DESCENT CONTROL SUBSYSTEM

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Preliminary Design Report (PDR)

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DESIGN OVERVIEW

The Parikshit CANSAT will undergo two stages of descent since its separation from the rocket – firstly, from 1000m to 500m and secondly, from 500m to 0m. During the first stage, the CANSAT is designed to descend at a velocity of 17 m/s (+-2 m/s), and during the next stage, the CANSAT will achieve a velocity of 2 m/s to 3 m/s. In both these stages, the descent velocity will be controlled by a single reefed Parachute. During the entire duration of descent, the CANSAT will be actively stabilized by the Gyroscopic System comprising Control Moment Gyroscopes, a type of Mechanical Gyroscope.

PRIMARY AND SECONDARY DESCENT MECHANISMS

DESIGN SELECTION

DESIGN 1 : REEFED PARACHUTE

The reefed parachute on board will be deployed as soon as the CANSAT is separated from the rocket body. The projected diameter of the parachute will be controlled by the reefing lines connected to the control line. During its first stage, the control line is kept shorter to make the parachute's area smaller. This will act as the Primary Parachute for the CANSAT. Once it reaches 600 to 500 m, the control line will be released to its maximum length, and the parachute will increase to its maximum projected diameter and area. This will act as the Secondary Parachute and Secondary Descent Mechanism, further lowering the velocity to 2 to 3 m/s.

DESIGN 2 : PARACHUTE AND PROPELLER

Once the CANSAT is separated from the rocket body, the Primary Parachute is deployed. This is a regular parachute with a fixed projected diameter. It will act as the primary descent control mechanism. The Propeller on board will start at 600 m to 500 m while the primary parachute is still attached. The Propeller will generate thrust in the opposite direction of the air inflow, therefore decelerating the CANSAT. It will be actively controlled based on the required thrust and velocity of the CANSAT.

FINAL SELECTION – REEFED PARACHUTE :

Reasons :

1) Less space and weight consumption
2) Less complicated than the latter design, still being innovative at the same time

3) Control is much easier in the former design

CONCEPT OF PARACHUTE AND REEFED PARACHUTE

A parachute is a device that is used to slow down the descent velocity of the CANSAT by generating drag while maintaining stability of the CANSAT. The descent rate can be primarily controlled by increasing or decreasing the drag area of the Parachute.

A reefed parachute is a type of parachute in which the opening load is controlled by restricting the canopy area at the skirt of the parachute temporarily. In the Parikshit CANSAT, the reefing technique known as Central Loop Control Line is considered for reefing the parachute. The reefing lines are attached to the loops (attachment point) of the suspension line of the parachute. These reefing lines then join the main, single control line. Controlling the length of the Control Line will either increase or decrease the canopy area of the Parachute. When the reefing lines are fully deployed and will be approximately the size of the radius of the parachute, then the parachute will be fully inflated.

At the terminal velocity, the gravitational force of the CANSAT is equal to the drag force of the parachute.

$$F_g = F_d$$
$$mg = 0.5 \times C_d \times \rho \times A \times v^2$$
$$A = (2mg)/(C_d \times \rho \times v^2)$$

Where, m is the mass of the CANSAT (kg)

g is the acceleration due to gravity (9.81 m/s^2)

C_d is the Drag Coefficient of the Parachute

ρ is the Density of the Air (1.225 kg/m^3)

A is the Projected Area of the Parachute (m^2)

v^2 is the required descent velocity (m/s)

In addition, a spill hole or a vent is added at the apex of the parachute. The spill hole is added in order to increase the stability of the parachute and reduce the swinging of the CANSAT. Usually, it is 1 percent of the constructed area of the parachute.

The parachute will be made from several gores stitched together. Gore is the canopy segment that runs from the skirt to the apex of the parachute. The material chosen for parachute manufacturing is Rip-Stop Nylon because of its high strength and resistance to tearing.

DESIGN OF THE PARACHUTE

DESIGN 1 : HEMISPHERICAL PARACHUTE

C_d = 1.5

1) For v = 17 m/s during first stage :
    a. A = 0.0475 m^2
    b. $D_p = \sqrt{4} * A/\pi$ = 0.246 m or 24.6 cm
2) For v = 3 m/s during second stage :
    a. A = 1.526 m^2
    b. $D_p = \sqrt{4} * A/\pi$ = 1.394 m or 139.4 cm

DESIGN 2 : HEXAGONAL PARACHUTE

C_d = 0.75

1) For v = 17 m/s during first stage :
    a. A = 0.07759 m^2
    b. $D_p = \sqrt{4} * A/\pi$ = 0.2993 m or 29.93 cm
2) For v = 3 m/s during second stage :
    a. A = 2.4914 m^2
    b. $D_p = \sqrt{4} * A/\pi$ = 1.696 m or 169.6 cm

FINAL SELECTION – HEMISPHERICAL PARACHUTE :

Reasons :

1) More stable during flight than the hexagonal configuration
2) Material requirement is less in Hemispherical than Hexagonal

DEPLOYMENT OF THE PARACHUTE

The reefed parachute will be connected on the outer body of the CANSAT. The area where the parachute will be stowed, would be closed by a lid. The lid will be secured by the servo motor arm situated in the compartment. The suspension lines of the parachute will be attached to the outer body of the CANSAT, while the control line will be in the area below the parachute housing. Immediately after the CANSAT is deployed, the servo will be triggered, the servo arm will be aligned to the slit on the lid. There would be a spring-loaded mechanism which will force open the lid. The lid is attached to the CANSAT by a hinge or a zip-tag. Another servo will be triggered on reaching a height of 600-500 m, which will open the latch mechanism, prompting the loop of the control line to fall and extend due to the high tension on the parachute. This is the disreefing process.

DESCENT STABILISATION

The innovative mechanical gyro-control system chosen, that would be present in the CANSAT, is Control Moment Gyroscope (CMG). Control Moment Gyroscope is a type of Mechanical Gyroscope which uses its gimbal to change the direction of the angular momentum of the flywheel in order to produce a Gyroscopic Torque in the required direction. Two Single Gimbal Control Moment Gyroscopes (SGCMG) will be oriented to produce control torques along the respective axes. The CANSAT would need to be stabilized along the pitch and roll axes, for which the two SGCMGs would be used. These SGCMGs need not stabilize the yaw axis, since the yaw axis would eventually be stabilized by the parachute itself.

DESIGN SELECTION

DESIGN 1 : SINGLE GIMBAL CONTROL MOMENT GYROSCOPE (SGCMG)
Single Gimbal Control Moment Gyroscopes (SGCMGs) are the most basic, but widely used CMGs. An ordinary SGCMG consists of a flywheel that will spin at a constant speed. The flywheel is rotated about the gimbal axis. With the flywheel rotating with a constant speed, the torque is controlled only by the gimbal rate δ. The torque vector so produced will be perpendicular to the angular momentum vector(h) of the flywheel and the gimbal axis.
The two Single Gimbal Control Moment Gyroscopes (gyroscopes having single gimbal) would be positioned one below the other, near the Center of Mass of the CANSAT. The SGCMGs will be actively controlled independently in order to stabilize the roll and the pitch axes.

DESIGN 2 : DOUBLE GIMBAL CONTROL MOMENT GYROSCOPE (DGCMG)
Double Gimbal Control Moment Gyroscopes (DGCMGs), though similar to SGCMGs, differ in the fact that they have an extra Degree of Freedom, providing one more gimbal axis, allowing it to produce torque in two directions, instead of one.
A single Double Gimbal Control Moment Gyroscope will be positioned at the Center of Mass of the CANSAT. It consists of two gimbals, one gimbal housed inside another gimbal. A single setup is sufficient for stabilizing each axis – roll and pitch axes.

FINAL SELECTION – SINGLE GIMBAL CONTROL MOMENT GYROSCOPE :
Reasons :

1) SGCMG is generally preferred in small satellites, than the DGCMG.
2) Complexity in structure and control increases in the case of DGCMG.
3) Chances of failure of the system increases when DGCMG is used, mainly due to gimbal lock, in which case control is lost completely.

Though SGCMG is more prone to singularity cases than DGCMG, such cases can be avoided by active control (using a PID controller).

DESIGN OF THE GYROSCOPIC SYSTEM

Single Gimbal Control Moment Gyroscopes (SGCMGs) are the most basic, but widely used CMGs. An ordinary SGCMG consists of a flywheel that will spin at a constant speed. The flywheel is rotated about the gimbal axis. With the flywheel rotating with a constant speed, the torque is controlled only by the gimbal rate δ. The torque vector so produced will be perpendicular to the angular momentum vector(h) of the flywheel and the gimbal axis.

The two SGCMGs would be positioned one below the other, near the Centre of Mass (COM) of the CANSAT. The flywheels of both SGCMGs would be identical and would rotate with the same RPM. However, the direction of rotation of the flywheels would be opposite to each other (i.e. one would rotate in clockwise direction, while the other would rotate in anticlockwise direction). This arrangement would ensure the cancellation of the possible torque produced along the yaw axis of the CANSAT.

In simple mathematical terms, the torque produced by a CMG is given by:

$$\boldsymbol{\tau} = h \times \delta.$$

Where $\boldsymbol{\tau}$ is the control torque produced by the CMG

h is the angular momentum of the flywheel

δ. is the rotation rate of the gimbal

The stabilization torque would be produced in a direction perpendicular to the direction of angular momentum of the flywheel and the gimbal axis. For the stabilization of the CANSAT, control torque has to act along the pitch (y) and roll (x) axes. The flywheel rotating along the +z axis would be utilized to produce the control torque along the roll axis. For this, the CMG would be rotated along the y-axis. Pitch control can be achieved by rotating the other CMG (with flywheel rotating along the -z axis) along the x-axis. The direction of attitude control of both the CMGs can be reversed by reversing the gimbal rotation axes.

The main components of CMG are : Flywheel, Flywheel motor (BLDC Motor), Gimbal Arm, Gimbal motor (Servo Motor), Brackets and Bearings

DESIGN OF FLYWHEEL FOR THE SYSTEM

The dimension of the flywheels mainly depends on the following parameters:

1) Required slew of CANSAT
2) Required control torque
3) Density of the material chosen for the flywheel

The required slew of the CANSAT is chosen as 15^{o}/ sec, by taking into consideration the estimated descent time of the CANSAT. This slew rate is then used to estimate the control torque required to stabilize the CANSAT.

The required control torque can be calculated as follows:

$$\boldsymbol{\tau} = \mathrm{I_s}\,\alpha$$

Where, I_s is the inertia tensor of the CANSAT
α is the angular acceleration of the CANSAT

The angular acceleration of the CANSAT can be obtained from the following equation:

$$\theta = 0.5 \text{ x } \alpha \text{ x } t^2$$

Where, θ is the required stabilization angle in time 't'

The control torque is calculated to be 8.099 mN-m. Stainless steel of grade SS-304 will be used for the flywheel, which is of density 7750 kg/m3.

The dimensions of the flywheel can be obtained from the below equation :

$$\boldsymbol{\tau} = \mathrm{mgsin}\ \theta \text{ x } \mathrm{L} = \mathrm{I}\omega\Omega$$

Where, m is the mass of the CANSAT (in kg)
g is the acceleration due to gravity (9.81 m/s^2)
θ is the maximum roll angle of the CMG (in radians)

L is the length from pivot point of CMG to its center of gravity (in m)
I is the moment of inertia of the flywheel: I = = 0.5 x m_f x r_f^2 (kgm2)
m_f is the mass of the flywheel (in kg)
r_f is the radius of flywheel (in m)
ω is the rotation rate of the flywheel (in rad/s)
Ω is the gimbal rate (in rad/s)

The dimensions of the two identical flywheels are as follows:

Mass of the flywheel: m_f = 85 g
Diameter of the flywheel: 2 x r_f = 5.3 cm
Thickness of the flywheel: t_f = 5 mm

The flywheel would be spinning at 10,000 rpm, at a gimbal rate of 15^o/s

SUBSYSTEM TEST PLAN

PRIMARY AND SECONDARY MECHANISM

(i) Wind Tunnel Testing : Monitoring the behaviour of the Reefed parachute during the reefing and disreefing stages, and checking for any instability in the attitude of the Parachute.
(ii) Drop Test : Testing stability of the Parachute setup when attached to the CANSAT Prototype or an equivalent object.
(iii) Reefing Mechanism Testing : Checking for effectiveness and time rate accuracy for the control line extension

DESCENT STABILISATION

(i) Functioning Testing : Verifying and testing gimbal roll angles, torques generated and the direction of the torque produced by individual SGCMGs and combined system in a modelled environment and in a controlled physical setup.
(ii) Pendulum Testing : Monitoring behaviour of the gyroscopic system when placed in a suspended CANSAT acting as a pendulum.
(iii) Drop Test : Testing stabilization of the CANSAT by the Gyroscopic system in the presence of the deployed parachute.

(iv) Failure Testing : Monitoring behaviour of the gyroscopic system and CANSAT as a whole when either of the SGCMG fails to work.

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