INTERVIEW WITH FRED WOJTALIK
INTERVIEWED BY STEPHEN P. WARING
HUNTSVILLE
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1. Waring Could you give us a brief overview of your involvement in the Space Telescope project and that sort of thing?

1. WojtalikI joined the Space Telescope project in 1983, approximately in March of that year. After that, I was the laboratory director and I was brought into the project to expand a system engineering function, not only here at Marshall, but also with our prime contractor, Lockheed in Sunnyvale, CA. Lockheed was the prime contractor and had the responsibility for a level 2 system engineering along with the Center, but it was viewed by some outside independent review teams that insufficient resources were being expended in that arena. So I was brought in by Dr. Lucas to expand that function and to become a deputy project manager, strictly associated with systems engineering. At the same time there was to be and was a second deputy project manager that handled the programmatic. In that time frame Jim Odom became the project manager so therefore we became a team. We certainly did look at the resources being spent and found that they were possibly adequate up to that time because we were entering the more expansive development integration period of time that we needed additional support. The contractor was therefore funded, this is Lockheed, in order to bring more people on board and we divided the system engineering into some 11-13 different disciplines. As and example, electrical power

management, networks, contamination control, communication, software. To augment it here at the Center, to bring the Center more into doing its job as oversight responsibilities for the government, we established the systems division within our systems analysis and integration laboratory devoted solely to the Hubble. We also established, along the lines again of 11-13 specific discipline areas of key interest, we had what we called review panels. Sometimes called working groups, depends on which project you are in and what period of time its in. We had a chairman, who was a Marshall employee, usually responsible in the sense, usually because as time marched on that was not totally possible. For example there is a laboratory in the center responsible for electrical. At that time it was the Informational Electronic Systems Laboratory, today they are called SCI. They have communications. Now there are division chiefs responsible for that within the laboratory. So we tried to go as high as we could in that chain to get the person who is regardless of whether he is spending a lot of time on it or not, responsible to answer to the Center that that system is meeting its requirements and one day he has to stand up and say it is ready for the mission. So he is fulfilling that obligation for many projects. What we try to do is capture some of his time or her time, to be devoted to specifically the HST in a function that he has to do anyway. Uses his people in order to do that in most cases. So then under that person who was the chairman of that review panel, we placed some of his people who are normally assigned anyway as his support, under his direction. Then we

have additional folks from the outside world that either had specific interest oversight in some cases, or they in their companies had the same responsibilities. Let me explain that. Lockheed, of course, you had the person who was responsible for designing and developing the electrical system in that panel and he had some of his people. From an oversight viewpoint we have the science working group make assignments. There was a second oversight organization at headquarters had established where they had support contractors from BDM, maybe you just want to call it support contractors at that time, who again divided themselves along that same line and they monitored all the sessions. It was a give and take and it became over a period of time a family arrangement. Those things are the way, organizing ourselves that way we progressed from that day forward all the way to the launch utilizing those teams. It became efficient for us to do that because as we went along, not only are the requirements being met the best you could tell from the data, but problems arise. Sometimes the problems are from within that discipline of itself, but many times it was a cross interface, so you had people from other panels discussing it and working it out. You knew exactly where to go, if it wasn't you had to create a ad hoc group again. They became, I think, very much, the feeling was hey this is my area. They were the sponsors of this solution and devoted a lot of their motivation time to get it get done on time.

1. Waring Would you say that network outsiders was anyway different from other projects?

1. WojtalikIt probably was a larger expansion of things that are normally called working groups. I had come from the HEAO project where I used working groups along this same line and it worked very successful for me, so when I was given this task and asked to strengthen that arena. Marshall has the definite government responsibility for oversight. We did a lot of things in Hubble also to support the development by agreement with Lockheed where our resources were better than theirs. Example, we did all of the battery tests both in nickel cadmium initially and later we went to nickel hydrogen batteries pioneering those types of batteries in low earth orbit. That facility is still operating in support of Goddard during the operation. We have batteries that are life batteries taken out of the same loft of manufactured batteries that flight batteries came from and we are about a year ahead, a little more than a year ahead, of the mission. So if we start to see anything on our battery testing here, it would be an indicator that maybe you are going to start seeing it in orbit. We also in order to make it realistic and such, we do everything that has gone on Hubble that is considered normal operations, where you don't go off normal pointing, where you don't charge batteries...

1. Waring You are talking about right now.

1. WojtalikRight now. We did it before based on modeling of what a normal mission would be. If they do anything different today

in the mission, that's usually tried here first if it is something that has never been done before. I will give you an example, the servicing mission required that you be without sun power for so long for battery charging. How long can you do that, what temperature the battery is going to be at, then you get orbiter power for maintaining triple charges and everything. But all of that was tried here before we said this is the scenario that we can live with in orbit.

1. Waring So, to get this correct here, the Center is running a power...

1. WojtalikIts a breadboard. It is called a breadboard. It simulates everything as far as loads are, voltage type condition, current conditions. So all of the loads are like we have in space, the temperature is what we have in space. If they do something such as they want to go off the sun line so long, that is going to be a different charging profile, load profile, how long can they stay out that way, how long should they then not disturb the system so it can get back all of its energy. All of that is tried here before it is done on the vehicle. That will continue as long as Goddard believes that its beneficial to the program, chances are it will continue quite for the next several years, at least. We did things of that type, I simply use that as an example. We did testing here for Lockheed where we had the ability they didn't, etc. It was very much a compatible, supporting arrangement and I believe worked successfully. Hubble

did a lot of things that people not in the program did not recognize it was doing. For example, pioneering of the nickel hydrogen low earth orbit. So those batteries have been used and are used today in geo-synchronist, high-orbitty that are constantly in the sun. But no one has ever used them so many times a day with light and dark, charging and discharging. We probably, we pioneered for example, at that period of time a lot of epoxy-graphite that people used, but not as much as we had on that vehicle. Now it has been pretty much publicized, but before then people knew we were working on it, but nobody much thought about it. There were more items that were actually designed for servicing on Hubble than have ever previously been designed into a vehicle. And as the last servicing mission provided evidence of what that meant to the system. Had the system not been designed for servicing, the astronauts I am sure could have taken care of a lot of things, but it would have been a lot more difficult and probably wouldn't have been able to be done in the time frame that we did as many things as they did.

1. Waring When you came on in 1983, wasn't there a decision to expand the number of items...

1. WojtalikWell, there is a history in that. See I am going to give you some of the things that I was on the outside looking in, but Hubble started off with the requirement that every five years it was going to be brought back down to earth and resurfaced completely. As time marched on and approximately in the time

frame of 1982 when I came in, it became very evident that although that is possible, it was going to be very costly and maybe there ought to be another way to do this. What they have done instead of allowing ourselves to presume that it is going to be on the ground where you can get at all places and you have your hands with rubber gloves, you don't have these astronauts with gloves and so forth.

1. Waring The original requirement of five years to bring it down to earth?

1. WojtalikIt was changed to say that we are not going to bring it down and see how many things we can make astronaut friendly and replaceable. So we went from some five items in 1983 that most people thought, hey you are liable to have to do something on orbit with them anyway, even before the thing gets down to the ground, to see how many other things we could make that way. We went from some five to forty-seven that became units. But we have to build special tools and procedures, things of that nature.

1. Waring Was that worked on primarily here at Marshall too?

1. WojtalikIt was done again as a team effort. There was some pieces of equipment that weren't Lockheed. There were others, like at that time Perkin-Elmer. Lockheed had the majority of them, either as items that they built or subcontracted. The

solar wings for example were replaceable units. Where Marshall fit into the scheme of things, we had people who were helping our contractors with advising, the schemes. We also had the astronaut crew that was assigned to us. Cathy Sullivan in particular and Bruce McCandless, both of whom have space missions before. When we start talking about what kind of tool and what we are going to do, we had them also to consult and give us advice. Tremendous amount of testing was done, both at Lockheed where under one g they tried, for example if we had a tool we said something, first thing was after kind of a breadboard design was made, the astronauts would actually use their gloves and see if they could do it there. Then they went into the neutral buoyancy simulator. It was a joint effort. It wasn't just Marshall or all Lockheed, it was a team effort all the way.

1. Waring What you have said so far has suggested several things for follow-up. Could you explain why systems engineering was such a tremendous challenge for the Hubble Space Telescope? How would you explain that to a general audience? Why was it so...

1. WojtalikI guess the way you want to look at this is at that time-frame and it goes to funding again. In the early days prior to '83 the project was with very few resources. Together as a team a decision's made as to what they should be putting their money on in order to keep things going and not run into a lot of trouble. However, there was a problem that occurred. You know one of our contractors, I really don't want to get into it if I

can stay out of it the project seems easy to clean up, there was a delay in the process due to some technical problems. So an independent board was brought in to look at what was going on. One of the things that they assessed, and it was very true, there was a lot of system engineering at the level 3. When you looked at level two which meant between one organization and another there was not as much as they thought necessary.

1. Waring So basically with the shortage of resources the managers made a decision to spend more money on hardware than systems engineering.

1. WojtalikAt this point in time. But also when one looked underneath the tents, the early paperwork, which meant interactive work, ICDs, IRDs, CEIs, all of that were very well done. So there was systems engineering going on in those days, but you didn't see an organization called Level 2. You have to also understand that we were, in that time frame, just starting to build up where spacecraft was starting to make its thing, the glass was already made. It was made in 1980 I believe in that time frame. Anyway, the pieces were now pretty much starting to roll, getting put together, and now you're going to be talking about integration. More level two people have to come on board. In addition, it became things that time marched on more obvious as the result of analysis and so forth. I'll give you an example, contamination, although definitely a concern because particulates, if you got enough of them on there it's like

putting, if you put all of them together it's like putting a sheet of paper over an area. You've lost that sheet of paper area. The more of that that you had on there, the less energy you're going to collect. You also get dispersions. The next point is if you had any molecular to a certain level of thickness, we could not do ultraviolet investigations. So contamination both from the molecular and particulate was a great importance, but it became more important as people started looking at more analysis of the data and so forth, so an extreme effort was put into making sure that we kept everything clean and in fact we probably at that time were probably the cleanest spacecraft that ever went into orbit. . . . I'm not sure, but we're talking about launching in about 1990 . . . went into that. Systems engineering which was one area brought out and the other was trying to get on board with making sure your operations are ready when you're going to integrate and it was not a different operations kind of scenario as to what we wanted to do, but by the numbers of experiments that we had and the numbers of the things that they wanted us to potentially look at in real time and be able to o have a quick reaction time for example, you could of have some super NOVA occur and want to swing from this observing program that you're in to another. It had a lot of attention, a lot of effort went into trying to do that in a good way. It was a big spacecraft, the biggest that went up there for a long time. So it had its challenges. We filled up just about the whole cargo bay on the shuttle. That itself is a challenge. The shipping something like that, keeping it clean from

California to the Cape is not some simple task like putting it on a truck. We had, at one time we planned to go by sea, but anyway, all the plans were generated for that to be sure that this vehicle took a lot of money and a lot of time and meant so much to the nation and the scientific community, we kept it safe. We plowed a lot of new ground in that regard. Ultimately it was shipped by air. The Air Force had a technique that could accommodate us and used the air shipment. Systems engineering had its role and it had an important job in this, but I want to say when one looks at the evidence, there was early systems engineering and then because of funding resources, it kind of moved into level three and became not as interactive as it should be and then of course in '83 and subsequently became interactive. The reason the outsiders may have looked at it as if very lacking . . . Hubble had a tremendous amount of contracts and there wasn't really one person other than govern maybe you could say that was over on top of all. Although we had a prime contractor, that contractor did not have the contracts with the science instruments. That was with Goddard. Marshall was the prime contractor, or the government agency responsible for the operations were Goddard's, the instruments were Goddard's, the interface was Goddard's. . . . for the mirrors with Marshall's, wasn't Lockheed's. Lockheed ended up with the spacecraft and also the solar wings were out of an agreement between the Government and the Europeans. Lockheed, although the prime contractor and they had a lot of prime contractor responsibilities, they did not have the contractual inroads into

the space systems. Again, systems engineering working under the government which was the bridge viewed to be a necessary thing to have implemented and we did.

1. Waring OK, another question which came to mind was what sort of, well, what was the impact of the Challenger accident and the delay in launching the telescope? How did that affect the program?

1. WojtalikOK, we were in the beginning, just starting the integration, environmental tests and so forth when that happened. What it meant is after we had completed in June of that year, the last of the environmental tests which was thermal vacuum.

1. Waring In '86.

1. WojtalikYeah, and we found several things that had to be, usually in thermal vacuum, you'll find one or two items that you need to change a little bit because many time you enter that with model data that says you should do this and find out that thermal protection in one place isn't as good as the other. So we had some of that that came out and had we been left on that particular schedule to launch in '86, latter part of '86, it would have been a challenging job, not to say it couldn't be done, but we would have to have worked a lot harder and a lot longer to make these corrections and retest on smaller scales to make that launch date. When this happened, of course the

realization that we may be on the ground for several years came into play and of course the corrections for those technical issues were scheduled, but were not longer on a fast paced. We did something else. At that time, we had an army on board that the contractors had all built up in that time frame. Luckily Lockheed still had a lot of business because of DOD type work, so they shifted many of their key people that we would need ultimately off onto other programs. So we operated on a small padre of necessary key people in the program and we began to do retesting. There were a couple of times when it was sitting on the ground and you know you'll have somebody else that has a problem and they say we found it. It's a result of this part having the program. If you have this part in your equipment, you might think about getting it out and we got caught by a couple of those so we ended up having to change parts and do things a little different. That's potentially a blessing, although on the other hand, many of the reasons why those parts weren't good was because they were on the ground, moisture got into them, and things of that nature. Anyway, we had that type of thing . . .

1. Waring Did Marshall, did Marshall shift some people away from Hubble?

1. WojtalikWell, it happens but there isn't that much work, so they did move on. We were also doing more operations etc. with Goddard. I can't even remember the numbers now, but there was a

shifting in just about every contractor and every organization. . . . never be able to retain.

1. Waring OK. Let's talk about operations. Could you describe Marshall's role in the operations of the telescope?

1. WojtalikI can do that and then you need to ask Olivier as well, because he was actually running one of the teams. As I said, Marshall was responsible for the entire project and of course we viewed Goddard as a sister center that we held responsible for designing the operations for Hubble. In that of course they met all the requirements. They had a subcontractor doing that for them. There was a lot of at that time under the review panel arraignment but they also had separate committees and groups and interactions that they normally called the operations working groups etc. For a period of time we met all of the necessary windows that have to be done. You've got to have practice sessions at Johnson won't let you launch. They call those joint integration verifications sessions. That may not be the right thing, but ask Olivier again! Anyway, all those windows were passed. We did all the integration, simulations, and these things are done where there'll be a group of people creating problems for you just to see that the team in knowledgeable enough to be able to get around it to sit down and resolve problems etc. So all of that was done and of course the arrangements were after that we launch Hubble, within a certain number of months, after we complete spacecraft verification,

observatory verification, and science verification, that it would then turn itself over to Goddard. Goddard would be the manager and we would be in support as long as they needed us. . . . the length of time . . .

1. Waring It seems like three months.

1. WojtalikIt was three or a little longer because we did run into some problems as you know. During that time, Goddard was still operating in the same way that we did previously where they provided us the service. They had the facility. They had the science institute that was going to do their contract . . . the observations in order to do what would have to be done to first determine that the bird was alive and working well. Next to do all the calibrations that have to be done and if you're trying to get 10th of arc seconds and all, the calibration is not just simple start from. The first finding where you are and then incrementally making, tightening the circle so to speak. You get results and you've got to modify things, etc. All of that took some time. During that period of time, Marshall had at Goddard a cadre of around 25 people, I'm guessing at that now . . . around the clock operations, supported of course by Goddard's people . . . had the mission operations manager and again we had three shifts so we were alternates on second and third shifts and we had one prime individual. We had engineering teams there, systems teams, and then we had that supported by direct engineering support out of the HOSC where we had a laboratories

and some of our support contractors including Lockheed. You couldn't have everybody at Goddard, we had that augmented here in case we had some particular issue came up and we had the right folks.

1. Waring Sort of a ballpark figure, how many people at Marshall involved in that? '50 or '60?

1. WojtalikYeah, I'd say in the '60s. You might even be more talking seven days a week. You've got to have 5 shifts of people.

1. Waring OK. [turn tape over 432]

1. Wojtalik. . . until if was sufficiently determined that we had characterized what the bird was, what its . . . were, which features were going to be a little bit of a problem but at least understood what they were and how they could live with it. In that time frame a transfer was made and the project became Goddard's total, and they used us to help them in refining some things like the control law that needed to be refined. We continued that for approximately a year, pretty diligently in some areas. Most of the knowledge is done with except for the battery area and we still support the power system area and we still support as we did for the first servicing mission, the facility here at the center, the neutral buoyancy simulator is heavily used, it's being used again for the second mission.

1. Waring The power system support is still going on and then for the manned side, the repair side, MBF, it will be used.

1. WojtalikIt will be used.

1. Waring Could we talk about Marshall's role in the repair mission itself? The first one?

1. WojtalikAs I told you previously, all these scenarios that they wanted to go through and exact times what they wanted doing, temperature wise and all were duplicated for the power system. Very key to being able to again deploy it to meet Hubble and be sure that your power system which was not being replaced was healthy. All that was done. As far as neutral buoyancy simulator, the lever of which that facility was capable of supporting a mission was not sufficient based on what the astronauts wanted to do. They wanted to have six hour EVAs and we were operating strictly on an air breathing system, breathing air rather than enriched air which is called nitrox. It has a lot more oxygen. Upgrading that facility in order to do that, when the message got out that in order to upgrade it to that level, the time frame was very short and people again, in contractors and governments, . . . etc. I think did a really good job. They got it ready in time for them to practice and . . . and Johnson were very pleased as far as I now. We had all sorts of accolades come in here.

1. Waring Do you remember how long a period between when they knew they had to upgrade and when they did it?

1. WojtalikRoughly January the word came out and like February the money. We knew that. They were ready for a full scale uptest I believe in October. If you want to access somebody who was responsible for doing that, you need to talk to Jim Strickland. He's in, do you know what EL lab means? Its systems analysis and integration lab. Try talking to him on the phone. But January is when we really got the requirements. February, they started the CV sources, funding coming in and in October, they were ready for that test.

1. Waring What year are we talking about? '91?

1. WojtalikLast year.

1. WojtalikLast year, '93.

1. WojtalikThe other thing that the astronaut corp was very much wishing to have was the remote manipulator arms that are available or were available since their simulations . . . exactly what happens on space. You try to do the best job you can, but you've got to make them more rugged because they are still affected by one G. We try to essentially neutralize the effect by buoyancy in it when it's in the tank. Well, none of them as

far as the astronaut corp was concerned was as good as they'd like to see when they reflected what they had in orbit. So they asked for a higher fidelity arm at Marshall and again that was done in the same time frame. Currently we have the highest fidelity arm simulated system that exists.

1. Waring RMA?

1. WojtalikRemote manipulator systems or . . . You might want to check that out too!

1. Waring OK. In terms of the hardware of the telescope itself that needed to be analyzed for the problems and then new design or fixes proposed. Was there a Marshall involvement in that area as well?

1. WojtalikAs far as I, for example the aberration that was seen at that time before the . . . ?

1. Waring Yes, I've read that.

1. WojtalikWell, at that time Marshall was still responsible as a manager and likewise we've had people that understood a little bit of what the equipment was there better than Goddard did at that time. We got the task, or received the task of trying to characterize the aberration. . . . data from available equipment. Again, going back to the alum board, you remember the

nolle corrector that was responsible essentially for creating this problems were used in actually the situation where the problem actually got created . . . the equipment fortunately for everyone was still available. . . . the culprit and it was a matter now of meticuously measuring the spacing and etc. and that use of equipment and then cross checking and verifying what the results were, would have ended up showing what basically what you saw in space. All of that was done at Marshall of course with Goddard's support at the time working with us. . . . very much interesting in getting the right results turned over. On course once that's known, then you can come up with a prescription essentially for correcting that. Now you loose a little of that in the process, but they didn't loose a lot. In fact, . . . part of that. We were part of helping to settle down the control system when the solar wings that prior to replacement were there. We actually provided info for information and control log that dampened the wings sufficiently to where a lot of science was done prior to the servicing mission. On the servicing mission, we would get calls from time to time about some question somebody had, but the majority of that work was done by Goddard. Thing I wish you could put in there because I still believe a lot of our people just haven't been given the right amount of credit for designing the vehicle to be serviceable. It only came out in the media in the last maybe two interviews we had . . . a lot of people worked like I told you Lockheed, etc. Perkin Elmer at the time and a lot of things in servicing that made the mission possible. . . . was actually cheap. I'm not taking anything

away from anybody, but I think that old work made a lot of things . . . and an easier fashion.

1. Waring Could you expand on that a bit and talk about some of the things that were done to make it serviceable back in the early era?

1. WojtalikWell if you don't have the right kind of connector that an astronaut can hold on to, you're liable to do two things. One, you may not be able to get the connections broken or he might, through no fault of his own, end up damaging things. Marshall build him tools that he can have access items the chances are he will not be able to get them off. We had again, the way this thing was designed initially, many many connectors in very close proximity and very tight locations etc. the right kind of equipment for them, the right procedures, it becomes very difficult. The astronauts have shown to be very capable and even vehicles where they weren't designed for servicing, they've done a good job. But the numbers of things in the short period of time that were accomplished . . . I thinking and worked on it. It was things like that.

1. Waring The hand rails and all that sort of stuff. You worked on the HEAO project. Could you compare and contrast the work on the two projects? How were they alike and how were they different?

1. WojtalikHEAO was of course restructured into three vehicles. TRW was the prime contractor on the HEAO program. They were much smaller . . . less. Contamination was of course a question but not to the same level as we have here. They were non serviceable. . . . times on them in the order, you now 1 year, 2 years, and all. They all lasted longer than that, but that was the lifetime on them. . . . during operations phase were not as real time active so you had a challenging job but it wasn't as challenging as Hubble. . . . of course became less of a problem because they were small. In that time frame they weren't simple tasks either!

1. Waring Were there lessons you had learned on HEAO that you can remember yourself applying to Hubble?

1. WojtalikWell you learn something from every vehicle. One of the lessons was I think working groups worked well for us, so I put that in on Hubble. It also gave the Center a feeling of ownership more so than if you didn't have that because each element began, "Hey this is ours." The other thing is testing is very important to me, and I'd hate to send anything up without any test time on it. On Hubble, you can almost say, and some people have said it, by virtue of it being on the ground so long, it ended up getting tested and tested and tested. On the ground we didn't have hardly, we had some problems of course, but not any indication that it will have solar wing problems. Of course we couldn't deploy the solar wings except on a water table and

that was done in Europe. But all the gyros worked well. We had no hiccups, no indication of any problems. I'm getting into inuendos now because we started off with a program that was supposed to launch in '86 and you go to '90 and you look back in history of when objects were picked. Many of them were not state of the art at the time we launched, but they were still good pieces of hardware. There was not indication they would not meet their requirement, and they are meeting their requirement. One of the key elements in Hubble is stability. If you're trying to get a resolution, you also have to have stability meaning no disturbances. The vehicle goes through transitions and so after maneuvering you will have some vibrations in a vehicle that big. It has some flexibility and in its quite mode, we're talking many times, three millia arc seconds requirements is seven millia arc seconds. I don't think anyone that I know of now, there may be things out there that I don't know that has achieved it. It's another place where state of the art and beyond has been achieved. I like to see testing done on a lot of hardware and not just one time but several times and this program is built well so that you ended up saying what I've got is true and I can believe it. We paid a lot of attention to that. We've learned though, we've all carried them. I had trouble with some gyros in the program, so I was worried about gyros, but we didn't have much of anything on the ground with the gyros. When we got to space, they lost a couple of them, lost several of them.

1. Waring Could you expand on that perhaps in talking about the lessons of the telescope program?

1. WojtalikOne of the lessons was to try to get contracts in the future or get programs in the future to be maybe less fragmented. . . . the level that we could is being done on the future things. I really don't want to get into where it may go because things do change with time, but that's one of the things. Like the prime contractor that has more things under his control. You probably, and is better off because that person feels more responsible for all of it and it also has the ability to take action faster. That's one of the lessons that people try to adhere to. I'm getting into areas now, and I'll tell you this that I don't expect to see in the book or anything because it's obvious that front up money helps you right. . . . since I don't know when, but front up money doesn't come.

1. Waring Front up money meaning in the design phase?

1. WojtalikWhen you start a program, make sure your requirements are right. Make sure you have all your difficult tasks, that are technical challenges proven and behind you maybe before you start spending a lot of money bringing the Army on board. That's a lesson learned from Hubble. When you start looking at how your funds come in, you can't get the money. I don't know when and if ever that will happen, but everybody knows that is what you

should do. Everybody quotes . . . improvement, and PQM where the Japanese had expounded that and where Demming has expounded.

1. Waring You're building quality from the beginning.

1. WojtalikFrom the beginning. How can you get all that money and do all that thing early when you don't maybe have a new start? Once you have a new start, you can't say I'm going to mess around here for several years trying to get my technology behind me. I don't know. It's a lesson that's learned, but I don't know how practically we can implement it. . . . philosophizing and that's why I don't want to, I really . . . .

1. Waring But something I've talked about in my chapter draft, in any project, there's technological problems that have to be solved. There's an engineering way of solving problems and then there's a political process that NASA's part of because its part of it discretionary part of the budget and Congress' funding of NASA follows a different logic than the engineering logic within the Agency.

1. WojtalikSee, now out of Hubble, the mirrors were lessons learned because that's where, although it wasn't the mirrors. In '83 when I said, we ran into a problem technically that all of a sudden put a screeching halt on a lot of our plans . . . .

1. Waring With the Optical Telescope Assembly.

1. WojtalikIt was the . . . features of that assembly other than the mirrors. The mirrors were already done. They were in storage, but the contractor ran into technical problems with the fine guidance system which currently today is operating great. But anyway, that put a screeching halt on a lot of things and Lockheed was expecting to get that optical assembly on a certain schedule. They had the Army so some funds were lost before they could start off loading people, and they did it then to. So when we got into AXAF which is a project we have now, Congress, some people remembered this company that made glass and mirrors had problems. Trouble is it wasn't the mirrors where they had, they thought they did a good job on it. Let's face it.

1. Waring The technology worked perfectly. It was the measurements that were off.

1. WojtalikAll you can say is human error unfortunately and you've read all about that and I won't open it up again. They though they had a beautiful mirror system. Where in that outer one third, it is beautiful and in fact that's what kept us alive because what we could see, we knew the prescription and what you could see you could then enhance accurately. But what you can't see because you've lost the light, you've lost two magnitudes of light . . . recaptured.

1. Waring You were going to say something about AXAF?

1. WojtalikYeah, well I'm saying that Congressional, some Congressional people remembered that this company was also building AXAF mirrors even though it's not the same company. Now its Hughes, Danbury Optical Systems. We ought to be out to have a show that we can build these mirrors so they gave us a mandate that we can start the program, but on a certain date, our date and our schedule, we have to prove that those mirrors met the specifications. So, you know what the x-ray cal facility is?

1. Waring Heard of it.

1. WojtalikIt's a facility that we had in HEAO because we had real beings, that is essentially a thermal vac. chamber connected by a long tube which can be vacuated where there is an x-ray source. . . . the focal length if you are dealing with the length of that tube has got to be longer or shorter. . . . since it's got a vacuum chamber, it's not like that's the only thing it's ever used for. And this one is being the work horse. In that sense, we built that which we have to have for the AXAF program and the time frame it took to finish those two, they said which mirrors are the toughest. Well, the two toughest mirrors are the outer mirrors, the biggest. One a parable and one a hyperbole on it. They said CK, build those prove to us you met the requirements and then we'll let you really go. Essentially we got funded simply for building those mirrors and we did it and then they gave us the go ahead.

1. Waring When were the mirrors tested?

1. WojtalikThat was . . . dates are starting to go.

1. Waring That's something that would probably be a paragraph in the conclusion anyway, talking about new projects.

1. WojtalikIf you want to know a lot of the scientific aspects of it, Martin Wisekoff is somebody maybe you want to talk to about AXAF.

1. Waring Who would be the best science person here at the center to talk about Hubble?

1. WojtalikWell, you're probably gong to have a problem. On Hubble, the project scientists, well I'll put it this way. There was a person here by the name Dr. Frank Six. You probably know him.

1. Waring I know his name. I haven't met him.

1. WojtalikHe was essentially the project scientist in residence because at that time we had a project scientist that belonged to Goddard who didn't want to move here. We lost the two or three that we had. Started off with Dr. O'Dell and then Dr. Brown is at the science institute and he got out of it and we ended up

with, I can't remember his name. I'll think of it. While he was there, Frank was kind of in residence here. Frank knows Hubble and knows what it is doing and so forth. He'd be a good one to access. He works for Rick Chappell on the ninth floor.

1. Waring Very good. Thank you for your time.

1. WojtalikWant me to send Olivier in here or do you want to break?

1. Waring Let me take a break. [end of tape 725]