INTERVIEW WITH DR. WILLIAM LUCAS
INTERVIEWED BY STEPHEN P. WARING
UAH
APRIL 4, 1994

1. Waring Could you describe the development of the first nose cone using aflation?

2. Lucas That would be a long process. Actually the aflation concept, the first use of that reinforced plastic, fiber reinforced plastic material, to insulate against high flux heat was not devoted to nose cones itself. The first work started with the development, or the attempt to develop, a jet vane for the Redstone Rocket. Are you familiar with that? The jet vane, eventually we came to gimbal the engines where the engine itself turns and provides the direction for the rockets. But in the nose cone, as was the case of the V-2, the guidance or the determination of the direction of the rocket was by a jet vane, a vane in the jet that operates just like a rudder on a boat. These four jet vanes, two obviously opposed to each other, were inserted into the jet itself, a very high temperature environment. Graphite had been used for the purpose. It was eroded of course, but also sometimes would crack. We were using in the early Redstone days, a transform of graphite that came in large blocks sufficient to machine the jet vane out of it, but before a jet vane was machined from a block, that block had to be evaluated to see if it had defects in it. It required a higher

level of quality in the block than was necessary for the transformer application. We had a process of X-raying, which in itself was a development, where the block, using a special technique, was x-rayed to determine if it was of sufficient quality to make a jet vane. As I recall, we were only accepting about 10% of the blocks so you would find 100 and use ten of those blocks for a jet vane. So the search was to find a replacement material--something that would be a lower cost, higher quality, more reproducible, more reliable material. For that purpose, we machined some jet vanes out of a material called micarta. It was a fiberglass reinforced plastic like you would make the early table tops out of - kitchen table tops.

3. Waring How do you spell that?

4. Lucas M-I-C-A-R-T-A. I can't remember if it was M-I or M-Y. I have a paper I wrote on this a long long time ago on this the, development of the aflation concept. You might be interested in a copy of that paper.

5. Waring We would.

6. Lucas As described in this paper, this material was machined into a jet vane and was tested out of White Sands proving ground. The material of course did what we estimated it might do and that is that it protected itself by consuming its surface. By aflating the surface would absorb heat and decompose it, and then

it would flow away and expose a new layer that had not been deteriorated. So there was a very steep gradient from a very high temperature at the surface, to a much lower temperature 200 or 300 degrees over maybe an eighth of an inch or so. That was very good, but the problem was that all this glass and the material flowing off of it interfered with the function of the jet vane. It would bind the jet vane so it wouldn't turn very much. So we never used that material as a jet vane material, but that was the beginning of the consideration to use it as a blader for protecting the nose cone. The early work in developing the nose cone materials was pretty much Edisonian. We've tried every bottle on the shelf. We tried the glass reinforced plastic which was eventually the thing that we used, but we also tried many other materials: heat seek kinds of materials - copper, nickel, steels, wood, even wet wood. We used wood that had a very fibrous structure, and we would vacuum and pregnate with water. We would orient the wood such that the fibers ran perpendicular to the surface. So you mount this little block of wood impregnated with water and expose it to a jet vane. It did just what one would expect. The evaporation of water absorbed a lot of calories, a lot of heat. So it was very good. Then we proceeded from that to impregnating with alum. An alum is a chemical compound that in its crystallization binds several molecules in water for each molecule of the compound. So, we'd make a solution of alum and impregnate that into the wood and that was even more effective than the water itself because in effect you had to use heat to break up this molecule and form the

water and then you had to evaporate the water. So you generate a lot of heat. The only impractical part of it was that putting this thing on there, and you have these fibers exposed, and this hot water didn't know which way to go, whether to come out or go back. It would blow itself off of the surface that you had it mounted to. That became an impractical consideration. I only throw that in to say one of the things that we looked at in terms of protecting the nose cone.

7. Waring Was this all done in ABMA's labs? Was there a contractor? Were there contractors involved?

8. Lucas This was done prior to ABMA. Early work was started when it was still just Guided Missile Development based at Redstone Arsenal. That extended into ABMA, but the start was prior to the beginning of ABMA. I haven't thought of these things recently, and my figures may be off a little bit, but as I recall, it was about 1953 that we did the first jet vane test and also nose cone tests were being done simultaneously at the Guided Missile Development operation of Redstone Arsenal. ABMA was not formed, as I recall, until January 1, 1955. So this work had started before that.

9. Waring And the first successful, don't they date the first successful aflation test at 1958?

10. Lucas Right. That was, well . . . .

11. Waring Of the nose cone.

12. Lucas First recovered one.

13. Waring The first recovered one.

14. Lucas The recovered one was then so that was ABMA at the time. But the work had started before ABMA existed. The tests were done in rocket motors themselves, little rocket motors. We had what was called a 4HT, four square inch high temperature test vehicle. If you're familiar with that it's just a little block of material four inches square, and it was exposed at some angle like this to a rocket exhaust. The rocket was started and then you inject that thing into it and run it for a period of time and calculate the heat flux and measure how the material had responded in that heat flux. Then we had another one called, I think it was the 164HT. It applied to the aperture or the exit, the diameter of the exit of the nozzle so we used a larger specimen like that. We also would even inserted some materials in the Jupiter rocket engines themselves for . . . .

15. Waring In static tests?

16. Lucas For static tests. The thing that you referred to happened in 1958 was the 1/3 scale nose cone that was mounted and flown on a simulated flight on the same vehicle that ultimately

launched Explorer I. That was one of the spin-offs out of Explorer I. I think I may have mentioned to you in the past that along about, I guess it was maybe 1955, '56 along there, when there was some planning being done for the international geofiscal year. The plan was to study Earth from Space, and Russia was of course going to develop a satellite and various organizations within this country, government organizations, imposed to launch a satellite. The Von Braun team proposed to launch a project called Arbiter which I think proposed a satellite to weigh about 15 pounds. The Navy and the Air Force both proposed, they were interested by this time in rocketry, and so the Navy proposed to launch a satellite weighing about 40 pounds, the Vanguard. The Vanguard program got the nod. I don't know, there was some speculation as to why that happened. It's easily justified because it was a larger satellite. I have always thought in my own mind that possibly the country didn't want to trust to a bunch of former Germans and their American colleagues the launching of a satellite for the United States. I can't prove that of course.

17. Waring Well I think I've read that in several places. I think that's the case.

18. Lucas Other persons think that. Nobody I guess can prove it, but I think that's probably right. Nevertheless, we lost that battle. Instead of just forgetting about the whole plan, the reason I started this story in the first place was to say

that we continued to develop the launch vehicle itself. To use the Redstone as the first stage and then develop two upper stages of solid rockets. Are you familiar with that?

19. Waring That's the Jupiter C.

20. Lucas Jupiter C, right. Then you know we had this little tub, a little rotating tub that was mounted on top of the Redstone rocket, and we had eleven, we called them low key rocket, a modified Sargent I think they were, in a circle. Inside that was a cluster of three more. So the eleven constituted the second stage, and the three more constituted the third stage. What we did, instead of flying up to put a satellite in, we just flew back down in the atmosphere and simulated a longer range rocket. Although discouraged because we didn't get the nod to develop the satellite, we went ahead and developed a launch vehicle anyway and justified it on the basis of testing nose cones. That was the reason that we were able to launch this rocket in 1958. There had been times, it was about a year before that, that the Vanguard was already in trouble. They were getting a lot of explosions and had not been successful and Von Braun again proposed that we could launch this satellite in a short period of time. Again, we were denied, but in this August we did launch the satellite Recovery and proved two things. One is we proved the nose cone material which is the reason you started this line of questioning in the first place, but in addition to that, we proved that it would have been right to have

given the nod in the first place. Then we could have been before the Russians because in August, a couple of months before the Russians launched their satellite, we had already launched this rocket successfully and recovered the nose cone. We'd actually done more than that. This nose cone was made out of this reinforced plastic material made in the laboratories in our shops. It was the beginning, it was a big demonstration of the aflation concept. There was a controversy at that time between the army who was pushing the aflation concept and the Air Force who was pushing the heat seek concept. So that eventually, we were derided quite a bit in the early days moving around with this hokey reinforced plastic stuff, but that proved to be the nose cone protection.

21. Waring What was the main advantage of it? Was it light in weight?

22. Lucas It was light in weight and was more effective in heat dissipation. With the heat seek where it was, you just had to have mass, enough mass there to absorb the heat. If you had a certain quantity of heat you had to have material with a high heat capacity and those kind of materials are quite heavy.

23. Waring So that limited the payloads that you could launch.

24. Lucas That's right. The reinforced plastic was much lighter and was much more effective because it peeled away the hot

surface and you've got black charred surfaces, but maybe an 1/8" below that char was virgin material. That concept of course is now well accepted and has been used on many applications since that item. We were right.

25. Waring It was used on all the Saturn missions, on the Apollo capsules.

26. Lucas Right.

27. Waring OK. Let's turn to talking about the Saturn era. Let's start by your giving me an overview of the laboratory you worked in. Say there was a visitor who came to the, I don't know what it was called in 1960, the Mechanical and Structures Division or Propulsion and Vehicle Engineering?

28. Lucas I can't precisely recall where that name changed. It was initially Structures and Mechanics.

29. Waring Structures and Mechanics.

30. Lucas And then eventually it became Propulsion and Vehicle Engineering.

31. Waring Right. Let's say a visitor came to that lab in 1960. What would you want them to know about the capabilities of that laboratory?

32. Lucas Well, that would be a very comprehensive capability. That was of course what we had at the time Marshall was officially formed. At that time, it had the capability for mechanical, structural design, systems engineering, materials engineering. So it had the capability of doing everything one needed to do in a rocket with the exception of electronics, guidance and control functions as far as the design was concerned. We had a structures branch that was responsible obviously for the structural design. We had a systems engineering branch that was responsible for bringing all the parts together and drawing up specifications and making sure that everything fit together. Then we had the propulsion division that was responsible for the main propulsion systems, for the auxiliary propulsions, for the pump, high speed machinery, all that kind of thing. Then we had a materials engineering division that was responsible for materials selections for everything on the rocket, not only structures and propulsion, but also guidance and control equipment as well. So it was very comprehensive like a small company within itself. Far more comprehensive in its coverage than many rocket companies even became, and they were not at that time. I was head of the materials division at the time. Dr. Willie Brunchick [?103] was the head of the, whatever it was, I think it was structures and mechanics . . . .

33. Waring Right, in the early '60s.

34. Lucas Then I became the director in 1965 I think it was. I moved from the materials division to the overall organization. One of the advantages that I had I think and one of the reasons that my own initial professional assignment was so interesting was that materials engineerings is involved in everything you do. So, by necessity I came to have an appraisal and appreciation for every aspect of the rocket not only the materials from which we built the parts but the things that went into it as well. The propellants, because we looked at them as a material and their interaction with a material. A lubricant for example. What do you lubricate your machinery with? All of those things were materials and nose cone was of course behind us at the time. That was a very interesting part of the operations then, and I credit that with my being able to broaden into more responsibilities at that time because of the education forced upon me.

35. Waring Now in these early Marshall labs under the Arsenal system you had engineering people and people with science degrees with engineering specialities too and you also had technical people. What was more of the blue collar type? What would be the mix in terms of proportions? Could you estimate that?

36. Lucas In the whole area?

37. Waring In this lab.

38. Lucas In this lab. This lab was largely engineering and science people. Actually we didn't make as much distinction between engineering and science as a lot of people made then and even today. For example, my background is in science. My background was in chemistry and metallurgy. I say that I became an engineer by association. We looked at the fundamental and basic engineering, basic science, and the application of the science. At that time, what was called the Structures and Mechanics Laboratory, if that's the right name, I would say that we probably had 65%, I'm just guessing, 65% engineering, and maybe 25% science, and the other 10%, I guess I left myself 10%, that would be technicians. It depended a little bit about what point in time we were. You talk about, you came to tour the laboratory, my laboratory in materials one, was the one that got caught on most of the tours because we had things to show. When you're in designing on a board, that was pre-computer graphics, well that's not too exciting to see a room full of 40 or 50 drawing boards. I mean you can talk about what you're doing and if somebody wanted to talk details, that's where they go. But just to take the average visitor, a Congressman or something like that, you would be lost in that. You wouldn't get anything. You would be lost in some of the others too, but you could make him think he knew what he was looking at. The same way with all of the design. It was largely design. The materials, most of those people had either engineers or draftsmen. Back in those days we had a fair amount of draftsmen, and they were usually people that

did not have an engineering degree, so I may have put a little too many people in engineers.

39. Waring There would be a clerical-draftsman category too.

40. Lucas That's right. A draftsman could do a lot of things. An engineer did some calculations and sketched out roughly what he wanted done, and then it was the draftsman's job to use the standard drafting practices to make this thing into a drawing that you could turn over to the shop and say "Build this thing."

41. Waring That's what computers do now. There's no intermediary now.

42. Lucas Oh yes. I guess when I retired, I bet we didn't have 10 draftsman in the whole organization. They were working on computer graphics. There was a tremendous change during that period of time. In the structures and mechanics laboratory, we also had a machine shop, as a matter of fact at that time and especially was attached to the materials division, but a machine shop to make specimens and to make test items. If an engineer wanted to design something, and they had the machine shop make it up. Eventually we consolidated those machine shops and also make test items, to make test fixtures, to do the test itself. If you have the structure, you have to have the fixture to hold that stuff together and hook it to the testing machine itself. So we had to have a number of those. We had test a laboratory or a

test organization that tested valves and things like that, do vibration tests and structural tests.

43. Waring That was in the lab itself?

44. Lucas It was in the lab itself.

45. Waring There was a test organization in the lab.

46. Lucas Yes. At one time what was called the Test Laboratory out there, ...

47. Waring Carl Hiemburg's lab.

48. Lucas Carl Hiemburg's lab. That was do to the major rocket testing itself. To do the hot, smoke, and fire as we said. Do the full rocket engine and maybe some pumps and that type of thing. But we also had within the other laboratories, the Propulsion laboratory, I mean the propulsion division of Structures and Mechanics Laboratory, had a lot of tests that they did on components, on heat exchangers, and on pumps themselves. Eventually, our pumps were operated as a bleed-off of the main combustion, but in the early days we pumped the fluid by decomposing hydrogen peroxide. Those decomposers that produced gas and turned the turbines within the pump. That was done for the most part in the propulsion laboratory. Of course the structures laboratory, they did the structural tests over in 4619

that large hanger type building. They did the structural test and squeezed the structure down to see how much it could stand or the vibration tests and things of that nature. They had several technicians that could do that kind of thing. I don't know if I gave you a good number on the division between scientists and engineers. Say 1960 to 1965, we probably had a greater proportion of technicians.

49. Waring Those declined and were pushed into the contracting.

50. Lucas That's right.

51. Waring Well that gives me a good ball-park figure. I wouldn't use those numbers anyway. Just to get sort of a feel for it. Well there's sort of two directions we can go here. We can start big and get small or we can start small and get bigger. Why don't we start big and maybe that will lead us into some of these smaller things. If you were to identify, in the work you did on the Saturn project, if you were to identify the three or four or half dozen greatest technical challenges, the things that, well I'll let you identify what the technical challenges were. What would be the things that you think would be key obstacles that had to be overcome in the '60s to make Saturn rockets as successful as they were?

52. Lucas Well, of the things which I was involved, first the matter of size was one thing. Just to build something this size

and be able to handle it was a challenge in itself because things this large had to be put together and transported on the ground a long way before we got to a launch site was a challenge in itself. As far as the technical things that were required to make Saturn work, you can look at the rocket engines themselves. That set that out as being a big challenge. The structure had to be a welded structure and it had to be light weight. So to use light weight, high strength alloys was a challenge in the development. In the early days, we were using what was called commercially pure aluminium as our structural material, and we wanted to use the higher strength aluminium alloy. For example, the aluminum copper alloys, the 2,000 series alloys. We went to the aluminium companies and we said "Hey, we need the higher strength alloy and we need to weld this alloy. We can't afford the actual weight that would be required if we hooked it together if we were going to be an airplane and furthermore this thing can't leak. It has to hold [?331]." They said, "Well, if you want to weld it you use this alloy." The aluminum companies themselves were not very helpful in the early days in developing welding techniques. So I would say that the development of the Saturn V drove the technology of welding aluminum and also drove the development of alloys, aluminum alloys, that could be welded and yet have higher strength than the so-called weldable alloys that we initially had available to us. The alloy that we eventually used in building the Saturn V first stage tank was a newly developed alloy, and we had probably the greatest use for the alloy. Welding I'd say, to do reliable welds, constituted a

very great challenge, and I think that made a great contribution to the state of the art.

53. Waring In developing, would you say the needs of the Saturn program were pushing this technological development? Does that mean in many cases Marshall was setting requirements and the contractor was developing innovation or was it primarily the labs that were doing the R&D research on these technologies and then saying "Here contractor do this for us."

54. Lucas That's right. It's the latter.

55. Waring The latter.

56. Lucas Very definitely so. Of course that's a capability that the government gave up in the capacity to do that. But in the early days, we could go from the idea to the proving ground and did. That was a necessary thing in the early days because there were not people who wanted to do this or were able to do it. For example, in the Saturn V, the first three Saturn V tanks were built in the laboratories of Marshall Space Flight Center using Marshall Space Flight technicians.

57. Waring For the first stage?

58. Lucas For the first stage, for the S-IC stage. When we got Boeing on board, the Boeing company brought in and was trained to

do the job at Marshall. So it wasn't a matter of going to the contractor and saying do this for us, it was a matter of going to the contractor and saying, "Here's what we want you do to do. Now you do it like this." That isn't to say that the contractor didn't make innovations as we went along and brought to the job what contractors do best, that is not mass production because we've never had mass production, but production in greater quantities than we had done earlier. But you remember, I don't know if you remember, you probably weren't even born then. You don't remember that unless you were reincarnated or something! The first Redstone rocket was built out there in entirety by Marshall people and when we wanted to get a larger number of Redstones built they knew that the arsenal concept was not what they wanted to do. They wanted to bring a contractor in. When we put out the first request for a proposal to produce the Redstone rocket, we didn't get any proposals. Then, Mr. Keller, who I think was Secretary of Defense at that time, went back to his boys as Chrysler and said "Hey, bid on this job." So they did, and they were successful obviously and they came down and had people live in our shops here and learn how to do the job and then they went on down to Michoud and built the rockets there or they built some in Detroit before they went to Michoud. Didn't build at Michoud until we started the Saturn V program. A distinctive to be made is that the changing of the capabilities from the early '60s until now are very striking. I don't say that's wrong. It's just that the arsenal concept has gone by the board as far as being able to do everything in house and properly

so. But in the early days, there was not a contractor work force out here willing and able to do the job. So it had to be done in house and that's a growth item.

59. Waring Boeing then went through a sort of a tutorial process at Marshall. Marshall had problems with the contractor that did the second stage, the S-2 stage, North American Aviation. Were you involved with those problems.

60. Lucas Yes.

61. Waring Could you tell me about that?

62. Lucas Well, they had some different problems. They have a large tank also and they had to build it out of aluminum. One of the reasons, I might just digress a moment and say that this also was a significant development. That is you had to use materials of construction that were compatible with what you were putting in them. There were two very great unusual compatibility problems that we encountered. One was the low temperature. For example, steel becomes very brittle at a low temperature so you had to use an alloy that was suitable for a low temperature and to get technical those were usually those that crystalized in the face-center cubic system. That was aluminum that was one of those. So the low temperature required placed a great deal of restraint on the material. The second thing is the compatibility, that is the chemical compatibility, because if you

take liquid oxygen and put many materials in it and supply a small amount of energy, it will explode. For example, titanium was one of those alloys that was very attractive. High strength, higher strength than steel, higher strength to weight ratio than steel, maybe even to aluminum to certain applications because you could make it thinner. Like the centaur tank, they wanted to make it out of titanium, but it's made out of stainless steel to make it very thin, but it was not compatible. For example, we developed, another person and I patented, well I don't believe we ever patented it. We provided it as an ASTM standard. The reason this is fresh in my mind is because I just visited the Marshall center about two weeks ago. They wanted to show my what was going in the materials laboratory, and they showed me that they are still using the lox impact compatible tester that we developed back in the '50s. It became the means of selecting the material for the use of liquid oxygen was the ASTM, American Society for Testing Materials, standard and it was accepted as a standard back then and is still the standard for acceptability of materials. So I was pleased about that. Those were two things that, two specific things, the compatibility with the material you're going to put in there. It introduced that when we were talking about the S-2 stages because they still had the same welding problems of aluminum. They were using the 2014 which we'd been told by the Aluminum Corporation of America was not weldable a few years before. We had to develop techniques of doing that. Then they had the insulation problem, the insulation of the liquid hydrogen. We'd been able to get by with liquid

oxygen by simply using a bare tank and letting it provide its own insulation. You know that in a tank of liquid oxygen will build up ice on the outside and that's a pretty good insulator. But hydrogen, which was another 100 degrees lower temperature, you couldn't do that because it would boil off. It had to have insulation on it. So the development of insulation was one of the great new problems in the S-II stage. Another very significant challenge in the S-II stage was the common bulkhead. Instead of having two different tanks, you had a common bulkhead just like we had on the S-I stage. The common bulkhead, if you had just aluminum between the liquid hydrogen and oxygen, you would fall away your hydrogen. So we had to develop this honeycomb insulation material, insulated bulkhead between the liquid oxygen tank and the liquid hydrogen tank. That created a lot of problems in developing that and also the insulation on the tank itself. Let's see. I've forgotten which one we used. We used I believe external insulation on the S-IVB tank but internal insulation on the S-II. That was quite a problem. You had to develop one that wouldn't crack when you shocked with that cold temperature or when you took the cold temperature out in testing it and not leak, not have any leaking, heat leaks in it. Those were two unusual problems associated with the S-IVB stage, the third stage, and the second stage.

63. Waring In reading some of the surviving correspondence, Marshall evidently felt that North American Aviation, the S-II

stage contractor, had management problems or technical, they weren't taking Marshall's technical advise fast enough or . . . .

64. Lucas That's right. They were not.

65. Waring That's the essence of it!

66. Lucas That's the essence of it!. They were not as responsive a contractor as I think we expected them to be. The Boeing company, I'd say that there are two things there. There's a very distinctive difference between the Boeing company and Rockwell as far as what I expected on the Saturn V is concerned. Our technical people would meet with the technical people of Boeing Company and we'd argue and argue. Each would present it's case. We'd debate the matter all day long. The Boeing company would go away and fix the problem. They would present their case, and they would present it strongly. But when they were shown to be wrong, they would aside and fix it. On the other hand, with Rockwell, they would argue all day long and you'd come back the next morning, and you'd start the same argument over again. You just didn't think you'd made any progress. So I just think they carried pride too far is my assessment.

67. Waring Do you think part of that had to with they were so far away in California and that contract started a little later or did Boeing have that more intimate relationship working out of Huntsville and out of Michoud?

68. Lucas That undoubtedly had some bearing on it, and I think probably the Johnson center handled them a little different than we did. They had a contractor already on the capsule itself, and the Johnson contractor, because of the nature of their people, they didn't have the heritage we had, and they handled them a little differently than we did and I don't think countered them as much as we did. But we clearly had the capability to do that. It wasn't just pride with us either because we'd been there. That was one of the philosophies of the Von Braun team is that we needed to have the shops so that we were arguing from knowledge not from emotion. We'd done the task before, and we knew what was involved. We had to know our business. But you know we undertook to work differently with, this happened with McDonnell Douglas, but it also applied I think to Rockwell. I remember the first trip when we first got the contract with McDonnell Douglas to do the S-IVB stage, actually the S-IV stage before the S-IVB, we were going out, Von Braun was sending a group of us out there. I guess there must have been 25 or 30 of us going out to have the first interface with our new contractor. I remember Von Braun called a meeting and had of us going out and said, "Hey look fellows. We've got a new contractor. They know what they're doing and don't go out there trying to tell them everything to do. Go out there and listen, see what they're doing, offer suggestions, but don't be trying to tell them we're the conceited bastards that know everything." We made that trip, as a matter of fact it was when the 707s were very new, and we flew from

Huntsville to Atlanta at about midday I guess or after, to catch a flight leaving early evening to fly out to Los Angeles on a 707. Most of us had never flown on one before and so they had engine problems and we didn't get off until the next morning. I mean we waited all night down there. Man, we could have flown with a propellor plane or almost hitchhiked and gotten there before we did. But we went out there, and we did what he said. But it wasn't long before we were arguing just like we had with other people and eventually worked those relations out OK. I think those two things, that I think of, the compatibility of the material, the welding of the material, and the insulation problems were very distinctive things on the S-II and S-IVB stage. There were some other problems also, I think. The fact that you had to ignite them for the first time after you had gotten out of the atmosphere.

69. Waring Restarting the S-IV?

70. Lucas Well, restarting the S-IVB, but even starting them the first time. We found out for example, there was a certain component on the J-2 engine that vibrated and broke on one of the early flights. Broke away from the, it was the [?595] off the main part of the engine and broke. What we found out was, what we had chilled down on the ground, do the ground test, you'd collected ice which is one the component which would dampen the vibration. But in the absence of the atmosphere, you didn't have

this ice form, and it vibrated a different way than it did on the ground and broke.

71. Waring Are we talking about the POGO problem?

72. Lucas No, that's not the POGO problem. POGO problem is still something else.

73. Waring That's something different. OK.

74. Lucas This was a problem, I've forgotten which one. If I'd reviewed a few notes, I would make more intelligent responses right now.

75. Waring The problem was that on the ground, you were working in one set of environmental conditions and then at the time of the first stage separation, you're in very different environmental conditions.

76. Lucas So those different environments. We had to account for those. POGO was another problem that we had on the stage.

77. Waring Why don't we talk about POGO for a while since that's come up. I've sort of read about the technical issues and I think I understand some of that. One thing that seemed real interesting to me is how [turn tape over]. Could you discuss that or?

78. Lucas Well, do you mean independent on the various stages?

79. Waring Well, yeah. It seemed that Marshall was doing tests and contractors were doing tests that everybody working out a few solutions, there was sort of a farming out of solutions and then a coming together and seeing which one's were the best. Is that sort of how it was done?

80. Lucas I think that's the way it was done. I don't believe it was unique to POGO. It might have been the first time it was done that way, but of course in a problem like that, it started off on one stage. I think it started out on the S-II stage if I recall. But we eventually had to address the problem on all the stages. With a problem like that being generated, information was exchanged with all the contractors and within the elements of Marshall itself about this problem. Check and be sure you have one. That was one of the things, one of the techniques that was used throughout the program is that if you encountered a problem, the identification of these problems and make sure it doesn't apply to you. So it was natural that as soon as the problem was identified or we had identified maybe what we thought the problem was, then that information was communicated to all elements involved, prime contractors and some of the sub-contractors we got into. Then Marshall was working on the problem. Then we involved a lot of people that were not directly involved in the Saturn program. As I recall, Aerospace Division of the Air

Force, I've forgotten what it's called, but anyway we involved several. These are university people who might have something to offer to this, and we formed what I think was called a POGO working group which I think what you were referring to that pulled all of this together where the various people were making their input. Each one working on his stage and Marshall was working on that. Overall, we had a POGO working group and before we got ready to fly, we had to get a sign off that all was well in the throttlings of this problem. That was a technique that was applied to other things as well ultimately.

81. Waring On the POGO research and fix for the POGO problem, Marshall did a lot of testing. Would you say that that was one of the keys for keeping the Saturn launch schedule on track was having the ability to do lots of testing?

82. Lucas No question about it. Particularly was that true when you have multiple set of contractors. It would make sense to have each of the prime contractors develop the capabilities for doing that test. It made a lot more sense to have Marshall do that in time wise as well as cost wise. That was not only true of that POGO test. It was true of the large structural tests that we did out in 4619, the static structural tests, the dynamic tests that we did over on the dynamic test stands and the test area and the static firing tests. Those I think did make a contribution and a reasonable contribution. You could have the experts there and you could have, not an disinterested party, but

one that's not quite as involved. For example, if you have to submit your work to your peers, that's about what it amounted to. You're judged by your peers, so the S-II people had to meet the same criteria that the S-IV and S-IC did.

83. Waring So they were doing their own test at their own sites and Marshall was doing tests . . . .

84. Lucas I'm not sure how much testing they were doing. They were doing some level of testing, but mainly it was engineering that they were doing. So the final proof tests were being done by Marshall.

85. Waring While we're talking about testing here and we've talked about that before in more general terms. Perhaps we could explore some of that. Could you describe Marshall's philosophy for testing and verifying hardware? Were there some rules of thumb that people used?

86. Lucas Well, actually if you want to be critical, you might say we tested till we wear it out.

87. Waring Overtesting.

88. Lucas Overtesting. Marshall had a strong commitment towards testing. I think that stood Marshall in good stead, and we've gone overboard in the other direction now. I think the early

testing and maybe this derived from Marshall, the early philosophy during the Saturn V program was a lot of testing. As a matter of fact, we had even headquarters approved testing. I've forgotten how many test items, hardware that we'd built for the first flight, before we flew the first flight hardware. We had a lot of testing on the ground before that. That philosophy was abandoned to a degree in the 70s at the beginning of the shuttle program because of so called economics and that was, in my judgement, one of the costliest mistakes that had been made.

89. Waring I've read that as much as 50% of the cost of the Saturn vehicle was for "testing."

90. Lucas I expect that's right. But you didn't have any failures, and that's always expected. I think maybe we overdid it in the Saturn V program, but we clearly under did it on everything since then. Well, you know Marshall started out, I said the headquarters endorsed the testing of the stages, the test hardware that we purchased, but the all-up concept was introduced by George Miller and others and that worked out alright in as much as we'd done the individual components. We start out to fly the first stage live and the other two dummy stages like we'd done in the Saturn I and Saturn IB.

91. Waring The building-block concept.

92. Lucas The building-block concept. Than we went to the all-up concept with the Saturn V. We flew it all up the first time, all stages live the first time. We had a good success on the first one. We almost lost the second one.

93. Waring That was the POGO?

94. Lucas That was the POGO. Than we manned the third one. That was a pretty gutsy approach to things. It had been based on a lot of component level testing. You can't do that if you haven't done the component level testing. You're foolish to do that I would say.

95. Waring Perhaps the most dramatic test in the Saturn program would be the static test of the F-1 engines for the first stage in terms of the noise and the awesome quality of it that some people often talk about. Would you agree that that's sort of the eye-catching?

96. Lucas There were two things. Maybe we're talking about the same thing, but the terminology may be a little different. There was one test stand where the engine, a single engine was tested, a single F-1 engine was tested. Then there was another test stand where the stage was tested.

97. Waring Was a stage test.

98. Lucas I think that's what you're referring to. All five engine blocks.

99. Waring Right.

100. Lucas No question about it. That's probably the most awesome thing that anybody has seen since because you never had done that much thrust on a test. That's 7.5 million pounds of thrust.

101. Waring Can you just tell me, just generally describe what it was like, some of the technical preparations for a test like that and sort of the physical, emotional sensations of the test itself?

102. Lucas Well, of course that first test was preceded by the normal conservative Marshall approach to things. We'd tested the single engines on the test stand. We had all the five engines mounted and we'd done flow tests on them. We went through countdown to everything except ignite.

103. Waring What's the flow test?

104. Lucas That's to match the hardware itself, the tanks itself, where the propellant fed out of the tanks rather than the ground tank. In the single engine test stand, you had some ground tanks out here, and the flow situation characteristics

might be different there than up here than with a tank. So when you have the hydrogen up here and the locks down here, you flow your propellant into your tank.

105. Waring You're using the normal fuel?

106. Lucas Using the normal fuel. Of course we'd done flow test with liquid hydrogen, and this kind of thing before preparatory to this. But when you get down to doing the test, you put the propellant themselves on and you measure the quality of the propellant, that is the chill-down time. You want to drop your propellants down till you first have them down to the valve ahead of the engine. Then you want them to flow on down to the engine and measure the temperatures because if you have, when you talk about the quality of propellants, we had liquid oxygen or hydrogen either. If it wasn't pure liquid, but had some gas in there, had a cavity, you'd be in big trouble with your pump. That pump is working as hard as it is, turning as fast as it is, on the liquid and then all of a sudden bites into some gas, it will explode, it will run it away and run so fast it will explode because it is already going so fast. We drop the propellant down, all the way down and let it flow into the engine, rechill the engine. Everything except ignite. Then you drain the tank and finally one day you're ready to go the whole way and then you almost do a kind of burp test. You ignite and then shut it off like that before anything could happen. Then you gradually build up, adding a few seconds and finally doing a full duration test.

The test itself was very exciting. You've seen the Saturn S-IC test stand.

107. Waring I've been to the test stands.

108. Lucas Have you seen the big pumps up on the hill above it there? There are about 10 or 12 pumps up there . . . .

109. Waring With water . . . .

110. Lucas . . . with water that started the water running into the flame bucket before you did the test. What you did was really fire up through a sheet of water and you had a big lake out there when it was over. Fortunately that test stand was pointed away from Huntsville. It worked out on the S-IB test stand, one of the stands was pointed just right to Huntsville.

111. Waring Just by coincidence?

112. Lucas By coincidence. The flame bucket was made sort of like this so when the flame comes down, it doesn't hug the ground. It kind of shot up in the air like that. When we had a cloud inversion, or a cloudy day, that just focused that sound right down on Huntsville. So we had people complaining about cracked plaster and windows broken and things like that. We examined some of that cracked plaster that had cobwebs in it! So there are always people like that. That was some of the problems

that we had. We didn't have that with the S-IC test stand because it was pointed in the other direction, pointed out over Triana toward Decatur.

113. Waring Can you recall just the physical and emotional sensation of what that test was like? Did you have to stand in the shelter?

114. Lucas In the early times, we could stand in the shelter, no we couldn't stand in the shelter. You were in the block house or you were way away. We figured, for example, do you know where building 4612 is? Where the structures and mechanics building is? You were not supposed to stand in front of any windows when that first firing went off. We didn't know what would break windows that far. You could be outside in the parking lot and watch it but you couldn't stand in front of a window and watch it. I remember on that first test, I was intended to be out watching it, but I was in my office on the phone, and I couldn't get off the phone. I knew that thing was going to go off at any moment, so I got down behind my desk under the window there. I had a table there so if there was any glass I would be protected if the glass broke. But standing out from some distance away when the firing was going off you could actually see it, if you had a tie like this, you actually see it and you could fell that vibration on your chest. It wasn't a constant pushing. It was something like this. You could feel that from that distance away, the distance from the parking lot of 4612.

115. Waring That's what a mile and a half? Two miles?

116. Lucas Two miles.

117. Waring Could you feel vibrations in the ground if you were closer than that?

118. Lucas I don't believe you could. There were vibrations in the ground because the sensitive items like the electron microscopes and things like that, we'd put them on isolated pads when we built the buildings. We knew that would be the case. So a lot of the guidance and control equipment, very sensitive equipment, as well as electron microscopes were on isolated pads where pads of concrete separated from the building that went down I don't know how many feet down into the ground so it would be isolated. But I never experienced, you know you're so excited about a test like that you don't feel everything. It's got to be pretty significant if you recognized it. So I could never say that I felt the ground shaking. You could tell buildings were vibrating, but I never felt the ground.

119. Waring Norman Mailer has a bizarre book about the first lunar launch, and I don't really care for all that's in the book, but he has a wonderful description of the launch itself that goes on for several pages. It was very exiting. We can't really use

it in our book, but I'm hoping to have a description of one of the Saturn I tests, I think that would be, the Saturn IB tests.

120. Lucas That was quite an exciting time when you consider that you, and in particular I'm sure that it has two different kinds of excitement. One would be an excitement with some interested party who just comes out to see it.

121. Waring An innocent bystander.

122. Lucas Innocent bystander so to speak. He is awed by how much power is generated there, and you really can not fully appreciate looking at it how much power it generates. That's just awe inspiring. There's another reaction though to someone who's invested a few years of his life working that thing. Here now we're at the point where it could all blow and that could be the end of it. It might not work at all. It might just explode.

123. Waring And you're back to ground zero or the project is cancelled.

124. Lucas Or whatever. Back at that period of time, we were still much more reasonable and more tolerant of failure because we knew it was a risky proposition. We'd had a lot of rocket failures. We'd never had one that big. In the early days of the Redstone, for example, I remember the first Redstone rocket test firing I ever saw, launch I ever saw. It got about 30 feet off

the ground and fell back and exploded. That was quite early. In the early 50s, and we had many more like that. Only after we'd had years of success had society become intolerant of failure and to think that we just had to be perfect.

125. Waring Were you almost expecting failure by the time you got to a final stage?

126. Lucas I don't think you were expecting it or we wouldn't have done it. I don't think you expected failure, but the reason you did the test was you knew that was a possibility.

127. Waring It was a possibility.

128. Lucas If it wasn't even a possibility, you wouldn't have wasted the time and money to do the test.

129. Waring You would have stopped and fixed problems early on.

130. Lucas Right. I don't recall having ever been a part of a test or a launch when you expected failure.

131. Waring But you felt apprehension?

132. Lucas There's apprehension because you knew that they were thousands of things that could go wrong that nothing you could do about. For example, in the airplanes, you fly airplanes, back

then you flew airplanes all the time and they weren't as safe as the ones now but there weren't very many things that could go wrong that an alert crew could not fix at least so you could land. You had a chance if something, if one engine goes out or blow a hole in the wing or whatever, you still had a chance. But we knew at any time that one lousy little 25 cent part somewhere could cost you the whole ballgame. It could go wrong, and there was nothing you could do. Even the last seconds of the firing itself was done automatic. You could override if you're quick enough to see what was going on. You had the impression that here I've invested this many years of my life, I've done everything I know to do, we've checked everything that we know to check and now, we know that we can't check everything.

133. Waring You'd see if you were right.

134. Lucas See if you were right. That gives a different kind of emotion I believe than the person who walks in off the street to see this spectacular.

135. Waring So what you're telling me is that when there was a test, it wasn't for the people who were most intimate. The engineers, and experts who were most intimate in developing the project, this was not a festive atmosphere. This was high tension.

136. Lucas High tension, right. I'm sure the person who came in off the street, and when I say that I mean someone not associated directly, was excited just to see the thing and was impressed, but here this poor guy's sitting over there digging their thumbs into there fingers or some would use little rubber balls. There was some little grummets that were used on the command module. I know Rocco Petrone used to always have one of those he'd be squeezing during this period of time. This was great tension. Not that you hadn't done something you should have done. It was the knowledge that there were so many things that could go wrong that could ruin you.

137. Waring Like the crossed wires on the second Saturn V launch.

138. Lucas Where you cut off a different engines. The valves were cross wired to the engines. Shut down one, you've got two that way. That can happen when you consider the thousands of people working on it and the fallibility of human kind. Those are things that added to the tension. But I tell you. Somebody asked me after the first launch of the shuttle I think, "Were you relaxed?" I said, "I have never have been relaxed!" I've seen a lot of them, and I've never been relaxed for any one. There's always an excitement there. It's a thrill that's hard to explain, but you feel a lot better when it's gone.

139. Waring Sort of related to this and related to testing, is the issue of using statistics as a part of risk assessments, probablistic risk assessment. That started to be a new development in engineering circles I guess in the '60s and has become more popular in manufacturing and commercial enterprise since then, well perhaps not risk assessment, but quality control and that sort of thing. As I understand it, NASA, including Marshall has never been especially enthusiastic about probablistic risk assessment and statistical techniques like that. Could you comment on that? I don't know if I really understand.

140. Lucas I don't think that's right. I think by some interpretation that might be right because in the early days as we discussed, Marshall depended more on testing than probablistic analysis. We did have an assessment even in the Saturn V. We had probability numbers associated with each of the engines so it's not as if we didn't have any probablistic ideas at all. We counted all those things up and we also did the testing developments to spend this type of thing. The concept has matured and developed and I think today Marshall probably does use that approach more so than ever before. I'm not sure though, I think it is much more generally or much more reasonably applied to a production function than to a first time R&D. If I were King and were doing a program with what we know today, I would certainly have that kind of analysis made. I would also do a very great amount of testing than we now do on a new program.

141. Waring As I read about this issue, and there hasn't been that much written about it and it's a subject that deserves more exploration in NASA's history, but another thing that is sometimes mentioned, well it's the same sort of thing that we talked about where ground conditions are so different from conditions in the upper atmosphere and in a launch. Those conditions change so quickly what the probability that you have for one condition may not exactly apply to another condition later in the launch. Its harder to use than in a commercial or manufacturing sort of process. As sort of a conclusion, what would you say were the primary technical lessons learned on the Saturn project? If you were to summarize as far as the engineering lessons learned. We've talked about lots of things here, but what would you highlight as the key things that an engineer should learn from a Saturn system?

142. Lucas Well, that would be hard to do in a short summary. I think some of the greatest lessons learned with the Saturn program were not engineering. I could comment on that.

143. Waring OK, that's fine.

144. Lucas But I'd comment on engineering first. I think that the thing that I'd say that an engineer would derive from the Saturn V program, engineering wise, is the importance of a very comprehensive test program. I think the test program that we had

on the Saturn V which has not been repeated since has proven. So irrespective how brilliant one might be in analysis, I think you ought to recognize that testing is the ultimate and should do that. I think the lessons learned is that there are many things that determine the use of a material in addition to its calculation, its pedigree, strength properties and so forth that material has to be tailored to its environment and the environment can determine a lot about how a material can behave. I think that's one of the things that should have been learned. I think welding technology came out of the Saturn program. Some innovative things about welding materials came out of that. I think inspection techniques also were derived from the Saturn program.

145. Waring Like x-ray imaging, ...

146. Lucas Like x-ray imaging and ultrasonic magnetic particle inspection. Various techniques that were developed and used during that period of that time. I think the importance of a team type of engineering whereas several specialities are welded together was focused in the Saturn program. I think also the importance of the integration and manufacturing within manufacturing was also important. We haven't discussed that here, but that's one of the significant things, I think, of the Arsenal Concept at Marshall because when we were designing over tin the designing laboratories, we had the people who were eventually going to have to inspect the hardware, who were going

to have to build the hardware making significant inputs to the designers. So we hear that talked about more these days about integrated factories but it was really practiced at that time.

147. Waring The designers and the doers were working together.

148. Lucas Working together. They would ultimately have to work together, but they were working together early one when you could you still do something about it.

149. Waring It's not a hand off from one stage to another. They're all together in the beginning.

150. Lucas That's right. We say that the further an engineer and designer gets from the hardware, the more reasonable every line on a piece of paper looks to him. You need to have someone in the shop say, "Hey, if you want me to build that thing, you've got to do it like this. You've got to change it here and there." I think that's one lesson that came out of it. But to summarize one of the greatest lessons, one of the greatest contributions made to the engineering was how one manages a large operation like this involving so many different disciplines, many different cultures even, that technique. How one integrates a large project, I think was one of the greater contributions that the Saturn program made. We had hundreds of thousands of people all across the country with virtually every engineering speciality that you could think of involved and yet the whole item came to

focus on the launch pad when you launched it. To integrate all that effort, the management techniques that were used, the program management techniques, the tracking of progress, those techniques were significant contributions to the profession.

151. Waring Would there be, this is some of the sort of engineering and management lessons. Do you want to talk some about some other wider lessons learned? Why were their political circumstances or that enabled that engineering management team to work?

152. Lucas I think unquestionably that was the case. It was a unique set of circumstances converged that enabled this thing to come about. I've said a number of times that some of the most significant decisions made in the Saturn program had little to do with engineering. They were mostly political. So to be successful in a major project like that, you have to have a national commitment to it, you have to have a defined goal, you have to have a timetable, and you have to have resources. That all came about. People had been dreaming for generations about space flight, and we'd been working diligently for 10 years in this country specifically toward that. Really what came about was a set of circumstances that caused a new young President to see how he could use technology as an instrument of international politics I think. He said then, "OK here's what we'll do. We'll set this goal. We'll do something that has never been done before. It's very exciting. It's very far reaching. It must be

impressive. It's never been done before. We'll do it on this schedule, and we'll do it safely and here's the money for it." All the technology in the world would not have done it without that commitment.

153. Waring Those underlying decisions.

154. Lucas Without those underlying decisions. We needed that program as in instrument of international affairs and the Bay of Pigs was pretty important to that. It was fresh off that fiasco.

155. Waring Roger and I were talking about even Kennedy's psychology was important. Historians have done lots of stuff about his concern for his masculinity that in the Bay of Pigs was a threat to his self image, and he wanted to make sure people understood who he really was. All those things factor in.

156. Lucas There's another part of the psychology I think that was important that he never doubted that we could do that. He didn't doubt it in the outset. He may have doubted it, but he didn't admit that. He couldn't have understood what was involved. He couldn't have understood the magnitude of the commitment. His people had told him that they could do it, and he accepted that and believed it and expressed continuing support for it.

157. Waring It was that confidence that the Americans' had in the late 50s and early 60s.

158. Lucas I think so. And of course we were coming off of a successful war, and we didn't think that anything, we weren't just willing to accept any kind of second place or challenge in the long run. We'd drifted down from that, and we allowed ourselves to be second place for a while, but that turned out to be good because we then did something grander than we would have done otherwise. I think also that the importance of having a unified government was important. For example, if Kennedy had of done this on his own as executive without some strong lieutenants over in the Congress, it wouldn't have happened either. There's a lot to be said.

159. Waring Having basically a democratic White House and a democratic Congress. It didn't have to be democratic, but having that consensus among the branches of government was very important.

160. Lucas Having a consensus between the legislative and executive branches of government which we don't really have now. I think there have been more support in Congress in recent years than from the executive branch. We thought that for a number of years that we could get anything. That Congress would approve anything that the executive would ask for. It has. Until this year, we've had a growing budget, a growing support. We'd always

listen carefully to what the President said in the "State of the Union" message, because that would signal what was going to happen. We counted on the Congress supporting that. Of course, now we don't have that. Although we have one party in control of both the Congress and the executive, I'm not sure that Clinton is committed to that.

161. Waring Well I think the key is, well his administration and his party is divided. There's those who want to take an investment strategy which would mean funding NASA. Then there are others like Lloyd Benson say in treasure who are primarily interested in deficit reduction. That works the other way. I don't think the Democratic party or the Clinton Administration can't make up their mind whether they want to invest or reduce the deficit.

162. Lucas That's right I think. Benson of course seems to be influenced by the job he has now. Benson has been a strong supporter of the space program, so I . . . .

163. Waring Well, Clinton wanted him because he would be tough on the deficit. He has a different role than he was when he was a Congressman. He was from Texas.

164. Lucas Just like environment determines engineering, the role determines the proponent within individuals sometimes. I think, as I indicated to you before that one of the big mistakes

that NASA made, and I'm not saying this to criticize individuals or NASA for that matter, but it was a mistake as it turned out, and that is to have tried to sell the program on the basis of an economic trade-off. You just don't do that kind of thing. If you'll look back at most of the major inventions that have infected our society, I think that as a historian you'd know that most of them, somebody didn't just sit down to say I'm going to invent the telephone or I'm going to do this, that, or the other. I'm going to invent something. Inventors are curious about the unknown but they want to understand more of the unknown. They want to unravel some of the things. I think as individuals and as a society, we ought to be able to afford a certain amount of our resource for that kind of thing. I'm sure that you and I know I spend a certain amount of my time doing some things that I really don't have to do.

165. Waring Don't have an immediate pay off.

166. Lucas Don't have any immediate pay off. They're interesting to me. I think there's something there that needs to be learned. So you invest a little bit of your time doing that, and companies invest a little bit of their time and a little bit of their resources, and nations should do that. Von Braun used to have a philosophy at Marshall that our people ought to be able to use 10% of their time doing things that didn't support their immediate project because they're going to be developing some things that were going to be used on the next project or it would

turn out that way. If you give a creative person an opportunity, he's going to develop something that will help you. I think we need to have a certain amount of restrained, unrestricted creativity and I think our nation needs to have an element, maybe it's NASA and maybe it's something else, but the folks out here that are working in areas that are not well-understood and say that we're doing that because this is what great nations do. We have opportunities, we have resources, and this is what we owe to society to do that. In that kind of a thing would support a NASA or a something else.

167. Waring Certainly in the '60s there was that willingness to push beyond the unknown and expecting that it would pay off somehow, but it didn't have to pay off right away.

168. Lucas That's right. It's a goal. OK, so you go to the moon. There are some things that you can do and there are some things that you can do, but most of those things are not immediate payoffs either. You could set up a telescope and you could see a lot of things. But, we could bet by without that. As much as I hate to say it, Proximire, who was always a thorn in the flesh of NASA, when he said about the Space Telescope about what he said about the Space Telescope. He said "It may be the greatest thing that has ever happened but why do you have to do it in five years? Why do you have to do it next year?" That's the kind of thing that you get into when you try and make an economic payoff.

169. Waring Well, very good, Dr. Lucas. Thank you very much for you're time. I've got lots of good technical material and this stuff at the end, that we'll find a way to work all this in somehow.

170. Lucas It probably doesn't make sense when you look at other things that when you're just trying to analyze it. Don't hesitate and say clarity because this hasn't been on the front of my agenda recently and so I may have said some things that were not . . . .

171. Waring Let me quickly look through my list here. I guess there is one technical question that we didn't address directly. That had to do with the decision to use liquid hydrogen as a fuel for upper stage. The information that I have says that that came from the Department of Defense and Silverstein who I guess was at that time in a leading position at NASA Headquarters. Did Marshall and ABMA initially oppose that decision? Do you recall?

172. Lucas No, I don't think so. I'm pretty sure they didn't oppose it.

173. Waring Question it maybe the better word.

174. Lucas Or even question it because it's clear that you've got higher requirements out of hydrogen than you can on a

kerosene or hydrocarbon type of fluid. To get the maximum out of a rocket engine, you want to have your exhaust contain the lowest molecular waste species that you can. So if you have a hydrocarbon here with 15 carbons in it somewhere and a bunch of hydrogens hooking on, that's going to break up in little pieces, but if you've got hydrogens, you can't go very much from it. It's not arguable technically that hydrogen is not the best propellant, better than a hydrocarbon propellant we'll say for upper stages or upper atmosphere. You can argue that on the ground. So for the first stage you have a figured [?192] that's called [?193] impulse that you got out of the propellant, but there's also another thing that is density impulse. For the first stage, you can get better performance out of a hydrocarbon influence because you have higher density. Upper stages though, it's not arguable that hydrogen isn't the best. It is the best. It is the best. It is the best. I don't know that I've ever heard any counter argument to that.

175. Waring Well it was just this was in Roger Bilstein's Stages to Saturn book. He says fairly directly that people in Huntsville questioned the decision, and it is not really made clear to me whether they thought that this fuel was too much beyond the state of the art or if there was something else they should be investigating. Obviously the resistance or questioning to that didn't last very long at all.

176. Lucas It might be a matter of timing. I don't recall that. Did it involve the M-1 engine?

177. Waring Was that for the NOVA?

178. Lucas Yes.

179. Waring I've just looked at a few files.

180. Lucas It might have been in conjunction with that. It might have been Marshall, I've forgotten who was to be first. Was it to be Marshall and then transferred to Lewis or Lewis to be transferred to Marshall. I've forgotten the details of that. I can't think of what, these writers sometimes want to, and maybe you're one, got to generate a controversy to have a good paper. I've noticed when I've talked with people, they don't want a logical presentation of fact, they want have some controversy come up some time and there was a controversy about whether we'd go direct to the moon or the Lunar Orbit Rendezvous. There was that controversy early on which I consider to be a positive thing. I don't get upset if people disagree if they do it reasonably and if they do it with a foundation. That assures or comes near to assuring that [end of tape 250]