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# Unusual Maneuvers on Nimbus and Landsat Spacecraft


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## Introduction

THE current version of the attitude control system used for both the Nimbus and Landsat series of spacecraft was first developed for use on the Nimbus 4 spacecraft. This control system has been used on the following five spacecraft now in orbit:

| Spacecraft | Launch date |
|---|---|
| Nimbus 4 | April 8, 1970 |
| Nimbus 5 | Dec. 11, 1972 |
| Nimbus 6 | June 12, 1975 |
| Landsat 1 | July 23, 1972 |
| Landsat 2 | Jan. 22, 1975 |

Despite a design life ranging from six months for Nimbus 4 to one year for Nimbus 6, all five spacecraft are still operational. Orbital life times range from almost two years to seven years.

This record of reliability was achieved despite several component failures and operational mishaps. One of the reasons this was possible is that the large number of commands and telemetry functions available provide great flexibility. Maneuvers have been devised and performed that were never thought of when the control system was designed. Several examples of such maneuvers are presented in this paper. These include a yaw turn-around maneuver using a failed gyro, elimination of cold gas thrusting to unload momentum, and adjusting the orbit without using the Orbit Adjust Subsystem.

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## Attitude Control System Description

The Nimbus/Landsat Attitude Control System (ACS) is a three-axis zero-momentum system that orients the spacecraft to the local vertical (pitch and roll) and the orbital plane (yaw). Reaction wheels provide normal control torques, and cold-gas thrusters are provided for momentum unloading. Infrared horizon scanners provide pitch and roll error signals. An inertial quality gyro is used in a gyro-compassing loop to provide yaw error signals.

The Nimbus 4 ACS has two features not provided on the other spacecraft. These are 1) a sun sensor to provide yaw error signals in the event of a gyro failure, and 2) a gravity gradient rod to be used in an auxiliary mode in which gravity gradient torques are used to unload momentum. The spacecraft operate in low altitude (920 to 1110 km) circular, near-polar sun-synchronous orbits. Orbital periods are 103 to 107 min, of which approximately one-third is spent in the Earth's umbra.

## Yaw-Around Maneuver with Failed Gyro

After one year in orbit the Nimbus 4 gyro spin motor failed. Yaw control was switched to the yaw sun sensor system. This system consists of two sensors, one facing forward and one facing aft. Both sensors are connected to provide stable nulls when facing the sun. This provision allows the spacecraft to fly always in the forward position. This is desirable for two reasons: 1) The Image Dissector Camera Subsystem includes a provision for image motion compensation; the images are distorted when the spacecraft flies backwards, and 2) solar arrays are driven by a fixed rate bias signal plus a sun sensor signal; when the spacecraft flies backward the tracking errors are larger in the sunlight, and the direction of rotation is incorrect in the umbra, leading to a large tracking error at sunrise.

However, with a stable null on both yaw sun sensors the spacecraft can fly either forward or backward. As the

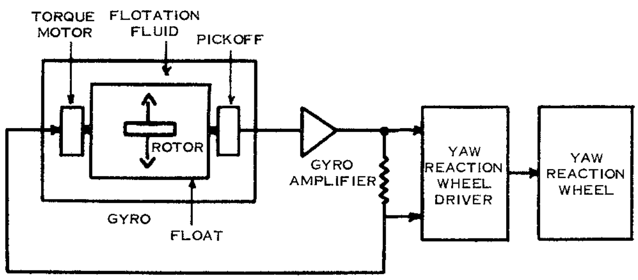


**Fig. 1 Gyro circuit block diagram.**

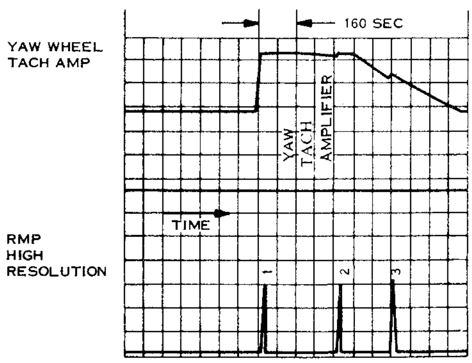


**Fig. 2 Telemetry records during turn-around maneuver.**

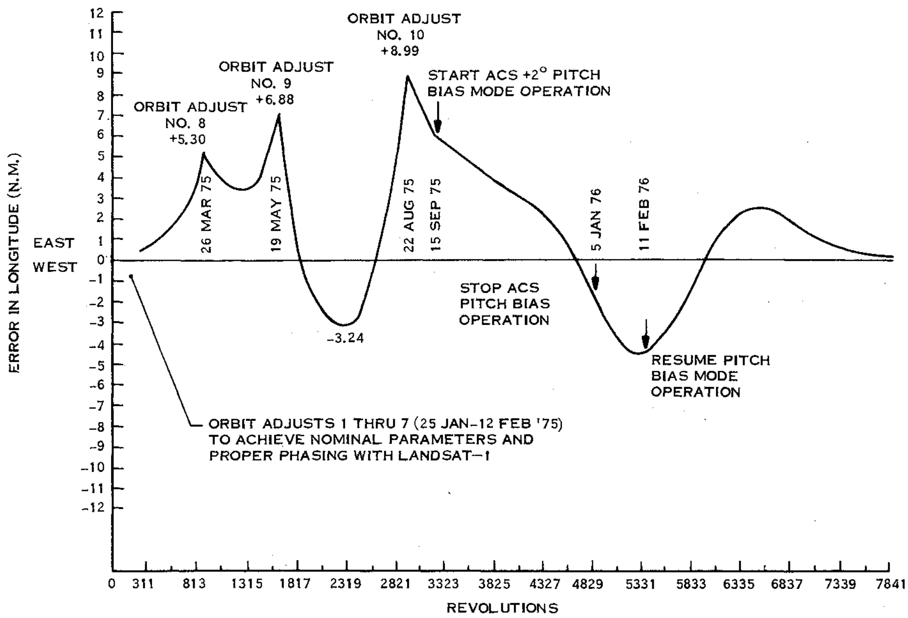


**Fig. 3 Effect of orbit adjusts and pitch position bias on Landsat 2 ground track.**

spacecraft enters the umbra, the yaw sun sensor signal vanishes, and the yaw reaction wheel momentum is transferred to the spacecraft body. If the spacecraft yaws sufficiently so that the aft sun sensor views the sun, the spacecraft will fly backward. This is what actually happened. The spacecraft yawed around and then continued to fly backward.

A turn-around maneuver was devised to cause the spacecraft to fly forward.[1] The maneuver is based on the partial use of the failed gyro. Figure 1 is useful in explaining the procedure.

Only the gyro spin motor had failed. When the gyro electronics are enabled, the gyro float is driven to its null position. Until it reaches its null position, there is an output to the yaw wheel driver. If the gyro is allowed to cool down, the float fluid becomes more viscous. This increases the time to drive the float to null, and therefore the duration of the output. What causes the float to be displaced is believed to be imperfections in the gyro. For example, float mass unbalance acted upon by vehicle accelerations, or residual torque in the float flex leads.

This maneuver was executed on Feb. 14, 1972. Three gyro "kicks" were commanded which provided a total of 13,300 yaw wheel revolutions which, in turn, provided a spacecraft yaw rotation of 94 deg. The turnaround was successfully accomplished. Figure 2 shows the telemetry records for the maneuver.

## Zero Cold Gas Usage

The Nimbus/Landsat ACS employs cold gas thrusting for momentum unloading. A 0.06 N-m-s "gate" in pitch or roll can be fired when the wheel speed exceeds a predetermined value.

After more than two years in orbit the Landsat 1 pitch reaction wheel stopped for a period of approximately 8 h. Procedures to maintain spacecraft control during this emergency period required a large amount of the available cold gas. When the pitch wheel restarted the available impulse from the cold gas supply had been reduced from 1870 N-s to 156 N-s (Ref. 2). At its existing gas consumption rate (270 N-s/yr) the spacecraft had a life expectancy of less than seven months.

To avoid loss of the spacecraft, a technique was devised to employ gravity gradient torques to perform all momentum unloading. In the pitch axis this was accomplished by commanding a bias in and out of the pitch error signal as necessary. Roll-yaw momentum was unloaded by decreasing the gain of the roll control loop during the several orbits per day in which the payload was not used. The resulting increased roll attitude error caused a roll gravity gradient torque sufficient to unload all accumulated roll-yaw momentum.

The spacecraft has been operating in this mode for almost three years. On July 6, 1977, available gas impulse remaining was 67 N-s. At this consumption rate the available gas will last two more years. Furthermore, there has been no gas consumption during the past six months.

## Orbit Adjust

The Landsat spacecraft has precise ground track requirements. An Orbit Adjust Subsystem which employs hydrazine thrusters provides the required adjustments to the orbit. The largest orbital disturbance is caused by the ACS pitch cold gas thruster firings used to unload pitch momentum. It was realized that if the number and direction of these thruster firings could be controlled they could be used to control instead of perturb the orbit, and with much finer resolution than that provided by the Orbit Adjust Subsystem. This mode was implemented by commanding a pitch bias signal in and out as required to produce the desired number of thruster firings.

Operation in this mode started in Sept. 1975 and has been used successfully ever since. The results are shown in Fig. 3.[3] It is obvious that this mode provides better control of ground track error than the use of the Orbit Adjust Subsystem.

## Conclusions

It is not possible to anticipate and plan for all of the control system problems that may occur in the several-year lifetime of a typical large complex spacecraft. By providing a large number of ground commands and telemetry data points, the spacecraft designers provide operational flexibility to the mission control staff. Maneuvers often can be devised, after the spacecraft is in orbit, to alleviate a problem or to improve performance. With the increasing emphasis on long life in orbit this capability is essential.

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