

2.3 Attitude Control & Orbit Control

The *attitude* of a satellite refers to its orientation in space. Much of the equipment carried aboard a satellite is meant for the purpose of controlling its attitude. Attitude control is necessary, to ensure that directional antennas point in the proper directions. In the case of earth environmental satellites, the earth-sensing instruments must cover the required regions of the earth, which also requires attitude control. A number of forces, referred to as *disturbance torques*, can alter the attitude, some examples being the gravitational fields of the earth and the moon, solar radiation, and meteorite impacts.

Attitude control must not be confused with station keeping, which is used for maintaining a satellite in its correct orbital position, although the two are closely related. To exercise attitude control, there must be available some measure of a satellite's orientation in space and of any tendency for this to shift. In one method, infrared sensors, referred to as *horizon detectors*, are used to detect the rim of the earth against the background of space.

With the use of four such sensors, one for each quadrant, the center of the earth can be readily established as a reference point. The attitude-control process takes place aboard the satellite, but it is also possible for control signals to be transmitted from earth, based on attitude data obtained from the satellite. Whenever a shift in attitude is desired, an *attitude maneuver* is executed. The control signals needed to achieve this maneuver may be transmitted from an earth station.

Controlling torques may be generated in a number of ways. *Passive attitude control* refers to the use of mechanisms which stabilize the satellite without putting a drain on the satellite's energy supplies; at most, infrequent use is made of these supplies, for example, when thruster jets are impulsed to provide corrective torque. Examples of passive attitude control are *spin stabilization* and *gravity gradient stabilization*.

The other form of attitude control is *active control*. With active attitude control, there is no overall stabilizing torque present to resist the disturbance torques. Instead, corrective torques are applied in response to disturbance torques. Methods used to generate active control torques include momentum wheels, electromagnetic coils, and mass expulsion devices, such as gas jets and ion thrusters.

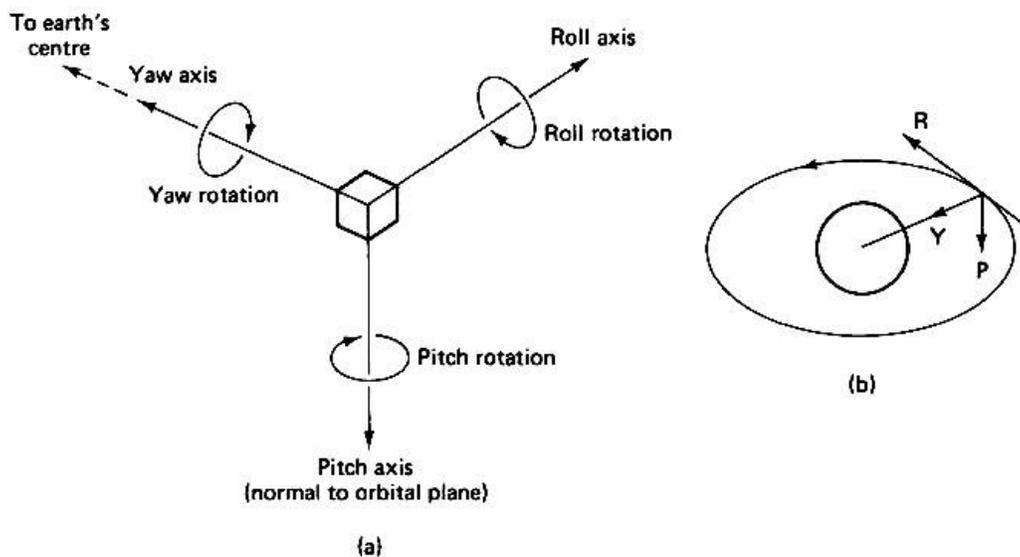


Fig 2.3 Roll, Pitch, and Yaw Axes (b) RPY axes for Geostationary Orbit

The three axes which define a satellite's attitude are its *roll*, *pitch*, and *yaw* (RPY) axes. These are shown relative to the earth in Figure 2.3. All three axes pass through the center of gravity of the satellite. For an equatorial orbit, movement of the satellite about the roll axis moves the antenna footprint north and south; movement about the pitch axis moves the footprint east and west; and movement about the yaw axis rotates the antenna footprint.

2.1.1 Spinning Satellite Stabilization

Spin stabilization may be achieved with cylindrical satellites. The satellite is constructed so that it is mechanically balanced about one particular axis and is then set spinning around this axis. For geostationary satellites, the spin axis is adjusted to be parallel to the N-S axis of the earth, as illustrated in Figure 2.4. Spin rate is typically in the range of 50 to 100 rev/minute. Spin is initiated during the launch phase by means of small gas jets.

In the absence of disturbance torques, the spinning satellite would maintain its correct attitude relative to the earth. Disturbance torques are generated in a number of ways, both external and internal to the satellite.

Solar radiation, gravitational gradients, and meteorite impacts are all examples of external forces which can give rise to disturbance torques. Motor-bearing friction and the movement of satellite elements such as the antennas also can give rise to disturbance torques.

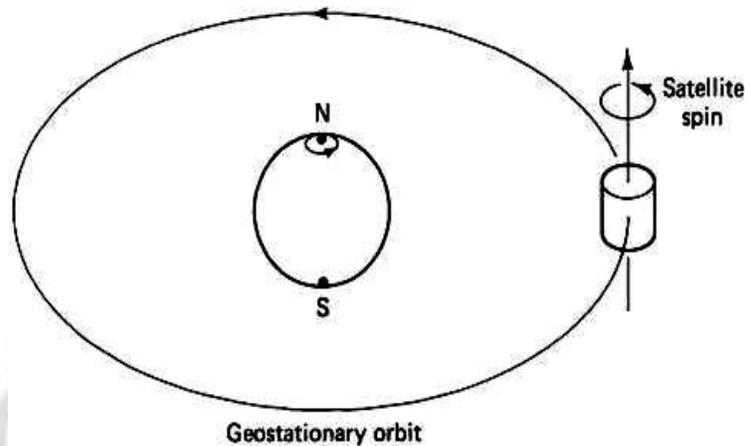


Fig 2.4 Spin stabilization in the geostationary orbit

The overall effect is that the spin rate will decrease, and the direction of the angular spin axis will change. Impulse-type thrusters, or jets, can be used to increase the spin rate again and to shift the axis back to its correct N-S orientation.

Nutation, which is a form of wobbling, can occur as a result of the disturbance torques and/or from misalignment or unbalance of the control jets. This nutation must be damped out by means of energy absorbers known as *nutation dampers*. The antenna feeds can be connected directly to the transponders without the need for radiofrequency rotary joints, while the complete platform is despun. Of course, control signals and power must be transferred to the despun section and a mechanical bearing must be provided. The complete assembly for this is known as the *bearing and power transfer assembly* (BAPTA). Figure 2.5 shows a photograph of the internal structure of the HS 376.

Certain dual-spin spacecraft obtain spin stabilization from a spinning fly-wheel rather than by spinning the satellite itself. These flywheels are termed *momentum wheels*, and their average momentum is referred to as *momentum bias*.

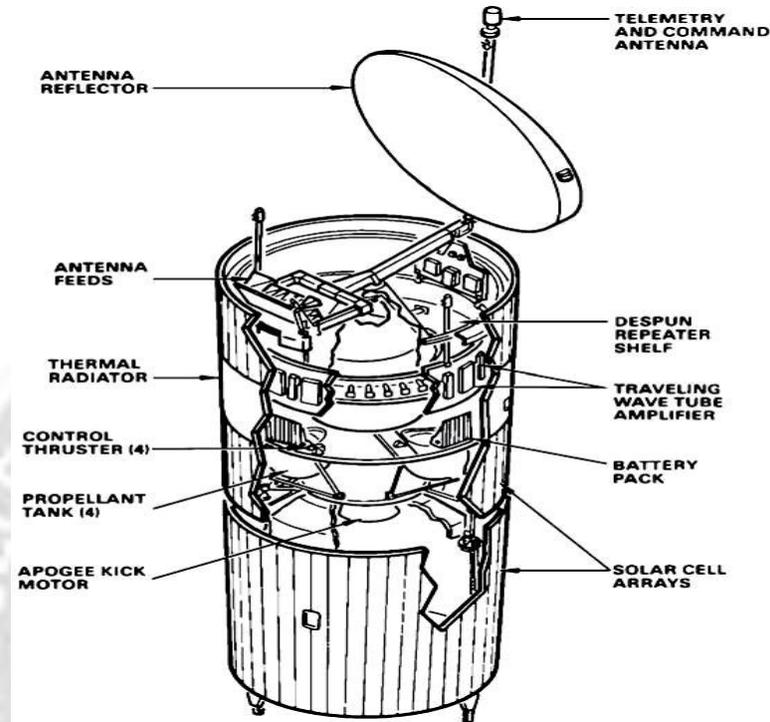


Fig 2.5 HS 376 Spacecraft

2.1.2 Momentum wheel stabilization

In the previous section the gyroscopic effect of a spinning satellite is shown to provide stability for the satellite attitude. Stability also can be achieved by utilizing the gyroscopic effect of a spinning flywheel, and this approach is used in satellites with cube-like bodies and the INTELSAT V type satellites. These are known as *body-stabilized* satellites. The complete unit, termed a momentum wheel, consists of a flywheel, the bearing assembly, the casing, and an electric drive motor with associated electronic control circuitry. The flywheel is attached to the rotor, which consists of a permanent magnet providing the magnetic field for motor action. The stator of the motor is attached to the body of the satellite. Thus the motor provides the coupling between the flywheel and the satellite structure. Speed and torque control of the motor is exercised through the currents fed to the stator.

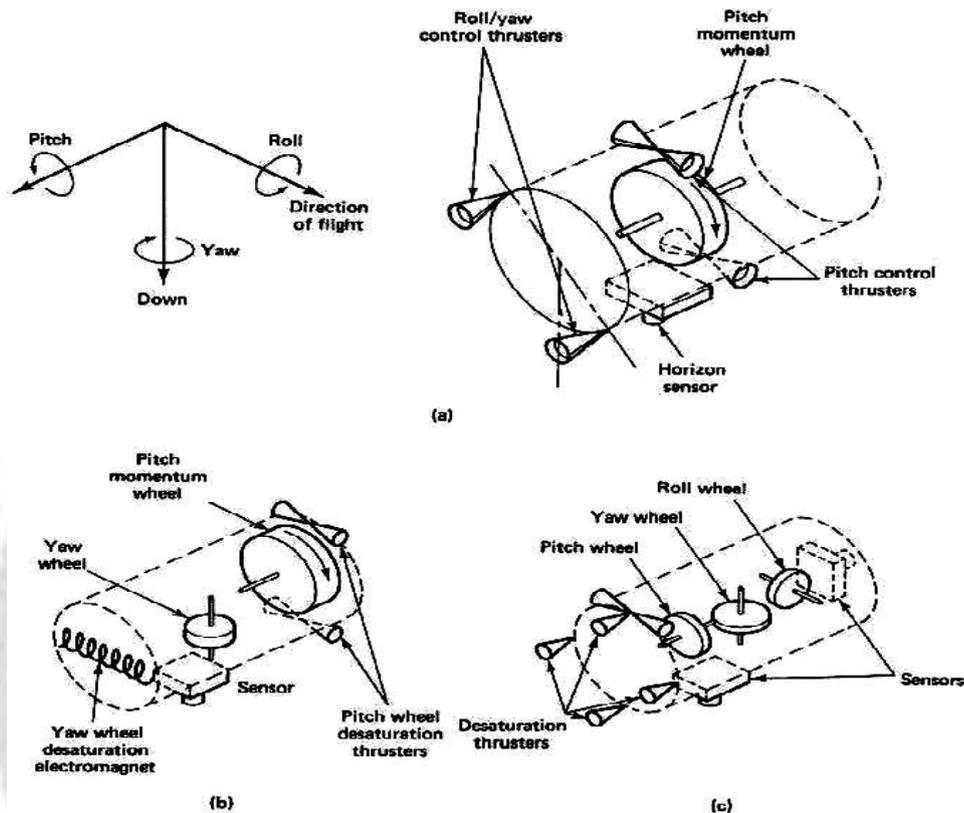


Fig 2.6 Alternative momentum wheel stabilization systems: (a) one-wheel, (b) two-wheel, (c) three-wheel

When a momentum wheel is operated with zero momentum bias, it is generally referred to as a *reaction wheel*. Reaction wheels are used in three-axis stabilized systems. Here each axis is stabilized by a reaction wheel, as shown in Figure 2.6. Reaction wheels can also be combined with a momentum wheel to provide the control needed.

Random and cyclic disturbance torques tend to produce zero momentum on average. However, there will always be some disturbance torques that cause a cumulative increase in wheel momentum, and eventually at some point the wheel *saturates*. In effect, it reaches its maximum allowable angular velocity and can no longer take in any more momentum. Mass expulsion devices are then used to unload the wheel, remove momentum from it. The operation of the mass expulsion devices consumes part of the satellite's fuel supply.