Attitude Dynamics, Control and Stabilization Of Spacecraft/Satellites

Anton V. Doroshin
doran@inbox.ru

Samara State Aerospace University
(National Research University)

Introduction to Spacecraft Attitude Dynamics and Control

Most of the spacecraft have instruments or antennas that must be pointed in specific directions:

– The Hubble must point its main telescope

– Communications satellites must point their antennas

The orientation of the spacecraft in the space is called its attitude

To control the attitude, the spacecraft operators must have the ability to

– Determine the current attitude (sensors…)

– Determine the error between the current and desired attitudes

– Apply torques to remove the error (with the help of actuators…)

The Spacecraft Attitude Stabilization:

- — Spin Stabilization methods
- — Gravity Gradient Stabilization methods
- — Magnetic Stabilization methods
- — Aerodynamic Stabilization methods

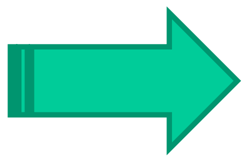
Actuators:

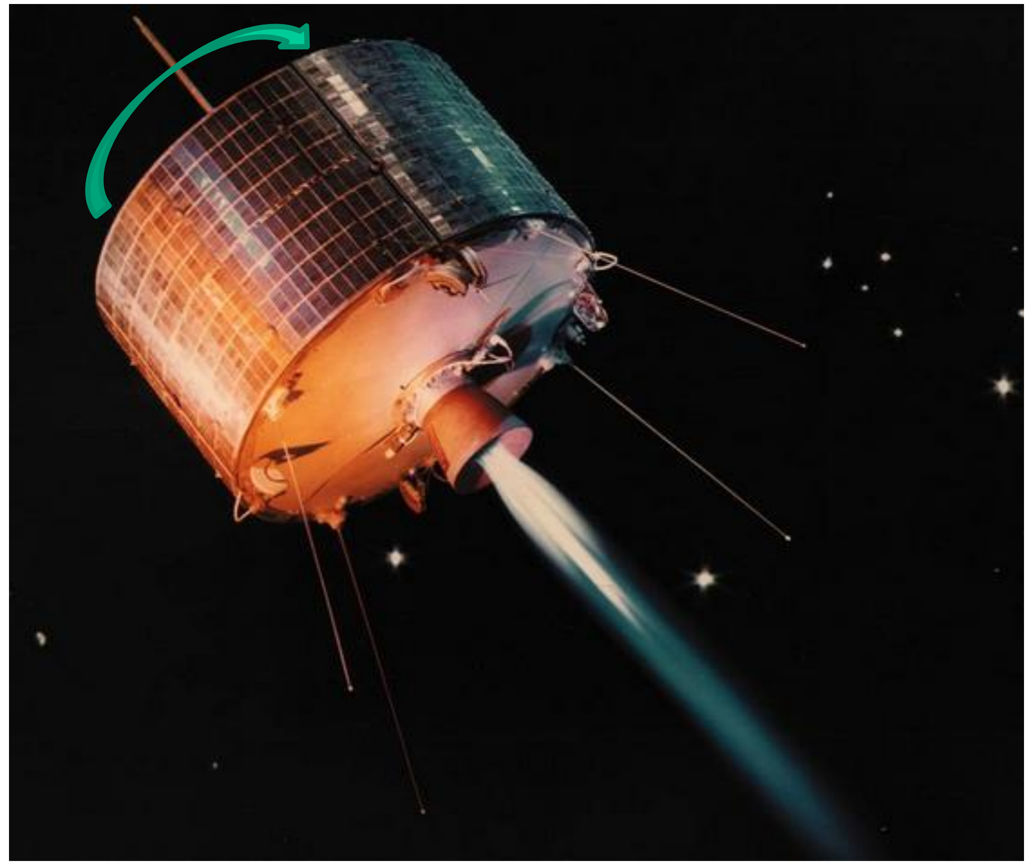
- — Reaction Wheel Assemblies (RWAs)
- — Control Moment Gyros (CMGs)
- — Thrusters

Spin stabilization

Spin-stabilization is a method of SC stabilizing in a fixed orientation using rotational motion around SC axis (usually symmetry axis) – "**the gyroscopic effect**".

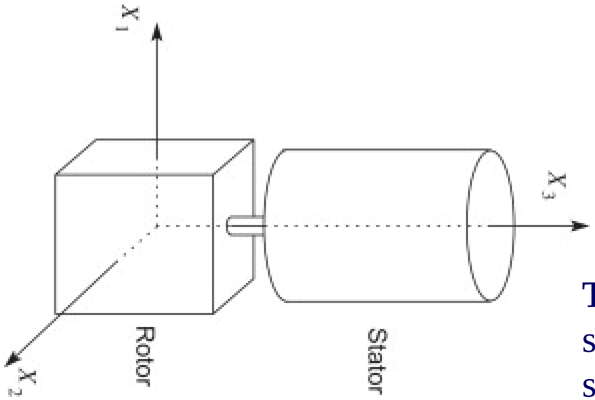
The Top



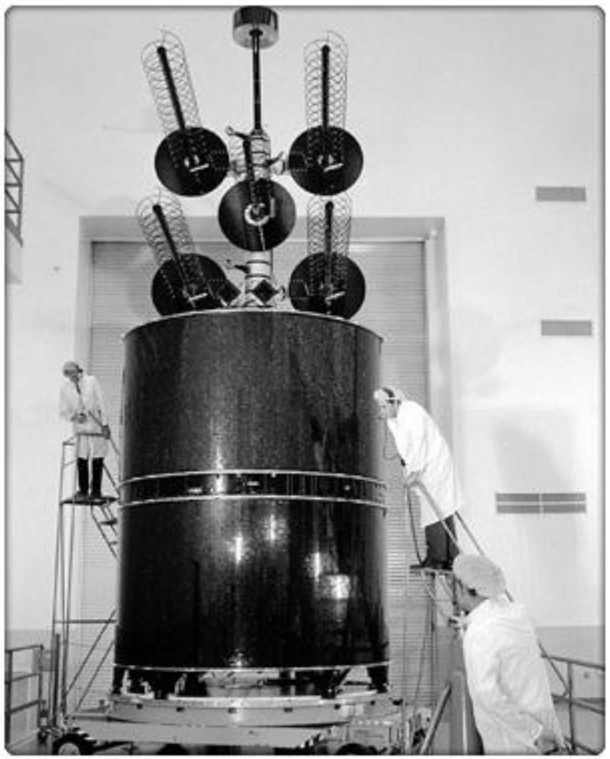


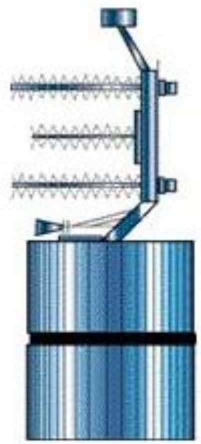
Spin stabilized spacecraft

Spin Stabilization
Dual-Spin Spacecraft



TACSAT I : The antenna is the platform, and is intended to point continuously at the Earth, spinning at one evolution per orbit. The cylindrical body is the rotor, providing gyroscopic stability through its 60 RPM spin

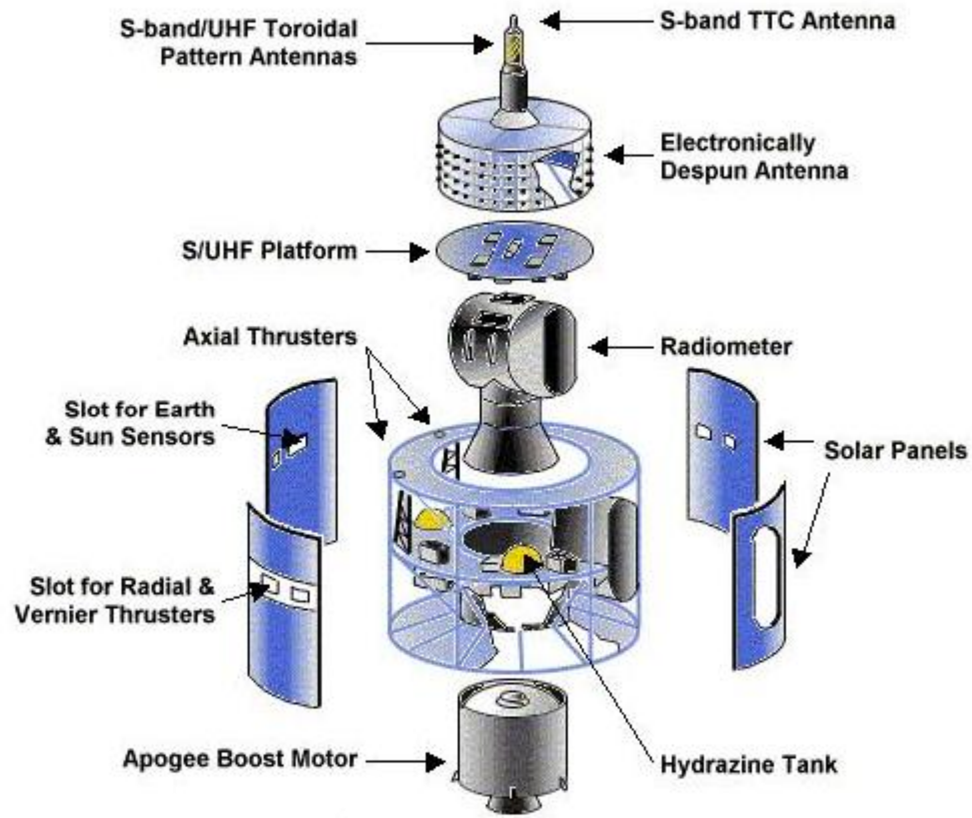




Diameter:
2.81 m (9 ft 3 in)

Overall Height
7.62 m (25 ft)

Weight in orbit
645 kg (1424 lb)



EUMETSAT

TACSAT I was the largest and most powerful communications satellite at the time when it was launched into synchronous orbit by a Titan IIIC booster 9 February 1969, from Cape Canaveral, Florida.

Spin Stabilization
Dual-Spin Spacecraft

The DSSC usually is used for the attitude stabilization by partial twist method: only one of the DSSC's coaxial bodies (**the «rotor»-body) has rotation at the «quiescence» of the second body (the «platform»-body**) – it allows to place into the «platform»-body some exploratory equipment and to perform of space-mission tests without rotational disturbances.

The dual-spin construction-scheme is quite useful in the practice during all **history of space flights realization**; and it is possible to present some examples of the DSSC, which was used in real space-programs (most of them are communications satellites and observing geostationary satellites):

- This is long-continued and well successful project "**Intelsat**" (the Intelsat II series of satellites first launched in 1966) including 8th generation of geostationary communications satellites and Intelsat VI (1991) designed and built by Hughes Aircraft Company.
-The "**Meteosat**"-project by European Space Research Organization (initiated with Meteosat-1 in 1977 and operated until 2007 with Meteosat-7) also used dual-spin configuration spacecraft.
-Spin-stabilized spacecraft with mechanically despun antennas was applied in the framework of **GEOTAIL** (a collaborative mission of Japan JAXA/ISAS and NASA, within the program "International Solar-Terrestrial Physics") launched in 1992; the GEOTAIL spacecraft and its payload continue to operate in 2013.
-Analogously the construction scheme with despun antenna was selected for **Chinese communications satellites DFH-2** (STW-3, 1988; STW-4, 1988; STW-55, 1990).
-Well-known **Galileo mission's spacecraft** (the fifth spacecraft to visit Jupiter, launched on October 19, 1989) was designed by dual-spin scheme.
-Of course, we need to indicate one of the world's most-purchased commercial communications satellite models such as **Hughes / Boeing HS-376 / BSS-376** (for example, Satellite Business Systems with projects SBS 1, 2, 3, 4, 5, 6 / HGS 5, etc.): they have spun section containing propulsion system, solar drums, and despun section containing the satellite's communications payload and antennas.
-Also very popular and versatile **dual-spin models are Hughes HS-381 (Leasat project), HS-389 (Intelsat project), HS-393 (JCSat project).**

Spin Stabilization
Dual-Spin Spacecraft

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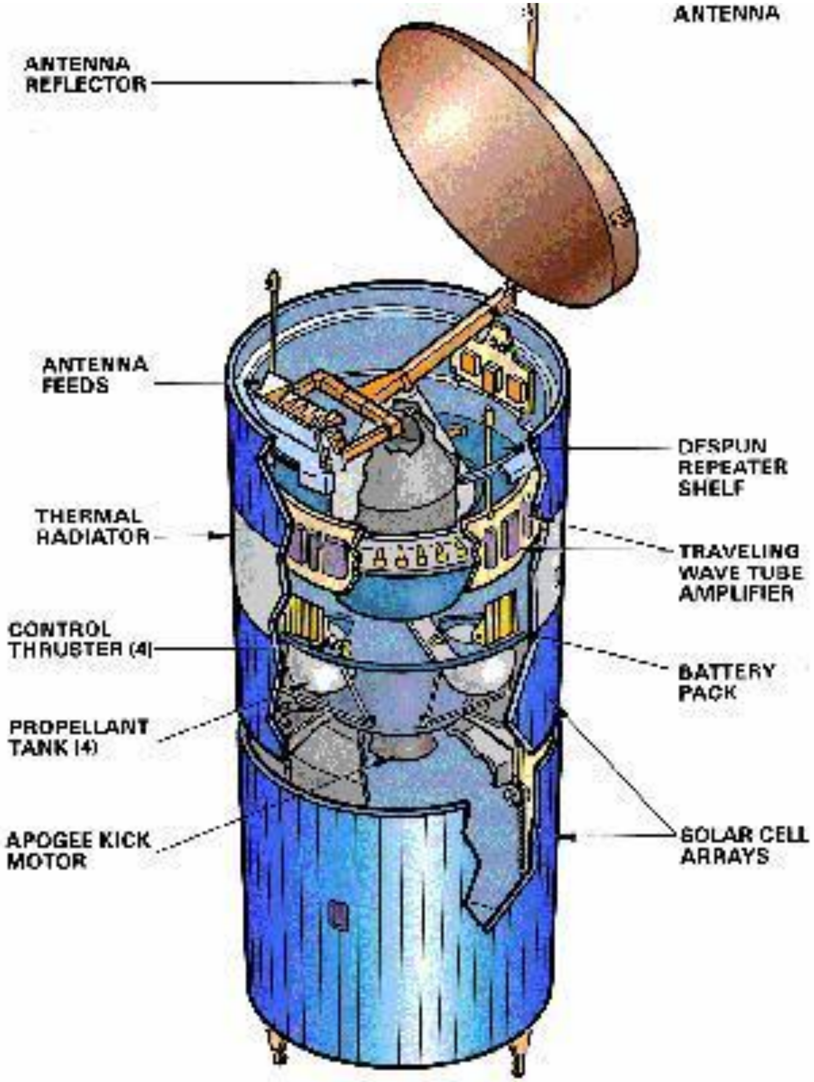

HS 376
SPACECRAFT CONFIGURATION

HS 376
Class: Communications.
Nation: USA.

Mass 654 kg at beginning-of-life in geosynchronous orbit.

Spin stabilized at 50 rpm by 4 hydrazine thrusters with 136 kg propellant.
Star 30 apogee kick motor.
Solar cells mounted on outside of cylindrical satellite body provide 990 W of power and recharge two NiCd batteries. 24 + 6 backup 9 W transmission beams.

HS 376 Chronology:
-15 November 1980 SBS 1 Program
-…
-22 November 1998 BONUM-1 Program

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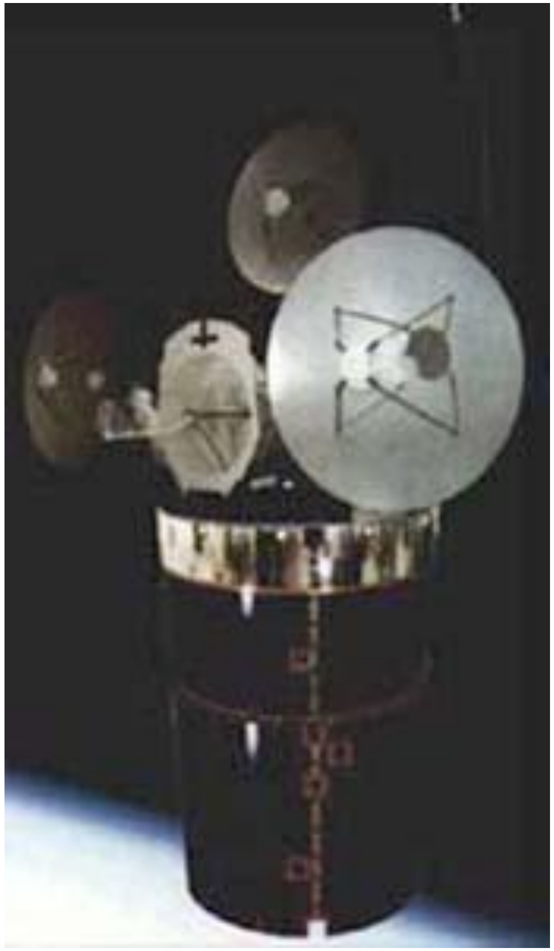
Spin Stabilization
Dual-Spin Spacecraft

Intelsat-6 [Boeing]



SDS-2 [NRO]

Hughes: HS-389

Ordered	Date	
Intelsat 601	1982	29.10.1991
Intelsat 602	1982	27.10.1989
Intelsat 603	1982	14.03.1990
Intelsat 604	1982	23.06.1990
Intelsat 605	1982	14.08.1991
SDS-2 1		08.08.1989
SDS-2 2		15.11.1990
SDS-2 3		02.12.1992
SDS-2 4		03.07.1996

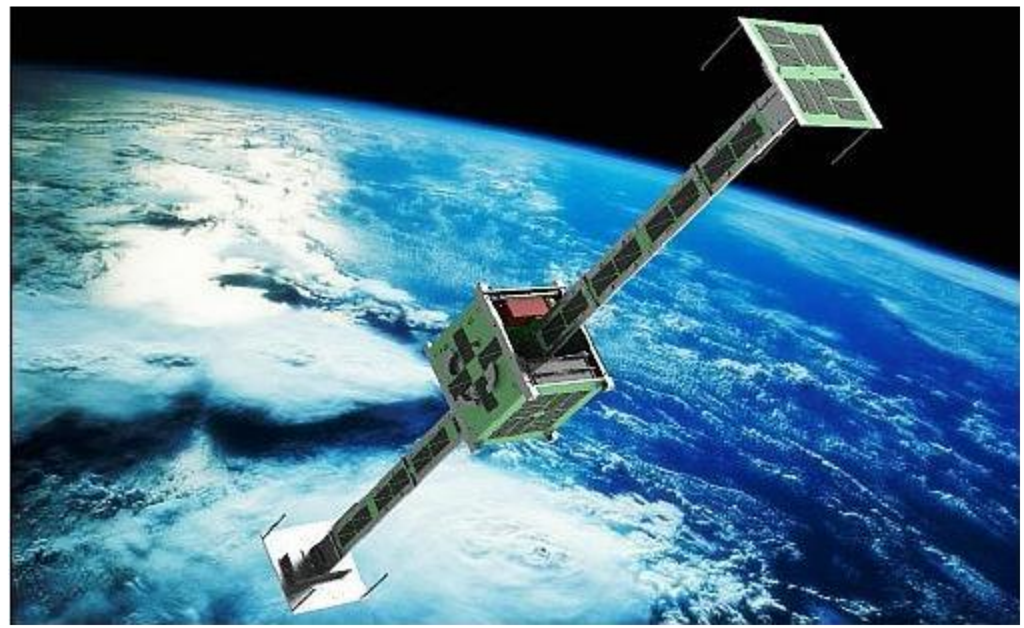
Gravity Gradient Stabilization

The Gravity-gradient stabilization is a method of SC stabilizing in a fixed orientation using only the orbited body's mass distribution and the Earth's gravitational field.

SC is placed along the radius-vector of the Earth

Physical pendulums

Tether-satellites

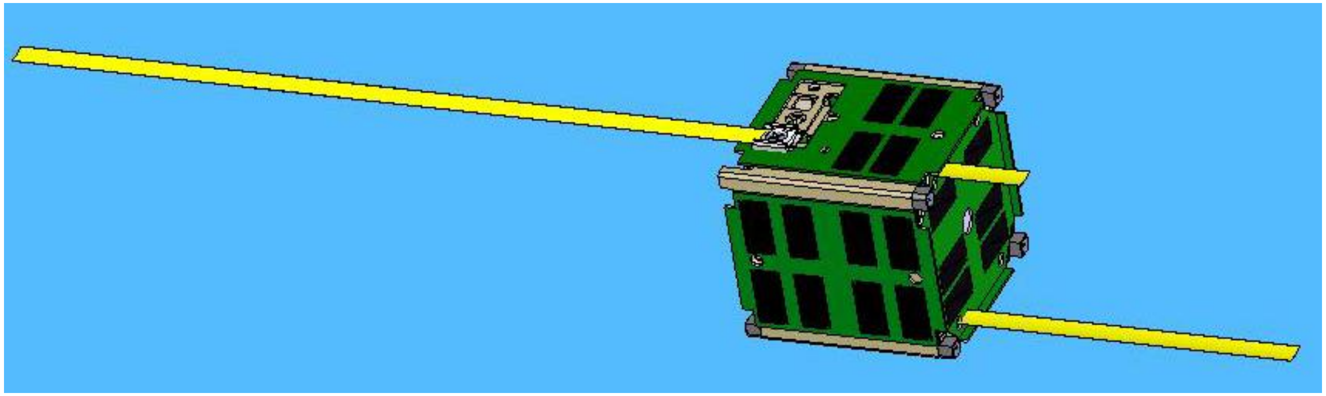


UniCubeSat-GG is the first CubeSat mission of GAUSS (Gruppo di Astrodinamica dell' Universita degli Studi “la Sapienza”) at the University of Rome (Universita di Roma “La Sapienza”, Scuola di Ingegneria Aerospaziale), Italy.

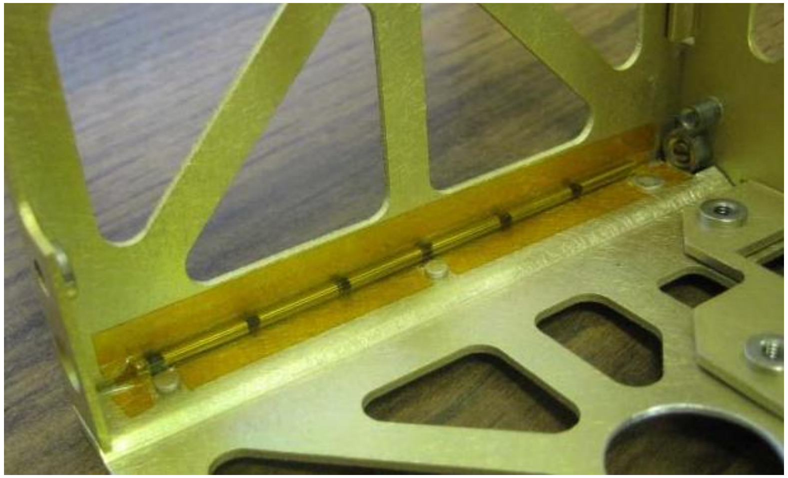
Magnetic Stabilization

Magnetic stabilization is a method of SC stabilizing using geomagnetic field of the Earth

SC is positioned along the magnetic lines of the geomagnetic field ("magnetic compass")



KySat-1 Passive Magnetic Stabilization System is used for antenna orientation and coarse camera pointing



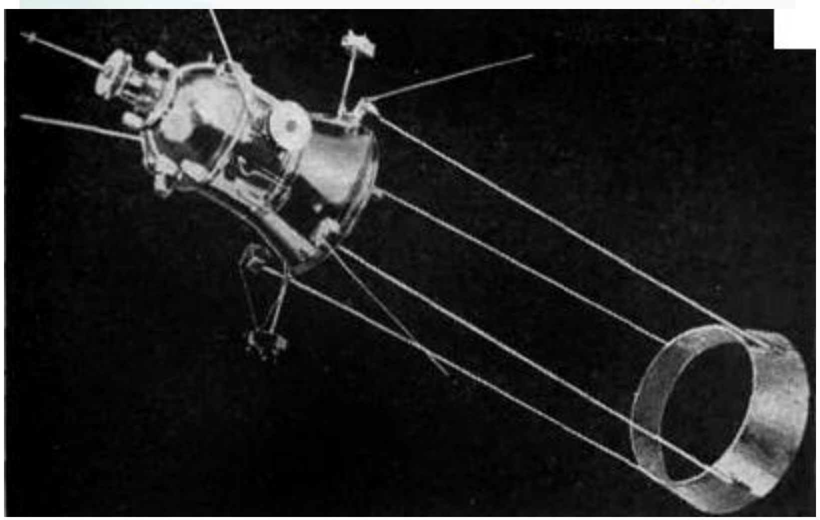
KySat-1, the first satellite project by Kentucky Space, is a 1-U CubeSat scheduled to launch in 2010 on a NASA mission.

← One of Four Alinco-5 Permanent Magnet sets on board KySat-1.

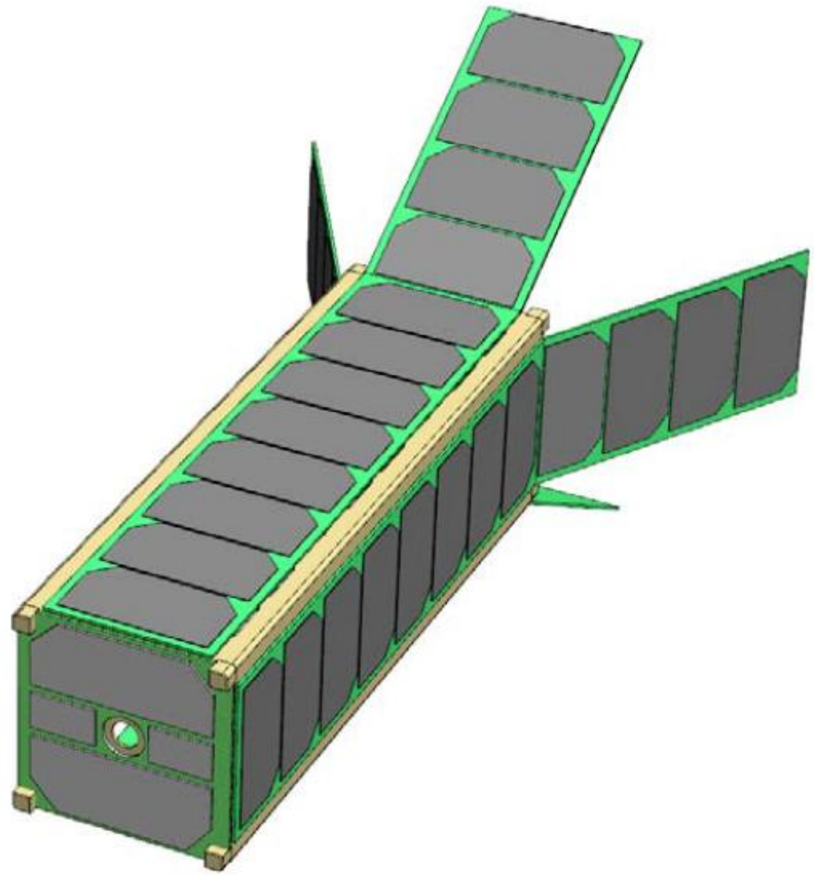
Aerodynamic Stabilization

The Aerodynamic stabilization is a method of SC stabilizing using aerodynamic force in rarefied atmosphere of low earth orbit .

SC is positioned along the orbital velocity vector



SC with tail unit



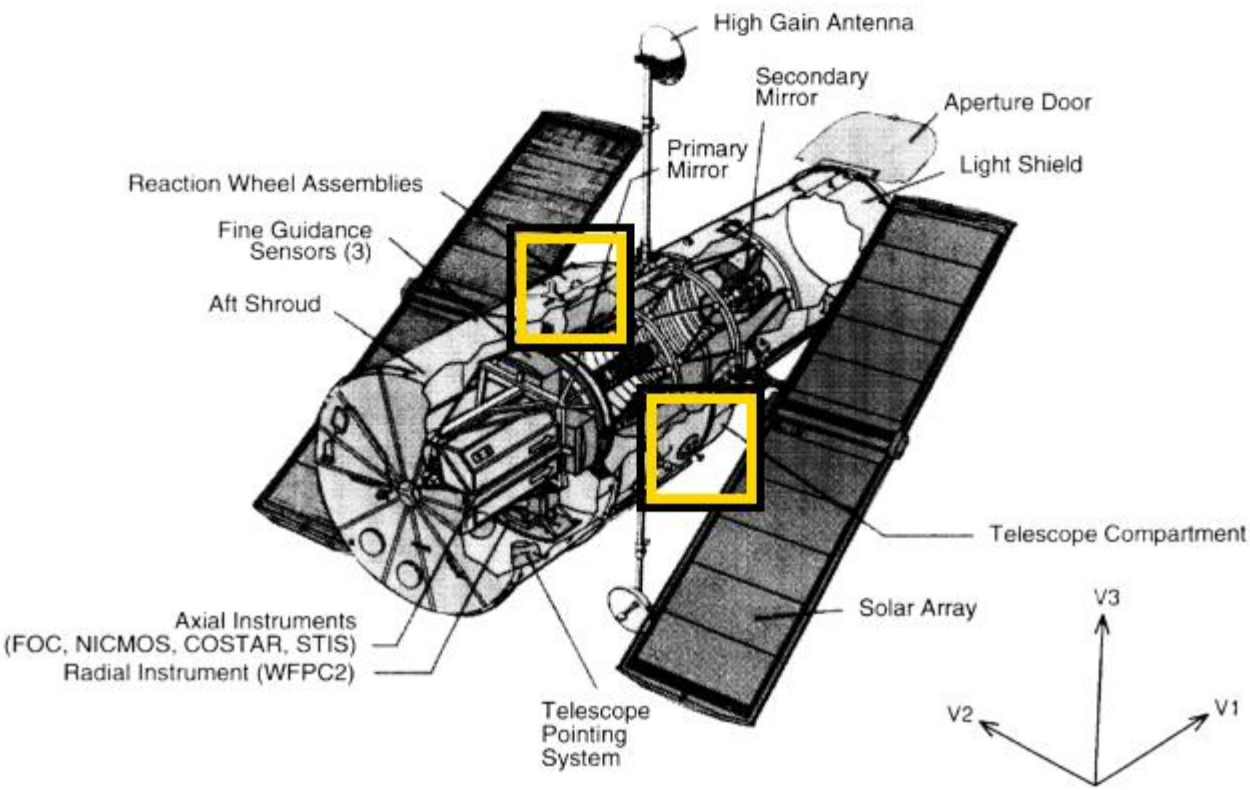
Aerodynamically Stable CubeSat Design Concept

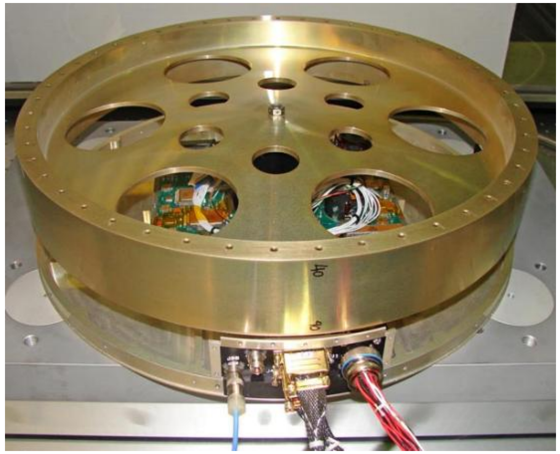
Actuators

Reaction Wheel Assemblies (RWAs)

RWAs are particularly useful when the spacecraft must be rotated by very small amounts, such as keeping a telescope pointed at a star.

This is accomplished by equipping the spacecraft with an electric motor attached to a **flywheel, which when rotated increasingly fast causes the spacecraft to spin the other way** in a proportional amount by conservation of angular momentum.

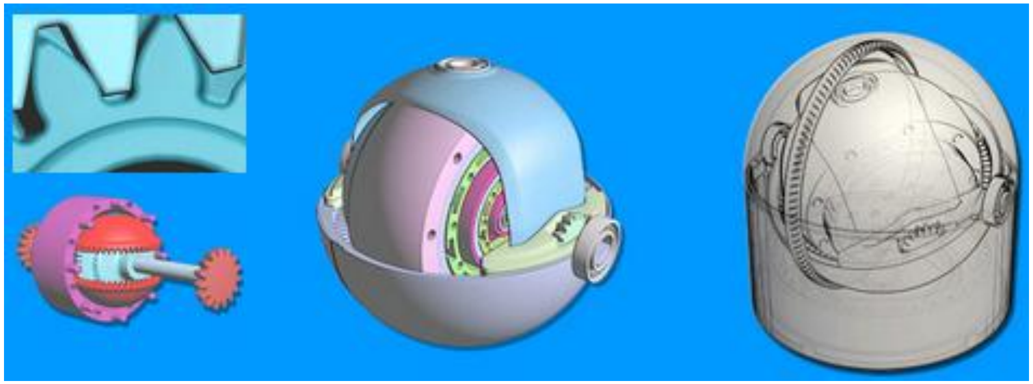


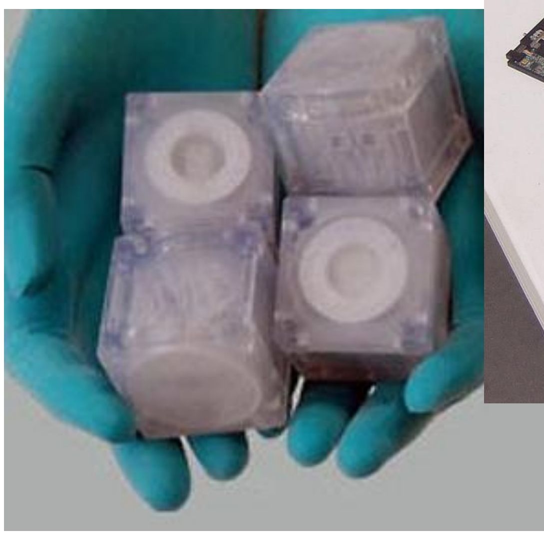


Actuators

Control Moment Gyros (CMGs)

A CMG consists of a spinning rotor and one or more motorized gimbals that tilt the rotor's angular momentum. As the rotor tilts, the changing angular momentum causes a gyroscopic torque that rotates the spacecraft.





Microsatellite with four control moment gyroscopes

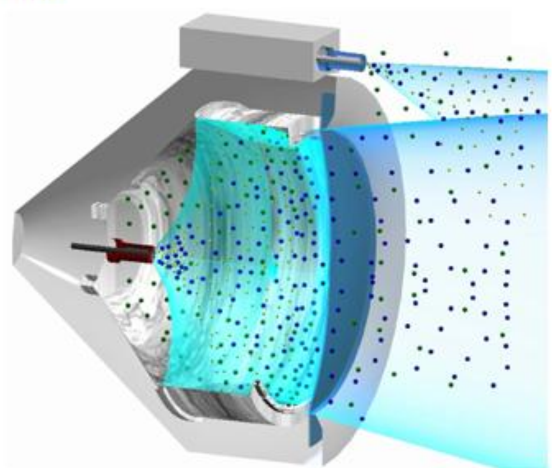
Actuators

Thrusters

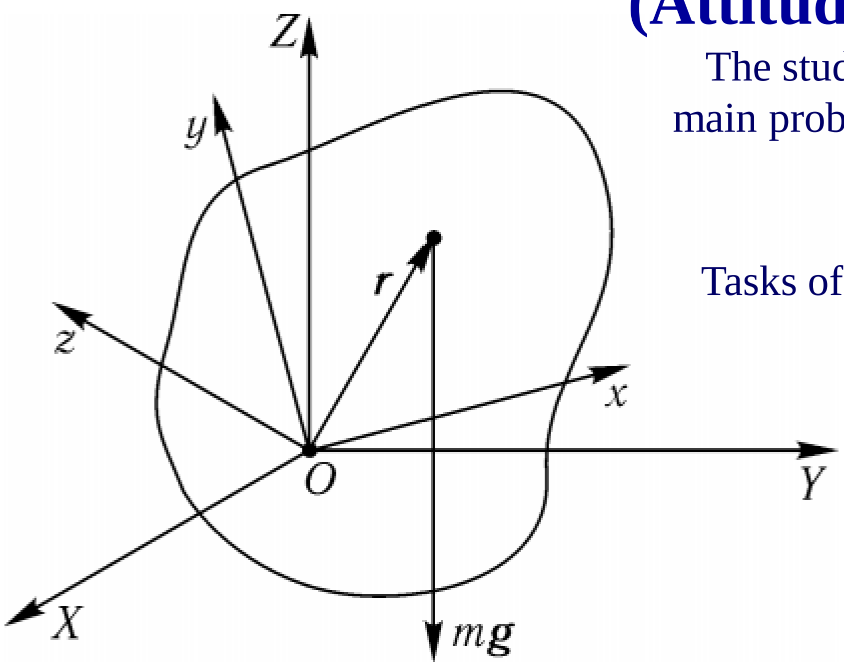
A **thruster** is a small propulsive device used by spacecraft for attitude control, in the reaction control system, or long-duration, low-thrust acceleration

Cyclone-3 LV thruster of 30 N thrust

Liquefied gases in high-pressure balloons



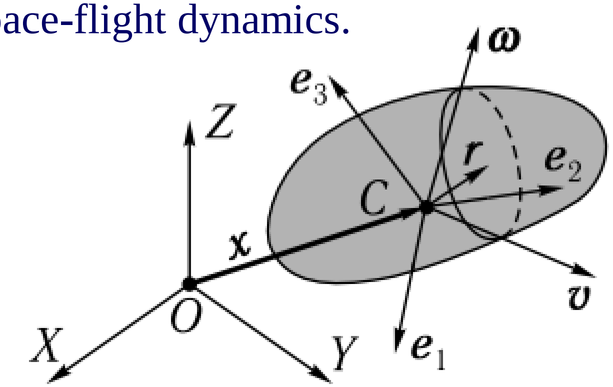
Main Equations of Angular Motion of Rigid Body (Attitude Motion of SC)

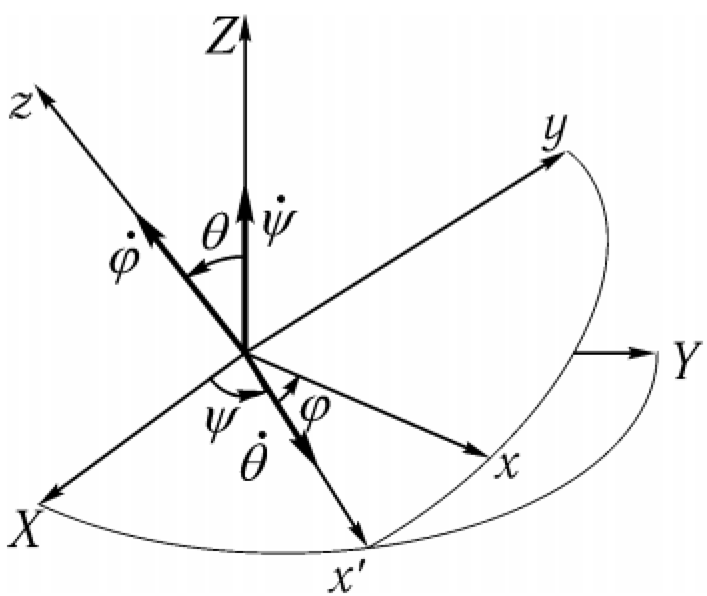


The study of the angular motion of the SC attitude dynamics is one of the main problems of rigid body systems dynamics in the classical mechanics.

And vice versa

Tasks of analysis and synthesis of the rigid bodies' motion have important applications in the space-flight dynamics.





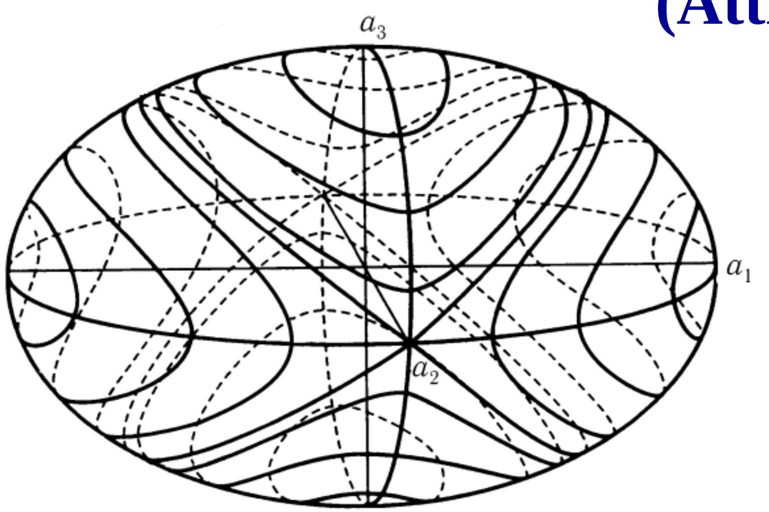
Euler dynamical equations:

$$\begin{cases} \mathbf{I}\dot{\boldsymbol{\omega}} + \boldsymbol{\omega} \times \mathbf{I}\boldsymbol{\omega} = \mu \boldsymbol{r} \times \boldsymbol{\gamma}, \\ \dot{\boldsymbol{\gamma}} = \boldsymbol{\gamma} \times \boldsymbol{\omega}, \end{cases}$$

Euler kinematical equations:

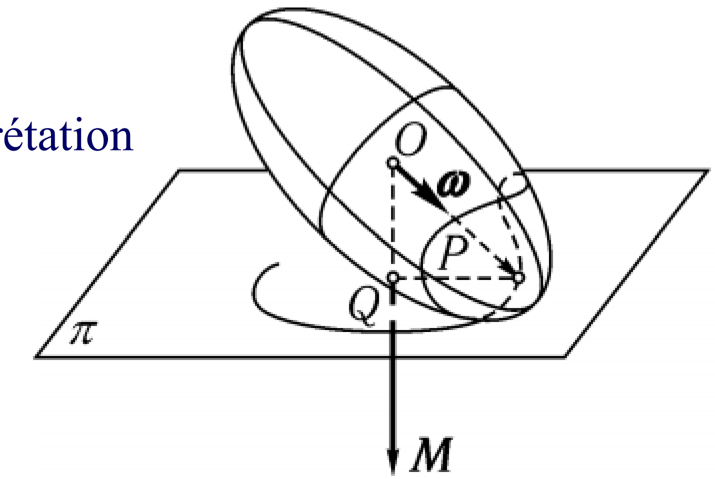
$$\omega_1 = \dot{\psi} \sin\theta \sin\varphi + \dot{\theta} \cos\varphi,$$
$$\omega_2 = \dot{\psi} \sin\theta \cos\varphi - \dot{\theta} \sin\varphi,$$
$$\omega_3 = \dot{\psi} \cos\theta + \dot{\varphi}.$$

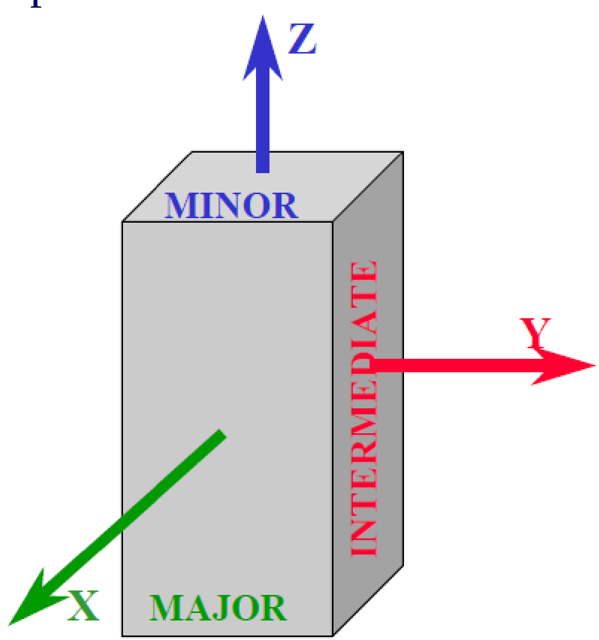
Main Properties of the Free Angular Motion of Rigid Body (Attitude Motion of SC)



Inertia tensor with polhodes

Louis Poinsot interprétation

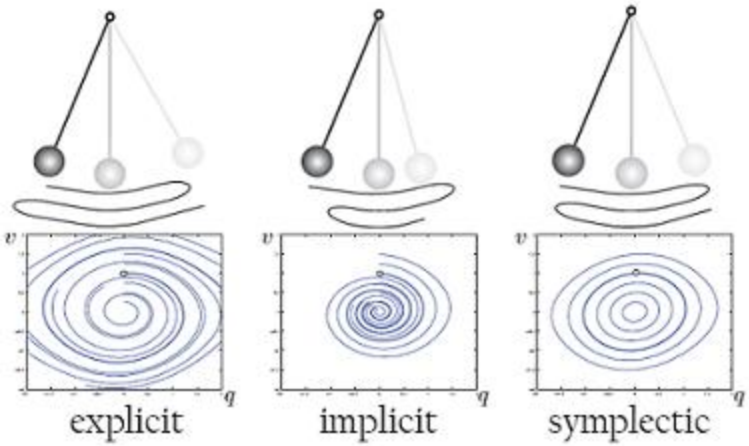


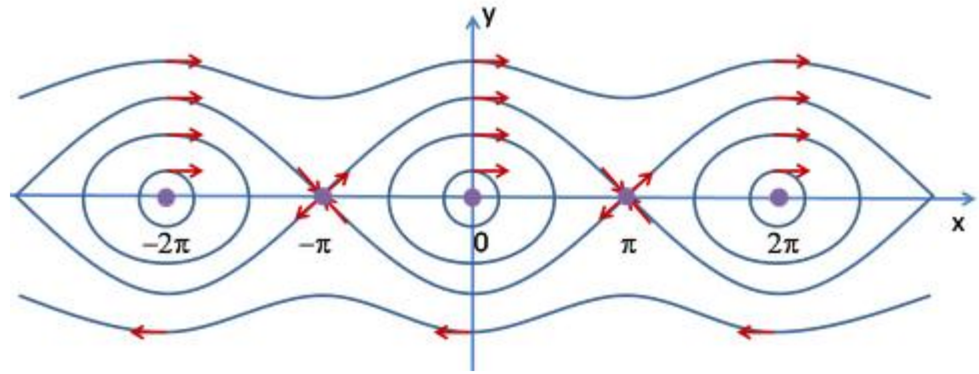


- $I_{xx} > I_{yy} > I_{zz}$
- Major axis spin is stable
- Minor axis spin is stable
- Intermediate axis spin is unstable
- Energy dissipation changes these results
  → Minor axis spin becomes unstable
- This is called the Major-Axis Rule

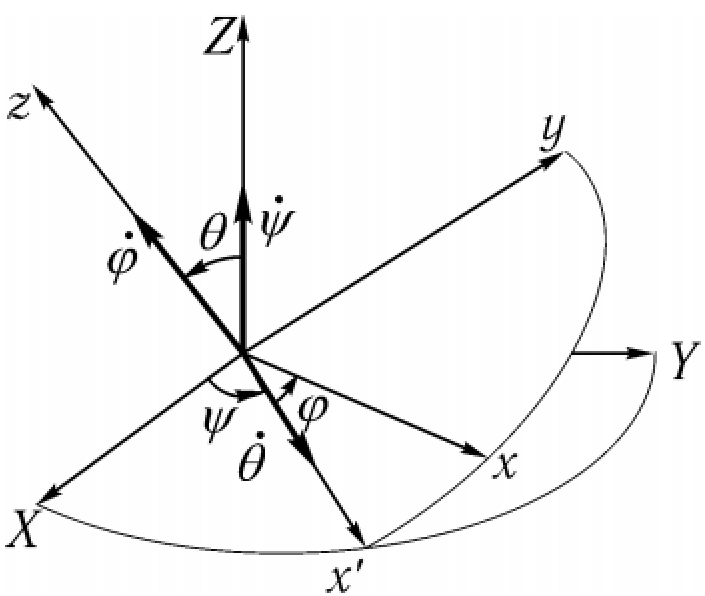
--- notation by C.D.Hall

Main Properties of the Free Angular Motion of Rigid Body (Attitude Motion of SC)





Pendulum phase space



If we consider rigid body angular motion on the base of Hamilton dynamics, than for rigid body motion we take pendulum phase structure:

x=tetta (nutation)

and

y = impulse (tetta) ~ d(tetta)/dt

Conclusion

The main properties of the attitude stabilization and control of SC (and multirotor systems) have been examined.

Research into attitude motion of the one-body-SC, dual-spin SC and spider-type-SC is very complicated.

Nontrivial and chaotic modes are possible in the SC attitude motion.