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## **HERBERT B. KELLER** (1925 – 2008)

**INTERVIEWED BY**  
**SHIRLEY K. COHEN**

**May 6 and June 13, 1996**

**ARCHIVES**  
**CALIFORNIA INSTITUTE OF TECHNOLOGY**  
**Pasadena, California**



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### **Subject area**

Applied mathematics

### **Abstract**

Interview in two sessions, May and June 1996, with Herbert B. Keller, professor of applied mathematics with a joint appointment in the Division of Engineering and Applied Science and the Division of Physics, Mathematics, and Astronomy. Dr. Keller received his BEE at Georgia Tech in 1945 and his PhD from New York University (Institute for Mathematics and Mechanics, later the Courant Institute) in 1954. At Caltech as a visiting professor in 1965; joined the faculty as full professor in 1967. Executive officer for applied mathematics, 1980-1985.

He discusses growing up in Paterson, N.J., with his older brother, mathematician Joseph Keller, and education in mathematics at Eastside High School. Matriculates at Georgia Tech and joins NROTC; in World War II, serves as a fire-control officer on the *USS Mississippi*.

After the war, he takes graduate courses in electrical engineering at Georgia Tech; soon follows his brother to NYU and the institute established there by Richard Courant. Recollections of Courant and Charles De Prima; fellow students: Peter Lax, Louis Nirenberg, Cathleen Morawetz, and Harold Grad. Bicycling trip in Europe, 1948, with his brother; meeting up with Courant in Switzerland. Thesis work with Bernard Friedman. From 1951-1953, he taught mathematics at Sarah Lawrence.

Recalls working with Robert Richtmyer at Courant on the Atomic Energy Commission's UNIVAC computer; becomes associate director of the AEC Computation and Applied Mathematics Center; Edward Teller and Hans Bethe as consultants; visits Los Alamos and Livermore. Initial invitation to Caltech in 1960 from Gilbert McCann, head of what was then called information science (now computer science). Happy at Courant and unimpressed with Caltech's offer, he declines, but visits Caltech in 1965 at invitation of Gerald Whitham, joining new applied mathematics program. Returns to NYU for a year, then back to Caltech to stay. Recalls applied math group—Donald Cohen, Philip Saffman, Julian Cole, later Joel Franklin. Recalls Jack Todd. Helps establish and for many years teaches one of Caltech's most popular courses: Applied Mathematics 95 (AMA 95).

Discusses early development of computer science at Caltech: Donald Knuth, Carver Mead, Charles L. Seitz., Ivan Sutherland, Mani Chandy. Discusses his relations with Caltech's pure mathematicians and aerodynamicists. Recalls sabbatical at INRIA [Institut National de Recherche en d'Informatique et en Automatique] and visiting professorship at Paris-Orsay. Visiting fellow at Christ College, Cambridge, and DAMTP (Department of Applied Mathematics and Theoretical Physics) in 1993. Concludes by recalling his impressions of K.O. Friedrichs and Fritz John at Courant and his work with his brother.

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### **Contact information**

Archives, California Institute of Technology  
Mail Code 015A-74  
Pasadena, CA 91125  
Phone: (626)395-2704 Fax: (626)793-8756  
Email: [archives@caltech.edu](mailto:archives@caltech.edu)

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**CALIFORNIA INSTITUTE OF TECHNOLOGY**

**ORAL HISTORY PROJECT**

**INTERVIEW WITH HERBERT B. KELLER**

**BY SHIRLEY K. COHEN**

**PASADENA, CALIFORNIA**

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**CALIFORNIA INSTITUTE OF TECHNOLOGY**  
**ORAL HISTORY PROJECT**

**Interview with Herbert B. Keller**  
**Pasadena, California**

**by Shirley K. Cohen**

Session 1                      May 6, 1996

Session 2                      June 13, 1996

**Begin Tape 1, Side 1**

COHEN: I thought we could maybe start with a little biography. Let's go back to early times. Tell us a little bit about where you were born, what your parents did, early education—things like that.

KELLER: Thank you. I'm very honored to have been asked to join this august company. I hope I can think of interesting things in my past.

I was the second of two kids. The other is my brother, Joe Keller, who's also an applied mathematician, a very well-known guy, at Stanford now. We were the only two children. There was a third child, who died within the first few weeks of birth. That was in Paterson, New Jersey, where we were born. I don't know how my father and mother settled in Paterson, New Jersey, but that's where my father's family settled.

My father came from Russia in 1905. His parents—my grandparents—had three boys, who were about draft age, and the draft in Russia at that time meant a lifetime of servitude. And 1905 also coincided with a mini revolution in Russia. So it was a good time to get out, and they did. Another part of the family emigrated about the same time and went to Canada. My grandparents and uncles and aunts came to Ellis Island, where apparently the authorities didn't speak Russian very well. So the family was there endowed with the name Keller. And the part of our family that went to Canada retained the name Kales, which was the original name. So when I go to Germany, everybody thinks I'm German and they love me; and when I go to Russia, everybody thinks I'm German and they hate me. [Laughter]

My mother came over in maybe 1900 or 1901, when she was an infant. She was born in Hull, England.

My father was rather well educated in Russia—spoke three or four different languages. He was always interested in arithmetic, as opposed to mathematics. And he knew all sorts of tricks for doing fast arithmetic, using his fingers and his fists and so on.

COHEN: He liked numbers.

KELLER: Yes. Everybody claims that's where my brother and I got it from. And he used to continually give us puzzles—you know, three men go into a room with four hats, and one of them is blind. [Laughter] That kind of thing. So we were being tested with puzzles all the time. It was a lot of fun.

COHEN: What did he actually do to feed you?

KELLER: Well, I guess the best feeding came while he was a bootlegger. In his youth, he and an uncle of mine somehow were in the trade of supplying liquor—from where to where I don't know—during the Prohibition years. My mother was very nervous about that, so my father became what my mother called a “gentleman bootlegger.” He would work only one day a week. [Laughter] But he soon got out of that business and got involved in real estate. He was in the real estate business for quite a while. But then there was the Depression when we were kids, and you had to do anything you could to make a living. And I guess my father went back to his early career of selling liquor, but this time as a bartender, or the owner of a bar. So for many years Keller's Bar and Grill in Paterson, New Jersey, was a hangout for a lot of guys who liked to play pool. My father had to become an expert pool player, or else he'd have lost his shirt. [Laughter] And I remember many Sundays my brother and I would go with my father to the local pool hall in downtown Paterson, where my father would learn the game. [Laughter] And play with real pros—not in any barroom situation, but in a poolroom situation. So he became a very good pool player.

Unfortunately, that didn't get passed on to us, nor did any knowledge of the Russian language get passed on to us. Because my mother, of course, didn't speak Russian; she was

from England.

COHEN: Was her family originally from Russia? Or was she English?

KELLER: I think they were from Russia—Poland originally, my great grandparents. My grandfather, however, was a painter in England for quite some years, so I don't know when that side of the family came over from Poland or Russia.

The name Bishop, of course, is a shortening. It's my mother's maiden name. But the name was originally something else starting with a B. And there's a well-known chemist down at Brooklyn Poly who has that name; he's a remote cousin—he has the original name.

COHEN: So you went to school. It sounds like you had a pleasant childhood, really.

KELLER: Well, yes. We had a pleasant childhood. There was the Depression on, and that made some hardships. We lived in a single-family home in a very nice residential area of Paterson. But my mother and father had to take in boarders to make ends meet. So we had Mr. Kaplan, the painter, living there for a while. And then he lived there with his son for a while. There weren't many people on the block who took in boarders, so we felt a little funny about it. But my parents were taking care of things. That's what we had to do to survive. And they did. As a matter of fact, they opened a delicatessen at one time. But my mother always claimed my father didn't know how to cut the stuff thin enough, so that's why that went under. [Laughter]

The local school was Public School No. 20. We walked a few blocks, maybe five. And sometimes we even walked home for lunch. In those days, you walked to and from the local school. It was quite good. We enjoyed going to school.

Our principal was D. Stanton Hammond, a very impressive figure. I don't know to this day what the "D" stood for. But one of the main events I do remember at that public school was that almost every Friday afternoon we had movies. And if you paid five cents or something like that, you got to see the movie. So that's where we saw *Tarzan of the Apes* and whatever else was going on in those days. I had many classmates, some of whom I'm to this day friendly with.

COHEN: Did you ride a bicycle in those days?

KELLER: No, we did not own a bicycle because I don't think we could afford one. No, that was much later.

I don't remember being particularly excited about mathematics in those days, or anything like that. You didn't get anything you could really call mathematics or science much in grammar school in those days. But I was very much interested in doing things with my hands—making things, and so on. I made model airplanes, which were quite popular then.

COHEN: How about radios? That seems to have been something that—

KELLER: No, that came a bit later. I didn't do much with radios, but I did make a lot of electrical things, I remember— electromagnets, small motors, and so on.

COHEN: You were very close to your brother, it sounds like?

KELLER: Well, yes, Joe and I. Well, there was a whole crowd of kids in the neighborhood, and we all palled around together. We joined the Boy Scouts together. Joe and I were very active in the Boy Scouts, right up until I left high school. Joe and I became senior patrol leaders, which is the senior guy helping run the troop.

But high school was quite different. That was Eastside High School in Paterson. That high school was really quite good. There were two high schools in Paterson—Eastside, which was in the fancy east side of town, and Central, which was for the rest.

Now, Eastside High School has become famous in recent times, because there was a movie made about the principal there who locked all the doors and went around with a baseball bat, patrolling the halls. And he was invited to see Mr. Reagan in the White House because he kept such law and order there. As a matter of fact, he was trying to keep out the drug peddlers and students with their drugs. But when I went there, you were forbidden even to smoke within the grounds of the high school. At lunchtime, people used to sneak away to restaurants and places nearby and smoke at lunchtime. I didn't take that vice up until after I graduated.

In high school, I was stimulated very much by the mathematics and science courses—but especially mathematics, because of the good teachers. I had two I remember in particular. One was a very stern old lady—seemed like a very old lady at the time; she must have been thirty at

least. [Laughter] No, a little older, perhaps; she had gray hair. A very tall, erect lady. And she was fantastic. She taught algebra. Then the head of mathematics in high school was a guy who was called “Chief” Doherty. I don’t know why we called him “Chief” Doherty—not to his face, of course. But he was very stern, a very imposing guy, and also a very good teacher. He taught me trigonometry.

Geometry was perhaps my favorite subject there. This stern lady I mentioned before was also the geometry teacher. I really loved geometry. And, as a matter of fact, we had a Mathematics Club in Eastside High School. I was a member of the Mathematics Club. One thing I remember about that club and those days, in contrast to the more recent past, is that most of the best students in mathematics were females. And the Mathematics Club was mainly populated by females. There were a few of us guys in there. But I’ve always heard that girls were dissuaded from taking mathematics. I’ve always thought that must have happened after high school, as a result of my experience in high school with so many of the better people.

COHEN: Were there a lot of Jewish people in this high school?

KELLER: Well, the east side of town—it was an integrated school. For instance, Larry Doby went there. I don’t know if you know who Larry Doby was. But he was maybe the second black to play baseball in this country. And he was a tremendous football, track, and tennis player. And there was a very large Italian population in Paterson.

COHEN: Well, your former colleague was from Paterson.

KELLER: Charlie DePrima, yes. We didn’t know him at that time, but his brother went to Eastside High School and was a track star while my brother was a track advocate. [Laughter] Joe finished every mile race, and Charlie DePrima’s brother won every mile race.

The other interesting thing about my high school career was that I had a great abhorrence for foreign languages. I think it came in part from being forced to go to Hebrew school for so many years, spending six years not learning how to speak Hebrew, but being able to read it. And given my interest in shop and so on, I took what was called the Mechanical Arts Program, which was a lot of shop work, mechanical drawing. I took all the science and mathematics I could take.

So I was prepared for college, with two provisos: One, that it didn't require a foreign language to get in; two, that it didn't require a foreign language to get out. I took no foreign language in high school and they kept telling me, "Well, you won't be able to go to college." But I thought I would find a way, and it didn't loom that important at that time. So I took no foreign languages but a lot of shop, for which I was very grateful. As a matter of fact, even in grammar school we had to take manual training—that was required—and it was great.

I've had two very important occasions to recall regarding manual training in trips to both China and Russia. When the people there asked me various questions about my views on this, that, and the other, I remember saying—especially in China—"Now, if all of your kids had to take manual training, can you think of 500 million people with hammers and how they could repair the place?" And the same way in Russia. It was beneath their dignity to repair things—to replace a fuse, and so on. I think that's one of the things that contributed to the deterioration of their poorly structured apartments. You go into an apartment and everything is so shabby; whereas in the States, as soon as some little thing goes wrong, whoever is living there fixes it. That manual training, to me, was great—besides, I loved it!

Well, back to high school. I had a very good science teacher—I forget his name. And I remember one of the most impressive things he told us was about galaxies and super galaxies and so on. Astronomy. This was in the early forties—I graduated in 1942. And this guy used to perform little experiments in class. So I somehow realized that the thing that would interest me for the future was engineering; but then I heard of something called engineering physics. And that was it! My idea was to go and study engineering physics, whatever that was.

COHEN: What was Joe doing already, because he must have been ahead of you.

KELLER: Well, Joe was ahead of me. As a matter of fact, he maybe finished a little early. But Joe wasn't all that interested in science, it seemed at the time. As a matter of fact, he went to New York University and majored in journalism. But somehow he got the word after graduation, and then he went to Princeton where he got a master's degree in physics. The war was on then, and he continued doing war work.

COHEN: So you thought you would do mathematical physics?

KELLER: No, engineering physics. I'd never heard of mathematical physics—didn't know that mathematics was connected.

When it came time to think seriously about college, as I say, I had this stupid requirement that you shouldn't need a foreign language to get in, or have to learn one to get out. And I was interested in engineering physics. So after surveying what was available in the United States, I found two schools that seemed reasonable: One was Rensselaer Polytechnic Institute, in Troy, New York; the other was Georgia Tech, in Atlanta. Since Georgia Tech was farther away, that's what I opted for. And I went to Georgia Tech with a very close friend of mine by the name of Raymon Alan. We're still very close friends. There was another fellow from Paterson who went with us—a guy by the name of Herman Liss. The three of us went there, but Ray and I roomed together. He was my roommate the first year; well, it wasn't quite a year because the war came on.

I had been accepted into the Naval Reserve Officers' Training Corps—NROTC. And Ray had joined some Army Air Force training corps. And then when the war came along, all of a sudden these nice ploys became very important because Ray was pulled out of school and sent to more serious training with the air force. And I stayed in school, but I was pulled out for several months to go to Mayport, Florida, and be on a submarine chaser. I was an apprentice seaman, even though I was a cadet in the NROTC. Apparently the German submarines were creating havoc with the oil routes around Florida to the East Coast—there were no pipelines in those days, and so these tankers had to come from the Gulf Coast up around the coast of Florida. And those are very treacherous waters, so they were sitting ducks for German submarines. So I was assigned to a submarine chaser out of Mayport. Of course, this was so early in the hostilities that submarine chasers hadn't really been developed yet. They used converted crab-fishing boats with little U-shaped regions cut out of the stern. And these big depth charges would be pushed out of the stern of the ship and the timer set, and you hoped it would go down and blow up the submarine before it blew up the stern of your ship. These boats were so slow that the latter would occur just as often as the former. As a matter of fact, these submarines were so adept and so nifty that occasionally they would mine the harbor and we couldn't get back, after a week at sea. It was difficult to come back in until the harbor had been de-mined. [Laughter]

COHEN: It sounds like you were doing quite dangerous work.

KELLER: Well, yes, but we didn't think of it that way. Being kids, it was a lot of fun. What was more fun, I remember, is that rationing had begun, but being in the navy we had more than enough to eat. And the rule was that you could never come back to shore with anything in your larder, or else you wouldn't get as much food next time. So on the way back in we used to take these steaks and whatever else was left and throw them overboard, and as the sharks came to get them we'd machine-gun them. Target practice. [Laughter]

COHEN: It sounds terrible!

KELLER: It *was* terrible! The most dangerous thing—I think, because we never came too close to a submarine that we were sure of—but you had to watch out for the Coast Guard. The Coast Guard had these airships that were also looking for submarines. But when you're on night duty and you're scanning the horizon, looking for the phosphorescent trail left by a submarine periscope, it's kind of hard to look up in the sky and see if somebody's flashing recognition signals at you. Of course, the rule was that all the Allied Forces had certain recognition signals. And you'd first flash that recognition signal, and maybe you'd wait ten or twelve seconds and then flash it again. And if there was not an instantaneous response, then you could open fire. So the main battle was between the Navy sub chasers and the Coast Guard dirigibles. [Laughter]

That lasted for three or four months, and then I was sent back to Georgia Tech to continue my career.

Of course, so many of the physics instructors were busy teaching these basic courses to the V-12 program. But the interesting thing was that the V-12 people had to wear gob-jockey suits—you know, these white things—whereas we wore midshipmen's uniforms. So it was much more attractive to the ladies, and we were very pleased. And of course we were hated by the V-12 guys because we had these fancy uniforms. [Laughter]

COHEN: You make the whole war sound like a joke. There must have been something serious in it. But not as you remember it?

KELLER: Oh, I lost four very close friends who were killed in World War II. That was serious.

But as I say, so many physics people were busy teaching the basic courses that they had

discontinued the course in engineering physics. And the navy said to me, “Well, electrical engineering is close to that. You’ll become an electrical engineer.” So I, of course, agreed with them. So I majored in electronics engineering and ended up with a bachelor of electrical engineering degree in electronics [Ed. note: 1945]. And that took two years and eight months because they were on a semester system. A semester was four months, and there were three semesters per year. No vacations, of course. So at the tender age of twenty, I got my bachelor’s degree, I got my commission, and I got my first wife—all within three days of each other, something like that.

And then I got a prime assignment. My first assignment was to go to the GOOS—Gunnery Officers’ Ordnance School. I was in the navy, and the war was still going on. Well, I went to the Gunnery Officers’ Ordnance School which was in Anacostia, Maryland, just outside of Washington, to learn fire control. “Fire control” means to control the big guns. And so I went there—I forget how long; it was rather rapid. One of the interesting things about that course was that I went out on an experimental gunnery ship. I think it was either a World War I or Spanish-American War vintage ship, which was used for training in gunnery. And on board that ship were the first vestiges of electronic computers built by Bell Labs to control the firing of guns. These were five-inch guns we were firing. And whenever they were fired more than two or three times, we had to go back and repair the computer because these electron tubes would just vibrate.

After gunnery school, I was assigned to the *USS Mississippi* as a fire-control officer. I was assistant division officer, I guess, for the third division.

COHEN: You were always close to the United States? You didn’t sail far away, did you?

KELLER: Well, we were about to head for the Pacific when the war ended. And then things got turned around and we did not go. It was then determined that we would be converted into an experimental gunnery ship.

One of the nastier aspects of being a fire-control officer was that we also owned the catapult. These old battleships carried scouting planes on board; and you’d shoot them off with this catapult, which was fired by putting a big charge in it. The gunnery people had to take care of the catapult; and that caused me trouble later on, after the war ended, because they had a point

system for deciding when it was your turn to be released to inactive duty. So one day I got all my points and I went to see the gunnery officer and I said, “Look, I have all these points.” He said, “All right, fill out these forms, and I guess you’re going to have to go.” And within two days there was a call to come and see the executive officer. And he said, “Keller, what do you think you’re doing? You can’t get out of here.” I said, “Why not?” He said, “You’re the only qualified catapult officer we have. And we have a catapult, so you can’t get out until you get a replacement.” And I said, “We’re on our way back to Norfolk to be decommissioned and turned into an experimental gunnery ship. They’re going to take off the catapult.” He said, “You know better than that. We have a catapult; we need a catapult officer.” Of course, we didn’t have an airplane anymore—the planes were gone. [Laughter]

That bad news really struck me. I went to see the gunnery officer and I said, “What do we do about this? I have the points and they won’t let me off. Nobody wants to be a catapult officer.” He said, “Herb, don’t worry about it. We just got four red-ass ensigns in from Annapolis. You put a little card up—‘Catapult School meets 0800 Monday morning’—and I assure you those four guys will be there.” [Laughter] So I did it, put the sign up; they came, and within two weeks we had four new qualified catapult officers.

Now, that’s funny. But what’s even more funny about it is many years later, when my son was going through the book you get when you get off the ship, he said, “Dad, did you know that Jimmy Carter was on your ship?” I said, “No!” “Yes,” he says, and he shows me a picture. And I said, “That’s one of those ensigns from Annapolis I trained to become a gunnery officer.” And I’ve been telling that story for quite a while. Carter was a good student—though I didn’t know who the hell he was at the time.

But just a short while ago I had this seventieth birthday celebration. And Eric Van de Velde, who was one of the guys putting it on, wrote to Jimmy Carter and reminded him of this item and said that I’d been saying that he’d been a good student of mine. And Carter wrote back, saying he didn’t remember becoming a qualified catapult officer but he *was* an engineering officer on the *Mississippi* at that time, and he wished me a happy birthday. [Laughter] So I have that note from Carter.

COHEN: So you were then decommissioned?

KELLER: Well, I was released on inactive duty. I went back to Georgia Tech to work for a PhD in electrical engineering since I was now an electrical engineer.

COHEN: You must have liked Georgia Tech to go back.

KELLER: Well, I had the “Georgia Peach” to whom I was married at that time, so that was also going on. Besides, I didn’t know quite what else to do, but I knew I wanted to get more education. I did a lot of reading on board the *Mississippi*—I had a lot of time to play bridge and to read—and I had some physics books and other things that my brother had sent me. I had asked him for some good stuff to read. By then he was becoming either an applied mathematician or a physicist—it wasn’t clear which—at that time. So I did a lot of technical reading on board ship. I wanted to go for a higher degree; and I went back to Georgia Tech, where I taught physics—I was an instructor—to earn money to supplement the GI Bill. And I started taking graduate courses in electrical engineering.

COHEN: Was that separate at Georgia Tech, or was that part of physics there?

KELLER: Oh, no, that was separate. We had a very good electrical engineering department. Georgia Tech in those days was not even a shadow of what it is now; it was not a very strong school. There were a few things that were good there. I think chemical engineering was very good there. They had quite a good electrical engineering department. Physics was, I’m afraid, very poor; most of the engineering was poor; they had an industrial arts program that was very good. But it was a mixed bag. To take a course in quantum mechanics, I had to take it in the chemistry department—from Pauling and Wilson, by the way; that was the text we used. [Ed. note: *Introduction to Quantum Mechanics*, by Linus Pauling and E. Bright Wilson, Jr.]

But things weren’t working out so well for me personally, so I left Georgia Tech and went up north. In those days, living in the South wasn’t all that pleasant in various ways. Anyhow, I went north to my parents’ home again, with my wife, and started looking for a job as an electrical engineer. And I had a number of interviews. One of the interviews in particular convinced me that I didn’t want to be that kind of electrical engineer anymore. I remember this interview; I went in and the chief engineer said to me, “Oh, so you’re a graduate electrical

engineer.” “Yes, yes.” Well, he gave me the requirements of a transformer. He said he wanted to convert from 110 to 220 with this power. How many pounds of iron did I need in the core? [Laughter] And that convinced me that I wasn't meant to be an electrical engineer.

Meanwhile, I saw that my brother was taking courses—or had maybe recently finished his PhD in mathematics [Ed. note: 1948] at New York University, where [Richard] Courant had come—of Courant-Hilbert fame. Courant was a very famous mathematician, and he had settled at NYU. And somehow Joe became attached to that group. So there was a little group that Courant ran; it was called the Institute for Mathematics and Mechanics. Their headquarters was in Judson, which was a girls' dormitory on Washington Square, because there weren't enough people to occupy a whole building. And Joe arranged for me to be interviewed by Courant about possibly becoming a student and getting some support.

And so for the first time in my entire career, I put on my navy whites. I wanted to make an impression. I had never had any occasion to wear my whites; but I put them on just to show Courant who he was dealing with. So I went and had this interview. And I remember Courant looked me up and down, and he saw how ignorant I was about mathematics. And he loved toying with people, so he said to me, “Well, let's see now. I think we can find something for you to do.” And then he looked up and down very pointedly at my uniform, and he looked out the window and he looked back at me, and he said, “Do you know how to wash windows? Oh, never mind, we'll find something for you to do.” [Laughter] That's how he accepted me.

And as a matter of fact, the first course I took—this was in the summer—was from Charlie DePrima, who was by then at Caltech. Charlie DePrima had a lady friend at the Courant Institute, and he used to go there every summer. And he had also been, I think, Courant's first student in the United States. So I took a course—an introduction to mathematical physics or something like that—from Charlie DePrima; and that was my first graduate course in mathematics.

Unfortunately, my brother thought I knew more than I did and so he advised me about what courses to take. So for instance, I started in the middle of a one-year complex variable course by just taking the second half. And the same way with abstract algebra, and that put me behind the eight ball. It was very hard getting started because I had had such poor mathematical training at Georgia Tech.

COHEN: They didn't ask you to take a test before you came in?

KELLER: Oh, no—I was Joe's brother! And Courant worked things out. Courant was a very, very paternal person, and he tried to run that place as if it were one big family. Connections meant a lot, I must say. But on the other hand, if you look at what he built there, it's a tremendous place. And while I was there, many of the people who are now very well-known applied mathematicians were my fellow students. It was just beginning to get off the ground. Peter Lax, Louis Nirenberg, Cathleen Morawetz, Harold Grad. Cathleen is the president of the American Mathematical Society—or just finished being that. She's now retired.

COHEN: So it was really a stellar group?

KELLER: Yes. We didn't realize it at the time, but it was. And one of the amazing things—and one of the tributes to Courant—is that he built such a permanent group which has been able to maintain itself and renew itself. Two years or so ago, for the first time, the Courant Institute got a director who was not from the inside. And in fact the university, I heard, insisted on that—they wanted to go outside to get a director.

COHEN: So it was an independent institute, but it was part of NYU?

KELLER: Oh, yes. Courant was a master at getting funding. For instance, he got the Rockefellers to fund the building at Göttingen. So the famous Göttingen Institute was in a building that was renovated or somehow refurbished by Rockefeller money. When he came to the States, it was a bit harder, however; and he worked many years trying to get support. He eventually did; and the Courant Institute, as it's now called in honor of Courant, is housed in Warren Weaver Hall. Warren Weaver was for many years a director of the Sloan Foundation, and they put up a lot of money toward supporting Courant and the institute, and building that building. And it still is a tremendous place for mathematics. One of its main features is the thirteenth floor, where there is a big lounge where people meet every day for tea. That's the tradition; and it's a great tradition. [Tape ends]

**Begin Tape 1, Side 2**

KELLER: Now, at the Courant Institute I became interested in wave propagations—many of us were doing that.

COHEN: Did you live in New York City? Had you moved into New York?

KELLER: Yes. I guess by then my wife and I had divorced, and Joe and I were living together on West 91st Street, just off Central Park West. We had one of these railroad flats. There were a number of people from the institute who lived near us.

At the Courant Institute, I took all the courses I needed for my degree and wrote a thesis under Bernie Friedman—I guess he was my official advisor although Joe was an advisor, too.

COHEN: Joe was already an instructor there?

KELLER: Yes, he was on the faculty.

There were several things. Number one is that now I had to pay for the fact that I didn't like foreign languages, because a requirement for the PhD was a reading knowledge of two foreign languages. And in my case that caused a delay in my getting my degree for a year, while I studied French and German and then took those exams. And by some miracle, I passed them. But my thesis and everything was all finished before I took the exams.

But then Courant came up to me one day and said, "An old friend of mine is at Sarah Lawrence College and she's looking for someone there to head mathematics. You might be interested in that." Of course he knew I was now a bachelor. [Laughter]

COHEN: And all those women! [Laughter]

KELLER: Yes. Sarah Lawrence is in Bronxville. It's a very nice school—one of the fancier girls' schools. I went out there to meet the head of the physics department, whose last name was Houtermanns. She was the ex-wife of Fritz Houtermanns, a well-known physicist. She had two lovely children, and her daughter became one of my students there.

COHEN: So you took this job?

KELLER: Yes. To be *the* mathematics department would require two or three days a week, something like that. So I just got partial relief at the institute, where I was doing research in electromagnetic stuff for the air force—we had big air force contracts. And I became the mathematics department at Sarah Lawrence College.

COHEN: You already had your degree at this time?

KELLER: No, I didn't have my degree yet; I got my degree officially in '54, and this was 1951.

Sarah Lawrence was a most interesting place because that's where I really got my liberal education. I met all kinds of people—very well-known people in the arts. Not in the sciences, because that's not what the little girls wanted, except for a few of them. There were a few special cases. In fact, almost everyone was a special case. So I ended up giving three different math courses.

COHEN: Did you enjoy teaching those girls?

KELLER: Oh, it was a lot of fun but it was a lot of work, too. You had to give the layman's course in mathematics, for the most part, to most of them, except for two very good students. One was Bamsie Houtermanns. And the other was the wife of Ed Frieman, who headed the Sherwood Project at Princeton; she also happened to be the daughter of the publishers of the *Washington Post*—the Grahams.

So those two wanted a somewhat more advanced course. And of course they had two different requirements. Since Frieman's husband was a physicist, she wanted a course that had nothing to do with application; she wanted something pure. And since Bamsie had a father who was a physicist, she was very much in love with physics. Well, it was easy to give them a course in linear algebra, which fills both of those bills, depending on your point of view. You can do it in a pure way or you can be very applied and geometric. Anyhow, that was a lot of fun, teaching those two. They were two very, very smart women.

Ed Frieman's wife—it's unbelievable. I think she died in childbirth, giving birth to

twins. That was very sad. She was an extremely good-looking young girl, and extremely bright.

COHEN: How long were you at Sarah Lawrence?

KELLER: Just three years. Joseph Campbell was one of my colleagues there. He taught me how to curse in Sanskrit, things like that. There are so many nice memories of Sarah Lawrence College. But after three years, I was getting more and more wrapped up in research.

New and interesting things were happening at Courant's institute. One of the things was that through his maneuverings, Courant was able to get the Atomic Energy Commission to put a UNIVAC at NYU. This was maybe the third UNIVAC ever made. He had connections with the head of the AEC, and we got this computer. So therefore someone had to start looking into what you do with a computer. The term "programmer" maybe hadn't even been invented yet; but five of us decided to study how you use these machines—not study it, because there was nothing to study, they were so new. So five of us turned ourselves into scientific programmers, and it was full-time. I had to give up Sarah Lawrence. That was in 1953.

COHEN: So you were really on the ground floor of this stuff?

KELLER: Well, yes. And one of the reasons, I think, is because I had been working quite a bit with my brother in wave propagation. But he was very well established and I realized that it was probably not a good idea to tag along with Joe. I thought I should be doing something quite different from what Joe was doing. And besides, I was very interested in computing and numerical things, although I'd never taken a course in numerical analysis. There weren't many places where you *could* take a course in numerical analysis.

But Courant, of course, was very interested in numerical things. Many people consider him the real founder of the finite-element method, even though he didn't push it that much. But he did, in 1942, write a very influential paper.

In the Courant tradition, and maybe even in mathematics, the tradition is that talent is handed down from father to son-in-law. Courant was the son-in-law of Carl Runge, a very famous numerical guy. His second wife was Runge's daughter, Nina. She lived until a couple of years ago, something like that. And Courant's son-in-law is Jürgen Moser. His other son-in-

law is the mathematician Jerome Berkowitz. So it's from father to son-in-law. And now, of course, Moser has two daughters. But we'll see. [Laughter]

I remember that Joe and I one summer went cycling in Europe—we didn't go to go cycling; we went to visit Europe. We'd never been to Europe. This was 1948—so I'm jumping back a ways. In 1948, Joe and I went to spend four and a half months in Europe. It turns out that we had a long lost French cousin who had resurfaced, so he helped us. And one of the things he suggested was to get some bikes and cycle; so we did that. Of course, it was hard to get bicycles in Europe in 1948. But we did, and Joe and I cycled all over Europe—from Trieste, through North Africa, to Copenhagen. We did that by bike—of course crossing the Mediterranean we went by air.

We had an appointment to meet Courant in Switzerland; we knew when he would be in Zurich. So we managed to be at the ETH [Eidgenössische Technische Hochschule] in Zurich when Courant was there. And that was rather fantastic, because we got there when the physics seminar was taking place. So Joe and I were able to go to this famous seminar, and Courant introduced us to all kinds of physicists, including Pauli. That was impressive, meeting Courant there.

COHEN: I can see that Courant was one of the really dominant figures in your life.

KELLER: Oh, yes. And the people at the Courant Institute—Courant and Friedrichs. K. O. Friedrichs—many people think he was the strongest analyst of this century.

COHEN: Five months on bicycles! But then there weren't many cars on the road.

KELLER: That's true, and especially in Europe in those days. But the dollar went a long way, so just because we were on bicycles didn't mean we didn't live well. For a few bucks we could stay in the fanciest hotel in town and eat well. And we had a good time. And you could really see the scenery that way, too.

COHEN: Let's come back to the computer.

KELLER: Yes. As I said, there were four or five of us who were turning ourselves into

programmers. Of course, we had a lot of contact with people from Los Alamos because this was an AEC computer. In fact, it was kept behind armed guards—the only time I've ever seen armed guards at a university. But it was an Atomic Energy Commission facility and there was a lot of classified weapons work going on there.

Therefore, Bob Richtmyer spent a lot of time there; he was one of the key guys with [John] von Neumann at Los Alamos. And as a matter of fact, Richtmyer, after spending a couple of years being the main rep from Los Alamos, changed from physics to mathematics; and he became a faculty member at the Courant Institute. So I had quite a bit to do with Bob.

I guess the first big project I was involved in was a weapons effects project for the air force. The object was to work on the problem of shooting down enemy missiles. We had two consultants for that project; one was Edward Teller and the other was Hans Bethe. That was my first introduction to real high-level projects research. Those problems are rather messy, and we had a whole staff of mathematicians, physicists, and numerical people working on it.

COHEN: How long were you involved with this?

KELLER: Well, I was involved with that project from beginning to end because I was its director. But the point is, we learned in the course of our work that this was not a project; this required a whole laboratory of its own. And that was our recommendation to the air force. And in fact they then developed Kirtland Air Force Base as one of the main places for research in weapons effects. They had thought that weapons effects was something you could do by giving out a few contracts, but it was a lot more complicated.

COHEN: So you did a lot of traveling in those days?

KELLER: Well, I stayed at Los Alamos for several months. And it was my introduction to computational fluid dynamics, which has stayed with me for quite some time. There were other things going on at NYU that I had also been involved in before that time, which were also related to the military—all these radar and wave propagation things.

I guess I really got interested in developing numerical methods from the difficult problems we had in this weapons-effects work—problems that have to do with shocks and

hydrodynamic motions in media that are moving, where relativistic speeds can't be neglected anymore. And of course the only way we were allowed to talk to people about it was to talk about exploding stars, because you weren't allowed to talk about weapons. I didn't learn anything about astrophysics, really—I guess I should have—but we were dealing with similar kinds of phenomena.

COHEN: If you talked to Bethe about it—

KELLER: Oh well, he knew all about it; he invented a lot of it. That was all very exciting. I must say we spent a lot more time with Teller than with Bethe, however.

COHEN: He's supposed to be a very kind man.

KELLER: Teller? Oh, yes. He was very friendly, very kind. As a matter of fact, I remember once when Bob Richtmyer and I were flying out to meet with Teller at Livermore, or San Francisco. And we heard on the plane that Edward Teller had just come out in favor of Eisenhower. And we were fit to be tied because we were both big Stevenson fans. And at the meeting there was also a physicist from the RAND Corporation who was very anti-Eisenhower and pro-Stevenson—either Dick or Al Latter, who are brother physicists. And the two of them got into very bitter arguments—Teller and one of the Latter brothers. The interesting thing is that two years later Teller and this guy wrote a book together on weapons effects. [Laughter]

**HERBERT B. KELLER****SESSION 2****June 13, 1996****Begin Tape 2, Side 1**

COHEN: I think we'll proceed with your association with Caltech—when that began and when you decided to come here.

KELLER: That's quite interesting, because I made a false start here first. I was invited in 1960 by Professor [Gilbert] McCann, who was at that time in charge of what they called not computer science but information science. McCann preferred to call it information science. And he had a small group, including Joel Franklin, who was a mathematician who had spent his first postdoctoral period at the Courant Institute, where I was a professor—it wasn't called the Courant Institute at that time. [Ed. note: It became the Courant Institute of Mathematical Sciences in 1958.] It was the Institute for Mathematics and Mechanics. So Joel and I had become acquainted back then. As a matter of fact, Joel's first paper was written jointly with me, so we go back a long way.

But anyhow, Joel I guess mentioned to McCann that I was a numerical analyst and he thought it would be good to get me here. And so McCann invited me to come to Caltech with the possibility of joining his group. Of course, in my field, which was applied mathematics, and particularly numerical analysis, Caltech was really very inactive then. And the salary level at Caltech was atrocious, and McCann realized that. I told him right off the bat. We had talked about what possibly might interest me.

I also wasn't too interested in his view of the field and the plans he had for the future. So it was really not attractive to me at all. I was very happy at Courant. I had a very responsible position. But Caltech is a well-known place, and I had never been here before. So I came out to see what it was like.

McCann asked me not to say "No" offhand—to please wait until I got a letter from [Caltech president Lee] DuBridge inviting me, and then tell DuBridge the reasons. Because McCann felt—and I think he was right—that the administration wasn't aware of certain of

Caltech's failings. And if they tried to get somebody who had some reputation in the field, and that person told them in a letter why he was refusing—McCann asked me if I wouldn't please do that, and indeed, I did do it. I got a very nice offer from Lee DuBridge—from Caltech, that is, but it's a letter from Lee. And in response I told him that it was just out of the question, given what their salary scale was and the fact that I was essentially in the best place in the world for my area. That offer was not a very sensible offer—all of which was true—and I had known it all along; but I had to make the point.

COHEN: Did you get an answer to that?

KELLER: I don't recall if I did or not. Well, I got a nice response from Gilbert McCann, who thanked me. And it would be nice to think that I helped get Caltech salaries raised. Probably I had nothing to do with it, but they did eventually meet the competition. [Laughter]

COHEN: When you came out in 1960, how did you find the place? Was it very attractive to you, given the difference from New York?

KELLER: Oh, well, yes. It was quite nice. I liked everything about it. And there were so many people I met here that I'd heard about, so it was a very attractive place. But given my interest in applied mathematics, at that time at Caltech there was relatively little activity of significance.

Well, maybe three or four years later, I got a letter from Gerry Whitham, who had also been a colleague of mine at Courant's institute. He was an associate professor there for two or three years, then he left and went to MIT for another couple of years, and then he migrated to Caltech. He was not here in 1960—he came here a year later. And he knew I had been here, and he knew that I had rejected the offer from McCann. In his letter, he said, "This has nothing to do with your previous encounter with Caltech. It's a completely different thing we're trying to start up. It's a group in applied mathematics." Why didn't I come out for a year and take a look—or even come permanently.

Well, I was too committed that next year, so I could not do that. But I said, "How about the year after?" Gerry said fine. So we made plans for me to come back to Caltech in '65 and I came for the year in '65. Of course, the people at NYU knew where I was going and they knew

Gerry was here. And [James J.] Stoker, who was then running the institute, said, “Ah, Whitham should be *here!*” [Laughter] “But go and see,” he said.

So I came to Caltech in '65.

COHEN: Did you have a family already?

KELLER: I had a family with two little children. And we rented a lovely home in Sierra Madre. And it was wonderful, it was tremendous. I really enjoyed it.

I guess I taught a course here. We had the beginnings of the applied math group. Whitham. [Philip] Saffman had just come; Julian Cole had been here before. I guess Don Cohen had just come at that time. And it was a very nice, small group. I think the program in applied mathematics was just about to begin.

COHEN: Wasn't that in the engineering division?

KELLER: No, at that time it was joint, very much joint, between PMA—physics, math, and astronomy—and engineering and applied science. It was a joint program. I think some of the funds for starting this program might have even come from the Ford Foundation—that the math department had gotten some money to help start such a program.

In any event, during that year, I became an even greater friend of my friends from the Courant Institute. And I had many visitors, including Courant himself, who came and spent a couple of days with me. And Jim Stoker came and spent a few days with me. And Peter Lax. And all these people made it clear how indispensable I was back at the Courant Institute.

COHEN: It's nice to be loved.

KELLER: Well, it *is* nice to be loved. And as a matter of fact, I was so impressed by all these guys coming out and telling me how much I was needed—I guess at that time I was the associate director of something called the Atomic Energy Commission Computation and Applied Mathematics Center. Peter Lax was the director, and I was the associate director. And that was rather a big deal, because it was a big center.

Anyhow, toward the end of that academic year, I decided I was going to go back. There

was much chagrin. Loretta, my wife at the time, was very disappointed; she loved it here. [Laughter] And all my friends were disappointed. And I went and I chatted with [Caltech provost] Bob Bacher, and I told him the reasons I was going back. And Bob said to me, “OK, Herb, but I don’t consider this as the end of it. I’ll be in touch with you.” I said, “Well, thanks a lot, Bob.”

Anyhow, we went back. And after about four months and beating some of the traffic up the West Side of Manhattan [Laughter] . . . . And it’s true that the Courant Institute had all these tremendous guys there, but day to day you did not see them or work with them. And I began remembering Caltech fondly. I came home one Friday evening, I remember, and I said to Loretta, “You know, maybe we made a mistake coming back here.” She said to me, “We made a mistake? I wanted to stay.” So I said, “Well, let’s talk about it.” She said, “No. I came back. I’m readjusting.” And then the phone rang.

It was Bob Bacher on the phone. Preordained. I said to him, “Bob, that’s amazing that you call now, because Loretta and I were just talking about Caltech.” And he said, “Well, don’t say another word, Herb, until you hear what I have to say.” And he renewed the offer to come to Caltech—in fact, refreshed it and made it even better. Somehow, everything was even nicer. And of course, I don’t know how to do those negotiations; that was not why I went back or anything like that. Anyhow, I was sort of gushing at the end of that conversation. I sounded very positive to Bob. He said, “No, no. Talk it over; get back to me in a couple of days.” And here I am. [Laughter]

So I came in ’67, then—in ’65 I was here as a visitor; I went back in ’66 to NYU; and I came here in ’67. And I’ve never had the slightest doubt that that was the right thing to do; I’ve enjoyed it very much. The applied math group was going—Whitham and Julian Cole and Saffman, and that’s the real nucleus of a group—and I joined them.

COHEN: Did you have anything to do with Gilbert McCann, then, when you came back?

KELLER: No, I had nothing to do with him. I mean, we were friendly and so on, but it was a completely different operation, much more to my liking. And I’ve never had any regrets, and I think we built a wonderful group. Whitham was clearly the driving force behind it all; and he was a great director. His judgment of people was superb. He never wanted to build too large a

group, which is maybe also a good thing. But he ran applied mathematics; he was the executive officer for maybe ten years [Ed. note: 1971-1980].

COHEN: Did you have anything to do with the mathematicians?

KELLER: Well, yes we did because we were joint. Myself, Whitham, and I guess Cohen at that time, were joint in both divisions, so we used to attend meetings in mathematics as well as applied mathematics. As a matter of fact, maybe my second year here I even taught sophomore calculus, which was perhaps a disaster, because I had not taught an undergraduate course in many years. But I managed to survive. So I was actually teaching a course given by the pure math group.

COHEN: Did you have anything to do with Jack Todd in these years?

KELLER: Yes, I did. Jack, of course, was a numerical analyst, and he was the numerical analyst who had been here all along. And Jack had trained an amazing number of very bright students who eventually turned to numerical analysis and are very well known. But of course there was no graduate program in numerical analysis—Jack couldn't do it all by himself—and I think the attitude of the mathematics department at that time was not to support numerical analysis. But he was a superb teacher of these young kids, and he got very many of them interested in it; and they went on to graduate school elsewhere. And many numerical analysts who have made a big mark were turned on to it by Jack Todd in the mathematics department. In applied mathematics, as a matter of fact, we never seriously taught undergraduates.

COHEN: That was strictly a graduate option?

KELLER: Well, it was until our friends in engineering came to us at one time and said, "Look, we have this course of mathematics for engineers and we're not particularly happy with it. Why don't you guys in applied mathematics take it over and teach it and maybe you'll do a much better job." We said we would, under one condition—that we do it our way, and we will give a good basic training in the mathematics that engineers and applied people need, and we'll call it Introduction to Applied Mathematics. They said okay, and so we took over that course. I forget

what it had been called or numbered then, but it became Applied Mathematics 95—AMA 95. And by now it's a tradition for the undergraduates to bitch about it. But they loved it, and they voted with their feet. And I think it's become at times the second largest undergraduate course.

COHEN: Have you continued to teach it?

KELLER: Oh, yes. It gets about 180 students each year. About ninety of them from engineering are required to take it, and the rest have heard that it's a good course. And we take that course very seriously, so our most senior people always teach it. When I became executive officer [Ed. note: 1980-1985], the course was such a chore that I thought it should be shared between two faculty members—let two of our senior faculty teach it each year; however they wanted to divide it was up to them. And what they usually do is split it in half, right down the middle—one and a half quarters.

COHEN: Is it just a lecture course?

KELLER: Well, there's recitation. We have maybe ten TAs. But when you teach that course, you cannot do much else; it's really a time-consuming course. Over the years we have, almost from the beginning, sought outside help. So people from various areas—usually engineering—have helped us teach that course. This year—I think for the first time—it was taught by two people neither of whom were in applied mathematics; one was in aero, one was in geophysics—David Stevenson and Dale Pullin. And as a matter of fact, for his teaching of AMA 95, David got the good teacher award.

Well, eventually McCann came to Whitham and me and said, "Look, you guys have this applied mathematics thing going on; you have some numerical analysis, and so on. I think Joel Franklin would probably be more at home with your group than with mine." So Joel eventually joined the applied mathematics group. He was already tenured at that time; he had been with McCann's group in information science, but he was sort of out of place there. And it was a pleasure for us to have Joel join us. Over the course of the years, we've had a number of young and very effective professors in numerical analysis helping. That became one of the core areas of our applied mathematics group. Of course, nonlinear waves and fluid dynamics was from the

beginning one of the basic things. And perturbation theory—Julian Cole was one of the stalwarts of perturbation theory. Whitham in nonlinear waves, and Saffman in fluids.

COHEN: And are younger people joining you now?

KELLER: Well, that's a big jump now, because my estimate is that by the year 2000, Whitham, Saffman, and I will be gone. And that means it will be of a completely different complexion than it was.

COHEN: You've had a long run.

KELLER: We *have* had a long run. In that interim period, I was saying, I got a lot of young people here, and I was also able to induce Heinz Kreiss to come here [Ed. note: 1978]. He had just been given a tenured position at the Courant Institute, but I invited him out here, and he loved it. So he came to Caltech, and he was with us for maybe eight or nine years.

COHEN: Now this is a long period of time, of course. I have here something about the early development of computer science at Caltech. How much did you have to do with that?

KELLER: Well, that's very interesting because as I say, when McCann had information science here, that was really the beginning of it. McCann was an engineer who had done tremendous things in analog computing devices, and he was just beginning to get out into the digital field. But there were a number of bizarre things going on here. There was a company in town [Ed. note: Burroughs] that made digital computers. And we had here in physics a postdoc, or an associate, who turned out to be a very good designer of computers and also did a lot of work in numerical analysis. He's a very well-known figure whose name is known to all early computer science people and early numerical analysts. The story I always heard was that Bob Bacher didn't like him because he dressed like a pig and used to go out for two-hour lunches. But the guy was tremendous. Yet he never built any group here.

Perhaps the most striking thing is that Don Knuth was a student here of Marshall Hall's. He got his degree at Caltech. And many people think of Don Knuth as the father of scientific programming. When I was here in '65, he loaned me four huge volumes of a text he was

writing—which was his well-known book [Ed. note: *The Art of Computer Programming* (1968)]. He has a series of four volumes on computer programming. And I guess we all knew that Don Knuth was a tremendous figure in that field. But he left Caltech in 1968 to go to Stanford, where he helped them establish their computer science thing.

I remember having meetings here when I first came, trying to get a program started in computing science. I'm not sure whether it was '67 or '65—it must have been when I came permanently. We had a little committee that consisted of McCann, myself, perhaps Franklin, Don Knuth, and maybe one other fellow, Fred Thompson—he just retired from computer science, in 1993—to try to plan this program: what to teach and what courses should be given. And there was a great disparity of views about what that program should be. Don Knuth and I always saw eye to eye with each other, but McCann and Thompson, and maybe to a lesser extent Joel, didn't agree about what should be given, so that got nowhere. It was about that time that Knuth received the offer from Stanford. It was a very good offer from them. And we immediately offered him tenure, and maybe even promoted him to full professor, with a lot of grumbling from the people in pure mathematics. He was at that time in pure mathematics, in combinatorics, because that's one of the fields that Marshall Hall specialized in. And that's what Don Knuth was trained in—group theory and combinatorics, which is a very important area; nowadays we talk about complexity theory, and combinatorics verges on that; it's a big theoretical area in computer science—and Knuth was one of the leaders. But he left. And Caltech for a long time had this history of just missing the boat in computer science.

But finally they got their act together. You know, we've had tremendous people here, and still do. Carver Mead can be accused of being a computer scientist just as well as he can be accused of being an electrical engineer or an applied physicist, or any of a dozen other things. Carver was a very strong force here. And somewhere along the line, we got Ivan Sutherland here [Ed. note: 1976], and that was a great thing. And Chuck [Charles L.] Seitz is tremendous. As a matter of fact, before they got their act together, somehow I was chairman of the search committee for computer science. I think I was compromise choice, because perhaps Carver and Chuck had trouble agreeing. So they could use some leavening. And since I was quite friendly with both of them and got along well with both of them, I mistakenly agreed to be chairman of the search committee.

COHEN: And this was to find a director for computer science?

KELLER: Well, they knew they needed several appointments in computer science. It was to get faculty as well as some senior person who could help run the thing.

COHEN: When was this?

KELLER: It must have been the late seventies. I don't remember the details but I do remember working hard. We had a lot of people go through the place. I remember quitting that job in a huff because we had a lot of people pass through. And we had one very good guy from La Jolla; I forget his name but he was a theoretical computer scientist. I thought he was pretty good. And Chuck and Carver more or less agreed and said okay, let's make the case. And so I went and did all the paperwork and got it all together. And maybe the next day we were going to make a presentation to the IAC [Institute Administrative Council] when Chuck and Carver came over to see me. I realized something was up. And apparently the two of them had gotten together and agreed that they didn't want this appointment. And I said, "Okay, I quit." Those guys wanted the thing run their way, and I was an outsider. This guy was quite mathematical, and they weren't interested in theoretical computer science of that kind. I think they did the right thing. They came to me. And there was never any hard feelings or rancor over it. But that got me out of a job I shouldn't have been in in the first place, because I'm not a pro in that business.

At about that time, Ivan Sutherland appeared on the scene [1976]. Ivan joined, and he immediately was able to get things going fairly well. It's a shame he didn't stay longer. [Ed. note: Sutherland left in 1981.]

COHEN: Where did he go?

KELLER: Oh, he went up to Rochester, or something like that, with an ex-student of his and he started some business. He was a great entrepreneur. He had started Evans & Sutherland when he was at the University of Utah, at Salt Lake City. That was maybe the main place in the world for computer graphics as a result of Ivan and his crew there. And they've always retained strength there. Ivan Sutherland brought Jim Kajiya to Caltech, and some other people.

I remember one of the things that maybe led to his leaving was the fact that he wanted us to get a very famous guy at Carnegie-Mellon who had visited here as a Fairchild Scholar. I forget his name. He was a very well-known computer scientist who was confined to a wheelchair at that time. So he was aging a bit, and it's true that he was perhaps over the hill, but he still had a lot of good life left in him, and he was also well known. And that helps get a place going—when you have two or three people with reputations at the same place. So somehow we made the case—I guess everyone agreed, Chuck and Ivan and Carver even agreed—that we should try and get this guy. And that's when [Robert] Christy was the acting president. And the story, the way we more or less got it, was that Christy's son killed the deal. [Laughter] Christy's son was a programmer. In fact, he's now one of the principals, or has been one of the principals, in one of these smaller computer manufacturing firms. He's a very good computer scientist. And I don't know where we got this story from—that Christy's son said, “No, Bob, he's over the hill,” or something like that.

COHEN: So that didn't work either?

KELLER: No, that didn't work. But our computer science group here somehow has always had a stormy time of it—recently, perhaps, more than ever. We finally got [Kianithra] Mani Chandy here [Ed. note: 1988], while Chuck was still here, and everything seemed to be going really quite well. And then Chuck left two years ago to form his own company.

COHEN: Maybe that's the nature of computing. It's a field that changes so rapidly.

KELLER: Well, it does change rapidly. Our students here at Caltech just gobble it up; they love it. And if we had a bigger, stronger computer science department, the students could do even better. But the department has always tried to be very selective in their students, and they have held it down. They didn't want the thing to explode and mushroom. Still, I think more students coming here—undergraduates—say they're interested in computer science than in anything else.

Of course, I'm talking more about computer science than I am about applied mathematics. I know something about computer science, but I know even more about applied mathematics.

COHEN: So let's talk about applied mathematics.

KELLER: Well, that program really took off quite well. We got very good students, and that was tremendous. I mean, the fact that at Caltech you can attract good students makes a tremendous difference. The Courant Institute also got good students, but there we're talking hundreds. We had literally hundreds of students in mathematics at the Courant Institute, and so, naturally, to get ten good ones is no big deal out of hundreds, especially when you have such a very good faculty as they had. But at Caltech we've always had a small number of students, and a large number of them were really very good. That makes your job as a faculty member much more enjoyable.

COHEN: So you could be more selective then?

KELLER: We were very selective and we turned out a lot of very good students. We always had a small number. I don't think we ever had more than twenty-five students in the graduate option at any one time. I think maybe now we're close to our maximum again. But it started slowly, and I think we've always had a very good record for turning out good students. They've gone on to make good reputations.

COHEN: Do you have any personal feelings about any you've worked with?

KELLER: Oh, I have a number of them. I've lost contact with many of them. Well, I guess one of the nicest things I remember is receiving a card in the mail, "Congratulations, you've just become a grandfather." And I knew this wasn't literally true; but Jim Keener, who is maybe my second student from here, had just produced his first PhD student, so he sent me this grandfather card.

COHEN: What is your feeling now? Do you think the department is going in the right direction?

KELLER: [Laughter] The good old days are always better. I'm not sure that we are going in the right direction. As a matter of fact, it's not clear that they think in terms of the right direction. And as a matter of fact, from the word go we were always a small group, and therefore thinking

in terms of direction wasn't the right way to look at it. It wasn't a question of getting three or four faculty to cover an area or dominate in that area. You had to do your own thing. But therefore, in selecting new faculty, we tried to get people who overlapped, at least on the fringes, with us—although we've always tried to get somebody in applied probability and never succeeded. And to this day, I think that's true. We've made do. Whitham taught a course in stochastics, and then Joel Franklin eventually started teaching that course, too. But we never had professionals do it. I must say that Whitham's course in that area was tremendous.

COHEN: Now does this have anything to do with your relationship with the mathematics department as such?

KELLER: No, I'm afraid we never cooperated with the mathematics department. I don't know why that was. I don't think Marshall Hall had much use for an applied math group, and he was the director for a long time. So we tolerated each other. I think some of Whitham's old words of wisdom are relevant here.

I remember that Whitham and I and Kreiss used to go to the faculty meetings of mathematics. And they'd discuss how they thought things should be done. And then eventually a vote would be taken. And as Whitham put it, the vote was always 3 to 1 to 1 to 1 to 1. [Laughter] In other words, the math people could never agree, and the three of us always had the same opinion. Not that we planned it that way but we just always came down on the same side of an issue.

COHEN: So really the problem was in mathematics?

KELLER: Well, that's what we say; but I don't know what the problem was. Besides, right now I think our mathematics department is as strong as it's ever been. We've always had a very good pure mathematics group. They were a bunch of individuals; and now there's a bunch of young people in very hot areas doing great things. They're very nervous right now because they need one or two more just to get over the hump. And they may even be right. But I feel that the provost isn't quite convinced of that now.

One of the problems with pure mathematics is that it's not as easy for them to interact

with and relate to the rest of the faculty. Pure mathematics is in a certain sense very narrow, because the motivation for doing it doesn't come from interacting with other people and other fields. There are connections; and frequently it ends up being very useful, and many pure mathematicians even get stimulation from those fields. But it's less likely that they will work closely with physicists, and so on. They're loners; it's the nature of it. And therefore, you don't get a lot of positive vibes from the rest of the campus like, "Hey, they need some more people." So it's hard for them to grow, but it happens. And they are doing very well now. As a matter of fact, some of them work very closely in these areas that are important in current physics—string theory, and so on—because it's very abstract. It relies a lot on low-dimensional topology, where we happen to be very strong right now.

In applied mathematics, we've always worked very closely with our colleagues in many areas—but the most, of course, with aero. I think it's fair to say that applied mathematics really grew out of aerodynamics here at Caltech. It's not that it sprouted from the minds of mathematics and so on, as some of the math people would like to think. But [Theodore] von Kármán, who was really responsible for strengthening aero, always had a few tame mathematicians working for him—because he, indeed, was a very good applied mathematician himself. And he had Paco Lagerstrom, who was trained in topology at Princeton. Paco did perturbation theory and other things.

Then [Clark] Millikan took over aero, and then [Hans] Liepmann took over from him. And I think it was while Liepmann was running aero that he got Whitham here; and I think he got Saffman here.

COHEN: Saffman has a joint appointment?

KELLER: Well, he does now. He's Kármán Professor of Applied Mathematics and Aeronautics, which is most appropriate.

But we always had very close ties with aero and did joint work with them. In fact, we even sit in the Firestone Flight Sciences building. Firestone is an ex-aero building.

COHEN: And aero has always been a very strong group.

KELLER: Oh, yes, they're a tremendous group, and that's been a wonderful, close association—and it still goes on to this day with our new people and their new people. So that's something that I think will continue.

COHEN: Do you want to say anything about Caltech in general? Have you enjoyed being here?

KELLER: Oh, I've enjoyed it tremendously! The fact that it's small and good—and it's well known that it's hard to stay small and good. Once you're good, it's very easy to grow; and that's the thing you have to resist. And, of course, some of us have grumbled lately that we're growing too much. I think that's a thing to be aware of and to hold down.

COHEN: So you really think Caltech's strength is its smallness?

KELLER: Well, I was trained long ago, when I was at the Courant Institute and behaving like an administrator, by one of the better guys there who was the associate director, a fellow by the name of Eleazer Bromberg. He always used to say to me, "Herb, the main thing you have to worry about is success. Failure takes care of itself. But success is very difficult to cope with. You have to guard it very carefully and make sure you continue it." If you just trade in the obvious ways with success, you grow and you get too diffuse.

But Caltech has pretty much been able to resist that. Some of us, at times, think we're growing too much. We all realize that you don't want to grow too much, but I think it was never said as clearly as Bromberg said it to me.

COHEN: Do you feel that perhaps biology is going to get out of hand?

KELLER: Oh, no! I think they've been very clever. If you look at the way biology has worked it, maybe they teach one or... [Tape ends]

**Begin Tape 2, Side 2**

KELLER: But, of course, biology is so important nowadays that they cannot live in that pristine way anymore. Just as this past century has been the century of physics, the next one will be the century of biology.

COHEN: You've been here all these years, but you must have gone off on sabbaticals?

KELLER: Yes. It was maybe twelve years before I went on my first sabbatical. And I travel quite a bit. But I guess my first real sabbatical was in France. I spent a year in France—'79-'80. I remember it was a tremendous year, because I earned more money that year than I had ever earned in my life. [Laughter]

There was a combination of things. First of all, I was going to be gone for the whole year; and the usual arrangement with Caltech is that you get half salary if you're gone for the whole year. Since I knew I was going to lose half my salary, I put in for a Guggenheim Foundation grant and got it. And then you begin to negotiate with the Guggenheim people about how much you need. And I said to them, "Well, I'm only going on half salary, so I could use the other half of my salary." Of course, at Guggenheim that would have been a huge grant, and they didn't give those kinds of grants. But I got one of the largest grants they ever gave, which was a very nice sum—I forget how much it was.

I had intended to go to Oxford or Cambridge—I forget which. But my wife at that time, after speaking to some of her friends who had gone there, said no, she didn't like this idea of going to England. They didn't treat women very well; you couldn't dine at high table, and so forth. She said she didn't want to go to England. So I said, okay, how about Paris? She was willing.

And I used to go there quite regularly—I have a number of French colleagues. So [Jacques-Louis] Lions, who was the leader of applied mathematics in France, offered me a position at INRIA [Institut National de Recherche en d'Informatique et en Automatique], which was a huge government establishment that had a lot of computing and applied mathematics going on. It was headquartered in Versailles. So he offered me nine months there and mentioned some salary. I said fine.

And then I began getting letters from French colleagues, saying that they understood

from Lions that I would be in France for the year. Would I be interested in being a visiting professor at Paris-Orsay for two months. And they mentioned some very nice figure for two months. And I'd say, "Oh, well, I told Lions that I would go there for nine months, but if he's willing to spare me for two months, take your pick, and I'll certainly do it." And then I didn't hear anymore. This happened maybe with two other groups. Of course, I didn't realize that in France at the time, multiple dipping was the name of the game. So they never bothered to check with Lions because they knew that he wouldn't mind. After all, it only meant going out to their place two days a week for four weeks. So I probably had income from three different universities. When you added it all up, it was tremendous. I had a very good year.

Oh, New Year's! Our kids were going to school in the States at the time. But over Christmas and New Year's vacation we had each of them come to spend two weeks with us. And they overlapped one week, which was the New Year's week. So New Year's, the whole family was together. And I made reservations at a very fancy restaurant near Saint-Germain-des-Prés. We had reservations at ten o'clock, got there at 9:30. Wait a little while, wait a little while. Well, we kept waiting and waiting and waiting, until maybe 12:15, when they sit us down at the table and hand us menus. "Monsieur, the kitchen is fermé." "Well, what are we doing with all these menus for?" Well, they still have the seafood out front. So we ordered two huge platters of assorted seafood and a lot of wine and bread.

COHEN: Sounds good!

KELLER: Sounds good? With my kids being clever kids, anything that didn't look quite right they gave to the garbage disposal—namely, me. [Laughter] And six weeks to the day after that, I was in Australia—I had to go to Canberra for some lecture. And something hit me, like that! It was hepatitis.

So eventually I got back from Australia, back to Paris, where I lay in bed for a month or two, watching the Winter Olympics. It's pretty exciting to watch cross-country skiing on television because a Frenchman once won it. [Laughter] Anyhow, it was a good time in Paris, and the hepatitis cleared up in a year.

COHEN: Did you have any other sabbaticals?

KELLER: A few years ago, I finally went to Cambridge, England. Of course, I was single at the time. I was Distinguished Visiting Fellow at Christ College and a visitor at DAMTP—the Department of Applied Mathematics and Theoretical Physics.

COHEN: How long were you there?

KELLER: A whole year. It was great. That was in '93. But somewhere in between, I had another sabbatical that maybe I took here at Caltech. It's not a bad place, whether you're teaching or not. [Laughter]

COHEN: Is there anything particular outside of your math and computing? Have you been involved in anything else here at Caltech?

KELLER: Well, I've been involved in a lot of things at Caltech. But I guess my main activity around here is cycling. I discovered cycling about twelve years ago. I had recently become single again, and I wanted to put in a little more time with my kids. My son at that time was going to school at Davis. And if you've ever been to Davis, the whole place is on bicycles. And I remembered that years ago when my brother and I were in France, we also cycled. So I figured, Well, maybe I'll get a bike, and Steve and I will—I had been invited to Germany for a week at Oberwolfach and some other places. And I thought we would go there and then cycle down to Switzerland. That's when I began cycling. I went and I got a very nice bike. And Steve and I went to Oberwolfach. But I had cycled only for a few months then. I was too stupid even to have gotten a helmet. So I cycled without a helmet.

Oberwolfach is a wonderful little place in the Black Forest in Germany, where the German mathematicians have a little hideaway.

COHEN: Is that the place that Jack Todd was involved with?

KELLER: Oh, yes, he's one of the heroes of Oberwolfach. Anyway, it's a wonderful place. And you go there for a whole week, and it's really very nice.

They let me bring Steve. You're not supposed to bring visitors, but somehow they let me bring Steve. And the lectures stop at twelve for lunch and resume at four, so you have four hours

off. And Steve and I used to go cycling those four hours, and then come back, and I could take a quick shower and go to the lectures. We did that for five days. And then it got time to go, to head for Switzerland. But then the cycling was a bit different, because then you put your panniers on. And that's around thirty pounds of added weight. And it's very hilly there.

The first evening, it must have been five-thirty, six. I was really getting tired. We were heading toward a town. I said, "Okay, Steve, we'll stop there." We were coming down a very steep hill, with a T at the end of it. And Steve went to the right, and I was following; and I figured if he could make the turn, I could. But I couldn't. I was going too fast; and I went across the street, headfirst into a pile of lumber, and I really hurt myself. My poor son heard the crash, came back, and he saw the bloody mass lying there. Fortunately, a car came by almost immediately and the driver spoke English. He had a car phone, which was a miracle, and they called for help. A helicopter came and took me to Schwenningen, I guess. And I woke up a day or so later, very fortunate that I had no permanent damage.

I lay in bed for about a week or two. Of course, I claimed that the nurse had been trained in Dachau—they were very strict there. But finally after almost a week, I said to Steve, "Bring me my glasses and a book." I was beginning to get back into it. So he brought me my glasses; and I put them on, and I opened a book and I said, "Oh, damn!" I couldn't see a thing. And then I took off my glasses, fortunately, and no problem! I wore bifocals at that time, but the blow to the head had done something to the optic muscles or something, and now I could see perfectly well. I'd been wearing glasses for many years up to that time, but instantaneously I was fixed. And to this day—well, just a short while ago I started using reading glasses again, but no bifocals. It's amazing. And I've spoken to several ophthalmologists, and they all know of one or two cases where some severe stress to the body has resulted in almost instantaneous change in the eye.

That was the beginning of serious cycling, anyhow.

COHEN: And now you devote two days a week to it?

KELLER: Well, I would say five days a week. I don't *devote* five days a week, but I cycle five days a week. And in recent times, Ruth Mackin and I are a household together. And Ruth is a very serious rider. We started riding almost about the same time—she started a little before me.

And after she'd been cycling for a few years, one of the guys we ride with—Steve Lubanski, who runs Open Road Bike Shop here in town—said to Ruth, “You know, Ruth, you should compete; you could do pretty well.” She said, “What do you mean? At my age?” He said “Yes, yes, let me train you a bit.” Well, it turns out that Ruth now has many national records. So recently I've been starting to race again. Last year, I entered the Senior Olympics at Saint George, Utah, where they hold them every year. And I got three medals and a ribbon—two silvers and a bronze and a blue ribbon, or something like that.

COHEN: There are two more things I'd really like to ask you. When you think back, do any particular people stand out as being influential or inspirational in your work?

KELLER: Well, certainly Kurt Otto Friedrichs is a tremendous influence. He was the number two guy at the Courant Institute; he was perhaps really the academic leader. Courant was a wonderful guy at arranging science, and he was also pretty good. But his contributions to mathematics didn't hold a candle to those of Friedrichs. Friedrichs was one of the best analysts, I think, of this century. And we were all very much influenced by him at the Courant Institute, those of us who were there at the time.

Another one, a much younger version, was a guy by the name of Fritz John, also at the Courant Institute. Fritz John was extremely good. And he was much more involved in numerical analysis, I'd say, than Friedrichs was. Although there's a famous paper known as Courant-Friedrichs-Lewy, which was the beginnings of modern numerical analysis in partial differential equations; this was a famous paper written in 1928 by Courant and two of his students—Friedrichs and Lewy. Hans Lewy was a professor at Berkeley for many years—also a tremendous analyst and guy.

COHEN: And I can't help but feel, since you've mentioned him so often, your brother must have been an inspiration to you?

KELLER: Well, of course. Well, I guess I didn't look upon him as an inspiration—after all, he was my brother. [Laughter] Yes, we worked together in the beginning very much. Joe's one of the world's experts in wave propagation, so I started working in wave propagation with Joe. But

it soon became clear that Joe had a very firmly established reputation in this area; and it would not be wise for me. Maybe my first three, four papers were joint with Joe, and I didn't think that was a good idea. It was very fortunate that at that time, opportunity came along. The institute was getting this computer, and this was a completely new area. And Joe had not dabbled in that yet. Of course, now he's seeing the light, so I find that my brother's doing more and more numerical stuff with people. And that's just fine. [Laughter]

We swap postdocs quite a bit. I've sent a number of postdocs up to work with Joe, and now I have some of his working with me. And that's a very fortuitous thing because we've both had very good students.

COHEN: Aside from your cycling awards, you have had others?

KELLER: Yes, I was president of SIAM—I don't know if that's an award.

COHEN: What does SIAM stand for?

KELLER: Society for Industrial and Applied Mathematics. That's the main applied mathematics organization in this country now. So that was quite an honor.

And then just a couple of years ago, I received the Von Kármán Prize, which is a prize given by SIAM maybe once every five years for some combined work in applied mathematics. And it was great getting that, because the people who had gotten it before me were a rather nice, illustrious group—including my brother.

COHEN: Anything else?

KELLER: No, I think not. Oh, I've written a lot of papers and a couple of books and some monographs. One of my monographs was just recently reprinted; and they allowed me to put as appendices a bunch of maybe my most important papers in this area related to two-point boundary value problems, and so on. And that was put out by Dover at a very low price. So I've been tremendously pleased that this book, including maybe six, eight, ten of my papers, is available very inexpensively to kids.