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# 2011

**14th Annual High School Mathematical Contest in Modeling (HiMCM) Summary Sheet**
(Please attach a copy of this page to each copy of your Solution Paper.)

**Team Control Number:** 3170
**Problem Chosen:** A

Please type a summary of your results on this page. Please remember not to include the name of your school, advisor, or team members on this page.


After mourning the retirement of the final U.S. Space Shuttle, NASA has dried their tears and enlisted our help to create a ten year plan complete with costs, maintenance, and flight schedules to maintain the International Space Station (ISS). In order to model this program in a realistic manner, we researched and established a variety of assumptions and parameters. We then set ourselves specific goals to include in our plan. Along with providing NASA with a detailed budget plan, payload, and flight schedule, we took it a step further to predict the total cost our plan will entail.

In order to provide the most cost-effective maintenance plan, we first determined NASA's budget. Using a linear regression graph, we projected NASA's future ISS Budgets until 2020, the last year of our ten year plan. Although the budget was not included in the equation itself, we took it into careful consideration when reallocating our funds and made sure the total cost of our plan did not exceed this budget.

Our model is divided into two sections. In the years 2011 to 2017, NASA will depend on foreign nations and private companies to provide U.S. astronauts and cargo with transportation to the ISS. Our plan entails a preexisting contract between NASA and two corporations that offer Commercial Orbital Transportation Services (COTS), privately built unmanned spacecrafts that supply the ISS with cargo. The model also includes the purchase of Russian spacecraft transportation services for U.S. astronauts. In these years we also propose NASA to begin using funds to build a multi-purpose crew vehicle that will be fully operational by 2017. This spacecraft, dubbed *Ophiucus*, will be a vessel that can be flown both manned and unmanned. It will render NASA and the U.S. government free from foreign and commercial dependence with regard to space travel. Since NASA will no longer have to purchase transportation through external resources, *Ophiucus* will also provide relief from this financial burden.

After formulating the plan itself, we inserted a series of estimates into our multi-variable model to find a predicted cost for all ten years. Our estimated total cost falls below the projected ISS budget. Our model exhibits robustness because variations to the parameters do not exhibit large changes to the overall result. We performed sensitivity analyses on all our parameters collectively to further ensure that our cost will not surpass our projected budget, and determined that our model was resistant to variability. Finally, we created a detailed flight schedule including the launch days of all projected missions in the next ten years.

# Problem A: Space Shuttle Problem: No More Space Shuttles

Team 3170

## Contents

# 1. Introduction

Earlier this year, NASA's 135th space shuttle mission marked the end of an era. The space shuttle pioneered space exploration, as the first reusable spacecraft created by humanity. The space shuttle played a crucial role in constructing and maintaining the International Space Station (ISS), the collaboration between nations and a facility for the some of the most unique research conducted in the world. The space shuttles may now be retired, but it is still necessary to maintain the ISS and send American astronauts there. As the economic condition of our country has been turning downward in the past decade, funding for space exploration has been decreased drastically, making it necessary to find a cost effective alternative to space shuttles. We propose a ten year plan for the maintenance of the ISS

# 2. General Assumptions and Justifications

**Assumption**: NASA's International Space Station budget will follow the projected linear trend.

**Justification:** NASA has projected budgets from 2011 to 2016 which follow a linear pattern with an $R^2$ value of .992

**Assumption:** The amount of money for any specific action will remain approximately the same throughout our plan.

**Justification:** For the purpose of our model, the value of the dollar does not change due to inflation or other economic factors.

**Assumption:** There will be no major spacecraft malfunctions that affect the monetary distribution of our plan.

**Justification:** Spacecraft has been tested many times to ensure the safety of the crew and cargo.

**Assumption:** Astronauts will serve a term of 6 months at the ISS.

**Justification:** In the past, astronauts have remained at the International Space Station for periods ranging from 136 days to 215 days.

**Assumption:** The ISS will need approximately the same amount of supplies per year up until 2020.

**Justification:** The goals and life support needs of the ISS will stay the same until 2020.

**Assumption:** Cargo needs to be delivered to the ISS approximately once every 4 months.

**Justification:** This is how it has been done for the past few years.

**Assumptions:** Russia's $60 million will provide a U.S. astronaut a round way trip, meaning both to the ISS and back.

**Justification:** Otherwise, our brave men and women will have no way to return. Also, it is not reasonable Russia would waste space on the return trip.

**Assumptions:** A spacecraft that can be flown both manned and unmanned will cost $3.5 billion to construct. The technology to make such a spacecraft is available.

**Justification:** A similar spacecraft *Orion* has this cost and similar functions.

**Assumption:** There are no new technological advancements that will significantly decrease the maintenance cost of the ISS up to 2020.

**Justification:** Since we are in the middle of an economic crisis, it is unlikely any innovations will be made.

**Assumption:** Russia has provided transportation to US astronauts in 2011.

**Justification:** Russia has provided several US astronauts with transport to the International Space Station for six month stay at the Station in the Russian spacecraft *Soyuz* in 2011.

**Assumption:** We have access to NASA's International Space Station budget

**Justification:** According to NASA's website, it is reasonable to assume the ISS budget would be used for the ISS.

# 3. Parameters

- Projected total ISS budget (2011-2020): $31,360.5 million
- Average supplies needed for the ISS per year: 12,000-16,000 lbs
- Amount needed to build new spacecraft that can be flown both manned and unmanned: $3,500 million
- Money paid to Commercial Orbital Transportation Services: $3,500 million
- Average cost to launch a spacecraft: $450 million
- Fee of Russia transporting an U.S. astronaut to the ISS: $60 million
- Average cost per pound of payload transportation by spacecraft: $5000-10000 (the price we will use is $7500)

- Average ISS supply cost: $1,500 million per year
- Amazing 10 year maintenance plan: *priceless*

# 4 Variables and Equations

$C_T$ – Total cost

$C_1$ – Cost 2011-2016

$C_2$ – Cost 2017-2020

B – Total budget put aside for space shuttles and ISS maintenance (2011-2020)

A – Number of astronauts sent to the ISS by Russian spacecraft

Y – Year from 2010

L – Number of *Ophiucus* launches

W – Weight of cargo and passengers (lbs) on *Ophiucus*

# 5 Objectives

NASA's last space shuttle, *Endeavor*, was recently forced into retirement after its 135$^{th}$ and final flight. Our task is to determine a ten year plan for the maintenance of the International Space Station (ISS). After extensive research of NASA's budget, contracts, and the ISS's maintenance needs, we determined that we would divide our plan into two time periods. From the years 2011 to 2016, we will uphold our contract with private companies and their means of commercial orbital transportation services to obtain supplies for the ISS (Commercial Orbital Transportation Services). We will also pay Russia to launch U.S. astronauts into space. We will implement a plan to build a new multi-purpose crew vehicle, *Ophiucus*, starting from 2011 and to prepare for it to deliver astronauts to the ISS by 2017. Therefore, as of 2017 we can use this spacecraft to perform both manned and unmanned cargo resupply trips per year.

To model the cost of this plan, we will create an equation predicting cost based on number of astronauts sent and weight in pounds of cargo. We will then find the average or projected cost based on parameters we will not use in our initial model. Lastly, we will create a detailed flight schedule for the next ten years.

# **Task 1:** Establishing Budget

## 1.1 International Space Station Budget

The Space Shuttle Program budget is projected by NASA from the years 2011 to 2016. Starting from 2013, all the projected budgets drop to around 800,000 US dollars per year [1]. We predicted the future budgets starting from 2017 will remain at 800,000 US dollars per year. As the funding for space shuttles has decreased so greatly, building another space shuttle in this situation would not be reasonable. Therefore, our missions to the International Space Station will be funded only by NASA's ISS budget, which in 2016 is estimated to be 3.17 billion US dollars. Using a linear regression equation, were able to project the annual budget for the years between 2017 and 2021.

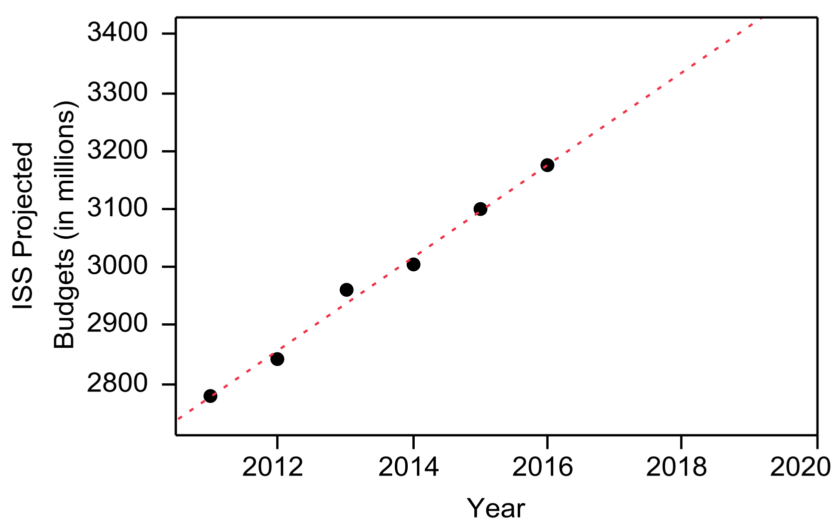



**Figure 1. Linear Regression for ISS Projected Budgets**

$$ISS\ Projected\ Budgets\ (in\ millions) = -157493.8 + 79.7\ (Year)$$

NASA's projected ISS budget follows a very clear linear model (Figure 1) with an $r^2$ value of 0.992, which indicates a very strong correlation in which 99.2% of the variability of the budget is accounted for by the year. The projected values for 2017 to

2020 were predicted from our initial model using the linear regression equation above. See Table 1 for exact annual budget values.

A residuals graph below shows approximately random scatter among the residuals, indicating that a linear model is appropriate for this model.

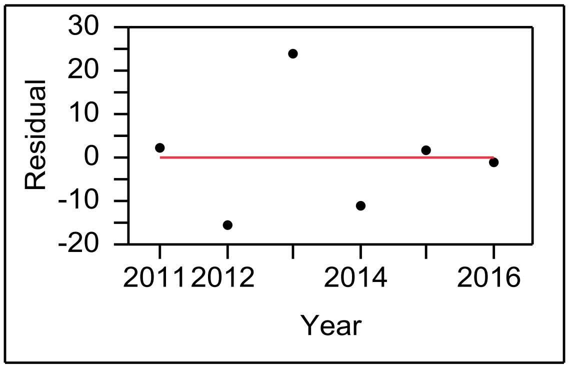



Figure 2. **Residuals Plot for ISS Projected Budget**

| Year | ISS Projected Budgets (in millions) | Residuals of ISS Projected Budgets |
|---|---|---|
| 2011 | 2779.8 | 2.37619048 |
| 2012 | 2841.5 | -15.620952 |
| 2013 | 2960.5 | 23.6819048 |
| 2014 | 3005.4 | -11.115238 |
| 2015 | 3098 | 1.78761905 |
| 2016 | 3174.8 | -1.1095238 |
| 2017 | 3255.6 | - |
| 2018 | 3335.3 | - |
| 2019 | 3415 | - |
| 2020 | 3494.7 | - |
| 2021 | 3574.4 | - |

Table 1. **Data table of International Space Station (ISS) projected annual budgets**

## 1.2 Total Projected Budget (2011-2020)

By adding the ISS budgets for each year, we calculated a total budget for sending missions to the International Space Station for maintenance. The sum of the ISS budgets from 2011-2020 is $31,360,500,000. This parameter will not be included in our model. It will only be taken into consideration when analyzing our predicted total ISS mission and maintenance cost. That is, we need to make sure our cost will not exceed this budget.

$$B = (Y_{2011} + Y_{2012} + Y_{2013} + Y_{2014} + Y_{2015} + Y_{2016} + Y_{2017} + Y_{2018} + Y_{2019} + Y_{2020})$$

$$B\ (in\ millions) = (2779.8 + 2841.5 + 2960.5 + 3005.4 + 3098.0 + 3174.8 + 3255.6 + 3335.3 + 3415 + 3494.7 + 3574.4)$$

$$\boldsymbol{B} = \$\ \mathbf{31\ 360\ 500\ 000}$$

# **Task 2**: Creating Cost-Efficient Model (2011 – 2016)

## 2.1 Manned Flights Provided by Russia

Without the use of a shuttle, NASA needs to invite the help of foreign nations and private industries to send both manned and unmanned spacecraft to the ISS. Russia offers to take U.S. astronauts on their own shuttles for a fee of $60 million per person [9, 15], and we propose to accept this offer for the first seven years of the plan (2011-2016).

## 2.2 Unmanned Missions Using Commercial Resupply Services

Commercial Orbital Transportation Services (COTS) is a NASA program that coordinates the delivery of crew and cargo to the International Space Station by private companies. COTS relates to the development of the vehicles, and Commercial Resupply Services (CRS) to the actual deliveries [5].

NASA has awarded contracts to Orbital Sciences Corp. and one to Space Exploration Technologies (SpaceX) for commercial cargo resupply services to the International Space Station. NASA has ordered 8 flights from Orbital and 12 flights from SpaceX. These fixed contracts are effective through Dec. 31, 2016 [7]. The contracts call for the delivery of a minimum of 40 tons of cargo to the ISS. Based on known requirements, the value of both contracts combined is projected to be $3.5 billion [5].

These agreements will fulfill NASA's need to procure cargo delivery services to the space station using a U.S. commercial carrier after the retirement of the space shuttle. 2 tons of cargo will be transported to the International Space Station on each flight.

## 2.3 Cargo Transport

The cargo itself costs an average of $1.5 billion per year. This includes everything purchased necessary to maintain the ISS. The following estimates are based on the amount that was necessary on a 2005 mission to the International Space Station [10]:

$70 million will be used for the development of new hardware (e.g. navigation, data support or environmental controllers).

$800 million will be used for spacecraft operations

$350 million will be spent on software to maintain the integrity of the ISS design and its continuous, safe operability.

$140 million will be spent for purchase of supplies, cargo and crew.

## 2.4 Total Cost of Cargo and Missions (2011-2016)

The cost of both of these arrangements can be modeled by the following:

$$C_1 = 60A + 1500Y + 3500$$

Let $C_1$ = Total costs 2011-2016 (in millions)
*A* = Number of astronauts brought to ISS by Russian spacecraft
*Y* = Number of years from 2010
*3500* = Contract fee for Commercial Resupply Services (CRS) by private industries (in millions)

# **Task 3**: Creating Cost Efficient Model (2017-2020)

In 2011, we propose to start modeling and constructing the new spacecraft, *Ophiucus*, which can dock at the International Space Station manned and unmanned. This spacecraft is scheduled to be fully tested and functional by the year 2017, and to be retired after 12 launches. Building a new spacecraft is beneficial to NASA and the United States in order to decrease its dependence on foreign resources. The estimated cost of building such a spacecraft is $3.5 billion, based on similar spacecrafts that have been built in the past [10].

After building this spacecraft, NASA will no longer require the purchase of flights to the ISS from Russia nor corporate space transportation. However, every launch of this spacecraft will require $450 million dollars [3]. We propose three scheduled cargo drops per year of 2 tons each at the ISS, knowing that *Ophiucus* can carry both astronauts and these 2 tons in the same launch. For every pound of cargo sent to the International Space Station, we must pay $5000-$10000. In our model, we will use the average of $7500.

Therefore, we can model the total cost of years 2017-2020 by the equation:

$$C_2 = 3500 + (0.0075W + 450)L$$

Let $C_2$ = Total costs 2017-2020 (in millions)

$L$ = Number of *Ophiucus* launches

$W$ = Number of pounds (payload) on *Ophiucus*

*450* = Cost per launch (in millions)

*3500* = Cost to build *Ophiucus* (in millions)

## **Task 4**: Combined Cost Efficient Model

By combining the total cost equations from the above models (2011-2016 and 2017-2020), a single cost equation can be constructed and used to predict the combined cost: $C_T = C_1 + C_2$

$$\boldsymbol{C_T = L(450 + 0.0075W) + 60A + 1500Y + 7000}$$

Let $C_T$ = Total cost (in millions)

$C_2$ = Cost of 2017-2020 plan (in millions)

$C_1$ = Cost of 2011-2016 plan (in millions)

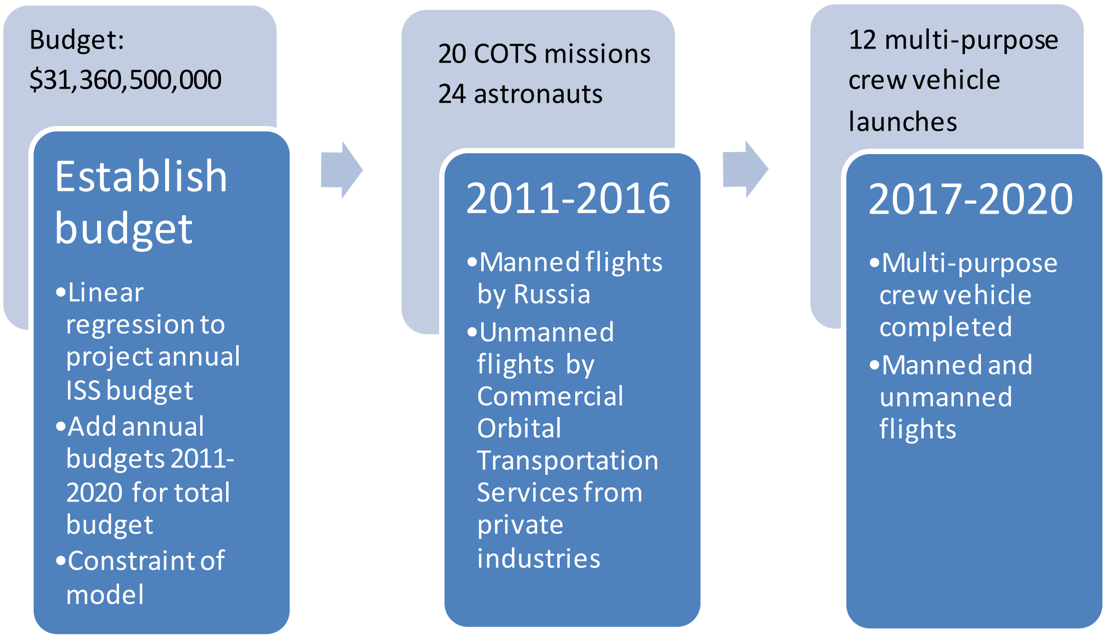
$L$ = Number of *Ophiucus* launches

$W$ = Weight in pounds (cargo and passengers) transported on *Ophiucus*

$Y$ = Number of years since 2010

$A$ = Number of astronauts

7000 = Combined cost of COTS contract fee and cost to build *Ophiucus* (in millions)




Flow Chart 1: Model Outline

# **Task 5:** Predicting Cost Using Estimates

## 5.1 Estimated Cost

$$C_T = L(450 + 0.0075W) + 60A + 1500Y + 7000$$

For the above equation our estimates are as follows:

L = 12 This is the number of launches made by *Ophiucus*. It is derived from the average of three COT resupply launches from the earlier year. Since astronauts and cargo can be delivered to the ISS simultaneously, we only need three total launches per year

W = 4310 This accounts for the 4000 lb average payload weight required to be transferred to the ISS per *Ophiucus* flight and the 310 lb passenger weight derived from the average human weight (155 lb) used in estimations for elevator and aircraft carrying capacities [3]. On each flight, two astronauts are present.

Y = 10 This is the number of years our model accounts for. Our ten year plan lasts from 2011 to 2020.

A = 24 We propose to deliver two astronauts per six months to the ISS. This means we need to purchase a total of 4 flights per year from Russia, for six years, totaling to 24 purchased flights.

$$C_T = 12(450 + 0.0075 * 4310) + 60 * 24 + 1500 * 10 + 7000$$

$$\boldsymbol{C_T = 29\ 227.8}$$

**Total Cost = $29 227 800 000**

$$B - C_T = \$2\ 132\ 700\ 000$$

Once the total cost is subtracted from the budget, we found that $2,132,700,000 remained. This money can be used in case of equipment malfunction or other such emergencies and needs.

## 5.2 Sensitivity Analysis

| Parameters/ Estimate | Original | % Change to Parameter | Modified Parameter | Result | % Change Result |
|---|---|---|---|---|---|
| Cost per *Ophicus* Launch | $450 000 000 | 5% | $472 500 000 | $29 497 900 000 | **0.923%** |
| Cost per Pound of *Ophiucus* Launch | $7,500 | 33% | $10 000 | $29 357 200 000 | **0.44%** |
| | | -33% | $5 000 | $29 098 600 000 | **-0.44%** |
| Average Weight per *Ophiucus* Launch | 4 310 lbs | 5% | 4 525.5 lbs | $29 111 530 000 | **0.07%** |
| Cost per Astronaut with Russia | $60 000 000 | 5% | $63 000 000 | $29 299 900 000 | **0.25%** |
| Cargo Cost per Year | $1 500 000 000 | 5% | $1 575 000 000 | $29 977 900 000 | **2.57%** |
| Cost to Build *Ophicus* | $3 500 000 000 | 5% | $3 675 000 000 | $29 402 900 000 | **0.60%** |
| All Parameters | Varies | Varies | Varies | $30 650 060 000 | **4.87%** |

Table 2 Sensitivity Analyses

In order to test our model's sensitivity to variations in parameters and variables, we performed a sensitivity analysis on each parameter or estimated variable that was subject to change. We used a sensitivity analysis by finding the percentage of change of the total cost when increasing each parameter or variable by 5%, with the exception of the cost of transport per pound by *Ophiucus*. For the parameter of cost of cargo per pound, we used the average cost of $7500 per pound and increased and decreased by 33% change because we were given the cost of cargo per pound as an interval of $5000-$10,000. We also calculated the percentage of change to the total cost when parameters and variables were increased by 5% and the cost of cargo per pound was increased by 33%. This was done to ensure the total cost did not exceed our projected budget. The percentage change of the total cost based on changed parameters and collectively changed parameters are displayed in the table above (Table 2).

For each individual parameter, the percentage of change when the parameter is increased is less than 1%, with the exception of the cost of cargo per year. This is expected because the cargo comprises nearly half of our budget yearly. This indicates that our model is very robust. When all parameters are increased simultaneously, the percentage of change is less than 5%. We performed this analysis in order to estimate our model's sensitivity and ensure the total cost does not exceed the projected budget in the most drastic scenario, where all parameters were more costly than expected.

## 5.3 Costs over Time

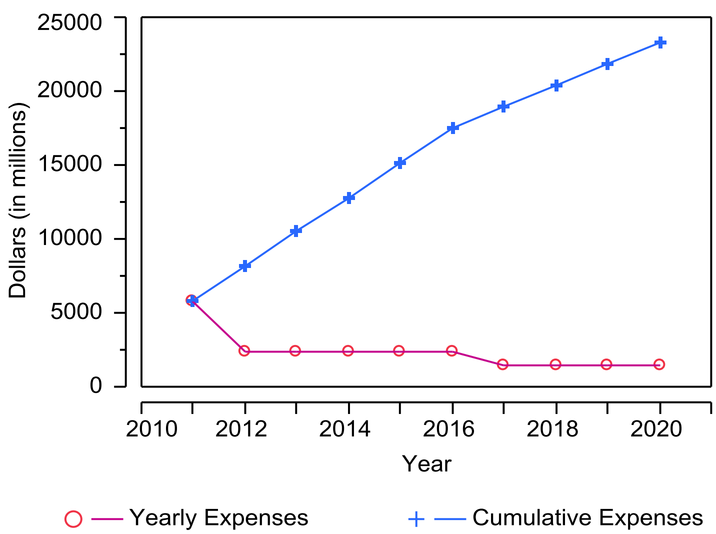



**Figure 3. Estimated Projection of Cumulative and Yearly Expenses**

| Year | Expenses | Cumulative Expenses |
|---|---|---|
| 2011 | 5823.3 | 5823.3 |
| 2012 | 2323.3 | 8146.6 |
| 2013 | 2323.3 | 10470 |
| 2014 | 2323.3 | 12793.3 |
| 2015 | 2323.3 | 15116.6 |
| 2016 | 2323.3 | 17440 |
| 2017 | 1447 | 18887 |
| 2018 | 1447 | 20334 |

| | | |
|---|---|---|
| 2019 | 1447 | 21781 |
| 2020 | 1447 | 23228 |

Table 3. Cumulative and Yearly Expenses

This graph shows the yearly and cumulative expenses of our plan. After the construction of Ophiucus in 2017, there is a significant decrease in the yearly expenses of NASA.

# **Task 6:** Developing the Flight Schedule

We have constructed two hypothetical flight schedules for the years 2011-2016 and 2017-2020. The first involves the use of Commercial Resupply Services (CRS) and Russia's services, and the second uses the spacecraft, *Ophiucus*. We have based it upon the most recent NASA missions to the International Space Station [12] and have spaced the missions out over a period of ten years. All planned dates are subject to change due to possible environmental factors or malfunctions.

## Flight Schedule (2011-2016)

The CRS cargo missions occur approximately every three months, occasionally four. These spacecrafts will collect debris from the International Space Station and then will be incinerated upon reentry into the Earth's atmosphere [2]. Since there are twenty missions contracted and only nineteen included in the schedule, we reserve a mission for a potential emergency situation. Astronauts are transported by Russian spacecrafts to the International Space Station approximately every six months [3]. Every mission is planned to last 12 days, the average duration of a space craft mission (given).

| Date Launched | Date Returned | Crew | Means of Travel |
|---|---|---|---|
| **Jul 8, 2011** | Jul 21, 2011 | 2 | Russia |
| **Oct 30, 2011** | N/A | 0 | COTS |
| **Jan 21, 2012** | N/A | 0 | COTS |
| **Jan 27, 2012** | Feb 8, 2011 | 2 | Russia |
| **Apr 26, 2012** | N/A | 0 | COTS |
| **Jul 21, 2012** | Aug 2, 2012 | 2 | Russia |
| **Aug 2, 2012** | N/A | 0 | COTS |
| **Nov 9, 2012** | N/A | 0 | COTS |
| **Jan 21,2013** | Feb 2, 2012 | 2 | Russia |
| **Feb 6, 2013** | N/A | 0 | COTS |
| **May 13, 2013** | N/A | 0 | COTS |
| **Jul 21, 2013** | Aug 2, 2013 | 2 | Russia |
| **Sept 20, 2013** | N/A | 0 | COTS |

| | | | |
|---|---|---|---|
| **Dec 27, 2013** | N/A | 0 | COTS |
| **Jan 21, 2014** | Feb 2, 2014 | 2 | Russia |
| **Apr 4, 2014** | N/A | 0 | COTS |
| **Jul 11, 2014** | N/A | 0 | COTS |
| **Jul 21, 2014** | Aug 2, 2014 | 2 | Russia |
| **Oct 18, 2014** | N/A | 0 | COTS |
| **Jan 21, 2015** | Feb 2, 2015 | 2 | Russia |
| **Jan 26, 2015** | N/A | 0 | COTS |
| **Jun 2, 2015** | N/A | 0 | COTS |
| **Jul 21, 2015** | Aug 2, 2015 | 2 | Russia |
| **Nov 9, 2015** | N/A | 0 | COTS |
| **Jan 21, 2016** | Feb 2, 2016 | 2 | Russia |
| **Feb 16, 2016** | N/A | 0 | COTS |
| **May 23, 2016** | N/A | 0 | COTS |
| **Jul 21, 2016** | Aug 2, 2016 | 2 | Russia |
| **Aug 30, 2016** | N/A | 0 | COTS |
| **Dec 7, 2016** | N/A | 0 | COTS |

Table 4 Flight Schedule (2011-2016)

## Flight Schedule (2017-2020)

The *Ophiucus* missions occur every six months to deliver astronauts to the ISS, and another unmanned flight occurs in between these manned missions. That is, the missions occur each January, April, and July of each year. All the manned missions occur over a period of 12 days, the average space shuttle flight duration.

| Date Launched | Date Returned | Crew | Means of Travel |
|---|---|---|---|
| **Jan. 21, 2017** | Feb. 2, 2017 | 2 | *Ophiucus* |
| **Apr. 21, 2017** | TBD | 0 | *Ophiucus* |
| **Jul. 21, 2017** | Aug. 2, 2017 | 2 | *Ophiucus* |
| **Jan. 21, 2018** | Feb. 2, 2018 | 2 | *Ophiucus* |
| **Apr. 21, 2018** | TBD | 0 | *Ophiucus* |
| **Jul. 21, 2018** | Aug. 2, 2018 | 2 | *Ophiucus* |
| **Jan. 21, 2019** | Feb. 2, 2019 | 2 | *Ophiucus* |
| **Apr. 21, 2019** | TBD | 0 | *Ophiucus* |
| **Jul. 21, 2019** | Aug. 2, 2019 | 2 | *Ophiucus* |
| **Jan. 21, 2020** | Feb. 2, 2020 | 2 | *Ophiucus* |
| **Apri. 21, 2020** | TBD | 0 | *Ophiucus* |
| **Jul. 21, 2020** | Aug. 2, 2020 | 2 | *Ophiucus* |

Table 5. Flight Schedule (2017-2020)

# 6. Discussion

## 6.1 Strengths

- Our model is simple and understandable.
- Our model establishes the independence in space travel from other nations and private corporations.
- Our model accounted for the possibility for future malfunctions of spacecrafts with the extra trips reserved from COTS.
- Our model also predicts the projected cost in addition to addressing the cost plan.
- As compensation for our multitude of assumptions, we performed many sensitivity analyses of our parameters.

## 6.2 Weaknesses

- Many assumptions were made.
- Parameters are likely to be subject to change.
- Our data estimating the ISS projected budget was obtained based on extrapolation, which could not be avoided since our plan consisted of projecting costs and financial situations for the future.
- Inflation was not accounted for in our parameters of cost.
- Our sources were sometimes vague or contradictory of each other, making it necessary to make further assumptions on which source had greater reliability.

## 6.3 Topics for Future Study

- If possible, a future model should be in accord with projected economic conditions. For example, inflation should be accounted for when developing parameters.
- Cooperation with other nations should also be considered. Although the US Space Shuttle could not be maintained on the US budget alone, if countries create and maintain a space shuttle alone. This space shuttle could be used for up to 10 years and perform more complex missions than individual space crafts.
- Higher technological advancements increasing maintenance efficiency should be predicted and accounted for. Increasing the efficiency at which resources are spent will, in the long-term, decrease costs.

- Future studies should create a plan that takes NASA's complete budget into consideration and plan for reallocation of money into the ISS maintenance program as needed.
- They should also divide the larger overall budgets, such as ISS Maintenance, into smaller individual budgets such as the materials that ensure the integrity of the ISS structure and those that are necessary for life support.

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# 8. Appendix

## 8.1 **Charts**

| **Space Operations** | **6,141.8** | **6,146.8** | **5,508.5** | **4,346.9** | **4,346.9** | **4,346.9** | **4,346.9** | **4,346.9** |
|---|---|---|---|---|---|---|---|---|
| Space Shuttle | 3,101.4 | | 1,609.7 | 664.9 | 79.7 | 0.8 | 0.8 | 0.9 |
| International Space Station | 2,312.7 | | 2,779.8 | 2,841.5 | 2,960.4 | 3,005.4 | 3,098.0 | 3,174.8 |
| Space and Flight Support (SFS) | 727.7 | | 1,119.0 | 840.6 | 1,306.8 | 1,340.7 | 1,248.1 | 1,171.2 |

Table 6 NASA FY2012 Budget Request

## 8.2 **Acronyms and Definitions**

- COTS – Commercial Orbital Transportation Services
- CRS – Commercial Resupply Service
- ISS – International Space Station
- NASA – National Aeronautics and Space Administration

- Ophiucus: The newly discovered thirteenth astrological sign found in the sidereal zodiac based on a moving zodiac, and is what we named our spacecraft after
- Payload: The total weight of passengers and cargo on a spacecraft.
- Shuttle: A rocket-launched spacecraft, able to land like an unpowered aircraft, used to make repeated journeys between the earth and earth orbit