AST 2000 - Part 3
Preparing For The Journey

Welcome to Part 3 of the AST2000 Spacecraft Project. In this part you are going to prepare for your space mission by first estimating the surface temperature of the planets in your solar system and thereby finding the habitable zone, then choosing your destination planet, going back and generalizing your launch procedure and making other preparatory calculations.

GOALS

- ∇ Create a simple model of your solar system's habitable zone.
- ∇ Choose your spacecraft's destination planet.
- ∇ Generalize the launch procedure from part 1.
- ∇ Calculating when your satellite is sufficiently close to your destination planet in order to enter orbit and finding out how close you need to be to your planet in order for it to appear on a picture.

1. The Habitable Zone

Relevant theory is described in Lecture Notes 1D. The habitable zone is the zone where planets with liquid water, and therefore possibly life as we know it, may exist.

1. We begin by assuming that the star is a stable black body. Find an expression for the flux received from your star at an arbitrary distance r. You only need to know the temperature and radius of your star as well as epxressions for flux and luminosity.

2. Once you arrive at your destination, your lander unit will require a source of electric power. To run the electric instruments on your lander, you need to produce 40 W of electric power using solar panels. The solar panels installed on your lander unit have an efficiency of 12%.

   You may disregard the day-night cycle, this is accounted for in the 40 W figure. You should also ignore the atmosphere on the planet; assume the flux incident on the planet is equal to flux incident on the lander unit.

   Use your expression to find a formula for the minimum solar panel area necessary for your lander to function.

3. Find an expression for the total energy received by a planet with radius R at a distance r from your star. You can assume the light rays received by the planet are parallel.

4. Assume the planets in your solar system are black bodies with stable temperatures; i.e., the net flow of energy out of the planets is zero. Use your expression for the total energy received by a planet and Stefan-Boltzmann's law to derive a model for the surface temperature of the planets in your solar system.

5. Use your new temperature model to estimate the temperature of each planet in your solar system.

   Our model for the habitable zone is based on whether liquid water can be found on the surface. Assuming liquid water can only exist when the surface temperature is within the range $260 - 390$ K ($\pm \approx 15$ K), calculate the boundaries for the habitable zone. Which planets are within the zone?

2. Choose your Destination

It is now time to choose your destination! Please note that you are not forced to travel to a planet within the habitable zone. Furthermore, we advise not travelling to gas giants (unless you enjoy high-velocity dust storms with very little visibility); their heavy gravity and thick atmospheres make it very difficult to land. It is also difficult to record cool landing videos on gas giants. [1]

Revisit the `SSView` application described in Part 2! It is much easier to visualise your journey if you can see the planetary orbits scaled relative to one-another.

Once you have chosen your destination, use the formula you derived in question 2 in challenge 1 to calculate how large your landing unit's solar panels need to be. (The size may be ridiculously large for planets farther out in the solar system. This may be disregarded.)

3. Generalized Launch Codes

Before you continue to the final challenge, you first need to generalize your program from challenge F in Part 1 in which you calculated the spacecraft's position and velocity, as seen from the solar system's frame of reference, at the moment the launch was complete.

As the solar system's frame of reference used AU units, your program also had to switch from SI units to AU units. In that challenge we forced you to launch at $t = 0$, but this will no longer be a requirement going forward.

Your task is therefore to use the planetary orbits from Part 2 in order to generalize the launch sequence to an arbitrary time t. What's more, you are also allowed to launch from any position on the surface of your planet (our launch site technicians work very fast). You should be able to use the exact same mathematics, program structure, etc.

Note that you may still ignore air resistance during the launch, and assume that the launch is *always* directed radially outwards.

4. The Dominant Gravitational Force

This is optional for those working alone.

Say a spacecraft is close to a planet in your solar system. Let the gravitational force from the planet on the spacecraft be k times larger than the gravitational force from the star on the spacecraft. Prove that the spacecraft is a distance l given by:

$$l = |\mathbf{r}|\sqrt{\frac{M_p}{kM_s}} \qquad (1)$$

from the planet, where $|\mathbf{r}|$ is the distance from the spacecraft to the star, M_p is your destination planet's mass and M_s is the mass of your star.

In part 5, we will use this formula with $k = 10$. What this means is that we consider the spacecraft to be sufficiently close to the destination when the gravitational force from the planet dominates the gravitational force from the star by a factor of 10. Performing an orbital injection maneuver is easier for higher values of k.

5. Are you Able to Take a Picture of Your Destination?

In part 5, you will launch you space craft. It will then be interesting to know how close your spacecraft needs to get to your planet in order for your destination planet to appear on pictures that the space craft takes. Your spacecraft has been equipped with a camera whose resolution is limited by the camera's number of pixels. It is commonly said that an object is resolved when it appears as more than one pixel on the resulting image. Assume that the camera has pixel dimensions $P \times P$ and field of view $F \times F$, where P and F are measured in pixels and degrees. Let R denote the radius of the planet and show that the distance from the spacecraft to the planet must be at least:

$$L \lesssim \frac{RP}{F} \qquad (2)$$

in order for the camera to resolve the planet.

START WRITING

Once you have finished and are satisfied with this part, it is time to take a step back and look at the project as a whole. If you have not started writing your reports, you should definitely do so. Most of the method sections are independent from each other and can be written with little regard to the composition of your report. You should also begin to produce a concrete plan regarding your report's structure, layout, etc.

FIG. 1. Orbitally motivational, trajectory-planning duck.

AST 2000 - Part 3
Tips, Hints & Guiding Questions

I. HINTS FOR SOME OF THE CHALLENGES

1. Calculations on the Habitable Zone

→ Remember that for a stable black body, the surface temperature is constant and given by Stefan-Boltzmann's law.

→ Efficiency:

$$\varepsilon \equiv \frac{\text{energy out}}{\text{energy in}} \tag{a}$$

→ In question 3, the light rays incident on the planetary surface are parallel. As the planetary surface is curved, it is generally very difficult to find the distribution of light across the surface. But do we actually need to take the curvature into account? Consider figure 2: what area of light flux is lost?

2. Camera Resolution

To find L you first need to find the angular size of a pixel, then use the small angle approximation for $\tan\theta$ in order to express θ in terms of R and L.

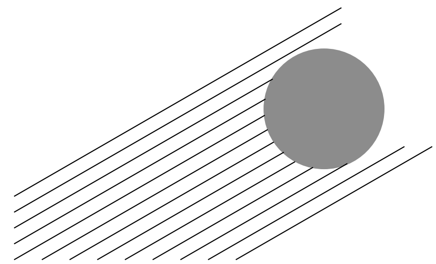

FIG. 2. An illustration of the area covered by parallel light rays when incident on a planet's surface.

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[1] For more information on the difficulties associated with landing on gas giants, check out the Kerbal Space Program.