NASA JOHNSON SPACE CENTER ORAL HISTORY PROJECT
EDITED ORAL HISTORY TRANSCRIPT

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INTERVIEWED BY REBECCA WRIGHT
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WRIGHT: Today is October the 8th, 2013, and we are visiting with Frank Hughes in Rocket Park in the Saturn V facility [Johnson Space Center]. We thank you for getting ready to walk us through and explain about this vehicle and what you did to help train people to be on it. [Interviewer is Rebecca Wright, assisted by Rebecca Hackler and Sandra Johnson.]

HUGHES: Good. I think that what we're going to do is amble down here to the back end, the engines, and start from there and come forward on the other side. We're passing here the SLA which is the [Spacecraft] Service Module/Lunar Module Adaptor, this conical thing. It got to be a big controversy in that we had to react to that a lot in the training. We'll talk about that, coming back. You mentioned that these vehicles are not all one unit, and as far as I know—

WRIGHT: There seems to be a controversy over is this really all one unit.

HUGHES: KSC [NASA Kennedy Space Center, Florida] does not have a real one, and that would break their little heart to know that. They've got some real engines, but there's a lot of engines that are not real, mocked-up. When Bob Rogers of BRC [Bob Rogers & Company] fame was working and put it all together, I think he was troubled with all that parts he had down there, that's the deal. When we go through here, one thing that we can't see when we come up the other side is that these are just tanks linked together, so that's why you had these humps. These are for wires. There's no plumbing going on; that's for wires and pipes going up the side of the vehicle. There's a couple of other things we'll show that you may not have thought about it. The first stage was built by Boeing at Michoud [Assembly Facility, Louisiana], where we built the ETs, the Shuttle External Tanks, and they're about almost the same diameter. A lot of the same machines were used to roll the steel to build it. This [second] stage was built by what was then called North American Aviation, and it's also 33 feet in diameter, 5 engines, but it's got oxygen and hydrogen propellants, where the first stage is oxygen and kerosene, RP-1, they called it.

As far as the simulation goes, we didn't have any of this to see. It's all virtual, so all we saw as the pressures in the engines and the activity of the gimbals, they would move so the whole stack would swerve as you were moving. Since we didn't have a motion base, what the crew didn't know is that when this thing moved or swerved, the crew guys were not prepared for that, so we just told them about it. When you start about rotating this huge vehicle, the center mass was down in the middle of the second stage. You can imagine that if the bottom wants to go left, it's turning the engines down here, well, the center of rotation is somewhere in the middle. Up for them, they didn't feel that rotation—it was like they were moving sideways. It's so big and so long that it was almost like they were doing yaw or pitch as opposed to any other roll that you're trying to do. It was a grabber for the Apollo 8 guys—it was like, whoa!

WRIGHT: A surprise.

HUGHES: Yes, it was a big surprise because a small motion at the bottom made a 4 or 5 foot change where they were, up at the other end. Of course, there was a lot of vibration in this thing.

It's not like the smooth ride you got on the [Space] Shuttle. The Shuttle wasn't very smooth either on first stage because the solid motors created a lot of vibration. We'll pick it up the conversation down here, and what I'm going to do is talk about the training that we did, while talking in the context of a launch, just what's going on at each step.

I want you to look inside this engine. You see that circular device down there with all the holes? This is a real engine. That's an injector. That was a big thing to do, to pump the oxygen and kerosene into one place and mix it and then make it burn efficiently. If you go down to KSC and try to get to the point where you look in there, it's just a plug, it's just a flat plate there, which means they had a nice-looking mock-up of the engine, but it's not a real one. That's not against anything—I loved F-1 [that huge mockup down there]. It was called F-1. We were kids, meaning 22, 23 years old, we climbed all over that damn thing because it was built to train the people how to lift it, how to stack it, put it on the crawler [transporter] and take it out to the pad, and do all those things. It was made as a mock-up. It was the real thing in everything except they didn't put the expensive pieces on, like the engines.

When we put it on display at KSC, they rounded up all the engines they could find, and made it as real as they could down there at KSC. The real ones, [SA-5]15 is over at Marshall [Space Flight Center, Huntsville, Alabama] and 14 is here, 514. [SA-]513 became Skylab, so the first two stages launched the third stage laboratory dry that you saw the other day.

When you get to this point, talking about any kind of engine, an important part of it is that you have to make sure that you mix the fuel and oxygen together in an efficient way. On top of that, did you ever take a chemistry class somewhere, and you made some oxygen and then you would take a little piece of wood, a burning wood shaving and stick it in there? It would go poof and burn so fast you could not see it.

The same thing here applies here. If you had too much oxygen in this engine, you don't get combustion, you get an explosion. It's the same combustion, but it's a rapid combustion. The mantra of people as they built liquid engines, back in the '30s and '40s, during the war, is "fuel lead." You always make sure you have lots of fuel before you put any oxygen in. [The fuel has to lead the oxygen into the engine.] There's a beautiful, beautiful [video] of a Saturn V start, and you can see the clouds coming down out of the engine, you're looking up underneath at a Saturn V.

You're spraying kerosene in, and so this whitish-looking stuff is falling down because it's a little bit heavy, it actually comes down, and then, all of a sudden, it just goes bam! You know, just like explosions, the scene goes away because it's so bright. They added the oxygen. It was already burning—there's gas in here, and right in the middle of that thing is where there's an igniter on each engine, so they had a thing that was like a blowtorch. It would fire into this area, but it's so the kerosene is just burning, so if you look inside the engine, you can see there's a glow, and there's some smoke and everything coming out of it, but nothing until the other pump then throws the oxygen in. Then, just all hell breaks loose underneath there, you can imagine.

The five of them, it was so big, they started it 9 seconds before launch, started lighting these things off. They lit one off every half-second, and it took about 4 seconds to get up to speed. If you add all that together, it means at about 4.5 seconds before launch, they're all running. Then, the computers are slow in those days, so it took 2 seconds to check everything, and so, everything got checked two more times. You checked it all to make sure the whole thing is ready to go before you'd say, "Launch."

In the simulator, we didn't have a motion system. They got shock coming—that was a big thing. All of this stuff is happening down there, valves clanking and things going on, you could feel them through the vehicle structure. All of a sudden, the noise of the engines, but it's so far away. Literally, there's a delay time even for the sound to get up to you because it's about a third of a second, if you think on sound, to get that far. A thousand feet is about 1 second, and the old count, one, two, three, four, five, on lightning.

Now, this thing is burning, some of those fuels, some of those areas, are oxygen and the other ones are fuel mixed in here, so it's going. The temperature right here would be 5,600 degrees, so if you're standing here, you would not stand long—5,600 degrees. It's about the same as you got out of the solid rocket motors on the Shuttle, how white that is and the difference is you see the flame there because it's got junk in it and particles and things like that, that's why there's so much smoke. Where here, it's smoke-free, it's almost a perfectly clean-burning engine. There's a lot of stuff when you start, but when you see it climbing up, there's nothing except this long, long, long flame, and no trail, no smoke trail.

The temperature of 5,600 degrees is way higher than the temperature of this metal. It would melt it. All of those little tubes you see all the way down, they're actually sending liquid oxygen through those tubes. It's coming down the length of the engine bell and then here, those tubes end and dump into an even larger manifold, and if you look over at that one, you see that manifold tube around the middle there? All of those are throwing oxygen into that manifold, and then it's going back up. By now, it's been boiling, so it's turned to gas. It's coming back up and it's been picked up in the top and fired into the engine. Now, you're putting in liquid oxygen, gaseous oxygen, and the kerosene, liquid kerosene, going in.

Each of these engines move, the four on the outside are gimbaled. The center one doesn't do anything; it's just pinned to one place. The vibration is extreme down here.

I want you to look here, we would simulate down to zero and then something interesting happened down here. All of the weight [of the entire vehicle] is resting on those four corners. You'd find them if you look above. All the weight of this whole 36-story building is on there, and when we launched the first one, well, actually they decided beforehand, there's a hold-down clamp. In other words, those engines are running for 4 seconds, so you had to hold it and make sure it wouldn't go. Then, at zero, they'd flop that hold-down clamp back and turn it loose.

The problem was that it's so big, there's so much momentum. Have you lived around a railroad or a train where the engine starts going? It starts clanking out like this, or it slows down, it compresses. This one is so big that it started compressing—in other words, the back end started moving before the front end knew that it was coming, and so it was compressing the whole vehicle. What they did to accommodate that fact is at each of those corners, they had a hole in the pad and they put a stainless steel rod, 18-inch-long stainless steel rod screwed up through the hole. The rod was about three-quarters of an inch in diameter, and the hole was a half-inch. For the first 18 inches, they intentionally slowed down the first movement that it could go so that the front end got moving, all the compression happened, and then they turned it loose. Imagine the force of just taking a stainless steel rod and pull it out four times all the way through a smaller hole. It just extruded it on the fly. That was a design that worked very well.

All of these engines had hydraulics done inside here, so there were hydraulic pumps, APUs, Auxiliary Power Units, they were all going on. It had its own hydraulics, the engines all four, so you could lose one and you could still steer it with three left. The center engine doesn't steer; it was just static. You can imagine all these things, that they only burned 2.5 minutes, and then all the fuel was effectively gone. This is what Jeff Bezos, the Amazon guy, went back and found, two of these. I don't know what flight they're from.

WRIGHT: Apollo 11, I think, is what he's claiming.

HUGHES: That's what they said, with the numbers, I think they tried to say that. You saw it before they cleaned it up here, right?

WRIGHT: Yes.

HUGHES: Do you see that this is S1C-14, see that? This is one from that 514 vehicle. There are four fins on it for stability. Once you got going fast they added stability. Only two of your fins mounted because once you stacked it, you'd put these other two on. They are not here now because this was a carrier. T hose fins would be down in the concrete here.

If you come up here, I'm walking along the [right] side going upstream here, the black and white paint, this is common for any test rockets. We did that because in the photography, you could see what's going on. Rotation, anything like that. You could see events happening.

If you can imagine, this is two tanks, this is an inter-tank [holding the two tanks together], because this is a tank and that's a tank up there, which one weighs more? You've got kerosene and liquid oxygen, that's a quiz, but liquid oxygen weighs more, so it's up there in front on the vehicle. You put the heaviest thing first, it's like the tip of the arrow, that's where the weight is. For stability, again, so in every stage, the heaviest component is always the first.

Later, it's hydrogen as the fuel, and hydrogen's obviously lighter than oxygen, so it's in the back. In the design, these gaping engines [on the first stage], each one burned 3 tons of fuel every second. Three tons a second, times five. When you see this thing taking off in the movies, it's getting lighter by 15 tons every second, just to make it go anywhere. In fact, it was burning 15 tons a second on the pad before lift-off, so you have to think about and you have to account for all that fuel in there. When you come along here, the pipes to feed the engines from this [hydrogen] tank were easy, they were very short, they went straight to each engine. But now you've got to get the oxygen from up here, all the way down there. Each pipe was 17 inches in diameter. You could crawl through these pipes. In order to feed them, all 5 needed its own 17-inch line. They had five pipes going through the fuel tank, one for each engine. Literally, they went toward the place they had to terminate, which is at the engine. They would suck it down—they used to talk about that it'd take seconds to get a home swimming pool emptied out—I can't tell you those numbers, but I used to know that, it wasn't very long, pulling that much fuel.

The problem was, here's these five big pipes going down through here, so remember, these tanks are hemispheres, so there's a hemisphere here at the bottom of this tank, and that's the wall, and then there's a hemisphere at the top of this one. These pipes drove right through the [hydrogen] fuel tank. It was designed that way, and it worked great. However, when we launched the first one [AS-501], the vehicle got into something called pogo. If anybody through your [interviews] talked pogo, what it amounted to is those five big pipes started acting like pipe on a pipe organ. The fuel that was going through it so fast, it was almost behaving like air does is an organ, so it starts vibrating longitudinally. It's the long way, and that's what happens. That starts this fuel pipe vibrating so the whole rocket is vibrating this way, along the direction of travel. If you're on a pogo stick, it's up and down, well, that's what the crew would be feeling. But they never felt that here, there was no crew members on 501. That's the kind of problem that they found and fixed early.

That pogo was a bad deal, so what they went on 502, they went in and physically changed these pipes just a little bit. They changed the length of them, they changed the diameters of them just slightly, it's a retrofit almost on the pad. They had to get in there and do this, Boeing made these changes and all the ones subsequent. They detuned them. At first, all the pipes were identical, they were all exactly the same length, so it was like you had a pipe organ with five pipes, then if you hit the five keys, you could get a really strong harmonic, is what it's called, so it actually amplifies and makes a much more powerful note. That's great on a pipe organ, but it's not really good on something you're trying to fly. They detuned those pipes and they put spacers in and just did lots of things to change the acoustics of the pipe. That was a big thing because that was a deal-breaker; you could not fly like that. The astronauts, they'd be eyeballs in and out going this way, at about five or six times a second. It's not good.

WRIGHT: Maybe just the concern of how the vibrations were going to deal with the structure?

HUGHES: It was going to tear up everything up there, yes. In fact, there was damage to that first stage during that flight. Fortunately, nothing catastrophic because we made it to the orbit as planned, but that was the worst event that happened on that flight.

We had to simulate some of the telemetry, and then the telemetry, this is a radio antenna, there was one on each side. Remember, the Saturn is its own spacecraft, separate from the Command Module [CM] and the LM [Lunar Module] up there, so it was talking to the ground all the time. We had a Control Center here, but there was another one in Huntsville that watched over the Saturns, aside from the guys on the ground at KSC who checked it out and fired it. You come up here [at the top end of the first stage], and at this point, this is the end of the Boeing world, here. You can see, if you take the vehicle and stand it up, it's almost as tall as Building 1. The interesting thing is this gray rig attached to the vehicle. It should be painted yellow. That was a not-for-flight; that piece didn't fly. If nothing else, we should go in here and paint it yellow, just so it should be accurate.

Have you ever seen them pick up the Shuttle, when they would stand it up? A crane on both ends, they'd pick it up, and then had a yoke, and they would gradually lower the back, and so you were standing vertical hanging on the crane by attachment points on the front. They had to do the same thing with this. That same yoke was used on this one, even, the same very thing. There was a pin down there where it sits on that yellow attach point on the side up there, that's where the yoke would hook on the back end, and of course, this hook, here, they'd lift it straight up about 100 feet and then gradually lower the back end down, so it would swing vertical, and then they would put it over onto the launch tower.

Now, there's something missing between these two, think about it. There's should be an inter-stage; this stage is 33 feet in diameter, it would be 10 feet between these stages, and there's a piece in here that's gone, and they're all gone. What happened is that somebody scrapped them, and they're all gone. We don't have any of these inter-stages left. This one, on Apollo 13, is a great thing. In the video of staging, it would drop off and fall until it became the O in Apollo. Where it would happen is that after you got the separation going here, this inter-stage was just for that reason, but we kept it wrapped around it to get these engines going. There was no debris or anything. Once they were running, then you let this inter-stage slide away.

You see that inter-stage, it becomes the "O" in Apollo 13, but physically, you can hardly see them go away because you're accelerating away from it. Two and a half minutes, all the first stage fuel is almost gone. "Almost" is not the same as all gone because remember, you don't want to get oxygen-rich in those engines, so when there's a sensor that says "low level," then it would shut down the five engines, shut them all down at the same time. You've been under 6 Gs [gravity]; this sucker's hauling. Then you go to zero-G, and then there was a timer that would blow this first stage loose and start turning on these second stage engines.

The fact is, is that when you do that, if you go to zero-G, then all the fuel that's in this [second stage] tank now starts tumbling around in there. It wants to do that, but there are solid motors on the base of this stage that would fire automatically, that would keep gravity on this second stage so you didn't feel the zero-G of no engines; you'd feel these solids kick on. There's a term called, if you haven't run into it, ullage. It's that acceleration to make sure that the fuel stays at the bottom of the tank, so that you'd take the fuel and oxidizer into the feed lines. That's what the idea is, that pressure is you're priming the pump, but you keep it going. This worked fine on all the flights until we got to [Apollo] 13. This beast [first stage] is so big that on that ring, there were solid motors pointing up, when they fired, they were made to slow the S-1C down.

It had so much inertia that the solid motors on the inter-stage was to slow it down, to make sure that they were separated. It just wanted to keep on going with you, and gravity is just not enough at that point because it had so much speed. By then, you're about 40 miles up and going about 5,000 feet a second, or something like that. At the same time you cut this first stage loose, you fire those solids to take this second stage forward. I said it wrong. The inter-stage, it was inert, the solids were on those fins, the ones pointing forward. They would slow the S-1C down at the same time that these rockets on the outside, here, are shoving this second stage forward and providing the ullage for the fuel and oxidizer.

These are five J-2 engines, and they're burning hydrogen and oxygen. You remember where the higher, heavy stuff is, the oxygen is up front.

Now, this is much easier to deal with, that is, we don't have the problem with the size of the tanks, but they did look at them and make sure there were no harmonics as far as the fuel coming through here. It took about 4 seconds for these engines to come completely up to speed, and by then, the solids were burned out and that was it, they're just done with their ignition process. Off we went with second stage, which is about six more minutes of burning until you got up about 23,000 feet a second.

On Apollo 13, this is pre-computer days, so this was like an electro-mechanical timer. It's like a very simplistic timer, and so, somebody screwed up the timer. The slow-down jets came on back in the fins before they cut the upper stages loose, 1 second early. For the crew, they were going 6 Gs, and all of a sudden, the engines were coming down and you can feel it, and all of a sudden, they're going backwards, so they slammed forward, all three of them, and smashed into several switches on the control panel. In fact, the little wickets around, like wickets around a croquet game, they protect you from putting your foot through there, your toes flipping switches, they're all flattened. They smashed them in, and when they got home, that's when I realized Lexan [polycarbonate resin thermoplastic] is a really good material. There were actually marks on it where they slammed it in, then that one second went, and this posigrade rocket fired. Now they were flung back the other way. They had this 1-second slam, bam, like this, and poor old Jim [James A. Lovell] said, "That's our glitch for this flight, we're good now. We had our thing." He wanted to eat those words for a long time.

What we haven't talked about in here, and we'll talk about it going from this stage forward because it's easier to see. The five engines, again, the center one is pinned, doesn't do anything, and the other four are steerable, so they have all the hydraulics to do all that maneuvering. When you have an engine running, pulling fuel out of a tank like that, it'll collapse the tank if you don't design around that. These silver pipes going around here and heading up actually have gaseous oxygen. You make some gas in the engine and send it up to feed the bubble in the tank. You had to make sure you don't collapse the tank because you have to send gas into the top, so you avoid pulling a vacuum in that tank. We're doing the same thing internally for the hydrogen back here, but this one, you can see four of them and they're racing up that way, going up, and if you go around on the other side, you can see where these things plug in up there. We go this way.

UNIDENTIFIED: These are J-2s [rocket engines]?

HUGHES: J-2s, yes.

UNIDENTIFIED: What are the ones on the other?

HUGHES: F-1, they're called F-1. Both built by Rocketdyne, at the time.

I wanted to talk about the inter-stage. That's 10 feet long, 33 feet in diameter, obviously they made one for every flight. We used 13 of them, but the last two are missing, they're gone. One is there for F-1 [at KSC] because nobody recycled it, but those are gone, and this one is gone. When you get up here, this one goes from 33 foot diameter down to 22, it's a truncated cone, but there's none of those either, that is, for these two vehicles—this one here and the one at

Marshall. Where the hell did they go? Somebody sold them to their brother-in-law's scrap metal place? I don't know.

WRIGHT: It would make a good chicken coop, who knows?

HUGHES: Yes, exactly. The other side of it, all the way down here, these are on the other side but these are where you have connectors into it. You put fuel in, take fuel out. Those connections, at T=zero, you see the movies, you can think about it more, but they have to unplug and close these connections because this vehicle, it's not like the Shuttle. It is covered with ice and that ice is falling off due to the vibration. There's no insulation on this sucker, and it's about half-inch thick steel back there because it's like a skyscraper building, it's holding up the whole vehicle. Underneath it, by the engines, it actually had big I-beams welded into the structure so it supported all the weight that's up above. It weighed 6,500,000 pounds, and the thrust was 7,500,000. You can imagine, when you got those engines going, it was going to go somewhere. All those swing arm connections had to unhitch carefully and swing out of the way to turn it loose to go. They had to move out of the way quickly.

Come up here [by the second stage]. This one was not half-inch steel; in fact, it was very slender and it's made with fiberglass. It was not strong enough to hold the load above it unless they fueled everything, until you put the cryogenics in it. Then you froze it, and it got stronger. They had a whole lightweight second stage, relatively, as far as strength. This connection covers the place where you could see that oxygen coming in there, but that's okay. You can see the same thing anyway on the third stage.

[Moving to the third stage.] This is the same J-2 engine back there on the second stage, with some modifications. This has a couple of sets of tanks, if you noticed back there. There's a couple of helium tanks, this system is pressurizing this tank with helium. Along the way, you could relight that single J-2 engine, so this one shut down, you were about 23,000 feet per second, you're traveling, and then you ran this one engine until you got up to about 25,500, so you're in orbit. Then you stopped, and you just stayed in orbit a couple of times around the Earth. We could leave for the Moon in the first orbit, the second orbit, third orbit. We never tried the first—we always tried for the second. We just let everybody have a chance to look at the vehicle systems and give the flight controllers a chance to see what's going on, and then when you are ready, you do the TLI [translunar injection].

When we did that, there was a button inside the Command Module which, when we would push it, it told the computer to proceed, turn on this third stage engine. The Saturn did its own calculation of where the Moon was. The internal computer was figuring where the Moon was.

[Playing planetary mechanics] You had to think if I'm the Moon and you're the Earth, you're going around Rebecca, here, and what you would have to do is where I'm going to be, I'm gradually moving around, I'm going to be over there, when you get there, but you would draw a line between the center of gravity of the two planets, and out the other side, that's where you'd fire your engines. You'd accelerate and you really didn't go to the Moon, you just went a real big ellipse up to there. If nothing happens, if the Moon didn't come along, you'd just go back down to Earth. It just was a 150 mile by 300,000 mile orbit, and you'd just go back.

Of course, I'm over here now, I'm the Moon, and I'm going to move over to where you placed this vehicle Now, what's going to happen is that I'm going to, at 30,000 miles out, just fall into my gravitational sphere of influence, and it starts warping the trajectory around and go back the other side of the Moon. Back on this side, when you hit that same line [between the centers of gravity of the Earth and Moon, that's when you burned to slow down. That's when you burn the SPS [Service Propulsion System] engine, slow down, and stay in orbit around the Moon. Now you're going around me. Takes every two hours to go around the Moon. It's a smaller planet, you're closer. The orbit is only 60 miles up but because of less gravity, it takes two hours to go around. The Moon doesn't have as much pull.

When we separated, though, these are solid motors. There's two of them on either side for ullage, so they would fire automatically to make sure that the fuel stayed down in the bottom in this first one. An interesting thing, in here, there was a second one—in other words, there's another charge in here, there are two solids, so that would fire again when it was time to restart two again. It's been in zero-gravity, so you don't know where the fuel is in there, and you know you got a pretty good-size bubble because you've used 10 percent of the fuel or something. When they started it, this thing would go for about 5 seconds as they'd start the process of getting the J-2 going.

[Between the S-IVB and the Instrument Unit] This is the top of the oxygen tank, on this third stage. McDonnell Douglas built this vehicle at the time. What you see in here, see all these markers with the wire? Those are sensors that's telling how much fuel is left in here. When they would go dry, it would change the resistance on the thing, so the computer knew when it got to low level. Any of these sensors, when they go dry, it just showed up in the computer. The computer, which is right behind you, up here, there's one here and one there. It was a backup. It was funny then; this design is so old that one is a digital computer, not everybody trusted digital, so they had an analog backup. Honest to God, that's how it worked, and they worked well.

Remember I talked about feeding the bubble? Coming up, here's these tanks and this is where it'd plug in, so that gaseous oxygen would get into the tank here, to make sure you didn't crush the tank when you pumped the fuel out of it. You had to do the same for the hydrogen, all at the same time, that's what's going on. If you think about all the circuitry and everything, this part, there's nothing missing—this would attach to that directly. You never separated from this stage.

When you get to this point, and when we go through this, it's interesting, if you look at all this hardware, wires and tanks, then you think about Fox News and all the people that say we faked all this. You think, "It was easier to do it than to fake it," you know? It's just crazy to think about this. It was easier than it would have been to fake it. Plus, if we had faked anything, the Russians would have been all over us. After we landed, they just sent a congratulatory telegram.

This whole IU [Instrument Unit] goes on. The brains of this thing, it's 22 feet in diameter but only 3 feet long. IBM built it, it's called the Instrument Unit. In here, if you see that ring up there, that actually had an inertial platform. Remember we talked about platforms for navigation and everything, so it has one like that. It'd sit there, so it was running itself and keeping it steady no matter what the vehicle did. It talked to the digital computer and the analog, both. They're the one that decided when to fire the engines. The crew had to say yes, or okay, it came up and says, "I've got a solution, it's ready to go." Then everybody on the ground read that one and compared that to the one they had on the ground, plus the one that the Apollo guidance computer had, and said, "Yes, go." Then the crew pushed the button in the CSM [Command and Service Module] saying, "Yes, proceed for TLI."

Then, they'd light off, and it burned about another 6 or 7 minutes, almost to completion, but it burned off. Remember that it's that big ellipse, in other words, your circular orbit, about 150 by 150, and now you're going to burn to go from 25,000 feet a second to 36,000 feet a second. That would put that apogee way the hell out there. If you did it right, you're leading the duck. You don't shoot where the Moon is; you're going to shoot where it'll be later because it came over, three days later. The crew used to joke about that. We didn't know much about the Moon and so you went into orbit about 200 miles up and then lowered to 60 miles, later went into 60, and we'd always think, we know nothing about the back of the Moon—if they have any 61-mile mountains back there or something. You're flying into the dark, and you're just crazy to actually do this.

Now, I want to drag out my [models]. In here, what's missing, you see this cruciform thing? I need a bigger one, I have a bigger one, I build models, but it's not the same. I'm going to talk about this later, but the LM is stored in here. The legs are folded up, so they're like this [demonstrates]. The knees on the LM, four places, is where this hinge is. That's not there [referring to metal braces]. That's to hold it together [for the display], and gravity wins all the time, so as you squish down like that.

When you think about it, so I'm here as the LM and I'm actually this way because the legs swing out this way, so if you think about it here, it's like this. There's an SPS engine sticking down here that winds up only 6 inches above this thing. Everything is packaged together as good as you can. The ascent stage is way up there. That DPS [Descent Propulsion System] engine is the back end of this LM descent stage

There's a big-ass engine called the SPS engine, Service Propulsion System, sticks down into it. It's just above the top of the LM, so that's what you see on the back of the Service

Module [SM]. This is folded up and everything is out of sight, so it's like this. What happens then, the crew's in here. When they get ready to go, they're going to fire it now. They're through with the Saturn V, it's inert, kind of.

They would hit a switch that said "CSM/LM Sep," and so you'd move the CSM out. They would go out 100 yards out in front. You'd turn around and look back, and here's this S-IVB and LM floating back there against the Earth below. The vehicle is not just the LM, it's this humongous vehicle floating out there. What they do is they come back in and they dock to the top of the LM, and it's the docking system that you saw over for Skylab. It is the same, identical thing. What they did then is they'd open up a hatch inside here, crawl in, and they didn't undo anything but there were two wires. They would make a connection between, when they opened this hatch, they could reach through and pull a wire out of the LM, connect it in here. It was launched with that wire available because it's all protected in here. Put it together, then close the hatch again. Now the CSM is connected to the LM.

Then, when they were ready, they would say, "LM Sep," "LM to Saturn Sep," it would blow the knees loose. On top of that, when we moved forward, I forgot to say it. As they went forward, they also blew all the way around that ring, and these are panels that flopped out. They're like flower petals. They're huge things, and so, where the knee is, it's a hinge, actually. When you opened it up, suddenly you looked back, and now, instead of the sleek-looking Saturn, it's open like a flower. There was a good picture back down there, a little bit past us, should have showed it to you. This way, when they blow it, now they just thrust backward and pull the LM out. That's it. Now, this crew is through with the Saturn. The early flights, Apollo 8 and Apollo 10, they put the Saturn into orbit around the Sun. They did it by just opening up the valves on the engine and just dump what's left of the fuel. They just made gas push, but a little push that took it away from where these guys are going.

Later, after Apollo 11, they crashed them onto the Moon. They redirected it intentionally; they'd orient it so that they hit the Moon, so that they would create a seismic disturbance, and they could see what's going on in the interior of the Moon.

When it was first designed, one of the things in the vehicle, these panels on the S-IVB, they would fly away. That is, they would open up and then they would pop loose, and so the four panels would fly away because people thought it was so difficult to fly in and touch, or there would be impingement and disturb the thing. In the simulations, we did that, and I would say, "Oh, Jesus, not a good idea." Because now it's not the LM and the old S-IVB but now you've got four other things floating around you have to make sure you know where they are because they're tumbling off in separate directions and you hope they have enough velocity to keep going. Let's get down in front, now.

I had a bigger [model], but I gave it to a nine-year-old to hold while I was talking and I got it back, there's no legs. It's in there, but the legs were missing when I got it all back. Here you are, flying along like this, now you put together. We talked about PTC [Passive Thermal Control], where you barbecue the thing because you're in the Sun, so this is the configuration it should have all the time [spinning the CSM/LM model]. When they got ready to land, you'd leave one person in here, two guys would transfer through, reassemble the tunnel with all the docking stuff, and then they would separate.

When we started out, we were in 60 by 60, and that's where we landed from that on Apollo 11 and 12. That is where this thing stands 60 up and they did a burn behind the Moon and they came down, so they were 60 by 9. Then, putting this aside, on the way down, then, so you came around the Earth back here, where if you're the Moon now, we're flying around, and now, you start slowing down. Let's transfer it so that this is the Moon. I'm going around across the Moon. At 9 miles up, I start firing, and as soon as you start firing to slow down, you're going about 2,000 feet a second in the 2 hours time to go around. About 2,000 feet, well, immediately, you start falling.

What happens is gradually, you'll tilt up so that the engine is pointing, not just along the direction you're going, but down, to control how fast you fall to the Moon. You thrust along the way. This descent engine was also throttleable. It's the first throttleable engine. Otherwise, it's just full-tilt, but because you're using up weight, it's getting lighter, so you didn't want to have too much thrust. Gradually, the thrust would come down until, if everything works right, you're sitting about 500 feet off the Moon, hovering, and that's why they used helicopter training and some of that other vehicle out there, LLTV [Lunar Landing Training Vehicle]. Then, you would come across, and now, in this thing, if you didn't like where you were going, you could pitch forward and go a little bit forward, you could go left, or you could go right, standing on this thrust.

Gradually, it came down and then touched down. As far as that, we've talked about how you get out and go through all this stuff. When you were going to go, then obviously, you'd pull this thing off—I'm not going to do it now, but you get the idea. I don't want to find all the pieces. You go back up, and so, just the silver part, you dock. The two guys go in, the rock boxes go in. Whatever pieces they want to steal from the LM, if they're going to take it home, put it on the mantle, and then that's it. That's why, if you've ever seen in Mission Control, there's a plaque from the Apollo 13 crew? It's a mirror, remember, mirrors are important in flight, especially if you're going to the bathroom or something like that. Anyway, that was the deal, the Apollo 13 took that mirror and gave it to the MCC.

We went through this time and again in the simulator. The Saturn stick software allowed them to fly this whole Saturn vehicle We had to work desperately on how to make it work right because the dynamics were awesome. Nobody was ready for the pogo, but we were already flying, the first Saturn V, [Apollo 4 was November 9, 1967]. When we came to December of 1968, we knew pretty much that we could make it. The second flew in April [Apollo 6 on April 4, 1968], so we were confident in the crew flying it in December on Apollo 8. We made it fly like those two, and then beyond that, it was a very gingerly thing. You didn't want to do a lot of control; you would move it slowly. That was the only thing we'd say because people said you could tear it apart. Those engines back there are so strong that they're ready to really rip you around. That's not so good. Fortunately, the damn thing worked every time and we didn't have to do any of that Saturn Stick flying. It's like RTLS [Return to Launch Site] in the Shuttle, I never wanted to think about an RTLS. We were ready to do it, but I didn't want to be there the day it happened.

We didn't talk about this umbilical connection between the CM and SM. The way it works is you flew, remember I showed you where the connecter was, this is where you separated the Command Module, where you plugged in. That would pop out and let the Service Module go away.

On the way up during ascent, you had that Launch Escape Tower on the front of it, and it was useful. If you got into trouble, and the crew had to learn how to do this, they would rotate a hand controller and it would fire the tower. It would tumble, intentionally. They're called "canards," they were things that stick up in the side, and it would start tumbling. That was a dynamic maneuver it controlled where you were going better at the time. It's kind of like having a Frisbee. Once you fired the escape motor, then this smaller rocket would eject the tower, it'd throw itself away. That same engine was used if you didn't ever need to fire the tower; then you ejected the unused tower with that engine, it would just sequence it away.

There was cork over the front of the Command Module so that the first part of the flight, you couldn't see out. The only thing you could see is a small window looking out the hatch, and the idea there was that that one window was just to say to people, you could signal to people on the catwalk. When it flew, ejecting the Launch Tower took away the cork cover. The cork cover actually broke apart as it went, just with the force of the tower ejection going away. Then, suddenly, the sunlight poured in. It was a daytime launch, and they'd say, "Whoa, look at the view," that kind of thing. If you had trouble, and we'd train so many times for aborts, there were aborts on the pad, then there were aborts they called 1A, 1B, 1C, for how high you were, then Abort 2 and 3 and so on, these different ones. Each one, it was a different speed, different altitude, gave you different things to do. We trained and trained in those things, and of course, the best thing that ever happened is we threw all those procedures all away and never used any of them, so that was great.

The sad part of this is that the SLS [Space Launch System] that we're talking about, or the Orion, we're doing that kind of system again. I say, I have never had a good day looking up the ass end of a big rocket engine. Remember, I talked about what went bad down there at that end? Why don't you have a big solid rocket here, underneath me, and blow me the hell out of there? That way, I'm getting something positive in a sense that I'm in control. This thing, if you look at the movies of it, it's scary to think what's going on. To be right in the flame part behind it. It's like lack of imagination because all they did is say, "They did it that way in Apollo, I read the books, so I'm going to do it all the same way." If we put crew on [SpaceX] *Dragon*, they've already got something different, you're sitting on the launch escape rocket, it's underneath you, they're going to take you away. That's nice to know.

We talked about the 16 jets and how you could control attitude, and this is a radio antenna, so there's one on each side.

WRIGHT: Little jets almost just look like they don't do much, but they do everything, don't they?

HUGHES: Yes, yes, exactly, and yet they did so much. You see the jets in the Command Module that you only use during entry, and some things. This is, you can do rotation or translation, but that CM system only is rotation because once you get through the Service Module, you're on the way coming home, you just make sure that the heat shield is in front. This CM is so rusty and everything, but that's a relic. That's the actual one we did training offshore, getting the crew out into the rafts and into the helicopters.

WRIGHT: Here?

HUGHES: Here, yes. We'd drop it in the water off a barge, and then the crews would get into it, and then they'd go pull them out with every flight and put them out with the helicopters, go through the whole recovery step. I think they did twice on every flight.

WRIGHT: It was the same capsule used all through that training?

HUGHES: Yes. That's why it looks like that.

WRIGHT: Does it have a special marking or a name?

HUGHES: It didn't have a name, never did. "Command Module."

WRIGHT: Missed your chance, didn't you?

HUGHES: Yes, yes, yes. Sorry. It doesn't have a real heat shield or anything like that. It was made mostly of cast iron, just like that. It's interesting; when they shut it down, the Service Modules were built in Tulsa, the Command Modules were built in Downey, and so you could go out and see a Command Module all the time. I personally never saw a Service Module until they were at the Cape [Canaveral, Florida]. I never saw one that was all disassembled. These white things over here are radiators. Remember, you had a thermal system—the thermal coolant loops would go through across that bridge thing that got the guillotine later, and that was the ethylene glycol, that was the thing that was flammable, which we shouldn't have been using but we did, if you go back to the first flight fire [Apollo 1 accident].

Do you know what Primacord is? It's an explosive, but it looks like a rope. What they do, there would be Primacord on these things, all around where you separate this thing away, when you would unzip the SLA. This SLA is the Service Module/Lunar Module Adaptor, and then all around the back end of that. Way up there in the point, where that hole is, you can see the hinges. See that they would fall out this way. When they fell out this far, in the early design, it's where they were going to then break the hinges and let them fly away, and that's when Wally

[Walter M.] Schirra took a look at that and said, "We ain't doing that." He was right. He was right.

WRIGHT: A profound and true statement, right?

HUGHES: Yes, exactly. He had a lot of good statements. I was in a meeting out in San Diego [California] about four months before he died. He was already sick, but it was great to have a chance to see him one more time. I didn't know, I don't think he knew, at the time, that he was sick because we'd have talked about it otherwise, but that's the deal. This is a different lecture—with the scale, they're a little better to see, they're this size. Since my LM has been legless and legs are a big part of this thing, so we do it that way.

WRIGHT: Yes, they were kind of needed, weren't they?

HUGHES: Yes, they were really needed. Heck of a thing. Any questions? I threw a lot of numbers about speed, do you guys understand orbital mechanics or orbital things? Maybe we should do that sometime, just briefly. Think about this. Have you ever fired a hunting rifle, pistol, anything? Let's just take a rifle. When you fire it, the bullet comes out about 3,000 feet a second, and the range, if you set it, is a mile, which is true—unless you fire it straight up because then it'll go further. Of course, then it comes down. If you add them together, you're counting on there aren't any deer up there. With the kids, I always go back to say, "Okay, take a Napoleonic cannon that fires cannon balls."

The thing is, if I could take this pen up 16 feet and let it go, it'd take one second to hit the floor. Starts at zero speed, gravity's trying to accelerate it, by 32 feet a second, per second, but since it started at zero, after one second, it's going 16 feet/sec. Let's take that cannon and put it up on a platform, 16 feet, and just fire it. Now if they tilted down, screwed up, and the ball rolled out of the cannon, the cannonball would fall for a second. Pick it up and put it back in, get it level, fire it at 3,000 feet a second. It's going out of the barrel, going 3,000 feet a second. How long is it going to fly? One second. As soon as the barrel's not holding it up, gravity takes over, and so it'll go clunk, right? How far did it go? Three thousand feet because it's going 3,000 feet a second. We're going to forget about the atmosphere for a minute, drag and all that stuff. Double the gunpowder, so now it's going to come out here at 6,000 feet a second, fire. How far is it going to fly? How long is it going to fly?

WRIGHT: A second.

HUGHES: One second. How far will it land?

WRIGHT: Six thousand.

HUGHES: Six thousand. Double the gunpowder, 12,000 feet. Fire. One second, 12,000 feet. You can see the angle gets more shallower, but it's still going to clunk up over there, and hopefully, if you had good aim, you did something to bad guys out there. Twenty-four-thousand feet, just double again, so it's just gunpowder, clunk. One-second flight. There's a magic number, though—at 25,500 feet per second, 16 feet up, you fired the gun, so the projectile's going at 25,500 feet a second, but the arc that it's following as gravity pulls down is the same as the curvature of the Earth, so it doesn't hit.

Theoretically, if you didn't have any mountains, we lived on a billiard ball, it could fly all the way around and come back and hit you in the back of the head. That's a satellite, that's all it is, except we don't live on a billiard ball, so you take up out of the atmosphere, far enough you can, you'll notice as the rockets go up, they also are pitching over all the time, so they're starting to get horizontal velocity. They're striving for 25,500 feet a second, or more; 25,500 is a good number, at about between 100 and 110 miles up. If you get up there and you're going horizontal and you shut down the engine, you are falling around the Earth. You're falling just like the thing did, but you just don't hit it because you're going so fast across the ground that it'll go around. And it will just keep going until drag—gravity always wins—slows you down and brings down a little lower, which means there is more air molecules and they get thicker and thicker until you fall in.

If you go up 200 miles, 300 miles, like the Hubble, it takes a lot longer for drag will slow you down. Now, it'll take 300 years before you fall down, and if you go up to geosynchronous, it's geological times before you fall back. That's all it's about. The neat thing about it is once you're there, let's say you go up 150 miles and you're flying along and you've got a buddy that's at 200 miles up, 50 miles up, well, now, there's a speed difference of about 2 feet per second for every mile you go up. In other words, if I'm down here at 150 and he's at 200, then that 50 miles, I'm going to be catching up at 100 feet a second, every second I'm out there. We play with that with the rendezvous, and that's how you set them up so the target vehicle is either ahead and above you, or they're behind and below you and you're going to catch up, or if he's active up here, he would go ahead in front of you and he'd come down to get you.

That's what we did here, that the Command Module did a mirror-image rendezvous, the LM jumped up out of the orbit here, it was always behind and below the Command Module, and when they computed the burns, they'd fire. If anything happened and they didn't fire, they'd say it on the radio. They did the same thing; he would have been coming down to get him. If they couldn't fire again, the Command Module Pilot would have made the next maneuver, and there was only three maneuvers or so before they'd come together. It's just a great way to think about it, in the sense of somebody designed that, but it's obviously the right thing to do. It's called a mirror-image rendezvous. [International Space] Station can't do that because it can't translate, not as far as going down to get—if something happened to the Shuttle, the Shuttle would just wave off and go home, you couldn't make it anymore, or we'd find another way to get it fired so their engines would get there. Shuttle's a different day.

WRIGHT: It is a different day. You were talking earlier, it made me try and figure out the best way to formulate this question, when you're training in the simulators, were there times because of that training it impacted a redesign?

HUGHES: Yes, yes. Especially redesign of the software. Sometimes, we found that it redesigned some hardware things inside the cockpit. Some silly example is that waste toilet thing, we didn't redesign it, they just said, "Toss it." All of those things, we went through a lot of things. I can think more on Shuttle than I can Apollo, but they're there, I pull back up.

WRIGHT: Yes, because obviously when you're talking about crawling through and doing all these things and making sure that they were done.

HUGHES: I know that the probe and drogue, we had one flight where we changed something on it, that is, when we were doing physically, because they had mock-ups where you would physically get in and change that thing, and there was one lever that was just too hard, we made it longer because they had to be able to grab it and torque it, and it was too hard, with originally it was too short, relatively.

WRIGHT: I know that you mentioned that when people come back, that they had the debriefing and they could tell what worked, and by the time you got through to the flights, you had it down pretty good.

HUGHES: That happened almost every time. When we debriefed, that the simulator guys would have a whole session, a whole 3-or 4-hour session with the crew. When, like, Apollo 11, when I remember it, we head back and it's a funny thing because they had debriefings for about six days. Before, they just took a rest, but everybody went. It was the Mission Control guys and it was the vehicle guys and then it was the Command Module guys and the LM guys and everything, and the simulator guys. We sat down and we went through it.

The great thing was they said, "It was almost right, it was pretty close, but here's what we saw." We fixed some things about the sounds, the sounds in the flight were different. That was a simulator change, not a vehicle change, but we captured that it was louder than we thought it was going to be when they're in it. Then, they went through there, there were some shortcomings about the mock-up, and we changed a lot because of where the lockers popped open and everything.

Like I say, I almost hesitate to talk about that because we didn't go back and look at that LM standing up there, but you can do that just by yourself, go over and just you can think about the different things they had to do to climb down, walk around that thing. I don't know if you heard this about all the photography that's going on, that takes pictures? It's so amazing because they say, "It should be dark in there." It's dark but it's not dark because I'm out here, I've got a white shirt, I'm throwing light in there. This hill that's right next to me is throwing reflected light is what's in there. It was bizarre. I just love them, I just love those guys.

WRIGHT: Yes, they keep everybody wondering, don't they?

HUGHES: They just said, "I don't believe anybody's smart enough to get to the Moon," and I said, "Well, you are not." I did, to this one guy.

WRIGHT: Yes, well, thanks, Frank.

HUGHES: I hoped that helped us get through it.

[End of Interview]