Geostationary Operational Environmental Satellite (GOES)-8 Mission Flight Experience*

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Abstract

The Geostationary Operational Environmental Satellite (GOES)-8 spacecraft was launched on April 13, 1994, at 06:04:02 coordinated universal time (UTC), with separation from the Atlas-Centaur launch vehicle occurring at 06:33:05 UTC. The launch was followed by a series of complex, intense operations to maneuver the spacecraft into its geosynchronous mission orbit. The Flight Dynamics Facility (FDF) of the Goddard Space Flight Center (GSFC) Flight Dynamics Division (FDD) was responsible for GOES-8 attitude, orbit maneuver, orbit determination, and station acquisition support during the ascent phase. This paper summarizes the efforts of the FDF support teams and highlights some of the unique challenges the launch team faced during critical GOES-8 mission support.

FDF operations experience discussed includes

- The abort of apogee maneuver firing-1 (AMF-1), cancellation of AMF-3, and the subsequent replans of the maneuver profile
- The unexpectedly large temperature dependence of the digital integrating rate assembly (DIRA) and its effect on GOES-8 attitude targeting in support of perigee raising maneuvers
- The significant effect of attitude control thrusting on GOES-8 orbit determination solutions
- Adjustment of the trim tab to minimize torque due to solar radiation pressure
- Postlaunch analysis performed to estimate the GOES-8 separation attitude

The paper also discusses some key FDF GOES-8 lessons learned to be considered for the GOES-J launch, which is currently scheduled for May 19, 1995.

Introduction

The Geostationary Operational Environmental Satellite (GOES) I/M series of spacecraft (see Figure 1) are a new generation of GOES satellites containing the latest in geosynchronous weather satellite technology. The GOES program, a joint effort between the National Aeronautics and Space Administration (NASA) and the National Oceanic and Atmospheric Administration (NOAA), is designed to provide continuous weather coverage of the United States. The GOES-I/M spacecraft are built by Space Systems/Loral (SS/L) and are designed to replace the current geosynchronous meteorological satellites, of which GOES-7 is the remaining survivor. Unlike the previous series, which began with the launch of Synchronous Meteorological Satellite (SMS)-A in 1974, the new spacecraft series are three-axis stabilized. They are designed to improve the accuracy of weather data and facilitate the preparation of long- and short-range forecasts of severe weather. In addition to meteorological functions, the GOES I/M spacecraft monitor the space environment, collect data from automated terrestrial sensors, and relay aircraft and marine distress signals.

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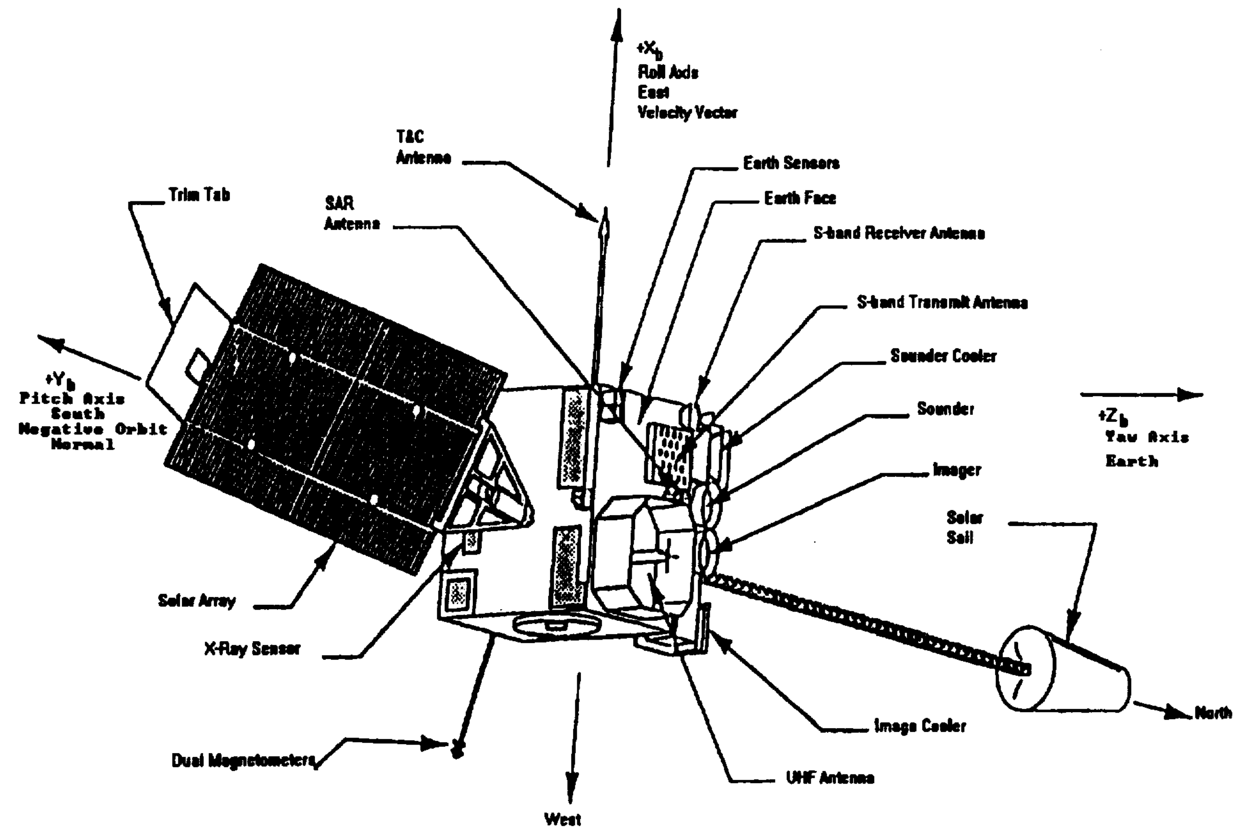

Figure 1. The GOES Spacecraft

The GOES-8 spacecraft uses an Atlas I expendable launch vehicle, which is Martin Marietta's commercially available configuration of the Atlas/Centaur. The Centaur stage inserts the spacecraft directly into a transfer orbit. The spacecraft is then maneuvered to its on-station position using its bipropellant propulsion system. Once on-station, the GOES-8 spacecraft maintains a continuous Earth-pointing attitude at a synchronous altitude of approximately 35,786 kilometers (km) and an inclination of not more than 0.5 degrees (deg).

The GOES-8 attitude and orbit control subsystem (AOCS) includes a 100-lb main satellite thruster (MST), twelve 5-lb AOCS thrusters, two momentum wheels, a reaction wheel, magnetic torquers, digital integrating rate assemblies (DIRAs), Sun and Earth sensors, and the attitude and orbit control electronics (AOCE).

GOES-8 is separated from the launch vehicle in a passive spin about the Z-axis; all appendages except the telemetry and command (T&C) antenna are stowed. After the AOCS is turned on, the Sun is captured on the -X face with a slow roll rate (0.75 degrees/second (deg/sec)) about the X-axis, when the solar array is partially deployed. During the ascent phase, GOES may be described as a zero momentum spacecraft with a closed-loop control system using thrusters as actuators. The AOCS uses a combination of sensor and gyro output to control the attitude and spacecraft body rates. Attitude maneuvers are performed by uplinking sensor offsets to the spacecraft. Following completion of the ascent phase, the GOES solar array and solar sail are fully deployed, the wheels spun up, and the spacecraft transitioned to the normal on-orbit control mode. On-station, GOES is a momentum bias spacecraft, with the attitude controlled by momentum wheels using pitch and roll data provided by the Earth sensor. A solar sail and an adjustable trim tab (on the end of the solar array) are provided to balance solar radiation pressure torques about the yaw axis of the spacecraft. Magnetic torquers and thrusters are used to dump any excess yaw momentum buildup in the wheel momentum vector.

The nominal maneuver sequence (see Figure 2) required to raise GOES from its transfer orbit to a checkout orbit called for a total of six maneuvers: three Apogee Maneuver Firings (AMFs), an Apogee Adjust Maneuver (AAM), and two Trim Maneuver Firings (TMFs). The AMFs raise the perigee height (to about 255 km below geosynchronous altitude), lower the inclination to 0.5 deg, and set the final right ascension of the ascending node. In addition, the AMFs were also required to rotate the line of apsides to set up more favorable Sun-Earth-spacecraft geometry for attitude targeting operations at the time of the AAM. The AAM was designed to lower the supersynchronous transfer orbit apogee to about 255 km above geosynchronous altitude. Finally, two TMFs were planned at apogee and perigee to trim the final orbit by another 100 km and stop the drift.

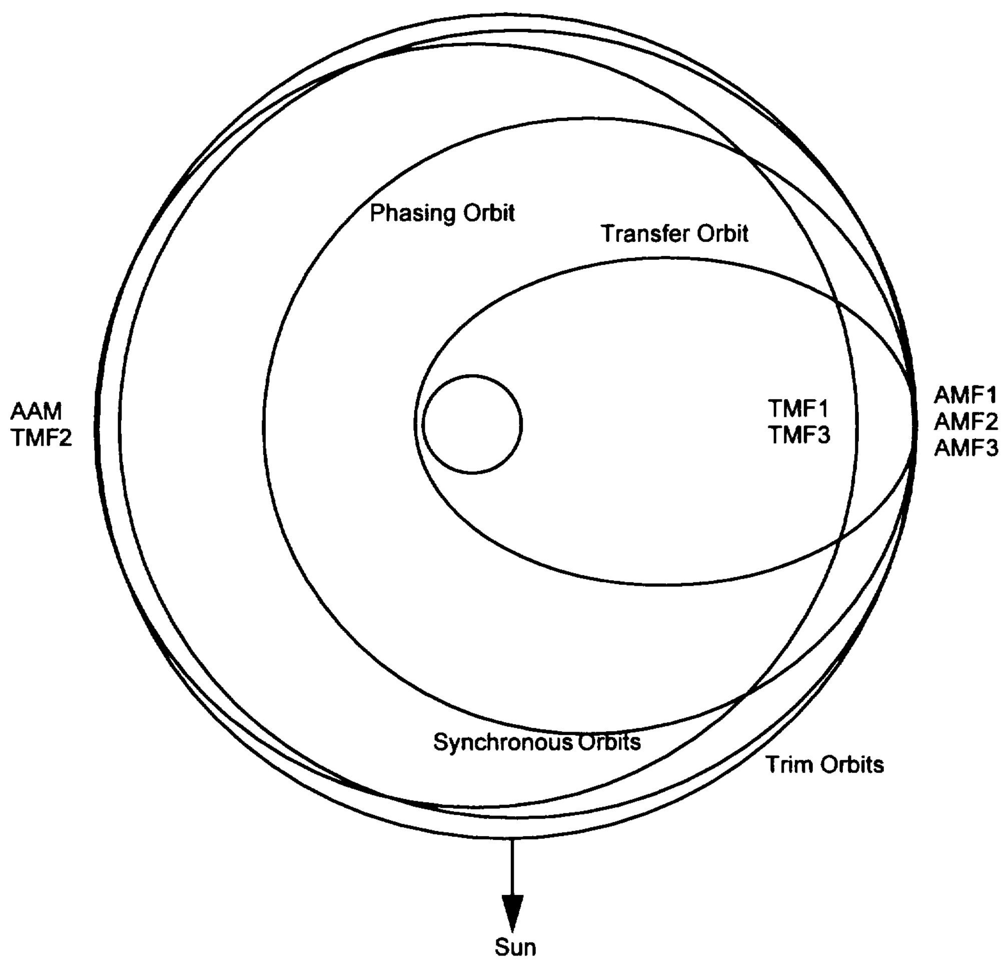

Figure 2. Nominal Maneuver Sequence

NASA's Goddard Space Flight Center (GSFC) is responsible for launch and early mission support of the GOES satellites until they are placed in geosynchronous orbit over the check-out longitude. During the ascent phase, FDF analysts work closely with the Mission Operations Support Team (MOST) in the NOAA satellite operations control center in Suitland, Maryland. After checkout, NOAA assumes full operational responsibility. The Flight Dynamics Division (FDD) has been involved with the GOES-I/M project since 1985. Software components including an attitude ground support system (AGSS), maneuver planning utilities, prediction and scheduling utilities, and dynamics/telemetry simulators were developed for the

GOES program to ensure safe and timely support of GOES I/M operations. High-level FDD requirements for the GOES mission are to

- Provide orbit and attitude support to achieve operational orbit
- Support the MOST and NOAA in on-orbit testing of GOES and its instruments to characterize system performance
- Hand over each GOES to NOAA for operations with sufficient onboard propellant for a minimum of 5 years of stationkeeping

Orbit Control and Mission Profile

GOES-8 was launched into an elliptical, supersynchronous transfer orbit with a 27.0 deg inclination, a 12.5 hour (hr) period, and a perigee height of 170 km. The minimum residual shutdown (MRS) option of the Atlas I launch vehicle, in which all usable propellant in the launch vehicle is expended, resulted in raising apogee by 6600 km above synchronous altitude. The decision to take advantage of the MRS option was made approximately 1 year before launch. By starting at a supersynchronous apogee, the delta-V needed to raise perigee and then lower apogee later was less than that necessary to raise perigee directly from a geosynchronous apogee height. Using the MRS scenario gained about 3- to 4 more months of spacecraft lifetime.

The desired GOES-8 checkout orbit had a geosynchronous semimajor axis with an apogee bias of 155 km above geosynchronous, a perigee bias of 155 km below geosynchronous, and a spacecraft longitude of 90 deg W. The biased orbit was chosen so that the spacecraft could later be relocated without propellant penalties. Removing the bias from either apogee or perigee allows the spacecraft to drift east or west at approximately 1 deg per day until the desired new longitude is reached.

The ascent maneuvers had to satisfy a number of constraints including the following, which were the most restrictive:

- The spacecraft had to be in view of at least two ground stations.
- The pitch angle could not exceed 3 deg, due to Earth sensor field of view considerations and associated nonlinearity affects introduced by supersynchronous altitudes.
- The burn duration for MST maneuvers lasting longer than 102.3 sec was limited to a 5-sec resolution.
- Maneuvers with the east face AOCS thrusters were limited to a maximum duration of 37 sec followed by a 15-minute (min) wait to allow the propellant management device (PMD) to refill.
- At least 30 min needed to be set aside for DIRA calibration before each burn.

AMF-1 Abort. The first maneuver, AMF-1, was performed at fourth apogee and was planned to be the largest in the sequence with a duration of 3910 sec. The maneuver started nominally on April 15, 1994, at 02:43:22 coordinated universal time (UTC). As the maneuver progressed, however, telemetry indicated that the MST flange temperature was exceeding the prescribed limits. The burn was terminated by the MOST after only 497.8 sec. The aborted AMF-1 provided about 11 percent of the planned delta-V, raising perigee by 854 km and lowering the inclination to 23.46 deg. At burn termination, the spacecraft was at a longitude of 136 deg W, with an eastward drift rate of 298 deg/day.

After reviewing AMF-1 and consulting with the MST manufacturer, the Project made the following three changes to AMF operations:

- The abort criteria were revised since it appeared that the specified limits were too conservative based on a review of the thruster flange thermal analysis.
- The DIRA calibration attitude was modified to keep the Sun off the MST and thus start the maneuver at a lower thruster flange temperature.
- The AMF sequence was increased from three to five maneuvers to reduce the length of MST firings.

The FDF replanned the rest of the ascent phase based on the above criteria.

AMF-3 Cancellation. The third maneuver, AMF-3, was originally scheduled for apogee 8, but was moved to apogee 14 after the abort of AMF-1. However, several hours before the maneuver was scheduled to begin, AMF-3 was canceled because of anomalous AOCE performance. Instantaneous spikes were observed in the gyro data, which were integrated by the AOCE causing anomalous firings of the attitude control thrusters. The Project chose to cancel the maneuver rather than risk such anomalous attitude thruster firings during the orbit maneuver.

After careful study, it was determined that the anomalies were probably due to electrostatic discharges caused by the passage of GOES-8 through the Van Allen belts. An unusually high geomagnetic index was recorded in early April, and the increased solar activity was thought to have contributed to the anomalies in the onboard electronics. The Project switched to the backup AOCE and requested that AMF-3 be replanned for apogee 16.

The effect of the electrostatic discharges on the AOCE posed a unique paradox because of the limitation imposed on maneuver duration following the AMF-1 abort. Even though it was important to get out of the electromagnetic activity region as quickly as possible, only small maneuvers were allowed due to thruster flange temperature considerations.

Revised Maneuver Profile. Following cancellation of AMF-3, a revised maneuver sequence was computed with AMF-3 rescheduled for apogee 16. The maneuver began on April 21, 1994, at 19:38:52 UTC with a duration of 1160 sec. AMF-3 raised perigee by 4108 km and changed inclination to 11.19 deg. The maneuver ended at 36.8 deg W, with an eastward drift rate of 202 deg/day.

All subsequent burns through the AAM were performed nominally. The TMFs were slipped by 2 days in the final sequence to avoid predicted lunar interference in the Earth sensor and to adjust for small errors in longitude and drift after the AAM. Table 1 presents the four maneuver plans and gives the apogee or perigee number where each burn occurred. Apogee 1 is defined as the first apogee after spacecraft separation, and perigee 1 follows apogee 1.

Table 1. Four Maneuver Plans Including Apogee and Perigee

Maneuver	Initial Schedule	Schedule After AMF-1 Aborted	Schedule After AMF-3 Canceled	Final Schedule
AMF-1	Apogee 4	Apogee 4	Apogee 4	Apogee 4
AMF-2	Apogee 6	Apogee 11	Apogee 11	Apogee 11
AMF-3	Apogee 8	Apogee 14	Apogee 16	Apogee 16
AMF-4	not scheduled	Apogee 17	Apogee 19	Apogee 19
AMF-5	not scheduled	Apogee 19	Apogee 21	Apogee 21
AAM	Perigee 9	Perigee 20	Perigee 22	Perigee 22
TMF-1	Apogee 16	Apogee 26	Apogee 28	Apogee 30
TMF-2	Perigee 17	Perigee 27	Perigee 29	Perigee 31

Maneuver Performance

Each orbit maneuver was calibrated to assess the performance of the maneuver and make corresponding adjustments to maneuver models to improve the accuracy of subsequent maneuvers. A 3-sigma attitude error budget of 1.57 deg was allowed. The effect of AOCS thrusting between and during the burns was accounted for using telemetered counts of thruster pulses for propellant remaining purposes. Table 2 provides a summary of propellant usage, delta-V error (with respect to planned), and the yaw attitude error (see Reference 1 also).

Table 2. Summary of Propellant Usage, Delta-V Error, and Yaw Attitude Error

Event	Propellant used (kg)	Propellant remaining (kg)	Delta-V error (percent)	Yaw attitude error magnitude (deg)
AMF-1	81.52	1041.40	-0.53[1]	0.59
AMF-2	149.94	889.57	0.87	0.44
AMF-3	191.05	888.11	1.08	0.05
AMF-4	418.61	277.74	0.88	0.63
AMF-5	48.25	228.60	0.23	0.30
AAM	43.56	184.32	0.29	0.08
TMF-1	2.59	176.75	2.03	0.60
TMF-2	2.08	174.52	0.47	N/A[2]

[1] Due to AMF-1 abort, this value takes into account only the planned delta-V for the time that the motor actually fired.

[2] An attitude solution could not be computed because no Sun sensor data were available.

At the time of the GOES-8 handover from NASA to NOAA, approximately 8.6 years of propellant lifetime was remaining, considerably more than the 5-year minimum required.

DIRA Calibration and Attitude Targeting

GOES attitude maneuver targeting is a two-step process involving first calibrating the DIRA (or gyro) then using the calibrated gyro and the Earth sensor (ES) to reorient the spacecraft to place the MST in the direction of the desired orbit delta-V. During the half orbits before orbit maneuvers, the Earth is captured in roll, and the spacecraft is placed in a quasi-inertial attitude for DIRA calibration. After calibration, the computed DIRA biases are uplinked, and the spacecraft is commanded to capture the Earth in pitch, using the Earth sensor to maintain nadir pointing. From this point on through the orbit maneuver, spacecraft yaw is controlled using the integrated yaw DIRA rate.

Gyro Temperature Dependence. Upon separation of the GOES-I spacecraft from the Centaur launch vehicle, a practice DIRA calibration was performed during the first half-orbit of the mission. Its purpose was to exercise DIRA calibration spacecraft operations and get an initial estimate of the DIRA drift rate biases before the first orbit maneuver at apogee 4. This practice DIRA calibration showed that computed DIRA drift rate biases were changing with time. The DIRA yaw drift (of most concern because the yaw gyro is used for position control during orbit maneuvers) continued to increase as the spacecraft approached apogee 1. An analysis of the calibration data and temperature information obtained from the MOST indicated that the gyros were more temperature dependent than had been previously expected—the specification value on the DIRAs was 0.03 deg/hr/deg C (Reference 2). As Figure 3 shows, a least squares fit of computed yaw DIRA drift bias solutions as a function of DIRA temperature yielded a linear variation with a slope of about 0.13 deg/hr/deg C.

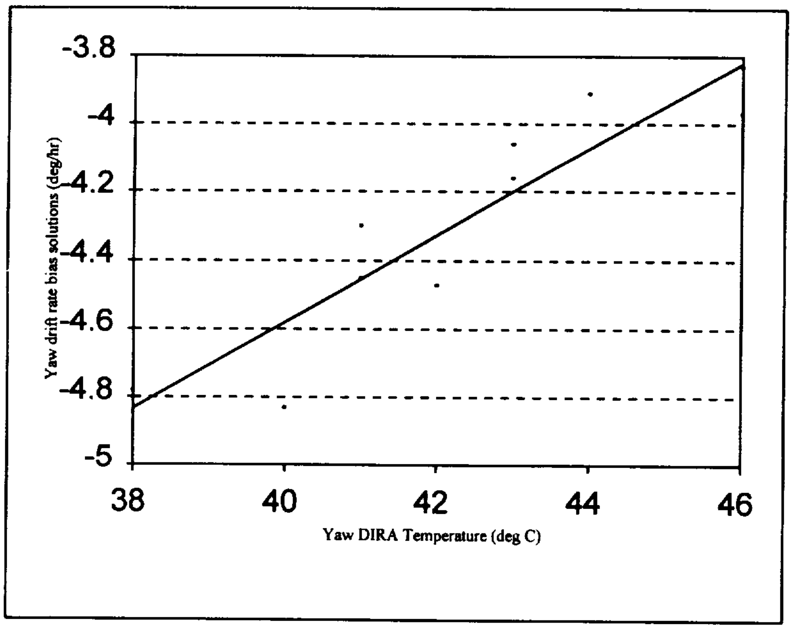

Figure 3. Yaw DIRA Rate vs. Temperature Pre-Apogee 1

Indeed, similar behavior had been observed for gyros used on the Earth Radiation Budget Satellite (ERBS), where variation of up to 0.24 deg/hr/deg C were reported (see Reference 4). The GOES I/M spacecraft use the same Northrop GIG6 gyros as those flown on ERBS.

As a result of this observed temperature dependency, a plan was devised to minimize DIRA temperature fluctuations by maintaining the spacecraft in a direct Sun-pointing attitude (0-deg yaw relative to the Sun-Earth-spacecraft plane). This approach was successful, preventing the Sun from shining on the -Y axis of the spacecraft (where the DIRAs are located), thereby keeping the DIRAs at a near constant temperature of 35 deg C; the corresponding yaw DIRA bias solved for was also constant at an approximate value of -4.25 deg/hr. However, following the abort of AMF-1, where high thruster flange temperatures were observed, this attitude profile was overruled in favor of an attitude designed to keep the motor cooler. The new DIRA calibration attitude, which used the maximum allowable -27 deg DSS yaw offset to keep the spacecraft -X-axis below the orbit plane and away from the Sun, yielded an 8 to 10 deg rise in DIRA temperatures before the burn. To effectively accommodate these temperature fluctuations, sliding 20-min batch least squares solutions were computed using the average temperature at the center of the 20-min span to track the DIRA drift versus temperature. In addition, a Kalman filter was used to provide real-time estimates of attitude and DIRA biases over time. Although linear in each case, the temperature dependence of the DIRA biases (as observed during calibrations for AMFs-2, -3 and -4) was not consistent from one maneuver to the next. The temperature profiles as well as the variations in the drift rate biases with respect to DIRA temperature changed from day to day. Throughout the ascent phase, the following variations in the rate of change of DIRA drift rate biases with temperature were observed:

yaw: 0.124 deg/hr/deg C to 0.242 deg/hr/deg C

pitch: 0.031 deg/hr/deg C to 0.128 deg/hr/deg C

roll: 0.084 deg/hr/deg C to 0.143 deg/hr/deg C

Attitude Targeting Considerations. The lack of consistency in the bias rate of change from one calibration to the next made it necessary to track the drift rates in near real time before each maneuver. A history of DIRA bias solutions and temperatures observed over the course of a calibration were established; then, DIRA biases were extrapolated based on the expected temperature at the time of the burn. Nominally, initial drift biases were supplied to the MOST about 2 hours before a burn, with an opportunity to update the biases within 1 hour of the burn if the temperature or drift rates had not behaved as expected.

When calibration was complete, the spacecraft had to be reoriented to the target attitude for the delta-V maneuver. This reorientation maneuver was accomplished by uplinking an offset to the yaw DIRA, which is used for yaw attitude control. The temperature dependence of DIRA drift rate biases meant that no matter how accurately a bias was computed during calibration, a change in DIRA temperature would cause the bias to change, and consequently, the yaw attitude would drift as the yaw DIRA was used for control. In most cases, the DIRA temperatures continued to vary even throughout the burn. Therefore, the commanded yaw DIRA offset had to include an allowance for expected drift based on anticipated changes in temperature.

Beyond AMF-4, the flange temperature ceased to be a driving concern since follow-on maneuvers were shorter (less than 15 minutes). It was, therefore, possible to use a Sun-pointing premaneuver attitude, which minimized DIRA temperature fluctuations and greatly improved DIRA bias stability.

Orbit Determination

During the ascent phase, GOES-8 used NASA standard transponders for communication through ground stations—primarily Deep Space Network (DSN) 26 meter sites. Other stations used were the Indian Ocean Station (IOS) early in the mission and Santiago later in the mission. IOS, the first station to see GOES-8 after separation, was primarily used for telemetry and commanding. IOS was also used, however, for orbit determination by collecting 3-way data once the DSN site at Canberra acquired the satellite but before the uplink was switched to Canberra. After the inclination had been reduced and GOES-8 was located over the continental U. S., southern hemisphere tracking through Santiago was necessary to determine the orbit accurately enough in the time allocated.

Sensitivity to Attitude Control Thrusting. Throughout the GOES-8 NASA support period, unmodeled orbit perturbations affected orbit determination solutions just before and immediately after the delta-V maneuvers. These perturbations caused considerable difficulty in determining the orbital state near the burns and limited the effectiveness of thrust scale factor estimation. Both elements were key to determining "quick look" orbit solutions and realizing rapid postmaneuver recovery. The perturbations arose from attitude control thrusting, which occurred at a low level throughout all orbits; however, significant increases were observed during the half orbits before delta-V maneuvers. During those times, the spacecraft was maneuvered into various DIRA calibration and delta-V attitudes and commanded into tighter attitude control modes. Such perturbations yielded systematic patterns, including oscillations and ramps in the tracking residuals.

During GOES-8 real-time support, the dynamic solar radiation force modeling, which existed in FDF software, was used to absorb the effects of the autonomous attitude control thrusting. This approach worked but only because most of the AOCS thrusting turned out to be parallel to the Sun line. Current analysis is underway, however, to model the large attitude thrusting on the half-orbits before delta-V maneuvers in more detail. Once modeled, improvements in orbit determination and thrust estimation before and following GOES maneuvers should be expected.

Reference 5 contains a more detailed description of this analysis and results.

Trim Tab Support

GOES has a trim tab on the end of the solar array that is adjusted in-flight to balance solar radiation pressure torques between the solar sail and solar array. The goal is to manage yaw angular momentum using the trim tab to eliminate the need to use yaw thrusters for momentum unloading, since this activity disturbs the imaging process. The trim tab is supplemented by magnetic torquers and thrusters, which are intended to absorb excess yaw momentum if the trim tab is not set exactly right. The trim tab angle is adjusted once per day by ground command to compensate for the average solar torque expected during the next day.

Before launch, SS/L developed a table providing the theoretical value of the trim tab angle as a function of day of year, based on detailed modeling of the GOES-8 spacecraft. Once on-orbit, the initial setting of the trim tab was selected from this table. However, it was recognized before launch that predicted values would not be sufficiently accurate for operational use; thus, SS/L developed an algorithm to be used in-flight to estimate the actual torques acting on the spacecraft. The process is to look at the thruster activity, wheel speeds, and magnetic torquer activity over 24 hours, calculate the residual torque acting on the spacecraft, and calculate the trim tab angle needed to compensate this torque as well as the change in the torque that would be expected as a result of the daily change in Sun declination.

After launch, it was found that the algorithm was overly sensitive to small, short-term variations in the residual torque. The telemetry readout of the actual trim tab angle was also noisier than expected and was biased by a few tenths of a degree, causing contamination of the calculations. As a result, FDF analysts developed a simplified procedure in which the trim tab angle was adjusted every day to track the Sun, based on a theoretical calculation. Every few days, a larger or smaller adjustment was made to minimize the magnetic torquer activity. The residual torque calculation was based only on changes in trim tab angle, not the absolute angle. This approach generally worked well—no thruster firings were necessary for yaw momentum control—but was too labor intensive for routine operations and not sufficiently accurate to keep the magnetic torquer activity as low as possible. SS/L subsequently developed and implemented a new algorithm in which an empirical power series model of the trim tab angle was fit over several weeks of observations and used to predict the trim tab angle for the coming week.

The trim tab approach worked well to control the yaw angular momentum. For example, the torque due to the solar sail or solar array alone was on the order of 3×10^{-4} NM. The sum of the two without the trim tab is about an order of magnitude less and is reduced to the range of 1×10^{-6} to 1×10^{-7} NM by proper trim tab adjustment.

GOES Separation Attitude

The baseline GOES-8 separation attitude required the spacecraft Z-axis to be placed at a right ascension of 61.7 deg and a declination of -25.0 deg, with a spin rate of 7 deg/sec about that axis. Martin Marietta (then General Dynamics) had requested that FDF attempt to establish the postlaunch GOES-8 attitude using any available spacecraft data. This estimate was to help Martin Marietta verify the accuracy of the launch vehicle separation. Analysts took two approaches:

1. Attitude sensor data (DIRA, DSS, ES) were used to try to directly solve for the attitude and rate

2. Doppler tracking data were used as an indirect measurement of spacecraft nutation angle.

DIRA data available approximately 25 min after separation indicated that the spin rate was 6.2 deg/sec about the Z-axis, with average rates of -0.5 deg/sec on the X-axis and 1.7 deg/sec on the Y-axis. Based on the maximum values of the cross-axis rates, the maximum deviation of the Z-axis from the angular momentum vector was about 30 deg at that time. Meanwhile, FDF analysts studied Doppler tracking data (References 6, 7) that suggested a spin rate of 6.86 deg about the Z-axis and a nutation amplitude of about 4 deg at the time of separation. These values are consistent with those Martin Marietta predicted prelaunch.

Additionally, Earth sensor data were obtained approximately 1.5 hr after separation, when an attitude solution was computed. Back-propagation of this attitude to the time of DIRA turn-on was attempted but was not reliable because of changing DIRA biases and the commanded high-rate mode of the DIRA (necessary to avoid saturation) that yielded a resolution of only 1.2 deg/hr.

GOES-J and Beyond

In January 1995, GOES-8 was moved from its checkout longitude at 90 deg W to its operational longitude of 75 deg W (over the east coast of the United States). On May 19, 1995, NASA intends to launch GOES-J, which will cover weather for the west coast at 135 deg W and replace GOES-7. Although the GOES-J mission should be virtually identical to GOES-8, slight modifications to both the spacecraft and operations are expected to reduce the number of complications experienced and improve spacecraft operations. The following is a summary of some of changes that have resulted from GOES-8 lessons learned:

- Fifteen kilograms of additional shielding has been added to the spacecraft to further guard against electrostatic discharges. To maintain the separation weight, the propellant will be reduced by 15 kg.
- The Santiago ground station will be scheduled in advance for tracking data support to improve accuracy and turnaround of orbit solutions.
- The GOES-J checkout orbit will not have a biased apogee and perigee. Such an orbit tended to complicate the instrument checkout for GOES-8, so a circular orbit will be targeted instead.
- GOES-J AMF abort criteria have been reviewed and revised following significant prelaunch analysis and spacecraft testing. A yaw reorientation maneuver will again be conducted to cool the MST before the delta-V maneuvers as a precaution for GOES-J. Performing a small initial calibration burn (less than 20 min) instead of a larger burn (longer than 60 min) in an attempt to characterize the thruster flange temperatures early in the ascent phase was considered. However, this idea was discarded to minimize the time spent in the transfer orbit where the possibility of electrostatic discharges poses a threat to the spacecraft.
- A quenching burn sequence will be scripted and practiced to reduce temperatures following the large MST firings. Quenching burns will be performed only as necessary.
- All FDF procedures have been updated to factor in GOES-8 lessons learned; in particular, new procedures have been implemented to streamline DIRA calibration operations and account for the DIRA drift rate dependence on temperature.
- FDF support shifts are to be streamlined and adjusted to provide quicker response to maneuver planning and product generation in support of station scheduling activities.
- Orbit determination procedures have been improved to accommodate periods of intensive AOCS thrust activity and decrease their effect on orbit solutions.

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