Orbiting Mechanisms and Intersections

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Null Hypothesis: The velocity required to enter the Hohmann transfer orbit of the rocket is larger when transferring to a planet with a larger orbit.

Alternative Hypothesis: There is not direct relation between the velocities required to make a transfer to other planets and the orbital radiuses of the aim planets. Push force caused by the light and other planets gravitational forces may disturbs the direct relation calculated with a single formula.

Introduction

When I was going to middle school our science teacher made us watch a documentary about space travel, after I got interested to interplanetary travel as learned more about the basic of orbital mechanisms in high school. From that time to now the technology has developed excessively which let humanity to further tasks which have to be achieved. The humanity has already sent human-free ships to the mars, however scientist couldn't send humans to mars and further planets due to the lack of our technology for that long journey. In this research I am going to observe the variables used in the space travel from on to another planet by not considering the way back.

A scientist named Isaac Newton put forward three basic theories that predicts the way objects are moving. Third law of Newton describes that for every action, there is an equal and opposite reaction force. Referencing from that law of Newton's first liquid propellant rocket was built in 1926. This law is important on how rockets work. The exhaust from the fuel burned in the fuel tank makes an action force on the ground and as response the spacecraft starts moving the opposite direction from the force applied as the ground applies a reaction force on the rocket.

When the rocket burns fuel and pushes the ground from the engine and creates an upward force which is called the trust force, however as the gravity from the earth is pulling the rocket down to the surface it is not that simple to launch a rocket. Therefore, the spacecraft needs enough fuel, so the reaction force of rocket is greater that the force of gravity. Thus, the trust force also must be applied to correct the direction along the way to a location.[1]

[1] *General Thrust Equation*. www.grc.nasa.gov/www/k-12/rocket/thrsteq.html.

A spacecraft needs to accelerate to at least 17,800 mile per hour to fly over most of the atmosphere in an elliptic path around the earth which ensure the craft won't be pulled back down to the ground. That path is the new orbit of the spacecraft in the space soaring around the earth. The next step is different according where you want to go. If the main aim to get to another planet the spacecraft must speed up to around 25,000 miles per hour. However also the best time to leave Earth to get to a planet must be figured out. To give example Mars is the nearest planet to Earth and they reach at their closest distance in every 2 years. This is the best time to make a journey to mars since the amount of the propellant will be limited. The spacecraft also must be sent at a specific time and velocity in spacecraft's order main and the aim planets orbits to intersect.

To understand the mechanics of the space, travel the Hohmann Transfer method has to be understand. The Hohmann transfer is commonly used to move a spaceship from a lower orbit to a higher one by firing the rocket engines at a certain time which changes the circular orbit of the spaceship.[2,3] This is the most energy efficient space travel technique as there is no gravity in space the spaceship will travel through the orbit without any action force.

When the space travel across planets is the main aim, it has to be as efficient as possible. To make it possible the spaceship must be already orbited earth. The reason for that both earth and the planet which is wanting to be travelled has to orbit Earth. For example, mars are the target planet and it also orbits the sun, but in much greater distance that earth. The rockets orbit designed must include both perihelion which is the closest approach to the sun and aphelion which is the farthest distance from the sun.[4] In the beginning the orbit of the rocket will intercept with the earth's orbit which is the perihelion and will intercept with Mars's orbit at the end which is aphelion.[5] This is known as the Hohmann transfer orbit.

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[2] *How Do We Launch Things Into Space? | NASA Space Place – NASA Science for Kids*. spaceplace.nasa.gov/launching-into-space/en.

[3] "Educator Guide: Let'S Go to Mars! Calculating Launch Windows." *NASA/JPL Edu*, 19 Nov. 2019, www.jpl.nasa.gov/edu/teach/activity/lets-go-to-mars-calculating-launch-windows.

[4] https://www.masterclass.com/articles/what-is-the-hohmann-transfer-calculating-the-hohmann-transfer-for-orbits

[5] "Guide and Examples for Users of the ?SPACEKAP? Style File." *Space Science Reviews*, vol. 60, no. 1–4, Springer Science and Business Media LLC, May 1992. *Crossref*, https://doi.org/10.1007/bf00216870.

However, before that, it is useful to examine Kepler's laws of planetary motion. Kepler gathered the movements of planets that rotate around the sun under three main laws. Today, in this law, its functionality continues even when a planet is substituted for the sun and a natural or artificial satellite is substituted for the planet orbiting the sun. For example, the earth moving around the sun, the moon circling the earth and the artificial satellites circulating around the earth act according to these laws. In short, objects that rotate around a fixed axis with a mass in the center continue their movements according to these rules. But in this study, we will consider the laws as heliocentric.

The first of these laws is known as the law of fields. According to the law of fields, planets revolve around the sun in an elliptical orbit. Since the orbit is elliptical, it has two focal points. There is also the sun in one of these foci. The planet approaching the sun moves faster, while the planet moving away from the sun moves slower. When this movement is examined at the same time intervals, it is observed that the areas they scan are the same.

The second Kepler Law is related to the first law. This law, like the first law, shows that a planet passing through the part of its orbit that is close to the sun moves faster, and its speed decreases as it moves away from the sun. This is because gravity increases as you get closer to the sun and decreases as you move away from it. The planet orbiting in its orbit is subject to the gravitational force towards the sun, while it is subject to the centripetal force outward from its orbit. These two forces must be of equal magnitude in order for the planet to continue its circulation in orbit. The higher gravitational planet increases its linear velocity to compensate for this, because the increase in linear velocity also causes an increase in centripetal force.

The third law is known as the law of periods. According to the law of periods, the periods of two different planets orbiting with two different radii are also different. The cube of the radii of the orbits in which the planets revolve is equal to the square of the ratio of their periods. A planet with a larger radius moves more slowly, so it takes longer to complete one full orbit. On the other hand, the planet orbiting in a small radius orbit has a smaller period because it orbits faster. By using this law, the masses of the planets Mars, Uranus, Jupiter, Neptune and Saturn and their density values very close to reality were obtained[6]

[6] Lea, Robert. "Kepler's Third Law: The Movement of Solar System Planets." *Space.com*, 20 Dec. 2021, www.space.com/keplers-third-law.

Calculating the External Velocity Required for the Hohmann Transfer Orbit

Finding the Time

It takes to the aim planet. According to Kepler's third law the squares of the orbital periods of the planets are directly proportional to the cubes of the semi-major axis of their orbits. (p^2=a^3) This law mentions that the period of a planet to orbit the Sun increases with the radius of its orbit.

According to that semi major axis of the Hohmann transfer orbit is the average of the distance from earth to sun plus the distance of the planet we are planning to go to the sun. This can be formulated like

$$\frac{1}{2}[R_1\ (radius\ of\ the\ earth's\ orbit)\ +\ R_2\ (radius\ of\ the\ aim\ planets\ orbit)]$$

Therefore.

$$a = \frac{R_1 + R_2}{2}$$

if we consider that, all planets have circular orbits.

$$p^2 = a^3$$

From this formula the time to reach to Mars can be found if the semi major axis is defined as astronomical units. When substituting period into the semi-major axis.

$$p = \sqrt[2]{a^3}$$

Equality gives the period of Hohmann transfer orbit. However, since this transfer is only one way through p divided by 2 gives the time to reach to aim target in years.

Variables During the Transfer

Orbital velocity which is the instantaneous velocity of an object moving in an elliptical orbit, due to the influence of gravity is a really important factor for satellites to remain in the orbit. Inertia of the moving body and the gravitational pull makes the body move in a straight line. Every satellite in the universe has its own angular velocity. The value of the orbital velocity is calculated by the formula[6]

$$V = \sqrt{\frac{G \times Msun}{R}}$$

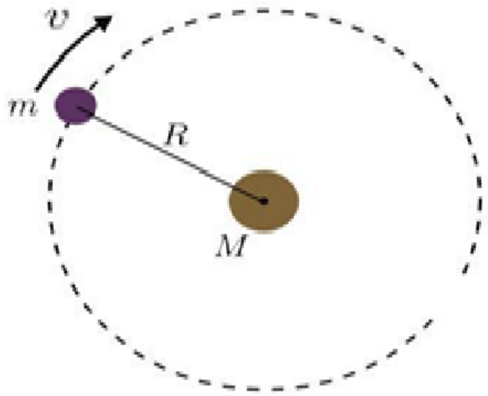


Figure 1: Rotation of the minor planet in a circular orbit around the major planet.

Figure Represents the mass of the center object and the distance of the body from the center object for understanding the orbital velocity better.

Variable Type	Variable	Measurement and Control Method	Justification
Independent	Orbital radiuses of each planet	Orbital Radius of Planets (Mars, Uranus, Jupiter, Saturn Neptun, Earth	It depends on the distance from Sun
Dependent	Delta V required for spaceship to enter the Hohmann transfer orbit	Depends on Orbital Radius	It depends on the Orbital Radius of Planets
Control Variables	G constant and $Msun$	Constant Values	Constant Values of G and mass of sun $Msun$

Table 1: The variables using in the formula and their justifications

Derivation of Formulas

1. If a satellite with mass of M_{sat} is considered doing a circular motion around a central body with a mass of $M_{central}$ the net force on the satellite is equal to the centripetal force given below

$$F_{net} = \frac{M_{sat} \ x \ V^2}{R}$$

2. This centripetal force is a result of the gravitational force that impacts on satellite on the central body,

$$F_{grav} = \frac{G \ x \ M_{sat} \ x \ M_{central}}{R^2}$$

3. As the $F_{net} = F_{grav}$ it is possible to say

$$\frac{M_{sat} \ x \ V^2}{R} = \frac{G \ x \ M_{sat} \ x \ M_{central}}{R^2}$$

4. From the equation above by dividing both sides with M_{sat} to get rid of M_{sat} from both sides. Also, as we multiply both sides with R leaves us with the equation:

$$V^2 = \frac{G\ x\ M_{central}}{R}$$

and when the square root of both sides is taken it leaves us with the final equation of **orbital speed** which is[7]

$$V = \sqrt{\frac{G\ x\ M_{central}}{R}}$$

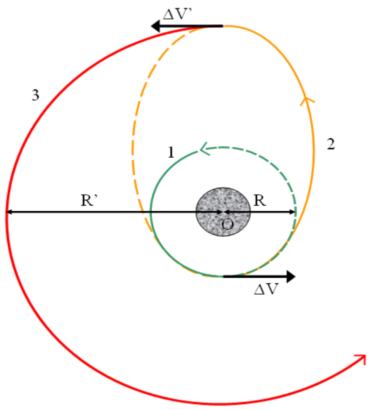


Figure 2: How the Hohmann transfer is made between two planets including the distance of the planets from the sun and the spacecraft's delta velocity.

5. Let V_1 is the velocity of the earth travelling around the sun on the green orbit according to the figure

$$V_1 = \sqrt{\frac{G \times M_{sun}}{R_1}}$$

6. Let V_2 is the velocity of the aim planet travelling around the sun on the red orbit according to the figure

$$V_2 = \sqrt{\frac{G \times M_{sun}}{R_2}}$$

Considering the yellow orbit in the Figure 2 is the Hohmann transfer orbit. The point where it is intercepting with the green orbit which in this experiment is the world's orbit is called **perihelion**. The other head of the Hohmann transfer orbit which is intercepting with the red orbit is called the **aphelion.**

[7] *Hohmann Transfer orbit.png - Wikimedia Commons*. commons.wikimedia.org/wiki/File:Hohmann_transfer_orbit.png.

During the Hohmann transfer the spacecraft starts its journey from perihelion by exerting a vector which is ΔV in order Hohmann transfer orbit to form. The propellers of the spaceship are cut down when the Hohmann transfer orbit is intercepting with the orbit of the aim planet. At the end of this process another ΔV is applied to the spacecraft in the aphelion to put the ship in an outer orbit which will be the aim planets orbit in this experiment.

Another variable important for the Hohmann transport is the distance from the sun. In the Figure 2 the following distances are shown as R which represents the distance of Earth from sun which is considered as one astronomical unit and R' represents the distance of aim planet from sun. This knowledge is important as the distance from sun gets higher the orbital velocity of the planet is decreased which is clearly seen in the equation:

$$V = \sqrt{\frac{G \times M_{sun}}{R}}$$

where r represents the radius of the circular orbit, G is the gravitational constant and M_{sun} is the mass of the sun. Change in the orbital velocity affects the ΔV needed for the propellers is the main reason why length of the orbital radiuses is an important variable.

The Relation of Orbital Velocity of the Planets with the Hohmann Transfer

Since the rockets going to be launched from earth, it is necessary to add the **earth's orbital velocity** to the equation. Also, an apart velocity is going to be applied to the spacecraft in order it to enter the Hohmann transfer orbit. Therefore, the equation for the velocity at the perihelion of the Hohmann transfer orbit can be showed as

$$V_{perihelion} = V_{earth} + V_1$$

In the formula V_1 represents the velocity of first rocket.

As the spacecraft is on the aphelion point travelled all the way from perihelion another ΔV_2 is applied to the rocket which makes the rocket enter the outer orbit. ΔV_2 is significantly smaller than V_1 as the spacecraft also has its own velocity and the vector needed for the spaceship to enter to the outer orbit is only an additional force for the rocket to enter the orbit. So, the equation for $V_{appelion}$ is:

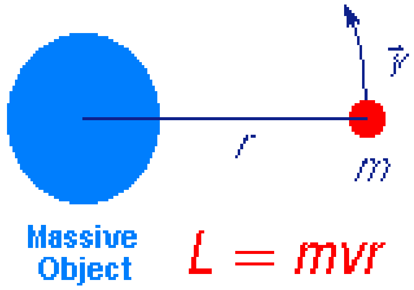
$$V_{perihelion} = V_{outer} - V_2$$

Calculations for Finding ΔV

During the Hohmann transfer, angular momentum and energy is conserved.

Conservation of angular momentum:

The image on the right illustrates how the conservation of the angular momentum conserved among satellites in our universe. Angular momentum in our universe can be transferred, but it cannot be transferred or destroyed. L is the angular momentum where m is the mass of the spinning object, v is the magnitude of its velocity and r is the distance between the smaller and the larger object.



If we apply this law to the Hohmann transfer the angular momentum of the spacecraft at the perihelion and at the aphelion should be the same. Therefore, the equation for that will be:

$$L = m_{rocket} \times V_{perihelion} \times r_{distance\ of\ sun\ to\ the\ earth} = m_{rocket} \times V_{aphelion} \times r_{distance\ of\ sun\ to\ the\ earth}$$

As there are m_{rocket} on both sides of the equation, the equation can be manipulated.

$$L = V_{perihelion} \times r_{distance\ of\ sun\ to\ the\ earth} = V_{aphelion} \times r_{distance\ of\ sun\ to\ the\ earth}$$

Conservation of energy: During the Hohmann transfer energy is also conserved. The energy can be transferred however, it can’t be created nor destroyed. Mechanic energy of the spacecraft at the first state which is the **perihelion** must be same at the **aphelion.**

$$E_{K1}\ x\ E_{P1} = E_{K2}\ x\ E_{P2}$$

If this conservation equation formulated appropriate variables of space travel: energy is going to be equal to,

$$\frac{1}{2}mv_p^2 - G\frac{m_{rocket} \times M_{sun}}{R_1} = \frac{1}{2}mv_a^2 - G\frac{m_{rocket} \times M_{sun}}{R_2}$$

In this equality above V_p means the velocity at the perihelion, V_a means the velocity at the aphelion.

Derivation of the ΔV Formula

To derive such a formula some terms must be written in other forms in order to get rid of excess variables. The best way to find the ΔV is from

$$V_p = V_1 + \Delta V_1$$

so other variables are except those in the equation are useless for this derivation. To start with first V_a variable should be omitted in the energy equation, in addition V_a can be written in the form of

$$V_a = \frac{R_1 \, x \, V_p}{R_2}$$

which is derived from the conservation of angular momentum formula,

$$V_a \, x \, R_2 = R_1 \, x \, V_p$$

The new energy formula for the Hohmann transfer will be,

$$\frac{1}{2}V_p^2 - G\frac{M_{sun}}{R_1} = \frac{1}{2}\left(\frac{R_1 \, x \, V_p}{R_2}\right)^2 - G\frac{M_{sun}}{R_2}$$

Simplification:

1. $\frac{1}{2}V_p^2 - \frac{1}{2}\left(\frac{R_1 \, x \, V_p}{R_2}\right)^2 = G\frac{M_{sun}}{R_1} - G\frac{M_{sun}}{R_2}$ → Gathering the variables in one side
2. $V_p^2\left(1 - \left(\frac{R_1}{R_2}\right)^2\right) = 2GM_{sun}\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$ → Omitting ½ by multiplying both sides with 2
3. $V_p^2\left(\frac{R_2^2 - R_1^2}{R_2^2}\right) = 2GM_{sun}\left(\frac{R_2 - R_1}{R_1 R_2}\right)$ → Equalizing the depositors in extraction equations
4. $V_p^2 = 2GM_{sun}\left(\frac{(R_2 - R_1) R_2}{R_1(R_2^2 - R_1^2)}\right)$ → Leaving the required variable alone
5. $V_p = \sqrt{2GM_{sun}\left(\frac{R_2}{R_1 (R_1 + R_2)}\right)}$ → In this step $(R_2^2 - R_1^2)$ is expended by difference of two squares formulas which takes $(R_2 - R_1)$ from the numerator and depositor and to find V_p square roots of both sides are taken

From this point the values for V_p and V_1 is known, therefore ΔV_1 can be fin through the formula

$$V_{perihelion} = V_{earth} + V_1$$

$$\Delta V_1 = \sqrt{\frac{G \times Msun}{R_1}}\left(\sqrt{\left(\frac{2 R_2}{(R_1 + R_2)}\right)} - 1\right)$$

$$\Delta V_2 = \sqrt{\frac{G \times Msun}{R_1}}\left(1 - \sqrt{\left(\frac{2 R_2}{(R_1 + R_2)}\right)}\right)$$

Result, Analysis and Conclusion

Data Collection Phase

Aim Planets	Distance from Earth in km
Mars	112,903,739
Jupiter	593,472,122
Saturn	1,380,893,379
Uranus	2,821,412,218
Neptune	4,333,425,777

Table 2: The closest orbital distance values of aim planets from earth in km

Calculations for finding orbital speed:

$$V_{earth} = \sqrt{\frac{G \times M_{central}}{R_1}} = \sqrt{\frac{[(6.6743 \pm 0.00015) \times 10^{-11}] \times (1.989 \times 10^{30})}{R_1}}$$

Aim planet	Orbital Radius	Hohmann Transfer orbit from Earth's orbit
Mars	1.52AU	2.9
Jupiter	5.20AU	8.8
Saturn	9.54AU	10.3
Uranus	19.19AU	11.3
Neptune	30.07AU	11.7

Table 3: Planets that are targeted for the Hohmann Transfer

Gravitational constant is used in calculating the attractive force between two objects which I called Newton's law of universal gravitation. According to this law G constant times the product of the masses of the two masses divided by the square of the distance between the object is equal to the attractive force between these objects. Value of this constant is $(6.6743 \pm 0.00015) \times 10^{-11}$ m^3 kg^{-1} s^{-2}.

Calculation for finding ΔV_1 depends on the planets,

Mars $\sqrt[2]{\frac{(6.674\pm\%0.0022)10^{-11}\times(1{,}989)10^{30}}{1.475\times10^{11}}} \times \sqrt[2]{\frac{2\times2.296\times10^{11}}{1.475\times10^{11}+2.296\times10^{11}}} - 1$ = 3104m/s = 3.1km/s

Jupiter $\sqrt[2]{\frac{(6.674\pm\%0.0022)10^{-11}\times(1{,}989)10^{30}}{1.475\times10^{11}}} \times \sqrt[2]{\frac{2\times7.408\times10^{11}}{1.475\times10^{11}+7.408\times10^{11}}} - 1$ =8724m/s =8.7km/s

Saturn $\sqrt[2]{\frac{(6.674\pm\%0.0022)10^{-11}\times(1{,}989)10^{30}}{1.475\times10^{11}}} \times \sqrt[2]{\frac{2\times1.470\times10^{12}}{1.475\times10^{11}+2.296\times10^{12}}} - 1$ = 10422m/s= 10.42km/s

Uranus $\sqrt[2]{\frac{(6.674\pm\%0.0022)10^{-11}\times(1{,}989)10^{30}}{1.475\times10^{11}}} \times \sqrt[2]{\frac{2\times2.942\times10^{12}}{1.475\times10^{11}+2.942\times10^{12}}} - 1$ =11376m/s=11.37km/s

Neptune $\sqrt[2]{\frac{(6.674\pm\%0.0022)10^{-11}\times(1{,}989)10^{30}}{1.475\times10^{11}}} \times \sqrt[2]{\frac{2\times4.473\times10^{12}}{1.475\times10^{11}+4.473\times10^{12}}} - 1$ =11717m/s=11.71km/s

Calculations for finding ΔV_2 depends on the planets,

Mars $\sqrt[2]{\frac{(6.674\pm\%0.0022)10^{-11}\times(1{,}989)10^{30}}{1.475\times10^{11}}} \times 1 - \sqrt[2]{\frac{2\times2.296\times10^{11}}{1.475\times10^{11}+2.296\times10^{11}}}$ = -3104m/s =-3.10km/s

Jupiter $\sqrt[2]{\frac{(6.674\pm\%0.0022)10^{-11}\times(1{,}989)10^{30}}{1.475\times10^{11}}} \times 1 - \sqrt[2]{\frac{2\times7.408\times10^{11}}{1.475\times10^{11}+7.408\times10^{11}}}$ = -8724m/s=-8.72km/s

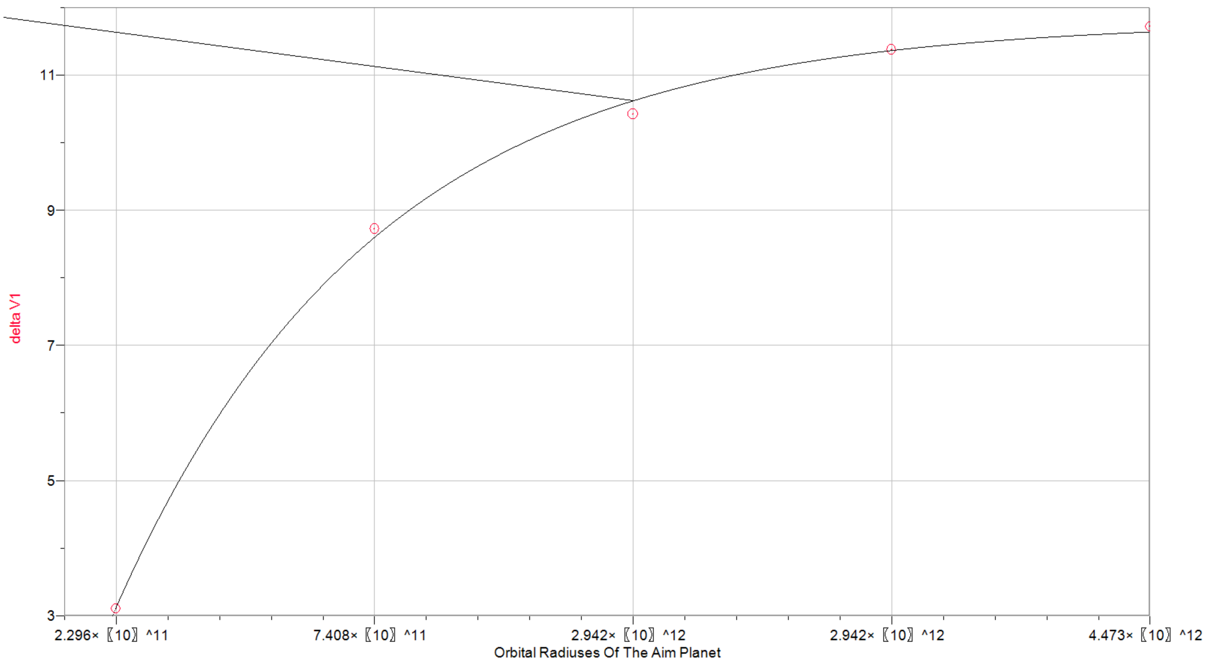
Saturn $\sqrt[2]{\frac{(6.674\pm\%0.0022)10^{-11}\times(1{,}989)10^{30}}{1.475\times10^{11}}} \times 1 - \sqrt[2]{\frac{2\times1.470\times10^{12}}{1.475\times10^{11}+2.296\times10^{12}}}$ = -10445m/s =-10.44km/s

Uranus $\sqrt[2]{\frac{(6.674\pm\%0.0022)10^{-11}\times(1{,}989)10^{30}}{1.475\times10^{11}}} \times 1 - \sqrt[2]{\frac{2\times2.942\times10^{12}}{1.475\times10^{11}+2.942\times10^{12}}}$ = -11401m/s =-11.40km/s

Neptune $\sqrt[2]{\frac{(6.674\pm\%0.0022)10^{-11}\times(1{,}989)10^{30}}{1.475\times10^{11}}} \times 1 - \sqrt[2]{\frac{2\times4.473\times10^{12}}{1.475\times10^{11}+4.473\times10^{12}}}$ = -11743m/s =-11.74km/s

Aim Planets	Orbital Radiuses of the aim planets in (m)	Orbital radius of the Earth in (m)	G (Gravitational constant) in ($m^3kg^{-1}s^{-2}$)	Mass of sun in (kg)	ΔV_1	ΔV_2
Mars	2.296×10^{11}	1.475×10^{11}	$6{,}674\times 10^{-11}$	$1{,}989\times10^{30}$	3.104km/s	-3.10km/s
Jupiter	7.408×10^{11}	1.475×10^{11}	$6{,}674\times 10^{-11}$	$1{,}989\times10^{30}$	8.724km/s	-8.72km/s
Saturn	2.942×10^{12}	1.475×10^{11}	$6{,}674\times 10^{-11}$	$1{,}989\times10^{30}$	10.422km/s	-10.44km/s
Uranus	2.942×10^{12}	1.475×10^{11}	$6{,}674\times 10^{-11}$	$1{,}989\times10^{30}$	11.376km/s	-11.40km/s
Neptune	4.473×10^{12}	1.475×10^{11}	$6{,}674\times 10^{-11}$	$1{,}989\times10^{30}$	11.717km/s	-11.74km/s

Table 4: How the values of $\Delta V_1$and ΔV_2 changes as the aim planets orbital radiuses increase where control variables are orbital radius of the Earth, G(Gravitational constant) and the mass of the sun which is the reference mass for all planets.



Graph 1: How the additional V force should be applied by the propeller to reach the aim planet vary as the orbital radiuses of the aim planets increase.

Justification and Conclusion:

Justification

Required additional thrust force which creates additional velocity ΔV_1 is observed and calculated in this experiment as the orbital radiuses of the planets increase as Hohmann transfer in applied to different planets including Mars, Jupiter, Saturn, Uranus, Neptune which begins from earth. The mass of the sun and the start planet for the Hohmann transfer are selected as control materials. As the orbital radiuses of the aim planets are increased the thrust force required in order the spacecraft to reach to the aim planet is exponentially decreased. According to the data obtained in the experiment, it was observed that the delta v1 velocity increased exponentially as the orbital radius increased. This is because the period value increases. Increasing the distance from the orbital point taken as the center, that is, the radius of the orbital, also increases the orbital's perimeter. In order to achieve the same period value, the velocity of the object circulating on the orbital must also increase. In this way, the period will remain the same and the Hoffmann transfer will be realized. According to this theory, when the experimental results were analyzed, it was observed that the velocity values increased as the radius increased and reached the values of 3.104, 8.724, 10.422, 11.376, 11.717 km/s, respectively, and these values were supported by the velocity vs orbital radius graph. ΔV_2velocities are negative because each planet has a certain orbital velocity. According to the Hoffman transfer, for the satellite to enter the planet's orbit, the planet's orbital velocity must decrease and therefore slow down. So $\Delta V_2$is negative follows like -3.10km/s, -8.72km/s, -10.44km/s, -11.40km/s, -11.74km/s because of the slowdown in order for the spacecraft to enter the aim planets orbit from its Hohmann transfer orbit.

Conclusion

Properties of Hohmann transfer are analyzed in this experiment. As the spacecraft is travelling through planets the time taken to reach the aim planet the exact angle in for the spacecraft to launch. For a planet to go around another planet properly, that is, its own orbit, it must have a certain speed, as explained in the theoretical part. A rocket that is expected to continue orbiting around a planet must generate a centripetal force equivalent to the gravitational force exerted on it by the central mass, just like planets orbiting the sun. In this way, the orbit around it becomes sustainable and it can continue to rotate around its central axis. When the equations are considered according to this equation, it is seen that the mass of the body that continues its circulation is insignificant. Besides, there are other factors that affect the rotation speed. The factors affecting this velocity are the G universal gravitational constant, the R orbital radius and the mass of the celestial body in the center of the M orbital. In some cases, an additional force may be required to achieve these velocity values. In this study, the rotational speeds of the planets around the sun were examined with starting from the earth. Required additional thrust force which creates additional velocity ΔV_1 is observed and calculated in this experiment as the orbital radiuses of the planets increase as Hohmann transfer in applied to different planets including Mars, Jupiter, Saturn, Uranus, Neptune, and the Earth. The mass of the sun and the start planet for the Hohmann transfer are selected as control materials.

Evaluation

Hoffmann transfer orbit is a theory based on Kepler's laws. These laws are put forward and calculated by considering that there are objects circulating around elliptical orbits, which are assumed to be the sun at one of their focal points. In elliptical orbits, the radius is not the same throughout the orbit, but the orbitals considered in this study are circular and therefore orbital radii have a uniform magnitude. In order to make the results of the experiment closer to reality, the R orbital radius lengths used in the calculations should be handled in a variable way. Although the obtained results are close to the theoretically calculated values, they are quite far from the real values. In addition, while the system was being set up, it was assumed that only the planet, which is thought to be in the center, and the satellite that continues to circulate in the orbit around it. But there are many planets and celestial bodies in space. Even if other celestial bodies are neglected, planets exert a considerable gravitational force even on satellites that do not orbit their own orbits, as they have very large masses. Ignoring this effect is also one of the factors that negatively affect the results of the experiment. In addition to all these, the rounding operations made in the calculations are among the factors that increase the margin of error, even if it is very small.

Issue	**Effect On Result**	**Correction**	**Type of Error**
Constant Orbital Radius	Mathematically Flawed	Radius of Elliptical Orbit	Systematic Error
Neglecting Other Masses	Mathematically Flawed	Not Neglecting Other Masses	Systematic Error
Rounding Error	Mathematically Flawed	Rounding up Correctly	Random Error

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