ENAE 483/788D MIDTERM – FALL, 2022 – *NAME:*

This is a closed book test, but you can have one 8.5"x11" page of notes (both sides). No cell phones or other internet-enabled devices, which also rules out calculator apps on your phones. Keep an empty seat between you and your neighbors if at all possible. Each question (or subquestion) is worth 5 points, for 100 points total without the extra credit. If you need extra room, use the back of the facing page, but be sure to label your work. Write neatly, and draw a box around your answers.

Some hints: if it seems like you need to iterate or do other "brute force" solutions, you are probably doing the question wrong. There's probably a simpler way. Some of these questions are very simple and some are more challenging. Don't get stuck on a hard one and run out of time to do easier ones. Time management is important, remember that all questions count the same amount.

Some possibly useful numbers:
$\mu_{Earth} = 398,604 \ \frac{km^3}{sec^2}$, $r_{Earth} = 6378\ km$,
$\mu_{Mars} = 42,970 \ \frac{km^3}{sec^2}$, $r_{Mars} = 3393\ km$
$\mu_{Moon} = 4667.9 \ \frac{km^3}{sec^2}$, $r_{Moon} = 1738\ km$

(1) NASA has selected the SpaceX Starship as the basis of their first Human Landing System (HLS) for returning humans to the lunar surface. Starship HLS has an inert mass $m_{in} = 130$ mt and a maximum propellent mass $m_{pr} = 1200$ mt. Its rocket engines have a specific impulse $I_{sp} = 380 sec$. HLS missions will begin and end in a near-rectilinear halo orbit (NRHO) at the Gateway station. The Δv to reach the lunar surface from Gateway is 2750 m/sec; the Δv to return to Gateway from the lunar surface is also 2750 m/sec. Just to be sure you understand: the vehicle departs fully fueled from Gateway. If the mission is to land and return, all propellant for the entire mission is on board at the initial departure from Gateway.

(a) The first uncrewed test flight is currently planned to be a one-way mission to land and stay on the lunar surface. How much payload could a fully-loaded Starship carry to the lunar surface in this expendable mode?

(b) The first crewed mission is planned to allow 100 mt of payload in both directions, to and from the lunar surface. How much propellant would be required for this mission?

(c) While carrying 100 mt of payload to the lunar surface will help establish and support a lunar base, there's only a requirement for about 5 mt of payload from the surface back to Gateway. How much propellant is required for this mission?

(d) One early design for HLS Starship had 24 smaller thrusters around the top of the vehicle which were used for the final landing to prevent the large Raptor engines at the base from kicking up lunar particles and damaging everything that might be in the vicinity. If each of these engines have a 99% reliability, what is the overall reliability for the engine cluster?

(e) How does your previous answer change if the system can tolerate failures in 2 out of the 24 engines?

(f) How does this further change if there is a 30% intercorrelated failure rate in the engines?

(g) HLS Starship will need to refuel at Gateway; the Starship tankers that will carry the propellents there will themselves need to refuel in low Earth orbit (LEO). To facilitate this, we might establish a propellant depot in LEO with a spherical propellant storage tank 30 m in diameter. Using the MMOD chart at the end of this exam, what particle size should you design for as the largest hit you would expect in a 20-year orbital lifetime for the depot? [area of a sphere=$4\pi r^2$, although you should really know that]

(h) Estimate the mass of the 30 m diameter sphere for the propellant depot, using the mass estimation relation that $m_{tank} = 12.2 V_{tank} \left\langle m^3 \right\rangle$. [You should also know that the volume of a sphere is $4/3\pi r^3$]

(i) The depot is located in a 350 km low Earth orbit to maximize payload for the Starship launchers carrying propellant to it from the surface. What is the atmospheric drag on the sphere at that altitude? For the sake of this problem, assume the drag coefficient of a sphere in Newtonian flow is 5/3. [density model for LEO $\rho = 3.875 \times 10^{-9} e^{-h/h_s}$, where h_s=59 km.]

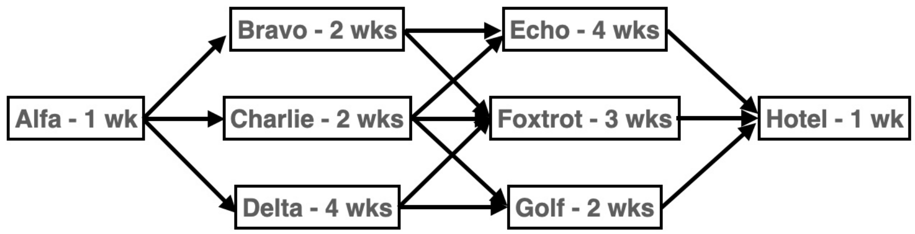
(j) The cost estimation algorithms for this category of spacecraft are as follows:

$$c_{NR}(\$M) = 12.23 m_{in}^{0.55}(kg)$$
$$c_{R1}(\$M) = 0.2904 m_{in}^{0.662}(kg)$$

Find the total cost for designing HLS Starship and building three vehicles, assuming an 85% learning curve on production.

(k) NASA has decided that they will hold a competition for a second HLS design, to have two dissimilar ways to transport astronauts to and from the lunar surface. Dynetics is going to resubmit their ALPACA design, which is much smaller than the Starship HLS. ALPACA will be totally reusable, so it will depart Gateway with sufficient propellant to land the 8 mt payload on the moon and return it to Gateway. The propulsion module has a stage inert mass fraction ϵ =0.10. Calculate the gross mass of ALPACA at the beginning of its lunar mission.

(2) For the program in the following PERT chart, find the critical path and total completion time.



(3) You are tasked with designing a mission to explore the moons of Saturn, of which there are 83 currently known. To do this, you need to design maneuvers in the gravity environment of Saturn ($\mu = 3.793 \times 10^7$ km^3/sec^2). For the purposes of this exam problem we are going to neglect the gravitational attractions of the moons themselves, and calculate maneuvers between their orbits around Saturn.

(a) We're going to start at Titan, the largest of Saturn's moons (and the largest moon in the solar system), which has an orbital radius of 1,222,000 km around Saturn. Your spacecraft arrives from Earth in the vicinity of Saturn with a hyperbolic excess velocity v_h =4.2 km/sec. What is the required Δv for it to enter the same orbit as Titan around Saturn?

(b) After exploring the region around Titan, you want to travel to Iapetus, the third-largest of Saturn's moon with an orbital radius of 3,561,000 km. What is the total Δv for moving from Titan's orbit to Iapetus' orbit using a coplanar Hohmann transfer?

(c) Oops, you just realized that Iapetus has a 14.5° inclination compared to Titan. How does your previous answer change if you do all of the plane change in the maneuver at apoapse?

(d) Hyperion is an interesting moon, as it is locked in a 4:3 orbital resonance with Titan, which means that its orbital period is exactly 4/3 that of Titan. What is the orbital radius of Hyperion around Saturn?

(4) You are trying to decide your what you think is the greatest of all real-space movies, so you decided to use the analytical hierarchy process to determine the relative strengths of your opinions. The table below lists your (actually, my) weighted scores in pairwise comparisons. Calculate the AHP values for each movie.

	The Martian	2001	Apollo 13
The Martian		3	.333
2001			0.111
Apollo 13			

(5) What are the names (first and last) of the other two members of your graphics project team?

(6) List something you tried to do in CAD that was either extremely difficult to do, or that you couldn't get to work at all.