National Aeronautics and Space Administration

NASA Case Study

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GOES-N: Long and Winding Road to Launch

Overview

Operating as a two-satellite constellation 22,000 miles above Earth's equator, the *GOES* (Geostationary Operational Environmental Satellite) observatories provided continuous meteorological coverage of 60 percent of the planet. *GOES-N*, the first in the next generation of *GOES* spacecraft, would be the most advanced meteorological observation satellite in space.

Figure 1 - Artist's Depiction of GOES Overlooking Earth. NASA image

Getting *GOES-N* into orbit, however, would prove to be difficult. The road to launch was marred by a series of unfortunate events, including lightning strikes in the vicinity of the rocket, launch-vehicle battery qualification issues, and contractor technician strikes. For months *GOES-N* sat on the ground, stacked and waiting, riding out a sequence of delays and resets as engineers and managers wrestled with a string of issues.

By the summer of 2005, Ken Yienger, systems manager for *GOES-N*, couldn't help but wonder, What next? "As a systems engineer," Yienger said, "you are always focused on making sure you have done everything possible to assure a successful mission right up to the moment of launch—testing, retesting, verifying, and validating everything multiple times. Then you close the launch vehicle fairing and say, 'Let's go!' You expect some unexpected things—bad weather that will delay you a day or so on the pad, or a shuttle mission might make you wait a few days. But nobody plans upfront to sit on the launch pad for a month."

With the *GOES-N* team facing a host of technical and programmatic issues and project members rescheduling commitments, and with the original launch date of December 2004 receding in the rearview mirror and the 2005 hurricane season approaching, the critical question was: When has an observatory and launch vehicle sat too long on the pad?

Best in the Sky

Developed by NASA for the Department of Commerce's National Oceanic and Atmospheric Administration (NOAA), *GOES* was essential for forecasting and tracking severe weather, such as hurricanes and tornadoes. *GOES* was known as the world's "eyes in the sky"—it was the only weather-forecasting tool for many of the 140 nations that received the satellites' data. The global meteorological community relied on the *GOES* satellites-- Remaining in one position relative to the rotating Earth-- to send a continuous stream of weather and environmental data. The observatories were also the linchpin to the SARSAT system, for search-and-rescue satellite-aided tracking, that relayed emergency signals sent from aircraft, marine vessels, and emergency locator transmitters. Over the past 25 years, SARSAT, assisted by *GOES*, had initiated the rescue of more than 18,000 people.

GOES- N: Leading the Next Generation

A three-axis stabilized spacecraft built on the Boeing 601 heritage design, the *GOES N* series of satellites (including *GOES-O* and *GOES-P*) was designed for a nominal 10-year mission life per satellite, with 14 years of fuel per satellite. The "stellar inertial-based" attitude-control system comprised three star trackers and a hemispherical inertial reference unit, or gyroscopes, for determination/control of direction; four reaction wheels to control the spacecraft in the normal mode; and 12 two-pound thrusters to manage momentum and maintain orbital location.

GOES-N (to be designated *GOES-13* once in geosynchronous orbit) carried a collection of Earth- and space-monitoring instruments that improved upon previous technology. It was built with more accurate prediction and tracking capabilities than any of its 12 predecessors. It was designed to improve, by a factor of four, image accuracy in locating severe weather events, largely by virtue of its star-tracker navigation system.

The primary instrument suite of *GOES-N* consisted of:

5-channel imager: a radiometer for producing images of Earth's surface, oceans, storm development, cloud cover, cloud temperature and height, surface temperature, and water vapor; developed by ITT

19-channel sounder: a supplementary device to the imager for gathering data for determining atmospheric temperature and moisture profiles, surface and cloud-top temperatures, and ozone distributions; also built by ITT

Solar x-ray imager: providing for early detection and location of solar flares and for gauging flare intensity and duration; developed by Lockheed Martin

Space environment monitor instruments: including a 3-axis magnetometer for measuring energy particles and Earth's geomagnetic field, built by SAIC, and a particle- and solar-monitoring suite from ATC (Assurance Technology Corporation)/Panametrics; provided by Boeing

GOES-N boasted other enhancements: a digital transmission system for dissemination of data products that were distributed in analog format in the previous generation of *GOES* satellites; an enhanced power subsystem using a single-panel solar array; and a satellite lifetime design enhancement, boosting expected lifetime from 7 to 10 years and the expected propellant lifetime to 13.5 years.

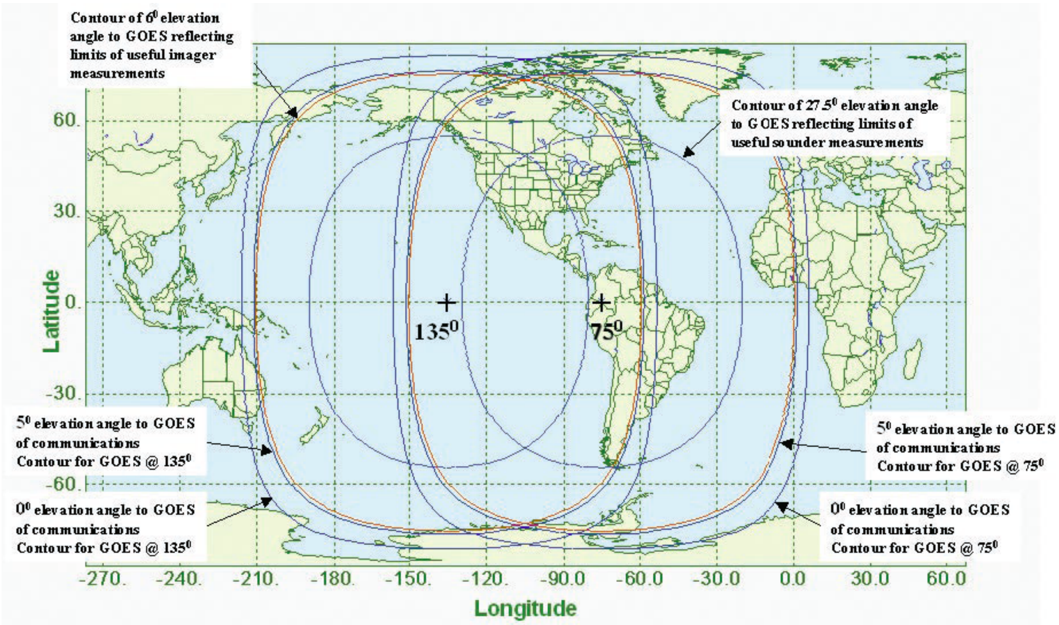

Figure 2 - GOES Coverage: Continuous observation of 60 Percent of Earth, Including the Entire Continental United States. NASA image

The Project Team

Three organizations made up the main *GOES-N* project team:

Boeing Satellite Systems, Inc., (BSS) was building the satellite, and Boeing Expendable Launch Services (BELS) was providing the launch vehicle, a *Delta IV* (4 + 2) rocket, as well as providing launch services.

The Goddard Space Flight Center (GSFC) was procuring the observatory components, including the observatory and instruments, and was responsible for overseeing the development, testing, and operation of the spacecraft, instruments, and ground equipment during the post-launch check-out phase, whereby the proper functioning of the satellites was verified.

The National Oceanic and Atmospheric Administration (NOAA) was responsible for the overall program, funding, system on-orbit operation, and processing and dissemination of environmental satellite data for the United States. It also had operational responsibility for the ground system.

BELS was to provide the launch services through a fixed-price "delivery-on-orbit" contract between NASA and BSS. The costs of any delays during the launch campaign—both observatory and launch vehicle (LV) costs—would be borne by the contractor. Under terms of the contract, there would be cost penalties for schedule-related delays that were specifically exercised by NASA—in other words, "NASA delays, NASA pays."

NASA and NOAA went into the *GOES-N* series acquisition with the mindset of a modified-commercial, "delivery-on-orbit" approach. This used a firm fixed-price contract for both the observatory development and launch services. While highly leveraging Boeing's experience in commercial satellite development and operations, NASA focused its expertise and involvement on delivering the government furnished equipment (GFE) instruments and on lowering and mitigating mission risks. It did this by working whenever possible within the scope and terms of the existing contract.

Figure 3 - The Delta IV Rocket for GOES-N, Launch Complex 37 at Cape Canaveral Air Force Station. NASA image

As a result, although technically frustrating to the NASA team, which wanted its own processes and styles to be followed, the arrangement meant, programmatically, that the risks and costs for schedule delays were borne by the prime contractors rather than NASA/NOAA. Nonetheless, any unilateral direction given or implied by NASA would place larger financial burdens on the agencies for the costs of both the observatory *and* launch-vehicle contractors.

Boeing was allowing 24 days after launching *GOES-N* for the spacecraft to reach geosynchronous orbit at 22,240 miles, at which time the satellite's instruments would be deployed and powered up. *GOES-N* would then be renamed *GOES-13* and turned over to NASA for the post-launch engineering checkout.

Eventually, *GOES-13* would be handed off to NOAA and placed in on-orbit storage mode. It would wait to be activated when either *GOES-11* (West) or *GOES-12* (East) suffered an anomaly or exhausted its fuel. Once called into service, *GOES-13* would deploy its instruments and begin its vigil of observing and measuring meteorological and environmental phenomena on Earth and in space.

Roadblocks…

But getting *GOES-N* to launch was taking years. Issues relating to observatory development accounted for little of the delay time. Rather, several delays and resets had occurred due to launch-vehicle-related technical issues after the spacecraft had completed observatory environmental testing.

About midway through the development of the spacecraft, the decision was made to manifest *GOES-N* through *GOES-P* on the new Boeing *Delta IV* launch vehicle. While the decision had little effect on the spacecraft's design and testing, *GOES-N* was one of the first launches for the Boeing *Delta IVs*. As with all new launch vehicles, development issues were causing the launch vehicle queue to slow down while the early flight issues were addressed. In addition, because *GOES-N* was the first launch of this series of spacecraft, NASA was more cautious with the launch windows, not allowing the launch of the observatory during the spring and autumnal eclipse periods. Those forces contributed to a slower-than-normal road to space.

Still, by March 11, 2005, the spacecraft had arrived at the launch site. Various tests had been completed, including spacecraft functional testing, instrument testing and cleaning, and blanket closeout. An issue in a solar sensor had been addressed. Support teams completed the observatory battery performance testing, or capacity check. On April 7 the spacecraft was fueled. On May 25, 2005, the spacecraft was mated to the payload attach fitting (PAF). It was encapsulated on June 3, and five days later it was transported to Cape Canaveral in preparation for the initial June 23, 2005, launch date.

Then a combination of problems converged to delay the launch attempt until August 15. Technical issues emerged about the spacecraft's communication boxes. A "close-in" lightning strike from a summer thunderstorm required evaluation and testing. Further, there were ongoing issues with the launch vehicle's composite overwrapped pressure vessel (COPV) tanks, containers for storing inert gases such as helium and nitrogen. For a spacecraft team, few things are more agonizing than having to wait while its spacecraft sits on the launch pad.

Ken Yienger, the systems engineer, recalled the frustration:

> *We had done everything we felt was necessary to launch, and had made some compromises to get where we were. We sat there, buttoned down in the fairing waiting for the next attempt, unable to fully and ideally test the observatory as we'd like.*
>
> *Meanwhile, additional "what-if's" and collateral hardware issues back at the factory continued to come across the radar screen. We alternated between being blessed with the GOES-O and GOES-P observatories still being tested in the high-bay—we could [resulting] troubleshoot anomalies on sister spacecraft—to being cursed, since now all issues were "launch liens," and needing to figure out, "How are we going to test THAT in a launch vehicle fairing?"*
>
> *Each issue, individually, was one we felt we could chase to the ground, but like snowflakes each one can aggregate into a much bigger issue. At the end of the day, we had to keep asking: "Are we still ready to launch?"*

Pre-Launch Reflections

It is August 14, 2005. You are the *GOES-N* mission systems engineer or observatory manager. You have successfully retired all pre-launch actions. Earlier in the day, the Launch Readiness Review (LRR) had gone well, and you have received concurrence from NASA Headquarters (HQ) and GSFC management to proceed with launch.

You review some of the key observatory milestones over the past year:

- The environmental (SCTV) testing and battery activation and acceptance testing were completed in August 2004.
- Ambient performance testing, a comprehensive check, was done in December 2004.
- Battery performance had been verified via a limited capacity check on March 25.
- The spacecraft had been fueled and flight-pressurized on April 7.
- The spacecraft was encapsulated on June 8.
- Batteries had been charged to flight state-of-charge (SOC) (70 percent SOC) on July 18.

You think back on some of the distinguishing characteristics of the mission:

GOES was a NASA "Class B" mission, meaning: high-value/high-visibility. The replacement cost for the *GOES-N* observatory was estimated at $500 million to $750 million. Launch delays were costly too. Commercial launch service meant "you stop, you pay." NASA-directed stand-downs incurred a penalty of $250,000 a day.

Figure 4 - Still Standing Ready to Launch at Cape Canaveral. NASA image

The launch service had a "ship and shoot" nature. This meant that testing capabilities at the launch site were limited by the availability of mechanical/electrical ground support systems, or MGSE/EGSE. Also, there were typical testing restrictions on the pad due to location and payload fairing (e.g., testing was limited to umbilical-provided services only, hard-line communications). Removing the spacecraft from the launch vehicle, called destacking, required a minimum of 25 days of work in order to get five days of "vehicle free" testing.

Finally, you think about the challenges that caused delays. Technical hurdles exposed some personnel and management issues, such as the extent to which technical personnel should play a role in assessing launch risk, and in the go/no-go decision itself.

Foremost in your mind is one question: What constitutes a reasonable on-ground duration without retesting. *How long is too long to sit*?

Decision Time

Four days later, now August 18, *GOES-N* is still on the ground. Two launch attempts—August 15 and August 16—were unsuccessful. The first was unsuccessful due to a pressure drop in the launch vehicle, related to the Composite Overwrap Pressure Vessels, or COPVs. The second launch was unsuccessful because of a battery problem in the LV. The second attempt was suspended only 4 minutes, 20 seconds from launch.

On August 18, to further complicate your life, the LV's flight termination system (FTS) batteries expired. New ones would not be available for a minimum of three weeks—pushing you into the autumn eclipse season. Based on all this information, your new launch date appears to be November 2, outside the autumnal eclipse season.

The observatory has now been on the pad for two months, encapsulated for more than five months. Some of the tests had been done as long as a year ago. That nagging concern about on-ground duration keeps coming back. It's time to decide:

- What will you recommend to the project manager: Sit and wait? Restack? Retest? Let the contractor make the call?
- What types of analyses might you recommend?
- What additional on-pad testing should be done?
- What criteria do you factor into your decisions?

Exhibit 1

GOES-N Launch Timeline

Date	**Event**
January 1998	Contract signed to procure next-generation weather satellites.
2001	Originally scheduled for launch in 2001; construction/launch extended to 2003 because the *GOES* satellites already on-orbit are working well.
2003	Scheduled for launch in December 2004, then January 2005.
Early 2005	Launch date reset to May 2005 to avoid launching during spring eclipse season.
April 2005	Concern about *Delta IV* rocket delays postpones to June; tanks replaced.
May 27, 2005	Mission Readiness Review (MRR)
June 2005	June 7: Safety and Mission Assurance Readiness Review (SMARR) June 13: NASA HQ Mission Readiness Briefing (MRB) Mid-June: Launch slips to late June to allow time to check for possible damage to rocket's electrical systems from lightning strikes. Late June: Uncertainty about a rocket battery postpones launch to July.
July 2005	Technical concerns about launch vehicle and satellite delay to August. July 22: Flight Readiness Review (FRR)
August 2005	August 14: Launch Readiness Review (LRR) August 16: Launch aborted with 4 minutes, 22 seconds to go. Because launch slips past mid-August, it is rescheduled for the first weekend in November 2005 to avoid risk of deployment in geosynchronous orbit during autumnal eclipse season.
October 2005	Spring eclipse season makes launch risky; rescheduled for after mid-April. Boeing takes satellite off rocket, rehabs both, puts them back together.
Nov. 2005	Boeing union votes to strike, launch is put on hold.
April 2006	NASA MRR, SMSR, and MRB successfully held, clearing *GOES-N* for May launch.
May 24, 2006	*GOES-N* launched on *Delta IV* to nearly direct injection to geo-orbit. After launch, Boeing schedules 24 days to get to geosynchronous orbit, deploy, and outgas all components, power-up (but not open up) instruments, and rename satellite *GOES-13*. 
June 13, 2006	After 20 days of preparation, Boeing turns *GOES-13* over to NASA for post-launch engineering checkout of approximately 240 days.
June 22, 2006	First visible image taken, five days ahead of schedule.

Source: Adapted from "*GOES-N* Launch Saga Timeline," http://goes.gsfc.nasa.gov/text/goesnstatus.html.