On-Orbit Mission Operations

As a platform for the payload and in support of the mission's objectives, the spacecraft undergoes or executes numerous operational events: configuring subsystems, orienting attitude, bus maintenance, compensating for environmental effects or changes, adjusting operational parameters, performing maneuvers. The operational events occurring on orbit are grouped into two categories: daily operations and periodic operations. Daily operations include events scheduled to occur, as determined in advance, based on normal spacecraft operations and adjusted to account for the seasons. Periodic operations entail infrequent but recurring events such as stationkeeping, space environment monitor calibration, attitude and orbit control subsystem adjustments, sun / moon intrusion, station relocation, etc., which occur over the spacecraft's life.

Typical Daily Operations

Daily operations for the Imager and the Sounder are structured to satisfy the meteorological needs of the National Weather Service. These operational scenarios for the GOES spacecraft Imager and Sounder also must comply with spacecraft state-of-health requirements and operational constraints. The initial, "Day-l", operational scenarios for GOES spacecraft feature one of three modes for the Imager: full disk, routine, and rapid scan. The Sounder has three modes which operate concurrently with the three Imager modes. The mode being used at any given time is related to the severity of the meteorological activity being observed.

Full Disk Mode

The Imager full disk mode consists of a full disk scan of the earth followed by star looks and a blackbody calibration. This sequence is repeated every half hour. The full disk scan is changed to an extended northern hemisphere scan once every 6 hours. This allows sufficient time to perform the 10-minute spacecraft housekeeping activities.

The corresponding Sounder operations follow a summer mode (June to November) or winter mode (December to May) schedule. This is a 6-hour repeated schedule. The schedule starts with a full regional northern hemisphere sounding repeated three times on one-hour centers; then a full regional southern hemisphere sounding (winter mode) or a limited regional sounding and a mesoscale sounding (summer mode), followed by a limited regional sounding. Spacecraft housekeeping activities are then performed to complete the 6-hour schedule. The soundings are interrupted for star looks each half hour and for blackbody calibrations.

Routine Mode

The Imager routine mode is a repeated 3-hour sequence. The 3 hours start with a full disk scan, followed by the half-hour sequence of an extended northern hemisphere scan, a continental U.S. (CONUS) scan, and a southern hemisphere-south scan which is repeated five times. The last southern hemisphere-south scan is omitted every 6 hours to allow for spacecraft housekeeping . Star looks and blackbody calibrations are performed every half hour.

The Sounder performs the same summer mode or winter mode schedule as during the Imager full disk mode.

Rapid Scan Mode

The Imager rapid scan mode is a repeated 3-hour sequence. The 3 hours start with a full disk scan. Then the half-hour sequence of a northern hemisphere scan is followed by a CONUS scan, a small southern hemisphere scan, a second CONUS scan, star looks and a blackbody calibration, and five more CONUS scans. The last two CONUS scans are omitted every 6 hours to allow for spacecraft housekeeping activities.

The Sounder warning mode is performed in conjunction with the Imager rapid scan mode. This is a 6-hour repeated schedule. The schedule starts with a limited regional sounding, then nine repeated mesoscale soundings. Then another limited regional sounding is performed, followed by eight mesoscale soundings, and then the spacecraft housekeeping activities. The soundings are interrupted for star looks each half hour and for blackbody calibrations.

Scan Sector Boundaries and Durations

The typical Imager and Sounder scan sector boundaries and scan durations are for the operational scenarios described above. The boundaries assume that the GOES-East satellite subpoint will be located at 75 degrees west longitude.

GOES-East Imager Scan Sectors – Boundaries and Duration for Day-1 Scenarios

(Subsatellite Longitude: 75° west)

					Scan Duration (minutes)					
							9.2 second		36.6 second	
Frame Name	Boundaries (Lat/Long)				Scan Clamp		Space Clamp		Space Clamp	
	North	South	West	East	West	East	West	East	West	East
Full Disk	Earth Edge				26.26	26.26	47.00	47.00	27.66	27.66
Northern Hemisphere	60°N	0°N	112°W	30°W	11.21	10.73	15.03	14.76	9.86	9.84
Northern Hemisphere-Extended	65°N	20°N	112°W	30°W	16.33	15.64	21.81	21.48	14.32	14.28
Southern Hemisphere-South	20°N	55°N	116°W	23°W	6.12	5.83	8.60	8.44	5.61	5.59
Continental U.S. (COUNUS)	60°N	14°N	112°W	64°W	5.99	7.40	6.23	6.65	4.70	4.75
Southern Hemisphere-Small Sector	0°	20°S	100°W	80°W	3.12	4.25	2.23	2.40	1.85	1.88

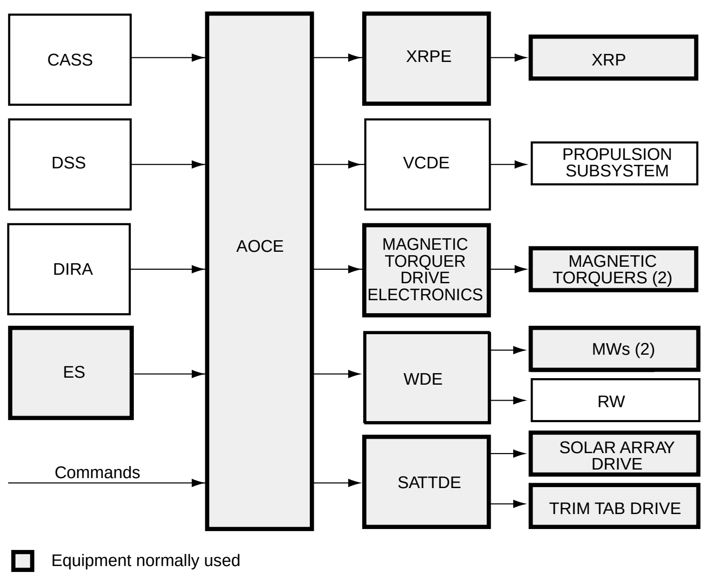
GOES-East Sounder Scan Sectors – Boundaries and Duration for Day-1 Scenarios

Frame Name	Boundaries				Scan Duration (minutes)
	North	**South**	**West**	**East**	
Full Regional-NH	51.5°N	23.3°N	120°W	63.6°W	52.1
Full Regional-SH	20°S	50°S	130°W	75°W	52.0
Limited Regional	50°N	26°N	118°W	66°W	39.8
Mesoscale-CONUS	43.6°N	26.8°N	106.2°W	87.9°W	12.2
Mesoscale-Tropics	24.7°N	15.0°N	70.2°W	44.5°W	12.1

(Subsatellite Longitude: 75° west)

Note: The mesoscale sectors included in this table are representative of a number which could be defined.

AOCS On-Orbit Control During Imager and Sounder Operations



Legend

AOCE	Attitude and Orbit Control Electronics	SATTDE	Solar Array Trim Tab Drive Electronics
CASS	Coarse Analog Sun Sensor	VCDE	Valve Coil Drive Electronics
DIRA	Digital Integrating Rate Assembly	WDE	Wheel Drive Electronics
DSS	Digital Sun Sensor	XRP	X-Ray Positioner
ES	Earth Sensor	XRPE	X-Ray Positioner Electronics
MW	Momentum Wheel		
RW	Reaction Wheel		

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Imager/Sounder

Imaging and sounding are performed at predefined scan coordinates. If scan frame coordinates are required, the GOES I-M tracking and command system (GIMTACS) requests the orbit and attitude tracking system (OATS) to provide scan frame conversion from scan lines and pixel number (or longitude and latitude) to cycles and increments for use by the Imager and Sounder. GIMTACS also specifies the stepping mode of the Sounder as part of the request. In response, OATS converts scan coordinates to cycles and increments for the Imager and Sounder and sends scan start and stop coordinates and scan start and stop times. These data are then used by GIMTACS in the command message to the Imager and Sounder.

For its daily schedule, GIMTACS requests from OATS star view command parameters of a specified duration. OATS responds with star view coordinates in cycles and increments, dwell times, and look start time for each instrument. Start time is the time at which the pulse command, star-sense start is received at the instrument.

Spacecraft

The daily operational procedure for spacecraft subsystems (for example, telemetry and command, electrical power, attitude and orbit control, propulsion, thermal, and communications) generally involves monitoring and control of operational parameters (such as bus voltages, battery reconditioning, roll/yaw controller gain, etc.). Housekeeping operations, such as trim tab slew and solar array adjustments, that generally allow controlled changes in spacecraft attitude are performed in the manual mode during intervals of 10 minutes each, at 05:50, 11:50, 17:50 and 23:50 hours, spacecraft local time. During each eclipse season the 05:50 universal time coordinated (UTC) housekeeping period will be replaced by periods at 03:50 and 07:50 UTC to accommodate earth sensor single chord operations. Bus maintenance, such as heater configuration changes, redundancy switching, etc., are performed as required.

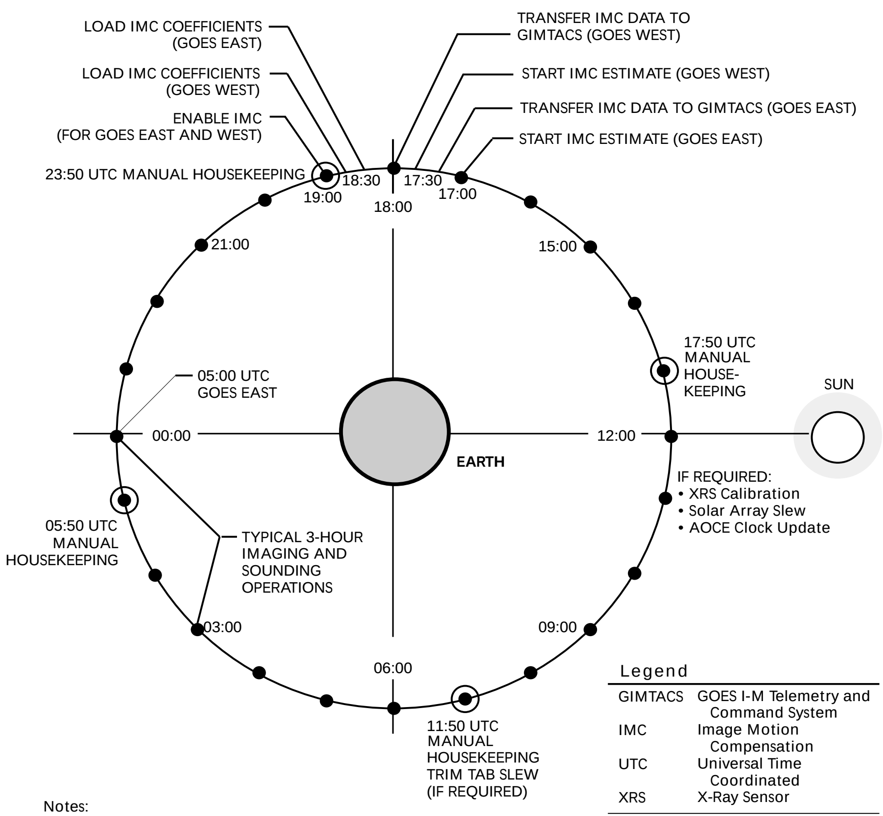
Space Environment Monitor (SEM)

The SEM is on and operational once the spacecraft reaches station. Calibration of the X-ray sensor (XRS) is performed periodically during the housekeeping period as required. Magnetometer and energetic particles sensor (EPS)/high energy proton and alpha detector (HEPAD) calibrations are performed periodically and can be done at any time without affecting Imager and Sounder operations.

Image Navigation and Registration

To support image navigation and registration (INR), a parent image motion compensation (IMC) coefficient set is generated every day and uploaded to the spacecraft. This is scheduled during the final hour of each day so the data set can be enabled at 00:00 hours UTC for the next operational day. Normally this set is effective throughout a coregistration period of 24 hours. OATS provides GIMTACS with the new IMC coefficient data set to be uploaded, the message normally being sent once a day and enabled at a time specified by OATS. IMC

Daily Operation Schedule (Typical)



Notes:

1. Typical 3-hour imaging and sounding operations are repeated for every 3-hour interval in normal, watch, or warning mode.
2. Timings are GOES East spacecraft local time unless otherwise specified.
3. GOES West (135˚ W) 00:00 spacecraft local time = 09:00 UTC.
4. GOES West operations are similar to GOES East but occur 4 hours later, except for IMC, which is performed as shown above.
5. IMC epoch of GOES West is 4 hours later than GOES East in terms of spacecraft tme.
6. Houskeeping times are typical.

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operation for GOES East and GOES West is performed together and keyed to GOES East spacecraft time, as it is closer to satellite operations control center local time.

Equinox Operations

The equinox seasons occur from about 28 February to 12 April for the vernal equinox and 31 August to 13 October for autumnal equinox. OATS determines the actual start times and duration of the solar eclipses that occur once a day during these seasons. For the duration of the eclipse (at most 72 minutes) the spacecraft depends solely on batteries for electrical power. Because battery capacity is limited, the spacecraft electrical loads are reduced before the eclipse starts. This is automatically accomplished by the load control function except for the Imager and Sounder scan motors, which must be turned off by ground command. Load reduction ensures that the maximum battery depth of discharge is not exceeded for the rated battery capacity and longest eclipse duration. The spacecraft loads are automatically reconfigured after the eclipse when the solar array resumes generating electrical power.

To conserve battery power and minimize ground commanding, noncritical thermal control heaters are turned off automatically upon entry into eclipse and turned on after emergence. The Imager and Sounder are in standby mode, with the scan motors and electronics turned off until the eclipse is over. Because the Imager and Sounder electronics are automatically turned off prior to the eclipse and turned on after the eclipse, the instruments can be quickly reinitialized after eclipse to return to normal operations.

Solstice Operations

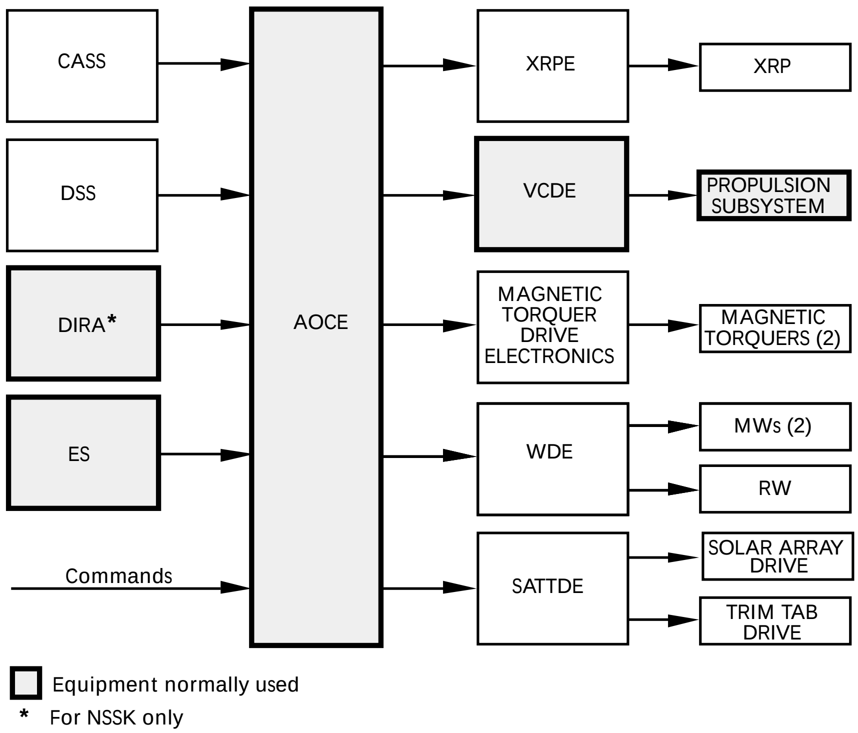
The solstice seasons occur approximately from 13 April to 30 August for summer solstice and about 14 October to 27 February for winter. Except for any periodic operations that need to be scheduled, the spacecraft has very few configuration changes during the solstice periods; it is the same as in the initial on-orbit configuration.

Periodic Operations

Periodic operations are infrequent but recurring events that are scheduled periodically through the spacecraft's on-orbit lifetime. These operations can be inserted into the daily operations schedule as needed and performed during one of the housekeeping intervals, the other scheduled functions being altered accordingly. Major periodic operations are:

- East / west stationkeeping (EWSK)
- North / south stationkeeping (NSSK)
- SEM calibration
- AOCS adjustments

AOCS On-Orbit Control During Stationkeeping



Legend

AOCE	Attitude and Orbit Control Electronics	RW	Reaction Wheel
CASS	Coarse Analog Sun Sensor	SATTDE	Solar Array Trim Tab Drive Electronics
DIRA	Digital Integrating Rate Assembly		
DSS	Digital Sun Sensor	VCDE	Valve Coil Drive Electronics
ES	Earth Sensor	WDE	Wheel Drive Electronics
MW	Momentum Wheel	XRP	X-Ray Positioner
NSSK	North/South Stationkeeping	XRPE	X-Ray Positioner Electronics

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- Solar array slew
- Sun / moon intrusion
- Image interaction dynamics
- Station relocation
- Propellant remaining estimation

East/West Stationkeeping

Frequent EWSK is required to counteract the effects of earth's triaxiality on spacecraft drift and solar radiation pressure on orbital eccentricity. The maneuver strategy is to start the stationkeeping (SK) cycle with the spacecraft at one edge of the longitude deadband (±0.5°), drifting across the deadband with negative perturbing acceleration. With an initial drift rate of just the right magnitude, the spacecraft drifts to the desired longitude, where an EWSK maneuver is applied to reverse the spacecraft drift and keep it within the deadband at the assigned station longitude (either 75° or 135° west). OATS software performs the necessary calculation for determining when to perform the maneuver and the corresponding command data for thruster selection and required duration.

North/South Stationkeeping

About once a year (for 0.5° inclination) NSSK maneuvers are required to counteract the gravitational forces exerted by the sun and moon on the spacecraft. The maneuver strategy is to start the SK cycle with the spacecraft at one edge of the inclination deadband (±0.5° of the equator) at the optimum node, allowing it to drift to zero inclination and then back to 0.5°. The maneuver is again performed to bring the spacecraft back to the beginning of the deadband (optimum node). This minimizes the velocity increment required and, hence, propellant used. OATS software performs the calculation for determining when to perform the maneuver and the corresponding command data.

For the 0.5° inclination deadband, the NSSK maneuver is only required once a year. Because the spacecraft south panel thrusters provide the needed orbit change thrust, the maneuver must be done at the orbit's descending node. When the maneuver is completed, the right ascension of the ascending node is at 270° from the vernal equinox. The required orbital configuration, together with constraints on the solar array orientation with respect to the south panel thrusters, suggests an optimum time for annual NSSK of noon time at winter solstice or midnight during summer solstice.

SEM Calibration

The operation of the SEM sensors involves periodic in-flight calibrations (IFCs) of the magnetometer, XRS, and EPS/HEPAD. An IFC of the magnetometer is performed to verify proper operation. The IFC mode lasts about 82 seconds and can be initiated at any time by ground command. Once initiated, a calibration signal is generated by the magnetometer and superimposed on the ambient magnetic field being measured. All three channels (X, Y, Z) receive the calibration signal simultaneously.

An IFC of the XRS is initiated by ground command to verify basic sensor operation and determine the electronic processing gain of the data processing unit to an accuracy of ±2%. IFC requires an XRS pointing offset from the sun of at least 13° to ensure that all solar X-ray emissions are out of the XRS field of view (FOV), thus obtaining a low background noise environment. The nominal calibration frequency is weekly. IFC is typically performed during housekeeping periods (when trim tab adjustment is not performed), thereby avoiding interference with Imager and Sounder operations. Conditions permitting, calibration can also be performed immediately after NSSK maneuver when the XRS is still in the stowed position.

An IFC of the EPS / HEPAD is initiated by ground command to verify proper operation of the instrument and to adjust the photomultiplier tube high voltage for optimum performance. Once calibration is initiated, the IFC circuitry provides a series of calibration signals to the dome, telescope, and HEPAD amplification channels. The calibration sequence lasts approximately 11 minutes and is self-terminating.

AOCS Adjustments

Adjustments in the AOCS are infrequent and involve wheel unload pulse widths, gain settings for the roll / yaw and pitch loops, pitch and yaw momentum desaturation levels, magnetic torquer parameters, and attitude and orbit control electronics (AOCE) clock update.

Normally, for pitch / yaw wheel unload a 5-ms pulse is required. A range of pulse widths is selectable by ground command and the present pulse width may be updated if required after a few days of on-orbit operation.

There are two sets of gains for the roll / yaw on-orbit mode operation: short-term roll / yaw control and long-term magnetic torquer controller gains. The short-term roll / yaw control gain sets are derived to give optimum performance in the V- and L-modes for imaging and housekeeping operations. High gains are used for housekeeping in V- and L-modes and low gains for imaging in V- and L-modes. Medium gains are used if roll / yaw performance shows a need for modification and are provided for contingencies. The selected on-board gain is available via telemetry.

Magnetic torquers are used to remove residual inertial roll / yaw torque and momentum, thus controlling the yaw error and the amount of momentum stored in the wheels. The magnetic torquer controller has four gain sets used for V- and L-mode operation. One set of two is used for V- and L-mode operation while both magnetic torquers are operational, the other set for the same modes when one of the torquers fails. These gains are used in conjunction with current limit off for the failed torquer. During normal imaging operations, the magnetic torquers' peak limit is constrained to improve yaw repeatability from day to day. This limit setting is based on the operational configuration of the roll / yaw control system during magnetic torquer startup operation.

INR functions are synchronized to ground station-maintained UTC via the 24-hour AOCE internal clock. Periodic resynchronization to the ground-based clock compensates for drift in the AOCE clock's crystal oscillator (16.384 MHz). Due primarily to temperature fluctuations, drift can yield a worst-case error of 20 parts per million (1.73 s / day), based on the nominal on-orbit temperature range of 0 to 40 ˚C. The INR process can accept a maximum clock error of 10 seconds, so that an uncorrected worst-case error would reach the acceptance limit in less than 6 days. Under nominal conditions, oscillator drift is lower than this worst case so a clock update would occur about once a week. The update can be performed at any time when imaging and sounding are not in progress, preferably at the 12:00 noon housekeeping period.

Solar Array Slew

The solar array is slewed to correct errors in pointing the array toward the sun and to meet NSSK maneuver constraints, if required. Errors will occur because the solar array cannot step during the period that trim tab slews are performed. These errors are measured by the east/west sun analog sensor (SAS) telemetry output, though SAS data cannot be used if the error exceeds ±2°. In this case the initial reset is performed using known spacecraft orbital time and readouts from solar array position telemetry. If the detected error exceeds 0.1° (XRS performance constraint), the solar array drive is put into slew mode, the slew direction selected, and the slew time commanded. After slewing, the solar drive is returned to run mode and normal stepping resumed. The SAS telemetry output is again monitored to verify correct solar array pointing.

Sun/Moon Intrusion

The sun, and to a lesser extent the moon, periodically interferes with spacecraft operations, affecting Imager and Sounder radiometric reference and spacecraft attitude control, which in turn degrades INR accuracy. The sun also affects telecommunications between the spacecraft and ground. The sun and moon at low declination can interfere with the Imager and Sounder. For the sun, this occurs during the eclipse season centered on the equinoxes (22 March and 23 September). Moon intrusion can occur at any time during the year, the height occurring in eclipse season when the moon is full or nearly full as it reaches low declinations. The sun is also expected to cross the command and data acquisition (CDA) antenna beam and degrade spacecraft communications during eclipse season.

Upon request from GIMTACS, OATS computes the orbital events and sensor intrusions given a future time span and provides the intrusion start and end times, the sensor(s) being impaired (Imager, Sounder, earth sensor (ES)), and the edge (east or west for the Imager and Sounder) or scan (north or south for the ES) being affected. With these data the GIMTACS scheduler determines when operations of a particular sensor are impaired and formulates commands to switch operating modes to account for the interference.

When the sun or moon enters the ES's FOV, one of the scans is affected. This requires that one of the ES scans be inhibited before the sun or moon enters the scan FOV in order to reduce spacecraft attitude error to an acceptable level. The intrusion occurs approximately 2.5 hours during each eclipse season and the moon intrusion occurs about 2 hours on any day when the moon's phase is near full.

The sun, when at a relatively low declination, is expected to pass through the CDA antenna radio frequency beam, degrading the telemetry and command (T&C) link between the spacecraft and ground station. Interference is also expected for other communication antennas, degrading the signal-to-noise ratio, as high as 30 dB. OATS predicts these events and provides the data to GIMTACS. As no direct work-around is feasible, the spacecraft controller simply adjusts the operating schedule to avoid uplinking commands during the time interval the communications link is impaired.

Image Interaction Diagnostics

Several periodic operations relate to the image navigation and registration (INR) process: dynamic interaction diagnostics, ES single chord operation, mirror motion compensation tuning, and image motion compensation calibration.

- **Dynamic Interaction Diagnostics.** A dynamic interaction diagnostic telemetry system is provided (in GOES-I & K) to measure excessive interaction between mechanical motion events (such as momentum / reaction wheel, solar array drive assembly, and Imager / Sounder mirror motion). Measurement data consist of three-axis angular displacement from the angular displacement sensor, three-axis angular rate and motion from the digital integrating rate assembly (DIRA), Imager and Sounder servo errors, and discrete event information related to solar array drive assembly stepping and Imager / Sounder mirror motion. The diagnostic data are used during initial on-orbit checkout to identify dominant effects that produce excessive interaction and to develop operational scenarios that avoid or minimize such interaction. Diagnostic telemetry can be used at any time during subsequent spacecraft orbital operations for the same purpose.
- **Single Chord Operation.** When the sun or moon intrudes into the ES's FOV, one of the scans is inhibited, yielding ES single chord operation. Inhibiting a scan before intrusion occurs is necessary in order to reduce the spacecraft attitude error to an acceptable level and meet INR requirements. From OATS predictions, the chord in which intrusion occurs and the intrusion start / end times are known to GIMTACS ahead of time. OATS also provides the star command data for the intrusion windows provided by GIMTACS to perform star sightings after inhibition of the affected scan.
- **Mirror Motion Compensation.** A set of mirror motion compensation (MMC) coefficients is established during initial on-orbit startup operations and updated yearly to account for spacecraft mass changes due to propellant consumption. MMC tuning involves a series of Imager and Sounder mirror motion command sequences performed by GIMTACS according to a predefined procedure. MMC tuning is typically performed at the same time of the day each time (fixed solar array position) throughout the spacecraft life to monitor trends in MMC scale factor. Tuning is performed during the post-NSSK stabilization period to minimize interference with normal payload operations, requiring at most 1 hour 15 minutes. OATS uses the resulting Imager / Sounder wideband data with spacecraft telemetry (wheel speed, DIRA data, etc.) to update the coefficients; these are then uplinked to the spacecraft via GIMTACS.
- **Image Motion Compensation Calibration.** A set of baseline in-flight IMC scale factors is established during initial on-orbit startup operations. This baseline, updated yearly, compensates for errors introduced by the digital / analog converters in the AOCE. The updated baseline provides the best agreement between commanded IMC offsets and actual instrument line-of-sight offsets. IMC calibration can be performed at any time if imaging and sounding operations are suspended during the IMC calibration period (at least one hour) and the instruments are specifically configured to support the

calibration process. IMC calibration involves performing a series of star sightings with different IMC offsets as defined by OATS. The resulting Imager and Sounder wideband data are used by OATS to update the east/west and north/south compensation scale factors which are then transmitted to the spacecraft via GIMTACS.

Station Relocation

Three station relocations are anticipated during the spacecraft's lifetime. On-station longitude is changed by applying an incremental velocity, typically at an apse, to maintain eccentricity within acceptable limits and change the radius of the opposite apse. If the velocity increment is applied in the direction of motion, the orbit radius is increased and the spacecraft drifts westerly with respect to earth; if applied opposite to the direction of motion, orbit radius is decreased and the spacecraft drifts easterly. When the desired on-station longitude is reached, an incremental velocity of equal magnitude but opposite direction is applied at the same apse as the first to arrest the drift. The total maneuver is essentially a pair of EWSK maneuvers separated by a period for the spacecraft to drift to its new station. OATS software provides the support needed to compute the maneuver sequences that place the spacecraft on a specified longitude at a specified time.

Propellant Remaining Estimation

The estimate of propellant remaining on board, and hence the remaining spacecraft lifetime, is divided into three phases: prelaunch phase, orbit raising phase, and on-orbit phase. In the prelaunch phase, the initial loading of propellant (fuel, oxidizer, and helium gas) is provided after propellant loading is completed.

The estimate of propellant used during orbit raising operations, about 86.2% of the amount loaded, is provided by Goddard Space Flight Center. The actual amount consumed is tracked through various telemetered parameters and subtracted from the initial loading. The estimate of propellant remaining based on available telemetry is compared with the resultant orbital incremental velocity data to calculate propellant usage and, thus, propellant remaining.

The on-orbit phase, consisting of the operational and storage/standby modes, uses the remaining 13.8% of the propellant loaded. Because maneuvers during the storage/standby mode are performed by OATS, the process of estimating propellant remaining is the same in all on-orbit modes. OGE/GIMTACS records and monitors remaining propellant during the on-orbit phase.

Deorbit

At the end of its operational life, the spacecraft is raised 350 kilometers (217 statute miles) above synchronous altitude to allow other spacecraft to use the vacated orbital slot. In this deorbit maneuver, the AOCS thrusters impart an incremental velocity to the spacecraft, typically at an apse, in the direction of motion, producing an elliptical transfer orbit to the higher orbit radius and a westerly drift with respect to earth. The new orbit is circularized by a second velocity increment applied at the opposite apse in the direction of motion. If the propellants are depleted before deorbit, the remaining pressurized helium can be used to achieve a 120-kilometer (74.6 statute miles) altitude above synchronous. The spacecraft payloads are then shut down to eliminate unwanted transmissions.