Dinámica de Vehículos Espaciales

Tema 9: Diseño de ADCS

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Diseño de un ADCS

- En las siguientes transparencias estudiaremos diferentes consideraciones a la hora de diseñar un ADCS (considerando tanto la parte de control como la de estimación).
- En primer lugar estudiaremos los requisitos y com estos se relacionan con otros subsistemas (trade-offs).
- En base a los requisitos expondremos los métodos antes vistos, que también se relacionarán con el tipo de apuntamiento necesario (inercial o hacia Tierra).
- Estudiaremos con más detalle los requisitos de maniobra y de las cargas útiles.

Diseño de un ADCS

- Requisitos típicos de un ADCS

TABLE 11-3. Typical Attitude Determination and Control Performance Requirements. Requirements need to be specified for each mode. The following lists the areas of performance frequently specified.

Area	Definition*	Examples/Comments
	DETERMINATION	
Accuracy	How well a vehicle's orientation with respect to an absolute reference is known	0.25 deg, 3 σ, all axes; may be real-time or post-processed on the ground
Range	Range of angular motion over which accuracy must be met	Any attitude within 30 deg of nadir
	CONTROL	
Accuracy	How well the vehicle attitude can be controlled with respect to a commanded direction	0.25 deg, 3 σ; includes determination and control errors, may be taken with respect to an inertial or Earth-fixed reference
Range	Range of angular motion over which control performance must be met	All attitudes, within 50 deg of nadir, within 20 deg of Sun
Jitter	A specified angle bound or angular rate limit on short-term, high-frequency motion	0.1 deg over 1 min, 1 deg/s,1 to 20 Hz; usually specified to keep spacecraft motion from blurring sensor data
Drift	A limit on slow, low-frequency vehicle motion. Usually expressed as angle/time.	1 deg/hr, 5 deg max. Used when vehicle may drift off target with infrequent resets (especially if actual direction is known)
Settling Time	Specifies allowed time to recover from maneuvers or upsets.	2 deg max motion, decaying to < 0.1 deg in 1 min; may be used to limit overshoot, ringing, or nutation

* Definitions vary with procuring and designing agencies, especially in details (e.g., 1 or 3 σ, amount of averaging or filtering allowed). It is always best to define exactly what is required.

Diseño de un ADCS

- Estudio de los requisitos derivados de/hacia otros subsistemas

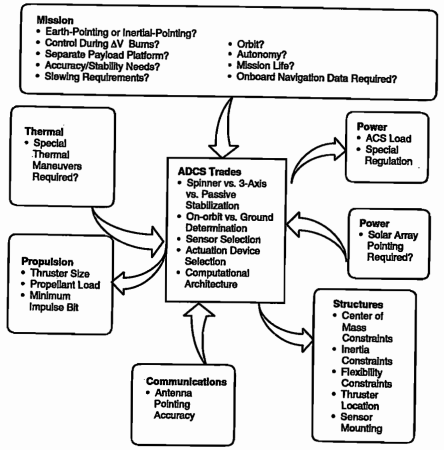

Fig. 11-2. The Impact of Mission Requirements and Other Subsystems on the ADCS Subsystem. Direction of arrows shows requirements flow from one subsystem to another.

Diseño de un ADCS

- Selección del sistema o sistemas a utilizar

TABLE 11-4. Attitude Control Methods and Their Capabilities. As requirements become tighter, more complex control systems become necessary.

Type	Pointing Options	Attitude Maneuverability	Typical Accuracy	Lifetime Limits
Gravity-gradient	Earth local vertical only	Very limited	±5 deg (2 axes)	None
Gravity-gradient and Momentum Bias Wheel	Earth local vertical only	Very limited	±5 deg (3 axes)	Life of wheel bearings
Passive Magnetic	North/south only	Very limited	±5 deg (2 axes)	None
Pure Spin Stabilization	Inertially fixed any direction Repoint with precession maneuvers	High propellant usage to move stiff momentum vector	±0.1 deg to ±1 deg in 2 axes (proportional to spin rate)	Thruster propellant (if applies)*
Dual-Spin Stabilization	Limited only by articulation on despun platform	Momentum vector same as above Despun platform constrained by its own geometry	Same as above for spin section Despun dictated by payload reference and pointing	Thruster propellant (if applies)* Despin bearings
Bias Momentum (1 wheel)	Best suited for local vertical pointing	Momentum vector of the bias wheel prefers to stay normal to orbit plane, constraining yaw maneuver	±0.1 deg to ±1 deg	Propellant (if applies)* Life of sensor and wheel bearings
Zero Momentum (thruster only)	No constraints	No constraints High rates possible	±0.1 deg to ±5 deg	Propellant
Zero Momentum (3 wheels)	No constraints	No constraints	±0.001 deg to ±1 deg	Propellant (if applies)* Life of sensor and wheel bearings
Zero Momentum CMG	No constraints	No constraints High rates possible	±0.001 deg to ±1 deg	Propellant (if applies)* Life of sensor and wheel bearings

*Thrusters may be used for slewing and momentum dumping at all altitudes. Magnetic torquers may be used from LEO to GEO.

Diseño de un ADCS

- Efecto de los requisitos en los sistemas a elegir

TABLE 11-8. Effect of Control Accuracy on Sensor Selection and ADCS Design. Accurate pointing requires better, higher cost, sensors, and actuators.

Required Accuracy (3σ)	Effect on Spacecraft	Effect on ADCS
> 5 deg	• Permits major cost savings • Permits gravity-gradient (GG) stabilization	***Without attitude determination*** • No sensors required for GG stabilization • Boom motor, GG damper, and a bias momentum wheel are only required actuators ***With attitude determination*** • Sun sensors & magnetometer adequate for attitude determination at ≥ 2 deg • Higher accuracies may require star trackers or horizon sensors
1 deg to 5 deg	• GG not feasible • Spin stabilization feasible if stiff, inertially fixed attitude is acceptable • Payload needs may require despun platform on spinner • 3-axis stabilization will work	• Sun sensors and horizon sensors may be adequate for sensors, especially a spinner • Accuracy for 3-axis stabilization can be met with RCS deadband control but reaction wheels will save propellant for long missions • Thrusters and damper adequate for spinner actuators • Magnetic torquers (and magnetometer) useful
0.1 deg to 1 deg	• 3-axis and momentum-bias stabilization feasible • Dual-spin stabilization also feasible	• Need for accurate attitude reference leads to star tracker or horizon sensors & possibly gyros • Reaction wheels typical with thrusters for momentum unloading and coarse control • Magnetic torquers feasible on light vehicles (magnetometer also required)
< 0.1 deg	• 3-axis stabilization is necessary • May require articulated & vibration-isolated payload platform with separate sensors	• Same as above for 0.1 deg to 1 deg but needs star sensor and better class of gyros • Control laws and computational needs are more complex • Flexible body performance very important

Diseño de un ADCS

- Efecto de los requisitos de maniobras en los sistemas a elegir

TABLE 11-7. Slewing Requirements That Affect Control Actuator Selection. Spacecraft slew agility can demand larger actuators for intermittent use.

Slewing	Effect on Spacecraft	Effect on ADCS
None	Spacecraft constrained to one attitude—highly improbable	• Reaction wheels, if planned, can be smaller • If magnetic torque can dump momentum, may not need thrusters
Nominal rates—0.05 deg/s (maintain local vertical) to 0.5 deg/s	Minimal	• Thrusters very likely • Reaction wheels adequate by themselves only for a few special cases
High rates—> 0.5 deg/s	• Structural impact on appendages • Weight and cost increase	• Control moment gyros very likely or two thruster force levels—one for stationkeeping and one for high-rate maneuvers

Diseño de un ADCS

- Efecto de los requisitos de la carga útil en los sistemas a elegir

TABLE 11-6. Effect of Payload Pointing Directions on ADCS Design. The payload pointing requirements are usually the most important factors for determining the type of actuators and sensors.

Requirement	Effect on Spacecraft	Effect on ADCS
Earth-pointing • Nadir (Earth) pointing • Scanning • Off-nadir pointing	• Gravity-gradient fine for low accuracies (>1 deg) only • 3-axis stabilization acceptable with Earth local vertical reference	***If gravity-gradient*** • Booms, dampers, Sun sensors, magnetometer or horizon sensors for attitude determination • Momentum wheel for yaw control ***If 3-axis*** • Horizon sensor for local vertical reference (pitch and roll) • Sun or star sensor for third-axis reference and attitude determination • Reaction wheels, momentum wheels, or control moment gyros for accurate pointing and propellant conservation • Reaction control system for coarse control and momentum dumping • Magnetic torquers can also dump momentum • Inertial measurement unit for maneuvers and attitude determination
Inertial pointing • Sun • Celestial targets • Payload targets of opportunity	• Spin stabilization fine for medium accuracies with few attitude maneuvers • Gravity gradient does not apply • 3-axis control is most versatile for frequent reorientations	***If spin*** • Payload pointing and attitude sensor operations limited without despun platform • Needs thrusters to reorient momentum vector • Requires nutation damping ***If 3-axis*** • Typically, sensors include Sun sensors, star tracker, and inertial measurement unit • Reaction wheels and thrusters are typical actuators • May require articulated payload (e.g., scan platform)

Diseño de un ADCS

- Con estas ideas se puede al menos tener una idea del tipo de actuadores y sensores necesarios, en base al tipo de sensor y requisito.
- Para más ideas de diseño inicial, se recomienda el libro "Space Mission Analysis and Design", de Wertz/Everett/Puschell.
- Una vez elegidos los sistemas, es necesario probar (inicialmente en simulación) los algoritmos de estimación, determinación y control que hemos estudiado a lo largo de la asignatura, y comprobar que al menos en simulación se cumplen los requisitos.
- Típicamente se analiza el comportamiento de los sistemas frente a perturbaciones con simulaciones de Monte Carlo (muchas simulaciones con diferentes perturbaciones "al azar").
- Una vez se tiene el hardware real, se pueden realizar simulaciones HIL (Hardware in the Loop).