MODERATOR: For centuries, man's imagination has been captured by the mysteries of the universe. Today he stands on the threshold of a first hand exploration, beginning with a trip to the moon. Ironically one of the major difficulties in taking this first big step is returning the Apollo spacecraft safely to Earth. In the final stages of its journey, the command module enters the severest and most dangerous lap of its whole mission. Dealing with reentry heating is one of the greatest problems of the whole program.

In their laboratories, scientists have simulated this awesome environment using machines that can produce temperatures up to 5,000 degrees Fahrenheit. They have experimented with hundreds of materials to find just the right protective coating for the heat shield. Once the spacecraft has reentered the Earth's atmosphere, the next critical step is lowering the command module with its cargo of three astronauts to a touchdown on Earth.

Engineers have devised a sophisticated landing system with parachutes of various sizes and shapes that will be deployed in a carefully controlled sequence. Though the parachutes will slow the spacecraft to a 15 mile an hour touchdown, still 10,000 pounds hitting the earth at this speed poses yet another serious engineering problem. Suspended under this Gantry tower is a model of the Apollo spacecraft.

To simulate landing, the module can be dropped on land or in a pool of water with various attitudes of pitch, yaw, and roll, and with various vertical and horizontal velocities. These tests provide valuable information about spacecraft design. How scientists and engineers have solved the problems of returning three astronauts from outer space is our story today on Science Reporter.

[MUSIC PLAYING]

FITCH: Hello, I'm John Fitch, MIT Science Reporter. Today we're at the National Aeronautics and Space Administration's Langley Research Center in Hampton, Virginia, to learn how scientists and engineers are overcoming some of the most imposing obstacles of the Apollo mission, getting the astronaut safely back through the atmosphere and down to Earth. It's a multifaceted problem. The first part of which is surviving the meteoric plunge into the atmosphere.

Think for a moment of an actual meteor speeding through space. As it draws near the earth, the gravitational force pulls it in toward the planet at ever increasing speeds. Suddenly it rips into the wall of the Earth's atmosphere. The friction of the meteor plowing through the denser air generates such searing heat that solid rocks are melted away and even the electrons are stripped from their atoms. In a few brief moments the meteor may entirely disappear in a fiery, gaseous display that we call a shooting star.

To find out what scientists and engineers are actually learning about techniques and materials for reentry to protect the astronauts and their spacecraft from this extreme heat, we talked first to Mr. William Brooks, head of the Entry Structures branch here at Langley.

BROOKS: When the spacecraft entered the Earth's atmosphere, by a process of compression and friction, a hot layer of air is formed over the frontal part of the vehicle. The temperature of this air may be as high as 20,000 degrees for the Apollo vehicle.

FITCH: Well, how does 20,000 degrees compare with what we might find here?

BROOKS: This temperature is three to four times as high as the temperatures created by welding torches. The intense heating that is associated with this high temperature air is such that no known materials can withstand it without melting or vaporizing or decomposing in some other fashion.

FITCH: Then what can you do about it?

BROOKS: Once we accept the fact that this degradation will take place, we found a class of materials called ablative plastics form very efficient heat shields.

FITCH: What do you mean by an ablative plastic?

BROOKS: Ablation is a word that we use to define the process of removing surface material by a mechanical, a chemical, or a thermal means.

FITCH: And to lose material.

BROOKS: You actually lose material from the surface.

FITCH: What makes a good ablative material?

BROOKS: The ablative plastic must have the characteristic of forming a tough char layer which resists the scrubbing action of the hot air. In addition, it must generate gasses which percolates out through the char and blocks some of the incoming heat. And the final, but important requirement is that these materials must be efficient thermal insulated.

FITCH: So it doesn't cook the people who are inside.

BROOKS: Right.

FITCH: Well, what have you found makes are good plastic?

BROOKS: At Langley, we have been researching a material which consists of phenolic resin. This material is similar to that used in fabricating countertops. This function is to bind the other ingredients and to form a tough hardened surface when it is degraded by heat. Another ingredient is nylon.

FITCH: Is this the same nylon they use in shirts and so forth?

BROOKS: It's the same nylon that is used in certain stockings, except here it's in a powdered form rather than more familiar fibrous form. Another ingredient-- these hollow microballoons which are made out of phenolic resin.

FITCH: Is it little spheres?

BROOKS: They are little spheres. To the naked eye, it looked like powder.

FITCH: Powder.

BROOKS: But when these are viewed under a microscope, you can clearly see a thin wall hollow sphere. Another possible ingredient is crossfibers which are used to reinforce the composite plastic.

FITCH: Mixes altogether then?

BROOKS: These are all mixed together. And then subjected to a molding process at temperature. And the material-- it hardens and cures out to a plastic composite such as this.

FITCH: Now how do you know that this will work?

BROOKS: That is one of the important aspect of materials research is to distinguish how these perform in a reentry environment. Mr. Wilson will prepare this for test, and we'll show you that test later on. The facility that we're using to test this material, based on the principle of using an electric arc to heat the air stream.

In this facility, we have three electrodes. They each consist of two concentric water-cooled copper rings. An arc is struck between the two rings, and is caused to rotate very rapidly by a magnetic field. There is introduced at the base of the electrode, and passes up between the ring, and is heated by this rapidly spinning arc. The individual streams are squeezed down into one stream, at a temperature of about 7,000 to 8,000 degrees Fahrenheit. And this steam envelopes the test model.

Now actually, the model is mounted on a L-shaped inserter outside of the stream. The instrumentation leads are connected. When the model is positioned, the facility is started. When the proper flow has been established, the model is then swung into place over the exit of the facility. Now the facility is actually controlled from a central control room, which I'd like to show you.

This is our control room. We operate several [INAUDIBLE] gas facilities from this room. Here we have instrumentation and controls which deal with facility parameters, such as gas flow rates, water flow rates, water temperatures and pressures. Here are the controls and instrumentation which involve the power applied to the facility.

For the particular run that we're making, with this type of facility, we can put upwards of 5 million watts into this heater. During the course of the test, the overhead monitor is used to determine the progress of the test. And we have a digital clock here on which is recorded the test time. The equipment in the center of the room is for programming and controlling very precisely the air flow or the flow of other gases used.

Over here are the data collecting instrumentation. The data is collected in the form of electrical signals, which represents temperatures, pressures, flow rates, and so forth. This data is transmitted by wire to a central computing station where it is reduced. Some of the reduced data is displayed on these charts for control purposes.

FITCH: I see.

BROOKS: The crew has been preparing for a test and are ready to commence. Mr. Wilson.

WILSON: Reactive sets.

MALE: Reactive sets.

WILSON: Flow rate sets.

MALE: [INAUDIBLE]

[BUZZER SOUNDS]

WILSON: Read the set tape data. Start the jets.

MALE: Jets on. [INAUDIBLE] Yeah.

BROOKS: In addition to the type of data that I described, that is temperature, pressures, and so forth, we also take close up motion pictures to permit us to observe the details of the test. Let's go back into the other room and examine one of those motion pictures.

FITCH: Fine.

BROOKS: The facility is being started and the flow being established. The specimen is swung into place and starts to ablade immediately.

FITCH: Why did the air begin to glow even before it hits the object?

BROOKS: This is because the air is heated to very high temperatures before it comes out of the facility and radiates energy. Note also that along the sides of the specimen there is illumination at a lower level, which is caused by the gases produced by ablation.

FITCH: That's what the astronauts actually see out the window, don't they?

BROOKS: Yes. Note that the ablation is uniform over the surface except a slight rounding at the corners where the test conditions are somewhat more severe. Lights, please.

FITCH: It's a very dramatic piece of film.

BROOKS: This is a typical tested specimen. You will note that a char has been formed over the entire surface. In a test such as this, we measure the surface recession, the surface temperatures, and internal temperatures. The specimen is then sectioned, and the char thickness is measured, and other characteristics determined.

FITCH: Is this test a good simulation of what actually happens?

BROOKS: It is not an exact duplication of an actual environment. We cannot produce these environments in the laboratory. But from tests such as these, we get the data which can be used with theoretical procedures, and can predict what will happen in an actual reentry. That is-- will this material make a good heat shield?

MODERATOR: The ablated heat shields for the Apollo command module are manufactured at the Research and Advanced Development Division of Amco Corporation in Lowell, Massachusetts. The outer shell of a spacecraft arrives here in four separate pieces. The blunt end of the cabin, which takes the brunt of the heating, is mounted upside down on its cradle, and has already been partly covered with its heat shield. This section fits on the bottom of the crew compartment in which the astronauts will ride. Above that is the forward equipment and parachute section. And finally, a small nose cap.

Because of the tremendous heat of reentry, all surfaces must be protected. To learn about the processes involved, we talked with Mr. Edward Offenhartz, director of Amco's Apollo operation.

OFFENHARTZ: The heat shield that we've developed at Amco consists of a honeycomb matrix to which we add an ablated material.

FITCH: Now what is the purpose of this honeycomb?

OFFENHARTZ: Actually it serves two purposes. One-- it gives us additional mechanical strength. And the other-- it assures us that we can have a good bond between the ablator and the steel.

FITCH: Well, how do you actually fasten the honeycomb onto the steel.

OFFENHARTZ: Well, we start with the steel. And we have to clean it. And incidentally, that's the reason for the white gloves. It's a clean area. And we cover the clean steel then with a tape, which is sticky on both sides.

BROOKS: Oh, yeah.

OFFENHARTZ: We lay it on top. And then we take some preformed sections of the honeycomb, and we put them on top to hold it down.

FITCH: And that really fastens it on tight?

OFFENHARTZ: Well, not quite. We have to go through a cure operation, which then puts and guarantees the bond. It ends up like this. We have a rigid attachment.

FITCH: When you have a honeycomb firmly bonded to the steel, then you fill these up with the ablated material?

OFFENHARTZ: Well, not quite. As you know, the heating varies around the vehicle. And for example, we have a higher heating here than we do up toward the top.

FITCH: So you want more heat shield around the edges?

OFFENHARTZ: That's right. We want the thickness to be greater here than it is towards the middle. And incidentally, it's not uniform. The heating also varies in the other direction as well. So we define the thicknesses in going around the vehicle in such a way so that we can provide the required protection and achieve the weight that is needed to do the job.

FITCH: Now how do you do this trimming operation?

OFFENHARTZ: Well, it is something that we have to accomplish with a machine. And we do that next door. In order to machine compartments of this size, we require the use of a 16-foot vertical boring mill. Because of the motions of the tool that we needed, we converted this machine to an electronically controlled tape, which enables the tool to be programmed so that we can cut the ablator and fix the thicknesses as we require around the vehicle.

After machining, we have to get the ablator into the honeycomb matrix. We do this by gunning. And what you feel and hear is a nose and forward compartment in the process initially of being gunned.

FITCH: He's actually squirting ablated material into the holes?

OFFENHARTZ: That's right. What we do is mix the ablator itself. It's a plastic. We have added in 5 inch microballoons to get the correct density. We load it into cartridges, which we can store for later use. When we get a cartridge, we load it in a gun. And it's heated, as you can pretty well tell from here.

FITCH: Oh, yeah. It's warm.

OFFENHARTZ: We have a nozzle at the end. And if you'll hold this, I'll try and see if I can duplicate what he's doing there. And you can see that the material does come out.

FITCH: You actually get air mixed in with it?

OFFENHARTZ: Right. The air actually entrains the material in the cylinder and loads the material from the base up.

FITCH: It feels like warm putty with fibers in it.

OFFENHARTZ: That's pretty much the consistency of the material.

FITCH: And he goes around and fills every one of the holes?

OFFENHARTZ: Right. We have quite a few on a vehicle.

FITCH: How many altogether?

OFFENHARTZ: There are 400,000 that need filling, and one is as important as the other.

FITCH: Then how can you be sure that you've got every single one filled?

OFFENHARTZ: We have an x-ray technique that enables us to tell. If you'd follow me-- What we do is x-ray the entire vehicle. And we have trained technicians who can read and interpret the x-rays. What you see here is something that been cored out for repair.

FITCH: Looks like those are holes punched right through the film.

OFFENHARTZ: That's right. First we identify the flaw, and then the x-ray is put back onto that part of the vehicle where the flaw occurs. And by punching the hole, we pick out that cell which requires repair. So we do the right one.

FITCH: So he just digs that one out and fills that one again?

OFFENHARTZ: Right. We do this until we have the completed section.

FITCH: Well, assuming that you've got every hole properly filled, what would be the next step in the process?

OFFENHARTZ: We have to then go through the oven cure or the set up of the ablator, the hardening process. Each compartment is rolled into the oven in order to enable it to undergo a cure, which results in hardening the ablator.

FITCH: How long does it stay in the oven?

OFFENHARTZ: It generally stays in the oven for better than half a day. And incidentally, the temperatures that we keep it at are greater than 200 degrees Fahrenheit. We, in addition, require a bagging operation.

FITCH: What's the bag for?

OFFENHARTZ: Well, we have to do the cure in an inert atmosphere so that we can drive off any volatile gases generated during the cycle. After the compartment comes out of the oven, the ablator sets up hard, and takes on this overall appearance.

FITCH: Oh, I see. Yeah.

OFFENHARTZ: We then go through a kiss with the machine to achieve a smooth surface. And then we apply a combination moisture barrier and paint, which gives us this overall finished product.

FITCH: Why do you need a moisture barrier?

OFFENHARTZ: Well, the material itself is of low density, and it would absorb moisture. You would prefer that it wouldn't. So it's a preventative maintenance aspect that we're concerned with here.

FITCH: I notice this crew compartment seems to have a lot of openings cut into it all the way around. What's the purpose of that?

OFFENHARTZ: Well, at assembly there are many detailed further connections and work that must be done so this provides access. The doors that fit in here are identical to the ablator as shown here. And what we have are the frames or gaskets to provide the seals.

FITCH: Thank you very much, Mr. Offenhartz. As efficient as the ablation process may be, it isn't the total answer to Apollo's reentry problem. To control the heating and the extreme stresses of deceleration, the command module will enter what's called a double pulse. First, a shallow dive into the upper atmosphere, followed by a skip back up to a higher altitude to cool off. Then the final descent to Earth.

MODERATOR: The Apollo command module returning from the moon must enter the Earth's atmosphere through a precisely defined reentry corridor. If it enters too steeply and drops below the corridor, the astronauts will be subjected to excessive heat and G-forces. Above the corridor, the spacecraft might not be slowed by the atmosphere, and miss the earth completely.

The center of gravity of the command module has been offset from the center line so that the spacecraft travels at an angle. As a result, a small lifting force is provided by the air in addition to the drag. The direction of this aerodynamic lift can be controlled by rolling the spacecraft with small jets. This permits the flight path to be controlled up and down or sideways much like a high speed airplane.

Under normal conditions, the automatic guidance system controls this flight down the reentry corridor. To avoid excessive deceleration and heating, the system is programmed to bring the spacecraft into the atmosphere in two separate stages. First, a shallow dive, followed by a steeper path, with a cooling off period in the upper atmosphere in between.

The pilot continuously monitors the entry trajectory. If the guidance and navigation system places the spacecraft in danger of encountering excessive G-forces, or of skipping out of the atmosphere with super circular velocity-- that is the speed that would take it out into space in a new orbit-- the pilot would take over control and complete the entry manually.

When the spacecraft begins to descend for the second time, the atmosphere slows the command module to less than the speed of sound. At 25,000 feet, small drogue parachutes are deployed to further slow the spacecraft. At 10,000 feet, pilot chutes bring out the main parachutes, which float the command module to its journey's end.

FITCH: While parachutes will certainly help in slowing down the Apollo command module, it's landing will be by no means gentle. When it finally hits the water, some 10,000 pounds will be going almost 20 miles an hour. Over here in this building, various command module shapes have been tested to see if they'll withstand the impact. This is Langley's impacting structures facility, an 1,800 foot towing tank, built before World War II, to test various amphibious planes. We talked with an aerospace technologist, Mr. Sandy Stubbs.

STUBBS: This facility here is used for war impact. We also can get land landings here. We have done tests on the Mercury, Project Mercury, the Gemini, and currently are running tests on the Apollo vehicle that you see here. This is a quarter scale model. Inside it we have accelerometers and pressure pickups to measure the deceleration and water pressures on impact.

The signals from the accelerometers and pressure pickups are fed through the cable here to the recording equipment over on the beach. We also have cameras located along the beach to record the dynamic motions of the model when it impacts the water. Now we can raise this up a bit, and run a test. Go ahead, George.

As you see, it's on a pendulum, a simple pendulum, which we use to obtain the desired horizontal velocity. A model is released about here, when the necessary vertical velocity is obtained by the free fall.

FITCH: And now what will be the conditions in this particular test that you're going to run?

STUBBS: The vertical velocity will stimulate parachute letdown of about 20 miles an hour vertical, and 20 miles an hour horizontal.

FITCH: All right.

STUBBS: The model will impact the water in a positive pitch attitude with the heat shield contacting the water.

FITCH: Is that a realistic landing, pretty much?

STUBBS: That's a normal landing.

FITCH: And what-- anything special we should watch for when landing?

STUBBS: There'll be a pretty big splash, and a violent pitching motion. And then the model will remain upright. And come to rest in an upright floating position.

FITCH: Okay.

STUBBS: Are you ready? Want to pull the sash forward? We'll back up just a bit.

FITCH: All right. I don't want to get too wet.

STUBBS: Okay. Let it go.

FITCH: Wow. It's quite a splash. Well, it stayed upright, so I assume the astronauts are all right on the inside.

STUBBS: Yes. This is a dramatic impact, but it turns out pretty good. We can show you a film next that'll show the same run again, and let you get another view of it. These tests show an earlier version in the Apollo spacecraft known as Configuration C. The landings were made in water, simulating paraglider letdown. And you'll see that the horizontal velocity is much higher than the vertical velocity in this case.

FITCH: Oh, I see, because a paraglider will be coming in at a much higher horizontal velocity than a parachute would.

STUBBS: That's right. This is at a much higher velocity simulating a smaller paraglider.

FITCH: Oooh. Look at that one. That wasn't a very good landing.

STUBBS: The next group of landings will simulate a hard surface or runway-type landing, in which the vehicles skids and rocks along the runway.

FITCH: Is this also what's coming in with a paraglider?

STUBBS: This is also at the paraglider landing speed.

FITCH: I think this was proposed at one time.

STUBBS: This is a view of Configuration A, which was the early proposal, the first proposal. The accelerations on this vehicle were a little on the high side, and we tried to cut them down with Configuration B, which had a better acceleration bottom shape.

FITCH: You don't get as much of a shock. Ohhh.

STUBBS: This one was unstable.

FITCH: I see. Try it again.

STUBBS: So we went from here to Configuration C with the same bottom shape as shown here. But with an extension of the diameter-- to a little bit larger diameter. Here we got a very good acceleration vaults. And the stability was acceptable.

FITCH: What do you use all this information to measure for?

STUBBS: The data that we obtain from the model is quickly analyzed here at Langley, and then shipped to the users. In the case of Apollo, to Manned Spacecraft Center in Houston. And then on to the prime contractor on the Apollo spacecraft. They, in turn, use the data for the basic design of the heat shield structure, the instrumentation mounts, and other important structural parts of the spacecraft.

FITCH: Thank you very much. Our guests today have been Mr. William Brooks and Mr. Sandy Stubbs of Langley Research Center, and Mr. Edward Offenhartz of Amco Research and Development Corporation I'm John Fitch, MIT Science Reporter.

[MUSIC PLAYING]