UNIVERSITY OF LEICESTER

School of Engineering

EG7040/EG4323 Coursework brief

Module Title Attitude and Orbit Control Systems	Individual	Semester 2 **Jan/May**	Module Code EG7040/EG4323
Coursework Title (e.g. CWK1) Modelling and simulation of spacecraft attitude dynamics and control			Hand out date: 26/01/2024
Lecturer Nadjim Horri			Due date: **27/03/2024** Online submission
Estimated Time (hrs): Word Limit*: 3000 words (not including figures, tables, etc)	Coursework type: Technical Report (Individual)		Weighting: 50% of the module mark
Turnitin Assignment to be submitted online via Blackboard: File types and method of recording: PDF (preferred) or MS WORD Mark and Feedback date: 14/04/2024 Mark and Feedback method: Electronic, via Turnitin document feedback summary			

Module Learning Outcomes Assessed in this assignment:

1. Calculate key operating parameters for AOCS using mathematical models and software packages based on fundamental scientific principles, assessing the effect of changing these on the system performance.
2. Simulate and design AOCS systems and components.
3. Extract pertinent data from appropriate sources and consider relevant industrial and commercial constraints in the design of AOCS systems.

Task and Mark distribution:

An attitude control system for a small Earth observation satellite required to be sufficiently agile to perform a manoeuvre requirement allowing for longitudinal stereoscopy on a circular orbit with an altitude in Km to be generated by running the file **randgenerator_AltitudePitch.m** once. The satellite is equipped with three orthogonal reaction wheels, three orthogonal magnetic torques and three control torques are also available from the thrusters reaction control system. Satellite mass is 150 kg.
The moments of inertia of the satellite are: $I_{xx} = 19.5\ \text{kg.m}^2, Iyy = 19\ \text{kg.m}^2\ , Izz = 12.6\ \text{kg.m}^2$

Perfect attitude measurements are assumed in this assignment. MATLAB/Simulink support files are provided in the folder **CW_MatlabSimulinkFiles.zip** and will have to be modified with the correct parameters and functions to answer the below questions. The file **SC_Model_Par.m** is the initialisation script to be run before the main Simulink model **SC_Model_Sim_w3.slx** to be used for questions 2, 3 and 4. For question 4 only, the file **DisturbanceTorques.mdl** includes simplified disturbance torque models including the aerodynamic and magnetic disturbance torques, that will need to be modified and integrated with the satellite dynamics.

Question 1 (10%): Reaction wheel Sizing

All 3 reaction wheels are assumed to be identical. A flat Earth approximation can be assumed during stereoscopic imaging. The pitch wheel is required to allow for longitudinal stereoscopy (a mission requirement for commercial considerations), with the minimal capability to keep pointing at a target imaging location on the ground during a manoeuvre from N degrees to -N degrees.

- Determine the required maximum pitch rate. Generate the desired pitch N using the file **randgenerator_AltitudePitch.m**
- Determine the required maximum wheel torque capability to perform this manoeuvre, assuming a bang-bang pitch manoeuvre.

In answering both questions, explain your reasoning.

Question 2 (30%) : Detumbling simulation analysis
Assuming any initial angular rate between 0.1 and 0.2 rad/s on all 3 axes and that maximum torque is 0.05 Nm for the thrusters and a maximum magnetic dipole moment of 20 $A.m^2$ for the magnetic torquers:

- Design a controller using thrusters to detumble the spacecraft on all three axes to 0 rad. s^{-1} and evaluate the effect of controller parameters on the detumbling rapidity, accuracy and energy consumption, using Matlab/Simulink based numerical simulations. Evaluate and discuss the implications for the fuel consumption assuming a fuel mass of 10 kg and an Isp of 200 seconds.
- Design and evaluate the performance of a magnetic torquing-based controller for satellite detumbling (eg. cross product law) to bring the angular velocities to:

$$\omega_x = \omega_y = \omega_z = 0 \text{ rad. s}^{-1}$$

Question 3 (30%): Attitude control simulation analysis

- Single axis manoeuvre analysis: Using the eigenaxis rotation principle for pitch stabilising control, design a PD quaternion feedback controller to achieve a suitable underdamped response (select the damping ratio) and for a range of student selected natural frequencies and initial conditions between 5 and 20 degree pitch. Evaluate the effect of parameter tuning on control performance in terms of settling time and energy consumption. Assume zero initial roll and yaw angles.
- Three axis control analysis: Using a trial and error based parameter effect analysis, tune a PD quaternion feedback controller for a 3-axis attitude stabilisation manoeuvre for a manoeuvre from 30 degrees on all 3 axes to zero, then for a manoeuvre from 0 to 30 degrees on all 3 axes.

Question 4 (20%): Analysis of external disturbance torques effects

- Add the aerodynamic and magnetic disturbance torques to the MATLAB/SIMULINK model. Assume a box-like shape of approximate dimensions: 0.78 m x 0.938 m x 1.17 m and take CD =2 and a residual magnetic disturbance of 1 Am^2.
- Evaluate short (manoeuvre time frame) and longer term (a few orbits) impacts of external disturbances on the control performance in terms of energy consumption and attitude control accuracy. Discuss control system robustness and how it could be improved.

Note: Any additional parameters (eg. arm lengths) not specified in this coursework brief will be chosen by the student after researching a realistic range of values for this class of satellite.

Report structure and presentation (10%):

A **3000 words** technical report (font size 11 will be used for the main text, font size 14 for main sections and size 12 for any subsections if applicable).

Submission is to be made through the Turnitin submission link on Blackboard.

The report structure should include:

- a summary (of the work done and main findings from the analysis)
- a table of contents down to subsection level (students will suggest their organisation of sections into subsections)

- one section per question,
- A general conclusion about the stability and performance of the different control modes (detumbling, 3-axis), disturbance effects and the challenges to implement a robust multimode attitude control system.
- **APA or Harvard referencing** will be used.

The word count excludes any figures or tables used by students to aid the explanation or to illustrate results.
Students are asked not to re-write the questions to avoid unintended plagiarism detection.
Students will use their own words and own analysis and ensure that they avoid any form of plagiarism (see notes at the end of this document)

Marking scheme

	Report presentation (10 marks)	**Question 1 (10 marks)**	**Question 2 (30 marks)**	**Question 3 (30 marks)**	**Question 4 (20 marks)**
20%-35%	Poor report writing, no apparent structure, no apparent organisation, no referencing, serious readability issues.	A lack of understanding of concepts of orbit design, and AOCS requirements and reaction wheel sizing are not understood and not used.	Weak understanding of detumbling control. None of the correct models, results or analysis are provided or they are fundamentally wrong.	Weak understanding of attitude control. None of the correct models, results or analysis are provided or they are fundamentally wrong.	The perturbation models are not implemented and interfaced correctly and the analysis shows a weak understanding of the modelling, simulation and performance impacts of disturbances
42%-45%-48%	Report is readable. The structure and logical order is present but can be improved, organisation is present but can be improved, parts like table of contents or references may be missing or	The fundamentals of orbit design, AOCS requirements and reaction wheels sizing are mostly understood. Some aspects of the mathematical models and	The basic fundamentals of detumbling are understood, some of the correct equations are provided but not effectively used in the simulations. Little justification of	The basic fundamentals of attitude control are understood, some of the correct equations are provided, but not effectively used. Little justification of the control design. Significant parts	The main fundamentals of the disturbance modelling and impacts are understood and partly implemented but some of the results are inconsistent with the

	not in a recognised format.	their application are present but significant errors are present.	the control design. Significant simulation errors. Little analysis of the results	of the simulation results are incorrect, with little analysis of the results.	theory, with little analysis of the results.
52%-55%-58%	The report is readable and structured, the logical order and structure are complete, but presentation lacks accuracy about references, figures not clearly labelled and presented, equations may be hard to read or need formatting.	The fundamentals of orbit design, AOCS requirements and reaction wheel sizing are well understood, but there are some issues of correctness and accuracy in the simulation, results and analysis.	The fundamentals of detumbling control are mostly well understood, but there are some issues of correctness and accuracy in the simulation, results and analysis. Results and simulations are partly correct, but with limited results analysis.	The fundamentals of attitude control are mostly well understood, but there are some issues of correctness and accuracy in the simulation, results and analysis. Results and simulations are partly correct, but with limited results analysis.	The main fundamentals of disturbance modelling and impacts are mostly well understood, but there are issues of correctness and accuracy in the simulation, results and analysis. Results and simulations are partly correct, but with limited results analysis.
62%-65%-68%	The report is easy to read and follow, generally consistent formatting, logical order, structure is complete, presentation may lack accuracy about references, figures centred with titles but may not be clearly	Good understanding of the fundamentals and competent modelling and simulation of the orbit design, AOCS requirements and reaction wheel sizing. There is some room for improvement in explaining the reasoning or in	Good understanding of the purpose and fundamentals and competent modelling and simulation of the detumbling control. There is some room for improvement in explaining the reasoning or in the results presentation.	Good understanding of the purpose and fundamentals and competent modelling and simulation of the attitude control. There is some room for improvement in explaining the reasoning or in the results presentation.	Good understanding of the disturbance models and effects and competent modelling and simulation of the those external disturbances and their impact on performance. There is some room for

	labelled/ presented, equations may be hard to read or need formatting.	the results presentation.			improvement in explaining the reasoning or in the results presentation.
72%-75%-78%	The report is very readable and very well structured. Consistent formatting. Logical order, structure is clear and complete. Equations and figures labelled, well presented and centred. Lack of accuracy in referencing or otherwise is rare.	Excellent understanding of the fundamentals and competent modelling and simulation of the orbit design, AOCS requirements and reaction wheel sizing. Detailed results analysis and good results discussion is provided, with some good elements of critical analysis.	Excellent understanding of the fundamentals and competent modelling and simulation of the detumbling control. Detailed results analysis and good results discussion is provided, with some good elements of critical analysis.	Excellent understanding of the fundamentals and competent modelling and simulation of the attitude control. Detailed results analysis and good results discussion is provided, with some good elements of critical analysis.	Good understanding of the disturbance models and effects and competent modelling and simulation of the those external disturbances and their impact on performance. There are some good elements of critical analysis.
82%-85%-88%	Professional report writing standards from the summary to the table of contents to the presentation and referencing, consistent formatting, no meaningful report writing weaknesses.	Excellent and deep understanding of the fundamentals of orbit design and AOCS requirements in the context of reaction wheel sizing rigorous modelling and simulation analysis results presentation and critical thinking.	Excellent and deep understanding of the fundamentals and advanced modelling and simulation analysis of detumbling control including the impacts on performance Excellent methodology, results presentation and critical thinking.	Excellent and deep understanding of the fundamentals and advanced modelling and simulation analysis of attitude control including the impacts on performance Excellent methodology, results presentation and critical thinking.	Excellent and deep understanding of the disturbance models including the impacts on performance Excellent methodology, results presentation and critical thinking.

90%-100%	Answer cannot be improved	Answer cannot be improved	Answer cannot be improved	Answer cannot be improved	Answer cannot be improved

Notes:
This is an individual coursework. While exchanging advice about use of MATLAB software is welcome, it is important that the answers to the questions are your own and that any form of plagiarism (including self-plagiarism) or collusion) is avoided at all costs. When the analysis gives freedom to chose parameter values, please use that freedom to perform your own analysis with your own controller gains settings, sampling time if applicable, and also importantly, with your own words. All references used must be cited. Direct paraphrasing from a reference is not advised as we are more interested in your individual discussion and analysis.