NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
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IN PARTNERSHIP WITH NOAA HERITAGE AND THE NATIONAL WEATHER SERVICE

AN INTERVIEW WITH THOMAS WRUBLEWSKI

FOR THE

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INTERVIEW CONDUCTED BY

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TRANSCRIPT BY

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Molly Graham: This begins an oral history interview with Thomas Wrublewski. The interview is taking place on September 26, 2019, in Lanham, Maryland. The interviewer is Molly Graham. We'll start at the beginning. Could you say where and when you were born?

Thomas Wrublewski: I was born in Havre de Grace, Maryland, May 16, 1954. Also, the birthplace of Cal Ripken, Jr.

MG: Was he a big figure in the town?

TW: No, he grew up in Aberdeen, but he was a famous baseball player. He's the only other person I know that's famous from that hospital.

MG: How did your family come to settle in that area?

TW: My father grew up in New York City. He was in the Army during the Korean War. He actually worked on the first ENIAC [Electronic Numerical Integrator and Computer] computer, ENIAC I and II, that did ballistics research at Aberdeen Proving Ground.

MG: Is that how he ended up in Maryland?

TW: Yes, yes. Aberdeen Proving Ground, they were Army, and they did ballistics research. Now they're merged with Edgewood Arsenal, which was, I don't know, twenty minutes down the road. They combined two bases, and Edgewood did biological and chemical warfare stuff. Actually, one summer, I worked for them. It was a very interesting job. I had a new appreciation for people that went to the Vietnam War because one day, we were out of the field measuring the air quality because they had buried mustard gas after the war. You could smell something was coming up. We were out there a little bit too long that day. You had to get clearance to go out there, but some sirens went off. The next thing we know, some artillery shells are going over our heads from about ten miles away, landing a few hundred yards down the road. We were having trouble adjusting our equipment that day, so we were out there longer than planned. They forget we were out there. That was as close as I ever wanted to be to artillery fire.

MG: Oh, my goodness.

TW: Yes. [laughter]

MG: Did your father spend his whole career –?

TW: Yes, his whole career was with the Army. He retired after thirty years. In fact, he was one of the people that if there was ever a major nuclear war, he had a badge, and he was supposed to go someplace that was underground that certain select people were supposed to survive after the war to restart things.

MG: Would it have been Mount Weather?

TW: He didn't really talk too much about it. All I know is he worked with the first computers.

MG: What did he tell you about that experience?

TW: Not really much, other than – some of the things they had were state-of-the-art. They had a fire detection system that shot off a gas to shut down fires, but they had to get everybody out of there because people couldn't breathe. It was a Halon system. It was funny because our house wasn't airconditioned growing up, but he worked in air conditioning all day. He was spoiled, going to work being in air conditioning.

MG: Is your father still alive?

TW: He has passed away.

MG: What would he think of computer technology today and the role they play in our lives?

TW: Computers have come a long way. It was interesting; I was looking at the NOAA 13 failure report the other day. It was written in 1994. One of the recommendations was for us to look into artificial intelligence back in 1994. We just had a briefing this past week about artificial intelligence, how it's going to start getting on our satellites and into our ground systems. I forgot that in 1994 it was recommended. In fact, years ago, when I went over to France, the French and their ground systems were already starting to use artificial intelligence. But we were a little leery to do that. We always liked to keep a person in the loop and have a person make the decision to shut an instrument off or shut a spacecraft off, whereas the French were more willing to rely on software to do that. So it's come full circle, and that's probably the wave of the future. You're going to see more artificial intelligence being done.

MG: Can you tell me more about your mother and her background?

TW: She was mostly a stay-at-home mom, but she went to college in New York, to Hood College. She also went to Towson State University of Maryland, and Morgan State University - Maryland, got her master's degree. She did some teaching in history. She went overseas to learn Polish. She went to Poland. I think she got arrested for jaywalking somewhere. I think it was in Warsaw, but she was an interesting lady. When she became an empty-nester, she did that and did some substitute teaching. She actually taught history at Morgan State University for a while.

MG: Tell me a little more about your immediate family, your siblings.

TW: I have an older brother who was in the Air Force. He's now retired. I have two younger sisters. The oldest young sister went to Maryland General Hospital in Baltimore and became a nurse. She's been a very successful nurse and was actually an RN [registered nurse] at two different places, one hospital, and I think one nursing home. Now she's working for a pharmaceutical company and traveling all over the United States. My other younger sister, she went to the University of Maryland and had a degree in soil science, but she's been working for the city of Havre de Grace in their water treatment plant all her career.

MG: Tell me about the schools you attended, growing up.

TW: Growing up, I went to the University of Maryland, Baltimore campus in Catonsville, Maryland. That's where I got my bachelor's degree, which was in geography. I originally started out wanting to be a biology teacher. The science there was pretty rigorous. I took a class in physical geography and had a new teacher that had just come from UCLA [University of California, Los Angeles]. He was a very impressive teacher. Even back then, in the '70s, was telling us how, in the future, there was going to be more severe storms and more severe weather. He was, I think, ahead of his time and got me more interested in the physical side of geography and climatology and weather. I became a geography major, while still trying to get the right science credits to be an earth science teacher, instead of a biology teacher. So I got the credits I needed to be an earth science teacher. Then, in the beginning of my career, I was an earth science teacher in Prince George's County, Maryland.

MG: What was the name of that professor? Do you remember?

TW: His name was Howard Mielke. I think it was spelled M-I-E-L-K-E. I had several professors out there. I took an ecology course. There were several that turned me more towards the physical environmental type part of science.

MG: What year did you graduate?

TW: 1976. I started teaching right away. At that time, if you were a science teacher, you could pretty much go wherever you wanted in Maryland. So I went to a lot of interviews and was offered jobs in multiple places. Some of the places, though, were a little bit too challenging to me. I was going to have students that didn't speak English as their native language, and I didn't think I was up to that, even though the salaries were higher in that county. So that's why I went to Prince George's County. I also took some community college courses, both in Harford County, where I grew up and also here in Prince George's Country, Maryland, as well as some small courses, like at Howard University, that specialized in microwave remote sensing. When I was a teacher, I worked my summers for NOAA [National Oceanic and Atmospheric Administration] doing things like their annual inventory down at Suitland, Maryland. After a while, after a few years of working for them during the summers, they asked me what would they need to [do to] convince me to quit teaching and come work for them full-time. Initially, I did take a little bit of a pay cut to come work for the government, but I don't think it was a bad decision salary-wise.

MG: You taught for four years before you came to NOAA.

TW: Yes, I spent two years at a junior high school in Upper Marlboro, Maryland. Then I went to Calvert County to teach in a high school. That's when we were having the energy crisis, and we were having to use our planning periods to go out and wait in line and get gasoline. So then I came back to Prince George's County and taught in a middle school. After those four years, that's when I came to work with the government full-time because every summer, I was working part-time for the government.

MG: In the meantime, had you earned a graduate degree?

TW: No. I was going to Bowie State University, and I took about eighteen credits towards a master's degree and secondary school supervision. But, I never finished it because when I came to the government, it was more important that I learned things like statistics and computer science and some Fortran computer programming, and things of that nature. They sent me to the University of Michigan to learn a little bit about infrared physics and remote sensing. So I took a different career path and took a lot of short courses that the government was offering. At the time, a lot of it was just learning from peers and others because satellites were a new thing; it was an up and coming, growing field.

MG: What was your first title? Who were you working for?

TW: My first title at NOAA is still my title; it was a physical scientist, but I was working in the calibration group. We had four people in the group. Two of us worked on the polar-orbiting satellites, and two of us worked on the geostationary satellites, but we had a ten and a half hour workday. So one day a week somebody was off. I would have to cover for that person on their day off. So you learned both jobs. You learned to do the polar side, as well as the geostationary side. Back then, the geostationary side was basically making a pretty picture for TV. The instrument had eight photomultiplier tubes. You would have to get the calibrations right and normalize the channel so that the picture would look right so you wouldn't have striping in the picture. That was one of the things I learned. There was a lot of just physics that you were being taught on how infrared and visible channels work. The visible channels are normally what they call linear calibration, and you have two points; you look at space, and you look at a warm point, like inside the instrument, and you draw a straight line between those two points. When you get data that fits on that curve – I call it a curve, but it's a straight line – then you know what the temperature or what the brightness level if it's visible, should be. Versus the infrared channels tended to have – they tended to be nonlinear. So when you did the prelaunch calibration, you would have to come up with the equation for the curve, be it a quadratic with a third or fourth or fifth-order polynomial that people would have to come up with this equation that any points that you get in orbit would fit on that curve. You would translate them into the right temperature. That was very interesting work to learn all the physics and science behind that. Some of the instruments weren't real well-calibrated back then. We were just learning how to do a better job and how to test them at different temperatures. My job was to primarily – on the TIROS [Television Infrared Observation Satellite] side, we had several instruments. So I would look at summary statistics for how well the instrument did every orbit. This was before we had computers that would automatically plot data. So we would maybe pull points off and manually plot the data to see how things were doing and to see how temperatures would change seasonally or during the course of a week or a month. So it was very interesting for me, and always exciting.

MG: Were you with NESDIS [National Environmental Satellite, Data, and Information Service] at the time?

TW: Well, it was called NESS at the time, National [Earth] Satellite Service. They changed their name later. But, yes. It was in the same area that I had worked in previous years doing their inventory for them. Also, back then, some of the computers were custom-built. We actually had technicians that would fix the computers if they broke. So if little lightbulbs or transistors or diodes or LEDs [light-emitting diodes] or something burned out, we had spare parts. They would go take out the old parts and solder in the new parts. We also had a huge tape machine that would record the data. It was called the TBM, terabyte memory machine, and it had really thick tapes that recorded the data. I know I got impressed, very early on, on the data rates, which in today's standards were not that high, but once we had an anomaly on the AVHRR [Advanced Very High Resolution Radiometer] instrument, and that instrument, the mirror, scans the earth six times a second. When I read about things like that, my mind didn't really appreciate how fast six times a second is. If you can think about a ten-inch mirror going around in one second six times, it's like watching your kitchen exhaust fan, but my mind didn't really appreciate how fast that was. It takes data, what they call, on a ten-bit system. So the scale went from zero to 1023 or one to 1024, however you want to call it, whereas things that were a thousand and twenty-three counts would be very cold, and something that would be low numbers would be something very warm. At any rate, we had an anomaly one day. We didn't know exactly where in the orbit the anomaly happened, so we went to go dump all the data from that one instrument. I think we went through four boxes of computer paper and burned out a printer printing all the data that came from that instrument. It made me appreciate how much data that instrument puts out.

MG: Was all of that data analog?

TW: Yes, but it was numbers. Like, "Oh, I forgot how many times across the scanline it was," but it was a lot of data. Yes. That thing moving six scans a second, it was pulling in quite a lot of data.

MG: Can you explain, for the record, the difference between the POES [Polar-orbiting Operational Environmental Satellites] and the GOES [Geostationary Operational Environmental Satellite]?

TW: Basically, the POES fly at a much lower altitude. They're at around five hundred and twelve miles, and they're going from pole to pole, so from the North Pole to the South Pole. The earth is turning west to east, so the polar-orbiting satellites see every spot on the earth at least twice a day. The ones closer to the poles will see more often as the earth is turning, whereas the geostationary satellites are way out there. They're at 22,300 miles out there. They're at what's called the sweet spot where geostationary and communication satellites like to be, that, as the Earth is turning, they're – I say, "slowly," but, really, they're going pretty fast, too. The polar-orbiting satellites are going more than twice as fast as the GOES satellites. That makes sense, too, if you think about gravitational pull. If you're closer to something, the gravity is stronger. So if you're closer, you have to travel faster, or gravity is going to pull you back in. At any rate, the geostationary satellites, as the Earth is turning, it's slowly turning with the Earth. I say, "slowly," but it's not really that slow. It gets to look constantly at whatever is in its field of view. It gets to constantly look at severe storms. The other big advantage is the instrument technology. One of the instruments that we have on the polar satellites is a microwave instrument that senses passive emitted radiation from the Earth. So with the microwave data, we know what the temperatures are, along with the infrared data; they married the two together. So we can do the surface of the Earth's temperature all the way up high into the atmosphere, and do the temperature roughly at one-degree kelvin resolution every kilometer, which is pretty amazing. The sea surface temperature part of it's even more amazing because the AVHRR instrument, even though it's 1978's technology, it can do one-kilometer resolution. Now with improvements in the algorithms, they're doing sea surface temperatures to the nearest quarter degree. Sometimes I kid people that you can go to NIST to get the best-calibrated thermometer and sit out there with your boat and not do that well. So it's pretty amazing what we're doing with the satellite technology. Whereas when I first started, they used to use the buoys to correct the satellite data. Now they know the satellite data is so good and so reliable, they know when they should take buoys out of service because the buoys need to be serviced or recalibrated. So we've come a long way in the thirty years, like with sea surface temperatures. Of course, in the future, people want to do better than just surface. They want to go three meters deep. So now you're talking [about] a new technology. You can't just have passive microwave and infrared instruments. Now you need to have active microwave instruments, like a radar, and send the signal out and get a reflection back. The cost goes way up for those more expensive instruments. At any rate, the geostationary satellites, they don't have the microwave technology yet, although the Weather Service wants that technology, and there's people out there at various places that have ideas on how to do it now. It will probably be on the next series of geostationary satellites. But with the microwave data, we can see through and below the clouds, so we know what the rain rates are, we know what the humidity levels are, we know if it's snowing, we know if it's sleeting, we know if it melts during the day and refreezes at night. That's all information that you get from the polar-orbiting satellites that you can't get from GOES. GOES can basically tell you there's a big, tall cold cloud there, and they can tell you what temperature levels are if there's not a cloud in the field of view. So you really need the microwave data and the two satellites to work together. But the big advantage of GOES is you get to look at whatever's below you all the time, versus us only being able to see that twice a day. That's why we need more than one polar-orbiting satellite, too. The polar-orbiting satellite, the older ones had other applications. With the data collection system, we were tracking animals that were migrating. There's free-floating buoys out there, so they're monitoring buoys. There's stream gauges that will automatically go off when there's flooding, so they're getting data from those automatic flood buoys. There's also the search and rescue system, and that's pretty amazing, too. Now if you have a GPS [Global Positioning System] capability on your search and rescue transmitter or your personal locator transmitter, whatever you have, that GPS signal will let us be able to know within about sixty yards where you are, so about half the length of a football field. If rescue people can get to you quicker, the quicker they can get to you, the chances of your survival goes way up. In the old days, we had to rely on two or more polar-orbiting satellites to get that signal. Then they did a doppler triangulation to figure out where you were, but it wasn't as accurate as if you had the GPS. A GOES also gets the search and rescue signals, too. That's a pretty important part of the system, in terms of saving lives every day.

MG: Was that method deployed or used when Malaysia Airlines Flight 370 went missing in 2014?

TW: I don't know the details on that. There are different transmitters. There are some that ships have that will automatically go off when they're wet. There's others that will automatically go off – because some of the problems they have are false alarms. Like, if a plane hits the ground too hard, sometimes their search and rescue transmitter will go off so they have to deal with the false alarms they get, or if somebody just throws it too hard into the trunk of their car or something like that. So that's been an issue, but they've been perfecting that. They've also been putting longer life batteries in them now they have the lithium-ion technology. So, yes, the search and rescue has come a long way, and they've made improvements. Also, the older satellites had space weather capability, too, so that we had instruments that could look at different levels of ions in the atmosphere. So when you have the aurora borealis, and you have magnetospheric eruptions or ionospheric eruptions, that was important because the ionosphere is used for certain communications, bouncing radio signals. If the space weather is high and the ionosphere is messed up, airplanes can't do their pass over the North Pole because they lose communications, and they want to have communication with planes all the time. So planes are just one industry where they have to redirect planes, and not go over the North Pole. At any rate, the space weather also affects power grids and things of that nature. They have to recycle because electromagnetic fields can actually affect transformers on the ground, so power companies are very interested in what the space weather is doing. Of course, astronaut safety, too. You don't want the astronauts walking around if there's increased particle activity up there. There's actually been some research on pilots and stewardesses showing that they're being exposed to more radiation than normal people, and having more incidences of cancer. So there's been discussions about – should they fly at lower levels when radiation levels are high? Or are there other things they can do? So, we keep advancing our knowledge of how things are interrelated, but space weather has been a big part of our program, as well.

MG: I interviewed someone yesterday who talked a lot about volcanic ash. Can that interfere with or be measured by the satellites?

TW: The volcanic ash is more if it gets in your engine; it can clog up the engine basically. We have several instruments. The visible instruments, AVHRR and VIIRS [Visible Infrared Imaging Radiometer Suite], can see the cloud. But our OMPS [Ozone Mapping and Profiler Suite] instrument, the ozone instrument, can also detect the sulfur dioxide and other trace gasses that are out there that are an indicator of where the cloud's going. Not just planes; it's human health, too. You don't want people breathing these noxious gasses. Things like sulfur monoxide, if it combines with water, it becomes sulfuric acid. Then you have acidic rainfall, too, in those areas. In fact, the Canadians used to be upset with us because we'd be burning a lot of coal in some of our power plants, and the clouds would be going towards Canada, so they'd be having more acidic rain, which would be killing their coniferous forest, their trees.

MG: This might be a silly question. How does the satellite get up and stay up?

TW: That's interesting, and it's actually changed over the years. In the earlier days, we used a lot of intercontinental ballistic missiles. When I started, we were using the Atlas E rocket. The Atlas E was an interesting rocket. I have a video somewhere that shows an Air Force captain pressing in on the side of the rocket because it was made of spun aluminum and about as thin as a dime. He could literally press in on the side of the rocket, like you could flex an aluminum soda can. If the rocket wasn't fueled, it wouldn't stand up on its own. They used to have to have it fueled or put it in what's called "stretch mode." They have to make sure they're holding on to it at both ends. John Glenn was brave enough to get on one of these rockets that wouldn't even stand up on its own. At any rate, we were using previous rockets that were intended to have ballistic missiles on them. We took them out of silos and refurbished them. Most people know about WD-40. Well, WD is water displacement. In the early days, WD-40 was used on the Atlas rockets to keep them nice and shiny and keep them from rusting. That's one of the early applications of WD-40. At any rate, the original launches were what we called a ballistic trajectory. The rocket would pretty much go up at a little bit of an angle, but the satellite had on its – on the base of the satellite, there was also something called an apogee kick motor, AKM for short. Those were made north of here in Elkton, Maryland by Morton Thiokol at the time; now, I think they're just called Thiokol. It was roughly about a thirty-seven inch round. I call it a big firecracker, but it's a big solid rocket motor. So when the launch vehicle launched a satellite to the right altitude, then this apogee kick motor on the satellite had to fire, and that basically circularized the orbit and put the satellite in the orbit around the Earth. If that motor didn't fire – and we were lucky; they always did – but if that motor did not fire, the satellite would come right back down and land in the ocean, just like shooting a bullet up in the air; it's going to come right back down. So the early satellites had to have this apogee kick motor, which had a whole list of safety issues related to it because you didn't want to have any static discharges or anything because these things could fire on the ground and be a really bad day. We also had to have propulsion systems that, when this solid rocket motor is firing, we had to have thrusters that could control the satellite's axes, and keep it heading in the right direction. It was a whole different challenge back then versus when we came along to the Delta II rocket that I think was used for maybe NOAA M – M or N, I forgot which one. The Delta II rocket we no longer needed that apogee kick motor. The Delta II rocket would put us right in the right orbit that we needed to be in. Ever since then, we got rid of that apogee kick motor. So, very good question. Now some of the rockets have more capability, so we're able to launch some other smaller satellites maybe along with those, or things that they call CubeSats, or some potential rideshare smaller satellites. Some of the rocket fairings are way bigger, too. You've probably heard of some missions where the fairings don't come off. Well, the fairings are pretty heavy. If the fairings don't come off, you're going to land in the ocean near Antarctica or somewhere. One of my early launches when I was still working at Suitland as a calibration technician, NOAA-B was a launch failure. That was an interesting launch because the satellite had a way of sensing liftoff. It had an inertial measurement unit on it and sensed the vibration of liftoff, which started a timer. The timer was set to – they had a voting scheme for how to know when you've separated from the rocket. That particular rocket for NOAA-B was very out of family. The rocket underperformed had what they called a very slow burn. Basically, all the conditions were set that we said, "We must have separated already." So we thought had separated already, and we hadn't. If we had stayed on the rocket long enough, they claim they would have eventually gotten us there, but we tried to separate too early and lost that mission. That was very sad to see that mission lost, but that was one of the first ones that I worked on.

MG: Can you describe why it's so sad? What goes into a launch?

TW: Well, people spend years. Typically, making an instrument is at least four years, four years of somebody working on an instrument, and months before that, people developing the specifications, reviewing proposals, awarding the contract. I was very fortunate in the late '80s to work with NASA[National Aeronautics and Space Administration]/NOAA people, developing requirements for the new instruments. We always try to make them as good as or a little bit better than the ones before. Even though we didn't have back then what's called level one requirements, we would have maybe a two or three-page letter from the Weather Service saying, "This is what we'd like you to improve in the future." We would take that to heart, and try to do that in various ways. Some of those ways, like you could reduce what they called "jitter" in an instrument, make the instrument more stable, make the noise in the channels lower. By doing things like – the HIRS [High-resolution Infrared Radiation Sounder], the infrared sounder, had a filter wheel in it that spun around at ten hertz, and it had nineteen filters in it. We could make that filter wheel stiffer and make the channels quieter. Every time we built an instrument, we tried to make it better. Some of the earlier instruments – for example, the HIRS had three different detectors; two for two sets, longwave and shortwave infrared, and a visible channel. They used the visible to know whether there was a cloud in the field of view or not. The earlier instruments didn't have a requirement that all three of those detectors had to be looking at the same column of atmosphere at the same time. Fortunately, all of them that were built, except for one, met a requirement that wasn't written. They all were looking pretty much at the same column of atmosphere. In fact, the one that did not meet a requirement like that flew on NOAA-D, which was – that was another story, too. NOAA-D was our "hangar queen" satellite that sat in the factory for about ten years. The reason for that was the Russians had already put up a search and rescue system on a Russian satellite. So we were in a hurry to put up our first search and rescue system on NOAA-E, which was a little bit bigger satellite. So NOAA-D got put to the side, and NOAA-E was launched before NOAA-D to get search and rescue up there. It was a whole set of different issues that we had to deal with.

MG: I think you described in the materials you sent me that you had worked on VAS [VISSR Atmospheric Sounder] and VISSR [Visible and Infrared Spin Scan Radiometer] instruments.

TW: The earlier GOES that I worked on, VAS was the visible atmospheric sounder. VISSR was before that; that was just visible. I was fortunate that I worked with some good scientists, like up at the University of Wisconsin, Dr. Paul Menzel, who is still there. He taught us a lot about – well, one of the problems with the early GOES was they spun at a hundred RPM [revolutions per minute]. That had good and bad parts about it. The good part about it, it was spinning like a top at a hundred spins per second, but most of its time is spent not looking at Earth. So the instrument would just step north and south basically, up and down, and that's how they would do scan lines of the earth. Then when they went to GOES-I through M, that series was what they called three-axis spin-stabilized so the instruments could look at the Earth all the time, which was a huge improvement. So they were able to totally change the technology, and get more data, and be able to take images quicker. Now you're seeing the benefits of the GOES-R series. The older instruments have started with GOES-I. It would take about twenty-six minutes to take a full picture of the Earth. Now, on GOES-R, the GOES ABI [Advanced Baseline Imager] instrument, they can do that same twenty-six-minute image in about five minutes at twice the resolution. It's tremendous advancement in technology. Their big fallback, I think, is they need to take the next step and get the microwave added, which I hope people are working on. There's people at Jet Propulsion Laboratory, MIT [Massachusetts Institute of Technology], Lincoln Lab, and over in Europe there's people. Hopefully, the time is right, maybe, to get all these smart people in the microwave world to work together and maybe build one instrument that could fly on multiple nation's satellites. That would really help with inner calibration and sharing of data. I think that's probably the next big advancement in remote sensing from satellites.

MG: I was curious about international coordination in terms of data collection and launches.

TW: When I started, we worked a lot with the United Kingdom, the UK Met Office. They actually provided an instrument to us called the SSU, the Stratospheric [Sounding] Unit. It did sounding levels of the upper atmosphere. We flew several of those. In fact, we flew one that was considered a grade below an engineering model. It was like almost Radio Shack type parts. We flew it instead of flying a mass dummy. It worked like gangbusters in orbit. It was one of the few times I actually got to sit at Suitland and send commands to turn the instrument on. That's because the British couldn't make it that day whenever we were doing it. So I don't worry too much about flying things that aren't space-qualified on a sample of one. That's like NOAA-D that we were talking about earlier, too. NOAA-D then sat around for ten years, and that was one of my first big responsibilities, getting NOAA-D refurbished and launched. We had to look at everything that was old and see what needed to be replaced. Like anything, that was pyrotechnic-related; for deployment, mechanisms had to be replaced. There were things like the hydrazine tank – that's one of the propulsion tanks – has a rubber bladder in it that was designed to operate for ten years or so. We had to get the lifetime extended on that. So we had to have the right materials experts look at that and get the lifetime extended on that. We put some of the older instruments on it, too. Some of the instruments sat around. The early AVHRRs only had four channels. Then they went to five. Now the older ones had six channels. We flew an older AVHRR instrument. I think it was serial number 101. I think it was one of the first ones. So we flew a bunch of old stuff on NOAA-D and launched it ten years after it was built. Then it lasted for fourteen years in orbit. It was funny because one of the problems at its end of life was it had too much power because instruments were failing. After fourteen years, you still had the solar array and batteries producing all this power, so they were having to offset the solar array so it wouldn't make as much power. It was not early-on anticipated to have that problem. Now, today, the JPSS [Joint Polar Satellite System] satellites, we can shut off portions of the solar panel. So if we ever have that problem at end of life, it's not such a big problem; we can just shut off sections of the solar array. But in the early days, we didn't think about that, and we had what they called shunt dissipaters, things that would dissipate the extra power. Those were starting to fail, too. So we learned a lot over the years.

MG: Are satellite lifecycles getting longer?

TW: Some things are getting longer. Most things are. Part of that is because geostationary satellites, a lot of the communication satellites, are being designed with fifteen year lifetimes. Sometimes I have to remind people that we can't build perpetual motion machines. Anything that moves is eventually going to wear out. You can reduce friction, but you can't one hundred percent get rid of friction. There's things like momentum wheels. If you think about a bicycle wheel, a bicycle wheel when it's spinning helps keep you up, it keeps you balanced, and it's very hard to fall over when that wheel's going fast. Or, if you ever hold a wheel that's spinning, like in a physics class, they used to show wheels, and you can really feel the torque. Or, a little toy gyroscope; if you play with those while they're spinning and try to move them, you can feel the torque. At any rate, they made momentum wheels last a lot longer, so they're getting fifteen or more years out of them; versus in the early days, we'd have some fail. We would have four, and you needed three for roll pitch and yaw axis, and the fourth one was called a skew wheel that could take over if any of the other three failed. But we had some failing, and we actually developed special software so we could use Sun sensors and Earth sensors to look where the Sun and Earth is, and keep the spacecraft pointed right without all three axes being carefully controlled. There's also electronic coils going through the spacecraft that you can energize to load and to unload momentum in the spacecraft. So we had people do special tasks to develop software. The computers we had were pretty minimal. Our first computers were – I don't know if you remember the Commodore 64, but it has 64K [kilobytes] memory. Well, we were flying – the first ones were 16K memory. Then we went [from] sixteen to thirty-two, and then to sixty-four, so it took us a while, basically because there wasn't computers designed for the radiation of space and the lifetime and the thermal extremes of space. So there wasn't space-qualified computers. In my mind, it's amazing what our software engineers were able to do when we had problems. They had ways, what they called overlays, to overlay software on top of software. Now we're looking at ways to automate things, too, that if they sense certain things going off-scale or out of limits, they can automatically get some software engaged that maybe will save a satellite. Both us and DMSP [Defense Meteorological Satellite Program] have blown up some batteries because we've overcharged them, and had some automated software that can sense that and take the battery offline or put it to a lower charge rate. When you think these are Commodore 64 class or less capability computers, it's amazing what the software engineers have been able to do.

MG: How are satellites decommissioned or taken out of orbit?

TW: That varies, too, by what satellite it is. The geostationary satellites, they basically just boost them up higher, about three hundred miles higher or so, and they call that a supersynchronous graveyard orbit. They're just basically going to be there until the Sun burns out. They're going to be there a long time. Versus the early polar-orbiting satellites, once we did that firing of the AKM, we shut down the propulsion system and isolate it. We never used it again and didn't put fuel on there because it takes close to – well, on JPSS, we now have a requirement to deorbit the satellites at end of life, but the early satellites didn't have that requirement. So they'll be up there for a long time, too, tumbling at end of life, and hopefully not breaking apart. At any rate, the newer ones, though we have to put fuel on. Roughly, close to eighty percent of the fuel that we put on is saved just to deorbit the satellite because you have to bring it down five hundred and some miles, and put it into the ocean. We don't have a lot of experience doing that yet, either. There's been a few NASA missions that have done it. But NOAA, it's going to be something new for us to learn. In the past, we used to let the satellite orbits just drift. Now we have the propulsion system capability to keep the orbits much more controlled, and not let them drift. That gives us much more repeatable science. So people that are doing climate and global change studies don't have to correct for orbital drift and different Sun angles and things of that nature. We are doing much better science that came along with the requirement to have to deorbit at end of life. So that's just something totally new, and you have to rely on certain subsystems to still be around at end of life to be able to bring that satellite back in the ocean. So there's more redundancy, and we have to watch that closely, that when we get down to something being single-string, somebody's got to make the tough call to bring it back into the ocean. That's going to be a whole new experience for somebody. [laughter]

MG: Can you talk about some of the cool or interesting things you've seen or measured because of these satellites?

TW: Well, sea surface temperatures, to me, is just amazing. When you think that seventy percent of the world is ocean, and we're doing better than a half-degree accuracy sea surface temperature, to me, that's phenomenal. We've seen big chunks of Antarctica break off, the big icebergs break off, that nobody would have seen before because there was nobody living there. They've captured those things with satellites. Not our satellites, but there's other satellites that have altimeters that are looking at ocean levels, and they can see tsunamis. Of course, NOAA has buoys out there, buoys that are mounted on the floor of the ocean that can detect tsunamis. We're doing a much better job with that. So not everything needs to be done by satellite. There are some things that maybe are still better done on the ground. Like with the GOES, they have a Solar X-ray Imager, so you're able to see these huge coronal mass ejections. You're able to see solar flares as they're migrating. You're able to get earlier warnings when some charged particle storm might be hitting the Earth and might affect communication satellites. If communication satellites go down, all of a sudden, maybe your gas pumps aren't going to work anymore, or you're going to have a power grid outage. There's just a lot of applications and things that – well, and the forest fire technology, too. With VIIRS, we're down to thirty-three-meter resolution; we're better able to see more exactly where the fires are, where they're hottest, and you're seeing the burn scars – where they've already been. Some of that you didn't see before. With the OMPS and other instruments, you're able to look at the ash clouds and where the various gasses are going. These are technologies that we didn't have before. With the ozone, in particular, I was amazed – we had a researcher at NOAA, who's since retired, Art Neuendorfer, who took the HIRS instrument data – and HIRS has nineteen infrared channels and one visible channel – and he was able to come up with what's called a total ozone product. The HIRS was never designed to produce that product. But, he was able to take that HIRS total ozone data and go back to when we launched the first TIROS-N back in 1978, and show that the ozone hole has been there every year since 1978, forming near the tip of South America and migrating towards Antarctica, and getting bigger, and was able to show that cycle year after year, and the various extents of it. That's just one example of that instrument wasn't designed for that, but researchers came up with a way to go back and relook at history. Same thing with the MSU [Microwave Sounding Unit] instrument, which was a four-channel microwave instrument. Now we have twenty-two channels of microwave. But the four-channel MSU instrument that the Jet Propulsion Laboratory built and first flew on TIROS-N, people were able to go back and look at climate and global change studies using just the microwave data. They had to adjust for orbital drift of the satellites, but there was a scientist that said – this was over ten years ago – saying, "We're not looking at just that MSU data. We're not seeing one definitive trend one way or the other toward global warming or cooling." That was more than ten years ago. But again, going back from the '90s, back to 1978. Now, of course, since then, it's been pretty decisive that we're in a warming trend. But that was just an example of somebody who's able to take old data and go back and look at it in a whole way that it wasn't intended for, and it wasn't intended to be precisely calibrated. The levels that they're trying to do things to is pretty amazing – the levels that they're measuring ozone to. In fact, we used to rely on National Institute of Standards and Technology, NIST, up in Gaithersburg, Maryland, to be the ground truth for visible calibrations and stuff. Some of the calibration accuracy that our science asks for, sometimes I had to push back a little because I said, “You can’t do that well in this lab. You can’t expect us to do better than that.” But a lot of our standards are traced back to NIST, that we try to calibrate the visible data. In the early days, they would look at things – like try to look at the White Sands deserts and deserts in Africa, and now, we’re able to look at the moon as another source. They’re putting deployable mechanisms on solar diffusers to get better calibration. So some of these things are letting us see things. When [Hurricane] Isabel came up the East Coast, we had the first VIIRS instrument up there, the Day/Night band low-light-level channel was originally not even a NOAA requirement; it was a DOD [Department of Defense] requirement. I was told one of the things DOD wanted to see was when caravans at night were turning their headlights on and moving at night. They wanted to be able to see that. When Isabel was moving up the coast, we had the right moonlight level, [and] were able to see the clouds of Isabel. That was a big improvement that nobody expected. When there’s power outages, we can see when the city lights go out. These weren’t necessarily NOAA requirements, but we’ve learned how to use the data better. The people in Alaska are loving our data, too, because they have the twilight conditions for so many months of the year, where they can use our low-light-level channels. They can see streams and rivers when the ice is starting to dam up and flood the areas. It’s just another example of something that wasn’t quite intended for that use, but it’s got an application. My recollection is, from the early days, the scientists used to say, “If you give us these channels at this resolution, we think we can produce X, Y, Z products.” Today, the science is a little more rigorous. They have to go out and simulate the data and prove that they can develop those products before we’ll go off and build the instruments. We’ve come a long way in terms of requirements, too. And there’s a little bit more cost/benefit analysis. Like, yes, you can do this technically, but it’s going to cost four times as much as what the old technology is, and is it really worth that added cost? There’s some things that we can probably do better in the future that we haven’t done due to cost. For example, our satellites could probably automate some things, like our Day/Night band gets switched in and out where the terminator of the Earth is. We could probably get the satellite to automate that. Because, in fact, our old satellites that had the 64K memory with the AVHRR, that satellite could determine where the terminator of the Earth was and switch infrared and visible channels in and out. Visible, you don’t want it on at night because there’s nothing to see, so you want infrared on. But we were able to develop software to do that. It’s pretty amazing what our programmers have done.

MG: How do people use this information? For example, the firefighter in California or someone in Alaska. Can they go online?

TW: Some of it is online. I know there’s specialized groups that do the fire detection. They’re using GOES data and probably data from other satellites, too. Some of it’s online. I don’t know how they’re all interconnected, but we also have a direct X-band broadcast that we’re improving for the next series of satellites, which are going to have even more data on it. Dr. Mitch Goldberg, our program scientist, he’s helped fund and spread out more of these, what they call, HRD [High Rate Data], high-resolution direct readout stations, all around the world. This will enable them to get all the satellite data down, whereas today, they just get a subset. In the future, they’ll be able to get all of it down, and they’ll be able to share it by internet or, however they decide the best way to share it. This will cut down on what they call data latency. So you’ll be able to get the data quicker, whereas, in the earlier days, we had to – the orbit is a hundred and two minutes roughly, and that data will get recorded on a tape, literally a tape recorder on the satellite that was built up in New Jersey; RCA built them. They will be played back to a ground station. Well, that data's already more than a hundred minutes old by the time it's being read down to a ground station. Our main ground stations originally were Fairbanks, Alaska, Gilmore Creek in Alaska, and Wallops Island, Virginia. We also had one in Lannion, France. Now, by having ground stations as far as Norway and in Antarctica, we're able to get the data every fifty minutes and get it a lot quicker. But by having more of these direct readout stations, you can start getting more data and start sharing it. So there's plans in place to improve the latency. We're also going to have the capability to use TDRSS [Tracking and Data Relay Satellite System] satellites; that's tracking data [and] relay satellites that NASA has. There's a system of TDRSS satellites that are up there at geosynchronous altitude. We can send data to the TDRSS satellite. So there's a cost involved to do that because they don't do this for free for you, but in theory, you can get the data quicker that way, too, by sending data to the TDRSS satellites. They also support us when we have backups and emergency issues. We can do commanding through them, as well.

MG: Who do those belong to?

TW: They're NASA satellites. There's been a series up there, and they're building a new series. So they're going to be around for a while. We've been doing studies with NASA, and talking about rates and costs and whatnot. It's going to be significant that you can get the data a lot quicker.

MG: I've been thinking that you must be so annoyed with "flat-earthers" and climate change deniers.

TW: A little bit. I saw a cartoon the other day that was funny. It showed all the planets of the solar system, and then it had Earth as a flat square. I don't know what you do. There are still people out there that don't believe. We got the data from the satellites that prove. Certainly, we're following the orbits. We have NORAD [North American Aerospace Defense Command] out there, too, that's tracking all the pieces from satellites. A little sidelight: NOAA's been working with the Air Force over the years. Once in a while, we'll put out something about our satellites being able to help Santa Clause navigate his sleigh better, and getting the infrared signal from Rudolph's nose, and that kind of thing, and using the GPS to land more accuracy, and the search and rescue if there's ever another issue. So we're keeping up with NORAD, and come Christmas Eve we're ready. [laughter]

MG: [laughter] Do you know the history of JPSS or NESDIS?

TW: I was involved a little bit with NPOESS [National Polar-orbiting Operational Environmental Satellite System]. I worked only briefly one summer with Chris Scolese, who used to be the director here at Goddard [Space Flight Center]. He had a team of people that were independently looking at the NPOESS contract before it got awarded. In general, we didn't have any big issues with it. It was more administratively trying to get NOAA, NASA, and DOD to all work together. One of the problems they were having is if DOD did a funding cut, NOAA felt like they needed to do an equivalent funding cut. These programs need to be adequately funded. We've had some real serious funding issues. Sometimes even when you're successful – like when we were doing NOAA-K in the late 1980s, we actually got ahead of schedule, and we were underrunning. Then, somebody decided to take about ten or more million out of our budget to go do climate and global change studies, which needed to be done, too, but as a result, we lost our place in the factory with all the boxes that were being built. They had to be put on hold, and you can't just necessarily get back in line where you need to be. So we wound up spending a lot more money because we got delayed for a good reason, but it was disheartening for the team to be working so well and get ahead of schedule. Then we actually had a program manager at RCA get fired over this, but it wasn't his fault. In the beginning days of JPSS, some things were not done. Like, NPOESS had something called a low-rate data stream, which was an upgrade from the automatic picture transmission that TIROS does. It basically was going to cost about ten or eleven million to add it to the satellite. Because of that cost, it got cut, and the Navy really wanted it. One of the reasons they wanted it is, it's much easier to receive that signal on a ship that's moving around in the ocean than some of the other things. I felt bad because NPOESS people did all the work on developing the requirements for it, and here it fell through the floor. Then when JPSS-2, 3, 4 came along, we made it part of the study before we put out the request for proposals. Amongst four different companies, the highest cost was something like three or four million dollars. Some were practically giving it to us for free. So some things probably weren't done due to cost reasons. There's other things. This automating of software that people want to do a cost/benefit study, whereas, in the old days, we just would do something because it made sense – "Let's go do this. It's the right thing to do. We don't need to go study it to death," kind of thing. But there's a little bit different mentality. Our simulators on JPSS – we have maybe a thousand pages of requirements, whereas on GOES N, O, P, back in '97 timeframe, we wrote maybe four pages and managed to get the simulators we needed that worked. To me, a key requirement is that they don't fail, that they work, that NOAA can rely on them. We have what was called a mean time between failure requirement. That's something that's not even a requirement in these thousand pages. So it's very difficult for us to write perfect specs, too. It seems like we always miss something. When we do stuff on firm-fixed-price contracts, it's hard to make changes. The NPOESS people had a requirement that carried over from DMSP, that the satellite be able to go for sixty or more days without any contact with the ground. Should a hurricane wipe out Wallops Island, Virginia and Suitland, Maryland, and wherever, and here the satellite could keep going, keep everything running, keep broadcasting data so all the other stations around the world could keep getting the data. That got killed for JPSS. We were told we didn't have a requirement; it was a military requirement. I think that's one I probably would have kept because – and DMSP developed it because they had Earth sensors and [the] same stuff as TIROS had. They spent maybe three million or more on the software, and we probably could have got it for a whole lot less than that since they did all the nonrecurring development work on it. Sometimes we do things because money is that tight. We don't necessarily make the best long term decision. Some of it might be political, that you have to show some pain when money is tight. So we've had our share of pain, but the NPOESS people did a lot of good work. I know there was a U.S. Air Force captain that worked on the space weather requirements on NPOESS. They changed one word in the requirement somewhere, and it meant basically that they didn't need to put the space weather instruments on every satellite. They could only put it on one of the four. When I uncovered that, that was like a two hundred million dollar mistake. You could fix it with money, but it was a big mistake that somebody made. So it's very difficult. They were also doing new things. They were going to SpaceWire, what they called data busses for the high rate data that hadn't been built, wasn't an industry standard for it. Some of it was pushing the state-of-the-art, and that's one of the things we get criticized for, that we like to do low risk, low-cost things, and not push state-of-the-art too hard. Sometimes we do, and we get burned by it, but you have to push a little, too. You have to find a happy medium of making progress, but you also have to realize your system has to work 24/7 365 days and be very reliable and maintainable.

MG: JPSS gets criticized for this?

TW: The program in general. Because it takes so long, it takes so long to go from requirements. Then you usually have to do phase A and phase B studies. Then you have to procure competitively and get the instruments built. Then you have to get the spacecraft built. Who knows what rockets are going to be around in ten or fifteen years anymore because the rocket industry has changed so much. It's pretty difficult to come up with all that and to do it on a fixed budget when things keep changing. Some things, like computer technology, used to always be getting faster and faster and faster, and sometimes cheaper, but it's leveling off now. It's not increasing like it was. It's very difficult to predict what the future's going to be in some of these technologies.

MG: When was JPSS formed or founded?

TW: I don't have the exact history, but there's a presidential directive that I can send you separately that basically has the end of NPOESS and the transition. We were fortunate that some people, like my former boss, Jim Morris, worked on NPOESS. So we were able to get some people to transition over, and some of the NASA people – like, Pam Sullivan was our first observatory manager on the NASA side, but she had also worked on the VIIRS instrument with NPOESS. So we were fortunate that we had some people transition over, some, like myself, that read the requirements and looked at proposals. At any rate, that helped a little, but there were also a lot of people just trying to figure out where all the money was spent, too. So that took a while just to do all the bookkeeping and accounting. Sometimes there's termination charges when you cancel a contract. So there were a lot of other distractions going on. You need a core team to be focused. We were pretty much told for JPSS-1 that we were pretty much buying the same as what NPP [National Polar-orbiting Partnership] was. So our hands were tied in terms of making too many improvements, unless they were what we would call low-hanging fruit, things that were easy to change and low-cost, low-risk, let's go do the right things here. For JPSS-2, we had a little bit more freedom to expand things. Even the instruments – they're learning each time they build an instrument. They're not production line. People tend to think that because we're launching another set of the same instruments, there's production line. But each time you learn something more, or you find that something that was built for NPP over ten years ago, you can't get the parts anymore. The new parts are slightly different, don't work exactly the same, and you wind up having to redesign your electronics. Usually, that's a lot of work. You would think it'd be a little easier than it is, but it's not.

MG: Before we were recording, you talked about TIROS. Was that the predecessor to GOES and POES?

TW: There was an early TIROS series that predated 1978, that goes back to the first April 1, 1960 launch, where they were just launching – basically had a visible instrument. They added infrared to it later, but the very first one was just visible. So that was your first real, I'll call it, semi-operational view of clouds and weather from space. There was the Nimbus series on the NASA side, where they had similar instruments. We benefited from them, and they were precursors to the HIRS instrument, the MSU instrument, and the AVHRR instrument. TIROS-N was actually funded by NASA. In the early days, NASA would fund the first satellite, even though NOAA operated it. That reduced our risk. We also had data from DMSP satellites over the years that we are now sharing quite a bit of that, too. But their emphasis was more on imagery, and that's why their microwave instrument was a conical scanner rather than a long track scanner because it gives better imagery. Whereas, we were more focused on the atmospheric temperature and humidity levels of the atmosphere – so more of importance to the National Weather Service modeling. The polar data is roughly eighty-five percent of the data that the Weather Service puts in their models coming from polar-orbiting satellites. So that's why the polar-orbiting satellites are so important. Plus, the polar-orbiting satellites can see the whole Earth and see the Poles, and the geostationary satellites do not see well up to Alaska and the Poles at all. That's another big difference between the two series of satellites. But they're complimentary, and you need them both.

MG: I wanted to ask more about how your career evolved unless you have more to add about the satellite technology.

TW: I've just been very lucky, being in the right place at the right time. When I was working at Suitland, I was very fortunate to be exposed to both the geostationary and polar instruments and learn how they were calibrated. It was really, to me – probably due to my own ignorance – reading about things – my mind just never pictured properly how they really looked. For example, the microwave instrument the Jet Propulsion Laboratory built had four channels, but in my mind, when I read about it, I only pictured one scan mirror, but it had two scan mirrors. It had a motor in the middle, and two scan mirrors on the side that brought in the four channels. That was an interesting motor, too, because the drive belt on the motor – actually, the drive belt was like a nylon belt that came from the IBM Selectric II typewriters in the early days. It was the exact same drive belt. They life-tested it and everything, and that's what drove that instrument. So you talk about technology, that's an interesting use of things. NOAA sent me to school to get the additional math and science and physics, and I was working with some very smart scientists. We didn't totally characterize some things. Like, the HIRS instrument had a bunch of optical elements in it; it would have mirrors, beam splitters that would split infrared and visible channels, and other lenses. We would look at all the pieces in the instrument and how well they reflected light and transmitted light and do calculations here on the ground, and test the piece parts and sample piece parts over various wavelengths to get all this data and convolve it into here's the real spectral response for this channel. That was a lot of scientists working on a lot of different data, and it had never been done before. Some of it was learn as you go. Back then, we had little Texas Instruments calculators; we were calculating and writing formulas for, knowing the Planck function and radiation curves. It was very interesting, and I worked with some really good people that were very patient with answering my questions. My first day at Goddard Space Flight Center, when I came out to work on GOES I through M, my very first day they handed me about ten inches of paper, put it on my desk, and said, "Here, read this because tomorrow the proposals are coming in." So I had to read the requirements. The next summer, I spent reading proposals and asking a lot of questions with some very good scientists and engineers, and learning from them. In fact, one of the things we learned – and this was just bureaucracy on proposal writing – is some people had a hard time reading certain type-size, so in the future we learned [to] specify the type size so that it's a little bigger and easier to read, and to limit how many appendices they could send in because one company literally sent a tractor-trailer full of books because we didn't limit the number of appendices they could put in. We limited the number of pages in the proposal, but appendices could be unlimited, and we had to read it all. So it was a lot of work. At any rate, I was very fortunate to work with a lot of good people over the years, both NOAA and NASA that were very patient. I always felt that on the NASA side, they were a little more open to tell you everything they knew, but a lot of the people I worked with were older, so I think they felt an obligation to teach the younger people. I was fortunate that I was able to travel and tag along with a lot of people. I was telling somebody the other day – we had one systems engineer, Gay Hilton, when we were first launching NOAA-K on a Titan II rocket, we're sitting at a meeting. The Titan II rocket had launched many times. The Air Force had reviewed it. Aerospace Corporation had reviewed it. This systems engineer was telling them their software sequencing was wrong because there's bolts that hold the rocket to the launchpad, but yet, the rocket has software that if it sensed insufficient thrust from the engines, it could shut the rocket down. He said, "But you've already fired the bolts that hold it to the stand, and now you're waiting for a gust of wind to blow your rocket over." They all said, "No, no. That can't be true." They went off and did a little meeting and said, "Yeah, he was right." But this had been through all kinds of reviews, lots of launches, and nobody ever found that problem that could happen, never happened, but it just makes you appreciate how much attention to detail you have to have. In the NOAA-13 failure report, that was NOAA-I, I became a believer in thirteen being unlucky because it failed thirteen days into the mission. Basically, the reason why it failed is the design in the power system wasn't very forgiving. There were some screws that weren't carefully controlled in their length, and some were a little bit longer than others. The technician would go get the screws and hand put them in. He also had an option whether he put one washer or two under a screw. One screw, they think, after thermocycling in orbit – heating and cooling expands and contracts – slowly worked its way through some insulation, caused the shortage in the power system, so shorted a battery out. At that time, we were going over Europe, which was maybe a five-hour period. It was long enough to drain all of the power down out of the satellite. If we had known soon enough what went wrong, we could have taken that battery offline and done the mission with the other two batteries. We didn't find out soon enough what went wrong, but it made you appreciate the attention to detail that these technicians had to have and how detailed the design needed to be, and how you need to carefully control things. They think they lost one of the Landsat satellites after launch because a piece of tubing, they think, exploded in the propulsion system. It made you appreciate how well you have to examine things, how well you have to control things. We do a lot of testing, but you can't test forever, too. You got to eventually launch. [laughter] If you test too much, you wear stuff out. So it's been a very interesting career path, and I've been very fortunate to work with a lot of very good – I call the "A-Team" – that I've been able to work with the A-Team on most of my programs.

MG: When you were talking about the screw, what kind of difference in size are we talking about?

TW: It was really small. Related to that is the type of insulation that you have. If you have a Teflon insulation, it tends to be a little softer. If you bend it, it does what they call cold flow. It will be weaker at the bend. In fact, people say the internet isn't always true. A few weeks back, I was looking up the GOES-G failure [report]. GOES-G was one of my GOES failures. I worked on the instruments on GOES-G. They probably had the best instruments we ever built. I got to see them go into the ocean because the rocket has explosives on the rocket. So if it's going off-course, somebody on the ground can press a button and blow up the rocket. It also has software that can automatically blow itself up that scares me, but there's no explosive stuff up in the fairing where the satellite is. So that one they blew up the rocket and you could see the satellite falling back down to the ocean. At any rate, what they think caused the rocket to fail was the original wiring in it had asbestos insulation in it. OSHA [Occupational Safety and Health Administration] wanted to make them stop using asbestos insulation. So they went to Teflon, and they think there was a piece that was rubbing against metal during the launch phase that shorted. But on the internet, it said the satellite was hit by lightning. I said, "No, that didn't happen," because we have requirements that you can't launch if there's lightning within ten miles or something. At any rate, the internet is not correct. [laughter]

MG: [laughter] So what was the fate of the NOAA-13?

TW: NOAA-13 is still up there, tumbling. It only worked for thirteen days. In fact, a few years ago, some of us came up with the bright idea that we didn't think of at the time, which is: okay, the satellite is tumbling, solar array, and everything is all deployed. When the satellite is going over Antarctica, it's probably getting reflected sunlight, hitting the solar array, even though it's tumbling. So the solar array is getting sunlight reflected from the snow and ice as well as from the sun, and that there was probably enough power on the spacecraft, when it's over Antarctica, to re-turn the satellite back on. We had what was called VHF [very high frequency] command capability. We have S-band and VHF. Well, NOAA no longer has the VHF command capability, but if we still had the VHF command capability, somebody said, "We might be able to try and command that thing back on after all these years," but no one thought about that years ago when it failed. That just shows you how you get smarter with time. It might not have worked, but it was something worth trying if we still had that capability. That would have been really amazing to recover a satellite after all those years.

MG: How do you lose a capability?

TW: It just went to a newer technology, a more reliable – just like our data rates have gone up, so S-bands are lower data rates. Now JPSS has a Ka-band capability. With the Ka-band, we can send more data down faster. Because satellites are going so fast, on the order of seventeen thousand miles an hour, which is really fast, you only have contact with your ground station a maximum of twelve minutes. So all your playback of data and recorders and sending commands up all has to be done within those twelve minutes or less. Versus, in the future, if you have TDRSS satellites, you can have more time to talk to other satellites, and things will be a little easier; [it] might cost a little more, but be easier in that respect.

MG: Where do launches take place?

TW: Well, for us, we launch from Vandenberg Air Force Base, which is near Lompoc, California. One of the unique challenges out there is there's oil rigs out in the ocean by Santa Barbara, California, south of us. So when we launch that way – like, JPSS-1 launched on Delta II, and we had nine solid rockets. So it takes off pretty fast because you have the main engine being lit, and it has ten thousand gallons of fuel on it. It burns out pretty much in two minutes. We had six solid rocket motors tied around it that are also ground-lit. Three of them are lit in the air, but six are lit on the ground. So you have all this firepower initially, but because there's those oil rigs out there, when the solid rocket motors burn out, we had to hold on to them a little longer until we cleared the oil rig. So there's a little bit of mass penalty to do that. And Vandenberg has issues with fog quite often, but fog is not a launch constraint. We can launch in the fog. We've launched in drizzle. In fact, NOAA-N Prime, NOAA-20, was launched in a dreary, drizzly day, and there were breaks in the clouds. You could see it intermittently. There's also a nice camera out there that the Air Force has on Santa Ynez Peak that usually we can see the fairing separate. That camera was down, but it was also not launch-critical. In the earlier days, we used to fly what they called (ARIA) [Advanced Range Instrumentation Aircraft] chase planes. The (ARIA) chase planes would follow the launch, so they would get telemetry as well as visual of the fairing coming off. We don't do that anymore; it's not required. But GOES launches from Florida – Cape Canaveral, Florida or Cape Kennedy, Florida. I was fortunate to work the GOES N, O, P launches. That's a much bigger rocket. We used the Delta IV, and it only had two solids, but the silods were really big. Some people said it was more impressive than watching the shuttle go off because it was so bright. People from sixty miles away could see the launch. I've seen some impressive things down there, but the rockets are really amazing. When you think how much – well, the GOES is now launching on an Atlas V rocket. JPSS II is going to be on an Atlas V rocket, much bigger rocket. Delta II had ten thousand gallons of fuel, and they called it RP-1, Rocket Propellent-1, but it's really a highly refined kerosene, but Rocket Propellant sounds more high-tech, right? At any rate, the Delta II had ten thousand gallons. Two minutes after launch, it weighs half what it did at the launch pad; it burns it that quickly. Versus the Atlas V has 66,000 gallons, so almost seven times more fuel. So it's a bigger rocket with a bigger fairing. We're looking at flying other potential rideshares with us because we'll have more mass capability. Of course, the rocket costs more, too.

MG: How much does a rocket cost?

TW: I'd say roughly around a hundred million dollars, but that's throwing in processing and other things. Yes, they're not cheap. Versus, when I did NOAA-D, getting an Atlas-E rocket out of the silos, it was less than ten million. In my career, I've seen the rocket launches go up more than a factor of ten. But yes, rockets are pretty amazing. There is a lot to saying – rocket science, there's a lot of stuff that has to – doesn't have to work long, but it has to work right. GOES-N was the first to do what they called a third burn of the upper stage. It's got three stages, but the upper stage is the last one below the satellite. We did three burns, meaning the engine fires, and then goes through a coast phase, and fires again and goes through a coast phase, and fires again, which gave us a much higher altitude. Plus, using the two solid rocket motors saved us a lot of fuel. So once the satellite got where it needed to be, we had over fourteen years of fuel on the satellite. So all three of those satellites have a lot of fuel on them and should be out there for a while if we need them. But now, they're starting to do four and five burns of upper stages. So the technology's advancing in that respect. They're able to do more and able to reduce orbital debris by bringing pieces of rocket back down to the ocean, too.

MG: I know you're doing a lot of education and outreach around the work you do. What has that experience been like?

TW: I haven't been doing much of that lately. In the earlier days, we worked a lot with – well, for every polar launch, we'd have an educator's conference, and we'd work with the Air Force. There was a group out there at Vandenberg. We would invite teachers for the launch. It was a challenge to keep them up for a two in the morning launch. Whereas Florida, we'd do something similar, but not quite as much challenge for a 7:00 PM launches. We'd have a longer launch window. Sometimes we would start a launch – we were supposed to go in daylight, and it might have been after sunset when we actually launched because we had a longer, what they called, launch window. Whereas the polar launch windows, you usually have ten minutes or less. You have to get off in those ten minutes, or you're not going. We've had some strange things delay launches. One of the Florida launches, there's a drop-off area where stages and things fall into the ocean, and you got to keep ships and boats out of there. Once, we had a ship going into our drop-off area, and I was amazed that the Air Force sent two helicopters out there and turned that boat around. I was saying, "It's never going to happen." Then he turned around. Out at Vandenberg Air Force Base, there's a train that goes up and down the coast. Once, we had to stop a train. Also, one of my launches there, we had a lightbulb burn out in a piece of ground support equipment. So nobody knew whether the equipment was working or not. It turned out it was a ten-cent lightbulb that burned out, and that held up a launch. [laughter] There was also one at Vandenberg where there was a multi-state power grid outage. The facility I was in, where we were monitoring things, all the screens went black. Now we didn't know that the launchpad is on a diesel generator, which kicks in, and everything was fine there, but we didn't know for a while because everything was black where we were. So we've had our share of surprises. Usually, the toughest problem out at Vandenberg is the Jetstream sometimes parks over there, and it has sometimes two-hundred-and-ten-mile-an-hour winds, and you have shear conditions that the rocket can't withstand. The smaller rockets need less wind. [laughter] As you go to a bigger rocket, there's usually a little bit more wind shear that you can take. [In] Florida, you tend to worry more about the weather and the lightning strikes. Don't get much lightning out at Vandenberg, but it does happen once in a while. That's one of our new challenges, to have lightning procedures for out there. [In] Florida, every time there's a lightning strike within so far of the pad, we have to recheck everything. So, yes, both launch sites have their own unique challenges. I highly encourage you to see a launch someday. My son got to see one of the launches. It was very cool because they let us use, at Kennedy, the VIP building that the space shuttle guests get to go in. It was, I don't know, six floors up or something, and they had a nice balcony. One of the shuttles was on the launchpad that was closest. One of the GOES was further out. It was very impressive for people to see that launch. Then, the rocket – it takes a little while for the sound effects to hit you after you're seeing it. It takes a lot to impress my son, and he was impressed.

MG: Wasn't he knocked over?

TW: [laughter] Well, yes. I wasn't with him, but yes, he said when that rocket made that turn, and the sound wave hit him, his eyes lit up. [laughter] One of my lessons learned – I was down at Kennedy Space Center a couple of years ago for a Falcon 9 launch at night. I'd been down there for another meeting, and the launch had been delayed. I said, "Do I want to get up at two in the morning to see this launch?" I decided to go see it because it had been delayed. The crowd wasn't as big because it got delayed. I'm three miles across from the launch pad. What I didn't realize is the video that's going out on Spaceflight Now has a delay built into it. So I'm listening to the video, counting down. Meanwhile, the rocket's taken off already. So I didn't have my camera ready. If you ever go there in real-time, realize there's an offset between what's broadcast and what you see. I guess they intentionally do that in case there's a problem; they can pull the plug.

MG: Is seeing a launch something I could do or anybody could do?

TW: Yes. At Kennedy, there's lots of places you can go. There's a causeway. There's Banana Creek [Launch Viewing]. The Kennedy Visitor's Center has areas where they open up. They charge people there, but there's plenty of free areas you can go to see launches. You can go to Cocoa Beach, and north of Cocoa Beach. Yes, there's lots of places. In fact, my first and only shuttle launch that I got to see from Cocoa Beach – everybody's looking a certain direction, and I figured the locals knew where to look. They were way wrong. It was thirty degrees to the west we needed to be looking. You live and learn. But yes, launches are very cool. Now, here in Maryland, they're launching shuttle resupply missions from Wallops [Island], Virginia, which is a three-and-a-half, four-hour ride away. One of these days, I hope to go see an Antares [rocket] launch. That should be cool, as well.

MG: Why do the launches take place at 2:00 AM? Because it's darkest then?

TW: No, that's when they were launching. That's based on the rocket trajectory, where the rocket needs to be. So based on what the mission is, their launch times will be different.

MG: I have in my notes that you worked on a joint NASA project, DSCOVR [Deep Space Climate Observatory].

TW: Yes, I worked on the beginnings of DSCOVR. DSCOVR was Deep Space Climate Observatory. It originally was the Triana spacecraft that sometimes was nicknamed GoreSat, I think. At any rate, it was a satellite that was built and had some problems, but it was put in storage and never launched. It was a smaller satellite, and it was intended to go to L1, which is libration point, about a million miles away between the Earth and the Sun. It had a camera called epic that was supposed to look back at the Earth and give full-time continuous coverage, visible coverage of the Earth, looking from a million miles away. NOAA was interested in putting a compact coronagraph on it that the Naval Research Lab, down the road here in Maryland, was building. It also had a magnetometer and some other instruments that were important to space weather that would give us early warning of sun flares and coronal mass ejections. So it was important to the space weather community. I worked on the very beginning of that, the formulation stage, helping to pull the budget together, looking at technical issues, and there were plenty because when they put the spacecraft in storage, they had some things they hadn't resolved yet. There were some things that weren't in the budget that needed to be put in. I helped work the requirements with the Air Force because the Air Force was going to supply the launch services. So I helped put all those requirements on paper for the launch services. I was working JPSS-1 and just the beginning of DSCOVR, so I just helped a couple of NOAA people out. That was a very successful launch.

MG: How many individuals are involved in each launch, and from what departments and organizations do they come from?

TW: Well, for us, we have a core group of people down at Kennedy Space Center, LSP they call them, launch service provider. They do our launch services. They do it as a group. They'll go out with a bunch of launch services and award contracts, and they will actually put our rocket on contract when we give them our requirements. Now, we don't know for JPSS-3 and 4 what the rocket's going to be. For JPSS-2, we're on an Atlas V, but that could change. That has its own set of problems because we're designing for multiple launch vehicles. So it costs you a little more to put in a little extra margin here and there in the mechanical area mostly. In fact, another thing we design for is acoustics, the noise levels. When we did GOES, and we added the solid rocket motors, one of the advantages of that is you get off the launchpad quicker, so you get away from the noise faster, too. That was a side benefit. You usually have fairing blankets inside the fairing that thermally help keep the spacecraft at a temperature, but they also help with the acoustics. Just like in your home, if you have insulation, it's going to help keep noise levels down in your home from room to room. So we have launch services people, but they're not full-time; they work multiple programs down there. I don't have a good number for how many people that is. Plus, they contract out to a company for the launch service. Again, right now, it's United Launch Alliance – they're based out of Denver, Colorado – that do the Atlas V, but those people work multiple programs, and our launch is just one of the launches they work. They have all kinds of specialized people that do what's called thermal analyses, and coupled loads analysis. They'll look at how does the rocket work with the spacecraft and instruments and make sure there's no funny new modes that develop or anything. They do a lot of that type of analysis and do all the trajectory analysis. They work with the Air Force people who control the range. The range has the radars. The radars are used to track your rocket and make sure it's on the right path. Somebody has their finger on the button to blow it up if it's going off-path. Also, the rocket has software that can blow itself up, which always has scared me. I'd rather rely on the person. So it's people, but they're not full-time. Then, we have four key instruments. They're built in Fort Wayne, Indiana; El Segundo, California; Boulder, Colorado; and Azusa, California, which is not far from L.A., maybe an hour outside of Los Angeles. Then we have four instrument teams, and the sizes of those teams vary quite a bit. Of course, a more complicated instrument needs more people. So I don't have good numbers on the sizes, but the instruments are quite a bit more complicated than what they used to be. They got a lot more computer smarts, a lot more telemetry comes down, a lot more software. The instruments have more software than our older satellites used to have. So the instruments are a whole different world – new technologies with different detector arrays instead of single discrete detectors, much higher resolution in general, more channels in general. Like the old HIRS instrument, I told you, had nineteen IR and one visible. The new CrIS [Cross-track Infrared Sounder] instrument has over a thousand infrared channels. So it's quite a significant increase. Versus the AVHRR had five or six channels, depending on how you counted them. The VIIRS has twenty-two. The early microwave instrument was only four channels. Our ATMS [Advanced Technology Microwave Sounder] microwave now has twenty-two channels. So the number of channels has gone up. In general, the resolution has gone up. Usually, with more channels, more resolution, you get better science, which leads to better forecasting. Here at Goddard, we have a handful of NOAA people. A fair number of people are just doing the budgeting for these four instruments and the rocket and the spacecraft. You've got budgeting people. You've got contracting offices for each contract. Sometimes, one covers multiple contracts. Then you have technical managers. Then you have subject area experts. You'll have an expert on contamination control, an expert on thermal, an expert on mechanical, software experts, and there's logistics experts. So, yes, it's quite a diverse team. When you look at all the subcontracted stuff, the instruments subcontract out – there's probably something being built in almost every state of the country that contributes to the program somehow some way. It's a pretty diverse, wide team. Versus in the older days, if we had a hundred people, you knew them all. I don't know everybody now, so it's a little bit bigger, a little more complex.

MG: In the time that we have left, could you tell me a little bit about your wife, family, and life outside of work?

TW: My wife was a math teacher at the first school that I taught at, junior high school. I was an Earth Science teacher. She'd been there for a year already. She grew up in Port Jervis, New York. If you ever look at a map of where New Jersey, Delaware, and Pennsylvania all together become one point, that's where she grew up. It's neat because, in five minutes, you can drive and be in three states, and get gas pumped for you in New Jersey – they still pump it for you there. [laughter] At any rate, we met there. [In] my third year, I went to a different school. The school we were in was being closed down and converted into administration buildings. So we both went to different schools, got married, and had three kids about a year apart each. We got to learn how much fun having three in diapers and three in college was at the same time. It was like buying a new car every semester, so that's why I'm still working. [laughter]

MG: You have grandchildren, too.

TW: Yes, I have three grandkids. I just had one born a couple of weeks ago. I have a grandson who's in fourth grade now, and he's getting ready to play a musical instrument, a trumpet, I think. That's going to be a new experience. I have a lovely two-year-old [granddaughter] who is getting to be quite impressive with her talking and singing. She can sing the nursery songs like "Twinkle, Twinkle, Little Star." She's getting to be quite a joy, and adjusting to her new role as the big sister. It's been an interesting few years.

MG: This has really been such a treat for me. Is there anything I forgot to ask you about or something we've left out?

TW: More than likely. But life goes on.

MG: It's not hard for me to come back. You'll also have the opportunity to amend the transcript and add more things later.

TW: Okay. Thank you very much.

MG: This has been a lot of fun for me. Thank you so much for your time.

TW: Alright. You're welcome. Thank you.

-----------------------------------END OF INTERVIEW-----------------------------------
Reviewed by Molly Graham 11/6/2019