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G. SCOTT HUBBARD
INTERVIEWED BY SANDRA JOHNSON
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JOHNSON: Today is August 20th, 2018. This interview with Scott Hubbard is being conducted for the NASA Headquarters Science Mission Directorate Oral History Project. Dr. Hubbard is speaking with us today by telephone from California and this is the second interview, the continuation of our first interview we had a year ago. The interviewer is Sandra Johnson. I appreciate you talking to us again, and I'm sorry it's been almost a complete year since the last time we talked.

HUBBARD: My pleasure.

JOHNSON: You had mentioned before we started that there was an episode that you had mentioned in the last interview that you were going to get back to, and then you didn't in that interview. So let's start with that one, and I believe it had something to do with [Former NASA Administrator] Dan [Daniel S.] Goldin.

HUBBARD: Yes. This goes back to about 1995. This story is really about the origins of the NASA Ames [Research] Center [Mountain View, California] assignment of astrobiology and something else called intelligent systems, which is a computer science discipline.

There's a phenomenon that you can document by looking back through the history of NASA that every time an [NASA] Administration changes there is often a move to realign Centers, reorganize Centers, and even close Centers. It seems it's tied to the political cycle. When NASA was born it was sized for the Mercury, Gemini, and Apollo Programs. Ten NASA Centers were created in those early years. For the 10 Centers, at that time, there was a huge amount of money put in over a very short period, and there was work for everybody. Then as I think I said somewhere else in the interview around 1975 [President] Richard [M.] Nixon made the decision to pull NASA out of its special category. The funding which was already going down got reduced to less than a percent of the federal budget, and that's where it's hovered ever since.

That meant that after the Apollo Moon landings 10 Centers were scrambling around competing with each other for a much smaller pot of money. The answer that numerous Administrations have had is well, why don't we close X number of Centers. In 1995 or thereabouts, the early '90s, Ames, which had been a target in the past because as a research center some people viewed that as being less critical than the flight centers, the ones executing the missions, once again became targeted for possible closure. This was in the early days of Dan Goldin's tenure as NASA Administrator, He was named by [President] George H. W. Bush in 1992 and then transferred and stayed on, one of a handful of political appointees that made it into the next administration, which I believe would have been [President] Bill Clinton.

Goldin's first job was to save the Space Station, which happened by one vote [June 1993]. Then Goldin announced that he was going to turn his attention to the makeup of the Agency, the centers and what they did. There was an infamous "red team white paper" that was produced that said, "We don't have enough money to fund everybody, so we're going to close a

couple of Centers, and we're going to close NASA Ames". Or at least we're going to reduce it down to just a few hundred civil servants working only on aeronautics. The planetary science work there, the space science work is going to be sent off to either JPL [NASA Jet Propulsion Laboratory, Pasadena, California] or [NASA] Goddard [Space Flight Center, Greenbelt, Maryland], and life science work is going to be sent off to Houston and the [NASA] Johnson Space Center [JSC]. Then we'll have everything properly aligned.

Of course in political reality Centers have a close relationship with local elected officials because they represent thousands of jobs in a given district. We had a Democrat in the White House and Democrats in the Congress, and there was a very very tense moment when Dan Goldin flew out to attempt to get an agreement with the guy who was then the Center Director, Ken [K.] Munechika. He wasn't there very long. He had been a Colonel or Lt. Colonel in the Air Force.

Goldin came out to get him to agree to reduce the number of civil servants from about 1,300 or so to 300, and to give up those assignments that the Center had and become just Ames Aeronautical Laboratory or something like that. I wasn't as high in the administration of Ames as I was later on, but was with a group of people there who were intent on saving what we saw as a very unique capability in science and in research.

It just so happens that word of this impending massive change got to the local representatives, the elected officials, about the time that Dan Goldin showed up. Dan had a piece of paper that he wanted Munechika to sign that would effectively reduce the number of civil servants by a huge amount. As this negotiation was going on there was a call from the Chief of Staff at the White House wanting to speak to Dan Goldin. Goldin took the call and he was told in no uncertain terms that he was absolutely not to do anything with Ames. In fact he was

supposed to give Ames assignments that were consistent with their capability and that would make them even more of a standout Center there in Silicon Valley, which after all was a major part of the American economy.

The net result of this was that Goldin, who had already put 300 as the number of civil servants at Ames, had to put a 1 in front of the 3 and make it 1,300, which was roughly the number that was already there. He went home properly chastised through the political process, and we, this group of us, about four, five senior people at Ames, had already been working on what we would do for the future.

We had three friends at NASA Headquarters. One was Wesley T. Huntress, Jr., who was then the head of all of science. One was France [A.] Cordova, who was then the Chief Scientist. One was Charlie [Charles F.] Kennel, who was then the head of what was called Mission to Planet Earth, basically the Earth Science organization. Those three folks and this group at Ames began working together on a way of characterizing the science that we did, which they thought by the way, honestly believed and said over and over again in public, was a unique interdisciplinary approach to solving questions like are we alone in the universe. It was an amazing meeting one Sunday afternoon. Wes Huntress was out there, I'm not sure if France Cordova was, and we were pondering what to call this field.

Cosmochemistry, which is one of Wes's favorite subjects, had already been taken. That was an existing discipline. People through different ideas out. I believe it was Wes himself who said, "Why don't we call it astrobiology?" This represented the confluence of Ames's historical work in space biology, with the Earth science work that was aimed at origins and evolution, and the space science work that had gone on through the Pioneer [Program] and the Galileo probe

and the people there like Jim [James B.] Pollack and Chris [Christopher P.] McKay who were interested in origins and evolution.

That's how astrobiology was born. As I recounted earlier in this set of interviews, I had the job of setting up the Astrobiology Institute, but the actual field was created, as things often happen, out of an existential threat to the survival of the Center. In addition to that, Ames's long long history that started with wind tunnels and computational fluid dynamics had become much more integrated with supercomputing. One of the very first Cray supercomputers was located at NASA Ames, way back in the '70s.

The other assignment came after Goldin had a chance to think about this for a little while—I think he had received lots of requests from congressional delegations and from senators and from the White House Chief of Staff. He went along with the directive, with the notion, of creating this new scientific discipline, and in fact really became quite enamored with it. He went on, Goldin did, to praise astrobiology as one of the forward-leaning things that NASA was doing. The other discipline, which grew out of the computational aeronautical work, was intelligent systems. The idea was to take advantage of Ames's location in Silicon Valley and connections to all the companies that were growing and the supercomputing capability and really advance the state of the art for space exploration of autonomous systems and highly sophisticated computation on leading-edge computers.

That was the backstory that I wanted to tell about the interesting origins of two of Ames' main roles in the Agency, astrobiology and intelligent systems, and how that came to be.

JOHNSON: I appreciate you adding that because that is interesting, and I've heard from a few other people we've interviewed different aspects of it. I do appreciate you giving the background on how that happened. As we know, sometimes things happen politically.

HUBBARD: Yes. But what happened in this case, and the two things that came out of it were good, made a lot of sense, a real contribution. Then shall we move back to where we left off?

JOHNSON: Yes, because it's interesting. Because like you said, Dan Goldin did ask you to become the person that set up that Astrobiology Institute. Then because of that experience with the Astrobiology Institute he tapped you again about coming to [NASA] Headquarters because he thought you did such a good job. He wanted you to—what you said last time was—"fix this mess" with what was going on with the Mars Program.

HUBBARD: That's right. Let me back up just a little bit more. In 1995, about the same time all of this other business was going on, there was an announcement out of the White House, out of the Vice President's Office, Al [Albert A.] Gore was extremely interested in science, about the apparent finding in a Mars meteorite of evidence of past life on Mars. This was a big deal. The paper was peer-reviewed and it was about to be published, and they arranged for this announcement that included Dave [David S.] McKay from Johnson Space Center, Dick [Richard N.] Zare, a professor at Stanford [University, California], and a number of other really solid people were on the paper that claimed through four different lines of evidence to have found some indication that there had been past life on Mars.

At this point there really wasn't much of a Mars Program. There was a Mars Program in name, but there wasn't a plan. Dan Goldin said, "We've got to take advantage of this apparent result and we need to really go after studying Mars in detail, and we need to bring a sample back as quickly as possible." He said, "I want to see an orbiter at Mars and a lander at Mars at every opportunity." Opportunity means a launch window, and a 20-day launch window to Mars is possible every 26 months. That's how the celestial mechanics work out with the launch vehicles that were available at the time.

As a result of that directive JPL and Lockheed Martin [Corporation] started work on an orbiter and a lander. But Dan Goldin added two additional conditions. He said, "This Mars Pathfinder Mission that this Hubbard guy thought of that was so successful, I want these two missions you're building, the orbiter and lander, together to cost no more than what one Mars Pathfinder cost." He wanted two missions for the price of one. And oh, by the way, you needed to follow his philosophy that he called "Faster, Better, Cheaper."

Experienced project managers shook their head in dismay because typically those three elements are balanced against each other and you can get any two of them if you give way on the third one. You can make things faster and cheaper if you give up on some of the requirements. Or if you have a lot of requirements and you want it faster you've got to spend more money. Goldin didn't want that traditional project management tradeoff to occur, he wanted faster, better, cheaper.

The Mars Climate Orbiter and the Mars Polar Lander were built under those constraints. The project people at JPL and Lockheed Martin in Denver [Colorado] were operating to try to reduce cost wherever they could. In the end, after the failure review board analyzed all this they concluded that the project team ended up taking foolish risks. You can take some risk if you

manage it and mitigate it. But they, as I'll come back to in a minute, ended up taking very foolish risks to meet those mandates of two missions for the price of one and everything faster, better, cheaper.

Mars Climate Orbiter was launched in '98. The Mars Polar Lander was launched a little less than a month later. They were right in that 20-day launch window. I was not part of those projects, but I was at JPL during the orbit insertion and then the landing time of the second mission. When Mars Climate Orbiter was supposed to go into orbit around Mars, the rockets were fired. It went around in the orbit, supposedly to be captured by Mars, and it was never heard from again. The details of all of the players and what happened are in the book I wrote [*Exploring Mars: Chronicles from a Decade of Discovery*]. But the first mission just vanished. Mars Climate Orbiter. The mission arrived in early '99 and the orbiter was never heard from. Within a month or so after that Mars Polar Lander was supposed to land, and the same thing happened. Everybody was sitting on the edge of their seat in the control area listening to the signals, and the narrator was describing what was happening and that it was coming in through the atmosphere and should shortly be landing on the surface and that we would hear from it as soon as Mars Polar Lander was safely on the ground. Nothing was ever heard, no signal appeared.

Of course this was a terrible outcome. The sadness, the disappointment in the room was palpable. Although Goldin, unlike some previous disappointments, didn't yell and scream and throw things, he was clearly though very upset.

Whenever a mission is launched by NASA, it is always a plan written that has actions you would take for various contingencies. There was a contingency you take if you have a small loss all the way up to loss of mission. Then over on the human side if there's a loss of crew, of

course that's the most serious kind of tragedy. In this particular case the loss of these two missions meant that there would be a major failure review. That was chaired by a gentleman I've come to know well and have immense respect for, Tom [A. Thomas] Young. Tom is the guy that often these days shows up to do a review when there's a problem. He just did a review of the James Webb Space Telescope and why it was not on schedule or budget.

Tom was called to do something called the Mars Program [Independent Assessment Team] MPIAT, basically a failure review, a big committee. During all this review he was writing his report up. He'd given a private briefing, sort of a preview, to Goldin. He said, "Look, there's all manner of problems here. There's not enough good systems engineering. These people took foolish risks. And oh, by the way, there's nobody that's really in charge of this Mars Program."

I was actually investigating an earmark, believe it or not, in my role as Associate Director for Astrobiology and Space Programs. Money had been put in for some type of an astrobiology program near Yellowstone National Park. I got a phone call, actually came in on the phone of a guy who was Goldin's Chief of Staff, who was out there with me. He said, "It's the boss," and held the phone out for me to take, and I believe I've already told this story. Dan said, "I'm going to be in California on the weekend. I want you to be there, I need to talk to you."

I flew down to Huntington Beach [California]. What Goldin said was, "This failure review report is coming out very soon, and it's going to say a whole bunch of things that are wrong with the program. I'm taking responsibility for this, I'm the one who pushed them into the corner and said two for the price of one and faster, better, cheaper. But it's clear that somebody needs to be in charge of this Program. Because of what you did with the Astrobiology

Institute and Mars Pathfinder, I'd like you to come to Washington, DC, take the job as this Mars Program lead, and fix the mess."

That period of time, which was about a year and a half, I worked with the Centers involved, mostly JPL, with the contractors, Lockheed Martin and others, with the science community that had to be engaged in any kind of redirection of this science program, and with the other people at NASA Headquarters, and put together a team at Headquarters. I was very fortunate in having a remarkable gentleman at JPL named Firouz [M.] Naderi who was my counterpart there at JPL to help do whatever we needed to do. He reported directly to the Lab Director, who at the time was Ed [Edward C.] Stone.

We set about a massive task really of organizing the science community to look very quickly—because as was the case with just about every initiative Dan Goldin was part of, it had to be done quickly, and it needed to be in time for the next budget cycle. I showed up at NASA Headquarters in late March of 2000 and we had to have something to present in time for the next budget cycle, next fiscal year, which means we had to make an announcement by early October.

I was very fortunate with the people that were supporting me at Headquarters, including Ed [Edward J.] Weiler, the Associate Administrator [AA], and I had Goldin's support. I won't in the interest of time go into all the stories, but we ended up with a brand-new mission queue. It was done very strategically, I believe very thoughtfully, in balancing the science objectives, the technology readiness, and the programmatics. Programmatics meaning what budget did you have, what were the mission schedules, what was the launch vehicle or launch opportunity. All those three different elements had to be balanced against one another and turned into a mission queue and then you had to go back and recheck that for consistency. That always had to reflect what were the highest level science objectives.

Out of that, we incorporated Mars Global Surveyor, which was operating. We introduced the Mars Odyssey mission, because it was launched in 2001. If you remember Arthur C. Clarke's *2001: A Space Odyssey*, it was actually named for that with Sir Arthur's agreement. We sent—I think in those days it was a telex, e-mail wasn't really operating in Sri Lanka, and he said, "Oh, yes, by all means please do name it for that."

Then came the twin rovers, Spirit and Opportunity. It was my decision after a very extensive discussion in public meetings as well as in private meetings with my Kitchen Cabinet that I cobbled together, it was split down the middle 50-50 of whether we should have an orbiter or a lander and my advisers couldn't make a decision. They said, "It's up to you, we're behind you 1,000 percent."

For a variety of reasons the launch opportunity in 2003 was a terrific one for getting more mass to the surface, and it fit with the strategy I'd put together, of orbiter, then lander, then orbiter followed by another lander. You want to do orbital characterization of another world and then you want to go and check those measurements by sending something to the surface. We used a lot of the heritage that had come out of the Mars Pathfinder experience and missions would, where possible, use science instrument sets that had been previously proposed but not launched. In other words, they had been through the peer review process.

The mission queue that NASA has been living with for almost 17 years, of Mars Global Surveyor, Mars Odyssey, the twin rovers Spirit and Opportunity, Mars Reconnaissance Orbiter, the Phoenix mission, and then Mars Science Lab Curiosity was the roughly decade-long mission architecture that I led putting it together and then selling it to all of the stakeholders: the science community, the House Appropriations and Authorization and Senate Appropriations and Authorization, and Office of Management and Budget, and all those people. I wore out a lot of

shoe leather going door to door to explain what we were doing and why we thought that "follow the water" was a good approach and why this set of missions met those requirements.

I have to say in reflection now, all these years later, it worked I think extremely well. Leading up to the recent detection of complex organics by Curiosity, all the evidence of past water, all the detection of water ice. The radar that we put aboard Mars Reconnaissance Orbiter was built by the same Italian group that the radar is that's aboard Mars Express. One of them, the U.S. mission, detected a huge glacier the size of New Mexico that was buried. The other radar by the same group has just detected what appears to be an underground lake 20 kilometers in width.

This was I think proven to be a very successful structuring of a major decade long multi [mission effort], if you add up all the missions over a period of 10 years or so, you're talking 5 or 6 billion [dollars] all told, and it's worked out well.

Then I had to make a decision about whether to stay on at NASA Headquarters or whether to come back to Ames.

JOHNSON: I have just a couple more questions before we go to that. As you were mentioning, Dan Goldin, he had that faster, better, cheaper idea. A lot of what you were talking about just now, that's a lot of bang for the buck. Especially with Spirit and Opportunity and how long they've lasted. Spirit is no longer working, but Opportunity and how long it's lasted. It wasn't expected obviously to last that long, although it was built well. I was speaking with Steve [Steven W.] Squyres when I interviewed him, and it was just such an interesting story, and I've heard it a couple other places how Dan Goldin actually came up the idea with when you were looking at the rover he said, "Why not two rovers?" Steve Squyres said that that was probably

the most astonishing phone call he's ever received in his life. If you wouldn't mind just going back to that decision and how that decision came about, because you were on the other side of it. You were one of the people that was on that phone call, I believe, when he was asked if he could come up with two payloads. Just go back to that decision itself and let's talk about that for a moment.

HUBBARD: Yes. Again, I think the details of the timeline I put in the book, because it was difficult to disentangle. There were so many things going on in parallel. But what happened was that we had to make very rapid decisions about whether to launch anything in 2001, because the missions that were right in the middle of development probably suffered from faster, better, cheaper shortcuts. I ended up canceling the lander that was going to be launched in '01 because it had as far as we could tell many of the same flaws Mars Polar Lander had, missing lines of code, and not doing a full check with the flight hardware and the flight software.

The 2001 decision we made quickly. But in parallel we had to decide, given the short period of time, what we were going to do for 2003. There were three options. Do nothing, skip that opportunity. Send an orbiter that would be maybe a slight improvement on what was done for Mars 2001 or Mars Global Surveyor. Or three, try to send something to the surface using the same techniques as Mars Pathfinder.

To help with this decision I surveyed all the stakeholders or people that might have something to offer. One of the options was a payload that Steve Squyres had developed called Athena, which was an integrated science payload that was supposed to have been launched on the 2001 lander but was not, and was pretty much complete, sitting in what they call bonded stores at Lockheed Martin in Denver awaiting a ride.

To evaluate this, there were multiple teams at JPL, some working on an orbiter, some working on a lander, using the Pathfinder landing system. They presented to this group of people that I put together out of folks at Headquarters, some of the people from the past. Jim [James S.] Martin, the legendary Viking Program Manager, was part of this group. Gentry Lee, another exceptional person who is still working at JPL.

We had presentations; this was a big meeting at NASA Headquarters, it was a decision meeting. The orbiter presentation was clearly a safe choice, something that could be done with high confidence. They'd already started going through all of the shortcuts for the mission that was Mars Odyssey and had gone back and fixed things that should have been done as a result of faster, better, cheaper, or to repair the shortcuts from faster, better, cheaper.

But the science payload for an orbiter based on the presentation would only be an incremental improvement. It wouldn't be one of these things that I was looking for, which was a major step function, each time we had a new mission pushing the resolution or the spectral range or something about it much further. Safe, but perhaps the science was just incremental.

Then the lander, it was called Mars Geophysical Rover I think at the time, using the Pathfinder airbag landing with a rover that would weigh about 150 kilograms and the Athena science payload that was already built that would be provided by Squyres. Steve did a great job. I've known him now for probably 30 years, and he's an extremely talented scientist and scientific leader. He made his case about what he could do that would be really groundbreaking new science, wouldn't just be an engineering demo like the Pathfinder rover was, but would be an honest-to-God mobile geophysical geochemical laboratory.

We excused the advocates from the room and I went around and took a poll, and as I said it was essentially 50-50. I think there were, I don't know, 15 or 20 people there in my little ad

hoc advisory group. Roughly half said, "Let's do something that's safe. We can't afford another failure. If there's another failure the program is done for." Then the others, including Jim Martin, said, "No. The Pathfinder system works, can be made to work again. You've got a science payload that's pretty much finished, and the new knowledge will be fantastic, A, and B, oh, by the way, 2003 is amazingly good. They come along every 15 years, there's an amazingly good launch opportunity to get more mass to the surface, or at least to the top of the atmosphere."

Jim Martin said that were he 20 years younger—I think he was already in his early 80s then or something—he would take the job on and guarantee it would be a success. We took a ballot and it was 50-50, and I think one of the people from another Headquarters area, Carl [B.] Pilcher, said, "You can do what you want."

I said, "Okay, let's take a pause. Let me think about this." I literally took a walk around the block and thought about it and came back in and said, "For these reasons I think we should go for the rover, for the lander. I know it's a greater risk, but I think that the scientific payload, the Pathfinder landing system that's already been demonstrated, and the fact that the science payload is essentially done means that this is something that would really advance the program." I think somebody else commented, "Oh, by the way, it would be a major accomplishment for international leadership and U.S. prestige and all those political things."

That's what I settled on, presented it then to Ed Weiler, who was at first really hard to convince because he didn't want to take a big risk. It took a lot of effort to get him on our side. I did this with the Program Scientist, Jim Garvin. By pointing out how this mission fit into the overall scheme and the things we'd already done, eventually Ed got on board.

Next, we had to convince Dan Goldin. Nine o'clock the next morning we went up with our set of charts. I'd learned by now it didn't matter if you took 1 chart or 20 charts up to see Dan, you would barely get through your introduction before he started hitting you with questions, because his mind would just race off, leap over where you were, and go on three or four or five jumps down the path.

I said, "Dan, we thought about this carefully. We looked at science, technology, engineering, programmatics, what have you, and we've come to the conclusion," and Ed nodded his head, "that we want to recommend a rover lander for the next mission." He asked a couple questions about I think why we were so certain and why that made sense. He, unlike Ed Weiler, was immediately convinced. It didn't take much time at all for him to be convinced that going from an orbiter in 2001 to a lander in 2003 was a clearly strategic move. The science payload would be terrific, and the landing system was something that had had one fully successful demonstration. He bought into that almost immediately.

Then after a couple more questions that's the famous point where Dan turned to me and said, "What if we were to do two? Could we do two? What would be the impact of that?" This is when you have to be very fast on your feet. The question of whether or not the value of—for example there was Pioneer 10 and 11 that were duplicates. Viking 1 and 2 were duplicates. Jim Martin had often, when I would have him in these review things, remind me of the power of having two. The Agency has gotten away from that. Now they often will just build one – it's called protoflight unit. It starts out as a prototype and then it ends up as the flight unit. They've eliminated a lot of this redundancy because it's expensive.

The idea wasn't a complete shock. Thinking on my feet, I said, "Okay, you got to do the following. If you're going to have two, Dan, they've got to be exactly the same. No fooling

around with a tweak to the payload and add a little something." I said, "It's got to be exact repeat. You've got to go buy another launch vehicle. Of course you've got to get the agreement with JPL and Lockheed Martin."

He said, "What would it do? What would it do?"

I said, "You're going to cover a lot more science. Same payload, but two completely different places." I told him Mars has 80 different sites, 80 different geological regions. You could sample that.

He said, "What about the failure? How does this contribute to mission success?"

I said, "I can't do the binomial statistics off the top of my head. I'll get you a number. But two is better than one, what can I say? In terms of if one fails you've still got the other one."

Later on I did the calculation and if you've got let's say a 90 percent probability of success of one, if you add a second one and if there's not a systemic or systematic failure problem—in other words all the transistors are bad in both vehicles—but it's just random failure, then your probability of success with one goes up to 98 percent. So all these things were swirling around in the room that we were discussing.

I said, "But sir, it's going to add a bunch of extra cost."

He said, "How much?"

I said, "If we're saying that the first one is going to cost $250 million and it's an exact repeat, then you add an extra launch vehicle, it might double the cost or something like that total. But we have to work through this."

He said, "Okay, all right, here. Here's what I want you to do. I'm going to Morocco next week. I'm the U.S. representative to a meeting over there. You run these things up. You talk to

JPL. You figure out what the statistics are and some rough number of the cost, and we'll talk about it. But it's got to be done soon."

I said, "Okay." That then set the ball rolling for a whole series of phone calls and discussions and calculations. First thing I had to do before I talked to Steve Squyres was to talk to Ed Stone at JPL and say, "Ed, you know what dealing with Dan Goldin is like. Here's an interesting idea that could be really good if we can pull it off."

I explained the background and he said, "Okay, let me think about it, try to write down what the conditions are on which the Center would sign up to do this, and we'll talk to our suppliers and Lockheed." Because Lockheed Martin would be building part of that. Most of it would be in house at JPL.

Then there was the call to Squyres in which I said, "Steve, we've got an interesting idea here. What about doing two rovers? I need to know two things. One is could you duplicate—exact duplicate, no changes at all—the science payload, and what would be the science payoff." Of course I had my own science group at Headquarters that was helping with that as well. Then we had to figure out what the incremental improvement would be. Then we had to work out what the cost would be.

We'll have to go back and modify what I just plucked out of memory a minute ago. But I think we were saying that a rover by itself would be around $350 million. But then another launch vehicle is another $50 million. Then it's an exact repeat, which shouldn't be as expensive. I think we came up with a number of something like total for the two around $750 million or something like that. It was a fenzied process, calls to all the folks that I mentioned, calculations, trying to get a quick sanity check from whoever we could. Goldin then called from Morocco. We put together a short description of what this project would be with a really rough

cost estimate, a statement by Ed Stone from JPL of under what conditions the lab would sign up to do both. I don't know if I included anything from Squyres then or not, can't remember, but we did talk to him and tell him that it had to be an exact repeat.

Goldin got that. We faxed it to him in Morocco. He looked at it in almost real time and said, "Yes, yes, yes, looks good, looks good. It's exhausting here, I'm really tired, I'm going to go to bed, you guys keep going."

We had an agreement that Squyres thought he could reproduce the second payload exactly, gave us a round cost. JPL, Ed Stone the Lab Director said he would sign up to it under the conditions that they were exactly alike and that they would have the full control over producing both of them. If they needed to take parts from one and give them to the other to keep schedule they would.

Remember, this decision was made with 39 months to launch. Usually you start these preliminary discussions five years ahead of launch time. This was just a shade more than three years. It had tremendous schedule pressure.

Then was the question of who's going to pay for this. In the book I describe the meeting that Goldin never attended, usually chaired by his Deputy, the former general, Jack [John R.] Dailey. It was a meeting of all the associate administrators. Goldin popped into this meeting, said, "Jack, I got something I want to bring up." I was there because Weiler and Goldin and I had organized the plan that this is where Goldin was going to twist people's arm and pass the hat. That's what happened. Goldin said, "We've got an extraordinary opportunity. It's a new program being put together. These guys have convinced me that the next mission in '03 should be a rover lander. Big science, but to mitigate risk and get more science we need to do two of them. So I'm here to collect $350 million from you guys." He went around the table and almost

everybody agreed to chip in. I think the one holdout at least at the meeting was from the Earth science people. Mike [Michael R.] Luther I think was the rep. He said, "I just don't have the authority, Dan, to commit a piece of this."

But that was quite an event, and in the end the money was identified and OMB [Office of Management and Budget] agreed to let us transfer it over. Congress agreed as well. You can't move more than $500,000 from one program line to another without an agreement and approval from Congress. That then set the path in motion.

When we rolled out this program and announced that we would have in 2003 two rovers, not just one, I remember being on *The CBS Morning News* with I think it was Bryant Gumbel. You remember him?

JOHNSON: Yes.

HUBBARD: He was incredulous. I said, "We're announcing in 2003 we're going to have two rovers going to Mars."

He said, "Why? Why are you going to waste that much money?"

I said, "Excuse me." I said, "We're going to be going and landing and roving around on the red planet. If you have two rovers you can get far more science, number one. Number two, it means that it really increases the chance that we're going to have a success."

He said, "Well, all right. Have a good weekend." He was noted for being cranky with his guests. So not everybody was enthralled with the idea of two rovers.

But the science community, people on the Hill, the advisory committees, everybody thought, once they'd had a minute to think about it, that this would be an extraordinary

opportunity for the program. At the time we had to set the mission success criteria. I could not find anybody who thought, with the dust collection that occurs everywhere on Mars, that it would last longer than six months. We set the so-called mission full success criteria; this had to be achieved in three months. As I often say, the warranty was only good for 90 days. But with a combination of help from Mother Nature, dust devils that blew off the dust, and a lot of good engineering, Spirit lasted for seven years and Opportunity has lasted longer, it's in its fourteenth year. Right now there's a global dust storm and we don't know if it's survived that or not. It's been silent now for I believe almost two months, certainly more than a month. We'll see if it comes back or not.

JOHNSON: A little longer than 90 days, anyway, 14 years.

HUBBARD: Way longer, yes. The taxpayers got their money's worth.

JOHNSON: I think so. I thank you for going back, and I know you've covered a lot of that in your book, but it's always good to get another perspective, since we've talked to different people around that decision. It's good to get these different perspectives in these oral histories, so I appreciate that. As you were going to talk about before I interrupted you, you did have a decision to make after the Mars Program.

HUBBARD: Yes. We successfully created, defined, and sold, if you will, the new architecture. We announced it to the world in October of 2000 and there then began a series of international

meetings because the rest of the world wanted to know how they could participate. At the same time Ed Weiler and Dan Goldin were both lobbying me to stay on at NASA Headquarters.

My late first wife and I had gone to Headquarters in a big rush. There was no time to do anything other than grab some luggage and the cat and find an apartment in Alexandria [Virginia]. I began thinking much more deeply about the future and where I wanted to go, where I thought I could contribute the most.

My Center Director back at Ames, Harry [Henry] McDonald, one of his deputies and a close friend of Harry and then became a friend of mine was Jack [Robert] Hansen. Jack dropped by Headquarters one day and said, "We'd really like to have you back at Ames to help to guide the Center." They were talking about a very senior position.

After weighing everything, my wife's connection with her family back in the Bay Area, the success of getting the program going and selling it with a budget profile that looked good for the future, and getting everybody's buy-in to that, and of course the coming change of administrations, I made the decision, a difficult decision, to go back to Ames. I went back there and accepted the position of being one of the Deputy Center Directors. This was the Deputy Director for Research. I was responsible for the whole research portfolio at Ames and information sciences and the new field of nanotechnology, astrobiology research, aeronautics, and also working on strategic collaborations with other Centers, and developing competitive proposals and overseeing what we were doing down and in in the mission component.

It was quite a high level job and one step removed from being the Center Director, and I was in that job for a year or so, 2001 to 2002, and then was the change of administration, and the new Administrator was Sean O'Keefe, who was brought over from OMB. I think he'd been the head or deputy head of the Office of Management and Budget.

As often happens, the new Administrator wants all new people reporting to him, and that means the Center Directors and the people at NASA Headquarters. So there was quite a lot of churning and changing. As part of that, there was a new guy in charge of the care and feeding of Ames at Headquarters. In those days each Associate Administrator in addition to responsibility for program content would have responsibility for certain Centers as well. The gentleman who was the head of Aeronautics at NASA Headquarters had responsibility for the Centers that had been or were major contributors to the aeronautics program. That included Ames, Langley, and Lewis, which is now Glenn Research Center in Cleveland [Ohio], as well as the Dryden Flight Research Center, which is now the Armstrong Flight Research Center, [Edwards, California].

I got a call from that AA one day. I was in actually a meeting being held at JPL. I think I was sitting in a meeting of the NASA Advisory Council. I was in the audience, I wasn't part of it. Somebody tapped me on the shoulder and said, "Headquarters is calling," and I stepped out. The Associate Administrator for Aeronautics, Jerry [Jeremiah F.] Creedon, said, "We need to have you come to Headquarters really fast, can you be here in the morning?"

I said, "Yes, I'm certain there's some kind of way to do it." I got a late flight out of LAX [Los Angeles International Airport] and off to NASA Headquarters. The result of that meeting with Jerry was that he told me that Harry McDonald was stepping down and that Sean O'Keefe wanted to have a new Director of Ames. He'd asked Jerry Creedon for his recommendation and Jerry said, "I recommended you. Would you be willing to do that?"

I said, "Yes, sir, how can I serve my nation's space program?"

They said, "Okay, you will be meeting in an hour or two with O'Keefe. How will you characterize what you would do as different than what's been doing, or what would be your new initiatives?"

I said, "There's a lot of great stuff there that I had a hand in. Astrobiology, intelligent systems. I would like to push the relationship that we just started working on in creating the NASA Research Park. I think what I would say to O'Keefe is that it's a terrific research center but it needs to have a little more I would say top-down strategic integration." The knock on Ames for all those years had been yes, it's on the left coast, and it's the University of Ames. I remember Jack Dailey once saying, "Only in NASA is a direct order considered an invitation to a debate." He was applying that particularly to the research centers although the flight centers were in there as well.

I sat down with O'Keefe and gave him my vision for the future and talked about integrating the strategic directions of the Agency with the capabilities of Ames and how that would work from the basic lab research all the way through mission applications, and how in my own experience I had seen that happen with things like Mars Pathfinder and the Astrobiology Institute and intelligent systems and thermal protection systems.

He then formally offered me the position as Center Director and I accepted. Then there was a period of a little bit of delay. He wanted to come out to the Center and have a major formal announcement. He had been very briefly something like Acting Secretary of the Navy. He really wanted to have something like a change of command ceremony which occurs in the military when you go from whoever was the commandant of the organization to the new person. But he could never pin Harry McDonald down on a date to do that.

Net result was that he came out in I think it was September of 2002, something like that, and we had a nice big meeting with all hands. Jerry Creedon was there and Sean and myself. I gave a presentation to the whole Center about how I saw the future and the things that we could

be involved in. It was quite a nice event, quite a nice ceremony. Then I began my role as the Director of NASA Ames.

JOHNSON: Talk about what you did envision for the Center, what you saw. Basically there were a lot of changes. Almost a reorganizing of the Center and streamlining of some of the operations, and then collaborations between NASA and academia and the private sector and those sorts of things that you implemented.

HUBBARD: Yes. The Center had undergone a major physical change or institutional change with the acquisition of what had been Moffett Naval Air Station. In 1994 the Base Closure Commission [BRAC] had decided that Moffett Naval Air Station was no longer needed, that they could consolidate west coast naval aviation up at one base further north.

Norm [Norman Y.] Mineta was then the congressman representing the Bay Area, I think the position now held by Anna Eshoo. He reached into the BRAC, Norm did, Norm Mineta, and pulled Moffett Naval Air Station out and gave it to NASA Ames. So overnight the size of NASA Ames went from 500 acres to 1,700 acres, the acquired its own landing strip and airfield.

Today there's still about something a little less than 3,000 people at Ames, about half contractors and half civil servants. Budget is in the $750-million-a-year range, with this big physical plant. Being the Center Director there is, like other Centers, akin to being a mayor, because you've got fire departments and police forces and buildings to worry about.

One of the things that we needed to do, I thought, was to have greater integration with some of the flight programs that were going on elsewhere in the Agency. This had been I thought a point of difficulty with Ames in the past, that because of how it was born out of World

War II in 1939 in what had been just—Silicon Valley wasn't Silicon Valley, it was orchards. It was nut and fruit tree orchards, agriculture. Ames Aeronautical Laboratory was very much an entity unto itself, self-contained because you had to be. There was no resources nearby. But of course by 2002 all of Silicon Valley was in its second or third generation of development going back to when Lockheed first came there back in the either late '40s or early '50s. I was determined to integrate the Center into Silicon Valley more thoroughly, and I thought this would pay benefits in the area of intelligent systems and all the work we were doing that was to be applied to the flight missions.

In particular one thing that I was responsible for was bringing Ames's supercomputing capability back up to par with the rest of the world. At the time that I took over as Center Director I think in the list of the top 500 supercomputing capabilities in the world Ames was number 499. We were about to fall off the list. The way in which we were able to leap to the top was an interesting collaboration with Intel, one of the world's largest computer chipmakers, and a company called Silicon Graphics, Inc. [SGI]. Two individuals there, Paul [S.] Otellini, who recently passed away unexpectedly, he was the COO and then the CEO of Intel, and Silicon Graphics, a gentleman there named Bob [Robert R.] Bishop, who I still work with, who was the CEO, and had a supercomputing architecture that was particularly useful for the kinds of scientific problems that Ames worked on, the computational fluid dynamics for aeronautics, the astronomy and astrophysics, airborne Earth science, and related types of projects. The flow diagrams for entry systems. All that research needed supercomputing capability.

That was Ames's interest. SGI's interest was of course in applying that, using their special computer architecture. Intel's interest was in regaining the championship for world's fastest supercomputer. There is a, I don't know what you call it, a Bake-Off, a competition every

year where companies that want to enter it run a certain type of algorithm called a benchmark algorithm, and whoever can run it fastest becomes the champ at least for that year. Intel really wanted to take that back from the Japanese. The Japanese had created the so-called vector machine that was the leader.

We worked on a very innovative—this is one of the things I think that I really brought to the Center. Working across public-private partnerships, working with industry and academia and whoever to really expand or leverage the capability of Ames into the rest of the world. The rest of the Agency but also Silicon Valley. This was a classic, I believe, example of how those three groups, SGI, Intel, and Ames, worked together.

I was very fortunate in finding a person at Ames named Walt [Walter] Brooks. He had a computer science background and was willing to take on the task, which was extraordinary, of bringing online at Ames in 120 days the world's fastest supercomputer. Walt had a saying, "A miracle a day is all we ask." As Center Director I made the strategic decision, worked the arrangements with Intel and SGI at the strategic level with my counterparts, also worked with the person who was then the Chief Financial Officer at NASA, Steve [Steven J.] Isakowitz. Steve had been the Office of Management and Budget branch chief who was there at OMB when I was the Mars Czar, and he was the guy I had to convince that the new Mars Program was in fact a good one and could be afforded and had good strategy to it.

Steve and I had become colleagues and friends and I think he trusted my judgment, in that if I was going to bring him something it would be based on solid thinking. When I brought this idea of a collaboration that would greatly improve NASA's capability and would win the flag for the U.S. and work in a public-private partnership, all the elements were very appealing to Steve, and so he was absolutely instrumental in helping move the money around in a fiscal year

to allow us to execute this amazing thing. In the span of four months we brought from a standing start to operating the world's fastest supercomputer. Ames had always led in that. It had declined over years to almost going out of business, and that one action brought it back I think, based on discussions I've had, to where the Center is today, still a leader in supercomputing for the entire Agency. If somebody wants to do some very special calculation they can go to Ames for that and they'll help them with the research. That was one thing I think that made a mark on the rest of the Agency.

I also worked out in 2005 the very first agreement between NASA and Google. Back when Google was not as ubiquitous a name as it is today, we signed an agreement for joint research and at the time for them to actually incorporate part of our Research Park footprint into research space. I believe that's moved ahead, but it was another thing where when we announced it the rest of the people in the Agency were saying, "You're working with who?" That was quite an accomplishment as well.

In terms of the program assignments, SOFIA [Stratospheric Observatory for Infrared Astronomy] flying observatory was getting well into its development phase. My tenure as Director would have followed a lot of the programs that I was interested in and that the Agency had capability for. But there was a tragedy that intervened in 2003.

On February 1st, 2003 the *Columbia* Shuttle [STS-107] disappeared, and of course we know that that was a tragedy, a lost crew, all the seven crew, loss of the vehicle. Per the prelaunch criteria there would be a *Columbia* Accident Investigation Board set up. I got called by the Deputy Administrator Fred [Frederick D.] Gregory. O'Keefe was down at the Cape [Canaveral, Florida] expecting the crew to land. This was about 6:30 in the morning west coast time February 1st, 2003.

JOHNSON: Did you know that it had happened before you got that call or did it wake you up?

HUBBARD: There's a whole story. In fact there's an hour, hour-and-a-half lecture that I give on lessons learned from that. I'll try to give you the short version. Six thirty in the morning 2003 February 1st. My late wife Susan had the radio on and she turned it and said, "Listen to this." The announcer was saying that the Shuttle is overdue for landing at Cape Canaveral, at Kennedy Space Center.

I knew that there's no such thing as an overdue Shuttle. That big heavy glider, once they commit to entering the atmosphere and returning to Earth they have almost no control authority. They line it up and they got to land it. That meant that something terrible had happened.

I raced upstairs, turned on the TV, and there was CNN with pictures over Texas of the Shuttle in the sky but what looked like a bunch of bright pieces surrounding it. It was that point where the phone went off, my cell phone, and it was the Deputy Administrator saying, "We're activating the contingency plan for an investigation board. It looks like the Shuttle is gone. We don't know what happened, but there is a slot for one NASA person, one and one only, on the investigation board. It has to be somebody not associated with the Shuttle Program because of conflict of interest. The Administrator, Sean O'Keefe, would like you to play that role."

I said, "Yes, of course, sir, I'd be glad to serve. What happens next?"

They said, "This afternoon the chairman," I think that O'Keefe had already talked to Hal [Harold W.] Gehman, a retired four-star admiral who had investigated the *USS Cole* bombing accident [Co-chair of *Cole* Commission], *Cole* terrorist accident, " [Hal Gehman] will be the chair. But this afternoon there'll be a telecon. We'll have the members of the board on the

telecon and then we'll talk about what we do next. All the members will probably assemble at one spot tomorrow or the next day."

At that point after the telecon what Hal Gehman thought we were doing was a 30-day investigation. As it turned out, it lasted seven months. That investigation was really a life transformative event in the sense of being involved in it for that period of time, having to find a way to still have the Center running with all of the things. We had a major agreement with the University of California system through the University of California, Santa Cruz, for development of our Research Park and NASA's University Affiliated Research Center. This was going to be a big element of developing this 1,200 acres that was the old Moffett Naval Air Station. That was running in the background that I had to keep on top of, as well as a whole lot of other decisions.

Now we were faced with a true tragedy and a very major impact on the Agency, the loss of one of the Shuttles. *Challenger* had occurred in 1986 [STS-51L], seventeen years ago. Here it was happening again. We had a very important job to do. I had to devote my full attention to that, because it turned out that it was not obvious. Unlike *Challenger* where they captured the breakdown of the O-rings on launch with one of the cameras that was watching the launch, and where the cause was known almost from the very beginning, notwithstanding the famous demonstration by [Richard P.] Feynman in front of the House committee, here the cause was not obvious at all.

That call in February led to a seven-month odyssey where the group—it was originally eight people all from outside NASA, people like the person who was the chief accident investigator for the FAA [Federal Aviation Administration], a person who was the head of safety

and mission assurance for the Air Force Materiel Command, and positions like that, and one NASA guy, who was me.

We self-selected into groups that would consider different parts of the accident. I put myself into the group dealing with the physical cause because I thought my background, the fact that Ames worked on thermal protection systems, and my training in physics might be better applied there.

There were two other groups. One was operations and the other was crew and different aspect of operations. Those people were doing interviews to see if they could figure out what had happened, if there was any operational reason for the Shuttle accident.

The three or four people who were interested in the physical cause got together, and we started looking at what little data we had. It was a huge search through snake-and-poison-oak-infested country in Texas to find the black box, the recorder that was on board. But they found that. It turned out only two cameras were operating and only one of those was high resolution, but we did have that. We had some ground signals that had been received. The recorder was eventually opened and the tape played back. That gave us more data about that accident. They started assembling parts. Some 20,000 people at one point were searching in Texas and Louisiana looking for the parts that had survived reentry to the surface.

But there was a continuous question about exactly what the cause was. The one piece of high resolution film, the 35-millimeter camera that caught the ascent down from Kennedy Space Center showed something falling from the area of the main tank. The Space Transportation System, STS, consists of what most people call the Shuttle, it's really the Orbiter piece where the crew sits, that was attached to the side of the main tank that had the liquid hydrogen and liquid oxygen and the two booster rockets on either side, solid rocket boosters, SRBs. Something

appeared to be falling from where the Orbiter was attached to the main tank and apparently hitting the left wing and then a big shower of shards coming out the back side.

This material, it turned out, was a block of foam that was used to cover the main tank and that basically kept that very very cold cryogenic tank from just being an ice ball. It was the insulation for the liquid hydrogen and liquid oxygen. I should say, by the way, that there have been three or four documentaries about the *Columbia* accident produced professionally and shown on TV. The best one in my view was the one that was shown by [PBS] *Nova* which I think is called *Space Shuttle Disaster*. It was originally shot by a French film crew and the PBS people, the *Nova* people, saw it and bought the rights to it. They recut it, did a few more interviews, and had it renarrated by Neil deGrasse Tyson. That gives a very very good process or step-by-step-by-step description of what led up to the accident, what happened, the people involved, and what the impact was. They interviewed me extensively on that, so that's part of the public record as well.

But the role that I ended up playing was sort of an extraordinary one in the sense that while the circumstantial evidence that the foam hitting the Shuttle must have played a major role if not the major role, not everybody wanted to believe that or could believe that. O'Keefe himself, who's not a scientist or engineer, he's a budgeteer, went on nationwide television and held up a piece of foam and said, "These foamologists," he called them, "think this did it but how can this? This is like you're throwing your Styrofoam cooler out the window at 60 miles an hour, and how could that possibly cause the problem?"

As it turns out, the relative velocity of the foam and the Shuttle rising on its rockets was more like 1,100 feet per second, or what would that be, about 750 miles an hour, hit your Styrofoam cooler. If you just do the basic physics calculation it shows that a piece of foam about

the size of a small briefcase weighing about 2 pounds or so hitting the very heat-resistant but brittle carbon composite leading edge of the Shuttle could in fact exert literally a ton of force.

In addition, many of the people at the Shuttle Program were highly conflicted. This was a sociological as well as psychological as well as technical issue. They struggled emotionally with having had this unspoken contract with the crew that the people on the ground will do everything they can to keep the crew safe on launch and operations and reentry, and the crew side of the bargain was they would do everything they could to make the mission successful.

It was clear as we were observing all these interactions that there really needed to be something more done other than a few pieces of film and some recovered remains where most of the left wing was missing sitting in a hangar at Kennedy Space Center or some thermocouples that went offline in the left wing. You could put those circumstantial pieces together and say, "Okay, something happened on the left wing, probably in the front, and then maybe the heat got inside on reentry and began to melt the Shuttle." That was the thinking. But because of resistance or disbelief or psychological issues of not wanting to feel they had violated this contract, there was a significant denial or lack of agreement on the physical cause.

Fairly early on when this all was starting to be clear at least to me and some other people on our team, I said, "We need to conduct a test that is as close as possible to actually what happened on the Shuttle." It turns out that thoughts about doing some kind of an examination of the possible effect of falling foam had been underway at Southwest Research Institute [SWRI] in San Antonio, Texas.

I proposed this test to the people over at Johnson Space Center who were working on a long-term program of materials testing using the device at SWRI, and they didn't want to do it. They said, "No, no, no, no, we can't possibly do anything quick. This is a long-term program."

I went back to Gehman and said to Hal, and the other people on the physical cause team were fully in support, "We really think we need to do something to make it very clear, to put an exclamation point, to connect the dots, whatever words you want to use, about the physical cause of this accident."

He said, "Okay. Let me make a few calls." What he did, he told me later, was to essentially call O'Keefe and tell him, "We're taking over your testing program. We're going to use it for the Shuttle accident right now." That's how I ended up being in charge of this program.

The people working on it, I had people from the Office of Naval Research, ONR, helping me, and people from FAA Commercial Space Office helping me. The people in charge of this, they called it the chicken gun, this is a facility in San Antonio used to test cockpit windshields on bird strikes. This facility existed but mainly what they did was to fire thawed out chicken carcasses at Plexiglas and windshields of different kinds of airplanes or at cowlings and engine intakes. Because that's a huge problem, bird strikes. If you ingest too many birds into a jet engine it'll tear it apart.

From about April or May until July 8th was this intensive program of me orchestrating a group at San Antonio Southwest Research, at NASA, mostly JSC but a few other Centers involved. Ames did a bunch of high-fidelity calculations using computational fluid dynamics of what the tumbling foam would have—where it would have hit.

All this led up to a series of tests starting using the fiberglass from *Enterprise* [OV-101, used for Space Shuttle Approach and Landing Tests]. That was the first Shuttle, just a fiberglass mock-up. We were using the fiberglass sections and firing pieces of foam at it. We would incrementally adjust things to make it as exactly like what happened on *Columbia* as possible.

But firing it at fiberglass of course is not the same thing as the Shuttle is made of. Fiberglass is flexible and will bend.

I told Gehman, after we'd done a number of these tests, that we were ready to do a real one, and we needed a piece of the real graphite composite material that made up the leading edge of the Shuttle. That ended up being a big kerfuffle, a huge fight, between the *Columbia* Board and NASA. It went all the way up to O'Keefe really. They kept pushing back, said, "It takes seven months to make these things and they cost $500,000 apiece and we only got two more in spares and if we give you the one off [Space Shuttle] *Atlantis* that means we're down to one spare and blah blah blah blah blah."

Gehman came back to me and said, "NASA really doesn't want to do this. They don't want to give you that piece to test. They're too expensive and they've only got a few of them."

I said, "Hal, you've heard the talk inside NASA." By now he had heard from his other investigators who were interviewing people about the denial and the uneasiness and statements like, "Did we not do a good job and couldn't it be something else?" People were coming up with all manner of explanations, lightning strikes, high altitude sprites, bolts that fell out of the bolt catcher, anything else other than the foam, which was something that the ground people controlled and put on the vehicle. If they didn't do a good job or something was lacking that meant they were responsible for the death of their colleagues. It was a big emotional issue.

Turns out that there had been foam strikes, small ones, every single flight of the Shuttle. The other groups were looking into the history of the Shuttle, and they found out this happened all the time and people just started ignoring it because it had never resulted in a severe accident. There's a whole set of lessons learned about how institutions forget and don't apply. If

something hasn't hurt you yesterday, it won't hurt you tomorrow kind of thinking, which is not very good thinking if you're operating in a high consequence high risk environment.

We only had two votes in the entire history of the *Columbia* Accident Investigation Board. The first vote was to select five more members. We started with eight, that was what was in the contingency plan, but we realized that we had certain skills missing, certain knowledge missing, and so five other people were added, including Sally [K.] Ride, who'd been on the *Challenger* investigation [Rogers Commission]. Sally became quite a friend as a result of all this.

The second vote we ever had was whether to tell NASA that we understand this is expensive and you don't have many of these but we need to do this. Hal set up a meeting of the whole board. I think everybody was in the room except two or three people who were on the phone. He said, "Okay, over to you, Hubbard."

I explained what we wanted to do, why we wanted to do it, why we thought it was absolutely critical we conduct this test, and why the test, if we didn't do it as exactly as we thought were the conditions with the Shuttle, it wouldn't be valid. We took a vote and it was 13 to nothing. It was unanimous. You've got to do this.

Hal said, "Okay." Admiral Gehman called O'Keefe and said, "We're taking your reinforced carbon composite panel and we're going to do this test."

Leading up now to I think it was July 8th, everything was in readiness. We were standing there, it was about 110 degrees out in the desert of Texas in San Antonio. We had all of the TV and reporter people over in a little area. Had a bunch of astronauts standing with me. The [Astronaut] Crew Office as you can imagine was extremely interested, because they had to sit on

the top of this bomb, (a launch vehicle is basically a controlled explosion that puts you into space) in how this was going to happen.

The people who were immediately helping me, a guy named Dave [David B.] Pye from the Office of Naval Research or Naval Research Labs, and Paul [D.] Wilde from the FAA, they'd been helping me do the calculations and do the setup. They said, "How are you going to report the results?"

I said, "What do you mean how are you going to report the results?"

They said, "We can do the test and you can take pictures of it. Are you going to hold a press conference then?"

I said, "You don't understand. There is going to be a live television camera watching this along with the rest of the world and with us." They were horrified.

I said, "Look, if we're not completely transparent somebody is going to come up with some crazy nut theory that NASA is concealing something or NASA is hiding something. The only choice we have, like all of NASA launches through all of its history, is you do it completely in the public for everybody to see. That's what we're going to do." They said, "Okay, all right, yes."

We stood there and counted down to the firing of this gun to the one and only test we were going to get with this graphite composite leading edge of the wing. There was this boom and a little haze because when the gun fires it creates a little condensation. There's a little mistiness around the impact. When the mist cleared—it took a second to do that—there was a hole 14 inches in diameter.

Everybody that was there went, "Huh!" It was just a sharp intake of breath. I had these two incredibly conflicting emotions. One was sort of, "Yes, this is what did it." Then

immediately saying, "Oh my God, this is how these people died." This made it completely undeniable.

I had engineers coming up to me with tears in their eyes saying, "Yes, this is what happened beyond all doubt." This foam at that velocity hitting that piece of brittle stuff punched a hole in it. Our calculations later said maybe it was only 10 inches in diameter in the actual accident, but it was a big enough hole as the Shuttle was reentering to let those 3,000-degree gases in, melt the Shuttle from the inside out, it broke apart, and that's how you lost the crew and the vehicle. That was one of the most extraordinary events in my entire professional career was doing all of that, and having it be on live television.

JOHNSON: It's out there where the whole world could see, as you said you planned for. But at the same time it's quite a result.

HUBBARD: Yes. We wrote the report and then I went back to NASA for several more years. We're about out of time and I'm about out of energy.

JOHNSON: Yes, I was going to say we've been going a couple hours. I think at this point we can stop. But I appreciate you talking to me today.

[End of interview]