Tape #1, Side 1
Interview with Leonard Bostwick and Mike Burns:

RB - One thing that I wanted to get at to begin with is why we went and something to liquid over solid propellant engines, some of the parameters involved there about the I specific barrier of 260 on solids. Does that mean anything? What's significant about that?

- Well, the reason we went to liquids was that the liquids are easier to control, or were at the time. There was a lot of trouble with control of solids. Also the liquids were able to give us a higher specific impulse so that you could get more output for the amount of weight you carried in fuel. So that kept the size in bounds.

- I think one other very important point, too was the fact that back at the time we developed the big booster engines the state of the art had actually advanced farther in liquids as opposed to solids.

- We did not have the capability at that time demonstrated in these large solids.

- We figured probably the most economical way to go as a matter of fact ________
____
This specific impulse is a big thing.

- Another thing that certainly played a part in it is that we had available a history of working with liquids up through the Redstone and Jupiter, and we could take for the first Saturn a modification of the Jupiter engines and the Jupiter tanks and the Redstone tanks. That combination allowed us to get large payloads up to find out what else we were going to need in the way of development much quicker than we could have if we had gone the other way.

RB - When you got into an engine of the F-1 calibre, there was no solid that came anywhere near that.

- No, not at that time. And F-1 was partly an outgrowth of some development work that had already been done on the E-1, which was an Air Force ________________

RB - Yes, I have a question on that further down the line, but as long as we are into it can we stop there because I've got two dates for the F-1 and maybe the C-1 helps explain the discrepancy. One date is '55 and the other date is '58 when the F-1 development started. Can you help me on that at all?

- The actual F-1 contract date was January 9, 1959. That began the actual contractual coverage for development of a large booster engine for ________________

RB - As far as Nasa

- Now at first, in January 1959 we contracted for a million pound thrust booster engine. At that time it wasn't even called the F-1. All they knew was that in order to go into orbit and make a landing on the Moon we would need a large space vehicle. And I don't think at that time it was even called Saturn.

- It had not been defined.

- But it was January 9, 1959...

- That's contractually. Before that ARPA had a contract and they had the first part of this one he's talking about which we picked up. I think you're talking about the day we picked it up.

- We picked it up, that's correct.

- Prior to that it was working out of ARPA. Before that, even, the Air Force had the engine that was the E-1 which was, I believe, either 400,000 or 500,000, I've forgotten it's been so long ago. I can find that out if it's pertinent.

- RB - No, not necessarily.

- But they had started this with Rocketdyne, again thinking that they were in the business of ballistic missiles and they didn't know what size engines they may have to go to there. They were perhaps looking at replacing the __________ or something of that sort. I'm not sure of the background of why they did it. But because that had been started there was some tooling available, there was a certain amount of development activity, some hardware had been made that gave them a start which indicated that was possibly the quickest way we could get to one of the sizes that we needed. And, of course, ARPA started the first contract and we picked it up. The first people working on it were ones that had been either from Headquarters and moved out there or ones that were hired by them. Then when Nasa picked it up we set up an office there and staffed with some of the ARPA people and some of our own people.

RB - so that gave you pretty good momentum since they already had some hardware..

- They had some hardware, not capable of the million pound, but certainly capable of demonstrating what you could do with large turbo machinery. They had gotten into the castings, some of the metallurgical problems they would have, they had built some injectors that would--so that they had some injector concepts that were not finalized, but at least they had some ideas of what would be required. We built on that. I believe that's one reason they got off to a good start.

RB - We were out talking to people at Rocketdyne once and I remember one of the guys, I think he was talking about the F-1, said in the early development stage they were going through the normal teething problems, etc. and they said they finally got it to run a little bit more smoothly; but the comment was made it's almost like a black art. You're working on several different things at once and finally it comes together, and you're not sure exactly which fix was the one that did the job so you just freeze it right there. It's just kind of guessing. You're not sure which one did it. Is that a feasible way to characterize it?

- I don't like to hear it called quite that way because what it really is, you have a set of pretty-well defined development portions, subsystems and parts being developed for a concept that all goes together, you think, by your analysis, will be correct. Then for each part that you're not sure will work, in other words you have not yet had experience, and you haven't had anything quite like it, you will usually have one or two alternates and they will be going along also. Now, in the process of this black art, as was mentioned, you're putting together some of the parts and maybe that doesn't quite work. So then you already have one coming along which is not just happenstance, but planned that if this doesn't quite do it, this will for very good technical reasons. And then you put those together. And then when you get something that will allow the thing to get through the transition you'll see it building up too fast, or the flame front is too far away from the face of the injector, or it's burning properly in the center but ragged on the edge. Or the other way, you've got some hot spots--and all you do there then, you begin to say, "OK, when I have this do I change my pattern of the flow of the liquids through and the way that the spray is spread out, or do I change the flow rates, or do I put a larger pressure drop in the injector itself, or do I put more cooling capability in the wall of the chamber and things like this.

- Now that's where your black art comes in because for each one of these you change it will change some other things in the whole system and you've got to balance that out. It's not quite like your taking a bunch of things that you don't know what they'll do. You know what each of these will do, but you don't know what the combination of them will do together exactly.

RB - So there is a certain amount of not quite being certain what things work specifically.

- You know what each one does individually, but the combination you don't know so you have to sometimes, like you may put a little bit more cooling in the wall because you had a hot spot there, but in doing this-- The way you would normally do is you would make the tubing size a little smaller to get the flow faster through there or you put a larger percentage through. Well, then that's going to have an effect on what's coming through the injector directly. And the same with pressure drops in the injector, you can get too much and then the flame front's in the wrong position. You don't want your flame front on the injector face, but you don't want it too far down in the chamber either because you can have problems there. ________________ where it won't burn.

RB - OK, well that helps me understand that remark then because that has always kind of intrigued me and bothered me.

- He's right, in a way, as far as the balancing out gets to be very difficult. It's much more difficult in the hydrogen engines for the final balance than it is in the other ones although hydrogen works for you as a fuel better than Kerosene. Hydrogen is so kind to you that it will burn over such a wide range that you can make things work that will lull you into believing you are in real good shape. But when you get further along in the development you find out it doesn't quite do what it is supposed to because of the wide range . Kerosene is usually a case of, it does or it doesn't work. So you real quick know you have to change.

RB - Engines have always been called the longest lead-time article, and I wonder if you could generalize about that and explain some of the reasons why. ~~Well, there are, I think, two~~

- Well, there's, I think, two good reasons. One of them is that you really cannot size the internal parts of the system for the stages until you know what the engine demands are going to be. If you know the thrust that you are looking for in an engine, fine, you can build a thrust structure for the stage, you can build a tank size. But you don't know the flow rates, you don't really know what size piping you're going to use, you don't know what kind of orificing you're going to have, you don't know what kind of screens you'll need or the particle size that the engine can inject without having trouble so you got to know that much about the engine before you can do very much with the stage, for one thing. Another thing you gotta know is how long is the engine going to be burning so you know the size of the tanks, what rate is it blowing and how long is it going to be burning. Now, you can calculate what it should be, but until you are able to get an engine that is far enough along that you know that's the way it's going to be you may have to have the thing burn longer, which means you design the tank differently. So the tank, I'm saying tank not meaning that portion of the stage, now the stage has a lot more activities than that, but the portion that is the heart of how they put everything together at the stage has to depend on knowing pretty well what the engine is going to require.

- So the first thing you do in the development of an engine, I mean a vehicle, at least it has been consistently that way, I think it's pretty much that way in aircraft too, you start a development of an engine of a certain size and type and certain capabilities. When it gets far enough along that appears it's going to do that, then you begin to say, "OK, with that I now need a stage to do this and you get the stage contractor going." That's the general first reason.

- The second reason is that, unlike the stage, you cannot test an engine by a simple pressurization of the thing to see if the thing is structurally ________ or not. You've got to run it because it's all moving machinery, and it acts differently in that environment than in any way that you can run to it. You've got to run that thing and find out where the weakest links are so that you'll see what changes you have to make.

- We start the engine development quite early and we get into this testing capability and we will rework parts and we keep that going, incidentally, all the way through the program until we have gotten enough time so that the whole mission possibilities, every part in the engine is seen at least that length of time before it flies for that length of time. And that's something you don't have to do with the stages. They can do most of their testing, with static testing, pressure testing, RB - Dynamic testing

- But they do have to do some dynamic testing so I don't want to take anything away from ____________. They've got a job to do. But if something can be done much simpler and in a shorter time and once you've done it on the ground you say that's fine. You can't do that with engines and so that's why that's the longest lead-time.

RB - Let me ask about the philosophy of the induced combustion instability and why it's done, and the earlier application in other engine programs prior to the Saturn, how it came in and why, etc.

- The first that I'm aware of was done on Redstone. Now there may have been some before it. But the reason it's done is that if you have combustion instability it's usually something that happens only under very transient conditions, and you can have one engine exactly the same design, built supposedly to the same drawings that will be fine, the next one would not be. And you can't have that because you would be in a situation where you would have a catastophic failure if you get the instability and it doesn't dampen out.

RB - Even the minute variations of the same manufacturing process may cause...

- If one is subject to instability it can be right on the threshhold and you won't, and it will be one would have it and the next would not. This is that ____________ So what you do with the induced instability is you deliberately disturb the flame front and you find out will it dampen itself out. And you have a criteria of how much can you stand for structural damage. Then you set that as a requirement, and if it becomes mandatory that all of the engines be tested by demonstrating that, now there's quite an art to doing that, you have to get just exactly the right bond size, you've got to get it in the right location, you've got to be able to force the instability, and then you've got to play around it a little because sometimes we found, for example, that you'd have a large disturbance and it would recover real quickly and be fine. Particularly was this true on JII. It took a small disturbance and it didn't recover. So it was very sensitive to small variations where you would have thought it would be more sensitive to the larger.

- So, it's that sort of thing. But the induced instability is done to give you a feeling of where the margin is because you might be operating in a regime that is right at the point where a very small change in the flow, like something blocking a tube in the injector, or a momentary surge in the pressure so that you get a little difference in the flow could, conceivably, cause you to have instability to start, and if it starts it doesn't dampen out and you have real problems. So what they do is they get a series of tests early in the program to find out what it takes to trigger it, what it takes to dampen it out. And then after you've gotten enough data of the range of information there, then you say, OK, in all my production endings I'm going to do that as part of the acceptance, and it becomes part of the reliability.

RB - So you actually go to the induced combustion instability in each of the production engines.

- We did it on some of them, we didn't do it on all of them. But the concept is that you have to demonstrate that, you could do it two ways. You could demonstrate it by enough testing development-wise to show that you could never have it with that particular design. But we even went further than that. We did put it on some production engines and we also put it on some production engines and stage combinations in a couple of cases just to be real sure. That's an added safety because, again, the system together may operate slightly different than it did as an individual ______________________________.

- One important thing too is the fact that on each one of our production engines we did have a hot fire. That was required.

RB - Did you do that in a battleship condition or

- You do it on a battleship before it's delivered to be sure that the stage is getting an engine that doesn't have any known defects. And then to check the stage-engine combination, every stage is fired.

- Actually what they did with the F-1. They would actually deliver it to Edwards and fire that engine ____

____

____

RB - And every stage was fired at MTF or ____________ or wherever.

- Well, we had some fired here in the early period.

RB - But even later on, downstream, all the stages were fired once before they got down to the Cape.

- I want to emphasize the reason for that is that, without firing that stage, as a combination, you could have the problem that is the human error. Someone could have inadvertently left something in the system that was missed in the stage and in combination after the hookup. Each one is individually ______________ ______________ supposedly perfect. __________________________ but you can have such things as someone leaving something in there.

RB - There was a lot of testing of H-1 engines at Marshall Space Flight Center. I'm almost beginning to see the answer to this, but not so much on the RL10 and the F1 & J2 and why was that?

- I'll tell you real simple on the H1 vs. F1. Two things involved there, no three things. One of them was, of course, the program when it started, the H1 program was an outgrowth of the S3D Jupiter engine and the one for the Thor. We already had the capability pretty well in hand here, and there was a recognized team already available, there were both contractor and government people here. So in the early part of the thing, as it went into the H1 engine, they did a lot of testing there to find out more about the H1 engine than we would find out in the normal amount of testing. In other words, there were a lot of limits testing, a lot of other concepts of things where they were weak ~~andxwherextheyxwerexstrong~~ things known as to sort of a backup to the contractor's effort in case something went wrong in the weaker areas. So we did a lot of that. We didn't do as much on the F1 because the similarity of the fuel combination we used the H1 to test some things that we thought might happen on the F1 in the larger size. Although the size difference was there it was calculated what would you have to do in the way of changing certain combinations of the operating parameters for the H1 to at least find out whether there was likely to be a problem on the F1.

- So it was used in some cases to prevent having to run an F1, which costs so much more to run, when you think about the large amount of fuel ______________________

- There were some other considerations too. For one thing, the size of the F-1 engine. They needed a test sight fairly close to the manufacturer's plant which was Edwards Air Force Base, cut down on our shipping costs obviously, and maybe damaged the engine in transit. So it was relatively simple for the contractor to take the engine say, like up to Edwards and fire it off there. And then return it to the plant for checkup. I think that was another consideration.

- That was certainly one of the big ones for the F-1 too, because ____________________

- That plus, for example, in safety. When they first developed the F-1 they had no idea what that ____.

- You covered the ____

- You know, for example, here you have a relatively ________________ populated metropolitan area. And we didn't know what the shock waves were going to be.

- If you recall we found out what the, running the H-1a here that under certain weather conditions, like we have today a little bit overcast, we had enough noise to cause people in Birmingham to think that they had an earquake. And we didn't have as much, surprisingly, when we ran the F-1, we didn't have near as much as we had had with some of the earlier ones. It turns out it's the smoothest running, it's more the sound of the engine

- What was rather amusing, and this is kind of off the record, also the fact that people would submit claims ____________ for any damage on broken windows. We had one amusing thing happen in Huntsville. The first time they fired the big Saturn V booster, the SIC, one woman complained that it actually had caused cracks in the plaster. So, of course, each one of these cases had to be investigated and they sent a team of investigators out there, I guess, and they actually found out the cracks were cobwebs. They obviously had been there before the stage was fired. But I think all these things had to be considered. Edwards Air Force Base of course, being isolated

- Well, that's the three reasons, one of them is the H-1 size and the fact that it could be used to duplicate some conditions that would give you answers on the F-1. The other one is the transportation, because if anything goes wrong you've got to take it back to the contractor. Nobody else has the facilities and equipment to do the repair or change out the injection thing at that time. Later in the program, we do have capability sometimes for certain components that you can remove in the field and ________________ but a lot of it has to be done back at the plant.

RB - But now, you said it was possible to test some of the F-1 characteristics through H-1 testing, but is it easy to scale up?

- It isn't, but such things as, one thing you could test, for example. You could take and put baffles on the injector and find out what kind of pattern you needed to get the baffled injector to work properly. You could do that on the H-1 and you could scale that up to the F-1 and it would have a fair chance of working, and it did come pretty close to it without much change. But you don't know, there are some things you can't do. For example, you could not run the turbo machinery except in some off conditions situations and even guess what that would do to one the size of the F-1 by comparison.

RB - Let me ask you something about that. When I was trying to bring myself up to speed on engines, which was still a difficult process, one of the things I came across and which has been my bible, was that thing by Huzel. Are you familiar with that? Do you know what I'm talking about? Although the illustrations in there show the injector baffles and everything else it doesn't tell which engines are shown. It all looks to me like H-1 and F-1 and J-2 parts, and I was wondering, wanted to confirm that if you knew anything about it.

- I don't know whether we could say for sure that it is. I would have to look back in the records. Now whenever they used anything like that they always asked for permission to publish papers and things and get permission from the Government for it. And I suspect we would find, if we checked in the record, something that shows that, yes, they did ask for and get permission. I'm not really familiar with whether they did or not because at the early part of the program, I was here during the early part of the buildup of the first Saturns up through the Saturn IB, in fact I was over, in charge of the ______________________ section and handled that portion of it. And, of course, we had the engines, we did a lot of the modification of the engines here, a fair amount, special instrumentation and things of this sort that were not put on by the contractor, things that he kind of reluctantly agreed he'd let us do. But we felt we needed to know more about it than we would be able to find out about this information, particularly on the early things, like the Jupiter we did a lot of it. And we kept that up on through the first ones.

- And they were built here by Government employees by getting just the tanks built outside, the valve built outside, the elbows and then we would build them here. And some of the stuff was actually built here.

RB - Build the engines, or the stages you're talking about.

- Stages, and part of the build-up on the engines. Now the engines were built and delivered, but we did some modifications here. ~~The H-1 came from Neosho~~

RB - The H-1s came from Neosho isn't that right?

- First they came from ~~Nova~~ Canoga Park and then they were moved to Neosho. Then Neosho was set up as a full-time facility for delivery.

RB - OK, I've got a specific question on the H-1. It's something I came across and it's been kind of open ended. In late '66 there was a question with the Haynes Stellite turbine blade on the H-1. And I'd like to have you comment generally about it. But one thing I'd like to know specifically, too, is that apparently these same turbine blades are used in military rockets so that they have to go back and change out all those turbine blades on military jobs too?

- They're also used in aircraft, a similar situation. What happened was, that we had the problem with turbine blades just breaking, ~~unexpedly~~ unexpectedly. And the problem turned out to be that after a fairly thorough investigation, of course everybody had no way of knowing where to look for the problem, but in going into it we found out that there were blades in there that were out of the wrong material. The question comes up, how do you get the wrong material. So, in looking at the contractor's plan you find out that he's got across an area like say across the ceiling here, a bunch of bins with material in it. He gets an order in and he needs so many of this particular material, he reads the thing, he pulls a chain and it drops down into his hand or a bucket. He puts the ticket in there and gives it out. Well, he apparently pulled the wrong chain.

(End of Side 1)

RB - O.K., so this guy reached up and apparently just read the right label and pulled the wrong chain or something like that.

- Alright, then the problem comes up of finding out where are they since they can be mixed. They wouldn't just bexinxanyxone necessarily be in any one turbine so the traceability becomes a problem; and you have to also alert everybody else. It's a part of the Government system that if you run across a problem of any kind of material or any contractor goof, or I guess you would say not only contractor--any goof--it could be a Government supply itself, but if there's a goof that's a human error or a materials error or something like this you send out an alert so that everybody else knows at that there is something wrong or possibly wrong. So they can also look into it or wait for you to find out what it is, if they don't have to use it right then, and then they can go in and take the corrective measures. So we have that kind of work relationship. They do the same for us.

- So this alert goes out, and what we had to do was to figure out some way to find them without disassemblying every missile. The way we did, somebody came up--and I was trying to think of who it was, it was out of Union Carbide which I guess Haynes must be a subdivision of Union Carbide. They were so concerned about this, because it obviously was their goof, that they contacted some of their other divisions for help, and someone out of Oak Ridge had developed an eddy current method that allowed them to tell the difference. And he said, if I can get a probe against the material I can tell you whether or not it is stainless steel or Haynes Stellite. They have different characteristics. He said, at least I can tell you in most cases. He said there may be a few who will not. Of course, we don't know this to be a fact so he's got to demonstrate that.

- So what he did, he gets some of each, he demonstrates that they tried different batches and they find out the range. And you get two curves that look like two bell-shaped curves and they overlap in one little area, but they are distributed such that all of the Stellites in one and all of the others in the other except for one little overlap area. So that says that you've got a pretty good competence that you can get rid of some of them without any question, say definitely it isn't and there is no possibility it's either this material or the other material. The other one was a range of values that said "hey, if it's sitting there and we can't say for sure we have no choice but to go down there and run some other kind of tests." That means you have to physically get it out where you can see it.

- But that meant that first he had to have that technique which a guy had to develop. The second thing he had to do was he had to develop a probe that would be able to get in through the accesses that were available without disassembling and get it against the blades. And what they actually did, and unfortunately I don't have an H-1 model, but they took off the solid propellant spinner motor that turns the turbine. And you could go up through that opening and snake around to where you could touch the blades. Then you could get the reading and crank the thing over to the next place and they took readings around, I think it was five places around the periphery of the thing to give them the possibility of detecting all the blades. It was quite an elaborate process.

RB - So they were able to check each blade.

- By putting the type probe he had it would cover a few blades in the tree and they could tell what they had.

RB - But this meant they had to go back and check the H-1, but then I would guess the SIIID engines that were ______________________________

- Any of the elements they had bought from there also had to be checked. And I'm not sure now, since that was not part of our activity, but we did alert everybody. I'm sure that they must have done the same thing.

RB - That closes up the question because I was never sure what happened.

- But they were at least able to isolate the batch of the bad steel, the wrong type of steel.

- You could isolate it, but you couldn't be totally sure that there ~~hand't~~ hadn't been another mistake similar to that. You could get that purchase order down and isolate it, but how many times in the past might the same mistake have been made. So what we did, of course, was have them change the location of the bins, for one thing, so that materials that looked somewhat alike could not be next to each other, so that by actually seeing it the guy would instantly know it was the wrong thing if he pulled the wrong chain. And then, also, we checked every batch after they were made up, before we put in all the future ones. I don't know of any other precautions other than that. That cost quite a bit of money and it was quite an effort. That's why Union Carbide, as the parent corporation, took a real, I think a very admirable, concerted effort on their part. They realized it was their goof, but some companies would say, "Well, so what." But they took a real interest in it. They looked all through their broader spectrum and found somebody who happened to have the right information. We were fortunate, I guess, that it was available. But I don't know what else you could have done except disassemble ____________________

RB - Awhile ago when we were talking about combustion instability, you mentioned the flame front. I need to come back to that a minute. I'm not quite sure what the significance of the flame front is, you know about the distance of it.

Tape #1, Side 2
Interview with L. Bostwick and M. Burns:

- Well, if you're burning too close to the injector you overheat it. Then it warps the plates. So in some injectors with the higher temperatures we actually have ________ metal, ______________________, so that you can get a cooling that way. But in the early ones we had a plate with a plate behind it and then between is flowing the LOX __________ before it goes into the openings. So it's cooling it by the actual flow passage of the LOX and the kerosene.

RB - How far would the flame front be? Now, how far would the flame front be? Are we talking about 1/16 of an inch or 2 inches or...

- I would prefer not to answer that because we'd better get one of our technical experts on the thing. Those things varied all over the place during the development, and I'm not sure. We're talking fractions of an inch.

- I think one bit of humor here ____ On every engine we had we they call we develop an engine model specification. We were talking about this the other day. One thing that we forced upon our contractors was a part of our F-1 engine model spec we had a statement that engine malfunction or ________ combustion would produce little or no damage to the Saturn V vehicle. And at that time Rocketdyne, the contractor, was quite worried because of the fact that, "What happens if this thing blows up over a major populated area or something like that? Is he then going to be responsible for the whole Saturn V vehicle?" Well, it was at that time we found out Lloyds of London, even though they sometimes made the claim that they insured for everything, did not. Rocketdyne, before they bought this particular thing _______________________ had gone to Lloyds of London and tried to insure themselves on the loss of the Saturn V vehicle. And they were turned down flat. At a billion dollars a vehicle they turned it down.

RB - I'd never heard that one before. That's beautiful.

- We were told this early in the negotiation of the engine model spec when we tried to force this down the contractor's throat because we thought _______________ ________________. This thing, if it malfunctions, or runs rough has got to produce either little or no damage to the vehicle. So at that time they thought to themselves, gee whiz, if that's the case, and they're stuck with it ___________ _______________ with a Saturn V vehicle had better insure themselves.

RB - So whatever happened to the spec? Did you _____________

- Well, they finally bought the spec knowing, of course, that the government is normally _________________________

- One thing about it, we had a roomful of lawyers, I won't mention any names. But the lawyers were trying to define, ~~in this case~~, what is really meant in this case by "little or no damage". One of the technical men steps up and says, "Well, in this case "no" means a little and "a little" means a lot. And of course that just broke up the meeting. One of the technical men jumps up like a bull in a china closet and says in this case "no" means a little and "a little" means a lot.

- That's why you don't have technical men sometimes during the final negotiations.

- That was one humorous thing part of the history in the development of the engine, the fact that the engine did not ____________ if the Saturn V engine blew up. could Rocketdyne, in fact, be held responsible for the whole vehicle. And they found out that there wasn't an insurance company in the world that would tackle it. They went directly to Lloyds of London and were turned down. They had no desire to insure the potential loss of a Saturn V vehicle.

RB - But that spec was still in the Rocketdyne _______________.

- I think the reason they did is, as these negotiations were going on, they began to have a little more confidence in their product, too. We didn't have to settle it that day. These negotiations sometimes take __________________

- What was funny at that time was the fact that at that time they were known as North American Aviation. And during the negotiation we were really trying to ______________________________________. Their project manager stood up and said, "Well, OK, if we buy this thing and one of them blows up we'll just turn the key to the plant over to the government." ____ ____. In other words, if you suffer a billion dollar loss over night you take it up with the government.

- The reason we kind of wanted to mention this is that to get a feeling for the risks that some of the people had to take. Somebody had to make that decision within the company that,"Yes, they would go along." The government had to insist on something to protect the thing because we were liable to all the other people in the stack because the engines were all furnished by the government to the other contractors. So, if they didn't work then you are liable for everything that they have in the way of loss. And we also had incentives on each of the other contractors, as well as on the engine contractor, for performance. So, what do you do if the engine causes the stage to fail? Does the stage man still get his incentive for a perfect flight? So that's your problem. So those kind of things made it very necessary to have in such statements as we were talking about here to be sure that the contractors understood that they had a pretty good stake in the thing.

RB - I remember talking to a guy named Lloyd Sawyer, who was at McDonnell-Douglas and he had been involved in this kind of thing. He started to give me some of the parameters. It was just like a Pandora's Box. There is another aspect of the F-1 I wanted to try and nail down a little bit, and this is furnace braising of the engine, which apparently began in 1965, as I recall. But now then, how was the braising done before 1965 and how would you explain the production then of the RL-10, and the H-1 and the J-2. Did they use furnace braising or were they hand braised? How did they do it before furnace braising on the F-1 came in?

- Well RL-10, as far as I'm aware, and I was resident manager of the plant during the development, we always used the furnace braising.

RB - They always had a furnace braising?

- on the RL-10 they did. We had some hand braising repair, but always had furnace braising.

RB - Of course there's a big difference in the size and a difference in the material.

- Now the H-1, as I recall, was hand braised up until they had the problem with self-embrittlement. The self-embrittlement came about with the nickel alloy tubes that they had were subject to embirttlement with the sulfur in kerosene after repeated firings. Now we found out that some of the test engines, after awhile in the program, that some of the tubes started splitting. With the tubes splitting, on the early engines, they had to look then at what could they do to correct it. You can't purify the kerosene. Well, you could, I guess, purify it to have gotten rid of the sulfur, but that didn't seem to be a practical approach because one of the reasons you were using it is so that you would have it readily available from any of several manufacturers. We did make a study of which ones had the most sulfur, which batches. Why were you having it in this test stand and not in the one here, for example, or vice versa. And it was traced to different batches of fuel bought from different contractors. The spec was such that they were well ____________ but some had a little more sulfur than the others. So they traced it down and found out that was really what was causing it.

- Then go to the next step knowing that stainless steel was being used by RL-10, I imagine that J-2 started off with stainless steel in the beginning also. I'm not sure, when did the J-2 contract start?

- We had a letter of contract on J-2 about 1961.

- So they probably were already in the stand ____________. So it was natural then for them to look into that area, could they use that, and with the stainless steel it was possible then to do the burnish braising. I'm not sure that you could have done the burnish braising with the nickel. I don't recall anybody trying it. I'm not a metallurgist so I'm not sure whether you could or couldn't. But I know that when they knew they had to make the change to stainless steel it made sense to make the change to burnish braising at the same time.

RB - That really helps clear up the problem I had. And the furnace braising, as I understood from reading the descriptions of it, really was a big breakthrough in terms in production.

- It was, there was no doubt about it. It reduces the time and gets a much better seal. It's a little hard to do. Again, it's a state of the art type thing. You have to get the right amount of braise material in the right location, temperature right, you've got to have the air flow such that it doesn't block back the melted braise out of the and leave voids in the space between the tubes--in The stacking and the spacing of the tubes is quite critical, the cleanliness of the tubes is quite critical, things of this sort. But once you've got that down the furnace braising is far superior to hand.

RB - Did they use furnace braising on the H-1, or how are H-1 engines or S-3 engines produced?

- The early H-1s were hand braised. The furnace braising on the H-1 came about with the tubes splitting. The tube splitting showed up first on the H-1. And the time frame there, what'd you say, '65, I don't recall whether the F-1 started out hand braised or not, but I think they were hand braised to begin with.

- I think the first R & Ds were probably hand braised.

- I'm almost positive they were for two reasons that I can think of right off the bat. One of them is that they didn't know they had the problem, and it's possible it probably wasn't a development made of methods for doing it on the nickel-type tubes. And the second one is, I would think, would be the size of it would be ____________________ for that size would probably be something that they would not have wanted to go into unless they had to.

RB - That was a very special facility....

- I know that the tube splitting on the H-1 made it necessary to go back and change and cross the board. We had to go back and ask for more money.

RB - What was it, sulfur you said?

- Sulfur

RB - That gets me too about even aviation fuel. Apparently back in the early days, that's what really sparked my memory, some aviation fuel performed better depending upon which part of the country the refinery was located at. And this variation in fuel strikes me as really...

- If you look at the specifications, they are fairly tight. And yet, minute differences between locations, maybe all of them will be within the spec but the combinations will be in different ratios.

RB - When you get into an operational phase it seems to me a lot of parameters start changing real fast. I want to ask a question about the thrust chamber extension on the F-1. Why wasn't it used on the H-1 or the J-2? And one special problem, was there a re-ignition in the thrust chamber extension area, using the fuel-rich gas generator exhaust? Am I totally confused on that?

- You've got more than one question there. The first question was why we had the extension on the F-1 and didn't have it on the H and the J. I know why you had it on the F-1. The size and the difficulty of making the thing didn't make sense to me. The lower part of it, where you've got that much expansion. Once you get to that point there were other methods of being able to cool it by having the coolant flow through the tubes. It's not practical to do so they had--what did we call those things, shingles, but..

RB - That's the term I had always seen, just shingles.

- I don't know it they had any other name. Anyway they had a way of handling the cooling of it without having to use the tubes which just wasn't practical ______ ______________________. Now, on the H-J, I would assume the reason it was never considered, they were well within the size that could be handled with the standard tube cooling format. And I would think that also the tube cooling format is better in that you don't have to replace. For the others you want to re-use it as we did for testing. You have to repair those thingles and replace the shingles __________ But one ____________________________ you wouldn't have any problem. But I think it was the size ____________________

RB - OK, the other thing that I was never clear about is that somewhere I got the idea that there was a reignition phase of some kind in the thrust chamber of the extension area. And that this was the fuel-rich gas generator exhaust __________

- What you did, you took the exhaust from the gas generator and they went down into an exhausterator and were fed back in to the chamber... If you've seen the F-1 pictures, you see that big, round bulge at the bottom, the gas engine generator exhaust, which is fuel rich, goes in and is fed back in there and it gets thrown into the hot gas stream there and some additional burning and thrust anyway from that rather than have it exhausted in a way that would cause you disturbance as far as, if you took the gas generator, for example, the output of it was about as much as you would get from say, an H-1 engine. So you would have a disturbance that would be hard to control from a control point of view. So you wanted it all to come out at the same place on the gimbal of where it was within the gimbal capability of the F-1 engine. So as far as having a second ignition I don't recall, I think it was just burning and it would be some more burning probably take place because..

RB - OK, that would be it because it comes in fuel rich and already hits those hot temperatures so..

- There was no additional ignition. But the real reason for putting it in there, I would think and from my knowledge of the vehicle, would be the control problem. If you had that much thrust exhausting somewhere else you would have to then worry about it as an off load thrust. That's a fair amount of thrust that comes out of the gas generator on that side.

RB - That's a 60,000 HP, as I recall.

- 65,000 HP turbo pump.

- The gas generator for that was as large as many of the engines we used earlier for the whole missile.

- You figure, for example on the F-1, that turbo pump, 65,000 HP was actually pumping 3 tons of fuel every second. Two tons of it with oxygen and one ton of RP fuel, so that's a lot of fuel.

RB There's another question I had on uprated. The engines were all uprated at one time or another, and I guess each of the engines H-1, J-2 and F-1 all went through uprating.

RL-10 also.

RB - So how do you uprate an engine. Were there general things or specific things. Take the F-1, for example.

- There are several things that are done, but you need to also know the reasons.

- As you get further into the development of the missile and its payload as a complete package you find out that the payload and the weight of the missile historically grow more than the optimistic estimates of what they can do. Then the engine is called on to make up the difference quite frequently. Now not in all cases. Some of the stages they were quite successful in going back and chemical milling of the surfaces to reduce excess weight and all that to make a good portion of the savings themselves. But in all cases the engines had to be uprated in order to take care of the payload increase to be on the safe side to give enough margin. So that's one reason. The second thing, how is it done?

- One of the ones you do is you up the thrust if the vehicle can take it, and that's a matter of growth that's built into the thing to start with if you want to have a..... well, take the million he mentioned first. It took a million pound thrust engine, you would probably design it at a million two or something like that to be sure that you get your million. Now you couldn't guarantee that you could deliver a million two because some of them would be somewhere between the million and the million two. So to uprate it you then increase the flow rates, you do some other things to change the characteristics of the burning. And you get a, the thrust is usually the shape of the bell itself and expansion ratio and the thrust is related to that and the temperature. But the additional performance you can get out it by changing the specific impulse is another way of uprating.

RB - How do you do that then?

- That is usually done by getting a better mixing thing so that you get a higher percentage of the fuel burned at the proper place in the cycle so that you don't burn it all ________________ so that you get the full expansion all the way down. And it gets back to the patterns that are at the flame front, the good mixing characteristics and things of that sort.

RB - So the engines are normally planned and built with this.

- You usually have to in order to be able to guarantee that you can deliver.. you usually have two parameters you have to guarantee. You have to guarantee thrust and you have to guarantee an ________________, which was the impulse you're going to get for a certain amount of input of propellants here per pound.

RB - One pound of thrust per second per pound.

- You've got to be able to guarantee that kind of combination so that the stage knows what it's going to have to deliver in order ______________ its sizing and flow rates. You usually, in both cases, the engine manufacturer will have to keep some margins. So he will have to build it to where it will demonstrate a little more than that. Well, as you get more confidence you then begin to creep into this cushion and find out where is the real upper limit of the thing. You may find out that, with a few minor adjustments here and there, it becomes possible to do it. Now I'll give you a good example. On the RL-10, we made a change there that was a fairly significant increase. And what we did, was took, at the throat, and just narrowed it down. It was necked down. The tubes were bent to a different shape. It was a very severe neckdown. OK, then the ratio of that opening to the old opening of the bell has changed so you've got a fantastic increase in the expansion ratio, which gives you a fairly significant change in thrust.

- You see you can't do that in some cases. In some cases you can make changes in the contour, you do it if it's within the capabilities of the system to do. Some you can't do that, some you can't work the other way.

RB - You really get into a myriad of tradeoffs on this.

- In the case of the F-1, for example, we went to a million pounds of thrust, but they just call it booster ____________ without identification of the vehicle. We finally ended up with 1.5 million...

- 1.522

- It meant some major designs in the turbo-pump and also the injector. In other words, this was a redesigned thing.

- You have to have more push through at a different rate, beef up your hardware so they can stand a little more pressure, a little more flow rate. In some cases, you have to put flow straighteners in if you have sudden, sharp bends. If you increase the flow rate you can't do it without putting straighteners in. You have to put in sometimes special castings that would be beefed up in a certain way that they could then have a bracket mounted to hold it so that when it gets the load it doesn't want to take it and just pull the casting out of position. So there are a lot of structural changes going through it too as you make that that decision. But normally the contractor will have planned to be sure he can deliver his, on all cases, he has to demonstrate this. Not only demonstrate it once, he has to demonstrate with repeatability so he fires a minimum of two firings, one that shows that it does when its supposed to and one that it will do it again.

- And with that, he's got to put in a little pad. Now, historically, as the payloads have grown or the weight of the vehicle has grown the agency comes back and says, can you get a little more out of it. We'll probably see it on the shuttle engine.

- Another thing that really aggravated the problem too is the fact that as you do this the engine weight also increases. You've got tradeoffs between... You've got to build more thrust in the engine to take care of the weight. The weight thing is all the way through the whole works. Historically, we have found that, like we guarantee that we can deliver 100,000 lb. payload. The payload might then be planing to be about 75,000, we'll just take some numbers out of the air, I'm not going to try to pin down what they really were. But then you find out it begins to creep up and before you get through the development of the stage xxxxxgoingxtoxbe that's going to be doing the boosting the payload now says 104,000. What does the center do? Do xxx they say I can't help you because mine only is guaranteed to 100,000. You see, then they have to look at it, what can I do to accommodate it to 104,000...

(end of Tape #1, Side 2)