INTERVIEW WITH GENE OLIVIER
INTERVIEWED BY STEPHEN P. WARING
HUNTSVILLE
JULY 20, 1994

1. Olivier . . . he recommended Spitzer. It was interesting. The whole concept of the science institute was pretty much developed by Bob O'Dell. How you have a focal point for interplay with scientific community was largely O'Dell's idea, but you know kind of worked with some of his colleagues. When O'Dell came on board, we had a, you know these instruments that you take in and out. It looked like one of these rube-goldbird things you see in the cartoons with all these pipes. It's just an interrelated intertwined series of optical beams going on and all these cameras. You couldn't tell where one stopped and the other started. He looked at that and said, "This is ridiculous." He said, "I want you to build everyone of them in an imaginary box and nobody can get outside that box and all the boxes are identical." He started the idea of the modulator. He added a lot. He was a very key person in formulating some of the fundamental characteristics of Hubble not only from a science polarization standpoint but also in many cases in fundamental engineering and serviceability and started us down some good paths that we had [15?].

2. Waring We will probably get into that issue. One thing, I think I have a fairly clear in understanding of some of the project management issues and overall idea of some of

the final engineering decisions, but what I would especially like your help with is in discussing some of the technical challenges of building a space telescope especially the final design phase and how Marshall people and the Marshall labs contributed to identifying those technical challenges and proposing solutions for it. We can start with a simple question that I'm sure will lead us a long way. What were the primary technical challenges that the design team was faced with?

3. Olivier The one that we obviously thought right up front was the optical systems. When the phase C/D started, we got our hands on a 72" mirror and we did technology work to see if we could polish it, large optical system. So we really concentrated on that. The other thing we concentrated on was the use of graphite epoxy for the metering structure that separated the primary and secondary. We were concerned, in those days very little work was done to fly graphite epoxy structures, and there was very little known about our ability to control the [33?] characteristics of it.

4. Waring Why was there a decision made to go with graphite epoxy?

5. Olivier This big barrel of this telescope was not an easy to thermally control because it required the loss of so

much heat under the telescope. So we didn't want to thermally control it actively. So we wanted a passive system if we could, but the thermal changes on the secondary mirror were pretty good, pretty big as you went around the orbit and changed attitudes. . . . low [38?] characteristics and structure. N-Bar was the next best choice. N-Bar was heavy and the control was not, although probably more predictable we thought, it was not quite as good, it couldn't be quite as low as graphite epoxy and it had a residual magnetic characteristic that it would retain some residual magnetism and when you go through the earth's magnetic field, it would be put into port on the vehicle. It would have to be overcome by the control system. We were concerned about that. There were a number of factors. Weight and thermal characteristics were the two biggest and they essentially drove us into the graphite epoxy. We had to discuss if we want a shell or do we a truss structure and that was kind of a secondary level trade that we went through and the guys at Marshall were very involved in that.

6. Waring Which labs in particular were involved?

7. Olivier Primarily the structure and propulsions laboratory. They were the ones that were deeply involved in the structural design. Practically the whole telescope structure was either fundamentally or in parallel stress analyzed here at Marshall. That graphite epoxy was spooked

by that stuff. It was not forgiving. With a manmade material, just make a bracket out of it and you load that bracket, it's liable to play it at a lot lower load limits than you'd think, because it wouldn't yield. It was just going to break and that was it. Snap, and it was gone. This stuff's made up of a little layers of fiber and one layer of fibers would crack then the next layer would crack and nothing could yield it to start kind of evening out the load. So there was a little concern about it. Turned out it was OK, but there was a number of structural tests that we did here at Marshall that led us to eventually get confidence in testing that at the contractor site. A lot of involvement in the structural and design and engineering here at Marshall. Stress analysis and loads. We did all the loads analysis for the Hubble here in house. Loads analysis, whenever it is in the shuttle and the shuttle is launched, all the loads that this thing has to experience from vibration and from acoustics and from acceleration loads both on the lift off on the pad whenever it is released, lift off transit during the pilot flight and even on the landing. All that stuff was worked here at Marshall to get the loads distributed back to the contractor who were building the spacecraft.

8. Waring What time are we talking about for the loads analysis?

9. Olivier Time frame?

10. Waring Yes.

11. Olivier It started at the very beginning. We did load cycles all the way through. We did about eight load cycles because the shuttle was being developed at the same time they were developing Hubble. About the time we'd think we'd get Hubble's under control, we'd get whole new set of forcing functions from JSC saying that we'd changed the orbiter loads. Right back to it again, and it may require a redesign on Hubble and it may not. Tighten up on the margins and the margins and design. Iteration after Iteration on that thing. A lot of work in that area. That was one area that was real big here at Marshall plus we had a lot of things, now you could imagine that you go through several years of that. Well, after you get about half way through between PDR and CDR, you can't just be changing the spacecraft all the time because JSC says the load's going up. You start using up margins. You start sharpening your pencil and going back and doing a better analysis of it and a more thorough analysis and you start getting tighter and tighter and you end up working your way into a corner. As you get further into that corner, then you start saying from a safety standpoint "Wait. I can't go any further unless I maybe take this area. I want to get a special test. I want to run a test on that component and see what it really takes

to break it." A lot of testing was done here at Marshall because the contractors didn't have the [81?] which would cost us so much money that we couldn't afford to have it there so we would test it here. We would build some of the test hardware or they would provide it and we'd put up the tests and the vibration. Big tests fixtures.

12. Waring Was that Lockheed for that contract?

13. Olivier Mostly Perkin Elmer because we got into trouble more on the spacecraft, the telescope than we did the spacecraft.

14. Waring Right.

15. Olivier See it led everything. Telescope was first with a long lead time.

16. Waring Right.

17. Olivier Spacecraft came in later. The spacecraft itself as far as having to back out of design, it didn't get caught up in as many of those load cycles as that telescope did and the science instruments. All of that work from a structures and material standpoint was a bit challenge. . . . big challenge. These are not necessarily in the order of importance.

18. Waring Let's got through them and then maybe rank them.

19. Olivier Go back and rank them. The next area was pointing and control. This system had a requirement of stability of 1/7000sth per arc second, .007. To do that, ...

20. Waring Can you explain in laymen terms what that meant? How accurate, how stable is that?

21. Olivier Well they have the analogy of if you were in New York and you were looking at a dime in Boston, that's the kind, I mean it's this small. It's extremely, it's not even intuitive it's so small. There is no way your mind can absorb the fact that it is that small. Just you keeping breaking it degrees business. One 60th of a degree to a minute and a 60th of a minute is a second and I've got 7000ths of one of those seconds. Just a very small number. You've got a number of problems when you do that. You've got to design that electronic control system and feedback, you can actuate these torquers, reaction wheels to actually stabilize it, to move the vehicle around to keep it pointed. The feedback would say, "OK, I'm moving off. Put me back where I'm supposed to. I'm moving off here until they but me back where I'm supposed to." All that analysis was the responsibility of Lockheed. They were the prime contractor

for that pointing and control system, but it got more complex because if you say "OK if I'm going to be moving back to where I should be," the question is how do you know where you should be? Well, 1/7000ths of an arc second is pretty small and to determine, to look at a star which is a natural, if I want to look at this star, that's going to be true to my guide on that star. I don't want to move off of it before the 7000ths arc second. You can't just use a little star tracker. We had to use the total optics of the system because of the fractions. We had to use the full telescope. That meant at the focal plane of the telescope, we had to use censors and we'd have to move these censors around to find a guide star and then we'd lock on that guide star. That's your error signal. So the first thing you had to do was to come up with a way to sense the error, and that was the fine guidance censor. It's 99.9% optics so we gave that to the telescope. So that's a Perkin Elmer job because it's optics. That meant we split the control loop right in the middle between the sensors and the actuators in the control system. So that complicated the control system and design because of interface but we thought that was the thing to do. The other thing you've got to worry about, once you build a control system that can respond to that little bitty error signal is you've got to have, this telescope is a huge thing, but as you move that telescope, that thing is flexible. It's really kind of like rubber at this level of flexibility. It moves, so you have to have reaction wheels that are torquing it back there. What they are moving against, eventually you've got to move that whole telescope around so the reaction wheels spins and then it brings this telescope around and the whole thing starts coming around and stop it and the whole thing's sort of sitting there. The whole telescope is doing that. I'm doing that, but we're talking about such small numbers that you couldn't even tell it was doing that. At that level, the whole telescope is moving around and the solar arrays are moving and that is going to affect how the antennas moving a little bit. So the flexible body dynamics of this thing characterizing that structure because the control system, the mathematics required to control it, it you were to assume it's rigid and I move it and it will do just like I want it to at the response of that sensor, that leads you to a certain kind of control logic. When you have to start feeding in a lot of other things like bending and all that, the control system complexity goes up and you've got to take into account a lot of non-linear affects. The pointing and control people in the dynamics laboratory, another person you might want to talk to, I don't know if you want to get that detailed or not, but Jerry Nurre, was a key person in that. He was our lead pointing and control person and he and his team modeled this stuff in intricate detail. Took that fine guidance sensor which had many many optical elements in it and sensors and they modeled it more, much more detailed than the contractors were able to do. And they modeled the total control loop. We'd take the structure and we'd test it in the labs to see what its mode of frequencies were and take that data out and they'd feed it into their models. Lockheed was doing some of that too, but our guys were doing more and it turned out to be a team between our pointing and control guys and the contractor team that together we kind of worked this whole thing. But our guys here did a line shed of work.

22. Waring And what lab?

23. Olivier Dynamics laboratory. ED. It's called ED lab now, but it's the dynamics laboratory.

24. Waring How would you characterize that problem? There's the electronic control that Lockheed was working on. There's the fine guidance censor that's basically an optical system that Perkin Elmer's working on. So the Marshall contribution, to give it a label, would be the dynamic analysis of the whole . . . .

25. Olivier Dynamics and, well everything. We worked in the control loop along with Lockheed . . . .

26. Waring So it's sort of systems engineering . . . .

27. Olivier Systems . . . .

28. Waring . . . of the pointing and control systems.

29. Olivier Right, exactly.

30. Waring I got you. To a general audience, I need a label.

31. Olivier The systems, the overall systems engineering of the pointing and control systems, but also it was a lot of very detailed work in certain critical areas not just systems engineering but it was systems engineering plus digging in depth in some of these elements, like that fine guidance sensors. That was so complicated. We had a problem with the sensor. Once we got a sensor that was stable enough we just error signaled that thing. Let me draw a picture. I want to show you something and then maybe you can tell how to explain it. [he's drawing] Let's say this is X and Y or X. This would be an error and say you're moving back and forth. We had a control mute that put out an error signal like this, let's say zero. If you moved off, let's say 0.007 this way or 0.007 this way, say if you move over here to this thing, it would give you a signal, say this is a + and this is a -. It says I'm getting a + signal so that means I'm moving this way. So it swings it back and then it gets it you back. Oops, I'm getting a - signal now so I'm over this far. So the thing is bringing

you back, it's trying to brink you in on zero. The problem is this thing, this hump right here took place at about 0.023 or something like that as a second, about another 0.007 more and you get to this hump. When you find that thing, if the telescope moved a little too much because of some disturbance, if the thing moved so far that the star went over that hump, now I've got an error signal that says keep moving me this way because I'm getting closer, in other words, the slope changed.

32. Waring Right.

33. Olivier So if you ever got off here what we call your lost lock and then it went, this other stable from here over. So you had to try to keep it in here. If it ever got off, if the star ever got off out here, it lost lock because this error signal is driving it in the wrong direction. . . . was a problem whenever the solar array started flooding. It kept tipping into lost lock.

34. Waring So this is a problem that had been anticipated but it became real . . . .

35. Olivier It became real when the solar arrays didn't work right. Then we got into this loss of lock, loss of lock. A lot of times, we'd go through the terminator. The solar arrays would jiggle and it would jiggle the line of

sight so much that it would go over this hump and you would lose lock on the fine guidance censor. The way you find it is, if you got a star here, they had a mechanical system . . . .

36. Waring OK, go ahead.

37. Olivier A mechanical system with mirrors that would move, these mirrors moving, and it would move the image of this star however way you wanted to turn this, it would start that circle, but it would keep it to cause it to move that star any way you wanted to by moving and diverting some mirrors that brought the star into this little sensor. So you could move this star around on this sensor by moving the mirrors out here in front of it. The telescope's not moving. It's just sitting there. The star comes in, goes through these relay optics and the way you move these servo that cause the star to move around. The way we would find this star, was if this if the star you're looking for and you point the telescope, the guide star in the star chart at the science institute would say, this star is located a certain run sensing declamation. I want you to find this star, but that star chart may be off by a 1/2 arc second. Maybe hold the proper motion of stars, they moved a little bit since that chart was made. You may be looking over here. . . . it's going to lose it if it gets this far out and here I am miles away so you had to go through a spiral

scan and search. When that thing found the star, then it locked in on it. Then it would be locked. Then you've got to hold it very stabile or it would jump off. So you went through search mode and you'd find a star and then it would change modes internally and it's going into this mode and then locked on it. That process had all kind of mirrors in it and moving things and everything had to be very stable in there and again, the Marshall guys were very much involved in the development of the fine guidance system. Here I'm talking about the optics people in EB laboratory, electronic communication gear, pointing and control hardware and that avionics system, but EB [207?] look it up for you. The optics people who were following the development of the primary optics were also following this because it's an optical device. So this fine guidance sensor became a critical technology thing, really pushing the state of the art to do that. We even had a focal plane figure sensor in there that would look at the star and determine the way front errors and determine from that, by sending the information into the ground, deconvolving it with [212?] polynomials that would determine whether the secondary mirror is, what's wrong with it? Does it need to be moved in out, focused or tipped or tilted, or what's wrong with it? So we had that thing built into it. That thing never did work right because of this spheric collaboration. It was swamped by this spheric collaboration. We never got that to work right. A lot of work and money went into that and it didn't pan out. But our guys were involved in that too. So the EB laboratory from the optics standpoint was very much involved in the development of the fine guidance system. A lot of that expertise of those labs supporting that.

38. Waring When they were doing their work on this, were they working with computer models primarily?

39. Olivier Primarily computer models. People would build models here, same thing with the pointing and control system. There were models here and at the contractor sight.

40. Waring That is actually mechanical models.

41. Olivier First the computer models predicting how it would perform. Once you'd get on paper you say, "OK this will work." Then you start building bread boards or various elements or if you say, "I think it will work but I don't know how good I can get this part, it's a key part." Then you go on and build a bread board and see if you can get it to work. If you can, then you can go back to the model again and say, "Yes, I can do that." Most all the bread boarding was done by the contractor as far as building bread boards and hardware because they had the hardware and they could build a bread board, but we spent many, many, many days and weeks on airplanes going back and forth.

42. Waring . . . primarily working with the earlier phase of computer models and then also checking the bread board work of the contractor.

43. Olivier Yes. The contractor would build computer models too, but we'd build them and see if we could answer it.

44. Waring In parallel.

45. Olivier Right. We'd take a test case. You take this input condition and I'll take the same and see if we get the same answers and that kind of thing. That's valuable because if you're not careful and your analysis is wrong and you build something that don't work and you don't know why but the analytical will tell you why. It's good to have a cross sketch. That's what we did on that. OK, so we talked about flexible body dynamics and the fact that the sensor itself was very complicated because the lense was done in at range and because of the optics inside of it. We talked about the fact that the control system had to have a lot of sophistication in it because it had to handle these flexible body dynamics. So then we say, "OK we're going to use reaction wheels." These reaction wheels now are going to be used to provide the muscle to steer it with. You know what a reaction wheel is. It's just a big wheel, like a DC motor. You can spin it up, reverse directions. As you

torque the wheel, you apply an opposite torque to the vehicle so it moves the vehicle. We had four of these reaction wheels that were used to actuate the vehicle. Based on what the computer told them to do in order to keep the error signal and all of that. We ran into vibration problems on those reaction wheels, bearing problems on reaction wheels. These reactions wheels would be running at say 5,000 RPMs and you go into the labs and these were built by Sperry I think back in those days. You'd go into the labs and you couldn't even tell this thing was running. You put your hand on it and you couldn't feel anything. You couldn't tell this thing was running 5,000 RPMs. You couldn't hear it, couldn't smell, it is just sitting there. The guy said, "This one's out of spec." It's just not even intuitive. So they did a lot of work at the contractor site on bearings selection. We finally got the bearings down to where we thought we could live with them. Then we said, No. We've got to do better than that." We want you to develop an isolator system. So we pretty much directed the contractor to put an isolator system. They had to develop a set of hydraulic and spring loader isolators that we could put these reaction wheels on to isolate them from the structure so it wouldn't be, because it was throwing it out of lock. It's the kind of thing, you know, internal vibrations in the telescope were throwing it out of lock. There was a lot of work in that. So the whole, I'm trying to paint a picture. The whole area of pointing and control was a nightmare problem. Just the gyros that this thing worked on, the way it worked . . . .

46. Waring Hold on a second.

47. Olivier I'm probably saying a lot of stuff you don't want to hear about.

48. Waring No. Some of this may have to be condensed into a few paragraphs.

49. Olivier If I tell you a little bit more than you need to know, at least you'll know how to condense it.

50. Waring That's right. We're primarily addressing more of a general audience, but we don't want it to look stupid to an engineering audience, and it's important that people understand the difficulty of the challenge. Before we go on to the gyros, these reaction wheels, what sort of work of work was Marshall doing on this?

51. Olivier Primarily in that case we were monitoring.

52. Waring Monitoring the contractors.

53. Olivier See, we had guys that had worked on CMGs and reaction wheels from other programs that were very knowledgeable to the mechanics of them.

54. Waring Like Skylab.

55. Olivier Skylab and that kind of thing.

56. Waring HEAO.

57. Olivier Those same guys, this was a long time ago. These guys are still around. They're not here any more, but they were still around. They were supporting it. They had been through this before. So they were very valuable in trying to help the contractors working with a problem. The control moment gyros . . . lost over something on the control system. The gyro is sitting there spinning. It is a reference, it becomes an inertial reference. These gyros, we had six of them that were spinning. As a gyro spins, it's trying to be totally stable in space. It's only if a torque, some kind of moment acts on that gyro will it change position. It's really your reference. With time, a gyro will drift because external forces are finite. You can get them very low, but they'll eventually drift off. What we used the fine guidance sensor for was to update the reference of the gyro. We had a gyro sitting there spinning and the axis is spinning in one direction and that's your

reference. This control system in the computer would go into the computer and go into the gyro and say, "Where am I?" The gyro would say, "You're moving a little bit to the left," and the computer will tell the reaction wheels to speed up or slow down or move the telescope back. Well how did the gyro know you're moving left or right? Within the gyro, the gyro was designed so that any motion of the that gyro, it would give out an error signal. That's fine, but how did it know where it was to start with. Whenever you found this star and locked onto it with the fine guidance sensor . . . you used a reference from that star to constantly update truth. Say, this is true. This is where I am. You kept telling the computer, this is where I am. I'm on that star. I'm locked on that star and the computer would tell that gyro OK that's true. Whatever you say, I'm subtracting from how much the star moves. So the gyro was what the computer read and what kept the gyro true was this fine guidance sensor. So you had two things in the computer reading the gyro and the gyro is being told what's true by the star, by the guide star. Gyros had two problems. They had one performance problem that they were too noisy. As they rotated, as they spun, they were spinning in a fluid, as they spun, . . . later, the electronics that were amplifying the signal in the output of the gyro was amplifying noise. There was noise in the system somewhere. The output of the gyro was noisy. We were trying to pick out of that . . . .

58. Waring Sort of false signals.

59. Olivier Yeah, you couldn't pick out how much it was really moving. You couldn't move it just a little bit because small motions were lost in the noise. We first redesigned the electronics and that seemed to be the biggest problems. We were redesigning electronics to put filters in to get the noise out. Well the noise came down by nearly an order of magnitude. You say this pretty late then you say, "I want to drain this thing if I don't all this if I don't want all this." So you drain the water but all these stumps were showing. So we knocked the noise down. Then the new electronics we'd run the gyros in the test labs still got these big noise flags. What we found is that the gyro as its spinning in this helium mixture, helium and some kind of other fluid, was creating turbulence flow in there and just helium was kind of fluttering in there and causing the gyros to vibrate so we had to go in and build little cages around these rotors, shrouds around these rotors to make them smooth and hug the walls so the characteristic distance was short enough so you got a laminar flow. That was another few million dollars that we put into it. It was slowly eating us out of lunch, but we finally got them quite enough. That's another whole little nightmare in pointing and control. As it turned out, the pointing and control system, I have to say, is the highest technology area that

we have on Hubble. It's been a number of [333?]. So many problems. Ordinarily it was EB laboratory and communications and data systems lab and dynamics labs. Those were the two laboratories that really came to grip with the pointing and control thing. The dynamics labs from a total systems analysis standpoint, that was Jerry Nurre, they were doing the total analysis of the system end to end systems on pointing and control. The EB laboratory people were working the components trying to get the noise out of the gyros, trying to get the reaction wheels quite, trying to get the fine guidance sensor to work. So they were really trying to get down the nitty gritty and make it work at a component level. Then Jerry Nurre's in the dynamics lab at the systems level saying what kind of control system that will work in the software required to make this whole thing work with real life hardware that the EB lab and the contractors will tell them the characteristics of trying to beat down problems. That's kind of how it worked.

60. Waring Basically, with the gyros here and the reaction wheels, contractors were building them but Marshall was inspecting them, testing them, and helping them trouble shoot problems.

61. Olivier Doing systems analysis to see if it really would do the job.

62. Waring Right.

63. Olivier Working problems if they popped up and all those things. To get the control system to work, we had to hang the spacecraft on wires and cables, maybe about that big, the whole spacecraft on cables hanging vertically and then we put air bags to separate the cables from the building and the triangle so that the vibration would get in there. We ran those gyros up in the cleaner room and ran up the reaction wheels to measure, they had accelerometers all over that thing, to measure small vibrations in that structure. Also, we would measure the output of the gyros whenever we would torque the reaction wheels to see what kind of transfer would happen between them. We torqued the reaction wheels and what did the gyro feel? Give it a nice square wave spike for torque over here, you're going to get a little rounded off edges over here because the structures had been solved. Transfer functions between one element to another, all that testing was done at Lockheed, but our guys were instrumental in some cases defining the test that had never been done and in other cases working with Lockheed in perfecting the details of the test. It was really a team effort.

64. Waring So that occurred later in the program?

65. Olivier Later in the program once you got the whole thing put together.

66. Waring So what, '87 or '88?

67. Olivier No, that test occurred in '86.

68. Waring What was the name of that test?

69. Olivier It was a 3-3 motal test. . . . shake it at various points and read the accelerometers on it. Again, they were trying to characterize the flexibility of the structure, how it would react to various disturbances externally. I think I've told you enough about pointing and control unless it's something else you've picked up. . . . you try to take a sip of water out of a fire hydrant right!

70. Waring Go ahead with what you were going to say.

71. Olivier I was going to talk about contamination.

72. Waring OK, contamination.

73. Olivier The next big unanticipated cost. In the Hubble program, we did not plan to have such an elaborate contamination problem. We thought that with good procedures on cleanliness control and that kind of thing, we could beat

the problems there. By the time Fred Speer got on board, we had the realization come about that we've got to do something more that what we were doing to protect against contamination.

74. Waring When was that? Was that '77, something like that when Speer came? I'll have to check the date.

75. Olivier '78 probably, but I can't think dates too clear.

76. Waring That's fine. I've got the date. I know what it is. I can look.

77. Olivier I can remember he had just come off of HEAO . . . about some of the meetings coming up and told him so he went to two or three of these meetings. The next time he called me over he said "Deep Trouble"! I said, "I know." He was really, he said, "Here I have just come off this problem and I'm wore out already and I thought this was a good program and now I've got this essentially nightmare work." It never let up on Fred. He got into this thing and it was just a nightmare. He was fighting off the alligators. He never got a chance to drain the swamp. Alligators were eating him up the whole time and one of the alligators was contamination. As it turned out, we finally got to the point that we had to bake out every piece of that

spacecraft because of molecular contamination. Graphite epoxy would absorb water and it would expand and then alignment was a problem so we had to keep the humidity kind of low. But we had particulate contamination that would get into science instruments and all these little bitty slits and small mechanisms and all that thing. Dust could get on the mirror and cause scattering of light particularly in the ultraviolet and that would ruin your ability to see faint objects. Then if contamination, if it got on the optics, it would cut out the ultraviolet. . . . wound up having to bake all that structure up before we could assemble it. Every piece of that structure that went in there had to be baked out and then stuffed all the vacuum chambers we could find all over the country, going through the lab written procedures to clean the chambers up and certify the chambers and instrumentation, put the hardware in there and bake it out at some temperature just above its operating temperature. Sometimes weeks before the instrumentation system was cleaned.

78. Waring What's the difference between molecular and particulate?

79. Olivier Ever sometimes, a brand new car, sometimes you get in this new car and you're smelling that smell and sometimes you could even see a haze on a the windshield,

molecular, that's molecules from this polymers and stuff in the seats and stuff . . . .

80. Waring Like an outgas thing?

81. Olivier It's outgassing and sticking to things. So it's molecules from . . . .

82. Waring Materials.

83. Olivier Any nonmetallic materials stuff would just give off various elements and that would stick. Oil, if you had any kind of oil for lubing out all these rotating [434?]. Lot of costs go into the defining and eventual use of brako which was a very low vapor pressure lubricant that if you would use it, it wouldn't outgas and it was so slow you could use the stuff in a vacuum and it wouldn't outgas. It would take hundreds of uses to outgas. Find that stuff and qualify and test every piece of material that went into that thing. Every piece of plastic or anything that went in that spacecraft that wasn't metal. Any paint you put on it, any MLI that was used for thermal control, anything that went into that spacecraft had to be tested in the labs and bell jars and piece of it for certain tests to see if it passed it. If it didn't pass it, you had to look for another material or find a different way to process it so that it would pass it. On and on and on and on and on. Then we

built this big clean room at Lockheed and had monitors in there . . . hydrates and we'd be in there and hear that damn bell go off and have to clear the clean room up and shut down the blowers because someway out in a land field somewhere two miles away the guys with a big bulldozer might have uncovered some stuff with ammonia in it and it would just getting out of there. It was that sense.

84. Waring Right.

85. Olivier I don't know how many of millions of dollars it cost to keep that contamination and control program under wraps. All the way through to the orbiter had to be specially cleaned. The cargo bay liner had to be cleaned. There was just no end to it. It was not forgiving because if you ever got it dirty you could never clean it up. We had to clean the mirror once. It was a nightmare to clean the mirror. You couldn't touch it. You had to clean it with a vacuum. Contamination was a difficult to quantify cost impact and materials laboratory here was right in the middle of that. They did a lot of very good work. Every piece of material that went into the Hubble was tested right here at Marshall in the materials laboratory for acceptability. A tremendous amount of just basic contamination control and analysis and fundamental work was done here to help the contractors. That turned out to be an area that Marshall really got involved in was the

contamination and control, really right in the middle of that contamination and control work. . . . power systems. . . . area in Hubble is it didn't have some of the kind of technology . . . .

86. Waring Hold on a second here.

87. Olivier When we started out in Hubble, we were going to use nichol and cadmium batteries. Lockheed had a vintage of nichol/cadmium batteries that they had a lot of experience with. Goddard Space Flight Center was promoting a NASA standard nichol/cadmium battery and that was a . . . very emotional strong feelings about from various centers around industry and NASA about what battery was best to use. . . . charged system that Lockheed proposed worked with these batteries without overcharging them. All that turmoil, we decided what we needed was just run long term testing. So we started in-house some long term testing on nichol/cadmium batteries . . . that plus other work that was going on and other spacecraft failures that were taking place in that time frame, in the early '80s time frame. It was very discouraging. We were just convinced that the first thing we would have to do is to was to service those batteries, because the first thing that was going to fail was going to be those batteries would fail. . . . so bad that Jim Odom, well, let me back up. Lockheed came in a one time and said, "Hey if you guys want to solve your battery problems, we

think what you ought to do s go to nichol hydrogen batteries because they're a lot better." But nobody has every flown a nichol hydrogen battery in a low earth orbit where all that charging has to do. It's all been [501?] work. . . . like to know how they're going to work out, but we think they would be good. . . . a lot but we just didn't have the money. We said we don't have the money. . . . incident took place. . . . period of time. One of the things that Jim Odom decided to do, he and Fred Wojtalik, they decided that what we should do it do develop nichol hydrogen battery. . . . nichol hydrogen battery developed late in the game. We had to redesign some of the spacecraft to interface with these batteries. We built up a total bread board of the Hubble power system over there in the lab and it's still working and it's supporting Goddard and that was used to, that along with, earlier than that some individual cells were tested over here and then six battery test we set up and was going on. So that was the real work horse for the power system, that six battery test that was done over in the laboratories, in the EB laboratory. The EB laboratory has got everything in it. Any kind of black box or electromechanical device or batteries or optical systems come out of that lab. It's a very diverse lab. The EB lab was again right in the middle of the batteries and the power system, solar arrays. So that development program, it was really pushing the state of the art for that kind of use for nichol hydrogen batteries in low earth orbit, but it was done for Hubble and it turned out very well. The batteries are still doing real well, and again Marshall labs did a lot of work and still do a lot of work even as I speak even in supporting servicing operations with the battery test on them. Like in the servicing mission, whenever Goddard wanted to go through a discharge cycle on the batteries or had to because of umbilical connect time line problems, they went over there and asked our guys to run through a certain profile these batteries to see if they would come back up so it's still an ongoing activity that has been valuable to those. . . . then we had the problem back on pointing and control and we had the problem with the jitter solar arrays. The guys here were the ones that came up with a fix, what they called SAGA, Solar Array Augmentation.

88. Waring Let's talk about that. Going from power system, lets switch back to the, I guess we'll call that the array jitter problem.

89. Olivier I was kind of going chronological, but I should have stayed on that.

90. Waring That's OK. We'll get it all in.

91. Olivier Jerry Nurre and Hans Kennel who was one of his brilliant key guys that worked with him, Hans is retired now, but Hans was a brilliant guy, still it.

92. Waring Kennel, K-E-N-N-. . . .

93. Olivier He worked for Jerry Nurre as one of his key guys and those guys developed this solar array augmentation modification for the pointing and control electronic software that control that and largely overcame all that stuff. To a large extent it overcame . . . developed it here and then convinced Lockheed that that's really the thing they ought to do. There were a lot of alternative ways to do it, but the one they came up with happened to be the best. Lockheed developed it and then perfected it and Goddard uplinked in into the spacecraft . . . Goddard at that time serviced the solar array, serviced the spacecraft, put the solar arrays on and asked him to come to see how this thing was going to work to see if they had to put SAGA back on or not. But since that time, it's been about the last time we've had much significant interplay with Goddard. It's pretty much under control.

94. Waring OK, could you briefly explain again how that worked? That was involved, that was part of the process that we talked about earlier?

95. Olivier Part of the thing is that the solar arrays were shaking so bad that they were throwing this thing out of

lock. Loss of lock was a consequence of the solar array disturbance.

96. Waring So it was basically a way of moving the relay mirrors to compensate?

97. Olivier No. If it was out and moving . . . the whole, and I'm getting beyond my ability to talk intelligently about it, but you can imagine you were trying to control something, you could control it very easily. If it was moving off, you apply a little bit of force to sort of move it back . . . if moves any I'm going to jerk it right back, the gain. If it moves it a little I'm going to multiply it by something and torque it a lot harder and I'm really going to tighten it up. But now, how you tighten it up? If you tighten it too much, this structure's got frequencies in it. Just flexible stuff, and if you get too tight on it, you start exciting the structure and all of a sudden you're doing yourself more harm than good because you'll excite some frequency out here in this structure and then it'll start vibrating and then it's really going to screw things. So they had to go through and characterize the structure and to tighten up whenever that solar array wiggled out here, they had to have enough controlled authority in that thing that by changing all these gains, these many gains depend on what frequency range they were talking about, to tighten it up and hold it on that target and don't let that solar array

do that. But this vehicle has so many complex structural characteristics to it, they had to kinda a figure out how they can tighten this control in a way that didn't excite the very thing they wanted to not excite. . . . they had to understand the structure. They had to do a lot of trial and error because some of the stuff cross coupled and tried to avoid this frequency, but avoiding that frequency, whenever they tightened up on it, wouldn't let it tighten up fast enough so they had to compromise and drop off a little bit here and pick up another frequency but had to get enough control authority to hold it on that target without exciting the structure out here. That was a trick and I don't even profess to understand how those guys do that.

98. Waring If I decide, I'll have to reread [turn tape over 627]

99. Olivier . . . my laymen way to see it is how to be able to provide the rigid control of that structure and force it to stay on that target even though the solar array's are trying to move it off, yet do it in a way that it don't cause the structure out there, the spacecraft structure itself, to start vibrating to the extent that you . . . I'm not sure I explained that right, but it's my mental image of what they were doing. . . . that took several months, many months to get that think worked out and finally checked out

and verified and on board. . . . and now we're going to contaminating in the batteries.

100. Waring Powers, power system. Any other things that Marshall was working on with power systems?

101. Olivier Power systems, batteries. . . . system, how the charge controller and everything worked, how they sensed that the battery was down, sensed when it wasn't fully charged and all. . . . a lot of work was done here to characterize how that would interact with these nichol hydrogen batteries even before that how they interacted with the [638?] battery. Lockheed had found that they had trouble with these [639?(same word as 638)] battery. They were overcharging them and burning the batteries up. Roland Mears, who was kind of a key guy there, finally figured out why they were doing that and recommended solutions that would, in the charge circuitry, that would preclude that. Roland Mears deserves faithful mention because he is a key guy.

102. Waring . . . probably will not . . . .

103. Olivier I know what you're saying. Everybody's got . . . .

104. Waring . . . one of our directives from center director . . . .

105. Olivier . . . people? Right.

106. Waring Yeah, if somebody had quoted or something like that, we usually use their name.

107. Olivier But the power, OK the power division, whatever that division, that laboratory, the power . . . .

108. Waring That we can do.

109. Olivier What's the power division? Another aspect, let me get a cup of coffee. Is that OK? You want some coffee?

110. Waring I'm OK for coffee, but I can stretch my legs. [tape turn off and back on] Say that again.

111. Olivier There was a time that I began to think this whole Hubble telescope was made out of unobtainables. There was no piece of it that didn't have something that didn't look like we were going to be able to figure out how to make it work. . . . power systems. Now let me talk to you just a little bit about solar arrays. The Europeans developed the solar array before how nieve we were at the very

beginning because we thought, we were under extreme political pressure to give the Europeans a portion of this telescope. We were asked to give them a science instrument. We were asked to give them the entire power system. We were asked to give them communication. We were asked to give them all kind of stuff, and then finally, we whittled it down and we thought we'd won. We'll just give them the solar array. Just stick them out there and we'll bolt on, it's out there. OK, we won that one. Give them a science instrument but it's a standard interface we had to do. First meeting we had with the Europeans after we had Lockheed on the contract, Lockheed guys came in here and said, "How are you moving this solar array?" "Well we have a stepping motor." . . . telescope. That thing's got to move very smooth. It's got to have an acceleration, like a jerk profile. The change and acceleration must be controlled so that you don't shake the thing and get it excited and it rattles around for several minutes and you get through and it don't really file everything off but saturate the gyro output. So the first thing is the European had to go back and redesign their whole control system. That didn't make them happy at all. Then we started running into problems with the solar array on the lifetime of the solar cells themselves. In the solar cells, the little silver interconnects tied all these cells together, they were failing because the solar array blanket was moving as it went in and out of the sunlight. It was just [668?] these little things. Big test problem. Europeans worked, they spent a lot of money on trying to get these interconnectors to work. Spent a lot of time in Europe, Germany, and all over the place over there trying to work the solar cell problem, solar array blanket problem. It finally got worked out. We did a lot of work here at Marshall, especially with testing and all, to test big samples of these things in a thermal vacuum environment. It had to go through 30,000 cycles without failing because that's five years worth of cycles. . . . that was a big area because again, the solar arrays were, the whole [674?] was nonmetallic and it had to contamination and control and it had to be thermally controlled properly and then we ran into, right in the middle of the program, we're at PDR when we found out that atomic oxygen is a big problem in space. . . . just atomic oxygen is up there and it just heats up anything that gets around it, oxidizes it. On the right side of the solar arrays we put samples of the solar array material and we exposed that stuff and it would eat them up. . . . go through and get the Europeans to put a protective layer of some kind of . . . that was not acted on by atomic oxygen. That was another big trauma. All the outside structure out there, just the metal and all, had to painted with stuff, overcoated with stuff to protect it because that stuff start coming off and the paint would turn into powder and all the binding would give away and make a big cloud rise. You know you'd get contamination. So we had to go around and overcoat everything on that spacecraft, the handles, the yellow handles that the crewman used to climb up and you'd see them all over, all of them were overcoated with a clear coated polymer of some kind that was atomic oxygen was just . . . material testing again had to go back and check for atomic oxygen all that stuff that gets pulled out in space. That was another big trauma, but it hit the solar array pretty bad. We had a lot of work with solar array on materials compatibility. Our electrical people were involved again to make sure that the cells and everything were putting out the right amount of energy and that interconnects were working right and didn't fatigue and all that. Turned out to be a very complicated interface the Europeans had. There were other things that can be worse, but that was a lot worse than they thought. Again, it wasn't just power. It was this whole dynamics because every time that solar arrays would move, it would shake the pointing and control system. Lockheed and our guys were right in the middle of the Europeans again trying to control the frequency vibration of these solar arrays. We thought we had it pretty much under control except it turned out that the thing didn't work properly and they were, worst of all [697?] at that point dynamically. They weren't working properly. A lot of work went into trying to make sure it did work properly and unfortunately it just didn't work out. . . . fly . . . big step. . . . solar array were a subset of the power system that even though we didn't develop them in the United States, between ourselves and Lockheed we had a very complicated and traumatic interface with the Europeans to put that thing together. Primarily that laboratory with the materials laboratory and the power guys in the EB lab. . . . more dynamics laboratory for the point and control characteristics. So we had three labs very involved in the solar array. We picked up huge . . . .

112. Waring . . . serviceability, or repairability, whatever we want to call it.

113. Olivier . . . concept for Hubble and everything on it. Every black box on it practically every motor could be serviced. . . . about a year into the program, we had a big cost crunch . . . thing to do was cut back on serviceability because the cost is taking all these new standards like boxes of other spacecraft come on and modify them to be serviceable. So we could eliminate a lot of that modification system just in boxes. Every time we took off a serviceable [713?]. So did all kind of analysis here at Marshall on reliability and want to call over analysis to see what might fail when and all kind of analytical work.

114. Waring This would have been in the early '70s? I mean in the late '70s?

115. Olivier Late '70s. About '79 or something like that.

116. Waring Marshall began doing tests on . . . .

117. Olivier Analytical work, not tests. Analytical work. Taking the mean time to phase data on all the boxes we could get our hands on, putting them in the computer program, simulate the vehicle and then running it and let them fail and do it 1,000 times and see what the statistical . . . box fail first and second and third. From that we determine which boxes ought to be serviceable.

118. Waring . . . already had data from the performance of the components and subsystems on other spacecrafts.

119. Olivier We had a lot of it. Some of it we had to just make a best, take a parts count and come up with our own best estimate or get the contractor to help us. Out of that came a module based analysis which determined, effort was aimed at trying to determine from a reliability standpoint which black boxes should be retained at servicing if we had to do away with some of the stuff.

120. Waring Basically trying to identify the least reliable components and subsystems.

121. Olivier Right and you can imagine in those days we still had not yet mastered the batteries the first thing . .

. gyros because some of these things, gyros we were flying had flown on HEAO and they had flew on IU and we knew even gyros would fail so we had gyros as one of the servicing items. . . . because when you take the performance, it would probably fail. . . . tape recorder taken off the list and then we put them back on the secondary. So we went back and forth on that. All service and went to minimum service in space . . . minimum service in quite some time because our plan in those days was every five years, you'd bring it the ground and every two and a half you'd service it in orbit. . . . Headquarters began to realize that was going to cost a fortune so we started running cost analysis and Headquarters finally concluded we can't afford to bring this thing to the ground. We can't do that.

122. Waring What time was that decision? Was that about the time of the crisis of '82 and '83?

123. Olivier I think it was whenever, about the time Odom came on board or just before Speer left. In that time, '82 or '83.

124. Waring That's right.

125. Olivier Odom, what Headquarters said, "We want to revise the operating plan for Hubble." It would exclusively [743?] . . . not any good now from a standpoint of . . .

made it an effort to TRW, again a lot of money, to go in and start looking at these boxes one at a time and see which ones could be upgraded with minimum impact. We already had the thing practically built. It was late in the game. It wasn't anymore academically which is the most likely to fail and all that stuff. It's what can I do with what I've got. So we went into a block, another block of ORUs that we started modifying the design as best we could on the ground to accommodate service. There were some of these boxes that we found, we didn't design that stuff for servicing but really we trained those astronauts well enough. We had JSC astronauts going to Europe and solar array. They were going to Lockheed all the time. I mean those guys, they were right in there with them, Bruce McCennon, Chappy, and those people, they went out there boy, just working with them. It was really a team. So they . . . total project decided on another group of ORUs.

126. Waring Kathy, what's her name.

127. Olivier Sullivan.

128. Waring I was thinking of a . . . .

129. Olivier Kathy Sullivan.

130. Waring That's what I was thinking of a news caster.

131. Olivier . . . went through and after that, after we got those installed, then we made another block of ORUs that said with extreme care, hard work might be with servicing. I mean it was tough. You had a box half as big as this table with maybe thirty connectors on this end and fourteen on that end and they were so close together, the guys couldn't get their hands in there. You had to come up with some kind of tool to break them aloose. Really, I couldn't do that in my back yard and not get it all back in there right. Some of that stuff, we went through and our astronauts worked with us. They came up with special little tools. We put little tabs on the things saying what each one was, color coded them so they would know which one to go back in . . . .

132. Waring Was that work done at Lockheed?

133. Olivier That was done at Lockheed.

134. Waring OK.

135. Olivier With our guys here, but primarily Lockheed and JSC. But we had some crew systems people and we did, oh I forgot the other part. All the neutral buoyancy work that was done here to verify the serviceability. First the neutral buoyancy was to take the primary design and make a

crude mock up and just see if you're in the ball park. If you can reach it, access it, that kind of thing. Then that confirmed your design. The next step is all these hand holds to figure out where those have to be. You can't see it on Hubble. You can't see it by looking at it, but all those portable flippers training to do in that servicing nature, there were little receptacles built in the spacecraft to stick those things and turn a set screw and lock them in. Dozens of those things located all around in strategic places. The location of those things would determine where they need to build the thing as part of the developmental work. Just have our own divers and our own crew guys go in there and work it and then when we get it close range . . . .

136. Waring So that was all done back in the '70s?

137. Olivier Yes. Then we'd bring the crew in here from JSC and they'd try it out and they'd verify that it was OK. It ain't going to move and located all these flipper strengths and all the different hand holds, verified that some of the things could be reached and some couldn't. Had to move some stuff around to get it more accessible. All that supportive development work on crew systems was done . . . large amount of Marshall Space Flight Center was used not only . . . . Then we started as a take off on that, we started working space support equipment for the first

servicing mission using the Spacelab pallets and designing. A lot of that equipment where all those instruments were located, all that stuff was developed at Marshall and built at Marshall but we just gave it all to Goddard when we got near completion. . . . . large fraction of space support equipment that we'd use on the first servicing mission . . . designed and in many cases, most cases developed here and turned over to Goddard. Not the solar array carrier, but the carrier that held the science instruments. . . . standpoint, antenna, low-gan antenna, pattern and measurement and all was done here on our ranges . . . that was done here, again . . . .

138. Waring . . . systems engineering.

139. Olivier Talk about transportation. Kind of a broader system. We got the telescope finally built at Perkin Elmer, we had to move the telescope to the west coast. . . . transportation council environmental . . . modified that.

140. Waring Hold on. Marshall was responsible for moving the OTA, optical telescope assembly, from Connecticut?

141. Olivier From Connecticut to California. . . . different activity we had to go through to get much oversized payload down a busy four lane highway interstate. . . . interstate first and then off of it down . . . .

142. Waring Right. And you said you used an ATM transport?

143. Olivier An ATM transporter.

144. Waring Transporter.

145. Olivier Cannister that you'd put it in to environmentally control it and tie it down and keep the loads from getting too high. But again the vibration loads and the loads from transportation, in some cases, if you didn't take some precautions, it'd be as high as some of the launch loads.

146. Waring What's ATM stand for?

147. Olivier Apollo Telescope Mount.

148. Waring Oh, it's surplus hardware.

149. Olivier Remember on the Skylab, ...

150. Waring Right, I know what it is, but that was surplus hardware from the . . . .

151. Olivier Surplus hardware, right.

152. Waring That's what I was wondering.

153. Olivier What it was, once Perkin Elmer got that thing to their dock, once they rolled it out to their dock, they said "It's yours Marshall."

154. Waring You bought this thing!

155. Olivier You bought it! So we had to arrange to get the trucks there, to do all the running up and down the road to make sure obstacles was high enough to get them through and make sure the road wasn't too rough. Dry runs with accelerometers in there to see if they didn't exceed the loads. Lot of work. But that was a Marshall responsibility. It wasn't the contractors job. Then when we moved the telescope from California to the Cape, Marshall was responsible for that, but we got the Air Force, . . . Air Force cannister, in fact we provided the design requirements for the Air Force cannister in the C5A . . . at the Cape. It wasn't a Lockheed job. It was a Marshall job. Of course we used the Air Force to help us, but we did all the planning. Those people at the Cape that would oversee all the Cape operations were down there for several months. . . . make sure we had the data link because when we got it to the cape, Lockheed left their ground support equipment at . . . power the vehicle up and run it at the Cape and check it out and make sure it was OK just before they put it on

the vehicle. During all the checkout down there to make sure it survived the transportation, it was checked out remotely from Lockheed. The guys were on the link saying it's now time to power it up and change configuration so Lockheed was controlling it from Lockheed, but Marshall had to arrange for the domsat and all to get the data from Lockheed to the Cape and back. We did a lot of that work.

156. Waring Could we talk about the intitial, what was it three months or four months of operations of the telescope?

157. Olivier It was the nightmare of my life.

158. Waring Well, tell me about that.

159. Olivier Goddard as you know was responsible for the operations. They developed the control center and provided the flight operations team . . . Marshall was responsible for the orbital verification system, the first thirty days to get the vehicle out. We were responsible for making sure it would work with JSC, worked the mission while we were trying to get it checked out in the cargo bay, get it off the arm, get it in a sun point mode, get the thing powered up, checked out of line and all that stuff was our responsibility. Then once everything was smooth, it becomes Goddard's. It never did get smooth. It was rough all the way. I was the head of the technical team that went to

Goddard to develop the work and to carry out the engineering, the decision making, technical decision making process required to support that mission. We had our own director of orbital verifications there that carried out, to oversee the daily operations of operations. We had a team of probably 18 or 20 people of about 5 months at a time. . . . procedures and everything we worked. It was a hand in glove job with Goddard. We were working as a team. We were working hand in glove with Goddard and it worked out real well. We sent a contention of people there to actually manage the mission. All the shots were called by Marshall and all the problems of getting the solar array out, all that nightmare of getting it off the arm and getting it to operational and then all the problems that we ran into, you know the high gain antennas stuck for a while and then one problem, I couldn't keep it out of safe mode. It always went into, like a kid with a bicycle. You say, "Ride it." You know you just can't right that thing and you think you will never learn how to ride a bicycle. That's the way it was trying to get that thing. Then the [856?] when we finally couldn't get it aligned. We tried and tried and tried and tried. Couldn't get it aligned. Again, Charlie Jones and EB lab was there with us and he was head of the optics work couldn't get it aligned and he finally began to realize that he had a fundamental aberration and it wasn't going to get any better. . . . came on something we couldn't fix. Everything else we finally overcame, but that one. Couldn't do it. It was five months to get it through to the point that we could hand it off to Goddard, the point they could do assignments. It was a hard five months. . . . Well it's in save mode again. Then you know, "God damn it . . fucked up you son of a bitch!" He's just chew our ass out!. "I want you in my office in one hour!" Get in the bus and go to Headquarters and get chewed again up there. Tail start would come back. Two days later it would be back in save mode again and we'd be back up there again. It was interesting! A maturing process. . . . we were all over there planning, once they started this, planning for their servicing mission, and our guys, quite frankly, it was a little bit of an adversarial relation when Goddard first was going to pick up this GSE. They were going to come down and look at us and space support equipment. They'd say, "That ain't no good. That will never work," and all that stuff. We wouldn't redesign it that way, but why we finally gave it to them, they used most of it the way it was so they got further into it themselves and found out that that was really what you had to do. During that time, it was very adversarial. Not very, but there was a lot adversarial relationship there. After they got the thing, it was completely theirs, then all that kind of cleared up and we kind of worked as a team. We helped them every bit we could to get that thing to work and it turned out to be a good relationship. Any time you're in a roles and mission kind of situation, it's always very bad. . . . a lot of that.

JSC gets this and Marshall get it. Guys that are really good friends, all of a sudden they're antagonist towards one another until it's all settled once they've done the you're going to do this and you are going to do that.

160. Waring It's when they're dividing the pie.

161. Olivier That's right. Whenever you feel, if I get this, I might have a chance to get this and I'm going to loose millions and oh my God. Fear and everything gets into it once management says we can do it this way. . . . back out [886?] again . . . does that a lot to themselves.

162. Waring We've got just a few minutes here. Could you talk about the lessons from the space telescope? The legacies of the space telescope, perhaps especially related to the development of the Center? It may be personal lessons or do you think or perhaps ways in which the Center has changed practices or changed organization because of the space telescope?

163. Olivier Been a lot of changes, not all because of space telescope. There's been a lot of changes on how we managed AXAF, I mean compare with AXAFs telescope.

164. Waring OK.

165. Olivier When we went into AXAF, Headquarters management, that was the same management on the Hubble, they said, "There's a lot of lessons learned on Hubble. We're going to apply them on Hubble. One of the lessons learned is that we're going to have one center responsible for the whole thing. We're not going to have one center developing the flight system and the other developing the operations." That was a very difficult thing for one center to operate it and another center to develop it because it takes an intimate knowledge and control of the vehicle design to make it real. . . . develop it and not split the project between NASA centers. That was a very important lesson learned, and we've followed it so far in AXAF. Another lesson that we were supposed to have learned but I don't think it's cut and dried as a lesson. That is we'll have one prime contractor. On Hubble, we had Lockheed as a spacecraft contractor and integrator. Perkin Elmer developing the telescope, but they weren't a subcontractor to Lockheed. They were our contractor. So when you try to work out interfaces between those two organization, you didn't have the authority to drive innovations. You always had to have the government in the middle. The relationship between Perkin Elmer and Lockheed never was all that great.

166. Waring Why was that? Different styles? Were they competitors?

167. Olivier Different styles. Whenever you're trying to resolve an interface issue, each guy's trying to resolve it to his advantage.

168. Waring Make more money.

169. Olivier Or, don't change my side. My side's already designed.

170. Waring Make it easy.

171. Olivier Yes. If you change my side, it's going to cause me a lot of heartache. Change your side. You caused it. You change your side. Then we got to wait a minute. We're going to change it the way it costs least. So each one of them determined which one, that kind of thing. Human nature. They couldn't be in a position to impartially arbitrate an interface because they had a conflict of interest to start with. Perkin Elmer realized that so they would resist it. We had to be in the middle. We had to chair all the interface working groups. It became, NASA had to resolve many, many, many, many issues that just couldn't get resolved between contractors. Neither one had the authority to resolve it. It took NASA to resolve it. We were right in the middle of it from a system engineering, see so the whole thing had no head unless Marshall was the head because they had all the contracts so Marshall was

systems engineering so to speak. We had to work all the interfaces and make sure all the systems level analysis was done. That's why Jerry Nurre was working pointing control across the board. That's why the thermal people here worked thermal models across the board. Structures could do a stress analysis. Loads for the whole thing. Systems engineering at Marshall. That's really the glue that held the Hubble together. . . . doing at AXAF is say, "OK, we've got TRW as a prime . . . your telescope contractor is your sir. Not our contractor, your sub. You work this interface. The science instruments can never be done that way because they are picked by NASA on announcements of opportunities so they're always directed for us so you always have an external interface there but we tried to keep the spacecraft, the observatory itself, as one contractor tune. . . . as it turns out though, somebody's got to resolve these interface interviews and TRW will try to resolve them, but again sometime it goes on and on and on. Of course their jockeying because their subcontractor's got a contract to him and if you change my side, I'm going to give you a change order so it's going to cost more money but we're on him to keep the cost down and so there's no ideal solution. I'm not sure that's a lesson we learned. We advertised it as a lesson learned, but there's just different kinds of problems depending on how you do it. And either way it will work, but neither way that I can see if vastly superior to another one. That was touted as a lesson learned on how you contract this stuff. It's not clear to me it was a lesson really. Another lesson learned though was develop your technology. It turned out to be simple in itself because it's really one big technology that's getting those big mirrors developed. Spacecraft on the AXAF is pretty straight forward. The Pointing and control system is nowhere near as complex as Hubble. The contamination control is about the same. A little tighter, but we already know how to handle that. So we've got one gigantic technology and we've structured the program to crack that technology before we start the spacecraft work really going heavy so we were able to do that. There's [961?] as we've talked about Hubble here, there's so many technologies with Hubble. I'm not sure we'd ever been able to do it anyway because we had pointing and control technology at work, mirror technology at work, power systems technology. Everywhere you look there was a technology, so I don't know where you would have started it if you said I'm going to hold off until I get my technologies done. You really didn't have a good handle on technologies that were required because there were so many of them. We were pushing so many fronts at the same time so that was a problem and I think the lesson learned there is don't commit to something unless you've got a lot money in it if you've got a lot of technologies to solve because you'll never be able to plan it, schedule it, tear it out on the schedule you want to, unless you throw a lot of money in it. And now days, you ain't got a lot of money to throw in it. So the technology, the stability of your technology base was a lesson learned. You've got to really know your technology before you commit all these eggs in that thing. You can do that on some programs better than others. Hubble was a lesson learned and we were able to apply that to AXAF, but I'm not sure we could have applied it to Hubble in hindsight.

172. Waring Yeah. Do you think people understood how much they were pressing the state of the art in the '70s?

173. Olivier I don't know how people thought it, but I know we in the program didn't understand it. We didn't realize, Lockheed had a tremendous background in the constant spacecraft for the Air Force. They've built spacecraft before they got the Hubble contract that they thought put them in the position to really be able to throw the egg. This is just spitting out something using technology base that we already fully understand. No way. They were fooled. Everybody was fooled. Technologies were much much more demanding across the board than we ever realized when we got into it. We were nieve. We really were. . . . lessons learned, the lesson learned that makes it very chigrind is do verification and testing cross-checking systems before you say they're ready to go, like in the optics. In Hubble, we put all our eggs in being able to do that thing right. Correct those spheres, tests those

spheres without any tricky instrumentation. Anybody can space something.

174. Waring Repeat that lesson again. That's obviously an important one.

175. Olivier The fundamental lesson that taught us all is you should have cross checks . . . is you go to a machinist and you say "Machine me a piece of metal that looks like that cup and here's the deminsion. Machine that." The machinist starts machining it. He gets his mike out and he mikes it and says it's right. You'd say, "How do you know it's right?" "I put my mike on it." . . . fallacy. You give it to the guy and you say, "I want you to give me this," and the machinist puts his mike on it and he mikes and says it's right and then you give it to a quality control guy and you say, "You put your mikes on it." Different set of mikes, different set of eyes, looking at it from a little different angles. "You mike it." . . . saying that.

176. Waring So there wasn't independent tests.

177. Olivier Independent test. The guys that were manufacturing the mirror with their little gadget that they manufactured it with . . . .

178. Waring Were using that same device . . . .

179. Olivier That process of manufacturing it and saying it's good also was the qualification. We didn't have an outside group of people or even the same people with an entirely different piece of measurement device come on and say "Check it."

180. Waring The test equipment itself had not been checked.

181. Olivier It had been checked, but there was no cross check. I didn't take one more ruler and put it on that ruler and say "My ruler says something different than your ruler." It's only one ruler see. Everybody kept saying, "This is a good ruler." So everybody that was asked to check on it, they were real firm on how good the ruler was. That was a problem, and we fell into it the following way. We said, we got these requirements. This thing's got to be six feet by a 60th of an arc second, or a 60th of a wave length action. That's our spec.

182. Waring What does that mean, one 60th of a wave?

183. Olivier If you have a wave of light and the whole light was coherent, it was vibrating all together, a wave came in parallel, hit that mirror bounced up, hit the secondary mirror, bounced back, and came to the focal plane,

it should still be detecting a flat wave. It shouldn't have any little humps and things in it. So you measure the fraction of a wavelength this thing is out of [034?]. That's the wave error that you don't want. Over a 60th of a wavelength at a 6328 angle. That's how good that wave must be when it hits. That was the measurement. Use a parameter for that. How in the hell can you come up with another way to do that? Couldn't think of another way. Laser unequal path and a parameter is the only way that we knew how to do it. We don't know how to do it again. Well, there was one other way to do it. That is you build a whole telescope and you build this big flat and then you shine a light, a star up through that whole telescope right back up through that flat right back to the telescope again and you, what they call allocolomate. Send a light out, hits the flat, comes back, and any error, since it's gone through the telescope twice, you divide it by two, that should be the error of the system. To do that would have required a tower about 80 feet tall, isolated, a big flat that was about 100 inches in diameter. Perkin Elmer didn't have the facilities for that and that would have cost us tens of millions of dollars to have built something like that. It would have been fantastic. Perkin Elmer wasn't set up to do that. They didn't propose that. We got in the program, we said, "How can we measure it at some reasonable way as accurate and double check?" Man, we couldn't come up with one. The flaw in the thinking is, hey guys, "It ain't got to be exactly that accurate. Give me sanity check. Give me another way to do it that if it is close enough so that if it was within that sensitive, that tested, it wouldn't be a polar disaster on orbit. . . . sanity check, I want a cross check, but it ain't got to be as good as the other way." It's just got to be good enough to it won't be a disaster if you fail it, if you didn't to it. That was our thinking. We talked ourselves into not coming up with another way to do it. By the way, I'm not sure there is a good way to do it that's still not still very expensive. It wouldn't be a factor of two or three [070?] and that. We didn't even apply that mentality to that. See what I mean? With AXAF, we're learning. Man, we cross checked, we tripled checked, we checked everything. I mean it's unbelievable how many cross checks we do. We got the cross check on cross check on cross check at Perkin Elmer on those mirrors. We've got cross checks that go back?. Then we'd bring it over here and put it in this big x-ray tank. That's our final check before we went along. So cross checks. Cross checks, particularly in these optical systems where we got burnt before. That was a lesson learned. That was a paramount lesson learned. Be sure to have cross checks in the systems. . . . optical service. Those things are so precise that they're very difficult to measure and they've got be systems level tests and that's not as simple as putting two different bolt mirrors on it, two different rulers. It's got to be an independent way to measure these things that do so difficult that you could measure them one way because it's too hard to come up with another one. . . . about a million dollar facility had to be built to do that.

184. Waring That's the . . . .

185. Olivier X-Ray calibration facility.

186. Waring I don't think I've been into that one.

187. Olivier You ought to go over there. It's an eye-opener. I'm not talking about Hubble any more, but it's impressive.

188. Waring Did they move that? Is it in the same place it was? It was originally designed for HEAO right?

189. Olivier Right.

190. Waring Was it moved or was part of it disassembled for a time? I'm not talking about the, there's a vacuum chamber there isn't there as part of a long tube. And then there is a long tube? Seems like I went looking for it. I was on a tour with Mike Wright.

191. Olivier A long time ago, it was on a small version of what's over there now. Small vacuum chamber, shorter tube. . . . government does it. We want facilities money to build a new x-ray calibration. Can't have it. Can do that. Can we get money to modify the facility? If get money to modify it, why can't you new? Because if we've got money for new, we'd left that old one, we'd built it, there were better places to build it than that. We'd built it in a lab, we could have got it, it would have been a lot better, but we couldn't get money to build a new facility. So, this chamber that it was in was only about 1/4th the size of the chamber. That chamber in there now, you can put a whole shuttle payload, that's a huge thing. You can put a whole shuttle payload that's 24 foot diameter, big. Tube is 1700' where the other one was about 1000'. All the sources are better. Everything is different. Clean room is better. Building is bigger, but we left one wall up. Tore the whole building down except that one wall. Took the chamber out, took the tube out. We left part that we used, some of the down streamed tubing, just left that wall, so we modified that facility.

192. Waring Well, it must have been. This was a couple of years ago, or maybe even longer ago. But when Mike and I were looking for it, it was probably in that construction phase.

O: If you drive down by the picnic area down there now and look across and see that big tube going down there, that's it.

193. Waring Right. Because we had a map and there wasn't anything that looked like that there. Well very good.

194. Olivier Well, I've got off onto AXAF now from Hubble.

195. Waring Well, no, that's, why don't we . . . .

196. Olivier I think that's all I know to tell you.

197. Waring I may have some questions for you here. I took a lot of notes today. [turn tape off 130]