Hot Air Balloon Modeling Project

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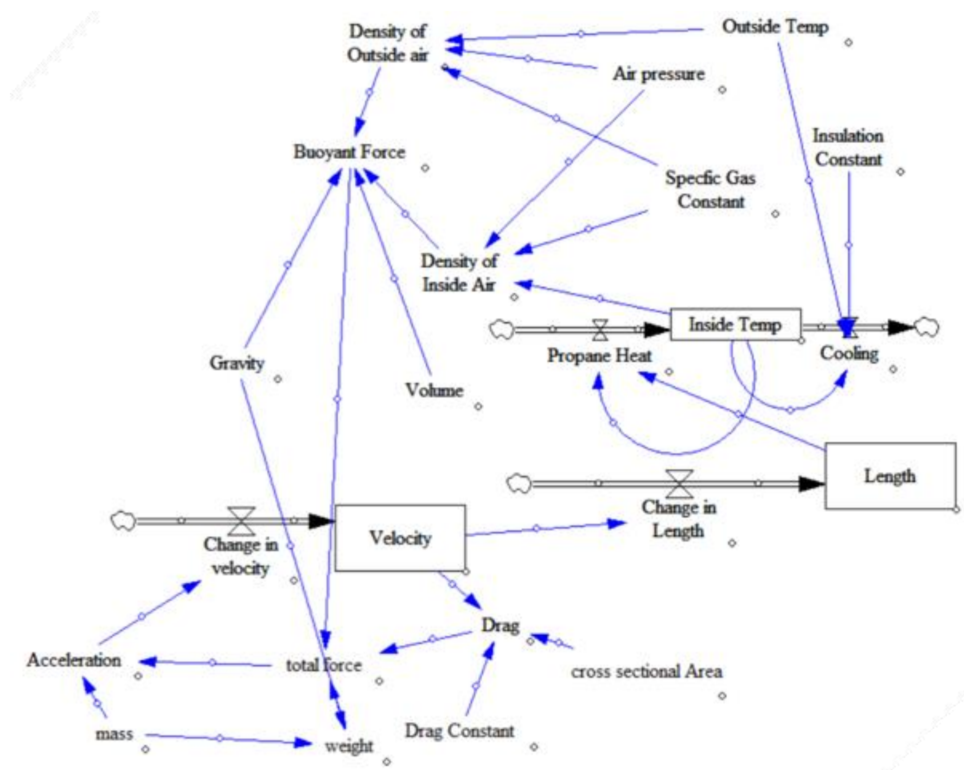
Introduction

To create a hot air balloon model, three models had to be put together. The three models used were: the physics models, the buoyancy model, and the inside temperature model. After connecting these three models, we used the results to answer some questions. The questions focused on the first and second burn and ascent of the balloon.

Model



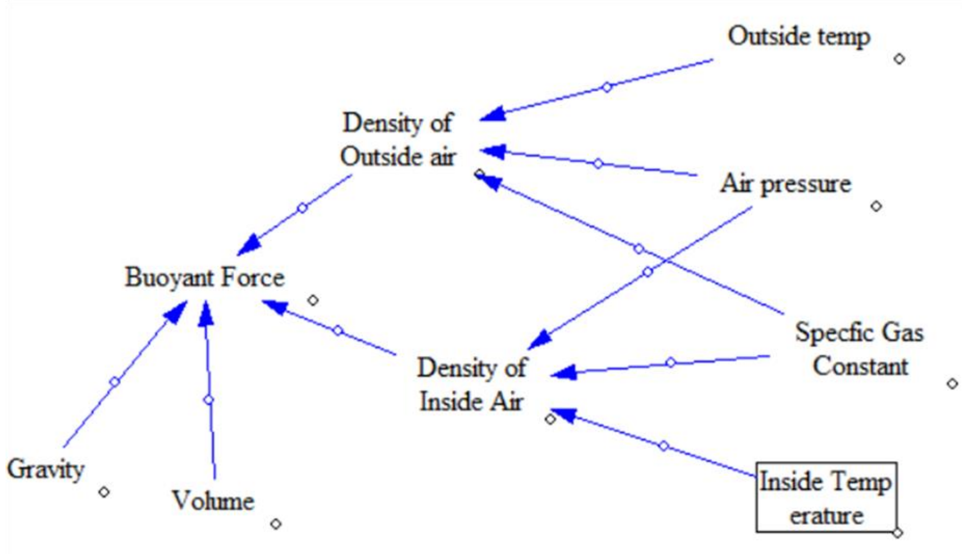
The first part of the project was to create three smaller models. The first model we created was the physics model, we had previously used this model before, in our falling without dying model. The second model was the buoyancy model, this is responsible for the balloon's ability to float. The third model was the inside temperature model, the burner turns on and off, heating and cooling the balloon.

1. Falling Physics Model

This is the model that captures the behavior of the balloon when it is just falling. Previously, the only forces employed were the Drag force and weight. Now though, there is another force added to our total force, buoyancy. This is what causes the balloon to rise.

2. Buoyant Force

A hot air balloon floats through the mechanism of buoyancy. Burning the fuel propane, under the balloon, heats the air inside the balloon. This heated air now has a lower density and mass than the air surrounding it. Because of this, the air on the inside rises, being lighter, and at the same time, air from the outside tries to push its way onto the inside. The pressure from this force is what causes the balloon to rise. The following graph shows the Vensim model for the Buoyant Force:



We have the equation for buoyancy as follows:

(Density of Outside Air - Density of Inside Air) * Volume * Gravity

The Density of Outside Air is modelled by the following:

Air pressure / (Specific Gas Constant * Outside Temp)

We have assumed that the Outside Temperature and Air Pressure remains constant, hence making the Density of the Outside air constant as well.

Finally, the Density of the Inside Air is modelled by the equation:

Air pressure/ (Specific Gas Constant * Inside Temp)

As we can see, Inside Temperature is one of the variables the Density of the Inside Air is dependent on. Unlike the Outside Temp, however, the Inside Temp doesn’t remain constant, thus fluctuating the value of the Density of the Inside Air as well. Thus, the Buoyant Force, being dependent on this Density of the Inside Air, changes in value as well. This brings us to our final sub-model, that of the Inside Temperature.

3. Inside Temperature

The next step to creating our model was connecting the models. The inside temperature model had an “Inside Temp” variable, which was replaced by the “Inside Temp” variable in the buoyancy model, the rest of the propane model was connected to that variable. The buoyancy and physics model were connected by an arrow from “Buoyant Force” to “total force”.

The equation we used for the propane heat is 2*IF THEN ELSE (Length<1000, 1, 0)*IF THEN ELSE (Inside Temp<393.15, 1, 0). There are two conditions that tell the burner when to turn on and off. The first IF THEN ELSE statement says that the burner will turn off once the balloon hits a height of 1000 meters. The second IF THEN ELSE statement says that the burner will turn off once the inside temperature of the balloon reaches 393.15 K. The inside temperature of the balloon keeps increasing until one of the two conditions are met.

The inside temperature model also contains a “Cooling” variable. The balloon cools down after the burners turn off. It is affected by the “Outside Temp”, “Insulation Constant”, and “Inside Temp”. This allows the balloon to cool at a consistent rate, so it won't go too high or crash to the ground. Although the inside temperature model turns the burner on and off, it is delayed. When the burner turns on the balloon will continue to descend until it warms up and then it goes up, even after the burner has turned off. The burner will not turn back on until the balloon has started to come back down. The “Inside Temp” part of the model is the difference between the “Propane Heat” and “Cooling”. It started with an initial temp of 313.15 K.

Tying all three sub models together, we get our final model. Thus, the Total Forces acting on the Hot Air Balloon are as follows:

Total Force = Weight + Air Resistance + Buoyancy
Lessons learnt

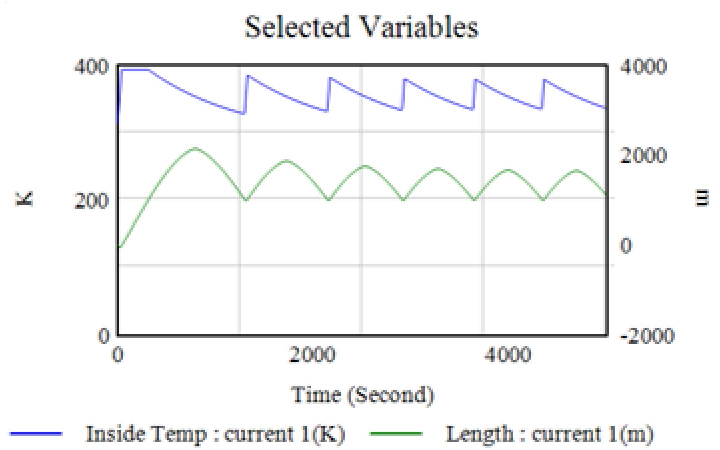
Something that didn’t work initially for us, but we were able to fix eventually is the rate at which the balloon rose. Initially, it rose extremely fast, throwing off our values. Upon closer inspection as to the reason for why this was though, we found that we had converted our rate of temperature change from 2°C to 275.15K. A rate of degree change would be the same value regardless of the meter though. Upon changing it back to 2, we were finally able to see the desired behavior.

Model Results

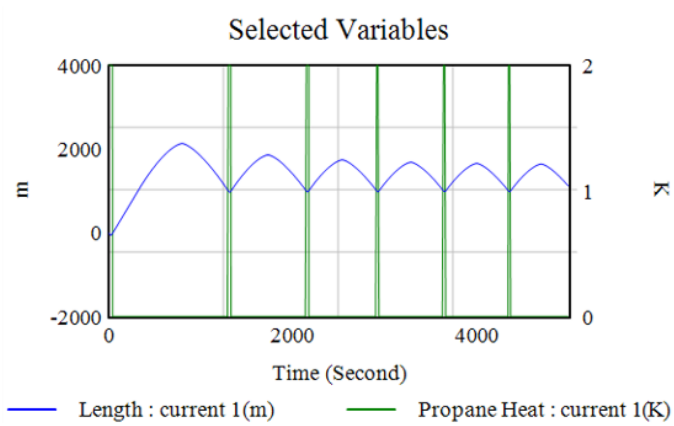
The balloon lifts off with an inside temp of 313.15 K. During the initial ascent of the balloon, the burners stay on for 41.375 seconds. To find this we looked at the graph that showed “Propane Heat” and after getting a rough idea for a time step, we looked at the “Propane Heat” table. The balloon reaches a max height of 2133.23 meters. We found this height by graphing “Length” and getting an idea of the time step and then conforming the time step on the “Length” table. After the burners have turned off the balloon continues to rise for 757.25 seconds. To find this answer we looked at the time step when the burners turned off and then looked at the time step of when the balloon hits its max height.

During the second ascent, the burners come back on at 1299.5 seconds. To find this time step, we looked at a graph showing “Length” and “Propane Heat”, we go a rough estimate for the time and then looked it up using the “Propane Heat” table. Even though the burners are on, the balloons continue to descend until it gets to a height of 968.119 meters. We found this out by looking at the “Length” graph and then finding the specific time on the “Length” table. Once the balloon rises it hits a max height of 1856.47 meters. To find the height during the second burn, we went from the lowest height on the “Length” table to the highest number, before it started to descend.

The graph below shows the Inside Temp of the balloon compared to its height. The temp starts to increase, as the balloon starts to rise. As the temperature cools down, the balloon keeps rising and then descends, once the balloon is the lowest it will go, the Inside Temp goes back up.



The graph below shows the height compared to the balloon compared to the propane heat, which is turning on and off. The burner turns on for a short period of time to allow the inside temperature of the balloon to heat up and then it turns off. During this time the balloon will go up and then it will go down after it descends the burners will turn back on.



Conclusion

If we had more time to work on our model, we would see how changing the outside temperature would affect the balloon. We would see if it would affect the buoyancy or the height of it.

In our graphs that show Inside Temp, you can see a flat line at the beginning of the first ascent. We are not sure what the line means or why it is there, but if we had more time to work on our project, we would try to understand what is happening.

The density of air decreases the higher the altitude. However, we had considered it to remain constant for the purposes of our model, this is a factor we would consider had we had more time to improve it.

Appendix

Variable	Formula	Unit
Density of Outside air	Air pressure/(Specific Gas Constant*Outside Temp)	kg/m/m/m
Outside Temp	288.15	K
Air Pressure	101325	N/m*m
Specific Gas Constant	325	N*m/kg/K
Buoyant Force	(Density of Outside air-Density of Inside Air)*Volume*Gravity	N
Insulation Constant	0.001	1/s
Density of Inside Air	Air pressure/(Specific Gas Constant*Inside Temp)	kg/m/m/m
Gravity	9.81	m/s/s
Volume	2500	m*m*m
Propane Heat	2*IF THEN ELSE(Length<1000,1,0)*IF THEN ELSE(Inside Temp<393.15,1,0)	K
Inside Temp	313.15	K
Cooling	-Insulation Constant*(Outside Temp-Inside Temp)	K
Length	1	m
Change in Length	Velocity	m/s
Velocity	0	m/s
Change in Velocity	Acceleration	m/s/s
Acceleration	Total force/mass	N/kg
mass	500	kg
Total force	Weight+Drag+Buoyant Force	N
weight	-Gravity*mass	kg*m/s/s

Drag	Drag Constant*cross sectional Area*Velocity* ABS(Velocity)	N
Drag Constant	-0.65	kg*m*m*m
Cross sectional area	250	m*m