[[1]](#footnote-1)

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# INTRODUCTION

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# Rocket trajectory calculation

To achieve the maximum payload ratio for the rocket the gravity turning is used to turn our rocket from a vertical state to a horizontal orbit. To describe the rocket trajectory, following equation system is used. This equation system is studied in the lecture note.

|  |  |
| --- | --- |
|  | ( 1 ) |

Following parameters are used in this equation system. The thrust is which changes with altitude. The air drag on the rocket is which also depends on atmosphere status. The mass of the rocket is . The radius of the earth which is assumed to be according to the International Standard Atmosphere model (ISA). [1] The horizontal position of rocket in a rotating coordinate which initially is The vertical position of rocket is which initially is also , the vertical altitude of the rocket which is the same as . The flight path angle between the rocket and the horizontal line is . The velocity of rocket is and and are the specific impulse of the rocket and gravitational acceleration of earth at sea level. The is according to the ISA. [1]

By using this equation system, the location, velocity and mass of a rocket at time given a set of initial values. However, more calculation is needed for several parameters above to increase result accuracy.

The thrust is a function of the external pressure which depends on the altitude . The relationship is:

|  |  |
| --- | --- |
|  | ( 2 ) |

The exhaust speed and the burn rate is assumed to be constant in this project so the thrust of our rocket should be increasing with decreasing external pressure. which is the area the pressure difference is acting on is assumed to be the cross section area of the rocket. However, it is optimal for the rocket to be launched in a condition that . This means that the thrust benefit from the pressure difference shall not be too big and thus can be neglected. So the thrust is then

From our source we can find at sea level. [2]

To calculate the air drag acting on our rocket we use the equation of air drag.

The density is a function of altitude which is described in the ISA model. We assume the cross section area of the rocket to be the area we can calculate with the help of the diameter of the rocket. The diameter of the rocket is . [3] The cross section area is then . Because that the rocket has a circular cross section area so we can use the value [4]. Here in our model the air drag coefficient is assumed to be constant.

Since we are using Falcon 9 which is a two stage rocket with more than enough power to launch our satellite, we can assume that the first stage is going to send our satellite to an orbit where the air drag can be ignored and then the second stage is going to launch our satellite to our goal altitude. So we can assume the air drag is and the thrust is constant at the second stage of the rocket.

But there is a problem with this model. With a too small initial velocity the change of the flight path angle will be huge since . This will give a very unrealistic result since the rocket launch shall start with a ridicules turning and fly toward unwanted direction. So we choose to let the rocket fly straight up for a very short time and after that the gravity turning shall take over the job of flipping the rocket.

So we decided that the rocket shall fly straight up for SSSSS seconds thus ending at the altitude HHHH m.

# References

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1. This paragraph of the first footnote will contain the date on which you submitted your paper for review. It will also contain support information, including sponsor and financial support acknowledgment. For example, “This work was supported in part by the U.S. Depart­ment of Com­merce under Grant BS123456”.

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