Morata, L., Felix

Describe the use of the continuous probe in other programs, because I believe that, as far as I know, we were the first ones to use it or one of the first ones to use it as a continuous device in at least the size of the tanks that we're talking about. In most cases the tank geometry changes and in some places where they had discrete sensors at certain locations of the tanks, as you get up to the top of the tank, the geometry of the tank changes. You come up to a dome, in most cases a domed area instead of a nice cylinder. And what happens there because you have a for real change in geometry up there in some cases some programs, and I believe the S-IC does it but I'm not particularly sure, they have a small 6-foot section of a continuous probe, up on top to take care of the tank geometry conditions

Yes, I think I remember seeing that.

I'm not positive of that but I think that's about the biggest application other than the ones we've had.

Okay now, how did you test this thing out? Did you have a big cryogenic tank and didn't you run into a lot of problems getting the right guidelines here? How did you do that?

Yes, as far as we had the vendor qualify it for us, since it was quite large, it was like I said 20-foot continuous piece, we had some ... went through a full development program and full qualification program at the vendor. We did have some debugging to do in the development phase of it, but it went through a, even though it was a large program, it was a large material, they had to have special fixtures for vibration wise just to take care of the length of it. But the program didn't go through a lot of undue hardships. As far as qualification was concerned, it was, I believe, pretty smooth. We had a lot of development kind of concerns in trying to get the right kind of capacitance changes and the right kind of vibration aspects of it, but in toto I think it was a pretty smooth program. One of the problems that we had was, to get real good correlation, cryogenic-wise, we ended up, we used to static fire our engines at Sacramento, and this is where we got our full cryogenic calibration. What we'd done is, in time, developed the kind of confidence and accuracy to know that the vendor is using what they call Freon and the temperature is somewhat different, but it gives us the same confidence. And we used to correlate the Freon temperatures with the LOX and hydrogen temperatures. And what we've done is ended up having full confidence that what we're doing, that the vendor is fine. And in fact, what we've proven now is that we've got full confidence in the system; we've used it on all the S-IV's, the Saturn IV's, and the Saturn IV-B's, and we know now that we've got full confidence in the calibration that we get from Minneapolis-Honeywell. And it's very very close, we don't even need the static firings at Sacramento to tell us what the calibrations are. From that aspect I think we've been very happy with the qualification.

Okay now, gee I'm almost embarrassed to ask this question, may be stupid as hell, you've got the capacitance probe in there which is in a vertical position, the rocket's in a vertical position, you take off. When you're in earth orbit, getting ready for that last fire for TLI, you're in a horizontal position. How are you at checking your capacity in that mode?

Oh yeah, in the capacity in the mode, we don't, the only time the propellant utilization system is used is while the engine is running. Okay, while you're in zero-g you don't really know where the mass is. But you don't need the probe at that particular time. You know, when you lift off, you asked a real good question because it's not as obvious as everybody seems to think; they're not exactly vertical. They're shaped to the geometry of the tank to make the electronics think it's vertical. Now as soon as we boost off, we've got acceleration and gravity so all the mass is down to the bottom of the tank, going towards the engine. So you've got forces, gravity forces, pushing you in the direction to make the mass stay at the bottom of the tank. So you've got continuous reading, and it's proper, because the mass is at the bottom of the tank. It's like you're forcing this up so the mass is staying down. Now, as soon as the engine stops, the role of the propellant utilization system is done. We don't need it anymore. We know, when the engine stopped, we can tell you where the mass, how much mass you had in that tank. Now we also know the boil-off characteristics of our tank, we know how much insulation we've got. We can tell you if we stay up an hour if we had so much mass, we'll have so much mass left after an hour, because we boiled off some. But we'll be able to tell you. Now, we have what we call an APS system on board, attitude auxiliary propulsion system, which are small pods on the side of the engine, which we use to give a little forward acceleration and settle the tanks.

The ullage.

Yeah, the ullage. So that's, as soon, prior to starting the engine we do that ... settles the tank again and we're back in business. So we're ready for restarting. Go ahead and tell you again how much we've got left and where we are when we stop the engine. We can tell you very very accurately how much, how many pounds left we have of hydrogen and how many we have left of LOX.

And then during the TLI phase you've got this mass settling down again in the bottom of the tank, you can start reading your ...

Yes, during the TLI burn, which is our restart burn for sending them to the moon, we're back in business. It's just like a good guage. It's like turning the ignition on your tank, when you see your gas guage go up. As soon as you shut it, it goes down. And while you're not in the car, or it's in zero-g, we can't tell you because the phenomenon of zero-g says that the mass might be trying to go away from the center of the probe towards the outside of the tank. Where it's displaced in such a manner that you can't get a continuous reading at all. That's a new, I think, subject that will probably be considered some time. Can you develop some method, some technology, to tell you mass under zero-g. But that will have to be some sort of device, a radiation device, a nucleonics kind of device, that can penetrate and measure bubbles no matter where they are, gas or liquid, or some density there that ... it won't be a continuous probe, it'll have to be some sort of nucleonics I believe that can give you that feeling.

So you're reading all the time that it's going up and when that thing shuts off and you go into earth orbit you know exactly how much was in there at the time. And then, even though you're still in zero-g, you can calculate very accurately the percentage of boil-off.

Yes.

This is kind of a new area for me. I hadn't thought of it ..

Oh no, it's not, you know it's a very good question because a lot of people, but we make no attempt to measure it, and what readings you would get, we get data back, but it's got no bearing.

You've only got one more burn after that now. You impact on the moon.

Yes but we don't burn with the main engine for that.

That's right, the APS.

After our TLI we go through what we call the evasive maneuver. And we there want to make sure that we're away from the astronauts and far enough separated from them and the way we do that is by turning on the APS system. We actually burn somewhat to separate them, or they separate a little bit from us on the evasive maneuver, and when we're separated enough from them, we're going on our particular way. At that time we were shooting for the moon. A few hours after that we get, if we haven't achieved enough of a velocity from that first burn, or first, what they call APS burn, we will get a command from the ground to burn again. Puts us in the right attitude to reburn a second time towards impacting the moon. But that's not done with our main engine; it's done with our APS engines. And at that time we're not reading the propellant utilization system was through as far as the mission was concerned right after TLI burn. So when we impact the moon, we have generated that particular attitude with the auxiliary propulsion system. Not the main propellant system. And we don't have any mass, continuous mass readout of the APS.

Okay now you said you were involved in the electronics. Did you have to get involved too in what kind of valves were going in there to make sure you were getting your . . . use a solenoid switch, or how do you accomplish that?

Oh yeah, the valve itself was a valve that at that time was a solenoid controlled valve with a motor in it. Now that was provided to us by Rocketdyne, the Rocketdyne Company had the development of the valve on S-IVB. And what we did there, when we were doing the design of the S-IVB, there was very very close liason because all the characteristics of the PU system and the inverted converter would have to be phased to supply the phases of the motor. It was a two-phase motor on that valve. One was what you call a fix phase, which was 115 volts, 400 cycles, and that gives you a reference. The other phase was controlled by the propellant utilization system. And that varied, because what we wanted to do with that, and that was known as the control phase, what you want to do is as a function of what was happening in the hydrogen tank, you wanted to compare what was happening in the LOX tank, generate an error signal, drive that through the electronics system, the propellant utilization system, and then drive the control phase of this motor, which was on the Rocketdyne valve for the S-IVB. And then the 115 volts gives you a reference to stabilize around and then the PU would then tell this motor: turn this way. You get an error signal, it would be amplified, and to the motor, it would look like some known voltage, some error, some plus error would say: okay turn 20 volts this way, and it would go this way. Some other error, some negative error, would make it seem like a negative 20 volts in the other direction, and it would turn the valve in the other direction. So you could go on either side of what we would call our engine mixture ratio of 50 to 1. The valve had about a 30-degree spread from its null position. It would start at 50 to 1. Could go to a mixture ratio of 55, which about, was equivalent to about 15 mechanical degrees. Or it could go from 50 to 45, which was another equivalent to about 15 degrees. So the valve would rotate about 30 degrees.

Is that a ball valve in there? A butterfly? Or what kind of a gismo is that?

I don't know. I think it was, the Rocketdyne valve itself is kind of a bypass valve, and I guess they're all butterfly to some extent. But the way we would do it we would bypass that particular valve, or flow some of the LOX around that valve to change the characteristics. I'm not familiar with all the finite details of the valve. But we were in very close coordination with Rocketdyne because we had to meet all the characteristics, the impedance characteristics, of the motor. We would have to know what the characteristics were involved with all the electronics, the solenoid control, or the actual motor itself. So what we ended up doing is in close coordination with Rocketdyne, we talked to those guys, our design people would talk to theirs. And we ended up getting a development valve from them. And we used it during our design phase of the, for our development test phase, to see that the marriage between our electronics and their valve was compatible. And that's how we ended up doing it.

Do you remember any details at all about the S-II propellant utilization? Did they have nearly as much of a factor involved?

What we did is, on the S-II PU system basically we used the same design concepts that we had developed on the S-IV and the S-IVB program.

Did they come over and just ask you about it? You gave the information out of that . . .

No, no. What we ended up doing was, we developed the S-II PU system for them.

Oh, I misunderstood.

Yes, we designed the S-IV and the S-IVB and the S-II PU systems. And so we acted as a vendor to North American. They defined to us the requirements. We had them working very very closely to the S-II people. We had designed the S-IV and the S-IVB, and the S-II was a natural follow-on to the S-IVB. We used the same concepts. We used the same parts where applicable. We ended up having them make a larger inverter and a larger box, because they had five valves, five engines, where we had one engine. But all the concepts, all the electronics were basically the same. And all the material that went in, all the designs that went into the S-IVB were just upgraded to take care of the five engines and the five valves. The probes were essentially the same as we had used on IV and IVB. And we bought them from the same vendor, same kind of qualification, same kind of development. We had had all the development history, so it was just kind of a natural outgrowth. We provided the probes and the electronics to North American on that basis, and ...

Minneapolis-Honeywell again?

Yes, Minneapolis-Honeywell has been the, our probe vendor since the S-IV days. So they provide the probes for us and for , for both S-IV, SIVB and S-II. We were very close with North American. North American defined all the specs that they wanted us to meet, and we compared them with the S-IVB and got with them and said, but we had to go through a new qualification program with the box because it was bigger. It was a different size because of the five valves. But we went through a full-blown qualification program for them. They've been using it ever since.

One of the things that's interesting about the Apollo program are the spin-off factors. Are there any other places you can use a capacitance utilization probe besides an S-IVB bird?

Well I think so. In time I think it'll be of great usage. I think one of the problems that you have now is that probably the concept is being used and I feel that any place, like in medicine, where you're trying to measure accuracies very very carefully _______________ where they'd be used. Right now not only the S-IVB, I believe the spacecraft is using continuous capacitance probes too. I'm not positive where they are but I believe in some of the tankage in the Apollo Command Module, Service Module, are using continuous probes now, but in smaller tanks. So I think any place in the future where it's very, you need to know, on a continuous basis where you are in particular spheres. I see particular applications sometimes in medicine where you're interested in looking at some things very very accurately. On beer trucks, you name it. I don't know directly where you would take one now and say hey if you stuck it in there it would . . . . But I think the concept is very useful because anyplace where you would have to know continuous, on a continuous basis, what particular mass you're interested in, I think you'll have a future application. And I'm sure that Minny-Honey is you know exploring that one considerably now.

I'm still a little bit vague on what this thing is constructed of. How is it fabricated? What kind of . . . .

The probe is, it's a continuous element, I've got some pictures of it I'll be glad to show you. It's made up of two elements, one's a stainless steel element and one's an aluminum element. And it's an extruded, long extruded element. Like about a 4-inch pipe. It's about 20 feet long. Here's what it basically looks like. It's kind of hard to see, but it's basically made up of a 20-foot span, and it's got an inner and outer electrode. The outer element is 2014T6 aluminum, and the inner element is stainless steel, 321 CRES. And it's about 20 feet long, and it fits into the tank. In our LOX tank we actually come in through the bottom of the LOX tank. There is what we call a feed-through. This is where the engine mounts. And we have a small feed-through and a flange, and the probe itself fits into a funnel arrangement. We have a baffling arrangement and a small funnel arrangement at the top of the tank and this probe actually slips into that funnel. And it's held there. We have some Teflon inserts here that fit up and are held at the top of the tank. And the feed-through mates right at the tank. And from an installation standpoint, you can actually remove the LOX probe without going into the LOX tank. You can replace the probe by just dropping the feed-through arrangement here and dropping it out. In the hydrogen tank it's a little bit different. In the hydrogen tank the probe, we have a manhole cover up at the top of the hydrogen tank. We put in the hydrogen probe and it's held by A-frame rings. And then the wiring itself, it's not an integral part of the feed-through. The probe is not an integral part of the feed-through at the top of the tank. You actually have to put the probe in through the manhole and thenattach it to the frames. And then you bring the electrical wiring associated with the top of the probe out to a feed-through on top of the tank, on the dome. Therefore, you can work on it electrically, but you couldn't work on it physically. You'd have to get inside the tank to get to the actual probe. And the hydrogen probe, both the hydrogen probe and the LOX probe are made of the same material. Have an outer element made of aluminum and an inner element made of stainless steel. And we have a coupling which is actually, it mates together with a ring, and we just held it, you know, it's held together about halfway up the probe on the hydrogen side. It's about 20 feet, 20 feet from here to the coupling and about 20 feet up above, so the whole span is approximately 40 feet. It would be very difficult to work at, unless you were able to get into the tank, whereas on the LOX side you're able to drop the LOX probe inself. If you ever have a problem with the hydrogen side probe, you'd have to work on it inside the tank.

Was this kind of a Propellant Utilization system really a Douglas thing or were there interfaces with ... did Marshall come and say why don't you try this, or...? Did you get into any problems like that?

Oh yeah, in the initial phases I believe that there were, everyone was interested. I think both Marshall and Douglas were interested in coming up with what is the best system to monitor the mass of the tank. We had certain requirements. Both Marshall and ourselves had certain requirements at that time that we wanted to be able to load very accurately, to be able to get data both in flight and on the ground, and to be able to minimize residuals. And by residuals, we wanted to make sure that both the hydrogen and the LOX depleted at the same rate and were minimal after you got through with the initial mission. And therefore you could optimize for a payload. So everybody was interested in that concept. That was everybody. That was McDonnell, North American, _______, and Marshall. And Marshall had asked us to look at the concept, that's what we wanted to do. Okay, what we did, based on those kind of requirements that we wanted to optimize for payload, minimize residuals, be very accurate as far as loading was concerned. We went and surveyed the industry of what was available to do that. And our people, at the initial phases of the propellant utilization scheme, came up and looked at all schemes, discrete level sensors, acoustical sensors, hot wire sensors, continuous capacitance probes, and they were all evaluated. There was a big parametric study made for about 3 or 4 months. What's available ...

Once you've defined the requirements you'd like to do __________things, what's available in the industry that you don't have to talk about developing, looking at? What can meet those ... and we went out and looked and surveyed, and at that particular time it looked like the continuous probe, delta capacitance change concept would provide the most assurance to meet all those requirements. The discrete levels could give you certain requirements, but they couldn't fulfill all the requirements, as accurately. So okay we came up at that time with this big parametric study. We all sat down together with Marshall and we said we think this is the best way to go to meet all those requirements. And I think Marshall agreed with us at that time. We showed them all our concepts or all the trade-off studies that were made against all the other systems. There wasn't anyone left off. They had __________ looked at the total industry like I said hot wire sensors, acoustical sensors, capacitance sensors of that time.

How long did this kind of a search last? Spend a month, 6 months, a year?

Oh no, I think there was about, it was about a few months were involved. I'd say probably 3 or 4 months.

Then you went to Minneapolis-Honeywell and you said this is what we want?

What we did is, no, what we did at that particular time is we said okay here's the concept. We defined the concept, we wrote what we call specification requirements drawings. Once we had evolved into the system that said yes we're interested in developing a capacitance type electronic closed-loop propellant system then we knew we wanted a capacitance type of device, a continuous capacitance type device. So what we did is we wrote requirements that said okay this probe has to give us these things. It has to give us an electrical signal with a change of capacitance so we can know the mass. It has to meet these vibration levels because it's going to see this in flight. It's going to have to see these cryogenic temperatures because it's going to have to see all these things. And we wrote all these things in the form of a requirement, what we call specification drawings. And then we went through what we go through in our normal procurement cycle. We put it out for bid. And so it went out to all the people that are interested in those kind of devices. And we got back a lot of responses. I don't believe I remember exactly the number of responses, but it went through a normal procurement cycle. And Minneapolis-Honeywell was chosen as the one to develop the concept. For the probes. And they did. So that's how it was done. And in that same requirement, in that specification requirement, we defined what development cycles it had to go through, what qualification cycles it had to go through, to prove that it was what we wanted, or that it met all the requirements that we had asked for. And that's what it was qualified to. So that's how Minneapolis-Honeywell got the particular job on the probes.

Are those probes now stored in the S-IVB stages that we saw over at North American?

Yes, they're inside the tank.

There's no deterioration problem as far as these things are concerned?

No, we haven't, we don't feel there is any and we've looked in both ... we've had some stages that we've had in long term storage at Sacramento now, which was a 206 and 208 stage, and we've looked at, we've gone inside the tank on both of them just for the probe and other things inside the tank and we haven't seen any deterioration whatsoever. And we do intend to look at the, we're going to look inside the tank for 210 and 209. And we'll be getting some history on those. But so far we haven't seen any detrimental effect whatsoever with long-term storage.

Did Minneapolis-Honeywell think that this was a particularly, or any of your vendors, think that this was a hard thing to do, you know, give them the cryogenic thing and the vibration level, the fact that this was continuous? Was this a real advance of the state of the art?

Well I think at the time that we started development I think it was. Like I said I don't know of anyone else that had developed one that was 20 feet or 40 feet long. So at that time I think it was at least an advance in the state of the art at that particular time. Maybe today not, but in 1960, 61 I think it was probably, the answer was probably yes to that.

You know a guy at Marshall named Schuler. I know he was involved in transducers and stuff like that. I seem to remember that he was talking about guages of one kind or another.

Oh I'm sure that 'ducers in general, a very fantastic thing, especially where, if you talk about electronics. Okay see in this particular case it's all mechanical, there's no electronics involved here. It's outside where it's not seeing cryogenics, the electronic portion is in a nice ambient panel, or a cold plate, where it's warm. I'm sure that you would, any 'ducer that you develop that had some electronics associated with cryogenics, you would have had some development concerns, because at that time the state of the art in cryogenics as far as electronics was concerned was not as far as it is today. Today you can probably