AST 2000 - Part 7
The Landing

Welcome to Part 7 of the AST2000 Spacecraft Project. That's right! You are finally landing your spacecraft at your chosen destination. This is the final part of the project in which the spacecraft is explicitly featured in your calculations. **Note that this part is one of three parts (the others are part 2 and 6) where you may choose to be evaluated only on how well you accomplished the challenges (including the code) as well as the results, conclusions and discussion part. This allows you to make the report/blog for this part considerably shorter. If this is what you prefer, you should start your report/blog stating this.**

GOAL

▽ Make some guiding calculations based on the atmospheric air resistance.

▽ Use a combination of simulations and intuition in order to land your spacecraft.

A COMMON MODEL OF AIR RESISTANCE

A common model for air resistance is the so-called drag equation, which can be mathematically written as

$$F_d = \frac{1}{2}\rho C_d A \, v_{\text{drag}}{}^2 \qquad (1)$$

Here, F_d is the air resistance experienced by a body with cross-sectional area A, travelling with speed v with respect to air with density ρ. The constant C_d is a dimensional variable called the drag coefficient, which in general is not a constant. The force of air resistance acts opposite to the direction of motion.

CHALLENGES

All previously invoked simplifications and assumptions are, obviously, also included in this part.

A. Air Resistance

Before you start simulating the landing, let us take a closer look at the effects of air resistance using the drag equation as our model. To simplify your calculations you can assume $C_d = 1$.

Note that in the context of your spacecraft travelling through the atmosphere, $\mathbf{v}_{\text{drag}}$ in equation (1) is not the velocity you measure using the `orient` command. Let $\mathbf{v}$ denote the velocity of your spacecraft with respect to the planet, and let $\mathbf{w}$ denote the velocity of the planet's atmosphere with respect to the planet.

1. Calculating Air Resistance

In Part 6 you derived a model for your planet's atmospheric composition, we are now going to expand our model of the atmosphere by including the atmosphere's motion.

Assume that the atmosphere follows the planet's rotation. In particular, the entire atmosphere travels with the exact same angular velocity.

1. Find an expression for $\mathbf{w}$ as a function of the position in the atmosphere.

2. Find an expression for $\mathbf{v}_{\text{drag}}$ in terms of $\mathbf{w}$ and $\mathbf{v}$. Use this expression as a means to design a function that calculates the air resistance experienced by your spacecraft as a function of its cross-sectional area and its position and velocity with respect to the planet.

2. Terminal Velocity

We are now going to take an analytical approach to find your spacecraft's terminal velocity, i.e. the velocity you spacecraft will reach after breaking in the atmosphere. Our interest in terminal velocity lies in the spacecraft's velocity during landing. You can have some control over this by adjusting the size of the parachute that you can deploy while descending through the atmosphere.

Your spacecraft's velocity with respect to the planet can be decomposed into two components: one radial component v_r and one tangential component v_θ. Mathematically speaking, $\mathbf{v}$ can be written as:

$$\mathbf{v} = v_r \mathbf{e}_r + v_\theta \mathbf{e}_\theta \qquad (2)$$

where $\mathbf{e}_r$ and $\mathbf{e}_\theta$ are the radial and tangential unit vectors.

1. Air resistance will immediately begin to act on the spacecraft once it enters the atmosphere. Assuming the spacecraft does not crash before reaching terminal velocity, can you give an argument that supports that the spacecraft will reach zero tangential velocity with respect to the atmosphere?

2. Argue further why the radial velocity v_r with time will stabilize on a constant velocity.

3. Let's assume $v_\theta = 0$, derive an expression for its constant terminal velocity v_r.

   After you have found the expression, rearrange it by solving for the area A (this corresponds to the total cross-sectional area of the lander, most likely with a deployed parachute).

4. Provide a reasonable estimate for A when the lander is close to the surface with $v_r = 3$ m/s. This is the maximum velocity required for a soft landing.

3. Landing Thrusters

Before continuing with the landing procedure, we must take a look at the landing itself.

In addition to the parachute, you are also given the option of using a set of landing thrusters. You are free to adjust the thrust output force of these thrusters in order to balance your terminal velocity during landing.

The force of these thrusters is denoted by F_L. Use $F_d + F_L = F_G$ (radial components only) in order to derive

$$F_L = \frac{1}{2}\rho_0 A\left(v_t{}^2 - v_{\text{safe}}{}^2\right) \qquad (3)$$

where $v_{\text{safe}} = 3$ m/s.

BEFORE CONTINUING

Before you begin the final challenges, we would like to encourage you to follow a controlled descent. The farther you travel through the atmosphere, the smaller the tangential component of your velocity will get. What this means is you will eventually fall straight down in a calm and controlled fashion. The landing thrusters give you the ability to break the speed of your satellite just before it reaches the surface. *Unless* you already have an idea of how you want to land, we encourage to follow this general scheme. This is also a great way to achieve an awesome landing video. [1]

B. Simulating the Landing

It is now time to begin your simulation of the landing. This challenge is in principle the same as challenge A in Part 5: your task is to design a program that simulates the trajectory of your spacecraft as it descends through the atmosphere. In the next challenge you are going to use this program in order to find the correct landing commands.

The program structure should, at the very least, include the following:

input	output
initial time	final time
initial position	final position
initial velocity	final velocity
simulation time	

It is essential that air resistance, gravity and the rotation of the atmosphere be present in your simulation. However, it is likely you will want to implement the various commands you have access to in the next challenge. *This is not required of course*, but here is a list of what you could implement if you want:

$\rightarrow$ Lander launch:
It is really not your whole spacecraft, but the spacecraft's landing module that will land on the surface. The lander is launched from the spacecraft at a specific time of your choosing, and with any velocity of your choosing. **Note that the lander does not have the same mass as the spacecraft. You can obtain the lander's mass from your `SpaceMission` instance.**

$\rightarrow$ Parachute deployment:
The lander carries a parachute with customizable surface area. You may freely choose the time of deployment, as long as the lander has been launched, and the area of the parachute (area is constant after it's been deployed).
(Hint: challenge A 2, question 3.) However, be aware that the parachute will fail if the drag force exceeds 250 000 Newtons! **Note that your spacecraft and lander in themselves have non-zero (and different) areas; you can obtain these from your `SpaceMission` instance.** You need these in order to calculate the breaking before the parachute is deployed.

$\rightarrow$ Landing thrusters:
The landing thrusters are equipped with a customizable thrust force of your choosing. Instead of a specific time, the landing thrusters are ignited once the lander unit is a specific distance, of your choosing, above the surface.

$\rightarrow$ Be careful with your lander! If the drag pressure on the lander exceeds 10^7 Pa it will be burned to ashes.

Check the `ast2000tools` documentation for a more detailed description of all available commands that can be performed through the `LandingSequence` instance. From your `SpaceMission` instance you can also obtain the following numbers: the spacecraft has a mass of 1100kg which includes the lander with a mass of 90kg. The area of the whole spacecraft is $16m^2$ and of the lander $0.3m^2$.

C.   Landing your Spacecraft

You will now begin the landing procedure. Your task is to determine the commands necessary in order to land on your chosen landing site. How you decide to approach this challenge is completely your own choice. Use your simulation as a guideline as to how your lander behaves in the atmosphere.

Your lander is capable of sustaining a radial velocity up to and including $v_r = 3$ m/s. All landings with v_r greater than 3 m/s are regarded as a crash landing. [2] If you find that your parachute fails or your lander is incinerated upon entering the atmosphere you need to slow down! Try to enter at a shallower angle to break more gently.

Lastly, you are not forced to land on your predetermined landing site. While this would be ideal, it is generally very difficult to achieve this. We will be very tolerant with regards to your landing position.

VERIFICATION/CONFIRMATION

In the event that your commands are able to successfully land your lander on the surface, a message is displayed in terminal. If you want additional confirmation you are always free to record an awesome landing video.

EXTRA CHALLENGE

Perfect your landing and shoot awesome videos. [3]

WRITE

After completing Part 7, you should be able to write all of parts 1 through 7. Parts 8, 9 and 10 do not depend on your results from parts 1 through 7. They do take place in the same solar system however!

FIG. 1. Oriented, trajectory-planning, motivationally orbital, atmospheric duck. Launched & landed.

AST 2000 - Part 7
Tips, Hints & Guiding Questions

I. COMMON PROBLEMS

There are some common problems that you may encounter:

- **Your spacecraft doesn't manage to land, it is thrown out in space just after entering the atmosphere:** Check your time steps. If your time steps are too large, you may suddenly experience too large forces (why?). Also check if you may have deployed the parachute too early?

- **The landing thrusters throw your satellite back into space**: Again check your time steps. There may also be another obvious reason.

- **You have landed but you can't see anything:** Take into account the planets rotation and direction towards it's star: you may have landed on the night side.

---

[1] You should know by now that we love awesome landing videos.
[2] Recall that lithosbraking is not allowed.
[3] I suggest contacting Hans Zimmer if you are looking for an original score for your film, though you may need to settle for Danny Elfman if he is unavailable.