Spacecraft Attitude Actuators (26.2)

There are two classes of spacecraft actuators:

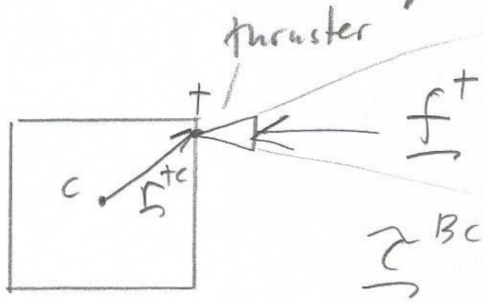
1) Reaction-Type Actuators
   e.g., thrusters, magnetic torquers

2) Momentum Exchange Devices
   e.g., reaction wheels, momentum wheels, CMGs

All actuators impart a torque on the spacecraft in a particular manner.

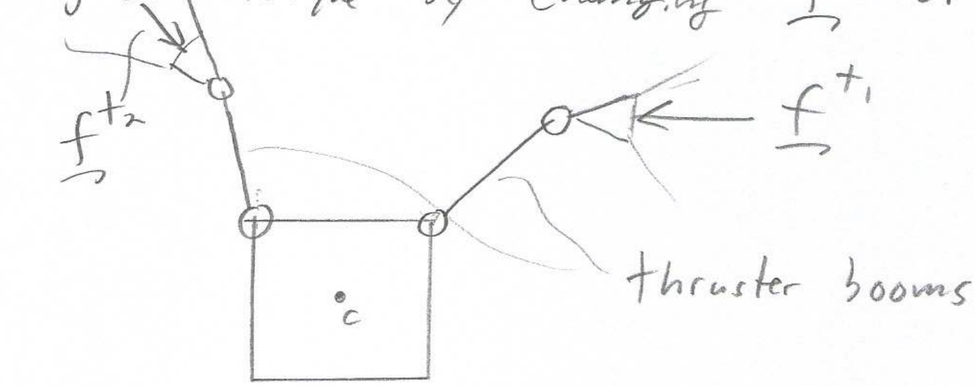
Thrusters

Thrusters eject mass to create a force.
They are often used for attitude control and to impart ΔV on the spacecraft for orbital maneuvers.



$$\underline{\tau}^{Bc} = \underline{r}^{tc} \times \underline{f}^{t}$$

Adjust torque by changing $\underline{f}^{t}$ or $\underline{r}^{tc}$

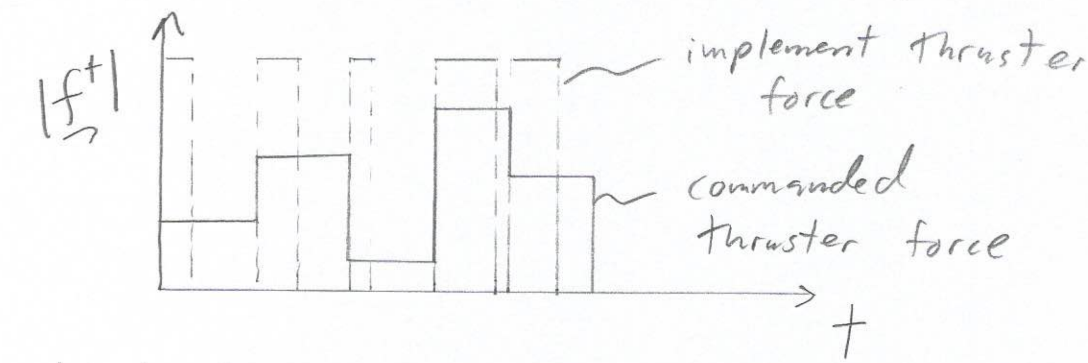


Pros: • Relatively simple control laws

Cons: • Only provide force in one direction
→ two thrusters needed to create both positive and negative torque about a single axis (6 thrusters for full attitude control, 12 for full attitude/orbital control)

• Typically only operate "on-off"
Magnitude of thruster force is fixed, but can adjust on and off times, and possibly boom positions
Often controller will assume variable thruster force and signal will be "quantized" using pulse width modulation (PWM).

Ex



• Limit to how small a thruster "on-off" pulse can be. This leads to a "dead-zone" and reduces accuracy of attitude control.

• Limited propellant (ΔV)

Magnetic Torquers (Magnetic Torque Rods, Magnetorquers)

A magnetic torquer is a wire coil that current is passed through to create a magnetic dipole $\underset{\rightarrow}{m}$. This interacts with Earth's magnetic field $\underset{\rightarrow}{b}$ to create torque

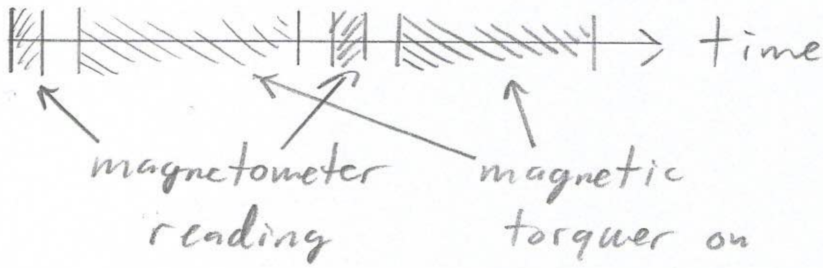
$$\underset{\rightarrow}{\tau} = \underset{\rightarrow}{m} \times \underset{\rightarrow}{b}$$

Pros:
- No fuel (propellant) required
- Useful for momentum dumping (management) when reaction wheels spin too fast.

Cons:
- $\underset{\rightarrow}{\tau}$ is perpindicular to $\underset{\rightarrow}{b}$, which means we can only perform attitude control about axes perpindicular to $\underset{\rightarrow}{b}$.
  Direction of $\underset{\rightarrow}{b}$ changes for non-equitorial orbits, so on average we can perform 3-axis attitude control over a full orbit.
- Earth's magnetic field is weak, so $\underset{\rightarrow}{\tau}$ is typically small
- Only useful in low Earth orbit

- Cannot operate magnetometer and magnetic torquers simultaneously.

Ex:



Reaction Wheels

Reaction wheels are nominally non-spinning wheels mounted in the spacecraft. Due to the conservation of angular momentum, if the reaction wheel starts spinning, the spacecraft will start spinning in the opposite direction.

This is a momentum exchange device, because the total angular momentum of the body is fixed, but angular momentum can be exchanged between the reaction wheel and the platform.

Pros:
- No fuel required
- Most precise attitude actuator.
- 3 or more wheels with different spin axes provide full 3-axis attitude control. Typically pointed in $\underrightarrow{b}^1, \underrightarrow{b}^2, \underrightarrow{b}^3$ if 3 wheels or in pyramid formation if 4 wheels.

Cons:
- Over time, disturbance torques will cause body's angular momentum to increase. The reaction wheel speeds will build up and eventually reach their limits (saturate)

Reaction-type actuators (thrusters, magnetic torquers) are required to unload this built up angular momentum.

Momentum Wheels

Same as reaction wheels, but are nominally spinning and can be used for dual-spin stabilization.

Typically, either

1) wheel speed is kept constant. (passive attitude control)
2) wheel speed is allowed to deviate from nominal speed
   ↳ same pros/cons as reaction wheels

Control Moment Gyroscopes (CMGs)

Similar to momentum wheels, except the wheel spin axis is allowed to change directions on a gimbal. Changing the wheel spin axis causes an exchange of angular momentum to the spacecraft platform. Typically the wheel speeds are kept constant and at least 4 wheels are useds.

Same pros/cons as reaction wheels with addition of:

Pros:
- Large torques produced by small change in gimbal angles (torque amplification).

Cons:
- Complicated control law.
  Singularities occur that make it difficult to determine gimbal angles needed to produce a certain torque.