Taller de Diseño de Picosatélites (CUBESATS) y Estaciones de Tierra

Session 3
Payload & Subsystems

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Content

- Picosat=Picodesign?
- System Engineering process
- Main elements of a mission/spacecraft
- System drivers
- Picosat payloads
- Picosat subsystems
  - Attitude and Orbit Control
  - Data Handling
  - Communications
  - Thermal
  - Structure
  - Propulsion
  - Power
• Terminology
  – Acronisms
  – English terms
• Too many slides
  – Adaptable presentation
  – Out of focus
• Acknowledgements
Picosat=Picodesign?
Picosat=Picodesign?

TALLER DE DISEÑO PRELIMINAR DE SATÉLITES (2009)

1. El diseño de satélites
2. Presentación del taller
3. Misión Espacial
4. Dimensionado preliminar de la estructura
5. Dimensionado preliminar del subsistema AACS
6. Dimensionado preliminar del subsistema de control térmico
7. Dimensionado preliminar del subsistema de potencia
8. Dimensionado preliminar del subsistema de comunicaciones
9. Dimensionado preliminar del subsistema de propulsión
10. Dimensionado preliminar de subsistemas auxiliares
11. Presentación de los trabajos realizados

NOTAS IMPORTANTES:
- Todos los contenidos se impartirán en la Sede Centro Herrera.
- Esta actividad académica se dirige para los titulares de segundo ciclo de la ETS Ingeniería Aeronáutica.
- El libro utilizado será el correspondiente impreso en www.senr.es
- Trabajos de evaluación y control de calidad se realizarán en equipo.
- Participantes: 1º de Diseño de Picosatélites y Estaciones de Tierra. ©J.M. del Cura

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Picosat=Picodesign?
• **Main differences**
  - Learning process
  - **Standard equipment**
  - Some decisions predetermined
  - Organisation
  - Schedule

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System Engineering Process

ESA

<table>
<thead>
<tr>
<th>0</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mission Analysis, Needs Identified</td>
<td>Feasibility</td>
<td>Preliminary Definition</td>
<td>Detailed Definition</td>
<td>Production/Ground Qualification Testing</td>
<td>Utilization</td>
<td>Disposal</td>
</tr>
<tr>
<td>MDR</td>
<td>PRR</td>
<td>PDR</td>
<td>CDR</td>
<td>AR</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

NASA

<table>
<thead>
<tr>
<th>Pre-Phase A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Advanced Analysis</td>
</tr>
<tr>
<td>MCR</td>
</tr>
</tbody>
</table>

DoD

<table>
<thead>
<tr>
<th>Pre-Milestone</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concept Exploration Needs Analysis Concept Dev.</td>
</tr>
<tr>
<td>0</td>
</tr>
<tr>
<td>SRR</td>
</tr>
</tbody>
</table>

MDR PRR PDR CDR AR

Taller de Diseño de Picosatélites (CUBESATS) y Estaciones de Tierra. ©J.M. del Cura
System Engineering Process
System Engineering Process

From "Understanding Space" by Jerry Jon Sellers

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System Engineering Process

Specifications

Design

Simulation

Testing

Analysis

Delivery

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System Engineering Process

Control Theory

Digital Electronics

Sensors and Actuators Technology

Structure Technology

Dynamic Simulation

Propulsion Technology

Software Engineering

Mechanism Technology

Communication Technology

Development Methodology

Standards And Norms

Mission Analyst

Thermal Technology
System Engineering Process
System Engineering Process

**CONCEPT EXPLORATION**

- Requirements Generation (Users and Operators)
  - Very Broad needs
  - Performance Objectives
  - Requirements

**DETAILLED DEVELOPMENT**

- Studies
  - Alternative Concepts
  - Concept Selection
  - Stable Design

- Prototyping
- Design & Test

- Resource Requirements and Constraints
  - Affordability Goals
  - Constraints
  - Firm Unit Costs

- Planning, Programming, And Budgeting (Sponsors)

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Mission Elements

Subject
Command, Control and Communications

Mission Operations

Mission Concept

Orbits and constellations

Ground element

Launch element

Space element

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Spacecraft Elements

From "Understanding Space" by Jerry Jon Sellers
Spacecraft Elements

Structure

Power
- DC-DC1
- DC-DC2
- DC-DC3
- Charge Circuit
- Solar Cell
- Battery

OBC
- RX TNC
- OBC
- uSW
- Flight Pin

Charge Circuit
- Flight Pin

Solar Panel(s)
- Battery
- Regulated voltage outputs

ACS
- Taller
- Diseño de Picosatélites (CUBESATS) y Estaciones de Tierra. ©J.M. del Cura

ACS Sensor(s)
- Payload Sensor
- Analog or Digital I/F
- Debug I/F
- RS422, RS232 JTAG
- Serial Synchronous RS422 Clock and Data
- Analog I/F
- ACS Actuator
- Battery
- Solar Panel(s)
- Parallel Bus
- Com1
- TX TNC
- TX
- OBC
- TX
- TLM
- TX
- Analog SW
- ROM
- RX TNC
- RX
- CW Gen
- CW
- Important Analog Sensors
- Digital Sensors
- Antenna Latch
- Flight Pin
- CMD
- TLM
- ACK
- Main
- Com2
- PWR5V
- Parallel Bus
System Drivers

- Size
- On-orbit Weight
- Power
- Data rate
- Communications
- Pointing
- Number of S/C
- Altitude
- Coverage
- Scheduling
- Operations

- Definition of the Preliminary Mission Concept
- Definition of the Subject Characteristics
- Determination of Orbit and Constellation Characteristics
- Determination of the Payload Size and Performance
- Selection of the Mission Operations Approach
- Design of the S/C
- Selection of the Launcher and Transfer System
- Determination of Logistics, Deployment, replenishment and disposal
- Cost Estimation
Payload Design and sizing

The payload is the combination of hardware and software that interacts with the subject to accomplish the mission objectives.

<table>
<thead>
<tr>
<th>Spacecraft Mission</th>
<th>Payload</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Communications</td>
<td>• Transceiver</td>
<td>• Milstar, Intelsat</td>
</tr>
<tr>
<td></td>
<td>• Transmitter</td>
<td>• DirecTV, GPS</td>
</tr>
<tr>
<td></td>
<td>• Transceiver</td>
<td>• Iridium</td>
</tr>
<tr>
<td>Remote Sensing</td>
<td>• Imagers and cameras</td>
<td>• Landsat, Space Telescope</td>
</tr>
<tr>
<td></td>
<td>• Radiometers</td>
<td>• SBIRS early warning,</td>
</tr>
<tr>
<td></td>
<td>• Altimeters</td>
<td>• Chandra, TOPEX/Poseidon</td>
</tr>
<tr>
<td>Navigation</td>
<td>• Transceiver</td>
<td>• TDRS</td>
</tr>
<tr>
<td></td>
<td>• Clock and transmitter</td>
<td>• GPS, GLONASS</td>
</tr>
<tr>
<td>Weapons</td>
<td>• Warhead</td>
<td>• Brilliant peebles concept</td>
</tr>
<tr>
<td></td>
<td>• High-Energy weapon</td>
<td>• Space-based Laser concept</td>
</tr>
<tr>
<td>In Situ Science</td>
<td>• Physical and life sciences</td>
<td>• Space Shuttle, Mir</td>
</tr>
<tr>
<td></td>
<td>• Sample collection/return</td>
<td>• Mars Sojourner, LDEF</td>
</tr>
<tr>
<td>Other</td>
<td>• Physical plant and raw materials</td>
<td>• Space Shuttle</td>
</tr>
<tr>
<td></td>
<td>• Solar collector, converter and transmitter</td>
<td>• SPS</td>
</tr>
<tr>
<td></td>
<td>• Lunar soil collector and processor</td>
<td>• Lunar Base</td>
</tr>
<tr>
<td></td>
<td>• Orbital hotel</td>
<td>• Various</td>
</tr>
<tr>
<td></td>
<td>• Remains container</td>
<td>• Pegasus</td>
</tr>
<tr>
<td></td>
<td>• Resource utilisation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Space power</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Tourism</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Space burial</td>
<td></td>
</tr>
</tbody>
</table>
Payload Design and sizing

- Selection of payload objectives
  - Payload performance objectives
- Conduct subject trades
  - Subject definition and performance thresholds
- Develop the payload operations concept
  - End-to-end concept for all mission phases and operating modes
- Determine required payload capability to meet mission objectives
  - Required payload capability
- Identification of candidate payloads
  - Initial list of potential payloads
- Estimation of the candidate payloads capabilities and characteristics
  - Assessment of each candidate payloads
- Evaluation of the candidate payloads and selection of the baseline
  - Preliminary payload definition
- Assessment of the life-cycle cost and operability of the payload and mission
  - Revised payload performance requirements constrained by cost or architecture limitations
- Identification of the payload-derived requirements
  - Derived requirements for related subsystems
- Documentation and iteration
  - Baseline payload design
Payload Examples - AAU

• Missions success criteria
  • That the involved students have achieved some useful knowledge of space technology.
  • That communication is established with the satellite and housekeeping information is retrieved.
  • Take and download any picture.
  • Test ACS performance.
  • Take pictures of certain locations on earth.
  • Take pictures of celestial objects and experiment with the various subsystems.
Payload Examples – CANX-1

Technology demonstration mission

- Training next generation of space engineers
- Color and monochrome CMOS imager to be used as star, moon and horizon sensor
- Testing performance of a custom-built OBC
- GPS receiver
- Active magnetic control system
- Data collection of GaAs solar cells and Honeywell magnetometer
Payload Examples – CANX-1

Figure 11 - CanX-1 Imager Board

<table>
<thead>
<tr>
<th>Legend</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Serial RS-232</td>
<td>GFIC</td>
</tr>
</tbody>
</table>

CanX-1 On-Board Computer (OBC)

Table 3 - GPS Characteristics

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power</td>
<td>1.2 W max</td>
</tr>
<tr>
<td>Dimensions</td>
<td>46 x 71 x 13 mm</td>
</tr>
<tr>
<td>Weight</td>
<td>22 g</td>
</tr>
<tr>
<td>Sensitivity</td>
<td>-135 dBm</td>
</tr>
</tbody>
</table>
Main objectives:
- Establish bus component design for pico satellites
- Reduce the total development cost by using commercial off-the-shelf (COTS) components
- Educational
- Separation mechanism

CUTE-I missions:
1) Communication mission
2) Sensing mission
3) Deployment mission
Main objectives:
• Bird-tracking mission
• On orbit demonstration of a CCD camera (PICOCAM)
• On orbit demonstration of a MEMS sun sensor
Main objectives:
• Provide life support, such as sugars the yeast can consume, and environmental control, such as temperature, for yeast growth in 48 independent micro-wells;
• Administer three groups of growing yeast with an antifungal agent at three distinct dosage levels, and one control yeast group with no antifungal dosage;
• Track the yeast population density and health in each microwell before, during and after administering the antifungal by using an optical density sensor and Alamar Blue, an agent that turns the yeast varying shades of blue and pink as they consume the sugars;
• Transmit the yeast population and health data, and PharmaSat’s system status data to Earth for analysis;
• Measure and determine the effect microgravity has on yeast resistance to an antifungal agent.
AOCS Subsystem

Objectives:

• It implements the three typical functions for both orbit and attitude:
  – Navigation
  – Guidance
  – Control

• To maintain the orbit parameters
• To perform all orbit operations in all mission phases, including
  – Parking orbit operations
  – Orbit Transfer
  – Orbit Maintenance or Station-Keeping

• To determine spacecraft attitude
• To define the spacecraft attitude reference
• To control the spacecraft attitude fulfilling pointing requirements
• To perform the spacecraft angular momentum management
• To perform all required manoeuvres
AOCS Subsystem

Main Components (I/VI)

- SENSORS
- ACTUATORS
- CONTROL ALGORITHMS
- ESTIMATORS
- FILTERS
- FAILURE MANAGEMENT
- MODES MANAGEMENT

Controller

Estimator

Act.

Sens.

System

control de actitud

controles en carga de pago

apunte de antenas

control térmico

control de órbita

orientación de paneles solares

control de potencia

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AOCS Subsystem

Main Components (II/VI)

Example: LEO AOCS

inputs

- forces
- torques
- ...

disturbances

- Atmosphere
- Solar Radiation
- Luni-solar
- ...

outputs

Controller

Estimator

Act.

Sens.

System

satellite

parameters

- Position
- Attitude
- ...

- Mass
- Inertia
- Geometry
- ...

reference y data
AOCS Subsystem

Main Components (III/VI)

Example: LEO AOCS

- Magnetic torquers
- Propulsion
- Reaction Wheels
- ...

Controller

Estimator

Sens.

Act.

System

reference y data

accessories

Stellar Sensors
Sun Sensors
gyroscopes
...

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AOCS Subsystem

Main Components (IV/VI)

Example: LEO AOCS

- Orbit Reference
- Pointing Reference
- Control Laws
- Reconfiguration Logic
- Wheels angular rate
- Activation times
- Intensities

Controller

Act.

System

Estimator

Sens.

reference and data

commands
AOCS Subsystem

Main Components (V/VI)

Example: LEO AOCS

- Orbit Reference
- Pointing Reference
- ... 

disturbances

- forces
- torques
- ... 

inputs

- Atmosphere
- Solar Radiation
- Luni-solar
- ... 

outputs

Controller

Act.

System

satellite

- Position
- Attitude
- ...

Estimator

Sens.

Control Unit

accessories

target y data
AOCS Subsystem

Main Components (VI/VI)

**POSITION**
- **Absolute Sensors**
  - GPS
  - Accelerometers
  - Ground Tracking
  - Celestial bodies
- **Relative Sensors**
  - Laser
  - Cameras
  - Pseudolites
  - Differential GPS
- **Actuators**
  - Propulsion
  - Solar Sailing
  - Tethers

**ATTITUDE**
- **Absolute Sensors**
  - Sun Sensor
  - Star Trackers
  - Earth Sensors
  - Magnetometer
  - Gyroscopes
  - GPS
- **Relative Sensors**
  - Laser
  - Cameras
- **Actuators**
  - Propulsion
  - Reaction Wheels
  - Control Moment Gyros
  - Momentum Bias
  - Magnetic Torquers
  - Solar Sailing
AOCS Design Process

1. Mission Requirements
2. Mission Profile
3. Orbit Insertion
4. Definition of control modes
5. Definition of requirements
6. P/L, Thermal and Power needs
7. Orbit, Pointing Direction
8. Disturbance Environment
9. Orbit Models
10. Quantification of Disturbance Environment
11. Orbit
12. Solar/magnetic Models
13. Mission Profile
14. S/C geometry
15. Mission Profile
16. Orbit accuracy
17. Orbit
18. Selection of AOCS control by control mode
19. Selection and Sizing of AOCS H/W
20. Definition of AOCS Algorithms
21. Iteration and documentation
22. ALL
23. Mission Lifetime
24. Orbit Conditions
25. S/C geometry
26. Mission Requirements
27. Slew rates
28. Pointing direction
Main Requirements

• Orbit Requirements
  – To maintain a certain altitude
  – To maintain a certain inclination
  – To maintain a certain ground track repetibility
  – To perform orbit transfers
  – To minimise propellant consumption
  – To minimise time for some operations

• Attitude Requirements
  – To maintain a certain pointing with respect to an object
  – To fulfil pointing requirements (Accuracy, range)
  – To fulfill stability requirements (Jitter, Drift)
  – To perform attitude manoeuvres (Settling time)
AOCS Subsystem

Main Control Modes

- Orbit Insertion
- Acquisition
- Normal
- Slew
- Contingency
- Special
AOCS Subsystem

Main AOCS Trades

- Type of stabilisation:
  - Spin
  - 3-axis
  - Passive
- On-orbit vs Ground Determination
- Sensor selection
- Actuator selection
- Computer Architecture

Mission
Thermal
Communications
Power
Propulsion
Structures

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## Selection of Attitude Control Type (I/III)

<table>
<thead>
<tr>
<th>Type</th>
<th>Pointing Options</th>
<th>Attitude Maneuverability</th>
<th>Typical Accuracy</th>
<th>Lifetime Limits</th>
</tr>
</thead>
<tbody>
<tr>
<td>GG</td>
<td>Earth LV</td>
<td>Very limited</td>
<td>± 5 deg (2 axes)</td>
<td>None</td>
</tr>
<tr>
<td>GG+MW bias</td>
<td>Earth LV</td>
<td>Very limited</td>
<td>± 5 deg (3 axes)</td>
<td>Wheel bearings</td>
</tr>
<tr>
<td>MGT</td>
<td>N/S</td>
<td>Very limited</td>
<td>± 5 deg (2 axes)</td>
<td>None</td>
</tr>
<tr>
<td>Spin</td>
<td>Inertial</td>
<td>Expensive in terms of fuel</td>
<td>± 0.1 deg to ± 1 deg (2 axes)</td>
<td>Fuel</td>
</tr>
<tr>
<td>Dual-Spin</td>
<td>Inertial or LV limited by despun platform</td>
<td>Expensive in terms of fuel for Momentum bias</td>
<td>± 0.1 deg to ± 1 deg (2 axes). + Despun</td>
<td>Fuel, DS bearings</td>
</tr>
<tr>
<td>MW Bias</td>
<td>LV pointing</td>
<td>Expensive in terms of fuel for MW bias</td>
<td>± 0.1 deg to ± 1 deg</td>
<td>Fuel, Wheel bearings</td>
</tr>
<tr>
<td>Zero Momentum + thrusters</td>
<td>Any</td>
<td>No constraints. High rates possible</td>
<td>± 0.1 deg to ± 5 deg</td>
<td>Fuel</td>
</tr>
<tr>
<td>Zero Momentum + RW</td>
<td>Any</td>
<td>No constraints.</td>
<td>± 0.001 deg to ± 1 deg</td>
<td>Fuel, Wheel bearings</td>
</tr>
<tr>
<td>Zero Momentum + CMG</td>
<td>Any</td>
<td>No constraints. High rates possible</td>
<td>± 0.001 deg to ± 1 deg</td>
<td>Fuel, Wheel bearings</td>
</tr>
</tbody>
</table>
AOCS Subsystem

Selection of Attitude Control Type (II/III)
Selection of Attitude Control Type (III/III)

- Mainly dependant on:
- Orbit insertion:
  - Large impulse
  - Plane changes
  - Maintenance
- Payload pointing:
  - Earth pointing
    - Gravity gradient for low accuracies
    - 3-axis with Earth LV reference
  - Inertial pointing
    - Spin
    - 3-axis
- Slew rates:
  - None/low
  - Nominal
  - High
# AOCS Subsystem

## Quantification of disturbance torques

<table>
<thead>
<tr>
<th>Disturbance</th>
<th>Type</th>
<th>Parameters</th>
<th>Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gravity Gradient</td>
<td>Constant (Earth) or cyclic (Inertial)</td>
<td>S/C inertias, orbit altitude</td>
<td>( T_g = \frac{3\mu}{2R}</td>
</tr>
<tr>
<td>Solar Radiation</td>
<td>Cyclic (Earth) or constant (Inertial)</td>
<td>S/C geometry and cog locations, S/C surface properties</td>
<td>( T_p = \frac{F_s}{c} A_i (1 + g) \cos i (c_p - cg) )</td>
</tr>
<tr>
<td>Magnetic Field</td>
<td>Cyclic</td>
<td>Orbit altitude and inclination, Residual S/C magnetic dipole</td>
<td>( T_m = D \cdot B )</td>
</tr>
<tr>
<td>Aerodynamic</td>
<td>Constant (Earth) or cyclic (Inertial)</td>
<td>Orbit altitude and S/C geometry and cog locations,</td>
<td>( T_a = \frac{1}{2} \rho C_d A V^2 (c_p - cg) )</td>
</tr>
<tr>
<td>Uncertainty in cog</td>
<td>Unbalanced and unwanted torques</td>
<td>S/C geometry</td>
<td>1 to 3 cm</td>
</tr>
<tr>
<td>Thruster Misalignment</td>
<td>“</td>
<td>“</td>
<td>0.1 to 0.5 deg</td>
</tr>
<tr>
<td>Mismatch of thrusters output</td>
<td>“</td>
<td>“</td>
<td>±5%</td>
</tr>
<tr>
<td>Rotating machinery</td>
<td>Stability and accuracy</td>
<td>“</td>
<td>Depending on design can be compensated</td>
</tr>
<tr>
<td>Liquid sloshing</td>
<td>Torques and variation of cog</td>
<td>S/C and tanks geometry</td>
<td>Depending on design, can be compensated</td>
</tr>
<tr>
<td>Dynamics of Flexible Bodies</td>
<td>Resonance and limited bandwidth</td>
<td>S/C geometry</td>
<td>Depending on the S/C structure</td>
</tr>
<tr>
<td>Thermal Shocks on Flexible Appendages</td>
<td>Attitude disturbance when in eclipse transients</td>
<td>S/C structure</td>
<td>Worst with long booms</td>
</tr>
</tbody>
</table>
AOCS Subsystem

Design parameters for selecting the sensors

- Decisions to be taken regarding the sensors:
  - Type
  - Number
  - Layout
  - Sensing combinations
- Sensors are selected according to the following features:
  - Pointing Accuracy
  - Field of View
  - Redundancies
  - Location and Orientation
  - Power
  - Mass
  - Data Rate

<table>
<thead>
<tr>
<th>Sensor</th>
<th>Typical Performance Range</th>
<th>Mass Range (kg)</th>
<th>Power (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>IMU</td>
<td>0.003deg/hr to 1deg/hr, 1 to 5x10^{-6} g/g² (from 20 to 60g)</td>
<td>1 to 15</td>
<td>10 to 200</td>
</tr>
<tr>
<td>Sun sensors</td>
<td>0.005deg to 3 deg</td>
<td>0.1 to 2</td>
<td>0 to 3</td>
</tr>
<tr>
<td>Star sensors</td>
<td>1arcsec to 1arcmin</td>
<td>2 to 5</td>
<td>5 to 20</td>
</tr>
<tr>
<td>Earth sensors</td>
<td>0.1deg to 1deg (LEO)</td>
<td>1 to 4</td>
<td>5 to 10</td>
</tr>
<tr>
<td>Magnetometer</td>
<td>0.5 deg to 3deg</td>
<td>0.3 to 1.2</td>
<td>&lt;1</td>
</tr>
</tbody>
</table>
AOCS Subsystem

Locating the sensors - Examples

LEO SSO12H – Earth Pointing

GTO Equatorial – Sun Pointing at Equinox
Design parameters for selecting the actuators

- Decisions to be taken regarding the actuators:
  - Type
  - Number
  - Layout
  - Actuation combinations

- Actuators are selected according to the following features:
  - Disturbance compensation
  - Redundancies
  - Location and Orientation
  - Power
  - Mass

<table>
<thead>
<tr>
<th>Actuator</th>
<th>Typical Performance Range</th>
<th>Mass Range (kg)</th>
<th>Power (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thrusters</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Hot gas</td>
<td>0.5 to 9000N</td>
<td>Variable</td>
<td>N/A</td>
</tr>
<tr>
<td>- Cold gas</td>
<td>&lt;5N</td>
<td>Variable</td>
<td>N/A</td>
</tr>
<tr>
<td>Reaction and Momentum wheels</td>
<td>0.4 to 400 Nms</td>
<td>2 to 20</td>
<td>10 to 110</td>
</tr>
<tr>
<td></td>
<td>0.01 to 1 Nm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CMG</td>
<td>25 to 500 Nm</td>
<td>&gt;10</td>
<td>90 to 150</td>
</tr>
<tr>
<td>Magnetic Torquers</td>
<td>1 to 4000 Am²</td>
<td>0.4 to 50</td>
<td>0.6 to 16</td>
</tr>
</tbody>
</table>
# Preliminary Sizing of the actuators

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Simplified equations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Torque from RW for Disturbance rejection</td>
<td>$T_{RW} = (T_D) \cdot (M \text{ arg in factor})$</td>
</tr>
<tr>
<td>Slew torque for RW</td>
<td>$T_{RW} = \frac{I \theta}{(l/2)^3}$</td>
</tr>
<tr>
<td>Momentum storage in RW</td>
<td>$h = T_D \frac{Orbital \ Period}{4} \sqrt{2}$</td>
</tr>
<tr>
<td>Momentum storage in MW</td>
<td>$T_D \frac{P}{4} = h \theta_a$</td>
</tr>
<tr>
<td>Torque from Magnetic Torquers</td>
<td>$D = \frac{T_D}{B}$</td>
</tr>
<tr>
<td>Momentum storage in Spinner</td>
<td>$\tau_D \frac{P}{4} = h \theta_a; \quad \omega_I = \frac{h}{I}$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>Thrust force level for external Disturbances</td>
<td>$F = \frac{T_D}{L}$</td>
</tr>
<tr>
<td>Thrust force level for slew rates (zero-momentum)</td>
<td>$F = \frac{I \dot{\theta}}{L}$</td>
</tr>
<tr>
<td>Thrust force level for slewing a Momentum-bias vehicle</td>
<td>$F = \frac{h \omega}{Ld}$</td>
</tr>
<tr>
<td>Thruster pulse life</td>
<td>Derivation of the total number of thruster pulses</td>
</tr>
<tr>
<td>Thrust force level for momentum dumping</td>
<td>$F = \frac{h}{Lt}$</td>
</tr>
<tr>
<td>Propellant</td>
<td>$M_p = \frac{Ft}{I_{sp} g}$</td>
</tr>
</tbody>
</table>
AOCS Examples - AAU

(a) Block diagram describing the implementation of subsystems in the satellite

(b) Block diagram showing hardware on ground

Taller de Diseño de Picosatélites (CUBESATS) y Estaciones de Tierra. ©J.M. del Cura
**The ADCS System:** The ADCS subsystem consists of a circuit board including a magnetometer, which is assembled with one of the battery packs on one board (7), three electro-magnetic coils for attitude control, which are placed on the satellite sides (1, 2 and 10), and the sun sensors and thermistors, which are mounted between solar panels on the five satellite sides (1, 2, 3, 4 and 10) and between the antenna ring and mounting for lenses (6).
Main characteristics:

- Imager pointing
- Rotating for capturing Earth and stars images
- Based on 3 magnetometers
- Magnetic torquers as actuators
Main characteristics:
- No attitude control
- Sensing package:
  - 4-axis gyros
  - 4-axis accelerometers
  - Sun sensor (CMOS)
- Ground attitude determination

Figure 5 CMOS Sun Sensor Circuit Board

Figure 6 CMOS Sun Sensor Block Diagram