MAE 180A: Spacecraft Guidance I, Summer 2009

Final Exam

Saturday, August 1st.

Part I: Questions. (40pt)

8:00AM-8:35AM.

Guidelines: Please turn in a *neat* and *clean* exam solution. Answers should be written in the blank spaces provided in these exam sheets. Vector quantities are denoted in **bold** letters in what follows. This part of the exam is **closed book, closed notes, no use of calculator allowed**.

Student's Name:.. **Student's ID:**.............................

Question 1 (10 pts).

State in words the three Kepler's laws.

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Question 2 (30 pts)

Select the true answer (only one) out of the choices from the list provided for each question. A complementary and *brief* mathematical proof of your answer on the available space would be welcome, but it is **not** needed in order to get full credit.

2.1 A polar orbit has an inclination i of

a) $45°$

b) $90°$

c) $0°$

d) $180°$

2.2 The geocentric-equatorial system of coordinates

a) is centered at the Earth and the x-axis points towards the Saggitarius constellation.

b) is centered at the Earth and the x-axis points towards the Aries constellation.

c) is perpendicular to the celestial equator.

d) is centered at the Sun.

2.3 A mean solar day is

a) longer than a sidereal day since the Earth is not a perfect sphere.

b) longer than a sidereal day because of the orbital path of the Earth around the Sun and the rotation of the Earth about its polar axis.

c) equal to a sidereal day.

d) shorter than a sidereal day.

2.4 The argument of latitude at epoch of a circular equatorial orbit is

a) always $0°$.

b) $90°$.

c) undefined.

d) $-90°$.

2.5 The ground trace of a geosynchronous satellite in a $45°$-inclination elliptic orbit is

a) a stationary spot on the same place of the surface of the Earth since the orbit is synchronous.

b) a distorted $8-$shape trace that goes from the northern hemisphere to the southern hemisphere.

c) a square of side equal to the periapsis radius.

d) a $5-$shaped trace.

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2.6 If the launch site is very close to the equator then

a) the spacecraft can be generally inserted into an equatorial orbit very easily.

b) it is impossible to insert a spacecraft into an equatorial orbit.

c) the orbit is always polar.

d) the orbit is always retrograde.

2.7 The specific mechanical energy of a satellite orbiting around the Earth

a) is not constant and varies sinusoidally with time.

b) is constant but only for US-manufactured satellites.

c) is constant if the satellite is not subject to any dissipative forces or external forces other than gravitational interactions.

d) is always constant.

2.8 The orbital period of a satellite in a circular orbit of radius r_1 around the Earth is P_1. The orbital period of another satellite in a circular orbit of the same radius r_1 around a planet of twice the mass of the Earth is

a) $2^{-1/2}P_1$.

b) undefined.

c) the same.

d) $2^{3/2}P_1$.

2.9 The angular momentum in an orbital motion is

a) constant and parallel to the orbit plane.

b) constant and normal to the orbit plane.

c) not constant, and it is parallel to the orbit plane.

d) not constant, and it is normal to the orbit plane.

2.10 An elliptic orbit of perigee radius $r_p = 4$ DU and apogee radius $r_a = 10$ DU is used to transfer a spacecraft from a circular orbit of radius $r_1 = 10$ DU to a smaller coplanar orbit of radius $r_2 = 3$ DU. Then

a) the spacecraft will arrive safely at the inner circular orbit.

b) it would take too much fuel to perform this maneuver.

c) this transfer orbit cannot be used since the spacecraft will not arrive at the inner circular orbit.

d) the transfer orbit is parallel to the equatorial plane.

2.11 A satellite is launched from the Baikonur Cosmodrome to a 45.8°-inclination low-Earth orbit (LEO), and it is about to be transferred to a Geostationary orbit (GSO). Then

a) it is more economical to perform the plane change to the equatorial plane when the satellite is still in the LEO before executing any other maneuver.

b) it is more economical to perform the plane change to the equatorial orbit at the intersection of the equatorial plane and the transfer ellipse (i.e. at the descending node of the transfer ellipse).

c) the launch azimuth was 0°.

d) the perigee radius is equal to the radius of the Earth.

2.12 The Molniya orbit is

a) a nearly-equatorial orbit intended for the International Space Station (ISS).

b) is a geosynchronous orbit.

c) has a period of 1 week.

d) a high-inclination, eccentric orbit of nearly 12 h period intended to give communication capabilities to high-latitude areas such as Russia.

2.13 For a given impulse and initial mass of the spacecraft, the smaller the specific impulse of the propulsion system,

a) the larger the propellant consumption.

b) the larger the eccentricity of the orbit attained.

c) the smaller the propellant consumption.

d) the smaller the eccentricity of the orbit attained.

2.14 In a Hohmann transfer from an outer circular orbit to an inner circular orbit, the spacecraft first undergoes __________ to become injected in the transfer ellipse, and then __________ for insertion into the inner circular orbit.

a) an acceleration / a deceleration

b) a deceleration / a deceleration

c) an acceleration / an acceleration

d) a deceleration / an acceleration

2.15 The regression of the line of nodes and the rotation of the line of apsides are produced by

a) the eccentricity of the Earth and are more important in nearly-equatorial orbits.

b) the eccentricity of the Earth and are more important in nearly-polar orbits.

c) the precession of the Earth's rotation axis and are more important in nearly-polar orbits.

d) the solar radiation.

2.16 The regression of the line of nodes causes the ground trace of a satellite in a direct orbit to be displaced more towards the __________ than it should be by only the Earth rotation.

a) East

b) North

c) South

d) West

2.17 An interplanetary mission is designed to take a space probe from Earth to Saturn by a Hohmann-type transfer trajectory. Once that the probe arrives at Saturn

a) it can come back to Earth by simply following the other half of the Hohmann transfer ellipse used to arrive at Saturn.

b) it has to be transferred to an elliptic orbit.

c) it cannot come back to Earth by simply following the other half of the Hohmann transfer ellipse used to arrive at Saturn since the phase angle between the two planets has changed.

d) it will run out of propellant.

2.18 The synodic period

a) is the time that the Earth takes to rotate 360° degrees about its axis.

b) is the time that the Earth takes to rotate 1 solar day about its axis.

c) is the time that Mars takes to rotate 1 solar year about the Sun.

d) is the period of time after which the relative position of two planets is exactly repeated.

2.19 For missions to inner planets in the Solar System like Venus and Mercury,

a) the spacecraft has to be launched with a negative hyperbolic excess speed (in the opposite direction to the Earth's orbital motion).

b) the spacecraft has to be launched with a positive hyperbolic excess speed (in the same direction as the Earth's orbital motion).

c) the spacecraft has to be launched at the escape speed.

d) the launch azimuth angle must be 180°.

2.20 In an acceleration gravity-assist maneuver around Venus,

a) the relative velocity of the spacecraft with respect to Venus increases.

b) the relative velocity of the spacecraft with respect to Venus decreases.

c) the velocity of the spacecraft with respect to the Sun increases.

d) the velocity of the spacecraft with respect to the Sun decreases.

MAE 180A: Spacecraft Guidance I, Summer 2009

Final Exam

Saturday, August 1.

Part II: Problems. (60pt)

8:40AM-11:00AM.

Guidelines: Please turn in a *neat* and *clean* exam solution. Answers should be written in the blank spaces provided in these exam sheets. Show all work. Vector quantities are denoted in **bold** letters in what follows. This part of the exam is **open book, open notes, use of calculator allowed**.

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Problem 1: The Geostationary-Orbit (GSO) Mission (30 pts)

A Geostationary satellite is launched by an Atlas rocket at the Cape Canaveral launch site (latitude 28° N) with an azimuth angle $\beta = 90°$, and it is injected into a circular low-Earth orbit (LEO) of 300 nautical miles altitude above the Earth's surface. The local sidereal time at the projection of the ascending node onto the Earth's surface is $\theta_{LST} = 30°$. The satellite is transferred to a Geotransfer orbit (GTO) at the ascending node of the LEO, and finally injected into a Geostationary orbit (GSO) at the intersection of the GTO with the equatorial plane. *In this analysis, the GTO is assumed to be a Hohmann tranfer ellipse. Note: a GSO orbit is a circular equatorial orbit of period equal to the period of rotation of the Earth about its axis, $P = 1$ sidereal day $= 23.98$ h.*

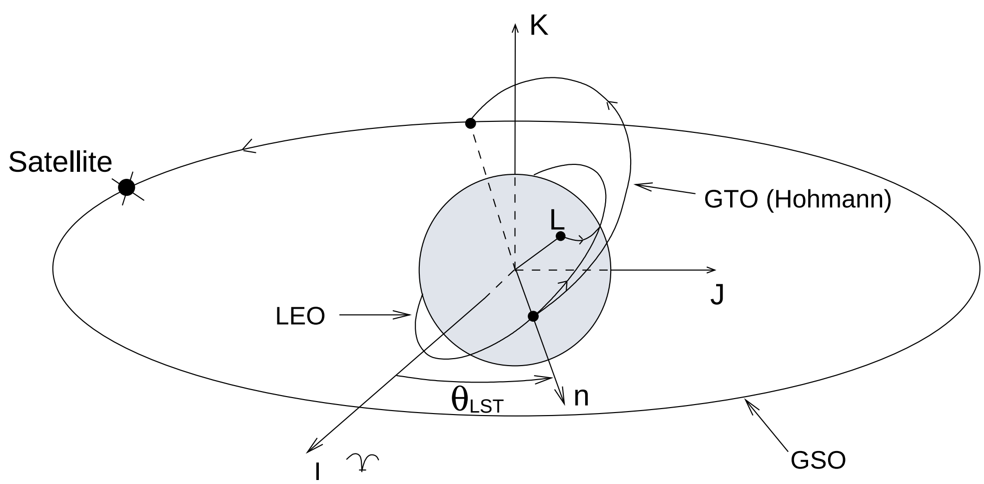

Figure 1: The GSO Mission.

Answer to the following questions:

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a) Calculate the semi-major axis, eccentricity, inclination angle, longitude of the ascending node and the argument of the periapsis of the initial LEO. Additionally, calculate the true longitude at epoch of the satellite at the transfer point to the GTO.

b) Calculate the orbital velocity of the satellite along the LEO, and the impulse ΔV_1 needed to transfer from the LEO to the GTO.

c) Calculate the time of flight from i) the transfer point to GTO to ii) the intersection of the GTO with the GSO.

d) Calculate the impulse ΔV_2 needed to change from the GTO plane to the GSO plane at the intersection of the GSO with the GTO.

e) Calculate the tangential impulse ΔV_3 needed to inject the satellite into the GSO once the plane-change maneuver has been performed

f) Obtain the total impulse $\Delta V_T = \Delta V_1 + \Delta V_2 + \Delta V_3$.

g) The company responsible for the satellite engines decides to install a new propulsion system in the satellite that has thrust-vectoring capabilities, such that the last two maneuvers d) and e) (plane change and tangential circularization) can be combined into a simultaneous single one. Calculate the ΔV_{23} necessary to perform this two maneuvers simultaneously and obtain the total impulse $\Delta V_T' = \Delta V_1 + \Delta V_{23}$. How much is the total impulse reduced by using the new propulsion system?

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Problem 2: The Mars-Lander Mission (30 pts)

A NASA Mars-Lander spacecraft is sent to Mars with the objective of human exploration of the the Martian surface. The spacecraft is composed of an Orbiter and a Lander, and its mass-distribution specifications are

	Structure	Propellant (MMH / N_2O_4)
Orbiter	2717 kg	1875 kg
Lander	500 kg	100 kg

The specific impulse of the Orbiter propulsion system is $I_s = 320$ s. Detailed design calculations have shown that an impulse $\Delta V_{CM} = 1$ km/s must be reserved for control maneuvers such as trajectory-control and attitude-control maneuvers during the interplanetary flight. The space probe is placed into the payload fairing of an Ares-V rocket before launch at the Cape Canaveral base (latitude 28° N) on the East Coast of USA, and it is to be launched from this place with an azimuth angle of $\beta = 90°$ in a direct orbit. After launch, the space probe remains attached to a powerful Upper Stage orbiting in a circular LEO of 350 nautical miles altitude above the Earth's surface. Simplifying assumption: The Earth and Mars orbits are assumed to be circular and are both contained in the ecliptic plane, which is inclined 23.4° with respect to the Earth's equator. Additionally 1 AU/$TU_\odot$=3.768 $DU_\oplus/TU_\oplus$, 1 $DU_♂/TU_♂$=0.12 AU/$TU_\odot$.
Answer to the following questions pertaining each of the mission stages.

Phase 1) Launch from Cape Canaveral. The spacecraft is launched with the azimuth angle specified above.

Question a) Calculate the inclination and radius of the initial LEO attained.

Question b) Calculate the circular velocity of the probe + Upper Stage in the initial circular parking LEO.

Phase 2) Departure. Permission for departure is given from the NASA mission center, and the Upper Stage performs a change of plane to the ecliptic and a subsequent impulse maneuver at the perigee of the departure hyperbola, to launch the spacecraft into the interplanetary trajectory, which is Hohmann ellipse tangent to the Earth at perihelion. After performing these two maneuvers, the Upper Stage is jettisoned and the spacecraft continues alone along the interplanetary path (see figure 2)

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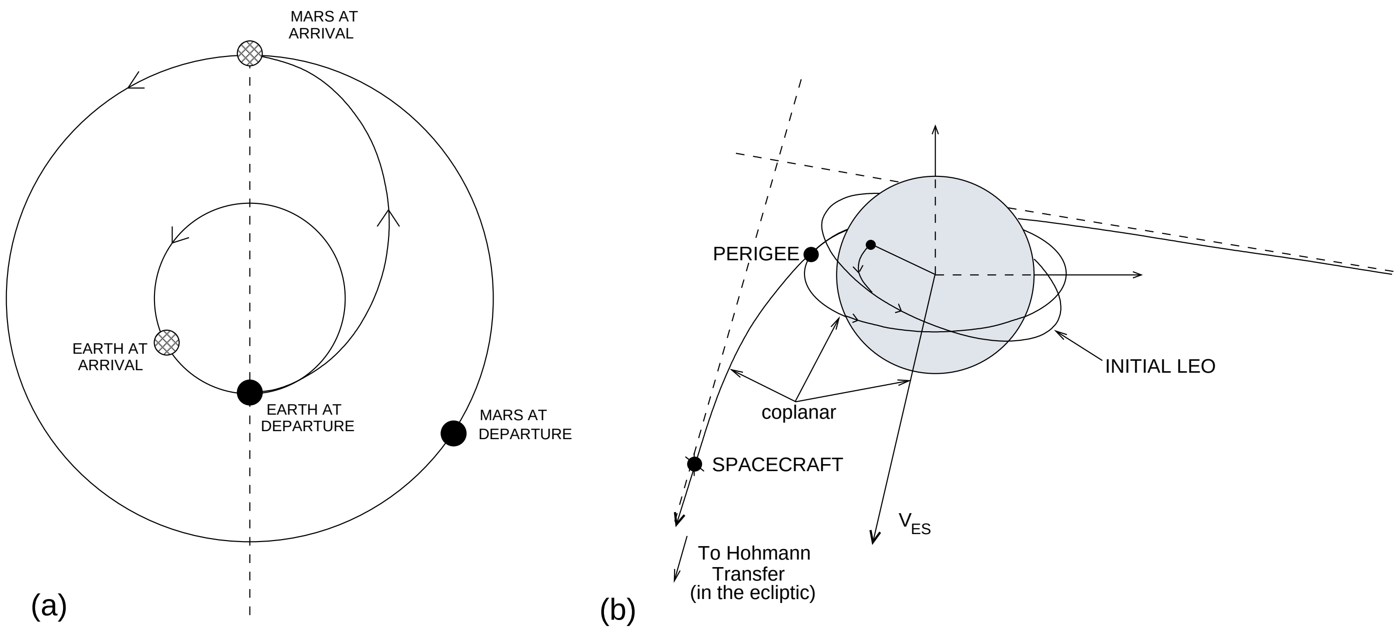

Figure 2: (a) Interplanetary trajectory. (b) Departure phase at the Earth.

Question c) Calculate the ΔV_1 needed to change planes from the initial circular parking LEO to an identical circular orbit on the ecliptic plane.

Question d) Determine the velocity of the spacecraft at the perihelion of the transfer ellipse.

Question e) Obtain the burnout velocity, the C_3 of the Upper Stage, and the ΔV_2 necessary to attain the injection velocity calculated in part d) for the interplanetary trajectory.

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Phase 3) Interplanetary Flight. The interplanetary trajectory consists on a Hohmann transfer to Mars as depicted in figure 2(a). During this phase, the spacecraft performs the Control Maneuvers to attain the correct arrival trajectory.

Question f) Determine the velocity of the probe at the aphelion of the Hohmann transfer ellipse.

Phase 4) Arrival at Mars. The arrival trajectory is a hyperbola of minimum approach distance $1.5b$, where b is the effective colision section (see figure 3). The retro-rockets of the spacecraft are activated at the periapsis to transfer from the hyperbolic trajectory to a tangent circular parking orbit.

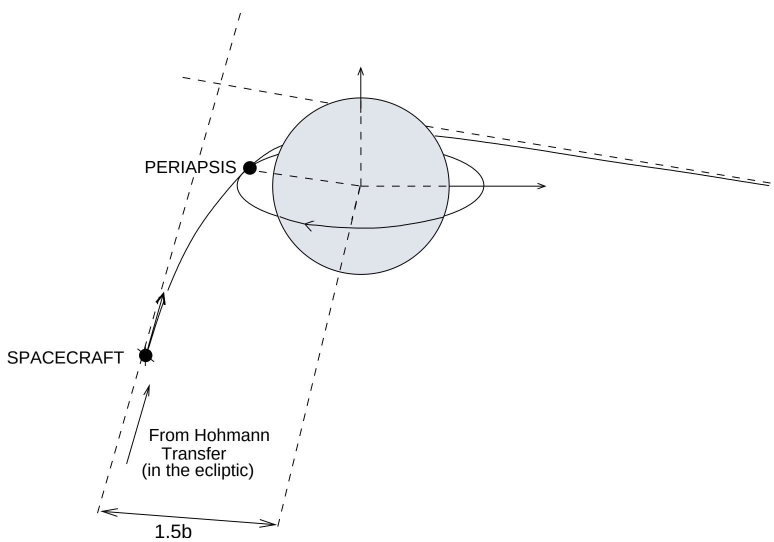

Figure 3: Arrival phase at Mars.

Question g) Calculate the hyperbolic excess velocity of the spacecraft at arrival.

Question h) Calculate the effective collision section b.

Question i) Calculate the impulse ΔV_3 necessary to transfer to the specified circular parking orbit.

Question j) Obtain the total amount of propellant spent by the spacecraft. Is there enough propellant on board the spacecraft to perform this mission?.

Phase 4) Lander Reentry in the Martian Atmosphere. At some point along its circular orbit, the Lander is ejected from the spacecraft tangentially to the orbit, leaving the Orbiter alone. This ejection maneuver causes the Lander to be tangentially injected into an elliptic ballistic trajectory towards the Martian surface (see figure 4).

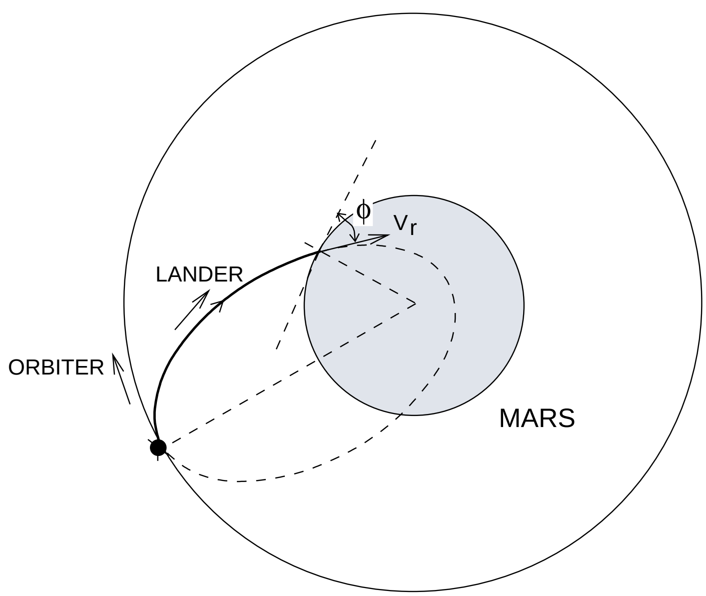

Figure 4: Lander Reentry maneuver.

Question k) Calculate the Lander ejection velocity with respect to the Orbiter, if the allowable reentry angle (i.e. the flight path angle) is $\phi = 11°$ for avoiding the Lander disintegration during the reentry. For this part, assume that the radius of the Martian atmosphere is approximately equal to the radius of the planet Mars.

Question l) Determine the Mach number at reentry, $M = V_r/a$, where V_r is the reentry velocity of the Lander and $a = 244$ m/s is a characteristic speed of sound in Mars.