SEMESTER 1 ASSESSMENT PAPER 2020/21

TITLE: **SPACECRAFT SYSTEMS ENGINEERING AND DESIGN**

DURATION – 24 hours

This paper contains **FOUR** questions.

Attempt all **FOUR** questions. Your answer to each question attempted should commence on a new page and be appropriately numbered.

All Questions are worth 25 marks (total 100 marks). An outline marking scheme is shown in brackets to the right of each question. Note that marks will only be awarded when appropriate working is given.

Your answers should be handwritten, unless you have a statement of additional examination requirements (AERs) approved by Enabling Services which specifies that you may type your answer.

You will need to be in a quiet space for the duration of your final assessment with no interruptions. You will need to check all your equipment to ensure that they are set up correctly.

This final assessment is recommended to take **approximately 4 hours of working time**. You are advised to allocate your time accordingly. Your answer file may be submitted at any time before the due time. Please allow time to complete the submission process.

Calculations should be done accurately, using a spreadsheet or similar such as Python and Matlab. It should be clearly stated when such a tool has been used.

It should provide explanations for every answer and indicate the unit(s) used in **ALL** calculations. All numeric answers should be provided with **FOUR** significant figures.

Results from the lecture material (anything on the Blackboard module site) can be used wherever needed. Any resources accessed from the internet must be properly cited.

Q1. A Visible/Near-Infrared imaging instrument is being used for a remote sensing mission to measure ocean currents. The satellite is in a circular orbit at an altitude of 746 km and the instrument scans the Earth's surface using a push-broom scanning approach. The instrument uses a linear CCD sensor with 14000 pixels, with an inter-detector spacing of 10 μm. The optical system of the instrument has a focal length of 20 cm. The radiometric resolution of the instrument is 8 bits.

Answer the following questions. Provide explanations for every answer and indicate the unit(s) used in **ALL** your calculations.

(i) Calculate the cross-track spatial resolution of the instrument.

[3 marks]

(ii) How many discrete Digital Numbers can be used to represent the reflectance of each pixel?

[2 marks]

(iii) Calculate the Field of View (FOV) and the swath width of the instrument.

[5 marks]

(iv) Find the uncompressed data rate which makes the in-track and cross-track spatial resolutions of the instrument to be the same.

[9 marks]

(v) A second objective of this remote sensing mission is to provide centimetre-precision, sea surface height data. Identify an appropriate instrument for this objective, explain why it is required, and comment on the likely impacts for the spacecraft subsystems.

[6 marks]

[Q1: Total 25 marks]

Q2. Use the given information to answer questions (i) and (ii). Indicate the unit(s) used in **ALL** your calculations

(i) A communications satellite in geostationary Earth orbit with zero eccentricity has a cross-sectional area of 20 m^2 and a dry mass of 4,000 kg. The solar radiation pressure coefficient of this communication satellite is 1.2. When it reaches the end of its life, it will be moved to a disposal orbit in compliance with the IADC space debris mitigation guidelines.

a) Calculate the semi-major axis of the disposal orbit for this satellite assuming that the final eccentricity is equal to the maximum value allowed in the guideline.

[4 marks]

b) Using a series of sketches, describe what manoeuvres would be required to achieve this disposal orbit.

[4 marks]

c) Calculate the required ΔV for the post-mission disposal of this communication satellite.

[8 marks]

(ii) A 1,500 kg remote sensing satellite is in a circular, sun-synchronous orbit at an altitude of 1,000 km when it reaches the end of its mission. 100 kg of propellant is remaining at the end of the mission, which is one-third of total propellant mass at launch. The satellite has 6 × 10 N hydrazine thrusters with a specific impulse of 180 seconds for orbit control. The cross-sectional area of the satellite is 1.5 m^2, and the drag coefficient of the satellite is 2.5.

Q2. Cont…

TURN OVER

Q2. Cont…

The remaining orbital lifetime in seconds of a satellite with mass m, cross-sectional area A and drag coefficient C_D on a circular low Earth orbit with semi-major axis *a* can be estimated using

$$t_L = \frac{H \cdot \tau \cdot B}{2000\pi a^2 \rho}$$

where *H* is the density scale height in m, τ is the orbit period (in seconds), ρ is the atmospheric mass density, a is a semi-major axis in m, and B is the satellite ballistic coefficient. For a density scale height *H* = 266 km and an atmospheric mass density ρ = 2.54×10^{-15} kg/m^3, answer the following questions.

a) Calculate the ΔV required to comply with the IADC space debris mitigation guidelines by lowering its perigee.

[7 marks]

b) Determine whether this remote sensing satellite meets the IADC space debris mitigation guidelines for the post-mission disposal of objects passing through LEO.

[2 marks]

[Q2: Total 25 marks]

Q3. Use the given information to answer the following questions (i) - (iii). Indicate the unit(s) used in **ALL** your calculations.

(i) An engineer tests an optical instrument for a Mars rover to determine if it will withstand the dust environment on the surface of the planet. For each characteristic below, say whether it can be considered to be a design parameter or a noise factor

- Instrument housing material
- Number of dust particles per cubic metre
- Location of the instrument on the Mars rover
- Ambient temperature
- Ambient pressure
- Lens thickness
- Time of exposure to the dust environment
- Size of dust particles
- Data rate generated by the instrument

[4 marks]

(ii) An IR detector used in a space-based telescope for detecting Near Earth Asteroids uses a fluid-loop cooling system in order to maintain a suitable thermal environment for the sensor. The parameters of the cooling system are to be selected using Taguchi's method to minimise the system cost. The engineers include three noise factors at three levels (low, medium and high):

- The cost of the coolant fluid: N_1
- The temperature of the surrounding support structure: N_2
- The input temperature of recycled coolant into the pre-cooler: N_3

They also include four design parameters, which are the temperature of the coolant fluid at different points in the fluid loop T_1, T_2, T_3, and T_4 at three different levels (low temperature, nominal temperature, and high temperature). The choice of design parameters is shown in Table Q3(ii)-1

Q3. Cont…

TURN OVER

	Design parameter levels		
	1	**2**	**3**
T_1	-31 °C	-28 °C	-25 °C
T_2	-42 °C	-39 °C	-36 °C
T_3	-41 °C	-38 °C	-35 °C
T_4	-40 °C	-37 °C	-34 °C

Table Q3(ii)-1

The signal-to-noise (S/N) values are given in Table Q3(ii)-2:

	Average S/N			
Level	T_1	T_2	T_3	T_4
1	-78.72	-72.67	-75.35	-77.89
2	-77.94	-73.12	-75.30	-73.23
3	-78.04	-73.57	-75.42	-72.55

Table Q3(ii)-2

a) Find the minimum number of experiments that must be conducted.

[3 marks]

b) How many experiments would be required if a Design of Experiments approach was not used?

[3 marks]

c) Identify the optimum temperatures for the coolant fluid T_1, T_2, T_3 and T_4.

[4 marks]

d) Propose a suitable quality metric (i.e. the value that the engineers would like to minimise or maximise) and provide a justification for your answer.

[4 marks]

Q3. Cont…

Q3. Cont…

(iii) A small satellite is providing images of the Earth from a dawn-dusk Sun-synchronous orbit at 1AU and with its long axis aligned with the local vertical. It uses body-mounted solar arrays mounted on the largest faces of the satellite to generate electrical power. The delivered power at the end of life can be estimated as:

$$P_{EOL} = S\eta\eta_p(1 - D)A_n$$

where S is the solar flux, η is the solar cell efficiency, η_p is the cell packing efficiency, D is the degradation factor and A_n is the effective surface area of the solar array. The properties of the solar array used in the satellite are listed as:

Average solar cell efficiency	27.5%
Degradation factor of a solar cell	0.15
Solar cell packing efficiency	85%

The effective surface area of the solar array is a function of both in-plane angle of the Sun and the out-of-plane angle as:

$$A_n = ab\cos\theta\,(\cos\phi + \sin\phi)$$

where a is the length of the longest side of the satellite, b is the length of the shortest side, ϕ is the in-plane angle of the Sun, and θ is the out-of-plane angle.

As the baseline design for body-mounted solar arrays, the science-derived pointing requirement means that the solar panels will not always be normal to the Sun, causing a reduction in the performance proportional to the cosine of the angle between the solar array normal vector and the vector to the Sun. Concerns have been raised regarding the variation that may occur in the power delivered from the solar arrays as the operating environment changes.

Q3. Cont…

TURN OVER

Q3. Cont…

a) Propose two design parameters and two noise factors.

[4 marks]

b) Identify one subsystem of this spacecraft, other than the power subsystem, that will have a strong influence on the choice of solar array configuration and explain your choice.

[3 marks]

[Q3: Total 25 marks]

Q4. Use the given information to answer the following questions (i) and (ii). Indicate the unit(s) used in **ALL** your calculations.

(i) A civilian airline operating long-haul flights from Europe to North America and Asia aims to provide its passengers with in-flight internet connectivity using a space-based system.

a) Compare and contrast two orbit options for this system by discussing at least **FOUR** set of advantages and disadvantages.

[8 marks]

b) Assume that the coverage area of each satellite just touches the coverage area of the nearest Easterly or Westerly satellite at the Equator, the region to be served spans from 130° West to 130° East longitude, and the minimum acceptable elevation at the edge of coverage is 50°. Calculate the number of satellites in Geostationary orbits that are required to deliver the in-flight internet service described.

[5 marks]

(ii) The company Space-Y plans to operate a constellation of small-satellites to provide future global data communication services on Mars. The constellation of 1200 satellites will be arranged in 20 circular orbital planes inclined at 89° and at altitude of 750km.

a) Assume an elevation angle is 45 degrees. Calculate the slant range at the edge of the coverage area.

[4 marks]

Q4. Cont…

TURN OVER

b) Assume the ground-based antenna is at the edge of the coverage area. Calculate the latency for a four-way “hop”.

[2 marks]

c) Identify three key design drivers that might have led to the selection of the altitude for the constellation; rank them according to importance, and justify your choice.

[6 marks]

[Q4: Total 25 marks]

END OF PAPER

