For office use only
T1 ________
T2 ________
T3 ________
T4 ________

Team Control Number
52214

Problem Chosen
B

For office use only
F1 ________
F2 ________
F3 ________
F4 ________

2016a
MCM/ICM
Summary Sheet

(Your team's summary should be included as the first page of your electronic submission.)
Type a summary of your results on this page. Do not include the name of your school, advisor, or team members on this page.

summary

Space junk has reached into a unbelievable number these days, as a result of high speed development in aviation industry. Thus, the space debris bring mankind serious obstacles in space exploration. Therefore, clearing the space debris has become a top-task to be dealt with.

To begin with, we have studied the time-space distribution pattern of debris, we have predicted the variation of fragments with time. After knowing the distribution feature of fragment's density in altitude and latitude, we have learned roughly that space junk's distribution mainly ranges from 800km to 1200km of orbit altitude, on which we are able to calculate flux to illustrate the collision of space fragments. Next step, we analysed the successful launching rate, and by combining two aspects, as a sort of risk parameter, we can assess the risk of different projects.

We adopt three normal methods for clearing space debris before making a cost analysis and a profit assessment respectively. .After assessing profit in each method, we draw a conclusion that Large satellites is the most profitable one. These two assessment can be later used as an essential indicator for all projects.

Following step is that we use analytic hierarchy approach to assess three projects' profit, safety, efficiency, applicability, by which we learn what weight coefficient can be when consider four indicators comprehensively and the advantages and disadvantages of each project's indicator. Using these weight coefficient as a indicator for fuzzy comprehensive evaluation of weight coefficient, we reach three projects' assessment with weight average principle. The results follows, Space-based water jets is fair, High energy lasers is better and Large satellites between two.

Since fragments will change with time, we last step apply Markov model to revise.Then comes our conclusion, that is clearing space junk is worthwhile for private company.

content

1. Introduction..1

1.1 Overview..1

1.2 Assumptions..2

1.3 Nomenclature..2

2 Model Theory..3

2.1 Evolutionary modeling Thought..3

2.1.1The basic sub-models modeling thought..3

2.1.2 Debris at a future time in the evolution..4

2.2 Space debris density distribution model..5

2.2.1 The basic concept of the track..5

2.2.2 Spatial density distribution..5

2.3 Risk Assessment Model..8

2.3.1 Mathematical model of the collision probability..8

2.3.2 Launch success rate analysis..10

3. Based on the economic evaluation model..11

3.1 cost analysis..11

3.2 Benefit Analysis..16

3.3 Analytic Hierarchy Model Select weight..17

3.4 Fuzzy Comprehensive Evaluation Model..20

3.5 Fixed time-based Markov model..22

4 Final Remarks..23

4.1 Strengths and Weaknesses......23

4.2 Future Model Development......23

4.3 Conclusions......24

The Executive Summary......25

Economic-optimized model for space junk

1. Introduction

1.1 Overview

Space junk is brought by human beings in aerospace activity, which generally refers to the fragments made from any disabled payload, rock body that distribute in spacecraft orbit, and from explosion and collision. Normally, they appear in different size and mass, show various distribution patterns in different altitude. Thereby, the running velocity can be different too.

Figure 1Status of space debris

Space junk has reached into a unbelievable number these days, as a result of high speed development in aviation industry. Besides, it will have collision with spacecraft in a remarkable speed, bringing safety problem to spacecraft itself. For example, The issue itself became more widely discussed in the news media when the Russian satellite Kosmos-2251 and the USA satellite Iridium-33 collided on 10 February, 2009.Clearing the space junk, therefore, has become a top-task to be dealt with, but at the same time, is also worthwhile for private company.

Being a private high-tech company, working out clearing space debris project should make sure the technique could be fully carried out, consider which theoretical project would be adopted and improved. Given understanding how to eliminate the fragments, such as space-based Water jets and high energy lasers and large satellites designed to sweep up the debris, among others, the difference of application scope, operation efficiency and cost, high-tech company is able to combine several projects according to its own demand. In addition, it is also obligated to asses if there is a appealing attraction in terms of economic profit through including cost and profit in economic point of qualitative or quantitative evaluation scheme, combing the risk of unsuccessful launching, the collision and explosion in orbit.

1.2 Assumptions

The accuracy of our models rely on certain key, simplifying assumptions. These assumptions
are listed below:

·The density of space debris is distributed over the longitudes uniform.

·High track density area similar variation with altitude and time with low orbit.

·Risk mainly the risk of collision risk and launch time, and does not occur other unforeseen circumstances.

·The private company has sufficient fundraising ability, not because of funding problems led to the stagnation of the project.

·Launch success rate can be used instead of the average of recent years.

·Probability of collision is small in space.

·Ignores the Space Debris Mitigation of natural factors.

·In the evaluation system, our weight setting is feasible and science.

·The costs and benefits of private companies chosen are reasonable.

1.3 Nomenclature

X	calculated period
A_X^j	the growth rate of parameter J in the X year.
δ	other factors
c_i	weight coefficient
M_X	the X year’ s model
Φ	latitude
h	latitude
N_Σ	the number of space fragments at concerned altitude
$P(i)$	Density with respect to the different heights of space debris distribution range of inclination i
$P(h_p)$	Density with respect to the distribution of near-Earth heights
$P(e)$	Density with respect to the distribution of eccentricity e
μ	parametric latitude
$P_{i=n}$	probability of collision in the N time.
M_h	mean anomaly of H
F	the average differential flux of particle projectile
A_c	cross sectional area
Φ	fluence
η	risky probability of launching
η_l	probability of unsuccessful launching
η_c	probability of collision

2 Model Theory

2.1 Evolutionary modeling Thought

2.1.1□The basic sub-models modeling thought

According to access to information, divided into the following types of space debris

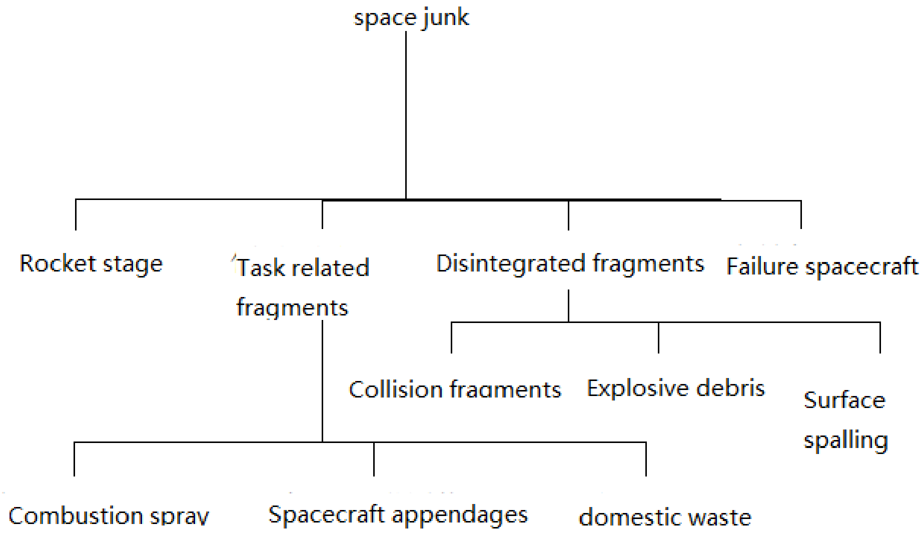


Figure 2 Classification of space debris

If there is no time to clean up the debris will continue to grow over time, so we need to change with time rate of debris, building debris evolutionary models in the coming time, to determine its quantity.

The so-called space debris is produced by the fragmentation of the events and non-events fragmentation, fragmentation of the event is defined by the explosions, collisions and other causes of debris. Non-fragmentation events in the debris into large diameter produced fragments (diameter ≥2 cm) and small fragments (diameter <2 cm) in both cases. Thereby dividing the basic model of fragmentation, large and small debris debris models models were considered as of the distribution of 31 December 1998 fragments in each model [1]. Taking into account the effect of atmospheric drag and other debris orbit perturbation, establish orbital debris transition model. Changes in the track model to 400 km orbit altitude for the sector, considered separately atmospheric drag and solar radiation pressure dominated the two cases.

2.1.2 Debris at a future time in the evolution

Consider fragmentation events and non-fragmentation events and related factors, the growth rate of the introduction of events:

$$A_X^j = \frac{\sum_{i=X-5}^{X-1} c_i A_i^j}{5} \tag{1}$$

Wherein, X is calculated year and X ≥ 1900; $c_i$as weights; A_X^j parameters for the desired growth rate in the first X years.
Taking into account other confounding factors, with δ represent these factors, such as the contribution of the collision between the fragments, taken at a future time in power and other debris environment.
Using mathematical language to describe the evolution of the debris as follows:

$$M_X = M_{X-1}\left(A_X^j, \delta\right) \tag{2}$$

In the formula, M_X represents the first model year.

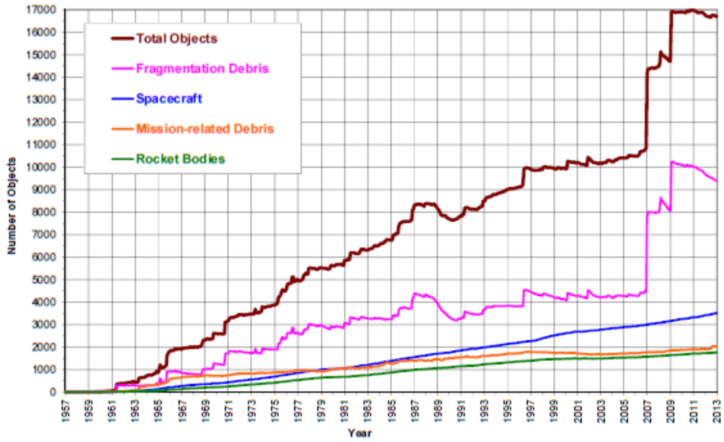


Figure 3 Space debris density versus time

2.2 Space debris density distribution model

2.2.1 The basic concept of the track

In reality, we generally only study of near-Earth orbit, because of near-earth orbit human space activity is concentrated, it is carried out including Earth observation, communications, meteorological research, broadcasting and other space activities in a very important natural resource. We can take its height in the range of approximately 200km ~ 2000km. Another reason is that we can calculate based on the model of the near-Earth orbit apogee height, so more research in LEO orbit.

The following figure shows the relationship between the geometric parameters of the orbit, will be used here only gives the basic relationship, assuming known data are: semi-major axis a, eccentricity e.

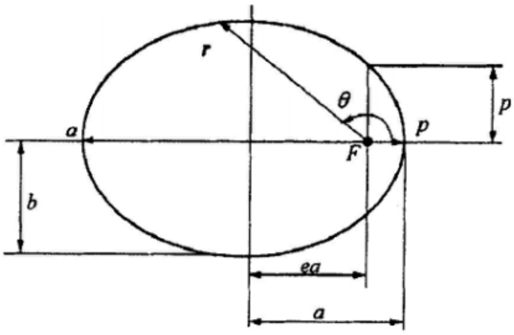


Figure 4 Geometrical relation on of the ellipse orbits

Can be obtained: half normal chord

$$p = a(1 - e^2) \tag{4}$$

Perigee height

$$h_p = a(1 - e) - R \tag{5}$$

Perigee height

$$h_p = a(1 + e) - R \tag{6}$$

From Kepler's third law, cycle operation of spacecraft in orbit T satisfies the relationship

$$T = 2\pi \sqrt{\frac{a^3}{\mu}}$$

Where μ is the Earth's gravitational constant $\mu = 398600 km^3/s^2$,

2.2.2 Spatial density distribution

Space refers to the probability density of space debris that appears on each spatial unit, can be used to describe the spatial distribution of debris in space, we remove space debris research method premise is further important factor affecting our economic model. Suppose the spatial density of space debris in the longitude is evenly distributed, so the space density distribution of space debris is only a function of latitude φ and altitude h.

Suppose $N(\varphi,h)$ is less than the height dimension h smaller than φ the total amount of space debris is defined:

$$p(h,\varphi) = \frac{\partial^2 N}{\partial h \partial \varphi} \tag{7}$$

Thus the combination of the spatial density and type definitions:

$$\rho(\mathrm{h}, \varphi) = \lim_{\Delta V \to 0} \frac{\Delta N}{\Delta V} \tag{8}$$

Wherein $\Delta V = r^2 \cdot cos\varphi \cdot \Delta h \cdot \Delta\varphi$,$\Delta\lambda$ is the volume unit by uniform hypothesis, longitude integrated, there

$$\Delta V = 2\pi \cdot r^2 \cdot cos\varphi \cdot \Delta h \cdot \Delta\varphi \tag{9}$$

Where r = h + R is the distance from the center of the earth, R is the radius of the Earth. and $\Delta N = \rho(h,\varphi) \cdot \Delta h \cdot \Delta\varphi$ (10)

thereby

$$\rho(h,\varphi) = \frac{P(h,\varphi)}{2\pi \cdot r^2 \cdot cos\varphi} = \frac{P(h,\varphi)}{2\pi \cdot (h+R)^2 \cdot cos\varphi} \tag{11}$$

It can be seen that the construction space density distribution, the key lies in the constructor $p(h,\varphi)$

When constructing spatial density, takes the following parameters () as an initial condition:

N_Σ:Total number of space debris at the height of interest;

P(h_p):Density with respect to the near-Earth height h_p of the distribution;

P(e):Eccentricity e relative density distribution;

P(i):Density with respect to the different heights of space debris distribution range of inclination i.

Here, p(h_p), P(e)and P(i) are independent of each other, they satisfy the following conditions:

$$\int_{h_p} p(h_p) \cdot dh_p = 1 \tag{12}$$

$$\int_{e} p(e) \cdot de = 1 \tag{13}$$

$$\int_{i} p(i) \cdot di = 1 \tag{14}$$

Function p(h, φ) through a two-stage configuration, the first consideration in the orbital altitude (h, h+Δh)within the scope of a thin layer of spherical space debris Average number ΔN(h, h+Δh); Second, consider the space debris in the first step on the basis of the given the distribution of the Earth's latitude, is ΔN(h, h+Δh, φ), the following relationship exists between these parameters:

$$\int_{\varphi} \Delta N(h,h+\Delta h,\varphi) \cdot d\varphi = \Delta N(h,h+\Delta h) \tag{15}$$

Clearly, the following relation holds:

$$p(h,\varphi) \cdot \Delta h \cdot \Delta\varphi = N_{\Sigma} \cdot \iiint_{h_{p,e,i}} \Delta P \cdot p(h_p) \cdot P(e) \cdot P(i) \cdot dh_p \cdot de \cdot di \tag{16}$$

among them

$$\Delta P = \Delta\tau(\varphi,\varphi+\Delta\varphi)\,\Delta\tau\,(h,h+\Delta h) \tag{17}$$

Is the probability of debris falling into the area [h, h+ $\Delta h,\varphi+\Delta\varphi$], Where $\Delta\tau(\varphi,\varphi+\Delta\varphi)$ and $\Delta\tau(h,h+\Delta h)$ are falling debris probability latitude layer [$\varphi,\varphi+\Delta\varphi$] FL and [h, h+$\Delta h$] of. $\Delta\tau(\varphi,\varphi+\Delta\varphi)$ can be determined by the following method. Located at latitude debris layer[$\varphi,\varphi+\Delta\varphi$] within the residence timeΔt, debris and orbital period is T, then

$$\Delta\tau\ \ (\varphi, \varphi+\Delta\varphi) = \frac{\Delta t}{T} \tag{18}$$

Let μ latitude parameters, namely,

$$\mu = f + \omega \tag{19}$$

Where f and ω are true anomaly and orbit perigee angular distance. μ and latitude φ there is a relationship:

$$\varphi = arcsin\,(\sin\mu \cdot sini) \tag{20}$$

or

$$u = arcsin(sin\varphi/sini) \tag{21}$$

Can be obtained

$$\Delta u = \frac{cos\varphi}{\sqrt{sin^2 i - sin^2\varphi}} \cdot \Delta\varphi \tag{22}$$

By symmetry orbits, available

$$\Delta t = \frac{2\Delta u}{\dot{u}} \tag{23}$$

where

$$\dot{u} = \frac{2\pi}{T \cdot \Phi(h_{p,}e,,h)} \tag{24}$$

Among them

$$\Phi(h_p,e,h) = \frac{(1-e)^2}{\sqrt{1-e^2}}\left(\frac{h+R}{h_p+R}\right)^2 \tag{25}$$

Can be obtained $\Delta\tau(\varphi,\varphi+\Delta\varphi)$:

$$\Delta\tau\,(\varphi, \varphi+\Delta\varphi) = \frac{1}{\pi} \cdot \Phi(h_p,e,h) \cdot \frac{cos\varphi}{\sqrt{sin^2 i - sin^2\varphi}} \cdot \Delta\varphi \tag{26}$$

The linear relationship between the flight time and the mean anomaly between, $\Delta\tau\,(h,h+\Delta h)$ is determined by the following method. The perigee height h_p and eccentricity e, according to the track dynamics can be obtained apogee height h_a, according h_p and h_a, $\Delta\tau(\varphi,\varphi+\Delta\varphi)$ determination can be divided into the following six cases:

1. $h_p \le h_a \le h \le h+\Delta h$, at this time $\Delta\tau=0$;

2. $h_p \le h \le h_a \le h+\Delta h$, at this time $\Delta\tau=\frac{\pi-M_b}{\pi}$;

3. $h_p \le h \le h+\Delta h \le h_a$, at this time $\Delta\tau=\frac{M_{h+\Delta h}-M_b}{\pi}$;

4. $h \le h_p \le h_a \le h+\Delta h$, at this time $\Delta\tau=1$;

5. $h \le h_p \le h+\Delta h \le h_a$, at this time $\Delta\tau=\frac{M_{h+\Delta h}}{\pi}$;

6. $h \le h+\Delta h \le h_p \le h_a$, at this time $\Delta\tau=0$。

Wherein: M_h and $M_{h+\Delta h}$ respectively h and h+Δh corresponding mean anomaly.

Based on the above analysis, it can be drawn from the function p (h, φ) expression:

$$P(h,\varphi)\Delta h = N_\Sigma \cdot \frac{cos\varphi}{\pi}F(\varphi)\cdot \iint_{h_p\,e} \Delta\tau(h,h+\Delta h)\Phi\left(h_p,e,h\right)P\left(h_p\right)p(e)dh_p de \qquad (27)$$

among them:

$$F(\varphi) = \int_i \frac{p(i)di}{\sqrt{sin^2 i - sin^2\varphi}} \quad (\sin i \ge sin\varphi) \qquad (28)$$

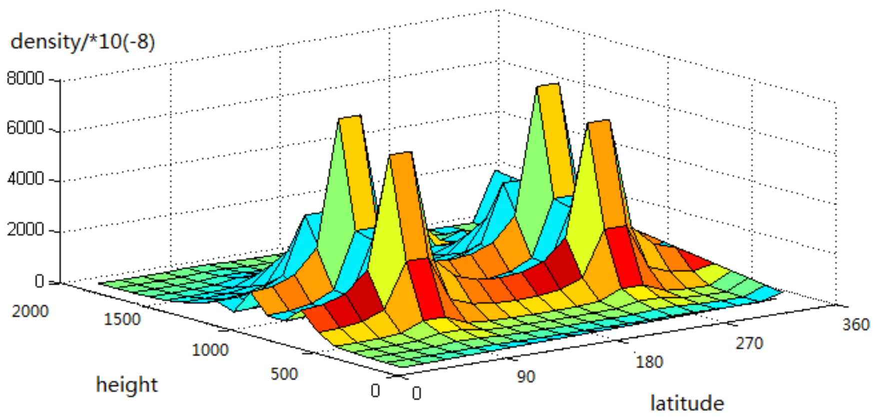


Figure 5Density variation with height latitude

2.3 Risk Assessment Model

2.3.1 Mathematical model of the collision probability

Spatial density of space debris environment usually fragments (Density) and flux (Flux) will be described. Description density of space debris in the distribution of space, the size of the density value represents the size of the local region within the spacecraft and space debris collision risk. Flux space debris refers to the unit time by unit. Number of cross-sectional area of space debris, debris flux and the spacecraft suffered the impact of space debris is proportional to the risk. Research on space debris flux density and can help us to determine the probability that we launch a spacecraft to collide with debris occurred.

According to kinetic theory of gases, known as A_c cross-sectional area of the space object at a constant rate v run on space debris density D of the track, the average differential impacting particle flux $F = Dv$, units of $m^{-2}s^{-1}$; the corresponding fluence $\Phi = F\Delta t$

In the limited time Δt the average number of collisions c can be given by the following relationship:

$$c = \Phi A_c = FA_c\Delta t = vDA_c\Delta t \tag{29}$$

According to the Poisson probability distribution theory, n times impact event occurred $P_{i=n}$ is:

$$P_{i=n} = \frac{c^n}{n!}e^{-c} \tag{30}$$

The probability of collision does not occur as follows $(P_{i=0})$:

$$P_{i=n} = \frac{0}{0!}e^{-c} = e^{-c} \tag{31}$$

It occurs once or more than once collision probability is:

$$P_{i\geq 1} = 1 - P_{i=0} = 1 - e^{-c} \tag{32}$$

For smaller c value, $c \sim 1$, the following approximate equation holds:

$$1 - e^{-c} \sim c \tag{33}$$

Truncation error is $O(c^2)$ of the order:

For the current relationship between the collision between the spacecraft and space debris, $c \sim 1$ in terms of the establishment, therefore it has the following equation holds:

$$P_{i\geq 1} = 1 - e^{-c} \sim c = vDA_c\Delta t \tag{34}$$

The above equations show very small probability of collision of formula $P_{i\geq 1} = 1 - e^{-c}$ and approximate formula $P_{i\geq 1} = c = vDA_c\Delta t$

results are very consistent in $c \leq 0.2$ $P_{i\geq 1} = 1 - e^{-c}$ less than 10% of the introduced, the differences between them as shown:

Formula $P_{i\geq 1} = 1 - e^{-c} \sim c$ of formula $c = vDA_c\Delta t$ constitute target collision with space debris and flux estimates on probability.

According to the data, we get the following table

table 1Collision probability distribution table

height/km	Average time/day	density	Cross-section	Collision Probability P
400	4.5	98.31	3.14	0.00001389
	1423.5	98.31	314	0.4394
	443110	98.31	31400	13678.40
	4983080	98.31	3140000	18469216.52
800	2.3	3115.41	3.14	0.000225
	365	3115.41	314	3.57057
	89425	3115.41	31400	87479.038
	647875	3115.41	3140000	63377670.6
1500	0.9	23.9024	3.14	0.0000006755
	547.5	23.9024	314	0.0411
	194910	23.9024	31400	1462.87
	1134785	23.9024	3140000	851697.852

2.3.2 Launch success rate analysis

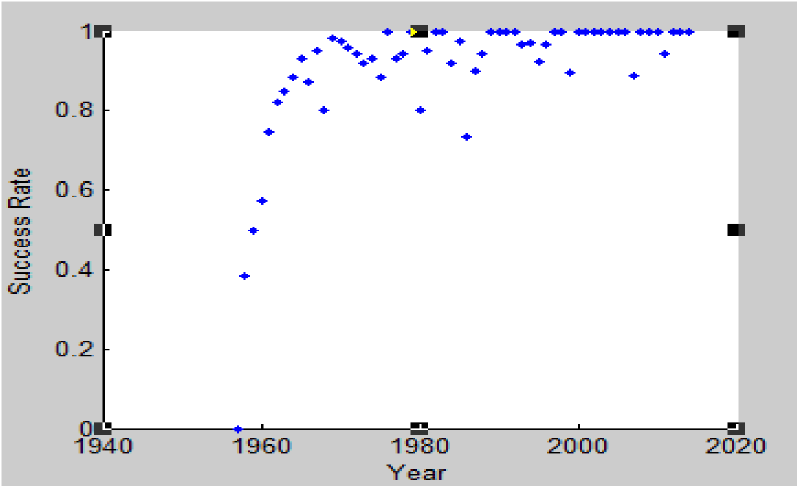


Figure 6 LEO launch success rate over the years

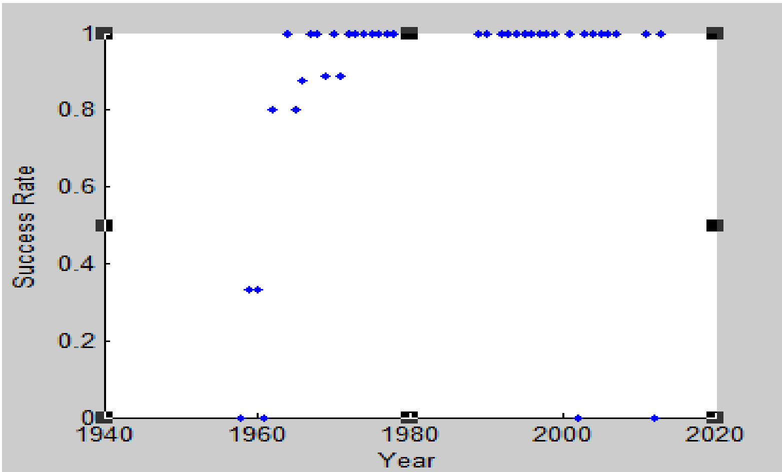


Figure 7High Orbit launch success rate over the years

After that, we according to NASA from 1957 to 2014 data, the success rate forecast emitted, because in the early stages of immature technology, the success rate is low, inconsistent with the current situation, so we use the 1970 data.

Among them, the average of LEO launch success rate variance $sum = 96.13\%, var = 0.003$.

The success rate was high rail transmitted $sum = 92.72\%$, the variance $var = 0.066$.

Variance smaller sets of data, we can go as their average success rate of emission, wherein the low-orbit launch success rate of 96.13%, higher orbit launch success rate of 92.72%.

Because we know that with the successful launch of collision events are independent, so we can learn from these two quantities are derived satellite launch risk assessment η:

$$\eta = \eta_l \cdot \eta_c \tag{35}$$

3. Based on the economic evaluation model

3.1 cost analysis

(1)Space-based water jet
each number as a percentage of overall cost:

Water jets generally is the use of water in space, under the premise of supercharged power, space debris to the ground, so as to achieve the purpose of clean-up, which is suitable for large-scale clean-up of debris. Of course, it also has cut several types of these different types of water jets cost roughly divided into the following points:

1. The cost of water

The cost of water is water jets total costs accounted for the smallest proportion of costs. It uses the national average of $ 3.51 per 1000 gallons, including maximum cutting water and cooling water. Total annual costs between $ 1,200 and $ 2,500. Of course, this value does not consider the additional cost of water, such as storage, transport and so on. So the next real cost will be higher.

2. The cost of electricity

Water jets require power supply. We assume that an average 7.46 cents per kilowatt-hour. Thus every year it costs between $ 3,700 and $ 9,400.

3. Cost of wear parts

Water jets are due to environmental factors work, vulnerability of its parts is very high, we will need a lot of maintenance costs. If we calculate the cost per hour, it takes about 5-22 US dollars per hour, so every year it costs about $ 77 to $ 32,000.

4. Abrasive costs

Water jets in the biggest piece of the cost comes from the abrasive. On average, we spend an hour abrasive between 18-36 US dollars. Let us assume that there are six hours cutting time every day, so every day we abrasive is 110-220, 550-1100 US dollars per week, $ 2,200 per month to $ 4,400 per year from 26,000 to 55,000 US dollars.

Because the proportion of each in the respective costs of different types of water jets, then their final total cost will be different, as follows:

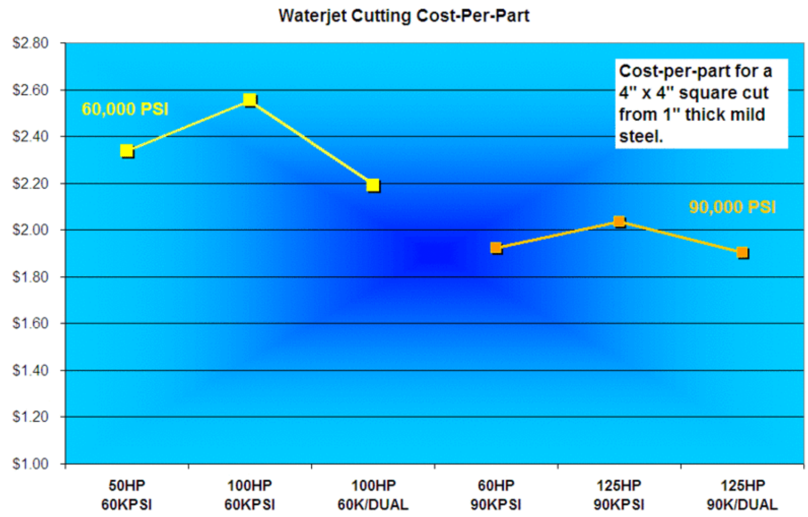


Figure 8Water jet Cutting Cost-Per-Part

Mentioned-above cost is only targeted at space-based water jets themselves, but for a company, we also need to consider the launch costs, labor costs, overhead, interest rates and so on, we can integrate these factors into an hour wage rate, plus on this condition, thereby to correct the true costs of space-based water jets:

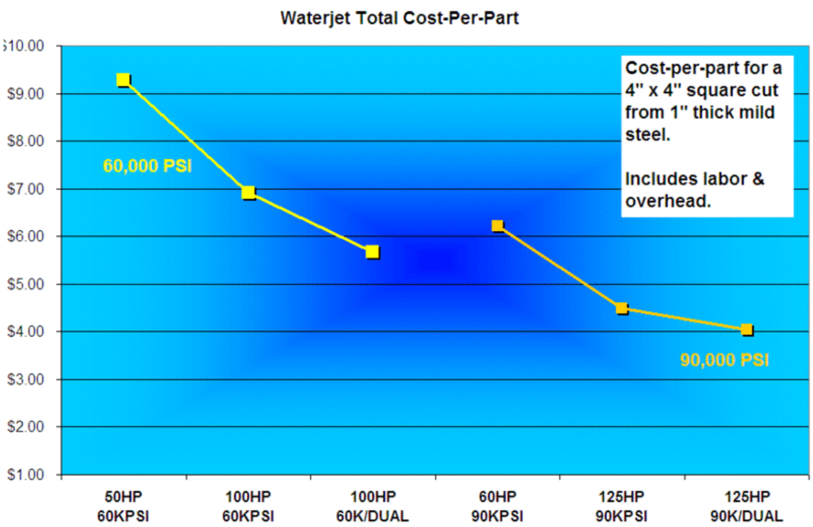


Figure 9 Water Total Cutting Cost-Per-Part

Therefore, the above, we can give space-based water jets annual average cost integrated: $ 680 million.

(2)High energy lasers

□ High Energy Lasers mainly to clean up space debris burning track down and capture the sublimation method.

1) Burning sublime way with an energy density of space debris during high energy laser irradiation is large enough, the rapid warming reaches of space debris material melting or boiling point, melting and vaporization achieve debris.

Space debris gasification evaporation threshold value is generally $0.1 \sim 1MW/cm$ within the intensity range. Generally require multiple sets of high-energy laser to work, before they reach the high energy density of the short-term energy. Mainly for small space debris.

2) Capture mode to track down space debris irradiated portion temperature exceeds the vaporization temperature of the surface of the material, the generated plasma expands outward scattering caused by surface material ablation, ablative material to produce a hydrodynamic reaction (anti-erosion jetting amount). Changing the speed of debris, perigee height reduced to 200km after debris gradually fall into the atmosphere and burn in air friction heat affected.

Centimeter of space debris in orbit distributed in height H = (800--1200) km range mostly along an elliptical orbit after orbit, at a perigee radius to take the minimum $r_0 = a(1-e)$. Atmosphere high H_0 =(80--100km), the earth's average radius R of about 6378km, when the high-speed flight of space debris is located $r_0 \le H_0 + R = (80 + 6378)km =$ 6458km, which will slow down gradually fall into the atmosphere under the effect on the atmosphere and burned under aerodynamic heating effect of the atmosphere.

Assuming that the initial parameters: H is 1000km; Assuming that the initial parameters: H is 1000km; velocity increment proportional coefficient $k = \frac{\Delta V_0}{v_0} = 0.05$. Velocity increment scale factor wherein the initial velocity $v_0 = \sqrt{\frac{\mu}{r_0}}$(where the Earth gravitational constant $\mu = 3.986 \times 10^5 km^3/s^2$) is calculated based on results of 7.350203km/s, that is available $\Delta V_0 = 367.51015m/s$.

Laser pulse interval is T_0,the number of single pulses per second to $n = \frac{1}{T_0}$, laser power E_g (energy supplied per second), total impulse per second is

$$n\bar{F}t_0 = nC_mE = nC_mE_g \tag{36}$$

Velocity increment per second as

$$\Delta v = \frac{\bar{F}t_0}{m} = \frac{C_m E_g}{m} \tag{37}$$

In the above formula: E is one-pulse laser energy; C_m is the coupling coefficient (impulse laser energy unit produced).

Let lasers $10^4 W$ level, providing energy for $E_g = 10^4 J$, common space debris laser materials, composite mate rials or aluminum coupling coefficient $C_m = (1.0{\sim}2.0) \times 10^{-5} N \cdot s \cdot J^{-1}$. Generated total impulse $C_m E_g \quad = (1.0{\sim}2.0) \times 10^{-1} N \cdot s$, velocity increment $\Delta v = (0.1{\sim}0.2) m \cdot s^{-1}$.

The orbit velocity increment required to $\Delta v_0 = 367.51015 {}^{m}/_{s}$.

$10^4 W$ laser class action time shown in the table.

table 2 Laser irradiation time

Space debris mass/kg	Velocity increment per $(m \cdot s^{-1})$	Laser irradiation time /s
0.02	5~10	73.5~36.8
0.1	1~2	367.5~183.8
1	0.1~0.2	3675.1~1837.6
5	0.02~0.04	18375.5~9187.8

Aluminum composite efficiency and maximum density $\rho_{max} = 2.7 \times 10^{-3} kg/cm^3$, the quality of m = 5kg, shape and this is a solid sphere of radius

$$r = \left(\frac{3m}{4\pi\rho_{max}}\right)^{\frac{1}{3}} \approx 7.6cm \tag{38}$$

Obviously, for a diameter of 15cm, the quality of a solid sphere 5kg of space debris, if the laser is $10^5 W$ stage, operating time of the laser 918.8 ~ 1837.6s. The power calculation formula W = Pt out of the energy consumption of about Joule power of 1x10^8 to --1.8x10^8

power of 8 joules. Assume substantially all of the power required by the fuel, according to the fuel efficiency of about 40% can be calculated cleared diameter 15cm, 5kg quality solid sphere of space debris consumed fuel costs. The following is the official parameters and cost of different types of lasers

table 3 Summarzing Qptimum ORION Parameters

Laser Type	Range (km)	Mirror Diameter D_b(m)	Total Cost (FY95 $)	Laser average Power(W)
Cw (iodine1.3μm)	400	4.2	25M$	500kW
	800	5.8	46M$	900kW
	1500	7.8	81M$	1.8MW
	3000	10.5	150M$	4.6MW
Solid State (1.6μm, 100ps)	400	3.5	25M$	32kW
	800	4.5	39M$	80KW
	1500	5.8	60M$	160kW
	3000	7.2	98M$	430kW
Solid State(1.6μm, 100ns)	400	6.5	71M$	210kW
	800	8.2	116M$	525kW
	1500	11	184M$	1MW
	3000	15	312M$	2.2MW

For a cost on the order of $160 million, orbital debris removal can be demonstrated as part of a phased program and the envelope of coverage extended to 1500km.Costs grow because requirements dictate larger primary mirrors(5 to 10m).

For example, total costs were derived to be $140 to $176 million. The breakdown for this configuration includes a0.1-ns pulsed Nd: glass laser operating at 2 to 4 kJ and 1 to 5 HZ and costing $45.9 to $66.9 million. Also included is a Government-furnished telescope with a6-m adaptive primary mirror costing $57.3 to $60.3 million. A new sodium guide star subsystem cost $7.1 to $10.7 million. Integration are expected to range from $12.2 to $15.5 million .The total costs for the other configurations were derived in a similar manner.

For a cost on the order of $20 million, orbital debris removal can be demonstrated. For an additional cost on the order of $60 million, or $80 million total, essentially all orbital debris in the 1- to 10-cm size range below 800 km can be eliminated over 2 to 3 years of operation, thus protecting the ISS and other assets against debris of these sizes. A cheaper system capable of debris removal only to 500km attitude could be used if the sole objective were to protect the ISS.

For a total cost on the order of $160 million and an additional year of operation, this envelope can be extended 1500km, thus protecting both ISS and Global star.

According to the above, we can know, because High energy lasers emitting laser is on the earth, so it's not necessary to consider the cost of emission and other costs, so integrated down, we can come up in this method, the cost of the company needs to spend roughly 2.1 One hundred million U.S. dollars.。

3)Large satellites designed to sweep up the debris

US EELV rocket spent $ 3.5 billion, higher research costs of the Ariane 5 rocket. On the development of the spacecraft, China in the 1990s developed the Shenzhou spacecraft to spend 3 billion, the Japanese started to develop in 1997 HTV cargo ship spent $ 850 million, since 1995 the European ATV cargo spacecraft development cost of $ 1.9 billion.

Being from the space X's official website data is "Dragon" spacecraft launch a single offer is $ 133 million, while per-year space shuttle launch up to $ 500 million " FALCON HEAVY "price of $ 90 M, Falcon 9 rocket emission standard cost of $ 54 million .Space X company said pusher development and test cost approximately $ 100 million, the next rocket launch may cost around $ 8,000,000. compares the cost of government aviation agencies to spend, the company's commercial space a more favorable economic development. the company will develop the rocket cost an order of magnitude reduction in this fee for the current minimum in the history of rocket launchers, rocket launchers we have this data as a reference cost data.

table 4 cost and parameter of "FALCON "

STANDARD DAYMENT PLAN (2016LAUNCH)	$61.2M		$90M	
LEO	28.5°	13150kg	28.5°	53000kg
GTO	27°	4850kg	27°	21200kg

Suppose five times each year, its research and development costs and launch costs roughly $ 560 million, plus this year, the company's labor costs, expenses, interest rates, etc., we can estimate the annual cost of about 890 million.

3.2 Benefit Analysis

table 5Benefit assessment

Benefit Analysis	Estimate damount/ year
NASA awarded contracts and government support	1--5
Other government agencies	$50M—100M
Risk Investment	6M—1200M
Sell products	1M—100M
Recycling reproduction	0. 1M—10M
Sale of non-core technology	10M—50M
Stock appreciation	20M—50M

Over the next ten years, the size of commercial space activities is expected to double the $250 billion today. Because of the space debris clean-up projects in the planning stage, there is no exact real income data, so we refer to space business company SpaceX, blue origins, planetary resources companies, financial discrete data reference, divided into the following indicators:

· NASA awarded the contract, his government; SpaceX in December 2008

had access to the US space agency official commercial resupply services (CRS) contract, the fixed price contract value of $1.6 billion, contains 12 freight service launch.

· business investment: get private enterprises, including many pieces

cleaning contract. June 2010 space X company to obtain the biggest commercial investment, using in a few pieces of Falcon 9 rocket launch iridium next generation, with a total value of $492m. April 2011 X Space company and the second phase of the development of commercial passenger transport $75 million. Companies involved in the COTS competition, in 2006 won the first phase of the COTS value of $1. In April 22, 2008 the American Aerospace Bureau awarded the Space company X to launch a service contract, $200 million to $1 billion.

·series products for sale;

·on the reproduction of the recovery of space debris, such as design

and manufacture for souvenirs, industrial parts of heavy use;

·and other commercial companies pay: according to optimistic tendency

of commercial space, commercial space tourism transportation company and development of space resources of private enterprises will gradually grew up, the premise of these space company of product testing and development projects need a good environment for the near earth, will be required to pay hire to clean up space junk, professional company.

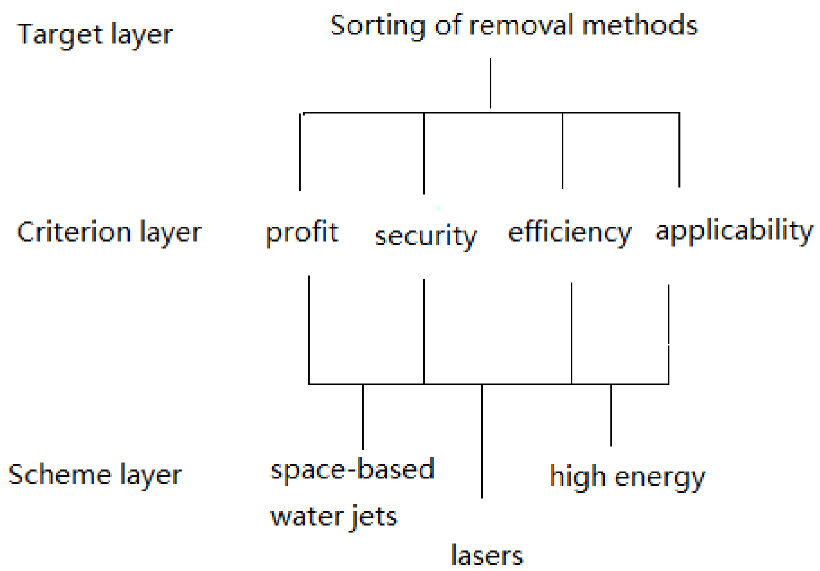
·hold stock price; Tesla shares five years ago to \$30 a share, and as

of December 25, 2015's share price has been as high as 230.57 dollars a share; Solar City five years ago the price just over \$10 a share, and as of December 25, 2015's share price has risen to \$51.98 A shares.

According to three cleaning method fragments source of revenue in all of the above accounts for the proportion of different, can be used to estimate the benefits of each of the three methods, to space-based water jets program, its cost roughly to 6.8 billion / year, it is estimated that the revenue accounted for 20% of the total income; for high energy lasers scheme, it is estimated that the cost of 8.11 billion / year, its income accounted for total income 40%; emission cleaning satellite cost 8.9 billion / year, its income accounted for 50% of overall.

3.3 Analytic Hierarchy Model Select weight

The main content of the Analytic Hierarchy Process: Target layer 、Criterion layer、Scheme layer。Structure is as follows



In the AHP, we set n to compare the impact of various factors on the target, thereby to determine their share of the proportion of the target, then we will get a judgment pairwise comparison matrix A. According to the table

Qualitative comparison result	Quantitative figures
Factor 1 Factor 2 compared to the same	1

importance	
Factor 1 Factor 2 as compared with the former slightly stronger importance	3
Factor 1 Factor 2 as compared with the former importance of strong	5
Factor 1 and Factor 2 compared to the former importance of significantly stronger	7
Factor 1 Factor 2 as compared with the former absolute importance of strong	9
Factor 1 Factor 2 compared to the relative importance between the level at	2、4、6、8

Construction of judgment matrix.

We construct guidelines to decision matrix layer is the target layer

$$A = \begin{pmatrix} 1 & 1 & \frac{1}{5} & \frac{1}{3} \\ 1 & 1 & \frac{1}{5} & \frac{1}{3} \\ 5 & 5 & 1 & \frac{1}{3} \\ 3 & 3 & 3 & 1 \end{pmatrix}$$

These matrices do not necessarily meet the consistency, but we can find a number of standard CI (consistency index) to measure the degree of inconsistency judgment matrix. and

$$CI = \frac{\lambda_{max} - n}{n-1} = 0.0145 \tag{38}$$

Among them, the judgment of the largest eigenvalue matrix A, n is the order of A.

Of course, with CI concept, we can find the average random consistency index RI. A maximum eigenvalues obtained in a sufficiently large sub-sample mean, according to

table 6Values of Random consistency index RI

n	1	2	3	4	5	6	7	8	9	10	11
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51

So we get RI = 0.9

With CI, RI, we can define the ratio of these two $\frac{CI}{RI}$=CR, CR also known as random consistency ratio.

$$CR = \frac{CI}{RI} = 0.0163 \quad < 0.1 \tag{39}$$

When CR <0.1, the judgment matrix has satisfactory consistency.

We construct the program layer to the profits judgment matrix

$$A=\begin{pmatrix}1 & \frac{1}{2} & \frac{1}{3}\\ 2 & 1 & \frac{1}{2}\\ 3 & 2 & 1\end{pmatrix}$$

$$CI=\frac{\lambda_{max}-n}{n-1}=0.0046 \tag{40}$$

$RI=0.58$

$$CR=\frac{CI}{RI}=0.0088\quad<0.1 \tag{41}$$

The matrix is consistency check.

The ratio of the three methods of total profit for the （0.1634，0.297，0.5396）

我们构造方案层到安全性的判断矩阵为:

$$A=\begin{pmatrix}1 & 3 & 5\\ \frac{1}{3} & 1 & 2\\ \frac{1}{5} & \frac{1}{2} & 1\end{pmatrix}$$

$$CI=\frac{\lambda_{max}-n}{n-1}=0.0018 \tag{42}$$

$$RI=0.58$$

$$CR=\frac{CI}{RI}=0.0036<0.1 \tag{43}$$

The matrix is consistency check.

The ratio of the three methods of total profit for the （0.6483，0.2297，0.122）

We construct the program layer to the efficiency index of judgment matrix

$$A=\begin{pmatrix}1 & \frac{1}{5} & \frac{1}{3}\\ 5 & 1 & 2\\ 3 & \frac{1}{2} & 1\end{pmatrix}$$

$$CI=\frac{\lambda_{max}-n}{n-1}=0.0018 \tag{44}$$

$RI=0.58$

$$CR=\frac{CI}{RI}=0.0036<0.1 \tag{45}$$

The matrix is consistency check.

The ratio of the three methods of total profit for the

(0.1095, 0.5816, 0.309)

We construct the program layer to the security of judgment matrix:

$$A = \begin{pmatrix} 1 & \frac{1}{3} & 2 \\ 3 & 1 & 3 \\ \frac{1}{2} & \frac{1}{3} & 1 \end{pmatrix}$$

$$CI = \frac{\lambda_{max} - n}{n - 1} = 0.0268 \tag{46}$$

$RI = 0.58$

$$CR = \frac{CI}{RI} = 0.0515 < 0.1 \tag{47}$$

The matrix is consistency check.

The ratio of the three methods of total profit for the

(0.2493, 0.5936, 0.1576)

3.4 Fuzzy Comprehensive Evaluation Model

Given two finite domain

$$U:\{profit, security, efficiency, appicability\}$$

$$v:\{Good, better, fair, worse, poor\}$$

U represents a collection of all the factors of evaluation consisting; V represents a collection of reviews of all grades thereof.

According to actual needs, we take a collection of reviews is composed of grades

$$v:\{0.8,\ 0.6,\ 0.4,\ 0.2,\ 0\}$$

If you look at the first i (i = 1,2,3,4) an evaluation factor u_i, its single-factor evaluation results for $R_i=[r_{i1}, r_{i2}, \ldots, r_{in}]$, gather information, evaluate the experts' recommendations, to give 1 Evaluation factors profits of a decision matrix to judge

U is a fuzzy relation on V.

$$R = \begin{bmatrix} R_1 \\ R_2 \\ R_3 \\ R_4 \end{bmatrix} = \begin{bmatrix} 0 & 0.1 & 0.2 & 0.3 & 0.4 \\ 0.3 & 0.3 & 0.2 & 0.2 & 0 \\ 0.3 & 0.3 & 0.2 & 0.1 & 0.1 \\ 0.4 & 0.3 & 0.2 & 0.1 & 0 \end{bmatrix} \tag{48}$$

According to the results of AHP, the weights of each evaluation factor allocation as follows:

$A = [0.3899, 0.3899, 0.1524, 0.0679]$

The fuzzy synthesis operation transformation, can get a fuzzy subset domain V on that comprehensive evaluation results:

The first program to get

$$C_1 = A \times R = [0.1899 \quad 0.2221 \quad 0.2 \quad 0.217 \quad 0.1712]$$

The second program to get

$$C_2 = A \times R = [0.3967 \quad 0.2542 \quad 0.217 \quad 0.1712 \quad 0.039]$$

The third program to get

$$C_3 = A \times R = [0.3 \quad 0.2221 \quad 0.278 \quad 0.1 \quad 0.1]$$

We calculate the weighted average principle to evaluate each method,

The weighted average principle is based on the idea: to be seen as a relatively level position, making it continuous. In order to deal with the quantitative, may wish to use "$1,2,\ldots,n$" respectively for each grade, saying its various levels of rank. Then B component corresponding to the rank of each grade weighted sum obtained by assessment of the relative position of things. Maximum membership degree principle can be expressed as:

$$U^* = \frac{\sum_{i=1}^{n} \mu(v_i) \cdot s_i^k}{\sum_{i=1}^{n} s_i^k} \tag{49}$$

Where k is undetermined coefficients (k = 1 or k = 2), the purpose is to control a larger role s_i, can prove $k \to \infty$, the weighted average principle is the principle of maximum degree of membership.

$C_1 = [0.1899 \quad 0.2221 \quad 0.2 \quad 0.217 \quad 0.1712]$,

$Evaluation\ grade v{:}\{good,\ better,\ fair,\ poor,\ worse\}$,

Each grade values $\mu = \{5,\ 4,\ 3,\ 2,\ 1\}$, According to the weighted average common formula to give $\mu_{k=1} = 3.0431$

That comprehensive evaluation of the results of the outcome of the general,

Similarly,

$C_2 = [0.3967 \quad 0.2542 \quad 0.217 \quad 0.1712 \quad 0.039]$

$$\mu_{k=1} = 4.0319$$

The results of this comprehensive evaluation of outcomes is better,

$C_3 = [0.3 \quad 0.2221 \quad 0.278 \quad 0.1 \quad 0.1]$

$$\mu_{k=1} = 3。5224$$

The results of this comprehensive evaluation of outcomes between better and fair.

3.5 *Fixed time-based Markov model*

Make a logical inference based on the evaluation results and access to information obtained by combining the front, we can get the following table:

table 7 The second probability distribution scheme selection

		Next time use		
		plan 1	plan 2	plan 3
Last use	plan1	0.2	0.5	0.3
	plan 2	0.3	0.4	0.3
	plan 3	0.2	0.6	0.2

$P_{ij}^{(n)} = P\{X_{m+n} = j \,\big|\, X_m = i\}, i,j \in I, m \geq 0, n \geq 1$ N-step transition probability of Markov chain

$P^{(n)} = (p_{ij}^{(n)})$ N-step transition probability matrix of the Markov chain。

$among\ them\ P_{ij}^{(n)} \geq 0, \sum_{j\epsilon I} p_{ij}^{(n)} = 1$ 。

When n = 1, $P^{(1)} = p$, the provisions of

$P_{ij}^{(0)} = \begin{cases} 0, i \neq j \\ 1, i = j \end{cases}$, $P^{(0)}$ is a unit matrix

Select the program for cleaning up debris, only to the current situation, not to the historical circumstances, and no memory, when the condition Qi Markov chains, after a long application, then the following equations:

$$\begin{cases} \pi_1 = 0.2\pi_1 + 0.5\pi_2 + 0.3\pi_3 \\ \pi_2 = 0.3\pi_1 + 0.4\pi_2 + 0.3\pi_3 \\ \pi_3 = 0.2\pi_1 + 0.6\pi_2 + 0.2\pi_3 \\ \quad 1 = \pi_1 + \pi_2 + \pi_3 \end{cases} \tag{50}$$

get: $\pi_1 = \pi_2 = \pi_3 = 0.333$

This shows that no matter how the first customers to buy the case, after long-term repeated use, the program uses a ratio 1 0.33, 0.33 2 ratio of use of the program, using the program 3 ratio of 0.33

4 Final Remarks

4.1 *Strengths and Weaknesses*

Our model is based on the flux space debris collision risk and the risk to launch spacecraft to evaluate the risk of the model, qualitative or quantitative analysis of the various methods of debris removal costs and benefits. This makes our model there are some advantages and disadvantages.

Strengths:

·We consider the variation with time debris

·We try to consider the impact of the size of the debris, density, speed and other factors on the risk of spacecraft

·Economic models consider various factors of a more comprehensive

Weaknesses:

·In economic models, it is difficult to find the data, the data had to choose some model or approximate range to replace, so decrease the accuracy of the model

·High orbit data is extrapolated based on low orbit, there will be some errors

·Risk factors and consider only the collision when the success rate of emission, and not considered very carefully

4.2 Future Model Development

As discussed in the previous section, many of the issues arising from such a generalized simulation is that the more unique factors of the scenario are overlooked. Also, many of the assumptions of the model are not realistic. In the future, we would further develop them odel in the following ways:

·Debris can do more detailed classification, with a more precise function to fit the space debris model change over time

·Factors affecting the distribution of debris can do more precise classification, but also consider the space of a collision, there are differences in point of view, the risk of making them more accurate.

·The base model in the optimization of space debris on changes over time, you can get a more accurate conclusions about the costs and benefits to optimize our choice of different methods

·It can be considered natural factors affect the company's earnings,

for example, enable reduction of space debris and other natural factors

4.3 Conclusions

Our model is divided into evolution model to predict the amount of fragmentation by using the collision probability and prediction success rate risk, as well as through cost and benefit analysis, evaluation of the merits of the existing four sections of three models, in order to consider the collision probability, we highly , latitude and density of relations, calculate flux using the Poisson distribution, predictive probability of collision. We also try to consider a combination of multiple programs. Finally, we consider the impact on the evaluation of the time factor, with longer practical. Our rating system is wide scope for us to make decisions on other aspects of nature are also a great reference value.

The Executive Summary

Space junk has become a major concern of this era hot spots. With a variety of countries in the aviation sector to start work, we study the universe more and more depth and pace of this exploration is unable to stop. In our study experimental process, but also to space launch numerous satellites, spacecraft, probes, etc., due to the technical problems of mankind, these high-tech products will inevitably become space junk. Over time, the garbage piled up, seriously affecting the safety of the spacecraft, so clear space junk has become a major event worldwide imperative. If we do not pay attention, many destined to become orbital debris orbiting spacecraft big problem, and clean-up costs could seriously undermine the aerospace industry. The longer the wait, the more difficult to reverse the situation in the near-Earth environment, but the price is also more expensive.

Thus, we have to space debris made a rigorous analysis, including its density with altitude, latitude, time of the distribution and size of the debris from these areas can be measured by spacecraft collision risk. Then we have the case in previous years, according to launch spacecraft, and also statistics showing the success rate of a spacecraft launch. Finally, these two make a risk assessment.

Summed up the debris distribution and relevant information, we initially selected three programs to clear space debris: space-based water jets, high energy lasers, large satellites. Consider some of the indicators of these methods, such as profits, safety, efficiency and applicability, we can roughly distinguish these methods to clear space junk merits of the case. Then we do a detailed investigation profits, the cost of each method generally includes the cost of products, research and development costs, launch costs, labor costs, interest rates, overhead, etc., which may be the source of revenue debris recycling, the national government It supports the sale of non-core technology, stock appreciation, risky investments, and so on. A combination of its costs and benefits, according to a lot of our data processing and modeling analysis, we can draw a rough initial value, that each method are considerable profits, coupled with the prediction of the future, its profits It will be increasing year by year, so remove space debris is present in commercial opportunities. For example, the company SpaceX spacecraft development, launch respect, perfect fit with the national government, not only to make a contribution, but also won a lot of profit. On the basis of our analysis of these methods, can make an optimal combination of solutions based on the distribution of debris larger than SpaceX company revenue opportunities, so I think in clear space debris, for the private sector is a very Great business opportunities.

Moreover, to give human-made space debris clearing a safe space environment, improve the safety of space exploration, space for us to understand the magic of the world to provide better conditions for us to explore space provided the world with a golden key.

So, if we want to stay ahead of the company to clear space debris. First, choose a reasonable proportion according to our modeling results of the three methods, although the pre-investment costs are great, but we have to look to the future, because the results of our modeling its future development trend is very good . Secondly, we want to introduce a large number of advanced technology and equipment, learn advanced aerospace knowledge, personnel training, lay the foundation for our company's technology development, so that the development of an excellent new product and a more efficient and cost of clean-up program. Again, we need to establish a company to improve emergency measures in the face of risk, and can make decisions quickly, so that the company's losses to a minimum. Finally, as the debris removal depth, also contributed to human society, we can use the power of the media to promote our company's program plan to improve social credibility and social influence of our company, this will bring us more The surplus value, such as government subsidies intensify, banks, investment companies, stock value, and so on.

According to the results of the modeling, the three methods remove space debris, the most profitable should be large satellites, of course, for the satellite, its cost is the highest, but also has some risks. Coupled with this method is mostly used for high regulation debris cleared, so the company can not only consider profit maximization, but only to take this approach to clear the debris. But we should take the best out of our modeling program, because the program summarizes the factors that aspect, more comprehensive, more scientific.

Therefore, the above said, I think the company should seize this opportunity to clear space debris, not only to contribute to society, but also reap tremendous benefits.

Reference:

[1]
王若璞.空间碎片环境模型研究.解放军信息工程大学.2010,4(20):2-106
[2]
叶松,徐敏强等.空间碎片质量分布模型建模方法研究.飞行力学.2003.21(1):853-1002
[3] Orbital Debris Quarterly News. 2013.17(1):8
[4]
尤春燕.2005.空间碎片环境模型SDPA建模原理研究.哈尔滨工业大学硕士学位论文.2-38
[5]
白显祖.空间目标轨道预报误差与碰撞概率问题研究.国防科技大学.2014.4(1):13-19
[6]金星等.
cm级空间碎片的激光清除过程分析.强激光与粒子流.2012.24(2):281-283
[7]http://www.hq.nasa.gov/office/pao/History/series95.html#monographs
[8]http://orbitaldebris.jsc.nasa.gov/fags.html
[9]杨庆等.**地基激光器清理空间碎片的部署研究.第一届中国空天安全会议文集**.2015
[10]http://ww.spacex.com/
[11]欧洲空间局空间碎片减缓手册.2003年3月第二版

Appendix:

Appendix 1

Descriptive Statistics

	N	Sum	Mean	Std. Deviation	Variance
VAR00008	45	43.26	.9613	.05647	.003
Valid N (listwise)	45				

Descriptive Statistics

	N	Sum	Mean	Std. Deviation	Variance
VAR00009	29	26.89	.9272	.25764	.066
Valid N (listwise)	29				

Appendix 2

```
plot(data(1:58,1:7),'DisplayName','data(1:58,1:7)','YDataSource','dat
a(1:58,1:7)');figure(gcf)
>> contour(data(1:58,1:7),'DisplayName','data(1:58,1:7)');figure(gcf)
>>
contourf(data(1:58,1:7),'DisplayName','data(1:58,1:7)');figure(gcf)
>> surf(data(1:58,1:7),'DisplayName','data(1:58,1:7)');figure(gcf)
>> area(data(1:58,1:7),'DisplayName','data(1:58,1:7)');figure(gcf)
>> surfc(data(1:61,1:2));figure(gcf);
>>
plot(data(1:61,1:2),'DisplayName','data(1:61,1:2)','YDataSource','dat
a(1:61,1:2)');figure(gcf)
>> stem(data(1:61,1:2),'DisplayName','data(1:61,1:2)');figure(gcf)
>> stem(data(1:61,1:2),'DisplayName','data(1:61,1:2)');figure(gcf)
>>
scatter(getcolumn(data(1:61,1:2),1),getcolumn(data(1:61,1:2),2),'Disp
layName','data(1:61,1:2)(:,2) vs.
data(1:61,1:2)(:,1)','YDataSource','data(1:61,1:2)(:,2)');figure(gcf)
```

Appendix 3

```
disp('输入矩阵A');

A=input('A=');
[n,n]=size(A);
x=ones(n,100);
y=ones(n,100);
m=zeros(1,100);
m(1)=max(x(:,1));
y(:,1)=x(:,1);
x(:,2)=A*y(:,1);
m(2)=max(x(:,2));
y(:,2)=x(:,2)/m(2);
p=0.0001;i=2;k=abs(m(2)-m(1));
while k>p
i=i+1;
x(:,i)=A*y(:,i-1);
m(i)=max(x(:,i));
y(:,i)=x(:,i)/m(i);
k=abs(m(i)-m(i-1));
end
a=sum(y(:,i));
w=y(:,i)/a;
t=m(i);
```

```
disp(w);disp(t);    %以上是权重的确定

%以下是一致性检验

CI=(t-n)/(n-1);
RI=[0 0 0.52 0.89 1.12 1.26 1.36 1.41 1.49 1.52 1.54 1.56 1.58 1.59];
CR=CI/RI(n);
if CR<0.10
   disp('一致性可接受！');
   disp('CI=');disp(CI);
   disp('CR=');disp(CR);
end
```

输入矩阵A

```
A=[1 1 1/5 1/3;1 1 1/5 1/3; 5 5 1 3;3 3 1/3 1]
   0.0955
   0.0955
   0.5596
   0.2495

   4.0435

一致性可接受！
CI=
   0.0145

CR=
   0.0163
```

```
disp('输入矩阵A');

A=input('A=');
[n,n]=size(A);
x=ones(n,100);
y=ones(n,100);
m=zeros(1,100);
m(1)=max(x(:,1));
y(:,1)=x(:,1);
x(:,2)=A*y(:,1);
m(2)=max(x(:,2));
y(:,2)=x(:,2)/m(2);
p=0.0001;i=2;k=abs(m(2)-m(1));
```

```
while k>p
i=i+1;
x(:,i)=A*y(:,i-1);
m(i)=max(x(:,i));
y(:,i)=x(:,i)/m(i);
k=abs(m(i)-m(i-1));
end
a=sum(y(:,i));
w=y(:,i)/a;
t=m(i);
disp(w);disp(t);   %以上是权重的确定

%以下是一致性检验

CI=(t-n)/(n-1);
RI=[0 0 0.52 0.89 1.12 1.26 1.36 1.41 1.49 1.52 1.54 1.56 1.58 1.59];
CR=CI/RI(n);
if CR<0.10
   disp('一致性可接受！');
   disp('CI=');disp(CI);
   disp('CR=');disp(CR);
end
```

输入矩阵A

```
A=[1 1 1/5 1/3;1 1 1/5 1/3; 5 5 1 3;3 3 1/3 1]
   0.0955
   0.0955
   0.5596
   0.2495

   4.0435

一致性可接受！
CI=
   0.0145

CR=
   0.0163
```

```
#include<stdio.h>
#include<math.h>
#define PI 3.14159
#define R 6378.14
void main()
```

```
{
   int i,j;
   double a[18][20]=
{{250,12,0,PI/9,2*PI/9,PI/3,4*PI/9,4*PI/9,PI/3,2*PI/9,PI/9,0,PI/9,2*PI/9,PI/3,4*PI/9,
14*PI/9,5*PI/3,16*PI/9,17*PI/9},

{350,48,0,PI/9,2*PI/9,PI/3,4*PI/9,4*PI/9,PI/3,2*PI/9,PI/9,0,PI/9,2*PI/9,PI/3,4*PI/9,1
4*PI/9,5*PI/3,16*PI/9,17*PI/9},

{450,121,0,PI/9,2*PI/9,PI/3,4*PI/9,4*PI/9,PI/3,2*PI/9,PI/9,0,PI/9,2*PI/9,PI/3,4*PI/9,
14*PI/9,5*PI/3,16*PI/9,17*PI/9},

{550,290,0,PI/9,2*PI/9,PI/3,4*PI/9,4*PI/9,PI/3,2*PI/9,PI/9,0,PI/9,2*PI/9,PI/3,4*PI/9,
14*PI/9,5*PI/3,16*PI/9, 17*PI/9},

{650,1459,0,PI/9,2*PI/9,PI/3,4*PI/9,4*PI/9,PI/3,2*PI/9,PI/9,0,PI/9,2*PI/9,PI/3,4*PI/
9,14*PI/9,5*PI/3,16*PI/9,17*PI/9},

{750,3721,0,PI/9,2*PI/9,PI/3,4*PI/9,4*PI/9,PI/3,2*PI/9,PI/9,0,PI/9,2*PI/9,PI/3,4*PI/
9,14*PI/9,5*PI/3,16*PI/9,17*PI/9},

{850,1810,0,PI/9,2*PI/9,PI/3,4*PI/9,4*PI/9,PI/3,2*PI/9,PI/9,0,PI/9,2*PI/9,PI/3,4*PI/
9,14*PI/9,5*PI/3,16*PI/9,17*PI/9},

{950,1971,0,PI/9,2*PI/9,PI/3,4*PI/9,4*PI/9,PI/3,2*PI/9,PI/9,0,PI/9,2*PI/9,PI/3,4*PI/
9,14*PI/9,5*PI/3,16*PI/9,17*PI/9},

{1050,4573,0,PI/9,2*PI/9,PI/3,4*PI/9,4*PI/9,PI/3,2*PI/9,PI/9,0,PI/9,2*PI/9,PI/3,4*PI
/9,14*PI/9,5*PI/3,16*PI/9,17*PI/9},

{1150,1281,0,PI/9,2*PI/9,PI/3,4*PI/9,4*PI/9,PI/3,2*PI/9,PI/9,0,PI/9,2*PI/9,PI/3,4*PI
/9,14*PI/9,5*PI/3,16*PI/9,17*PI/9},

{1250,2175,0,PI/9,2*PI/9,PI/3,4*PI/9,4*PI/9,PI/3,2*PI/9,PI/9,0,PI/9,2*PI/9,PI/3,4*PI
/9,14*PI/9,5*PI/3,16*PI/9,17*PI/9},

{1350,1203,0,PI/9,2*PI/9,PI/3,4*PI/9,4*PI/9,PI/3,2*PI/9,PI/9,0,PI/9,2*PI/9,PI/3,4*PI
/9,14*PI/9,5*PI/3,16*PI/9,17*PI/9},

{1450,730,0,PI/9,2*PI/9,PI/3,4*PI/9,4*PI/9,PI/3,2*PI/9,PI/9,0,PI/9,2*PI/9,PI/3,4*PI/
9,14*PI/9,5*PI/3,16*PI/9,17*PI/9},

{1550,317,0,PI/9,2*PI/9,PI/3,4*PI/9,4*PI/9,PI/3,2*PI/9,PI/9,0,PI/9,2*PI/9,PI/3,4*PI/
9,14*PI/9,5*PI/3,16*PI/9,17*PI/9},
```

```
{1650,158,0,PI/9,2*PI/9,PI/3,4*PI/9,4*PI/9,PI/3,2*PI/9,PI/9,0,PI/9,2*PI/9,PI/3,4*PI/
9,14*PI/9,5*PI/3,16*PI/9,17*PI/9},

{1750,78,0,PI/9,2*PI/9,PI/3,4*PI/9,4*PI/9,PI/3,2*PI/9,PI/9,0,PI/9,2*PI/9,PI/3,4*PI/9,
14*PI/9,5*PI/3,16*PI/9,17*PI/9},

{1850,52,0,PI/9,2*PI/9,PI/3,4*PI/9,4*PI/9,PI/3,2*PI/9,PI/9,0,PI/9,2*PI/9,PI/3,4*PI/9,
14*PI/9,5*PI/3,16*PI/9,17*PI/9},

{1950,44,0,PI/9,2*PI/9,PI/3,4*PI/9,4*PI/9,PI/3,2*PI/9,PI/9,0,PI/9,2*PI/9,PI/3,4*PI/9,
14*PI/9,5*PI/3,16*PI/9,17*PI/9}
  };
  for(i=0; i<18; i++)
  {
    for(j=2; j<20; j++)
    {
      a[i][j]=a[i][1]/(2*PI*pow((a[i][0]+R),2)*cos(a[i][j]));
      printf("%.11f\t",a[i][j]);
    }
    printf("\n");
  }
}
```

	Near-Term On-Orbit Demo Options (using Proven Technologies) Demonstrate acquisition, track, handover, irradiate, spot maintaince, de-orbit in approximately 1 year from go-ahead		System A Clear out 200-800 km altitude range in less than 3 years from approval Options for near Term System (using Proven Technologies)	
System Component	**Demo Option 1**	**Demo Option 2**	**Option A1** (4 hrs/day operation)	**Option A2** (20 hrs/day operation)
Laser Device	1–10 ns pulsed NdYag (100 J) (GFE L. Hackel Laser at PL)	1–10 ns pulsed NdYag (100 J) (GFE L. Hackel Laser at PL)	5 ns pulsed NdYag (5 KJ, 1–5 Hz) (Beamlet Design, Hot Rod mode, Cooled between bursts)	5 ns pulsed NdYag (5 KJ, 1–5 Hz) (Beamlet Design, Hot Rod mode, Cooled between bursts)
Estimated Cost	1.3–3.0	1.3–3.0	28.6–31.6	33.3–37.3
Beam Director Optic	GFE 3.5M Telescope with modifications required	GFE 3.5M Telescope with modifications required	GFE 3.5M Telescope with modifications required	New 3.5M Telescope
Estimated Cost	3.4–6.3	5.2–9.9	4.0–6.0	35.0–40.0
Guide Star System	GFE LLNL Sodium System & SOR Rayleigh System	GFE LLNL Sodium System & SOR Rayleigh System	New Sodium System	New Sodium System
Estimated Cost	1.4–2.3	2.0–4.0	4.9–6.5	6.5–9.7
Acquisition/Tracking	GFE passive EO (sunlight illumination) (4 h/day operation) GFE 3.5 M telescope **1)** demo acquisition/ handover to remote low-power illuminator with retro-reflector orbiter	Haystack/Have Stare/Millstone (24 h/day operation) **1)** demo acquisition/handover to remote low-power illuminator with retro-reflector orbiter **2)** demo acquisition/handover to remote pusher laser with orbiter target	Passive Electro-optical (sunlight illumination) (4 h/day operation-1 crew shift) acquisition/handover by small telescope at Pusher site with real debris Targets	Haystack/Have Stare/Millstone (existing radars @ need sole' use)(24 h/day operation – 3 shifts) acquisition/handover to remote pusher laser with real debris targets
Estimated Cost	5.0–9.0	5.5–9.8	5.4–8.1	7.2–12.3
Target Set	Up to 300 km altitude special demo targets (shuttle–deployed)	Up to 300 km altitude special demo targets (shuttle–deployed)	Up to 800 km altitudes existing debris populations	Up to 800 km altitudes existing debris populations
Estimated Cost	0.5–1	0.5–1	0	0
Integration				
Estimated Cost	1.2–2.1	1.5–2.6	4.0–5.0	8.3–9.7
TOTAL P. E. Cost Range	**$13M–$23M**	**$16M–$28M**	**$57M–$69M**	**$93M–$108M**

Orbits	Hight/km	Percentage
LEO	200--2000	64%
MEO	2000--35586	27%
HEO	35586--35986	9%

Table 2 Various Orbits

continued on page 6

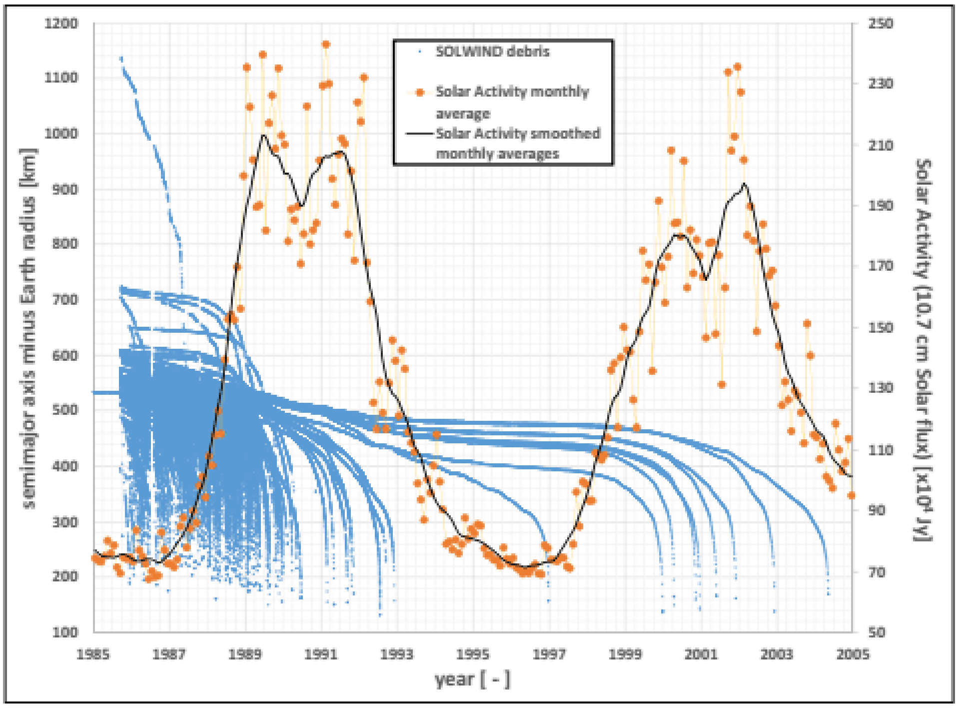


Figure 4. The orbital evolution of the P78 debris cloud over the time span 1985-2005, referenced to the left vertical axis, and accompanied by the historical solar flux, referenced to the right vertical axis. Clearly visible is the effect of high solar activity on the on-orbit lifetimes of debris cloud members. During this time span, debris cast as high as 1150 km altitude decayed, leaving no debris on-orbit by 2005. When the solar flux is high, the atmosphere is heated, expands, and increases the atmospheric drag on debris at a given altitude. As drag increases, energy is withdrawn from the orbit and it will eventually reenter.

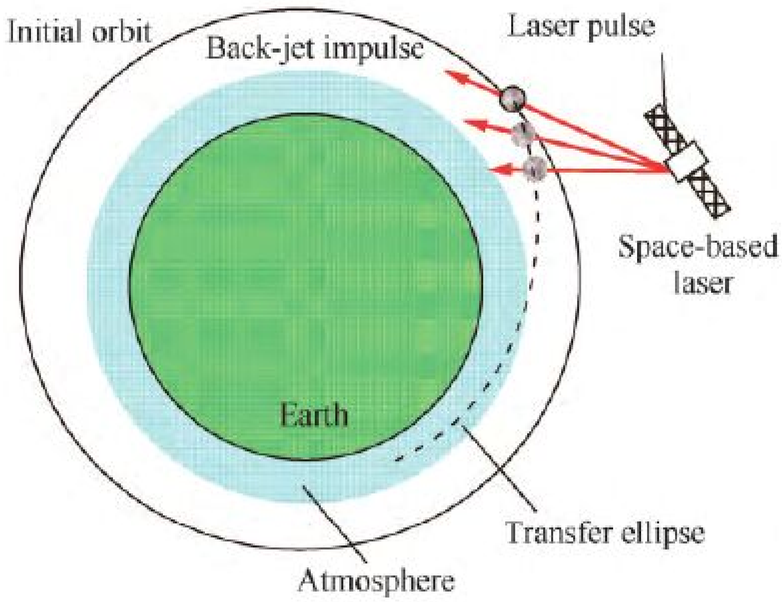


Fig. 1 Removal process of a debris particle.

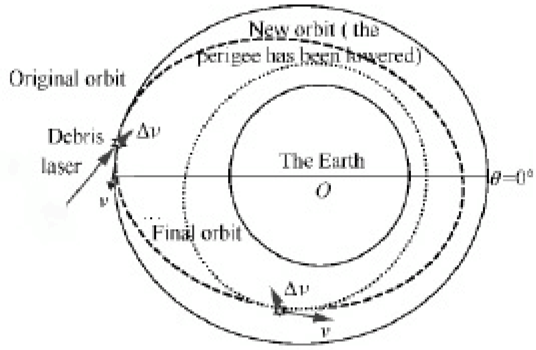
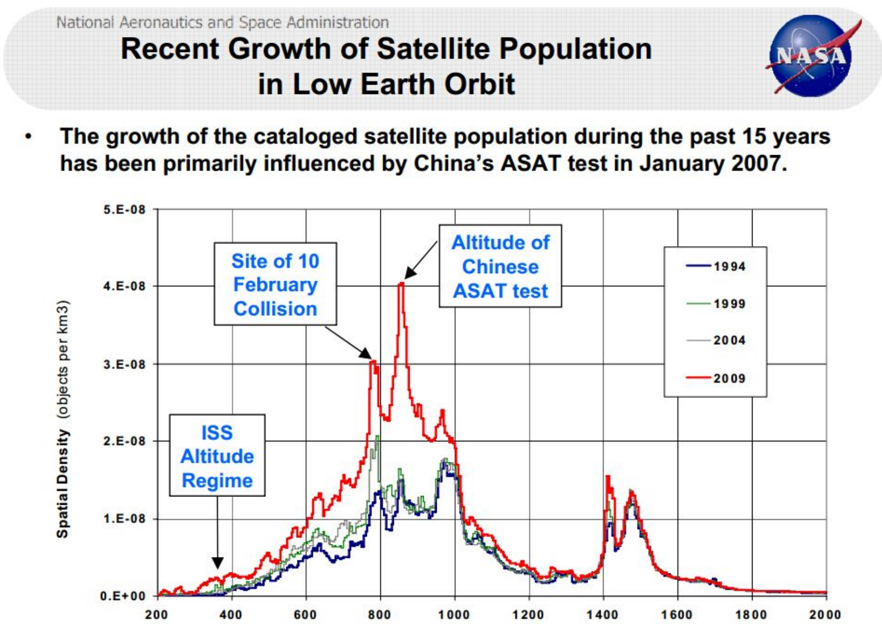


Table 7
Satellite hardware cost

Cost unit: FY07$M	Unshielded design
Scientific payload	111.58
Propulsion	14.48
ADCS	19.41
TT&C/DH	13.91
Power	20.61
Thermal	2.57
Structure	12.47
IA&T	43.07
Program level	56.49
Total	294.59



U.S. Government Spacecraft Record

(Includes spacecraft from cooperating countries launched by U.S. launch vehicles.)

	Earth Orbit[a]		Earth Escape[b]	
Calendar Year	Success	Failure	Success	Failure
1957	0	1	0	0
1958	5	8	0	4
1959	9	9	1	2
1960	16	12	1	2
1961	35	12	0	2
1962	55	12	4	1
1963	62	11	0	0
1964	69	8	4	0
1965	93	7	4	1
1966	94	12	7	1[b]
1967	78	4	10	0
1968	61	15	3	0
1969	58	1	8	1
1970	36	1	3	0
1971	45	2	8	1
1972	33	2	8	0
1973	23	2	3	0
1974	27	2	1	0
1975	30	4	4	0
1976	33	0	1	0
1978	34	2	7	0
1979	18	0	0	0
1980	16	4	0	0
1981	20	1	0	0
1982	21	0	0	0
1983	31	0	0	0
1984	35	3	0	0
1985	37	1	0	0
1986	11	4	0	0
1987	9	1	0	0
1988	16	1	0	0
1989	24	0	2	0
1990	40	0	1	0
1991	32[c]	0	0	0
1992	26[c]	0	1	0
1993	28[c]	1	1	0
1994	31[c]	1	1	0
1995	24[c, d]	2	1	0
1996	30	1	3	0
1997	22[e]	0	1	0
1998	23	0	2	0
1999	35	4	2	0
2000	31[f]	0	0	0
2001	23	0	3	0
2002	18	0	0	1[b]
2003	28[c, f]	0	2	0
2004	8[c]	0	1	0
2005	10	0	2	0
1996	30	1	3	0
1997	22[e]	0	1	0
1998	23	0	2	0
1999	35	4	2	0
2000	31[f]	0	0	0
2001	23	0	3	0
2002	18	0	0	1[b]
2003	28[c, f]	0	2	0
2004	8[c]	0	1	0
2005	10	0	2	0
2006	20[d]	0	2	0
2007	16	2	2	0
2008	22[f]	0	0	0
2009	24[f]	1	0	0
2010	15	0	0	0
2011	16	1	3	0
2012	13	0	0	0
2013	18	0	1	0
2014 (through September 30, 2014)	19	0	0	0