Attitude Determination and Control

ADCS a major vehicle subsystem
Requirements can drive the whole spacecraft design
Components tend to be
    Massive
    Power hungry
    Require specific orientation
    Tight alignment tolerances *
    Field of view requirements
    Subject to structural frequency response
    Structural damping

Definition of Attitude
Angular orientation of a defined body-fixed coordinate frame with respect to a separately defined external frame.
- Geocentric inertial system (GCI) – earth fixed but doesn’t rotate
- Heliocentric Inertial system (HCI) – sun fixed, earth in plane, polar axis @ 23.5°
- Local vertical, local horizontal (LVLH)

Attitude Determination – process of measuring spacecraft orientation
Attitude Control – maintaining or returning a spacecraft to a desired orientation

Errors
- Inexact measurements of orientation
- Inexact execution of maneuvers
- Time lags
Passband and Jitter
Passband = 1/τ Hz  Frequencies > 1/τ Hz are not sensed by the ADCS
Jitter is the inability to respond to these higher frequencies
- Due to electronic noise, mechanical vibration, etc
- We assume Jitter has a Gaussian distribution with mean=0 and variance=σ²
- Central limit theorem: sum of many independent zero-mean probability distributions converges in the limit to a Gaussian distribution.

Bias
- Long term integration of the data = θ_a which is different than desired attitude, θ_d: Bias
- Bias: sensor or actuator misalignment, disturbances, or control algorithm issues
- If Bias is constant then we have a pointing problem
- If Bias is not constant then we have a tracking problem

Euler Angles
Euler angle set = (φ, θ, ψ) roll, pitch, yaw of the spacecraft body
Relative to a rotating local vertical frame; i.e., an inertial frame
May be referenced to vehicle velocity vector, or LVLH
Rotational sequence 2-1-3
\[ T_{I\rightarrow B} = [\psi][\phi][\theta] \]
Transformation matrices are orthonormal: transpose = inverse
\[ T_{B\rightarrow I} = T_{I\rightarrow B}^{-1} = T_{I\rightarrow B}^T \]
Singularity
Can often work around them by altering the order of rotation (12 possibilities)
Quaternions avoid this but normally aren’t necessary
Rotational Dynamics

Rigid Body Dynamics

Space Vehicle Disturbance Torques
- Aerodynamic drag
- Gravity gradient torques
- Solar radiation pressure
  - Dominates above 1000 km
- Magnetic torques
  - Can be used as a control torque to counter other torques

Miscellaneous Disturbance Torques
Results in an external torque
The momentum change to the vehicle is the integral of this torque
- Venting
- Jettisoned parts
- Internal torques – rest of the spacecraft works to keep the overall momentum constant (*angular momentum conserved*)
  - Antennas
  - Solar array motion

Passive Attitude Control
- Passive stabilization techniques take advantage of basic physical properties and naturally occurring forces.
- Design the spacecraft to use the above disturbance torques to help control the vehicle
- Can be inaccurate
- Inflexible response to changing conditions

Spin Stabilization
- Make spin axis and momentum vector coincident
- Geo-satellites are usually spin stabilized during burns to Geosynchronous orbit

Gravity Gradient Stabilization
- Minimum inertia axis in a vertical orientation
  - \( I_{xx} < I_{yy}, I_{zz} \)
  - Free to rotate about vertical axis (if not acceptable, it has to be dealt with)
  - Useful for long life
  - Must have very broad attitude stabilization requirements
Aerodynamic and Solar Pressure Stabilization
- Not widely used but possible

Active Control
- Feedback control
  - Attitude is compared to the desired value
  - Error signal developed and used to determine corrective torque
- Reaction wheels
  - No net torque generated
  - Vehicle reacts in opposite direction (need one wheel per axis)
  - When spinning as fast as it can, it is saturated
  - Reaction control jets may be required to "desaturate" the system
  - Avoid operating near the max RPM
- Momentum Wheels
  - Similar to Reaction Wheels, but operate at a higher RPM
  - Provides substantial gyroscopic stability (good for pointing)
- Control Moment Gyros
  - Gyiballed Momentum Wheels
  - Very effective, but heavy and noisy
- Magnetic Torquers
  - Takes advantage of the planet’s magnetic field
  - Relatively low control authority
  - May be useful in supplementing reaction jets
- Reaction Jets
  - Common and effective
  - Need consumables
  - Pulse length can provide proportional control
  - Coupling between attitude and translation (cross axis)
  - Plume impingement

Attitude Determination
- Sun sensors
- Star trackers
- Magnetometers
- IMU
- Gyros
- Earth horizon scanner
- Differential GPS

Design Considerations
- Actual center of mass probably not coincident with geometric center
  - Coupling between attitude and translational maneuvers
  - May result in undesirable orbit change
  - Offset estimate = error included in analysis

Conserve angular momentum
- Structural flexibility
  o Affects sensors which can get in the feedback loop leading to divergence.
  o RCS effects can be very different – torque achieved may be different from desired
  o Structural stiffness is very important