Spacecraft Mechanisms
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- One-shot Devices
- Deployable Structures
- Continuous and Intermittently Operating Devices
- Components
- Materials
- Tribology
- Testing and Verification

Mechanism Functions

- Any device that is required to move, rotate, slide or separate
- Characterized by displacements vs. small displacements of structures
- Scale: quite small (1/4 inch or less) to very large (100+ ft)
- Often a mechanism functions as structural member prior to, during, or after deployment

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When Do Mechanisms Function?

AT LAUNCH
• Electrical and fluid disconnects

DURING ASCENT
• Fairing jettison
• Spacecraft and sub-satellite separation
• Ion thruster gimbals

AFTER ACHIEVING ORBIT
• Doors and covers that open or close
• Solar array, boom and antenna deployments and unfurlments

THROUGHOUT MISSION
• Solar array sun tracking
• Pointing antennas and instruments
• Active doors and shields
• Gyrosopes and reaction wheels
• Fast steering mirrors, optical delay lines

PRIOR TO RE-ENTRY
• Dampers for re-entry and landing forces

Mechanism Design Guidelines & Selection

- Build in redundancy
- Provide high force/torque margin
- Design to preclude improper assembly or installation
- Allow for visual inspection
- Thermal considerations (materials, clearance, preload)
- Vacuum considerations (outgassing, cold welding, heat dissipation, lube)
- Vibration considerations (potting, positive locking, preload change, wear)
- Cycle life, including ground testing
- Design for ease of analysis and test

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Mechanism Parts

- Bearings
- Lubrication
- Force/Torque
  - Application
  - Multipliers
  - Dampers & Load
  - Absorbers
- Release Devices
- Power & Signal Transfer
- Telemetry Devices
- Extension Devices

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Separation Mechanisms

Marmon clamp

![Marmon clamp diagram](image)

(a) Mechanism closed

(b) Mechanism opened
Release Devices

PYROTECHNIC (EXPLOSIVE)
- Cable and Bolt cutters
- Pinpullers and pinpushers

OTHER
- Motor-driven latch
- Non-explosive initiators
  - Pinpullers and pinpushers (non-pyro)
    - Paraffin
    - Shape Memory Alloy

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Pyrotechnic Cable and Bolt Cutters

Power Cartridge propels Cutter through the target and into the Anvil
- Cutter Assembly with Power Cartridge

Advantages: fast actuation, high load capability, low weight, simple design

Disadvantages: high shock, safety

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Shear-Tie Release Mechanism

- **Key Features:**
  - Utilized in sets of 3 minimum
  - Preloaded steel rods and cables prevent gapping of cup-cone interface during ascent
  - Relative motion between spacecraft and reflector is prevented by cup-cone shear tie seats which react in-plane loads
  - Redundant pyrotechnic actuated cutters are used to sever restraint rods for deployment
  - Kick-off washers/springs at each cup-cone interface ensure separation

- **Advantages:** resettable low weight, uses heater circuit
- **Disadvantages:** low force output and capability, slow actuation, overtemp self actuation

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Frangibolt
Non-pyrotechnic separation device (for valving)
Use of shape-memory alloy

Extension Devices

- LAZY TONGS
- EXTENDIBLE REEL
- COILABLE MAST
- TELESCOPIC
- INFLATABLE

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Hinges

- Redundant spring driven
- Heated viscous damper for rate control
- Preloaded ball bearings or journal bearings
- Hard stops and latches on a large radius for improved deployed repeatability

Deployment Hinges
Extendible Tube Mast

Typical cross sections for deployable tubular booms:

(a) Lenticular welded double element
(b) Overtapping single element
(c) Overlapping double element
(d) Interlocking double element

Deployable Camera Mast
Umbrella Antenna
Galileo Spacecraft

Solar Array Drive Assembly

Usage on S/C:
• 1 location per solar array wing

Key Features:
• Provides precision stepping rotation for sun tracking in forward and reverse directions.
• Provides power transfer across rotating interface between the solar array and spacecraft
• Tracking rate 1 rev/day
• Consisting of:
  – Stepper Motor with redundant windings
  – Harmonic Drive Assembly
  – Fiber Brush Slip Ring Assembly
  – Redundant Potentiometers provide telemetry

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Solar Array Drive

Giotto De-Spin Mechanism

Dual-spin spacecraft
Reaction Wheel Assembly

Usage on S/C:
• Qty (4) per Spacecraft, internally mounted

Key Features:
• Function:
  – Apply reaction torque for three-axis attitude control
  – Bi-directional angular momentum storage
  – Operates at x1000 rpm
• Consist of
  – Drive electronics, brushless motor, and a inertia rotor enclosed within the housing.

X-Band Antenna Pointing Mechanism
Antenna Gimbal

- **Key Features:**
  - Contains two nearly identical, orthogonally mounted drive mechanisms
  - Each drive consists of a stepper motor with redundant windings that is coupled to a drive transmission
  - Redundant course and fine potentiometers for angle telemetry
  - Heaters and thermal tape on housings

Force/Torque Application

**STORED ENERGY**
- Compression spring
- Tension spring (not usually used due to its failure mode)
- Torsion spring
- Constant-force spring (Ne’ gator)
- Lenticular strut (Carpenter Tape)
- Gas pressure – Gas Springs

**ELECTRICAL ENERGY**
- Motors
- Solenoids

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Dampers and Load Absorbers

\[ F = ma; \text{ without control, loads would be excessive} \]

DAMPERS
- Rotary and Linear
  - Viscous fluid
  - Induced electrical current (Eddy current)
LOAD ABSORBERS
- Elastomer Bumpers
- Friction washers – Brake Shoes
- Crushable Honeycomb

DC Brush Motor

- DC brushed motors
  - Simple electronics: two wires going to motor
  - Low cost
  - Can operate open loop (which is good and bad!)
  - Rapid wear of the brushes (especially under vacuum)
  - Need purging during ambient testing with special brushes
  - Current spikes may occur under vacuum
  - Requires EMI shielding
  - Concern about restart after storage
  - Concern about brushes during vibration
  - Shorting risks due to brush wear debris
  - Used on one-shot deployables

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Stepper Motor

Stepper motors (DC brushless)

- Weight
- Few wearing parts
- Simple construction, simple electronics
- Can operate open loop (which is good and bad!)
- Each step is a structural excitation - May excite modes of other equipment and structure
- May have stability problems that depend on friction, damping, and frequency
- Good unpowered detent torque
- Used on Lockheed Gimbals and Solar Array Drives

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DC Brushless Motor

- DC brushless torquer motors
  - Motion control, torque ripple, life are all advantages
  - Low vibration
  - Relatively complex electronics
  - Commutator reliability
  - Low unpowered detent torque
  - Intolerant to stall condition
  - Used on Lockheed Reaction Wheel Assemblies

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**Force/Torque Multipliers**

*Harmonic Drive*
- Flexspline
- Wave Generator
- Circular Spline

*Planetary Gears*
- Sun Gear
- Ring Gear
- Planet Gears

**Advantages:**
- low backlash, high stiffness
- torque capability, different gear ratios based on operation

**Disadvantages:**
- torque efficiency, torque ripple, fatigue life
- backlash, wear

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**Power & Signal Transfer Mechanisms**

*Slip Rings*

**Advantages:**
- full rotation, low friction

**Disadvantages:**
- failure mode, lubrication issues for long life, signal noise

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Bearing Choices

Bearings (in some form) are used in almost all mechanisms to provide for smooth relative motion

- **Journal:** Shaft in round or square hole
  - Advantages: simple
  - Disadvantages: susceptible to small changes in lubrication
- **Flex pivot:** Beam in bending
  - Advantages: low friction, no wear, environment insensitive
  - Disadvantages: ± 30° rotation, center shift, low radial load capability
- **Rolling element:** Ball, Roller, Linear
  - Advantages: low friction, combined radial and thrust capability
  - Disadvantages: more packaging space radially, expensive

![Diagram of bearing types]

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Bearing Choices

- **Magnetic:** Magnetic levitation
  - Advantages: non-contacting, controllable stiffness
  - Disadvantages: complex control, poor axial stiffness, high power req’d
- **Typical Problems:**
  - Torque / force required
  - Performance at temperature and loads
  - Instability
  - Lubrication
  - Strength / fatigue life
  - Stiffness / deadband

![Diagram of magnetic levitation]

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Lubrication

- **Solid films** how applied:
  - bonded (thick), impinged (thin), sputtered (control thin)
  - MoS₂
  - Graphite
  - Tungsten Disulfide

- **Composites & Transfer film**
  - PTFE (Teflon, glass reinforced)
  - Polyimide (Vespel)
  - Polyacetal (Delrin)
  - Polyimide-imide (Torlon)

- **Soft Metals** (ion-plated, ion sputtered)
  - Gold
  - Silver
  - Lead

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Lubrication

- **Oils/Greases**
  - Mineral oil (KG-80)
  - Silicones (F-50)
  - Perfluoropolyalkylether (PFPE) (Bray, Krytox, Fomblin)
  - Trialkylated cyclopentane (TAC) (Pennzane)
  - Poly-α-olefin (PAO) (Nye 179A)

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Sensors for Telemetry

• Potentiometer
  – small size, weight, easy electronics
  – can be unreliable for large number of cycles
  – single-turn potentiometer
    • multi-turn potentiometer not used often
    • carbon pot (actually graphite in a plastic matrix)
      essentially infinite resolution, low inductance
  – thermal stability, stair-step linearity (less precise)

• Resolver
  – Rotary transformers that provide voltage output proportional to rotation angle
  – No sliding or rubbing parts and low voltage mean high reliability
  – Electronics to drive and interpret resolver can be expensive

• Encoder
  – small size, weight (sometimes)
  – low power requirements (but more than a potentiometer)
  – High accuracy / cost

Test of Deployment Mechanisms

• BALLOONS
  – reflector deployments
• OVERHEAD TRACK
  – solar arrays
• CABLE AND SPRING
  – jettison, booms
• CONICAL PENDULUM
  – booms
• ROCKING BEAM
  – separation
• BALANCE BEAM
  – separation, deployments
• WATER FLOATS
  – masts
• AIR BEARING
  – large deployments
• SERVO-CONTROLLED SUSPENSION
  – unusual motions
Progress and Dragon Docking and Berthing with ISS

Docking and Berthing Mechanisms

Gemini-Agena Docking
Apollo Probe and Drogue Docking Mechanism

Apollo-Soyuz Docking Mechanism
Future NASA Common Berthing Mechanism

Next Time: Space Robotics