UNIVERSITY OF SOUTHAMPTON SESA3041W1

SEMESTER 1 FINAL ASSESSMENT 2022/23

TITLE: **Spacecraft Systems Engineering and Design**

DURATION: 120 MINS

This paper contains **FOUR** questions.

Answer All **FOUR** questions on this paper.

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.

The following will be provided on request:

1. An Engineering Data Book by Calvert and Farrar
2. Graph paper

Note that The Astro Equation booklet is provided separately

Only University approved calculators may be used.

A foreign language direct 'Word to Word' translation dictionary (paper version ONLY) is permitted, provided it contains no notes, additions or annotations.

Q1. Use the given information to answer questions (i) and (ii).

(i) A telecommunication satellite in geostationary Earth orbit with zero eccentricity has a cross-sectional area of 55 m^2 and a dry mass of 3,500 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. It uses a mono-propellant hydrazine thruster for both station keeping and post-mission disposal, which provides a thrust about 20N at a specific impulse of 242 seconds.

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

[3 marks]

b) Assume that this satellite uses approximately 25 kg of propellant annually for station keeping. This satellite has initially 300 kg of hydrazine for its mono-propellant hydrazine thruster. Estimate the maximum operational time of the satellite in compliance with the IADC space debris mitigation guidelines. Give your answer in years.

[10 marks]

Q1. Cont…

Q1. Cont…

(ii) PAD-B (Plasma-thruster-based Automated Deorbiting-Block system) is a variant of a vacuum arc thruster used for shortening a spacecraft's orbital lifetime or enable controlled re-entry and safe recovery of 1U and 2U CubeSats. The total system mass of the PAD-B is 200 g including 110 g of metallic propellants. It provides a thrust of about 15 μN at a specific impulse of 350 seconds. The drag coefficient of a 1U CubeSat is 2.2, and its maximum cross-sectional area is 100 cm^2. The remaining orbital lifetime in seconds of a CubeSat 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

$$t_L = \frac{H \cdot \tau \cdot B}{2000\pi a^2 \rho} \qquad \textbf{(Equation Q1-ii-a)}$$

where *H* is the density scale height in m, τ is the orbit period (in seconds), ρ is the atmospheric mass density, a is the semi-major axis in m, and B is the satellite ballistic coefficient in kg/m^2. Use a density scale height of *H* = 266 km and an atmospheric mass density $\rho = 3.54 \times 10^{-16}$ kg/m^3.

Assume the mass of 1U CubeSat (without PAD-B) is 1.2 kg. Use the given information to answer the following questions.

a) Calculate the maximum altitude of 1U CubeSat without using PAD-B while complying with the IADC space debris mitigation guidelines. Give your answer in km.

[4 marks]

b) Assume PAD-B can apply ΔV instantaneously. Calculate the maximum altitude of a 1U CubeSat with using PAD-B while complying with the IADC space debris mitigation guidelines. Give your answer in km.

[8 marks]

[Total 25 marks]

TURN OVER

Q2. A 1,200 kg remote sensing satellite including 300 kg of propellant is in a Sun-synchronous circular orbit at an altitude of 650 km and inclination of 97.85°. This satellite has an advanced hyperspectral instrument for monitoring natural resources and atmospheric characteristics, including information on land cover and crop status, pollution quality of inland waters, soil mixture and carbon cycle. The design of the advanced hyperspectral instrument is based on a pushbroom scanning approach providing hyperspectral imagery of 250 bands at a spatial resolution of 25 m on a swath width of 30 km. Data quantisation of multispectral images is 12-bits with a spatial sample rate of 25 μm.

Answer the following questions.

(i) Calculate the instantaneous field of view of the instrument in μrad.

[2 marks]

(ii) Calculate the focal length of the instrument in mm.

[2 marks]

(iii) Find the uncompressed data rate for which the in-track and cross-track spatial resolutions of the instrument are the same. Express your answer in Mbps.

[10 marks]

Q2. Cont…

Q2. Cont…

(iv) Assume that this satellite has 8 × 10 N hydrazine thrusters with a specific impulse of 180 seconds for orbit control. At the end of the mission, its perigee should be lowered to an altitude of 250 km in order to satisfy the space debris mitigation guideline of the IADC. Calculate the minimum amount of propellant to comply with the IADC space debris mitigation guidelines.

[9 marks]

(v) How many discrete digital values can be used to represent the reflectance of each pixel?

[2 marks]

[Total 25 marks]

TURN OVER

Q3. A company manufacturing an IR sensor for remote sensing satellites is having difficulty with its current yields. IR sensors are made on a large die, cut into pieces, and each one is tested to match specifications. The company has requested that you run experiments to increase processor yield. The factors that affect processor yields are temperature, pressure, doping amount, and deposition rate. **Table Q3a** shows the operating conditions for each parameter and level.

Through conducting three trials for each experiment, the performance characteristics, which need to be maximised, are obtained as the **Table Q3b**.

Using the given **Table Q3a** and **Table Q3b**, answer the following questions.

(i) Compute the S/N ratio for each experiment for the target value case.

[9 marks]

(ii) Identify the most robust design parameter combination.

[16 marks]

Q3. Cont…

Q3. Cont…

Design parameters	Description	Level 1	Level 2	Level 3
A	Temperature	100 ℃	150 ℃	200 ℃
B	Pressure	2 psi	5 psi	8 psi
C	Doping amount	4 %	6 %	8 %
D	Deposition rate	0.1 mg/s	0.2 mg/s	0.3 mg/s

Table Q3a. Design parameters and their levels.

Experiment number	Variables				Performance characteristics		
	Temperature, [℃]	Pressure, [psi]	Doping amount, [%]	Deposition rate, [mg/s]	Trial 1	Trial 2	Trial 3
1	100	2	4	0.1	87.3	82.3	70.7
2	100	5	6	0.2	74.8	70.7	63.2
3	100	8	8	0.3	56.3	54.0	45.7
4	150	2	6	0.3	79.8	78.2	62.3
5	150	5	8	0.1	77.3	76.5	54.0
6	150	8	4	0.2	89.0	87.3	83.2
7	200	2	8	0.2	64.8	62.3	55.7
8	200	5	4	0.3	99.0	93.2	87.3
9	200	8	6	0.1	75.7	74.0	63.2

Table Q3b. Performance characteristic values for conducted experiments

[Total 25 marks]

TURN OVER

Q4. Use the given information to answer questions (i) and (ii)

(i) A space-orientated service provider plans to operate a constellation of satellites to provide global internet services.

a) 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 150° West to 140° 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 24-hour internet service.

[7 marks]

b) Assume the minimum acceptable elevation at the edge of coverage is 10°, and the orbital height of the constellation is 5400 km. Calculate the number of satellites in the constellation that are required to deliver complete (24-hour) global internet service.

[6 marks]

(ii) The company Space-Z plans to operate a constellation of small-satellites to provide future global data communication services for autonomous ships. The constellation of 42 satellites will be arranged in 6 circular orbital planes inclined at 89° and at an altitude of 750 km.

a) Calculate the in-plane spacing between the satellites and the node spacing.

[4 marks]

Q4. Cont…

Q4. Cont…

b) Assume the ground-based antenna is at the edge of the coverage area**.** Calculate the latency for a four-way "hop" if the minimum acceptable elevation at the edge of coverage is 30°.

[4 marks]

c) The company Space-Z should comply with the IADC space debris mitigation guidelines Identify to maintain the sustainable use of outer space. Specify the four fundamental mitigation measures.

[4 marks]

[Total 25 marks]

END OF PAPER