EARLY DAYS IN THE SPACE AGE (1959-1999)

Technical Problems, Calculation Methods, and Variety of Managers

College days: The Physics Dept. at Wesleyan did research on the electrical properties of plated quartz crystals, supported by the U.S. Army Signal Corps. In the spring of my freshman year, Prof. Van Dyke invited me to join this program. In my junior year he asked me to develop a theory to match the experimental data, which I did. My professor encouraged me to do something that I thought was way beyond my capabilities. Years later, I realized he asked me to do something that he could not do himself! My unspoken reaction had been: "Who, me?"

Graduate school: search for new mesons. I decided to build a new cloud chamber with a liquid plastic (something new) that would harden in a wooden mold. Prof. J. Curry Street, my faculty advisor did not discourage me, but was skeptical. As a backup, he designed a cloud chamber from metal, and asked the machine shop to build it. Mine worked fine, but my professor insisted I go to the machine shop, thank the machinist that made it, and take it away. It was an important lesson in appreciating the work by others, -- even though it was never used.

Prof. Van Vleck taught a course in mathematical equations, not only how to solve equations, but also how to understand parts of an equation, and how to generate new equations. He had a relaxed way of teaching, so a few months passed before I realized how much I was learning. This was invaluable later, in developing new equations for spacecraft thermal design and satellite orbits. An equation is not just a recipe to calculate a number; it is also a key to understanding our physical world.

RCA (NJ): My job was to predict the temperature of the first weather satellite TIROS, launched April 1, 1960. We had to choose between conduction and radiation as the primary form for heat transfer inside the satellite. One possibility was to calculate the temperature distribution of a hollow metal cylinder (quite a challenge without a computer). We chose a simplified radiation model with 3 nodes. The temperature telemetered after launch agreed with our predictions. As I learned in school, it's good to simplify the model so the answer can be calculated, but not simplify it so much that the answer doesn't mean much.

After the first launch, the spin axis did not remain constant in space, as expected, but changed daily – why?

In building RELAY, an active communication satellite, unexplained click noises in a traveling wave tube delayed the launch. The technician thought it was the test equipment, and spent two weeks testing it. He then told the engineer, who spent more time to re-check the equipment. Good management could have launched RELAY sooner by putting the TWTs in pressurized containers. To get an alternate design started sooner we needed better communication between top management and the technician on the job.

A final satellite test before launch was operation in a vacuum at expected temperatures. To match the temperatures we used either solar simulation or walls at controlled temperatures. We recommended the latter test. The NASA project manager insisted on solar simulation. We did both. At the end of program, the project manager admitted he was wrong.

After two years I had accumulated some knowledge, and our group had grown. The thermal design manager, Jim Owens had a dozen engineers in his group, and suggested I teach a course. I kept putting him off. He insisted I set a starting date. I picked a far off date, which finally arrived. After this course was taught several times, I taught other courses in satellite orbits, satellite reliability, spacecraft technology and link budgets. This finally led to co-authoring two books on communications satellites: a handbook[1] and a graduate level textbook[2].

Comsat Laboratories (MD): 1) Intelsat IV satellites were the first to rotate around the axis of minimum inertia. They needed a damper in the non-rotating part of the satellite to offset damping by fuel slosh in the rotating part. Comsat Labs was asked to measure the effect of the fuel slosh. The Comsat chief engineer was not satisfied with the time it might take – he insisted on a tighter schedule, and forced Comsat Labs to speed up the program.

2) After many months in orbit, one of the Intelsat IV satellites started to wobble. A joint effort was started to determine the cause and cure of the wobble. This included Hughes (CA) that built the satellite, the Satellite Control Center (DC) analyzing telemetry data, and Comsat Laboratories (MD) simulating the problem with a computer simulation and an analog simulation (glass tubes and water). Hughes figured out the problem (a bubble in the fuel line), the Satellite Control Center thought of the fix, and Comsat Laboratories predicted the final results.

Intelsat (DC): Eclipses by the **earth**'s shadow on geostationary satellites are well known. Eclipses by the **moon's** shadow on geostationary satellites happen less often. Intelsat hired a Princeton student (end of her junior year) to work with me. In the summer of 1991 she learned FORTRAN, and calculated tables and graphs for all lunar eclipses from 1990 to 2055[3]. Amy E. Fronduti precisely followed <u>all</u> my directions, and yet had the initiative to find solutions on her own when she was stuck.

Amy and I presented a technical paper to a section meeting of the American Institute of Aeronautics and Astronautics (AIAA). It was well received. The director of Comsat Laboratories was enthusiastic, saying it was the best technical presentation he had ever seen. I wrote to two or three Princeton professors, suggesting that Amy present this talk, but no forum was available for undergraduate presentations.

W. L. Pritchard & Co. (MD). Globalstar launched a satellite system to communicate directly with hand held receivers. The system included 48 communications satellites at low altitude (not GEO) – 6 satellites equally spaced in each of 8 orbits. But they started service with 40 satellites (5 satellites in each orbit). My job was to program the transition, to move 4 of the 5 satellites in each orbit to make room for the 6th satellite. A maneuver to start or stop the drifting of a single satellite required several commands from the satellite control center. Globalstar wanted no more than one maneuver per day. The second constraint was to maintain communications for the users throughout the transition period of several months.

I made out a transition schedule, proved the service was acceptable, and showed the results with graphs. I was surprised when one graph showed that near a specific latitude, at a few times of day, users had better communications with 40 satellites than with 48 satellites. Globalstar engineers had made similar calculations, but had their results in tabular form. They had missed this interesting anomaly (but not important), because in a large table of numbers they hadn't noticed it, until I told them where to look. Graphs often provide more information than tables.

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[1] Morgan, W. L., and G. D. Gordon (1989). *Communications Satellite Handbook*. Wiley, New York.
[2] Gordon, G.D., and W. L. Morgan, (1993). *Principles of Communications Satellites*. Wiley, New York.
[3] On Sep 23, 2014, a geostationary satellite at 180° E will have a 3.4 hour partial eclipse by the moon.