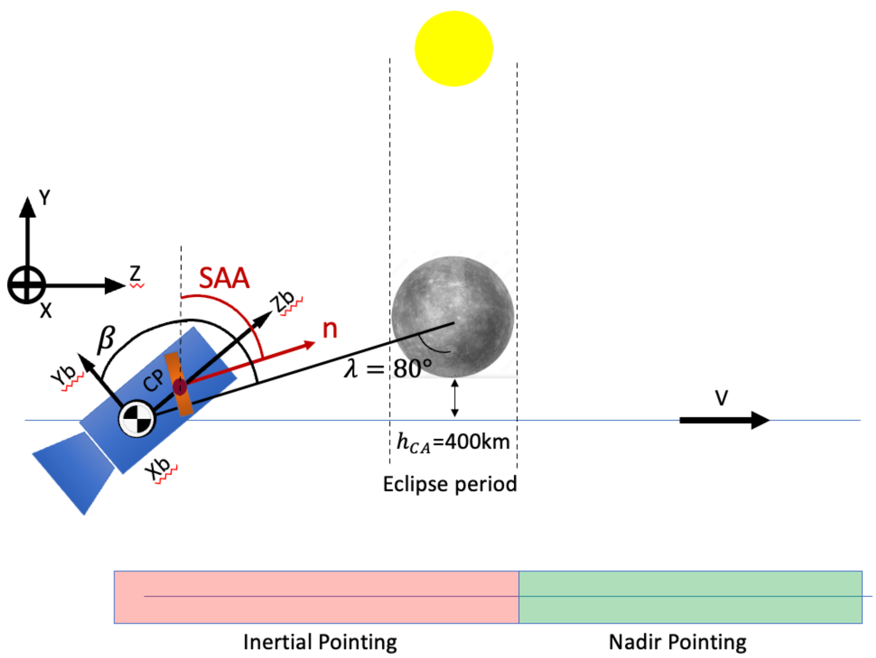
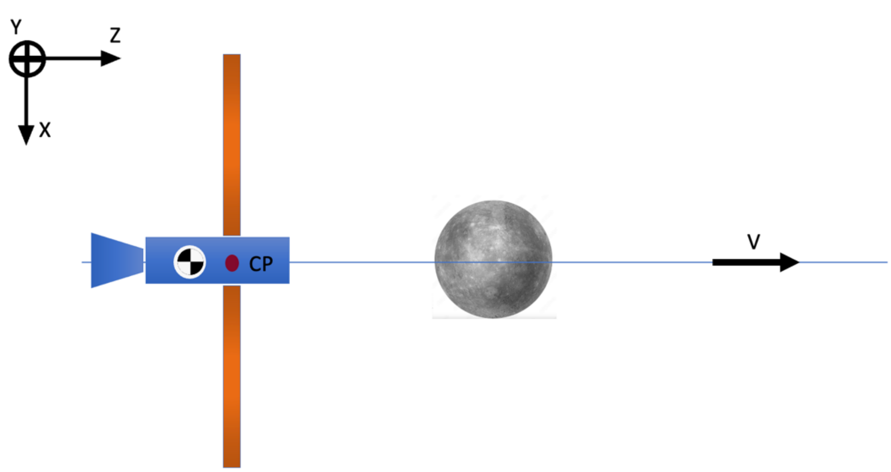
Space Missions and Systems 2022:
Homework #2

BepiColombo is an ESA-JAXA mission launched in the October 2018. In October 2021, the spacecraft performed its first flyby around Mercury, when the planet was at 0.387 AU from the Sun.
For simplicity, suppose that the motion of the probe relative to Mercury during the flyby is rectilinear and uniform with a constant speed of 7.7 km/s (positive along the Z-axis, null other directions). The distance at closest approach, h_{CA}, is 400 km. The angle, λ, between the spacecraft position with respect to Mercury at closest approach and the spacecraft position with respect to Mercury at time t_0 = 0 s is 80 deg. During the flyby, BepiColombo enters in eclipse with Mercury. Consider the spacecraft in eclipse when the distance from the closest approach point is smaller than the Mercury radius, i.e., when the spacecraft is behind Mercury. The flyby geometry is shown in the figures below.





Before the flyby, the attitude of BepiColombo is quasi-inertial and the spacecraft is not rotating. The rotation angles between the body fixed reference frame [Xb, Yb, Zb] and the inertial reference frame [X, Y, Z] are respectively: $[\theta, \psi, \varphi]$ = [40.60083, 0, 0] deg. The spacecraft has two solar panels along the Xb-axis (represented in orange in the picture). The total solar panel area is 42 m^2 and they are exposed to the Sun with a constant solar aspect angle (SAA) of 75 deg ($\hat{n}$ is the normal to the solar panel). The center of pressure (CP) is 2 m away from the center of mass along the positive Zb-axis, thus the spacecraft is subject to a torque produced by the solar radiation pressure along the X-axis. Assume that the spacecraft bus does not produce any torque.
Suppose that the spacecraft control system for the X-axis is composed of one reaction wheel oriented along the positive X-axis and a total of four 10N thrusters, located at 1 m from the X-axis. Consider that the thrusters provide pulses for a minimum time of 0.01 s.

The desired attitude of the spacecraft is: $[\theta, \psi, \varphi]$ = [40.6000, 0, 0] deg, with a pointing requirement of 1 arcsec.

1) Evaluate and report the magnitude of the disturbance torques that could affect the spacecraft attitude.
2) Design a control law that brings the spacecraft to the desired attitude in no more than 30 s and maintains the desired pointing also during the eclipse period (report the eclipse begin and end time with respect to t_0). Comment your choice and results providing all the significant plot with a zoom in significant time periods (angle error, control torque, wheel angular speed, currents and power).

Immediately after the eclipse, the science team requested the spacecraft to be nadir pointed (i.e, the BepiColombo Yb-axis must point towards the center of Mercury).

3) Control the spacecraft attitude to satisfy the nadir pointing request with an error less than 1°. Comment your choice and results providing all the significant plots. Can the reaction wheel alone perform this maneuver? Maintain the nadir pointing until the wheel reaches saturation.
4) Perform the desaturation maneuver to maximize the interval between two subsequent maneuvers, considering a maximum pointing error of 1 deg from a new desired attitude of $[\theta, \psi, \varphi]$ = [51.5, 0, 0] deg. Compute at what time from t_0 the spacecraft must perform the first desaturation maneuver and its minimum duration (for simplicity consider only the solar pressure torque). Plot and comment the results.

It's recommended to use the same controller (same type and gain) for all mission scenarios.

Read carefully the following information:

- Solar flux at 1 AU (ϕ): 1371 W/m^2
- Mercury radius: 2439.7 km
- GM of Mercury: 22032 km^3/s^2

- Solar panel reflectivity coefficients: Cs specular 0.3, Cd diffuse = 0
- Spacecraft moment of inertia: [8817, 26609, 26971] kg m^2
- Wheel moment of inertia: 0.054 kg m^2
- Wheel maximum angular speed: $\pm$4000 rpm (revolutions per minute)
- Wheel maximum torque: $\pm$0.211 Nm
- Wheel initial angular velocity: 3000 rpm

Remember that:

The electric equations of the reaction wheel are:

$$i_{W=}\frac{T_C}{K_M}$$
$$P_W = V_M i_W = (K_W \omega_W + R i_W) i_W$$

K_M = 0.118 Nm/A, K_W = 0.003 V/rpm, R = 1.2 Ω; Pmax = 29 W.

The solar radiation pressure can be modelled as follows:

$$\vec{F}_{SRP} = -\frac{\phi}{c}\left(\frac{1AU}{R_{BEPI}}\right)^2 A\hat{n} \cdot \hat{s}\big((1 - C_s)\hat{s} + 2C_s(\hat{n} \cdot \hat{s})\hat{n}\big)$$

$\hat{s}$ is the Sun direction, $\hat{n}$ is the normal to the solar panels. The angle between $\hat{s}$ and $\hat{n}$ is the solar aspect angle.

The Gravity Gradient torque along the controlled axis can be modeled as follows:

$$G_x = \frac{3}{2}\frac{GM_{MER}}{R^3}\left(I_z - I_y\right)\sin(2\beta)\cos\left(\varphi\right)$$

Where R is the distance from the planet and β is the angle between Yb and the radial direction.

Consider the dynamic of the spacecraft attitude as uncoupled.

Upload on Google Classroom a zip folder containing a working computer code printing and plotting the relevant results (MATLAB is recommended) and a **comprehensive and short** note (a pdf file **outside the zip folder**) containing **ALL** the relevant mathematical procedure, results, comments, tables and figures by Monday 16 May 23:59.

Only questions pertaining to the text published on Classroom will be answered.