SEMESTER 1 FINAL ASSESSMENT 2022/23

TITLE: **Advanced Astronautics**

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. A medium LEO satellite at an altitude of 800 km requires 7.0 kW of power for a nominal 5-year lifetime. The same satellite also requires 800 W of power to charge a secondary power system. The primary power system of this satellite uses a photovoltaic cell, and the power system of this satellite uses a peak power tracker. The minimum and maximum operating temperatures of the solar array are 301 K and 401 K, respectively.

The electrical output characteristics of the used photovoltaic cell at BOL is shown in Figures Q1a and Q1b. The temperature coefficient of the used photovoltaic cell for voltage is -2.0 $\mathrm{mV/K}$ and increase by 5% per year due to radiation. Its temperature coefficient for current is 300 $\mathrm{\mu A/K}$ with decreasing by 2% per year due to radiation. EOL degradation (5 year) for both voltage and current at maximum power is given as 90% of beginning- of-life (BOL) capacity for both voltage and current at maximum power.

Use the given information to answer the following questions.

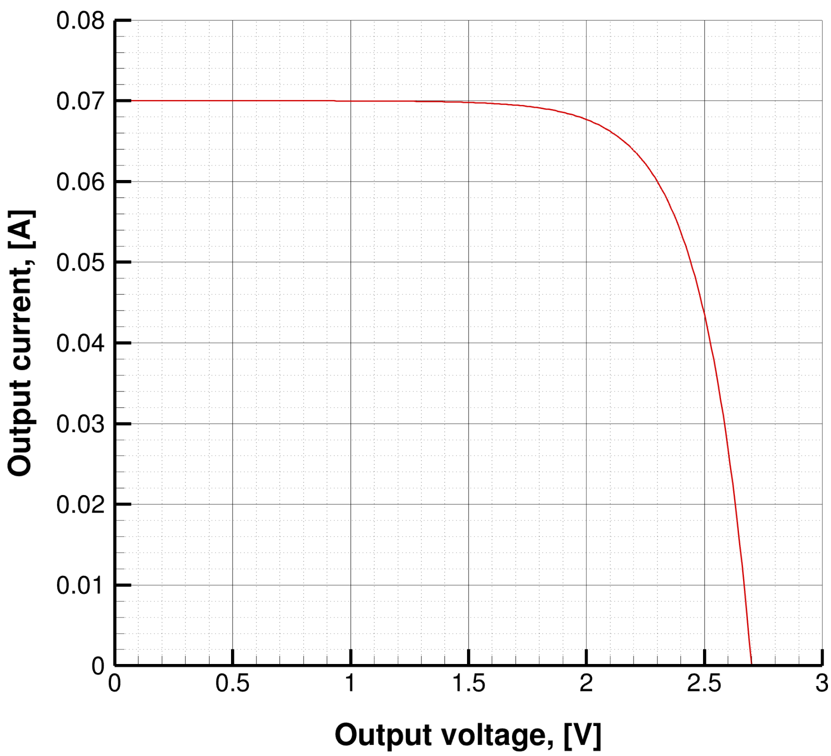

Figure Q1a. I-V curve of the used photovoltaic cell at 301 K

Q1. Cont…

Q1. Cont…

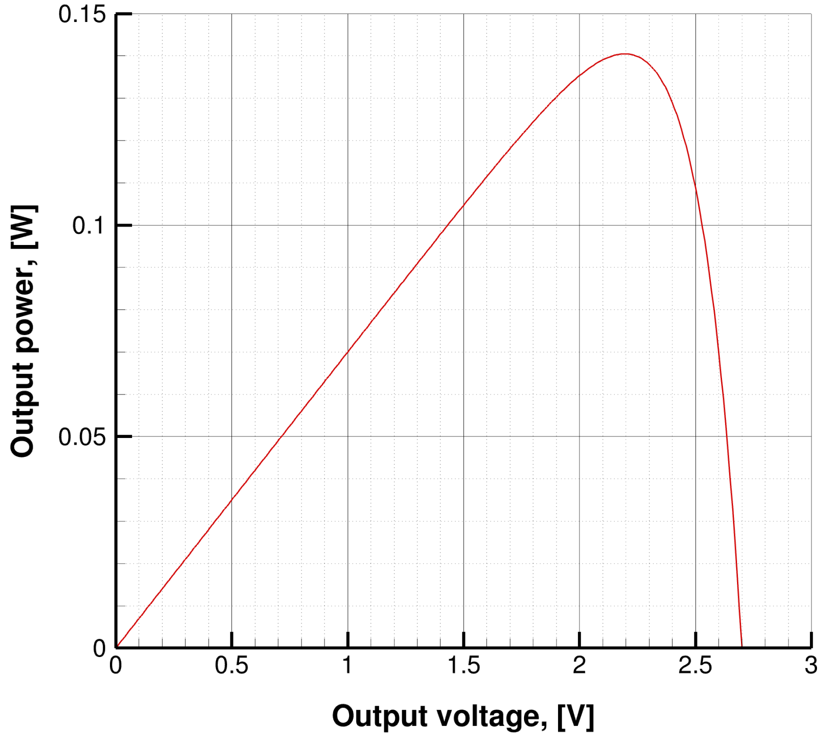

Figure Q1b. P-V curve of the used photovoltaic cell at 301 K

(i) Determine the bus voltage of this satellite and justify the selection of the satellite bus voltage.

[5 marks]

(ii) Assume that a string of the solar array needs to generate 120 V ± 1.2 V at the EOL when it is operating at maximum temperature. Determine the number of photovoltaic cells in a string and justify your answer.

[8 marks]

Q1. Cont…

TURN OVER

Q1. Cont…

(iii) Assume that a string of the solar array generates 120 V at the EOL when it is operating at maximum temperature. Calculate the minimum number of strings in the solar array to support the satellite power requirement at the maximum operating temperature during the entire mission period and justify your answer.

[7 marks]

(iv) As a first order approximation approach, the required number of solar cells can be calculated as:

$$n_{solar\ cell} = \frac{Total\ required\ power\ of\ a\ satellite\ to\ support\ the\ mission}{Power\ generated\ by\ a\ single\ solar\ cell}$$

Using the given first order approximation, estimate the expecting minimum power generated by the solar array at the BOL.

[5 marks]

[Total 25 marks]

Q2 Two directly opposed, parallel circular disks are floating in space and 0.6 m apart. The diameter of both disks is 1.2 m, and they are both shaded from the sun, albedo, and Earth IR radiation. The IR emissivity of both disks is 0.4, and one of the disks (disk A) is maintained at a temperature of 150 ℃ on both sides. The other disk (disk B) is thin and highly conductive so that the temperature on both sides is the same. The radiation view factor from disk A to disk B is 0.7176.

Use the given information to answer the following questions.

(i) Calculate the radiation view factor from disk A to space.

[5 marks]

(ii) Provide the Oppenheim network with appropriate notations.

[5 marks]

(iii) Estimate the energy input needed at disk A to maintain its temperature at 150 ℃.

[5 marks]

(iv) Calculate the temperature of disk B.

[5 marks]

(v) Explain why a white painted surface exposed to solar radiation in space will remain at a relatively low temperature.

[5 marks]

[Total 25 marks]

TURN OVER

Q3 The Foton spacecraft is an unmanned spherical re-entry capsule and re-enters in Earth's upper atmosphere with an angle of attack of -22.3 degree at the end of the mission. The structure of Foton is a sphere of 2.5 m in diameter and an entry mass of 2.2 tons. The capsule houses the scientific payload and landing parachute. It is equipped with three circular hatches, two on opposite sides for payload installation and removal, with a third hatch giving access to the parachute trunk.

From LEO, the Foton re-enters at 7.6 $\mathrm{km/s}$, and its drag coefficient is about 0.47. The capsule's aluminium-alloy structure is covered with ablative material for protection against frictional heat during re-entry. For the prediction of the air density during the re-entry, a new isothermal exponential model can be used as:

$$\rho(h) = \rho_s \cdot e^{-\frac{h}{H_g}} \qquad \text{(Equation Q3a)}$$

where $\rho_s = 1.225\ [\mathrm{kg \cdot m^{-3}}]$ and $H_g = 8435\ [\mathrm{m}]$.

Using the **given isothermal exponential model** and information of the Foton spacecraft, answer the following questions

(i) The cover of the parachute container is jettisoned, and the parachute system begins to deploy when its velocity reaches 200 $\mathrm{m/s}$. Find the corresponding altitude in km.

[5 marks]

(ii) Calculate the altitude of the Foton re-entry vehicle at which maximum deceleration occurs during atmospheric re-entry.

[5 marks]

Q3. Cont…

Q3. Cont…

(iii) Calculate the altitude of the Foton re-entry vehicle at which peak heating occurs during atmospheric re-entry.

[5 marks]

(iv) The maximum deceleration that the scientific payload can withstand is 150 $\mathrm{m/s^2}$. Determine whether the scientific payload can survive the re-entry. If it cannot survive, provide range of re-entry angles, which is defined as the flight path angle in negative direction, for which it can survive.

[5 marks]

(v) The Foton is equipped with a silica-phenolic ablative TPS (Thermal Protection System) material**.** During peak heating of the EDL sequence, the ablative heatshield of the vehicle has to withstand a thermal load of more than 5,700 $\mathrm{J/cm^2}$ with a turbulent air flow around the entry vehicle. At this point, Long-range IR sensors show that the peak heat rate on the heat shield is greater than 200 $\mathrm{W/cm^2}$. The emissivity of a silica-phenolic ablative TPS material is shown in Fig Q3a. Calculate the minimum surface temperature of the heat shield at peak heating.

[5 marks]

Q3. Cont…
TURN OVER

Q3. Cont…

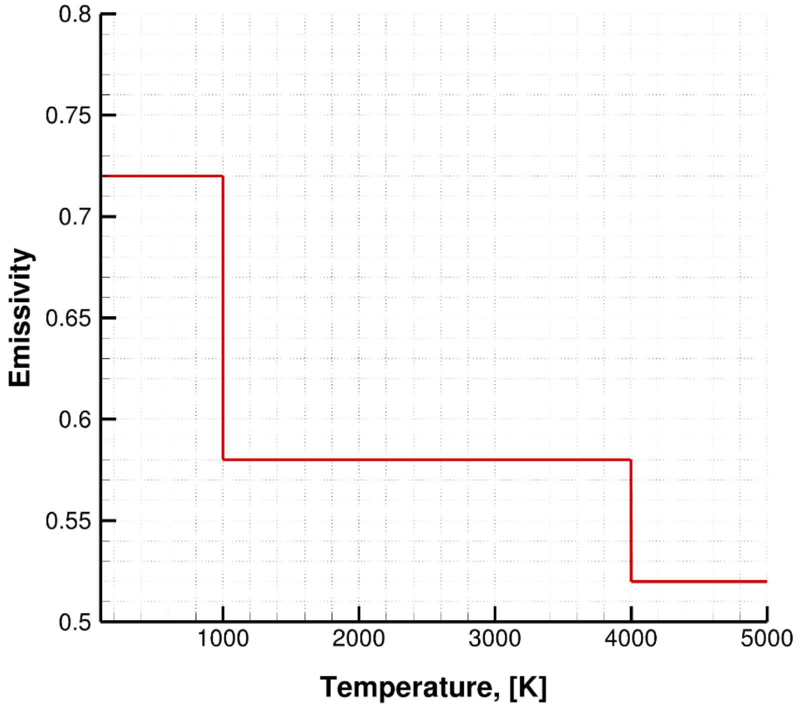

Figure Q3a. The emissivity of a silica-phenolic ablative TPS material.

[Total 25 marks]

Q4. A satellite is in orbit around Earth. Along its orbit, the maximum distance it reaches is 12,000 km while the minimum velocity attained is 5 km/s, both relative to the center of the Earth.

A ground station located in Southampton and is currently scheduling to contact the satellite. From antenna pointing restrictions, it has been determined that for the next orbital pass contact is only possible between true anomalies of 5° and 42°. Furthermore, antenna gain restricts the satellite radius from the center of the Earth to below 7,500 km.

The nominal raw data rate of the communication link is 9600 bits per second, with a total protocol overhead of 15%.

(i) What is the satellite orbit's semi-major axis and eccentricity?

[5 marks]

(ii) Calculate the true anomalies along the next orbital pass when the satellite enters and leaves the communication window.

[5 marks]

(iii) If the satellite passes perigee at 13:47:00 UTC, at what times (UTC, rounded to nearest second) does the communication window open and close?

[10 marks]

(iv) How much user data (payload and telemetry) can the satellite down-link during that communication window (in kB)?
Note: 1 kB = 1024 bytes.

[5 marks]

[Total 25 marks]

END OF PAPER