Drag Force in Space

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Project idea

The idea behind our experiment is to measure drag force of air at LEO altitudes through a system which will contain a free mass, some sensors placed inside the CubeSat, and data we have found on the web. The inside of the CubeSat will be modified in order to simplify the experiment given the fact that the CubeSat rotates. All the data collected will then be applied to Newton's Second Law which will allow us to measure drag force.

Materials and intermediate steps

1. Free mass inside the CubeSat

   There will be a free mass (probably a small metal sphere) placed inside the CubeSat with a hook (we will make changes to the Cubesat to make the touch recognition easier and more accurate) on the free mass' surface. After the CubeSat starts to orbit the Earth, the hooks will disengage from the CubeSat to let the free mass travel with the initial speed of the CubeSat. Since there is no force applied to the free mass there will be a relative motion between the CubeSat and the free mass (for the principle of inertia).

2. Deceleration and panels opening

   To increase the deceleration of the CubeSat we will be deploying a system of panels to improve our braking surface. While the CubeSat starts to decelerate, because of the drag force, the free mass inside is going to maintain the same speed as at the beginning (by considering that there is no drag force therein). Many sensors will be placed into it which will help us find the time (Δt, that we have already measured with a theoretical calculation) needed by the displacement of the free mass, through which we will calculate the acceleration. We expect the movement to be about 3 cm of distance in relation to its initial position in the CubeSat. The small free mass will "move" inside the CubeSat due to the deceleration of this last, instead the free mass will maintain the same speed as at the beginning.

3. Data survey and transmission

In the free mass we will put:

- A sensor that will measure the distance between the small mass and the CubeSat surface;
- A sensor which will tell us when the displacement is reached

In the empty space of the CubeSat, we will insert these devices:

- A sensor which will measure the time that the free mass spends travelling a determined distance more than the CubeSat;
- An accelerometer and a thermometer;

Objectives

Our goal: we want to calculate drag force in space and gauge its average value by measuring the displacement of the free mass in relation to time and to measure its acceleration inside the CubeSat. With this we can also calculate the density of air.

We also want to compare the accuracy of the acceleration we calculate with a measured acceleration by using an accelerometer.

Formulas

We started from the formula: $F = \frac{\rho C_D A}{2} v^2$ where:

- ρ is the air density
- C_D is the drag coefficient
- A is the area of the object the air presses on
- v is the velocity of the moving object

to calculate the drag force (F) and we simulated theoretically the experiment. So we've found some density (ρ) measurements on the Web (from NRLMSISE-00 Atmosphere Model, see link below), which we used to calculate the drag force, through the speed (v) that we've also calculated. Since the force is approximately constant then the relative motion between the free mass and the CubeSat body is uniformly accelerated (with the acceleration a = F/m) and by that we can estimate Δt, the time spent travelling the distance from the free mass to the CubeSat body. $\Delta t = \sqrt{\frac{2\Delta x}{a}} = \sqrt{\frac{2\Delta x}{F/m}} = \sqrt{\frac{4\Delta x m}{\rho C_D A v^2}}$

A =	0.05	m^2	G =	6.67E-011	Nm^2/kg^2	M =	2.10E+000	kg
C_d =	0.47		E_M =	5.97E+024	kg	Δx =	1.75E-002	m
			E_R =	6.37E+006	m			
h (m)	ρ (data from NRLMSISE-00 Atmosphere Model)	v (m/s) = sqrt(G*E_M/E_R)	F (N) = 0.5*ρ*A*C_d*v^2	a (m/s^2) = F/M	Δt (h) = sqrt(2*Δx/a) /3600			
2.00E+005	2.35E-016	7.79E+003	1.68E-010	7.98E-011	5.82			
3.00E+005	1.30E-017	7.73E+003	9.11E-012	4.34E-012	24.95			
4.00E+005	1.33E-018	7.67E+003	9.17E-013	4.37E-013	78.62			
5.00E+005	1.78E-019	7.61E+003	1.21E-013	5.76E-014	216.50			
6.00E+005	3.21E-020	7.56E+003	2.15E-014	1.03E-014	513.17			
7.00E+005	9.53E-021	7.51E+003	6.31E-015	3.00E-015	948.30			
8.00E+005	4.51E-021	7.45E+003	2.94E-015	1.40E-015	1388.07			
9.00E+005	2.67E-021	7.40E+003	1.72E-015	8.18E-016	1816.71			
1.00E+006	1.71E-021	7.35E+003	1.09E-015	5.18E-016	2283.89			

So we estimate that, at the ISS LEO, it needs about 80 hours to complete the measurement. During this time the Cubesat will travel about 14 orbits, so we'll be able to evaluate the average drag force acting on it along this path.

References

We used the following links to elaborate the theoretical part of the experiment.

https://www.weatheronline.co.uk/reports/wxfacts/Troposphere.htm
https://ccmc.gsfc.nasa.gov/modelweb/models/nrlmsise00.php
https://ccmc.gsfc.nasa.gov/workshops/workshop2018/03_Wednesday_PM/2_Pilinski_satellite_drag_seminar_20180425_v2.pdf
https://www.youtube.com/watch?v=gDuKxrY7Rvw
http://tesi.cab.unipd.it/49688/1/Manzetti_Giulia_1061217.pdf
https://ccmc.gsfc.nasa.gov/RoR_WWW/SWREDI/2015/SatDrag_YZheng_060415.p
https://ntrs.nasa.gov/search.jsp?R=19730018598
https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/19730018164.pdf
https://pdfs.semanticscholar.org/f276/ee10558a64b9f43d656d4f706e960d7402dc.pdf
http://www3.ogs.trieste.it/bgta/pdf/bgta40.3.4_TOUBOUL.pdf

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