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The MECB (Brazilian Complete Space Mission) remote sensing satellites (RSS) will operate from a circular polar heliosynchronous orbit to take pictures from the Earth in the visible and near infrared bands, with global coverage of 4 days. These satellites will be three axis stabilized with active attitude control. This paper presents the operating modes of the attitude and orbit control subsystem (AOCS) and the several manoeuvres necessary to lead from unknown attitude and angular rate, after separation, to nominal Earth pointing for picture taking.

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ATTITUDE CONTROL MODES FOR THE MECB REMOTE SENSING SATELLITES

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São José dos Campos, SP

ABSTRACT

The MECB (Brazilian Complete Space Mission) remote sensing satellites (RSS) will operate from a circular polar heliosynchronous orbit to take pictures from the Earth in the visible and near infra-red bands, with global coverage of 4 days. These satellites will be three axis stabilized with active attitude control. This paper presents the operating modes of the attitude and orbit control subsystem (AOCS) and the several manoeuvres necessary to lead from unknown attitude and angular rate, after separation, to nominal Earth pointing for picture taking.

I. MISSION OVERVIEW

The system requirements for the RSS mission call for a low spatial resolution, a large swath, two spectral bands (visible and near infra-red) and a repeatability of four to five days[1]. To accomodate these requirements, the MECB/RSS is designed to fly in a circular, near polar, heliosynchronous, phased orbit. The orbit parameters are listed in Table 1. The launches are supposed to occur at night.

A specification of less than 1% image distortion gave rise to a required pointing accuracy better than 1° and a residual angular rate lower than 3×10^{-3} °/s for pitch and roll and 5×10^{-3} °/s for yaw[2]. Although these requirements are ten times coarser than those for Spot[3] or Landsat, they demand a high performance AOCS due to the small size of the RSS.

Table 1. MECB/RSS mission parameters

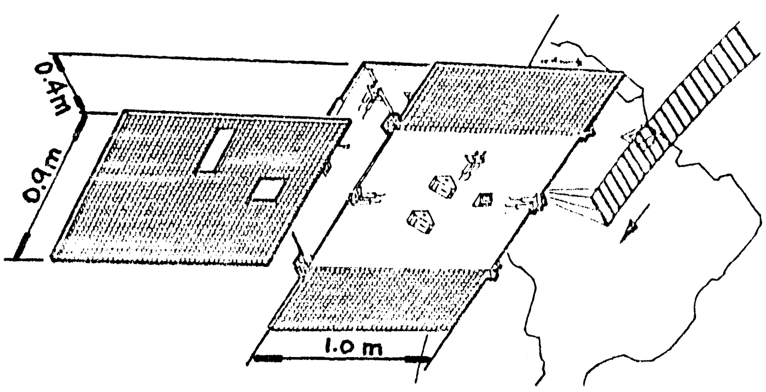
Altitude	640 Km	Global coverage	4 days
Inclination	97.94°	Intertrace at Equator	679 Km
Orbital period	97.52 min	Swath (two cameras)	732.5 Km
Local time (descending node)	8:30 AM	Pixel size	200 m

The mission may be divided in three phases: initial attitude acquisition, orbit acquisition and routine operation. The first phase comprises the first six to seven orbits; the orbit acquisition will take place in the following 15 days in a series of low-thrust transfers until the nominal orbit is reached when the routine operation begins. The expected life span of each satellite is two years.

II. THE SATELLITE AND ITS AOCS

The RSS is to be launched by CTA's VLS, a Scout-like solid fuel rocket, now under development. This launcher has limited payload mass and dimensions, so the satellite mass has been limited to 170 Kg and the area of the solar arrays (and so the available power) is also limited. Steerable solar arrays have been precluded. These constraints led to the conception of a very small satellite, as depicted in Figure 1. In the power/mass/volume budget, the AOCS was awarded with less than 51 Watt in the nominal operating condition, less than 39 Kg, excluding fuel and thrusters, and less than 0.08 m^3.

These limitations also have impacts on the orbit choice. Without steerable solar arrays it is a hard task to design a Sun-synchronous satellite passing through the equator much later than 8:45 AM.



mass.........170 Kg
moments of inertia:
roll.....22.8 Kg×m^2
pitch....31.5 Kg×m^2
yaw......14.9 Kg×m^2

Fig.1.MECB/RSS outlook with deployed solar arrays

The AOCS hardware is listed in Table 2. In spite of the mass/power limitations this is quite a complete set of sensors and actuators for a general purpose three axis stabilized bus. Everything is controlled by an on board computer, except for a special logic to detect malfunctions on the computer itself. Single point failures have been precluded by duplicating all critical parts, except the reaction wheels.

Table 2. AOCS Hardware utilization. See text for acronyms.

sensors/actuators	qty	RR	CSA	FSAL	ES	EL	NAO	RWD	OM/C	SURV
Coarse Sun sensors	2	x	x							x
2-axis digital Sun sensors	2			x	x	x	x	x	x	
IR Earth horizon sensors	2				x	x	x	x	x	
Yaw rate/rate-integ. gyro	2	x	x	x	x	x	x	x	x	x
Reaction wheels	3						x	x		
Hot gas thrusters	12	x	x	x	x	x		x	x	x
Computer	2	x	x	x	x	x	x	x	x	x

The acquisition manoeuvres will be performed by hydrazine thrusters. The same thrusters will be used for attitude control and orbit transfer and correction. The thrusters will be modulated with minimum 50ms pulses. Maximum thrust output is 2N. This is quite high for attitude control but represents a compromise between the two functions the thrusters must perform.

III. AOCS OPERATING MODES

1. rate reduction (RR)

Although the last stage of the launcher is despun by a yo-yo, the residual angular rate (up to 5 RPM) may be too high to allow any attitude control. The first operating mode of the AOCS is the rate reduction, which consists of firing the thrusters against the angular velocity until it is reduced to acceptable levels (below 0.5 RPM). As the satellite has only yaw rate direct measurements this mode will be started only when the Sun is visible. The angular rate is estimated with the yaw gyro and the coarse Sun sensors.

At separation the RSS is spinning around its yaw axis but, due to the damping provided by the hydrazine tanks, it is likely to be found spinning around the pitch axis. This fact, however, is not easily verifiable by simulation, so, at least in this preliminary design phase, no assumption will be made about the initial attitude. Anyway, the rate reduction mode have to cope with any initial attitude because it will be used also to reduce angular speed in the survival mode, should a thruster valve fail to close.

Preliminary simulation results show that, in the worst case, this mode is expected to be complete in 50 seconds. This elapsed time is very low due to the high torque the thrusters provide and the low inertia of the RSS. Figure 2 shows the magnitude of the angular velocity vector against time during a typical simulation.

2. coarse Sun acquisition (CSA)

The next step in the attitude acquisition phase is to point the solar arrays to the Sun in order to assure power supply and to place the Sun in the field of view of the fine Sun sensor, enabling further modes. This manoeuvre will be attempted as soon as possible to avoid battery run out. The entrance conditions are unknown attitude, a low angular rate and Sun visible by the coarse sensors. During eclipses this mode will maintain the yaw rate close to zero. As soon as the Sun is visible again the pointing manoeuvre is repeated.

A coarse pointing accuracy is required in this mode. Keeping the Sun in a cone up to 10° half-aperture, centred in the pitch axis is acceptable. Attitude and angular rate are estimated with the yaw gyro and the coarse Sun sensors. Figure 3 depicts the evolution of the angle between the Sun axis and the pitch axis, starting from a near 90° separation. This is a safe mode and the RSS may remain coarsely pointing to the Sun indefinitely.

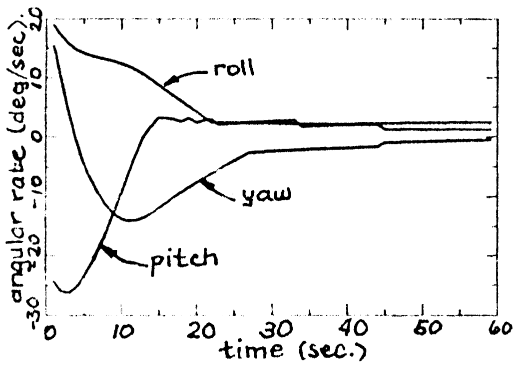


Fig.2.Angular rate decay in the rate reduction mode

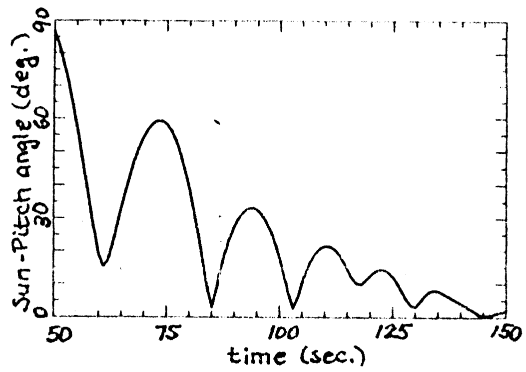


Fig.3.Separation between Sun and pitch axis in coarse Sun acquisition

3. fine Sun acquisition and lock (FSAL)

This is a preparatory manoeuvre to acquire the Earth and the nominal attitude. It keeps a satellite-fixed axis pointing to the Sun. This axis, referred to as SSA, is defined as the Sun-satellite axis at the descending node for nominal orbit and attitude. The resulting condition is the satellite turning slowly (less than 0.5 RPM) around the SSA which is a good condition to acquire the Earth. Figure 4 depicts the evolution of the angle between SSA and the Sun direction, starting with the Sun aligned with the pitch axis, which is the condition left by the coarse Sun acquisition.

4. Earth searching

This mode aims to place the Earth in the range of the horizon sensor, while keeping the SSA pointing to the Sun. The manoeuvre consists in turning the satellite around the SSA until the Earth is within the range of the horizon sensor. Should the residual angular rate from the Sun lock mode be not enough to complete the searching in less than two minutes the satellite will be accelerated by firing the pitch thrusters. The angular rate around the SSA can be measured by the yaw gyro as SSA is not perpendicular to the yaw axis.

5. Earth lock

Earth acquisition is completed by reducing the pitch angle to near zero while still pointing the SSA to the Sun. This will place the satellite near its nominal attitude if the manoeuvre is attempted in the descending node. The manoeuvre will last no more than 2.5 minutes, as depicted in Figure 5.

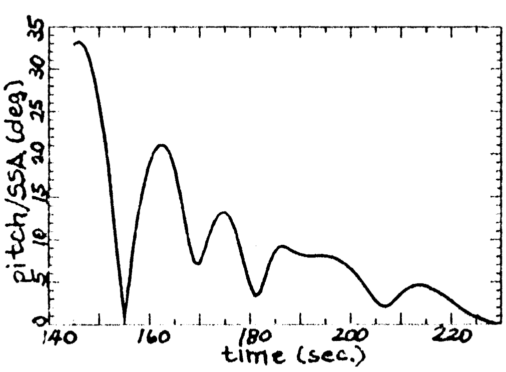


Fig.4.Sun to SSA misalignment reduction in the FSAL mode

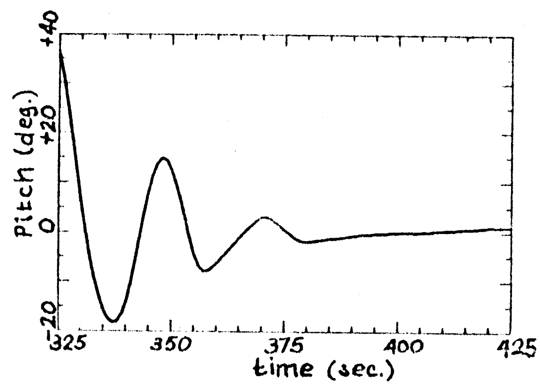


Fig.5.Pitch angle reduction during Earth lock mode

6. nominal attitude operation (NAO)

The previous mode left the satellite attitude in the range of convergence of the nominal attitude controller. In this mode SSA is released and the control objective is to reduce the pitch, roll and yaw angles to near zero, using the reaction wheels. Yaw measurements are obtained by integration of the yaw gyro. The gyro drift is compensated by the readout of the fine Sun sensors.

Due to the definition of the SSA the transition to this mode will be the smoothest if it is attempted in the descending node.

Preliminary simulations show that the proposed control and estimation policies will meet the performance specifications but further studies, with more realistic simulations, are required to confirm it. The main concern resides in the estimation of the angular velocity with the required accuracy.

7. reaction wheel dessaturation (RWD)

Dessaturation of a reaction wheel by firing gas thrusters will be performed whenever its speed reaches a critical value. This mode will never be entered when the payload is working, in order to avoid large angular rate disturbances. Due to the high thrust available the dessaturation will take place in less than 1 minute. At the end of the operation the nominal attitude controller takes over again.

8. orbit manoeuvres and corrections (OM/C)

The purpose of these modes is to maintain the spacecraft attitude close to a specified one during the orbit transfer and correction manoeuvres. In the orbit manoeuvres a non-zero yaw angle may be required in order to implement simultaneous corrections of semi-major axis and inclination.

The reaction wheels are not used here as they are not fast enough to cope with the thrust fluctuations. Instead, torques will be applied by thruster modulation. Those thrusters which are firing for propulsion will be off-modulated and those which are not will be on-modulated. Preliminary simulations show that the specified maximum misalignment of 1° is easily attainable.

9. survival (SURV)

The AOCS has to cope with two kinds of faults: minor faults that can be detected and corrected by software, and major faults which require a complete reconfiguration of the AOCS. Among the latter are hardware or software faults on the computer itself. Should a major fault be detected a special circuit turns all actuators off and reinitializes the attitude acquisition sequence with the backup computer, entering the rate reduction mode and proceeding to the coarse Sun acquisition. The other modes may be activated later, under telecommand.

Minor faults are corrected by software, switching off the faulting device and on its backup unit. An analysis on the attitude and angular rate of the satellite is performed to verify whether the current mode may be resumed or the entire sequence of modes, starting from rate reduction, must take place. This is done to avoid unnecessary entries in the survival mode.

CONCLUSION

Despite the modest spatial resolution of the RSS images, the mission have severe attitude control requirements, together with strong restrictions in mass, volume and power. To cope with these requirements a complex, yet not heavy AOCS was proposed. Preliminary simulations show that the proposed attitude control policy is feasible.

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