Chapter 5: Three Decades at Hughes Aircraft

Life at Hughes got off to a fast start at the age of 36, quickly leaving missiles behind and jumping into spacecraft, though ICBM rockets are one with the vehicles that satellites ride to orbit. The location in El Segundo looked right out on the runways at Los Angeles International Airport (LAX) if you were lucky enough to have a window. A junior Member of Technical Staff (MTS) like myself shared an office with another and had no window. Within weeks Hughes was in a competition to design and build a weather satellite for Japan called Geostationary Meteorological Satellite (GMS), a weather monitoring satellite to be launched to the geostationary orbit[1]. Our competition[2] was Philco-Ford Aerospace who were under contract developing a US GMS termed Synchronous Meteorological Satellite (SMS), to be launched in 1974. The task of designing the satellite attitude and antenna pointing control and writing its description for our proposal as assigned to me. Only on board a couple weeks, I could hardly believe what they were asking, but there was lots of work and management hadn't so many options. With help from bosses, colleagues, and prior proposal documents in about 60 days we had a proposal ready to submit to the Japanese.

Hughes won the competition for the Japanese GMS and I spent much of the next couple years designing and supporting the production and testing of the attitude and orbit control system. For terminology orientation we inject an analogy for clarification of "attitude" and "orbit." Imagine an airplane taking off from the Los Angeles airport. A couple minutes after takeoff it may be one mile west of the airport at an altitude of 3000 ft. traveling upward and southwest at 300 nautical miles per hour. This position and speed information is analogous to *orbit* of a spacecraft. At the same instant the airplane, in a climb and turn, maybe in a pitch up angle of 10° and a roll angle to bank southwest of 15°. This orientation of the airplane body is the *attitude*. These two concepts will dominate my professional life for more than the next 30 years. Not all moving bodies like the airplane are in orbit, but for a satellite that is in orbit, the orbit is known by knowledge of its position and speed at one instant in time. As a result, the term orbit control is often interchanged with velocity control as if we speed it up or slow down it enters new orbit.

The GMS satellite was launched in 1977 and led to the Hughes win of a similar weather satellite for the US termed Geostationary Orbital Environmental Satellite (GOES). Several generations of GOES satellites have been the backbone of weather observation for the US for 40 years, some versions made by Hughes and some won by competitors.

Over the years between 74 and 77 I worked on numerous technical studies, research projects, and new spacecraft designs and proposals for planetary probes and commercial communication spacecraft. It was an exciting era as every new spacecraft request for proposal had their own one-of-a-kind requirements driving a need for as new and unique design for customers US like military, planetary exploration (NASA), civil government, and telecoms around the world. Also pressures were mounting to take on administrative

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[1] The geosynchronous orbit is at a distance 22,767 nautical miles from Earth center such that it has period of 24 hours equal to Earth's rotation period. When the plane of the orbit is the equatorial plane the satellite stands still over the equator and is termed the geostationary orbit. Satellites in this orbit have the great advantage of being tracked by an Earth fixed antenna with line-of-sight to the orbit station.

[2] The long evolving Philco-Ford Aerospace, later becoming Space Systems/Loral (SSL) in 1990, and purchased in 2012 by Maxar Technologies has always been a major competitor of Hughes (itself purchased by General Motors in 1986 and by Boeing in 2000) in mostly the commercial satellite arena.

and management responsibilities. This resulted in promotions through the management chain to Section Head, Department Manager, and Laboratory Manager continuing up to about 1992 when a large shift in the Hughes culture rather abruptly shifted me to a purely technical position with Chief Technologist title. Management duties included assessing engineering staffing needs, interviewing, hiring, facilities management and related tasks.

With my PhD and now lots of formal academic background I did not have a real keen interest in these management tasks, and mentally noted that I should handle that with 30% of my time while pursuing engineering that contributed to the business and challenged me with the other 70%. I noted that many 'engineers' seemed to be occupied in visiting and interacting with venders, going to meetings, and such administrative functions. I found a way and always appreciated that I could apply the theories and techniques I learned in college to real productive problems at Hughes. Of course I was not alone as Hughes, as I detail some below, had lots of smart and innovative people, some of whom I hired.

One interesting administrative task was in provision of computing capability to my organization. Slightly ahead of spacecraft, this was the age of computing evolution. When I arrived we had one teletype terminal connected to a main frame IBM off in a distant building. The terminal accommodated punched paper tape and for larger jobs you walked to the building with the IBM and dealt with punched cards and a single impact printer. Printer outputs were delivered by courier a couple times per day. Gradually we got another terminal or two, then a few more terminals in scattered offices and hallways with CRT screens and maybe floppy disk input capability.

Some large industrial neighbors Hughes had in El Segundo were Mattel Toys, Xerox Copiers, and our sometimes competitor TRW. On one occasion my boss, Bill Herron, and I, for some forgotten reason, maybe shopping for copiers, were at Xerox and they introduced and demonstrated a new innovation from the Palo Alto Research Center (Xerox PARC). It was basically a computer terminal with CRT screen and keyboard. However, it had this extra unique pointer – as you moved the pointer around on the desk an electronic pointer moved on the CRT screen. With buttons on the desk device one could enter commands into the terminal and hence the computer. Further, one could actually grab things on the screen and drag them around. This was magic. Back in the office I told Bill we should strive to get one of those on the desk of all our control engineers. This was the "mouse" and original "graphical user interface" (GUI) that Steve Jobs usurped and put out on the first McIntosh computer sometime after, and that soon became ubiquitous on every PC shortly thereafter in the mid 80s. By 1990 nearly every desk did have a PC and a few of the more intensive stations, e.g., the computer network administrator, had much more powerful Sun (Microsystems) workstations.

Key Largo

By 1977 I was writing technical papers for conferences sometimes. Once I went to a conference at Hollywood, Florida to give a paper. On an off-day a colleague invited me to go down with a couple others to Pennecamp Park on Key Largo for an afternoon of snorkeling or SCUBA diving. I was only qualified to snorkel, but the reef was ***spectacular***. As we returned to shore in the evening a few of us in tattered shirts and sandals bent to the humble task of rinsing sand and debris from fins and other dive gear. It's too much diversion here to repeat all, but in the footnote I share a story oft told by my Father of a

farmer fixing the tire on the automobile that was transporting Henry Ford,[1] Harvey Firestone, Thomas Edison, and Moses on a tour across the country. I felt like the farmer. Gathered round that rinsing hose were Tom Spenser, Dan DeBra, Art Bryson, both Stanford Professors, and Phil Dahl, a group equally famous in my field. When I mentioned Hughes, Bryson said "do you know Harold Rosen and Bob Roney?" When I acknowledged I at least knew their names, he related that they were together as the first three Hughes Ph. D Fellows at Cal Tech. At that time Roney was President, and Rosen VP of Engineering of Hughes Space & Communications Group. Ultimately my meeting these colleagues would have happened anyway, but I was impressed with the gathering and conversation around the rinsing station. Years later, DeBra and Bryson would invite me to Stanford as a guest lecturer. The snorkeling was so good that within a week back in California I was enrolled in a SCUBA certification course at Dive n' Surf, in Redondo Beach which led to an avocation to include more than 200 dives at many places around the world.

As time went on I came to know and work some special on-orbit anomaly tasks with Bob Roney, and Rosen became a close mentor, boss, colleague who appears over and over in these writings. Illustrated here and mentioned elsewhere is the "Technology Company" nature of Hughes Aircraft, exemplified by these people in the leadership positions. Those mentioned above were the Fords and Edisons of the spacecraft technology.

About Hughes Aircraft

Hughes Aircraft Company really did build aircraft at one time, but that was long in the past when I arrived. The origins of the company are to my knowledge pretty much like you see in the movie *The Aviator*, though this deals more with the man than the company. Howard was very independent and forceful individual, and though he was building products the Air Force wanted badly, he didn't get along well with the bureaucracy. At some point when a divorce for Howard and the Air Force was evident, Howard formed the Hughes Medical Institute, endowed it with Hughes Aircraft, and stepped out of the picture. I believe this was after the infamous flying boat, the Spruce Goose, which may have been Hughes Aircraft's last aircraft? In any case the result became a very high technology company, privately owned and totally managed by the resident executives – not having to answer or report to anyone. As such it was sometimes characterized as a 'national resource' that could do things without explaining to anyone, or even telling anyone, like build spy satellites or a *Glomar Explorer*[2] to covertly raise a sunken Russian missile submarine. With 30 – 40,000 employees, this was for a long time the largest non-government employer in California. If you had a little ambition

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[1] Before I existed and he was a farmer, my Father was in automobile businesses. A story I've heard him tell is that in early days when autos and highways weren't as reliable, well heeled travelers had a support car traveling along. On one occasion Henry Ford, Harvey Firestone, Thomas Edison, and John Burroughs (the naturalist), traveling together, were separated from their support car and had a flat tire. Darkness came and they enlisted help from a local farmer to change the tire. As the farmer worked, the four decided to have some fun. "Do you know who I am?" asked Ford. "I'm Henry Ford, I made this car." Firestone similarly, "I made that tire you are changing." In turn, Edison says, "I made the light you're using." Whereupon, the farmer looked up at Burrows, with his voluminous white beard and exclaimed, "If you tell me you are Moses I will throw the wrench! (These guys really did hang out together http://en.wikipedia.org/wiki/John_Burroughs)

[2] *Glomar Explorer* was built by Hughes Summa Corp., but it's mission was directed from our building in El Segundo. https://en.wikipedia.org/wiki/Glomar_Explorer .

it was a wonderful place to work, unlike airframe companies, among the engineers it had a very scholarly, or even somewhat 'University' like environment. Junior engineers like myself actually had offices, not working in bull pens as reputed in those companies. There were bi-weekly lunch time seminars from noted scholars and luminaries in many fields, not always obviously related to our business. We often had after hours courses taught by well known scholars from close by universities. I was privileged to attend a semester of math instruction given by Dr. Richard Feynman, of Cal Tech and Manhattan Project fame. He taught me how to recite the value of n/7 to an arbitrary number of significant digits from mental calculation – a completely trivial trick, but in line with this Nobel Laureate's lighter side. In this era Hughes maintained one of the most prestigious scientific research laboratories in the world, overlooking the ocean in Malibu, Ca., where along with many achievements, the laser was invented.

Only about three people that I ever encountered had even seen Howard, much less knew him. Hughes died in 1976 and subsequently a review of the tax exempt status of the Hughes Medical Institute precipitated the sale of the Aircraft Company to General Motors (1985) in order to diversify the Institute's assets. As the age of the God of "shareholder value" advanced and the objective of companies providing products or services faded into history many technology older companies succumbed. While IBM seemed to be loosing its way it hatched "executives" to go out in the world and unlock value in other laggard organizations, e.g. Nardelli (actually the protégé of Jack Welch at GE) at Home Depot and Chrysler. At Hughes we got Mike Armstrong who carved the company up into saleable pieces and sold them. When he left all that was left was Hughes Space and Communications. Mike, who was very good to me by the way, went on to lead the demise of AT & T – that's the old AT & T which had been since purchased by one of the baby bells it spawned and the baby bell itself renamed AT & T. In 2002, Hughes Space was sold by GM to Boeing, so technology company becomes airframe company. At this writing the only remnant of Hughes Aircraft is Hughes Network Systems, which was a small ground systems company started by a former Hughes executive in the 80's and has flourished. Much more detail can be found at about http://en.wikipedia.org/wiki/Howard_Hughes about Howard and the Aircraft Company.

Birth of Commercial Satellites

Stepping back a few years, at the inception of Hughes Space, every space endeavor was either military or government funded, supervised and experimental. Most famous of the Hughes programs was Surveyor achieving the first soft landing on the moon. Another such endeavor was to introduce a communication relay terminal in space. One concept espoused at AT & T Bell Labs, *the communications company*, was a satellite in low earth orbit which had to be located and tracked overhead on each orbit every few hours or more frequently. To establish any continuity multiple satellites were necessary. An alternative was to use the geostationary orbit, described above, perhaps first sited in modern times by Arthur C. Clarke in 1945, and strongly favored by Harold Rosen[1]. Rosen had hired two

[1] As a result of Rosen's push for exploitation of the geostationary orbit Rosen, the engineer, and Clarke, the science fiction writer were acquainted on some level and I believe one Clarke book is dedicated to Rosen. Rosen did honor Clarke in 1990. I recall being at a Hughes celebration of the 100th Hughes geostationary commercial communication satellite on the Queen Mary in Los Angeles Harbor when a real time via satellite video communication link was set up between Clarke on Sri Lanka and Rosen, et.al. on the Queen Mary.

other engineers, Donald Williams and Thomas Hudspeth. At this writing I cannot cite facts, but rumor has it that these three approached Pat Hyland CEO of Hughes Aircraft of which Hughes Space was a component with a proposal that Hughes support building and launch of the GEO ComSat, otherwise they would quit, form their own company and attempt to do so. Ultimately Hyland and Hughes Space did support it, leading to the launch of Syncom 1, 2, and 3 in 1963 and 1964. These satellites were of course experiments and a degree of government support was provided.

The Syncom success led to the start of the GEO ComSat business with the first launch for Canadian telecommunications company Telesat satellites ANIK. This first Hughes GEO ComSat model, termed HS-333 pioneered the commercial communication satellite business. In addition to Canada, versions were sold to Indonesia and Western Union in the US with perhaps 8 or more satellites. Geostationary satellites require periodic small maneuvers to maintain their orbit station, so their useful life is determined by the amount of fuel launched for this purpose, termed "stationkeeping." Hs-333 models had 3, 5 or 7 years life. Consequently, by the late 70s it was time for replacements.

Life Away from Hughes

In 77 after my Key Largo experience I became a certified SCUBA diver. I would frequently dive from the beach with Bob Weakley, or we took dive boat trips to Catalina and other channel islands. We also made week long dive trips to Cozumel off Mexico and Grand Cayman. Pat and I bought a house in Torrance about a year after return from Colorado. She was very social, had many friends, some in California from the Cimarron area that we visited frequently. Shortly, in 75 -76, we jointly agreed to divorce. Without details, perhaps we had just grown apart, maybe with large changes in my life. By that time Pat was also working at Hughes where she stayed until retirement 25 years later. Pat remarried a few years later, nevertheless to the day of her passing in 2023 we remained friends, visiting often.

My social life somewhat disappeared with Pat. I was born and lived my childhood in an era and neighborhood where the adults 'worked' and the children often played. On the dairy farm there seven day a week work and mostly the adult pleasure was visiting relatives or friends on a Sunday afternoon. By the late 70s this situation seemed to be reversing where adults went camping, backpacking, skiing, sailing, bicycle riding, SCUBA diving, all while sometimes wrestling with what to do with the kids while the adults played.

Consequently to restore some social life beyond work, I had to learn to play!

This began with SCUBA diving but soon branched to many things. With Bob Weakley I began river kayaking and by mid 80s actually learning to swim short distances in the ocean. For 15 years during spring snow melt, Bob and I

Figure 5.1 Horseshoe Rapid on the Lower Kern River.

regularly kayaked the Kern, driving from LA Saturday mornings, camping that night and paddling Saturday afternoon and Sunday morning. We also made intermittent trips to the Kings, Tuolumne, Colorado, and once to the Rogue and others in Oregon and Northern California. I hiked frequently with the Sierra Club and went on multi-day camping trips.

Figure 5.2 Ewings Rapid on the Upper Kern.

My PhD advocate, Jon Petway, had a sailboat and taught me to sail. Later I became custodian of his boat with lots of weekend day-sailing and occasional week long trips to Catalina Island for about five years. My sister, Barbara and husband Mern, shared a week long sailing adventure to Catalina. Meantime, on visits to their ski cabin in Ruidoso, NM, they taught me to snow ski. They also became certified SCUBA divers and together we made diving excursions to all the Caymans, Turks & Caicos, Bonaire, Hawaii, and multiple times to Cozumel, Mexico.

Bob Weakley and I made many camping trips to Baja Ca. I got a VW bus at some point and equipped as a camping vehicle so we could just go by the grocery and be off on a weekend. Tres Hermanas, Baja became a regular Labor Day visit and over the long Christmas holiday we went to Mulegé on the Baja east coast, or drove via Tucson down mainland Mexico through Hermosillo to San Carlos on the mainland west coast. The latter village, about 15 miles north of Guaymas, had abundant beach camping, huge Baja shrimp at give-away prices, and was a winter haven for many American motor home full-timers.

Second Generation Commercial Geostationary Satellites

By the latter 1970s the Hughes HS-333 were approaching end of life and demand for GEO ComSats. Also some competition was arising at Loral, and satellite divisions of GE and RCA. Hughes put together a very much advanced satellite HS-376. Both HS-333 and HS-376 were spin stabilized but the latter was much higher power and greatly advanced communications capability. HS-333 was like a passive spinning disk, while HS-376 required active stabilization of spin about its "long axis" (minimum axis of inertia) leading to much more complex attitude control and mission dynamics. Both models had non-spinning platforms to allow continuous pointing payload antennas to Earth. I was lucky to lead and perform much of the HS-376 design over several years.

Through the 70s to early 90s commercial satellites were a very new and novel endeavor and most were sold to foreign or international companies. In the beginning they were most popular in less developed countries that did not have a large developed ground communications infrastructure. Countries like Canada with its large undeveloped north, Indonesia with islands over thousands of mile span, Malaysia, Brazil, Australia were ready customers. Further, putting your own satellite in orbit was an act of great national pride. As a result every country wanted the satellite launched and controlled from their own soil. Of course rockets only launched from a couple places in the world. Typical mission consisted of a 30 minute rocket ride to a low orbit of 250 to 400 nm altitude. Here the satellite was dumped from the rocket and made its way under its integral propulsion over 1 – 2 weeks to the geostationary orbit about 20,000 nm higher under control from the station in the country of its new owner. In the earlier days there was often local TV presence at the control center. During this orbit raising period some principal engineer for each subsystem, attitude control, propulsion, power, etc. was available at the control station in the event of questions or anomaly regarding their system. As chief designer I was always present attending to attitude and orbit control. This introduced me to extensive international travel. If the mission went smoothly it was a vacation, if not, things could get quite busy and uncertain. I soon learned to love it. Often after a week or two mission I would extend my time with a travel vacation to the Amazon, or diving at the Great Barrier Reef, etc. at the end of the mission.

Simultaneously, I advanced through management so to manager of the attitude and orbit control organization at Hughes as such active in hiring many engineers, staffing and budgeting programs in my discipline. With many programs for many customers, Intelsat, NASA Venus probes, Pioneer Venus, and our share of "black" government work I was very much technically aware or participating in all.

While at Hughes we were developing second generation HS376 communication satellites with first launch in 1980, NASA was developing the Space Shuttle reusable cargo launch vehicle/spacecraft. The first commercial payload on the shuttle, 1982, was two HS376 satellites, 2nd generation Anik for Canada and another for Satellite Business Systems (SBS), a conglomerate of IBM, Comsat, and Aetna Life Insurance.

Genesis of a Used Satellite Market.

In 1984 a space shuttle carried two HS376 satellites up and ejected them into the low parking orbit at about 250 miles altitude, one for our customer Western Union, Weststar, and the other for Indonesian Telecom, the satellite named Palapa. These

satellites ejected about 24 hours apart from the shuttle would normally fire their own integral rocket which injected them into a highly elliptical transfer orbit on their way to their final operational geostationary at 22,000 mile up. On the first satellite the rocket motor failed and, leaving the satellite in the low shuttle orbit. Much agony and debate followed in the next 24 hours about what failed and whether the second satellite, still riding in the shuttle cargo bay, should be deployed or returned to Earth. Almost as quickly speculation began that the first satellite, Weststar, was in the low shuttle orbit so might be retrieved and returned. Ultimately it was decided to deploy Palapa also and its rocket failed also, now leaving two new satellites in the low orbit. The Weststar failure had barely happened when speculation began around the control center that this presumably perfectly good but stranded satellite could be retrieved and returned. Then hours later there were two stranded satellites.

Figure 5.3 Time Magazine Cover, November 1984.

Over the next few weeks the anticipation built. Could we design and build hardware and develop a procedure for retrieval? Who, how would a retrieval be funded? Who owns these stranded satellites? Turns out the insurers were owners and I recall but cannot presently find reference to a PBS special treating the intrigue of getting legal and ownership details worked out for the retrieval. Over a few months many details were worked out and a method of capture and securing in the shuttle bay was developed. With extensive interaction with Houston Space Center and the chosen mission astronauts the necessary hardware and retrieval procedures were developed and practiced. The retrieval was carried out in November 1984 with little mishap.

After some minimal refurbishment, both satellites were resold and successfully launched into service a couple years later, initiating the first used satellite market. An interesting vignette circulates as follows. The central figure. a former General in the Chinese military, He Kerang. In that era a commercial satellite launch cost about $100 million and typical communications satellites $80 m to $200 m. Facilitated by their low cost and to break into the competition the Chinese were selling Long March rocket launches for $10 m. He bought one of our used HS376 satellites for about $30 m

and a long March rocket for $10 and started the Hong Kong satellite communications company Asiasat for about $50 m. On one trip to Beijing I found myself at a celebratory party associated with the launch. Another vignette goes like this. Several years earlier one of my colleagues was crossing the street between Hughes buildings. Waiting at the cross-walk for traffic he was accosted by a gentleman inquiring " where is Harold Rosen's office?" After getting direction he went unannounced to Harold's office and attempted to sell rockets to Hughes. At the time, early 90s, the US government was not ready to allow rocket purchases from China, however by the late 90s we really were buying rocket launches on the Long March.

Changing Times

As noted, in 1976 Howard Hughes died. As a result of years of estate settlement, probate and tax authority scrutiny in 1986 the Hughes Medical Institute, owner of Hughes Aircraft, our parent was required to put the company up for sale. We were now known as Hughes Space & Communications (SCG). General Motors, perhaps with temporary goals of becoming bigger than a motor company, had recently, 1984, bought the technology company Electronic Data Systems (EDS) from Ross Perot. In 1986 GM bought Hughes Aircraft. This was about the time that electronics was finding its way into automotive product beyond just power windows. Systems like automatic braking (ABS) and traction control were being studied at GM and there were halting attempts to integrate or cooperate in engineering. For a short while in El Segundo we had teams analyzing and building computer simulation of ABS and perhaps other technologies. The technology interchange was fragmented, mostly disappointing, and short lived. More important was the cultural change.

The early Cold War ICBM and space flight development era was gradually coming to its end. Companies like Lockheed were buying competitors and combining so Lockheed became Lockheed-Martin while Boeing bought aerospace companies like Rockwell International, developer of early GPS, and Douglas Aircraft, maker of the phenomenally reliable Delta launch rocket. Simultaneously commercial spacecraft were becoming a commodity more like cars or washing machines – Hughes sold upwards to 100 HS-376 spacecraft with payloads and mission adapted to each customer but basic satellite subsystems, power, propulsion, attitude control nearly identical. And finally, Hughes now had stockholders to answer to.

Both launch rockets and satellites were rapidly evolving, spinning satellites could no longer accommodate required power and payload capabilities so through the 1990s the body-stabilized satellite came to dominate, at Hughes the HS-601 and 702. The launch and orbit acquisition missions came to be executed from one central control center at the manufacture's location. Ultimately around 2001 Boeing bought Hughes.