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Team Control Number
54731

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2016
MCM/ICM
Summary Sheet

The amount of small debris in orbit around earth has been a growing concern. There can be a threat to satellites currently in operation. The size of the diameter from space debris larger than 10cm can be tracked by NASA. Satellites currently in operation there have also described to change the trajectory against crashes. Defense Technology for the radius of 1cm below the object is ready. Therefore, we want to talk about modeling for the disposal of orbital debris of less than 1~10cm. In order to improve the orbital debris problem, we propose a model using "Solar heat reflector".

There are two classification to dispose of the orbital debris. The former is how to remove the waste by applying a force in the Earth, such as the Laser broom. The latter will send the unit to solve the garbage problem in space, such as Space Sticky. Solar heat reflector is the latter. The reflector giving energy to the debris they are moved out of the orbit. Geometry were applied to determine the shape of the reflector in order to increase the efficiency of the reflector. Astrophysics was used to escape the orbit of space debris.

The main principle which is used to remove the space debris is the Yarkovsky effect. The Yarkovsky effect is a force acting on a rotating body in space caused by the anisotropic emission of thermal photons, which carry momentum. Thus, by heating the debris, we can shunt the debris to de-orbit.

The results are so positive. But actually there are many factors that can change the amount of time it takes to further increase waste removal. If you think that a good performance method covering 20 degrees of debris a year, it can be seen that the Solar heat reflector have comparable or better performance. Our model lacks a description of the changed orientation of the orbit space debris. In fact, the debris is not a rotating globular form. And debris is rotating. So actually there may be a difference in the results.

Because the sun is the source of energy it is more economical than other methods. Even though part of the paraboloid failure, it still can work. (This is why we choose the paraboloid form, not the lens.) It can cause problems if used for military purposes. And you may not be able to use the other side of the Earth.

EXECUTIVE SUMMARY

In this summary, we described form of our model which can remove orbital debris and we determined that an economically attractive opportunity exists.

Firstly, we described form of the model. For modeling, a number of options and principles were considered. And then, we can get major modeling results and limitations of our modeling

We consider orbital debris which are more than 1cm and less than 10cm. Because large orbital debris (> 10 cm) are tracked routinely by the U.S. Space Surveillance Network. Thus our satellite can avoid the debris by evasion flight. Also, satellites can defend orbital debris which size is less than 1 cm. In addition, we supposed that orbital debris is perfect sphere shape. Because it can be calculated easily. Also, we assumed that the shape of the solar heat reflector is parabola. Because we should use the reflective property of parabola.
Actually, the rotation speed of the orbital debris is not zero and not infinity. So, we suppose that the rotation speed was assumed to have an appropriate fixed value.

Then, we account for our modeling's principal. If orbital debris undergo solar energy continuously, its temperature rises and then goes down. In the process of its temperature going down, the heat turns into a form of photons. This photons have momentum and it escape orbital debris from its orbit. Then the orbital debris are sent to the earth's atmosphere and they are burned.

We can explain that our model is effective for removing the debris. Other methods of removing the debris are very high-priced, disposable, and too much time is needed. However, our model can eliminate a large number of space debris up to when the end of life of the satellite. Therefore, our model is much more efficient.

Secondly, I account for economic benefits of our model. It costs a lot of money and manpower to lunch just single satellite. However, if this satellite is

broken by collision with an old-satellite before the end of its life, causing huge economic losses.

Now many satellites are located in space. Furthermore, since the launching more satellites will increase the space debris. Therefore, efficient way to get rid of space debris is required and will be needed for many countries. If you have the most efficient one of these ways would be a huge economic benefit. In particular, our model will have more economic benefits than the methods which is currently available.

There is no repair costs. Although the parabolic reflectors would be some damage, there does not significantly affect collecting light in focus. Therefore, there is no need to repair the satellites.

No more charging energy costs due to using the solar energy. Thus it can be used for unlimited energy.

Relatively, our model is less expensive. Usually, a huge sum of money is needed in the space industry. Thus this industry is national business. But, in our case, private firms could adopt as a commercial opportunity to address the space debris problem.

Once satellites launched, they can eliminate a large number of space debris up to when the end of life of the satellite.

<Introduction>

Our goal is to make a good model to develop a time-dependent model to determine the best alternative or combination of alternatives that a private firm could adopt as a commercial opportunity to address the space debris problem. This model eventually becomes a general model which include quantitative and/or qualitative estimates of costs, risks, benefits, as well as other important factors. To construct model, find the necessary element of how we can get rid of orbital debris. And among them will choose the elements of general application. Then selected elements will make the model. First, before we do that, let us try a few simple assumptions. Seconds, it created a model on the basis of the selected elements. Our modeling of the principle is as follows. If orbital debris undergo solar energy continuously, its temperature rises and then goes down. In the process of its temperature going down, the heat turns into a form of photons. This photons have momentum and it escape orbital debris from its orbit.

<Our targets debris>

- Orbital debris which are in 750-800 km and size of the debris is more than 1cm and less than 10cm.[1]

- Reasons

  Large orbital debris (> 10 cm) are tracked routinely by the U.S. Space Surveillance Network. Therefore our satellite can avoid the debris by evasion flight. Also, satellites can defend orbital debris which size is less than 1 cm. however, we can't avoid and defend orbital debris which size is more than 1cm and less than 10cm. Therefore our modeling should target the orbital debris. (>1cm, <10cm) [2]
  Most orbital debris reside within 2,000 km of the Earth's surface. Within this volume, the amount of debris varies significantly with altitude. The greatest concentrations of debris are found near 750-800 km. Therefore our modeling should target the debris in 750-800km.

<**Modeling**>

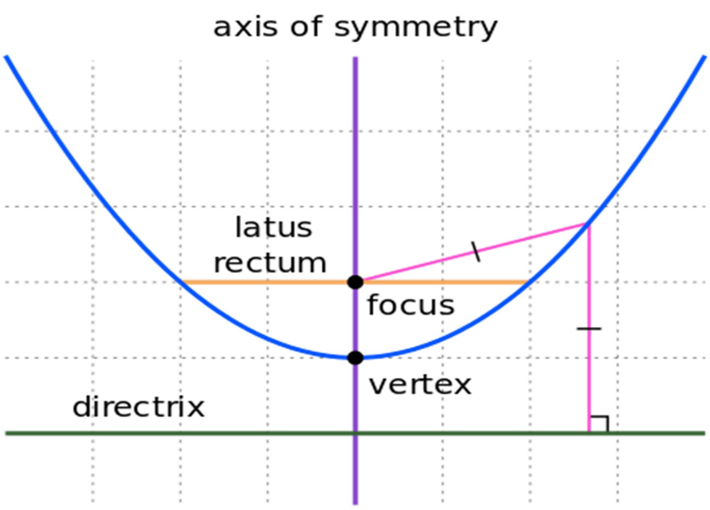
- Base for modeling

① The Yarkovsky effect should be considered.[3]

The Yarkovsky effect is a force acting on a rotating body in space caused by the anisotropic emission of thermal photons, which carry momentum. It is usually considered in relation to meteoroids or small asteroids (about 10 cm to 10 km in diameter), as its influence is most significant for these bodies. To transfer momentum of debris, we will use this force.

② The Shape of the Solar Heat Reflector should be considered.

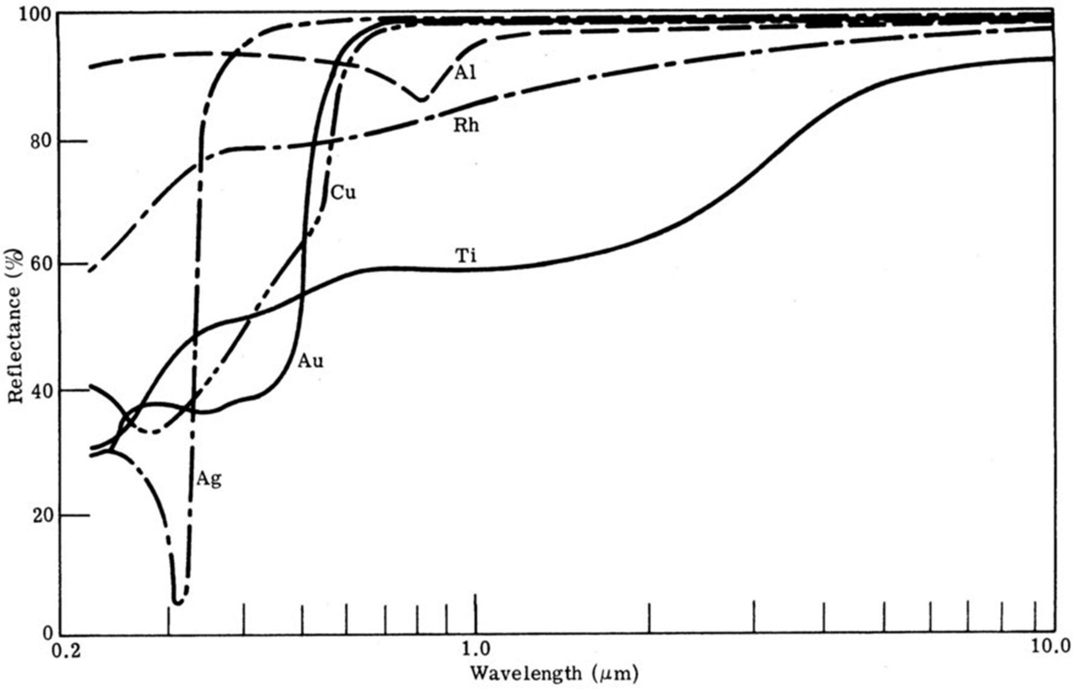
We decide that the shape of the solar heat reflector is parabola. Because parabola has a very important characteristic which is the reflective property. The reflective property states that, if a parabola can reflect light, then light which enters it travelling parallel to the axis of symmetry is reflected to the focus. The reflective property states that, if a parabola can reflect light, then light which enters it travelling parallel to the axis of symmetry is reflected to the focus.



③ Shape of orbital debris is considered.

Suppose that orbital debris is perfect sphere shape. Because it can be calculated easily.

④ Raw material of the Solar Heat Reflector should be considered.



The above material is a graph of the relationship between wavelength and reflectance for a typical metal. Metals generally have high reflectivity. We want to use this to determine the material of the reflector.

⑤ Reflexibility of the raw material should be considered.

The average of the reflectivity of aluminum is approximately 85% and the average of the reflectivity of titanium is approximately 60%, Aluminum and titanium are the main ingredients used to make the satellites. Also it assumes that the reflector is made of these two metals. Therefore, the reflectance of the reflection plate is assumed to be approximately 70%.

⑥ Raw materials of orbital debris are considered.

Glass fiber, Carbon Composites, Titanium -based alloy material, and aluminum are being used for satellites since they are durable and light

- Final modeling

① All of thermal energy is converted to kinetic energy (maximum)

Denote $\mathbf{h}$ to height of the space debris from earth atmosphere.

Let $\mathbf{M}$ = mass of Earth (kg), $\mathbf{m}$ = mass of debris (kg)

Then, we have $\boldsymbol{E_p + E_k = -\frac{GMm}{r+h} + \frac{1}{2} \cdot \frac{GMm}{r+h} = -\frac{1}{2} \cdot \frac{GMm}{r+h}}$

, where $\mathbf{G}$ is gravitational constant and $\mathbf{r}$ is the radius of the earth.

Now, we are giving any force (F) should change the distance $\mathbf{r+h}$ to 200km

$\boldsymbol{-\frac{1}{2} \cdot \frac{GMm}{r+h} + F = -\frac{1}{2} \cdot \frac{GMm}{r+200}}$, and so $\boldsymbol{F = \frac{1}{2} GMm\left(\frac{1}{r+h} - \frac{1}{r+200}\right)}$

Let $\boldsymbol{E_{in} = S \cdot 1366/60}$

, where $\mathbf{E_{in}}$ is receiving energy coming from the sun, $\mathbf{S}$ is area of parabola

And let $\mathbf{E_{out} = E_{in} \cdot reflectivity}$

Let t be a time to change the orbit of the space junk.

$$t = \left|\frac{\frac{1}{2}GMm}{reflectivity \cdot S \cdot 1366/60}\left(\frac{1}{r+h} - \frac{1}{r+200}\right)\right|$$

For example, Let $\mathbf{m}$ = 5kg, reflecivity = 70%, $S = 100\mathrm{m}^2$

Then, we have $t \approx 3\ \mathrm{hour}$

② Consider the Yarkovsky effect

Emission of thermal photons, which carry momentum. Because heat is an infrared wavelength lambda is the wave length from 10^3 to 10^6

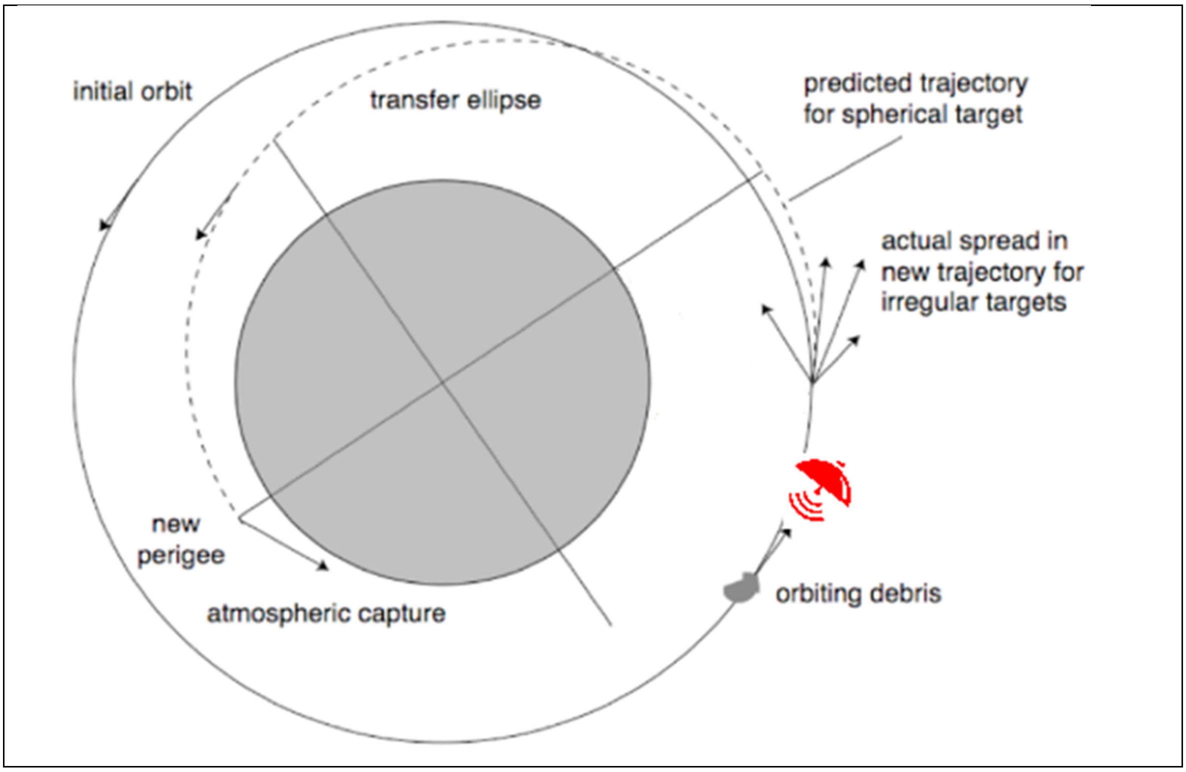
Hence, the energy of one photon is following;

$$\mathbf{E = hv = \frac{hc}{\lambda}}$$

It has the following formula substituted with F (above 1) instead of $\mathrm{n_p}E$

$$t = \left|\frac{\frac{1}{2}GMm}{n_p E}\left(\frac{1}{r+h} + \frac{1}{r+200}\right)\right|$$

Because second law of thermodynamics, all of heat cannot be converted into kinetic energy. Assuming that 90% of heat loss, we have **t** which 10 times in last example.



<Limitations of modeling>

- We can't understand modeling of orbital debris since it is too difficult. Thus, we aren't able to use orbital debris' modeling in our modeling
- There is an error when our modeling apply to actual environment since we suppose that the shape of the debris are spherical

<Limitations of Approach>

- We cannot simulation
- Lack of physical knowledge

<Strengths and Weaknesses>

(1) Strengths

- No energy costs because it uses the solar heat and it is very plentiful.
- It can be used several times. (nondisposable)

- Energy efficiency is very high because we can take advantage of using reflective property
- Even if the model is damaged partially, we can use it.

(2) Weaknesses

- It may be used for military purposes.
- It is likely to create new debris by conflicting with other orbital debris due to being changed its orbits
- Heavy objects are not available.

<Compare our model with other removing debris methods>

Method / Attribute	Our Model	GOLD	Boom supported Aerobrake	Rigdizable Space Inflatable	PROPULSIVE
Risk of Large Debris Object Generation	High	Low	Medium	Highest	Lowest
Risk of Disabling Other Satellites	Low	Low	Low	Low	Lowest
Variable De-Orbit Rate	Yes	Yes	No	No	Yes
Targeted Reentry	Yes	Yes	No	No	Yes
Works with Tumbling Derelict Satellites	No	Yes	Yes	Yes	No

Works Equally Well for Any Orbit Inclination	Yes	Yes	Yes	Yes	Yes
Works for Any Spacecraft Attitude	No	No	No	Yes	No
Works for Any Orbit Altitude	Yes	No	No	No	Yes
Relative Mass	High	Low	Low	High	High
Cost to Add to Satellite	Low	Low/Medium	Low	Low	Highest

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[2] “Technical Report on Space Debris” Link

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