UNIVERSITI SAINS MALAYSIA

Second Semester Examination
2017/2018 Academic Session

May/June 2018

ESA380/3 – Orbital Mechanics
[Mekanik Orbit]

Duration : 3 hours
Masa : 3 jam

Please check that this paper contains **FIFTEEN (15)** printed page, **TWO (2)** pages appendix and **FIVE (5)** questions before you begin the examination.

*[Sila pastikan bahawa kertas soalan ini mengandungi **LIMA BELAS (15)** mukasurat bercetak, **DUA (2)** mukasurat lampiran dan **LIMA (5)** soalan sebelum anda memulakan peperiksaan.]*

Instructions : Answer **ALL** questions.

***[Arahan** : Jawab **SEMUA** soalan].*

Appendix/*Lampiran*

Table A. 1 Astronomical data for the Sun, planets and the Moon. [**2 pages**/*mukasurat*]

Student may answer the questions either in English or Bahasa Malaysia.

[Pelajar boleh menjawab soalan dalam Bahasa Inggeris atau Bahasa Malaysia].

Answer to each question must begin from a new page.

[Jawapan untuk setiap soalan mestilah dimulakan pada mukasurat yang baru].

In the event of any discrepancies, the English version shall be used.

[Sekiranya terdapat sebarang percanggahan pada soalan peperiksaan, versi Bahasa Inggeris hendaklah digunapakai].

1. [a] From the Newton's Law of Gravitation, the weight W is defined as

$$W = G\frac{Mm}{r^2} = m\left(\frac{GM}{r^2}\right) \qquad \text{or} \qquad W = mg$$

where

$$g = \frac{GM}{r^2}$$

Explain about W under the condition of gravity and free fall.

(10 marks)

[b] Draw the location of the equilibrium points that also known as Lagrangian Points for Earth-Sun system. If a spacecraft for Sun observation is planned to be launched, which point of Lagrangian Point is suitable for this mission? Explain.

(40 marks)

[c] Relative to an earth-centered non-rotating frame, the position and velocity vectors of a spacecraft are

$$\mathbf{r}_0 = 3450\hat{\mathbf{i}} - 1700\hat{\mathbf{j}} + 7750\hat{\mathbf{k}}\ km$$
$$\mathbf{v}_0 = 5.4\hat{\mathbf{i}} - 5.4\hat{\mathbf{j}} + 1.0\hat{\mathbf{k}}\ km$$

(i) Calculate the distance and speed of the spacecraft after the true anomaly changes by 82°, see refer Appendix for equation.

(ii) Show that the specific angular momentum h and total energy ε are conserved.

(50 marks)

2. [a] Draw the orientation of the orbit in three dimensions and list all the classical orbital elements.

(50 marks)

[b] If the eccentricity of the elliptical orbit depicted in **Figure 2[b]** is 0.5, calculate, in terms of the period T, the time required to fly from P to B. Given the mean anomaly and eccentric anomaly of this type of orbit are as follow

$$M_e = E - e\sin E$$

$$E = 2\tan^{-1}\left(\sqrt{\frac{1-e}{1+e}}\tan\frac{\theta}{2}\right)$$

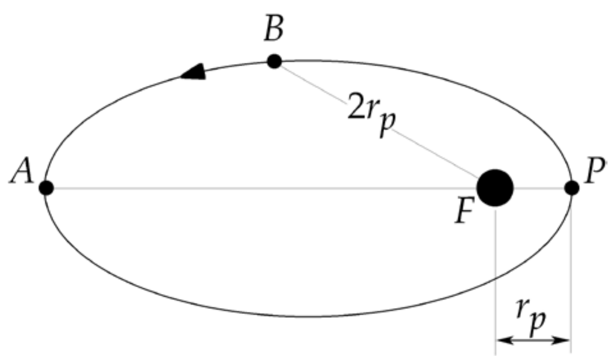


Figure 2 [b]

(30 marks)

[c] An essential aspect of a satellite mission is the occurrence of solar eclipses. Select a satellite orbit such that the satellite is in full sunlight throughout its mission lifetime. Give the definition of the selected orbit.

(20 marks)

3. [a] NASA is planning to launch a satellite for monitoring global sea rise by gathering environmental intelligence from oceans. Suggest an orbit for this satellite and explain why you choose the orbit?

(20 marks)

[b] For a spacecraft, the following orbital parameters are given: $e = 1.5$; perigee altitude $= 300\ km$; $i = 35°$; $\Omega = 130°$; $\omega = 115°$. Calculate $\mathbf{r}$ and $\mathbf{v}$ at perigee relative to the geocentric equatorial frame.

(30 marks)

[c] A space vehicle in a circular orbit at an altitude of 500 km above the earth executes a Hohmann transfer to a 1000 km circular orbit (refer **Figure 3[c]**). Calculate the total delta-v requirement.

(50 marks)

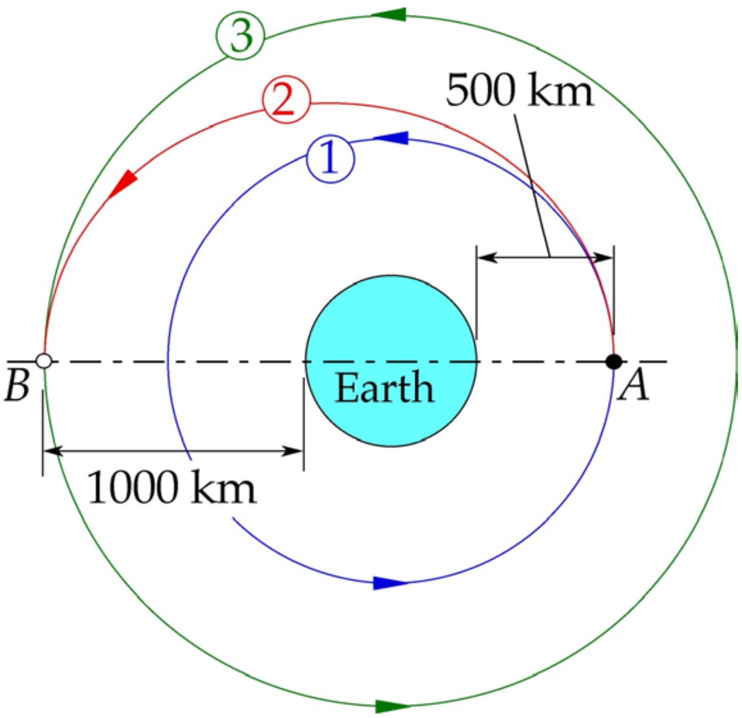


Figure 3[c]

4. [a] ESA wants to place a communications satellite into a Geosynchronous orbit from a low Earth, parking orbit (refer **Figure 4[a]**). What is the ΔV_{total} for this transfer and how long will it take? Given that R_{orbit1} = 6570 km and R_{orbit2} = 42160 km.

(50 marks)

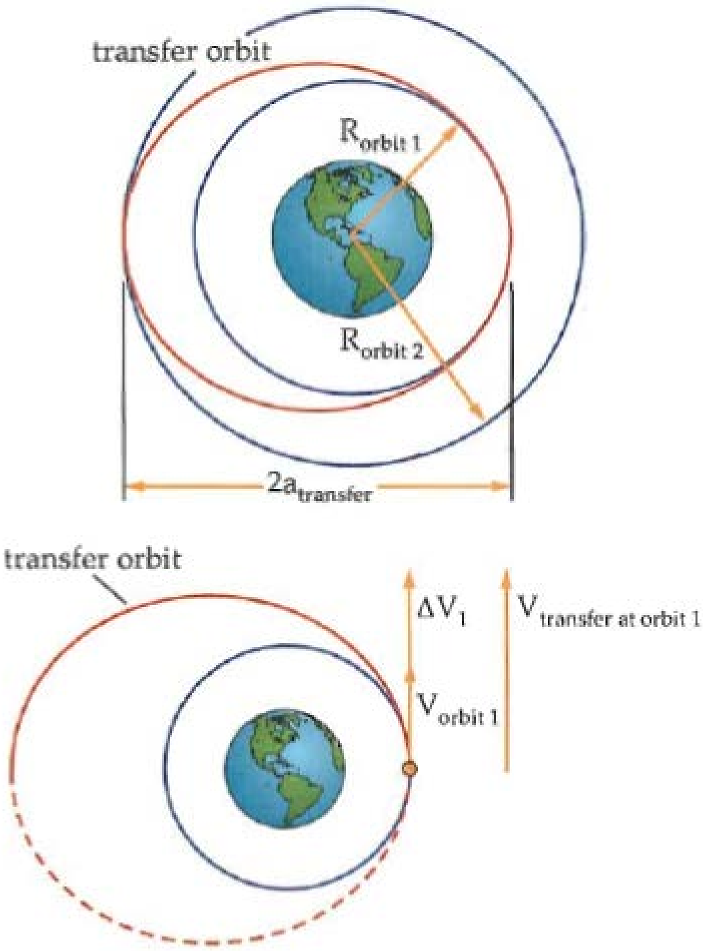


Figure 4[a]

[b] A spacecraft conducted a bi-elliptical Hohnmann transfer from a geocentric circular orbit of 7000 km radius to 105 000 km radius. The apogee of the first ellipse is 210 000 km. To summarize, r_A = 7000 km, r_B = 210 000 km, r_C = r_D = 105 000 km

(i) Sketch the orbit path of the transfer

(10 marks)

(ii) Find the total delta V requirement for the transfers

(40 marks)

5. [a] **Figure 5 [a]** shows the re-entry vehicle during the Apollo mission. Explain FIVE characteristics of the shape selection for the re-entry vehicle.

Figure 5[a]

(10 marks)

[b] Satellites *A* and *B* are in the same circular orbit of radius *r*. *B* is 180° ahead of *A*. Calculate the semi-major axis of a phasing orbit in which *A* will rendezvous with *B* just one revolution in the phasing orbit.

(20 marks)

[c] Estimate the total delta V requirement for a Hohmann transfer from Earth to Mercury, assuming a $150\ km$ circular parking orbit at Earth and a $150\ km$ circular capture orbit at Mercury. Furthermore, assume that the planets have coplanar circular orbits with radii equal to the semi major axes listed in **Table A.1**.(Appendix)

(70 marks)

1. [a] *Daripada Hukum Gravitasi Newton, berat W didefinasikan sebagai*

$$W = G\frac{Mm}{r^2} = m\left(\frac{GM}{r^2}\right) \quad \textit{atau} \quad W = mg$$

di mana

$$g = \frac{GM}{r^2}$$

Terangkan tentang berat W di bawah keadaan gravity dan jatuh bebas.

(10 markah)

[b] *Lukis lokasi titik ekuilibrium yang dikenali juga sebagai titik Langragian untuk system Bumi-Matahari. Jika kapal angkasa untuk memerhati Matahari dirancang untuk dilancarkan, di manakah titik Langrangian yang sesuai untuk misi ini. Terangkan.*

(40 markah)

[c] *Relatif kepada bingkai tidak berputar dan berpusat kepada bumi, kedudukan dan vector halaju sebuah kapal angkasa adalah*

$$\boldsymbol{r}_0 = 3450\hat{\boldsymbol{\imath}} - 1700\hat{\boldsymbol{\jmath}} + 7750\hat{\boldsymbol{k}}\ km$$
$$\boldsymbol{v}_0 = 5.4\hat{\boldsymbol{\imath}} - 5.4\hat{\boldsymbol{\jmath}} + 1.0\hat{\boldsymbol{k}}\ km$$

(i) *Kira jarak dan laju kapal angkasa itu selepas anomali benar berubah kepada* $82°$*, lihat Appendiks.*

(ii) *Tunjukkan momentum sudut spesifik h dan jumlah tenaga adalah abadi.*

(50 markah)

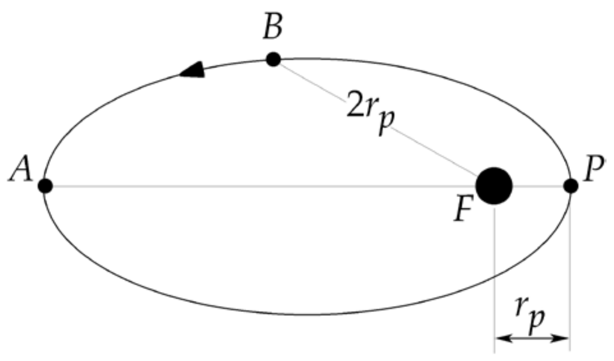
2. [a] *Lukis orientasi tiga dimensi dan senaraikan semua elemen orbit klasik.*

(50 markah)

[b] *Jika eksentrisiti pada orbit elips di dalam* ***Gambarajah 2 [b]*** *adalah 0.5, kira, di dalam masa T, masa yang diperlukan untuk terbang dari P ke B. Diberikan min anomali dan eksentrik anomaly untuk orbit jenis ini adalah seperti berikut*

$$M_e = E - e \sin E$$

$$E = 2 \tan^{-1}\left(\sqrt{\frac{1-e}{1+e}} \tan\frac{\theta}{2}\right)$$



Gambarajah 2[b]

(30 markah)

[c] *Satu aspek penting di dalam misi satelit adalah kejadian gerhana. Pilih satu orbit satelit supaya satelit sentiasa menerima cahaya matahari penuh sepanjang misi di orbit. Beri definisi orbit yang dipilih tersebut.*

(20 markah)

3\. [a] *NASA merancang untuk melancarkan satelit untuk memantau kenaikan paras laut secara global dengan mengumpulkan risikan persekitaran daripada laut. Cadangkan orbit untuk satelit ini dan terangkan kenapa orbit ini dipilih.*

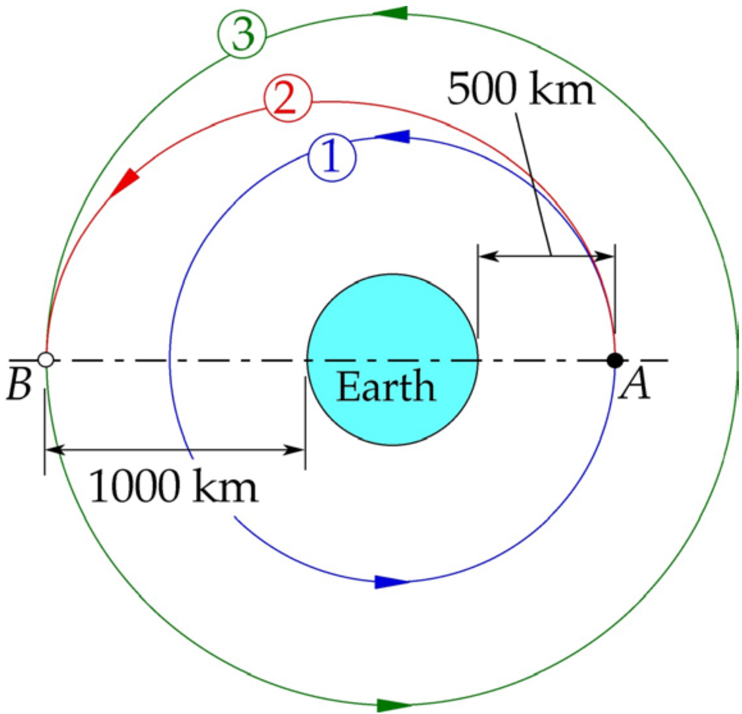
(20 markah)

[b] *Untuk sebuah kapal angkasa, parameter orbit diberi seperti berikut:* $e = 1.5$; *ketinggian perigee* $= 300\ km$; $i = 35°$; $\Omega = 130°$; $\omega = 115°$. *Kira* $\boldsymbol{r}$ *dan* $\boldsymbol{v}$ *pada relatif perigee ke bingkai geopusat khatulistiwa.*

(30 markah)

[c] *Sebuah kapal angkasa pada orbit bulat di ketinggian 500 km dari permukaan bumi menjalankan pemindahan Hohnmann ke orbit bulat 1000 km.(rujuk* ***Gambarajah 3[c]).*** *Kira keperluan jumlah delta-V.*

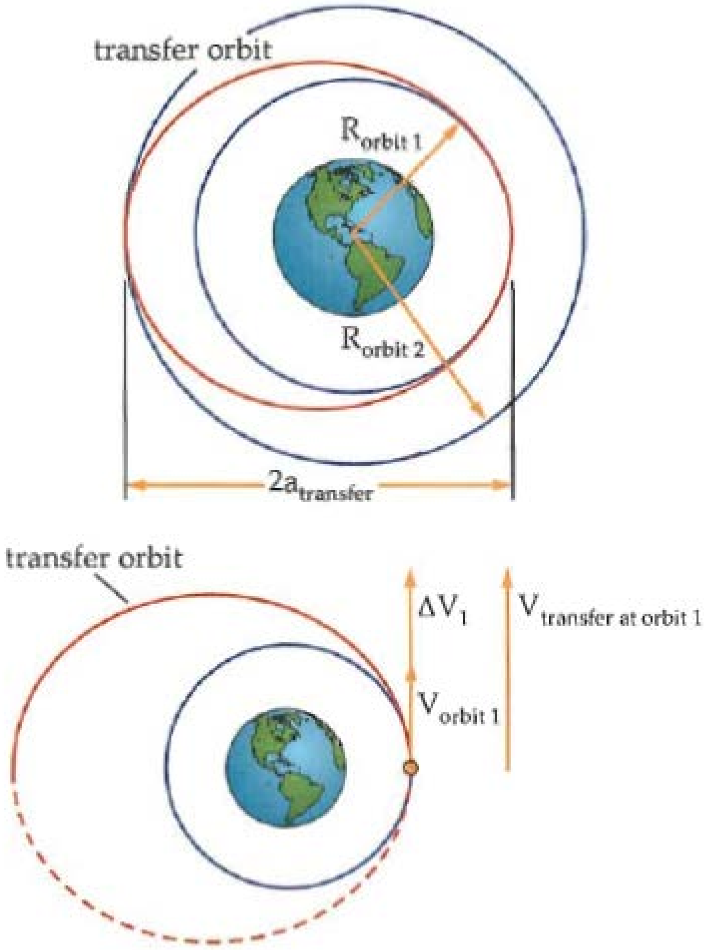
(50 markah)



Gambarajah 3[c]

4. [a] ESA ingin meletakkan satelit komunikasi di orbit geosegerak dari orbit parking di orbit rendah bumi (rujuk ***Gambarajah 4[a]****). Apakah* ΔV_{total} *untuk pemindahan ini dan berapa lama ia mengambil masa? Diberi* R_{orbit1} *= 6570 km and* R_{orbit2} *= 42160 km.*

(50 markah)



Gambarajah 4[a]

[b] *Sebuah kapal angkasa menjalankan pemindahan Hohnmann secara bi-ellips daripada orbit bulat geopusat dengan jejari 7000 km ke jejari 105 000 km. Apogee untuk orbit ellips pertama adalah 210 000 km. Kesimpulannya,* r_A *= 7000 km,* r_B *= 210 000 km,* $r_C = r_D$ *= 105 000 km*

(i) *Lakarkan perjalanan orbit untuk pemindahan ini*

(10 markah)

(ii) *Cari jumlah delta V yang diperlukan untuk pemindahan ini.*

(40 markah)

5. [a] ***Gambarajah 5[a]*** *menunjukkan kenderaan masuk semula ketika misi Apollo. Terangkan LIMA karakteristik untuk pemilhan bentuk kenderaan masuk semula.*

Gambarajah 5[a]

(10 markah)

[b] *Satelit A dan B berada di orbit bulat yang sama dengan radius r. B adalah 180° di hadapan A. Kira axis semi-major di orbit pemfasaan yang mana A aka berjumpa dengan B di dalam satu revolusi orbit pemfasaan.*

(20 markah)

[c] Anggarkan keperluan jumlah delta-v untuk pemindahan Hohmann dari Bumi ke Utarid, anggarkan orbit parking Bumi adalah $150\ km$ dan orbit parking Utarid adaah $150\ km$. Tambahan, anggap planet-planet adalah di orbit bulat koplanar dengan jejari sama dengan paksi semi major di ***Jadual A.1****.(Appendiks)*

(70 markah)

APPENDIX 1/*LAMPIRAN 1*

Table A. 1 Astronomical data for the Sun, planets and the Moon

Object	Radius (km)	Mass (kg)	Sidereal Rotation period	Inclination of equator to orbit plane	Semimajor axis of orbit (km)	Orbit eccentricity	Inclination of orbit to the ecliptic plane	Orbit sidereal period
Sun	696000	$1.989{\cdot}10^{30}$	25.38 d	7.25 º	-	-	-	-
Mercury	2440	$330.2{\cdot}10^{21}$	58.65 d	0.01 º	$57.91{\cdot}10^{6}$	0.2056	7.0º	87.97 d
Venus	6052	$4.869{\cdot}10^{24}$	24.3 d	177.4 º	$108.2{\cdot}10^{6}$	0.0067	3.39º	224.7 d
Earth	6378	$5.974{\cdot}10^{24}$	23.93 h	23.45 º	$149.6{\cdot}10^{6}$	0.0167	0.0º	365.25 d
Moon	1737	$73.48{\cdot}10^{21}$	27.32 d	6.68 º	$384.4{\cdot}10^{3}$	0.0549	5.145º	27.32 d
Mars	3396	$641.9{\cdot}10^{21}$	24.6 h	25.19 º	$227.9{\cdot}10^{6}$	0.0935	1.85º	1.881 y
Jupiter	71490	$1.899{\cdot}10^{27}$	9.92 h	3.13 º	$778.6{\cdot}10^{6}$	0.0489	1.304º	11.86 y
Saturn	60270	$568.5{\cdot}10^{24}$	10.66 h	26.73 º	$1.433{\cdot}10^{9}$	0.0565	2.485º	29.46 y
Uranus	25560	$86.83{\cdot}10^{24}$	17.24 h	97.77 º	$2.872{\cdot}10^{9}$	0.0457	0.772º	84.01 y
Neptune	24760	$102.4{\cdot}10^{24}$	16.11 h	28.32 º	$4.495{\cdot}10^{9}$	0.0113	1.796º	164.8 y
Pluto	1195	$12.5{\cdot}10^{21}$	6.387 d	122.5 º	$5.870{\cdot}10^{9}$	0.2444	17.16º	247.7 y

Table A.2 Orbital Mechanics Useful Formulas

Langrage coefficients in terms of the change in true anomaly,

$$f = 1 - \frac{\mu r}{h^2}(1 - \cos\Delta\theta)$$

$$g = \frac{r r_0}{h}\sin\Delta\theta$$

$$\dot{f} = \frac{\mu}{h}\frac{1 - \cos\Delta\theta}{\sin\Delta\theta}\left[\frac{\mu}{h^2}(1 - \cos\Delta\theta) - \frac{1}{r_0} - \frac{1}{r}\right]$$

$$\dot{g} = 1 - \frac{\mu r_0}{h^2}(1 - \cos\Delta\theta)$$

where,

$$r = \frac{h^2}{\mu}\frac{1}{1 + \left(\frac{h^2}{\mu r_0} - 1\right)\cos\Delta\theta - \frac{h v_{r0}}{\mu}\sin\Delta\theta}$$

$$v_{r0} = \frac{\mathbf{r}_0 \cdot \mathbf{v}_0}{r_0}$$

$$h = r_0 v_{\perp 0} = r_0\sqrt{v_0^2 - v_{r0}^2}$$

Mean anomaly

$$M_e = E - e\sin E$$

$$E = 2\tan^{-1}\left(\sqrt{\frac{1-e}{1+e}}\tan\frac{\theta}{2}\right)$$

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