AAE 532 – Orbit Mechanics
Problem Set 8
Due: JD 2459160.1875 (UT)

Problem 1: Recall Problem 2 in PS7. You computed the cost $|\Delta\bar{v}|$ and TOF associated with a Hohmann transfer to Jupiter. But, in that preliminary analysis, you neglected the local gravity fields.

(a) Re-examine the Hohmann transfer but <u>include the local fields</u>. Assume the planetary orbits are circular; the Earth dark-side departure is from a 250 km altitude parking orbit. For the Juno spacecraft, the eventual science orbit at Jupiter was very close to the planet. So assume that arrival at Jupiter occurs on the light side and the spacecraft is captured into a circular Jovian orbit of radius $2.8R_{Jupiter}$. Of course, include all diagrams representing the local views.
Compare the results with the cost Δv_{dep}, Δv_{arr}, and Δv_{total} as well as TOF in PS7. [The Earth departure maneuver is Δv_{dep}; then the maneuver to capture at Jupiter is Δv_{arr}.]
Does adding the local fields impact the total $|\Delta\bar{v}|$? Does the inclusion of the local fields increase or decrease the cost? Does the maneuver cost increase or decrease at Earth? at Jupiter?

(b) The cost will differ depending on the capture orbit at Jupiter. As an alternative, assume into a capture orbit that is similar to the insertion orbit actually used by Juno—an eccentric Jovian orbit. Let capture orbit characteristics be $r_p = 2.8R_{Jupiter}$ and $e = 0.90$. Consider insertion into the capture orbit at perijove and compute the insertion cost, that is, the $|\Delta\bar{v}_{arr}|$.
Does the total cost improve in terms of Δv_{arr} and Δv_{total}? Why do you think this difference occurs?
The Juno spacecraft first entered this eccentric orbit at Jupiter, then used a series of maneuvers to reduce the size and eventually reach the science orbit. Discuss: why do you think the eccentric insertion orbit was used for Juno?

(c) Reconsider the Jupiter arrival. Assume that the vehicle arrives at Jupiter but does not capture. Instead, it is just a flyby. You should already have the arrival conditions in the heliocentric orbit: $r^-, v^-, \gamma^-, \theta^{*-}$ from (a).
If there is no capture maneuver, determine the characteristics of the new heliocentric orbit of the spacecraft after the Jupiter encounter: $r^+, v^+, \gamma^+, \theta^{*+}$. Compute the orbital characteristics of the new heliocentric orbit: $a, e, r_p, r_a, period, energy, \Delta\omega$. Did the spacecraft gain or lose energy?

(d) Plot the old and new heliocentric orbit of the spacecraft in Matlab.
Compute the equivalent Δv_{eq} and α. Will the spacecraft reach the orbit of Saturn? Uranus?
If timed correctly, could encounters of Saturn and, maybe, Uranus now occur?

Problem 2: The US is currently planning for humans to reach the Moon in 2024. Consider a Hohmann transfer to the Moon. Assume departure from a 190 km altitude circular Earth parking orbit; <u>include the local gravity field at the Moon</u>.

(a) Determine the Δv and TOF for a Hohmann transfer to the Moon if the spacecraft drops into a circular orbit at the Moon with radius of altitude 200 km. Assume arrival on the near (light) side.

What are the transfer characteristics for the geocentric orbit: $r^-, v^-, \gamma^-, \theta^{*-}$ at lunar arrival, $a^-, e^-, r_p^-, r_a^+, IP^-, \mathcal{E}^-$?

Phase angle at departure from the Earth parking orbit?

(b) If the spacecraft does not execute the capture maneuver, determine the orbit of the vehicle relative to the Earth, that is, the new geocentric orbit. What turn angle δ is delivered by the Moon?

What are the orbital characteristics, relative the Earth, after the lunar encounter, i.e., $r^+, v^+, \gamma^+, \theta^{*-}$ at the Moon after encounter, $a^+, e^+, r_p^+, r_a^+, IP^+, \mathcal{E}^+, \Delta\omega$ in the new orbit.

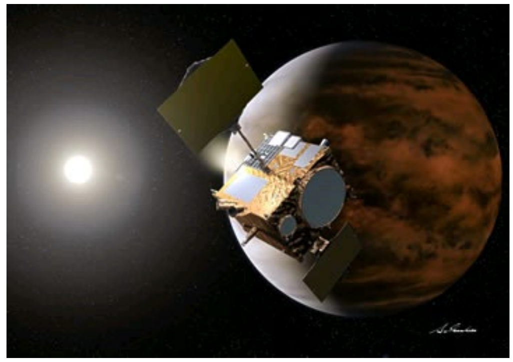
Does the spacecraft gain or lose energy? Why?

Will the new orbit come close the Earth? If there is a crew onboard and the lunar capture maneuver is not successfully implemented, can the crew return to Earth?

(c) What is the equivalent Delta-V, i.e., $\left|\Delta\overline{v}_{eq}\right|$ and the in-plane angle α, produced via the lunar flyby in (b)? Express the $\Delta\overline{v}_{eq}$ in terms of VNB coordinates.

(d) Plot the initial Earth orbit in GMAT and use a two-body Earth propagator. Add the equivalent $\Delta\overline{v}_{eq}$ to reflect the impact of lunar gravity; the $\Delta\overline{v}_{eq}$ is added in terms of its VNB components. The new orbit should be the same as the outbound orbit in (b). Compare the new orbital characteristics from GMAT output.

Problem 3: Some years ago, JAXA, the Japanese space agency, launched a Venus orbiter May 20, 2010 to study the planet's climate. The mission was known as Akatsuki. The spacecraft arrived at Venus December 7, 2010. There was a valve problem, however, and the capture maneuver failed. Nevertheless, assume that you are preparing a preliminary trajectory design for a mission design to Venus. Assume that Earth and Venus are in circular, coplanar orbits; <u>include local gravity fields in the analysis</u>.



(a) Start with a Hohmann transfer from Earth to Venus. What is the TOF? Determine the phase angle required to arrive at Venus.
Include a diagram of the heliocentric view; indicate the velocity vectors $\bar{v}^+, \bar{v}^-, \bar{v}_\oplus, \bar{v}_{venus}$. Locate Earth at departure and Venus at departure and arrival.

(b) Consider a spacecraft (e.g., Akatsuki) departure from Earth in a geocentric diagram. What is the $\bar{v}^+_{\infty/\oplus}$ that the spacecraft must possess to be on the correct heliocentric transfer orbit? Assuming a 210 km altitude Earth parking orbit, what $\Delta\bar{v}_{dep}$ will yield this $\bar{v}^+_{\infty/\oplus}$? In the diagram of the geocentric view; indicate the velocity vectors $\bar{v}^+_{\infty/\oplus}, \bar{v}_\oplus, \Delta\bar{v}_{dep}$.

(c) The spacecraft arrives at Venus along a light side passage and enters a circular orbit at an altitude of 2000 km altitude. Determine arrival conditions: $r_p^-, r_a^-, \boldsymbol{\mathcal{E}}^-\ r^-, v^-, \gamma^-, \theta^{*-}$. What velocity $\bar{v}^-_{\infty/venus}$ results from the Hohmann transfer? What is the required orbit insertion $\Delta\bar{v}_{arr}$? Include the Venus-centered diagram. What is the $\Delta v_{dep}, \Delta v_{arr}$, and Δv_{total} for this transfer plan?

(d) Consider the trajectory consequences if the Venus orbit insertion (VOI) maneuver implementation fails. Compute the turn angle δ and $\bar{v}^+_{\infty/venus}$.
What is the new heliocentric velocity in terms of $r^+, v^+, \gamma^+, \theta^*$? What is the equivalent $\Delta\bar{v}$ due to the flyby, i.e. $\left|\Delta\bar{v}_{eq}\right|, \alpha$? Has the spacecraft gained or lost energy?
Compute the following characteristics of the new heliocentric orbit: $r_p^+, r_a^+, \Delta\omega, \boldsymbol{\mathcal{E}}^+$.

(e) Plots the orbits in Matlab: Earth orbit, Venus orbit, transfer orbit, new heliocentric orbit that results post-encounter. Mark the $r_a^-, r_a^+, \Delta\omega$.
Is the spacecraft ascending or descending after the encounter? Will the spacecraft cross Earth's orbit again? Will the spacecraft reach the orbit of Mercury?
Discuss: How might the new heliocentric orbit change of the Venus encounter was a dark-side passage?