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EDITED ORAL HISTORY TRANSCRIPT

EARL R. KEENER
INTERVIEWED BY REBECCA WRIGHT
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The following information is from an oral history session conducted on July 17, 2014, with Earl R. Keener in San Jose, California, as part of the National Advisory Committee for Aeronautics (NACA) Oral History Project, sponsored by the NASA Headquarters History Office. The interviewer was Rebecca Wright, assisted by Sandra Johnson; also present was Keener's daughter, Malinda Alves. At the conclusion of this text, readers will find "recollections" he wrote in 2006 providing additional information about his long career as an aeronautical engineer. Keener graduated from Wichita State University in 1949 as a member of its Aeronautical Engineering Class No. 2 and soon after joined the NACA. First, he was an aerodynamic scientist for 14 years in flight research at the NACA High Speed Flight Station in Edwards, California, then for 29 years was involved with wind tunnel research at the Ames Research Center, Moffett Field, California. He is the author or co-author of more than 50 research papers. He began the oral history session by sharing how he first became interested in a career that spanned 43 years.

KEENER: My memories go back to a friend of mine that started building model airplanes. That got him involved, and it helped me to understand the word "aeronautics." Instead of building models, I got interested in wind tunnel work.

For school I needed to write two English papers, so I decided to look at the history of aeronautics, of flight, up to the World War II. In order to carry that out, in order to get more acquainted with it somehow, I went to the back of the stacks of libraries, and lo and behold—found out about this place called NACA, National Advisory Committee for Aeronautics.

What I learned was there was a group, a NACA group at Langley [Research Center, Hampton, Virginia], and there were other groups. These men were looking ahead and at what was ahead. It was growing, also, with the time. So, instead of a model airplane, I built a model wind tunnel. It would do about 27 miles an hour. I had a lot of fun, building that. I was never able to completely have a satisfactory measuring system, which is an area all to itself.

It's important I go back before World War II, and the airplanes—the pursuit airplanes, the high-speed airplanes. These were expanding towards the end of the World War II. The importance of this is because we were losing airplanes and we didn't know why. They would flip up and crash. There was an effort for supersonic flight.

When I was a senior in high school, I first got acquainted with a graduate of Kansas University. He was planning ahead for an engineering college. He found there was a wind tunnel up in our science building, up in the attic. He prepared the tunnel so that he could take data on models that were of interest to the Air Force. I got interested. That occurred after World War II. Later, he was busy buying up used equipment from the war buildings—surplus buildings and a machine shop. I looked him up, and met him in the machine shop; he was a good machinist. This was a young man that was captured by the Japanese, and the Japanese tried to file his teeth down. I don't remember his name, but I talked to him many times.

It was around this point, I had to answer the question of where I should go to college. I had to make a decision between MIT [Massachusetts Institute of Technology, Cambridge], or go towards the West Coast to Caltech [California Institute of Technology, Pasadena], or stay with the Municipal University of Wichita. I chose to stay in Wichita where I have many fond memories of Dr. Melvin Snyder, who encouraged the students tremendously, myself included.

In college, I spent some time in the aeronautics school, just making myself available. I joined up with another engineer from Boeing; his dad was one of the designers for Beechcraft [Aircraft]. He had big plans to build a wind tunnel. He got together with one of the technical people—they designed a wind tunnel and proceeded to test a small and a large tunnel.

Then, I didn't know much about certification and that kind of thing. At the time [Kenneth] Razak developed this school [Wichita State University College of Engineering, Kansas], and I got more interested and finally decided to go to school there. He started classes and I started going. His engineering school developed, and a whole Ph.D. program. I graduated in the College of Aeronautics. I was in aeronautical engineering class number two, and Bob [Robert Burnham] was in number one, class number one. Very good engineer. I knew his father and his father was one of the [Beech Aircraft] designers. In fact, they designed a racing plane and won the annual meet that they had with the Air Force.

I was ready to graduate, and I had been hearing stories about this X-1 vehicle. They [NACA] didn't have recruiters, but I saw tacked on to the [school] bulletin board, a standard government employee job offer from Langley and also at Lewis [Research Center, Cleveland, Ohio]. I was really into the possibility of working for NACA, National Advisory Committee for Aeronautics. There was an actual committee. This was in my senior year, I got a return [on my application for the job]. It came from Langley; it was offering a job, but not at Langley. It was for the Flight Research Base [Muroc (now Edwards), California]; they had a group there. Most, I think, were at Langley, but they sent out an offer, then, for the Flight Research Center. One of the interesting things was that they offered jobs directly out of school, and that highly irritated some congressmen.

They sent me an offer to go out to Edwards, but I would have done anything. My soon-to-be wife was very accommodating, and I don't know of any other girl who would have gone out to Edwards. They did have some women in mathematical work.

ALVES: Who was that? Wasn't it my mom?

KEENER: You're right. See what I mean? (laughter)

ALVES: You went back to Wichita and married her, and then took her out.

KEENER: Yes. I went ahead. I'm conservative, and I went out there to Edwards, and they expressed an interest, then we went.

WRIGHT: Can you tell us about your first task? What did they ask you to do when you got out there to work?

KEENER: I did go out, and the first on the job was, as you might expect, had to do with research on stability and control. That was the chief job. We all met with the chief research engineer, who was De E. Beeler at that time, he was making the assignments. We were such young engineers.

Going to my assignment, then, a very unique thing occurred that I didn't know until later, that had to do with [Chuck] Yeager's X-1. Yeager's X-1 had a rocket, or had rockets, actually four of them, so it couldn't collect much data. Here was my assignment—this airplane. It was subsonic, and they needed somebody—or some people—to run tests, subsonic, to fill in, I guess you could say, the gap. It was important; we needed a vehicle that would do flight research.

There are ways that's common in flight research: you pull up and take data while you're pulling up, and then record it. Had a system that worked with the ladies [mathematicians] who were working up the data with a lot of plotting; then they had a remarkable machine for integrating the data. The results ended up in a report. A lot of data is in there, and I chose to put a lot of the description in the title. It is possible, I think, that the title itself then ended up being a description of what was in each report.

They needed a vehicle that would fill in Mach number and flight and that vehicle did not have to be supersonic. The X-1 supersonic data was highly restricted because all he could do is go that-a-way and then pull back. Somebody, maybe from Langley—that was a brilliant decision—they would design that airplane that would fill in most of that gap. This is with the D-5581.

When I came aboard, I worked with pressure measurements. It turned out that every one of us, within a year, were up to date with the research, the control, particularly of stability, that kind of control. The pressure measurements, somebody set it up to measure pressures on the full-scale airplanes; mine was one of them. A lot of my career was the pressure measurements. I chose to do more than just record it and send it back—I made a research effort out of it so someone would have to analyze the data. I preferred to do it myself.

WRIGHT: Tell us about what you thought when you arrived at the Center.

KEENER: I was introduced to the vehicle, D-5581, a Douglas [Aircraft Company] design. I was able to fill in, so to speak; the pressure measurements were mainly on the wing. Of course, the stability and control people were marching through, doing stability data. Douglas also designed a supersonic. It was a combination of rocket and jet. They could actually switch these. I wasn't personally assigned, but we made some pressure measurements for that test. The D-5582, then, was a supersonic vehicle. This was gradually developed.

WRIGHT: That was a Navy plane?

KEENER: It was a Navy design. I got the impression—I wasn't on the inside—that there was a planned approach. [A. Scott] Crossfield was assigned to run—they must have dropped him from an airplane like they did the X-15. I don't think that that type would take off and land. My work had to do with pressure measurements. He proceeded, in a planned program, to try to get to Mach 2. He made many flights. They'd go up and come down, and he was trying, trying, trying to get Mach 2 out here. Finally, I remember being there, listening; he finally made it to Mach 2.

Then, Yeager came along. They had upgraded the X-1 and a couple of things like the escape hatch to get out of the airplane; he would never make it, if anything had gone wrong. Made Mach 2.5 a week later. He paid for it because he got up to about 30,000 feet and the airplane went into a tumble. Tumbling was not necessarily a problem, but after a few moments, he was going down in altitude, and so he was able to control it just from the air.

WRIGHT: How close did the engineers work with the pilots when you were out at the Flight Research Center? Did you work closely?

KEENER: That's an interesting question because I personally didn't have much contact with them, yet I followed the flight. I'd like to get over to the test; one of the airplanes was a delta wing. They would plan, and then I'd make measurements. The Air Force, [XF] 92-A was a delta wing, was a flat delta, you know what I mean? The wings were flat. I measured the pressures, and I really didn't know what was going on until later. There was also one, I'll just throw in that there was a one of these vehicles had variable sweep wings. I think the administration or our planners found that there was an engineer in Germany that discovered the swept wing. There was a lot of discussion of that. This X-5 had a variable control on sweep.

Ames was interested in seeing whether you could fly an airplane without a horizontal tail. The director of Ames got interesting in that project, and so, that was the X-4. The X-5 was the variable sweep. There was no X-8. There was an X-3—unfortunately, it tried to get to Mach 3 and it crashed.

WRIGHT: Were you there when it crashed?

KEENER: Yes. There was a lot of discussion because it was not a supersonic design as such. They were using the forces from a rocket in order to try, and I think he made Mach 6, but everything came apart. I hadn't thought of that for a long time.

The delta wing, that was a very interesting program. I don't know who started it, but I was asked to lay out pressure measurements. It was an Air Force project. It was intended to reach about 1.4. They did some wind tunnel testing on it, not in the 40 x 80, but the 1.5 wind tunnel. The reason I'm smiling is the [aviation company] is trying real hard to get supersonic, and they're not quite making it. So, they send their Ph.D. there. He was in a room with me and two others, and one of the others came up with this riddle: there was an old engineer, he had so many data points, he didn't know what to do. (You know what least squaring is? It's a way you can take a bundle of data points, and it's a mathematical way of selecting which ones to go, what the best fairing is.) He least-squared them all, but then had the gall to fair through only two. He had quite a reputation for being humorous. I can't quite put it together, except that here we are with one or two, an initial test of an airplane.

They kept flying. It wasn't the only thing wrong. It turned out the engines were not the right engines. We had trouble with that quite often out at the Flight Center, with the design. They tried to design an airplane with proper engines, and there always seemed to be something wrong with it, and they can't use the engines that they designed.

There was an engineer back at Langley that was well known for developing a way of designing the airplane, the delta wing, and it was to remodel and clock the cross-section of the airplane. When they did that, they realized that in the center was a pump. He got the idea of that pump being related to Mach number. His theory then was to smooth out the cross-section. When he got through, the cross-section developed by that method, and we got to calling that the "Marilyn Monroe" section because it had the hour-glass shape. The company was able to modify what we had in the 102. They called it the 102-A, I think. They added a little bit here and then took away a little bit and reduced that pump, and sure enough, it went supersonic. Then, the engines weren't capable of 1.4, so that was kind of the atmosphere that we were exposed to.

Also, you get various responses to various models, and this would be in the category of a pursuit airplane. We got into a study with Lockheed—Lockheed had a hypersonic tunnel. We developed a relationship with him, and this was a medium. We had a model. Some of those models were $1,000,000 or so.

Here's an example of what I did with this data: you see I've got the chordwise pressure distributions, but when I cross-section, we had, I think through Ames, developed some flow conditions that occur on a delta wing. You can see this change in here, very likely with a shockwave. I cross-plotted all of this, and this is what we came up with.

This is where there would be a very large change, in along the leading edge. The interesting thing, somebody thought of—we called it conical camber because the leading edge is dropped and you go to the root, the camber is zero, but it grows. They designed it to be conical shaped, gradually increasing. I studied the flow over the wing, and our interest in flight was this sort of thing, was it still there at Mach 1.5 and 2? We wanted to trace the Mach number. Of course, this was one of the things that I was most interested in. The delta wing and the Marilyn Monroe shape.

I can jump ahead a little. As you know, there was a complete change with NASA, and those of us with our heads still back in NACA, we had to find new work. That's a whole era.

We were looking at Langley's wind tunnel work. First of all, the project for the delta supersonic airplane—it was supposed to have so many passengers. The British airplane was the Concorde, Mach 2. Our computational people that made these, they were designing different ways and means of flying. By this time, they had good support from computational, and so, they were trying to develop what type of shape would give the least drag. I came in on that. I had, down at the Flight Center, I'll just describe it—a company had designed skin friction measuring. That applied the way to look at the boundary layer surveys and all of that. I learned that this company had designed a skin friction balance, they had a fluid dynamic—actually, fluids have viscosity. Ames had, what it is, is very, very good accuracy, and it tended to go downstream. We measure that tendency, I think, is a way to say it.

We would determine how much drag there was in this. They had a technique in designing the supersonic transport. Part of the project, they needed to calculate the drag. The designer people thought of drag in terms of passengers. That was a big thing, then, was to make a comparison on the basis of number of passengers that could—you could look at it at either plus or minus the number of passengers that could fly at that rate. That skin friction balance, which balanced a floating element in the center. It was very carefully designed. I was aware of a smaller one that had brought into the Flight Research Center, so I brought it into Ames. We started making measurements of drag. In the meantime, the designer people were heavily into design before they finally canceled it, due to the sonic boom.

By the way, I heard the first sonic boom down at Edwards. We had been hearing these noises, and the farmers, particularly the ones that were raising minks, they called in and they'd say, "Well, there's been an explosion out here, my way," and they'd never find it. I don't know exactly the steps in how they recognized what they were listening to. That's a very famous thing, the sonic boom, in aeronautics. It would sure wake us up in the middle of the night. The pilots learned to do that, and those shockwaves were strong. They had some show going on that actually created a very heavy shock and broke some timber, some of the walls of the aircraft in a part of Palmdale. They found that it could do some damage, so they set up a test—"they" being, I think, the administrators of whatever was going on. They had a pilot fly at, I think, 30,000 feet, and perform what would be a shock and boom. They rigged it up so that we could hear the conversation with the pilots, and they were talking back, letting us know when we should have it. A sonic boom travels at something like 5,000 feet? It caused a lot of discussion about what would happen.

Another interesting thing, I lived in Mojave—right then, they were testing the atomic bomb. I can remember driving to work and seeing the plume from Mojave and Lancaster—just over the mountains. It turned out that was about 400 miles from there. Some people would go up into the mountain, hike up into the mountain so they could watch that. The most spectacular thing is they rigged one up so that they could hear it in Los Angeles, from Lancaster. It was all set up on what you could hear. They had a countdown, and all of us saw it. The whole light, the whole area just lit up, and real intense light from Lancaster. That was part of our technology, I guess.

WRIGHT: Tell me about this picture here, with these points.

KEENER: We heard from Langley that you could make, we called them four-bodies, in the front end of an airplane. The Langley people—it was one of serendipity, I think they call it. They were just testing a probe of some sort, and found that it would create a side force. We were looking for something to do, and Langley told us about there, and we realized that this was a whole area, a whole, complete area of aerodynamics. We joined in, and there were some questions: one was conical, and it created quite a side force; tangent ogive created a side force. What I was interested in was, what happens if we blunt the nose of the vehicle and the side force diminished? We did quite a bit of work with that.

ALVES: My mom was telling me that scientists from around the world were working on the nose shape of airplanes. My dad was involved in completing the statistics on that, then they went out and actually started blunting the noses of the airplanes. He was involved in all of that.

KEENER: We did quite a bit. Why I emphasized that is high angle of attack used to be up to 15-18 degrees, but when we went in there, it was ±90 degrees, and we were making measurements.

You've seen them shoot a rocket off of a submarine, and if you look closely, the rocket goes off and goes like this and recovers and goes off. We didn't know whether it would recover or not because of the side force. We did quite a bit of research on that.

WRIGHT: Did you publish a paper about the blunt nose? How was that received?

KEENER: Yes. They were major papers at that time on that subject. I had some important people. The professor was such a big help to me. He would walk around Ames with his library in each hand. I hate that I can't remember his name. [He was] out of the Illinois University, I think it was. He was well known at the Center, there. He would talk to us. He was really great on unsteady. He pointed out that these flows are not steady, and most of my research was based on steady flows. That brought another part that opened up the unsteadiness, and what it might have.

WRIGHT: Tell me about why this picture tells us so much.

KEENER: This was an agreement we had with, what did I say, Lockheed? The agreement was that we'd design one that had this shape, and they would design other. What we're looking at is the flow with the oil flow. The flow here, it comes to mind, this was the design condition, angle of attack of 5 degrees, and what happens to the flow? What is this Mach number, 4? Not 4, but 9/10. It was decided by the group of us, and then I was assigned to run these tests, so I increased the Mach number to about 9/10.

You see a big vortex, here, that formed. It was of great interest to us. I forgot to tell, I think, one of the most important—some brilliant engineer from Langley, I'd say, probably, that got the idea, I guess I told it, that they could fill in the intermediate area. I think I went through that. The X-1, and then my main job until I left was measuring pressures. There's a case of conical camber.

For a swept circulation control model in the 6 by 6-foot transonic wind tunnel at Ames, I was asked to set up a test. We got interested in a circuit control. This was to investigate circulation. It was sort of astounding, but they built an airfoil that had a blunt leading edge, they found that they could blow over the leading edge and create lift. At zero angle of attack, they could create lift at this. I just designed a test.

Tested both, un-swept and swept. I ended up being able to corroborate what had been found about sweep. We could sweep it and get the same result at flow that's approaching at the angle, which was important. And the Shuttle. We had already gone through with this other design group that was looking at that kind of design. They designed the M-2, the lifting body.

The idea was to try to get enough lift, I think this would be just—our tests, I know the model was dropped. They tested down at Edwards before I left, and I got into the wind tunnel testing of it. I didn't do any of the design of it, but this thing was designed to fit on the head of a Titan missile, and would hold something like eight people, or corresponding. Air Force came along and wanted something longer, so that's what happened to this project, here.

I was also there when he crashed. Let me tell you about that. This was something. I was in on preparing for the test. I had two jobs. I liked the boundary layer research, and I liked that, but I had the responsibility of just making the wind tunnel test. This was the year before we made the test. I went up on a hiking trip into the mountains, and one of the fellows on the trip was the one that was the pilot on this crash. It was the first time that the outside had photographed. We had a design problem, and so, we asked the pilot not to fly it below angle of attack of, I think it was 5 degrees. They dropped him, and somehow, this was a subsonic relation, there was a helicopter to one side. They dropped him, and I could tell this way, they were following him with the test plane, and this was all un-powered. He was just dropped. I forget where I was. Maybe I might have seen the results of it later. I'm not quite sure whether I was right on that spot. They dropped him, and somehow, he got into this—it's this kind of thing—instability. I think it was this test that he came in for a landing, but the lake down there at Edwards is very flat, and it has a runway on the lakefront, on the lakebed. He lost sight at the landing strip.

We had a cheapie model, and the landing gear, they decided to design it so that it would just drop by gravity. Somehow in there, he lost his track, and he went into that rolling, since it was a cone, or a half a cone, actually, went into that rolling, and rolled down. It was [Bruce] Peterson, the same guy that was on this camping trip. He said later that he thought he'd hit the helicopter, but he didn't. He lost his sight on that landing strip, and that probably increased the angle, the angle of attack. They got him out, and knowing after the fact that he had an eyelid, as I understand it, an eyelid cut, I've heard a couple of things. He had a helmet, probably helmet problem. I had heard later that if you lose an eyelid, it's possible to lose your sight, so I tell, you got here just in time, I guess.

Along comes the X-15, and some argument over the design of it actually, a hypersonic shape, the wings would be swept back. That's it. Langley ran some studies and found that they couldn't land with a delta shape or nothing because it would be too much force on the nose gear. That caused them to design the X-15 with more of a straight wing.

[We studied] the space plane. Since then, they've had many space planes. The idea was that they wanted to take off to orbit. Take off to orbit. I remember [the Illinois professor I mentioned earlier] comment, "Well, at least it'll have five more years of hypersonic research." Just like the rest of us, we didn't believe it at this time. I was getting involved in—the shape of our wind tunnel models is never the same as what is going to be built because the next day, they may change it. We build research models, and this one [shadowgraph photograph of jet plume] is supposed to be right when you turn it upside down because that's like a wing. It's like a wing with a rearward surface. We measured the pressure across here. I probably went out on contract for a couple years.

It was the eighties, early nineties. I can't believe this—this required five different groups. You can barely see the shadowgraph photographs, and then we have the pressures on the body. That led to the possibility of computation. We had a very young, excellent, I think he was under contract, too, for calculation. He ran a calculation on the flow, and it was very close. Depended a lot on whether it's turbulent or laminar. Partly what was involved is Gary, he was my supervisor, in fact, I had an opening for a job. I went to Gary and he and I had a remarkable relationship. We could talk faster than—you can get a lot more done if you talk faster. He was fascinated by this project. He was on the main committee.

It's very interesting to trace what the exhaust does on a space plane, or on any of the Shuttle, or what happens. As you increase the Mach number, as you get to higher Mach numbers, the flow can't flow out of the exhaust as normal. To get into orbit, you have to then use, it's real simple and very important... They would get some thrust out of, seemed to me, whatever it was they were discharging. That can't know how to put it, but just by blowing, instead of like a jet, it's over and above a jet. Releasing oxygen or releasing a jet, or not jet, but fluid, which you don't normally do, I don't quite know how to put that.

WRIGHT: What was your conclusion about the aerospace plane? Did you think it would fly, when you were working on the study?

KEENER: You're talking to someone who didn't think the X-15 would fly. My record on that, that was a beautiful research, and went up before I transferred to Ames. It was X-15 when we went to Mach 6 on that, pretty fast. They were going to even go higher, but they didn't make it.

WRIGHT: Did you ever want to fly? Did you want to be a pilot?

KEENER: I joined the Air Force. That doesn't mean that I wanted to fly. I joined the Army Air Corps, and as a cadet, went in as a cadet, and they closed the system. They closed the program. I think I sat through maybe one or two days. The next day, we were out, just walking around. You don't do that, normally, on a base. Some lieutenant stopped it, asked why we weren't marching in concert. I let him know that the program had closed down. I looked for another job on the base, got my trombone out, and joined the band. The base was in Texas, right on the Mexican border.

At any rate, that's a whole subject on itself because the Chinese, they were training their pilots on two-engine research. We would have some times when the general, the Chinese general, would come. The head of that center was a colonel. He was very happy with the results, and the general was happy, and so the colonel was happy. The colonel told us, "March through the headquarters building, playing your instruments." We did that, except I had a little problem—to my horror, I had lost my mouthpiece. I played through that without it. I think, a couple of the officers looked rather strangely at my horn—it had dropped out someplace.

[End of interview]

Earl R. Keener: Recollections of a Wichita University Engineering Graduate
NACA Flight Research Center, Edwards, CA
August 1949 - May 1963

Wichita University Aeronautical Engineering Class No. 2 of 1949
Aerodynamic Research Scientist
Flight Research at NACA Flight Research Center, 14 years
Wind Tunnel Research at Ames Research Center, 29 years
Author or Co-Author of over 50 research papers

List of Events

Bell X-1 flight to M=1.1
Three X-1 explosions
Douglas D-558-I flight to M=0.95

Swept Wings
Douglas D-558-II flight to M=2
Yeager's flight to M=2.5 in Bell X-1A, stretched version of the X-1
Delta Wings
    Convair XF-92A Air force aircraft. Subsonic.
    Convair YF-102A, Subsonic until modified: *Area Ruling, Coke Bottle, Marilyn Monroe*
North American X-15
    Engine Ground Test
    First Landing
    First Powered Flight?
    Aerodynamic Heating
    Q" Meter
    Crash on Mud Dry Lake
    High Altitude, Reentry Flight
Northrop M-2F2 Lifting Body
    Predecessor to Space Shuttle
    Spectacular crash of *Million Dollar Man*
Boeing Dyna-Soar
    First reentry aircraft
    Never Built

INTRODUCTION

NACA, a United States government civilian department called the National Advisory Committee for Aeronautics, was started about 1915 to develop the new field of aeronautics. My mother witnessed the first flight of the Wright Brothers in their aircraft over Dayton, Ohio, in 1908. I have a commemoration medal from that event.

Laboratories were built at (Langley) Hampton, VA; (Lewis) Cleveland, OH; and (Ames), Moffett Field, CA. Since World War I, aviation was developed further by barnstorming, air racing, and then passenger travel. Some of these aircraft, like the Ford Tri-motor passenger airplane are in museums around the country, like the one at San Martin, CA.

In 1929 the Beechcraft Mystery-S Airplane was the first civilian racing airplane to out race the military by about 100 mph at the National Air Races. Walter Burnham, of Wichita, KS, was one of the designers. His son Robert (Bob) was in the first aeronautics class of 1948. I was in the second class of 1949. The second designer was Herb Rawlins, who had an airport near Wichita in 1949. A Beechcraft museum is located near the birthplace of Walter Beech (as I understand it), in Tullahoma, Tennessee, home of the Air Force's large aeronautical engineering testing center.

The NACA Flight Research Center in California was started due to the problems with the fighter planes of World War II. In the late 1940s, the fighter planes ran into stability problems at high subsonic speeds, near sonic speeds of Mach 1, the ratio of actual speed to the speed of sound. The NACA High Speed Flight Station was organized to study the problems. The Station was centered at the Air Force Base in the Mojave desert at Muroc, CA, about 100 miles north of Los Angeles.

My purpose here is not to recount the research results that we were privileged to obtain, but to recount my recollections of some of the notable experiences of flight testing and the flight-research pilots that flew the aircraft.

My presence at the Flight Station represented Wichita University in this great enterprise. Later, from WU came Perry Rowe, John Cary, and John Pyle.

MY RECOLLECTIONS

I was part of a group of recently graduated students in Aeronautical and Mechanical Engineering and Physics that were hired by the NACA (National Advisory Committee for Aeronautics) directly out of school in 1949 to help expand the NACA High Speed Flight Station (later promoted to a Research Center). We were "Forty Niners" but 100 years late.

At 6:30 a.m., on August 8, 1949, I walked onto Muroc Air Force Base to a World War II aircraft hangar marked NACA. What a surprise and delight for an aeronautical graduate, not yet experienced enough to be called an engineer. There was not only one Bell X-1 supersonic aircraft but also two others, the X-1-1 and the X-1-2. Later came the X-1-D and the X-1-E, "modified and stretched" versions of the X-1s, later the X-1-E.

There were also other research aircraft that I did not recognize. The Base was located next to the famous Muroc Dry Lake, which was over 10 miles long by 5 miles wide. It was perfectly flat due to the smoothing action of the winter winds pushing the rain-water back and forth. It was ideal for aircraft research.

The head of personnel identified several of the aircraft: the D-558-I (transonic) and D-558-II (supersonic) research aircraft. These were built by Douglas Aircraft Company for the Navy's contribution to transonic/supersonic research. Next, I met Walter Williams, a former engineer at Langley Research Center in Virginia, who became head of the High Speed Flight (HSF) Station. (Later on, the Station became a full-fledged Research Center.)

Williams was well known in aviation circles as the manager of the construction and direction of the HSF Station with engineers and pilots from Langley. I vividly remember the look on his face as he looked at me as if he couldn't believe that he had hired such young engineers, so "wet behind the ears." I worked under De E. Beeler, Chief Research Engineer, also from Langley. They both remained to manage the Station; later, many of the Langley engineers returned to VA.

The new engineers developed into the backbone of the center. We were quickly trained and caught up in the business of conducting research projects on secret aircraft designed for research. I was assigned to measure and analyze wing pressures on the D-558-I. This turned into a research career of measuring and analyzing wing pressures for 14 years on the X-1E, D-559-II, XF-92A delta wing (triangular), F-102delta wing, X-3 supersonic, and X-15 hypersonic research aircraft. From this work I became interested in aerodynamic air-flow over aircraft wings and bodies and spent my career studying these phenomena. There were many aeronautical journal papers and NACA research center papers, plus my research, to study to get ahead of the field in all of the areas of research at our Center and other Centers.

The Flight Center was a good place to see and meet well-known personalities in aeronautics. Joe Walker became the NACA lead pilot after the early pilots returned to Langley. Joe was joined as research pilots by Scott Crossfield and Neil Armstrong—all three flew the X-15 in the late 1950s. About 1958, Walt Williams left the Flight Center and joined the space program in charge of the ground-based tracking system from the Mercury project through the Saturn project, and the moon landings. Neil Armstrong left to pilot the Gemini spacecraft, followed by the Saturn spacecraft, eventually became the first man to walk on the moon. Scott Crossfield went to North American Aviation to become its Chief Test Pilot for the X-15 supersonic aircraft program. Later he became a Vice President for Eastern Airlines.

There were many interesting flights, many of which were landed safely only through the skill of the pilots. During the development of the NACA High Speed Flight Center, the Air Force and Navy developed Flight Test Centers at Muroc, which later became Edwards. The Air Force developed its famous Flight Testing Center for the prototypes of their military aircraft. Captain Chuck Yeager was a part of this group, flying the X-1 to a speed greater than Mach one (speed of sound) through the sonic (compression) barrier. At this point I must say that there were experts on both sides of the question as to whether or not the aircraft would go hopelessly out of control at Mach one. The details are in the literature. Suffice it to say, the high-speed aircraft were indeed going out of control at speeds approaching Mach one. It took Yeager and his associate engineer/pilot, Major Jack Ridley, and NACA to find the answer to flying supersonic.

The flight tests were flown by both NACA and Air Force test pilots. Research pilots are a different kind of people. They are obviously superior in their craft and intensely interested in flying and in producing good recorded measurements to be analyzed by themselves and ground-based engineers. The Air Force established its own Flight Test Group and their pilots also took great risks.

Yeager was the most famous test pilot and well known to the public. I saw him once suiting up for a test flight on the X-1, the first supersonic manned aircraft. He suited up in an old WWII trailer. Nothing fancy. I had the privilege of meeting a number of famous pilots, such as Joe Walker, Scott Crossfield, Jack McKay, Stan Butchart, Milt Thompson, Bruce Peterson, Bill Dana, and Neil Armstrong, and others.

Our NACA chief research pilot was Joe Walker. He was an usher in our church and my wife, Dorothea, was his children's Sunday School teacher. We lived for two years at the famous forty-niner desert town of Mojave, with the Southern tip of the Sierra mountains close by. We car-pooled 30 minutes to work at Edwards Air Force Base. I often had one or two pilots in my carpool. Notable were Jack McKay, who crashed the X-15 but survived to fly again, and Stan Butchart, who piloted the B-52 that carried the research aircraft to 40,000 ft altitude to drop them for the test flight. Also there were Milt Thompson, Bruce Peterson, and Bill Dana, X-15 and M2-F2 research pilots. We also had "Pappy" Day, a physics major and older engineer. He was an ex-pilot of B-17 raids over Europe and inventor of electronic simulators of some of the research aircraft. A few times we had dinner at the infamous Happy Bottom Riding Club, owned by the famous aviatrix, Pancho Barnes, who once owned a Beech Mystery-S aircraft.

I should mention that before the X-1 flights and before my arrival, the Air Force had the first jet aircraft built, the P-59. It was a secret program and so the Air Force chose Edwards to test the P-59 jet. There was an aircraft with that designation and so they put a fake propeller on the aircraft and shipped it to Edwards. A secret base was built for the tests at the north end of Edwards Dry Lake. Later, one of the U-2 spy plane made some flights out of North Base. I saw the takeoff. It flew almost straight up to high altitudes.

SOME EVENTS IN THE FLIGHT RESEARCH PROGRAM

First Bell Aircraft X-1 Flights:

Two years before, I arrived in August of 1949, Chuck Yeager made his first supersonic flight in the X-1. The civilian test pilot, flying under contract, wanted too much to make the flight and so NACA turned to the Air Force knowing that there were pilots there that would fly anything. The X-1 was built like a tank with an unusually thin wing and a pointed nose for the supersonic shape. There was an escape hatch that probably would not have been safe. There were problems with the aircraft handling as it approached the speed of sound, called Mach one. In fact several high speed WW-II aircraft became uncontrollable as they approached supersonic flight. Some of them crashed, which led to the X-1 project. Some aerodynamic experts predicted from available subsonic wind tunnel tests that the X-1 would also become uncontrollable and it almost did, except for the ingenious method of Yeager and his engineering cohort in the Air Force. Yeager had considerable stability difficulties as he approached sonic flight. He used the control over the horizontal tail and the “flying, all-movable horizontal tail” was born to increase the controllability and make a supersonic flight. It was possibly fortunate that the civilian test pilot did not make the attempted supersonic flight. By the time that I arrived the engineers had analyzed the X-1 wing pressures and had pretty well determined the flow characteristics that led to the sonic problems. It had to do with the shock wave movements over the wing and tail and their interference with the flow at the surface as the local wind flow became supersonic.

Three X-1 Explosions

When I arrived the X-1 was still being flown to gather more data. A problem developed in which an explosion occurred inside the rocket engines at the liquid oxygen tanks. My first recollection of the first explosion occurred just as we were leaving to go home. I heard a very loud explosion down towards the Aberdeen bombing mission. Aberdeen had a program to drop newly designed bombs across the lake and to track them as they dropped to develop the bomb—drop tables. Anyhow, many of us ran towards the runway until we could see the cause. The B-52 drop plane was at the end of the runway with one of the X-1s mounted underneath, which was exploding. Hot sparks showed around the center of the B-52 until it finally collapsed in the middle. We learned later that the X-1 had been brought back without being dropped. The pilot and crew chief were securing the X-1 when the first of several X-1s explosions occurred. They ran and escaped most of the hazard, except the pilot was reported to have been hit in the back by a glob of liquid oxygen. As I recall, it was discovered that an exotic gasket in the engine had something to do with the problem.

During the X-1 Program at least two more X-1 aircraft were destroyed by explosions, this time in flight. The X-1 was attached to the B-52 at the bomb bay. The B-52 flew to about 30,000 ft. where the pilot had to climb down a ladder and scoot into the cockpit of the X-1 and close the hatch. On one flight with the X-1A, an expanded version of the X-1 with ejection seat, NACA Chief Pilot Joe Walker climbed down the ladder, scooting into the cockpit of the X-1A. He then readied the X-1A, pushing whatever buttons were necessary. The aircraft suddenly experienced an explosion and Joe was immediately helped out of the cockpit and up into the bomb bay where a crewmember gave him an oxygen mask because of the high altitude. He was already dressed for high altitude. There were no more explosions and the chase plane, flown by Neil Armstrong flew in close and reported that there were no signs of further trouble. Of course, they could not continue the X-1 flight and could not land safely with the X-1 attached to the B-52. Stan Butchart was first pilot on the B-52 and he flew around for what may have been the better part of an hour trying to determine some way to save the X-1. They even thought of trying to fly low over the lake-bed and to drop the X-1 as gently as possible. This idea was rejected because the X-1 had a gravity landing gear and the explosion blew the gear down. The main concern was that the X-1 would rebound off the lake-bed into the under belly of the B-52. They finally, and reluctantly, released the X-1 on the other side of the lake-bed from a safe altitude. The two crew members that helped Walker out of the X-1A were cited for bravery and given medals. Other awards were given.

The other explosion in flight had a humorous side to the story. The X-1 pilot was the commander of the Air Force Base, a General, and an experienced test pilot. At about 30,000 ft. the General climbed down to the X-1, pushed a few buttons, at which time an explosion occurred. It was obviously an emergency, worse than that of Joe Walker because of evidence of fire. Therefore, the B-52 pilot ordered the General to abandon the X-1 and quickly dropped the aircraft. I understand that it was not clear that the General had cleared the X-1, however, this might not be correct. There was great relief when the General appeared to be unharmed.

Douglas aircraft's D-558-I, Navy Phase One, Transonic:

When I arrived I was assigned to the second D-558-I. It had an unusually thin wing like the X-1 and the wing was not swept. It was being tested to eight tenths, and higher, of the speed of sound, to test its controllability. Each flight increased the Mach number from 0.8 to its maximum of nearly Mach 1. I remember Scott Crossfield flying this aircraft making "pull-ups" to fairly high angles of attack to the flow. The wing had a nasty stall characteristic as determined in wind tunnel tests at Langley. There was at least one flight in which the aircraft wing stalled at high angle of attack and threw the pilot around quite a bit. We heard his exclamation over the radio.

Swept Wings:

It was discovered in the U.S. and in Germany that swept wings reduced the effect of supersonic flow. Three such winged aircraft were tested at Edwards during the NACA time frame: the transonic, variable-sweep Bell X-5, the transonic/supersonic D5588-II, the Air Force XF-92A delta wing (triangular), and the low-supersonic Air Force Fighter delta-wing aircraft, XF-102A. They had some interesting flow characteristics, which we explored in flight.

Douglas Aircraft's D-558-II, Navy Phase Two, Transonic and Mach 2 Supersonic:

This aircraft was interesting because it could be tested with either of two engines: a jet engine for transonic testing and a rocket engine like the X-1 for supersonic flight. It also had a swept wing for transonic flight. Scott Crossfield was trying to make a flight to twice the speed of sound (Mach 2). He made several flights to around 60,000 ft. along a selected trajectory that reached nearly Mach 2 but not quite. Then, the day came when he made it and entered the record book as the first pilot to do so. On this flight or on a similar one, with this aircraft, or perhaps the XF-92A, Scotty glided back so close to the hills that "it was said" that he had pieces of Joshua tree on the wing leading edge.

X-1A, a stretched version of the X-1:

Scotty made Mach 2 just in time. A week later Chuck Yeager flew the new X-1A to Mach 2.5. In this historic flight he reached Mach 2 but then lost control in the thin supersonic air. The aircraft tumbled head over heels until it recovered at a lower altitude. Chuck Yeager stayed with the aircraft and landed safely. On August 8, 1955 the X-1A exploded in another flight, as previously discussed.

Delta (Triangular) Wings:

The XF-92A was an older aircraft. The Air Force had a prototype, the YF-102, delta wing plane designed for supersonic flight as a fighter airplane. When tested the YF version could not reach supersonic flight. Coincidently, at this time, some interesting wind tunnel tests were under way that solved the problem. They found that by shaping the fuselage like a coke bottle (technically called cross-sectional area ruling, but dubbed the Marilyn Monroe shape, my favorite for obvious reasons) that the sonic drag was significantly reduced. This YF fuselage was modified to represent this shape. Also, the wing leading edge was modified according to other wind tunnel tests. With these changes the YF was able to fly supersonic, one of the first Air Force aircraft to do so, and so the F-102A was born. As design techniques advanced and the engine power increased, the large aircraft drag force was overcome and flights made to higher supersonic speeds and altitudes.

North American Aircraft X-15 Hypersonic Research Airplane:

Rocket power design progressed to the point where a rocket-powered aircraft was envisioned and then designed. This project in the 1950s led to the famous X-15. The aircraft utilized many new features and concepts for flight characteristics in conditions of aerodynamic heating. The corresponding critical design and pilot safety considerations were crucial.

Engine Ground Test: The first rocket engine that could be throttled was designed and tested. In a ground test of the engine, it was mounted in an X-15 fuselage, firmly fixed to the ground and tested while held in place. Scott Crossfield was now the X-15 lead pilot for North American and was in the cockpit to test the engine controls. A huge explosion occurred that blew the forward half of the fuselage forward with Scotty inside. Fortunately, he was uninjured, being firmly strapped into the cockpit. When the X-15 was finally built, the engine was successfully flown with only one incident that I recall where the throttle failed, discussed later. The incident, as well as many others, is well documented in the NASA film archives.

First Landing: The first landing was exciting. The aircraft was dropped from the B-52 with Scotty Crossfield aboard, and proceeded to glide to a test landing. I was watching from the office and could see the X-15 approaching the dry lake in the distance. I could also hear the transmission from the pilot. As he approached, I could see the nose pitching up and down. Scotty "held on" and brought the X-15 to a safe landing. Adjustments to the pilot-assisted control mechanism solved the problem.

First Powered Flight? I think that the first powered flight ended in an emergency landing on Rosamond Dry Lakebed. I don't recall the reason. It was too late to vent the fuel tanks so that the X-15 landed with the weight of the fuel. This caused the pilot to increase the angle of attack. Upon landing, the nose rotated hard to the ground and the fuselage broke behind the pilot's compartment, which was bolted to the rear section of the fuselage. Scotty was unharmed and the aircraft, one of three, was repaired.

Aerodynamic Heating: As the flights progressed, the Mach number (speed) of each flight increased into the region of strong aerodynamic heating. A flight was planned to take pressure and temperature data. The velocity of the X-15 was shown to the pilot from ground radar. Joe Walker was flying and the ground crew reported to Joe that he needed to increase the heating by dropping a little bit to a lower altitude. Joe did so but became concerned that the aircraft was overheating. He could tell because he could hear the popping noise of the cabin (like an iron stove) as the aircraft heated. Joe used his instinct to limit further heating, took data, and returned to the ground. It turned out that the radar velocity was in error on the low side, so that Joe might have been in serious trouble if it were not for the instinct that research pilots have.

"Q" Meter: During this time I invented a Q-meter to read the dynamic pressure (Q) related to heating. It was placed in the aircraft instrument panel and used on most succeeding flights. It would have aided Joe Walker in his flight, but he used his experience to avoid catastrophe.

Crash on Mud Dry Lake: My car-pool pilot friend, Jack McKay, experienced a spectacular crash landing on Mud Lake. As the flight velocity increased, they always dropped the X-15 near a dry lake that was manned with a helicopter and emergency equipment. They always dropped the X-15 with the throttle on idle, to be certain that the engine was working. On this flight they dropped Jack and he advanced the throttle. There was no response. It is interesting and important at this point to state that they had developed the X-15 simulator on the ground so that the pilot of the next flight could practice all of the emergencies that they could think of. This was especially important because the pilot was so trained for emergency that he could concentrate on flight plan.

Therefore, Jack proceeded to Mud Dry Lake, as planned for the location of the drop. As he approached, he tried to lower the fail-safe wing flaps to reduce the landing speed (which was high). The flaps failed, which was not disastrous, since they practiced such an event. The aircraft had skids instead of wheels for aerodynamic heating, which worked well on the dry lake surface. Next, however, the horizontal tail that controlled the pitch angle, did not know that the aircraft had landed and so it rotated forward, trying to lift the nose. However, the aircraft was on the ground skidding at a high speed. The tail produced a large download on the skids, which was not, in itself, disastrous. But, there was a crack in one skid that had not been revealed by the usual ground tests. The skid failed and the aircraft rolled, wiping out one wing. With a quick reaction, Jack jettisoned the canopy to prevent being trapped.

Unfortunately, the top of the pilot's seat acted as a plow and it shoved a large amount of Lakebed soil down on the head and shoulders of Jack. Jack survived and after a few days he left the hospital. It was said that he was 1/2 inch shorter, but he lived to fly the X-15 again. Jack's survival was due to some heroism from the ground crew and a medical doctor and the helicopter. The ground crew positioned the helicopter so that it blew the ammonia fuel fumes away from Jack. The crew donned gas masks and proceeded to dig him out. Later, there were citations to those who had risked their own safety.

High altitude, Re-entry Flight: Joe Walker made a maximum altitude flight above 300,000 feet that qualified him as an Astronaut. Joe and I shared the same dentist, who did a complete goldwork on Joe’s teeth. He was proud that he had the highest flying teeth in the country. Joe’s descent into the earth’s atmosphere (about 100,000 feet) was different from other flights in that he had to know the correct angle for the horizontal tail to prevent serious pitching and heating. This was determined by ground computer simulations. However, Joe experienced some rolling oscillation that increased as he descended. Again, Joe used his experience to bring the X-15 home safely. The reason was determined by examining the flight records.

M-1/M-2 Lifting Body Research:

The M-2 Lifting Body Research program was the predecessor to the Space Shuttle. The program started with a lightweight model built out of fiberglass by a local boat company. My greatest memory of the program occurred before I transferred to the NASA Ames Research Center. I took a hike into the high Sierras for a fishing trip with a group that included some engineers and Bruce Peterson, who was the pilot of the M2-F2 lifting body experimental spacecraft, built by Northrop Corporation. The M2-F2 was dropped by the same B-52 that dropped the X-15. He liked to call me “Raisins Keener” because I carried raisins in my pack. The others wouldn’t eat any. After I left the Flight Center, Bruce made his spectacular crash landing on Edwards Dry Lake that has been seen by millions as the introductory scene in the TV series “Million Dollar Man.” Bruce survived by being securely strapped into his seat.

Dyna-Soar

Before I left Edwards, the Advanced Missions people were designing a rocket space aircraft. I believe that it was to be dropped at Edwards, accelerate to high speed, circumnavigate the earth one time, and test land the aircraft at Edwards. It was never built.

After the X-15 tests I transferred to Ames Research Center to conduct wind tunnel tests on research wings and bodies. The wind tunnels are now mostly silent as aircraft design is accomplished by use of computers. Research now concentrates on space flights. I had the privilege of being a part of an era in aeronautics in which the aircraft of today were developed using our research and the skills of the designers.

Ref. 1: AVIATION WEEK article, November 5, 1956. Dramatic Story of X-1A Rescue