ORAL HISTORY TRANSCRIPT

GEORGE A. WATTS
INTERVIEWED BY CAROL BUTLER
CANYON COUNTRY, CALIFORNIA – 7 MARCH 1999

BUTLER: Today is March 7, 1999. This oral history with George Watts is being conducted in Canyon Country, California, for the Johnson Space Center Oral History Project. Carol Butler is the interviewer, assisted by Rebecca Wright and Summer Chick Bergen.

Thank you for joining us today and inviting us to your home.

WATTS: Glad to have you here.

BUTLER: Thank you. To begin with, let's talk about how you became involved in aeronautics and aerodynamics. How did you get started?

WATTS: Do you want me to go right back to the beginning, perhaps?

BUTLER: Sure. That would be great.

WATTS: It goes a long way back.

BUTLER: Okay.

WATTS: I was born the year after [Charles] Lindbergh made his flight, and when I thought about it retrospectively after I received your questions, I began to realize that that influenced my life quite a lot. I remember now at about age four or so, or five, that I had a little Lindbergh helmet, a leather helmet with goggles on it. It was a replica of his. My son had one of Davey Crockett later on, it just dawned on me. I remember going to a birthday party of Freddy Moore when I was about that same age. I took a book on Lindbergh's flight. I think that's what it was. Anyway, obviously I couldn't read at that age. Freddy later became the chief acceptance pilot for the RCAF [Royal Canadian Air Force]. He accepted C-100 aircraft. I met him again years later when we were both about twenty-eight…

Let's see. I guess that sort of got me—I made a few notes here.

BUTLER: Okay.

WATTS: I guess I'll just mention a few of the other things. I used to keep a little scrapbook that I'd cut pictures out of magazines and newspapers of airplanes, and filled that up. I guess it wasn't aerodynamics at that time; it was just flight.

BUTLER: Do you still have that scrapbook?

WATTS: No, I haven't. I wish I could find it again. I lived in British Columbia, which was mountains up and down, and one of my jobs as a little boy was to go downtown and get the groceries and bring them back up the hill. It was always an arduous trip down and back up, and every once in a while an airplane would fly over the town. I used to marvel at how they didn't have to go down and up; they just flew straight across. So some of the practical ramifications of flight struck home to me at a fairly early age.

BUTLER: I can imagine.

WATTS: I guess starting around eight years of age or so, I started building model airplanes—I guess many young boys do that—starting with just solid wooden models, one of which I remember dropping out of the second-story window and it would actually pull up as it came down to the ground. And that was seven or eight years of age. From then I went to flying models, rubber-powered, and I guess I built them from about age eight till about fifteen, when I became more interested in real flying.

When I was about twelve, we had to move East because of the war. My father worked for the Inspection Board of the United Kingdom and Canada, filling shells and torpedo [war]heads and things like that. There I saw the migration of aircraft overseas that were built in the U.S., mostly, and I saw hundreds, perhaps thousands, of airplanes fly overhead. I could identify every one, even by sound at that time. I continued to build model airplanes, now with little engines and so forth.

Then at the end of the war, we went back to British Columbia and I became interested in true flying. My father, a wise person, said, "If you do well in senior matric," which is the first year of university in Canada, in British Columbia, that he would let me take flying lessons that year. And I did the best year ever. [Laughter] I wasn't a terribly good [school] student anyway, but that year I—he didn't expect that, but he did let me take flying lessons.

BUTLER: That's neat.

WATTS: So it was just two or three days after my eighteenth birthday, I soloed a plane in Vancouver, and that same year I got my private pilot's license. So I was getting up into the little bigger time now.

BUTLER: It must have been exciting for you.

WATTS: Yes, it was. It was a great time. My father didn't like aviation, actually, because his cousin, whom he went to visit in the First World War on leave in France, when he got there his cousin had just been killed, been shot down and killed, and I think that [bad] taste stayed in his mouth the rest of his life, but he did let me go to school and study airplane design in Tulsa, Oklahoma, in Spartan College of Aeronautical Engineering. It wasn't very heavy on aerodynamics, but it was very heavy on structures, structural design of aircraft.

So when I graduated from that, I applied for jobs in every company in the U.S., and there were no jobs in 1949. There had been a tremendous buildup of [civil] aviation after the Second World War, especially light aircraft, but by 1949 it was in a complete slump. But fortunately I was able to get a job with A.V. Roe [AVRO] in Canada. They were moving ahead quite aggressively, and that's where I started the AVRO experience. And, of course, what they really needed was structural designers. They had lots of aerodynamicists, but their structural design was pretty weak, I'm afraid. They had civil engineers from various universities working there, and they were not aircraft structures they were designing. So I went up like a rocket in that organization, which—but I guess I'm getting off the track a little, am I?

BUTLER: No, no, not at all. We can move right into your work with AVRO.

WATTS: Okay. You said something about space flight. Do you want me to go back on that also?

BUTLER: Were you interested in space flight early on?

WATTS: Not particularly, but I can give you the history on that.

BUTLER: Okay.

WATTS: Again, when I was very young, maybe seven or eight, there was a children's encyclopedia called *The Book of Knowledge*, and in that it had a painting, I guess a picture, of trains going to different places and out into the stars and so forth. I remember to this day that one train was going to the moon, and I think, if I remember, it was twenty-two something, and I believe it was twenty-two weeks to get there. So that was my first experience with thinking about that, you know, maybe people could visit the moon some day. I didn't know I would be working on the first such expedition a few years later.

I think what influenced me about space flight itself was a comic strip called "Buck Rogers." …Around 1936, if I'm not mistaken, he predicted the first manned flight to Mars would occur in 1949. So I sort of waited anxiously to see if that would happen. But it was kind of strange that 1949 came, but just twelve years after that, I was working on the first space flight to another heavenly body. So he didn't miss it by that much. It was the wrong place.

I have to say, though, later when I got into the aircraft industry, well, during the war, of course, the V-2 showed that you could go very high and very fast. But I didn’t think a lot about space flight after that, except when about the last year in AVRO I met somebody from the British Interplanetary Society and he seemed sort of a little bit laid back and a little bit strange, an Englishman, of course. I thought maybe some day fifty years or two hundred years from now, and I didn't take it seriously at all. I guess this is leading on into your question on Sputnik, but we'll get to that later, I guess. I was fascinated by Jules Verne's books, too, though.

BUTLER: Have you read most of those?

WATTS: The technical adventures were quite appealing, to—at least to a young boy.

BUTLER: I'm sure they were.

WATTS: I think they still are.

BUTLER: Yes. They're still pretty popular nowadays...With all your interest and then your schooling, you did move into working with AVRO. What was your first project there as you came on?

WATTS: When you speak of projects, the projects usually are different aircraft or different tasks on an aircraft. I wasn't sure what you meant by that. The types of aircraft I worked on at AVRO were the C-102 Jetliner. In fact, that was my first job. It had flown about two months before I got there. A nose wheel door had blown off on one flight, so my very first job was to redesign the hinges.

BUTLER: Important. Very important.

WATTS: So that was my first design. They said to me, "Don't worry about the weight," because it was tail-heavy. And years later, when I knew a little bit more, when I had a little bit more experience designing things, I saw my design, and that door would never fall off. [Laughter] So that was my very first job, and that was in design. I was placed in the nose section, and my friend Ken Lenz from Spartan wrote me a letter when I told him that, he said, "Well, that's where they put all the snots, isn't it?" [Laughter] Incidentally, that was before he was married, and just last year I helped him celebrate his fiftieth wedding anniversary.

BUTLER: Wonderful! That's great. That's great you've been able to keep in contact with old friends like that.

WATTS: Yes. I did a little bit more work on that airplane. The first airplane had flown and we were designing a second prototype, which was quite a bit of improved structure and so forth on it. It never flew; it was canceled. But I did work on redesigning the forward pressure bulkhead, which was a very interesting thing to design because it sat up in the nose and the canopy came out of the top of it, so there was a change in direction there. Then the nose landing gear trunion attached to it, and, of course, it also supported the rudder pedals and things like that. So it was a good introductory exercise in design.

BUTLER: And a very important area to be working in.

WATTS: Yes, it was. I did a few other things. I was only there for under a year in design, and did some fairings, wing-root fairings, where the air-conditioning ducts came in, and a window de-misting system. Even in those days they were worried about such things. It was a transport airplane, of course.

Then I transferred into the stress department. That was my original ambition, but I took the job in design to get started. I figured I could learn more about design, stress-analyzing many designs, than I could in designing a few myself, and I guess that was sort of true. My first job as a stress engineer was to analyze the ailerons on the Jetliner. They were piano-hinge-supported, control surface with a single actuator, and so I applied a beam on an elastic foundation to distribute the concentrated load from the actuator through the piano hinge. That was something that seemed quite natural to do but hadn't been done before.

Also I began to work another—always control surfaces… It had split flaps, and they also wanted to use double-slotted flaps, so I worked on the design of those for a while, too.

Then they were designing a swept-wing version of the C-100 airplane, at that time called the C-103. It was never built either. But I designed and stress-analyzed the flaps on that machine, and they were kind of tricky, because the flaps were in two pieces with hinge [lines at different sweep angles]. There were two hinges, and [I] had to design a link between the two [surfaces] to transfer the actuator forces from an inboard segment to an outboard. So I had to use descriptive geometry to figure out where that link went as the flaps went down, and calculate the forces that were transmitted. So that was a nice exercise.

Then after that, because of my experience with control surfaces, when they needed to put together a team to design the C-104, which later became the C-105 fighter, I was chosen to design control surfaces, so I joined a team of about twelve people to do the conceptual and preliminary design on that airplane. That was in the end of 1951, December of 1951. Most people don't realize that the AVRO Arrow was begun that early, so that's kind of interesting.

BUTLER: That is interesting.

WATTS: And it was a difficult job, because most airplanes have wing sections that are 15 percent thick or so. This had wing sections that were 3 percent thick, so when you got back to the trailing edge [the control surfaces] were long and thin.

BUTLER: That must have been challenging.

WATTS: And then it was a supersonic airplane, so all the air loads, due to control-surface deflection, are behind the hinge line, so they had huge hinge moments. So they had the two things: a very thin surface and very huge hinge moments. At first it looked as though it wasn't possible to design control surfaces. I tried making one out of solid steel actuated at one point, and it was still not stiff enough. When I had been at college, I had designed the flap system for the Spartan Model 12 Executive, just as a school exercise, so that [experience] taught me about using multiple actuators, so I designed a multiple actuator and bell-crank system that distributed the hinge moment along the surface and was able to get away with a quite light control surface, just thin aluminum skins and so forth. That preliminary design was actually used in the…Arrow that you see flying up there on the wall.

BUTLER: That's great.

WATTS: And the elevator…design…type was used for the ailerons and the rudder as well. So that was my contribution to the early design of the AVRO Arrow.

BUTLER: How did it progress? You said this was the early design of the Arrow and then it progressed forward and it did change a little bit.

WATTS: Oh, yes, it did evolve, but it was twin-engined and two people, a navigator and a pilot, right from the time I began, but before that it had been other things, I later found out. I didn't know that at the time. It really changed very little from the time I worked on it till the time it flew.

How did it go, you say? Okay. About that time I began to realize—I didn't know very much about—I had to accept the air loads from other people to design the structure. This is not a good situation. I wanted to know more about where the air loads came from. That's perhaps, you might say, where my great interest in aerodynamics [began].

So I decided to go back to the University of Toronto and learn something about aerodynamics. I spent two years getting a master of applied science degree, the first year not leading to a degree, but making up for a lot of missing subjects…from Spartan, which was just a two-year college. So I never got a bachelor's degree; I just went from an AA [Associate of Arts degree] to a master's degree.

But the University of Toronto Institute of Aerophysics was a superb place to learn, and I spent most of my time there working on supersonic aerodynamics, which was quite strange because I had a professor, Gordon Patterson, say in one of his lectures that "It's too early to be designing a supersonic airplane. People would be insane to be working on a supersonic airplane with this small amount of knowledge about the subject." I was working on one, and I couldn't tell him, because it was highly secret, but I was doing what he said couldn't be done. [Laughter]

BUTLER: That's very thought-provoking for you, I'm sure it was.

WATTS: Yes. So my first experience with aerodynamics was supersonic aerodynamics, and I didn't learn the subsonic until years later. [Laughter] But it so turned out that was a good thing to have learned, to work on the Arrow.

So when I came back to work after those two years, I transferred into the Loads Section, and then two years later, I guess it was, I was in charge of flight loads for AVRO, for both [subsonic and supersonic] aircraft. So that was basically the route I followed.

One of the reasons they…chose me for flight loads analysis was because of my now rather extensive structural experience. I knew what the air loads were going to be used for, so I was able to write them down in a way that would lead to a reasonable structure. You have to be very careful with loads. If you give one set of loads, the designers will design to those loads. And then if the [actual] load happened to be a little off to one side, the structure might collapse. So I learned how to get around those guys because I had been one of them myself.

BUTLER: That's a good combination, having both areas of experience to be able to work with.

WATTS: And you asked me about NASA. I studied many NASA reports, of course, during the time I was working in loads, so I knew an awful lot about NACA [National Advisory Committee for Aeronautics][1], [as] it was at that time. I knew a lot about them before I ever was invited to work on the space program.

BUTLER: Okay. Great. You mentioned taking a break to go back to school. Did you continue any work at AVRO at the time or were you on leave?

WATTS: I notice you mentioned coops. I don't think coop programs were in existence at that time, but we had summer students. No, what I did was actually take a leave of absence for the seven months. A year's study in Canada at that time was seven months long. That's the fall and spring semester…there were no summer sessions at all. So it's five months off in the summer and then seven months for the rest of the year. And that worked out very well. That worked out very well.

I had a very tiny assistantship for the second year. I think it was $900 for the whole year, 150 a month, and then they just forgot the last month. [Laughter] But it enabled us to survive. My first wife supported me during that time.

BUTLER: That's great.

WATTS: She was really good at that.

[1] NACA became NASA in October 1958.

BUTLER: That's very good. I'm sure even though that $100 was important at that time. I know what it's like being a student. Every little bit counts.

WATTS: They say that giving money is an inappropriate gift, but that year my parents sent me a check for $100, and tears rolled down our cheeks when we opened the envelope. [Laughter]

BUTLER: That's great. Well, parents are pretty good at figuring out what their kids can use.

WATTS: That's true. That's quite true.

BUTLER: That's great. You did go back to work at AVRO, and you mentioned getting into the loads [group]. At that point were you at all involved with the Arrow?

WATTS: Yes, but in the year or two before [I became group leader]. [19]'55 and '56, I was involved with the Arrow, but I did a lot of work on the C-100 at that time, air loads and rocket [pod] loads, rocket launch loads. I actually did—I think it's one of the first [elastic] dynamic analyses of a wing running into a [vertical] gust. We had very heavy tip pods, and we put four-foot extensions on each wingtip of the C-100 to get [it] to fly to higher altitudes. We had [28] 2.75-inch rockets in a pod on each wingtip, and you had this huge mass bobbing up and down on the wing. I thought, you know, the [structural] dynamics in that could be interesting. So I used John [C.] Houbolt's recurrence matrix method on that, so I knew of him before I got to NASA. I later took courses from him at NASA and I used his method.

It took me a long time to do it, but it was one of the first uses of the computer. We had a—what was it? CRC-102A, Cash Register Corporation, I believe it was. 102A was [our] first computer…It had tubes, not any of the modern types of electronic elements in it.

It had to be cooled with fans. But it did allow us to calculate the dynamic response of the airplane flying into a fifty-foot-per-second gust, and [it] turned out that the wing was 15 percent understrength.

So then we had to go to—we [had] built quite a few of them by that time, so I had to go to Ottawa to see the government, with Carl Lindow, the chief of stress, and argue our case why [it] was probably still okay. The National Aeronautics Establishment [NAE] recommended that [the structure] be left alone and it was okay. So there were fun things like that to do.

BUTLER: That's good. It's always good to have a little fun in your job.

WATTS: And I was also looking after rocket [guided missile] launch loads on the C-105. We also did canopy ejection loads. At supersonic speeds we wanted to be able to eject people out of the clamshell canopy, but it was pressurized, so as soon as you let it go, it's going to go somewhere. So we had pyrotechnic devices to deploy the canopy and hold it open while the pilot ejected. We used a computer on that, too, digital analysis of the trajectory, of the doors and so forth, and the loads were quite high, but we did design it to be able to do that. Nobody ever ejected at supersonic speeds [from the Arrow], and I don't know that it would be a very wholesome thing to do.

BUTLER: Probably not.

WATTS: But we did do the analysis. And I did myself the fin and rudder loads on the C-105. It's interesting to realize that the Arrow was virtually a brand-new type of airplane in those days, and the usual rules, the regulations and so forth, the military specs for designing airplanes, when we tried to apply them to that kind of design, it would make the fin, for example, so heavy that the airplane would never fly. So we had to put together our own specifications and prove [to the Air Force] that they would be adequate. So I gained a lot of experience doing new kinds of regulation-writing that stood me in good stead when it came to the space program. There was nothing written down as to what to do, so we put together all the specifications for manned [space] flight. I think on Project Mercury we did that, and to a large extent those were used on Project Apollo. So it all built up, one step led to another and so on.

BUTLER: That's good. That's kind of the way it's supposed to work, I guess, step by step.

WATTS: I think I've been very fortunate in my life to have a lot of very good jobs. And then on the other hand, I was also fortunate enough, perhaps, to be ready for the next step when it came along. So, being prepared is not a bad motto. [Laughter]

BUTLER: Not bad at all.

WATTS: You never know what's around the next corner.

BUTLER: That's right. You never know.

WATTS: I was terribly curiosity-driven by about everything, though, and that helped a lot. For instance, when we were doing the rocket pod, we also did rocket pod launch loads on the aircraft. They were fore and aft, whereas the gust loads [had been] up and down. We found out that every time they fired rockets on that airplane—I did a very simple dynamic analysis on that two-degree-of-freedom system and found that every time they fired the rockets, they went to the limit load, which is the maximum design load on the airplane.

BUTLER: Oh, my.

WATTS: Which was okay as long as you didn't fire more than about 1,000 sets of rockets. [Laughter] Any self-respecting structure should be able to take about 1,000 applications of limit load without developing fatigue cracks. But it was quite unnerving to people to realize that, and they [had] wanted to put some two-inch rockets, more of them, [in the pod] but the blast loads were much higher on those. I actually tested pods in a concrete tunnel, firing them and measuring the blast loads, and I actually designed a nose fairing that dropped the blast loads in half. These were Redstone two-inch rockets. For a number of reasons they didn't ever use them, one of them being that the exhaust was extremely corrosive.

But that was fun, firing rockets into sand, and you could see the hydrodynamic deformation of the rocket [warhead]. They weren't explosive; they were just dummy warheads. But you could see the way the high dynamic pressures of going into the sand just deformed them beautifully and symmetrically, just as though they'd been fired into water or something like that. You could almost see where the hydrodynamic pressures developed over the rocket [forebodies].

In examining the high-speed photos we took of rocket launches, I could see how the exhausts impinged on the front of the rocket pod. It looked very much like the kind of flow that you see in hypersonic flight. I mean, the flow sticks right to the surface, [it] comes back [from the rocket nozzle] and then sticks to the surface. So I said, "Fine. We'll use hypersonic logic to design the rocket pods." And I did that and was able to drop the blast loads down to a half. The mechanics were very happy to show me [by test] that we had accomplished what we had set out to do. I didn't tell them I'd really designed it to cut the loads down to 20 percent. [Laughter]

BUTLER: Let them think everything went the way you planned it. [Laughter]

You mentioned you used a concrete tunnel and firing into the sand, and the computers for analyzing. Were there other methods that you used for testing and analyzing?

WATTS: Well, the high-speed photography was very important. When we tried to make the C-100 Mark 4 with the four-foot extensions on it, one of my jobs was to make it fly to higher altitudes. I'm not answering your question exactly, because what I'm trying to show is that we used photography a lot. We put tufts all over the wing and then flew it up high and photographed it from another airplane to see what the flow looked like.

We were determining—there was a shock boundary layer detachment that prevented us from going higher. I spent quite a bit of time using vortex generators trying to improve the boundary layer so to reduce the detachment area. But I wasn't able to increase the maximum altitude for the simple reason that although it improved the flow and the shock separation was better, I also added profile drag with the vortex generators, and the two canceled out. But at lower altitudes, the vortex generator allowed them to pull more Gs, higher load factor, so they worked. The engine thrust just wasn't enough to let it go any higher, so we got [the airplane] to about 54,000 feet, though, which was very high in those days.

BUTLER: That's pretty good. Pretty good.

WATTS: Another thing, too, when we launched rockets from that machine, the rockets would leave, be fired through a nice streamlined nose cone, and that changed the aerodynamic shape and it blew a tail cone off, too, so they had now a nice blunt object there. Well, that meant that the flow had to go around a less streamlined body, and there was more kinetic energy in the flow going around it, and that led to large shock load factors. That's the same process that occurs in parachute [opening]. So I had some insight into what parachute shock loads would be later on.

So everything sort of fit together, as long as you just let your curiosity prompt you to ask the questions why things happen, and then it's amazing how often the solution to one problem will be around for new problems. It's still happening today where I'm working now as a consultant.

BUTLER: That's good, you can just learn from each step and keep an open mind and be able to figure it out as you go along. Great.

While you were working in AVRO and with the Arrow, it eventually got canceled.

WATTS: Yes.

BUTLER: Were you aware beforehand of the possibility? And then how did you hear about that coming about?

WATTS: Yes, we had heard a year, half a year ahead or so of time…The Prime Minister had threatened to cancel it, and I knew that, and I think everybody in the country realized that, but the people inside the company were kind of blinded by the [length of time] the project had been going thus far, and they managed to persuade me that it wasn't going to happen. [Laughter] But, of course, it did happen. If you ask me what was my response to that, my response was to run all the way to the Credit Union and sell my AVRO stock.. [Laughter] And I managed to catch it just before it went fwttttt, and got my money out, just exactly what I paid for it. [Laughter]

BUTLER: That's good. Quick thinking. [Laughter] Very quick thinking.

WATTS: Okay. On a more serious vein, it was a disappointment, of course, but we did have a year—'59. Let me see. About a year of flight testing. So we had shown the machine to do everything we had hoped it would do, and we'd learned our lessons as engineers from it, so that we were more or less finished with that machine except for, from a structural point of view, finding out those important things about how long will the structure last before [it] fatigue fails and things like that. We never got those questions answered. As far as all the other technical things, they were pretty well answered, and the machine performed—I think the word "flawlessly" might be a bit of a misnomer, but virtually flawlessly. It did everything we expected it to do, without any major modifications.

BUTLER: That must have been very satisfying for you.

WATTS: It was. Yes, it was. As a matter of fact, when it was canceled, I got home and I told my wife, "You know, I've been laid off." Everybody in the plant was laid off. Fourteen thousand people were laid off at three o'clock in the afternoon.

BUTLER: Unbelievable.

WATTS: And she looked at me and she laughed. It wasn't until the next day that she finally realized I was telling her the truth, when I was looking through the paper for jobs. A friend of mine who ran a poultry processing operation, I mean designing of equipment for poultry processing, offered me a job at about a quarter of the pay I'd been making at AVRO. [Laughter]

BUTLER: Oh, dear.

WATTS: But that was very good of him, anyway. But that Sunday evening I received a call from AVRO and they asked me to come back, so I didn't even miss one day of work. About 1,000 of the 14,000 were brought back. The reason they were brought back was to help shut the place down in an orderly fashion. The company had some ideas of organizing the out-of-work engineers into teams and letting them out to do other tasks. So I had the most unpleasant task of interviewing my comrades and asking them about their education and their experience and so forth, and writing it down. It almost would have been better to be with them than to have done that. As far as I know, I don't think they ever got any other jobs.

So about two months after that, the opportunity came. I stayed on to work on some large radar antennas that were going to be put up on the northern part of Canada. And we got the job offer to go to NASA.

BUTLER: How did you hear about that opportunity?

WATTS: Well, I think NASA sent some people up there. It's a little vague to me at the moment, today, and I don't remember having a formal interview from NASA. I think Bob [Robert R.] Gilruth may have been there and asked me a few questions, but basically we were hired based on Jim [James A.] Chamberlin's recommendations, I believe. He put together a team of about thirty people to go down there and do the engineering work on Project Mercury, and I was one of the first thirty. Dick [Richard R.] Carley was two doors down in the same Empire Motel in Buckroe Beach in Virginia for several months until we got settled down in [Virginia]. It was a great time. My wife, though, was left behind to sell the house, and, of course, with 14,000 people out of work, the real estate market was—

BUTLER: Not doing well.

WATTS: —doing very poorly. After two or three months with me phoning her and making one or two trips back, telling her about how wonderful it was swimming down on the nice beaches in Buckroe Beach, she said, "Look. I'm not sitting here any longer." As soon as the kids got out of school, she came down and we rented the house for a few years until we could sell it.

BUTLER: That's good. That's good. It must have been hard having the family up in—

WATTS: It really was tough. I remember, I guess, about fifteen years after we were married, we were talking at a New Year's party or something, I said, "You know, those first fifteen years of my life (this was quite a few years later) were the happiest of my life." And out of the dead silence in there, my wife said, "They weren't for me." [Laughter] Sitting at home, settling arguments between two little children in the dead of winter, with no car sometimes. It was awful. And here I thought I was a very sensitive, caring person, and I had never realized that.

BUTLER: Oh, my.

WATTS: Am I getting off the track?

BUTLER: Not at all. Not at all. To jump back just a little bit, Sputnik was launched while actually the Arrow was still active and you were working up there.

WATTS: That's correct.

BUTLER: Did that have at the time any impact on you? Or was there any discussion about it around AVRO?

WATTS: I remember hearing about it on the radio, driving in the car at night somewhere. You have to remember that in those days the idea of artificial orbiting bodies was, you know, it wasn't even thought of. It was a totally new thing. So I must admit, my reaction, and I think most other people, was just complete surprise and, I would say, in my case, perhaps others' as well, a great deal of fear, because you have to remember I'd spent the last ten years building fighters to shoot down Russian bombers.

BUTLER: Yes.

WATTS: They did not have our good interests at heart. To think of them orbiting something right over our cities—of course, at that time we didn't know it was a small basketball-shaped thing—but that was very scary. It was very scary.

BUTLER: I'm sure.

WATTS: And we knew the moon orbited the Earth, but we didn't think of man being able to make artificial satellites like that. The word "satellite" was hardly used. "Environment" was a new word in those days. We didn't even talk about the environment at all.

BUTLER: Wow.

WATTS: To give you an idea of the lack of discussion or knowledge or interest in what we now call the environment, my father, as I said, worked for the Inspection Board [of] the

United Kingdom and Canada, and one of his jobs was to supervise the manufacture of mustard gas in Canada, which was never used, of course. But we were ready. If the Germans used it, they would have got it back very fast, and I guess they knew that. But to give you an idea of what happened, the entire production of that plant during the war was put on two large barges and towed out into the Atlantic Ocean and sunk.

BUTLER: Really? Oh, my.

WATTS: The logic being, the cans, barrels, will corrode in time and gradually release the contents and it shouldn't hurt anything. And that was it. But can you imagine that happening today? [Laughter]

BUTLER: Oh, that would cause a little furor. That's interesting.

WATTS: As a historian, you must realize that people's perceptions of things were greatly different then than they are today.

BUTLER: Absolutely.

WATTS: The manned bomber was our threat then, although about that time I did become aware that there had been work on ICBMs [Intercontinental Ballistic Missiles] going on, just in magazines, and I didn't quite know what they were at first. So that was my introduction to suddenly it's in your face space, you know. [Laughter]

BUTLER: When the U.S. started making attempts to get a satellite up and those were unsuccessful at first, was that a cause for concern as well?

WATTS: Well, it was more of like watching a Charlie Chaplin movie to us. We just laughed. [Laughter] It was at the Vanguard Project by the Navy, wasn't it?

BUTLER: Yes.

WATTS: A week or month after month, there it would go, blow up on the pad, full of glory. So they were sort of the laughingstock at the time.

BUTLER: Do you remember when you heard about Explorer going up and being successful?

WATTS: I do recall that, but I didn't know much about it. That was Redstone arsenal. Yes. In fact, it was Wernher von Braun that finally got into the act and got something up into space. They used a Redstone or something like a Redstone, didn't they?

BUTLER: Yes. Jupiter C, just a modified version.

WATTS: Yes. That was the first. Mercury shot was on a Redstone. I remember that very well.

BUTLER: Talking about Mercury, we talked about how you came down to NASA and went down to Virginia. When you came down, what was the reception like for you coming into the newly formed Space Task Group?

WATTS: Okay. Did I mention before how we actually came across?

BUTLER: No. Why don't you tell us about that.

WATTS: Okay. The U.S. Consulate in Toronto was shut down in the afternoons until the thirty of us were processed through, and we came through on a special act of Congress, the first thirty of us.

BUTLER: Wow.

WATTS: The reason that we were hired, I think, was partly because the pay scale in the rest of industry in the U.S. was about 30 percent greater than NASA was paying in those days, and they couldn't really attract anyone from U.S. aviation to go and work there. I'm sorry, I said 30. The pay scales in the rest of industry were about 15 percent higher than NASA could pay, but ours were about 15 percent lower in Canada, but 30 percent lower than U.S. industry. So we could go to NASA for a pay increase. Of course, the fact that we were out of work also had something to do with it. [Laughter]

BUTLER: Big incentive. [Laughter]

WATTS: So I think that they recognized—actually, we didn't do the design of Project Mercury. That was done by Max [Maxime A.] Faget and the people from Wallops Island, I think under Bob Gilruth, even at that time. And those guys were really brilliant, not only technically but in their ability to handle the government of the United States and get funds. That I take my hat off to them. That was a really creditable job they did. But they did not have the engineering manpower, and that's what they needed, and that's why we were hired to come down, to make their ideas work. And that's what we did.

BUTLER: And you did make them work, that's for sure.

WATTS: Yes, it was quite an interesting whole thing.

BUTLER: Many people have said that without your group that came down, without the AVRO group, that NASA wouldn't have gotten where it did in the amount of time it did. Do you have any thoughts on that?

WATTS: Well, it's hard to say now, in retrospect, but I'm sure the U.S. could have done it by pulling—I'm not so sure. I mean, you can't go hauling people out of industries and forcing them to work. It wasn't Russia. So the fact that we were able to work there, we did it. No, some others could have done it, probably they could have, but we were there and we did it, so that was that. [Laughter] And the fact that we'd worked on such an advanced airplane, I think, was very important. That machine, the AVRO Arrow, that you see up on the wall there, it was far ahead of any other airplane being designed in the United States at that time.

WATTS: We tested our intakes in a one-sixth-scale model in the NASA—or NACA. This is from a little book I taught a course from a year or two ago on aircraft aerodynamic design. Let's see. Where was I?

BUTLER: The intakes.

WATTS: Yes. We took the one-sixth-scale model of the airplane from about here forward, with the intake just on one side, I believe, if I remember correctly now, and we had a plug [out]let at the back so that we could vary the mass flow through the inlet. Then we tested it in an eight-foot supersonic tunnel at Lewis Laboratory, and the performance of the inlet was almost exactly what we predicted. Just the previous occupant of that tunnel had been from North American, and their supersonic inlets at Mach 2 got 30 percent recovery, and they went home in tears, I'm sure. [Laughter] And 78 is what we got, 78 percent efficiency.

BUTLER: That's great.

WATTS: It was great. My job on that test was to look at—what do you call it? The organ-pipe mode in the [inlets]. The shock ingested into it would result in an oscillation of the air inside that gave overpressures, and I had to keep track of when that happened.

The only thing we changed was this reverse scoop underneath. We made it larger. What this did was suck air [off] the perforated inlet, the boundary-layer air, and then it went out through [the] reverse scoop. That's so that the shock boundary layer interaction going into the inlet wouldn't be too severe. It was called intake buzz. I was trying to remember the word. Intake buzz is what I looked after on that test. We actually had high-speed 12,000-frames-per-second movies showing the shock buzzing in and out of the inlet…The machine itself—John [D.] Hodge actually did the design of the inlet. He had, for some strange reason, had been looking after the loads [group]. He was my predecessor in flight loads at AVRO, and I took the job over from him. I worked in the loads group while he was the group leader, and then he went on to operations at Arrow operations, and later on he went to NASA as operations. Have you spoken to John?

BUTLER: We haven't had a chance to speak to him yet, although we are hoping to do so soon, possibly later this spring.

WATTS: He was a very close friend of ours.

BUTLER: I'll make sure to mention—

WATTS: Say hi to him.

BUTLER: Absolutely. We're hoping to get up there, so if I do, I'll let you know that we are going to go see him. We're always glad to do what we can to pass words on for you.

WATTS: His family and my family, way back then and up till the time I left the Manned Spacecraft Center [MSC] in Houston, then we went to Rocky Mountain National Park once after that, and that's the last time I guess I saw him…maybe '6[6], I think. I can't remember. A few years later was the last time we saw him.

BUTLER: It's been a few years.

WATTS: It's been a while, yes. So I got off the track there. What was the question again?

BUTLER: We were talking about—that's a good question, what the question was. I think we were talking about the AVRO group coming into NASA and how you fit in and how you were accepted.

WATTS: Well, I noticed that things were a lot different at NASA than I'd expected them to be. I'd read a lot of NASA reports and had tremendous respect for [the authors], and I found that there were some very, very—well, there were a lot of older, better, very knowledgeable engineers, scientists, really, and I got along with them. Houbolt was one of them. I took courses from him.

BUTLER: While you were at NASA, you took courses from him?

WATTS: Yes. [NASA] offered very good training programs there through the University of Virginia and the Virginia Polytechnic Institute. They were offered at NASA [Langley], so we could just go over there and take these courses. I took several courses from him, and later on he wrote the letter of recommendation that allowed me to go to school at Caltech.

BUTLER: Oh, that's great.

WATTS: He helped me to go there. So that was great. So we had a corps of people that were quite experienced, and in supersonic flight…Some of Project Mercury's flight [path] was at subsonic speed and [some at] supersonic speed...How to test, what to do, and what was important and what wasn't important…Some of the inexperienced new people [were from] NASA—NASA was one year old at that time, [and] they didn't know much about engineering, and that really kind of dumbfounded us a bit, that some of the things they did not appreciate, but then again, that wasn't their work [and they were very young too].

So, I don't know, I guess I can't answer your question whether it could have been done or not. I just know that we were there and we did it.

BUTLER: That's good enough. Just looking for your thoughts on it.

WATTS: There were a lot of very good guys at NASA, like Al [Alan B.] Kehlet. Have you spoken to him?

BUTLER: No, not yet. Not yet.

WATTS: Well, say hi to him. He…designed the Apollo capsule, reentry capsule. I was there when he designed that, the aerodynamic design of that. He later became a high muckamuck in North American. I haven't seen him. I just saw something in the paper about him one day a couple of years ago.

To get back to your question about how we were treated by NASA, and I guess we were talking about Al Kehlet. That's a good place to answer your question. We were very warmly received into NASA, very warmly received, and we were treated very well. Al Kehlet particularly, he and his wife [Lois], took my wife and myself and the kids out in their motorboat, out to an island out in the sound, where we had a barbecue.

BUTLER: Well, that's nice.

WATTS: You know, it was really very nice, a picnic. I had a section there and I had people, NASA people, some new hires in the group. May Meadows worked for me. She had worked at NASA a long time. I'd read papers that she'd co-authored, in fact, on turbulence response.

BUTLER: May Meadows was a woman engineer?

WATTS: Yes.

BUTLER: That must have been different at the time.

WATTS: There were a few women engineers there, or scientists, I guess, more properly. She particularly welcomed us. The kids loved her. She introduced us to Southern cooking. She was from North Carolina. She became a very warm friend of the whole family's. Dick Carley knew her, too. She was very nice, a very nice person.

So the answer, it was very nice to go there.

BUTLER: It must have been nice to see after having just had this massive layoff and trying to find a job, and being so well accepted.

WATTS: Yes. We lived on Foxhill Road there, and the kids went to a little school out at the end of the road, and they loved that. [Our house] was only about two miles from the south gate at Langley, where we worked, so it was just idyllic, just beautiful.

BUTLER: The family liked coming down to Virginia?

WATTS: Oh, yes, they really loved that. Fish fries and things. Yes. The kids used to love catching crabs with a piece of chicken neck on a string, [lower] it down and then swoop a net underneath and catch the crab, and boil them and have them for dinner.

BUTLER: That must have been fun for them.

WATTS: It was, yes.

BUTLER: When you did come to NASA, what did you first work on there, or what division were you in?

WATTS: Okay.

BUTLER: Want to take a break?

WATTS: I'd like a little bit of water.

BUTLER: Absolutely. [Brief interruption.]

I guess now we could move into what you did when you first came to NASA and what you were involved with.

WATTS: Essentially my duties were very similar to those at AVRO. I was put in charge of flight loads analysis on Project Mercury. I was the section head of loads. That was my title. I worked under Max Faget. Jim Chamberlin, I guess, arranged that, and I went to work for Max. Then Bob [Robert O.] Piland—do you know him?

BUTLER: Yes, we've been able to talk to him.

WATTS: He was a very nice fellow. I really liked him a lot. Max was very busy, I didn't see him a lot, of course. He was the original designer of the Faget couch and so forth. I guess he had a lot to do with the original planning of the whole thing. A very brilliant man.

So I had a group of four or five people: Bill Rogers, Walter West, May Meadows, of course, and—let me see. I can't remember. There were a couple of others who came along a little bit later. Jim Bergen, he was a very important one. He was a meteorologist. He'd been offered a job at Langley and packed up his belongings in Seattle or Washington state, and drove all the way back there to be told, when he arrived, that the job had vanished, only they were going to be good to him, they weren't going to charge him for moving his furniture. [Laughter]

They said, "If you like, you can go around the field and see if anyone needs to hire [a meteorologist]." So he came into our building, and somebody walked into my office and said, "Do you need a meteorologist?" "Yeah, I guess so." So, okay. I guess they let me talk to him for a while and then they said, "Okay," and so we had him. He was very, very important. He became very important. I wish I knew where he was today. I'd like to hire him again. [Laughter] But if you can ever find him, he's a very good man, Jim Bergen. If you can find him, let me know where he is. [Laughter]

BUTLER: Absolutely.

WATTS: He did a lot of work on Project Mercury. We had to do a survey of the winds around the world between plus and minus thirty degrees latitude, to find out what the conditions would be for landing in the ocean. So he did a masterful job of putting that together, for one instance. It turns out that the winds over the oceans are very well known, better than they are over land, from the logs of sailing ships.

BUTLER: I hadn't thought of that.

WATTS: So, from hundreds of years ago they've been recording data, and it's been updated and brought up for use today, ocean currents and wind speeds and so on. That was just one of the many jobs that Jim did for me. He did windrose work at Cape Canaveral [Florida], to find out the probability of launch success by month around the year, and so many other things I can hardly bring them to mind, but he was very, very—and also he established a liaison with the U.S. Weather Bureau, between Manned Spacecraft Center—or I should say the Space Task Group [STG] in those days—and the U.S. Weather Bureau. He was the one that established the linkage there and made their vast resources available to us. So he deserves a lot of credit for that while he was working with me in the loads group.

BUTLER: That's great that he came from not even having a position there and—

WATTS: Yes, to being extremely useful. I didn't know anything about waves or anything, and he informed me that waves—yes, "what shape is a wave?" And I thought, sine wave. "You don't look at things…[very carefully]. It's trochoidal, you know, like this. And it has a maximum slope of about nine degrees." Well, that was important, because the capsule would swing underneath the parachute as it was coming down, so we had to get the worst combination of angle of incidence to the water and the parachute swing, to get the loads on the capsule as it hit the water, which were very large. NASA did tests, and I monitored them, where they dropped capsules into the water and they ruptured 1,000-pounds-per-square-inch pressure gauges mounted on the capsule.

BUTLER: Oh, my.

WATTS: So these were enormous forces. And that later led to the idea of the deployable heat shield that was squooshed down when they hit the water. So, anyway, that's getting off the track a little bit.

Bill Rogers did a lot of the launch escape work, the trajectory analysis, and the loads on the tower and so forth. We did have to beef the tower up. It turned out it was a good thing we did, because that helped [increase] the bending frequencies in the Mercury Atlas launch vehicle later on, because it's part of the launch vehicle. Walt West was the one who actually did the dynamic analysis of that by hand, if you will.

BUTLER: By hand? Oh, my.

WATTS: It's a method I brought down from AVRO. He did that under—they all worked under my supervision, of course. So we had a lot of fun. We just tackled problems as they came along. As they came up, we worked on them. Then we would have to go to St. Louis and look at the loads made by the contractor [McDonnell Aircraft Corp.] and comment on them, and suggest they change them in certain ways and everything.

Jim Chamberlin was in charge of the Capsule Coordination Office, and his job, in a sense, was monitoring and looking after the development of the capsule, coordinating the work between NASA and McDonnell. It wasn't McDonnell-Douglas then; it was just McDonnell. So he was the pipeline between the two, and they also had the people looked after—I mean, there were always extra charges made every time…a change to the contract [was made]. The contract change proposals we would make and they would respond with the changes, with the cost for the changes and so forth.

So, actually, this is getting off to the side a little bit, but the financial management of Project Mercury was very good. The people of the United States got their money's worth on Project Mercury for sure.

BUTLER: That's good to hear.

WATTS: In the early days, NASA was so penurious or so out of money, or whatever, that we didn't even fly on commercial airliners, which were all propeller [driven] in those days. NASA had its own DC-3, and it used to fly us around from place to place and a whole group of us from Langley Field to St. Louis or to Cleveland or to Florida.

BUTLER: That must have been an experience.

WATTS: And we shared motel rooms. I remember, in fact…I shared a motel room with John [H.] Glenn [Jr.] one day. Of course, he was just a brand-new astronaut, ex-Marine pilot, and wasn't famous at that time. But, I mean, it was a no-nonsense operation. It was done very efficiently, economically.

BUTLER: It must have helped to be able to get things done when you needed them to.

WATTS: Yes. It was important, too, that we had a great deal of flexibility to make changes, and without that we would have been totally dead. They were always debated beforehand, and we used to have a big meeting downstairs in the—I've forgotten the number of the building now. You probably know it. On the south side of—let's see. Which side? On the Hampton side of the field, anyway. Have you been there?

BUTLER: No, I have not been to Langley. I've been up to Goddard once, briefly, but I haven't had the opportunity to get to Langley yet, although we're hoping to make a trip out to the East Coast sometime this spring, so hopefully then.

WATTS: The only person I knew from Goddard was a man whose name, by the way, was also Butler. Tom Butler. He was the person who first acquainted me with the idea that NASTRAN, a structural analysis model, would be required on all contracts submitted to the government for adjudication. But I won't go into that here, I guess.

BUTLER: Okay.

WATTS: Where was I? I was talking about how they operated. So I had a little office upstairs with my people in it, and aerodynamics, with Al Kehlet, was next door. The thermodynamics, with Ken [Kenneth C.] Weston, was up there also. The operations people were in another building. That's where John Hodge and Tom [Thomas V.] Chambers and all those guys were, Fred [C. Frederick] Matthews. So I wasn't very intimate with the astronauts. We had occasional problems we had to deal with.

I remember one time a funny one, in a way, and that was that a pogo-stick oscillation in Mercury Redstone. I was asked to look into it a little bit by Jim Chamberlin, who was a very modest gentleman, but, I mean, superb man, my idol, I guess. I said, "Okay, fine, I'll look into it. What's the problem?" He says, "Well, the astronauts don't like what's going on?" I said, "Well, what is it?" Oscillations [can] cause your eyeballs so you can't focus and you get tunnel vision. That's one thing in fighter airplanes that happens on the older airplanes, [in] the low altitude gust penetration. He wouldn't tell me. Finally, I said, "Look, I've got to know." He says, "It's testicular pain." [Laughter] "Okay."

BUTLER: "Okay, we'll work on that one." [Laughter]

WATTS: That was funny. I just had to tell you that one story.

BUTLER: It's good to hear.

WATTS: Okay.

BUTLER: Share some of the intricacies of—

WATTS: Yes. [Laughter] How modest people don't wish to discuss things like that.

BUTLER: That's right.

WATTS: The aeromedical problems, they did a lot, and I used to hear about a lot of these things because I had to go to the meetings on loads, where they covered a lot of subjects. They were very interesting, too.

BUTLER: I'm sure. This was all very new, because we hadn't put men in space before. Coming up with a new design for the capsule, to do that, figuring out how to get them up there without too many little problems here and there, and getting them through it alive.

WATTS: Yes, yes. We took elaborate pains to see that—as far as safety was concerned. Not just structural safety, which is what I was involved in, but safety from every other aspect, too. So we would have multiple backup systems. If one system failed, we would switch to another system. We tried to have them all operating under different physical principles. I mean, if they're all electrical and you had electrical failure, you'd lose them all. So we'd have, say, an electrical one and a hydraulic and then a manual backup. So we had at least three backups for every conceivable failure that we could think of. And I think it was that meticulous attention to safety that resulted in no astronauts being killed in flight.

BUTLER: That's good. That's very good.

WATTS: One of the questions farther down was, what did I find [to be] the most important thing to me, and that was that there were no structural failures that led to any death or serious injury on anything I worked on. So that was my greatest reward on the projects.

BUTLER: That's definitely rewarding.

WATTS: I had seen, at AVRO, a pilot eject at low altitude after having both wingtips break off, and he got entangled with his oxygen mask, and saw [him], or his life [support] system fall into the weeds. I didn't see it myself personally, but somebody had taken photographs on an 8-millimeter movie camera at an air show, and I analyzed those frame by frame to find out what had happened. Once you've seen that, you take your work very, very seriously.

BUTLER: Absolutely. That's a hard way to have to go about it.

WATTS: The airplane itself, in retrospect, it was pilot error. It was judged to be pilot error, but the airplane was placarded to fly at no higher than Mach .79 below 4,100 feet, and it was an air show and he was trying to catch up to his buddies, and he went beyond that point.

The funny thing that happens on a straight-wing airplane is that the aerodynamic center of lift moves forward before it moves back to go supersonic, at supersonic speeds. Moving forward that little bit tends to make the machine unstable in pitch, and at that low altitude, at that high dynamic pressure—that is the product of air density and forward speed squared—meant that the machine, when he pulled back [on the stick] to try to pull up, [he] put on about 20 Gs per second for a fraction of a second, half a second, and broke both wingtips off just as they'd failed in structural tests. So in retrospect, it was really, I think—no airplane should be designed that way. Though he did violate the rules and paid for it with his life, the airplane shouldn't have been designed that way.

BUTLER: Yes, unfortunately. Talking about designs and the human aspects of it, what did you think of the Mercury design when you came in and saw this? Did it seem a logical approach? Were you aware of some of the other discussions that had gone on about lifting body designs and other approaches?

WATTS: It was the simplest and most direct way to do it, and with the small lifting capacity of the Atlas, which was, I think, about the only booster they had in those days, they didn't have a lot of choice. So that became very clear. In fact, one of my chief worries on that project was that the weight would grow too high to go into orbit, and I was responsible for increasing the weight a couple of times when the radiation shingles had [to be] made of thicker material to resist burn-through on reentry, and that bothered me a lot. I did wind-tunnel tests on panel flutter, [in the] Unitary Plan Tunnel on another side of the field [at Langley]. We did tests at Daingerfield, Texas, in a Navy Hotshot Tunnel, where we actually had heated air that simulated the reentry, and you could just see it knifing though the thin panel. So we did recommend thicker ones, and they were used on the machine.

BUTLER: This is the paneling on the side?

WATTS: Yes, the radiation shingles. It had a beryllium heat sink on the tail cone back there, and so they actually had both kinds of heat shields. I notice you later asked about that. Walt West…supervised the tests at Daingerfield, Texas. I think he's retired now. I heard that a few years ago. I haven't heard of Bill Rogers. Do you know of him?

BUTLER: No.

WATTS: He may still be there, for all I know. He was a little younger than I was.

BUTLER: We can look and see what we can find.

WATTS: He could sure give you a lot of information about that period, and if you can dig up Walt West, you'll probably find him fishing on some bayou…somewhere. [Laughter] I remember he and I were running along the beach in Florida one night during one of the shots, just for exercise, and we got really hot, so I ran into the water. He came out swimming with me and came back to shore, and he says, "You know, George, that isn't a very good idea. The sharks come in to shore to feed at night." [Laughter] "Oh, thanks."

BUTLER: That's good of him to warn you, although it would have been good to know earlier. [Laughter]

WATTS: Yes.

BUTLER: Talking about some of the structural and talking about the Atlas a little bit, I know you weren't directly involved with the Atlas part, but did you have any concerns or was there anything you did knowing that the Atlas was having some problems with stability and being able to launch successfully and so forth? Were you at all involved in—

WATTS: They pretty well had the bugs out by the time Mercury came along, as I recall. I did go out to Convair San Diego, though, and spoke to people in the Stability and Control Division about the control system gains, because I wanted those so we could calculate flight through turbulence to find the dynamic loads on the whole booster. But our part of it was just the spacecraft and the adapter, and they were responsible for everything else. But we had to look at the whole booster, though, in order to do that.

I had a terrible time getting gains out of them. Gains are the—let's see. How do you describe that? In the control system, how much response you get when you [pitch] over and the instrument measures an angular rate, for example, and generates a signal, how much of that goes back to tilt the rocket motor, how much is the gain of the control system. I had a terrible time getting gains out of them. Suddenly it dawned on me, they can't tell me because they're changing them every day, which was fine, you know. So I said, "Fine. I'll design my own," when we got back.

So people at Langley actually did the work, that is, the analog simulation of the Mercury Atlas with the bending modal data in it that we had calculated and we ran analyses, trajectory analyses, over there. They ran them for us. But we just designed our own gains then to give us a satisfactory stable thing, realizing they [Convair] would have to do the same thing. [We were] able to come up with some interesting things about how booster capsules respond to atmospheric turbulence. Unlike an airplane that has big lifting surfaces where one gust will do you in, multiple repeated gusts on a very lightly damp[ed] structure…is the thing that causes…the oscillations and loads to increase with time.

BUTLER: Interesting.

WATTS: I had done a little bit of gust work at AVRO, but not a lot. Fighters were pretty simple as far as gust response was concerned, but transport airplanes are another matter. I had later worked on that at Lockheed and the statistical…response…[to random] turbulence.

But we had an awful lot of fun [on] Project Mercury. We even, on Project Mercury and Apollo, would go down at the Cape. We'd go up to the Cape just before a launch and get radiosonde meteorological balloon data showing the wind profile, and [we] actually calculate the dynamic response of the vehicle to the winds, to see whether we could [launch] or not. We'd give that data to the flight director and he used it only as a check, because the primary responsibility was with the booster people. But it was surprising, it had a very simple single degree of freedom analysis, and I was coming out to within a few percent of the loads they were getting with their big multi-degree of freedom analysis. So we had a lot of fun.

May Meadows and I would go up there [to the Cape] and she would work on the hand-operated calculator. [Laughter] While I put together all the numbers and things for her to work with. So that was a lot of fun.

BUTLER: Were you able to go down, then, for most of the launches?

WATTS: I went down for several. I was trying to remember. I know I was there on MA-1 and MA-2, and I probably was there for some of the others, MA-3, maybe. I can't remember. And I was there for the Apollo SA-6 launch, I know that. I may have been there on others. I probably was.

MA-1 was very important, because the adapter failed…[and] the capsule fell into the ocean. I was watching the oscillograph at the time, and Bob Gilruth, the director, was looking over my shoulder, and we saw these strange wiggles on there. He says, "What's that?" I said, "Oop, it's probably signal dropout." It wasn't; it was the adapter failing. We had strain gauges on it, and this was telemetered back to wiggly lines on paper for us that we could look at. [I] should have known what was going on.

Jim Chamberlin—well, it became very evident very quickly what was happening, because you could watch the thing falling. You could see the gyro swinging around on the paper as the capsule fell down into the sea. But once Jim Chamberlin poked his nose in, he was quite satisfied with what had happened, I mean at knowing what the problem was, and he vanished and disappeared back to St. Louis to initiate immediate redesign of the adapter.

Then on MA-2, the adapter held okay, but MA-2, the booster failed to pitch over into trajectory, so it was destroyed by the range safety officer. I happened to be watching it through binoculars from a mile or two away…and it was interesting. You'd see this little [shiny] thing going up. You could see it about this big. Then it blew up and the whole field of view filled with red flame, the whole field of view of the binoculars. Then you could see the fuel continuing to move upwards, with no skin around it, blazing away, and then [the fire] went out. Then there was just little pieces of silver foil tinkling in the sky as they fell down to the ground…The launch escape system [was used]. That's the only time I think it was ever used, but nobody was on board, of course. It was just a flight, just a test flight.

BUTLER: And the escape system worked on that trip?

WATTS: It worked fine, came down on the parachute and everything. Somewhere I have a copy of a 16-millimeter movie of that, and I don't know where it is. If I find it, I'll let you know, unless you have a copy of it.

BUTLER: No, not that I'm aware of.

WATTS: I used it in a lecture at University of Houston on structural loads, and I ended it by saying, "And if you're not successful, this is what happens." [Laughter]

BUTLER: [Laughter] That's a big incentive. That's great. I think we'll take a quick break here and change the tape over.

BUTLER: ... some of the work you've been doing. At this time were you also working on the parachute work with Mercury? Was that some of what you were doing?

WATTS: Of course, we used parachutes, but most of the parachute design work was under John Lee, John B. Lee. Have you spoken with him?

BUTLER: No, not yet.

WATTS: He's a very good man. Of course, I needed to know about the parachutes in order to put out the loads [from] them. The ring-sail chute, the reefed ring-sail chute, I had the information on that to issue loads.

But there were some interesting experiences with parachutes. One of them was, they were going to drop a Project Mercury capsule out of a C-130 to test its ability to both stabilize, deploy the drogues and so forth, and make a parachute recovery. I think they'd had a failure or something on the steel cable that linked…canister [to the main chute]. The way the system worked was, there was a canister on the back of Project Mercury, and in that canister there was a mortar that fired a weight out. At the end of…the rope attaching the weight pulled the drogue out of the canister. That drogue inflated with a cord on it [attached to the canister], and that stabilized the [capsule] as it came down.

Then, finally, when they wanted to deploy the main chute, they just [broke] the canister loose, and that was dragged aft [by the drogue], then another piece of steel rope on [the canister]…pulled the main chute out of the top of the circular, cylindrical…aft end of the capsule. They had designed the steel cable to be strong enough to take the loads they knew the drogue…[would produce], but it was breaking and they didn't know what to do about that. They said it shouldn't break. I mean, it's twice as strong as the loads are on this thing. I thought, okay, it was breaking, so I said, "Why?"

It turned out that the drogue chute put a high load into the canister and then as it pulled it out, it added a lot of kinetic energy, so the canister itself was moving quite rapidly when it got to the end of the cable. So what I did was say, "Okay, I'll calculate the kinetic energy in the canister at that point." And the kinetic energy was greater than the strain energy required to break the cable. They wouldn't believe me particularly, but they said, "Eh?" I said, "Well, do this. Next time you drop it, use your present cable, but take another one and make it longer. If the first one doesn't fail, the second one won't be needed. But if the first one breaks, the second one will keep it from crashing into the ground."

So they dropped it out of the airplane. Sure enough, it came back with the first cable broken and the second one not broken. So they thought that was wonderful. [Laughter] Whenever you go to work for a new company as an engineer, it's…a philosophy, you want to do one of those "rabbit out of the hat" tricks for them just to get in well with people. [Laughter] So that was a lot of fun. I didn't tell them that I went back and retested the cables and found that both of them should have broken, [by] my analysis.

BUTLER: Luckily, they didn't. [Laughter]

WATTS: So that was a lot of fun.

BUTLER: As you were working on the parachutes, was there any discussion that involved you with other designs, like a glider or a balloon system?

WATTS: On the Gemini, they were contemplating using…a paraglider sort of thing. It was something like a hang glider…today. Actually, I've flown as a passenger in a hang glider just about three years ago, just for fun. But at that time it was Rogallo wings [named for Langley Research Center engineer Francis M. Rogallo], is what they called it in those days. It has sort of two lobes, has [three] beams. I saw what they were doing. They had built, I think, a solid model of it and tested it in the wind tunnel and had pressure distributions, and I had developed a lifting surface method for the Arrow, for delta wing, using the computer. I had made that work. So I used that method on the Rogallo wing and was able to come up with the measured forces on it. So that was about as far as I got into it. But I think it probably would have worked.

In future machines, they probably will make use of that, maybe. I don't know. [Laughter]

BUTLER: I guess with the X-38, they're looking at not a wing, but a sail-type parachute adapting, kind of in-between kind of—

WATTS: See the X-33 on the computer? See the X-33 on top of the 747? That was a little model we tested in our little wind tunnel out here at Lockheed. It was kind of interesting—naivete again—but they said, "Do you want wings on it?" Somebody said, "Oh, no, we just want the body on it." Of course the wings affect the flow over the aircraft a lot more than the body does, [but] they had the model built [without] and they asked me to design the wings. Well, I had no idea what the wings on the—well, I had an idea what the wings were like, but just a rough idea. So we looked up on the Internet to see what was going on, and I designed the wings on that [model] as closely as I could to the wings on the 747 [from a photograph].

BUTLER: Very good. Very good. Also from another area of concern was the heat shield. Were you involved with those studies?

WATTS: [I was] not in [aero]thermodynamics at that time,…just loads, when all the decisions were made. But I was certainly around and heard the arguments. I was convinced that the only way to go was with an ablation heat shield. It's kind of interesting. Back at the University of Toronto, my master's thesis was to eject a jet forward into a supersonic flow, and the reason for doing that was because they wanted to use ablation cooling on reentry systems. At least that was the idea behind this. And this was to simulate the ablating material, the jet of air coming out up forward. So I was a little bit familiar with the idea and the concept.

As far as I was concerned, the ablation was the only way to do it. There's a number of reasons for that. First of all, if you use a heat sink, where does the heat go? It goes into the heat sink and stays there, so it gets very hot. So after you've finished reentering, you're still sitting above this very hot piece of metal and you're cooking the spacecraft all the way down to the ground.

BUTLER: I'm sure the astronauts wouldn't enjoy that.

WATTS: No, they would not enjoy that. But with the ablating system, first of all, on Project Mercury, which was a relatively low enthalpy machine compared to Project Apollo, the idea there is to come in and you have a big normal shockwave in front of the heat shield. What that does is compress and heat the air, but it doesn't ionize it, so the air doesn't glow. Then the kinetic energy of the machine is converted into heated air, and the heated air goes away, it doesn't heat the machine up. With ablation, the ablation products also leave with it. The temperature would be far too hot for any metal to withstand, unless it were enormously thick.

So that was the idea there, and it was the way to go. Especially on Apollo, there was no question at that time I was actually—when Ken Weston went on to get his Ph.D. degree, they put me in charge of aerothermodynamics later on for nine months or so. On Apollo, with the 36,000-foot-per-second reentry speeds, the air actually ionizes. It's such a high enthalpy, that when the air goes through the shockwave, it glows white hot. So what happens then [to the air], instead of just getting hot and blowing away, it radiates heat, and half of the heat, in principle, half the radiated heat goes into the heat shield and half away. So that's far more heat than is required to vaporize everything, including the astronaut.

So the ablative heat shield design was a very, very tricky endeavor. You had to sort of, if you will, reflect part of the heat away if you could, and the liquids and ablative products that were generated as the heat shield became undone. As a matter of fact, the people, Bob

[Robert C.] Ried [Jr.] and John [Bertin]—what's his name? Not Martin. I've forgotten the name. They were looking after all of that, and Ken had laid all the groundwork, but they were doing tests with AvcoRad, in which they used shock tubes. The Institute of Aerophysics [University of Toronto] did wind-tunnel testing and shock tubes. Those were the main tools…used [there]. So I was familiar with shock tubes, too.

But in that case they fire a shockwave down the tube and it reflects off the end, and in that double [compression] it heats the air to such a temperature that it can ionize and then it gives off just an instantaneous flash of light. They were analyzing that flash of light to determine what the radiation spectrum was so they could design the heat shield to get rid of it. They did that work. It was really very brilliant. That's one place where we were really very far ahead of the Russians and could make that very difficult design task work. Project Apollo was more than just a small step ahead beyond Project Mercury; it was a very large step as far as heat rejection design. [R.] Bryan Erb looked after the design. Ken Weston and the aerothermal group looked after what is it that's happening, that [Erb] looked after the design. Do you know Bryan? Have you worked with Bryan Erb?

BUTLER: We haven't worked directly with him, but another member of our group has talked with him briefly about the project, and we're hoping to talk with him soon also.

WATTS: Get Ken Weston and Bob Ried. I can't remember the other man's name [John Bertin]. He's now a professor at the University of Texas, has written books on aerodynamics. I should remember his name. [Laughter]

BUTLER: It'll probably come to you. That's W-E-S-T-O-N?

WATTS: T-O-N. Ken. A student of W. E. Moekel.

BUTLER: As we're talking about the heat shields and the stresses on entry and so forth, during John Glenn's flight there was indications of potentially the heat shield had deployed.

WATTS: You mean his Mercury flight.

BUTLER: His Mercury flight, yes. I guess I need to remind myself now he's had two of them. During his Mercury flight, there was indications that the heat shield had deployed and then there was talk about leaving on the retrorocket pack. Were you involved at all in looking at how that could affect his reentry?

WATTS: No. I remember that now that you mention it. I hadn't remembered it. I can't remember whether they left it on or not. Did they leave it on?

BUTLER: They ended up leaving it on.

WATTS: What was the question again?

BUTLER: I was wondering if maybe you were involved in any discussion.

WATTS: In the thermodynamics of that problem?

BUTLER: Even as to if they left it on, would it cause any loads or stresses that would affect—

WATTS: It would have to be burned off in that case, and the question is then what happens to the products of that as they impinge on the heat shield. I wasn't in on the discussions of what to do. I guess it was just it came up and was during the flight, and they had to—I couldn't remember whether they elected to come in with it on or not. They did, didn't they?

BUTLER: They did.

WATTS: I think what they were afraid of, and this is really speculation on my part, was that if they released the retrorocket, they might have also released the heat shield, which was deployable on a big accordion-like thing that broke the water impact shock. If that had happened and the heat shield were not attached, he's a cooked goose. [Laughter] So I can understand why they would elect to take that alternative and try it, rather than take the risk of it being fatal the other way. I guess they feel [at] the end that it really hadn't deployed, the heat shield hadn't deployed in flight.

BUTLER: Yes, I believe they found it was a faulty signal. Always better safe than sorry, I guess.

WATTS: Yes, you have to do what you think is the best course of action usually of two bad choices. [Laughter]

BUTLER: Absolutely. We talked briefly about the launch escape system and that it was used at one time and did work successfully. How did you study that in relation to the capsule and how it would affect the flight and so forth?

WATTS: Well, with my work on rockets at AVRO, I'd had to look at the exhaust plumes from solid-propellant rockets, so I had a bit of familiarity with what did go on. Of course, the gas dynamics of a jet [is] similar to that of a supersonic wind tunnel, anyway, so…I was able to put together what the [flow] field would be like that impinged on the capsule when the rocket went off, and what would happen to it as the machine took on an angle of attack and [the jet] bent back. We just put together some very simple momentum transfer studies, no computer or anything like that, and spatial steps to see where the trajectory of the rockets would go. The machine itself was stable aerodynamically, so it would tend to go where it started to go. But then we did pull very high angles of attack at times, and that caused a large bending moment on the tower. It was those loads that required us to beef the tower up, so we did have to increase the strength in the tower to do that.

Especially on Project Apollo—I'm trying to remember on Mercury. I'd have to look at my notes in here. But we were afraid of the booster blowing up, so there's a compression wave that goes through the atmosphere and would crush the capsule, so we had to make sure that we had adequate warning that things were going wrong, because with the oxygen JP4 or whatever it was, it was a kerosene product on the Atlas, and liquid oxygen, and those two sort of form a gelatinous mixture not unlike dynamite [if one leaked into the other]. And [the] same or similar to that on Apollo. So we had to sort of estimate yields, explosive yields, of these mixtures, what we could possibly get, and try to make sure that the rocket, the launch escape rocket, carried the [capsule] outside the [compression] field, so that when the pressure wave overtook it, it expands spherically and drops the pressure very rapidly as [the front] gets farther away, that the pressure was low enough so it wouldn't crush the capsule. The capsule is designed [to] about a five-pound-per-square-inch overpressure, it seems to me, and so we had to do those trajectory studies and yield studies and so forth.

We actually used some experimental data from atomic bombs. [Laughter] To look at [methods]. At least we used those to try and see whether our analyses were making any kind of sense.

BUTLER: I guess if it works with those, then—

WATTS: And it also leads to an interesting speculation. I did not work on Gemini very much, but you asked about the use of ejection seats and parachutes on Gemini. I was just thinking the other night, as I sat here thinking about it, that we didn't have the same problem there, because the propellants of the Titan II were hypergolic. What that means, as soon as they touch each other, they blow up. They ignite right away. Whereas it was felt that the liquid oxygen and JP4, or even the hydrogen in the other vehicle, would not ignite right away and could mix to make a…large volume of explosive, but that could not happen on Titan II, because the two propellants that had to be mixed ignited on contact, so you couldn't develop a large mass. So you couldn't really develop an explosion on that. I suspect that that was one of the reasons…they were able to use parachutes on Gemini and not on the other two vehicles. That's a bit of speculation on my part. You see, you ask[ed] some very provocative questions.

BUTLER: That's good.

WATTS: It's interesting, too, now to look at history, and that is that the ejection seats and the opened canopy were very, very similar in principle, not in actual detail design to those used on the AVRO Arrow. They opened up and the astronauts would shoot out of there.

Another thing to remember, too, is that both these systems, the launch escape system and the ejection seats, were only for atmospheric flight, for low-altitude atmospheric flight, so the parachutes would have worked quite well where they're most needed. It's just post launch, launch, just prior to launch, and just after launch, until you get up to, I don't know, maybe maximum dynamic pressure. It was only about 600 pounds per square foot on those vehicles. I think Apollo it was. Maybe a little higher on Mercury and at about 30,000 feet. If you [knew] that, you'll perhaps understand a little bit more what I'm talking about. I'm speaking not to you so much as to the audience in general. I know you may not understand the technical things, but there are other people who will.

BUTLER: Absolutely. Yes, we want to make this available to a wide audience, so that's great.

We've talked a little bit about some with Mercury and even Apollo and how you did kind of have a crossover on what you did and Mercury affected your work in Apollo. Were there any specific lessons learned that you got from Mercury that you applied to Apollo, that you can think of?

WATTS: Yes. The adapter failure on MA-1 was the one very significant structural failure on anything, and as a result of that, I was sent to Caltech for nine months…I guess it was, to study the problem. I did experimental work on small shells like that. I actually made the shells. They were copper shells made by electro—it's like electroplating without—just melt the stuff that's inside and you're left with the electroplated copper shell. I had to find the vibration modes and the structural damping of these, and they were later to be tested by others in the wind tunnel to see what the dynamic response was. So I put together a paper or two there describing how to do that at Caltech.

When I came back, we instituted [analysis at] that on the Apollo Project. We had a boilerplate service module that was sixteen feet in diameter and sixteen feet long. It was actually, by pure coincidence, just a factor of twelve larger than the ones I'd done at Caltech, which were sixteen inches.

BUTLER: That's interesting.

WATTS: And we had one flown from Huntsville [Alabama] to Houston and landed at—what's the Air Force base there that we were on?

BUTLER: Ellington Field.

WATTS: Ellington, yes. And that was before the Space Center was built at Clear Lake. We set it up in the hangar and we put shakers on it and vibrated it and found its natural vibration modes and dampings for about a week, I think, we spent doing that. We drove everybody crazy with the racket, but it was fun. We found an interesting thing, and that is—I'd also found that at Caltech, was that we could get the best signal-to-noise ratio at about 2 a.m. That's because all the other electrical equipment in the city was virtually shut off at that time, so there's not much noise going through the electronics.

And also the temperature change. The temperature changes during the day would actually affect the natural vibration frequencies [during] that time. It was fairly stable, so we got good data at [2:00 AM]. The idea…was to take the boilerplate command module, which was very strong compared to what they were planning for the production machine, and fly it and record the response of the shell and then deduce back, deduce from that what the environment had been that was vibrating the shell, and then use that environment and apply it to the Project Apollo service module.

I left NASA before that actually all came to pass, but Otto Krenwelge, who worked with me, picked up that work. He actually wrote a Ph.D. thesis, I think, at Rice University or University of Houston, I'm not sure which now, on the subject, and he did a lot of work on it after that. So in a way I kind of founded the study of that problem at NASA. So there's a clear case of where an experience of Mercury played—had a large effect on Project Apollo. That was one thing.

Of course, the launch escape systems were similar on the two, so a similar type of analyses…were done on Apollo, not by me, but by some of the other people in my group, and also the booster…launch loads and the gusts, of course, but then there was a hardover failure where something goes wrong and the booster engine tilts all the way over at maximum rate and pitches the machine. That gives very large [elastic] dynamic loads. That was also used, and [the structure] had to stay together until that was finished, until you at least initiated a launch escape.

Those are some of the things that come to mind. There were probably other things, too.

BUTLER: Those are some pretty important factors.

WATTS: Probably the launch, parachute swing, and that sort of thing also…carried over.

BUTLER: You mentioned going out to Caltech. When did you go out there?

WATTS: '61, in the fall, and back in the spring of '62.

BUTLER: In 1961, as Mercury was just getting up to speed—

WATTS: That's right.

BUTLER: —President [John F.] Kennedy said, "We're going to go to the moon by the end of the decade and we're going to bring a man safely back, too." What did you think when you heard that?

WATTS: Well, of course, I had known that we were planning to do that for some time, but, still, it was very stirring to hear him announce it…on a television set. But there's also sort of a little story there. John Hodge and his family were down in our back yard on Foxhill Road having a cookout or a picnic or a dinner…on a picnic table, a redwood table, I [made]. But anyway, as the moon came up over the horizon, John and I said to our wives, "That's where we're going next." It was very emotional.

BUTLER: I bet.

WATTS: Because we really were going to the moon.

BUTLER: That must have been something not just at that moment, but all throughout the years, as you were working on this, to see the moon most every night and see that as your target.

WATTS: It was a beautiful yellow moon. I remember it clearly. I remember the trees over the swamp…It was very wet, tidelands Virginia, and it was very impressive. Yes.

BUTLER: That's great. Were your families excited about the opportunity?

WATTS: Oh, I think so. They said, "Would you like some more potato salad?" [Laughter] They were used to us, of course.

BUTLER: As you were working on Mercury and Apollo, did you have any involvement with Gemini?

WATTS: A little bit. Jim Chamberlin was…the man behind Gemini. It was…his planning and his doing that it came into being. Dick Carley had a lot to do with it, but I had very little to do with it. [Jim] had one problem on the Gemini adapter, which…had a large piece of equipment hanging off the inside of it, and he was worried about that vibrating loose during launch. So he and I sat on a plane and calculated the dynamic response of that, with the tools that I'd developed at Caltech, on the way to Florida. We decided that it was safe. They actually instrumented it, and when they flew it they found that the vibration response was about a third of what we'd predicted, so we were quite conservative, but at least we weren't unconservative.

And I knew what was going on in Gemini. At least I knew some of what was going on with Gemini, but I didn't really do any loads on Gemini. That's strange, because Jim Chamberlin—in fact, sometimes they referred to Gemini as "Jim and I." [Laughter] For Jim Chamberlin. He and I had worked very closely at AVRO since about 1951, so I had known him for a long, long time. He was always a controversial person, but he knew what he was doing. He knew what needed to be done, and he was very determined as well, but in a very nice way.

BUTLER: Very good. You've mentioned Jim Chamberlin a few times and some of the other individuals you worked with. It must have been good to work with such a group.

WATTS: Oh, yes. Yes. The spirit that existed at AVRO was quite different than the spirit you see today in the aircraft industry, and that is…when I started there in 1949, it was four years after the end of the [Second] World War. The company had started from scratch in 1945, I guess. So in four years they'd developed a jet fighter, a jet transport, and the engine for the fighter with a [peak] workforce of 4,000 people...at the end. It peaked, of course, at the end…so those were people that were no-nonsense people. At the end of the Second World War, when the soldiers came home, they felt they'd wasted the last six years, and [there was to be no more]…wastage of time for them. You could not—I mean, if you walked up and spoke to them and it wasn't exactly on what they were working, they'd tell you to get lost, go away, they're busy. And absolutely. And they were a tough bunch, too.

I noticed in the university, when I was going there…a lot of the people were ex-servicemen, and professors got away with nothing. But then I went and took some courses a few years later, when most of the servicemen were through…it had come right back again. The professor would come in and start writing on the blackboard, write on it, and walk out, never talk to the students. They would never have got away with that with the servicemen. They would have been beaten up in the alley if they had. [Laughter] These were people that, you know, saw the most awful things in Europe and participated in them. They were there to get their education, and then when they were in the industry itself, they worked like absolute beavers. There was no nonsense at all. And it was a thrilling time to work.

I think some of that was carried over into NASA, although I must admit that during the later days in AVRO, things were not as tight as they had been at the beginning. In NASA, they were pretty good. Apollo didn't have the same spirit. I guess they had done it once and would make it again. I've seen it at Lockheed and other places, too. It's nothing like it was the[n], except now in the Skunkworks it's a bit like that again.

BUTLER: That's good.

WATTS: So there's [some]…observations on working, people's work ethics and [such].

BUTLER: Sure. And it's different everywhere you go, I'm sure.

WATTS: I'm sure it is, yes.

BUTLER: Working on Apollo, we've kind of talked a little bit about Apollo here and there. Were there other aspects of Apollo that you were involved with that we haven't touched on yet?

WATTS: I'll take a look, if that's okay.

BUTLER: Absolutely.

WATTS: There's this many pages, by the way.

BUTLER: Oh, my.

WATTS: Of notes.

BUTLER: It looks like you could be ready to put together a book of your own.

WATTS: Probably. I had often thought I was going to do that, so I was very glad when you came along and volunteered to relieve me of a lot of that work.

BUTLER: Well, hopefully what we do here can help you if you do decide to pursue such an avenue.

WATTS: To let you know what I come up with?

BUTLER: Yes, absolutely let us know what—

WATTS: Probably more of the philosophical things is what I would put in a work of my own, I think, if I had more time to think about them.

We rented the Pregnant Guppy to fly that adapter from Huntsville to Houston. I remember the number. It cost $28,000.

BUTLER: Oh, really. That must have been interesting.

WATTS: I remember seeing it coming into view, flying along this huge, monstrous, bulbous body, and landing.

BUTLER: That must have been—of course, that has its own aerodynamic challenges.

WATTS: Well, just another thing. Just to continue a little bit with how things developed, we didn't get into Apollo yet too much, did we here? On Apollo, when I came back from Caltech, a few—I don't remember exactly when, but a few months after that, I guess maybe a year, a few months after that, I was promoted to the branch as assistant branch chief, so I just got a little bit away from the actual daily loads work, and Milt Silveira took over my work from that point.

A few other things I did. The last—okay. I was also a member of the TAG, the Technical Advisory Group, for SVAE, Shock Vibration and Associated Environments. That was a U.S. Navy civilian group with representatives from NASA Centers and a lot of naval centers that were in charge of recommending the release of classified documents related to shock and vibration. So that was kind of an interesting experience, working there. As a matter of fact, it was on a meeting with them up in California in 1964, at Asilomar up in—do you know where that is, up here at Monterey?

BUTLER: No, I haven't been up there.

WATTS: Monterey Peninsula. It's a beautiful place. I was walking along the beach and I found a dime on the sand, and I picked it up and I said, "Mmm, is this an omen?" And that fall I came to California. I don't know if that had a lot to do with it, but it was kind of cute.

I think we've covered most of the things. My last job out there was as the assistant chief. I was also structures subsystem manager on the lunar excursion module. That was just for a few months before I left to go to Lockheed. Went to Grumman to see the machine and so forth. I also looked at—

BUTLER: What did you look at on that?

WATTS: Mostly propellant tanks at that time. The short time I was working on it, it was mostly the liquid propellant tanks, these spherical, beautifully machined and designed tanks.

But one thing I would like to also mention, relative to flight tests at the Cape, one of my jobs on Mercury and Apollo was to advise flight test instrumentation for structural test purposes, so we planned that. That was one of our tasks…to review the data as it was being accumulated during the flight and then analyze it afterwards and publish the results.

I'll make a comment on that, something I recommended that was never followed, and that was the structural flight test instrumentation load levels were set so that if there had been a failure, they would have recorded what happened, but most of the flights, the loads were exceedingly small, so small that the instrumentation was not sensitive enough to pick up the information. So for most of the flights the instrumentation yielded nothing of scientific value. And one of the things I recommended, but wasn't able to [implement]—I said, "Look. Let's take 10 percent of the instrumentation and set it for the levels we expect, so we can find out what's going on." You know, money being what it is, they didn't want to waste 10 percent on that. It "was seen as a waste." So they didn't follow that.

BUTLER: That's too bad. That would have been interesting, I'm sure.

WATTS: It would have been interesting, but whether it would have helped the project, perhaps not. Maybe they were wise to save money. But you never know. And it's the curiosity, you know. The things you learn today serve you well on the next program, wherever you are. And I perhaps was preparing for the future.

BUTLER: When you were working with Apollo, were you also involved on the selection board for picking the contractors?

WATTS: Yes. Yes, I was.

BUTLER: What were the criteria that you looked at?

WATTS: The way the proposal would come in, there was a business proposal, of course, and technical proposal. Then that technical proposal was broken up into each different discipline. I participated in the review of those dealing with structural loads, of course with a lot of other NASA scientists and so forth doing the same thing. And so that's where I played a little part in the review of the proposals.

BUTLER: When you were reviewing them, do you remember how many companies had turned in proposals?

WATTS: Boy, I'm trying to remember. It was about four, I think, but I really honestly don't remember. I think Lockheed [Aircraft Corporation in conjunction with McDonnell Aircraft Corporation, Hughes Aircraft Company, and Chance-Vought Corporation] turned in and, of course, North American [Aviation, Inc.], and I don't remember what the other two were now. [Three others—Grumman Aircraft Engineering Corporation in conjunction with Space Technology Laboratories, Inc., General Electric Company, and Douglas Aircraft Company; The Martin Company; and General Dynamics/Astronautics in conjunction with the Avco Corporation.]

BUTLER: I'm sure that's in the records.

WATTS: I'm sure it is, yes.

BUTLER: Do you remember anything that stuck out about the reports or your recommendations to it?

WATTS: It seemed to be almost a universal adjudication that North American, who won, put out the worst proposal of all, and we could not understand why they were chosen. But, of course, it was for political reasons. There was a perceived need to put that money in that contract in California, I would presume. I think North American itself—I'd spoken to North American people, and they were amazed that they had won. [Laughter] That's the one significant thing I do remember about it. The only other one I remember much about or any at all about was the Lockheed one, which I thought was probably pretty good. But they [North American] did actually make it work, so it turned out.

The one feeling I had about that was that I felt that they were extremely wasteful in expenditure of money, and I think that we spent probably—in my own view, maybe ten times as much money to do what we did as was necessary, and that was one of the reasons I left NASA. I did not want to be part of that anymore. That's rather painful, but I have to say that.

Boilerplate Little Joe 2, I think Little Joe 2, one of those, they charged 14 million dollars for the thing and they could have got it in a shipyard for about 140,000 dollars.

BUTLER: Oh, my.

WATTS: It was 100 times as much. But I'd say on an average [that] on everything, they probably came out about ten times what could have been done if you'd had a really efficient organization as we had on Mercury.

BUTLER: That must have been frustrating, having seen the success of Mercury.

WATTS: Yes, it really was very frustrating, but the only thing that made it, in retrospect years later, seem not so bad was that they spent four times as much bombing the hell out of Vietnam, and this was an infinitely better way to spend the money.

BUTLER: That's true. That's really true. It's much better to spend it on such a good goal, to get to the moon.

WATTS: Yes. But also now it's part of history and that's what I noticed about it. Of course, I was very young then. I was about half the age I am now. I must admit I have mellowed a bit since then and don't feel so strongly about that, but just for the record, that's the way I felt at that time. I don't know if many others did. Maybe it's my Scottish background, I'm not sure.

BUTLER: Maybe so. Were there other reasons that you did decide to move on from NASA?

WATTS: Well, yes, of course. I had known of Lockheed for a long time. In fact, even at Spartan we used the Lockheed Constellation as a model for exercises in airplane performance and so on. They [Lockheed] were at that time working on the SST [Supersonic Transport] proposal and then on helicopters, and that sounded really intriguing to me, to work on helicopters.

So, combined with the disenchantment with the way the space program was going and the thought that I could see very clearly at that time that I would be spending the rest of my life working on the Shuttle, and after flying to the moon, just going into Earth orbit didn't seem terribly challenging. And I find that wasn't an erroneous decision at that time, because the next twenty years, the people in my group got to be old men working on the Shuttle. The Shuttle's a worthwhile thing, but it's still—NASA's funding must have dried up a lot after that, because there wasn't an awful lot of work done. And I had a lot of very interesting work at Lockheed, so I don't regret the decision to [leave].

I was one of the first to leave, but over the next two or three years, nearly all the rest left, too, for probably different reasons. I remember seeing Owen [E.] Maynard. Have you spoken to Owen? I'm sure you have.

BUTLER: We've talked with him on the phone. We haven't been able to sit down with him yet, although we're looking at doing that later this year. We were going to try—we went up to Toronto last year, but unfortunately he was down in North Carolina while we were up there. In fact, we talked to Stanley [H.] Cohn while we were up in Toronto.

WATTS: I didn't know him, I don't think. But Owen, he and I were in a car pool, I remember, when he first started to work at AVRO. He and I rode together in a little Morris Minor, if you can imagine, smaller than a Volkswagen, English car.

BUTLER: Oh, my.

WATTS: And there were four of us in it. So I've known Owen for a long time. He always loves to kid me. He used to say of me, "I'm as strong as an ox and every bit as clever." [Laughter]

BUTLER: [Laughter] Oh, my.

WATTS: But we had a lot of fun. He actually looked after the design of the Gemini—not the Gemini, the lunar excursion module. He pretty well was in charge of the design of the lunar excursion module, [and] he did an excellent job on that, too.

BUTLER: We'll be sure to ask him about that when we do get a chance to sit down with him.

WATTS: You tell him he's no longer as strong as an ox, but still just as clever. [Laughter]

BUTLER: Okay. [Laughter] We'll be glad to do that. We'll be glad to.

Did you ever work down at the Manned Spacecraft Center or did you leave NASA as they were—

WATTS: No. No, when I returned from Caltech, I went to Houston, so I worked there for the next two and a half years or so. That's where we did the Apollo adapter and a few of the other things.

BUTLER: What was it like to come down to Houston? Here you'd come from Canada, then to Virginia, now all the way down south to Houston.

WATTS: Do you want me to be frank about Houston? I know you all live there. [Laughter] At that time, and it may [be] quite different today, but at that time we weren't enthusiastic about going to Houston. The British Government used to pay its employees tropical pay for working there.

BUTLER: Oh, really.

WATTS: Yes. And at that time the oil refineries, in the wintertime, used to just pump pollution into the atmosphere until it wouldn't hold any more, I think. I remember one day in the middle of winter, going out. We lived in—where did we live at that time? We lived just north of the old airport. That was *the* airport at that time. The houses had little white pillars out in front and all that sort of thing. The next day after this tremendous, terrible bout of smog or whatever it was, in which my wife collapsed and fell face forward into a bowl of cereal on the table—

BUTLER: Oh, my!

WATTS: —I noticed that all the white paint had turned gray. [Laughter]

BUTLER: Oh, my.

WATTS: So it was really bad. But the summers were very nice. The vertical convection carried all that away and we were hot, but it was very nice. The most beautiful clouds I've ever seen were in Houston. So we were adapting to it, finally, but California beckoned. [Laughter]

BUTLER: California still has some nice weather.

WATTS: I had somebody apply to work in Houston from California. We didn't hire him, and the reason for that was, [he] said, as a reason for wanting to work there he was trying to escape from his wife. [Laughter] So when [we] move[d] to California with the high divorce rate, I thought, well, I'd better start treating Norma a lot better. [Laughter]

BUTLER: I'm sure she would appreciate the thought.

WATTS: She had visited Los Angeles in 1948 when she was just a young girl, on a tour around the country, and she said she hoped she never lived there. It was really smoggy in those days. They used to burn garbage in incinerators, and there's an inversion layer that traps all that stuff about a couple of thousand feet below that altitude. And if you climb to the tops of these mountains around here, you can see where the layer begins. Of course, inversion layer is caused by the Earth not being heated enough to [produce] vertical convection to carry that stuff away, so the more socked in it gets down there, the sun reaches the ground less and less and it really is stable. So it used to be really terrible. They've cleaned it up enormously since then.

BUTLER: That's good.

WATTS: And out here, of course, we're outside of that, a valley ringed by mountains. So it's not bad. I got a lot into meteorology, and I hope to give a course on meteorology for airplane designers before too long.

BUTLER: That should be fascinating.

WATTS: Surprising. They don't know a lot about the sea they sail through, and they should.

BUTLER: Absolutely. Absolutely.

WATTS: I think I strayed from your question, didn't I?

BUTLER: No. We were talking about Houston.

WATTS: Yes. Houston. That was before the Space Center was built. I guess I was there when they were planning it and during the planning and doing all the other work as well.

BUTLER: Do you remember whereabouts in Houston you were posted at the time?

WATTS: It was in a motel that was converted into offices. It was a brand-new motel that had never been opened, and it was on a little creek. I've forgotten the name of it. It was a brand-new system and they just left out some of the walls and made them into offices. Gilruth's office was in a great palatial plant, an office, single-story. I shouldn't have said "palatial." It was very elegant, but it was not extravagant. It was within walking distance of where our motel was, where we had our offices.

I remember I wanted to walk up and talk to him one day, and while I was walking, it started pouring rain. I was wearing one of these new wash-and-wear suits in those days, and I was soaked right through the skin when I walked into his office. [I] said, "I'm afraid I've been taking some liberties," and he looked shocked when I said that. "With the wash-and-wear concept." [Laughter]

BUTLER: [Laughter] Oh, my.

WATTS: We had a lot of fun. It was a lot of fun.

BUTLER: Talking about Dr. Gilruth, did you work with him frequently, on a daily basis?

WATTS: Not on a daily basis. Well, a weekly basis. There was a meeting that he presided over at the Capsule Coordination Office. He was usually there. Max [Faget] was there, Bob Piland, too. Yes, I knew him very well. In fact, I'm not sure whether it was that day or another day, he was flying to Washington [DC], and I had to go to Washington. He said, "Well, come with me," and he took me in his private airplane, or his NASA Gulfstream, and we flew there. We actually made it in this turbine propeller-driven airplane faster than the jet transports, because we could go right close to our destination and take off very close. He and I were the only two passengers on it that day.

BUTLER: That's nice.

WATTS: He was a very, very fine gentleman. I have some reports right here that he wrote when he was in NACA around 1938 on an airplane roll, what constitutes adequate roll rates in aircraft, an NACA report he'd written.

I remember going to some of the meetings. I will tell you this because it was true. The aeromedical people were there giving a dissertation or a talk on the progress they'd made, and they had all these wonderful things they were doing and so forth. He got a little bit tired of all this. When they were telling him about putting a new sensor they had for body temperature they could put in their mouths, he said, "In two years, all you guys have done is taken the thermocouple and taken it out of their asses and stuck it in their mouths." [Laughter] I don't know if I should be letting all this sort of stuff out, but these are things that really happened.

BUTLER: It adds some of the human interest to the story.

WATTS: Of course, the aeromedical people weren't enthusiastic about that response. [Laughter]

BUTLER: [Laughter] Oh, my. He seems like he had a good sense of humor.

WATTS: Oh, yes. And he was very responsible, too. He listened to everybody. Bob Gilruth.

BUTLER: I've heard a lot of good things about him. It's good to hear.

WATTS: As a matter of fact, if you go over to the Space Museum over in New Mexico—what's the name of the place, where they did some of the launch testing, I think, there?

BUTLER: White Sands?

WATTS: Just right next door to White [Sands]—Alamagordo. They've got some nice write-ups on Gilruth and Max Faget and a few of the others in there, as well as all the other rocket scientists that ever tested or had their things tested out there. It's a worthwhile place to go some day. You get some visual views as to what was going on. They have a Little Joe 2 rocket mounted outside of the building.

BUTLER: That's good.

WATTS: On a stand.

BUTLER: That's where they were testing those, from that region. That's good.

WATTS: I had to do the loads on those things, too, of course. And kind of interesting, we were firing—I can't remember whether it was the one for Mercury or the one for Apollo, but we were worried about flutter of the fins and NASA engineers had done some flutter analyses and said, "Nah, they're fine." And the next time [we] fired one of these things—it had four rockets and they were supposed to be fired one after the other, but somehow or other, I don't know how this could have happened, but apparently two of the rockets ignited the other two, and so the whole thing went off together at one time. The thing went to very, very high dynamic pressures. I mean, like four times the dynamic pressure they were supposed to have had. [They] said it wouldn't flutter up to that speed [but] there was no need to test it. [Laughter] We did have fun.

BUTLER: That's good. Talking about fun and interesting events, after you left, we did finally get to the moon and landed on the moon. Do you remember watching Apollo 11 or where you were at the time?

WATTS: Yes. I don't remember exactly where I was, but I remember I took several days off work to watch it, because it was probably the most significant event in human history, I think, in the technical human history, anyway. It was very stirring, as well as exciting and scary and everything else. I'd been out of there for several years by the time that took place. I left at the end of '64, and I think that was, what, about '68?

BUTLER: '69. Must have been rewarding to see that something you had put so many year into—

WATTS: Yes. It was very, very stirring and very worthwhile, and I did agree with the speech he made. It was a giant step for mankind.

BUTLER: Absolutely. You moved on from NASA to work with Lockheed. What did you work on there? What were your roles and responsibilities as you first came in?

WATTS: I started with Fred Hoblitt's group in structural dynamics. That's where I…didn't go into a supervisory position. Lockheed was one of the few companies that had specialists, and I was a senior design specialist. They promoted them, they said, which they did. I was more interested in doing the technical work rather than getting into the political aspects of things.

So I worked on statistical turbulence response of transport airplanes with Fred Hoblitt for about two years. Most of that was on the SST proposal, and that was canceled on New Year's Eve 1966. I remember that very well. I was sitting in front of the TV and had a drink in my hand, of course, and they announced this over the television set. My wife came over and filled my glass up with booze. [Laughter]

BUTLER: That must have been frustrating to hear it from the TV rather than from—

WATTS: Yes. And when we got into work after the holidays were over, there wasn't a speck of it in view anywhere. The company had removed all drawings. Everything was gone, just like that. All the consultants—I wasn't a consultant, I was an employee, but all the consultants were relieved of duty and all that, so they just marched on, on to the L-1011. But in retrospect, I think it was a wise decision that the government made to cancel it in the long run, because neither—you asked something about that, didn't you? I think I wrote a few things down.

BUTLER: Yes, briefly, if you could tell us about what it was and what it involved.

WATTS: Lockheed and Boeing were competitors on [the SST], and the Lockheed proposal was for a delta-wing airplane, much like the airplane I'd worked on, like the AVRO Arrow. Boeing was a swing-wing version. Boeing won the contract for the swing-wing version, and shortly after that…discovered it would be too heavy to be commercially feasible, and they reverted to a configuration like the one that Lockheed had proposed. Then after a while they just decided that [it] wasn't an economically feasible thing to do, and so they bowed out of their contract to build it. So that, in a nutshell, is what happened.

Now, if you ask me what I think, I think that neither design was optimized, neither was a very good design, and although I don't know a lot about the Boeing design technically, I suspect that having to make that big flip-flop in the middle, they hadn't had much time to work on it, that probably it was a wise thing to cancel them both.

BUTLER: What were the goals of the supersonic transport? What was it anticipated to be able to do? What was the idea for it?

WATTS: Ours was to fly at three times the speed of sound, fly across the oceans and so forth. And sonic booms, which probably [are] as much a political problem as anything else, made it not feasible to fly over land. I'd say the main reasons for canceling the supersonic projects were that the ranges were too short and the costs were too high. If you look at the Concorde, you see that's the case. They can fly across the Atlantic at supersonic speeds, and it's a beautiful flight, I understand, but the costs are very high. Passenger prices are very high. I don't know what you can do about that.

You see, a supersonic airplane, unless it flies at very high speeds, uses an awful lot of fuel, so therefore it can't go very far. Now, what do you want to do? If you're going between two places, if it takes you four hours to get there, you can sit there that long. Shaving off two hours and quadrupling the cost, you're probably not going to do it. But if you're going to be on a fourteen-hour [flight] and you cut that down to four hours, then it would be worthwhile. I've flown from Auckland [New Zealand] to L.A. [Los Angeles] nonstop, fourteen hours, and that is a pain in the legs. [Laughter]

BUTLER: I'm sure.

WATTS: So for a supersonic transport to make sense, it has to have very long range, and they just really don't want to have long ranges unless they go at very high speeds. Like the SR-71, for example, has flown from the [West] Coast to the [East] Coast without refueling. I think it took about two hours to make the trip. About two hours, I think. And that's quite amazing for that kind of an airplane, but it flew at very, very high altitude, 80,000 feet or more. It's a very lightly built machine, too, and practically all fuel. So for strategic reconnaissance, it's fine, but passenger transport, maybe some day.

BUTLER: Have you followed at all or been aware of some of the studies, there's been talk about a transport that would go up and basically skip on the atmosphere and thus take less fuel?

WATTS: Yes. Well, is that proposed as a transport? That was a reentry technique that was used for the Dyna-Soar project. Yes, I've heard of that. I've never worked on it. But it's interesting. It is interesting.

BUTLER: Seems like maybe some day someone will come up with the right idea.

WATTS: I think that a plain supersonic transport won't happen, but a hypersonic transport might. It has to be very fast, because strange as it may seem, the faster it goes, the closer it gets to orbital speed and the less the drag and the greater the range.

BUTLER: Sure. That makes sense. Makes sense. After the supersonic transport was canceled, what did you move on to then?

WATTS: I did the antisymmetric response on the SST, [to] statistical turbulence, and that was [during] the two years I worked for Fred Hoblett.

Then on the L-1011, I worked on, actually, a rather strange project. We wanted to land it at LaGuardia Airport and fly it to Chicago. It turned out that LaGuardia Airport has its runways extending over the East River on pile supports, just a slab of concrete on these pilings over the river. Part of it, anyway, half of the runway…or part of the runway. Then I had a job doing engineering of the slab to see if it could take the…higher weights of the L-1011, so I was working with Port of New York Authority drawings and so forth, and doing analysis of pre-stressed post-tensioned concrete for about a year.

I learned a lot. It was very interesting. I learned to greatly respect civil engineers for their structural work. Airplanes are basically made of sheet metal and it's thin, and so there's a definite way of analyzing that, but concrete's thick, and the stress analysis of that is much more complicated. I was doing the dynamic stress analysis of that for about a year, and then after that, "Hmm, do I really want to continue doing this for very much longer?" And I decided I'd either leave or go to rotary wing, and then I got the chance to go to rotary wing.

BUTLER: What did you do there?

WATTS: I did research on high-speed helicopters out there for about seven years and tested rotors, stiff rotors, in the Ames [Research Center] wind tunnel. To verify theoretical analysis, we put together for dynamic loads [and] vibration of high-speed helicopter rotors. It was very rewarding. I remember Kurt Hohenemser, who was an acknowledged leader of U.S. helicopter [research], telling me after a lecture that I'd added materially to the understanding of that subject, which was a nice pat on the back.

BUTLER: That's very nice. That's good.

WATTS: I had a lot of fun doing that. I had a lot of fun with everything I was able to do. That's one of the reasons I stayed at Lockheed so long is that I didn't advance in the organization, but I had a lot of freedom to move around and go into different interesting tasks, tasks that other people gave up on, said, "Oh, give it to George." [Laughter] So, fine. Sometimes I could and sometimes I couldn't [solve them]. That would be my recommendation to any young people: Do not look for easy work to do. Look for the toughest jobs you can get. If you fail to do it, okay, it was a tough job. But if you succeed, then you've done something. You choose easy jobs and you win, so what? And if you don't do it, you're gone. [Laughter]

BUTLER: [Laughter] That's right. It's always good to have a challenge.

WATTS: Absolutely. Yes, yes, indeed. From there, where did I go? Rotary wing. We did some interesting work in rotary wing. I won't go into that, I guess.

Are we just about out of time?

BUTLER: If there's more that you'd like to share with us, we—

WATTS: Let's keep on going until you get tired.

BUTLER: Okay.

WATTS: Okay. Yes, I won't go into a lot of the helicopter work. But then after the helicopter [work], I went into the flutter group…I was always interested in flutter ever since AVRO, where John McKillop was in charge of flutter…who's a good friend of mine. I wanted to learn how to do that, so I got into the flutter group, and the task they assigned me there was to look into supersonic unsteady aerodynamics. It's a very highly technical subject, and I spent six years working on that, mostly streamlining or finding errors in an existing method.

My friend Fox Conner, with the aid of some computer algebra routines, we managed to solve some very difficult problems…and that helped the company win the F-22 project—

although our programs were not used, they were used to check out—I think it was Zona 51 done by Danny Liu over in Arizona State University, were used on it. But [Lockheed] couldn't have told whether his programs worked or not if they [hadn't] know[n] what the answer[s] [were], and ours supplied that. His was a little more general than our method and it would work closer to transonic speeds. That's the reason his was chosen by the company to do [the work].

After I worked in the flutter group—[the subject], unsteady aerodynamics was part of the structural dynamics and flutter group, whe[n] really it was an aerodynamic subject and not a structural subject. So I lobbied to have that discipline moved to the aerodynamics department. So [that was] the first time I was…in [an] aerodynamics department itself, and I continued doing the research on that [subject] and some…others. Then I went to advanced research from there up in Rye Canyon, another branch, and I worked on high-angle-of-attack aerodynamics for fighter airplanes. The time had come along and…fighters were not good for slow, close encounters. U.S. fighters like the F-18 and the F-16 and…F-15, were designed to fire missiles at a target that did not know they were there, so they fired, the missiles would go twenty miles and hit their target.

But then began [the] develop[ment] [of] an all-aspect missile which was a short-range missile that you can just point the airplane and fire at any aspect the other airplanes [were] coming at, and it made it very difficult to—those airplanes were dead meat for a fighter equipped with that, so we had to develop airplanes that were very maneuverable for close-in combat, and that's what my task was, to try and perform research on that topic, and so I did that for, oh, I don't know, three or four years, just before I retired.

I retired in '91 and started teaching at the Lockheed Technical Institute, and I've done that since then off and on over the years. I enjoy teaching. As I mentioned earlier, it's a way of dotting I's and crossing the T's in a lifetime of work, finding out what really was going on, and also a chance to help young people. One of the most rewarding things in that is having a man who took my course in '91, who is now a supervisor in aerodynamics, come back and tell me that that course had materially helped him. It was a course in aircraft drag estimation. Materially helped him in his career.

BUTLER: That's great.

WATTS: That's happened several times, people have used the work.

BUTLER: That must be very rewarding to be able to see that return.

WATTS: So it's full circle, and that's where we are.

BUTLER: Good. So you're continuing to do some of that now?

WATTS: Two years ago I was working in the little wind tunnel where these were done [pointing to pictures on wall]. These are our little wind tunnel—Bob Burrin. I would go in. Once in a while I'd get paid on a purchase order for 5,000 bucks or something like that, but often I'd just go in just for fun. I helped them set up the tunnel. In fact, my task at advanced research was to bring those tunnels from Georgia out here, so I did do that. I was going to do that. Bob Burrin, thank goodness, stepped in to take over doing that, and he's a superb experimentalist, and I thank goodness he did it. He put them in Rye Canyon and then had them moved up here a few years later, so now we have quite an extensive low-speed wind-tunnel capability at Lockheed-Martin. I still go out and offer my advice, which he's glad to get. [Laughter] He says he's glad to get. He's a very good guy.

BUTLER: That's good. That's very good.

WATTS: So, still at it.

BUTLER: Still at it. It sounds like you've been able to enjoy a good career and have fun doing it.

WATTS: It's kind of interesting, I've gone really through the aerodynamics on this Aerocraft Project that was just announced in *Aviation Week* a week or so ago, and it was sort of not classified, but it was proprietary. I did a lot of the aerodynamic design at the beginning [of the project], so that was fun, but now I've turned around and am looking at the design of pressure-stabilized structures. That is, blimps are pressure-stabilized structures. That type of a structure, anyway. And that's been very interesting, my latest work in the company.

BUTLER: That's interesting to have kind of come—

WATTS: Full circle.

BUTLER: —full circle, all the way to—

WATTS: Back to structures again, structural design, aerodynamic design and structural design. Structural analysis, mostly, but you get into the design, too, because something won't work and then you have to suggest what may work. And it's fun working with the young people today.

It's a vastly different culture than it was long ago. I remember going into AVRO in the design office, and what you'd see is rear ends and elbows over drawing boards, a sea of them. Now you go in and you see people sitting in front of terminals, no paper.

BUTLER: You've certainly seen a change in tools that you've used.

WATTS: Started, there were no computers at all in the aircraft business. We actually literally did things by hand or with mechanical calculators. I remember when the Frieden [calculator] that took square roots came along. That was a huge advance, because finding square roots on a mechanical calculator without that is a real pain in the neck. And now we've seen it go all the way to supercomputers of today and solving the Navier-Stokes equations on a laptop.

I have some young friends who are consultants that work with us. Harold Youngren is one. He's a superb practical but theoretical aerodynamicist, and I enjoy working with him. And Ken Grosenick is the one I work with on structures. He just lives a mile from here. He's a NASTRAN expert. So there's a lot of very interesting things still going on.

BUTLER: I'm sure you'll manage to stay involved with them, still.

WATTS: I hope so. I really do want to get back to teaching a lot. These last two years has been a lot of engineering work, and that's fine. I think if anyone is going to teach engineering, they should be doing engineering, because it's changing so rapidly and dramatically. But it has robbed me of the chance. Some of my courses are over there. The next one I want to give is on aircraft aerodynamic principles. The company out there wants how-to-do courses, but then [the management] said the students aren't interested in all the theory and everything. Every time I give a class, at the end I say, "Would you be interested in the theory and principles?" I get a unanimous "yes" answer from the students.

BUTLER: Have to have them fill out some surveys saying, "We want more."

WATTS: So I think they're going to let me give the course on principles whenever I get it ready.

BUTLER: That should be interesting.

BUTLER: Looking back, you mentioned earlier that one of your greatest accomplishments or times was Mercury and seeing that be structurally sound and secure. What were some of your greatest challenges?

WATTS: I did write something down on that. I guess the biggest challenge would be to keep the weight down. It's easy enough to make things very strong, but you might just—I remember on Project Mercury just saying, if I continue to do this, especially the radiation shingle weight increase, the Atlas could only lift 6,000 pounds, period, and put that into orbit. It couldn't put anything heavier than that into orbit, and we were right there.

So this was the biggest challenge, was to keep the weight down of these vehicles, and that's one of the reasons, I think, why Gemini went to the parachute ejection, because you save a lot of weight. When you have that big boom out in the front, the launch causes bending moments in the capsule…and you have to have structure in there to carry those bending moments. Although the tower disappears, it's not carried into orbit, the structural weight used to support the tower is carried all the way to the moon and back, in the case of Apollo.

So the biggest challenge, I think, on that was keeping the weight [down], especially on Project Mercury. Of course, with Apollo we designed massive boosters, but it was only a tiny fraction, a few percent was the payload that went to the moon. I don't know what percent, a percent or two, something like that.

BUTLER: That's pretty small when you look at the whole rocket.

WATTS: A million and a half takeoff pounds' thrust and 30,000 pounds was the weight of the lunar excursion module or something like that. It's a very tiny fraction.

BUTLER: Were you ever able to see a Saturn V launch?

WATTS: Not a V, but the SA-6. I saw Saturn. We had to do structural flight testing on the Saturn Apollo SA-6. It's funny, the Mercury Atlas was MA and Saturn Apollo's were Saturn Apollo. They reversed the order. Yes, they were very stirring things to do.

The first Saturns had multiple tubes for the first booster and the [Saturn] V had just a single [tube] first-stage, so we had to look at structural dynamics of all these tubes and the way they would wiggle around. It was fun. A lot of very interesting problems on those systems.

BUTLER: Certainly never lacked for something interesting to do, it sounds like.

WATTS: No. I did work a little bit on the…docking simulator in the early days, and I learned a lot about how to make frictionless systems so that you could simulate the motion in space where there, of course, is no friction. A lot of that work helped later on.

Part of that came from AVRO Arrow, too. It had a landing-gear failure. When you retracted the gear, [it] had to both retract and shorten and twist to fit within the smaller hole in the bottom of the airplane. In doing that one time it didn't shorten, so it kind of caught fire when it landed. It was still at an angle like that. So we had a big job of trying to figure out why that happened. It turned out in the end that the friction coefficient can be—there's a rule that it can't be greater than one, but with certain geometries it can go very much higher than that. That sort of understanding helped the design of some of the early docking simulators when I was working on [them].

BUTLER: That's interesting.

WATTS: So what you learn in one project carries over to another again and again.

BUTLER: That seems to be a very important lesson that can carry on.

WATTS: That's what I find today. It's almost embarrassing. They come up with some horrible problems and I can say, "Well, this is what we did before, that worked." And it happens again and again and again.

BUTLER: Looking back, was there a particular moment that was most memorable and most rewarding to you?

WATTS: At AVRO, the most rewarding and most memorable moment was watching the C-105 take off for the first time, and I was responsible for its structural integrity. In fact, the week before, I had found that when they lowered the nose landing gear, that the door caused a pressure head to go into the air-conditioning system, that would have blown the whole air-conditioning system up.

BUTLER: Oh dear.

WATTS: Then we had that beefed up. That was actually a couple of weeks, a month before, I guess, and they beefed it all up so it was okay. But realizing how many things did I forget, and watching it take off and climb, you've heard the expression "hair stands up on the back of the neck." Quite literally, mine did. I could feel the back of my hair sticking straight up as I watched that first flight. So that was probably the most exciting and rewarding thing at AVRO.

Of course, watching the space shots, especially watching them on telemetry where you could see technically what was going on, was very, very interesting, seeing all the hard work come to pay off. It was a lot of fun.

I guess you asked about the controversy [between] parachute ejection and escape towers. I think I'd have to say in the end to that, that probably the escape tower provided greater safety. I will say that for it. But that's what you paid the heavier weight for. It was probably safer under more general conditions.

You did mention something about the fire, and I've forgotten which spacecraft it was now, that the three astronauts were killed.

BUTLER: Yes, the Apollo 1 fire.

WATTS: Yes. I knew one of the pilots. What was his name?

BUTLER: There was Gus [Virgil I.] Grissom—

WATTS: Grissom. He's the one. I knew him. But I hadn't realized myself that they used 100 percent oxygen and then pressurized it on the pad to 5 psi above atmospheric so they wouldn't have to repressurize it after that. And I thought to myself, every high school student knows that you can burn anything in that kind of an atmosphere. With any heat at all, anything will burn. And they had Teflon insulation in there as well, which is poisonous, the gases from that are poisonous. How could they be so ridiculous? So I was just appalled that

that accident ever happened. But I noted later that they used a two-gas mixture after that. Was it helium and oxygen? I think it was.

BUTLER: I think it may have been. Very unfortunate occurrence.

WATTS: Oh, yes. Gus nearly bought it on Project Mercury, too. You know that story, I guess, where his neck dam wasn't sealed. His suit was filling with water, and the helicopter came over and he was waving frantically for it to come down. As his dam was filling, he was going to go down. So they waved back. Luckily the guys got in the water and got to him before he did go down.

BUTLER: Must have been a frightening experience for him.

WATTS: Oh, yes.

BUTLER: I can imagine.

WATTS: Yes.

BUTLER: I'm going to let them change the tape here real quick. [Brief interruption]

Okay, we're back on.

WATTS: We're in challenges.

BUTLER: Challenges. Were there any challenges?

WATTS: I just made a summary of some of these. I guess I mentioned the ultra-thin highly loaded control surface of the AVRO Arrow was one of the early big challenges. I guess I mentioned a lot of these things.

BUTLER: Okay.

WATTS: Yes. I did mention the Apollo heat-shield design was a huge challenge, not for me, but for the others. That, I think, pretty well covered the Lockheed and NASA and AVRO challenges.

BUTLER: Okay. Were there other challenges as you came to Lockheed?

WATTS: At Lockheed, in the statistical turbulence loads analysis, they had a formula, when you put random turbulence into something, it came up with how many exceedances of a certain load level took place per unit time, but didn't know quite where it came from, and I managed to unscramble that. That was a quite interesting solution to that problem, was quite interesting.

Another one was trying to get usable data from helicopter rotor blades in the wind tunnel, because the wind tunnel is enormously turbulent, so every time the rotor blade goes around, it takes a different flight path. So I naively looked at the first one, and the first one looked one way and the next passage of the blade looked different. I thought, oh, my God, how am I supposed to prove or verify the theory? Finally we determined that we could use an RMS over a large number of revolutions so we could get data where the zigs canceled out the zags and we'd get good stuff that verified our theories.

Another really good challenge was when bombs began to be put in airplanes and the L-1011, DC-10 and 747 all had this problem, and [the bombs are] often in the cargo department, in the luggage. So the FAA [Federal Aviation Administration] made a rule that you had to take a 20-square-foot hole in the side of the luggage compartment, had to be able to withstand that suddenly appearing at any altitude.

BUTLER: Oh, my.

WATTS: Of course, the floorboards, you'd have the full pressurized cabin above and straight floor underneath it would bend down and break, and especially bad on the Lockheed airplanes where the control cables ran right along the middle of that floor.

BUTLER: Oh dear.

WATTS: So my job was to set up a test program in which we could actually simulate the volume of the cabin and the volume of the under-floor compartment and develop vents along the side that would allow the air to escape out through [them] before it broke the floor.

BUTLER: Interesting.

WATTS: It was a lot of fun. Did that in Rye Canyon in a high-altitude chamber that simulated the outside environment, and then we had a volume inside a tank and we put some [seats and] anthropomorphic dummies and everything in there to see that nobody followed the air [out] through the hole, and things like that. Then we tested an awful lot of [vent] designs there. It was fun. As soon as we opened a huge valve that simulated the hole, then air would rush out and the cabin would fill with fog instantly.

BUTLER: With fog?

WATTS: Yes, because the temperature drops down and so it drops below the dew point, and the water vapor condenses instantly everywhere to opaque fog in the cabin.

BUTLER: Oh, my.

WATTS: And it was kind of interesting that the air underneath the cabin expanded out through the hole and its temperature would drop, but then when the air from up above would relatively slowly come down, the temperature would rise again. That was predicated analytically and we measured it with sensitive instruments and found that that's exactly what did happen. So it was technically a lot of fun. I enjoyed that exercise.

BUTLER: And that's certainly something rather important, too.

WATTS: That's right. On current airplanes, you're pretty darn safe on the 747 and DC-10 and the L-1011, and probably all the rest, too, now, that you don't need to worry about that too much unless you happen to be sitting right over the bomb.

Another thing that was very interesting was that I had worked with developing lifting surface methods when the computer first became available, and before that, there were very-difficult-to-apply methods for finding lifting distributions on low aspect ratio winds, like delta wings. But the computer came along and [I] realized that it could be used, and I adapted some NASA methods and developed a method for the lifting surface method [in 1956].

It appeared to me that I could make that into totally unsteady, too, for any kind of dynamic motions, so I developed [the unsteady part] quite a long time ago, about fifteen, twenty years ago, but it was too intensive, too computer-intensive, to be used in those days for flutter analysis. But on this Aerocraft design lately, it's come in very, very handy for calculating virtual inertia, and with the high-speed computers now, it's a breeze to use…So there's something else that came forward from the past.

We're also designing a water channel installation to verify that the [analytic] answers we get are [the same as those by test]. Those are some of the things.

I guess, technically, getting Fox Conner, I mentioned to you, [to] help me with the supersonic unsteady aerodynamic method, and it was for interfering surfaces, not just flat plates. Well, flat plates, but interfering, [vertical] tails and so forth on them. We were getting the thing working wrong. We found there was an error in the fundamental theoretical method, but solving [for] the correct solution was a nightmare. He had to learn a [computer program] called Maxima. It's a computer algebra program. He's a very religious guy. Not really, but I heard him using words that I never thought I'd hear him use. He worked for about three months to [be able] to use the program and then he solved the problem, and it worked like a charm. So that was very exciting to get that one.

I guess another thrill I had was when in the rotary wing they needed some ballast one day and asked me to go for a ride in the Lockheed L-286 helicopter, and they let me fly it. That was a lot of fun.

BUTLER: That's great. Have you kept up with your flying?

WATTS: Not much. I flew some Ultralights about three years ago, but I decided they were too darn dangerous. Very difficult to fly and very dangerous and very impractical, since they fly at 35 miles an hour.

If the wind comes up, you can't get home, for one thing. And if you fly when there's any thermals or anything, they stall at such a low speed that you could be upset, and if you're close to the ground when that happens, forget it. So I thought, you know—it was shortly after my wife passed away and I didn't care whether I lived or died very much anyway, so I did that for a while, and thought, hmm, you know, let's not do this anymore.

BUTLER: It must have been neat to get to fly the helicopter.

WATTS: Oh, that was fun, yes. Had to slow it down, so I slowed down and watched the air speed go down, down, down to zero. If you're used to flying a fixed-wing airplane, it's a strange feeling. [Laughter]

BUTLER: Oh, I bet.

WATTS: That was a helicopter that Lockheed had developed and had actually sold some to Belgium, but they didn't ever—they could have sold them, but they didn't.

I guess one of the most thrilling rewards lately is just receiving—the last time I gave my aircraft drag estimation course, which was the third time I'd given it, the students all clapped, gave me an ovation at the end…and half a dozen of them came up and shook my hand and thanked me. That was a big thrill.

BUTLER: That's really great to get that recognition from them. That's pretty special.

WATTS: Yes.

BUTLER: To know that you have touched a newcoming generation of engineers.

WATTS: There's a big reward in doing that, too, because you begin to understand things that you only vaguely had an idea about before. So I was really surprised that more retired men have not done that. I thought everybody would be doing it, but I'm the only one I know who has gone back to teach, and I don't understand that. Golf can't mean that much, surely, can it? [Laughter]

BUTLER: [Laughter] Surely not.

You've had extensive experience with the space program and aerospace and all in general. What are your thoughts on the future? How do you see things changing or moving on?

WATTS: Okay. I'll quote an old phrase…that used to be used in the thirties…when something came along. I'd say the manned space program was "ahead of its time." The reason I say that is that chemical propulsion is really not powerful enough or efficient enough for practical missions such as mining on the planets and transporting heavy equipment around. So I would say that it was very well worth doing, because one thing that I hadn't expected, but one of the big side effects of that was it familiarized the people. NASA was very good about spreading the word around to the people who paid for it, and that was a new breakthrough for me, because I'd always worked on military things before that. But having the people understand and feel they were doing this was a huge thing, and that's the kind of spirit that it will take for space flight in the future.

So I think it was really a very well worthwhile thing to do, because you have to develop all these other [aspects of spaceflight], too, and all the things and lessons we've learned are worthwhile. But what we really need is a lot better propulsion system. So my recommendation would be to—I'm talking about colonizing the planets. Man's destiny, I feel, is to move throughout the whole universe, not just the solar system, so I think scientific research, as far as astronomy and cosmology and so forth, trying to understand the basic nature of things, is extremely important. And is the speed of light an ultimate limit? I don't know. It's common knowledge that it is, but common knowledge often proves to be wrong when you look at it really very carefully.

So I would say that the main thing to do would be, for the future, continue with the manned space program as they're presently constituted, go to Mars, do all these things, but, for goodness sakes, put lots of work into new propulsion systems that have a lot higher specific impulse. I mean orders of magnitude higher specific impulse. Get into nuclear fusion, light element fusion or something like that, to develop energy. When that has been done, then the whole solar system for sure will be open to us, but perhaps beyond that.

BUTLER: Be interesting to see what happens. Have you followed at all the tests on the deep space probe and its using the ion propulsion?

WATTS: Ion propulsion?

BUTLER: Yes.

WATTS: No, I haven't followed that lately. I probably should get back into that a lot.

BUTLER: I think that's been very recent.

WATTS: Yes. As a matter of fact, the reason I went back to school, when I was fifty-two, I went back and got a master's degree in physics, because I'd been complaining around the house for a long time that we needed to get into hydrogen fusion. After a while, my wife said, "Look. Either do something about it or shut up." That hurt my feelings. So I said, "Okay." So I went back to school…half-time for three years, was taking a master's degree in physics at Cal State, California State University at Northridge. And I thought, in my arrogance, that a physicist won't do this, an engineer will, so I'd better learn what I need to know from the physics end of it in order to be able to contribute to that.

And what I found out was that it was extremely interesting. It was well worthwhile, although it cost about $30,000 in lost pay. But I found out that the young people who are out there working will be able to carry the load. I don't have to do it. [Laughter] Nor anyone else of my age. But they do need to be supported and encouraged, especially encouraged, and funded today, because I cannot see kids working—my new daughter, my wife's daughter, is twenty-one, just graduated from CSUN. But she's had to work full time while she's carrying a full load of courses, and she just graduated at twenty-one from the school, a four-year degree in accounting.

But I think that young people should be sponsored and not have these enormous debts to pay back with student loans. I think that's criminal. The best thing that came out of the Second World War was the G.I. Bill, absolutely without question in my mind, and we ought to have that for every kid. At one time a university education was virtually free, and it should be. If you want this country to be the leader in the future, you're going to have to have that.

BUTLER: It certainly is hard nowadays to get a good ongoing education because it is so expensive.

WATTS: I think saddling someone with a huge debt to pay back at the end is also—I don't know where our minds are. You need to spend your time studying when you're going to school. You can't spend it working all day and then go in and take courses at night or something like that.

BUTLER: Very difficult.

WATTS: So we'll probably get around to that. I mean, it's interesting today, and one of the big changes is that my mother didn't have to have a side job. My father was able to support her. I think that was the case with everyone I knew. The mother stayed home and looked after the children and all the social aspects of the family. Today when both parents have to work, I think that's not good for the society in general. They talk about equal opportunity for women, yeah, equal opportunity to die an early death is what it boils down to. That's why women outlive men, or used to outlive men…because the men were out fighting at work, you know, through work, [while at] the [same] time [then women] were out looking after the kids and so on. So I'm not sure that this "freedom" is a very useful thing.

My wife actually worked to support me going through school, too, but after that she had odd jobs for many years, temporary secretaries and things like that, but over the long haul, most of the time she'd be able to spend at home looking after the social aspects of life, which are very, very important.

BUTLER: Very important.

WATTS: Especially in the military or the government, as you're probably well aware of, where you come from.

BUTLER: That's right. Looking back over your career, when you first got started, you were interested in aviation from a young age, but would you ever have imagined where your life would lead you, where your career would lead you?

WATTS: No. I expected to get a degree in engineering and spend the rest of my life as a pauper, doing what I wanted to do, and [to have] the idea that I could ever help build a machine to fly to the moon was totally beyond my comprehension at that time. So life has been very rewarding. I have no complaints at all.

BUTLER: That's good. I think at this point I'll—

WATTS: I'll say one other thing, though.

BUTLER: Okay.

WATTS: And that is, to the young people who sit around today and think that everything's been done, that's not true. Knowledge is like the stars in the sky at night. It's little pin pricks. That's what we know. All the black in between is what we don't know, and it's what we don't know that will propel us into the future. That's why education and understanding physics and mathematics from first principles is so important.

BUTLER: That's a great thought. You're right, there is a lot to learn out there. There's still a lot that we can—

WATTS: And I think that there's no better time to live than today, for a young person. I wish I were young and starting out again, there's so much to do.

BUTLER: There's still plenty that you can do.

WATTS: I hope so. [Laughter]

BUTLER: And be involved with.

I think I'll ask Summer and Rebecca if they have any questions.

WRIGHT: We certainly have enjoyed hearing all that you've been able to accomplish in, to me, a very short time, but I'm sure that your days were very long. Did you feel like, especially during those early days when you joined the NASA force, that it was just one long continuous day? Or was it one long continuous adventure you got up every morning to continue doing?

WATTS: It was a long continuous adventure, and there was home life and social life that did go along, which I didn't touch on, that was also very rewarding, and making new friends and seeing how society operates under different kinds of stress. Some people divorced their wives and ran off with their secretaries, which would never have happened in a normal course of things. That was really kind of surprising to me. [Laughter] And the astronauts, they chased around and were made idols of. It was fun being with them and seeing how human beings adapt to that sort of stress, in a sense, but it can be nice stress as well as unpleasant stress. But the rewards of understanding were tremendous, and to actually see the visions and pictures from space and everything, it was just worth every bit of it.

WRIGHT: You've left quite a legacy, and we thank you.

WATTS: It's my great pleasure to be able to tell you a few of those things.

BUTLER: Is there anything that you can think of that you wanted to share with us that we didn't cover?

WATTS: Actually, I think you covered it fairly well. [Laughter]

BUTLER: That's rewarding for us to hear.

WATTS: Yes. You've prepared me very well, and it was, I think, an excellent job. I'll be anxious to see what my brothers have said and told you about and how they contradicted me. [Laughter]

BUTLER: From what I've heard and shared with you today, I don't think I've heard any contradictions, particularly, from previously, but we'll certainly keep you posted on how things go and who else we talk to.

WATTS: I'd be glad to. I'd like very much to hear how it goes. I wish you the best of luck in your very worthwhile project.

BUTLER: Thank you. We thank you for participating. It's been great for us, and it's been a fun project. We've been lucky enough, like you, to be able to enjoy our job and have fun with it. It's been very good.

[End of Interview]