Photo taken in July 2007

ANTHONY LEONARD
(b. 1938)

INTERVIEWED BY
HEIDI ASPATURIAN

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Subject area

Engineering and applied science

Abstract

An interview in four sessions, November 2012, with Anthony Leonard, Theodore von Kármán Professor of Aeronautics, emeritus, in the Graduate Aerospace Laboratories, Division of Engineering and Applied Science.

Dr. Leonard grew up in the Midwest and later moved to Ventura, California, with his family. He discusses his undergraduate years at Caltech, where he was active in athletics and majored in mechanical engineering, graduating in 1959. As a graduate student at Stanford (PhD 1963), he specialized in nuclear engineering, working with Joel Ferziger. In 1966, after three years at the RAND Corporation working on propulsion systems and fusion power, he returned to Stanford to teach nuclear engineering. He moved to NASA's Ames Research Center in 1973, working on computational fluid dynamics. In 1985, he joined Caltech's GALCIT as a professor of aeronautics, after a year there as a visiting professor. He became von Kármán Professor in 2000 and Professor emeritus in 2005.

In this interview, in addition to discussing his research, particularly on turbulence and vortices, and offering recollections of his GALCIT colleagues and students, he recalls his work on the Freshman Admissions Committee, the Administrative Committee on Supercomputers, the Academic Policies Committee, the Caltech Alumni Association, and the Caltech Y.

Administrative information

Access

The interview is unrestricted.

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Contact information

Archives, California Institute of Technology
Mail Code 015A-74
Pasadena, CA 91125
Phone: (626)395-2704 Fax: (626)395-4073
Email: archives@caltech.edu

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ORAL HISTORY PROJECT

INTERVIEW WITH ANTHONY LEONARD

BY HEIDI ASPATURIAN

PASADENA, CALIFORNIA

http://resolver.caltech.edu/CaltechOH:OH_Leonard_A

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CALIFORNIA INSTITUTE OF TECHNOLOGY ARCHIVES
ORAL HISTORY PROJECT

Interview with Anthony Leonard **by Heidi Aspaturian**

Pasadena, California

Session 1	**November 6, 2012**
Session 2	**November 9, 2012**
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ASPATURIAN: This is November 6, 2012—election day. And this is interview session number one with Professor Tony Leonard. I usually begin by asking about family background—where you were born and where your parents come from.

LEONARD: All right. I was born in Rock Island, Illinois, in 1938. My parents were both from Iowa, and they met at the University of Iowa. My mother was a creative writing and English major. She finished and got her degree. My dad was in engineering, but he didn't quite get a degree, because they got married and he wanted to get a job while he could still get one. So he worked for—I think it was—the Corps of Engineers that worried about flood control systems on the Mississippi River.

ASPATURIAN: Was this under FDR's New Deal?

LEONARD: Well, no, this would have been before FDR, but after the great crash. So anyway, when I was about a year old we moved to Davenport, Iowa, right across the river. Then we moved to Cincinnati after that. I think my father was still working for the Corps of Engineers. But he was inventing things on the side, and he came up with a miles-per-gallon meter for automobiles, and he sold the rights to produce it to some automotive company. Then he thought he could retire. By this time, I was probably in kindergarten or first grade. So, on the assumption that my dad had retired, we moved to my mother's father's farm in Columbus

Junction, in the eastern part of Iowa. My grandfather had a nice twenty-acre farm, and he raised all kinds of things on these twenty acres. This was very pleasant for me, to be on the farm. But then the money from the patent didn't really start coming in. So we moved to Webster Groves, Missouri—that's a suburb of St. Louis—and my dad started working again, I believe for the Corps of Engineers.

ASPATURIAN: How old were you at that time?

LEONARD: Probably the third grade.

ASPATURIAN: So you moved to Mark Twain country, basically?

LEONARD: Right.

ASPATURIAN: With all this movement throughout the Midwest, did you have frontier roots in your family?

LEONARD: Well, my father's parents came from Italy. In fact, my father's father's name was Leonarduzzi, but apparently, like many other immigrants, they kind of simplified the name. But my grandfather on my mother's side was born in Iowa. And my grandmother on that side was born in Wisconsin. She passed away when I was only one year old.

I enjoyed Webster Groves a lot. I eventually got into in a little classroom with three grades—fourth, fifth, and sixth—and I skipped a grade at that point, so I missed out on something, although I can't remember what it was. But my father had always wanted to go back to California.

ASPATURIAN: Had he been there?

LEONARD: He was a young lad with his family in Glendale, in the early 1920s. His parents owned a movie theater. But I think the big studios started buying up movie theaters and taking over the whole business, so my grandparents and my dad moved—to Des Moines, I think. But my dad remembered the fantastic weather of Glendale, and he had this vision of California being

so great. So he finally found a position at Port Hueneme with the U.S. Naval Civil Engineering Lab.

ASPATURIAN: That's near Oxnard?

LEONARD: Near Oxnard. He had to take a cut in grade, but he really wanted to come to California, so that's when we moved to Ventura. It was May of '51. I started the end of eighth grade at Ventura Junior High and also went there for ninth grade, and then Ventura Senior High was ten, eleven, and twelve.

ASPATURIAN: When did you realize that you were interested in, I would assume, mathematics, and also science?

LEONARD: I think I got more intrigued with math first. My dad and I would work on math problems, and they were always fun to do. I knew about the Pythagoras theorem when I was pretty young, and I kept trying to prove it, but I never did. The proof is really not too hard if you know how to do it. [Laughter] So I always enjoyed math. I don't know when the engineering part came along, but that's later.

ASPATURIAN: Would your father's positions and occupation have played a role in that?

LEONARD: It might have. Certainly when it came to suggesting colleges that I apply to, he's the one who came up with Caltech. So he obviously knew about Caltech. And I really didn't know much about it.

ASPATURIAN: Did you come down and take a look at it? You weren't far away.

LEONARD: No, I don't remember that we did. In high school, I was also editor of the newspaper, and that's when I met my wife-to-be. We dated the last half of senior year, and then she went off to the University of Colorado. We met up again later when I was in graduate school.

ASPATURIAN: You said your mother had a degree in creative writing. Is that where the editing-the-newspaper side comes from?

LEONARD: No, I think it was more that in ninth grade we had a really inspiring teacher named Betty Whiteman who taught English, but I took her class in journalism. I really enjoyed her as a teacher, and she ran the newspaper as a faculty member. So maybe that was it, I don't know. High school was very enjoyable. When we moved to California, everything in school was a lot easier than in Webster Groves, Missouri. Well, the schoolwork wasn't too hard in Webster Groves, but it was certainly easier in California.

ASPATURIAN: Coming from the Midwest, were you really struck by California when you first saw it? Was it quite a different environment?

LEONARD: I don't remember being that struck by it, although it was fun to see the ocean. I think when we drove out for the first time we came all the way out Route 66 and ended up at Santa Monica beach. I remember that—of course Ventura has nice beaches, too. So the classes were pretty easy, and I never had to do homework, really, so that was quite a shock, to come to Caltech. [Laughter]

ASPATURIAN: I'll bet.

LEONARD: I liked playing baseball, and I played in whatever league is after Little League.

ASPATURIAN: Junior League? No, Junior League is the society organization.

LEONARD: [Laughter] I don't know what it was called, but I enjoyed that. And I tried out for the high school team, but I was a senior and they already had an established infield, and I didn't quite make the team, so the coach said, "Why don't you try out for track?" I did, and I ran the quarter-mile for the high school team.

For college, I applied to Stanford, Berkeley, and Caltech. Stanford sent me a nice letter; Berkeley I never heard from. That's interesting. And as far as Caltech goes, Professor Hallett Smith, the English professor, who was head of the Humanities [later Humanities and Social

Sciences] Division then, came to our high school and interviewed us—there were three or four of us—so that was kind of impressive. So I decided to go to Caltech. And there we are.

ASPATURIAN: So you started in the fall of 1955?

LEONARD: Right. And I remember Frosh Camp for several reasons. One, it was in the mountains of San Bernardino, where I think they've been back to recently—I'm not sure.

ASPATURIAN: I believe that's right, after many years.

LEONARD: They were in Catalina for a while, and Ventura, actually.

ASPATURIAN: That's right. One or two years at Ventura.

LEONARD: I remember a talk by Dave Leeson, who was a sophomore in electrical engineering. He gave a talk around the campfire, and he said, "You know, when you're here, you should just try things and extend yourself and take advantage of everything." I thought about that a lot. So I decided to go out for football, which I'd never played. I played frosh football and got involved in frosh track.

ASPATURIAN: So you got involved in athletic activities here pretty early?

LEONARD: Yeah. I remember I took every Saturday off from studying, but then I made up for it Sunday, Monday, Tuesday, Wednesday, and so on.

ASPATURIAN: Do you recall what the environment was like here in the fifties? What were your impressions?

LEONARD: Well, I remember I started out in Section A—that was a group of fifteen or twenty of us—so everybody thought I was really smart.

ASPATURIAN: Would that be in math? Section A?

LEONARD: No, Section A was a group of students who went to every class together.

ASPATURIAN: I see.

LEONARD: So everybody thought I was really smart, but I knew that there was something funny about it, and it turned out that it was just a random selection; after the first term, they figured out who the smartest twenty kids were, and *they* got into Section A. [Laughter] It wasn't me. So, I don't know, everything was a lot harder than in high school, obviously. I had to live off campus the first quarter, because they didn't have enough room, and I went through a rotation and picked Ricketts House because they seemed like a nice bunch of people. Apparently it drifts around quite a bit over the years, but in those days Ricketts students were known as the politicians. They essentially ran for and won all the student offices. Fleming had most of the athletes.

ASPATURIAN: The jocks. Caltech jocks.

LEONARD: Dabney residents were the gentlemen, and Blackers were the nerds. That obviously changes. I don't know what the situation is now.

ASPATURIAN: So you lived off campus, though, for your first semester?

LEONARD: Yes. Apparently they thought—well, the reasoning is not too bad—that because I lived close, seventy, eighty miles away, I could come down and arrange my own housing, which I did. People from Boston couldn't do that, so they got preference, which is actually reasonable. But by the end of my first term, I moved into Ricketts House. I remember that Foster Strong was a professor of physics, and I think he was dean of freshmen. He came up with so-called Strong problems for physics, and they were really hard. In math I did OK. The professor was Richard Dean [professor of mathematics, emeritus]. I remember Linus Pauling [Nobel laureate, chemistry, 1954; Nobel laureate, peace, 1962, d. 1994] and his slide rule. He would give the chemistry lectures, and then he'd say, "OK, I need to calculate this ratio," and he'd get out this little tiny slide rule and he'd rattle out eight digits of accuracy. It was pretty funny.

ASPATURIAN: Who else did you take classes with?

LEONARD: Let's see. Later on, I had Paul Eaton [associate professor of English, d. 1975] for English. And I had Gerry [Gerald] Neugebauer [Millikan Professor of Physics, emeritus], who taught a physics lab—it might have been my sophomore year.

ASPATURIAN: Was he an undergraduate at the time?

LEONARD: He was a graduate assistant. This is before the Feynman lectures, so we had this really old textbook in physics [*Mechanics, Molecular Physics, Heat and Sound*] by Millikan, Roller, and Watson. And it was really an old one. I didn't like it very much.

ASPATURIAN: I suppose the content was pre-quantum mechanics, just classical stuff.

LEONARD: Exactly. In fact, I had a friend in physics and it wasn't until his senior year that he got quantum mechanics. It's amazing!

ASPATURIAN: It is, because one thinks of Caltech as in the vanguard.

LEONARD: [Laughter] I know. But that's what I remember.

Certainly the honor code was an amazing thing, and it seemed to work really well. I remember my favorite place to take a test was the second floor of Dabney Hall [of the Humanities]. There was a little classroom or conference room. Everybody had a master key, and people didn't seem to worry about it. Yeah, that was nice. You could have this whole room to yourself and say, "OK, I've got three hours to do this." The undergraduate houses were pretty much self-governed. They didn't need people to be on their backs very much. They had discipline problems, but they had these upper-class committeemen for each alley, and they would kind of keep an eye on people and make sure people were OK. And if things weren't OK, you got called into the RA's [resident associate's] room with the upper-class committeemen there, and they'd say, "How come you were doing this?" I don't think too much went all the way to the dean.

ASPATURIAN: It was an all-male campus in those days?

LEONARD: Right, except for maybe a few graduate students.

ASPATURIAN: I assume you took a lot of basic courses in math and physics to start. At what point did you begin to evolve in the direction of engineering?

LEONARD: In those days, your freshman-sophomore years were pretty well laid out for you. The major change came in the junior year, and I decided to go toward engineering.

ASPATURIAN: What prompted that?

LEONARD: Well, probably it was just that I was never really comfortable with physics, although later on I enjoyed physics a lot. But I had a hard time keeping up with the physics. A lot of my colleagues or classmates were just eager to get into physics—and, I don't know, that's when I went into engineering.

ASPATURIAN: You never considered chemistry or biology?

LEONARD: Well, biology was available, but only a handful of my classmates went into biology. Hardly anybody took advantage of that in those days. A lot of my good friends were engineers. I don't remember exactly what prompted that.

ASPATURIAN: But you did gravitate in that direction?

LEONARD: Right. My sophomore year, my grades suffered quite a bit, because I had a football injury that put me in the infirmary for three weeks in the fall. So that was hard on my grades.

ASPATURIAN: Did Caltech make an accommodation for you? I mean, you were injured playing football for the school.

LEONARD: Yeah, well, no. [Laughter] I just took the hits. I never flunked a class, but I got some pretty bad grades that quarter. But then my junior year, my grades went up quite a bit.

ASPATURIAN: Once you recovered?

LEONARD: Yeah. Part of it was that the really smart kids went into math and physics. [Laughter] That's part of it. It was highly competitive. I think the physics department didn't really want all these people, so they really put the screws to the kids. Really tough classes! So, during my Caltech junior year—this is kind of an interesting little story—my grades were getting much better. And in my early senior year or late junior year, Dean Paul Eaton called me into his office and said I was eligible for a scholarship. It turned out that there was a scholarship sponsored by a mortuary in Ventura—I can't think of the name of it now—and it was supposed to give preference to a Ventura-based student. And I'm sure that my former girlfriend's father had prompted this mortuary to pay attention and tell Caltech that they should look at the preferences there. So it seemed like Dean Eaton was resigned to the fact of giving me this scholarship.

ASPATURIAN: Mortuary scholarship.

LEONARD: Right. So that was for $1,000, which was pretty good. But Dean Eaton explained that he would only give me $500, because, since I was a senior, I was going to be out of school and working by the next year and so I didn't need the $1,000.

ASPATURIAN: I see. He made that executive decision. What did you think about engineering when you got into it?

LEONARD: Oh, I liked it.

ASPATURIAN: It must not have been unfamiliar to you, because of your upbringing and your dad.

LEONARD: Right, there's that. And I kind of got into the swing of things. I had one class where—I remember this very specifically—there was some problem about a flywheel that turns around and stores energy, and I couldn't quite come up with how to calculate in the way the professor wanted. But I said, "OK, I'm going to guess that such-and-such is true." So he actually thought that was really great, even though I didn't solve the problem his way. I thought, "Oh, that's nice! You use your common sense and you can get a reasonable answer."

ASPATURIAN: I often think there's a time in a young person's life when they get into a field of study or an activity and they think, "My brain goes *this* way." It sounds a little like that's what happened to you.

LEONARD: I think that's true.

ASPATURIAN: So who were your teachers?

LEONARD: Oh, Allan Acosta [Hayman Professor of Mechanical Engineering, emeritus]. I asked him to be my advisor, because I really had a nice relationship with him. He taught fluid mechanics. I still see him every once in a while. Rolf Sabersky [professor of mechanical engineering, emeritus] taught thermodynamics, and he was very good. There were a couple of textbooks by [George] Housner [Braun Professor of Engineering, emeritus; recipient, National Medal of Science, d. 2008] and [Donald] Hudson [professor of mechanical engineering, emeritus, d. 1999]. I don't think I ever had Housner, but I did have Don Hudson for a teacher. And I had Harold Wayland [professor of engineering and applied science, emeritus, d. 2000]. He had a nice math-for-engineers book that I still have and use every once in a while. And Carver Mead [Moore Professor of Engineering and Applied Science, emeritus; recipient, National Medal of Technology] actually taught us about transistors as a guest lecturer in our electrical engineering class.

ASPATURIAN: It must have been an exciting time to be an engineering student—all those developments in earthquake engineering, aeronautics, and electrical engineering. I don't know if at that time they were applying quantum theory to electrical engineering yet, but it must have been moving in some interesting directions.

LEONARD: Well, it was. Oh, and this brings me back to that Dave Leeson speech. I had a hole in my schedule and I remembered "I can try anything I want," so I took a class in geophysics from Frank Press, who was a very famous guy. [Press was subsequently science advisor to President Jimmy Carter and president of the U.S. National Academy of Sciences and chairman of the National Research Council, 1981-1993. –*Ed.*] That turned out to be a lot of fun. Mostly I had geophysics graduate students in class with me, but I managed to get through it. I think Press

appreciated the fact that here's this undergraduate engineer who'd wandered into his class. [Laughter] My senior year, I started taking this class in engineering design, but then I started reading about nuclear engineering and the fact that the Atomic Energy Commission gave fellowships. I thought, well, that might be something for me to go after as a graduate student. So I opted out of engineering design and went into a course on nuclear physics taught by Milton Plesset [professor of engineering science, emeritus, d. 1991]. It was actually nuclear physics in the engineering division. But it was a pretty good course. He was a pretty thorough guy. So I had a good time. And then I applied for a fellowship, and that's how I got into that business.

ASPATURIAN: I wanted to ask you about this quote I found in the 1959 *Big T*. [Quote from the 1959 Caltech yearbook, which was included in interview outline, reads as follows: "Not content with being about the nicest guy you'll ever met, Tony took off a little spare time to manage ASCIT athletic affairs, coach the cross-country teams, play three years of football, and run four seasons of track. In the process he earned the Goldsworthy track award and an honor key, as well as the undying gratitude of a multitude of classmates whom he carried through the Engineering Option. Nuclear engineering at Stanford is the next big step. . . . but it's a fair bet that he'd rather be down at Doheny, riding the waves with the boys."]

LEONARD: Yeah, I saw that. I don't remember that quote.

ASPATURIAN: Well—

LEONARD: That's fine. Let's talk about it.

ASPATURIAN: Let's start with some of your athletic activities and involvement. I did read where you lettered in what would be the 800—

LEONARD: In those days it was the 800 yards—half a mile.

ASPATURIAN: So tell me about athletics at Caltech.

LEONARD: When I was a freshman, I ran the half-mile, and I also ran the 100-yard dash, just because they needed people to fill in spots. But I was much better at middle distance than a sprint. I managed to do OK in the sprints. But the half-mile seemed to be the right distance for me, and I set a school record that lasted for a while, but then in the early 1970s a guy named Alan Kleinsasser really smashed that half-mile record. And it turned out that his sister was in the '84 Olympics for the U.S. A good friend of mine, Dick Van Kirk, was a year ahead of me; he was a long-jumper, and his record is still there.

ASPATURIAN: We wrote about him one year—I don't know if you remember—in [the Caltech alumni tabloid] *Caltech News*. He ran the Special Olympics program in Los Angeles.

LEONARD: OK, right. I still keep close contact with him.

ASPATURIAN: So did your athletic prowess raise your profile on campus?

LEONARD: I don't know. Just within the track team. [Laughter]

ASPATURIAN: They were proud of you.

LEONARD: I also played football. As I mentioned, I had this knee injury my sophomore year, and I injured my other knee in my junior year.

ASPATURIAN: What position were you playing?

LEONARD: Well, mostly end, but then I had to be a backup linebacker. I had hardly ever played that position, and I got hit from the side. But we had a very good team. Van Kirk was the quarterback.

ASPATURIAN: Your knee injury didn't curtail your track career?

LEONARD: No, it didn't. Later it came back, so I finally had a knee replacement, five years ago. But anyway, in my junior year the football team won four games, including Occidental

[College], and lost three. And then there was a serious flu that went through all of Southern California, and we only had seven games. It was a good team, but it wasn't thanks to me. [Laughter] Then, during my senior year in the fall, I was not able to play football because of my knee, so I became the cross-country coach to the freshmen and varsity teams.

ASPATURIAN: Was that an interesting experience?

LEONARD: It was fun, yeah. We had some really good cross-country people, especially on the frosh team, but they didn't last; they left Caltech.

ASPATURIAN: Did you learn something about mentoring, do you think, from that experience?

LEONARD: I think a little bit, yeah.

Oh, I remember something else I wanted to tell you about: summer jobs that I had during Caltech. I always enjoyed getting away from campus during the summer. I don't see how these SURF students do it. [The reference is to Caltech's Summer Undergraduate Research Fellowship program, most of whose students remain on campus for most of the summer. *–Ed.*] But it was good for me to just get away. After my freshman year, I had kind of a connection to the Point Mugu Missile Test Center, near Oxnard.

ASPATURIAN: How did that come about?

LEONARD: It turned out that my mother passed away when I was fourteen, and so my dad was seeing this very high-level administrative assistant at Point Mugu, and somehow I got a summer job there. It was a lot of fun, because they wanted to test the moment of inertia of a missile. The moment of inertia is kind of the equivalent of mass, except you're dealing with rotating devices. You want to know how fast a body will rotate if you put a torque on it. The moment of inertia is a key element of that. So they would attach a missile to a test thing that was a torsion bar, and then they'd twist it and let the bar do an oscillation and twist.

ASPATURIAN: Kind of a shimmy?

LEONARD: Yes. So the oscillation frequency of that twist would give the moment of inertia. But somehow I discovered—I had enough freshman physics to see it—that their formulas were wrong. I thought, "This is amazing!" So I wrote up a little page or two to say, "You know, you really should use this formula, not that formula." [Laughter]

ASPATURIAN: This was as a freshman?

LEONARD: I was a freshman, yeah. So that was kind of fun. [Laughter]

ASPATURIAN: I bet. And did they take your advice?

LEONARD: They were very happy that they fixed their formula. [Laughter] So then, in my sophomore year, Pacific Telephone was a heavy recruiter from Caltech, and they hired a lot of people from campus if they could. So I got a summer job in Ventura, which was nice, working for the local Pacific Telephone company headquarters. But instead of just giving me some dumb job, they had me be a trainee—three weeks here, three weeks there, three weeks somewhere else. It was kind of fun. I installed telephones for three weeks. I was in the central switching station for three weeks. And this and that.

ASPATURIAN: What an interesting summer-job trajectory. One summer you're preventing the military from screwing up their missile-inertia tests and the next one you're installing telephones and relay switches.

LEONARD: Of course, I'd get some of the dirty jobs. I'd go out with a crew, and they'd say, "OK, you get to crawl under the house." [Laughter]

ASPATURIAN: Did you get to go up the poles and hang the high wire?

LEONARD: Yeah, I got to go up the poles.

ASPATURIAN: You never worried about an errant shock or anything like that?

LEONARD: No. Those days were different, I guess. Now you'd be protected from yourself.

ASPATURIAN: Head to toe, probably.

LEONARD: But then my junior-year job was really neat, too. A number of us interviewed with Westinghouse Electric Company for a summer job in Baltimore, Maryland, and four of us managed to get these positions. We all showed up at their headquarters in Pittsburgh and got the briefing on what our job was about. Then the four of us went to Baltimore, where Westinghouse had a big facility at Friendship Airport. So we got to be engineers at this thing. We rented a little cabin near the Severn River. It was really nice, although it didn't have air conditioning. Dave Luenberger was one of my colleagues there, and Ron Forbess and Dick Baugh. Dave and I went to Stanford grad school, and Dave is still teaching there. Anyway, that was a great summer job.

ASPATURIAN: That was your junior year?

LEONARD: Right. Then, during my senior year, I got to know Milton Plesset pretty well.

ASPATURIAN: From the physics course he was teaching?

LEONARD: From the physics class. He knew I was going into nuclear engineering, and he managed to get a job for me at Atomics International, which was at that point a division of North American Aviation. Rocketdyne was another division. So I worked at Atomics International. Oh, no, no, I'm sorry, I'm off a year. OK, after my senior year, I finally had to have a knee operation. So I went to Huntington Hospital and had my knee operation, and then I joined four or five other Caltechers at a summer job with a small company right on Ventura Boulevard. Systems Laboratories Corporation

ASPATURIAN: Out in the Valley?

LEONARD: Yes. It was fun to be roommates with these Caltechers in the San Fernando Valley. Mike Milder [David Michael Milder, also of the class of ’59] was one of them. Another was Marty Tangora.

ASPATURIAN: What were you doing?

LEONARD: My boss wanted me to do some so-called maximum likelihood computations. So I had to learn how to program this funny little computer they had that used paper tape. You had to punch in the code on paper tape and then feed this paper tape into the computer. This is 1959. This computer would crunch all night long and finally come up with a few numbers.

ASPATURIAN: Was it a huge thing?

LEONARD: No. It was about the size of one of those glass things there [indicating an Archives Rare Book Room glass display case]. It was not huge, no. Not like the UNIVAC.

ASPATURIAN: So probably five feet by three-and-a-half?

LEONARD: Something like that. I wrote this fairly impressive report that I don’t remember a thing about. [Laughter] On noise effects, on radar systems. It doesn’t sound very mechanical.

ASPATURIAN: Well I suppose a Caltech background prepared you for a lot.

LEONARD: That’s what they tell us, and it turned out to be true.

ASPATURIAN: Was that your first experience working with a computer?

LEONARD: Yes, it was.

ASPATURIAN: And with programming?

LEONARD: Yes. But one other thing I remember is that at Caltech, money was always a little bit tight, even though the numbers in those days seem very small compared to what they are now. So I was a student waiter all the years I could be.

ASPATURIAN: Was that in the student houses?

LEONARD: In the houses, yes, not at the Athenaeum. Although some people did wait tables at the Ath. So I was a Ricketts House waiter, and I also tutored high-school students on the side. One of the people I tutored eventually ended up being Rose Queen, which was kind of fun.

ASPATURIAN: How did your girlfriend at Colorado feel about your tutoring the Rose Queen?

LEONARD: She and I had kind of separated. She didn't know or care, I guess—at that point. Then I worked at a little company called Wianko Engineering part-time in my senior year.

ASPATURIAN: It seems you kept your grades up, however, judging by your—

LEONARD: I did OK my junior and senior year.

ASPATURIAN: You got an honor key, as well as "the undying gratitude of a multitude of classmates whom he carried through the engineering option." I assume that wasn't just yearbook hyperbole.

LEONARD: I don't know who wrote that, but I had a few of my friends who needed a little extra help, and that's OK.

ASPATURIAN: And you decided to focus on mechanical engineering. Was there a particular reason you chose that?

LEONARD: No. I just liked the thermodynamics, and I liked Acosta's approach to things. Then I decided nuclear engineering is what I wanted to try next.

ASPATURIAN: It seems that you must have had a good time as a Caltech undergrad. I say that partially because you've gotten quite involved again with the campus as a faculty member here.

LEONARD: Right.

ASPATURIAN: So I can only assume that you felt a real sense of kinship with the community.

LEONARD: Oh, yes. I got into the Freshman Admissions Committee almost right away when I came in 1985.

ASPATURIAN: We'll talk about that when we get to it. I wondered if you have any other recollections of your time on campus as an undergraduate that you'd like to put on the record. Pranks?

LEONARD: I was never really part of any of the pranks. I remember that at one point some people from Ricketts were trying to rig the Occidental bonfire [a bonfire traditionally lit at Occidental College before the annual football game with Pomona College. –*Ed.*] to have it go off way before they wanted it to, and I can't remember if they were able to do that or not. When Ditch Day came for me as a senior, we just ditched school and went to the beach. There were some people who rigged their rooms.

ASPATURIAN: You didn't do that?

LEONARD: No.

ASPATURIAN: From the *Big T* write-up, it also sounds like you were a surfer.

LEONARD: Oh, yeah. A friend of mine in high school and I bought surfboards. We'd surf during high school. I was never really too good at it, but I kept my board, brought it to Caltech, and I did go to Doheny Beach, down near San Onofre, a few times, but that's a long drive. There weren't many good freeways then. But then I'd also surf during the summer when I was in

Ventura, especially the summer between my freshman and sophomore years. We'd surf—it's called County Line—just south of Santa Barbara County.

ASPATURIAN: It's beautiful up there.

LEONARD: There's a nice surf spot up there. But I never was very good at it.

ASPATURIAN: But you enjoyed it?

LEONARD: Yes. And at the end of my senior year, the Gnomes invited me to join them. That's a good group of people. I still hook up with them.

ASPATURIAN: Was that a "by invitation only" type of thing?

LEONARD: Yes.

ASPATURIAN: How did they make those selections?

LEONARD: I don't know. I've been on the Gnomes board recently, and I know that they ask the dean and the head of the Caltech Y and a few other people for the names of people who really stand out as good citizens and so forth. It's a nice idea—the idea that you just get together and have a good time. But you try to help Caltech in some way, too.

ASPATURIAN: Do you want to put in the record what the Gnomes are?

LEONARD: Sure. I'm sure there's a better way to express it, but they try to provide scholarships for Caltech students and to help the alumni if they see a need to do some function for Caltech. One of the things they work on is providing informal career counseling to Caltech students. A lawyer in the Gnomes, for example, would have lunch with students who want to be lawyers. Anything else in that quote you wanted to cover?

ASPATURIAN: Well, we've covered surfing, football, academic record. They also mention Stanford; I think that brings us up to that. You decided you were going to go to Stanford for graduate school in nuclear engineering?

LEONARD: Right. I also applied to Caltech. But I was kind of anxious to get away. It was really tough. And Stanford was something different.

ASPATURIAN: Did they offer you a fellowship?

LEONARD: Well, I got my own fellowship from the Atomic Energy Commission. I could probably have taken that to most places, because they were happy to get a free student. So I went up there, and I got a stipend plus tuition. But I was trying to save a little extra money, so my first year there I was a night clerk at a place called Escondido Village, which was housing for married graduate students. They needed people to take care of the emergencies at night. So there were four of us, and we got a free room. That was the deal—you'd get a free room, and every fourth night you had to be on call. If any emergency came up, you'd take the emergency call and call the right people to take care of the emergency. It was an easy deal to save on room expenses.

ASPATURIAN: Nuclear engineering in those days—what did that consist of? Building accelerators? Nuclear energy for peacetime use? Was it nuclear energy for the military? All of the above?

LEONARD: Yes. Probably in the late forties, when it first became apparent that there was such a thing, there were a lot of really wild speculations—like we'd have airplanes powered by nuclear energy—but then expectations gradually became more sensible. And certainly the nuclear power for submarines was really going full blast at that point. And central-station power was starting to really take hold.

ASPATURIAN: You mean the design of peacetime reactors?

LEONARD: Yes, domestic energy. There were few examples in existence in '59, but it looked like an up-and-coming thing. Stanford, led by a mechanical engineering professor, applied to the

Atomic Energy Commission to start a small research center, and they received funding to build a little research reactor. It was slightly away from campus in what used to be a high-voltage lab—just like we had a high-voltage lab at Caltech. In previous times, high voltage was a problem, I guess, and so Stanford had a separate building away from the main part of campus, and they put this reactor there. Just before I got there, they hired Thomas Connolly; he was a chemical engineer from UCLA. And they hired Rudy Sher, who was an experimental physicist from Brookhaven National Lab. He knew something about the nuclear physics. And they hired another fellow, who became my advisor, but he left the next year.

ASPATURIAN: It doesn't sound like he was part of your academic career for very long.

LEONARD: No, although it's an interesting side story. He came into the nuclear-engineering teaching business because he had taken a class from a very young guy who was a graduate student at [the University of] Michigan and who eventually came to Stanford and became my professor: Joel Ferziger. That was the situation.

So the first step is a master's degree. And I didn't quite like the requirements for mechanical engineering, so I found there was a way to get the classes I wanted. It was called a master's in engineering science. All you had to do was go see the dean and get a signature. So I did that. I knew from my Caltech days that you just have to go and find what you want. [Laughter]

ASPATURIAN: What was your thesis topic?

LEONARD: My thesis topic was energy-dependent neutron transport theory.

ASPATURIAN: And what was that relevant to?

LEONARD: It was relevant to finding the neutron densities in nuclear reactors, for example. Because to design a nuclear reactor, you have to know the power distribution in the reactor. But that's a very complicated thing, because it has all these fuel rods, and it has water acting as a coolant.

ASPATURIAN: Did you somehow—I know I'm putting this simply—need to know the neutron densities to be able to calibrate how the reactions took place?

LEONARD: That's correct.

ASPATURIAN: OK.

LEONARD: So the neutron density would then tell you about the power being produced at that location. But that power is also a source of new neutrons, so it's a big complicated feedback system. So when Ferziger came to Stanford, I became his grad student. I had a research problem that I had already started with this other professor who had left. And Ferziger thought my problem was pretty good, but I was only in my second year, and we needed to do a lot more to it. So we ended up taking classes together in statistical mechanics.

ASPATURIAN: You and your advisor? He sounds like an interesting guy.

LEONARD: Yes. He was one year older than me, and he didn't have his PhD yet. He still was writing his thesis. [Laughter] But anyway, we took all these fancy physics classes together, and then he said, "OK, we're going to see Felix Bloch." And he's a Nobel Prize physicist [1952] at Stanford. I said [dubious voice], "OK." So here we go to see Felix Bloch, and I'm trying to explain my problem to Felix Bloch.

ASPATURIAN: How did that go?

LEONARD: Well, he was really nice, but he didn't have any ideas for us. I was a little bit uneasy going to see this Nobel Prize-winning guy when I had this stupid little problem. But eventually Ferziger—oh, before that there was the summer job I mentioned earlier, at Atomics International after my master's year.

ASPATURIAN: So you must have come back down to Southern California for that?

LEONARD: That's right. And before that summer, during my master's year, Gretchen, my future wife, had come from Colorado, because she and a group of her friends had started teaching elementary school in Sunnyvale. So we got to see each other again.

ASPATURIAN: You reconnected?

LEONARD: We reconnected.

ASPATURIAN: That's a nice story.

LEONARD: So the summer after I got my master's degree, we got married [July 1960]. I remember our first little apartment was down in the San Fernando Valley. But anyway, I worked at Atomics International, thanks to Milton Plesset. That was a very nice job, too. I got to do a lot of interesting stuff. But then the next summer, I applied for a summer job at RAND Corporation, and that was really great, too.

ASPATURIAN: What year are we in now?

LEONARD: 1961, after my second graduate year.

ASPATURIAN: What were you doing at RAND?

LEONARD: Well, they put me with a propulsion group—a group that worried about advanced propulsion devices. RAND was almost totally Air Force-funded in those days, and the Air Force was very good about it. They just let RAND do what they thought was right, which is kind of refreshing. So we had the job of studying propulsion systems that all these people came up with, and we gave our recommendations to the Air Force about which ones were really viable and which ones had problems.

ASPATURIAN: These were propulsion systems for aircraft, not spacecraft?

LEONARD: Both actually. There were some really wild spacecraft ideas in those days, but aircraft also.

Some material in this session was originally recorded during Interview Session 2.

ANTHONY LEONARD

SESSION 2

November 9, 2012

ASPATURIAN: I think when we stopped last time, you were completing your summer job at the RAND Corporation after your second year at Stanford. You were probably starting work on your dissertation around this time?

LEONARD: Yes. I looked back at that, and it turns out that all the way up until the end of my third year, I was still working on this other problem that never turned out to be a thesis. But my advisor, Ferziger —

ASPATURIAN: This is the kid who was a year older than you?

LEONARD: Yes. He was anxious to get publications, and he had this calculation started on a completely different subject, so he said, "Why don't you finish this calculation, and we'll get a publication." And sure enough, that was my first publication—in *Physical Review*.[1]

ASPATURIAN: You were in your early twenties?

LEONARD: Yes. We submitted that in June, and it got published in the fall of '62. So then I went back to RAND for the summer after my third year. When I came back to Stanford after that summer, Ferziger was kind of upset. He thought I should have stayed during the summer and done research, but I needed the money, because the fellowship, which was for three years, ended that summer. The funding in those days was not that reliable for research students. So he came up with this thesis topic, and it turned out to be a really good one.

ASPATURIAN: I have a question. Did you need security clearances in connection with your summer jobs at RAND?

[1] Ferziger, J. H., and A. Leonard, "Multiple scattering of neutrons in the static approximation," *Phys. Rev*., 128 (5) 2188-90 (1962).

LEONARD: No, they just gave us unclassified things. It was too much trouble to get a clearance for a summer job. But that's a good question, because RAND had a lot of restricted work.

So anyway, Ferziger gave me this topic to work on that I mentioned last time—energy-dependent neutron-transport theory. There was a simplifying assumption we could make right away, and that led to the first result, which we actually got published. But then the more general case was the rest of the thesis, and that took a while. But I did have to leave Stanford in February of '63, because I ran out of money. We had a one-and-a-half-year-old daughter. That's when I went back to the RAND Corporation.

ASPATURIAN: So you left Stanford at that time with your PhD?

LEONARD: No. I had to write it up at night. I did get it done in time for a June graduation.

ASPATURIAN: So your thesis was basically on a theoretical problem, not an applied problem.

LEONARD: It was pretty theoretical, although presumably it could be used eventually.

ASPATURIAN: It had applications, but you were working on the theoretical side?

LEONARD: Right. So in June '63, I got my degree. And it's interesting that my sister got her bachelor's degree at the same time, at Utah State, and my dad got his bachelor's at USC at the same time. He had gone to work in 1930 or so without a degree. He retired later and decided he wanted to get a degree. He got a bachelor's at USC and then a master's at UCLA, which is kind of amazing.

ASPATURIAN: Also in engineering, or did he decide to go into something else?

LEONARD: In engineering. So that takes us to the RAND Corporation, I think, right?

ASPATURIAN: So you went to RAND for a couple of years, it looks like.

LEONARD: About three years. As I think I covered earlier [Session 1], my main job was working in the propulsion group, and that group was part of the aero-astronautics department, headed by a fellow named Richard Schamberg, who was a GALCIT [Graduate Aeronautical—since 2006, Aerospace—Laboratories of the California Institute of Technology] PhD. So the main part of my job was to assess advanced propulsion system proposals, and some of them were really crazy and some of them were reasonable; but the Air Force wanted to know which ones they should put their money into. One of them, just to give you an example, was by a division of General Atomics in San Diego. It was called Project Orion. The idea was that you had a spaceship, and the spaceship had a big round circular pusher plate that was attached to the main rocket with a spring. So you'd fire a nuclear device out the back; the nuclear device would detonate, sending momentum to the pusher plate. So the thing would go *boom, boom, boom*!

ASPATURIAN: Is this the project Freeman Dyson was involved in?

LEONARD: Freeman Dyson worked on that.

ASPATURIAN: I remember. He's never gotten over it. He writes about it a lot. Did you ever meet Dr. Dyson?

LEONARD: No, oh no. I never did.

ASPATURIAN: OK.

LEONARD: There's a famous person in fluid mechanics, [Michael] James Lighthill, who passed away, but apparently he and Dyson were No. 1 and No. 2 wherever they went—[the University of] Cambridge?

ASPATURIAN: Princeton [the Institute for Advanced Study], I think, is where Dyson ended up.

LEONARD: I'm thinking wherever they went to school.

ASPATURIAN: Oh, I think he did go to Cambridge.

LEONARD: Lighthill was extremely famous in our world—Sir James Lighthill. But apparently someone asked Freeman Dyson once, "Whatever happened to James Lighthill?" And he said, "I can't remember James Lighthill."

ASPATURIAN: Oh, dear. That's quite an endorsement.

LEONARD: [Laughter] So they had some really big names working on this project. And in fact, General Atomics was one of the companies I interviewed with before I decided to go to RAND permanently. The other one was Los Alamos.

ASPATURIAN: Why did you decide to go to RAND instead? I would imagine Los Alamos would have been interesting.

LEONARD: I was intrigued by Los Alamos, and they had an interesting job for me. But I just liked something about RAND. Of course, it was close to where we were living. The General Atomics job—I just couldn't see myself being attached to this project.

ASPATURIAN: You mean Orion?

LEONARD: Yes. I would rather have had a different job there. They had a reactor theory group, working in the area of gas-cooled reactions. It never really took off, but it was a nice concept. There were some really good people working on that project—which was a more sensible project to me—but they didn't have any openings. Something else we did at RAND was to investigate fusion power, because fusion power might ultimately lead to interesting things for the Air Force. So we visited the Princeton Plasma Physics Lab. Los Alamos, Oak Ridge, and Aerojet General up in Northern California also all had fusion projects. So we'd visit these places and get their presentations, and they all said it would only be five years before there would be a breakthrough.

ASPATURIAN: What was your take on this? Did you believe them?

LEONARD: Well, it seemed like there was a lot of hope there, but I wasn't sure about the five years. This was 1965, you know. It's still a possibility, but—

ASPATURIAN: It's still five years away?

LEONARD: [Laughter] Right.

ASPATURIAN: I wanted to clarify. Orion was a project concerned with space propulsion, right? It was looking at space travel?

LEONARD: Right.

ASPATURIAN: It wasn't Earth-related?

LEONARD: No, it was all space. So that's one thing. Also at that time, there were several UCLA grad students who were working part-time at RAND, and two of them were interested in my thesis topic and wanted to do something related to that. So that was my first experience being a mentor to PhD students. That was a good experience and a lot of fun. Also, I connected with one of the mathematics people, Tom Mullikin, at RAND, because we had overlapping interests in transport theory. We hit it off real well and collaborated on five or six papers. So that helped my publication record, even though I wasn't that anxious at that time to get a publication record, but eventually it was a good thing. He went to Purdue as a math professor later on—he's retired now. But I've kept in touch with him all this time. And then, at Caltech—I'm trying to think, who was running nuclear reactor theory at Caltech?

ASPATURIAN: Was it the Lauritsen brothers at that time? Jesse DuMond?

LEONARD: No, it was in the engineering division. I believe it was Milton Plesset or Harold Lurie. Anyway, I was at RAND, and he contacted me and said, "We have this course called Advanced Reactor Theory, and the person who usually teaches that is a head scientist at Atomics International. How about you teaching it?" So that's when I became a lecturer in applied mechanics, part-time.

ASPATURIAN: While you were still working at RAND?

LEONARD: Right. So every Tuesday and Thursday, kind of midday, I'd drive over to Caltech and teach an hour-and-a-half class in advanced reactor theory—for the whole year. It was kind of a fun experience. There were only three students in the class.

ASPATURIAN: It was more like a seminar?

LEONARD: Yes. One of them was Jim Duderstadt, who went on to become president of the University of Michigan, and another one was Robert Conn, who went to Wisconsin and UCLA as a professor and ended up down in San Diego. The third one I don't remember. But it was quite a class.

ASPATURIAN: Had you been a teaching assistant at Stanford?

LEONARD: No, I hadn't. With my fellowship funding, I hadn't needed to teach. You would have thought Stanford would have found me a position like that when I ran out of money, but they didn't.

The other thing about RAND that I thought was interesting was that of course we had to give a fair number of presentations to our sponsors—Air Force people and so forth. And whenever we were to give a paper or two at a society meeting, we had to do a practice talk in front of a former Hollywood film director—I don't remember who it was. But he was from the old school, and he would sit in the back of the room and watch your talk and later on he'd critique you. Kind of interesting. One of the best parts about RAND was we could go to the beach at noon and play volleyball. That was a good deal.

ASPATURIAN: For someone who liked surfing at Doheny, that must have been a nice perk. And then you went back to Stanford. How did that come about?

LEONARD: That came about because Tom Connolly, who was head of the three-person nuclear energy division of Stanford—the nuclear engineering division of the mechanical engineering department—called me in the spring of '66 and said, "The three of us are up for sabbatical, one after the other. We would like you to come up and teach nuclear engineering for three years." So that's how it happened.

ASPATURIAN: Do you know how they happened to think of you? Had you kept close ties with them?

LEONARD: You know, they probably went through their recent graduates and decided who was ready to do this. There weren't a whole lot of choices, and some of them were in the nuclear Navy and it was probably impossible to get them away. So, I don't know. Well, Ferziger and I had continued to collaborate all the way up through '65, because we were still trying to refine my thesis into a paper. So that was part of it, maybe. My wife Gretchen and I treated it like a permanent move, because we bought a house, and it worked out fine. There's one amusing story—there are probably quite a few—but this is from 1966, my very first year up there. On Christmas Eve night, I got a phone call that the alarm had gone off at the research reactor. Christmas Eve night! It turned out I was the fourth person on the call list but nobody else was available. So I had to go out there and find out what was going on. And my brother-in-law, who's a doctor, came with me. And he thought it was really funny, because he's always getting calls at night. But it turned out to be kind of a harmless thing. Some monitor had gone off.

ASPATURIAN: But memorable because of the timing?

LEONARD: Yes. So anyway, the three years at Stanford ended up being seven years, because while I was there Stanford started having serious budget problems in the late sixties, and they eliminated the nuclear engineering division.

ASPATURIAN: Was this a reflection of what was happening in the field nationwide, or does this just apply to Stanford?

LEONARD: I think that the more widespread doubt about nuclear energy came later. I know what happened, but I don't know the inside information. I think it was just that the Atomic Energy Commission provided Stanford with a nuclear research reactor and there were no additional funds to support it. And while there were four of us there, one of them had gone on sabbatical, and we were not very adept at getting research grants—none of us. Anyway, the tenured people got homes in mechanical engineering, but I was the untenured guy. But I did manage to stay for

four more years. It was good—I got a chance to teach some classes that were outside of nuclear engineering, which I think eventually helped me quite a bit.

ASPATURIAN: In what fields? Do you recall?

LEONARD: Well, one example was post-master's engineering math. Bill [William] Reynolds was a professor at Stanford at the time, and he was a very charismatic guy and a very good teacher, so we team-taught this class, which was a good experience. And then I taught a class in complex variables for graduate students, which was also a good experience.

So, also, because of my nuclear engineering and nuclear scattering research and being a nuclear engineer, you're interested in how neutrons scatter off ordinary materials like water. So to predict things like that, you have to know statistical mechanics. When I knew I might have to change fields, I started getting interested in fluid mechanics and turbulence. I came in at this kind of theoretical level.

ASPATURIAN: Did this arise because of research currents that were going on around you, or did you collaborate on a paper?

LEONARD: Well, that's a good question. Part of it was because a little later on, the three of us—that's me, Joel Ferziger, and Bill Reynolds—got some seed money from NASA Ames to look into computational fluid mechanics. Which is kind of strange, because Bill Reynolds was the fluid mechanics person of the group, and none of us had really much to do with computational methods.

ASPATURIAN: Did NASA Ames come to you?

LEONARD: They came to us. The head of NASA Ames, Hans Mark, knew Joel Ferziger pretty well. Hans Mark had been head of Lawrence Livermore Lab, and then he became head of NASA Ames. He went on to become chancellor at the University of Texas, and then he served as Air Force secretary. But, anyway, he had a mission picked out for Ames—to become really top-notch in computational methods. They already had a very strong computational fluid mechanics group, but they weren't interested in turbulence. So Mark thought he'd get some

activity going there that would spill over into Ames, and he gave us a little seed money to, say, pay a graduate student a little bit of our salary. That was one thing that got me going. And just being interested in turbulence seemed like a natural thing. That was another plus for my last few years at Stanford.

ASPATURIAN: Was some of this research more mathematically based than what you previously had been doing? Because you strike me from the get-go, in your intellectual development, as a mathematics guy.

LEONARD: It was very mathematical. I did manage to graduate seven PhDs in my seven years at Stanford. It was a very good experience. So, after my seven years I had to move onto the next job.

ASPATURIAN: Are you at this point still doing any nuclear engineering work?

LEONARD: Oh, yeah, I forgot about that. Actually, when I first came to Stanford, in '66, I hooked up with General Electric's nuclear division [GE Nuclear Energy] in San Jose, and I spent one day a week consulting for them. I kept that up for a long time—in fact, all the way into my Caltech years. That was my connection with nuclear engineering. It kept going.

ASPATURIAN: You were gradually evolving in a new direction?

LEONARD: That's right. So, in 1973 I had another chance to go to Los Alamos if I wanted to, but the job opening they had was not in a group that made sense for me: It was in experimental nuclear physics. And then there was a job with a company in Kent, Washington, that specialized in fluid mechanical research but contracted to the Navy and basically did contract work for government. They had a lot of good people, but there was also an opportunity at NASA Ames that looked very good.

ASPATURIAN: It fitted in more with what you'd already been doing.

LEONARD: Exactly, right. So I went there, first as a senior postdoc.

ASPATURIAN: Where is NASA Ames?

LEONARD: It's in Moffett Field, right next to Mountain View [California].

ASPATURIAN: So it's where you already were.

LEONARD: Yes. So that was also nice. We could just live where we were. So that turned out to be a good choice for me—working in the Computational Fluid Dynamics Branch. Harv [Harvard] Lomax was our branch chief. A very nice guy—hands off. But every once in a while, he'd come in and give me a hint that the boss's boss would really be interested in such-and-such a question, and then he'd walk away.

ASPATURIAN: This is interesting. This was part of the space program, obviously, and yet it sounds like you were pretty much left alone to do pure, fundamental research.

LEONARD: I think they were able to do that, for some reason. They turned out enough good stuff to keep everybody happy, and so somebody like me could dabble in something interesting. It turned out OK.

ASPATURIAN: Who was the director of the lab at this time?

LEONARD: Still Hans Mark.

ASPATURIAN: He must have been very good at that sort of thing.

LEONARD: Yes. Harv Lomax's boss was a fellow named Dean Chapman. And it turns out that Dean Chapman was a Caltech undergrad and a GALCIT PhD—pure Caltech all the way through. Anyway, Hans Mark was also interested in turbulence. And so almost every Saturday, he'd have a few of us join him in his office, and we'd chat about turbulence. He had his own views of turbulence, but at least he was interested.

ASPATURIAN: Can you explain in layperson's terms what it is you were looking at?

LEONARD: Well, turbulence is fluid motion that's very chaotic and unpredictable, kind of like the weather, almost. For engineering purposes you don't necessarily care about the time-dependent motions of all the little eddies, but if you have a turbulent flow over an aircraft, you'd like to know how much fluid force is applied to the aircraft's skin by friction. If the flow is laminar and smooth with no turbulence, you can predict that easily. But with turbulence, there's so much going on that you don't know how to predict it.

ASPATURIAN: So you're trying to distinguish patterns within this apparently chaotic motion?

LEONARD: That's one idea—to try to find key elements of turbulence and use those as building blocks. That's an approach I've been looking at for a long time. But even that doesn't work completely. Predicting the weather day to day, you have to know what all the little eddies are doing all over the Earth, and try to extrapolate from that what they're going to do in two weeks. If you're trying to predict climate, you don't care about the weather in the next two weeks. You'd like to know what the average temperature is going to be ten years from now, averaged over, say, a whole year. You can't possibly predict what's going to happen on a day ten years from now. That's the essence of the problem, and it's still a nagging problem. One approach that we had started at Stanford was to do calculations with a computer that would simulate the motions of the largest eddies, which we could do since we had enough computer power to compute the large scales.

ASPATURIAN: What scale are we talking about?

LEONARD: Well, just to make it specific, say you had a channel that was about a foot tall. At that time [indicating with hands], you could afford to put maybe fifty grid points from here to here. So for any eddy that was bigger than, say, several of those grid points, you could sort of compute what they were doing. And since computers get more powerful all the time, today you can actually do several thousand little grid points between here and here. And then you'd have to have a thousand this way, and a thousand that way, so that's one billion grid points. So we can do that now. But, unfortunately, for all the interesting engineering Reynolds numbers, the scales are really small. All the scales of turbulence go from the larger scales down to really

small scales. So you have to model what's going on at the very small scales and get their influence on the scales that are bigger.

ASPATURIAN: So is it correct to say that you take a precise reductionist approach and try to see how it scales up globally within a certain parameter?

LEONARD: That's right. So one approach is to do an exact calculation on a smaller scale, where you can get all the little eddies and look at them and see what they're doing and try to model them as you go.

ASPATURIAN: Are there competing theories that say no, that's not the way to do it, you need to go top-down?

LEONARD: There are competing ideas in that sense, and in some cases they get pretty good answers, too. To re-express what I think you're saying, that approach would say that you can just compute the large eddies and the small ones don't matter that much. Sometimes that kind of works, but not always. Anyway, so I got into that business, and the process I just described is called large-eddy simulation. What that means is, you're simulating the motions of the large scales and somehow taking into account the small scales.

ASPATURIAN: And you did this on a computer?

LEONARD: You do it on the computer. But there has to be some theory behind it.

ASPATURIAN: Were there real-world applications that this work fed into at the time you were involved in it?

LEONARD: Oh, yeah. It's a really big industry now.

ASPATURIAN: How about back then?

LEONARD: Well, back then there were a few groups working on it, and one was at the National Center for Atmospheric Research in Boulder [Colorado]. There was a guy there doing what he called atmospheric boundary layers. He had a code that would compute the eddies and atmospheric boundary layers and model the small scales. There were a few applications like that. This is in the early 1970s. It's a huge industry now. You know about the San Onofre reactor problems? The San Onofre reactors are going to be shut down for a long time, and it's going to be very expensive. [In 2013, Southern California Edison, which oversees the San Onofre Nuclear Generating Station near San Diego, announced that the reactors would be permanently closed. –*Ed.*]. Apparently, from what I just read in the newspaper, the problem is that they have a heat exchanger where they have one fluid that comes in and heats another fluid that's running through these heat-exchanger tubes. So you have one fluid running through these tubes, and another fluid coming in and trying to heat the tubes. And apparently they couldn't predict the vibrations of these tubes correctly, and the result was that they vibrated too much and cracked. So that's another topic I got into later—fluid-structure interaction. Whoever did the computations for San Onofre apparently was way off in predicting the effect.

ASPATURIAN: That's too bad, considering the stakes.

LEONARD: Considering how expensive that is. And today people use this methodology to compute things with combustion and more complicated flows with all kinds of things happening.

ASPATURIAN: It interests me that by this time—the early 1970s—the Apollo program had ended, and I guess things were revving up for the shuttle missions. NASA's funding had been cut, and yet it sounds like Ames was able to keep this very theoretical wing going for quite a while.

LEONARD: That was nice. We were kind of low-cost, compared to the rest of that stuff. NASA had really good people to work with there. Another thing that made it good for me was that some very good Stanford students wanted to come and work with some of the topics that our branch was investigating. So I actually ended up being the unofficial advisor to quite a few Stanford students, and the ones I worked with were terrific. I also found that Ames had postdoc positions that nobody was using. So you could actually find and fund a postdoc and bring him into the group. So that worked well, too. Another thing that I thought was very good at Ames

was that once a year, you'd sit down with your branch chief and you'd present him with two or three paragraphs saying what you'd done the year before and what you wanted to do for the next year. You'd go over the two or three paragraphs, and he'd say, "Did you do that?" And you'd say, "Yeah, I did most of that." And that was it. The bureaucracy was a little bit tough on foreign travel, I must say, but other than that, it was not this grinding-out-proposal stuff.

ASPATURIAN: I wanted to ask a bit about your family at this point. Was your wife still teaching?

LEONARD: No, no. She taught second grade the one year before we were married, and then she taught only for a few months, and she had to tell the principal that she was pregnant, and that was it. So she stayed home and raised our kids. We had a daughter in '61 and a son in '64, and so she stayed home. Once the son started going to school, she decided to take flying lessons and became a private pilot.

ASPATURIAN: How did you feel about that?

LEONARD: Oh, I was fine.

ASPATURIAN: Did you take lessons also?

LEONARD: She took me up for a couple of rides, but then she kind of soured on the whole thing because she was flying in and out of San Jose, and that was a busy airport. I think she decided it was fun to learn to fly but, "What am I going to do with it?" So when our son was about ten or so, she started going back to school. She got a master's degree from San Jose State, and she got a teaching job in counseling and psychology at De Anza College. She held that for eight or nine years, until we moved down here.

ASPATURIAN: A lot of opportunities started opening up for women in the seventies.

LEONARD: Oh, yes. Part of her job was to help other women get jobs in computing, because computing was becoming quite the deal, and De Anza had classes on how to use a computer and so forth and so on. She tried to get people jobs, and actually Ames would hire good people like

that, so it was a good connection. So that's pretty much Ames. It was 1983 when I got invited to GALCIT to spend an academic year down here.

ASPATURIAN: Who invited you?

LEONARD: Well, Don Coles [professor of aeronautics, emeritus, d. 2013] was the guy I was in contact with, but I'm not sure who was behind the offer. It might have been Hans Liepmann [Von Kármán Professor of Aeronautics, emeritus, d. 2009].

ASPATURIAN: What in particular interested them in what you were doing?

LEONARD: I can kind of guess. They knew that engineering schools in other universities were getting heavily involved in computational fluid dynamics, but they were always a little bit leery of what was going on, because there was a lot of kind of fake CFD, not very good quality. I had developed this different way of looking at problems that maybe they thought was interesting. I'm not sure. But they also invited Bill Reynolds to come down at the same time, as a Fairchild Scholar. So we came down here at the same time, and they thought that would be a nice interaction for seeing what's going on in the CFD world. And it turned out that Ames had a nice procedure for doing this. Some kind of interagency exchange was available as long as the other agency was going to pay half or part of my salary. It wasn't that hard to arrange the paperwork. So anyway, I came down.

ASPATURIAN: Can I step back for one minute?

LEONARD: Oh, yeah, sure.

ASPATURIAN: I think I recall reading that you had developed something in the mid-seventies that gradually morphed into a standard for the field? What was that?

LEONARD: It could be the large-eddy-simulation work that I did.

ASPATURIAN: Can you explain why it was so important?

LEONARD: Well, if you're going to do the type of full turbulent-flow simulation I talked about earlier, you have these equations called the Navier-Stokes equations. They're time-dependent partial differential equations. So if you want to do turbulence without modeling, you have to convert that system of equations into some kind of a grid, or however you want to solve them, and then put that on the computer and run the code and look at the results. But with almost all engineering applications, you couldn't afford to do that, so you have to model the small scales. But to model the small scales, you have to at least write equations for the large scales. So that's where I came in. I figured out how to write some equations for the large scales so people would have something to start with. I also was able to give some ideas of what the small-scale part of those equations would do to the large scales. It wasn't the complete story, but at least it was a start.

ASPATURIAN: It provided a framework that hadn't existed before?

LEONARD: That's right.

ASPATURIAN: I'd like you to talk a little about your thought processes working in this area. Did you basically approach this mathematically? Do you visualize? How do you come at these problems?

LEONARD: I'm not sure, but I was used to the idea of filtering. If you have a signal that has a lot of fluctuations in it and you want to just see what the trends are, you filter the signal. So I just applied that idea to these equations, and I went a little bit farther. I was able to identify some features of the term that couldn't be handled computationally. It's easy to filter equations that are linear, because this one filters, this one filters, and that one filters and then you're done. But these are nonlinear equations, so when you filter a nonlinear term you get some terms where you don't know what to do with them because you don't have equations to handle these terms. So that's what I remember anyway. [Laughter]

ASPATURIAN: It sounds a bit like you "saw" something and asked yourself, "How do I express this mathematically?"

LEONARD: Yes, I think that's how it went. The other thing I was known for by the time I got to Caltech was this work I did at Ames on a numerical method that's based on vortex dynamics. It turns out that in the simplest of cases, you can treat vortices as kind of interacting particles. So you have a vortex here and a vortex here, and there's a certain rule that says these guys interact in a certain way. It's very interesting how that works: If you happen to have a vortex spinning this way and another one doing the same thing, they just kind of rotate around each other.

ASPATURIAN: The particle theory came out of what? Classical mechanics? Quantum theory?

LEONARD: It's all classical. The simple cases had been known for many years. In fact, when he was still in Germany, [Theodore] von Kármán himself used vortices to figure out the theory of flow past a cylinder in the simplest case. He and his assistant were investigating flow past a circular tube, two dimensions. Just a long tube, and you send flow past it. Now, if the flow is very, very slow, you just get a nice time-independent flow pattern around it. But if you gradually increase the speed of the flow, pretty soon you get one vortex here and later another vortex here. You get this alternating vortex pattern. It's called the von Kármán Vortex Street. And von Kármán kept telling his lab assistant, "You have to do it more carefully; you shouldn't get this vortex street." Well, it turned out that von Kármán later used this pattern to figure out the theory for what the spacing was between the vortices, and which ones are and are not stable.

ASPATURIAN: He discovered it meant something instead of being just an irritant?

LEONARD: Yes. So anyway he used the phenomenon I just mentioned—that each vortex has an influence on the other one—to come up with this theory.

ASPATURIAN: At what point in your own work—and I assume this was at Ames—did vortices, which subsequently played such a role in your research, start coming to the fore?

LEONARD: When I first came to Ames, in 1973, they put me in an office with a guy named Bob Rogallo. His father was Francis Rogallo, who invented the Rogallo wing of hang-glider fame, and his son was a very clever guy who was interested in two-dimensional vortex dynamics, the ones I just mentioned to you. So he was actually in the midst of trying to develop vortex

methods that would compute in more detail these type of two-dimensional flows. He got pretty far with it, but then he couldn't complete it—it didn't fit his personality. There were too many things that could go wrong. In other words, the method he was using would get very interesting-looking results until you said, "OK, I want to refine my calculation and do even finer scales," and then things would kind of blow up.

ASPATURIAN: He wasn't comfortable with so much uncertainty? Some people are like that.

LEONARD: So he decided to quit that. But then I decided, well, that's kind of neat. Maybe I could salvage it and take this 2D thing and go to three dimensions. So that's what I did. To go into three dimensions, you have to have vortices that can follow a space curve. Things get more complicated, but you can still compute using this idea. Instead of having 2D vortices that are just in X, Y location, you now have 3D vortices that can follow a tube that can go in any curve in space. You just have to imagine lots of vortices with interlocking, so that's what I did.

ASPATURIAN: And you succeeded in resolving it?

LEONARD: I was fairly successful. That particular method had very limited applications. There's still a number of people who use that same idea, but they don't try to follow curves; they just have little sticks of vorticity. I don't know if that's making any sense, but they have millions and millions of little vortex 3D elements that are little sticks. I think it's the simplest way. So you have a little vector of vorticity, and it occupies a volume, and you have millions of these things.

ASPATURIAN: It sounds like you tried to do it on a continuum, and they kind of quantized it?

LEONARD: Exactly.

ASPATURIAN: Although not literally.

LEONARD: That's right. They can do that now because we have so much computational power. So, anyway, we're back to my first appointment at Caltech.

ASPATURIAN: I think from a chronological standpoint we can do Caltech proper in the next session. But I wonder if you'd talk more about vortex research, since that's obviously central to what you went on to do. Why is it so important?

LEONARD: I wrote a review article for *Journal of Computational Physics* while I was still at Ames, and that really helped me put down some of the main problems, the main applications, and the remaining challenges.[2] It's the usual thing: When I'm doing it, I'm swearing at myself, asking, "Why did I say I was going to do this?" And then it turns out to be a good thing. I think the vision of vortices dancing around is a very helpful one in understanding what's going on physically, and more people should pay attention to that, I believe. The other approach that people think about is that the Navier-Stokes equations have a pressure term. And the pressure is kind of a nebulous thing, because there's a low pressure here and a high pressure here [indicating a range with hand gestures], but how do you find out what the pressure is at some point in between? But, to me, if you know where the vortices are, that's all you need to know. You don't have to worry about the pressure. I should clarify that: If you're interested in high-speed flows, supersonic or even flows at Mach numbers close to 1—

ASPATURIAN: That's the speed of sound?

LEONARD: Yes—then you really have to pay attention to things other than vortices. But there are many cases, such as when you're driving your car down the street, where you don't have to worry about anything but vortices.

ASPATURIAN: I guess from a purely qualitative standpoint, which is where I usually am, the vortex is kind of a humble and yet a deep thing. You see the water swirling down the drain, but it turns out to be applicable on scales throughout nature.

LEONARD: Oh, yes. That's right.

ASPATURIAN: Nature is pretty conservative, so there must be a reason why it chose this, right? Do you ever concern yourself with these questions?

[2] "Vortex Methods for Flow Simulation," *Jour. Comp. Phys.* 37:3, 289-335 (1980).

LEONARD: Well, you know, during my visiting year at Caltech I took a class from Kip Thorne [Feynman Professor of Theoretical Physics, emeritus] in the theory of general relativity. It was enjoyable, but I should have done the homework. But I think they're finding just recently that this idea of vortices in general relativity is an important thing. That's good. Yeah, you can apply this idea to a lot of things.

ASPATURIAN: Probably more things than we're aware of currently. On that note, it's been an hour. I think that's good.

Some material in this session was originally recorded during Interview Session 3.

ANTHONY LEONARD

SESSION 3

November 14, 2012

ASPATURIAN: I think when we left off we were in the early 1980s, and you had been recruited to come back to Caltech for a year.

LEONARD: The 1983-84 appointment was just an academic-year personnel exchange. But in November 1984 I got an offer to come to Caltech permanently. Gretchen and I had to discuss it for quite a while, because it meant a big change for her. She had a nice job at De Anza College. So finally we decided to go to Caltech.

ASPATURIAN: What tipped the balance, finally?

LEONARD: Well, I think it was just an opportunity for me. She was kind of happy to retire, too. And it wasn't for sure that my job at Ames would be a steady, wonderful job to the end. Poor NASA has its ups and its downs; it goes through all kinds of things. Although it was a terrific job.

ASPATURIAN: You said last time that you thought Hans Liepmann had a hand at bringing you back?

LEONARD: I believe so.

ASPATURIAN: Did you know him well at that time?

LEONARD: Not very well, but I knew his reputation. In January of '85, there was a big symposium in honor of his seventieth birthday. So they invited a lot of people to come.

ASPATURIAN: I think I remember that. I had started at Caltech the year before, and I was involved in writing about it for one or another of our publications.

LEONARD: It turned out that they invited Bill Reynolds and me to give a joint presentation on computational fluid mechanics and what its promise was, and so forth. We kind of split our presentation. And everybody remarks—and I'm sure it's true—that Reynolds would go through things in rapid fire, and I was kind of a slow speaker. [Laughter] It was kind of a contrast in styles. And then the proceedings of that symposium were going to be published as a book, so Reynolds and I had the job of writing up our chapter. But Reynolds—this is typical Reynolds—just doesn't concentrate on things he's not interested in, so it was totally up to me. All I had was a transcript that a secretary had made from the audio version of the talk, and I started with that. It was a lot of work, because Don Coles was the editor and he's very particular. Anyway, how'd I get off the track there?

ASPATURIAN: Well, I asked you about Dr. Liepmann. I was interested because he was quite a character.

LEONARD: Did you get to know him?

ASPATURIAN: A little bit. I was talking to him about something once, maybe it was the birthday celebration symposium, and somehow or other—he grew up in Germany before the war—we got on the subject of Adolf Hitler. And I still remember this: He looked at me and said, "I ask you: Vhy vas this man *so* attractive to women?"

LEONARD: [Laughter] That sounds like Liepmann. [See also Session 4]

ASPATURIAN: It was quite a conversation.

LEONARD: And then his family moved to Turkey.

ASPATURIAN: I had heard that. They split up apparently, something that happened to a lot of people during the war.

Anyway, so you come back to Caltech. You'd been gone for a quarter of a century. How had things changed?

LEONARD: [Laughter] Certainly above San Pasqual [Street], lots of things physically had changed. Beckman [Auditorium] and of course even the Millikan Library were new. The old administration building [Throop Hall], I guess, they had to tear down.

ASPATURIAN: After the 1971 Sylmar quake, I understand.

LEONARD: But not the west side of the campus—the biology part and the geological sciences part. I always liked that section of the campus, I guess because it stayed the same.

ASPATURIAN: The Church-Alles-Kerkchoff [laboratories] area and the Mudd and Arms buildings. Yes, that's a pretty part of campus.

LEONARD: It is. I guess the administration of Caltech had changed somewhat. They had more vice presidents, I believe. In my day, they only had one, who was head of financial operations or something. So that was quite a change. And, of course, there were a lot more postdoctoral fellows.

ASPATURIAN: And the school was coed also.

LEONARD: That's right. Yeah, that's a big change. Even the north [student residence] houses were new to me. I had been back to visit, so I knew they were there, but they were built after I left.

ASPATURIAN: It sounds like the physical layout had evolved a lot in the intervening decades.

LEONARD: The new Braun gym [Braun Athletic Center] hadn't been built yet. It was yet to come when I came in '85.

ASPATURIAN: That reminds me, on this flyer about your seventieth birthday party, they talk about you surfing. Did you continue to surf?

LEONARD: No, no. I gave it up, gee, a long time ago. But I kept my surfboard for a long time.

ASPATURIAN: Oh, maybe that was all it took.

LEONARD: I remember surfing in Santa Cruz a few times, but it was so cold.

ASPATURIAN: I've noticed that people who surf at Pismo and farther north are always wearing wetsuits.

LEONARD: We didn't have wetsuits. It was really cold. I must have given up surfing when I was at NASA Ames or even at Stanford as a professor.

ASPATURIAN: It sounds like your reputation carried on, since they're still writing about it years later.

LEONARD: When did that appear?

ASPATURIAN: This is dated 2008. In the preface it says, "Tony hardly looks seventy today, and many of us attribute his youthful look to his passion for sports—traveling, surfing and football have been his passions."

LEONARD: OK.

ASPATURIAN: It sounds great.

LEONARD: I think that part of me is kind of blown out of proportion.

ASPATURIAN: So you joined the faculty of Caltech. What was your title at that time?

LEONARD: Professor of aeronautics.

ASPATURIAN: What were you doing?

LEONARD: Well, my first assignment was teaching a class in computational fluid mechanics. I had already interviewed students to be my PhD students, and I talked to four promising people. I

decided I could go ahead with three, and I picked three of them. They all wanted to get me back into the vortex dynamics stuff that I'd done maybe five or ten years ago.

ASPATURIAN: This is the work you'd done at Ames?

LEONARD: Right. But at Ames, I'd gradually shifted over to a slightly different approach to computational fluid mechanics. Nobody at Caltech was interested in it, so I decided, "OK, we can start on this." One of my original PhD students is going to appear at our house Friday. He teaches in Belgium. In fact, I have three of my PhDs in one department in one university in Belgium [Université catholique de Louvain], which is really kind of unusual. One of them was one of my very first students, Greg [M. Grégoire] Winckelmans [PhD 1989]. And one was about ten years after that, and one is very recent.

ASPATURIAN: Are they sort of the kernel of the discipline at that university?

LEONARD: Yes. Part of the reason is that Greg Winckelmans was my first student to arrive there, and he knew that anybody who graduated from Caltech was likely to be an asset to his department, so he was eager to snatch them. My third guy, Philippe Chatelain [PhD 2005], is already from Belgium anyway. The other guy is Greek, and he wanted to be near his family, and a position in Europe looked better to him than one in the U.S. OK, so back to the first few years?

ASPATURIAN: Yes. Colleagues, students, research?

LEONARD: Well one thing that comes to mind is that there was a new, young Von Kármán instructor who had just arrived in applied math, at the same time I did—name is Steve [Stephen] Wiggins.

ASPATURIAN: I know the name. A lot of red hair?

LEONARD: That's him. He had just come—he was a very young guy but already a big player in what they call dynamical systems and chaos and theories about that. I was quite intrigued by that myself, so I took his class. That was really a great experience. He ended up with a grad student

whom I helped mentor—Vered Rom-Kedar. She had come from Israel. Her father was a GALCIT grad from some time ago, and she was really good. She's back at the Weizmann Institute now. She finished her PhD in three years, which is really incredible.

So that was a great experience. I also worked with quite a few of Steve's students, and it was interesting. Vered was from applied math. Igor Mezic was mechanical engineering, I think. Kayo Ide was aero. There was a chemical-engineering guy and a physics guy. All those people I worked with, and they were all from different departments. That's the beauty of Caltech.

ASPATURIAN: I was just going to say that. You don't find that virtually anywhere else.

LEONARD: Right. So that was really neat. I think it was that first year I started doing Freshman Admissions Committee work.

ASPATURIAN: What drew you into that? Anything in particular?

LEONARD: Just the idea that I'd gone through that interview process with Hallett Smith when I was applying to Caltech [Session 1], and I thought it would be a neat committee to work on. And also in those days you could get excused from one term of teaching if you served on that committee, because it was really a lot of work. I'll tell you about it. The way the committee worked in those days—this is the late eighties—the faculty really were the key element in evaluating the applicants, and we traveled to interview them. I believe there were around eighteen faculty members on the committee, and they each were responsible for covering a portion of the U.S. I was replacing somebody else, so I ended up with Florida, Alabama, Mississippi, Tennessee, and Georgia—the Southeast.

ASPATURIAN: The Confederacy.

LEONARD: Right. In those days, we would only get about 2,000 applications.

ASPATURIAN: The freshman class was about the same size as it is now, though.

LEONARD: Pretty close. So I might have maybe 100 files to look at—no more than 120. Each file already had some kind of numerical score, because there was some index—I can't remember whether it had a name—that was based on their SATs and their grades and whatever numbers the admissions staff could crunch. So there was that kind of thing to help you get started. And from those numbers, they would evaluate my set of files and say, "OK, you can admit so many yourself—period, no questions asked. And you have to fight for the rest of them with the other members of the committee." So we would get started on that, and then we would go visit these high schools. You have to meet with all the applicants; you can't just say, "I'm going to talk to so-and-so." I think I visited twenty-four high schools.

ASPATURIAN: This would all be in the space of a couple of months, right?

LEONARD: What would work for me is to take a full two-week trip and visit two or three high schools each day. In Miami or Atlanta, that's pretty easy, but some places it's not so easy. But I thought that process was really good. Some students looked good on paper, but you could tell a lot more in person. Just to give you an example, there was some guy I visited who couldn't talk to me. He had no ability to communicate at all. I thought that was not a good sign. And then there was another case where I was looking at somebody in Florida who didn't look very good on my list, but I was really impressed, because he was taking care of his sick brother and he was doing this and that. So we admitted him, and he did very well, and he went on to get a PhD from Caltech.

ASPATURIAN: How interesting. His grades and scores were not impressive?

LEONARD: He wasn't that impressive that way. I always thought it was a good recruiting strategy to show up at a school. And the counselors would be impressed—here comes somebody from Caltech. So there was that plus, also. It took two weeks of my time but I didn't mind it. It was kind of different, you know.

ASPATURIAN: How many years were you on the committee?

LEONARD: I did three or four years that time, and then I did another three or four, and then I believe I did another three or four. So I did maybe nine or twelve years altogether.

ASPATURIAN: I think it would be interesting to put something more into the record about the deliberations for admitting Caltech freshman. There's not a lot out there.

LEONARD: Sure, that would be fine. Over my first three or four years with the committee, the chairman, Mike Hoffmann [Irvine Professor of Environmental Science], decided that these traveling faculty interviews weren't going to work anymore. He claims he couldn't find enough people to serve on the admissions committee because the trips were too time-consuming, and maybe he was right. I remember there was a lot of discussion about changing over to a system where you didn't visit applicants before admission. So they transitioned to a slightly different scheme, where you could volunteer to go to receptions to meet students who had been admitted but hadn't committed yet. So, for example, I'd go to Texas because my daughter lives there. We'd go to, say, Houston, Austin, and Dallas, and the admissions staff would set up a coffee or after-dinner meeting with all interested admittees and their parents. I'd give a little slide show, and I'd answer questions.

ASPATURIAN: But this meant that the opportunity to assess applicants in person was gone.

LEONARD: All gone.

ASPATURIAN: Do you think that was—?

LEONARD: Oh, no, I missed that. I thought it was good, and I was sorry to see that system go. So that was kind of how they transitioned into that mode. I haven't served for several years, but during my most recent term on the committee, I saw that they do get some of the students involved, reading folders.

ASPATURIAN: That's what I understand.

LEONARD: Some of them put a lot of good work into that, and also they still get faculty to read folders. But the staff read folders too, and I'd say the admissions director and the staff have become much more important. I don't know what they do about traveling to visit students. The alumni in the Gnomes say they are willing to go meet with admitted students, but I don't know how far that has gotten.

ASPATURIAN: But nobody goes and talks to applicants anymore in any systematic way?

LEONARD: No, not to their own hometowns. That's long gone, as far as I know. Unless they can get alumni to do that. But I don't think they like to get alumni involved in that sort of thing officially—maybe unofficially. There's another story connected to this. The admissions director had left, so they got me to chair an admissions-director search committee.

ASPATURIAN: What year was this?

LEONARD: I wish I could tell you. [Laughter] [It was 1991. *–Ed.*]

ASPATURIAN: Do you remember who'd left? Was it Dan Langdale?

LEONARD: I believe it was.

ASPATURIAN: He went back to MIT, I think.

LEONARD: Yes, he came from MIT, and then he went back. Well, anyway, Jack [John] Roberts [Institute Professor of Chemistry, emeritus] was on my committee, and so was David Elliot [professor of history, emeritus; d. 2007]. I remembered David from my undergraduate days. We had a couple of good students and maybe a staff member. Anyway, we found this gal from USC, Carole Snow. She was terrific.

ASPATURIAN: She had been the graduate student of the father of my best friend from high school.

LEONARD: The graduate student of the father of your best friend from high school? No kidding?

ASPATURIAN: Carlfred Broderick was her advisor. Anyway, go on, I'm sorry. It's a small world.

LEONARD: We were really pleased to get her. But then, after she arrived on campus, good old Gary Lorden [professor of mathematics], vice president of student affairs, decided to add another layer to his hierarchy. So he had an assistant vice president who would oversee the admissions director instead of having the admissions director report directly to him.

ASPATURIAN: Would that be Jeanne Noda? No, I think she was earlier.

LEONARD: There was a Jeanne Noda, but I think it was—Sharon? Sharon Something. [It was Sharon Slavin. –*Ed*] Anyway, this is a bad thing for Carole Snow, because Carole and this gal who's now going to be her boss had been equals at USC, so Carole was not happy. She left for Illinois Institute of Technology. But later on, we had another situation. Remember Rick [Richard] Bischoff?

ASPATURIAN: Yes. He left a few years ago.

LEONARD: He left because he got this wonderful offer from somewhere else [Case Western Reserve University], and there was no way we could match it, according to my sources. This is all conjecture on my part, but had he been up at this level, maybe we could have kept him. I think Anneila Sargent [Bowen Professor of Astronomy; vice president for student affairs, 2007-present] might finally have corrected that situation.

ASPATURIAN: I talked to him for a couple of stories. He seemed very smart, I thought.

LEONARD: Oh, he was very good. I did one of my terms on the committee with him as admissions director. I remember that. He was very good.

ASPATURIAN: How do you think the students Caltech admits now compare to the ones who were admitted during your first circuit on the committee?

LEONARD: You know the competition has gotten so fierce. You have to have a lab with a Nobel Prize winner when you're in high school. Oh, jeez. It really is something. But one thing I noticed—they always want to get more women, more minorities, but, at least during my periods on the committee, we never hedged on that. They had to be totally qualified. And I think that was good, because you don't want people coming and then failing just because there are numbers that you want to attract.

ASPATURIAN: It's interesting that you say that. When I came here in 1984, I remember that there was some muttering among some of the undergraduates and a few of the faculty that Caltech was lowering its standards to increase the number of females who were admitted. And I remember talking to some of these students—Eliza Sutton, Candy McCoy, Minami Yoda—and they were exceptional.

LEONARD: I remember Minami Yoda.

ASPATURIAN: Oh, gosh, she was an impressive girl. You knew her?

LEONARD: She's now at Georgia Tech [professor of fluid mechanics].

ASPATURIAN: Can I digress for a moment?

LEONARD: Please.

ASPATURIAN: In '84, I wrote a story about a group of SURF students and their projects, and she was one of the students. She was working on some sort of fluid-mechanics problem, I think. She explained it to me so clearly it just blew me away, and I subsequently discovered that she was sixteen years old. I nearly fell through the floor! I've never forgotten her.

LEONARD: We've never had a problem with lowering standards—I mean, during my ten to twelve years everybody we admitted pretty much was top-notch.

ASPATURIAN: It was interesting that this kind of grumbling took place.

LEONARD: I don't believe it was justified. At least from my viewpoint, I don't believe it.

OK, what else, that first couple of years? I started to think about how I was going to get grant money to support my students. The very first thing I got was from Herb Keller [professor of applied mathematics, d. 2008]. He was in applied math and had some kind of a grant—some computation thing from the National Science Foundation, I think—that he was kind enough to stick me on; so that was a source of support for a while. I also got on a committee, chaired by Aron Kuppermann [professor of chemical physics, emeritus, d. 2011], which was supposed to look into the future of computing at Caltech. That was good.

ASPATURIAN: Was this also in the 1980s?

LEONARD: In the late eighties. And eventually our committee [Administrative Committee on Supercomputers] went to the administration and told them we wanted to raise some money to get a large computer for Caltech.

ASPATURIAN: Were you looking at what was going on in Booth [now Powell-Booth Laboratories for Computational Science] and [Earle M.] Jorgensen [Laboratory]?

LEONARD: That's right. The administration said, "Fine, you can try to do that, but—" Who was the chair of Intel?

ASPATURIAN: Gordon Moore? [Caltech alumnus Gordon Moore cofounded the Intel Corporation, served as chair of the Caltech Board of Trustees, 1993-2000, and is now trustee chair emeritus. *–Ed.*]

LEONARD: Gordon Moore, right. They said, "Don't touch Gordon Moore." But he was the guy we wanted to approach, because we had designs on a big machine.

ASPATURIAN: Why did they not want you to approach him?

LEONARD: Well, they had their own plans for him. [Laughter]

ASPATURIAN: Of course.

LEONARD: But anyway, somehow we ended up with this Intel computer, the Intel Delta, which was, for a few weeks, the most powerful computer in the world.

ASPATURIAN: For a few weeks?

LEONARD: Yeah, because people were building new ones all the time. It was only a few weeks.

ASPATURIAN: You wanted a machine that could do really powerful computational stuff?

LEONARD: Yes. So I had one or two students use it, pretty successfully. But then it kind of died out, because these things get old fast.

ASPATURIAN: I remember something else from around that time, called the Cosmic Cube. Geoffrey Fox used that, I think, and some other guy who also left.

LEONARD: There was a physics professor—

ASPATURIAN: Chuck [Charles L.] Seitz?

LEONARD: And Chuck Seitz. Yeah, Seitz was kind of the inventor of that, I believe. And this physics guy—

ASPATURIAN: I think that might have been Geoffrey Fox.

LEONARD: Geoffrey Fox! Very good. He was a big promoter of that, and he had a lot of good ideas, too. He finally left and went back East somewhere. And Chuck Seitz had his own company.

ASPATURIAN: Did you ever use it?

LEONARD: Did I ever use the Cosmic Cube? I had a colleague at JPL [Jet Propulsion Laboratory] for a while, and he and I did something simple on it—I don't remember what. Anyway, out of this Kuppermann committee, we finally got our act together and went to the National Science Foundation and said, "Look, we have this big machine, but it's very poorly understood how to use it efficiently." So we managed to get a nice NSF grant for three or four years, and that helped all of us use this new machine more efficiently.

ASPATURIAN: Did it allow you to hire somebody?

LEONARD: Grad students and a postdoc.

ASPATURIAN: I see, who could kind of demystify it.

LEONARD: Right. So that was another example of where I kind of got together with a larger group. That seemed to be my mode of operation for many of the years I had grad students. Here's another example, starting in the late 1990s: There's a professor at USC named Fred Browand, and he had some colleagues at Lawrence Livermore. And they had this notion that we should take a look at truck aerodynamics and maybe design a more fluid-dynamically efficient truck. The only thing that trucks had going for them at that point were these shields over the cab that kind of deflect air up and over. And that is a big deal, actually. But there were all kinds of other gadgets that were being promoted as energy-saving and drag-reducing. But who could say whether they worked or not? So we managed to get fairly long-term support from the Department of Energy. This was a large group that included USC, Caltech, NASA Ames, and Lawrence Livermore.

ASPATURIAN: Did you come up with new designs?

LEONARD: [Laughter] Well, at least through all this effort, we did manage to show the quantitative effect of putting flaps on the rear of the trucks. In other words, if you put these flaps on instead of having just a squared-off rear end, you can save quite a bit more in fuel.

ASPATURIAN: It reduces drag?

LEONARD: Yes. And some people use them now. And if you put skirts on the wheels instead of having the wheels rotating in the air, that helps a lot too. I think some of that stuff is being used, because it does help a lot.

ASPATURIAN: It's interesting that you mention it, because trucks are the most common means of transporting cargo in this country.

LEONARD: That's right.

ASPATURIAN: If they have nothing but this kind of sloped hood on the cab all these years—

LEONARD: Yeah, that's right. But some truckers don't like the looks of those things—and they don't care that much—and so they just have these big funny things on their hoods. Another kind of nice thing I had going was with a guy named Ari Glezer at Georgia Tech. Ari is a former student of Don Coles at GALCIT, and he has a really nice experimental program at Georgia Tech with different kinds of flow control. He wanted to go to the Air Force with a big proposal, and he needed a team of people to do this work. He had a control-theory person from Georgia Tech, a heavy-duty computational person from Illinois, and he needed somebody like me to do some fluid-mechanical modeling. That worked out, and we actually got two different grants.

ASPATURIAN: What time period are we talking about?

LEONARD: This is starting ten years ago [c. 2002] and finally ending only two years ago, because of the proposal stage and the fact that we had two different grants. So this helped support some more students.

ASPATURIAN: Did the balance of your research relative to seeking funding for student support alter over the years, or has that been pretty consistent?

LEONARD: Pretty consistent. I would always take the minimum path, the quickest path, to get money. I wasn't trying to cheat the agencies—in fact, some of my students were so good that they could do the job that the contractor wanted and still have enough time to do whatever independent research he or she wanted to do. That worked out fine, because everybody was happy.

ASPATURIAN: Who are some of your most memorable students? Or the ones who did particularly interesting work? Where they are now?

LEONARD: Probably the one I keep in touch with most is Petros Koumoutsakos [PhD 1992]. I latched onto him when he was in the graduate fluid-mechanics class I taught one year in the late eighties or early nineties. He was originally from Greece, and he'd gone to the University of Michigan to study naval engineering. But he didn't like naval engineering at Michigan, so he got a master's and then came to Caltech. I took him and another Greek guy in the same class—Tasso Lappas—on as grad students, and they stuck with me. Petros now has a chair at ETH Zurich, and he likes to come to Caltech for a couple months during the winter and just teach a class and do some research. So he's coming again in January [2013]. And I go back there every once in a while to spend a couple of weeks with him. In fact he was one of the organizers of this thing [the Anthony Leonard Seventieth Birthday Celebration].

ASPATURIAN: There he is. In fact, he seems to be the fellow who wrote this about your surfing and football.

LEONARD: OK, thanks, Petros. [Laughter] Tasso Lappas is a different story. Tasso was also a very brilliant guy, and after his PhD [1993], he went to work with Disney.

ASPATURIAN: That's a different career path.

LEONARD: Well, his first job was [the animated feature film] *Pocahontas*. They had the Pilgrims coming over across the Atlantic. His job was to make the waves look realistic.

ASPATURIAN: That's what you do with a Caltech PhD?

LEONARD: Well, yeah. It sounds like something for a computer-science person, but he was so good that he convinced Disney he was good at this sort of thing. What do you call it? Computer graphics.

ASPATURIAN: I guess so, but it sounds like it went somewhat deeper.

LEONARD: Well, the fluid-mechanics part helped him with that job. He was a very skilled computational person. Extremely adaptable. He eventually went to work for some other special-effects lab, and now he contracts out his own work to these people. He doesn't feel like working full time. That's a different path than a hard-nosed professor who does the usual professor things.

ASPATURIAN: One of the things I've noticed, hearing you mention these two students, is that over the years there seem to be a number of Greek faculty and students in aero and fluid dynamics. There was a professor named George Gavalas [professor of chemical engineering, emeritus].

LEONARD: Yeah, I know George.

ASPATURIAN: I wondered what the connection was. And now, of course, the chair of your division [Ares Rosakis, Von Kármán Professor of Aeronautics and Applied Mechanics, and chair, Division of Engineering and Applied Science] is originally from Greece as well.

LEONARD: Well, I think the same thing happened with Canada for me. I had a few French Canadian and non-French Canadian grad students coming to me early on, and I ended up getting more applying. They were especially valuable to me, because early on they brought their own fellowship money. So that was really nice, but I think Canada sort of eliminated that after a while. And so I think perhaps the same thing happened here—word gets around. I don't know too much about George. I know he's in chemical engineering.

ASPATURIAN: Right, right. Different area.

LEONARD: [Paul] Dimotakis [Northrop Professor of Aeronautics and professor of applied physics] was a key player for Tasso Lappas, because Paul had a really nice grant from the Air Force, and I didn't have money for Tasso. But Dimotakis and I knew that Tasso was a terrific guy, so Paul was nice enough to take him on and finance Tasso. So that was good.

ASPATURIAN: From how many different agencies did you receive funding for projects over the years?

LEONARD: We also had a long-standing grant from the Office of Naval Research—due mostly to Anatol Roshko [Von Kármán Professor of Aeronautics, emeritus], who had a long history with ONR. And, of course—same old thing—the old days were wonderful. I guess Anatol would say he knew the ONR contract officer, and they were all very sharp people, and they would tell Anatol to just write them a paragraph.

ASPATURIAN: Those were the good old days.

LEONARD: But we went through several of these ONR guys, and we had a long grant with them on what's called fluid-structure interaction. You have some kind of a structure that by itself is usually not very interesting, but if you run a fluid past it, it can start vibrating, and all kinds of bad things can happen.

ASPATURIAN: Can you give a concrete example?

LEONARD: Well, there's a fighter called the F-18, and the tail included these two semi-vertical wings at the back. Under certain flight conditions there'd be a very strong vortex that would come off the leading edge of the primary, horizontal wing and shake this vertical tail. In the early days you'd get a failure. I mean the tail would just break off.

ASPATURIAN: Oh, my gosh!

LEONARD: So they finally figured out that they could semi-fix the problem by putting a certain device in the front to make sure this vortex stayed kind of controlled instead of wobbling all over the place.

ASPATURIAN: In the front of the plane, you mean?

LEONARD: In the front of the plane, yes, near the front edge of the wing. Another example is the San Onofre power plant problem, which I mentioned last time [Session 2]. This is most likely a fluid-structure problem where you have these tubes that carry hot fluid and you want to exchange the high-temperature fluid with the other fluid that is moving past these tubes. And if you don't design it right, these tubes start flopping around and bouncing into each other and cracking and breaking. Yeah, it's a big business. Mory [Morteza] Gharib [Liepmann Professor of Aeronautics and Bioinspired Engineering] was in on this, too, for a bit, with Anatol and me. We have a string of students who went through and did some really interesting stuff. Two of them were actually experimentalists, and so I ended up being the advisor to experimentalists.

ASPATURIAN: Were they working with the wind tunnel?

LEONARD: A water tunnel. I also had my own Air Force grant for a while—a real nice grant—then Congress got into the picture. They noticed that all these Air Force grants were going to California, a whole lot of them. And they had to pull back. They actually removed our grant.

ASPATURIAN: For political reasons?

LEONARD: Yeah. They had to take our grant away. I thought that was amazing.

ASPATURIAN: When was this?

LEONARD: Oh, this is probably in the early nineties.

ASPATURIAN: That must have been upsetting. Purely for political reasons?

LEONARD: Absolutely. No question.

ASPATURIAN: The NSF?

LEONARD: Only through this Herb Keller thing and this grant I mentioned earlier that we received to use the Intel Delta machine efficiently. Another large grant I got involved with was with Dan Meiron [Jones Professor of Aeronautics and Applied and Computational Mathematics] of applied math—he's now in aerospace. He headed up a team that went after some money from the national labs. This was a project having to do with stewardship of our nuclear arsenal. Of course we didn't get directly involved with that, but the national labs—Los Alamos, Livermore—are always trying to use computer codes to predict what's going to happen under very extreme conditions.

ASPATURIAN: So they try to simulate various disaster scenarios?

LEONARD: They try to simulate all kinds of— Well, we didn't get involved in that, but we would get involved in, you know, if you take a chunk of material and blast it into a plate, what would happen?

ASPATURIAN: So like if someone decided to dive-bomb a nuclear reactor, would that be an analog to what you were doing?

LEONARD: [Laughter] Well, it could be, yeah. They have codes that try to predict these really hard-to-predict situations. And my own feeling was that the national labs wanted to make sure that there were people coming along to fill lab positions who at least had a good start on understanding what was going on and who could use these big codes.

ASPATURIAN: So what was your role in this?

LEONARD: I just picked off a little piece of the project. They allowed us quite a bit of latitude in the kinds of topics we would pick, so long as what we were doing looked promising. So I was interested in how fluids mix—coming back into this dynamical systems and chaos work. If you

put a blob of dye, say, in a fluid, how does it get transported around? I had a student working on a model—this is extremely hard to compute also, because it's hard to keep track of interfaces. You can imagine having a computing grid that's, say, 100 by 100 by 100, and you have these interfaces between the dye and the fluid—how does that interface move through this grid?

ASPATURIAN: So this would be an analysis of what we'd think of as a superficially simple thing, like dye spreading through water?

LEONARD: Yeah, or just putting cream in your coffee and stirring it.

ASPATURIAN: Really, and it turns out to be immensely complicated.

LEONARD: Well, it's very difficult to predict where things are going to go.

ASPATURIAN: Can it be predicted?

LEONARD: Well, it can if you have enough computing power, and you know exactly the initial conditions. But we were attacking it from the angle of supposing you don't have enough computing power. It goes back to the large-eddy-simulation work I did quite a few years ago, and which I talked about in maybe our first or second interview [Session 2]. It's a similar problem, because since you don't have enough computing power to see where this stuff goes, you have to model some of the interactions that you aren't able to follow.

ASPATURIAN: So the question is, how do you fill in the blanks?

LEONARD: Yes. So I had a student working on that. This is a topic of interest, because if we come up with a reasonable technique to handle this problem, they presumably could apply it to these more complicated situations.

So that program lasted quite a while, and now Michael Ortiz [Marble Professor of Aeronautics and Mechanical Engineering] has another, similar one. This first DOE program had a competition early on, and then they narrowed it and asked each of the finalists to make a large proposal. So Caltech was fortunate enough to get one of the five major grants that they handed

out. They had to get renewed after five or six years, and after eleven years it's over. But then they started another competition, and Michael Ortiz was able to get another large grant for Caltech, but I'm not part of that.

ASPATURIAN: What was DOE's specific interest in this?

LEONARD: Well, it could be Congress again: Congress or whatever committee funds the national labs told them, "OK, we're going to give you a huge amount of money to study the so-called stewardship problem. But we want you to take ten percent of that money and give it to the universities." The numbers are like, I don't know, $250 million. "So you better give $25 million, not in one year, but over so many years." I don't know what the deal is on the next round.

ASPATURIAN: Interesting. Too bad you can't model those policy deliberations.

LEONARD: You're asking the wrong guy. I think it's just that you can't test these things anymore. And they know they're deteriorating, so what should be done about them? Are they going to work if we need them? Like I said, they also want some young blood to come back to start working in the labs.

ASPATURIAN: So are these codes that they still rely on considered to be provisionally obsolete, and they don't know what to do about it?

LEONARD: Well, I think the codes always need improvement.

ASPATURIAN: This is not terribly reassuring.

LEONARD: The real devices themselves, who knows? They have a certain lifetime, and they don't know what to do. That's what I think.

ASPATURIAN: What devices are we talking about?

LEONARD: The nuclear devices—the bombs. Someone like Steve Koonin or Dan Meiron would be a lot better at explaining this. [Steven Koonin, formerly a professor of theoretical physics at Caltech, served as the institute's provost from 1995-2004. *–Ed.*]

ASPATURIAN: I did an oral history with Tom Tombrello [Kenan, Jr., Professor of Physics] a couple of years ago, and I remember he talked about this. Koonin was involved to some extent also.

LEONARD: I know Koonin worked most recently for the Department of Energy.

ASPATURIAN: He was the DOE undersecretary for science.

LEONARD: Yeah, then he took off.

ASPATURIAN: Now he's at NYU [New York University]. He's got his own think tank.

LEONARD: He left Caltech to become chief scientist for BP, right?

ASPATURIAN: Yes. Then to DOE for a couple of years. I don't know why he left. Maybe he felt he wasn't getting anything done. The bureaucracy must be fierce. But I heard recently that Steve [Steven] Chu [Nobel laureate, secretary of energy, 2009-2013] wants to leave also.

LEONARD: Oh, is that right? Because he's the one who probably convinced Koonin to come.

ASPATURIAN: Probably. It's been an hour. Shall we stop here?

LEONARD: Yeah, why don't we.

ANTHONY LEONARD

SESSION 4

November 21, 2012

ASPATURIAN: When you came to Caltech, you were hired directly by GALCIT, is that correct?

LEONARD: Yes.

ASPATURIAN: And who was the director at that time?

LEONARD: Hans Liepmann.

ASPATURIAN: Do you have particular recollections of Hans? I think I asked you about him last time, but we went on to something else.

LEONARD: Yes, I certainly do. Well, he's quite a character, and he seems to have a lot of favorite people he likes—and then he either likes you or he dislikes you. That's what I think. He wrote a really interesting autobiography that's floating around somewhere; I don't know what the status of it is. He has quite a background. Did anyone do an oral history with him?

ASPATURIAN: I believe so.

LEONARD: Most of it's covered, I suppose.

ASPATURIAN: How did you find him to work with? Did you have much contact with him?

LEONARD: Not as a research colleague. On other topics he was certainly easy to deal with. I had the feeling when I was hired that he had a big say about who was going to be hired and who wasn't. It seems to be much different now. The committee of five people who do the searching can come up with their favorite candidates, but it's still quite an effort. They have to make a really good case for this or that person to get it all the way through the system. That's my

feeling anyway. But I just have the suspicion that Hans had such a powerful say in matters that he could say, "I think we should hire so-and-so." So I guess I'm thankful for that.

ASPATURIAN: Do any particular anecdotes about him come to mind?

LEONARD: [Laughter] Well, he and Don Cohen [Powell Professor of Applied Mathematics, emeritus] were always kidding each other. I think they had a great relationship. After Hans retired, while Cohen was still teaching, Hans came back to give a lecture on the physics of tennis, with Gene Broadwell, a longtime research associate at GALCIT. I think someone actually videotaped it. Sometime during or after the seminar, Cohen came up to Liepmann and said, "Professor Liepmann, I heard you used to work here." And in a flash, Liepmann says to Cohen, who is still supposedly an active professor, "Well, I heard you did, too." So he had a quick wit. After he retired, he actually took a small office next to mine, and he would come in every once in a while. And he had this funny little push toy. It was a little duck that flapped its wings and made a quacking sound, and he said that he had threatened the administration that if they didn't do whatever he thought was right, he'd walk around campus with this thing. Another thing I remember is that he and somebody else within GALCIT proposed a course. If you read the whole course description, it was total nonsense. But somehow they managed to get it all the way through up to some high level as a new course. It was just a joke.

ASPATURIAN: It was done as a hoax?

LEONARD: Yeah. I'll see if I can find the course description.

ASPATURIAN: Yes, we could add it to your oral history. That would be fun.

LEONARD: So this was typical Liepmann. I think his mode of operation when he was still active was that he'd get up really early—I don't know, like four o'clock in the morning. And then he'd work on stuff—his own research, whatever he was interested in—until about eight or nine. Then he'd come in and do his GALCIT directorship duties and leave right at five.

ASPATURIAN: Very organized.

LEONARD: Probably a good plan.

ASPATURIAN: He was succeeded by Hans Hornung [Johnson Professor of Aeronautics, emeritus, GALCIT director, 1987-2004], is that right?

LEONARD: Yes. That's right.

ASPATURIAN: Did you work with him?

LEONARD: Again, not directly. But I'd gotten to know him quite well. He's in Zurich right now getting an honorary doctorate. There had been a search committee for a director to succeed Liepmann. At its formation, which must have been in 1986, some rumor or threat went around that they were going to eliminate this position. Apparently a lot of GALCIT alumni sent e-mails and letters and made phone calls to the administration to say this would be a big mistake. So they did hire Hornung as the director. I think he was a great choice.

ASPATURIAN: Whom did you work with most closely on the faculty during your years here?

LEONARD: Well, probably the longest working relationship I had was with Anatol Roshko. But smaller bits with Allan Acosta—I worked with him and a student named Doug Hart, now at MIT, Tim Colonius [professor of mechanical engineering], and Dale Pullin [Von Kármán Professor of Aeronautics].

ASPATURIAN: That's a familiar name.

LEONARD: Yes. When I got hired here, they promised me a colleague who was interested in computation. So Dale came from Australia—Queensland—and he's been very good. We have some areas where we overlap quite a bit, but then he does a lot of things that I don't get into. He and I shared a graduate student, Mark Brady [PhD 2000], so we split the duties pretty evenly with Mark. That was a lot of fun. I mentioned Dimotakis. And Ares Rosakis and I taught a class together, which was also a lot of fun. It was in the fundamentals of mechanics.

ASPATURIAN: Was it a graduate or undergraduate course?

LEONARD: It was a 100-level course, so either one, but mostly graduate students. I did the fluid-mechanics part, and Ares did the solid-mechanics part, but there are a lot of fundamental equations that both use as a basis. So it was pretty good. I enjoyed it quite a bit.

ASPATURIAN: What else did you teach?

LEONARD: I think I mentioned undergraduate and graduate fluid mechanics and sort of a post-master's class in computational fluid mechanics. And one year I taught a post-master's class in advanced fluid mechanics. Dale Pullin had taught that before me, and he had some really nice notes that I could use, which is always extremely helpful. Then I taught a course in dynamics, control, and stability of aircraft, which Brad [Bradford] Sturtevant [Liepmann Professor of Aeronautics, d. 2000] had taught.

ASPATURIAN: Would that have been a little more applied than what you usually did?

LEONARD: Yeah, oh, yeah. Especially the aircraft aspect. But somehow I'd promised to teach this because of Fred Culick [Hayman Professor of Mechanical Engineering and professor of jet propulsion, emeritus]. It was kind of his baby, and then he retired, and Brad Sturtevant was interested in teaching something else. They were looking for volunteers, and so I volunteered.

ASPATURIAN: Did you enjoy it?

LEONARD: Yes, I did. It was a lot of work to teach a new class.

ASPATURIAN: I wondered about that.

LEONARD: I had about ten students—it was about half undergrads and half grads. I remember one of the undergrads was really good, although I don't know what happened to him. OK, and here's another class I taught. After we revamped the core curriculum—

ASPATURIAN: Yes, I want to get to that.

LEONARD: We were concerned about the math preparation of freshmen who came to Caltech. The ones who had a really good calculus background and were good at calculus could go into the regular program. Then there were a group of students who never had calculus.

ASPATURIAN: You have students at Caltech who've never had calculus?

LEONARD: Well, we did when I was teaching this class, about seven or eight years ago. There weren't many of them, but they got their own class and presumably they could catch up. But then there were quite a few students in between. They had taken calculus in high school, but they had had bad teachers, or they didn't quite get it. So we offered this new course. It was called Math 8, and I was the first instructor, as far as I know. It was kind of fun. The students got three credits, and there was no homework, but it was two days a week. Eight-thirty to ten, they'd come to my class, and then at ten they'd go off to their regular calculus class. It really was pretty successful, I think. I would give a short lecture on what's being covered, and then we'd have the students do problems on their own or with their little groups and present their work on the board.

ASPATURIAN: So that way they could head off to the next level of calculus with a refresher?

LEONARD: Exactly.

ASPATURIAN: That sounds like a very good idea.

LEONARD: All they had to do was show up two-thirds of the time to get credit.

ASPATURIAN: I imagine a lot of them were really happy to be able to do that.

LEONARD: I think so, yeah. It seemed to work pretty well for most of them. For some of them, it was kind of early in the morning. [Laughter] So after I taught that for a couple of years, Gary Lorden taught it. I don't know what's happened to it. I hope it's still being offered.

ASPATURIAN: Sounds like it was a very good idea.

LEONARD: Yes, I think so.

ASPATURIAN: I wanted to ask about the evolution of GALCIT. Its research directions have changed in the last couple of decades.

LEONARD: Yes, they have.

ASPATURIAN: What do you think of it?

LEONARD: Right now, it's quite an interesting mixture with the addition of, I'd say, bio-fluid mechanics.

ASPATURIAN: [John] Dabiri [professor of aeronautics and bioengineering] and his jellyfish?

LEONARD: Dabiri and his jellyfish, and Mory Gharib and the fluid mechanics of the heart, even looking at the heart of an extremely small fish with a guy in biology [Scott Fraser, now at USC]. And then Joe Shepherd [Johnson Professor of Aeronautics and Mechanical Engineering] is off doing a lot of detonation. He's also interested in fluid-structure interaction of a type that is much different than what I do: If you have a detonation going down a tube, how does the tube respond? Does it break? Or things like that. When Hornung came, he built this fantastic structure—it's called a shock tunnel—on the roof of GALCIT. That's still being used, because it's a unique facility. They have several versions of it in Australia—Hornung came here from Australia—and they still use it here because it can produce extremely energetic flows. It's not so hard—although it's not trivial either—to get high Mach number in a test facility, but it's very hard to get reasonably high Mach number and also flows that have lots of energy in them. This facility does that.

There are also topics that stay really interesting and don't go away. When I came, Don Coles was especially interested in boundary-layer turbulence, and now we have Beverley McKeon [professor of aeronautics], who does boundary layer turbulence but with a new twist to it. She does a lot of interesting stuff. And then with the solid-mechanics group, there were

several years where they were really into crack propagation and crack initiation and how things started tearing apart. Rosakis picked that up and connected with the earthquake people. There are some earthquakes that are supersonic in some sense, and he made a nice collaboration there with some of the people in earth sciences.

ASPATURIAN: It's amazing how you can do that at Caltech.

LEONARD: Yeah, that's the beauty of the place. So, now, in the solid-mechanics group there's also Michael Ortiz, who came maybe ten years ago, and he's very big in computational methods for solid mechanics. I mentioned last time [Session 3] this contract we had with the Department of Energy that looked at things of interest to the national labs. Now Ortiz has the next version of that, and he's running a five-year program that they hope to get renewed.

ASPATURIAN: What do you think about the move into bioengineering? A good direction, in your opinion?

LEONARD: Oh, well, I think so, yes. It's just that I don't know too much about it. Along with Mory Gharib and John Dabiri, there are some really serious biologists who are in that group, too. I'm not sure what they do. [Laughter] You just can't cover all the interesting bioengineering problems. And as long as it makes sense to do what you're doing, I think it's good.

ASPATURIAN: It seems to be a big field in a lot of places. There's major growth in it as a discipline, I think.

LEONARD: Well, I just got back yesterday from the American Physical Society fluid-dynamics meeting, and there were thirty-three simultaneous sessions, and many of them were in bioengineering. They had a session in large swimmers and medium swimmers and micro swimmers and flapping animals. [Laughter]

ASPATURIAN: Exploring a lot of niches, aren't they?

LEONARD: It makes sense, because there are some things that animals do that we could take advantage of; we just don't know how to do it yet. In fact, some people say we can actually do better than they do if we're really clever. It may be true.

ASPATURIAN: It's a whole new area to explore, it's true. One of the things I saw in your birthday celebration flyer is that your former student talked about how your research had applications in fields ranging from plasma physics to computer graphics to astrophysics.

LEONARD: [Laughter]

ASPATURIAN: I assume the computer graphics reference was about your graduate student [Session 3] who went to Disney.

LEONARD: I think that's where it came from, yes. There are some things that we do that they perhaps took advantage of. A couple of years ago, I had a chance to visit one of my former postdocs, Ron Henderson, who works for DreamWorks [Animation], just over here in Burbank. He had one of his people working on a new idea to create smoke—you know, if you have a fire, you have the smoke coming up, and they have a heck of a time getting smoke to look realistic.

ASPATURIAN: Making the smoke rings look correct?

LEONARD: Well, just anything looking reasonable. He said they tried using vortex elements, and he showed me what they did, and it's so simple, and it looked good. The vorticity, I'm sure, in one of these real flames is pretty complicated, but all they did was to take a few sticks of vorticity—they don't show it, of course—and those sticks of vorticity cause the smoke to do interesting things. I thought that was pretty clever, and it works for the person looking at the movie.

ASPATURIAN: Right. It creates the illusion.

LEONARD: I don't know about plasma physics. I guess some of the things we do could apply to plasma physics. You just have to add a few bits and pieces to get everything right, but I've never done it myself.

ASPATURIAN: And the reference to astrophysics?

LEONARD: [Laughter]

ASPATURIAN: Galaxy formation, maybe? Solar nebulae?

LEONARD: Yeah, I mean these things can sometimes be attacked by what are known as particle methods. The simplest example would be instead of little elements of vorticity representing a fluid flow, you can have little elements of mass that are starting to form a galaxy. Almost the same computational methods can be used that we use. Of course, it's pretty simple to imagine: Everybody knows how two masses interact, so if you went through all this groundwork to produce a heavy-duty code to do vorticity, you can do mass particles too. So perhaps that's the idea.

ASPATURIAN: Have you ever worked directly with any people in astronomy or planetary science or at JPL?

LEONARD: I did, but I've never coauthored a paper. There was a guy in the Caltech Center for Advanced Computing Research—John Salmon—who came out of the physics department, I think [PhD 1991]. He did some of this galaxy-formation work, and he won a big computing prize one year because he had managed to compute the interaction of zillions of mass points and show how they might form a galaxy.

ASPATURIAN: Pretty impressive.

LEONARD: Oh, yeah, it was impressive. He was responsible for developing some of these particle methods that we wanted to use in our group, and one of my grad students, Greg Winckelmans, worked with him to transfer some of that. So Greg was working with John, and

learned all of his stuff, and managed to transfer some of it over to our area. So that was very useful.

ASPATURIAN: Probably a little different, too. Of all the areas of research you've been in—and there are clearly quite a number—was there one project or problem that you found most rewarding?

LEONARD: Well, let's see. A couple of examples, but I'm not sure I have a favorite. One is the work I did with Roshko and our students, and to a certain extent Mory Gharib. That had to do with some basic problems in fluid-structure interaction, where you had flow past a body that could somehow vibrate—and trying to understand the mechanisms for when this thing would vibrate wildly and when it wouldn't.

ASPATURIAN: Would that be like air moving over an airplane wing?

LEONARD: A little bit like that, except that this wing might be extremely flexible and might be subject to vibration. But it's a basic fluid-structure-interaction problem. We had several students do experimental work on it, and then we had computational people, and we had some really nice theory that came together to kind of explain the whole business as best we could.

ASPATURIAN: Does this have potential applications in, say, seismology or earthquake engineering?

LEONARD: No, I don't think so. Some people are thinking they can harness ocean-wave energy with some of these things. There are some proposals out there. Near the shore, of course, you have ocean currents coming in and going back out. The idea is that you have these flexible structures sticking up into the currents, and these structures could rock back and forth, and you'd harness some of the energy that goes into them. Most of the time, people are worried about destructive forces when things start to shake too much, so that's another application. I've had a lot of fun with working with a Georgia Tech group to try to understand this better, and I've had a student working on this with me, who has since graduated. But there's a multi-university grant that we had for five years to study some kind of advanced control device that you could use on a

wing to create more lift or more moment by a very simple flow-control device. It worked, but at the time nobody understood how. So we managed to model this whole process with some pretty simple vortex-mechanics ideas. And the nice thing was that eventually—it took a long time to get this thing to work correctly—we could give our results to people who design controllers to control the wing. It's not our business, but the control people just had really poor models of what was going on, so their control theory didn't work. So that worked out really well, I think. I'm perhaps remembering the more recent stuff.

ASPATURIAN: There have been several [engineering] division chairs while you were here. I'm trying to remember. Now it's Rosakis; before him it was Murray—

LEONARD: Richard Murray [Everhart Professor of Control and Dynamical Systems and Bioengineering]. And before him, John Seinfeld [Nohl Professor and professor of chemical engineering] and Paul Jennings [professor of civil engineering and applied mechanics, emeritus]. My offer letter came from Roy Gould [Ramo Professor of Engineering, emeritus], but by the time I was able to figure out that I wanted to come and my wife wanted to come too, it was Paul Jennings. Did I tell you this story? When we actually moved down here, in 1985, I complained to somebody that it was very nice for them to move us down here but I just had to pay for air freight for my dog and my cat. They sent me to—who's the gal that was in the provost's office?

ASPATURIAN: Sharon Bourbon?

LEONARD: Yeah, Sharon. They told me to go see her, and she filled out a travel order for my dog and my cat. [Laughter] I wish I had a copy of that.

ASPATURIAN: That's pretty Caltech.

LEONARD: Yeah. [Laughter]

ASPATURIAN: So, do you have a favorite among the division chairs?

LEONARD: Well, I know Paul Jennings pretty well. He's been great, no matter where he's located. The guy was provost twice. I didn't know Roy Gould that well. I talked to him scientifically every once in a while. I thought Seinfeld did a great job. When he was stepping down, I was coming back from my sabbatical, and somehow Steve Koonin convinced me to be the search committee chair for the next chairman. [Laughter] It was interesting. My committee split up, and we interviewed everybody in the division one-on-one, to see if they had any good ideas. So we ended up with four or five candidates we considered seriously, and we presented two of them to Koonin. I knew that Koonin already liked Richard Murray—you could tell.

ASPATURIAN: They were both undergraduates here.

LEONARD: Yes. And I remember that Tom Tombrello was very keen on Richard Murray, too. Anyway, so Richard became our chair. He had some things to deal with. I'm not sure some of my colleagues were real happy. We were trying to hire some new faculty at GALCIT, and somehow that didn't come about.

ASPATURIAN: What happened?

LEONARD: I don't know. Richard wanted to tread lightly for a while and see how things were going, as I recall. But eventually we hired some people. So I don't know if I have any favorites.

ASPATURIAN: How has GALCIT's relationship with the rest of the division evolved during the time you've been here?

LEONARD: I think it's improved quite a bit. When I came, I think for some reason there was some animosity between Liepmann and the rest of the division, especially mechanical engineering.

ASPATURIAN: That's interesting.

LEONARD: That's the feeling I had. They [mechanical engineering] felt like poor cousins, I guess, or something, but now it's much different, and I think much better. Many of our aero

people have joint appointments with mechanical engineering. There are some connections with applied physics. Dimotakis has a joint appointment there, although I don't know how much he participates in their discussions. So I think it's better.

One thing that's worth mentioning that is a little different now is the applied math group. When I arrived in 1985, they were extremely strong in fluid mechanics with [Philip] Saffman [Von Kármán Professor of Applied Mathematics and Aeronautics, emeritus, d. 2008] and Gerry [Gerald] Whitham [Powell Professor of Applied Mathematics, emeritus, d. 2014], and so forth. Dan Meiron. And then they decided—and they were probably right—that they'd spent a lot of time in fluid mechanics and would start getting into other topics. So they started hiring people in different areas. Still, it had been nice to have them close by in Firestone [Laboratory]. They occupied pretty much the second and third floor there, and now they're gone, which is kind of too bad. Actually, Tom [Yizhao Thomas] Hou [Powell Professor of Applied and Computational Mathematics] also had a lot of interesting background in vortex methods, so he was good to talk to.

ASPATURIAN: A lot of your work is theoretical and mathematical and computationally based. How does it differ from what an applied mathematician does in fluid mechanics?

LEONARD: Well, it's very similar. Herb Keller in fluid mechanics was another one I worked with. But, for example, Phil Saffman did some really terrific work in things that overlapped with my interests, but he'd be in what I would call the very highly idealized fluid mechanics. This is where Dale Pullin and Saffman got together a lot. They would collaborate quite a bit, because Dale was very interested in the very mathematical part of fluid mechanics. This is applied math, not really engineering-type stuff. At the other end of the spectrum, one of my students [Greg Winckelmans] now is very heavily involved in aircraft-weight vortex hazard. He holds international meetings and so forth. There's still a lot of controversy about the Airbus A380, which is their new giant aircraft. It's the Airbus—the European conglomerate, competitor with the Boeing 747.

ASPATURIAN: I don't like huge airplanes. They make me nervous.

LEONARD: According to my student, Airbus is being penalized unfairly because people think the wake of that aircraft is more dangerous than a 747's. So all the airports in the world have responded by saying, "OK, we're going to add two more miles to the danger zone of an A380."

ASPATURIAN: This is once it's airborne, not on the runway?

LEONARD: When they're landing or taking off. So if an A380 is coming in for a landing, there's a forbidden space behind it. It's now two miles more than the 747's. Anyway, there's a lot of money riding on things like that.

ASPATURIAN: Right. Why would you have an Airbus instead of a Boeing if you have to increase the airspace?

LEONARD: That's right. So this is a problem my students are interested in. But Saffman's students would probably not be. They would highly idealize that problem. I don't know if I'm being fair, but there's a whole spectrum of fluid-mechanics problems you can work on—

ASPATURIAN: —that are actually divorced from any application?

LEONARD: Yes. But they eventually could somehow give you some insight.

ASPATURIAN: I see. So there's some overlap.

LEONARD: There is overlap.

ASPATURIAN: Is there anything else you'd like to say about your time here as a researcher and a professor? Otherwise, I'd like to move on to the Academic Policies Committee, which you chaired, and some of your extracurricular Caltech activities.

LEONARD: Let's do that. Let me see. After the Academic Policies Committee, I spent a few years on the Caltech Y board, the alumni [Caltech Alumni Association] board, and then the Gnomes.

ASPATURIAN: The Gnomes. Do you want to talk about the Academic Policies Committee and the revamping of the core curriculum?

LEONARD: Sure, yeah.

ASPATURIAN: That started, I believe, in the 1990s?

LEONARD: That's right. September of '92 was the charge to our committee. I have our charts here. Jack [John] Richards [professor of organic chemistry and biochemistry] was chair of the faculty, and he invited me to lunch one day. I didn't know what was going on. But he wanted me to head up a new committee to study the Caltech core, and he thought it would be best to just do it as part of the Academic Policies Committee. So I said OK, and we made up a list of possible committee members.

ASPATURIAN: What led you to agree to it?

LEONARD: Well, he did a good sales job, and I figured I may as well do something helpful here.

ASPATURIAN: Any idea why he chose you?

LEONARD: Well, he knew I had been an undergrad here. Other than that, I have no idea. He might have already tried some of the other more obvious choices like Nate [Nathan] Lewis [Argyros Professor of Chemistry]. Anyway, he and I made a list that was heavily oriented toward faculty who had been Caltech undergrads, and we managed to get Nate Lewis and Michael Aschbacher [Hanisch Professor of Mathematics], Bob McEliece [Puckett Professor and professor of electrical engineering], Julie [Julia] Kornfield [professor of chemical engineering], and Joe Kirschvink [Van Wingen Professor of Geobiology].

ASPATURIAN: All former Caltech undergrads.

LEONARD: Yep. And Rod [D. Roderick] Kiewiet [professor of political science] joined us, and maybe a few others.

ASPATURIAN: What, as far as you know, led up to this?

LEONARD: I think there were rumblings that might have dated back to the Sunney Chan [Hoag Professor of Biophysical Chemistry, emeritus] curriculum committee a few years before that.

ASPATURIAN: That's right. I remember talking to him about that committee.

LEONARD: And there was some concern that there was no biology in the core. I'm paraphrasing this. But the core seemed to be unstable: It would change; the teaching quality was not uniform; and the question was, What can we do about that? And if we add biology, do we subtract something? Issues like that.

ASPATURIAN: For the record, I think Caltech has probably the most rigorous core curriculum in the country, and the math and the physics are unusually intense.

LEONARD: Yes, they are.

ASPATURIAN: I seem to remember that there was some discussion about whether there was too much math, perhaps, and whether prospective students whom the institute wanted to enroll were being driven away.

LEONARD: Not only that, but did particular kinds of math come soon enough? Because the physicists wanted certain a type of math right away, to do what they wanted to do, and the mathematicians were going at their [own] pace, and that sort of thing. So we had this really good collection of people, and we'd meet once a week, I think. For the first couple of months, it seemed that we were making some progress and gathering information, but then people started to get unhappy, because we would just meet as a big group, and it seemed like it was difficult to get things moving. I was starting to have a rebellion on my hands. So I decided to go around and talk to my committee members one by one and tell them I wanted to have a task force for each subject, like math and physics. But I didn't want a physicist to head the task force in physics, so I got Julie Kornfield to head up the physics group and Bob McEliece, from electrical engineering, to head up the math group, because I knew he used a lot of math, and so forth. So

that seemed to work pretty well and make everybody a little happier. There were three proposals that finally came out of this thing. One of them was to stick to fundamentals and keep the core very much like we had it but to add biology. Then physics and math would have to sacrifice a quarter each—something like that. Before this committee met, they got two full years each.

ASPATURIAN: What were the math and physics courses that were the two full years? Was it a series of introductory survey courses, or could students pick from a menu?

LEONARD: No, no. It was just solid physics and math.

ASPATURIAN: No deviations?

LEONARD: Yeah.

ASPATURIAN: So one proposal was to keep things pretty much as they were, but to add biology?

LEONARD: Pretty much the same. Another proposal was to have a standing core-curriculum committee to oversee the core on an ongoing basis. And then a third proposal was to have hardly any core at all. There were a few people who wanted that, but it didn't really fly. Oh, there was something else. We found out from the alums that the students really needed to express themselves better in writing, and we figured we had to do something about that, although HSS [Division of the Humanities and Social Sciences] did have some writing requirements. But the undergraduates didn't know how to do any scientific writing or how to give oral presentations, so I think that recommendation came out of that. Engineering [and Applied Science] had a required course where you had to give three scientific talks—one was with a few graphs, one with slides, and one with—

ASPATURIAN: Finger puppets.

LEONARD: [Laughter] Chalk or something, I don't know. Of course, it's probably changed by now. But the other divisions didn't have requirements like that. Our committee thought that they should. And then the idea of a menu of courses might have come out of my committee.

Anyway, what happened was that after a year and a half I gave a final summary of my committee's work at a Caltech faculty meeting.

ASPATURIAN: So this would have taken us into late '93?

LEONARD: Early '94.

ASPATURIAN: Oh, you have the faculty minutes there.

LEONARD: You'll see somewhere where I start my spiel. But what happened after that was that Jack Richards said he was going to get a new committee to really carry our work on and finish it off. Well, that turned out to be the [David] Goodstein [Gilloon Distinguished Teaching and Service Professor and professor of physics and applied physics, emeritus] and [Harry] Gray [Beckman Professor of Chemistry] committee, and they didn't quite make it either. So then David Stevenson [Goldberger Professor of Planetary Science] had a committee, and they got the job done. I volunteered to be on the Stevenson committee, but Dave is a very organized guy and he got things done.

ASPATURIAN: How much of what your committee recommended was embodied in the final revamping?

LEONARD: I think the core-curriculum oversight committee was implemented, along with the biology requirement and some sacrifice of physics and math. There was some restructuring of the math core—there were a lot of people who wanted probability theory early on in math, and so we managed to add probability theory into Math 1A. And I thought everybody would be happy, but I'm not sure whatever happened to that. When I was teaching Math 8 several years later, I do know we covered calculus and probability theory in Math 1A. So what else? I think maybe strengthening the writing requirement might have come from my committee. You know there's been a recent look at the curriculum again.

ASPATURIAN: So I understand.

LEONARD: I don't know how much they went back and looked at our efforts. They maybe looked at Stevenson's committee—I'm not sure.

ASPATURIAN: As someone reporting on this occasionally and hearing about it, a lot of the crux has been: Should Caltech retain these very demanding physics and math courses that make the institute unique, or is it worth it to sacrifice a little of that in the interests of getting more students to come here? That seems to be a hard balance to strike.

LEONARD: That's right. I went to one or two of the full faculty meetings last year about this. It seems like there is still complaining that there's too much math and physics in the core. And I don't know; I think that's good for them. So I don't know exactly what has happened more recently. It's changed a little bit, I guess. I think Stevenson's committee introduced the idea of a menu of course choices for freshmen. They tried to get divisions to offer courses that would give the freshmen a flavor of what each division does. They're always looking for volunteers to teach something like that.

ASPATURIAN: I'm sure they are. Are you doing any more teaching now that you're emeritus, or have you stopped doing that?

LEONARD: No, I'm not.

ASPATURIAN: Did you like teaching?

LEONARD: Oh, yeah. But to do a good job, it really ties you down, and I enjoy not being tied down. [Laughter] I think Steve [Steven] Frautschi [professor of theoretical physics, emeritus] is still teaching. Good for him.

ASPATURIAN: Have you ever worked with SURF students?

LEONARD: Yes, I have—maybe four or five different ones. It's a lot of fun.

ASPATURIAN: Were they from engineering fields or did they come, as SURF students sometimes do, from different disciplines?

LEONARD: I had one undergraduate physics major who was interested in something that interested me, and so I worked with him. I had one guy from Poland apply. I needed somebody to work on a project I had money for, and he turned out to be a nephew of somebody on the faculty—I can't remember who—and he was good. One time I worked with an undergrad who ended up getting a PhD with me. That's a good program.

ASPATURIAN: I think it's a rewarding program.

LEONARD: Although, as I think I told you earlier, I was glad to get away for the summer as an undergraduate.

ASPATURIAN: That's right. I guess now students are happy sticking around. So I guess this brings us to your Y and Caltech Alumni Association work. What led you to get involved in these activities?

LEONARD: Well, I did two different terms on the alumni association board of directors.

ASPATURIAN: I know your second term was quite recent. Do you remember what years that first time around covered?

LEONARD: No, I'm afraid I don't. That was quite a few years ago. But they liked to have a member of the faculty on the alumni board, and it was a nice way to see what the alumni association is doing. Wasn't too much of a commitment.

ASPATURIAN: Do you remember who the director was, that first time around? Was it Judy Amis?

LEONARD: I'm almost sure that it was.

ASPATURIAN: That would put your term somewhere between the late eighties and mid-nineties, I think.

LEONARD: That's right. Sure. And after that it was Andy—

ASPATURIAN: [Andrew] Shaindlin; he's at Carnegie Mellon now.

LEONARD: OK. Well, for my more recent assignment, they kind of desperately needed somebody because— Who's the guy—he's a physicist—who worries about snowflakes?

ASPATURIAN: Oh, Ken Libbrecht [professor of physics].

LEONARD: He was on the alumni board, and he decided he didn't want to do it anymore. He left two and a half years into a three-year term, so I said, "OK, I'll fill in his term." Andy was director, and Liz Allen was head of communications. Patsy Gougeon was there, and Karen Carlson was still there. Terrific staff and director. So it was good. But then toward the end of my term—well, I stayed on another year or two, because they told me to find a replacement when my time was up and I didn't get around to it. Somehow they decided I should find my own replacement—that's a good trick. [Laughter] So anyway, I stayed around another year or so. But, boy, things have changed. Karen Carlson left. But she had a nice position to go to—her old college.

ASPATURIAN: She went back to Minnesota or Wisconsin, I think.

LEONARD: Concordia [College], in Minnesota. She did a lot of good stuff. The association had this book award, which I thought was really good. She championed that. I thought it was really clever, because you give a book award to some junior in high school and it's got Caltech all over it.

ASPATURIAN: And the signature of some prominent person the student admires.

LEONARD: It kind of puts an idea in their head that maybe Caltech is where they really want to go.

ASPATURIAN: Are they still doing that?

LEONARD: It died, because they couldn't keep it going. I tried to convince people that this is a good idea, but somehow they argued back that, well, it wasn't really an alumni function. I thought, "Well, aren't the alumni here to do the right thing for Caltech?" So, anyway, then Peter Hero [vice president for development and institute relations, 2009-2011] came and reorganized the whole structure.

ASPATURIAN: Yes, he certainly did.

LEONARD: Boy.

ASPATURIAN: Yes?

LEONARD: It's a similar situation to what I described about the admissions director. There used to be a director of alumni relations reporting directly to a vice president. And the new structure of Peter Hero was that he had these five columns of excellence or something, and the alumni association director is now at the bottom of this thing somewhere. So Andrew left, and Liz Allen left. Patsy is still hanging in there. It's not as good as it used to be. That's sad.

ASPATURIAN: I was going to ask you what you thought the association's relationship with Caltech is like right now.

LEONARD: Well, I just have a feeling that it's not near as good as it used to be. As I mentioned, Ricketts House had all these politicians when I was an undergrad here, and a lot of my Ricketts friends from the fifties became presidents of the alumni association. Anyway, a lot of them were part of this memorandum of understanding that was drawn up at some point between the alumni association and the institute, which said that the director of the alumni association should report directly to a vice president.

ASPATURIAN: When was this put together?

LEONARD: I don't know. I could dig it up.

ASPATURIAN: So it's some years back?

LEONARD: Oh, yes. But it's gotten violated, of course. Anyway, a lot of them were upset, too. I don't know if they can repair that thing or not. I don't know what's happened. Do you?

ASPATURIAN: Well, you know, they don't have the trips they used to have, and of course they deep-sixed *Caltech News*, which I thought was foolish, and *E&S* is completely changed.

LEONARD: The *Caltech News* was really nice.

ASPATURIAN: Thank you. That's nice to hear. I liked it. I liked doing it.

LEONARD: It was really attractive in its latest version.

ASPATURIAN: Yes, when we went to four-color in 1997. Thank you very much.

LEONARD: I can't believe that it's not worth doing.

ASPATURIAN: Well, it was another one of Peter Hero's inspirations. And unfortunately, in my opinion, a large number of them survived his departure. It's too bad. So that happened. And the fact that Andy went to what is essentially a promotion at Carnegie Mellon kind of suggests that maybe his departure wasn't such a great move.

LEONARD: No. That's too bad.

ASPATURIAN: Do you talk to alumni who were associated with the board and the CAA? What are they saying?

LEONARD: Well, I was on the board when this was kind of happening. I know there was a lot of concern among the board members, but they didn't quite have enough power to counteract this thing, I think. But on the plus side, the Caltech Y board was fun.

ASPATURIAN: What led you to join that? And when did you join?

LEONARD: Who's the gal who's head of the Caltech Associates, Lee Silver's [Leon Silver, Keck Foundation Professor for Resource Geology, emeritus] wife?

ASPATURIAN: Arlana.

LEONARD: Arlana, yes.

ASPATURIAN: She's retired now, a couple of years ago.

LEONARD: I think Arlana called me quite a while ago—maybe she was on the Y board—and she said, "How about you joining the Y board, and your wife, too?" So she described what they did, and it sounded good. And Gretchen likes people, so she was agreeable. It was really nice. We always enjoyed that. We did six years, and we quit for a while, and then we did six more years.

ASPATURIAN: What do you do as a member of the Y board?

LEONARD: Well, there's "Make a Difference" Day, and we both volunteer for that. That's some Saturday in April, typically. The Y staff lines up all these different volunteer jobs for the students. We have, oh, I don't know—there must be 150 or 200 students who show up. So we register the students, and I drive them around—a lot of them need transportation to get to these places. We try to help pick good Friends of the Y events—you know, they have this category of Friends. If you give so much a year, you can become a Friend of the Y, so you get special invitations to dinners. A lot of it is to raise money. [Laughter]

ASPATURIAN: That's what boards all do, isn't it?

LEONARD: Yes. Well one of my positive contributions is that, as a faculty member, I noticed that when you give to United Way though Caltech, you can designate the Y and Caltech will match that money. So I said, "OK, this is good. If we can get this message around, you can raise a lot of money." They latched onto that. I don't know, but I think it helps a little bit. And then one year I was head of the committee to recruit more members to the Y board. That was kind of fun. More recently they've decided to have a golf tournament every year, and I know that Nancy Lan, who's John Hall's [professor of civil engineering] wife, is very active in that. So some of the members of the Y board really put in a lot of time—for example, Susan Murakami-Fisher and Lee Fisher. I can imagine it's a lot of work. It's a good outfit, and it's good for the Caltech students to take part in the Y.

ASPATURIAN: Were you involved in the Y—I guess it would have been the YMCA at the time—when you were an undergraduate here?

LEONARD: No. But some people were. Frank Dryden, who's so active on the Y board they even have a room named after him, was already very active when he was an undergrad, but I wasn't.

ASPATURIAN: It's nice working with all those undergraduates, I'm sure, and to see all the students.

LEONARD: They are really good.

ASPATURIAN: Has the caliber of Caltech undergrads and graduate students changed over the years? Or just the nature of the students you have. Have you noticed anything?

LEONARD: Oh, I don't know. They're so good. It's hard to say.

ASPATURIAN: I also wanted to ask about your involvement with the Gnomes.

LEONARD: I got invited to join the Gnomes when I was still a senior. I joined, but all I remember is a few Gnome parties; some alumnus had a pool party for us. Once I moved up to Northern California I never really paid much attention. But then when I came back to Caltech

for the academic year ’83-’84, my wife and I started going to Gnome parties, and they were a lot of fun. In the eighties, when we were going to lots of parties, they’d have the summer party and the Christmas party. And Founders’ Night—March 9th—was the more formal dinner, where they’d introduce the new Gnomes. There were still some quite active Gnomes from the 1930s who would come to these parties. There was one gal who eventually married three different Gnomes? Do you remember?

ASPATURIAN: Oh, yes! She married Ted Combs. What was her name? She died herself recently.

LEONARD: She was almost one hundred. She finally became a Gnome in her own right. Viva Something. Four-different-names Viva. But you’re right; Ted Combs was one of them.

ASPATURIAN: Oh, Viva O’Leary—O-something? Viva Hazel-something?

LEONARD: O’Haver. [Viva Williams Hasernot O’Haver Combs] Mike O’Haver was one of her husbands.

ASPATURIAN: OK, it’s starting to come back to me in bits and pieces.

LEONARD: Very good.

ASPATURIAN: I’m impressed that you remembered her first name. I couldn’t find it in my memory banks.

LEONARD: I can just picture her exactly, so I should know. The Gnomes are a good outfit. They’re trying to help Caltech students and Caltech.

ASPATURIAN: It’s all Caltech alumni, isn’t it? It’s not like the [Caltech] Associates, where outsiders can join?

LEONARD: No, no. Some Caltech staff and faculty get invited to be Gnomes, and they can join if they want.

ASPATURIAN: What have you been doing since you became an emeritus professor? Are you still doing research?

LEONARD: Oh, yes, yes. I actually still had several grants, up until a year ago. And I had grad students all the way up until two years ago. I still have three research projects that I'm carrying out, sometimes with a former student and sometimes on my own. It's kind of fun, and it keeps me going.

ASPATURIAN: What else are you doing? Do you travel?

LEONARD: Yes. Several years ago, we went on the alumni trip that visited the coast of Croatia.

ASPATURIAN: Oh, Dubrovnik and Split?

LEONARD: Yes. We were on a fifty-passenger boat that came out of Venice.

ASPATURIAN: That must have been a fabulous trip.

LEONARD: Oh, it was great. We travel quite a bit. Gretchen and I just spent a month in Wales and England. Half was vacation, and the other half I was working at Cambridge. I keep up those connections, and I especially like Cambridge. So I keep after these things. It's fun.

ASPATURIAN: It sounds like you've had a good experience with Caltech, all the way around.

LEONARD: Yes, it's been great.