UNIVERSITI SAINS MALAYSIA

Second Semester Examination
2015/2016 Academic Session

June 2016

ESA 380/3 – Orbital Mechanics
[Mekanik Orbit]

Duration : 3 hours
[Masa : 3 jam]

Please ensure that this paper contains **FOURTEEN (14)** printed pages included **ONE(1) page appendix** and **FIVE (5)** questions before you begin examination.

*[Sila pastikan bahawa kertas soalan ini mengandungi **EMPAT BELAS (14)** mukasurat bercetak termasuk **SATU (1)** mukasurat lampiran dan **LIMA (5)** soalan sebelum anda memulakan peperiksaan]*.

Instruction : Answer **FIVE (5)** questions.

*[Arahan : Jawab **LIMA (5)** soalan.*

Appendix/*Lampiran*

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

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

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

Each questions must begin from a new page.

[Setiap soalan mestilah dimulakan pada mukasurat yang baru].

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

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

Where

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

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

(10 marks)

[b] Derive the equation $\ddot{\mathbf{r}} = -\frac{\mu}{r^3}\mathbf{r}$ from equation of motion of two bodies.

(10 marks)

[c] Please complete the following table:

Parameter	Definition	Circle	Ellipse
e			
r_{peri}			
T			
ε			
v_{apogee}			

(30 marks)

[d] By referring **Figure 1,** the perigee of a satellite in a parabolic geocentric trajectory is 5000 km. Find the distance d between points P1 and P2 from the centre of the earth.

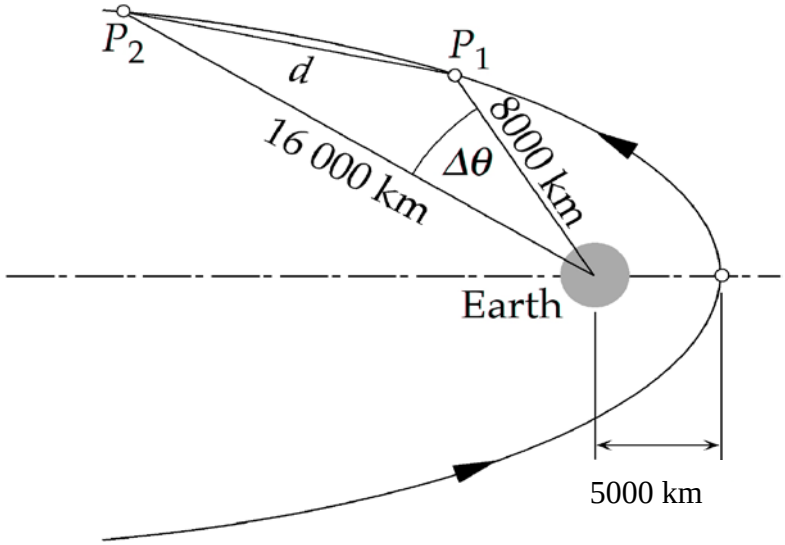


Figure 1 : **Parabolic geocentric trajectory**

(50 marks)

2. [a] NASA, ESA and JAXA are going to launch a constellation of satellites with missions to support global weather forecasting, thunderstorm and typhoon locations monitoring and meteorology research. Suggest an orbit for this constellation and explain why.

(20 marks)

[b] A planet X with mass 5×10^{25} kg, orbiting the Sun in a circular orbit with radius 3 AU. Make a sketch of the situation when the gravitational attraction of this planet X on a satellite around the Earth is largest and smallest. Point out a centre of reference frame in the sketch.

(10 marks)

[c] By referring **Figure 2**, find

(i) True anomaly, $\Delta\theta$ is swept out between t = 1.5 hr and t = 2.0 hr after perigee passage.

(35 marks)

(ii) Area swept out by the position vector during that time interval.

(35 marks)

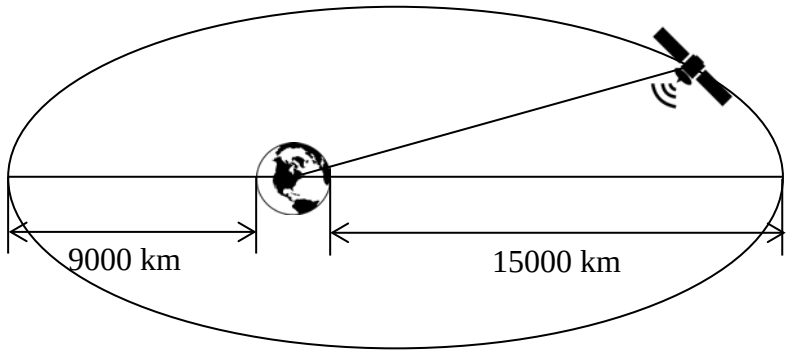


Figure 2 : **An elliptical orbit for satellite**

3. [a] Define the theorem of Lambert. Sketch the position vectors of point P1 and P2 on the path of mass *m* around mass *M*.

(20 marks)

[b] Given that

$$J_0 = 367y - int\left\{\frac{7\left[y + int\left(\frac{m+9}{12}\right)\right]}{4}\right\} + int\frac{275m}{9} + d + 1721013.5$$

$$\theta_{G0} = 100.4606184 + 36{,}000.77004T_0 + 0.000387933T_0^{\,2} - 2.583(10\text{-}8)T_0^{\,3}$$

$$\theta_G = \theta_{G0} + 360.98564724\cdot(UT/24)$$

Calculate the local sidereal time (in degrees) at

(i) Los Angeles, California (west longitude 118°58′) at 20:00 UT on 4 October 2007.

(15 marks)

(ii) Tokyo, Japan (east longitude 139º 41´) at 3:00 UT on 3 Mar 2005

(15 marks)

(iii) Santiago, Chile (west longitude 70º 40´) at 12:00 UT on 12 July 2014

(15 marks)

(iv) Balik Pulau, Pulau Pinang (east longitude 100º 14´) at 10:00 UT on 6 June 2016

(15 marks)

[c] Describe the definition of eclipse. An eclipse has consequences for at **least 3** subsystems of the satellite. Identify these **3 subsystems** and discuss the consequences for each one briefly.

(20 marks)

4. [a] A sample return mission to 108906 (2001 PL9) asteroid with diameter 1.7 km is planned on 2017. Calculate

(i) One-way travel time for a Hohmann transfer from Earth to asteroid.

(10 marks)

(ii) The synodic period for the system Sun-Earth-asteroid

(20 marks)

(iii) Mean motion of Earth around the Sun and of the asteroid around the Sun

(20 marks)

($\mu_{sun} = 1.3271 \times 10^{11} km^3/s^2$, distance Earth-Sun = 1 AU, distance asteroid-Sun = 0.95 AU, 1 $AU = 149.6 \times 10^6 km$)

[b] Consider a transfer from circular parking orbit at 185 km and $i = 5^o$ to the geostationary orbit (GEO) (T = 23h, 56m, 4s, e = 0). Calculate

(i) The radius of geostationary orbit

(10 marks)

(ii) The circular velocities in the original orbit and in the target orbit

(10 marks)

(iii) The velocities in the pericentre and the apocentre of a Hohmann transfer orbit

(15 marks)

(iv) The total ΔV that would be required for the orbit raising for Hohmann transfer.

(15 marks)

5. [a] Calculate the radius of the sphere of influence of Mercury. (**Refer Table A1)**

(20 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.

(30 marks)

[c] Consider the situation where the cargo vehicle Dragon is to dock with the International Space Station (ISS). Both are orbiting Earth in a circular (coplanar) orbit at 400 km altitude (refer **Figure 3).** The ISS is 90° ahead on the Dragon vehicle. You are responsible for designing the transfer between the two, where Dragon is the active vehicle and the ISS the (passive) target. In order to catch up with the ISS, Dragon will be taken to an elliptical (*i.e*. non-circular) transfer orbit with a different orbital period.

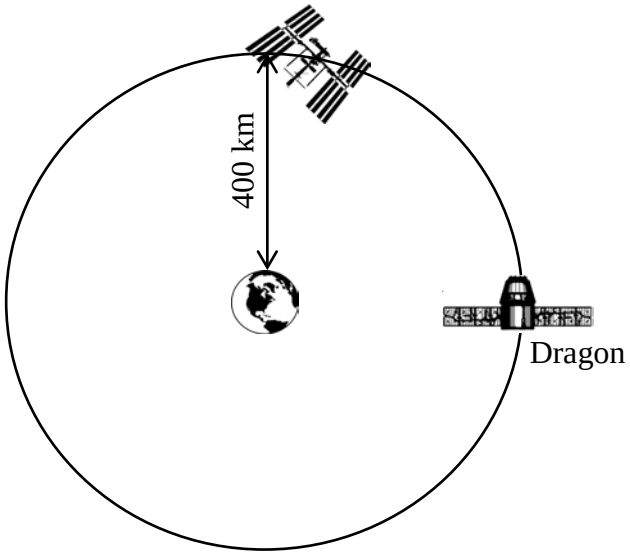


Figure 3 : Circular orbit for ISS.

(i) In order to rendezvous with the ISS, choose the position of orbit of the Dragon. Explain why you make the selection.

(10 marks)

(ii) Calculate orbital period, T and circular velocity at an altitude of 400 km.

(10 marks)

(iii) Consider the situation that one wants to have Dragon to complete 15 revolutions in its elliptical transfer orbit, before it does the rendezvous with the ISS. Calculate the required shift per revolution of Dragon in its transfer orbit with respect to the ISS

(10 marks)

(iv) Calculate the orbital period, $T_{transfer}$ of this transfer orbit, where the total transfer is to be completed after exactly 15 revolutions.

(10 marks)

(v) Calculate the required total velocity change for this transfer scenario.

(10 marks)

1. [a] *Daripada hukum kegravitian Newtom, berat, W didefinisikan sebagai*

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

Di mana

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

Terangkan tentang W di bawah keadaan graviti dan jatuh bebas.

(10 markah)

[b] *Hasilkan persamaan* $\ddot{\mathbf{r}} = -\frac{\mu}{r^3}\mathbf{r}$ *daripada persamaan pergerakan dua jasad.*

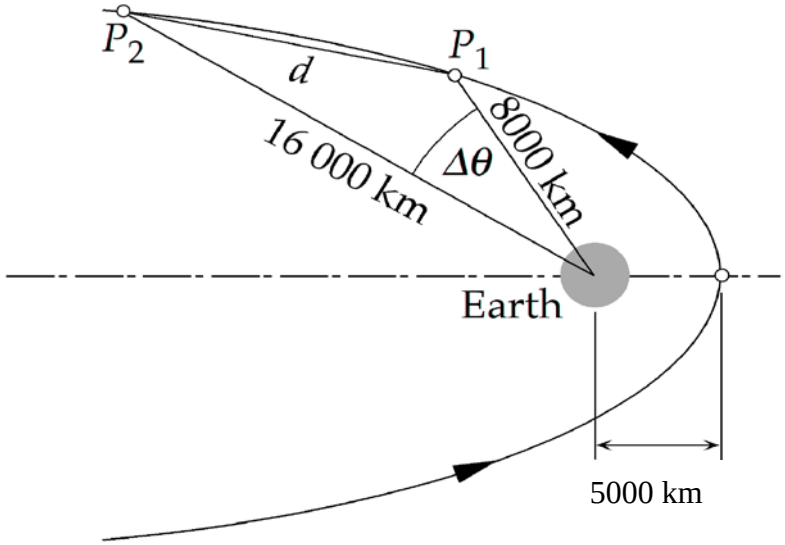
(10 markah)

[c] *Sila lengkapkan jadual berikut:*

Parameter	Definisi	Bulat	Elips
e			
r_{peri}			
T			
ε			
v_{apogee}			

(30 markah)

[d] *Merujuk kepada **Rajah 1**, perigee satelit di trajektori adalah 5000 km. Cari jarak d di antara titip P1 dan P2 dari pusat bumi.*



Rajah 1: Trajektori parabola geosepusat.

(50 markah)

2. *[a]* *NASA, ESA dan JAXA akan melancarkan konstelasi satelit dengan misi untuk menyokong ramalan cuaca global, pemantauan lokasi kilat dan taufan dan kajian meteorologi. Cadangkan orbit untuk konstelasi ini dan terangkan kenapa.*

(20 markah)

[b] *Planet X dengan jisim 5×10^{25} kg, mengelilingi matahari di dalam orbit bulat dengan jejari 3 AU. Buat lakaran situasi di mana tarikan graviti planet X pada satelit yang mengelilingi bumi adalah di titik terkuat dan terlemah. Tunjukkan pusat bingkai rujukan di dalam lakaran tersebut.*

(10 markah)

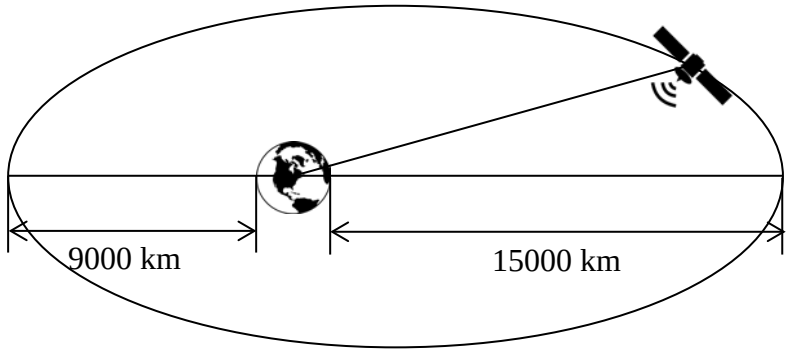
[c] *Rujuk **Rajah 2**, cari*

(i) *Anomali benar, $\Delta\theta$ kawasan yang dilalui di antara masa t = 1.5 jam dan t = 2.0 jam selepas laluan perigee.*

(35 markah)

(ii) *Kawasan yang dilalui oleh vektor posisi ketika selang masa tersebut.*

(35 markah)



Rajah 2 Orbit eliptik untuk satelit

3. *[a]* *Terangkan teori Lambert. Lakarkan posisi vector untuk titik P1 dan P2 pada laluan yang dilalui oleh jisim m mengelilingi jisim M.*

(20 markah)

[b] *Di berikan*

$$J_0 = 367y - INT\left\{\frac{7\left[y+INT\left(\frac{m+9}{12}\right)\right]}{4}\right\} + INT\left(\frac{275m}{9}\right) + d + 1721013.5$$

$$\theta_{G0} = 100.4606184 + 36{,}000.77004T_0 + 0.000387933T_0^{\,2} - 2.583(10\text{-}8)T_0^{\,3}$$

$$\theta_G = \theta_{G0} + 360.98564724\cdot(UT/24)$$

Kirakan waktu sidereus tempatan (dalam darjah) di

(i) Los Angeles, California (longitud barat 118°58′) pada 20:00 UT pada 4 Oktober 2007.

(15 markah)

(ii) Tokyo, Japan (longitud timur 139º 41′) pada 3:00 UT pada 3 Mac 2005

(15 markah)

(iii) Santiago, Chile (longitud barat 70º 40′) pada 12:00 UT pada 12 Julai 2014

(15 markah)

(iv) Balik Pulau, Pulau Pinang (longitud timur 100º 14′) pada 10:00 UT pada 6 Jun 2016

(15 markah)

*[c] Terangkan maksud gerhana. Gerhana akan memberi kesan kepada sekurang-kurangnya **TIGA subsistem**. Kenalpasti **TIGA subsistem** ini dan bincangkan kesan tersebut kepada ketiga-tiga subsistem ini secara ringkas.*

(20 markah)

4. *[a] Misi membawa pulang sampel ke asteroid 108906 (2001 PL9) dengan diameter 1.7 km telah dirancang pada 2017. Kirakan:*

(i) Masa yang diperlukan untuk pemindahan Hohmann sehala dari bumi ke asteroid.

(10 markah)

(ii) Tempoh sinod untuk sistem matahari-bumi-asteroid.

(20 markah)

(iii) Min gerakan bumi mengelilingi matahari dan asteroid mengelilingi matahari.

(20 markah)

($\mu_{sun} = 1.3271 \times 10^{11} km^3/s^2$, *jarak bumi - matahari* = 1 AU, *jarak asteroid - matahari* = 0.95 AU, 1 $AU = 149.6 \times 10^6 km$)

[b] *Anggap pemindahan daripada orbit henti bulat di 185 km dan i = 5º ke orbit geotetap orbit (GEO) (T = 23h, 56m, 4s, e = 0). Kira*

(i) *Jejari orbit geotetap.*

(10 markah)

(ii) *Halaju membulat di orbit asal dan orbit tujuan.*

(10 markah)

(iii) *Halaju orbit pemindahan Hohmann di peripusat dan apopusat*

(15 markah)

(iv) *Jumlah ΔV yang diperlukan untuk peningkatan orbit untuk pemindahan Hohmann.*

(15 markah)

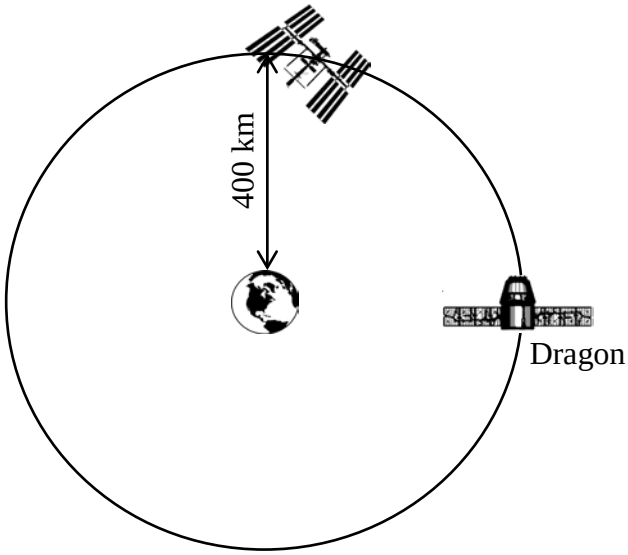
5. *[a]* *Kira jejari bulatan pengaruh untuk Utarid* ***(Rujuk Jadual A1)***

(20 markah)

[b] *Satelit A dan B berada di orbit bulat yang sama dengan jejari r. B berada pada 180º di hadapan A. Kira paksi semi-major orbit fasa di mana A akan bertemu dengan B di dalam satu revolusi di orbit fasa.*

(30 markah)

[c] *Anggap situasi di mana kenderaan kargo Dragon akan berlabuh di Pusat Angkasa Antarabangsa (ISS) . Kedua-duanya mengelilingi bumi di dalam orbit bulat pada ketinggian 400 km* ***(Rujuk Rajah 3).*** *ISS berada di 90° di hadapan kenderaan Dragon. Anda bertanggungjawan untuk merekacipta pemindahan di antara keduanya, di mana Dragon adalah kenderaan yang aktif, dan ISS menjadi sasaran pasif. Untuk mengejar ISS, Dragon akan mengambil orbit pemindahan elip (bukan bulat) dengan tempoh orbit yang berbeza.*



Rajah 3 Orbit bulat untuk ISS.

(i) *Untuk bertemu dengan ISS, pilih posisi orbit untuk Dragon. Terangkan mengapa pilihan tersebut dibuat.*

(10 markah)

(ii) *Kira tempoh orbit, T dan halaju membulat pada ketinggian 400 km.*

(10 markah)

(iii) *Timbangkan keadaan di mana seseorang inginkan Dragoon unutk melengkapi 15 revolusi di dalam orbit pemindahan eliptikal sebelum melakukan pertemuan dengan ISS. Kira shif per revolusi yang diperlukan oleh Dragon dengan berkait dengan ISS.*

(10 markah)

(iv) *Kira tempoh orbit, $T_{transfer}$ untuk pemindahan orbit ini di mana jumlah pemindahan mesti dilengkapkan selepas setepat-tepat 15 revolusi. .*

(10 markah)

(v) *Kira jumlah perubahan halaju yang diperlukan untuk senario pemindahan orbit ini.*

(10 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

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