Tom Patterson (7/27/23)

I Remember COMSAT 1967-1996

by Tom Patterson

I joined COMSAT Labs in June of 1967 as a Member of the Technical Staff, directly from graduate school. The Labs was located at 2100 L Street NW in downtown Washington. COMSAT also occupied two nearby buildings. Headquarters was at 1900 L Street (not certain of this address), and the rest of the company was at 1835 K Street.

I worked on spacecraft attitude dynamics issues for Jim Owens in the Positioning & Orientation Branch of the Spacecraft Laboratory of which Fred Esch was Director. The only INTELSAT satellites in orbit at the time were INTELSAT I and the first three INTELSAT IIs, each of which was a single body, spinning about its axis of maximum moment of inertia. Each of these satellites was inherently stable because any nutational motion (coning of the spin axis) resulting from perturbations would damp out due to energy dissipation such as that caused by propellant sloshing. Because these satellites were stable there was minimal demand for operational support from our group.

Jim Owens and Bill Billerbeck had proposed a spacecraft design in which three flexible solar arrays with tip masses would extend radially out from a spinning cylinder in order to provide more power than was achievable with a single solar array constrained to the outside of a cylinder. During transfer orbit the arrays would be stowed by wrapping them around the cylinder. While this design would be inherently stable in both transfer and synchronous orbits, there were questions about the dynamics of the system as the flexible arrays were unfurling.

Modeling the dynamics during deployment was a rather challenging problem because the spinning spacecraft would be slowing down as the flexible arrays were moving outwards. I decided to simplify by first considering it as a two-dimensional problem, ignoring nutation and any twisting of the arrays. I modeled each array as a string under tension as it deployed. Even this simplified model required writing partial differential equations and solving them with a digital computer simulation. Choosing an appropriate timestep for the simulation was tricky. At one point I chose a timestep that was so short and an amount of time to be simulated that was so long that the program exceeded the Fortran limit for the number of times through a DO loop. The simulation ended prematurely without an error message. Since each run of the simulation had to be submitted to the IBM 360 as a card deck to be run overnight, it took a few days to determine the cause of the premature termination. In the end we decided that an analog computer might be more suited to solving the problem, but we didn’t have access to one at the Labs and the project was eventually set aside.

Having outgrown the 2100 L Street location, COMSAT Labs moved into its brand- new facility in Clarksburg, Maryland, in September of 1969. Although the move was a positive experience overall, there was a period of withdrawal from the easy access we’d had to the variety of options for lunch in the nearby Washington restaurants. I have fond memories of working for COMSAT Labs downtown, including sharing an office with Paul Schrantz. One particular highlight was an amazing outdoor cocktail party hosted by COMSAT on L’Enfant Plaza in the spring of 1968 to celebrate the company’s move to that new location. Another memory was a visit by Siegfried Reiger, Vice President Technical, to the Labs. While the Director of COMSAT Labs, Bill Pritchard, was out of town, Reiger decided to make an unannounced inspection of the 2100 L Street location. Technicians were in the process of disassembling a piece of equipment, and parts were strewn all over the lab. When Reiger got back to his office, he reported that it looked like the Labs had been hit by a “----storm”.

INTELSAT III spacecraft were spin stabilized with a mechanically despun antenna. Like the INTELSAT I and INTELSAT II spacecraft they were nutationally stable. My only significant involvement with the INTELSAT III program had to do with INTELSAT III F-8, launched in 1970. Contact with this spacecraft was lost halfway through a 30-second apogee motor burn. In order to support the failure review board, I added attitude sensor models to an existing dynamics simulation and was able to show that the coning motion of the spacecraft during the first 15 seconds of the apogee motor burn was consistent with a body-fixed transverse torque that was growing linearly with time, confirming that the apogee motor itself had failed. Since F-8 was the last of the INTELSAT IIIs, however, the exercise was somewhat academic.

A major focus of our group beginning in 1968 and continuing into the 1970s was the nutational stability of the INTELSAT IV and IV-A spacecraft. These spacecraft were built by Hughes Aircraft Company and incorporated a recent design concept, developed by Hughes, called the Gyrostat. Like the INTELSAT IIIs, these were spinning satellites with a mechanically despun antenna. Unlike the INTELSAT IIIs, however, the INTELSAT IVs were shaped more like a pencil than a disc and spun about their axis of minimum moment of inertia. Energy dissipation due to propellant sloshing on the spinning portion of the spacecraft would have tended to make the spacecraft tumble, but Hughes showed that this nominally unstable configuration could be stabilized by adding sufficient energy dissipation to the despun portion.

To provide the required energy dissipation an eddy-current nutation damper was located on the despun portion. This passive damper consisted of a permanent magnet attached to the end of a pendulum. As the pendulum swung back and forth due to nutational motion, the magnet moved over a conducting metal plate, creating swirling electrical currents, i.e., eddy currents, in the conductor. As the eddy currents dissipated, they removed energy from the system.

In order to ensure that any nutational motion would be reduced completely to zero, it was necessary to demonstrate that the pendulum pivot did not contain stiction. Otherwise, the pendulum might “stick” while a small amount of nutation remained. An experiment was carried out at the Labs to confirm that there was no measurable stiction.

The overriding stability problem associated with INTELSAT IV, however, was determining the amount of energy dissipation caused by propellant sloshing on the spinning portion. If the dissipation were too great, it would overwhelm the passive damper on the despun portion, the spacecraft would be unstable, and nutation would increase until the spacecraft was tumbling, a condition known as flat spin.

In the Spacecraft Lab Ernie Martin oversaw the construction of an apparatus to investigate the motion of a fluid in a transparent tank as it was subjected to accelerations similar to those expected on INTELSAT IV. This experiment provided some insight into the expected behavior of the propellant, but it could not directly measure energy dissipation.

Definitive measurements of energy dissipation caused by propellant sloshing were eventually performed using a scale model of INTELSAT IV, mounted on an air bearing at Hughes Aircraft Company. The amount of dissipation was strongly dependent on the fill fraction of the propellant tanks, and there was concern that there could be some undiscovered resonant condition for which the energy dissipation might be large enough to cause instability.

Because of this concern it was considered prudent to investigate methods to recover an INTELSAT IV spacecraft if it were to wind up in a flat spin. I performed a number of dynamics simulations confirming the existence of more than one method of recovery. As a result of my work on this study, I was invited to join the launch team for the first INTELSAT IV spacecraft in January of 1971. The launch was successful and there were no stability issues. Subsequently, the entire launch team was invited to a memorable party at Dr. Charyk's home.

In addition to my involvement with the INTELSAT IV and IV-A programs, I performed dynamics simulations in support of several other programs that made use of spin stabilization such as Marisat and Comstar, but the main focus of the Positioning & Orientation Branch was shifting to the study of three-axis stabilized attitude control systems. In these systems the angular momentum is provided by a spinning wheel, allowing the main body of the spacecraft to be three-axis stabilized. Several different configurations were studied including systems with single- or double-gimbaled wheels.

One of the ways we investigated these systems was with the use of an air-bearing facility in our lab. Sun sensors, Earth sensors, and wheels were mounted to a frame which was supported by an air bearing. Stationary Sun and Earth targets were provided for the sensors, and the frame was free to rotate in response to the attitude control system. It was necessary to balance the apparatus so that the center of mass coincided with the center of the air bearing, and achieving the proper balance could be a tedious procedure. The air-bearing facility, however, proved to be hit with Lab visitors.

In November of 1976 I left COMSAT Labs and transferred to the COMSAT project office in Palo Alto, California, where Ford Aerospace was beginning work on the INTELSAT V program. At the time COMSAT was still responsible for monitoring the construction of all INTELSAT satellites. I reported to Arnie Satterlee, who was responsible for all spacecraft bus subsystems.

INTELSAT V was the first INTELSAT spacecraft to be three-axis stabilized. The attitude control subsystem was subcontracted to Messerschmitt-Bölkow-Blohm (MBB), located near Munich, Germany. At MBB the subsystem was tested using a three-axis servo-table. Rate gyros, Sun and Earth sensors, control electronics and momentum wheels were all included in the testing. A test computer calculated the motion that the spacecraft would experience as a result of control system actions and drove the gimbals of the servo-table accordingly. Countless hours of testing were conducted in this facility, located in a basement at MBB. I have many memories of trips to Munich for design reviews and testing. Occasionally, we would have a free weekend to ski in the Alps, but more frequently we would visit the Mathäserhaus, a large beer hall in Munich with an oompah band.

INTELSAT V, like all previous INTELSAT spacecraft, had a solid apogee motor and needed to be spin-stabilized in transfer orbit. Following the firing of the apogee motor, the spacecraft had to transition from the spin-stabilized configuration to a three-axis stabilized configuration. The first part of the maneuver to accomplish this required reducing the spacecraft's angular momentum nearly to zero, a first for any INTELSAT spacecraft. With such low momentum, i.e., small body rates, there was a concern that the telemetry and command (T & C) antennas might point away from the Earth for extended periods of time during which the spacecraft could not be commanded and telemetry would be unavailable.

Attitude control modes such as Rate Damping, Sun Acquisition, Earth Acquisition Roll, and Earth Acquisition Pitch were designed to prevent lengthy periods of T & C outage, and, ultimately, they worked as expected. In the months leading up to the first INTELSAT V launch, however, all aspects of this transition from spin stabilization to three-axis stabilization were simulated and rehearsed extensively.

Overall, the INTELSAT V program was very successful. Following the launch of the first INTELSAT V spacecraft, however, two significant problems arose for which we provided support to the INTELSAT operations team. One problem manifested itself in erratic stepping of the large, flexible solar array as it tracked the Sun over the course of a day. The cause was eventually determined to be the excitation of a higher-order torsional mode of the solar array by the stepper motor. Prior to launch only the first torsional mode of the array had been included in the analysis of solar array stepping, but in hindsight higher-order modes should have been modeled as well. On later spacecraft the stepper motor was energized continuously to ensure smooth stepping of the array.

The other problem discovered following the first INTELSAT V launch involved Sun and Moon interference with the Earth sensors for geometries in which interference was not expected. The regions of interference varied somewhat from sensor to sensor, and it quickly became obvious that it would be necessary to map the field of view of each individual sensor to minimize pointing errors. Kurt Eriksson devised a plan to collect and organize the necessary data as the declination of the Sun and Moon varied throughout the year. Internal reflections in the Earth sensor optics turned out to be the source of the problem, and a design change was eventually implemented.

Ultimately, nine INTELSAT V and six INTELSAT V-A spacecraft were built in Palo Alto. In 1983 INTELSAT V F-7 became the first INTELSAT satellite to be launched from French Guiana on an Ariane rocket.

The first trips to the South American launch site were particularly noteworthy because of the remoteness of the setting and the presence of the French Foreign Legion. On one memorable trip a small group of us traveled up the Sinnamary River on a motorized canoe and spent the night in a camp in the middle of the rainforest. On another occasion on a moonless night, we were returning to Kourou from the western part of French Guiana where we had been watching turtles laying their eggs on the beach. Around midnight we got a flat tire in the middle of the rainforest, but the sky was so dark that we got a great view of Halley’s Comet. When we got back to our hotel, we found it surrounded by French Foreign Legionnaires, demanding to see our identification. It turned out that a few hours earlier, the United States had bombed Libya, and since nearby Suriname was a close ally of Libya at the time, the French were concerned that Suriname might respond by attacking the Guiana Space Center.

The INTELSAT VI spacecraft were spin-stabilized using the same Gyrostat concept as the INTELSAT IVs and IV-As. Since they were built by Hughes Aircraft Company in El Segundo and I was in Palo Alto, my support of INTELSAT VI was minimal. INTELSAT VI was the first program for which INTELSAT was in charge of the monitoring activities. COMSAT engineers, however, supported the INTELSAT team in a consulting role.

In 1988 as the INTELSAT V-A program was winding down, Ford Aerospace won the contract for INTELSAT VII so the COMSAT office in Palo Alto was able to remain open, providing technical support to INTELSAT.

INTELSAT VII was a three-axis-stabilized spacecraft like INTELSAT V, but unlike INTELSAT V it had a liquid apogee motor. The lower disturbance torques associated with firing the liquid motor allowed the spacecraft to be three-axis stabilized in transfer orbit as well as in synchronous orbit. Three firings of the liquid apogee motor were typically required to achieve synchronous orbit. Prior to each firing the spacecraft had to be reoriented into the correct firing attitude. Digital integrating rate gyros provided the attitude reference for these maneuvers.

The INTELSAT VII program was also quite successful. A total of six INTELSAT VIIs and three INTELSAT VII-As were eventually built. As I recall, three of the INTELSAT VIIs were integrated and tested at the Aerospatiale facility in Cannes, France. In 1995 I spent five months in Cannes, monitoring the testing of all bus electrical subsystems for INTELSAT VII F-9.

Also noteworthy was the fact that INTELSAT chose to launch INTELSAT VII-A F-8 on a Long March rocket from Xichang, China. I was part of the team that traveled to the launch site for prelaunch testing. There were many memorable experiences on that trip, including a dinner at a local restaurant at which more than two dozen of the most unappetizing items imaginable were served. Unfortunately, the Long March rocket failed just as it cleared the launch tower.

COMSAT engineers in Palo Alto also provided consulting services to customers in addition to INTELSAT, mostly in the later years when INTELSAT was not funding our office at 100%. I consulted briefly on programs such as INMARSAT, TV-SAT, ITELSAT, and Artemis (an ESA program). Our office also provided technical support over an extended period of time to the Japanese customer of the Superbird program for which the spacecraft were being built in Palo Alto.

Following the launch of the last INTELSAT VII satellite in 1996, the COMSAT office in Palo Alto closed. Kurt Eriksson, Jeff Robinson, and I, the only remaining engineers, were laid off. Each of us had more than 25 years of service with COMSAT.

Throughout my years at COMSAT it was my great privilege to have Kurt Eriksson as a colleague and friend. Kurt was an outstanding attitude control system engineer and a constant source of good advice and good humor. He was also the source of many wonderful memories!