ACCIDENTAL ENGINEER

A SIXTY-YEAR TREK THROUGH TECHNOLOGY AND BEYOND

DEAN Z. DOUTHAT
For Doris
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After getting a bachelor’s degree with a triple major in Mathematics, Physics and Philosophy from St. Louis University, I married another student there, Doris Helen Nigg, in August 1957. I was 21 and aiming at a career in academia; I focused on Mathematics, earning a master’s degree on the way to a planned doctorate. But then we had our first baby, Denise, in January 1959. That spring we moved from St. Louis, Missouri, to South Bend, Indiana, to pursue further graduate work. After we had our second baby, Daniel, plans changed. For the next 60 years, I was an accidental engineer.

Accidental because I never took an engineering course but worked as an engineer with trained engineers and even taught seminars. Accidental because of a Forrest Gump-like penchant for landing on projects of historic and technical interest—or just plain funny. The following are stories of an accidental engineer’s encounters with real engineers and engineering.
Early car engines were started by hand-turning a crank, requiring significant upper body strength and producing more than a few broken arms due to backfires. Vincent Bendix patented the automatic clutch, which made it possible to start an internal combustion engine with an electric motor. That clutch mechanism is still known today as “The Bendix.” He founded Bendix Corporation with headquarters in South Bend, Indiana, in 1924 and used the large revenue stream from the electric starter patent to diversify. The company made components and subsystems for automotive, aeronautical and aerospace manufacturers. In all cases, Bendix strove to be at the technological and engineering forefront. After Bendix moved its corporate headquarters from South Bend to Detroit, Michigan, in 1943, the old South Bend headquarters plant on Lincoln Way West was repurposed to make landing gear and brakes for light airplanes.

Bendix Advanced Development Center was started by engineers and scientists from the Talos missile project located in a nearby Bendix facility in Mishawaka, Indiana. RIM-8 Talos (a Remote Inter-
cept Missile) was a long-range, ramjet-powered surface-to-air missile defending Navy ships against air attack. It was the final result of the U.S. Navy’s “Operation Bumblebee,” a 16-year program following World War II to develop better protection of ships against air attacks. Heavy losses in that war from kamikaze aircraft and air-launched glide bombs revealed the insufficiency of anti-aircraft guns alone. In Greek mythology, Talos was a bronze giant protecting the Isle of Crete by throwing rocks at hostile ships. Bumblebee aimed at a similar kind of defense-in-depth with long-range missiles, medium-range missiles and guns. Bumblebee also produced two shorter-range missiles, RIM-2 Terrier and RIM-24 Tartar. Together, Bumblebee alums were called the “three T’s.”

Bendix Mishawaka had responded to an Army Request For Proposal with an extended version of Talos as an anti-ballistic missile interceptor. But they lost the competition to Bell Telephone Laboratories, who proposed an extended version of their Nike surface-to-air missile system called Nike Zeus. Nike had been developed under U.S. Army auspices, so some Army-Navy rivalry may have been at play in the decision. Anti-ballistic missile defense was actively underway even while ballistic missiles were still in the development stage and had not been deployed. Further, even though ballistic missile decoys were merely conceptual, not even in development yet, the Bendix proposal contained technology for distinguishing decoys from actual warheads. This part of the Bendix bid impressed the Army officers who evaluated the proposals. As a result, they directed Bell Labs to give Bendix a subcontract, called Project Target, on that subject.

The South Bend brake plant had some empty office space behind the production floor. With Talos missiles in production needing little engineering support and the Bell Labs subcontract for Project Target in hand, the chief engineer for the Mishawaka Talos project talked the general manager of the brake plant into letting them use that
office space. About 50 Talos scientists and engineers moved from Mishawaka to South Bend and started the Bendix Advanced Development Center. I was hired there in 1959 after Doris, Denise and I moved from St. Louis to South Bend. I was still pursuing an academic career at the University of Notre Dame but needed the job to supplement a meager graduate fellowship. Then Daniel came along; emphasis was shifting.

My job in Project Target was software development. I picked up programming on the fly. My university studies in Mathematics and Logic helped me to understand how to write software. There were no courses available; universities were pretty much blind to the emerging engineering discipline. Nor was there any Computer Science. The only source of information was the IBM 650 Programming Manual. Using that and experimenting with small programs, I became proficient in the skill. Back then, we called them “data processors,” not “computers.” Speaking of a “computer” was referring to a person who used a calculator plus pencil and paper spreadsheets to analyze data.

I developed programs for determining the trajectory of re-entry vehicles and also for a two-color sensor analysis. The brake plant had an IBM 650 Magnetic Drum Data Processor. It was programmed directly in an assembly language called Symbolic Optimal Assembly Program—commonly known as SOAP—using punched cards. The data processor filled a large room with racks full of vacuum tubes. It had an 80-column card reader input, an 80-column card punch output and a 132-character line printer output. It also came with a card sorting machine. The processor’s main memory was a rotating drum with 40 tracks of 50 words of memory and one read/write head per track. Each word had ten decimal digits plus a single bit to represent the positive or negative sign of the word. The digits were represented in a bi-quinary format. This representation is identical to that of an abacus. It had one component with five states and a second
with two states. The latter indicated whether to treat the former as lower \((0,1,2,3,4)\) or upper \((5,6,7,8,9)\) digit values.

Unlike modern computers, each instruction word for an IBM 650 contains the address of the next instruction to execute. This is needed because one or more word positions on the drum has already passed the read/write head depending on running time of the current instruction. Rather than waiting for a complete drum rotation every time, operations can be optimized by placing the next instruction at the position on the drum that will be under the read/write head when the current instruction ends. At 12,500 RPM, a new word is under the read/write head every 96 microseconds. Knowing the running time of each instruction, the optimum next instruction address can be calculated and the instruction placed there. If that address is already occupied, then the next available higher address is used. Originally I had to write instructions in machine code, compute instruction addresses, and place instructions at those addresses. Later, the IBM 650 assembly language SOAP automated this process. SOAP also moved one step up from machine-language by accepting symbolic representations of machine operations (opcodes) and translating that to machine language. This made programming more readable and reduced strain on memory. The 650 was leased by the accounting department of the brake plant, and they let us use it on the graveyard shift from midnight to 8:00 a.m.

In the spring of 1959, the Soviet Union issued a maritime warning. The warning designated latitude and longitude bounds of an area in the South Pacific well away from regular shipping lanes. For a 30-day period starting six months after the date of the warning, the USSR announced that it would be conducting operations in that area that could be dangerous to shipping.

The U.S. military knew this was to be a test firing of an Intercontinental Ballistic Missile. Being flanked on both sides by broad
oceans had engendered in Americans a somewhat smug feeling of invulnerability. This feeling was reinforced by the general remoteness of battles during World War II, still fresh in the national consciousness. The advent of Sputnik just over a year earlier jolted the country out of that attitude. Oceans are nothing for an ICBM. Sputnik rode into orbit atop a Soviet rocket that was significantly larger, more powerful, and had a heavier payload capacity than U.S. counterparts. Ironically, this came about because of superior U.S. technology that reduced nuclear warhead size and weight to the point that less powerful rockets could still attain inter-continental range.

In response, President Dwight D. Eisenhower accelerated enhancement of deterrence by U.S. ICBMs such as SM-65 Atlas and explored defense by anti-ballistic missile interceptors like Nike Zeus. Those of us at the Advanced Development Center working on Project Target were considered to have the nation’s best technology in remote sensing and processing of re-entry events. So the Army came to us and asked if we could put together an airplane with sensors and data capture to observe the USSR ICBM re-entry. Our timeline was less than six months. Project Sea Trojan was born.

The U.S. Navy loaned a P-3 long-range patrol airplane to us. We sent Ed Crosby to the Arizona airplane graveyard to find and retrieve a working top turret from a World War II-era B-29 bomber. We all called him “Electric Ed,” not only because he was an electrical engineer but also because he was an electronics hobbyist nut. Ed ran in sports car rallies and had installed a quartz electronic clock in his car to provide precise timing for checkpoints. During World War II, he served in the Army Air Corps as a B-29 top turret gunner. This electric motorized turret originally mounted twin .50-caliber machine guns and was remotely aimed in azimuth and elevation by a joystick controlling two gimbal motors.

For Project Sea Trojan, we cut a hole in the top of the P-3 and
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mounted the B-29 turret there. In place of the guns, we mounted two Image Orthicon video cameras, one for visible light and one for infrared. Each camera was recorded on its own video tape. A small TV screen displaying video from the visible light camera was mounted below the turret near the joystick controller for the turret. The operator used this image to track the re-entry object. We trained several Navy P-3 crewmen on tracking operations in South Bend. Finally, we extracted signals from the P-3 inertial system and azimuth and elevation signals from the turret and displayed them as meters on a panel. We had a movie camera photograph the panel at 30 frames per second. The soundtrack of the 35 mm film recorded time codes.

The airplane was finished in time and stationed at the Navy base on Kwajalein Island in the Ralik chain of the South Pacific Republic of the Marshall Islands. Kwajalein Island is about 2400 miles southwest of Honolulu and 500 miles due south of the most famous of the Marshalls, Bikini Atoll. It is at the corner of No and Where and is leased by the U.S. Today, it is involved in anti-ballistic missile testing along with several other South Pacific islands as part of the Ronald Reagan Ballistic Missile Test Site. Nike Zeus, the first anti-ballistic missile system, was tested there in the 1960s.

The Navy rotated P-3 crews through 24/7 ready alerts in anticipation of the event. At launch of the USSR ICBM, the Navy P-3 crew had about a 30-minutes warning to get to the impact area. The P-3 got there in time. The Navy also stationed a submarine in the area whose sonar gave an accurate time of splash down. Finally, a radar on Kwajalein Island followed the re-entry and we had video recording from it. This radar was not a precision tracker—it only had azimuth scan—but the radar return video provided additional data on scintillations from the plasma surrounding the vehicle as it oscillated in yaw and pitch.

To analyze the re-entry event, we had video from the two
cameras, video from the radar, splash time from the submarine and movie film of the photo panel showing P-3 location and attitude plus turret pointing angles. My task was to use this data to establish the trajectory. The first problem was that the syncro-repeater dial reporting B-29 turret elevation gimbal angle had failed and was just spinning. So, we had no elevation data for the two video cameras. Yikes!

Looking at video from the visible range camera, I noticed another somewhat bright object besides the ICBM passing through the frames from time to time. What could it be? So, I took the video and hopped on the South Shore Interurban to Chicago to show it to the astronomers at the Adler Planetarium. They identified the object as Venus. What a piece of luck! With Venus as reference and using airplane latitude, longitude, altitude, attitude, azimuth of B-29 turret, camera lens parameters, and time, the astronomers were able to help me reconstruct elevation angle throughout most of the re-entry track. Spherical trig-orama. Using a moviola, I read the 35 mm film frame by frame to extract a time series of all data displayed on the photo panel and punched the data onto cards.

With a full data set, I was ready to start finding the trajectory. The IBM 650 was the key for trial-and-error fitting of trajectory to the observed data. The memory of the 650 was too small to hold the entire program and its data. So I broke the processing into two phases. At the end of the first phase, intermediate data was punched out onto standard 80-column cards. Then the punched cards for the second phase were loaded along with the intermediate data to finish the processing. So significant manual intervention was required.

In the midst of our calculations, the brake plant accounting department decided they needed the data processor on the third shift too. So, we rented time on another IBM 650 at the IBM Service Center in the Chicago Loop. Again we got the third shift; two of us
drove to Chicago each night to work from midnight to 8:00 a.m. It was 10 below zero in Chicago one night, but the heat generated by the 650 was so high that we had to open the windows to maintain a decent temperature. When we took a break for lunch around 4:00 a.m., I shut down the IBM.

Coming back an hour later from lunch, I realized that I forgot to close the windows so it was down to near zero in the room. We quickly closed the windows and I said that I knew how to warm up fast. I turned on the IBM and was greeted by a horrific, ear-splitting screech coming from the main rack cabinet. I quickly shut the IBM back down. We waited for the room to warm up and then called the IBM field engineer on duty. He came right away. When he opened the cabinet containing the memory drum, it released a thick, black, foul-smelling smoke.

Here’s what happened. The 40 read/write heads were mechanically suspended close to the rotating drum surface; flying heads had not yet been invented. Some bright IBM engineer worried about the possibility that a head might touch the drum’s surface and damage its ferro-magnetic coating. If touching, the head would heat up from the friction. So, to avoid drum damage, the heads were mounted on bimetallic strips that would pull a head away if it touched and got hot. Now cool the heads to zero degrees and the bimetallic strips will slam all 40 heads hard against the drum surface. When I fired up the IBM, the heads were pressed so hard against the drum that they actually folded under and all 40 dragged along the drum surface screeching. This, of course, destroyed the drum.

Despite our pretend innocence, IBM engineers figured out what had happened. Credit to IBM, they flew in a new drum from Armonk, New York, and had the 650 back up and running the next night. As to the IBM engineer who decided to mount the heads on bimetallic strips, he did not think it all the way through. Suppose a
head touches the drum surface, heats up, and is pulled away by the strips. Good. But then it cools back down to its previous temperature and the bimetallic strip uncoils to its previous position—touching the drum. Rinse and Repeat.

Years later, I met a man who had been an IBM field engineer. As soon as he heard my name, he told me that I was mentioned by name in the IBM 650 Field Service Manual. I was notorious as the only person ever to destroy an IBM 650 drum.

After many trips between South Bend and Chicago, I was finally able to determine a trajectory for the re-entry vehicle that matched our video tracking, the splash time and the radar data. Then I turned my attention to processing the video data from the two cameras. I was able to produce the mathematics for the physics that allowed us to determine the product of drag coefficient and reference area. I programmed a numerical solution for the math on the IBM 650 and fed the video intensity data through it. From the trajectory and the recorded video from the Kwajalein radar, we determined drag coefficient and therefore the area. As it turned out, the Soviet aerodynamics engineers used the rear area as reference and so we determined the area and diameter of the back of the USSR re-entry vehicle where it mounts to its launching rocket. We sent our final report, classified SECRET, to our Army sponsors. Project Sea Trojan over.

Well, not quite. About two weeks after we sent in our report, half a dozen guys in dark suits showed up. They explained that the fact that the U.S. knew the diameter of the launch rocket’s top end (same as that of the re-entry vehicle’s back end) was classified TOP SECRET. If it got out that we knew this dimension, it might compromise one or more U.S. intelligence sources. This was a higher classification level than our report and, moreover, a higher level than anybody at ADC had clearance for. The FBI guys confiscated all
copies of Sea Trojan reports and our working papers, lab books, and memos. They also told us that everybody who worked on Sea Trojan would be contacted and scheduled to go to the Pentagon for debriefing.

When it was my turn, I was escorted down a corridor at the Pentagon passing doors with one-star and two-star general insignia. My escort stopped at an unmarked door and waved me in. Entering, I was confronted by a giant, angry-looking Marine who took me into a room bare of furniture except for a table and two chairs. He had me take a seat. Shortly afterwards, the debriefer came in and we had a chat about how Project Sea Trojan's findings could compromise certain U.S. intelligence assets and therefore I was to forget all about it and never discuss our conclusions with anybody. I have forgotten the USSR missile's back diameter, so the debriefing worked. RIP Sea Trojan.

Meanwhile, the Air Force decided it needed an instrumented airplane to observe re-entries of U.S. missile test shots on the Atlantic Missile Range, which ran from the launching site at Cape Canaveral, Florida, southeastward to re-entry near Ascension Island. This volcanic Atlantic island is about 1,400 miles due east of the easternmost bulge of South America at Recife, Brazil. Each year, thousands of green sea turtles make that long swim from feeding grounds offshore of Brazil—a remarkable feat of seamanship and navigation. After nesting on beaches at Ascension Island, both they and later their young offspring make the long return swim.

The Air Force issued a Request For Proposal for a downrange airplane that was pretty much aimed at the Advanced Development Center. Sea Trojan had secured our reputation. Naturally, we submitted a proposal. Unbeknownst to us, a couple of years earlier Bendix headquarters in Michigan had established a bright and shiny new high-tech Aerospace Systems Division in Ann Arbor, Michigan.
Bendix HQ spent a lot of money constructing a new building on Plymouth Road near the water tower and recruiting high-priced talent from the University of Michigan and elsewhere. This division also submitted a proposal to the Air Force.

Later we learned that the president of Bendix Corporation got a phone call from the Air Force Project Manager evaluating the proposals. The Air Force manager told him they had two proposals from Bendix Corporation, one from the Ann Arbor Aerospace Systems Division and another from the South Bend brake plant! He must have been shocked that a brake plant was bidding on a high-tech downrange airplane. The Air Force wanted to know which one should be evaluated. Embarrassed, he had no choice but to say both. As if that wasn’t bad enough, the brake plant won—OK, the Bendix Advanced Development Center won.

Bendix HQ didn’t even know we existed before this, nor what we did. All our administrative processes including contracts went through the brake plant. Bendix HQ was not going to be embarrassed again. They dissolved the Advanced Development Center and transferred its contracts to the Ann Arbor Aerospace Systems Division. All Advanced Development Center employees received transfer offers to the Aerospace Systems Division with relocation expense reimbursement. And that’s how Doris, Denise, Daniel and I came from South Bend to Ann Arbor in the summer of 1960.
With zero prospects for employment in South Bend and academia fading into impracticality, moving to Ann Arbor was a no brainer. But there was nothing for me at Bendix there. Project Target and Project Sea Trojan were done and I had at best a minor role on the Air Force downrange airplane project. So we took advantage of Bendix’s help with finding a place to live in Ann Arbor and paying moving expenses. I tried continuing academically with a course or two at the University of Michigan, but job travel and responsibilities made attendance spotty. That career beacon finally flickered out. I soon quit Bendix in Ann Arbor to join a startup called Conductron. In the early 1960s this company pioneered stealth, which at that time was called reduced radar cross-section technology.

My role at Conductron was unrelated to this emerging technology line. I worked on an Air Force contract for analysis of high-altitude nuclear bursts producing a destructive electro-magnetic pulse. Such a pulse could destroy the main transformers of the electric power grid and wipe out silicon-based computers over a wide area. That means
no power and no transportation as cars, trucks, locomotives, airplanes and ships would all grind to a halt with their controlling microprocessors dead. A solar flare aimed at Earth would have the same effects but much more widespread.

I analyzed inhomogeneous and anisotropic plasma and consequent radiation. In other words, Difficult Math. Projects Target and Sea Trojan had involved similar analysis on the radar video scintillations produced by the plasma surrounding a re-entry vehicle. Prior research by scientists in the U.K. and U.S. on Whistler Waves launched into the ionosphere by lightning strikes was relevant. These very low frequency radio waves range between 1,000 and 10,000 Hz and peak around 4,000 to 5,000 Hz—well within human range of auditory sensitivity. When detected by a radio frequency receiver, they produce a whistling sound. By monitoring these Whistler Waves, we know that there is a lightning discharge somewhere on the Earth at an average rate of about 100 times per second. Yes, the Earth is big. Half of these strike the surface. You can win many a beer with barroom bets if you go armed with this information.

For this project, I also consulted with Sam Harmon, an engineering professor at the University of Michigan working in the Physics Department on plasma state physics with an eye towards engineering nuclear fusion. Near the beginning of 1963, Sam told me he was working on an idea for using a TV camera tube to process side-looking radar. This type of airborne radar produces high-resolution mapping of objects on the ground. Sam was planning to pursue this idea and wanted me to come on board. Sam knew Don Glaser, also a professor in the Physics Department. Don won the 1960 Nobel Prize in Physics for inventing the bubble chamber. This chamber uses a transparent liquid at high temperature to track the paths of charged particles after a collision experiment. The story going around was that Don got the idea for it after ordering a pitcher of beer at the
Pretzel Bell. He denied that story during a 2006 lecture, but it was a great story and should have been true. He did confess that he tried using beer as a medium in a bubble chamber during early experimentation. Don was a physicist who knew nothing about investment. So, he turned over his Nobel Prize money to a skilled money manager named Ken Heininger. That money changed the trajectory of laser technology in the early 60s.

Union Carbide in Chicago had developed techniques to grow large rods of synthetic ruby. Three senior technicians working there had perfected a process for using the rods as lasers. Specialized instruments polished the two ends of the rods optically flat and parallel to each other. They then fully silvered one end and partially silvered the other. This produced a light amplifying resonant cavity (Fabry–Pérot etalon)—as long as the ends were flat within a quarter of the wavelength (~700nm) and parallel within a few arcseconds. These polished rods were the key element in early powerful lasers. The three technicians were unable to convince Union Carbide management to adopt these new-fangled lasers as a product line—a familiar story. The three quit Union Carbide, got seed money from Ken and the Nobel money, moved to Ann Arbor and started Sensor Dynamics in 1961. Sensor Dynamics was located in a building at the northwest corner of Main and Jefferson which was owned by Don Glaser—purchased with his Nobel money. Ken knew how to make money for his clients. Sensor Dynamics was best known for making the laser rod that was used by MIT in 1962 to shoot a laser beam through a telescope, bounce it off the moon, and detect the reflected light. They enjoyed a monopoly position and piled up a lot of money. Ken advised them not to pay out dividends which would be taxed again as ordinary income. Also, he advised that their monopoly would likely not last much longer. So, he suggested they invest in high-tech development which would have better long-term prospects and could eventu-
ally yield capital gains via stock offering. After Don introduced Sam Harmon to Ken, the side-looking radar division of Sensor Dynamics was born with an initial staff of me and Sam.

In the aftermath of World War II, the Pentagon was determined never to be caught by surprise again by foreign aircraft as happened at Pearl Harbor. To that end, it set up institutes under the auspices of major research universities including MIT, Stanford University and the University of Michigan. In Michigan, the Willow Run Research Center was oriented to Army needs. Colloquially called Willow Run Labs, it had offices and laboratory space in a building that was part of the Willow Run Bomber Plant operated by the Ford Motor Company to produce B-24s during World War II. The runways and some buildings at Willow Run were being used at that time as the commercial airport for Detroit although it was less than 10 miles from Ann Arbor and about 30 miles from Detroit.

One focus of Willow Run Labs was using airborne radar on a combat airplane to map ground threats and targets. The main problem is to produce a radar beam fine enough to produce good resolution of the ground. A small beam size requires a large antenna aperture; these two are inversely related. But carrying a large antenna on a fighter size airplane is a showstopper. To get around this, Willow Run Labs engineered advanced synthetic aperture radar, aka side-looking radar, which was pioneered by Goodyear Aerospace.

A small antenna is mounted on the airplane pointing out to one side, perpendicular to the flight path. Mapping resolution in the cross-track direction is determined by pulse width of the radar. The aim is to match the along-track resolution with the cross-track. As the airplane moves along, radar returns are coherently summed to create a virtual or synthetic aperture in the flight path direction, which produces a very narrow virtual beam at right angles to the flight path. To create an image of the ground, a holographic method
is applied using antenna theory. Radar return video is recorded in flight and played back after flight through optics to create the ground image.

This system was producing decent images, but it required delicate and hard-to-use instruments for processing. And images were only available post-flight. In other words, it was hardly suited for Army field use. Mathematically, the processing was an analog computer forming the cross-correlation of the radar return video with a transmitted reference signal common to all points. The result was a hologram of the image requiring illumination by coherent light to finally produce the image. This optical process was invented at Willow Run Labs by Emmet Leith, co-inventor (with Juris Upatnieks) of the modern three-dimensional hologram. Thundering commercial jets constantly arriving and departing at the airport caused vibrations throughout the buildings. To counteract those, Emmet’s optical bench was a slab of granite floating on a pool of mercury. Emmet was the archetype of the absent-minded professor. He visited us at Sensor Dynamics one morning and we discussed radar processing for an hour or so. About noon, Emmet came back; he had forgotten his brown bag lunch. Another Emmet story I heard involved taking his car to the shop for an oil change. He decided to stay in the car reading a book while it was being serviced. When he went to use the men’s room, he forgot that the car was on a lift, stepped off into thin air and broke a leg.

Sensor Dynamics aimed to develop a simpler, more robust means of producing side-looking radar images. Early television camera tubes were very insensitive. Broadcasters required studios flooded by extremely bright lights that produced so much heat that they also needed powerful air conditioning. Using natural light outdoors was out of the question. So much for sporting events. This situation changed dramatically with the invention of the Image Orthicon tube
by the Radio Corporation of America. This tube changed television broadcasting from a studio-bound novelty to a massive economic and social revolution. Its importance to the television industry cannot be overstated. The Emmy awards are named after this camera tube. The Image Orthicon’s nickname is “Immy,” but the award statue featured a woman so its name was feminized by changing the first letter. The Image Orthicon camera tube is truly a TV star.

![Image Orthicon schematic from datasheet for RCA 5820 tube. Used with permission from Hagley Museum and Library, Wilmington, Delaware.](image)

**THE TUBE CONSISTS** of an image section in front and a scanning section at the rear. Inside a flat glass on front is a photocathode that emits electrons proportional to the intensity of light (number of photons per second) hitting point by point. These electrons are heavily accelerated by an electric field and steered by a magnetic field onto a thin sheet of glass parallel to the photocathode called the target. As this electron image impacts the target at high energy, it kicks out multiple secondary electrons at low energy. A fine mesh in front of the target is held at a voltage slightly positive relative to the target so it allows the high-speed primary electrons to pass right through but captures the low-speed secondaries. This leaves a positive charge image on the target.
that is a point-by-point amplification by several times more electron charges than the photocathode produced. The image section alone improves sensitivity by a factor of eight or more. But that’s not all.

The scanning section behind the target forms a beam of electrons and raster scans the target using dynamic magnetic fields created by controlled currents in side coils. This produces the scan pattern required for standard television video format. A thermal cathode assembly produces electrons, forms them into a beam and accelerates them toward the target. A large positive voltage is maintained at the face of this assembly so that the electron beam arrives at the target at zero speed and returns. Thus the full name of the tube is “Return Beam Image Orthicon.” An analogy is throwing a ball straight up with speed such that the ball reaches the ceiling at zero vertical speed, just touches, and starts back down.

The returning beam of negatively charged electrons completely discharges the positive charge on the target point by point. At return, then, the beam is a negative image raster scan of the target; where the target charge is “bright” (more positive), more electrons are removed from the scanning beam so the return is “dark.” The returning electron beam is steered into the entrance of a five-stage electron multiplier. As an electron hits the first stage at high speed, it kicks out three or four secondary electrons which are then accelerated and hit the second stage at high speed. Each then kicks out three or four more secondary electrons so nine to 16 electrons leave the second stage. Continuing through all five stages produces a cascade of electrons, and an additional amplification of more than 500. Both the amplification at the target and in the multiplier are free of Johnson noise, so it’s a real improvement in signal-to-noise ratio. Lastly, an inverting video amplifier at the final electron multiplier stage restores the negative image to a broadcast-standard voltage and positive image
video signal. Net result is a camera tube that is actually quite a bit more sensitive than the human eye.

The Sensor Dynamic approach to side-looking radar imaging was to insert radar return video into an electro-optical delay line positioned in front of an Image Orthicon tube and project light through the delay line onto the face of the tube. Each point of the Image Orthicon’s target grid acts as a cross-correlator between the modulated light and the common reference signal applied as modulation on the target grid. That is, it can form a side-looking radar image.

For a proof-of-concept experiment, Sam and I rented one of the TV production studios at the University of Michigan. It was equipped with RCA Image Orthicon cameras. We had hired Ken Monroe, an electronics engineer who had built a modulator and light sources. We opened the camera and added the modulator to the target mesh. We then placed flashing lights in front of the camera and were able to demonstrate the cross-correlation effect. As we were winding up, the Chief Engineer at the TV facility caught us and was duly horrified. However, we were able to get the camera back into full working order and escape any consequences.

About this time, the laser side of Sensor Dynamics was changing. They were well-known and high profile. But, as Ken Heininger had anticipated, their monopoly was coming to an end as several competitors entered the market. Alternative means of establishing the light amplifying resonant cavity had been invented using external curved mirrors rather than the ends of the rod. This greatly relaxed precision flatness and parallelism requirements for the rods and neutralized Sensor Dynamics’ technical polishing advantages. The three principals were getting up in years and decided to cash out, pay the taxes and retire. They did leave us with the corporate shell and the name Sensor Dynamics. Thus did Sam and I lose our only source of funds.

We struggled along by laying off Ken Monroe, taking no salary for
ourselves and using personal funding to work on the project for a couple of months but were running out of money. Sam and I decided we needed to approach one of the major radar development companies. The two most prominent at that time were Raytheon, near Boston, and Hughes, near Los Angeles. We chose Raytheon because the air fare to Boston was cheaper. We didn’t know anybody at either company so I just made a cold call to Raytheon’s main switchboard. I asked the operator to connect me to anybody at Raytheon interested in side-looking radar. She connected me to Tom Cheatam. After the call, I remarked to Sam that the name had an ominous ring to it.

During World War II, Paramount Motion Pictures had made airborne ground-mapping cameras for Army reconnaissance airplanes. About a month before my call to Raytheon, they had acquired the Paramount military operation and many former Paramount employees had become Raytheon employees. As it happened, the switchboard operator who took my call was one of them and her old boss Tom Cheatam was another. She also knew he was interested in ground mapping by side-looking radar so she connected me to Tom. When he heard the words “side-looking radar” and “Ann Arbor, Michigan,” he knew there might be something to it. After we gave a brief rundown of our approach, he invited us to visit Raytheon for further discussion.

Sam and I flew into Logan Airport on an early morning flight. It was about the last to land before Logan was closed by a major snowstorm. We got a rental car and set out for Raytheon on Route 128. Traffic was snarled by the storm and we arrived over an hour late. Tom Cheatam ushered us into a conference room where about ten Raytheon scientists and engineers were gathered. We spent the rest of the day answering questions and talking radar processing with the group. Afterwards, Tom suggested that we send an unsolicited proposal to the Air Force for an exploratory development project.
The Air Force awarded a contract to Raytheon as prime contractor and two subcontractors—Sensor Dynamics and RCA. With funding in hand, we succeeded in making ground map images using recorded radar video supplied by Raytheon and Image Orthicons supplied by RCA. Unfortunately, the image quality was poor. We traced the reason to non-uniformity of the target glass in the Image Orthicon. This is not a problem when the tube is operated normally; the non-uniformity only shows up when the target mesh voltage swings down near zero with respect to the target. RCA was not able to control this well enough to produce good images. Thus ended Sensor Dynamics.

There was one lasting outcome from this venture. I reframed the mathematical modeling for side-looking radar. Previously, the approach was to consider the moving airplane as generating a large synthetic antenna and antenna theory was applied. I imagined the airplane as suspended unmoving in space with the ground scrolling below it as if on a belt. I then showed that each point on the ground generated a linear frequency shift by the Doppler effect as it moved through the physical antenna beam. This is similar to standing alongside a railroad track while a locomotive passes with its whistle blowing. While approaching, the whistle has a high pitch that drops lower as the locomotive passes and recedes. This model reduced the problem to one previously solved, viz., chirp pulse compression for improved range resolution. Eventually, the chirp model led to real-time ground mapping for side-looking radar using digital signal processing. This entails a multichannel version of the single channel range solution. As such, the imaging process is well-matched to modern, highly parallel graphics hardware. Satellites in low earth orbit now produce ground maps in real time and with high quality using this multi-chirp model.
Ken Monroe and I were on an American Airlines flight headed for a meeting with General Dynamics radar engineers in Fort Worth, Texas. Our flight was due to land at Love Field in Dallas at 11:15 a.m. CST on November 22, 1963. The captain came on the intercom and said that all inbound flights were being directed into holding patterns to clear Love Field for Air Force One bringing President John F. Kennedy to Dallas. There was much happy anticipation among Texans over the glamorous first couple’s visit to Dallas hosted by the Vice President Lyndon B. Johnson and Lady Bird Johnson. Our flight finally landed about 30 minutes late. We rented a car and started for Fort Worth, but traffic on the access road leading out of Love Field was still jammed up. We decided to eat lunch at the Holiday Inn restaurant and wait for traffic to clear. In the middle of my tuna salad sandwich, a woman ran through the restaurant screaming, “They shot the President.” Everybody in the restaurant, customers and staff alike, ran into the lobby where there were several TV sets showing the
aftermath of the shooting. We watched dumbfounded until Walter Cronkite reported that JFK was dead.

Stupidly, we got in the rental car and headed for Fort Worth. The Interstate was backed up with cars blocked by police. The police told us nobody was allowed to leave Dallas. While negotiating a turn-around, we could see B-58 Hustler strategic bombers taking off from Carswell Air Force Base near Fort Worth. They had long black pods underneath, fully armed with nukes. A terrifying sight. We got back to Love Field, turned in the rental car and waited in the airport, clustering around TV sets. The FAA ordered all commercial and private aviation flights outbound from Dallas canceled. The airlines canceled all commercial flights inbound to Dallas, too.

A couple of private inbound flights did land at Love Field. The first one unloaded several dozen men in black suits and ties—FBI. I was glad to see them in hopes they would quickly grab the shooter. Another unloaded about two dozen reporters and photographers from Time-Life magazines. Their first draft of history is still being revised.

And one outbound flight. We saw the hearse roll up to Air Force One and load the coffin into the cargo hold. Feelings of disbelief, dread and uncertainty came unbidden. We also saw the limos drive up taking Jackie Kennedy, Vice President Johnson and Lady Bird Johnson to Air Force One. Johnson was still VP; he was sworn in as President aboard Air Force One. I guess we didn’t have a president for a few hours that afternoon. I wondered how the new presidency would unfold—likely much different than before. We saw Air Force One take off back to DC toward a different world.

After Lee Harvey Oswald was captured, Dallas re-opened. By this time, the airline schedules were a total mess. There were many airplanes stranded at Love Field. The airlines just started making up flights on the fly and at no charge. They would announce over loud-
speakers that a flight to New York LaGuardia was forming at gate A12, a flight to Los Angeles at gate B22, a flight to Chicago at B2, and so on. We were too late to get on a flight to Detroit Willow Run, so we caught one to Chicago and then got a regular Chicago to Detroit flight, the second leg of a West Coast redeye. I got home about 5 a.m. the next morning.

Here is a photo of me from an *Ann Arbor News* article on February 13, 1963, ten days before my 27th birthday.

![Fig. 2. Dean Z. Douthat. Photo by Duane Scheel. Ann Arbor News, Feb. 13, 1963. Courtesy of the Ann Arbor District Library. © 1963 MLive Media Group All Rights Reserved. Used with permission.](image-url)
NOWADAYS, a 27-year-old might still be living in mom’s basement having just dropped off his parents’ auto and health insurance. At age 27, I was supporting a family of six and had already been through a Cold War operation, a top-secret intelligence debriefing, a major corporate shake-up, and a presidential assassination. More to come.
After the fall of Sensor Dynamics in 1965, I joined the Ann Arbor Computer Corporation located in back of an old factory building at 415 W. Huron on the south side of the street just west of the Ann Arbor Railroad overpass. I was hired to work on a project for computer control of a machine tool. It was a hydraulic punch press machine for punching holes in metal plates or sheets. Project Manager Roger Buiten had put together a team with diverse skills and talents. Neither he nor anyone else anticipated that those talents extended beyond engineering to include musical performance.

The punch press had a screw oriented left/right that moved a rider nut and the attached workpiece from side to side (x-coordinate) when turned by a direct current servo motor. It had a code wheel on the other end of the screw that emitted an electrical pulse whenever the screw turned by an angle that moved the workpiece 0.001 inch. Mounted on the workpiece carrier for the x-coordinate was a second motor, screw, nut and wheel oriented at a right angle to move the workpiece forward and backward (y-coordinate) with the same pulse
resolution of 0.001 inch. Each motor could move the workpiece at a maximum of 5 inches per second for a total of 10,000 pulses/second maximum if both ran all out. Driving these two motors and counting pulses could position any point on the workpiece below the hydraulic press head. In this head was an eight-position turret that could hold different types and shapes of dies. Once the correct turret position for the required die is selected, the hydraulic press is ready to operate.

The position and types of holes to be punched in the workpiece are coded by a technician from an engineering drawing using an ASR 33 Teletype. This user interface device had a keyboard and printer like an ordinary typewriter and it had a reader and punch for eight-level paper tape. The tape reader and punch whizzed along at ten bytes per second. Codes for x-position, y-position and turret selection were typed on the keyboard of the teletype, which displayed the typed codes on its printer. With the tape punch turned on, it also punched each keystroke into a paper tape. The finished production tape was then loaded into a high-speed paper tape reader on the punch press controller itself where it was read and converted into position and turret commands and punch signals.

The object of the Ann Arbor Computer Corporation’s project was to run the press using a PDP-8 computer. We anticipated improvements to two main problems with the punch press system. First, the existing relay controller was expensive and built on inherently less reliable electro-mechanical components. Its motion control was crude, with significant overshoot plus error due to backlash of rider nuts on the screw. Gear backlash arises after turning in one direction and then reversing. A small amount of turn of input shaft occurs before any movement of the traveling nut. It’s essential because some gap must be allowed to permit any turning at all. The legacy
controller took no account of backlash, so some positions were inaccurate.

Second, directly punching keystrokes into the paper tape on the ASR 33 was unforgiving of errors. If the technician noticed an error immediately, he could hit the delete key which backed the tape up one character and punched the DEL character—all eight holes. Tape readers will just ignore any DEL character they see. But many errors aren’t noticed until too late for that. Then the correct codes must be retyped from the point of error to the point where the error is noticed—a considerable amount of extra work. Later, the erroneous section is cut out and the tape respliced. Finally, the spliced tape is copied from the tape reader to the tape punch on the ASR 33 to produce an error-free production tape with no splices. Usually, the production tape was mylar rather than paper for durability.

Using the PDP-8 computer was intended to address both of these problem sets. First, it would directly control the motors, turret and punch in real time. Each pulse from either code wheel would assert the single interrupt line of the PDP-8 by a wired-OR circuit. Each peripheral device connects to one line via a transistor and signals by shorting the line to ground. In this way, device A OR device B OR, etc., can signal using only one input to the computer. The interrupt line causes the PDP-8 to stop executing its current program and answer an urgent request for service. Additional interrupt sources on the same line were limit switches marking the zero points of both positioning screws and the turret, plus an interrupt when the head returned after completing a punch and one when the tape reader had a byte ready to read. All interrupt sources asserted the single interrupt line, so polling was required to isolate the source. This required handling up to 10,000 interrupts per second to update counters tracking workpiece positions; that is as little as 100 microseconds between interrupts. Since the PDP-8 instruction took 1.6 microsec-
onds with no memory reference and 2.6 microseconds with memory reference, this meant a worst case of as few as about 50 instructions could be executed per interrupt.

Second, the PDP-8’s in-memory editor eliminated all retyping as well as all cutting and splicing. Even at the same time as the job was running, the computer’s console teletype could be used for entering codes for a different workpiece to an in-memory editor with the tape punch turned off. Keystrokes representing punch press positioning and die selection commands were captured into PDP-8 memory. The editor had the ability to print out all codes so the operator could check for errors and correct them in memory before punching a final production tape. My task was to write the interrupt-driven real-time background control program; another engineer wrote the editor program. I had available the lower half of memory, 2048 words, for my programs, while the editor used the upper half.

The PDP-8 had a 12-bit memory bus and it therefore could address 4096 words of magnetic core memory. It was the world’s first Programmed Data Processor with a list price under $20,000 (in 1965, it cost $18,500). It was comparable in price to the extant relay-based controller, especially with anticipated multi-unit purchase discounts. The word size was chosen to hold two six-bit bytes: five bits of data plus a parity bit for error detection. This six-bit byte architecture was inherited from its predecessor PDP-5 and reflected the older Baudot-Murray five-bit code. The ASR 33 Teletype adopted the then new seven-bit plus parity ASCII code giving the eight-bit byte that is now common.

The PDP-8 entered production in 1965, the same year as our project started and we had ordered one but it had not yet been delivered. But we had an old PDP-5 to start working on. The PDP-5 was bigger, more expensive, slower and with half as much memory. Still, the instruction sets were nearly identical; the newer additions were
handy but not necessary. So the same software could run on either. Neither of the PDPs had any memory external to its basic core. So there was no external technical means to get started and load a program into core. That means was provided by a set of toggle switches on the front panel. To load a program, first I had to toggle in four-digit (base-8, octal) machine language for a bootstrap loader using the 12 data switches along with other switches on the front panel setting where the data was to be stored. In this way, a simple loader program of about a dozen instructions was entered and commenced running. It can then load a more featured loader from the tape reader to a fixed starting address high in memory. Finally, this loader can load the actual program from its tape to a designated variable address. Later running programs usually reused the memory where the loader had been for data storage. Every PDP programmer had memorized this set of octal codes from long practice and could toggle it in while half-asleep.

During setup of the press before actual production, each screw needs to be driven until its nut meets and trips a limit switch. That identifies the zero position for each coordinate. Additionally, as the screw is backed out from its zero position, the backlash count is measured by another interrupt as the limit switch releases. I was able to eliminate the overshoot problems with the legacy controller by ramping down the speed of the servo motors before reaching their target position. I eliminated the backlash error by noting which direction a screw needed to turn to reach the next target. If turning in the same direction as the initial zero-setting, I set the target as the actual requested position. But if moving in the opposite direction, I set the target slightly past the requested position and then reversed to that position and added the measured backlash count. Thus every requested position was approached from the same direction and no backlash was present.
Inserting a computer directly into the control loop using interrupt processing was previously uncharted territory explored by our team. At the end of each machine operation, the PDP-8 sets the instruction register to the address of the next instruction and then checks the state of its interrupt line. If that line is asserted (low volts), the value of the instruction register is stored in core location 0000 and the instruction register is set to core location 0001. This is the start of my control program which first polls all connected peripheral devices to determine which caused the interrupt. It then services that interrupt as appropriate. For example, if the interrupt was caused by a count on the x-axis, the x-axis counter in memory is stepped by one. After finishing servicing the interrupt, the control program sets the instruction register to the value stored in location 0000 which causes the interrupted program to continue exactly where it left off, oblivious to the interruption. This is the skeletal outline of basic computer-in-the-loop, interrupt-driven hardware control. At Ann Arbor Computer, we were making it up as we went along. Modern computer hardware provides facilities to make the software more efficient and easier to write but the fundamental concepts and structures remain. For computers to work, thousands of logical elements must operate in strict unison. To enforce that, computers are driven by a master clock that synchronizes throughout. But the real world is asynchronous; things happen whenever they happen. The interrupt mechanism provides the bridge between the synchronous computer and the asynchronous real world.

Our demonstration of the finished product punched the holes in an aluminum sheet for sockets, cable feedthroughs, corner cutouts, and mounting bolts of a TV chassis. We ran two workpieces through, one with the legacy controller and one with our PDP-8 controller. Result: per customer stopwatch, our controller finished the work in 30% less time and subsequent inspection showed improved accuracy.
Recurring production cost was about the same as the legacy system. While running on our controller, a technician was simultaneously coding another drawing. Last but not least, we regaled the customer’s representatives with a rendition of “The Irish Washerwoman.” Not with our atrocious singing voices. Nor with any musical instruments. Music was courtesy the PDP-8.

Early in the project while we were still working on the PDP-5, the engineer writing the editor program brought in a small transistor radio and set it on top of the main rack housing the processor. When a PDP-5 program started running, a static noise came out of the radio. We quickly surmised that the computer was radiating weakly in the AM broadcast band and the radio was picking it up. Forget the punch press software, the challenge was on: could we write a program that would cause a clean tone out of the radio? After a few hours of experimentation, we were able to set up loops that produced a pure tone by amplitude modulation.

One of the hardware engineers had some musical training and piano lessons. So next we set up programs covering three octaves of the 12-tone scale based on middle-A at 440 Hz with frequency doubling over each octave. To make the tonal spacing even over an octave, we set each semitone frequency by a constant ratio with its neighboring semitone frequency. Since 12 semitones must cover a doubling of frequency, the ratio must be the twelfth root of two (1.05946). We linked the tones to ASR 33 keystrokes laid out roughly like a piano keyboard. Now our musical guy could play tunes. Finally, we made our “piano” into a “player piano” by adding capability to store keystrokes in memory during play and later saved them by punching paper tape. When we switched to the PDP-8, we had to readjust all our loop programs to account for the faster execution speed. Our boss, Roger Buiten, knew all about our musical pursuits and approved of them. He understood creative people.
Our best recording was “The Irish Washerwoman” tape that we played at the customer demonstration. The customer representatives loved it. The teletype keyboard was slower than a real piano. We created the *accelerando* by first recording a slow version, and then we used software to repeat the recorded note codes three times, increasing tempo each time. That was my first and last musical episode with computers.

To the best of my knowledge, this was the first instance of a computer-in-the-loop machine tool in the world. Usually, pioneers are the ones face-down in the mud with arrows in their backs. We were fortunate enough to duck that fate.
In 1966, I celebrated a decadal birthday: I was 30 years old and we now had two more children, Dorian and Douglas. In that same year, Bendix Aerospace Systems Division in Ann Arbor, Michigan, won a contract from NASA as prime contractor to develop the Apollo Lunar Surface Experiments Package. These scientific experiment packages were deployed and set up on the moon by the astronauts. The system included a Central Station, a power generator and a variety of experiments. Bendix was prime contractor managing the entire project and, in particular, was also responsible for the Central Station and the seismometer experiment. That experiment was on every Apollo launch intended for a moon landing up through Apollo 16. General Electric had a subcontract for the power generator, which was a Radioisotope Thermoelectric Generator with the heat provided by decay of a Plutonium-238 rod. It supplied 70 watts of power that sufficed to run the Central Station and all experiments. Experiments were supplied by researchers under contracts from
NASA. Different Apollo launches had varying arrays of experiments other than the seismometer.

The Central Station provided a transmitter and receiver for communications with Earth, power conditioning for converting the input from the GE generator into the various voltages needed, power distribution for controlling power to components and experiments, a data processor for collecting experimental and housekeeping data and formatting it for transmission to Earth, and a command decoder for interpreting transmissions from Earth and taking action. The transmitter was considered most likely to have problems, so the Central Station had two of them operating as standby redundancy giving fail-operational/fail-safe functionality. After one transmitter failure, the Central Station continues to be operational. After a second transmitter failure, S-band is safe for radio astronomy. The Central Station also was required to provide thermal conditioning to hold the temperature of electronic elements to a tolerable range in the face of lunar temperature excursions from 260 F above zero to 280 F below zero. During daytime, a thermal plate with a sun shield radiated heat away to the black body of space. At night, electric heaters warmed the thermal plate.

Experiments were carried on top of the thermal plate and Central Station electronics attached to the underside. There was also an antenna and a mast pole to mount it. Astronauts unpacked the Apollo Lunar Surface Experiments Package elements from the Apollo Lunar Module bays and extracted the plutonium rod using a five-foot-long grabber. This rod was in a graphite cask held on cantilever arms outside the lander’s skin. This cask was designed to protect the rod from burning up and to allow both cask and rod to stay intact in case of accidental re-entry of a Lander during return flight to Earth. Plutonium’s decay process has a half-life of just under 88 years and emits relatively harmless alpha particles. These are low-
energy alphas, not the so-called long-range alphas from fusion or cosmic radiation. An intact landed cask and rod after re-entry poses zero radiation risk to anyone finding it; it would not penetrate past the skin. But plutonium scattered into the atmosphere and then inhaled could damage the lungs and possibly other organs. There is a plutonium rod somewhere on the bottom of the Pacific Ocean courtesy of Apollo 13. After the explosion in the Apollo 13 Service Module, the Lunar Module acted as a “lifeboat” until re-entry to Earth’s atmosphere. The Lunar Module burnt up, but the cask and plutonium rod re-entered intact.

On the moon, astronauts fueled the Radioisotope Thermoelectric Generator by opening its top, inserting the plutonium rod, and closing the top back—all the while staying about five feet away from the rod by using grabbers. This distancing was needed because of the high temperature of the rod, not because of its alpha radiation. Both the Central Station and generator were mounted on pallets that had sockets in the bottom. Astronauts inserted the antenna mast into both sockets, creating a single unit for carrying the elements out to a deployment site. This arrangement with RTG on one end of the mast and Central Station on the other was called Barbell Carry. It is exactly like the top, fully-erect position in a barbell deadlift exercise. But it was an easy deadlift: on the moon, the entire ALSEP exerted less than 60 pounds of downward pull.

At the deployment site, astronauts removed experiments and deployed them out away from the Central Station. They set the generator near the Central Station and connected the power cable between them. Then they set up the mast and mounted the antenna, aiming it at Earth using a bullseye sight.

During Apollo 16 ALSEP deployment transit, the RTG was apparently not fully locked onto the antenna mast and it fell off. It dropped slowly to the surface (at one-sixth gravity, a fall of, say, one
meter would take over 1.2 seconds on the moon compared with less than a half second on Earth. The generator bounced and rolled into a shallow crater. A video camera on the Lunar Rover transmitted the whole incident in real time back to Houston, where it was recorded. But NASA had a ten or 15 second delay loop that they used to cut off the public video feed of the incident. Nothing that showed astronauts making a mistake or in any way looking bad was ever to be exposed to the public. During this Apollo 16 ALSEP/RTG incident, NASA’s public feed showed: “Technical Difficulties have temporarily interrupted television from the moon.” Astronauts John Young and Charlie Duke recovered the RTG, reattached it to the mast, and continued with the deployment. At that point, the “technical difficulties” cleared up and public TV from the moon resumed. Kudos to GE, the RTG worked just fine delivering its full specified power. At the next management meeting in Ann Arbor, NASA brought video of the incident as a lead-in to improved redesign of the mast locking mechanism to provide a positive indicator of proper lock.

The transmitter had an output power of one watt in S-Band, or 2200 to 2300 MHz. NASA ground stations have a 90-foot diameter parabolic dish antenna whose gain is more than sufficient to attain a clean signal from the transmitter on the moon. To provide continuous coverage throughout the day as the Earth turns, NASA maintains three such 90-foot stations. One is in California, another in Spain, and the third in Australia. The seismometer was the highest priority experiment, so it got the lion’s share of the data downlink.

America was feeling confident about the race to the moon. The highly successful Gemini program was just wrapping up. Project Gemini advanced from the Mercury program’s one-astronaut crew to a two-astronaut crew. McDonnell Douglas Aircraft in Saint Louis can take a bow for having engineered both the Mercury and Gemini capsules. Just as important as doubling the crew size, Gemini devel-
oped advanced rendezvous and docking techniques, investigated effects of extended time in space environment, and added extravehicular activity testing that perfected space suits to support work in space. And Apollo itself was well underway. It was looking good that we would meet President Kennedy’s schedule before the end of the decade. Beating the Soviets was another question. Nobody who was talking knew how well the USSR moon shot program was going. And anybody who knew wasn’t talking. In stark contrast to NASA, the Soviet program was shrouded in secrecy, making it difficult to assess how far advanced it was. Still a year away was the excruciating tragedy of the Apollo 1 fire, its daunting setback of the whole enterprise, and the near-miracle recovery.

In 1966, I went back to Bendix to work on the ALSEP project. My job title was Systems Engineer, which was a laugh as I had zero experience in that field. But the actual work was to help lead the massive amount of testing involved in developing complex equipment to operate for years in hard vacuum and harsh thermal conditions. The extensive testing regime included individual Central Station components, the Central Station as a whole, each experiment, and the full system: Central Station, the RTG generator, and all experiments.

To monitor all this testing, NASA located inspectors on site at Bendix. Most NASA inspectors and all senior ones were degreed engineers. Every test at any level was conducted according to a documented test plan. The test was conducted by one or more Bendix technicians as needed: it was usually observed by a NASA inspector and always by a Bendix engineer. The technician(s) conducting the test followed a step-by-step written procedure that detailed the expected response(s). Minor deviations could be handled on the spot providing the NASA inspector and the Bendix engineer agreed and initialed the “as-run” test procedure copy. In that case the test could
continue. A major discrepancy caused the test to stop and a Discrepancy Report to be generated, signed by the two observers, and forwarded to the Material Review Board for resolution. This board included NASA senior inspectors, Bendix design engineers and Bendix test engineers. I was on that board.

An atmosphere of mutual distrust existed between the scientists building the outside experiments and us Bendix engineers. We knew that hardware built by scientists was often badly designed and fragile. Because academic scientists usually work in clean, climate-controlled laboratories, they tended toward a baling wire and chewing gum slapdash approach. On the other hand, academic scientists viewed us as mere engineers and working in the grubby private sector at that. Therefore, Bendix management had insisted to NASA that externally-supplied experiments must meet the same conditions as the Bendix-built seismometer. Specifically, all outside experiment Principal Investigators must also deliver a test set that could fully exercise all commands to the experiment and collect all data from the experiment. Along with the test set, experiment PIs were required to provide a step-by-step functional test procedure using the test set to fully exercise the experiment. All experiments had to pass a functional test before they were allowed to connect to the Central Station. Moreover, the experiments had to undergo a number of environmental tests: shock and vibration on a shaker table, vacuum and thermal cycling. The functional test was repeated after every environmental test or during the test for thermal cycling.

The Suprathermal Ion Detector Experiment from Rice University in Houston, Texas, first flew on Apollo 12. The SIDE test set illustrates this mistrust. Rice’s scientists included a high-speed paper tape punch to catch us in the act should we do something to damage the experiment. Every command or application of power to SIDE was recorded on this tape. So, too, was every command response, house-
keeping values report, or data from SIDE. The very first step in the
test procedure was to power up the paper tape punch on the test set.
As commands were sent to SIDE, the tape punch operated for a
burst of several seconds. The punch was a cheap screw unit that you
might find at Radio Shack. It used stepper motors which blasted out
electrical noise. At random, this noise would corrupt the command,
the response or both. This major discrepancy stopped the test dead
in its tracks and caused a Discrepancy Report to be generated. The
Material Review Board assessed the situation and determined that
the tape had no functional role in the testing itself. Therefore,
running the test with the paper tape punch off was approved.

After each test completed successfully, we notified the Principal
Investigator who demanded the tape. He was very reluctant to accept
the explanation as to why no tape was produced. Of course, at Rice
he had never run the test set with the tape on. No need for it when
the test set was in his capable hands. The only purpose of the tape
was to catch any errors by us Bendix buffoons. He suspected we were
covering up something. After a few rounds of this, I had enough. I
opened the tape punch chad box, emptied a bunch of chad into an
envelope, and mailed it to Rice. I included a note saying: “Here’s your
paper tape data; just complement it.” He finally got the message that
we were not going to turn on his precious tape punch. We never
heard another word from him about the tape.

This tale illustrates the difference between life in academia and
life in the real world. The problem was that if SIDE was in some
particular states, a particular command could cause the high voltage
power supply to arc over and cause damage to the experiment’s
sensors. The academic focus immediately homes in on who’s to
blame. Thus the Rice “solution” to this problem was to add that
clumsy and noisy paper tape punch for the purpose of blame-identifi-
cation. The real-world engineering solution would have been to add a
DEAN Z. DOUTHAT

bit of simple logic such that in those particular states, any dangerous command received would simply be ignored. Perhaps a command response in that case would be added, such as “Command illegal in current state,” to alert the user to the situation. Good engineers make friends among users. Anyway, the Rice “solution” calls to mind the old riddle:

*Why is academic in-fighting so vicious?*

*Because so little is at stake.*

The deeper reason the SIDE PI never ran the experiment with the tape punch powered up is simple: it’s dangerous to identify blame when there’s nowhere to shift it.

The most challenging ALSEP testing operation was the full system deployed in a simulated lunar environment. This test required operating the entire system—Central Station, the RTG generator and experiments—for a full lunar cycle of 28 days. To simulate the lunar surface environment, Bendix had procured a massive vacuum chamber. It was a cylinder with a diameter of 20 feet and length of 27 feet oriented with axis horizontal. The chamber was built on a foundation and then a building was erected around it. This building was called the “South Lab,” as it was located about one-tenth of a mile south of the main building on Plymouth Road. The driveway entrance to South Lab was off of Green Road but there was an interior gravel walking path as well. Usually we just walked the short distance between the buildings rather than driving out onto Plymouth and around to Green. The chamber had eight mechanical vacuum pumps backed by eight diffusion pumps. It took a week or two to pump the chamber down to its lowest vacuum depending on the amount of outgassing of the contents. It was able to attain a vacuum of 5 millionths of a Torr (6.5 billionths of Earth’s atmosphere). The cylinder was
closed at the back and had a 20-foot diameter access door on front. This door weighed many tons; it had to withstand over 90 tons of atmospheric pressure when the chamber was pumped down. The door was suspended from an overhead rail that allowed it to roll off to the side and out of the way. A floor was installed in the cylinder about one-quarter of the way up to support objects under testing. It did not extend all the way to the rear; it was approximately square so there was a gap at the back. There were several viewports of thick glass including two near the top of the door. We kept a large stepladder in front of the door to reach the viewport.

Besides the vacuum chamber, there were a number of other test facilities located in South Lab. There was a shaker table that could simulate the vibration time history of a Saturn V launch. That same table could also produce shock events that would simulate explosive events such as the staging of launch rockets and firing of in-flight rockets for translunar injection and lunar orbit. There was a thermal test chamber that could simulate the temperature extremes of the lunar surface. There were also a couple of small vacuum chambers for stand-alone tests of experiments or other components. Every ALSEP experiment and Central Station were subjected to these environmental tests and full functional tests following or during. These test items were called Qualification Models. They were identical to corresponding Flight Models.

I had participated in a number of environmental tests for experiments and for the Central Station. GE had already run the RTG through individual environmental tests before delivery to Bendix. It was time for the full-up system lunar cycle test for the Apollo 12 ALSEP Qualification Model. I was the designated lead test engineer. Central Station, RTG with fuel rod, and all experiments were set up on the floor of the big vacuum chamber. Over each element of ALSEP, we had suspended a high-powered mercury vapor arc lamp to
simulate the sun that pounds the lunar surface unimpeded by an atmosphere. Because these arc lamps would be firing in a hard vacuum, they would not be able to dissipate their large amount of heat into the air as they normally would. So we had piped cooling water into the chamber and bathed the back side of each lamp with it. At one side of the chamber there was a vat holding about thirty gallons as a reservoir for the pump circulating cooling water. Water was pumped from the reservoir, through piping and cooling coils for all the lamps, and then back through return piping and into the reservoir. There were seven of these lamps and altogether they drew considerable current.

After two weeks of pumping, we achieved a low enough vacuum and the 28-day test began. It started at lunar night as the powered-up ALSEP communicated with the S-Band transmitter and receiver suspended inside the vacuum chamber. Test crews were monitoring the operation 24/7 through the 14-day lunar night. Simulated lunar dawn happened one night during graveyard shift.

Ah yes, graveyard shift: home to the lowest seniority, least experienced, and minimally qualified technicians. And absent both NASA inspector and Bendix engineer. Per the as-run procedure, they used a hose to fill the water reservoir, primed the pump, and verified that they had good cooling water flow from the return that emptied back into the reservoir. They then threw the switch to fire up the solar lamps. Instantly, a 100 amp fuse blew. Naturally, they fetched another 100 amp fuse, plugged it in, threw the lamp switch again and blew the second fuse. I believe they would have tried a third fuse if they had one.

At this point, the graveyard crew wrote up a Discrepancy Report and went back to their card game. On their next inspection tour half an hour later, they noted in their log that the water level in the reservoir had fallen. So they got out the hose and filled it back up. Again,
on the next inspection, the water level in the reservoir was down again so they topped it off again. The third time this happened, they just left the hose running slowly into the reservoir. That fixed it!

As overall supervising test engineer, I had messages waiting for me as I arrived at my office the next morning. I immediately walked down to South Lab to take a look at the situation. I instructed the technician to turn on the work lights inside the chamber and climbed up the big ladder at the front door. Unsurprisingly, I was able to see the work lights glistening off the water in the floor gap at the rear of the chamber. I climbed back down and headed directly to the NASA inspectors’ office and asked them to convene the Material Review Board right away. Reluctantly, the MRB agreed to break vacuum and open the big door. As the door rolled off to the side, a cascade of water gushed out down into the drain pit below where the pumps were located. Luckily, the water had not yet reached the level where about 10 million dollars ($80 million in 2020) of ALSEP equipment was sitting. And so it was that, after firing the entire graveyard crew, the accident investigation began.

At one side of the vacuum chamber, there was a feedthrough panel where all wires, cables, plus the feed and return pipes for cooling water passed through. On the vacuum side, there was a place where the insulation of the solar lamp power line wire had been accidentally scraped bare. This wire was laying on the feed pipe of the cooling water. When the solar lamp switch was thrown, a direct short to the grounded cooling line pipe blew the fuse. It also blew a hole in the water line. The second fuse blew the hole even wider. Amazingly, nobody on the graveyard crew wondered why the fuses blew nor did any of them wonder where the water was going.

It took over a month to clean up the vacuum chamber mess. The most time consuming were the eight dual vacuum pumps. Because we didn’t have a good handle on how long the cleanup would require,
Bendix dropped into the critical path for launch. This is not a nice place to be; corporate officers got lots of phone calls. After cleaning up the chamber, the full system test was successfully redone and we got back out of the critical path.

Fast forward about 25 years when Bendix had gotten out of the aerospace business. In fact, Bendix as a separate entity had ceased to exist; it was absorbed into a conglomerate, Allied Signal, which later merged into Honeywell. When Bendix closed down the Ann Arbor Aerospace Systems Division, it sold the property and buildings on Plymouth Road and Green Road to the University of Michigan for one dollar. U-M used the buildings but tore down the main building after a while. The South Lab was not torn down because of the massive iron monster inside. In 1981 there was a fire at the Economics Building on the main U-M campus in downtown Ann Arbor. The fire was quickly handled by the sprinkler system, but many books and papers had serious water damage. The damaged items were hauled out to South Lab, put in the chamber and pumped down. This salvaged those books and papers.

We at Bendix had an excellent relationship with the contract monitoring people from NASA’s Manned Spacecraft Center in Houston. Long after the ALSEP program ended, we had reunions every five years. Most of the old NASA crew would fly up on their own dime for the reunions at German Park in Ann Arbor. Tom Fenske, ALSEP Program Manager, always led the festivities. At one reunion in the mid-1990s, Bendix folks tried to talk NASA into firing up one or more station’s transmitters but they said it would be too difficult to get time on the big 90-foot dish.

During the ALSEP program, a small contingent of NASA managers came up from Texas each month for a management meeting. The NASA managers and engineers all came for the main reviews: Preliminary Design Review, Critical Design Review, Qualifi-
cation Review and Flight Readiness Review. The first two happened only once but the last two happened for Apollo 11 through 17. Our NASA counterparts would bring us inside stories and information from Manned Spacecraft Center.

Houston, Texas is near the buckle of the Bible Belt. NASA Houston got many letters during the Apollo program. It was widely known that Bendix was involved. The only branded consumer product with the Bendix name was the Bendix Washing Machine, which was the first successful home automatic laundry appliance. Bendix didn’t actually build the washing machines; they licensed their name to another South Bend company. One letter NASA got was from a Texas lady not attuned to such distinctions, who wrote: “Bendix should stick to washing machines.” Another letter writer said, “Why don’t those astronauts stay home and watch television as God intended?”

All astronauts scheduled to be on the moon came to Ann Arbor to train on setting up ALSEP. In the South Lab, we set up a “sand-box” with a fine-grained gravelly sand surface. Astronauts trained in full space suits just as they would on the lunar surface. Additionally, they wore parachute harnesses connected by a line to an overhead lift system that took five-sixths of their weight, simulating the lunar gravity. The training versions of Central Station, RTG, and experiments were one-sixth the weight of their real counterparts. This gave them quite a realistic simulation of conditions they would face. During training, I became acquainted with many of the astronauts. Fast forward to the late 1990s when the movie “Apollo 13” was playing. I took my grandson to see it; he was about eight or nine at the time. As we were walking out of the theater, I said, “You know, Michael, I knew those guys.” His eyes widened in amazement, his mouth gaped, and he said, “You knew Tom Hanks?” I almost fell on the theater lobby floor from laughing so hard.
For Apollo 11, NASA was unsure how difficult working on the lunar surface would be and the planned extravehicular activity was short. NASA didn’t want astronauts heavily tasked for 11. So we developed the Early Apollo Surface Experiment Package. It was designed to be set up by Buzz Aldrin in just a few minutes. EASEP was a single package with just the seismometer experiment and a laser ranging retro-reflector. EASEP was powered by solar cells covering panels near the top of the Central Station and covered with a protective glass plate. It was not expected to survive the low temperature of the 14-day lunar night. All Buzz had to do was carry EASEP out about 150 feet from the lander and deploy the two experiments. We told Buzz he could walk out in any direction except to the east. When the ascent stage takes off to rendezvous with the Command Module, it flies east. For specificity, we said go south.

At the next management meeting after the Apollo 11 mission, the NASA people brought us a video tape. It was from a camera looking straight down at the ascent rocket plume during takeoff of Apollo 11 ascent stage from the moon. It showed the hot rocket plume passing directly over and impinging on EASEP. Buzz Aldrin had put EASEP in exactly the worst possible direction. This explained why we were getting only about half power out of the solar cells. The protective glass covering the cells was probably cracked by the hot rocket plume destroying some of the solar cells. Unexpectedly, EASEP did survive the lunar night and operated about 21 days before the seismometer stopped working and the transmitter was commanded off.

Today, the laser ranging retro-reflector is still bouncing laser beams from Earth back along the same path. There was even an episode of “The Big Bang Theory” television series about it. The laser ranging retro-reflector provides absolute refutation of those claiming the moon landings were faked on a Hollywood backlot.
My second stint at Bendix Ann Arbor ended in 1968 as I left to join Sam Harmon again in another startup. After that ended, I came back again to work on ALSEP. For continuity, the ALSEP and Bendix story is finished here—out of strict chronological order.

Beginning with Apollo 17, NASA decided to upgrade the ALSEP by striving for a longer predicted life and a larger experiment load and variety. The latter was to be attained by eliminating the seismometer, freeing up large amounts of weight, power and data bandwidth for newer experiments. Design life of ALSEP originally was one year. For Apollo 17 and later, it was two years. My job title this time was Senior Engineer, Central Station Electronics. At Sensor Dynamics, I had picked up electronics design on the fly; my return to Bendix solidified that new skill. I led about 50 people working on the redesigned Central Station electronics. Most of them were electrical engineers but I also had a couple of mechanical engineers involved with packaging the electronics to withstand the rigors of rocket firings and aerodynamically-induced stress. I also had a couple of thermal engi-
neers taking care that the heat from the electronics was adequately removed. The size of the thermal plate was enlarged to permit more experiments to be carried. It also gave room for reworking electronics with more redundancy for longer life expectancy. Using stringent failure modes and error analysis, we were able to identify potential weak points and reinforce them. We also added a second command receiver in standby redundancy. The expected time to failure for the Central Station reached 125 years.

I made inspection trips to Texas Instruments with our quality assurance inspector for precap visual inspection. Every integrated circuit used in ALSEP Central Station was examined in detail through a microscope before being closed up by a cap. For the redesign, we had switched from Diode-Transistor-Logic to the newer and faster Transistor-Transistor-Logic for digital application. The faster rise time for TTL produced harmonics well into radio frequency range. Accordingly, we convinced NASA engineers to apply the RF grounding standard instead of the ordinary single-point grounding standard applied in earlier Central Station electronics. We then gold plated the underside of the thermal plate and used it as distributed RF ground.

I also was monitoring two subcontracts for elements of the Central Station. One was for the S-Band transmitters which was to Teledyne. This contract was easy; there were very few problems and these were quickly addressed by Teledyne. The other was to Bulova Watch Company in New York City. A nightmare. This component was foisted on us by NASA. Our S-Band (2200-2300 MHz) transmitters are fairly close to the 2700 MHz radio astronomy band. Radio astronomers petitioned NASA to have a backup for turning off the ALSEP transmitter after its design life in case control from Earth was lost. Bulova had an early electronic watch called Accutron; its time reference was a minuscule tuning fork whose frequency was counted
down by electronics to drive miniature motors moving the hands. Bendix issued a subcontract to Bulova for a modified Accutron that eliminated the motors and hands. It would emit a signal that could turn off power to the transmitter after its design life—two years in the case of the enhanced version of ALSEP. This component had been on all previous Central Stations.

Bendix had several watches delivered for testing. The tests could never get those watches to give a consistent signal. One would fire after two months, another after six months. They just were not reliable. I sent an engineer to Bulova several times to work with them but to no avail. When loading ALSEP Central Station into the Lunar Module bay, one of the last steps is to insert a battery into the Accutron. Rumor has it that NASA quietly told the Bendix technicians doing the loading to skip the battery insertion. Bulova had a major advertising campaign with the tagline, “Bulova Accutron: The Watch That Went To The Moon.” It went all right, but sans battery.

To be fair, I was not personally able to verify that rumor. Also to be fair, some astronauts wore Accutron watches. Still, to insiders, that ad is a hoot.

One other Apollo 17 story is worth sharing. As mentioned above, the size of the Central Station thermal plate was increased to allow for a larger experiment load. Once the revised thermal plate drawing was finalized, I was dispatched on a flight to New York City, drawing in hand, to visit the Grumman Aircraft Engineering Corporation’s Lunar Module program in Bethpage, New York, on Long Island. The Central Station was held in a Lunar Module equipment bay on a pair of slide-out rails. Grumman needed to modify these rails to accommodate the larger Central Station. Legendary chief engineer of the Lunar Module, Tom Kelly, personally escorted me to a huge drafting room. There were at least 80 drafting tables set up in rows of four and an aisle down the middle. Tom guided me to the drafting table of
interest. He introduced the designer, one of over 7,000 people working on the program. He had already pinned the rail drawing on his table. He took out his electric eraser and started erasing the rail. I made some silly remark about being sorry to make him erase. Tom said, “The pay’s the same, drawing or erasing.”

Far and away the worst Principal Investigator we had to deal with was Professor Joseph Weber at University of Maryland. Scheduled to fly on Apollo 17, his experiment was the Lunar Surface Gravimeter, and it aimed to detect gravity waves as predicted by Einstein’s General Theory of Relativity. In his first visit to Ann Arbor, Professor Weber announced that he had been a student of Einstein at Princeton—as, of course, none of us Bendix peons had been.

A gravimeter works by balancing a weighted beam against a spring. The beam has a plate on the end centered between two other fixed plates. This forms a capacitor that is wired into a radio frequency circuit. If the beam moves, it alters the RF circuit, changing its frequency slightly, and is thereby detected. If the local gravity changes, the beam will move up or down against the spring and be detected. With the Lunar Surface Gravimeter on the moon and another gravimeter in College Park, Maryland, the pair might be able to detect a gravity wave passing the Earth-Moon system. Such a gravity wave was expected to have a very long wavelength so the roughly quarter-million-mile baseline is essential to the experiment. After the LSG is in place, the beam must be balanced by fine-tuning with a movable weight that rides on a worm screw turned by a geared-down motor. An analog is the common scale in a doctor’s office with a beam and a sliding weight that is moved until the beam balances without touching. Then the weight is read off markings at the position of the weight.

In the step-by-step test procedure, the first step after unlocking the transport clamp is to command the motor to move the weight to
the end of its travel. As the weight moves, LSG sends data indicating its position. During testing, the weight moved all the way to the end and fell off. When this was mentioned to Professor Weber (who told us often that he studied under Einstein) with recommendation to add a mechanical stop, he demurred. Just run the motor until near the end and then stop it, he insisted. Bendix engineers argued that a stop would be a good idea anyway, just in case. LSG, Weber explained, was right up against its weight limit and couldn’t afford to add anything. Bendix suggested no added weight was needed: instead of a stop, just heat up the end of the worm screw and hammer it to spoil the threads. The Professor (who studied under Einstein) noted that He Himself (who was a student of Einstein) would be operating the LSG from NASA Mission Control in Houston so there would be no problem.

So here comes the big day down in Houston and Professor Weber (who studied under Einstein) proceeds to command the weight to move toward the end. Watching the position indicator, he (who was a student of Einstein) commanded the motor to stop just before the position got to the end. And the weight fell off. The weight position indicated in Houston showed where the weight had been about 1.3 seconds earlier on the moon. And when the Professor (who was a student of Einstein) sent the command to stop, it was about another 1.3 seconds before the motor on the moon actually stopped. Too late; Professor Weber (who was a student of Einstein) forgot about the finite speed of light.

The ALSEP deployed by the Apollo 12 crew had the longest life—almost eight years. It started operation on November 19, 1969 and was still fully operational on September 30, 1977 when all ALSEP transmitters were commanded off. Not bad for a one-year-life design goal. At one time, there were five ALSEP systems in operation on the moon. NASA decided to shut them down for monetary reasons and
because they were generating so much data that the scientists were unable to keep up with it.

During development of the upgraded ALSEP, researchers at Stanford University who studied conditions and phenomena in Antarctica contacted Bendix. They wanted to use ALSEP Central Station to support experiments they would build and deploy in Antarctica. It could easily handle the conditions there, which were much less severe than on the moon. The RTG would sustain the system through the months-long night. The transmitter and receiver would communicate with researchers in Palo Alto by relay through a geosynchronous satellite. We gave them documentation from the original ALSEP: engineering drawings, printed circuit board schematics, art work, stuffing diagrams and silkscreen masters. We also gave them some leftover Central Station Qualification Model components.

Early in its life, Bendix Ann Arbor had been highly successful in winning proposals. By the time the enhanced ALSEP design work was winding up, the win rate had fallen to 17% and management was concerned enough to hire a consultant, Bob Eisenhardt. A major part of the problem he identified was that proposals were being written by engineers. Engineers are notoriously poor writers even for simple expository purposes—user manuals and the like. Winning proposals require the ability to write persuasively, an even more daunting challenge. The recommended solution, adopted by Bendix management, was to create the “Proposal Management Department” to write all Bendix proposals. This small group of staff must be not only skilled at persuasive writing but also technically adept across a broad spectrum. They would decide which requests for proposal would be bid and the general strategy. They would then interview the engineers doing preliminary design work for the proposal and decide who would be assigned to the project should the proposal win. From these interviews they would write the technical sections of the proposal. Simi-
larly, they would interview the manager(s) that would be assigned to
the program to develop and write up the program plan portion of the
proposal.

My work as lead engineer for the ALSEP Central Station elec-
tronics upgrade was all but formally finished. I was selected to head
the new Proposal Management Department, which I ran for its first
year of existence. Notably, we bid on three scientific experiments to
ride the Viking Lander onto the surface of Mars. The stringent power
requirements were regarded as near impossible. We proposed using
Application Specific Integrated Circuits and were able to meet those
requirements. Bendix won all three of the experiment contracts. We
raised the overall win rate to 50 percent.

At the founding of the Proposal Management Department, Bob
Eisenhardt recommended that management run a division-wide
contest to identify potential staff. It was a blind writing test. Along
with the announcement and rules of the contest, a set of engineering
specifications and drawings for an item was published. Employees
were required to write a description of the item and how it worked
for non-engineer readers, along with a sales pitch.

Upon receipt of submissions, Bob’s secretary prepared them for
blind review. With nearly 2,000 employees at the division, we got
about 150 entries. Bob and I read and evaluated them and found that
all but one were not even minimally passable. That one was outstand-
ing. The author turned out to be a young man named Andy Lawler
who worked in the print shop operating photo-offset presses.

Andy attended a Historically Black College on a full-ride basket-
ball scholarship! He said he was the only white guy on the basketball
team and almost always the only white guy in class. He had recently
graduated with a chemical engineering degree but had not found
work in that field. The director of marketing at Bendix, Joe Conway,
later left to start a venture capital operation funded by the National
Bank of Detroit. At NBD, Joe hired Andy as a management and marketing advisor to their clients and put me on retainer for technical due diligence assessments. After working with many startups, Andy became an Adjunct Professor at University of Michigan Business School teaching about venture capital, startups, IPOs and the like.

So, the Proposal Management Department launched with just two members. Later I added some outside hires, using the same writing test, reaching six staff within a year. I laid down a few operating principles. We must strive to be the first proposal to be picked up from the pile and read. That first read becomes an unconscious standard by which all other proposals are judged. Also, we must always keep in mind that there are at least two audiences, management and engineering—both important, but in different ways. Engineers make recommendations; managers make decisions.

I noted that most bound documents are printed single-sided on standard 8.5-by-11-inch paper in portrait orientation. They are bound along the longer edge, often with staples making it difficult to lay out flat. So we printed in landscape orientation with spiral binding along the shorter edge. Besides the necessary identification text, our front covers always featured a graphic of some sort—a photo, an artist’s sketch, etc. The same, or often, another related graphic was printed on the outside of the back cover so graphics were visible no matter which side of the proposal was up. Pictures are much more attention-grabbing than text and can be apprehended even without reading glasses. We also printed on both sides of the paper so our proposal might have as many pages as a competitor’s, but half as many sheets, so it was thinner. These differences of external appearance greatly enhanced the odds of being first picked from the pile.

Inside, we continued that pictorial approach. Laid out flat, each left-hand page contained a graphic of some sort—a photo, engi-
neering drawing, artist’s sketch, block diagram, flow chart, schematic, etc. The corresponding right-hand page contained text about the image. To accommodate the “mature” eyesight of older managers, we used 18-point text instead of the typical 12-point and arranged it in two columns for easy and accurate return of the reader’s eyes from one line to next. With the spiral binding facilitating laying out flat, the proposal became a series of two-page “scenes”—a kind of slow-motion or stop-action movie. For management readers, we focused on photos or artists’ drawings to provide an easily-grasped pictorial understanding. In the text, we emphasized analogies to foster understanding of technical issues. Analogies are not effective for persuasion but are excellent for explanation and understanding. Following these approaches tripled the win rate for Bendix in just one year.
Between the ALSEP testing gig (1966-68) and the Central Station electronics upgrade and proposal management gig (1970-73), I again joined Sam Harmon in another Ann Arbor startup called Datamax. This company was focused on data communications and particularly error correction. When transmitting data over a noisy medium such as a telephone line, errors can occur. The common means to handle this is to transmit data in fixed-size blocks with a parity word appended. That parity is computed over the entire data block by a defined algorithm. The receiver applies the same algorithm over the data portion received and compares the two. If they agree, the receiver sends an acknowledgement message back to the transmitter, which then proceeds to transmit the next block. If they differ, an error has occurred somewhere in the block. In that case, the receiver sends a non-acknowledgement message back to the transmitter, which then proceeds to retransmit the same block. This method is called backward operating error correction.

Provided the communications channel is not too noisy and there
is minimal delay between sending a bit of data and receiving it, this backward operating method works just fine. But those conditions do not always pertain. A method that does not involve retransmission is then needed. We called this forward operating error correction. The idea is to add parity information to each transmitted byte so as to be able to determine not only that an error has occurred but also which bit is in error. Then simply flip that bit and continue.

Others had tried solving the issue with exotic mathematics, but these led to major decoder difficulties of complexity and expense. I had the idea to approach the problem backwards by first defining a simple and inexpensive decoder that I knew how to build and then searching for parity codes that matched that decoder. I programmed a brute force search on a time-shared PDP-10 and turned it loose. It was not an elegant engineering approach, but I'm only an accidental engineer. The program found codes that could correct up to three errors in a block. We then built encoder/decoder hardware suitable for demonstrating the capability.

Time, Inc. had leased a channel in one of the transatlantic cables between its New York office and its London office. Over time, the quality of the channel had deteriorated to the point that the backward operating error correction just kept retransmitting the same data block over and over. It was useless. In the winter of 1969, Datamax installed encoder/decoder pairs in both offices using five bits of data and three bits of parity on each eight-bit byte. This rescued the channel.

That June, I traveled to Los Angeles to install an encoder/decoder in the Time LA office communicating with the New York City office. My co-worker Tom and I were staying at the Beverly Hilton and we watched an NBA finals game with the Lakers in Boston on TV. The game ended about 7:30 LA time and we decided to go out to dinner. I gave our valet ticket to the attendant and noticed a Chinese lady and
another lady waiting for their car. A white Ford sedan pulled up and the two ladies hopped in and drove off. I told Tom that I thought that might be our car. About then, an identical white Ford drove up. We got in, Tom driving, and I immediately opened the glove box where I had previously stashed a map of LA. No map. I told Tom that this is not our car and we got out and started explaining this to the valet attendant.

About then, the first white Ford sedan pulled back in and the two ladies got out. They were embarrassed and apologetic. The Chinese lady said: “We are so sorry that we stole your car. To make it up, you must come to dinner with us. Follow us, but first we must go pick up Anne.” We agreed and followed their car to a massive mansion in Beverly Hills. Anne was waiting and as she got in the other car, I recognized her from the movie “The Graduate”; she was Anne Bancroft. The Chinese lady was Nancy Kwan who starred in the movie “Flower Drum Song.” The other lady was Ms. Kwan’s secretary and assistant. We followed them down to a restaurant in Chinatown where we had a delightful dinner that Ms. Kwan ordered for us in Chinese. Both stars were down-to-earth regular people who were fun and interesting to be with.

Though Datamax had some success, we again ran out of money and folded. The codes we discovered were published and are still used by NASA for deep spacecraft communications. The data delay for those can be an hour and more; backward operating error correction is out of the question.

A few years after Datamax folded, Sam Harmon and his family moved to Nairobi, Kenya. He worked as an advisor to the government there in matters of science and engineering as related to development. He spent the rest of his working career on international development issues. Sam died in March 2020.
The AAM-N-10 Eagle missile, a long-range, air-to-air missile, began development in 1957 with Bendix as prime contractor. The Navy was pursuing a concept of fleet air defense based on detection of hostile airplanes at long range before they could launch anti-ship weapons. The concept involved a large airplane carrying an advanced track-while-scan radar and a heavy load of long-range, air-to-air missiles. Its design objective was to be able to simultaneously track and attack multiple targets. Initially, the Eagle missile development was centered at Bendix Pacific Division in North Hollywood, California. Later, Eagle development transferred to the Aerospace Systems Division in Ann Arbor.

Bob Eisenhardt, his brother Harris, and Gene Jordan were lead engineers who moved to Ann Arbor among a large group from Pacific Division. When Eagle was canceled in 1960, these three decided to start a company called Veda. Its business model was based on the idea that the Navy still needed a next generation fighter weapon system—airplane, radar, and missile. They were able to acquire contracts from
the Naval Air Systems Command in Maryland to plan a new fighter, radar, and missile program. Harris Eisenhardt led this project. Eventually, this planning resulted in the F-14, the AWG-9 radar, and the AIM-54 “Phoenix” missile (arising from the ashes of Eagle). Bob and Gene got contracts advising the Naval Air Development Center in Pennsylvania on related engineering and technical issues.

Veda had a small subcontract from Bendix under ALSEP. It produced the gimbals and aiming devices that astronauts used to line up the ALSEP antenna to Earth. Harris Eisenhardt had excellent high-level contacts in the Department of Defense and was engaged in strategic consulting on advanced technology. As I approached my one-year anniversary heading the Proposal Management Department at Bendix, Veda principals were having a disagreement. Harris wanted to relocate the company near D.C. to facilitate his high-level DOD consulting. But Bob and Gene wanted to stay in Ann Arbor and focus on guided missile technology. They decided to split up. Harris took the Veda name and some employees to Alexandria, Virginia. Bob and Gene stayed in Ann Arbor and they brought on board Lou Belcher as administrative manager so they could continue to focus on technology. They invited me to join their newly formed company, the First Ann Arbor Corporation. My title was chief scientist and vice president, and I was a co-owner.

The Naval Air Development Center in Johnsville, Pennsylvania, a suburb of Philadelphia, was a focus of engineering related to the U.S. Navy air combat mission. NADC was charged with monitoring Hughes Aircraft’s contract for developing the Phoenix missile. So Gene or I traveled there frequently and attended all design reviews in Culver City, California. Naval Air Systems Command had analyzed results of air combat during the Vietnam War and determined that Navy air crews were not using their air-to-air homing guided missiles effectively. They concluded that more realistic training was needed.
To this end, NAVAIR initiated the Air Combat Maneuvering Range. The range used a pod mounted on an airplane missile station communicating with ground tracking using microwave communications. The contractor for these elements was the Cubic Corporation of San Diego, California. They supplied a multilateration microwave tracking system that received messages from the pods. Multiple ground receiving nodes scattered throughout the training area reported via landlines back to a central node. Using differential time-of-arrival at pairs of receivers and solving a set of equations, the transmitter can be located at the intersection of three or more spheres. This provides real-time tracking of positions of all airplanes on the range. Multilateration is like GPS, but inverted. Both use multiple time differences to locate the user on the intersection of three or more spheres. In GPS, there are multiple transmitters (satellites) and a single receiver. Multilateration has a single transmitter and multiple receivers.

When a fighter’s missile fire button (the pickle) was pushed, a signal was sent to the ground which started a missile simulation. The simulation used the tracking data of the target as input and determined hit or miss. In case of a miss, a reason for miss was relayed to the pilot and available for post-flight review and replay.

First Ann Arbor Corporation won the contract from NADC to provide missile simulations for this new training range. I learned missile guidance, control and aerodynamics on the fly and worked on the simulations. The target host platform for the simulations was an IBM 360 mainframe. According to IBM sales literature, the 360 covered the full 360-degree circle of applications. Our contract required the simulations to support four missiles in flight at the same time. The 360 was a batch processing machine with no means of multi-tasking. I had to create a time-sharing framework in our programming language, FORTRAN. As we began testing at NADC
Johnsville, we found we were not able to run four missiles at once. We were close, but just shy.

I had developed good relations with a somewhat eccentric employee at NADC named Ed Lawler. I had heard stories. Ed carpooled with three other NADC employees. On one occasion, it was Ed’s week to drive and he dutifully showed up at the first house at 6:15 a.m. After waiting a while, Ed became impatient and began honking his horn. After much honking, his carpool mate emerged from the house agitated and in his pajamas. Yes, it was Saturday. On another week when Ed was driving, Johnsville had a sizable morning snowstorm and employees were sent home early. Unfortunately, Ed’s car was stuck in the snow, so his three passengers got out and pushed. Once clear of the snow, Ed drove right on off leaving his carpool stranded.

Ed and I discussed the possibility of using quaternions instead of Euler angles to simulate the rotational geometry and kinematics of the missiles. Quaternions had been used in the guidance computer of the Apollo Command Module to handle its celestial navigation and were known to be fast and efficient. Together, we worked out the mathematics of an improvement on the original Hamiltonian quaternions called Complex Factored Quaternions. It took me about six months to prove the key central theorem of our new quaternion kinematics. I have written a monograph on CFQs. These proved even more efficient than the quaternions used in Apollo. Revamping the missile simulations to use our new quaternions saved enough computation time that we were able to sustain four missiles in flight at the same time, as required. So began the Air Combat Maneuvering Range. Today, there are 14 training ranges, all far advanced beyond the original, able to handle dozens of missiles in flight and a dozen or more airplanes. Most are operated by the U.S. Navy and Air Force but some U.S. allies also operate them. All weapons simulations—guns,
missiles, smart bombs—for all ranges were developed and supplied by First Ann Arbor Corporation and its successors.

Even though I published a Navy technical report on Complex Factored Quaternions, no competitors have been able to take advantage of them. It requires a major shift of mental framework to understand how to use them. I gave lectures on CFQs at week-long seminars to the U.S. Naval Research Laboratory in D.C., the Air Force Research Laboratory in Dayton, Ohio, McDonnell Douglas in Saint Louis, Missouri, and Naval Air Weapons Station in China Lake, California. As a result, NRL was able to identify and correct a design error in their anechoic chamber. They also awarded us a contract to simulate an AGM-82 Harpoon—an air launched anti-ship missile. They were able to use that simulation to identify an error in design of gimbals for the radar seeker. At NAWS, they were able to use Complex Factored Quaternions to more accurately simulate and analyze the free gyroscopic seeker in the AIM-9 Sidewinder air-to-air missile. Before, they had been restricted to modeling only small seeker deflection angles where they could use approximations to trigonometric functions.

In 1978, Lou Belcher won election as mayor of Ann Arbor. For First Ann Arbor Corporation, Lou handled personnel, accounting, finance, and contracts. He was an outgoing kind of guy with a talent stack well suited to politics. He thrived in the limelight. One big issue that Lou focused on was saving the Michigan Theater on Liberty Street from demolition. He pushed for formation of a renovation board that raised funds and oversaw restoration of the theater to its Art Deco glory. Lou appointed me to that board, which was interesting and fun. Somewhere in the Michigan Theater there are two seats with Doris’ and my names on them.

Lou continued working with us; mayor was not a full-time job. A city manager handled day-to-day operations. By then, First Ann
Arbor Corporation had moved from our original location up the hill on Research Drive off Huronview Boulevard and North Main Street at the exit from M-14. We now occupied all three floors of the building at 214 East Huron Street—the next building west of the City Center Building, which is on the southwest corner of Huron and Fifth Avenue. This was just a short walk for Lou to City Hall on the northeast corner of Huron and Fifth. Our building dated from just after the Civil War and had been a hotel and retail store over the years. Lou had an office up front off the lobby with a big plate glass window. Any of his political fans or foes could walk along Huron Street and get a gander of Lou hard at work. Lou loved it.

At that time, there was a local bank called Ann Arbor Bank and Trust Company. Lou kept getting calls from people who assumed First Ann Arbor Corporation was the holding company for that bank. Lou found this tiresome and possible politically detrimental. So the company name was changed to FAAC, Inc. It still operates under that name, occupying several buildings in the business park off Oak Valley Drive on the south side of Ann Arbor.

In upper circles at the Pentagon, quality versus quantity was a hot issue. Most U.S. analysts favored using technological advantages in highly sophisticated and complex weapon systems. These naturally cost more so fewer can be afforded. Opposing militaries opted for simpler weapon systems but more of them. The theory was that the outnumbered U.S. side will prevail because of the greater capabilities. But this theory, though widely accepted, was untested in practice. The Defense Advanced Research Projects Agency decided to run a controlled experiment. They wanted to conduct fairly realistic combat engagements on the Air Force training range near Nellis Air Force Base, which is just north of Las Vegas, Nevada. A Blue Team flying Navy/Marine F-14 and Air Force F-15 fighters was to take on a Red Team flying F-16 fighters. Red forces would use foreign adver-
saries’ tactics and outnumber Blue forces in each engagement, 4-on-1, 4-on-2, 2-on-1, etc. This program to evaluate tactics when outnumbered was called ACEVAL. The experimental hypothesis was that the better radar and longer range missiles of the Blues would overcome the Reds, despite their inferior numbers.

A second test objective was to determine what to do in case the standoff attack didn’t finish off the Reds and the Blues had to engage in a dogfight. These situations devolve into turning contests, each fighter striving to reach a relative geometry to permit successful firing of guns or a short-range missile. The bigger and heavier Blue fighters are disadvantaged in such an engagement. To overcome this disadvantage, DARPA proposed a short-range missile that can hit targets even when launched from inferior relative positions. The second objective of the controlled experiment at Nellis was to evaluate a thrust-vectorized, short-range missile concept. The concept was to use deflection of the rocket exhaust to the side to quickly turn the missile early in flight. A “paper” design was created and a simulation built to run on the training range. Evaluation of the advanced missile concept was called AIMVAL.

DARPA ACEVAL/AIMVAL program management and engineers came to NADC to discuss weapon simulations. Both Gene and I attended. The program manager opening the meeting said: “We are trying to select which missile simulations to use in the ACEVAL/AIMVAL project. Frankly, we don’t favor yours for two reasons: they are too fast and too cheap.” In other words, they suspected that our simulations were not very accurate. NADC and FAAC showed the extensive validation and verification runs we had made using engineering simulations from the missile manufacturers as reference. The matches were good enough to convince DARPA to use the FAAC simulations. Gene designed the concept missile, which was named AGILE, and I wrote its simulation for the range.
simulation was a fully dynamic, six-degrees-of-freedom model. AGILE was able to hit a target at four o’clock relative to its launch airplane, that is, when the Blue airplane had essentially “lost” the dogfight in the traditional sense. In that scenario, AGILE flies out ahead of the launch airplane, nearly stops, then turns around and intercepts the pursuing airplane behind the launcher. At very low speed, it can readily flip around even 180 degrees if required. I used that simulation to map out conditions under which it could hit, which is called a launch zone. The “paper” functionality of AGILE has now been mostly realized in the deployed AIM-9X Sidewinder heat-seeking missile.

Besides AGILE, the Blue Team had an upgrade of AIM-7 Sparrow semi-active, medium-range missile. Version E was already deployed and version F had just finished development testing and was about to enter active deployment. One significant change for AIM-7F was a reduced thrust of its rocket with a longer burn time. Energy was the same in both cases but the lower initial acceleration allowed a quicker initial turn. I traveled to Nellis AFB to brief the Blue Team on AIM-7F and AGILE.

The Blue Team leader was legendary Air Force ace pilot, John “40 Second” Boyd. His nickname came from a standing bet about a dogfight. He would let a challenger start in the ideal position on Boyd’s six, that is, directly behind and following. If he couldn’t get a reversal within 40 seconds, he paid the challenger $40. Boyd never lost. After I finished my presentation about AIM-7F I invited questions and comments. John Boyd objected to my statement that AIM-7F was slower than AIM-7E. He had live-fired both in test shots against drone targets. He said F looked much quicker as it flew out front. I suggested he was perceiving it as quicker because, while having lower speed, it was able to turn faster—just as one slows down a car to make a sharp curve. The idea is simple: “There is no benefit
in proceeding rapidly in the wrong direction.” After some discussion, he agreed with my analysis.

Our range simulation for AIM-7F had difficulties. As mentioned, we received an executable binary of the engineering simulation from Raytheon to compare against for validation of our simulation. We ran Raytheon’s simulation and ours with identical initial conditions and the same target and we consistently found lower performance. After extensive in-house review, we told NADC that we believed our results were correct and Raytheon was overstating performance. After much acrimonious back and forth between FAAC and Raytheon, the Navy had enough. They told me and Gene to come to Johnsville and bring the source code of our simulation. They also brought some Raytheon engineers with their source code. They put us in separate rooms and we exchanged source code listings. After a couple of days staring at listings, I noticed that Raytheon had modeled the autopilot in a subroutine. However, the call from the main program to that subroutine had been commented out. They were in effect modeling the autopilot performance as perfect. It appeared somebody at Raytheon had commented out the autopilot to simplify while debugging. And forgot about it.

On the training ranges, our simulations did real-time flyout against the actual target when receiving a fire signal. We also had a fast-time mode flyout where the target was assumed to continue its current velocity and acceleration. This ran continuously and produced a figure of merit if a shot was taken. Gene had the idea to use this as the basis for a new approach to fire control. A fast-time simulation would use radar track and assumptions about target behavior to generate the figure of merit and to search out maximum and minimum ranges. Also, when a missile was fired, a real-time simulation would run against target radar data indicating when intercept was expected and probability of successful hit. We convinced the
Avionics Laboratory at Wright-Patterson AFB in Dayton to give the idea a try. It was called Zone Acquisition Processor, or ZAP for short.

The project would use the dual dome flight simulators at McDonnell Douglas using F-15 in both domes. One would have the normal fire control and the other would have ZAP. At FAAC, we tested simulations and algorithms on our mini-computer. This had to be ported to the F-15 mission computer—an IBM 4PI. Just as IBM touted the IBM 360 as covering the full circle of data processing applications, hence 360 degrees, they touted the 4PI as covering the entire three-dimensional sphere of embedded applications—hence $4\pi$ steradians. It was sometimes referred to as half a 360; it had a 16-bit address bus compared to 32 bits for the 360. Both used the same offset addressing style from four base registers with 4PI having eight offset bits compared to 16 for the 360. The 4PI machine language instructions formed a subset of 360 instructions. A separate floating point processor was standard on the 360, optional for 4PI. That same ruggedized computer was the flight computer for the Apollo Command Module performing celestial navigation using quaternions.

To make the software port, I lived for about eight months in O’Fallon, Missouri—about 20 miles west of McDonnell Douglas at Saint Louis airport. I picked up the 4PI assembly language on the fly and was able to complete the port. ZAP also involved additional graphics on the F-15 Heads Up Display and I worked with F-15 engineers to implement those. I gave the seminar on Complex Factored Quaternions for interested scientists and engineers at McDonnell Douglas. Their fire control system that ZAP was aiming to displace was called Deterministic. One participant was the author of it, and we called him “Dr. Deterministic.” In my lecture, I defined quaternions using matrix algebra rather than the ad hoc fashion used by mathematician William Rowan Hamilton in his original definition. At one point in my lecture, I established a field isomorphism between a
subfield of quaternions and the real numbers. Using this shows that my derivation was equivalent to Hamilton’s original. Dr. Deterministic couldn’t accept this substitution, which he called an illegitimate trick. I tried to point out that it amounts to nothing more than relabeling but he would have none of it. Just a last-ditch heel dig, I think, as he watched his baby circling the drain.

Testing in the domes showed a major advantage for the F-15 pilot with ZAP. After the testing in Saint Louis was done, the Air Force and McDonnell Douglas were both pleased with the results. The Air Force ran additional tests flying F-15s with and without ZAP on the Nellis training range versus Red Team. Again, ZAP dominated. As a result of these tests, the Air Force and McDonnell Douglas installed ZAP throughout the F-15 fleet. Since then, ZAP has also become the installed fire control for F-16, A/F-18, and F-35 (all three versions) fighters. FAAC is the sole supplier of ZAP and training range weapon simulations used by the U.S. Navy, Marines and Air Force plus the militaries of several allied nations.

With experience using simulation for military training, FAAC turned to making training simulators for ground vehicles. Initially, these trainers were for over-the-road semis but FAAC’s scope expanded to include oil drill rigs, municipal buses, police cars, and others. The U.S. Marines had contracted with Oshkosh Truck in Oshkosh, Wisconsin, for a new truck with extensive off-road capability. The Medium Tactical Vehicle Replacement had many modern technical features such as the ability to vary tire pressure on the fly to adjust to soil type and conditions. It also has seven variants on a common chassis and powertrain. Each variant has different handling characteristics and some different operating controls and displays tailored to its payload. Based on its extensive experience with commercial vehicle trainers, FAAC bid on and won the MTVR trainer contract. In view of the demanding MTVR requirements and
the need to flexibly handle so many variants, an improved real-time platform was in order.

I had left FAAC during their entry into ground vehicle training to work on several complex real-time projects. These are related in a subsequent chapter, but for continuity the FAAC story is finished here. When FAAC management of the MTVR project learned of my availability, I returned to FAAC specifically to design a new real-time software framework and lead its implementation and testing. This framework handled MTVR simulators and it was also applied to an F-15 cockpit simulator at Eglin Air Force Base in Florida. The Eglin simulator had weapon hardware electronics in the loop. For that simulator, I developed multi-computer networking software and designed analog electronics to interface with AIM-9 hardware. I also implemented a device driver for audio hardware to produce sound effects during training simulation. Later at FAAC, I continued to advance the military simulations side. I developed and implemented an improved algorithm for seeding ZAP range searches. I also updated several training range missile simulations.

Few Ann Arborites realize that the fire control systems for virtually all U.S. and allied fighter airplanes are built locally. FAAC now occupies several buildings in the Oak Valley Business Park just east of Lohr Road and a building on Ellsworth Road east of State Street. FAAC provides training simulations for tactical air combat and for semi-trailer trucks, buses, subway trains, off-road oil drill haulers, and other military and civilian ground vehicles.

In the bigger picture, FAAC provides a valuable counterweight to part of the massive U.S. weapons industry. It has a concentration of engineers versed in the arcane technology of computer simulation of homing guided missiles. Because test firings of homing guided missiles are very expensive and because of the large number of variables affecting missile performance, computer simulations are essen-
Test firings serve as validation points for the simulations. Then the simulations are used to determine if the development contractor has met the contractual performance requirements. There are several concepts involved in this technology:

- Target sensing – semi-active radar, active radar, infrared
- Inertial line-of-sight track – measure LOS turning rate
- Proportional navigation – guide toward zero LOS rate
- Autopilot – attain commanded acceleration via control surfaces
- Aerodynamics – model upsetting and restoring torques
- Propulsion – model thrust, base drag and vectoring

The key concept, proportional navigation, forms the outermost closed control loop. The idea is to steer the missile’s motion at the point where the target will be when the range between them decreases to zero. This is assured if the line-of-sight is not turning. Suppose you are driving on the interstate and you spot a moving object, say a running deer at 10 o’clock going toward the highway. If the image of that deer stays at a fixed angle on your windshield, you are headed for a collision. In this scenario, the only relative motion between the deer and the car is along the line-of-sight, which isn’t turning. Bang! Missile guidance involves the same ideas but in three dimensions rather than just two.

The guidance loop issues acceleration commands that attempt to drive the measured line-of-sight turning rate to zero. To the extent it is able to keep this rate at or near zero, it will hit or at least come close to the target. Mathematically, this outer control loop has loop gain that is inversely proportional to the range between missile and target. That means the gain will increase without bound as the missile closes in, forcing the outer loop to become unstable. The
trick is to delay onset of instability until the missile is close enough that it makes no difference. Tricky engineering indeed.

The inner loop is also called the autopilot. Its job is to convert the acceleration commands from the guidance loop into deflections of aerodynamic control surfaces and/or thrust deflectors. Modeling it requires detailed aerodynamic coefficient applications within parameters of mach, altitude, dynamic pressure, etc.

Add in the other technologies outlined above to gain an appreciation of the breadth of engineering skills needed. FAAC is the only non-manufacturing organization with such a set of engineering skills. As a result of both its ZAP fire control work and its training simulations, FAAC is a continuing check on performance claims by manufacturers.

And what became of FAAC’s erstwhile parent, Veda? They grew successfully with both high-level strategic consulting to the Pentagon and contracted IT and other services at multiple military bases. In 1997, Veda joined with two other companies to form Veridian Corporation. One of its partners was Calspan, which originally was Cornell Aeronautical Laboratories under Cornell University. Calspan no longer had ties to the university. The other partner was Systems Research Laboratory. Meanwhile, back in Ann Arbor, Willow Run Labs had also cut its ties to the University of Michigan. They had expanded beyond image generation to interpretation of images from both airplanes and satellites. Their focus shifted from military objectives to environmental ones. They moved from Willow Run to occupy the same building on Plymouth Road built by Bendix and changed their name to the Environmental Research Institute of Michigan. In 1999, they were acquired by Veridian. Thus did multiple circles close.
In between stints at FAAC, I worked as an independent consultant. The National Bank of Detroit started a venture capital subsidiary investing primarily in advanced technology. I worked on retainer with NBD to provide due diligence assessment of the technological soundness of potential investments. I also consulted with the Naval Air Development Center helping them monitor development of the advanced Tactical Air Combat Training System at Fallon Naval Air Station, Nevada, about 60 miles east of Reno on U.S. Highway 50. This was a considerable upgrade and included a live bombing range, surrogate foreign electronic countermeasures, and a full-up Soviet Integrated Air Defense System.

When I visited NAS Fallon, someone pointed out to me an RV parked on the shoulder of Highway 50. The highway runs along the southern edge of NAS and air-to-ground training flights passed over it while trying to jam the surface-to-air missile systems. Folks at NAS called the RV parked there the “Soviet Winnebago.” It was stripped and stuffed with electronic snooping gear listening to electronic
countermeasures emissions from overflying U.S. combat airplanes. At least they had the decency to “Buy American.”

I became interested in artificial intelligence, or more exactly adaptive learning systems, but not the symbolic expert system or chess playing sort. Bob Eisenhardt was also interested and we decided to start a not-for-profit company called the Institute for the Study of Intelligent Systems. We also incorporated a shell for-profit subsidiary called Adaptive Learning Machines, Inc. In the early 80s, neural networks were where the action was. But I had learned about genetic algorithms and classifiers which were invented by John Holland at the University of Michigan. Genetic algorithms are computational entities that emulate Darwin’s theory of evolution and natural selection. They evolve over generations—a sort of imaginary time. Classifiers are computational entities with two parts: a condition word and an action word. The condition word of each classifier in the population is matched against the current state of the system described as a word of the same size (number of bits). One matching classifier is selected randomly to be allowed to post its action as system output. So the classifier is basically an “if-then” rule. Probability of being selected is proportional to the fitness or strength of the classifier. The selected classifier must pay for the privilege of posting. That payment goes to the classifier that made the post in the last cycle, moving the system to its current (matching) state. Then the posting classifier collects the reward, if any, resulting from its post. In this way, value is passed back along the chain of classifiers that led to the current state. This mechanism is called “The Bucket Brigade” and it emulates free markets. “The Bucket Brigade” solves the so-called “Allocation of Credit” problem where only the element posting rewarded action gets any value. Those elements whose postings led up to and put the rewarded element in position to succeed are left out in the cold.

Finally, genetic algorithms emulating both sexual reproduction
and mutation are applied to the classifier population. Two classifiers are selected randomly with probability proportional to fitness or strength acquired from posting. These are then used in the crossover operation emulating sexual combination of DNA followed by a possible mutation at one binary site. Together, genetic algorithms and classifiers promised to yield powerful machine learning. Genetic algorithms had been around longer than classifiers and had real-world successes. For example, General Electric used them to evolve a better shape for jet engine turbine blades and got a significant increase in fuel efficiency.

Willow Run Labs had cut its ties to the University of Michigan in the 1970s and changed its name to the Environmental Research Institute of Michigan. It now occupied the same building on Plymouth Road that originally housed Bendix Systems Division. (Bendix had dropped the “Aerospace” from its Ann Arbor division name as it was working on autonomous ground vehicles also.) ERIM had expanded into processing images from side-looking radar or satellites. The aim was to identify objects of interest automatically by computerized methods. Such objects might be tanks and trucks in a military context or cultivated fields and forests in an environmental context.

In furtherance of this research, ERIM had worked out some mathematics called image algebra. These algorithms operate on all pixels in an image, so they are good candidates for parallel processing. ERIM had worked with NCR (originally National Cash Register) to produce an integrated circuit specially configured to support the image algebra. NCR had strung together a number of these chips to create a parallel processor with over 10,000 computing nodes of Single Instruction Multiple Data architecture. I came across a data sheet for the NCR chip and noted that a pair of these image algebra processors would make a classifier—one for the condition and one for the action. The entire machine could support a population of over
The larger the population, the more efficient the genetic algorithm. Also, each computing node had an open drain connection to a chip-wide line forming a wired-OR connection. This gives a global signaling functionality which would support the classifier matching. The state word can be broadcast on the wired-OR and all matches made in parallel. This functionality reduced computation time from being proportional to population size (e.g. 5,000) to being proportional to condition word size (e.g. eight bits). It also promised to support ever larger population sizes with advancing integrated circuit capability.

So I set out to acquire the NCR machine and funding to try making a Genetic Algorithm/Classifier Engine, or GACE for short. Previously, I had done some cooperative work with Harry Klopf, a scientist at the Avionics Laboratory at Wright-Patterson AFB in Dayton, Ohio. He was experimenting with simulated neural networks using drive-reinforcement learning. I proved a theorem on stable asymptotic convergence of nodal weightings for Klopfian neural nets. I had met his boss and remembered that he had previously worked at NCR headquarters in Dayton. Through him, I was introduced to the Research Director at NCR and explained that I had a commitment for funding from DARPA for a project to use the NCR machine to demonstrate advanced machine learning. But I needed the hardware in order to proceed. He was intrigued by the idea but said he needed to think about it and consult others.

I then contacted the DARPA project manager we had worked with on ACEVAL/AIMVAL. Through him I was introduced to the DARPA manager handling artificial intelligence and machine learning. I told him that NCR had committed to giving us the machine provided the project was approved for funding by a legitimate scientific agency. Several back-and-forth talks with both DARPA and NCR followed. I made sure that the two of them never talked
to each other. I finally got both the funds and the machine. DARPA sent funds to the Air Force Office of Scientific Research at Bolling AFB in Washington, D.C., whom they designated to manage the contract. At our first meeting, the contract manager at Bolling said he had reviewed my proposal and didn’t believe we would succeed.

I picked up parallel programming on the fly. I did the classifier modeling and the genetic algorithm on the parallel hardware. Kevin Ross, our new hire fresh-out from the University of Michigan Engineering School, did the learning environment and displays on the host PC. Kevin had been the drum major of the marching band—the leader who bends over backwards and touches hat to turf. We were able to get the beast working and we demonstrated all conditioning and learning types as seen in animals. We showed classical conditioning, instrumental conditioning, and operant conditioning. Beyond that, we showed learning behavior that is only observed in primates—the ability to abandon a well-rewarded action in favor of a better one. This behavior requires continuing search of a state space even while profiting at a given state.

As part of the deal with NCR, I was required to give a report on results at an NCR facility of their choosing. They chose their silicon foundry on the campus of Colorado State University, Fort Collins. That integrated circuit facility had produced the image algebra chips. I gave a lecture there to an audience of NCR engineers and scientists, plus some invitees from the university.

Not long after the GACE project finished, DARPA decided to sponsor a study of neural net machine learning. The National Neural Network Study was conducted by MIT Lincoln Labs. Due to the success of GACE, I was appointed to Panel IV, Systems Applications. Our panel toured a number of universities and research facilities where we were briefed on their research. Almost all the work was on
neural networks, which was then in a primitive stage and not very impressive.

In the 1980s, the U.S. and the People’s Republic of China were doing cultural and scientific exchanges. I was selected to be on one exchange dealing with complex and chaotic systems. It started at a convention sponsored by the Institute of Electrical and Electronic Engineers in Beijing in Summer 1988—Tiananmen Square was still over a year in the future. Ilya Prigogine pioneered mathematical characterization of chaotic systems with his book “Order out of Chaos.” He was scheduled as keynote speaker, but fell ill and was unable to attend. Chaotic systems show a disconcerting behavior: small, seemingly insignificant changes in state evolve into radically varying outcomes. Meteorologists have a saying: “A butterfly flaps his wings in the Amazon and a hurricane hits Miami.” Planetary atmospheres were identified as chaotic systems early on, but others include Darwinian evolution, solar atmospheres and free markets. Mathematically, such chaotic entities are represented by systems of non-linear, cross-coupled partial-differential equations. Calling such systems hard to predict is a massive understatement.

Prigogine and others who have studied the mathematics of such systems note that some have associated periodicities. For example, a planetary atmosphere is affected by the rotational period of the planet which is dragging the atmosphere along. In such cases, temporary structures can come and go. For example, a hurricane is such a structure. In fact, the Great Red Spot on Jupiter is actually a hurricane which is wider than Earth’s diameter and has lasted for more than the 400 years or so that we have known about it from telescopes. Reasonably accurate predictions are possible in periodic chaotic systems over a few cycles, say four or five. But anything beyond that quickly becomes unreliable. Predictions beyond about ten cycles are totally useless. Our everyday experience of weather
forecasts is a good example. For climate forecasting, the pertinent periodicity is one year. For sun spot predictions, the periodicity is about 11 years.

The exchange schedule was for about six weeks in China touring scientific facilities. I flew to Seattle two days before the delegation gathered. The group that gathered in Seattle had about two dozen members. We flew from Seattle to Narita International Airport serving Tokyo. We had a one-day layover there to reduce the effects of jet lag. The flight from Japan to Beijing was on China Air. The inflight movie was “Good Morning Vietnam,” which was slightly ironic. Vietnam and China have a long tradition of rivalry and animosity including kinetic military action as recent as 1979. After landing in Beijing, we were taken by bus to the convention hotel, which was designed by I. M. Pei.

After the convention, our group traveled by bus to see the Great Wall. After visiting the wall itself, I was walking back toward the gift shop aiming to buy some sort of memento. I stepped on a round manhole cover that spun and my right leg plunged immediately into sewer water up to my hips. I wasn’t hurt other than a scrape on my knee. I was able to go on to the gift shop and bought a calendar with photos of the Great Wall. But I wasn’t very popular on the bus going back to our hotel.

For the remainder of our time in China, we went from city to city mostly by bus, occasionally by train for longer distances. At every minute, we were escorted by two or three guides. They made sure to keep us in modern urban settings with high-tech rail transport, subways, modern buildings and the like. But even in those places the atmosphere was third-world. There was virtually no cultural impetus for sanitation. Open markets on the street displayed unrefrigerated meats and fish at elevated summer temperatures, unprotected from flies or other contamination. On one occasion, our bus driver got lost.
and wandered off the beaten path into a rural village. It could have been a scene from “Monty Python And the Holy Grail.”

At each institution that we visited, they gave presentations of their work and some of us gave presentations of our work. We rotated which presentations we would make according to the type of institutional research facility we were visiting. My presentations on GACE did not engender any interest. After our presentations, we always allowed time for questions and answers; GACE never inspired a single question. That was my first inkling that our GACE project was way ahead of its time. The Chinese presentation that most impressed me was in Hubei Province just outside its capital, Wuhan. The lightning research center there had hardware that could create spectacular arcing bolts of lightning. Its main focus was testing electrical power grid components and improving resistance to lightning. The tour ended in Shanghai, and then our delegation flew to Hong Kong for a two-day visit. Hong Kong was a fascinating blend of almost Victorian British with almost imperial Chinese. The latter reminded me of the Chinese proverb, “Heaven is high and the emperor is far away.” The soaring architecture is stunning, the hustle and bustle insane, and the optimism infectious. I bought some silk items there as gifts. The first leg of our return flight took us to Seoul, where we changed planes and headed back to Seattle.

Shortly after returning from China, Bob Eisenhardt told me he wanted to quit the Institute for the Study of Intelligent Systems. His wife had taught high school French for many years in the Ann Arbor Public Schools and was retiring from an administrative position there. She wanted to move to Virginia and Bob also wanted to retire. So we split.
As funding for the kind of machine learning represented by GACE was not on the horizon back then, I decided to switch gears and activate Adaptive Learning Machines, Inc., the for-profit shell company. The new market direction would be toward commercial business-to-business sales. Accordingly, ALMI registered a doing-business-as name: Osiris Business Systems. We had referred to the Institute for the Study of Intelligent Systems as ISIS for short. The Egyptian god Osiris was the brother of the goddess Isis. He also married her; shades of European royalty Using ancient mythology for naming is common practice: Apollo, Artemis, Phoenix, Talos, etc.

Osiris was located on the first floor of the building at 214 E. Huron formerly occupied by FAAC. The four FAAC owners owned the building. Gene and I retained ownership after FAAC moved out, and we converted it into condos in the mid- to late-80s. It was the first instance of condominium conversion of commercial property in Michigan. Each of the three floors was a separate condo. There were
DEAN Z. DOUTHAT

law offices on the second floor and a shopping flyer publisher on the third.

From our vantage point on East Huron Street, we had a front row seat for the Ku Klux Klan visits to Ann Arbor in 1996 and 1998. They came from northern Indiana after winning a long, drawn-out series of legal battles against the City of Ann Arbor. The city fought a valiant but doomed rear-guard legal action against the ACLU. The KKK was given space and a PA system on a balcony of City Hall facing Fifth Avenue. The city built a solid chain-link fence all around City Hall up to the sidewalks to separate the KKK from counter-protestors. This plan worked out well; one group tried to breach the fence, but police inside quickly stopped them and plugged up the hole with some barricades.

A group from Detroit called “By Any Means Necessary” marched along Huron Street past our office chanting, “No Free Speech for KKK,” and carrying signs saying the same. Acceptable means for this group obviously ranged up to and including lynching—agreeing on that score with the KKK. They seemed to think they were opposing the KKK, but in reality they were opposing the ACLU. They mentioned no substantive message or policy. Rather, they showed so little faith in their own unspoken policy as to advertise its inability to withstand the absurd “logic” of the KKK. Perhaps that fear was justified by the sameness of the two.

Both KKK visits played out about the same. There was lots of yelling and noise from the anti-KKK crowds surrounding City Hall. The KKK spewed their nonsense over loudspeakers, but were drowned out at our vantage point by the peripheral din. Most importantly, thanks to careful planning and work by Ann Arbor police officers and Washtenaw County sheriff’s deputies, no violence. I suspect the lack of violence discouraged the KKK from any further attempts beyond the two.
Launching Osiris was aided by business contacts from Bob Eisenhardt as he ramped down to retirement and prepared to move to Virginia. He had been very active in the Ann Arbor Lions Club and had served as president for several years. He also held office in the Michigan Lions Club, the statewide parent organization. Lions Clubs work on issues of blindness and vision problems. For example, they support the Leader Dogs for the Blind training school in Rochester, Michigan. Using his Lions influence, Bob arranged for us to visit to talk with the dog trainers there. Leader dogs, we were told, can learn to recognize up to about 25 words or phrases and attach meaning to them. And this meaning can be quite complex. For example, one trainer told us about a dog that would recognize when his human said “Aunt Sally’s” and start walking to Aunt Sally’s house, a route which was long and complex. Before he left, Bob introduced me to the head of another organization supported by Lions Clubs of Michigan—the Michigan Eye Bank and Transplantation Center.

MEBTC had headquarters and a processing laboratory in the Kellogg Eye Center building on Wall Street in Ann Arbor. Owned by the University of Michigan, this building housed both research and clinical operations. The eye bank was having problems with tracking and logging information generated in its far-flung activities. Once a decedent’s next of kin gives permission to harvest eyes and/or other organs, quick response is essential. In order to reduce response time, MEBTC had many offices throughout both Michigan peninsulas. Most of these offices had a single employee, and were often located in that person’s home. Those remote operators had to handle recovering and preserving eyes, arrange transport to Ann Arbor, and fill out the related paperwork. The paperwork burden kept increasing as accreditors required more detail and audit trail traceability on all medical records. Once the intact eyes reached the laboratory in Ann Arbor, they had to be quickly processed to extract and preserve the corneas,
and occasionally the sclerae. Additional record keeping was required for these procedures. Further complicating the issue was MEBTC’s acquisition of the Illinois Eye-Bank with headquarters and a laboratory in Chicago. They also had offices scattered around their state and a similar but different paper-based approach. MEBTC management was convinced of the need to replace both antiquated paper messes with a common computerized system. This is where Osiris came in.

MEBTC needed a multi-user computer system. Anywhere from two to five technicians might be working in the lab at the same time and remote agents might also need to connect. They needed a distributed database that could be installed in Ann Arbor and Chicago and automatically synchronized with each other. Finally, the database system needed to be journaled—that is, recording date, time, user, and contents of every data change. Private use of the Internet was just beginning in 1990, so using modems over telephone lines was the only available option. QNX was chosen as an affordable multi-user operating system that can run on inexpensive PC hardware. Commercial database systems that were distributed and journaled were well out of the affordable price range and they only ran on mainframe hosts. So I picked up database engine implementation with B+ trees on the fly and created Qbase Engine. Qbase is distributed, journaled, multi-user, and uses the popular dBase format for records and indices with Rushmore technology.

The total system included a PC in each remote office in Michigan and Illinois, database servers in Ann Arbor and Chicago, and a leased phone line between the two cities. All computers ran the QNX real-time operating system. Each lab had multiple simple terminals for technician use. The two QBase databases were synchronized frequently. The system was successful and was accredited by the Joint Commission on Accreditation of Healthcare Organizations. It was
later installed at the Eye-Bank of Northern Ohio and the North Florida Eye-Bank. When we closed Osiris in 2002, all our employees were hired on at MEBTC and continued to improve the system. By then we were using the Internet instead of phone lines. MEBTC has installed the system in many more eye-banks. MEBTC is no longer housed in the Kellogg Eye Center building. They have their own building just off State Street south of the Ann Arbor Airport.

The eye-bank system would be classified as soft real-time; our next project was very hard real-time. A company in Rochester, Michigan made computer systems that manage automated teller machines and point-of-sale transactions using credit or debit cards. Banks and credit unions used separate processors so as to unburden their mainframes. The company was called InterPro, short for Intercept Processing, because its computer system intercepts those transactions, processes the details, and minimizes traffic with the financial institution's mainframe. The InterPro system sits at the center of three sources of traffic: first is a string of 20 to 50 local ATMs; second is a wide area network communicating with other financial institutions; third is the institution's mainframe. This hardware infrastructure supports a wide variety of transactions.

The simplest set of transactions (use-case 1) arises when a card issued by this financial institution (an own card) is inserted into an ATM. In this case, the InterPro system just handles the various ATM actions available, like check account balances, transfer funds between accounts, make a deposit or dispense cash. Once an ATM session is completed, the InterPro system updates the net changes in balances on the mainframe. Use-case 2 is when a foreign card is inserted into an ATM. Then those same action requests must be sent across the WAN to the issuing institution and responses relayed back to the ATM. Use-case 3 is when an own card is inserted into another institution's ATM. Then net changes to balances resulting from requests
and responses must be relayed to the mainframe. The same topography applies to use-case 4, when a customer uses an own card at a point-of-sale to buy something. All messages to and from the ATM and to and from the WAN are encrypted. Messages have to be decrypted, translated from sending format to receiving format, and re-encrypted.

Both WAN and mainframe communication channels have hard real-time deadlines. When the WAN delivers a message, it expects an answer within a short fixed time, which is determined by the type of request. Similarly, when the mainframe delivers a message, response is sometimes required within a short deadline. Failure to respond before the deadline will cause the WAN or the mainframe to resend the message. If the system is still unable to respond in time, it enters a death spiral. The worst cases are use-case 3 and use-case 4 described above. The WAN demands a quick response, but the main frame is often slow to respond. To handle that situation, the InterPro system has stand-in functionality. It keeps a running set of account status and balances that duplicate those in the mainframe. If the mainframe response is slow, InterPro will respond to the WAN using its own duplicated data. Later, when traffic is low and the mainframe is more responsive, the two sets of data are reconciled—InterPro sends stand-in transactions to the mainframe and the mainframe updates InterPro data with any changes from its independent operations as they happen.

An ATM is a finite state machine driven by keystrokes by the customer on the one hand and messages from InterPro on the other. The simplest way to control one is with a matching finite state machine in software. To handle this, a finite state machine server was implemented to provide this functionality to however many clients were required at one time. With the Qbase Engine and the QNX real-time operating system, the redesigned InterPro improved perfor-
formance dramatically. Under a stress test that fires synthetic transactions at the InterPro, the old system could handle about 20 transactions per second before a death spiral. The replacement system handled over 100 transactions per second on the same hardware platform.

InterPro held an annual conference in Rochester attended by bankers and credit union personnel. I was asked to give a presentation on the redesigned system. In addition to the performance improvements, I noted that we had upgraded the encryption strength on all transmissions. I assured them that this would mean greater security, not counting the backdoor Osiris had built in for ourselves. That’s when I discovered that bankers have zero sense of humor.

The National Park Service hires about 10,000 temporary seasonal workers each year, mostly in the summer. Each park submits a form indicating the skill sets needed for each position. Applicants fill out a form detailing what skills they have. NPS headquarters then needs to match 80 to 90 thousand applications against the typically 10 thousand or so positions to find the best fit score of potential hires for each park and position. The results are ranked hiring lists for each position sent out to the parks. Both position skill requirement forms and applicant skill forms use mark sense reading, in which items are designated by coloring in a circle with black pen. These are then read by mark sense reading machines that input the data to the computer for processing.

NPS contacted Osiris after they read an article about our eye-bank system. We got a contract to revamp their seasonal matching processing. The kickoff meeting for the contract was held in San Antonio, Texas, in the Alamo. There are offices, conference rooms, and work areas where artifacts are restored behind the museum itself. In the private back rooms there are many more artifacts once owned by Davy Crocket, Jim Bowie, and others.
NPS’s existing system used PC hardware and a commercial database. A seasonal matching run took about three weeks. Our Osiris system used QNX and Qbase engines to replace the software on the same existing PC hardware. It was able to complete a seasonal run in about 15 minutes.

Another high-profile application of QNX and Qbase was on the Human Genome Project. The University of Washington in Seattle had contracted with an engineering company called Orca Systems located in Redmond, Washington. Orca developed the hardware and I wrote the software for the system. Initially, the Human Genome Project was estimated to take two or more decades and cost several billion dollars. The Orca system was an automated biochemical laboratory that drastically reduced both the time and cost of the project. The major driver of cost was the wide variety of highly specialized and costly reagents needed to produce cuts at defined locations of DNA.

The Orca system had a turntable that held DNA samples in small glass tubes with inner diameters less than one millimeter. A glass tube was loaded by a robot arm onto the turntable at the start and moved with the turntable as it turned and then stopped at defined angles. Each station around the table had a modified Hewlett-Packard inkjet printer drop shooter. We had determined that each pulse of the inkjet shooter produced a consistent 90 nanoliter drop. Thus the amount of a reagent at each station was easily computer controlled by the number of shots. As each glass tube moved among the 36 HP shooters, the mixture and proportions of reagents were set up per recipe by the number of shots into the glass tubes. The recipes were stored in a database for easy accessibility to each experimental run. At the end of the rotation, the glass tube with DNA and reagent mixture was removed by a robot arm, shaken, and placed in a tray for oven baking.
The Orca system reduced the volume of expensive reagents by about a factor of 30 and speeded up the number of recipes processed per day by about a factor of 15. After the system was thoroughly tested at the University of Washington, it was replicated and sent out to about four dozen universities in the U.S. and Canada, each working an assigned region of the DNA. Suddenly, the Human Genome Project was finished way ahead of schedule and drastically under budget.

A few smaller projects rounded out the life story of Osiris Business Systems. One was helping Baylor College of Medicine in Houston, Texas, with some combined neuro-physiological and behavioral experiments. They were tracking the eye position of monkeys using implanted devices and needed to distinguish between voluntary eye movements and involuntary saccades. I designed a real-time server that fit a running cubic spline to position data, differentiated the spline, and eliminated movements showing the high speed associated with saccadic eye movement. Another involved working with University of Toledo Professor Emeritus of Accounting Wes Sampson. Together we developed a technology called “Data Pattern Index,” which revolutionizes auditing by adding processing of the journal. Accounting data entries are called transactions. A transaction is a set of dollar amounts posted as debit or credit to two or more accounts. Total debits and credits in a transaction are expected to balance. The set of accounts in a transaction defines a pattern about which statistical information can be extracted from the journal records. From these statistics, auditors can characterize rare or unusual transactional patterns which indicate possible fraud. I used Indexed Sequential Access Method for this and it led to U.S. Patent 6,058,392.

During this time I also appeared as an expert witness in three different lawsuits—two for plaintiff and one for defendant. The first one had a furniture company suing a bank’s subsidiary. The bank had
done a lot of business factoring for small furniture retailers and decided they could leverage their contacts into a new line of business. So they created a subsidiary to develop and market software to run on an IBM PC for managing furniture retailing operations including inventory and stocking. Their software customers were all retail operations with a single storefront. Except one—the plaintiff in the lawsuit.

The plaintiff had two storefronts in Michigan and a separate warehouse servicing both. The defendant claimed to the plaintiff that their PC software could handle multi-tasking, multi-user operations for three computers in the three locations. This, of course, is absurd for a single-user PC platform. As a result of trying to use the software in this manner, the furniture retailer data files were corrupted so they lost control of their inventory and eventually went bankrupt. The case never got to trial. After I published my report showing how the software corrupted the records, I sat for a deposition. As a result of their inability to impeach my report and testimony, the defendant decided to settle.

The bank headquarters was in Minneapolis, Minnesota, and its subsidiary was in Des Moines, Iowa. The law firm representing the defendant was also in Des Moines. Later that law firm was defending a software development company being sued for breach of contract. I made a report and prepared to be deposed about software development and contracts therefor. I flew to Des Moines for the deposition, but that same day the defendant settled out of court.

The third case was the most interesting; I actually got to testify at a hearing. I was hired as an expert witness by one of the two plaintiff lawyers in the furniture store case. He was now plaintiff lawyer for Daisy Air Rifle Company suing NCR (nee National Cash Register) which was a subsidiary of AT&T at that time. NCR had sold computer hardware and software to Daisy for managing in-process
manufacturing inventory, finished goods inventory, and product orders. This system had some bugs that caused the Daisy inventory accounting to become corrupted, costing Daisy a lot of money in production hang ups, lost sales, etc. The hearing was in Federal District Court in Jackson, Mississippi. In August! Rumor is that Jackson natives take August vacations in Hell to cool off. There was no jury, just a judge. Opposite the lone plaintiff lawyer and myself were three AT&T lawyers and four software engineers from Bell Telephone Labs. Two of their lawyers were older men looking grizzled in serious suits and ties. The third was a young lady. I was sworn in and ready to testify about my report that I had written and submitted months earlier. Before I could start, the young lady asked the judge for “voir dire,” or preliminary questioning; they didn’t think I qualified as an expert witness. The judge approved and she commenced.

She asked, “Have you heard of the I. E. E. E. organization?” pronouncing each letter separately.

Me: “Yes, but we call it ‘I triple E.’”

She: “It is a prestigious engineering institute, is it not?”

Me: “Yes.”

She: “Why are you not a member?”

Me: “I am a member.”

She: “But that’s not on your resume; why not?”

Me: “I don’t consider it very important for a resume. I am in fact a charter member. In the 60s, there was the American Institute of Electrical Engineers focused on electric power generation and transmission and the Institute of Radio Engineers focused on electronics. These two merged to form IEEE and members of either of the prior two became charter members of IEEE. I was a member of IRE so I became a charter member of IEEE.”

At this point, I could see that the Bell Labs guys had their hands over their mouths hiding their laughter. But she wasn’t done.
She: “When you reviewed the source code for NCR software, did you notice what language was used?”
Me: “Yes.”
She: “What was that language?”
Me: COBOL.
She: “At the bottom of your resume, you list what computer languages you know but COBOL is not included. Why not?”
Me: “Because if you put COBOL on a resume, people want you to do it.”

By this time, the Bell Labs guys were really having a hard time. Even the judge was trying to cover up a laugh. Then one of the AT&T lawyer suits leaned over to whisper something to the young lady and she stated the witness was acceptable and “voir dire” was done. The judge declared a 30-minute break and I went to the men’s room down the hall. Some of the Bell Labs guys were also there and they mentioned that they had seen my resume and had no doubt as to my qualifications. After testifying, I flew right away back to Michigan and finally escaped the oppressive heat and humidity. It turned out that Daisy lost the case. The lawyer said it was mostly because of some technicalities that I did not understand.

During the life of Osiris, 1990 to 2002, Doris worked there taking care of all administrative tasks. We decided to close down Osiris and send our other three employees to work for the Michigan Eye-Bank. After returning to FAAC as a contract employee, the plan was to retire at age 74, but Doris was becoming more disabled with chronic conditions. The amount of passive income then available might be insufficient. So, in spring 2010 I joined Endra Life Sciences for my last job before retiring. I was the fourth hire at this startup, which aimed to develop a pre-clinical imaging system that could produce three-dimensional images of small animals. This product was aimed at scientists and scientific organizations doing medical research using
small animals, usually mice. In addition to mapping of the human genome, the mouse genome was also fully mapped. As a result, almost all medical research—probably over 95%—is done with mice. Endra was located in the same office park at Research Drive where FAAC started. FAAC was near the top of the hill and Endra near the bottom. Endra was starting to develop a product called Nexus128 based on the photoacoustic effect.

Alexander Graham Bell discovered the photoacoustic effect and wrote about it in 1880. He experimented with a rotating disk with alternating sectors, blocked and clear. Shining a light through the disk onto a glass tube produced a pop-pop-pop sound emitted from the tube. When light coming through a clear section of the disk hits the glass tube, air inside is heated a bit and so expands. Then when the light is cut off by the next opaque section of the disk, it cools and contracts. That expansion and contraction produced a sound—pop, pop, pop. Endra was developing an instrument to use that photoacoustic effect to produce an internal image of the organs and tissues of an animal. Instead of a disk, we used a pulsed laser that turned on for a short time: 7 nanoseconds, or 7 billionths of a second. The laser pulses 20 times per second. A pulse that short will produce sound centered around 2-4 Mhz, which is well within range of standard ultrasound transponders. A hemispherical bowl has 128 of these acoustic sensors arranged in a spiral pattern to pick up the sound waves produced by the laser. The bowl rotates through a full turn so that the various sensors have direct paths to all parts and aspects of the target object. Then a tomographic process similar to that used in a CAT scan produces a three-dimensional image of the interior of the animal. The tomographic mathematics are more difficult than for CAT because CAT works over planes while photoacoustic imaging works over spheres.

My job was to develop software to control all the hardware.
subsystems and to coordinate and synchronize those subsystems so as to get the necessary data as input to the tomographic processing. There are five major subsystems that had to be controlled. The laser is a Neodymium-doped Yttrium Aluminum Garnet with non-linear crystals that allow tuning output wavelength from 680 to 950 nanometers, that is, from a bright red to near infrared. Laser software was required to control motors that position the crystals as well as to control the basic pump laser itself. The laser has power in the neighborhood of 10 megawatts but low energy peaking at about 15 milli-Joules at about 700 nanometers wavelength. Power is energy per unit time so even though energy was low, the time is so short that power is high. Energy varies substantially according to wavelength and also slightly pulse-to-pulse. So a second subsystem was an infrared energy meter able to measure the energy of every laser pulse. A DC servo motor was the third subsystem; it was used to rotate the bowl. The fourth subsystem was the data processor which had 128 channels that converted acoustic signals in all 128 sensors from analog to digital, averaged them if requested, and transferred all that data to the main computer. Finally, the fifth subsystem was the water conditioner which circulated water through the bowl and maintained water temperature at about 38 C, or near the body temperature of a mouse.

To scan, the bowl must rotate through a full turn with data gathered at approximately evenly spaced points in the turn and energy measurements made of the same laser pulses that created the acoustic data. After the scan, the digitized acoustic data must be conditioned in preparation for image reconstruction. I was also responsible for the pre-processing chain that normalized the data against varying laser power plus a few other clean-up operations. After pre-processing, the data is processed tomographically to produce the image. This was done in a parallel processing graphical plug-in card and takes from 30 seconds to 2 minutes after the scan depending on the
number of views. I was co-inventor for the tomography processing using microwave stimulus instead of a laser on U.S. Patent 10,687,789.

We were able to build Nexus128 systems that produce high quality three-dimensional images of animal interiors. Over a dozen are currently in operation at research organizations in the U.S. and Asia. They do not use ionizing radiation, which is a major advantage in some research settings. For example, to study metabolic effects, images can be made as frequently as six seconds apart. Trying that with a CAT scan would only result in a dead mouse. Since retiring in July 2019, I continue to support those installed instruments on a minimal part-time basis working entirely from home. A classic rocking-chair job.

Endra threw a very nice dinner party for Doris and me at retirement in July 2019. They made a large poster with messages and signatures from all employees wishing congratulations and happiness in my new stage of life. Following tradition, Endra gave me a watch as a retirement gift. Not a gold watch; rather it’s a Galaxy Watch that talks to my Galaxy phone. Very nice. I use its watch face that has a huge “old guy” font. I can even place and answer phone calls on it—shades of Dick Tracy.
In the summer of 1957 while working on my Master’s in Math, I worked at McDonnell Douglas at the St. Louis airport. I was assigned to Flight Test Data Analysis, specifically dealing with the pitch-up problem for F-101 Voodoo fighters. This airplane had a high T-tail design where the horizontal stabilizer and elevators mount high up on the vertical tail fin. Viewed from the rear, they formed the letter “T.” In certain conditions of speed, altitude, and flap settings, the horizontal stabilizer drops into the turbulent wake of the wings and suddenly loses lift. This drops the tail, pitches up the nose, and stalls the wings, often resulting in a flat spin. Test pilots were flying deliberately into those conditions in order to map the parameters at the boundary of the stall. The aim was to use this data to warn pilots when approaching the pitch-up stall.

To record test flight data, two methods were used. First was a multi-pen strip chart that traced six parameters. These provided continuous analog records but resolution and accuracy were only fair. One channel always plotted time marks at one-tenth second intervals.
Second was a photo panel, a bulkhead panel with multiple meters mounted that was filmed by a 35 mm camera at a nominal 30 frames per second. Time codes were recorded in the soundtrack of the film to provide better accuracy. Post-flight, the film was wound through a manual flat-plate moviola and dial reading data was entered frame by frame in columns of paper spreadsheets. Actual frame rate was adjusted according to the time codes. Data was also read from the strip chart, time matched to the film data, interpolated to fill in times from the movie, and entered in columns of the same spreadsheets. A typical period of interest during a flight test might generate 30 or more pages of spreadsheets.

Once the data columns of the spreadsheets were all filled in, my job was to program the computers. Programming was done by writing the formulas at the top of the empty columns for computing that column using preceding columns to the left. Once the spreadsheets were programmed, I would take them down to the computers. Computers, in those days, meant persons that performed computations. They were located in what we engineers called “The Sweaty Lady Room” in the basement. It was dank and windowless with wall-to-wall desks, each occupied by a sweaty lady and her cat-puke green Marchant calculator. The Marchant was used because it could find a square root and what a sight it was when doing so. It clicked and clacked and its carriage jumped around like a berserker. All engineers were afraid of the Sweaty Lady Room and especially the head sweaty lady. She was six feet tall and weighed around 300 pounds. She had both the heft and presence to keep all the sweaty ladies’ snark and snarl in line.

After analyzing a few dozen flight tests, we were able to identify when a plane was approaching the pitch-up danger zone. The results were used for a series of warnings: first to play a recorded warning into the pilot’s earphones when nearing pitch-up, then to sound a
claxon upon closer approach, and finally to push the stick forward just before trouble. I also designed a circular nomogram for pre-flight planning use. A circular nomogram is similar to a slide rule but using concentric disk scales instead of straight scales.

The pitch-up problem is by no means unique to the F-101. Other notable examples are the recent Boeing 737 Max crashes and the North American F-100 Sabre, a contemporary of the F-101. F-100 pilots dubbed the pitch-up stall the “Sabre Dance”:

Don't give me a One-Double-Oh  
To fight against friendly or foe  
That old Sabre Dance  
Made me crap in my pants  
Don't give me a One-Double-Oh.

The next fighter airplane developed by McDonnell Douglas was the famous F-4 sponsored by the Navy. It had the distinctive “droop” tail with stabilizers and elevators angling downward at 60 degree angles on each side. Viewed from the rear, the vertical tail fin and the two elevators split the circle in three equal 120 degree sectors. The design assured that much of the elevator area would be in clean air outside the wing wake regardless of angle of attack. The F-4 unintentionally became a tri-service fighter as it was adopted by both the Marines and the Air Force, and saw extensive action in Vietnam.

After graduating with a master’s in Mathematics in 1958, I worked full time at McDonnell Douglas Aircraft. There I first started looking into the effects of high altitude nuclear bursts. Doris and I had moved to an apartment near the airport. By early 1959, I was ready to resume graduate school at Notre Dame. I had applied to work at Bendix in South Bend and was scheduled to travel there for an interview. We drove down to Joplin, Missouri; the plan was to leave infant
Denise in the care of my parents while Doris and I traveled to the interview. Before leaving Joplin, I also had minor surgery to take care of a congenital pilonidal cyst on my tailbone. The morning of scheduled departure, I had quite a bit of pain when seated and I noticed drainage from the incision. On a phone call, the doctor assured us that drainage and odor were expected and I should not cancel the trip. The drainage was extremely foul-smelling and too heavy for a simple bandage. Doris, a registered nurse, rigged up a solution using Kotex pads and, with me clutching a spray can of air freshener, off we went to the airport.

Our first flight was from Joplin to St. Louis in an old DC-3. I was frantically spraying my air freshener. Halfway there, my dressing needed changing so Doris and I headed for the toilet at the rear. It was barely big enough for one, let alone both of us, so we had to leave the door open as I dropped my drawers. The stewardess was sitting in the rearmost seat near us and was smoking furiously to mask the stench despite the “No Smoking” sign blazing above her head. By the time we landed at St. Louis, my trousers were soaked through. We took a cab to our apartment to change clothes. I was spraying away furiously but not effectively in the confined space of the cab. The driver opened his window despite the frigid winter air blowing in. At that point, anybody with half a brain would give up and just stay home. Not us. We took another cab back to catch our next flight: St. Louis to Chicago. My trusty spray can was running low.

In flight, my dressing needed changing again; both Doris and I were able to go into the toilet. Afterwards, she left, leaving the door unlocked, while I was still getting my drawers up and pants on. A passenger, seeing Doris leave and naturally thinking the toilet was now free, opened the door and was shocked to find me pulling up my trousers. You can guess what he must have thought we were up to. Back to our seats and back to spraying. In Chicago, another dressing
change was needed but where? The ladies’ room? Men’s room? Doris found a door marked “Conference Room” and went in. There were about half a dozen people attending a meeting. Doris told them she needed the room for changing my dressing and they all cleared out for us. Finally, one more flight and we got to our hotel room in South Bend. Doris went out to a nearby store and bought a new spray can of air freshener. I soaked in the tub and we turned in for the night.

The next morning, I went to my appointment at Bendix. I found then that I was expected to take a battery of tests administered by brake plant HR. My actual interview was not until 2:00 p.m. As the morning wore on with more tests interspersed with lectures and presentations, I was feeling worse and worse. Finally, towards noon, I told them I couldn’t continue because of my pilonidal cyst surgery. I hailed a cab back to the hotel. Again soaked in the tub and had a nap. About 5:30 that afternoon came a knock on the door which opened to Earl Crisler. He explained he had been scheduled to interview me and when I was a no-show, he inquired as to why. He understood my pain and discomfort because he too had just had the same surgery. After we conversed for a while, he hired me on the spot. He also had his doctor come to the hotel and prescribe an antibiotic for me.

And that’s how we got to South Bend, Indiana.
My paternal grandfather, Zahn Douthat, was one-half Miami Indian. His grandfather was Aloysius LaFontaine. His father was Little Turtle. I am one-eighth Miami and registered on their rolls. My maternal grandmother, Clarissa (Valliere) Showalter, was one-half Quapaw Indian so I am also one-eighth Quapaw and registered on their rolls. In total, I am one-quarter Indian.

Grandmother Clara, as she was called, was also half French. Explorer DeSoto was Spanish but on his expedition he took along some French mercenary soldiers. In 1541, he sailed from the mouth of the Mississippi up to the present-day Twin Cities in Minnesota and back. At that time, the Quapaw tribe occupied present-day Arkansas with headquarters at Hot Springs. When DeSoto reached Arkansas on the way back down, the French mercenaries deserted and married Quapaw women. That’s the source of my French heritage.

Grandmother Catherine (Foley) Douthat was purely Irish. She immigrated through Ellis Island with her entire family, parents and two older sisters, as a young girl of 12 or so. Other European roots
add fairly large doses of British and German elements to my genealogy.

On a cold February Sunday in the early 80s, I was driving from Ann Arbor down to Dayton to meet with Air Force Avionics Laboratory engineers at Wright-Patterson Air Force Base. I had an appointment the next day to discuss the ZAP fire control development and test results for F-15. The simulator tests at McDonnell Douglas in St. Louis had been a resounding success. My meeting was for planning further tests on the instrumented training range at Nellis AFB in Nevada. Tiring, I stopped overnight at a Holiday Inn in Wapakoneta, Ohio. It’s less than an hour’s drive on from there to Dayton.

Auglaize County in west-central Ohio is bisected by the Auglaize River, whose Indian name is “River of Fallen Timbers.” In the days when the Miami Nation ruled this area, it was a dense forest. Spring flooding undercut the tree roots, causing them to fall across and into the river. The last great Miami National chief was Little Turtle, my ancestor. He headed a confederation of several tribes—the dominant Miami plus Maumee, Chippewa and others. The Nation’s territory included parts of present-day Indiana, Ohio and Michigan. The Miami Nation lends its name to cities in three states: Ohio, Oklahoma, and Florida.

Little Turtle was eventually defeated by General “Mad” Anthony Wayne after whom Fort Wayne, Indiana; Wayne County, Michigan and Fort Wayne in Detroit are named. The conflict involved numerous battles, negotiations, and temporary truces. Wayne built a number of forts to advance his plans. Besides Fort Wayne in Detroit and in Indiana, he built Fort Recovery in Ohio, completed in March of 1794. It is located on the Wabash River within a couple of miles of the present-day Ohio/Indiana border line. Its name derives from a prior set-back in battle dealt to Wayne’s predecessor, Arthur St. Clair, by an alliance of the Miami Nation with the Shawnee. The fort is
long abandoned, but a small town of the same name remains near there today.

After Little Turtle was finally defeated at the Battle of Fallen Timbers, the Treaty of Greenville signed in 1795 ended the long-running conflict. Before the giant leap to reservations in Oklahoma and Florida, Little Turtle made his last homeland encampment at the site of the current Auglaize county seat: Wapakoneta.

Now surrounded by countryside as flat and as scenic as a pool table, Wapakoneta is the original hometown of Neil Armstrong—the first man to step on the moon. A museum commemorating this feat snuggles there beside southbound Interstate 75. At night, from the freeway side, it presents an earthen mound topped by a lighted dome whose weathered paint suggests lunar topography. It shares the Holiday Inn parking lot. Moon rocks collected by Armstrong and his space suit worn on the moon are among artifacts displayed. When I visited in the 80s, there was also a five-inch-high scale model of the Lunar Excursion Module (lander and ascent stage). A gift from the people of France, it was financed by donations solicited by a Paris newspaper. It was made by Cartier out of solid gold. In 2017, it was stolen and probably melted down as it would otherwise be impossible to fence.

I have never understood why the moon landing project was called “Apollo Program”—he is the Greek god of the sun! Far more appropriate would be Greek goddess of the moon Artemis and her Roman equivalent, Diana. Somebody at NASA finally figured this out; the project to return to the moon by 2024 and establish permanent bases there is named the “Artemis Program.” Only about 50 years late and a couple of dollars short! Gene Jordan described the Apollo Program era as “The days of iron men and wooden computers.” That last is literal—we sent men to the moon using slide rules made of wood.

NASA’s Artemis Program has objectives much along the lines that
I along with many other Apollo veterans envisioned as logical next steps to begin in the 1980s. Canceling Apollo missions 18 and on made it clear that governmental impetus was insufficient to sustain human space exploration. Private enterprise alone can supply both motive and means for the long haul plus the cost-cutting innovation to make it profitable. The Shuttle was a long and expensive detour in the wrong direction. It’s taken forty years or more to get back onto the right track.
WAPAKONETA LAMENT

Hard by the River of Fallen Timbers
On icy blacktop car park nigh the Holiday moon,
Highway downtrodden, my mind unlimbers
Where Little Turtle once danced to crazy Tony’s tune.

Here in the home of Artemis’ Adam
It’s one small step to call back how NASA’s Vulcan team
Once I had pulled as feet trudge macadam
To bend and forge and hammer fair Diana’s new beam.

Hear how my father’s great-great-grandsire’s
One giant leap still echoes through blood of my own blood.
WAPAKONETA LAMENT

Soft! Why no sound from my sons’ campfires
That sing and rhyme and water intrepid
lunar bud.

Tourist traps and Star Wars toys and plastic
redchief feather
We cannot hear songs of the spheres—just
news, sports and weather.
Looking back over 60 plus years, it seems almost like a dream. Incrementally adding skills one after another did not seem all that unusual at the time. Bouncing from application to application felt purposeful as events unfolded, but it was an accidental appearance of natural order. So gradual were these events and changes that I barely noticed. But seeing them all together in the process of this writing leaves an aura of incredulity and an appreciation of the vicissitudes of chance in the making of an accidental engineer.
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