Spaceflight Adventures

(Never Left the Ground)

By Spike Field

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By E. L. “Spike” Field

Long after retirement I decided to write about events that occurred while working on America’s space programs at NASA. It is written with the intent that family members and future generations might know what we did.

Projects

Section 1: **SATURN S-II STAGE** - (’58 –‘65) – ABMA & NASA; Saturn rocket evolution; Industrial participation; S-II Stage development; Sloan Fellowship Page 3

Section 2: **SKYLAB** - (’66 – ‘73) – America’s first space station; Orbital Workshop (OWS); launch issues; mission support Page 28

Section 3: **HUBBLE** – (’74 – ‘81) -- Telescope Support Systems Module; Astronomers; hardware development; mission success Page 39

Section 4: **SPACELAB** – (’82 – ‘93) McDonnell Douglas Co; Spacelab Project; Private industry perspective Page 52

SATURN S-II STAGE

Army Ballistic Missile Agency

The job was in the Program Coordination Office, a staff entity of Dr. von Braun's Development Operations Division. My first assignment was to coordinate closure of Unsatisfactory Condition Reports with the R & D Laboratories. I also helped evaluate technical changes, and prepared cost estimates and schedules for the Redstone and Jupiter missile programs.

The building I worked in had the offices of Dr. Wernher von Braun, MGs J. Bruce Medaris, and Holger N. Toftoy. There I was, at one end of a third-floor wing, with von Braun's office at the other end. What luck to be figuratively rubbing elbows with the celebrated rocket scientist! My desk was in a large bullpen with windows facing the test stands where rockets were routinely static fired before transport to Cape Canaveral for launch. Whenever a firing was scheduled, we would gather to watch. Static tests got the attention of the civilian population nearby, as the ground seemed to shake during firings. Some Huntsville townspeople complained about acoustic damage to their property; in fact, large windows on storefronts at the Parkway Shopping Center cracked.

Sometime in '58, the Huntsville Times published an article saying that the average age of ABMA personnel was about 30 years, which was my age at the time. Many of us had served in the military during WW-II or the Korean Conflict. In fact, some of the younger crowd had been drafted or received ROTC commissions and were sent to Redstone Arsenal for duty. ABMA had a need for technically trained personnel, and the Army knew where to assign its young soldiers – especially graduate engineers and science majors. Many had grown up during the depression when they repaired farm equipment or built hot-rods. Fixing things was either a necessity or a fun thing to do. We were a "can-do" bunch, and not afraid of getting our hands dirty.

I went to the Cape Canaveral Missile Testing Range with several other engineers in January '59 to see ballistic missile launches. Polaris, Pershing, and Jupiter R&D missiles were successfully launched, except for the Titan, which blew up as it started to rise off the pad. The image of thousands of bright sparklers appeared to be instantly expanding in front of an orange-colored blast flame. The bright objects were pieces of shattered aluminum missile skin being thrown out, just ahead of the fireball. Appreciating the amount of effort that went into producing a missile, it was a depressing sight.

ABMA was authorized to launch a couple of deep-space payloads called Juno. There was even talk about putting a "man-in- space", and something called "Project Able." It turned out that Able was one of two monkeys launched in a Jupiter nose cone. It got a lot of press, but didn't contribute much to learning about the effects of the space environment on primates, except that they survived. Although the agency's primary job was development of Redstone and Jupiter missiles, the potential of manned space exploration was on everyone's mind.

I was caught up in the enthusiasm, along with everyone else. One of the problems discussed was the potential effect of high-G on humans during launch and reentry. My navy diving experience gave me an idea: If a human were partially submerged in water (with head kept dry), the effects of high-G acceleration would result in pressure evenly distributed over submerged body surfaces, instead of concentrating forces on one's backside while lying on a launch couch. With encouragement from my boss, I submitted the idea into the suggestion system. Dr. Ernst Stuhlinger, Director of the Research Projects Lab, replied saying that my idea showed knowledge of the physiological functions involved and contained some good ideas, but that the immersion method had some tricky engineering problems. He also said that recent experiments at the Wright Air Development Center, using conventional techniques and new anti-G protection suits, provided a more practical solution to the problem. It was a wild idea, but at least I was thinking!

Dr. Hermann Oberth, who had been dubbed "father of German rocketry," occupied an office in our building. He was employed for one year by ABMA, and we were encouraged to talk with him about space ideas. Before receiving Dr. Stulinger's reply, I took the opportunity to ask Dr. Oberth about my water immersion idea. I had some difficulty understanding his heavily accented English, but appreciated his fatherly way of saying the idea had been proposed sixty years before by a Russian scientist. To make sure I had the name correct, he tore a piece off his brown paper lunch bag and wrote, "Konstantin Tsiolkovsky", and gave it to me.

Saturn-Apollo Beginnings

July '58: President Dwight D. Eisenhower signed an Act that authorized America's new civilian space agency, the National Aeronautics and Space Administration (NASA}.

October '58: The Advanced Research Project Agency (ARPA) funded ABMA to build a million-pound thrust ground-test booster, which became the first Saturn hardware.

December '59: The Silverstein Committee recommended development of upper stages to burn high-energy liquid hydrogen and liquid oxygen propellants, which led to NASA's first LH2 /LOX upper stage, the S-IV.

President Eisenhower sent a letter to the NASA Administrator, T. Keith Glennen, stating the need to accelerate the building of a super booster. The purpose was to get ahead of the Russians, and going to the moon soon became the main objective.

July '60: President Eisenhower directed the transfer of all Army (ABMA) space-related activities to NASA, including 4,670 civilian employees, about $100 million worth of buildings and equipment, and 1,840 acres of land - all assigned to the new NASA, George C. Marshall Space Flight Center (MSFC) at Huntsville, AL.

From ‘60 through ‘62, the Huntsville NASA team studied a variety of Saturn launch vehicle configurations; from the initial ground test booster to the C-1, C-2, C-3 (C-4 was never considered); and the C-5, known as Saturn V.

The Space Task Group (STC) at Langley Research Center worked parallel to Huntsville with the common objective of sending men to the moon. STC was responsible for America’s manned space flight programs, Mercury, Gemini and Apollo. STC relocated to Houston, TX when the Manned Spacecraft Center (MSC) opened in 1963. MSC envisioned a manned circumlunar flight, followed by a lunar landing.

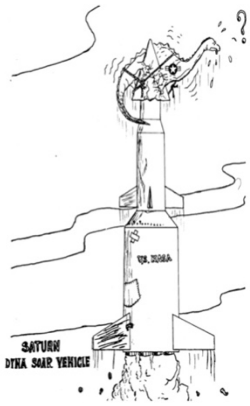
Much of the conceptual work leading to the Saturn V launch vehicle system was centered in Hermann Koelle’s Future Projects Branch of Marshall Space Flight Center’s Structures & Mechanics (S&M) Lab where Frank Williams evaluated concepts and design approaches. Bob Lindstrom was project engineer in charge of the Saturn ground test booster and later became project manager of the Saturn I and IB Projects. Lee Belew managed the liquid engine contracts, along with Bud Drummond, Frank Stewart and Sonny Morea. Dr. Oswald Lange headed the Saturn Systems Project Office, which was where I worked.

Payload Ideas

The Saturn S-I booster and S-IV Stage hardware were already being developed before the lunar mission was fully defined. Although it was understood that the ultimate goal was “man in space,” the Saturn C-1 configuration was a reality that could easily launch heavy payloads into orbit. Some of us at the Marshall Center were increasingly anxious to identify a payload, any payload, to fly on Saturn, so several were examined.

An ABMA electrical engineer, Jurgen Unger, did a study and prepared a proposal titled, the Saturn 24-Hour Communication Satellite. Jurgen prepared the technical portion, and I assembled the cost and schedule volume. We presented it to General Medairis who sent it to the Army Signal Corp in early ’60 for consideration. It was never seriously considered, but the idea had “legs” as evidenced by the thousands of functionally similar telecommunication satellites currently in synchronous earth orbits. Bell Labs heard about it, recognized Jurgen’s potential, and quickly hired him. He was a bright guy who had flown ME-109’s as a teenager during the last months of WW-II.

The Air Force had planned development of a space plane called Dyna-Soar since ’57, and we thought it could be a potential payload for Saturn. The Air Force intended to use a Titan II booster with high-performance upper stages, but shelved it and sought go-ahead using a Titan III. Our engineers calculated that any Titan boost capability was marginal at best, and felt that the Saturn I, with an S-IV second stage, was a much better solution. Frederich von Saurma was assigned to head a Saturn/Dyna-Soar study effort, hopefully leading to possible go-ahead. Dr. Lange assigned Dick Young and me to work with Fred, but our efforts started and stopped within a span of a few of months, ending with a report submitted to the Air Force in April ‘61. The Air Force wanted to be the nation’s leader in manned spaceflight, but plans for Dyna-Soar and a Manned Orbiting Laboratory (MOL) were terminated when "peaceful use of space" became the national objective and NASA was assigned the job.



One aspect of the Saturn/Dyna-Soar potential was that a "winged payload" would require tail fins on the booster in order to position the "center of pressure" closer to the vehicle's "center of gravity" thereby making attitude control (steering) easier during powered flight. It is noted that the S-IB first stage design suddenly "grew" tail fins when the possibility of a Dyna-Soar payload was being evaluated. Without a winged payload, tail fins were not necessary; however, large fins became part of the S-IB first stage design anyway. Although Dyna-Soar never matured, the idea of a space plane was realized a generation later with Shuttle.

S-IV Stage

Max Smith and I prepared the S-IV Stage "Model Specification" in early '59 while still in ABMA's ARPA/NASA Project Office headed by Dr. Oswald Lange. The S-IV was NASA's first high-energy Liquid Oxygen/Liquid Hydrogen (LOX/ LH2) upper stage. With advice from an old-timer we used a military specification document for an outline, filled in details and distributed drafts to the Labs for recommended changes. After several iterations, it took shape and was approved.

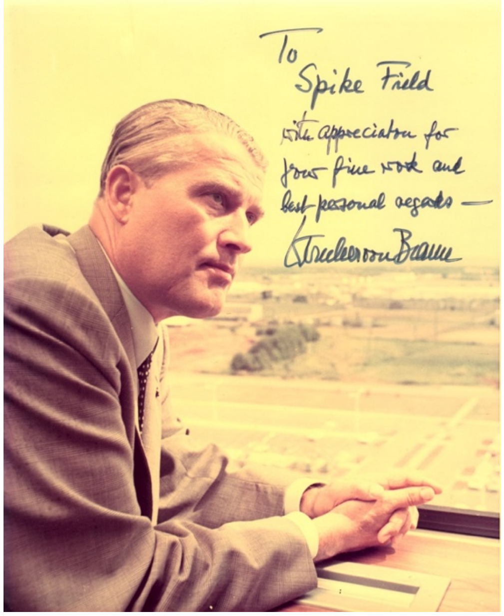
The S-IV Model Spec became the principal technical definition of what NASA wanted to buy from industry. It defined stage performance requirements, use of government- furnished engines, physical size, propellant capacity, and the need for simple interfaces between adjacent stages. A comprehensive component test program was also required. An RFP (Request for Proposal) was given to 20 firms in February '60, and eleven were received.

An S-IV Source Evaluation Board (SEB) included nine senior officials: Oswald Lange was Chairman, Wernher von Braun, Eberhardt Rees, Milton Rosen, Ernie Bracket, and others. My job, as secretary to the SEB, was to assure security and accountability of all proposal copies and evaluation materials, coordinate communications with the technical and business committees, and write the Board's minutes and conclusions. The final report was delivered to the NASA Administrator, Dr. T. Keith Glennen, who selected Douglas Aircraft Company (DAC) as the S-IV Stage contractor.

Chrysler Missile Division quickly challenged the S-IV selection, claiming their proposed cost was about half of the announced Douglas' cost, and that the government may have made a poor business decision. A GAO examiner reviewed the SEB files and said, "This is the best evaluation I have ever seen."

NASA’s first high-energy liquid hydrogen upper stage contract was issued to Douglas in the summer of ’60. Ten stages were built and flown in the Saturn 1 and 1B launch configurations. The first few were suborbital test launches, leading to SA-5, when a propulsive S-IV stage put a heavy Jupiter nose cone payload into orbit in Jan ‘64. JFK applauded this launch as the one that would place U.S. lift capability ahead of the Soviets.

Dr. Lange assigned me to prepare a Saturn C-3 development plan. Dr. von Braun’s secretary, Bonnie Holmes, typed a note on the cover that read, “Dr. von Braun: You wanted to see the version of the C-3 report that went out to Mr. Rosen. BH 8/17/61.” Beneath her note von Braun wrote, “Dr. Lange, please furnish answers to my questions scribbled in this (excellent!) paper. [signed] B.; Field to analyze.” I was encouraged by his comment and saved a copy of the cover.



“LOR” Decision and Presidential Commitment

As soon as the United States decided to build bigger boosters and develop high-energy upper stages, going to the moon became NASA’s principal objective. The next step was to decide the method of getting there and back. Dr. von Braun had considered many schemes over the years, but as the crucial time came to decide, he abandoned his Earth Orbit Rendezvous (EOR) scheme, and accepted a Lunar Orbit Rendezvous (LOR) approach that John C. Houbol of the Langley Research Center proposed. Dr. von Braun agreed to LOR in June ‘62 for fiscal and schedule reasons, rather than technical rationale. EOR was a more conservative approach to get to the moon, but it was considered more complex and costly, requiring two successful Saturn launches to support a moon landing. LOR, however, was quicker and less costly, although it was considered more risky. James Webb, NASA Administrator, announced the LOR decision in July ‘62.

After President John F. Kennedy made his famous speech at Rice University on September 12, 1962, we were off and running. He said, "We choose to go to the moon in this decade and do the other things, not because they are easy, but because they are hard, because that goal will serve to organize and measure the best of our energies and skills, because that challenge is one we are willing to accept, one we are unwilling to postpone, and one which we intend to win, and the others, too.”

S-II Stage Competition

I began accumulating data from the labs during the fall of ’60 for a second stage to fly on a three-stage Saturn C-2 configuration. The work culminated in an S-II Stage Model Specification intended for industrial competition. On March 27, 1961, Dr. Lange assigned me as Acting S-II Project Manager. Three days later, NASA Headquarters invited the aerospace industry to participate in a two-phase proposal cycle. After the first proposal phase eliminated less-qualified contractors from further competition, James Webb, issued a "memo for record" stating that although the C-2 configuration had been defined for the first phase, C-3 was to be the configuration for the second phase competition. The C-3 S-II Stage was to have four J-2 engines, be 320-inch in diameter and have a propellant loading capacity of one million pounds. Webb's memo identified four contractors most qualified to compete. Competitive proposals were received on July 28, 1961 from Aerojet General, Douglas Aircraft, General Dynamics-Astronautics Division, and North American Aviation's (NAA) Space and Information Systems Division (S&ID).

The S-II Source Evaluation Board (SEB) established technical and business committees and approved evaluation criteria. Board membership consisted of Oswald H. Lange, MSFC (Chairman); Milton W. Rosen, NASA Headquarters; Hartley A. Soulé, Langely Research Center; Ernest W. Brackett, NASA Headquarters; Wernher von Braun, MSFC; Eberhard Rees, MSFC; and Harry H. Gorman, MSFC. I served as the SEB secretary and got a first-hand view as how these NASA leaders worked with each other, expressed ideas, and perhaps most important, listened to each other. I prepared the final report, which was signed by each Board member. The NASA Administrator was the decision-maker and chose North American Aviation's (NAA) Space & Information Systems Division (S&ID) for negotiations. The bid price was $320 million for an S-II (C-3 configuration) development, including delivery of ten flight stages.

Having helped guide the S-II procurement through the proposal and evaluation process, it was a relief to reach a point when we could start working on the largest high-energy upper stage ever attempted.

Just about the time NAA was selected, Dr. von Braun invited the Saturn development group to prepare materials for a special issue of the American Rocket Society's publication, Astronautics. MSFC personnel, including a few laboratory directors, contributed articles. Other authors included Bob Gilruth, Director of NASA's Space Task Group, Krafft Ehricke from General Dynamics – Astronautics, and Dick Canright, from NASA Headquarters. Contributions were published in the February '62 issue of Astronautics, describing all elements of the proposed Saturn-Apollo Program. My contribution was the S-II Stage.

Troubled Beginnings

About two months after the S-II job was awarded to NAA's System and Information Division (S&ID), a totally unexpected event happened. NASA Headquarters announced that S&ID was chosen to develop the Apollo Spacecraft as Saturn's principal payload. It was quite a coup for the contractor, but a major problem in the making. I was told, in confidence much later, that Harrison A. Storms, president of S&ID, went into a "fit of denial" about having to develop the S-II Stage. He clearly wanted only the Apollo.

Not long after both contract awards were announced, Look magazine published an article naming Harrison Storms as the nation's "Space Quarterback." The implication that Storms was the leader in the race going to the moon stung von Braun. His displeasure was obvious, but who could blame him when this new guy on the block, who had never even looked seriously at space exploration, got the "Space Quarterback" label.

With the NAA Corporation responsible for four major NASA space developments (F-1 and J-2 engines at Rocketdyne, and the S-II and Apollo at S&ID) it was a big order on any contractor's plate. No one had anticipated that a single contractor, let alone a single division within a company, could win both these development jobs. At MSFC we were nonplused. That was not the way the government normally chose major contractors. It usually spread the wealth around. Jim Webb made the decision, and we wondered what could have influenced him to put two major jobs into one shop. However, it is noted that Bob Gilruth, head of the NASA Apollo team, and Harrison Storms had been close associates during WW-II when they jointly solved a P-51 air scoop structural problem. Clearly, Gilruth had confidence in Storms.

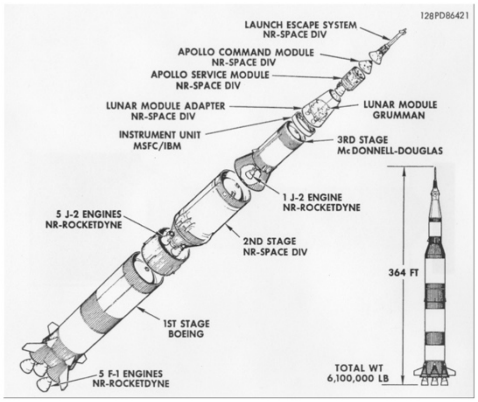
Fifty years later, I was still wondering why both S-II and Apollo had been awarded to a single division within NAA. Out of curiosity, I sent an e-mail inquiry to NASA's Chief Historian, Steven J. Dick. He replied, stating that no "Memorandum for Record" was found in the NASA files dating from the time of the Apollo selection in '61. However, he sent a copy of a '67 Congressional Record, which featured questions from Senator Margaret Chase Smith that delved into the original Apollo selection process. The reason for the Senate committee hearing was the Apollo 1 launch pad fire when three astronauts died. Regarding the Apollo selection process, Webb testified that the Martin Company had been rated slightly higher than North American Aviation for its proposed "technical approach", but that NAA had by far the greatest technical competence. Further, although the Martin Co. was ranked highest by the Source Evaluation Board in the overall ratings, NAA was chosen on the basis of its less costly proposal and its extensive experience in designing "manned" applications (i.e., fighter aircraft and the X-15). That statement was made in press release #67-122 on May 11, 1967.

To back up Webb's Senate Committee hearing testimony, Dr. Robert C. Seamans, NASA Deputy Administrator, wrote a Memo to File on June 9, 1967, five years after S&ID was selected for Apollo. It explained the SEB process and identified reasons why NAA was chosen over the Martin Company. It also stated that Webb, Dryden and Seamans made the decision jointly. Although the memo did not address a specific reason for having both the Apollo and S-II jobs at S&ID, it stated that each competitor provided information relating to the impact of "other business" on their operations. The business cited was the Titan II in the case of Martin and the S-II in the case of NAA/S&ID. Dr. Seamans stated that both companies were judged to be capable of handling their total potential future workload. From my point of view, the Administrator and the Headquarters selection team missed the mark in assessing the NAA/S&ID workload; however, I believe that NAA was the best contractor to do the Apollo job. However, considering the overall magnitude of the workload associated with having these two major NASA contracts in the same shop, I don't think it was a wise choice.

S-II Stage Contract Begins

A “letter contract” was issued in September ’61 to S&ID by NASA’s Western Operations Office authorizing S-II preliminary design studies to run concurrent with the broader NASA/Contractor effort required to do the lunar program. A separate contract for Architect-Engineering (A&E) design of the new Seal Beach S-II assembly facility was issued at the same time.

S&ID’s preliminary design effort provided input to Marshall, leading to the C-5 configuration that became known as Saturn V. The S-I-C first stage was to be 33-feet in diameter with five F-1 engines; the S-II second stage was to be 33-feet in diameter with five J-2 engines; and the S-IV-B third stage, 21.5-feet in diameter with one J-2 engine. An Instrument Unit (IU) would provide the guidance and control function for all stages. Saturn V was destined to be the launch vehicle that would take Americans aboard an Apollo spacecraft to the moon. I revised the S-II Model Specification to reflect the C-5 configuration, and S&ID was authorized to proceed with design and development.



About a month later, S&ID announced a $420M Rough Order of Magnitude (ROM) cost estimate for the S–II Stage in a C-5 (Saturn V) configuration. It was $100M more than proposed a year earlier for C-3. MSFC management reacted negatively. After all, the only S-II changes required to upgrade to C-5 was to add one engine and increase the stage diameter from 320 inches to 396 inches. Besides, the J-2 engines were government furnished equipment (GFE), provided at no cost to the contractor, and propellant loading remained the same at one million pounds. The additional engine meant that the thrust structure would have to be designed for the extra engine and propellant feed lines added. The larger diameter, however, would eventually bite both the contractor and NASA, because of the complexity of the huge, elliptically-shaped bulkheads.

Quarterly Management Reviews

Quarterly Reviews enabled NASA management to get a snapshot of a contractor’s progress and offer instant feedback. The reviews were usually one-day forums and were held in the ninth-floor conference room of Building 4200 where a huge walnut table dominated the center of the room and three projection screens filled the north wall. Dr. von Braun usually attended the reviews along with lab directors and engineers. A few chairs were reserved at the table for visiting contractor officials.

The first S-II quarterly review was held in February ’63 soon after the Saturn V was given the go-ahead signal, and after S&ID had announced it’s $100 million cost increase. S&ID’s first presenter didn’t get very far in his talk when the subject of the cost increase was denounced in no uncertain terms by von Braun's deputy, Eberhard Rees. He effectively said, "You got the contract at a bid price of $320 million and now, you want to increase it by over $100 million - that is unacceptable!" It was a remarkable moment because Rees rarely said anything during those reviews. I suspected that von Braun felt equally chagrined, but gave the reprimand duty to Rees so that he might reserve his comments for technical matters. Storms went away chastened, and the ROM was withdrawn.

S-II Project Office

After the initial S-II contract was signed in the fall of '61, I started building a small staff of project engineers. There were not many volunteers - mainly because lab engineers felt that project office work had to do with money matters and schedules, and that was not the kind of work they wanted to do. The general thinking was, if it wasn't purely technical, it wasn't for them. Besides, the exciting work for engineers was in the Labs. Luckily, the few who volunteered for S-II project office duty were bright, can-do guys who wanted to see the big picture, not the more limited field-of-view available to engineers in the laboratories.

With S&ID getting underway and building its manpower base, it became necessary to establish a government Resident Office at the contractor's plant. One of the first project engineers to staff the office was Don Bowden, a propulsion guy who had previously worked in Test Lab, but had come over from S&M Lab. He was willing to move his family to Downey, CA, and agreed to become the S-II Resident Manager.

Other engineers who joined the S-II project office in Huntsville included Jim Odom, Porter Bridwell, and Bob Boerner. Although each had a few years of experience, they exhibited a high degree of aggressiveness, stamina, and to some extent, management creativity. These young guys were really "systems engineers" in the making. In order to do the "Project Office" job, they had to understand the whole system, and be able to integrate the constant flow of information coming from both the contractor and in-house organizations. Several of the early S-II project office recruits distinguished themselves at Marshall and went on to major management positions within NASA and industry.

Move to California

Not long after Don Bowden set up the Resident Office at Downey, Dr. Lange asked if I would move to Los Angeles for one year starting in September '62. He told me that Eberhard Rees wanted someone he knew (he hadn't known Don before) to be at Downey during the first year of design effort. I agreed, and moved my family and household to Manhattan Beach in time for our three kids to start school. We left Huntsville in a '57 Volkswagen Beetle with rack on top stuffed with essentials. The cat and dog flew. It was an exciting cross-country trip. While traversing the wilderness of west Texas, the VW's generator quit a couple of hours outside of El Paso. I found a piece of rubber inner tube alongside the road and used it to hold an armature brush in place – it worked! A curiosity stop-off at Juarez resulted in an unexpected car search when we returned to the border. The rest of the trip was uneventful and it was a relief to pass the Great Divide and coast toward LA.

The first event I attended after settling in at the Resident Office in Downey was at the groundbreaking ceremony at Seal Beach where the S-II was to be manufactured, assembled and tested. The site was a unique idea proposed by NAA anticipating that the Navy would allow NASA to have a facility built there. A “use agreement” was signed, and the Navy’s Bureau of Docks proceeded to do the construction. The site was located across the Pacific Coast Highway from what seemed like a mile of “igloos” where the Pacific Fleet’s ammunition was stored. Being there was a momentary nostalgia trip for me since I had been there fifteen years before as a Navy Frogman loading TNT and C-3 explosives from the Seal Beach dock to a destroyer anchored offshore.

Tulsa Issue

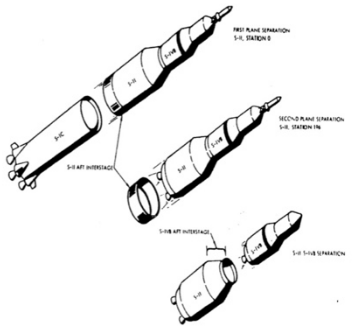
After moving to Los Angeles, NAA made a sales pitch to NASA management to have the S-II development job substantially moved to a corporate facility at Tulsa, OK. That was Senator Bob Kerr’s territory. The fact that Kerr and James Webb, the NASA Administrator, had been business associates wasn’t lost on any of us (Webb, Kerr, McGee Oil Company). Dr. Lange was annoyed that such an idea would be suggested after S&ID had been awarded the contract on the basis of performing the S-II design and development in the LA area; and besides, the Seal Beach facility construction had already started. NAA was determined to make the move and presented detailed plans as to how S-II could be (1) manufactured (maybe even designed) at Tulsa, and (2) barged by canal to the Mississippi Test Facility (MTF), thence to Cape Canaveral. S&ID also claimed that waterway dredging had already started and would be available for transporting the S-II by barge to the new Mississippi test site.

NASA compromised by agreeing to manufacture mostly “dumb” structural items at Tulsa, like the engine thrust structure and forward and aft skirt inter-stages. These structures were not considered critical, as were the huge pressurized tanks that would hold cryogenics. Dr. Lange was adamant that all engineering and stage assembly must remain at Downey and Seal Beach as originally proposed. NAA’s idea to get S-II out of LA surfaced again when it was suggested that Eglin Air Force Base, FL, be a possible site for S-II assembly - because it would be closer to the Mississippi Test Facility and Cape Canaveral. The only advantage for a Florida site was less transportation time. NAA’s efforts to get S-II out of the LA area was clearly intended to preclude S-II from competing for the west coast engineering labor pool. The move would have benefited Apollo, but it would have crippled the S-II project and jeopardized the presidential commitment to go to the moon in that decade. The Florida plan didn’t fly, either; however, in time, I came to believe that it was fortunate that the structural items were outsourced to Tulsa because the Downey workload was way overcommitted.

Dual Plane Separation

S&ID originally planned to separate the S-II from the S-IC in flight at a single plane using linear shape charges (LSC), followed by firing ullage rocket motors. Ullage motors were intended to settle propellants during staging and move the S-II away from the S-IC, followed by the J-2 engines firing up. The original scheme was considered risky because of potential side load forces induced by S-IC engine tail-off and retrorocket firings. Potential interference between the J-2 engines emerging from the SII inter-stage was the concern.

Aerodynamic engineers studied the problem and concluded that a two-plane separation would better assure a more safe separation. The revised plan was to: 1) separate the S-II inter-stage at a plane close to the S-IC forward skirt while retro rockets were firing; 2) ignite S-II ullage rockets while the aft skirt was still attached to the stage; 3) start the J-2 engines; and 4) about 25 seconds later, separate the remaining S-II aft skirt from the stage at a plane close to the thrust structure. This “two-plane” approach allowed a fully powered stage to pull away from the cylindrical inter-stage structure as engine jet-flow accelerated separation. It was a good idea. Authorization to implement Dual Plane Separation was given in September ’62, followed by successful separation impingement tests in February ’63. A movie of the first live S-II dual-plane separation (AS-501, Nov ’67) was taken by CCTV cameras located on the S-II aft skirt, looking aft. It worked smoothly.



Explosive Separation Devices

Explosive Linear Shape Charges (LSC) were used to separate stages while in flight. The design effectively blew a “linear hole” through tension straps, going all the way around the inter-stage’s circumference as if instantly sliced by a knife. The force of the explosion was localized to the straps and directed outside the inter-stage structure. It was a clever way to instantly cut through structure to effect separation.

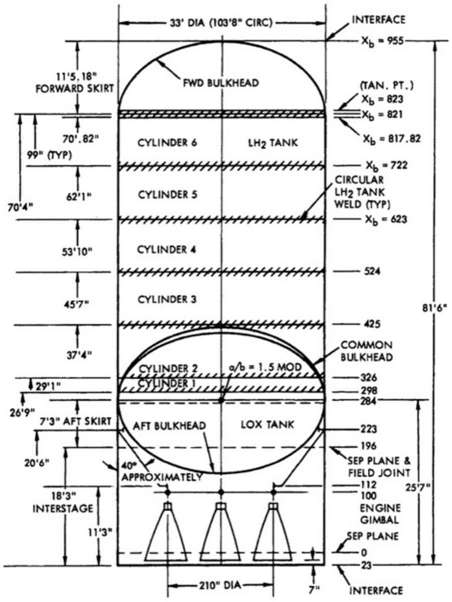
Confined Detonating Fuse

Confined Detonating Fuse (CDF) was used to explosively propagate detonation between an ignition source and remotely located items such as ullage rockets that had to be fired simultaneously. It was a “contained” explosion using PETN as the explosive material - the same as used in Primacord. CDF looked like braided rope. The PETN at the core was contained within a lead sheath, surrounded by a plastic jacket, and covered by fiberglass wrapping. Because of the relatively small amount of explosive material per inch and the many protective layers surrounding it, the force of the explosion was contained within the protective coverings. Both ends were capped with detonators. An Exploding Bridgewire (EBW) detonator initiated the firing of the CDF that fired the ullage rockets. A manifold was used to couple EBW detonators to multiple CDF legs required for igniting four ullage rocket motors instantaneously. The design worked so well that S&ID was authorized to provide CDF to other stage contractors.

Exploding Bridge Wire (EBW)

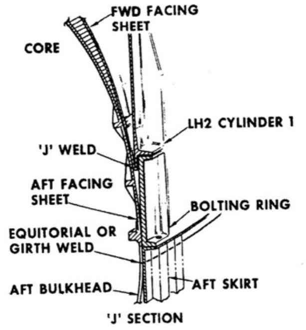
Exploding Bridge Wire (EBW) firing units were used to avoid inadvertent ordinance ignition caused by possible "stray voltage" sources. The EBW detonator was an electrically actuated device used to ignite LSC and CDF assemblies. They could function only when energized by a 2,300-volt electrical potential. It was an in-house MSFC design and all Saturn contractors were directed to use it. Standard on-board electrical power of 28 volts DC loaded capacitors in the EBW units to be ready for discharge to detonators when given the signal to "fire" LSC or CDF. The Apollo Program used "low voltage" detonators that fired at 120 volts.

Cryogenic Tank Configuration



The S-II Stage structure was 33-feet in diameter and 81.6-feet long. It had three ellipsoidal-shaped bulkheads, six Liquid Hydrogen (LH2) cylinder rings, a thrust structure that mounted five J-2 engines, and inter-stage structures, fore and aft, that interfaced to adjoining stages.

Each bulkhead was made up of twelve pie-shaped ellipsoidal aluminum gores with a close-out disk at the apex - all welded together to form an ellipsoidal half-shell 33 feet in diameter and 6 1/2 feet high. Four bulkhead shells were required to make a complete S-II propellant tank assembly. The "common bulkhead" that separated the Liquid Oxygen (LOX) and LH2 propellants was an assembly of two shells bonded to a phenolic honeycomb core. Although the two shells had the same ellipsoidal shape and diameter, each had different thicknesses and details to accommodate the launch loads imparted by the first stage's five engines generating seven and a half million pounds of thrust.



The LOX tank bulkheads were joined at its equator to the aft inter-stage skirt, and to the first LH2 tank cylinder as illustrated in the adjacent sketch. The forward bulkhead, at the top of the stage, was separated from the common bulkhead by six cylinder rings, stacked and welded to form the larger LH2 tank volume.

Bulkhead Manufacture

S&ID ‘s original proposal was to have another NAA division, Rocketdyne (producer of Saturn’s F-1 and J-2 engines), develop an explosive forming method to shape the ellipsoidal gore segments needed for the 33-foot diameter propellant tank bulkheads. Rocketdyne was slow in coming up with a process, so the job was given to NAA’s Long Beach Division where experienced aircraft metal workers quickly came up with a solution. Using T-1 steel, four inches thick (used for submarine hulls), they made dies needed to explosively form the large ellipsoidal-shaped gores required for bulkhead manufacture. Explosive forming was done at the El Toro Marine Base near Irvine, CA, which was the closest place in the LA area where high explosives could be used.

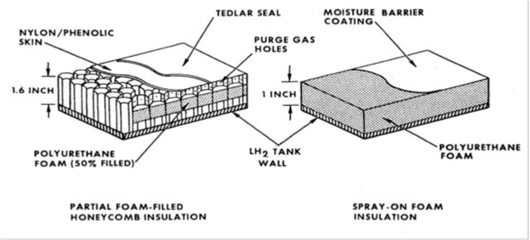
Each bulkhead shell was made of twelve pie-shaped gore segments about 16-feet long. Most gores were explosively formed to achieve the required ellipsoidal contour; however, the LH2 side of the common bulkhead had gores thin enough to be stretchformed. Gores were welded together and closed out at the apex with a small plate. The aft LOX tank gores were the heaviest and were made in two sections. The outer, heavy “knuckle” area, had deep machined “waffle” pockets and was explosively formed separately from the thinner gore sections.

Many problems were encountered in the manufacture and assembly of the propellant tanks. Difficulties were exacerbated by the need to have the thinnest possible skin sections and still have sufficient strength to withstand launch loads. Chemical-milling methods removed a considerable amount of material to reduce weight, but the edges of the parts had to be kept at a uniform thickness to assure adequate strength in the heat-affected weld zones. Inspection methods included x-ray, dye-penetrant, and Magnaflux – all used to detect cracks, and to verify weld quality.

Development of tooling and welding techniques for forming, machining and assembly of the huge elliptical bulkheads was a continuing challenge. As soon as one method was tried and failed, another was devised. It was an empirical process that took time. To successful accomplish making long welds over curved surfaces, it required special equipment to do just about every operation – trimming, welding and x-ray inspection - all done in one pass.

LH2 Tank Insulation

Cryogenic hydrogen, at -423° F., required that the outside surfaces of the LH2 tank be insulated to reduce boil-off during filling and long countdown holds. One reason for using external, instead of an internal insulation design (that was used on the S-IVB), was to take advantage of the greater strength of 2014-T6 aluminum alloy at cryogenic temperatures.



The S-II used two insulation designs. The early stages had honeycomb panels bonded to external tank surfaces. The panels were purged with helium gas, intended to preclude atmospheric moisture from condensing and freezing on the outside metal tank surfaces. The second, and much improved design, used sprayed-on foam that adhered better and provided significantly improved resistance to heat transfer. It was used on most flights after Apollo 11.

Helium gas was used on early S-II stages to purge atmospheric air from the honeycomb cells, intended to prevent condensation and the formation of "liquid air," or ice, on the outside of the super-cooled tank skin surfaces. Purging of the panels was done prior to, and during LH2 tank filling operations, and continued until launch or de-tanking. The design had 1 ½ – inch thick phenolic honeycomb panels bonded to the outer surface of the LH2 tank cylinder walls and to the upper LH2 bulkhead. As helium was injected into the honeycomb core, a partial vacuum was applied at intermediate levels to retrieve it for reuse rather than allow it to escape to the atmosphere. The honeycomb was covered with a bonded nylon/phenolic sheet, and sealed with Tedlar film to prevent moisture absorption. The honeycomb core was perforated and had grooves cut on the face adjacent to the tank skin to allow the helium gas to flow upward within the area between the tank skin and the outer Tedlar cover. The original panel design was modified to fill the honeycomb cavities with open-cell polyurethane foam, and continued with the helium purge. It was a slight improvement and was used on early S-II flight stages; however, the panels continued to randomly de-bond when LH2 was loaded. To make repairs, sprayed-on polyurethane isocyanide foam was applied directly to tank skin areas where panels had de-bonded or had to be removed. The foam was the same chemical substance available in hardware stores, called "Great Stuff."

Covering all tank surfaces with sprayed-on foam was a simple and effective process. The foam material was sprayed directly on the entire LH2 tank exterior and forward bulkhead after welds were completed and the tanks pressure tested and inspected. After curing, excess foam was shaved-off to achieve a uniform, one-inch thickness. It bonded to the aluminum skin much better than the honeycomb panels.

Essentially, the foam was a matrix of small "closed cells." The expanding, inert gas that formed each cell during the spray and cure process remained sealed inside each cell. When exposed to cryogenic temperatures, gas inside each cell condensed, forming a partial vacuum. Heat transfer was inhibited, thermal conduction minimized, and convection was virtually non-existent. Foam worked far better than anything else tried, short of a Dewar-type vacuum jacket. A decade or so later, the foam was used successfully on the Shuttle's External Tank, and is used in many commercial cold-fluid container applications.

Reflections on Year in California

Looking back on my year at Downey (September '62 – July '63), S&ID made significant progress, and board design was well under way. The contractor worked well with MSFC's aerodynamic engineers to quickly reach agreement on the dual-plane separation approach. S&ID produced some full-scale mock-ups. A&E architects completed design of Seal Beach facilities, and two critically needed buildings were ready for beneficial occupancy. The Los Angeles Division developed the steel dies for explosive forming bulkhead gores, and facilities were started at the El Toro Marine Base. Rocketdyne's modification of the Santa Susana Coco-1 test stand (CA) for S-II Battleship testing was nearing completion, and facilities construction for the Electro-Mechanical Mock-up (EMM) at Downey had started.

By being on-site I met many company engineers, designers and managers. Also, I found that Don Bowden, our Resident Manager, was firmly established and staffing the office to do the vital job of evaluating the contractor's progress, and making on-the-spot decisions when needed. He had a knack for sniffing out problems that the contractor was reluctant to admit. His appointment was a good fit. Some problems that we found were obvious and foreshadowed future scheduling snafus.

I moved my family back to Huntsville in June '63. The cat and dog flew as we drove home in a new Chevy station wagon – quite a contrast compared to our westward journey in a VW Beetle. Friends from Huntsville ended their vacation in California and came back with us through Yosemite. When leaving that spectacular park, I found the drive down Tioga Pass (under construction at the time) to be scarier than when one unexpectedly meets a sea lion in the murky surf off of California! After getting our household settled, it was back to work for me, and school for our kids.

The Saturn Systems Office at MSFC had increased in floor area and number of personnel, but everything else was the same, except that I was facing the contractor from a different vantage point.

MSFC Reorganization

Marshall Space Flight Center reorganized in September '63, forming two major elements: Industrial Operations (IO) and Research and Development Operations (R&DO). A few staff offices reported directly to the Center Director. R&DO was still home to the R & D laboratories that continued to be led by German-born directors. Lab functions remained basically the same as they were previously. New staff groups, whose functions previously had been performed within the labs, were placed under the R&DO Director, including Advanced Systems (Future Projects), Technical Systems (System Engineering), and Operations Management.

A completely new Industrial Operations (IO) organization paralleled R&DO and was similar to that which existed previously in ABMA. Staff groups like Contracts, Facilities, Logistics and Resource Management reported directly to the new IO Director, Air Force Colonel (later Brigadier General), Ed O'Connor. The Saturn Systems Office was abolished, but its functions continued in three new Program Offices, all reporting to the IO director: Saturn I/IB, led by Lee James; Saturn V, led by Arthur Rudolph; and Engine Programs, led by Lee Belew. Arthur Rudolph became my new boss. He had recently transferred from ABMA where he was Project Director of the Redstone and Pershing missile systems.

Bill Sneed called a meeting with all stage and engine project managers to brief us about the reorganization and our new Saturn V boss, Arthur Rudolph. Bill told us to not be concerned about rumors of Rudolph’s role while manufacturing the German V-2 rocket during World War II. Rudolph had come to America with the von Braun group and moved to Huntsville in 1950. There had been continuing talk that he had been a member of the Nazi party and in charge of an underground V-2 rocket production facility using slave labor. Sneed said that Rudolph had been “cleared” by the Defense Department after being thoroughly investigated. I think most of us accepted his explanation.

In December ‘63, Erich Neubert was assigned as S-II Project Manager and I became his deputy. Erich previously had reported directly to Dr. von Braun and Eberhard Rees in the Center Director’s Office. It was jokingly said that I should be flattered that it took the numberthree man at the Center to take over my job. Eric and I got along fine as he “gently” supervised, and let me run the day-to-day operations. He was one of the original Germans to come over with von Braun, and was well liked by all who knew and worked with him.

I was in Rudolph’s Saturn V organization from September ‘63 until June ’65 when I left to go to M.I.T. After returning in July ‘66, I served on his staff six-months before reassignment to the new Apollo Applications (Skylab) Program. The entire time I worked for Rudolph I found him fair and considered him technically knowledgeable and a decent person. He went out of his way several times to let me argue different approaches to resolve technical and program problems. The only thing I didn’t like were his long, interminable meetings when he insisted that everyone was expected to be present, sitting obediently, as problems were discussed and dissected ad nauseam. There were many nights that I missed dinner at home, and some when I didn’t get there until after midnight. To me, and for most of my associates, those meetings could have ended with a decision made much earlier. However, I liked him personally, considered him a friend, and regret that the federal government treated him so shabbily after he retired.

Contractor Oversight

Quarterly Reviews every three to four-months enabled MSFC’s engineering management to be appraised of contractor progress and ask penetrating questions. Dr. von Braun was in attendance often. The reviews were sell-outs with every seat taken. It seemed as if S-II quarterlies were charged with electricity and too much coffee.

Informal “Working Groups” included contractor personnel who met with MSFC civil servant counterparts and other contractors to coordinate interfaces and resolve common problems. The groups were relatively small, coming from the various technical disciplines: structures, aerodynamics, mechanical, electrical, instrumentation, manufacturing, test, and flight evaluation.

Over-sight of contractor activities was viewed by MSFC as a benefit to the program, and by the contractor as a bothersome hindrance to getting the job done. Robert E. Greer, NAA’s (second) S- II Program Manager, was quoted as saying, “Marshall's ubiquitous engineers and direction from Huntsville reached the point where North American Aviation's attempts to catch up were snarled by NASA's red tape.” In contrast, Eberhard Rees, MSFC’s Deputy Director said, “Loose reins on the contractor had not always worked out well from the MSFC point of view. It became clear as the development progressed, that close and continuous surveillance of contractor operation was required on an almost day-to-day basis." NASA paid the bill, so NASA got its way!

Government/Contractor Relationships

The S-IC [first stage] and Instrument Unit (IU) designs were started in-house at MSFC before contracts were awarded to Boeing and IBM. After the awards, civil service and contractor personnel worked side-by-side doing design and manufacture in Huntsville. In some cases, the contractors were treated as “in-house” support contractors during the early years. That was the way ABMA dealt with Chrysler during the Redstone and Jupiter missile developments, and MSFC continued the practice during the early phases of the Saturn I/IB and Saturn V programs. It was a cultural theme that was ingrained in the Center’s way of doing business. In contrast, the Los Angeles-based contractors, Douglas and NAA’s Space and Information Systems Division, were not under the close surveillance of the MSFC’s laboratories, and could work relatively independently.

Douglas Aircraft Company (DAC) was effectively given free-reign to do the S-IV stage design beginning in ‘59. Dr. von Braun made it clear that the labs should not dictate design details. In fact, he specifically told them to accept DAC’s use of 2014 T6 aluminum alloy that was successfully used on the Thor missile. Because of the S-IV’s early start, DAC gained valuable experience, compared to S&ID, regarding hydrogen technology experience. Further, it earned Marshall’s respect during the early S-IV design and development period and was given the S-IV-B on a sole source basis. S&ID was initially treated much like DAC had been and allowed to pursue the S-II design and development with relatively minimum over-sight, partly because the laboratories had their primary attention on the S-IC and IU developments. However, when S&ID began missing scheduled milestones that threatening the nation’s objective of going to the moon, NASA applied considerable pressure to improve performance.

Activities in 1964

S&ID conducted successful flame impingement tests of S-IC/S-II separation to verify the two-plane separation approach. In July ’64, the “Battleship test stand” (Coco 1) was completed at the Rocketdyne Santa Susana, CA facility, and single engine testing had started. Also, hydrostatic testing of a common bulkhead test tank was successfully conducted at Santa Susana. The Coco-4 flight stage test stand build-up was competed in July, but was not activated as a result of redirection to ship the All Systems Test vehicle (SII- T) and all follow-on flight stages to the Mississippi Test Facility (MTF) instead of to Santa Susana. The Electro-Mechanical Mockup (EMM) was completed in August ‘64 and used to test J-2 engine gimballing; however, it was subsequently terminated to reduce costs.

An S-II behind-schedule problem became worse when S&ID was directed to redesign to accommodate Apollo Lunar Lander payload weight increases. S-II took the brunt of the weight reduction task resulting in an unusually high “mass fraction,” which is a measure of design efficiency expressed as the ratio of total stage fueled weight to burnout weight. If the S-IV-B had been tapped for the Saturn weight reduction task, one pound of weight reduction would have provided one pound of payload increase; whereas, it took over five pounds of SII weight reduction to achieve one pound of payload weight increase. The sticky part of shaving S-II weight, with its [already] efficient structural design, was that the margin of safety for ultimate loads would come perilously close to the maximum strength capability of the structure. In other words, as more weight was shaved off the stage, the ultimate load margin of safety became less and less, approaching zero.

Cost Constraints

It is noted that "cost plus fixed fee" (CPFF) contracts provide whatever funds are necessary (within fiscal limits) to get the job done, but only permitted additional fees for "new work" authorized by contract changes. Because of the broad, inclusive language included in the Model Specification, some changes that S&ID attempted to "sell" were rejected because they were considered to be "within the scope" of the contract statement of work. In effect, the S-II Project Office said, "S&ID, you contracted to design and develop the S-II to meet the technical requirements stated in the Model Specification; and, this [new] proposed change clearly appears to be within the requirements – so, do the work [in-scope], as necessary."

The S-II project office continued to apply this rule until May '65, which was when Arthur Rudolph opened the money floodgates. Until then, the S-II "negotiated contract value" had risen only 15% over the initial $320M; however, actual costs incurred greatly exceeded the contract value. Clearly, S&ID's rising expenditures indicated that a sizable "overrun" existed and would probably get worse. In comparison, Boeing's S-I-C contract value, including negotiated fee, had skyrocketed during the same period, resulting from many "directed" changes.

Search for Solutions

NASA Headquarters became increasingly anxious about Saturn/Apollo's rising costs and schedule slippages being experienced by contractors. As a result, the Centers were asked to critically assess overall program status relative to meeting President Kennedy's commitment to go to the moon in that decade. I participated in the first month-long (Aug – Sept '64) "Apollo Program Assessment" - much of it done at S&ID in Downey.

As concerns about cost, and schedules continued to escalate, each project was asked to "beat the bushes" to find ways that might help. With an eye toward achieving schedule objectives, I suggested to Arthur Rudolph that the entire dynamic test program be deleted, or significantly modified, in order to reduce the number of S-II (and other stage) hardware items currently in the pipeline. The thought had been reinforced by discussions with knowledgeable persons about the objectives and practicality of doing a full-size dynamic test, which was intended to determine bending frequency and locate nodes. I had been told by some associates that the necessary data could be derived analytically with ample accuracy instead of physically stacking hardware over three hundred feet high and applying lateral force "nudges." During the actual test, suspension cables (massive in themselves to support the loaded vehicle) added spurious vibrations that had to be dampened using kluge rigs of 2x4's and ropes, all of which degraded measured data. The idea was not accepted, but precipitated considerable discussion at midnight sessions in Rudolph's Saturn V Control Room.

Another potential candidate for cost reduction was deletion of vibration test hardware that had been added to each Saturn contractor's scope of work to satisfy a perceived need to acoustically "blast" shortened structural elements in order to determine the environmental effect on components during launch. It was obvious to me, at least, that the environment induced during S-I-C static firings could provide more than sufficient test data to verify launch pad and lift-off environments to which flight components would be exposed. Besides, most component qualification test criteria were overly conservative by intent. I argued to eliminate this expensive acoustic test program to reduce cost, but it became evident that the labs had irreversible plans to expand their facility capabilities. Arthur Rudolph supported me in discussions to eliminate test hardware items up to a point; but, he felt the heat from lab directors to not eliminate any MSFC in-house test programs. Years later, one of the structural test guys laughingly told me, "We sure blew a lot of money on those test programs," effectively saying that, indeed, the Saturn "lily" had been gilded to an extreme.

Activities in 1965

During the winter of '64-'65, a NASA review team invaded S&ID at Downey and Seal Beach at the behest of MG Samuel C. Phillips, the Apollo Program Director at NASA Headquarters. I was on the S-II team and observed General Phillips run the review in his calm, reserved manner. Small disciplinary groups of every stripe systematically reviewed each contractor's status. Many Working Group and "Tiger Team" reviews followed that first Phillips visit during the following months, and well beyond. Information and conclusions from the first major review were summarized in presentation material, which I helped prepare for the Space Technology Panel of the President's Scientific Advisory Committee (PSAC).

On January 26, 1965, a contracting officer's TWX was sent to W. F. Parker, S&ID's Program Manager, directing NAA to implement the followed changes:

> Delete S-II-D; and use S-II-S for dynamic tests.
> Terminate EMM in Oct 65 & refurbish GSE for use at MTF, Stand A-1
> Deliver S-II-T to MTF instead of Santa Susanna
> Deliver Coco 4 Ground Support Equipment (GSE} to MTF for the A-2 Stand
> Deliver S-II-F directly to Kennedy Space Center (KSC), instead of MTF
> Delete 2 sets GSE

The directive was major program surgery. It deleted the S-II-D Dynamic Test stage, but did not eliminate planned Saturn V dynamic testing at Marshall, as I had proposed to Arthur Rudolph earlier. Termination of the Electro-Mechanical Mock-up was Arthur's idea (not mine), and deletion of two GSE sets was an added cost reduction.

This direction was intended to cut costs and improve the ability to meet schedules. It was also intended to get the contractor's attention that NASA was deadly serious about holding schedules. In addition, George Mueller's gutsy decision to launch the first Saturn V (SA-501, Apollo 4) with all stages "live" showed the whole Saturn/Apollo community that the cards were on the table. However, subsequent unexpected events altered this monumental program change when the Structural Test Article (S-II-S) was destroyed at Seal Beach in September '65, and the All-Systems Stage (S-II-T) exploded at MTF in May '66.

Eric Neubert left the S-II project office in January '65 to return to von Braun's office, and I was named Acting Project Manager for a brief period until Air Force Col. Sam Yarkin arrived and was assigned as S-II Project Manager. I continued as deputy manager until June, when I left to go to M.I.T. for a year of study. After a coffee and cake party in Rudolph's Saturn V Control Room, I moved my family to Wellesley Hills, MA, to occupy a house that another Sloan Fellow had lived during the preceding year. It was back to books for me.

Sloan Fellowship

The yearlong Alfred P. Sloan Fellowship program has been facetiously referred to as a finishing school for managers. There were 45 Sloan Fellows (Sloans) in my class. The course syllabus concentrated on three themes; economics, finance and behavioral science, and their application to the field of "management science". Behavioral science was a favorite, and economics was a close second. Sloans were expected to share their work experiences as part of the educational process, so I had opportunities to reflect on my own, as well as learn from fellow Sloans. We were required to bring our families, which became an educational experience for wives and kids, although in different situations. The first two weeks were committed to "sensitivity training" with full days of "T- Group" discussions when 15 individuals, plus a "trainer," discussed whatever the group wished to talk about. The purpose was to desensitize us from the "work world" in preparation to learn in the "academic world". T-Groups had their origin at the National Training Lab (NTL) at Bethel, Maine, which was a behavioral science laboratory where M.I.T. researchers explored human behavior in the context of organizations and interpersonal relationships as applied to management methods and theory.

It was a tradition that each Sloan give a memento of their prior work to others in the class. Being strapped for funds I needed something that wouldn't cost too much, but would represent my association with NASA. I asked if Dr. von Braun could autograph photos of a Saturn launch touse as my gift. Bonnie Homes, VB's secretary, had him sign 50 copies, which I gave to very appreciative classmates and the Dean's staff. The photo, signed by von Braun, is of SA- 8 (Mission AS-104) that flew a boilerplate Apollo Command Module on May 25, 1965.

Early in the school year, I wrote a paper for a class led by Bob Kahn, a Michigan University professor, who was on sabbatical leave to M.I.T. His book, Organizational Stress: Studies in Role Conflict and Ambiguity, was the subject being discussed. The book hit home for me. It read like a job description for a Marshall project manager and led to my choosing a thesis subject from which real-life data could be quantitatively examined, and draw conclusions concerning project management; thus, the title, Problem Solving in Government Project Management.

To obtain data needed to define and analyze how project problems are solved, I went to the source – the Marshall Space Flight Center – and interviewed fellow project managers and their associates. For purposes of structuring the study, "Associate Groups" were defined as those with which a project manager dealt to accomplish his job, including individuals in the R&D labs, other Saturn V projects, supervisors, staff groups, resident managers, subordinates, and contractors. Project managers identified real problems, which they, and their associates had experienced. Questionnaire and interview techniques were used to collect quantifiable data from seven interdependent launch vehicle and engine project groups. Variables relating to problem solution techniques were correlated with solution outcomes and methods of resolution parameters. The data were collected during 171 interviews with project managers and their associates, covering 56 different problem situations.

The thesis was a case study that found technical problems generally result in more satisfactory outcomes than program problems (cost and schedule); that satisfactory solutions result from use of mutual agreement resolution techniques; and that projects with fewer in-house government personnel working on them have more satisfactory problem solution results than projects employing a higher number of government employees. The latter finding appears to be contrary to claims frequently expressed by proponents of the "government arsenal system."

Sloans were given an opportunity to nominate an executive from business, industry or government to participate with small groups during evening seminars. Harrison Storms, President of S&ID, was invited at my request, but a couple of weeks before the scheduled seminar (January '66), the school received notice that he would not be able to attend because of a heart attack.

Near the end of the school year the entire class went on a field trip to Europe to visit industrial and government organizations located in London, Paris, Bonn, Frankfort, Milan and Zurich. The trip was partially financed by a $1,000 award that came with the Alfred P. Sloan Fellowship.

After returning to Boston from Europe, the class attended graduation ceremonies when each Sloan was awarded the degree of Master of Science in Industrial Management.

Back in Huntsville

After my family and I returned to Huntsville in July '66, I was assigned to Arthur Rudolph's Saturn V Program staff for six months before reassignment to the new Apollo Applications (Skylab) Program. I quickly got caught up on details about what had happened while away. The S-II project had suffered two separate test failures resulting in destruction of the Structural Test

Article and All-Systems Test Stage. I also learned that NASA Headquarters' Apollo Program Director, Major General Samuel C. Phillips, had authored a stinging letter to Harrison Storms' corporate boss, Lee Atwood, citing management failures and unacceptable technical performance at S&ID. George E. Mueller, Associate Administrator for Manned Space Flight, also sent his message to Atwood, admonishing NAA for poor performance. Both letters were blistering dispatches. As a result, NAA assigned Air Force MG (Retired) Robert Greer to take over as S-II Program Manager, while Bill Parker, who began as S-II Program Manager, stayed on as Deputy Manager.

S-II Test Failures

The Structural Test Stage (S-II-S) ruptured and was destroyed at Seal Beach during ultimate load testing in September '65. The failure occurred on the aft skirt at 144% of limit load while simulating end of S-IC boost, thus demonstrating the optimum design and verifying the structural integrity of the stage. In spite of the loss of full-scale stage hardware, which had been intended for dynamic testing at MSFC, the test was considered fully successful. Because the design requirement for ultimate load was 1.4 times limit load, the failure at 144% equated to excellent structural design, and demonstrated that the S-II was an extremely lightweight stage that met the structural design requirement.

The All Systems Test Vehicle (S-II-T), was destroyed on the A-2 test stand at MTF on May 28, '66. An explosion ruptured the empty LH2 tank during ambient (no cryogenics) testing due to over-pressurization. A second shift crew attempted to pressurize the tank, not knowing that a previous crew had disconnected the tank's pressure sensors and switches. The S-II-T had been at MTF since Oct '65 and had undergone eight hot firings, including one successful full-duration firing about a week before the explosion.

S-II Flight Anomalies

S-II engine-out conditions occurred on flights SA-502 Apollo 6 (S-II-2) and SA-508 Apollo 13 (S-II-8). Because of having five-engines (redundant capability), if an engine were to shut down, the Instrument Unit (IU) "adaptive guidance system" could compensate for the lower thrust level and steer the launch vehicle in a revised trajectory and still deliver the payload to orbit. However, the time it took, and the path to get to an orbital injection point, took much longer due to lower thrust levels.

First Engine-Out Event (SA-502, Unmanned Apollo 6)

On April 4, 1968, shortly after the second stage powered flight had begun on SA-502 (Apollo 6), two of its five J-2 engines stopped. Engine #2 cutoff occurred about 6 minutes, 53 seconds, into the second stage's powered flight. Engine #3 cutoff followed less than 3 seconds later. The remaining three engines continued firing and shut down 9 minutes, 36 seconds, longer than planned. As a result, the second stage did not reach its planned altitude and velocity before propellants gave out and the expended stage dropped away. To reach the required orbital ejection velocity, the S-IVB third stage also burned longer than planned, and put the spacecraft into an orbit of 178 by 363 kilometers, instead of the intended 160-kilometer circular orbit.

The problem was that the LH2 line feeding the igniter on Engine #2 broke due to vibration. As a result, the igniter fed pure liquid oxygen into the pressure chamber. Normally J-2 engines burn a hydrogen-rich mixture to keep the chamber temperature lower. The excess liquid oxygen flow caused a much higher temperature locally and eventually the pressure chamber failed. The sudden drop in pressure was detected causing a shutdown command to be issued by the IU. Unfortunately, the shutdown command signal for Engine #2 was cross-wired to Engine #3. When Engine #3 shut down, its pressure sensor sent a shutdown signal back to Engine #2. Dual failures occurred – one component failure, and one assembly/quality control failure.

In addition to the S-II engine-out anomalies, the third stage (S-IV) “second burn” did not occur resulting in Apollo 6 mission objectives to only be partially met. However, the unmanned Command Module was successfully retrieved in the Pacific Ocean after a 10-hour flight. NASA learned valuable lessons from these failures in order to make future manned missions safer.

Second Engine-Out Event – SA-508, Apollo 13

On April 11, 1970, the SA-508 (Apollo 13 manned mission) lift-off was normal, but during the S-IC boost phase, oscillations (called “POGO”) caused abrupt measurement changes. Then, during the second stage burn, the center engine of the S-II stage shut down 132-seconds short of the planned 650-second burn. This caused the remaining four engines to burn 34 seconds longer than planned, and the S-IVB third stage had to burn nine seconds longer to put Apollo 13 into orbit. It was lucky that the center engine shut down when it did because had it kept running a few seconds longer, it might have either torn itself off its mounts or fractured the thrust frame, either of which would probably have caused the disintegration of the stage. In effect, the vibration caused two tons of engine weight that was solidly bolted to a thrust frame to bounce up and down with an amplitude of three inches at 16Hz. What saved the flight was that average chamber pressure fell off enough to trip a low-pressure switch, and the IU flight computer shut the engine down on general principles.

"POGO" was an oscillation phenomena occurring within the propellant feed system, which caused variations in thrust when propellant oscillation frequencies resonated with supporting structure and propellant duct frequencies. The POGO problem was reduced, not eliminated, for subsequent flights by adding a surge suppressor (accumulator) in the LOX propellant feed line of the center engine. It acted as a shock absorber to damp fluid mass oscillations.

Fortunately, a potentially catastrophic failure of this manned mission was avoided by the fortuitous shut down of the S-II center engine. The engine-out event seemed minor at the time compared to the subsequent rupture of an Apollo Service Module oxygen tank while the Apollo 13 spacecraft was halfway to the moon. The explosion forced the crew to abort the mission and circle the moon without landing. It took heroic efforts by both the flight and ground crews to return the Command Module and astronauts safely to earth.

Separation Plane Failure – SA-513, Skylab-1

During the SA-513 (Skylab-1) launch on May 14, 1973 the S-II second separation plane failed, probably resulting from impact by Skylab's meteorite shield that had been ripped away, and loss of one solar array during S-IC powered flight at about 63 seconds after launch. The incident occurred 2 seconds after Saturn V passed its most critical aerodynamic flight phase, called Max Q.

Telemetry data revealed that the area forward of the J-2 engines, near the LOX bulkhead, was experiencing higher than normal temperatures. Post flight performance evaluation revealed that the inter-stage had not jettisoned; however, due to vehicle performance margin, the desired orbit was achieved.

Telemetry data also confirmed that only one of two Linear Shape Charge (LSC) detonators had fired, suggesting that meteoroid shield debris destroyed a portion of the LSC. An independent source observed that the inter-stage was, indeed, still attached throughout the full powered flight. It was estimated that approximately a third of the separation plane tension straps had not been severed. Considering the magnitude of meteorite shield debris that raked the sides of both the payload and the launch vehicle and the loss of one solar array, it is remarkable that the two-stage launch vehicle survived the entire launch phase and was able to deliver Skylab to orbit. Other than potential failure from overheating S-II engine components, the possibility of a partially separated inter-stage interfering with four gimbaled engines could have been an even more serious threat.

It is noted that when Skylab separated from the two-stage Saturn V, the expended S-II stage gradually moved away and burned up during re-entry on January 11, 1975, after 606 days in orbit.

Reflections

In retrospect, technical and program challenges became apparent almost every day throughout the development and manufacture of the S-II Stage. They became evident early in the program, and continued well after the first moon-landing mission, Apollo 11.

In spite of many difficulties, the S-II Stage supported an unprecedented 100% successful Saturn V launch record, starting with the “all-up” SA 501 vehicle (Apollo 4) on November 9, 1967, and ending with the SA 513 launch of Skylab 1 on May 14, 1973. Of particular significance, the SA 506 (Apollo 11) vehicle launched the first manned lunar landing mission on July 6, 1969, and the world watched as America’s astronauts walked on the moon’s surface.

Saturn/Apollo’s success was achieved as a result of events and conditions that happened at a time in history when most of the required technology was available, and the work force, in government and industry, had the capability to accomplish the task.

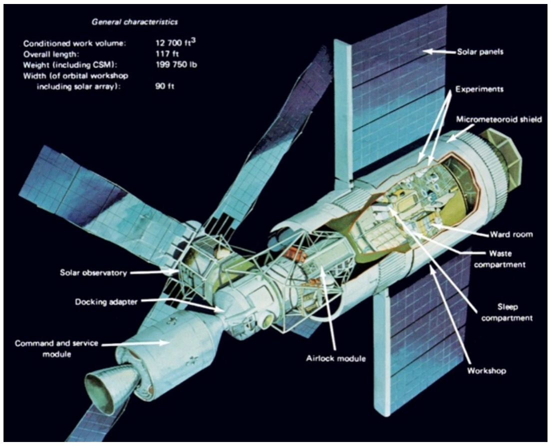
The Russian’s launch of Sputnik 1 into orbit was the event that prompted President Dwight D. Eisenhower to initiate the U.S. space venture. Eisenhower took the challenge, and Congress passed the Space Act of 1958 that established NASA.

German rocketeer, Wernher von Braun, had the idea to explore space long before most of us. Robert R. Gilruth, an aeronautical engineer from Langley, VA, had designed supersonic and rocket-driven aircraft, and was always looking to advance the manned flight knowledge base. In addition, industry and government agencies had gained considerable experience designing and producing rockets as weapons for the Defense of Department. The United States had the “critical mass” of technical capability, and President John F. Kennedy kicked off the Saturn/Apollo project by declaring the unambiguous goal of going to the moon.

Had it not been for President John F. Kennedy’s desire to do something challenging in the aftermath of Sputnik and the Bay of Pigs failure, America’s moon project might never have happened. Also, if it were not for James E. Webb’s unique ability to secure the necessary federal funds and lead a multifaceted enterprise, we would never have completed the project – at least not in that decade. Webb presided over the build-up of a new “government - industrial complex”, thus enabling engineers, technicians and managers to get the job done. Could something like it be done again? Possibly, but only if a confluence of key events and conditions were to occur.

SKYLAB

In early 1966 I transferred to the newly formed Apollo Applications Program (AAP) that eventually became known as the Skylab Program. That was three and a half years before Apollo 11 landed men on the moon. The purpose of AAP was to evaluate the use of existing Saturn/Apollo hardware for possible future orbital exploration operations. The initial concept was to have suited astronauts enter a spent S-IV-B tank after propellants were exhausted. That very early concept evolved to a fully outfitted space station to be built on the ground and launched into orbit where astronauts could live in a shirtsleeve environment and operate experiments. Lee Belew was the AAP Program Director at Marshall, and I was a project engineer in George Hardy's systems engineering group.



Skylab was an assembly of three modules. An S-IV-B propulsive launch vehicle was converted to the Orbital Workshop (OWS) where astronauts could live, and operate in a shirtsleeve environment. An Airlock/Multiple Docking Adapter (AL/MDA) provided the utilities needed to operate Skylab and served as a docking interface for astronauts to enter the orbiting space station. A solar observatory, called the Apollo Telescope Mount (ATM), was mounted external to the MDA. The Skylab configuration shown here illustrates the three modules, along with an Apollo Command Module docked to the MDA.

Skylab was America's first space station. It was launched unmanned by a two-stage Saturn V launch vehicle. It was followed into orbit by three separate astronaut crews in Apollo Command Modules, each launched by two-stage Saturn IB rockets to rendezvous with the orbiting Skylab. The 3-man astronaut crews spent a total of six cumulative months living in a weightless environment and performing experiments.

Airlock Module

The Airlock Module provided the utility services needed to operate Skylab. It was hard-mounted between the Orbital Workshop and the Multiple Docking Adapter. A 5-psi mixture of oxygen and nitrogen gas was used for breathing air inside the space station. A molecular sieve with charcoal filters scrubbed carbon dioxide and odors from the air. Star trackers and rate gyros were used to determine Skylab's orientation in space and helped maintain attitude control. High gain and low gain antenna transmitted telemetry and communications data to ground stations. The electrical system had storage batteries and a power distributor to manage the electricity generated by solar arrays that were mounted on both the OWS and ATM. A hatch permitted space-suited astronauts to exit the pressurized environment in order to replace ATM film cassettes and to do needed repairs.

Bud Drummond became the Airlock/MDA project manager when Skylab was approved for development in ’70. Previously he had been the J-2 Engine Project Manager on the Saturn Program.

Multiple Docking Adapter

The Multiple Docking Adapter (MDA) was a ten-foot diameter cylindrical structure that was bolted to the forward end of the Airlock. A docking port was located at the conical end to allow Apollo Command Modules to latch onto Skylab. The Apollo Telescope Mount (ATM) was located forward of the MDA during launch and rotated 90 degrees to the side for solar viewing operations controlled from a crew station inside the MDA. Marshall civil servants designed and built the MDA structure and Martin Marietta – Denver was the systems integrator. The MDA was mated to the Airlock at St. Louis and verified as the AL/MDA unit before shipment to KSC.

During the early AAP phase I was the MDA project engineer until Skylab was approved for go-ahead in ’70, which was when Bill Johnson took it over. He had come to Marshall from Wright Patterson Air Force Base.

Apollo Telescope Mount

The Apollo Telescope Mount (ATM) faced the sun during the entire Skylab mission to allow solar observations and record radiation intensity, solar flares, and surface activity using eight sun-viewing instruments. Scientists from academia were responsible for the telescope’s development, and Marshall engineers designed, built and assembled the hardware. The ATM was positioned at the side of the MDA for operational viewing of the sun’s surface activity. It had solar arrays that looked like cruciform paddles extending from the telescope’s body. Skylab was a natural candidate for “solar science” because one side of Skylab always faced toward the sun in what was called a “solar inertial attitude.”

Rein Ise was the ATM project manager. I first knew Rein at ABMA when he was a second lieutenant.

Orbital Workshop

After Apollo 11 landed men on the moon in ‘69, a number of Saturn engineers transferred to Skylab. Bill Simmons, was named Project Manager of the Orbital Workshop (OWS) and I was his deputy. Bill had been the Saturn Instrument Unit (IU) project manager. We were responsible for managing the McDonnell Douglas Co. (MDC) contract by directing the technical effort, authorizing changes, and assessing contractor performance. Bill and I got along well, but I seemed to get most of the travel assignments.

The design, development and assembly of the Orbital Workshop was contracted to McDonnell Douglas Corporation (MDC), located at Huntington Beach, CA. The job was to convert two (one flight and one backup article) propulsive Saturn S-IV-B stages to a "dry workshop" configuration. To effectively manage the contract, I had to travel back and forth frequently between Huntsville and Los Angeles. Weeklong trips, sometimes twice a month, were necessary. Spending time away from my family was unavoidable; however, I liked dealing with the engineers and technicians doing the work.

Habitability Design Features

Because astronauts were to be confined inside the Skylab space station for long periods, it was felt that a submarine's closed environment would be comparable to Skylab's. After all, what better example would there be than the confined quarters of an atomic submarine during routine ninety-day submerged operations? I visited a George Washington class submarine docked at Point Loma, CA along with several MDC engineers. We examined the sleeping, eating, and personal hygiene accommodations of a modern submarine.

NASA Headquarters asked Raymond Loewy to recommend human-to-hardware interface design features. The photo shows him talking with me in a mock-up area. He was a world famous industrial designer, credited with originating the hourglass shape of the Coca Cola bottle, as well as contributing to the '48 Studebaker's unique auto design. He recommended that Skylab's living quarters be made comfortable for the astronauts – in short, be habitable. Afterward, the term "habitability" became a key word in our vocabulary, and his recommendations were implemented in the eating, bathroom and sleeping areas, as well as overall color schemes.

Compartments for eating, sleeping and personal hygiene were located between an open grid floor and ceiling that permitted adequate flow of breathing air in all areas. A triangular-shaped table was located at the center of the "wardroom" where the crew ate, read, and relaxed. The room had storage cabinets, refrigerator, freezer and microwave oven - all of which helped make it seem like being back on earth. A large window at the center of an exterior tank wall permitted casual viewing of the earth as Skylab orbited.

The "waste management compartment," or bathroom, had special equipment to accommodate weightlessness when performing toilet functions. Kevlar sleeping bags were tied between floor and ceiling to keep from drifting, and an accordion-like folding shower helped to contain water droplets from escaping into the living and work areas.

Refrigeration requirements took advantage of the heat-sink capability of dark space. Because one side of the Skylab always faced the sun, a radiator located at the aft end of the OWS faced toward "cold space," providing an effective heat sink. Refrigeration coolant fluid circulated between the radiator and insulated containers inside the OWS, where food and bio-medical equipment was stored.

The open-grid floor and ceiling permitted air to flow evenly from one end of the OWS to the other, aided by fans and air ducts. These structures provided a visual reference to simulate one-G surroundings and give crewmembers a feeling for "up and down" in the weightless environment. Compartment floor and walls supported cabinets and experiment equipment. A small airlock in the floor allowed trash to be disposed into the evacuated [S-IV-B] liquid oxygen tank. Also, personal restraint devices and handholds were installed at specific locations to keep astronauts from drifting around in the weightless environment.

At Home in Huntsville

During the mid-to-late 60's, our two older children, Mike and Kathryn, were students at Huntsville High, while Scott was at Whitesburg Junior High. We lived in a Cape Cod style home on Haven Street.

Bettie and I were members at St. Thomas Episcopal Church. She kept the church's financial books and served on the Altar Guild. I helped at work parties, served on the vestry, and was elected warden the year before going to Cape Canaveral in September '72.

Both boys, Mike and Scott, scooped ice cream at Baskin Robbins and accumulated nice bank accounts before going to college. As a Co-Op student at Georgia Tech, Mike used some of his savings to buy a new VW. Kathryn took dancing classes and performed *en pointe* during local productions.

I spent the summer of '72 at Huntington Beach, CA, to supervise the OWS's factory checkout and to sign-off on its "delivery" to the government. After OWS was stowed aboard ship for transport to Cape Kennedy, Bettie, Kathryn and Scott joined me for a much-anticipated vacation (Mike was busy at Tech). We went to Disneyland, Pacific beaches, and visited friends. Upon returning to Huntsville, I was not surprised to learn that NASA expected me to support the OWS pre-launch checkout at the Cape. Since all three kids were in college, Bettie and I packed up and drove to Titusville.

Prelaunch Checkout

The OWS was delivered to NASA's Kennedy Space Center (KSC) before we arrived in Florida. It was "stacked" on top of a two-stage Saturn V launch vehicle in the Vertical Assembly Building (VAB), and the Airlock/MDA and ATM were added to the stack. Because the OWS took the place of an S-IV-B stage in the stack, Skylab's launch configuration almost looked like the Saturn-Apollo, but without an Apollo spacecraft on top.

The way KSC operated was to let everyone know that it was totally "in charge," but delegated the hands-on checkout operations to the contractors that built the hardware. The MDC launch-support team was the same that performed the factory checkout, and I represented the

Marshall Center. My job was to approve contractor test procedure changes and flight hardware modifications. Each day's work plan was reviewed early in the mornings in a room halfway up in the Vertical Assembly Building (VAB) at a level adjacent to the OWS. Test equipment and facility resources were verified ready for use each day. If a procedure during the prior day's operation was considered incomplete or had failed, it was listed as an open item and rescheduled.

MDC was responsible for conducting the checkout and for implementing solutions to issues that arose. Most issues were resolved quickly; however, if a problem could potentially impact a scheduled milestone, especially the launch date, the KSC engineer in-charge and I jointly decided on action to be taken. Also, if an issue were considered critical or remained on the incomplete list too long, it could be identified as an anomaly and we had to decide what to do. One issue turned out to be of little consequence, but it took several days and a lot of conversation to resolve. A helium gas leak "out-of-spec" condition had been detected on a pressure bottle temperature transducer. It couldn't be corrected without replacement, which would have resulted in repeating other tests. Because it was found near the end of checkout, it became a potential schedule issue that could have delayed the launch. After considerable discussion, the anomaly was accepted because the leak rate was low, and would not affect mission performance.

At Home in Florida

Bettie and I thoroughly enjoyed our eight-month "vacation at government expense" in Florida. St. Gabriel's Episcopal Church in Titusville was a comfortable away-from-home church, and we occasionally played bridge with the rector and his wife. The nautical-motif stain glass windows in that old, white frame building were unique and very appropriate for its setting near the sea. We rented a small villa at the Royal Oak Golf and Country Club in Titusville. It was finished with dark paneling, which gave it a rustic appearance inside and out. It had a small kitchen, living room, two bedrooms and screened porch.

A Red Lobster restaurant in Cocoa Beach was the first of many seafood places where we enjoyed evenings out. Weekend trips included Disney World and St. Augustine. We also visited my great aunt, Edith Cruikshank, at St. Petersburg. She and I had traded Scott family genealogical data for several years.

Being in Florida, I couldn't resist scuba diving and was fitted for a wet suit. Manatee Springs, near the Suwannee River, had a freshwater cave that was 125 feet down a narrow flue, and then traversed about 300 yards to another exit. It was my first experience to dive in a cave, and I wasn't anxious to explore any more after hearing stories about fatal caving accidents.

Mike and Leanne announced their engagement while we were in Florida. Leanne was working on a master's degree in microbiology at the University of Georgia, while Mike was nearing his last year at Georgia Tech and working at a Co-Op job. They were married the next year. Mike graduated with a BEE with Highest Honors in August '74, and then began his first engineering job at Texas Instruments in Austin.

Kathryn married before graduating from Stephens College. She was fitted for a wedding gown and arranged all the activities by herself. Since both kids had one more year of school, they settled in an apartment until graduation in June ’74. Kathryn majored in the classics and graduated cum laude.

Scott finished at Grissom High and was accepted by Birmingham Southern College. When he left home for college in September ’72, Bettie and I also left Huntsville at the same time, headed for Cape Kennedy. Four years later, he graduated *suma cum laude* and went on to medical school at UAB.

Apollo 17 was the last lunar mission and it was the only night launch of a Saturn/Apollo rocket. Kathryn and her husband were visiting us at Titusville and got to see the launch.

After seven months of checkout in the Vertical Assembly Building (VAB), Skylab rolled out to the launch pad in the usual vertical position. It stood on the pad a few weeks undergoing launch readiness tests, including loading propellants and pressurized gases, pyrotechnic installations and last-minute storage of frozen food. On the Saturday before launch, family members went out to the launch site to see the product of our efforts before it went into space. Bettie is the lady in the photo wearing the green jacket.

Skylab Goes Into Orbit

There was an air of cautious optimism on May 14, 1973 during countdown. Several officials from Huntsville had come to KSC, including Rocco Petrone, who recently became Marshall’s Center Director. Because he had been a launch director at KSC in a prior job, he knew his way around the Cape. As part of the engineering management team, my station during launch was in the O&C Conference Room, participating as an observer.

Skylab (SL-1) was launched on time, and we watched telemetry data on CRT screens. At 62 seconds into the flight a glitch was noted. Preliminary analysis indicated that the meteoroid shield had deployed prematurely. It was clearly an anomaly, but whatever else happened wasn’t known until after the automatic deployment sequencing was completed. An ominous silence pervaded the conference room for several minutes when it was confirmed that the ATM solar cell arrays were the only ones producing power. It was evident that the OWS arrays had not deployed. It didn’t take Rocco more than a few minutes to recognize a major disaster and ordered all Marshall personnel to immediately get back to Huntsville to work the problem.

Bettie and I had planned to leave Titusville the day after the launch, but with the urgency of the moment, we loaded our car and left immediately. I was shocked at the turn of events, and definitely apprehensive, but we made the trip safely and I was on the job immediately after returning home.

The situation with Skylab was constantly under evaluation as telemetry data was being analyzed. One OWS solar array and the whole meteorite shield were confirmed lost; however, the other array was still attached, but not deployed. With the shield gone, skin temperatures were 200 degrees F. above that which it was designed for resulting in an internal air (nitrogen at launch) temperature that reached 130 degrees F. To minimize heat absorption, gaseous nitrogen thrusters were used to orient the longitudinal axis about 45 degrees from the sun, thereby allowing sunlight to partially illuminate the deployed ATM solar arrays and reduce the sunlight's incidence on the OWS' skin. Spacecraft stability was maintained using on-board rate gyros and nitrogen gas thrusters; however, electrical power was limited because the ATM arrays were not fully facing the sun as they otherwise would have been in the "solar inertial" attitude for which Skylab was designed.

The world's spotlight was on Huntsville. It was our hardware, and our job to do whatever was necessary to fix it and hopefully salvage the mission. Loss of the meteoroid shield and solar array cascaded into a multitude of other problems that had to be addressed and resolved. Without the shield, overheating within the OWS led to concerns about degradation of polyurethane foam insulation and possible toxic gases. Ground tests showed that at 130 degrees F., the gases generated probably would not be a problem, but as a precaution, ground controllers repeatedly pressurized and depressurized the OWS to flush any toxic materials overboard. Hundreds of engineers and scientists worked around the clock studying telemetry data, evaluating thermal models and analyzing potential scenarios. Mock-ups were fabricated along with newly designed tools for the crew's use in-orbit to hopefully save the mission.

Ideas about how to salvage the space station were offered by organizations and individuals from all over the world. The first (SL-2) astronaut crew insisted that if they could get up to Skylab, they might be able to deploy the trapped solar array and determine what else could be done. The high temperatures inside would prohibit any long-time human habitation; consequently, a fix was needed to block sunrays from overheating the OWS. Within a couple of days, engineers and technicians built and tested various sunshade devices and tested potential solar array deployment techniques. The Skylab 2 crew practiced potential repair tasks in Marshall's neutral buoyancy facility using make-shift tools and equipment. Deployment of the remaining solar array still attached to OWS and installation of a makeshift solar radiation shield were the most critical on-orbit repairs needed to be done.

Eleven days after Skylab (SL-1) was launched, the Apollo Command Module's (SL-2) three-man crew docked to the MDA and entered Skylab to assess damage and attempt repairs. During a spacewalk, Astronauts Pete Conrad and Joe Kerwin were able to release the trapped solar array and get it fully opened and generating power. A make-shift parasol sun shield device was then deployed through a scientific experiment airlock. It partially replaced the lost meteorite shield's thermal blocking function. Because of this fix, the internal temperature was reduced somewhat, allowing the crew to stay aboard for the full 28-day mission even though it was still very warm. Don Bowden, an engineer from the OWS project office, helped build and test an improved sunshade (shown in the photo), which was deployed during the second (SL-3) manned mission. After installation, it reduced internal temperatures to an acceptable level.

Mission Operations Support

It was Marshall Spaceflight Center's job to deliver Skylab to the Cape. Then, Kennedy Space Center was responsible for pre-launch checkout and launch operations. When Skylab deployed into orbit, it was then Houston's Manned Spaceflight Center's responsibility to operate Skylab. The "division of responsibility" was simple – after the SL-2 launch, Houston controlled all communications with the on-orbit crew, up-linked all commands and software patches, received and distributed all telemetry data, etc. In short, Houston was in total control of the Skylab mission. Huntsville's participation was strictly in a support role to the Houston flight director's team. Our job was to provide engineering support from the Huntsville Operational Support Center (HOSC) located on the second floor of the Computation Lab. It had a large conference room surrounded by cubicles staffed with support groups. There were separate rooms for Spacecraft Stability and Control, Electrical Control, Structural & Mechanical, Thermal Control, and Crew Systems. CRT screens were in every room, displaying real-time telemetry data.

The HOSC was occupied 24/7 by four teams of engineers who had intimate knowledge of the hardware's design and operational capabilities. Each day, three support teams with about 20 engineers, stood 8-hour shifts around the clock. Each team manned the HOSC for eight consecutive days, and then were off two days. Every ten days the teams moved up to the next (later) shift. In that manner, four teams stood watches for the entire eight months that Marshall was in support of orbital operations. I was Operations Director on one of the teams. Most engineers at the HOSC generally knew each other before the operation started, but after eight months in close quarters we were well acquainted.

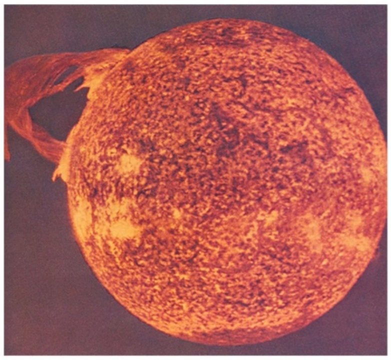
The first 28-day manned mission (SL-2) was physically and mentally stressful for several reasons: 1) Skylab had barely survived an almost complete disaster, 2) success or failure was uncertain until the first flight crew came back, 3) personal adrenaline was high, 4) we were exhausted from round-the-clock devising possible “fixes” and making contingency plans, and 5) almost everyone had never worked shifts that cycled every 10 days, which introduced further stress due to circadian rhythm disruption. Eight-hour shifts started and ended with key members from each discipline team meeting with the next shift in order to “hand-off” the watch.

Time-line schedules of each astronaut’s activities were issued daily, so we generally knew what the crew was doing in orbit; however, Houston flight controllers rarely talked to the HOSC unless there was a schedule change, equipment failure, or if they wanted clarification about equipment or an experiment operation. Our job was to monitor telemetry, watch for glitches in the data, and be ready to respond to flight director requests for information or action. Dialogue between the two Centers occurred mostly during daylight shift hours while the flight crew was awake and active. After nine o’clock in the evenings, tedium was the norm until a blast of music woke the astronauts at five in the morning.

Houston’s flight director rarely permitted HOSC to hear conversations with orbiting crews; however, we occasionally heard bits from TV newscasts that Houston released for PR purposes. One discussion with the crew that we were allowed to hear directly pertained to a student experiment involving live spiders. The experiment’s purpose was to determine if a spider could weave a web in weightlessness. The problem discussed pertained to an arachnid that refused to eat the bug food it was given. The spider spun its web, proving that it was oblivious to weightlessness, but then died.

During long midnight shifts we had plenty of time to review the many photos the crew had taken during the preceding mission. One shot showed the image of a strange satellite, so I reported it in my daily operations report. I looked for the photo during the next shift, but it was missing, so I surmised that someone had purloined it for a personal collection, or some security guy removed it for another reason.

Biomedical experiments were on board to determine the effects of prolonged exposure of weightlessness on the human body. Sixteen medical experiments were conducted. A rotating chair was used to evaluate inner ear (vestibular function) effects in zero-G, which were compared to test results previously taken on the ground of the same individual. Cardiovascular (blood circulation) tests were conducted using a lower-body negative pressure device and a stationary bicycle (ergometer) was used to determine the physiological effects due to exposure in zero-G during pulmonary and leg muscle conditioning. Stool and urine samples were routinely frozen and returned to earth for post-flight evaluation, and the crew’s vital signs were recorded and down-linked to medics on the ground. Although prior manned weightless studies showed loss of body fluids, bone calcium and muscle mass, the regimen of physical activities performed by Skylab crews appeared to ameliorate those effects. Post flight evaluations concluded that with proper exercise and nutrition, humans could operate in weightlessness for long periods without deleterious physical effects.



Earth resource studies used special cameras with different filters to photograph the earth's terrain by surveying croplands, watersheds, forest areas and oceans. One of the more productive scientific operations was the use of the Apollo Telescope Module (ATM). Astronauts spent many hours at an MDA station watching sun activity and pointing the telescope's instruments to areas of interest on the sun. Near the end of the last manned mission (SL-4), Astronaut Gibson filmed the birth of a solar flare, which was the first such recording in history. Solar observation results included photographs of eight solar flares, thereby producing valuable data that would have been impossible to obtain with unmanned spacecraft.

The most satisfying part of my time working on Skylab was during the design and development phase, but that was all over after the first manned mission (SL-2) was salvaged by releasing the fouled solar array. From then on, HOSC duty seemed routine and was generally a drudge; however, it was a privilege to have participated in the Skylab on-orbit operation, even if in a support role.

At Home

After the SL-3 mission (second flight crew), I looked forward to outside activities, particularly when night shifts allowed free time during daylight hours. It was a relief from the tedium of standing late night watches – just doing something else! A few of the guys on my shift had VW Beetles. Jerry Thomson's car was in need of an engine overhaul, so I helped him with it. After Jerry's was done, George Hopson's son's VW was next, which was totally inoperable at the time. Another off-duty activity was scuba diving with Scott. In retrospect, the months in HOSC turned out to be relaxing, but only after getting into the routine.

It may have been a mid-life crisis when I bought an MGB. Years of "tooling" around in VW's gave me the ersatz feeling of driving a sport car without the top-down experience. The MG satisfied a latent desire that had been festering in my psyche all along. Besides, it was fun to drive! Bettie and I took it to Austin and Maine, which were adventurous vacations to say the least.

Mission Complete

The third (SL-4), and last Skylab crew, ended a record 84-day manned mission when the Command Module came back to earth on February 14, ‘74. I returned to my office from HOSC to prepare lists of equipment, tools and residual hardware for disposal, and the last job was to sign-off on inventoried items. One item was the back-up flight OWS, which was a carbon copy of the one that flew. It went to the Smithsonian Air and Space Museum in Washington, DC for public display. Later, when visiting NASA Headquarters when working on the Hubble Telescope, I’d spend lunch hours at the museum enjoying nostalgic trips. A carbon copy of the transducer that threatened to delay the launch was right there in full view!

Many Marshall personnel were given awards for bringing Skylab through years of toil and trouble. The photo shows NASA Administrator, James Fletcher, presenting the NASA Exceptional Service Medal to me. Bettie and I had spent over eight years of our lives while I worked on Skylab. During that time, our kids grew up and went through both high school and college.

The following is a statement from Rocco Petrone’s Foreword to NASA’s chronology, Skylab, Our First Space Station: “The finest accomplishment of Skylab was the demonstration of the uniqueness of man in space in solving problems and overcoming obstacles in the face of extreme adversity. The Skylab team – flight crews in orbit, and engineers, technicians and support personnel on the ground – converted awe-inspiring challenges to opportunities that demonstrated man’s role in space.

HUBBLE SPACE TELESCOPE

Astronomers dreamed of viewing the cosmos long before man-made satellites were able to go into space. That dream became viable after the Apollo lunar program and other satellites demonstrated that an orbiting platform could be held stable long enough to provide exceptionally high-resolution data from cosmic objects.

As early as ’23, Hermann Oberth, the German rocket pioneer I met at ABMA in ‘58, suggested putting a telescope into orbit above the Earth’s atmosphere. In ‘46, Dr. Lyman Spitzer, a theoretical physicist and astronomer at Princeton University, postulated that resolution of the Palomar telescope was only 60 times better than the human eye, but, if it were operated above the atmosphere, it could be 3,000 times better.

Soon after the Apollo 11 moon landing in ‘69, Spitzer asked Dr. C. Robert O’Dell to be the “point man” for the greater astronomy community, suggesting that he work as a civil servant scientist within NASA. Bob reluctantly gave up his career as a professor at the University of Chicago, and Director of the Yerkes Observatory to become a government scientist at the Marshall Space Flight Center and to represent university interests in the development of the new large space telescope that became known as the Hubble Space Telescope.

Jim Downey led the telescope’s early definition team within the Program Development Division at Marshall when I joined after leaving Skylab. Jean Olivier was chief engineer, and Bob O’Dell was astronomer-scientist. Others from Skylab came onboard at the same time, included Bill Keathley, Max Rosenthal, and John Humphreys. Marshall’s Astronautics Lab supported the study effort, including optics specialist, Dr. Joe Randall, and control system expert, Dr. Gerald Nurre. This was the beginning of a project team that would manage and direct the design and development of the Hubble Space Telescope.

Establishing a engineering team to plan the space telescope development was one thing, but it was most important to have knowledgeable input from the university-based astronomy community. A small group of astronomers and instrument scientists occasionally met with NASA engineers during “working group” meetings, which provided a forum for defining design and operational criteria. Bob O’Dell was chairman at the meetings. I attended as an observer, listening and learning while various telescope design features were discussed.

The astronomers were visionaries (pun not intended) who operated on a different technical level than engineers. However, one key scientist, Jim Westphal, had a knack for explaining astrophysics and scientific instrumentation in a way that even I could understand. He was a geophysicist by training (not an astronomer, or PhD) and had previously designed and built large telescope light-sensing instruments. He was a distinguished professor at Cal Tech, which said a lot about him! Another telescope expert I found easy to talk with was Bill Fastie. Both Jim and Bill had built instruments used at Palomar and other ground-based observatories.

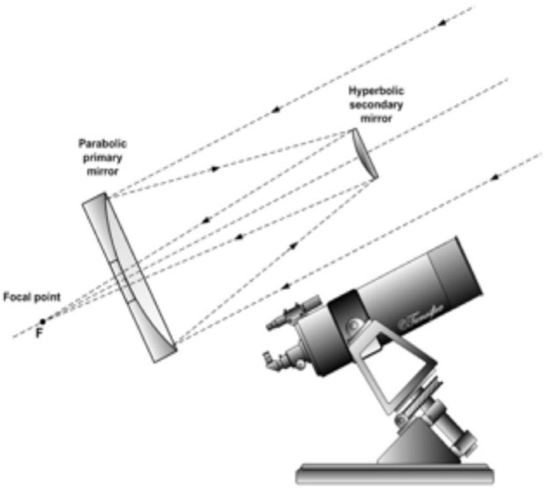
In-house design studies and prototype testing progressed hesitatingly until ’77 when the project was funded for contracting with Industry for the design and production of flight hardware.

Marshall Space Flight Center had the project responsibility for the telescope portion (Optical Telescope Assembly) and the spacecraft control section (Systems Support Module). The Goddard Space Flight Center at Greenbelt, MD, was responsible for development of the telescope’s Scientific Instruments, and for providing a Science Center where the orbiting Hubble was to be operationally controlled, and where astronomers would implement their observations.

Three Module Configuration

Hubble’s flight hardware consisted of three major elements: the Optical Telescope Assembly (OTA), Support Systems Module (SSM) and Science Instruments (SI).

Optical Telescope Assembly (OTA)



The major element of the Optical Telescope Assembly was a Cassegrain reflector mirror assembly of a Richey-Cretien design. The primary and secondary mirrors were made of Ultra Low Expansion (ULE) glass. A graphite-epoxy structure, called a metering truss, separated the two mirrors, and annular light baffles were attached inside the truss to attenuate reflected stray-light. Science Instruments (SI) were positioned behind the primary mirror where they registered photons and radiated energy coming from cosmic objects being observed. Fine Guidance Sensors (FGSs) provided stability reference data using known bright stars for reference. The adjacent diagram traces how light is reflected off the two mirrors, then passes through a hole at the center of the primary mirror to a “focal plane” area behind the primary mirror.

Bill Keathley led the OTA project during preliminary design from ‘74 until ’77, at which time he became the Marshall Space Flight Center’s Hubble Program Director.

Systems Support Module (SSM)

The Systems Support Module was a platform that supported and enclosed the OTA and Science Instrument assemblies. It performed all spacecraft functions and shielded the telescope assembly from direct sun radiation, reflected light, and thermal variations as Hubble orbited the earth. Its principal job was to point the telescope’s line of sight toward selected areas in the sky and hold very still while the Scientific Instrument sensors registered light photons and radiation data. The SSM contained all systems needed to operate orbital spacecraft functions, such as attitude control, electrical power generation and distribution, command control, telemetry, and data management – all needed to support the OTA and SI's.

The SSM's most challenging design requirement was to move the telescope's line-of-sight from one celestial object to another within a pointing accuracy of 0.01 arc-seconds, and then hold on to an "object of interest" with a stability of 0.007 arc-seconds for up to 24-hours duration. To appreciate this requirement – if the telescope were in Washington, DC, it could focus on a dime in Boston and not stray from the width of the coin.

The key to assuring long orbital lifetime was a unique requirement to have astronauts perform on-orbit maintenance. This was derived from Skylab experience when launch-damaged hardware was repaired and failed components were replaced by astronauts, thereby allowing completion of all three planned missions. Based on that experience, Hubble was specifically designed for replacement of Science Instruments and critical components during planned onorbit maintenance missions. I delivered two papers at symposia on the subject: 1) The Space Telescope, A Long-Life Flyer, delivered at the November '79 American Astronautical Society's Annual Meeting, and 2) the Space Telescope Design for Maintenance given at the IEEE ESCON 80 Conference in Oct. '80.

I was the Marshall Center's project manager for the Support Systems Module. The job was to manage and direct hardware design and development effort contracted to Industry.

Science Instruments (SI)

Five Science Instruments were positioned at the OTA's focal plane to sense and record observed data, including the: 1) Wide Field and Planetary Camera (WF/PC); 2) High Resolution Spectrograph (HRS); 3) High Speed Photometer (HSP); 4) Faint Object Camera (FOC); and 5) Faint Object Spectrograph (FOS). The cameras recorded visual wavelength data that produced photographic-type images. The spectrograph instruments recorded ultraviolet and infrared data used to determine the chemical composition of celestial objects The photometer instrument used photon-counting digicons to measure the flux, or intensity, of an object's electromagnetic radiation.

The Wide Field and Planetary Camera (WF/PC) proved to be the most productive Hubble Science Instrument. It recorded the many high-resolution photographic-type images that amazed the world's science community and sparked the public's interest. As a high-resolution imaging device primarily intended to register optical image data, it could also detect nearinfrared and UV data using filters. Charged Couple Devices (CCD) sensed light and registered the intensity of photons during observation periods. The original WF/PC instrument, and subsequent orbital replacements, produced over 80% of the highly acclaimed discoveries credited to Hubble during its 20-plus years of operational lifetime. Cal Tech's Jim Westphal was the Principal Investigator (PI) responsible for the WF/PC design, and he gets the major credit, in my book, for Hubble's success.

George Levin, at the Goddard Space Flight Center, managed the development of the Science Instruments.

Project Planning & Implementation

Financial constraints and frequent estimate-to-completion revisions plagued the project throughout preliminary design and continued during the development phases. During the early years, the project's future was constantly in doubt as the design approach and estimated cost were kicked about between the Goddard and Marshall Centers, NASA Headquarters, Congress, and various astronomers. As early as '72, Goddard estimated approximately $500 million; and Marshall estimated $900 million for a plan that included a ground-test breadboard, an allsystems test article, and one flight article. When NASA Administrator, James C. Fletcher, was told of these estimates, he reacted by arbitrarily pulling a number out of the air, saying that NASA's fiscal climate at the time was not conducive for starting large projects. A "back to the drawing board" effort resulted in deleting most ground test hardware, leaving only a single proto40 flight article. To enable on-orbit replacement by astronauts, a uniform Science Instrument envelope about the size of a telephone booth was chosen. Also, an earlier plan to return Hubble to earth for major overhauls was deemphasized in favor of having astronauts replace failed components during on-orbit maintenance operations.

From the very beginning, the Marshall Center was in competition with Goddard for the project's principal management role. With encouragement from university astronomers, the spacecraft and telescope hardware development job was assigned to Marshall, and Goddard got the longterm job of managing and operating the observation mission phase after launch. There was an apparent atmosphere of rancor between the Centers then, and continued for years. Because astronomers from several countries were planning to use Hubble for observations, it was appropriate that the international community partner with NASA to help pay for the development. Discussions between NASA Headquarters, Marshall, Goddard, the European Space Agency (ESA), and even Congressional Committees resulted in a plan for European interests to supply the SSM solar arrays and one Scientific Instrument. For the consideration of future scientific viewing time, ESA's 15 % contribution was based on the estimated cost for hardware items it supplied, as compared to the total estimated development cost, exclusive of orbital phase operational costs.

Officials at NASA Headquarters believed that the Marshall Center's historical propensity to provide technical support, advice and direction to its contractors resulted in excessive project cost. Headquarters believed that the magnitude of cost overruns was directly proportional to the number of civil servants assigned to work on projects. Using that rationale, Headquarters directed Marshall to limit the number of government personnel working on Hubble.

Contracting to Industry

Preliminary design contracts were awarded to selected companies considered to have the capability to build the hardware. Itec and Perkin Elmer were chosen for the OTA package preliminary design competition; and, the SSM spacecraft preliminary design competition was assigned to Boeing, Lockheed, McDonnell Douglas and Martin Marietta. The Goddard Center chose Princeton and Johns Hopkins Universities to submit plans for the Science Center. Also, various university-based astronomers were chosen to refine design requirements for the U. S. supplied Science Instruments.

During the preliminary design phase, three telescope sizes, with primary mirror diameters of 1.0, 2.4, and 3.0 meters, were studied. It was well known that the astronomer community preferred the largest possible diameter mirror that could fit in the shuttle's payload bay, but high costs would prohibit selling it to NASA Headquarters and Congressional interests. Furthermore, a 2.4-meter diameter mirror had already been made for military applications, so the mirror size became a foregone conclusion.

The next phase of the procurement cycle was for detailed design, development testing, production, and delivery of hardware. Proposals from competing contractors were evaluated by NASA Source Evaluation Boards (SEBs). The fun part of evaluating proposals were visits to contractor plants to see the facilities and meet the management teams proposed for the project. The following photo shows Jim Downey, Jean Oliver and me (in the middle), which was taken while visiting one of the competing SSM contractors.

Bill Keathley was the OTA Source Evaluation Board (SEB) chairman and I was the SSM SEB chairman. Before beginning evaluation activity, a potential conflict of interest question was raised because my brother-in-law was a Lockheed employee at the time. NASA's legal staff quickly put it aside because he was in an engineering group – not in management. Technical and business SEB teams scoured the proposals, looking for strengths, weaknesses and discriminators. When completed, the Center Director, Jim Downey, Bill Keathley and I went to Washington in July '77 to brief NASA Headquarters. Robert A. Frosch, NASA Administrator at the time, chose Lockheed for the SSM and Perkin Elmer for the OTA. Johns Hopkins University was selected as the site for the Science Center.

With NASA ready to commit major dollars for detailed design, Marshall established the Hubble Program Office and assigned Bill Keathley as Hubble Program Director. Max Rosenthal replaced Bill as the OTA project manager, and I continued as the SSM project manager.

Negotiating the SSM contract with Lockheed was a simple matter of agreeing to boilerplate language, estimated cost, and using the SSM Model Specification as the technical statement of work. Lockheed was cautioned to gradually increase manpower levels and to make sure that Perkin Elmer's OTA interface design was fully coordinated. Bill Wright was the Lockheed SSM program manager and Bert Bulkin was his deputy. Both had extensive experience working on defense-related satellite jobs and the company had plenty of engineers with appropriate hardware and software experience.

The European Space Agency (ESA) assigned the SSM solar arrays and Faint Object Camera (FOC) developments to industrial firms in several countries. British Aerospace (BAe) at Bristol, England had the overall solar array job but subcontracted the solar cells to Telefunken at Hamburg, Germany. EMI in London, and Matra in Paris developed Faint Object Camera components that were later integrated and tested at Leiden, Holland by ESA.

I flew to Europe several times to check on contractor progress and to work with ESA counterparts. The trips were always busy, but were fun because of the sightseeing potential and opportunities to eat different foods. Driving in Paris was a challenge, especially in heavy traffic going around the Arc de Triumph's six lanes at night, and in the rain! Also, taking the highspeed train from London to Paris via the Chunnel (English Channel Tunnel) was a new experience.

Hardware and Operational Requirements

The SSM equipment section was a rugged annular box structure, or ring, designed to contain the components and subsystems necessary to operate Hubble. The entire mass of the OTA was supported at a three-point interface inside the equipment section. Solar arrays, magnetic torquers and high-gain antennae were attached to the external surface of the equipment section. The rest of the SSM structure, extending fore and aft of the equipment section, consisted of cylindrical aluminum shells covered with multi-layer insulation to shield the OTA and Scientific Instruments from the sun's thermal energy and stray light. A hinged door at the front end acted as a sunshade to minimize direct and reflected light from entering the aperture. Control moment gyros (CMG's) were reaction wheels located in the equipment section near the Hubble's center of gravity. Three CMG's delivered the reactive forces necessary to move Hubble from one celestial object to another, and then hold it stable while light and radiation data from the target star was being registered by Science Instruments. Acceleration of the wheels, operating in either direction, reacted against Hubble's mass to cause it to move. CMG wheel rotational speed could potentially build up to 3000 rpm, so stored energy was managed with use of magnetic torquers that reacted against the Earth's magnetic field. Three CMG's were needed for spacecraft attitude control, but two could do the job, albeit slower, if one failed.

Rate gyros provided an inertial reference when moving the telescope from one object to the next, and helped maintain stability during viewing. While observing a faint object, at least two Fixed Head Star Trackers (FHS) locked on to known (brighter) "guide stars" that were used to determine Hubble's location in space and to provide error signals for pointing stability using the OTA's Fine Guidance sensors.

SSM solar arrays converted sunlight radiation to approximately 6000 watts of electrical power. When the telescope moved from one target star to another, the arrays automatically moved to keep them normal to the sun in order to assure maximum power generation. Electrical energy generated by the arrays was stored in batteries and distributed to operate components and subsystems. Ground commands were received and telemetry data transmitted through low-gain antennae. Science data was downlinked using articulating high-gain antenna directed at synchronous satellites, which relayed the data to ground stations.

Hubble was exposed to extreme heat variations during each orbit while orbiting Earth, going from “night to day” every 96 minutes. To minimize the effects of temperature extremes on mirror alignment and instrument performance, the outside of the SSM was covered with multiple layers of a mirror-like Mylar material to block the sun’s radiation and protect the OTA. A hinged door at the front end helped prevent direct sunlight and earth’s albedo light from entering the aperture. The door was closed during launch, and when Hubble was being serviced during maintenance missions.

Project Events and Personal Notes

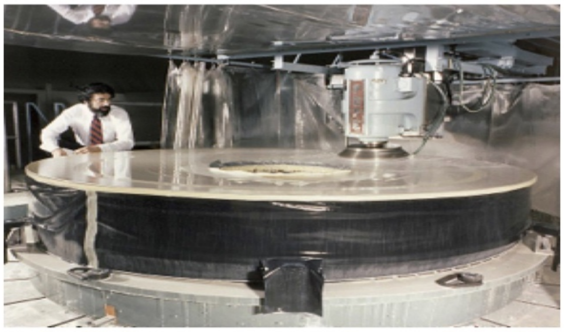
Just before Christmas ’79, Bill Keathley moved to an apartment near my home after his wife initiated divorce proceedings. He did not have a car at first, so I drove him to work for a couple of weeks. While driving back and forth we naturally discussed the project. One day, he surprised me by asking what I thought the Center Director (his direct boss) would do if Hubble were severely overrun. I replied without hesitating that “he would probably crucify you.” Shortly after that exchange, Bill announced that he was leaving Marshall to take a promotion at Goddard. Most assuredly, his departure was not a result of my answer; however, a possible theory as to why Goddard hired Bill away from Marshall could have been because he won most of the project turf battles between the two centers. By hiring him, Goddard removed their nemesis. As the saying goes, “If you can’t beat ‘em, hire ‘em!

Just after Keathley left, I asked Bill Lucas, the Center Director, for the Hubble Project Director’s job. He said he would consider it, but a week later it was announced that Dr. Fred Speer was to be the new Hubble Director. Fred had just come off the HEAO project that was finished under cost, although a couple of flight items had been deleted from the original plan to keep project cost down. Fred’s cost-saving deletions pleased NASA management; however, the HEAO astronomer-scientists were not happy.

Fred and I got along well and he seemed pleased with the way I managed the Lockheed contract. When my job title was changed from “SSM Project Manager” to “Space Telescope Associate Director for SSM” (without a corresponding financial reward), it was apparent that they threw a bone for me to chew on.

In the Spring of ’80, an opportunity came to combine a business/vacation trip with my wife, Bettie, that included personal leave time. While attending meetings at ESA, she strolled around Leiden and was given a personal tour of an old windmill museum located in the center of town. With meetings over, my vacation time began, so we took a train to Austria to visit old friends and prior Huntsville neighbors. Fritz and Anna Marie Brandner drove us to Vienna to see the city where he grew up, and gave us a personal tour of St. Stephen’s Cathedral, Karl’s Kirk, a cellar where Holy Roman Empire royal heads of state were entombed, and the famous Vienna Woods.

In the middle of my vacation, Fred Speer called, asking me to go to Bristol for an unscheduled meeting with BAe. The trip became a four-week marathon, and I resolved that would be the last time I would combine vacation with business.



Lockheed Missiles and Space Division's work on the SSM progressed satisfactorily; however, timely polishing of the primary mirror at Perkin Elmer' (P-E) was a chronic concern. Corning delivered the primary mirror blank on schedule, but P-E had difficulties learning to use their new, computer-driven, polishing equipment. As a result, the schedule was progressively squeezed, and estimated cost-to-completion rose inversely as the schedule was compressed. The photo shows the primary mirror being polished at the P-E plant in Danbury, Connecticut.

With two years into the development at Perkin-Elmer, progress continued to lag, contributing to Hubble's cost and schedule problems. Fred began looking for ways to cut overall project costs and hopefully enjoy the fiscal success that he had on the HEAO Program. His first idea was to eliminate the aperture door, which was there to block light that would otherwise degrade the quality of exposures. The door also protected mirror surfaces from being contaminated during launch and maintenance operations. Bob O'Dell objected strenuously, as did every astronomer, so the idea was quickly dropped. Next, Fred decided to eliminate the majority of launch replaceable units (LRUs), and their corresponding flight hardware interfaces, including handholds that astronauts would need to replace failed items such as gyros and electronic packages. His objective was to avoid cost. Fred was convinced that he had to do it to hold down the ever-increasing project estimates, in spite of the obvious risks to orbital longevity. After much discussion, I reluctantly directed Lockheed to delete the LRU interface designs and handholds, knowing that if any critical item were to fail while in orbit, it could not be replaced and Hubble's operational lifetime potential would be severely shortened.

The work at Perkin-Elmer (P-E) continued behind schedule and seemed to get worse each quarter. Primary mirror polishing was hesitatingly slow. In early '81, P-E stated that polishing was nearly complete and that the mirror had an almost perfect "figure." Mirror figure measuring techniques, using available instrumentation, confirmed their opinion; however, it was actually flawed, and not discovered until after Hubble was launched and in orbit a decade later. An issue was discussed about that time regarding a P-E request for additional funding to buy test equipment that also required a facility modification. It was refused; however, such requests were not unusual as P-E frequently asked for additional funds. It may never be known if the equipment and facility mod might have helped reveal the flaw that was discovered after launch.

During the late spring of ’81 Marshall conducted a Critical Design Review (CDR) at Lockheed. CDR’s are major milestones when the government conducts detailed evaluation of a contractor’s development results before proceeding with building flight hardware. The review at Lockheed was completed without significant problems, and I authorized the contractor to proceed with manufacturing.

Opportunity Knocks

Just before the July 4th holiday weekend in ’81, NASA offered an early-out retirement option for personnel who met the age and time-in-service criteria. I was tempted and talked it over with Bettie, who said, “If that is what you want, do it.” It would be a big step and I thought long and hard while painting the dormer on our home that weekend. With 25 years of service, including military time, I qualified, so I decided to do it. Bettie cheerfully agreed and the next day I went to the personnel office to file papers. A long line was there - most applying for retirement. Over 300 signed up before the option was shut down. Fred Speer appeared shocked when I told him; however, he asked me to stay on until after the European hardware CDR’s were completed.

During the month of August, a small team went to Europe to conduct design reviews of ESA’s hardware. First, we went to Bristol for the solar array CDR. Next, the Faint Object Camera (FOC) component designs and prototypes were examined at EMI in London and at Matra in Paris. The final review was Telefunken’s solar cell development in Hamburg. During our last evening there, the ESA Hubble Project Manager, Jon Berger, took several of us to dinner at a country inn, called the Rosengarten, where we were introduced to the strange flavor of eel - a delicacy for our hosts, but not for us.

Back at Marshall, I spent a few days cleaning up loose ends and was entertained at a coffee and cake farewell party on September 25, 1981 marking the end of my NASA career. I was 53 years young! While driving home that day, I reflected on the fact that it was the first time in my life when I was not employed. It was a strange feeling.

Post Script

Two years after I retired from NASA, Bob O’Dell and Fred Speer left to pursue their careers elsewhere. The new Hubble director, Jim Odom, reinstated all the LRUs and handholds that Fred had ordered deleted. It is noted that Jim was one of the first engineers I recruited for the Saturn S-II Project Office twenty years earlier.

Hubble had been scheduled for launch in ‘86; however, the Shuttle Challenger’s tragic failure and loss of life caused a hiatus for all Shuttle launches, including the Hubble Space Telescope. The down-time for Hubble was used for continued testing and evaluation of the hardware’s readiness at the Lockheed facility, followed by long-time storage in a vacuum chamber needed to protect sensitive optical surfaces from atmospheric contamination.


DISCOVERY / STS-31 DEPLOYS HUBBLE (NASA)

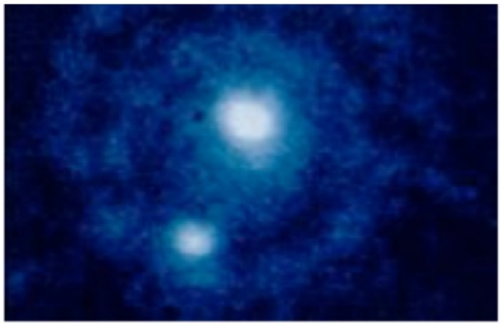
After the Shuttle Program returned to flight status, Hubble was delivered to the Kennedy Space Center and launched aboard Shuttle Discovery in April ‘90. Hubble was deployed remotely by astronauts and parked in a nearly circular orbit about 340 miles above earth at an inclination of 28.5 degrees. Marshall engineers and Hubble contractors conducted on-orbit deployment and flight verification operations at the Science Center before handing operational control over to the Goddard engineers and eager astronomers, who were ready to conduct their “observations.”

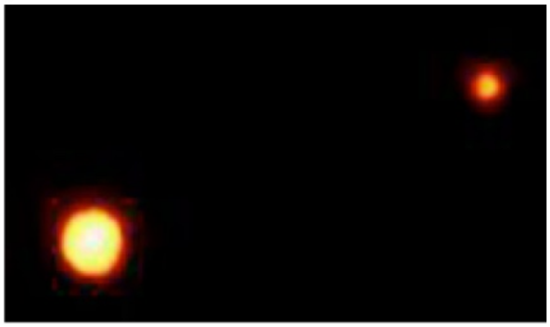
It was not long before the astronomers at the Science Center discovered that the quality of optical images were unacceptable. The telescope's ability to focus on faint objects was compromised. It was deduced from the evidence that the primary mirror had been shaped incorrectly during the polishing operation at Perkin Elmer. A spherical aberration resulted in an out-of-focus distortion. The mirror’s figure was too flat near the outer edge by about 1/50th the width of a human hair. Instead of focusing light at the focal plane as intended, photons were spread over a larger area, thus producing a fuzzy halo effect. As a consequence, images of objects such as faint stars and galaxies were blurred. The flaw did not affect spectroscopic observations, and bright object observations were largely unaffected; however, an out-of-focus halo surrounded faint objects, severely compromising the usefulness of the telescope.

In spite of the loss of cosmological viewing, Hubble carried out a large number of productive observations during the first three years of on-orbit operations before repairs could be attempted. Because the flaw was well characterized and stable, astronomers were able to optimize some results obtained using sophisticated image processing techniques; however, very distant faint objects could not be viewed. They had to wait until after the first servicing mission to obtain the phenomenal images that amazed the world.

The first Shuttle Servicing Mission (SM1) flew in December ’93, delivering two replacement scientific instruments designed to compensate for the primary mirror's incorrect shape. Astronauts aboard the Shuttle also installed a number of Launch Replaceable Units (LRUs). Also, new solar arrays were installed, designed to help reduce low frequency vibrations caused by thermal flexing when going from night to day while orbiting Earth. Gyroscopes and some electronic units were replaced. The mission was one of the most complex EVA operations ever undertaken, involving five lengthy spacewalk periods. The result was a resounding success for NASA, and it was an enormous boon for Hubble. This first servicing mission not only improved Hubble's vision, which led to a string of remarkable discoveries, it also clearly validated the effectiveness of on-orbit servicing by astronauts, which Marshall engineers had championed following Skylab experience.

After Hubble’s new "eyeglasses" were installed, images were significantly sharper, illustrated by exposures of Pluto and Charon taken before correction in ’90 (left), and after correction (right) in ‘94.





The second servicing mission (SM2), in February ’97, delivered two new scientific instruments and replaced a tape recorder with a solid-state recorder. In addition, the Shuttle was able to boost Hubble to a higher orbit after maintenance operations were completed.

The SM3A servicing mission in December ’99, replaced all six gyroscopes, a fine guidance sensor, the flight computer, and thermal blankets were installed on top of the original reflective foil. The SM3B servicing mission in March ’02 replaced the last original instrument that was still on board, and a new cooling system was installed for use by an infrared instrument.

Servicing mission, SM4, was postponed, and then cancelled after the tragic loss of the space shuttle Columbia in February ‘03. Following the shuttle disaster, and re-examining risks, the last Hubble servicing mission was launched in May ‘09. It was Hubble's most challenging and intense servicing mission. Over the course of five spacewalks, astronauts installed two new instruments that improved the earlier optical fixes for the spherical aberration problem. The new instruments increased Hubble's observational capabilities in the ultraviolet and visible spectral ranges by a factor of 35. Also, astronauts were able to repair two failed instruments and replace rate gyros, a fine guidance sensor, the Science Instrument command data handling unit, and six nickel-hydrogen batteries. The original batteries had not been replaced during prior servicing missions and were 13 years beyond their design lifetime. The SM4 crew took this photo of Hubble as the Shuttle pulled away for the last time. There would not be another servicing mission because Shuttle flights terminated in 2011.

Observation Results

Hubble helped resolve some long-standing problems in astronomy, as well as turn up results that require new theories to explain them.

While Hubble observations helped refine estimates of the age of the universe, it also cast doubt on theories about its future. By observing distant supernovae, astronomers uncovered evidence that, far from decelerating under the influence of gravity, the expansion of the universe may, in fact, be accelerating.

Hubble showed that black holes are probably common at the centers of all galaxies, and studies of the data established that the masses of nuclear black holes and the properties of galaxies are closely related.

The collision of Comet Shoemaker-Levy 9 with the planet Jupiter in '94 was fortuitously timed for astronomers, coming just a few months after servicing mission SM1 had restored Hubble's optical performance. Images taken of the planet were sharper than any taken since the passage of Voyager 2 in '79, and were crucial in studying the dynamics of the collision of the comet with Jupiter, an event believed to occur once every few centuries.

Other discoveries included evidence of the presence of planets around sun-like stars and the optical counterparts of mysterious gamma ray bursts. Hubble also observed objects in the outer reaches of our Solar System, including the dwarf planets, Pluto and Eris.

Before Hubble, no telescope had the resolution to see distant galaxies. This image is called the **Hubble Deep Field**. Intrigued by its potential, astronomers turned Hubble cameras on what appeared to be an extremely long exposure that otherwise could have been used for higher priority needs; however, the results turned up a treasure trove of 3,000 galaxies, large and small, shapely and amorphous – all burning in the depths of space.

Hubble produced many images that helped improve the understanding of processes inside nebula. One of these, a photograph known as the Pillars of Creation, depicts large regions of star formation. The small, dark areas are believed to be proto-stars. The columns, which resemble stalagmites protruding from the floor of a cavern, are composed of interstellar hydrogen gas and dust, which act as incubators for new stars. Inside, and on their surface, astronomers found knots, or globules of denser gas, called evaporating gaseous globules. Stars are being formed inside a portion of these globules.

The Sombrero Galaxy, M104, is about 28 million light years away from Earth. This image was voted the best picture taken by Hubble. Dimensions of the galaxy are as spectacular as its appearance. It has 800 billion suns, and is 50,000 light years across.

SPACELAB

My last day at NASA was September 25, 1981. Retiring at the age of 53 was a big surprise to everyone, including me. I did not have a plan as to what I might do next, except, hopefully, get employment with a local aerospace company. After a few weeks, Bettie made a few pointed comments wondering what was next. I suddenly realized that I better get busy and look for a job. Local aerospace companies were on my list, including a couple of machine shops, and I hesitatingly started calling for interviews. Inquiries at Teledyne Brown, Lockheed Missiles and Space, and General Products started the process. Teledyne Brown was unique in that it scheduled interviews with each of its several divisions. After the first interview, I waited a couple of days for a call to come for the next one. This went on for the better part of two weeks, and as the days went by I began to wonder if they were really interested in employing me.

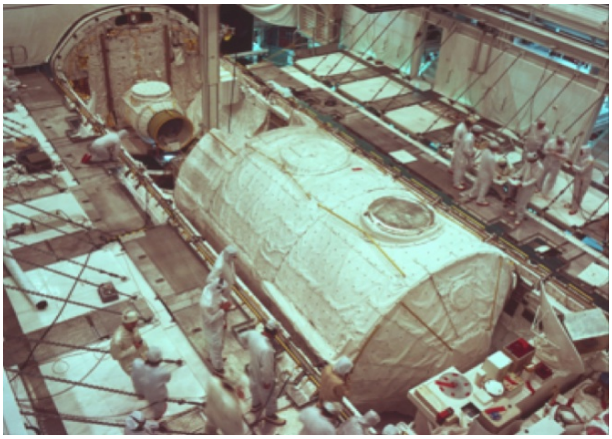
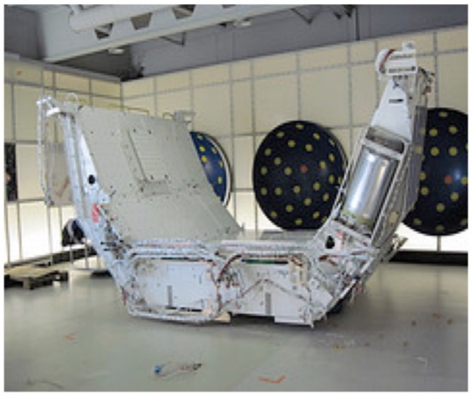
McDonnell Douglas Corp. (MDC) was not on my list, although I had done business with company individuals at its Southern California and St. Louis plants, but not in Huntsville. When an old NASA associate, Bill Simmons, called and asked if I would be interested in working at McDonnell Douglas, I said sure, and was interviewed by Volker Roth who hired me on the spot. My first job was to review and sign off on Engineering Orders (EO) associated with the Spacelab Tunnel.

Spacelab Project

Spacelab was a reusable laboratory comprised of various components hard-mounted in the Space Shuttle's cargo bay. Spacelab modules and other components were arranged in various configurations to meet the needs of each mission and to allow scientists to perform experiments in the microgravity environment.

Laboratory Modules were pressurized and connected to the Shuttle's aft flight deck by a tunnel that permitted shirt-sleeved Science-Astronauts to access and operate experiments. Unpressurized Pallet Modules were U-shaped platforms for mounting equipment, instruments, and experiments requiring exposure to space. They also permitted a large field of view for telescopes.

Experiments flown on Spacelab missions included astronomy, solar physics, earth observation, material science, technology and life sciences. They came from all over the world - from universities, industrial firms, and governments, all delivered to KSC and installed on Spacelab for operation aboard an orbiting Shuttle. McDonnell Douglas-Huntsville did the engineering to assure that the experiments were compatible with Spacelab hardware and software interfaces.



The photo at the left shows a “long” Laboratory Module and “short” Tunnel in the KSC assembly area. A Pallet Module is shown at the right.

Mission and experiment objectives determined the type of Spacelab modules flown on any given flight. A mission “designator” defined the type of module used for a mission. For instance, Spacelab SL-1, 2, and 3 were Laboratory Module configurations; and OSTA, OSS, SLS, SRL were Pallet missions. Some countries had their own “science astronauts” for experiment operations. Germany had Spacelab D-1 and D-2, and Japan had Spacelab-J missions. When modifications to Spacelab hardware or new support items were needed, such as special foot restraints, MDC sometimes used local machine shops to manufacture them. I frequently went to the shops to answer questions and resolve problems.

Varied Career at MDC

I began as project engineer at McDonnell Douglas, responsible for the Spacelab Tunnel; then graduated to Spacelab Laboratory Modules; became a Spacelab Mission Manager; then had various company new-business assignments; and lastly, I served as branch chief in the company’s Advance Program Development and Product Support Division.

NASA encouraged Industry to come up with new ideas for space experiments, especially if companies were willing to pay for them. Materials processing was a high-priority objective. MDC committed corporate funds to design and build a small furnace intended to grow gallium arsenide boules in the orbital microgravity environment. The planned process was similar to making silicon boules on earth, except the furnace had to meet NASA’s flight safety criteria. The objective was to demonstrate that a more perfect boule, with fewer flaws and a more uniform density would result when “grown” in microgravity. MDC was in the process of having a prototype furnace built by a firm in New Hampshire when the project was abruptly terminated after the Space Shuttle Challenger crashed during launch in ’86, and seven crewmembers tragically died.

The shuttle disaster was caused by an O-ring failure in a solid rocket booster joint that resulted from exposure to excessively cold temperatures prior to launch. A presidential commission investigating the accident concluded that NASA's organizational culture and decision-making processes were contributing factors that resulted in the fatal accident. Several of my previous

NASA associates were questioned during a Congressional investigation, which was broadcast on television and viewed by the whole world. It was a poignant time for me, the space community, and indeed, the nation.

Because the Shuttle was grounded indefinitely, there were layoffs at MDC, including me; however, I was recalled after a few months and was assigned to monitor NASA's Shuttle "return to flight" efforts. All elements of the Shuttle, including hardware designs and procedures, as well as NASA's own technical management and organization were exhaustively examined to determine possible reasons that led the failure. After a 32-month hiatus, Shuttle Discovery was launched in late September '88. In all, the Shuttle system flew a total of twenty-two Spacelab missions between '83 and '98. When Spacelab hardware was eventually decommissioned, follow-on experiments were assigned to the orbiting International Space Station.

Whenever a Request For Proposal (RFP) was issued by the government, interested industrial firms responded by submitting technical and cost data in hopes of winning the contract. Having served on several NASA Source Evaluation Boards, I found myself at the other end of the stick at MDC. It was an exhausting experience to either prepare or evaluate a proposal – whether you were on the giving, or receiving end. At MDC, I helped prepare two major proposals in response to RFP's, but neither were a winning bid because the government terminated the projects before they began.

Volker Roth was my supervisor during much of my time at McDonnell Douglas. He was the older son of one of the original German scientists that had come to the United States after WW-II. Volker was not much older than our first son, Mike, and he had been with MDC ever since graduating from the University of Southern California. I respected his technical and management abilities, and thoroughly enjoyed working for him.

Company Projects

During my last year at MDC, I was assigned to the Advance Program Development and Product Support Division, working under Jim Blackman who had several patents for converting solar energy to electricity using mirrors and unique "solar furnaces." I was responsible for a small, diverse group of engineers whose efforts were directed toward developing ideas that, hopefully, would lead to new business. One associate was experimenting with rubber compounds for use in solid rocket motor fuels. His idea was to meter the flow of a liquid oxidizer to a solid fuel mass, thereby varying thrust and even shutting down a rocket motor's operation by controlling the oxidizer's flow rate. Another colleague was mentoring UAH graduate students who were developing a process for imbedding non-metallic ceramic particles in an electrodeposited three-part alloy. The student's process was successfully demonstrated, and MDC lawyers filed for a patent. Patent No. 5,338,433 lists my name, along with the student's and other MDC engineers as the "inventors." It was issued a year and a half after I had retired from MDC.

Reflections

The eleven years I worked at McDonnell Douglas seemed more satisfying from a professional and personal standpoint than much of my career in the federal civil service, possibly because I was more relaxed and enjoying the challenges.

Make no mistake, I feel deeply honored and proud to have been a part of America’s scientific-engineering endeavors while working at NASA. During the early years, when the Marshall Center was building rockets to go to the moon, it was exhilarating and exciting to be associated with the “von Braun rocket development team”; however, in the later years I felt increasingly inhibited by a perceived bureaucracy that is typical of aging government organizations. Also, there was an apparent technical caste atmosphere at Marshall that devaluated project managers vis-à-vis engineers working in the labs.

At McDonnell Douglas, it was different because I could deal directly with other engineers and express my ideas freely. Working in industry was a breath of fresh air for me!