very critical that it has a low possible final weight if you want to get a high velocity. So what they did then perhaps I'm sure you all are familiar with the top when you pull the top instead of down you know, it stands up and it stays pointing in the same direction. So what they did is they spun this thing up on the ground so it was spinning before it took off. They fired it up through the atmosphere and then they tilted the whole works with this thing still spinning. It took some, it took some force to turn this thing around because this thing was spinning. But once they had it aimed the way they wanted in this directions and they fired this thing off, it would stay spinning in the same direction and that's why they didn't have to have any guidance because this thing was spinning and it wouldn't, it wouldn't process rapidly enough before they fired off the second, third, and fourth stages. So the movie now which we're going to see shows this rocket sitting out on the launching pad just before and just as they're starting to spin this final three stages and the satellite on the ground. And then we go inside the control room, which is inside a blockhouse and we see people in there as they start the countdown and then we finally see the rocket being launched. So we start then with the satellite being spun up.

39:17 Dr. Harshbarger: Well unfortunately, we're running out of time so I'm not going to spend too much time on research but perhaps I should just give you a brief idea of the types of research missions which rockets and satellites can be used. If we could have the first slide, please? This is a schematic diagram of the Earth in black, the atmosphere which is the air around us, which extends up to on the order of 50 miles, and then the ionosphere which is still air but it's just thinner and it has been exposed to the extreme radiation which comes from the Sun and has been ionized so there are electrons and ions in this region of the ionosphere and it extends from approximately 50 to 200 miles. And then finally beyond the ionosphere and extending out to infinity is what's known as the exosphere. I think it's called the exosphere because the lighter elements such as helium and hydrogen are supposed to, which are energetic enough, are supposed to go on out to infinity.

40:26 Dr. Harshabarger: Well, if we now take, there's several types of research we can do. One type is to fire a rocket called a sounding rocket, off from the Earth and have it go straight up probe into the ionosphere or perhaps into the exosphere, and then fall back down to the Earth. And in doing this then, it is possible to then map as a function of altitude going out and back different things that you're interested in, the electron density or the electron temperature in the ionosphere. Perhaps, you're interested in seeing how intense the radiation is coming from the Sun, perhaps, you want to measure the micrometeorite density but in the sounding rocket, you go out and then you come back. You probe through the whole distance and then come back but unfortunately, you don't go around the world. In a satellite however, you launch a satellite out and then fire it around and it starts to circle around the Earth and then by this manner then you can see how these various parameters vary as you go around the Earth but the satellite doesn't go in and out so you don't see what's happening with altitude as much as you do going around the Earth.

41:44 Dr. Harshabarger: Now, of course, satellites have elliptical orbits and so there is some variation in altitude which you experience, but certainly nothing down too low into the ionosphere. And then finally of course, there's another type of research which we've been recently trying to achieve and that is a probe, which goes deep into space such as to the Moon in which you try and map the parameters on the way for a great distance. We could have the about, well, let's have the next slide. This is a small sounding-rocket, this is just the top end of it and you'll see they have located in here the instrumentation package here, another instrumentation package here. In the center is a type of mechanism which is something like a parachute which allows one of these packages to be recovered on the way down.

42:37 Dr. Harshbarger: If we could have the next slide. This is the launching rack for this particular instrument package. The instrument package is located up here. This is a booster, this is a second-stage rocket and this is the first-stage rocket or a booster rocket. And the next slide, please? And here is a typical trajectory for this particular sounding rocket, which goes up to on the order of 700,000 feet and traverses a distance on the order of four or five hundred miles. This rocket then is fired, and at the end of 24 seconds, the first stage drops off and the second stage continues. And at this altitude, the nose cone material which protects the instrument package drops off and then it continues on up above the, into the ionosphere and then re-enters. And on the way down, there is a radar which tries to locate the point of recovery and at the point of impact, there's a small dust bomb which goes off so that they can visually track the location of which the rocket comes down.

43:52 Dr. Harshbarger: Oh yeah, and there's another slide, I guess. This is just a picture of a satellite going around the Earth performing measurements. I'd like to be able to talk more about the research which we can conduct from both satellites and sounding rockets, but I'm sorry I don't have time. I would now, before going on to the final movie - which I'm sure you're going to enjoy - like to first say that tonight, this afternoon we've looked into both the history of rockets and something about the principles of rocket flight, Newton's Third Law of Motion, and why it's necessary to use more than one stage if you want to get to extreme altitudes. If any of you are interested in reading more about rockets and haven't or are unfamiliar with rockets, then I have a sort of a good first book. If you have a very much familiarity with rockets, however, this isn't a particularly good first book. And that is a book called *Rockets and the Exploration of Space* by Willy Ley. I'd also like to thank the United States Army, the Jet Propulsion Laboratory, and Convair for making these films available, and I'd like to thank Meg Kelly for drawing these beautiful slides.

45:07 Dr. Harshbarger: And now, I'd like to tell you a little bit about this movie we're going to see. This is the most exciting movie I think, it's a movie of the Atlas and the photography I think is excellent. I think you are all quite familiar by now with the fact that there is a countdown you know, you count ten, nine, ten, nine, eight, seven, and so on. [Audience Laughing]. And this procedure starts many hours in advance of the actual firing, it's necessary to check out all the instrumentation, check out the guidance. It's necessary to load the fuel and oxidizer tanks, and finally, the last counting, which starts around 30 seconds before the rocket is fired is a count which is heard throughout the entire station.

46:02 Dr. Harshbarger: And this count is made audibly so that people who are listening in earphones all around can hear the countdown because they have instrumentation, they have cameras, they have radiometers, they have all sorts of instrumentation which they are told to start at 30 seconds before the thing goes off or five seconds and so everything has to be synchronized to the countdown. Another thing that has to be determined is exactly what the weather is going to be. If the wind is too high then the rocket just as it takes off is moving very slowly, is going to be blown over. So they have to, they can't have too high of velocity of the wind or else it makes a very poor launch. So you determine the velocity's right, then you start this launch checkout procedure and things get pretty tense and pretty exciting as you start the last countdown. I've been at several of these myself and generally, the things blow up, haha, and everyone hits the deck. Now, this is a very successful flight and I think you'll be able just to feel the tension that exists in the blockhouse, we'll spend most of our time in the blockhouse and you'll hear the man counting down and just before the thing goes off, you'll hear a guy in the background saying "come on baby, come on baby." [Audience Laughing]. And this rocket, the last procedure that happens is there's a pressurization that takes place; the fuel tanks are pressurized, this happens just before the rocket starts. And in Atlas, I suppose, there are turbines which pump the stuff out of the fuel and oxidizer into the rocket motor, and so everything has to get started right before. About ten seconds before the thing goes, they just press a button and they just cross their fingers. It's all over. They just got to pray that everything goes right. They have one button left they can push, which is a panic button if they want to stop the thing down and blow the Atlas up. So let's look at the Atlas. [Audience Clapping].

48:01 Dr. Harshbarger: That's it. [Audience Clapping].

48:14 Ms. Longstreth: I hope you've realized what a great privilege we've all had in having someone who is working in rocketry explain this to you and show you the movies he helped to make. I think it's wonderful. Thank you very much.

48:29 [Audience Clapping]

48:41 Ms. Longstreth: And I'd also like to introduce [unclear]

48:48 [Audience Clapping]

48:56 Ms. Longstreth: Dr. Harshbarger, would you have any time to answer a few questions?

49:00 Dr. Harshbarger: A few minutes.

49:03 Ms. Longstreth: Do you have questions from the floor? All right.

49:11 Speaker 1: Does the pressurization of the fuel tanks start at zero?

49:16 Dr. Harshbarger: Well, it all depends. The question was does the pressurization start at T equals zero? Every flight test group has its own method of counting down. I think you remember in the Atlas that fired off, I don't know whether it was X plus 10 minutes, I beg your pardon, X plus five seconds, the thing fired off. And I remembered in the picture there, about T minus five seconds, you started to see the the, he main stage firing and there's about 10 seconds. It appeared to me to be about a 10-second build-up in the motor. In other words, they start pumping in the fuel and they wait till the fuel stages yet the combustion gets fully developed before they let this thing go and it's just arbitrary whether it starts at 0 or whether it starts at 10 or minus 10 or plus 10. I think in the Explorer, the pressurization started at X plus five seconds so it's just completely arbitrary. If you were setting it up, you can make it any way you wanted it to. Yes.

50:22 Speaker 2: What remains, what happens to the focus of the ellipse as the satellite is spinning around the Earth, when the Earth is going around the Sun, [unclear]

50:37 Dr. Harshbarger: That was a pretty complicated question. I don't think I'd care to even try to answer that.

50:45 Ms. Longstreth: Another question. Right here.

50:49 Speaker 3: In the telemetering equipment from the Atlas rocket, do they use microwaves?

50:54 Dr. Harshbarger: I beg your pardon. Is the telemetering equipment microwave? Yes, it is. Yes.

51:03 Speaker 4: What is the burnout time on the Atlas?

51:05 Dr. Harshbarger: I, I can't answer that question. I don't really know. I imagine it's several minutes.

51:13 Speaker 5: You said there was a man in the United States who worked on that? Was he working by himself or was he affiliated with a group?

Dr. Harshbarger: That's correct. His name was, he was not affiliated with a big group. He was a professor at a small college in the, in the New England states and he was receiving money from a national academy, just a few thousand dollars a year, and his work was successful enough that they gave him money to work out at White Sands [Missile Range] for a while, but it was just a one or two man effort. Yeah, his name was Robert Goddard by the way. Yes, ma'am.

51:53 Speaker 6: [unclear]

51:57 Dr. Harshbarger: Yes, they were. Oh, the question was when the Atlas took off, you saw these things go back like that and the question was were these clamps really holding the Atlas down? Well, something was holding it down. I assume those of the clamps were holding it down. They just got out of the way in a hurry and the Atlas took off. A lot of these questions I'm not able to answer directly because either I'm not allowed to or else I don't know the answer so it's, you get to pick your choice but I don't know the answer. Haha.

52:31 Speaker 7: In the Atlas, in that last film, did it have Verneer Rockets?

52:36 Dr. Harshbarger: Were Verneer rockets being fired? I assume there were, there had to be. Any other questions? Yes, oh wow.

52:47 Speaker 8: Practically how far up in the exosphere will a rocket ever [unclear]

52:53 Dr. Harshbarger: Well, it depends a little bit upon, the question was how far up in the exosphere will the rocket go before it returns. And the correct answer is after the gravitational force of some other heavenly body becomes greater than that of the Earth and it will be attracted to some other heavenly body. And so in general, this is when it reaches about a velocity of seven miles a second at, at burn out, this will leave the gravitational field of the Earth and be attracted to some other gravitational field.

53:25 Speaker 9: [unclear]?

53:30 Dr. Harshbarger: Well, there are several ways of, the question is how do they tilt the rocket and there, it's a very good question by the way because once the rocket is outside the atmosphere, they don't have any veins aerodynamic methods of tilting the rocket and so they can't use conventional methods. And so what they do is they have auxiliary rockets, small rocket on the side of the big rocket, which force the rocket to move around, and this is the way they, they apply the force. The method by which they command the change of attitude however, there are many ways of doing this: they can command it from the ground by radio or it can be programmed into the rocket itself. The rocket can have a, a small brain inside of it which tells it where it is and it just tilts itself. But in most of the, most of the satellite experiments, they are commanded from the ground.

54:29 Speaker 10: Does the Atlas have a gimbaled rocket?

54:31 Dr. Harshbarger: Yes, it does. Excuse me, the question was, does the Atlas have a gimbaled rocket and the answer is yes.

54:41 Speaker 11: In the liquid fuel rod at the burnout point, they shut off the fuel and control it that way. What would they do in a solid stage?

54:51 Dr. Harshbarger: The question was, the question was in a liquid-fueled rocket, they have valves which they can shut off the flow of fuel and oxidizer and so therefore, they can stop the burning time anytime they want to. They can make the rocket go a short distance or long distance by shutting off the fuel with valves. And the question was when you go to a solid rocket which apparently burns the entire time without being able to stop it, is there any way in which they can stop the burning and I'm afraid I won't answer that. Haha.

55:25 Ms. Longstreth: There was a question over here. Would you stand up, please?

55:28 Speaker 12: When you are shooting for the Moon or objects out in space, how accurate is the initial guidance systems? I have always heard that, so far, they are two, two and a half, three degrees off.

55:38 Dr. Harshbarger: Well, I don't know that I could give you any numbers. I don't, I'm sorry, I don't know any numbers.

55:47 Ms. Longstreth: Are there any other questions?

55:51 Speaker 13: I would like to know what are the guiding rockets on the larger rockets. Are they solid propellant or liquid propellant?

56:05 Dr. Harshbarger: Well, the question is on the larger rockets, are the guiding rockets liquid or solid propellant? And I think that in almost all cases they are liquid propellant because you can control the fuel flow to the small rockets and thereby control whether you are giving a large thrust or a small thrust in any given direction.

56:27 Speaker 14: In the rocket where they are using a telemeter system, do they use a different transmitter for each frequency they want to telemeter something or do they superimpose all the information on one carrier?

56:39 Dr. Harshbarger: The question is with regards to telemetry of information back to the ground from a rocket, did they use one frequency, one carrier frequency, and superimpose the information on one frequency or did they use many frequencies and the answer is they do both; they use several frequencies and they also superimpose information on the same frequency, so they send an awful lot of information back via telemetry. That's it.

57:08 Ms. Longstreth: Thank you very much, Dr. Harshbarger. And I have one announcement to make. We are going to have an opportunity for a lecture on the 25th of January. The General Atomics has agreed to give [unclear] lectures on various aspects of fission and so forth. I am sure that you will enjoy them very much [unclear] remember to take your time to come and learn while you have the opportunity, from the scientists who are working in their special field and who are giving so much time and thoughts to prepare lectures for you.

57:50 [Audience Clapping]