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# Utilizing an Asteroid's Trajectory for the Purpose of Space Exploration by Landing a Space Station Drone on Its Surface

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## Abstract

**Outer space and interstellar exploration has previously been performed by unmanned spacecraft such as Voyager 1, launched on 1977 by NASA. The aim of this paper is to demonstrate how an Asteroid's trajectory can be utilized bylaunching onto its surface a Space Station Drone (SSD). An Asteroid can be selected based on its trajectory of interest, as it approaches the earth. Then, once it turns around the earth and back towards outer space, the SSD launch can occur. Once attached to the Asteroid, then basically it would be a "free ride" for the SSD. The SSD will continue to send images/information back to earth. Methodology was based on a typical known Asteroid trajectory, as an example with indicative calculations. Calculations have shown that for an Asteroid travelling at 20 km/s and coming with 500 km distance of the earth, the SSD will require a thrust of 320,000 N over 30 s and 250 km distancein order to gain the required speed of 20 km/s (Asteroid's speed). Then the SSD's trajectory can be fine tuned as it travels the final 250 km to land on the Asteroid, consuming 2,132.2 kg of liquid hydrogen fuel. An alternative solution was also demonstrated with a lower thrust but longer distance travel to reach the required speed. The conclusion has shown that by selecting specific Asteroid orbits, it is possible to explore uncovered space regions, including interstellar and intergalactic space with relatively insignificant propulsion energy, considering the distancetravelled by an Asteroid. However, good *space weather* forecasting is important for a successful space mission.**

***Keywords:** Asteroid; Space station; Space exploration; Interstellar space; Intergalactic space; Solar system*

## Introduction

Discovering outer space isn't just a passion, it provides details of what is happening within our Solar System and Galaxy. There have been several attempts in the past, but due to limit of propulsion, the trajectory is usually straight with occasional deflections by other planets along the space vehicle's route, as the case is with Voyager 1. There is, however, an opportunity to utilize the trajectory of an Asteroid for space exploration, effectively limiting the amount of fuel required to propel a space craft. In vacuum, the specific fuel consumption for the space shuttle near earth has a 450 pounds of thrust for a pound of propellant per second. Therefore, the specific fuel consumption (SFC) can be estimated at 1 pound of fuel per 450 pounds of

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thrust a second, which is 222 gram/kN.s, these figures will be used for demonstration purposes. [1]. This can be done as will be explained in this paper by selecting a specific trajectory of interest, such as (a) towards the sun, around the sun within a safe distance, and back towards earth. Information can be sent back to the earth. (b) finding an Asteroid trajectory towards other Solar System planets and back to

earth, and (c) out of the Galaxy's flat plane, away from our Galaxy, then back towards our Galaxy, and then back towards earth. What is required is to get the SSD with sufficient propulsion power ready in position waiting in space till the Asteroid of interest arrives. Then the SSD can be launched towards it. Thus, only limited space propulsion is required, just sufficient to home in and land on the Asteroid. The rest of the exploration journey is executed by utilizing the Asteroid's trajectory of interest.

Asteroids are typically composed of rock material. They orbit the sun as planets do but are much smaller than the planets. Asteroids are not usually spherical, measuring from a few kilometers and up to a few hundred. The fact that they are made of rock and have approximately circular orbits around the sun near the inner planets distinguishes them from comets, which tend to contain water, ice and dust and fly through the Solar System on very sweeping orbits beyond the outer planets. The asteroid belt, a region with a particularly large number of asteroids, lies in an orbit between the orbits of the planets Mars and Jupiter. By far the largest object in the asteroid belt is the Ceres with an average diameter of just over 900 kilometers. All other bodies in the asteroid belt are less than 600 kilometers in diameter. Asteroids have been frequently visited by space probes since the 1990s. The Japanese probe Hayabusa took rock samples from Asteroid 25143-Itokawa in 2005 and then in June 2009 dropped a capsule containing samples back to earth. This proves that it is possible to land a man-made station on an Asteroid, as suggested in this paper an SSD [2,3]. In a similar published proposal, it was suggested to turn Asteroids into self-contained spacecrafts [4]. The difference in what is proposed in this paper is that the SSD simply lands and anchors itself on the Asteroid. With the possibility of launching its own probes at various locations along the Asteroid's surface, with the mission of reporting data back to the earth from selected orbits.

## Background theory

Space exploration with a degree of control, by utilizing the trajectory of an Asteroid. Thus a planned explanation section of the universe can be accomplished in an efficient way. Typical Near-earth asteroid orbits (NEAs) are shown in Fig 1. The Aten orbit types are NEAs, the orbital half-axis of which is typically less than one Astronomical Unit (AU). Where 1 AU is equal to 1.50e11 m, the approximate distance from earth to moon. However, their aphelion (furthest point from sun in an orbit's path) is in all cases outside the earth's orbit. This means that Aten asteroids with eccentric orbits can cross the earth's orbit from within, see Fig 1 [5].

Unlike planets, the majority of asteroids do not follow a circular orbit, with the exception of the main belt asteroids and the Cubewanos in the Kuiper belt. Asteroids trajectories follow eccentric orbits while their planes are in many cases intensely inclined towards the ecliptic. There are so many orbit patterns available to choose from. Asteroid orbits do pass one or more planets. For illustrative purposes, this paper focuses on the Aten type orbit. Other orbit types can follow the similar presented methodology. The proposed methodology allows for:

1. Geospace:

A region in outer space near earth, including the upper atmosphere and magnetosphere [6].

2. Cislunar space:

Earth's gravity keeps the Moon in orbit at an average distance of 384,403 km (238,857 mi). The region outside Earth's atmosphere and extending out to just beyond the Moon's orbit, including the Lagrange points, is sometimes referred to as cislunar space [7].

3. Deep space:

Is defined by the United States government and others as any region beyond cislunar space (Definition of Deep space). The International Telecommunication Union responsible for radio communication (including satellites) defines the beginning of deep space at about 5 times that distance (2 × 106 km) (ITU-R Radio Regulations, 88) [8].

4. Interplanetary space:

Interplanetary space is defined by the solar wind, a continuous stream of charged particles emanating from the Sun that creates a very tenuous atmosphere (the heliosphere) for billions of kilometers into space. This wind has a particle density of 5–10 protons/cm3 and is moving at a velocity of 350–400 km/s (780,000– 890,000 mph) [9].

5. Interstellar space:

Interstellar space is the physical space within a galaxy beyond the influence each star has upon the encompassed plasma [10].

6. Intergalactic space:

Intergalactic space is the physical space between galaxies. Studies of the large-scale distribution of galaxies show that the Universe has a foam-like structure, with groups and clusters of galaxies lying along filaments that occupy about a tenth A star-forming region in the Large Magellanic Cloud, perhaps the closest Galaxy to Earth's Milky Way of the total space. The remainder forms huge voids that are mostly empty of galaxies. Typically, a void spans a distance of (10–40) h−1 Mpc, where h is the Hubble constant in units of 100 km s−1 Mpc−1, or the dimensionless Hubble constant [11].

Regarding size of SSD, it is recommended to keep the SSD mass sufficiently low in relation to the Asteroid’s mass so that the Asteroid’s mass is not significantly altered by the landing as this change in mass may change the Asteroids trajectory, caused by changes in gravitational forces. Based on Newton’s of universal gravitation; “every particle attracts every other particle in the universe with a force that is directly proportional to the product of their masses and inversely proportional to the square of the distance between their centers” [12].

## Method

Select an Asteroid orbit based on the general orbit patterns shown in Fig 1. Then plan a strategy to launch an SSD on to an Asteroid, as in Fig 2. The SSD can be propelled as shown in the Results and Calculations section towards the Asteroid. This can be done from the earth or a manned space station, using remote control methods and Artificial Intelligence (AI). Nearby satellites can act as signal boosters and can also be used to communicate with the SSD in its mission. The SSD will be equipped as follows: -

- Limited thrust vectoring for a safe landing onto the Asteroid with extra fuel if a secondary re-launch is required, e.g. a liftoff from the Asteroid.
- Solar panels and rechargeable batteries.
- Cameras for still and VIDEO with memory chips.
- Gravitational sensors.

- Radiation sensors for measuring various types of radiations.
- Temperature sensors for measuring its own temperature as well as that of space, and planets, sun, stars, and detected objects.
- Distance measuring sensors of what is listed in ‘f’.
- Robotic anchoring mechanism, see example Fig 3.
- Antenna.

AI will be used to refine and analyze what is listed in ‘a’ to ‘g’. For an example if memory space becomes critical, data can be sent back to earth before memory is 70 % full. Deleted memory once data is confirmed received by a nearby satellite. If the SSD loses contact with nearby satellites, then VIDEO filming stops. This can be for an example if the SSD is behind the sun in relation to earth. Data can be stored until communications are established. System comments can be chosen to at least follow one entire Asteroid orbit cycle. In item “h” anchoring is required

to hold the SSD firmly throughout its journey. For this reason it is recommended that a solid rock Asteroid surface is selected. This will allow the SSD to drill and anchor its self in position. What is also suggested in Fig 3, is that the SSD can launch several cameras at different locations. With just sufficient data transmission equipment to communicate with the SSD. The SSD with the major memory can, with the help of AI, process data and transmit back to the earth.

Suitable telescope and zooming technology to cover further distances than current space telescopes. An emphasis on item ‘e’ above. It is known that the space between galaxies is filled with gases so hot that it’s not possible for scientists to see using visible light telescopes. Such gases can only be observed by X-rays or gamma rays. This allows scientists to look at that gas and determine how much there is between galaxies in clusters. It was this methodology which allowed scientists to discover the existence of at least five times more material in the clusters than originally known. The undetectable invisible matter is known as dark matter. Therefore item ‘e’ is of high importance and will need radiation detection equipment, see discussions section [13].

What is also shown in Fig 2 ‘1’ as the dashed line path is a possible trajectory of launching a probe on its own. Even though a probe is luanched on to a simliar trajectory to that of an Astroid, the probe may not survive the sun’s gravitational pull. This is due to the probe’s lower mass, and hence lower momentum. An Astroid of a high mass is likely to survie the sun’s gravitaional forces, due to its higher momentum.

## Results and Calculations

Asteroids can exist in various shapes and trajectories. A sample calculation is performed limited to the SSD unit. Transporting the SSD from earth to its location as in the above example can be treated just like any satellite payload. Therefore no calculations were thought to be necessary for this paper, except for the scope ‘a’ to ‘b’ as in Fig 4.

Assumptions were made for illustrative purposes, based on a known Asteroid trajectory. Calculations can be fine- tuned to fit any Asteroid trajectory.

Assume the asteroid has a velocity of 20 km/s (20,000 m/s), the SSD has a total of mass of 100 kg and the distance ‘a’ to ‘b’ is 500 km (500,000 m). Once the asteroid arrives on a determined location, then

**Stage 1:** For these reasons, the present study was dedicated to pharmaceutical dosage forms.

**Stage 2:** The present study was to investigate the application of these reagents in the spectrophotometric analysis.

- The spectrophotometric analysis
- pharmaceutical dosage forms

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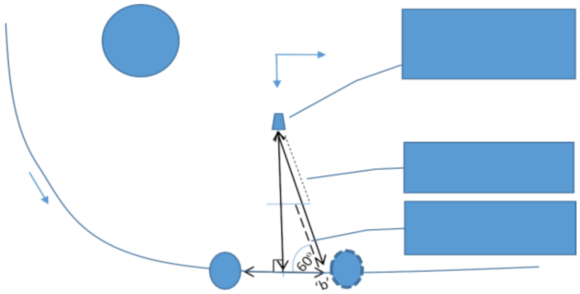


**Fig 4.** Velocity, distances and acceleration - SSD and Asteroid.

The following calculations are indicative and can be refined for specific loads. If the assume fuel mass is 80 kg, then this mass will get reduced during acceleration. Some of this fuel will have to be preserved for final flight vectoring to the point of docking on to the steroid.

Referring to Fig 4. Solving horizontal components, ‘c’ to ‘b’;

Speedcbx-Asteroid = 20,000 m/s, this is the Asteroid’s travelling speed. (1)

Calculating the SSD’s flight speed;

Speed-SSD’aa’-‘b’ , divide Speedcbx by cos60 (see Fig 4).

20,000 ÷ cos60 = 40,000 m/s (2)

At the above speed with the homing distance and 30 s of flight, trajectory fine tuning can be performed, See Fig 5.

Law of motion v2-u2 = 2ax (3)

$$Acceleration - SSD_{\text{'}a\text{'} - \text{'}aa\text{'}} = \frac{(Speed - SSD\text{'aa'} - \text{'b'}_2) - (\text{initial Speed2})}{2 \times 250,000} \tag{3a}$$

$$Acceleration - SSD_{\text{'}a\text{'} - \text{'}aa\text{'}} = \frac{(40{,}0002)\text{-}(\text{initial speed2})}{2 \times 250{,}000} = 3.200\text{m/s2} \tag{3b}$$

To calculate required thrust for the SSD’s total mass (m) 100 kg;

F=m× Acceleration-SSD’a’-‘aa’ = 100 × 3,200 (4a)

F=320,000 N 320 kN

To calculate the required amount of fuel propulsion in producing the 320,000 N for 30 s, requires the following steps. Pointing out that equation (4a) was used for illustrative purposes in this paper. What actually happens is that as the SSD travels, the propulsion unit’s mass begins to drop as propulsion fuel is consumed. A quick look at equation (4b) shows if m decreases than Acceleration increases.

$$Acceleration = \frac{F}{m} \tag{4b}$$

$$\text{m}.u_r + \sum F = M.\frac{ov}{\partial t} \tag{4c}$$

However for indicative purposes, equation (4d) can be used based on existing space data propulsion.

222 gram/kN.s × 320 kN × 30 = 2,131,200 gram

= 2,132.2 kg (4,691 lb) This figure represents the amount of fuel required to propel the SSD in Fig 4.

The above calculation (4d) was based on available hydrogen space (vacuum) propulsion data.

Another form of a rocket propulsion equation is given (4c), where if M is the remaining oxidant and fuel at time t then it is a function of t. This means the acceleration($\delta t/\delta v$) cannot be constant, even if ṁ.ur and the F are constant [14], and will have to be considered when refining calculations. Flight vectoring along the path ‘aa’, ‘bb’, and ‘b’.

If a=”required acceleration at travel distance”, then F=”zero thrust”. (4e)

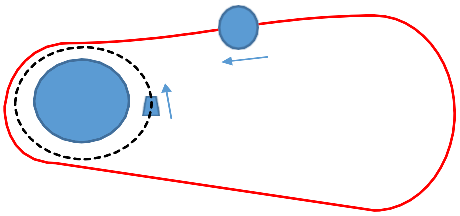
Elseif a=”required acceleration at travel distance is low”, then F=”step up propulsion till (4e) reached” (4F)

Else a=” required acceleration at travel distance is high”, then F=”step down propulsion till (4e) reached” (4g)

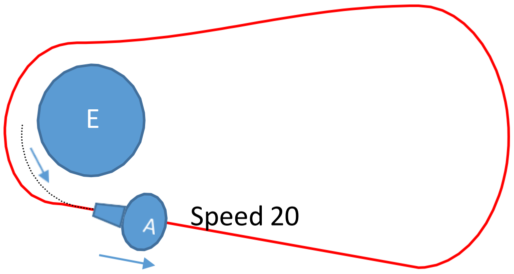
Similar to above equations can be applied to vectoring, till correct orientation and velocity are achieved for a safe Asteroid landing.

An alternative way is to rotate the SSD around earth, till A arrives near earth and then make a landing. Fig 6 shows an example.

Practically anything can happen with regards to changing a spacecraft's momentum. Example in 1967 NASA's Mariner 4 spacecraft ran into a dust cloud while cruising through the Solar System at space [15]. The spacecraft experienced a shower of Meteoroids for about 45 minutes, ripping away bits of insulation and temporarily causing a change in the spacecraft orientation. Therefore, with regards to maintaining acceleration in brief AI control description, than equations (4e) to (4g);



**(1)**



**(2)**

**Fig 6.** The alternative method, where SSD rotates around the earth at a suitable orbit to that of Asteroid, image '1'. Then lands on the Asteroid as shown in image '2'.

The required thrust estimate can be seen in the following example. Using a lower acceleration force over a longer distance travel, achieving the required example velocity of 20 km/s.

SSD leaves the earth and is positioned into orbit at 384,403 km (similar to approximate moons orbit distance). The SSD will carry the earth's rotational angular velocity.

$$(2\times\pi)\div(24\times3600)=7.27\square-5\frac{rad}{s} \qquad (5)$$

Linear velocity = (384,403 + 6,357)e3 × 7.27$e-5$ = 2.84$e4$ $m/s$ (28.44 km/s) (6)

For calculating acceleration over travelled distance in order to get the SSD in matching the asteroid's speed of 20 km/s, equation (3) was used. The differences between the methods illustrated in Figures 2 and 6 are:

a. Fig 2 method relies on a shorter travel distance to pint of docking, but higher thrust to achieve the necessary speed.

b. Fig 6 method relies on a longer travel distance, but a lower thrust to achieve the necessary speed.

Regarding sizing of SSD, it is recommended that its mass is kept extremely low relative to the Asteroids mass. This is for reasons discussed in the Background theory section: avoiding significant changes in the Asteroid's linear momentum and gravitational pull towards other plants and the sun as it passes by planets/sun.

$$F = G\frac{m1.m2}{r_2}$$

Where m1 is the combined mass of the asteroid and the SSD and m2 is the mass of the planet or the sun, G the gravitational constant, and r the distance between m1 and m2. Now if the Asteroid has an original mass of 100,000 kg and the SSD's mass is 100 kg, then the total mass is 100,100 kg. That is the SSD's mass is at least 0.1% of Asteroid. Subsequently the gravitational force 'F' in equation (7) is not significantly impacted, and causing the Asteroid's orbit to change.

## Discussions

A way in carrying space exploration along a selected route of interest, where the carrying vehicle is Asteroid. Thus no propulsion is required along the selected Asteroid route. Propulsion fuel will need to be just sufficient for reaching the Asteroid and allow for possible space dust storms. Propulsion can be varied as required with AI control, as briefly reflected in equations (d) to (f). Good 'space weather' forecasting is essential, checking out for weather storms dust clouds before launching along a suitable path. Sufficient preparation time is required ahead of an arriving Asteroid, in a NEA position. The SSD will need to be ready in position on time.

The SSD listed onboard equipment shown in the Method section are indicative. The plan is to transport data back to earth covering specific areas of interest. Detail planning and accuracy are important. For example, launching the SSD on to an Asteroid's surface needs the following:

- Fast Asteroid surface data analysis carried out by the SSD itself and the operating crew with the help of sensors and AI.
- The approaching SSD's speed and mass should be such that the Asteroid's path is not altered as a result of the SSD's Asteroid touchdown.
- Select an Asteroid of a suitable size where a relatively flat rock surface can be used for landing the SSD.
- Consider a location for the SSD's antenna from where it can easily send signals back to earth. If possible, a secondary drone antenna signal booster can be launched from within the SSD. Maximizing communications exposure with earth's satellites.
- If the mission is to go round the sun, then consider materials suitability to the sun's heat radiation and an Asteroid of a trajectory path as close to but as safe as possible to the sun.

Some Asteroids travel within our Solar System, within its flat plane. While others shoot out as shown in Fig 7. This allows the SSD to provide data collection unforeseen before, providing us more details about or Solar System and the Milky Way Galaxy.

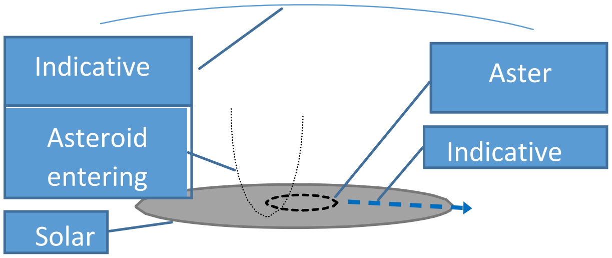


**Fig 7.** Asteroid examples; within the Solar System and out of its flat plane interstellar.

So far, the furthest travelled spacecraft is the Voyager 1, which is within the flat plane of the Solar System. With known Asteroid trajectories different routes can be opened for exploration. With relatively negligible propulsion power required, long distance space exploration can be achieved. To keep the size of the SSD as small and as practically possible, another drone powered vehicle (DPV) can be used to deliver the SSD to its location. Once near the Asteroid, the SSD separates away from the DPV and relies on its limited vectored thrust.

Fig 8 shows an example image of an Asteroid entering the Solar System [16], but not through its flat plane. This is similar to what has been disused in Fig 7. An SSD following such a trajectory can no doubt provide unforeseen data. Unlike Voyager 1, following a trajectory such as that of Fig 8, allows for;

a. A relatively faster interstellar space exploration.

b. Provides data on the Solar System by looking towards its horizontal flat plane, See Fig 8.

c. Possibly intergalactic space discovery, though it is not known what orbit shape such an Asteroid takes. Will such an Asteroid remain within our Galaxy or, exit and head towards another Galaxy (see Figures 7 and 8)? The proposed method can provide an answer.

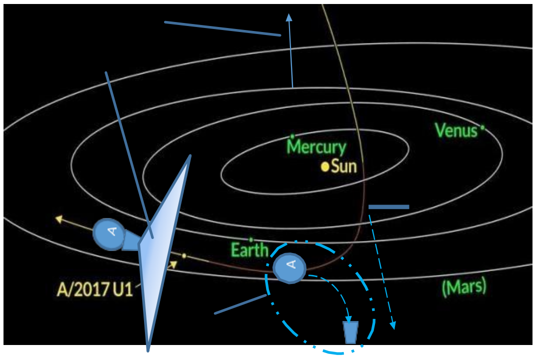


**Fig 8.** An interstellar asteroid crossing the Solar System. Image from published material [14], excluding the blue text boxes and what has been discussed in this paper.

In the methodology section, item 'e' radiation sensors was highlighted. Since an Asteroid as in the example of Fig 8 can be utilized, it is worth exploring the gravitational lens outside the Solar System. The gravitational lens is a distribution of matter between distant sources of light [13]. For example, how accurate is the theory of gravitational lensing if the Asteroid in Fig 8 is below the flat plane of Solar System and if further away, interstellar? By using the sun as the light sources and how light rays bend. Gravitational lensing effects and the amount of light bending were predicted by Albert Einstein's general theory of relativity [17,18].

The proposed approach can also allow for a second re-launch as shon in Fig 8. For an example if interstellar exploration is required to travel directly below the Solar System's orbit, then a suitable Asteroid trajectory can be selected such that the SSD will be carried by the Asteroid to a suitable launching point. Then the SSD switches to its own propulsion, and takes another trajectory of choice, "hitchhiking" an Asteroid. At a suitable lift off position from the Asteroid, the SSD can with thrust vectoring utilize the Asteroids travel speed. Example if the SSD starts a Re- launch at location X in Fig 8, then by some limited thrust vectoring, the SSD will be realigned. Direction of re- launch can be in the Z direction.

Some asteroids like the A/2017 U1 are travelling with very high speeds, which make them unsuitable for current space propulsion due to the current space propulsion technology. Therefore it is recommended to select an Asteroid of suitable speed. Appendix 1 Fig 9 [19] shows an image with estimated Asteroid speed and size. However, launching the SSD from the earth means that the SSD will possess the earth's angular velocity. A quick look at equation (6) shows an angular velocity of 28.44 km/s, based on calculated parameters, signifying that such Asteroid speeds as that of A/2017 U1, estimated at 26.3 km/s are possible with careful planning. Fig 10 shows an Asteroid which has just recently passed near earth. Its relatively high momentum has allowed it to survive the sun's gravitational pull, and then move away from the sun. If a probe was placed in this Asteroid's trajectory, it is likely that the sun may pull the probe crashing on its surface. Since a probe weighing just 100 kg, will not have a momentum of sufficient magnitude to survive the sun's gravitational pull.

## Conclusion

A swath area of space discoveries can be achieved with relatively low costs, considering the large distances covered by asteroids which can be utilized to their full potential by launching Space Station Drones on to their surfaces.

Basically introducing the concept of a "free ride" and "hitch hiking" an Asteroid. It's a matter of selecting an orbit path of interest. Not only providing more information in how Asteroids travel and where they go, but what is out there. Whether it's within the Solar System or interstellar or even possibly intergalactic space. As of now, there is no clear evidence if there are any objects (or Asteroids) travelling between different galaxies. If an Asteroid such as that of Fig 8 can prove that it may go beyond our galaxy or at least travel toward its edge, then with such an approach this may shed light onto this subject.

In such a strict flight path scheduling accurate space weather furcating is important such that the SSD's momentum isn't impacted. Artificial Intelligence can be built into the SSD to cater for propulsion needs and cater for possible bad space weather storm conditions.

The saving in space vehicle fuel propulsion would be tremendous, since the SSD propulsion is limited to a short powered flight. An example calculation for Fig 4 has shown that; for a limited powered space flight of 30 s, propelling a 100 kg (220 lb) vehicle, the amount of hydrogen fuel propulsion is 2,160 kg (4,752 lb). An alternative method in Fig 6 can reduce this fuel quantity by utilizing the earth's orbital angular velocity but will have to be limited to Asteroids falling within the SSD orbit orientation. The SSD can benefit from an Asteroid's momentum and survive gravitational effects from planets, and the sun, continuing with space exploration journey as the Asteroid would have continued its journey.

## Recommendations

Further mapping of Asteroids and prepare more information on suitable Asteroid sizes of suitable landing surfaces for the SSD.

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