AERO0036 SPACECRAFT CONTROL

PROJECT DESCRIPTION

SCOPE

This document describes the problem proposed to the student of class AERO036, spacecraft control for year 2023-2024 Master 1, aerospace engineering – second session.

This project shall be realized per group of 2, 3 or 4 students.

CONTEXT

Mandalor is under attack by empire. There are still a few he Kom'rk-class fighter ships ready but most Mandalorian are fighting on ground with jetpacks. They need to be equipped with auto-pilots!

Kom'rk-class fighter- lean configuration

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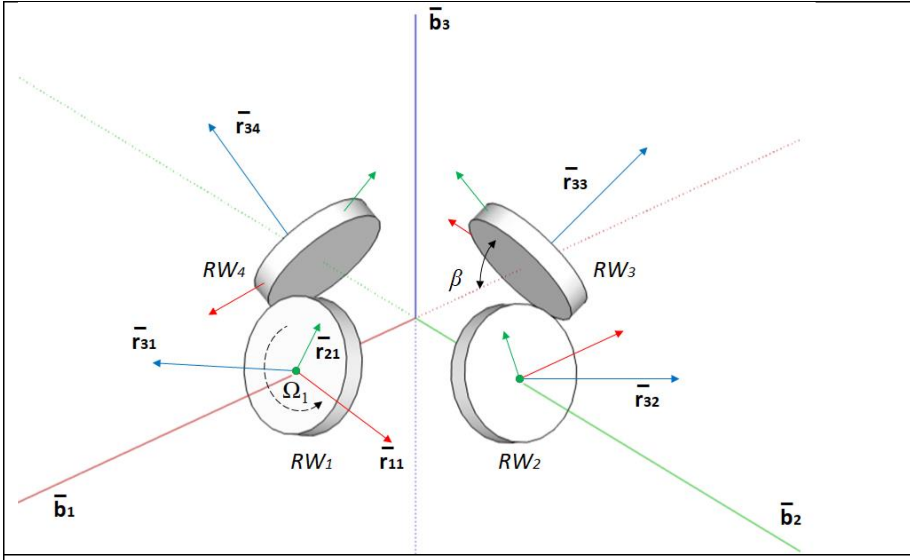
You are part of the team, responsible for the guidance, navigation & control. Your mission is to develop the necessary controllers allowing the ship to maneuver quickly around Astro-cruiser and tie fighters.

The spacecraft shall be 3-axis stabilized. You have the following technologies available in the rebellion hangar:

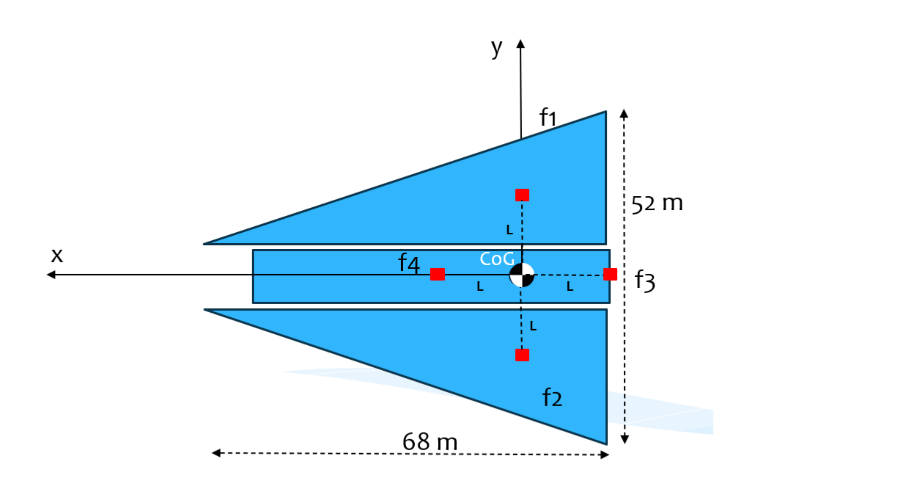
- Reaction wheels (RW) accommodated in a pyramid configuration. A RW cluster is defined a group of 4x RW (RW_1, RW_2, RW_3, RW_4), mounted on the faces of a pyramid characterized by an angle **β**, as depicted below.

- Reaction jet thrusters set (multiple pairs of thrusters) that you can accommodate at the sides of vehicle (thrust vector along the z-axis) as depicted below.

<table>
<tr>
<td>
</td>
<td>b_1, b_2, b_3 are the body reference frame unit vectors.

r_{1k}, r_{2k}, r_{3k} are the rotor axis unit vectors of the reaction wheel "k"

β is the elevation angle of the pyramid

Ω_k is rotation speed of the reaction wheel "k"</td>
</tr>
<tr>
<td>
</td>
<td>f_1, f_2, are the thrusters mounted on the sides

Pitch motion is created by actuating f3 & f4 together in opposite orientation

Roll motion is created by actuating f1 & f2 together in opposite orientation

L = 13 meter</td>
</tr>
</table>

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PROBLEM

The chief engineer gives you're the following requirements to work with:

- The ship shall be able to change its orientation of 90 degrees in roll (+x) in 5 seconds with maximum 20% percentage overshoot and being fully stabilized (i.e. settling time) with a pointing accuracy of 10%.
- The ship shall be able to change its orientation of 30 degrees in pitch (+y) in 2.5 seconds with maximum overshoot of 5% and with maximum error of 2 degree.
- When its shield is hit by a laser → yaw (+z) torque of 4 kNm for 0.5 seconds. The ship shall be able to recover its initial orientation within 5 seconds with a pointing accuracy of 5%.

Your are free to use any technology you'd like to achieve the objective, one or multiple. Yet there are limitations. The initial structure of the ship impose an inertia of

- 1,000,000 kg m² along X and Y
- 2,000,000 kg m² along Z

The mass of the ship is 30 tons (without your design). The Chief engineer let you know that your design shall be able to comply with the following mass & power requirements

- Mass of your subsystem < 5 ton (**incl. all hardware + fuel for 25 maneuvers or each axis)**
- Max Power of your subsystem < 0.75 MW (with max voltage < 100kV)

In your quality of Control Engineer, you shall propose a controller meeting the above time domain specifications while maximizing the phase & gain margins to insure as much robustness as possible.

Additional information:

- Beta angle of 63.4 deg.
- Wheels have a maximum speed of 7000 RPM
- Wheel motor have an internal resistance of 50 Ohm.
- Wheel motor has torque constant of 1 Nm/A
- Wheel bearings & lubricant have a damping factor of 1e-4 Nm/(rad/s)

- Thruster offers 1kN thrust.
- When firing, each reaction jet thruster burns 50 kg of fuel / second (i.e. 100kg/sec when opposite thrusters are fired at once)
- Thruster mass = 1 ton

Should you use RW, you are invited to propose wheel dimensions (diameter & thickness of a full cylinder, stainless steel of density 8,000 kg/m³ and thus compute the inertia of such wheel) and required by your chief engineer to write the requirement on bus voltage to allow your wheels to deliver their torque (i.e. identify the maximum voltage your need to operate your wheels). Remember that the higher the voltage, the more difficult it is for the electrical engineers to propose a design.

With propulsion, you shall propose a tank size (diameter of a sphere) knowing that the thickness of the tank needs to be 20mm. Tank material density 8,000 kg/m³ and the fuel density = 1 kg/dm³.

Last remarks = all your design shall remain smaller than the ship dimensions.

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HINT

Because you are new at Rebellion, your chief engineer gives you some hints on where to start

- First, compute the minimum torque and momentum you need in pitch, roll and yaw to cover your needs.
    - Draw the satellite momentum profile H(t) and the torque profile
    - (if using wheels) compute the initial current & voltage required at t = 0
- Use the angular momentum conservation equations (provided in annex) to provide the state-space representation in roll, pitch and yaw.
- Propose LQR controllers (i.e. matrix K) that meet your requirements.
- Propose a Lead, Lag, or Lead/lag control (i.e. expression of transfer function) that meet your requirements (using SISO tool to size your controller). Note that SISO tool is single input, hence, choose your input/output appropriately. Example: the difference of input voltage between wheel 1 & wheel 3
- Compare the LQR & PID phase & gain margins.
- Draw a Simulink model using the closed loop transfer function that output the states and verify that your maneuver can be done within the requirements.

Note: if at any point your controller is not able to meet the requirement or you find any difficulties meeting the requirements, please feel free to propose new requirements that you can meet. It is always better to propose a design that works instead of no design at all.

REPORTING REQUIREMENTS

In order to limit the reporting work, you need to respect the following constraints.

1. Report shall be maximum 20 pages long
2. Report shall NOT include the equations development, only the final step (equation modelled)
3. Report shall focus on explaining:
    a. Your assumptions (incl. what you changed + why)
    b. Your method of design (e.g. how you sized your control)
    c. Your results and the physics behind them
    d. Your conclusion, remarks, explanations on the requirements (if you changed them) and/or if you opted for different technologies/performances than the one proposed.
4. Report shall include the Matlab code and/or Simulink model and/or Python as annex files, both being commented so that the reviewer could easily run it on its own machine.
5. Report shall be submitted to Julien.tallineau@veowarespace.com by the **6th of September 2024, 09:00 PM at latest**.

ANNEX

See power point.