Mission to Ryugu

Target launch date: December 2020

Introduction

There are thousands of Asteroids which are rich in minerals and water. There is a great opportunity to mine them and make a lot of money. Also, it can enable a number of other space related missions and move humanity forward.

This is a plan to go to the Asteroid Ryugu in Dec 2020, mine it for water and/or metals and bring back the mined metal or water (in ice form). This document describes the following:

- Ryugu and why it is a good candidate for mining
- Possible trajectory to go from Earth to Ryugu and return
- Stages of the mission, including Δv and propellant requirements
- $ cost of the trip
- $ value of the minerals recovered from Ryugu

Why Ryugu

- **Large $ Value** – According to the Asterank database, this asteroid is worth over $80 billion, so that makes it a good candidate for mining.
- **Reasonably accessible** – This asteroid is close to Earth, and in 2020, it will be pretty close. The Δv for a roundtrip is between 4.6 – 5.0 km/s.
- **Recent trips by Hayabusa2** – Hayabusa2 recently reached Ryugu in June 2018 and is getting samples from the Asteroid to earth. It used an ion engine for the trip, further proving that maneuvering in space with an ion engine is possible.

Possible Trajectory for a roundtrip to Ryugu

Trajectories for potential asteroid trips can be calculated using the NASA website: NASA Ames Research Center Trajectory Browser. This is a very useful tool that can provide different trajectories that optimize for trip duration or Δv. These trajectories are based on Hohmann transfers from LEO to get to the Asteroid. In order to follow this trajectory, the mission will require a chemical rocket e.g. Liquid Hydrogen & Liquid Oxygen.

Max Δv constraint due to current rocket technology

Additionally, this trajectory was calculated with a constraint of a max Δv of 5km/s for the entire trip. This constraint was necessary because each additional 0.5km/s increase Δv increases propellant requirements by 15-20%. Since the propellant for the entire trip needs to be carried from earth at the cost of $10,000/kg, it makes the trip expensive and unprofitable. Additionally, some of the commercial rocket technologies can't carry more than a certain amount of payload, which is another reason to keep the propellant requirements low.

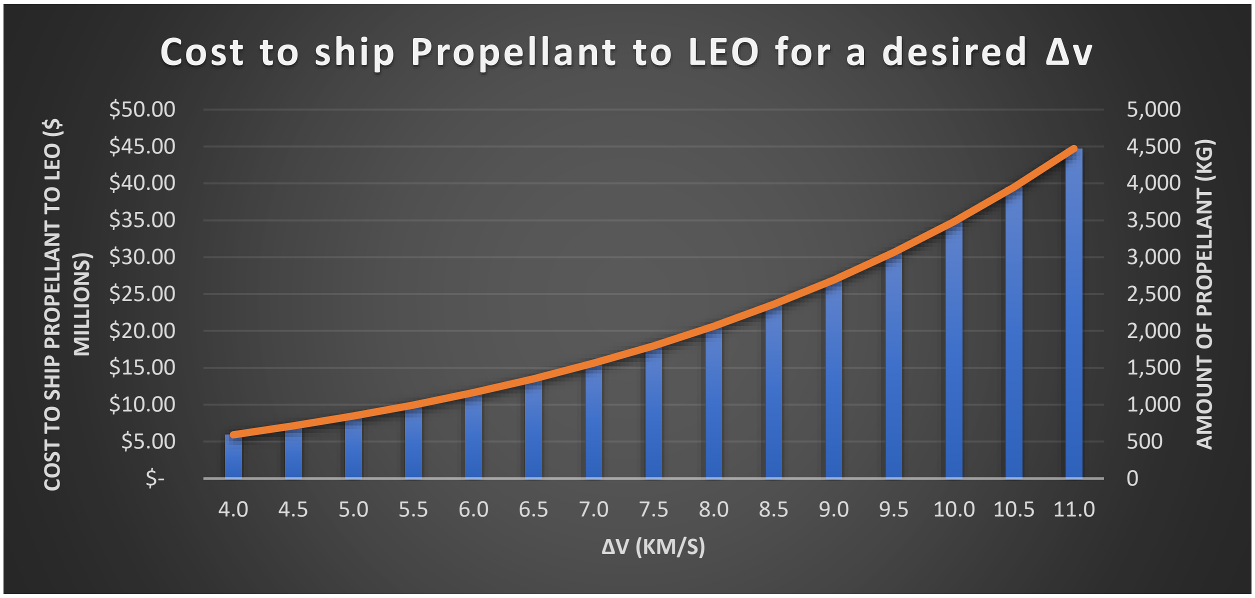
The chart below shows cost to ship propellant to LEO as a function of Δv.

The chart assumes the following:

- Exhaust velocity of the rocket: 4.4km/s (Liquid Hydrogen/Liquid Oxygen)

- $ Cost/kg to lift payload to LEO: $10,000/kg
- Dry mass (mass of the ship and mining equipment): 400Kg

All values are calculated using Tsiolkovsky rocket equation.

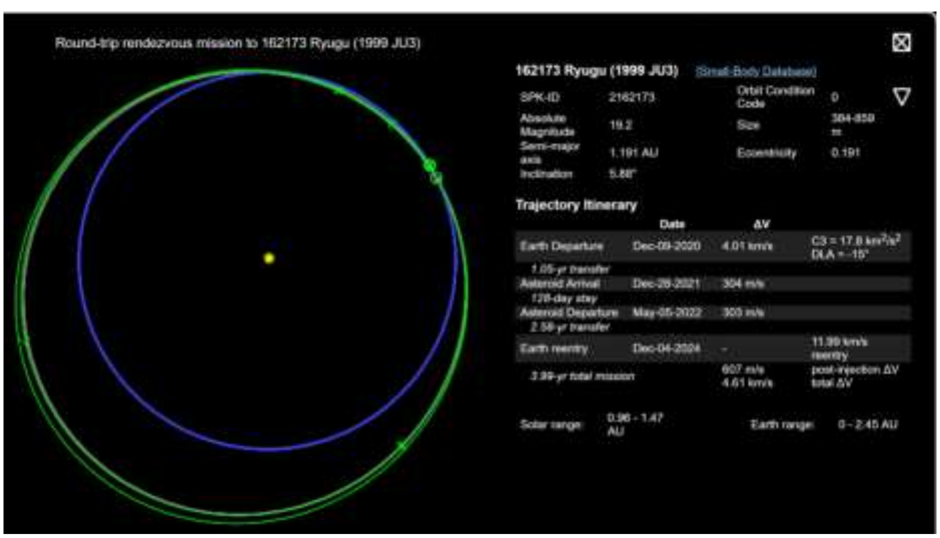


As can be seen from the chart, for Δv more than 5km/s, the costs increase significantly.

Possible trajectory

Below are the steps in the chosen roundtrip trajectory:

	Stage	Departure date	Δv	Duration
1	Earth to LEO (200km)	TBD		
2	LEO to Asteroid	Dec 05, 2020	4.01 km/s	1.05 years
3	Get into Asteroid orbit	Dec 28, 2021	0.304 km/s	128 days
4	Asteroid to LEO	May 05, 2022	0.303 km/s	2.58 years
5	LEO to Earth surface	Dec 04, 2024		
	Total		**4.61 km/s**	**4 years**



As can be seen, the total trip takes 4 years. The departure from Earth to LEO will be done via one of the several commercial launchers like SpaceX or Vector.

A possible shorter trip

A shorter trip with a duration of 125 days is possible, but doesn't make financial sense. The table below shows the trip:

	Stage	Departure date	Δv	Duration
1	Earth to LEO (200km)	TBD		
2	LEO to Asteroid	December 11, 2020	3.74 km/s	45 days
3	Get into Asteroid orbit	January 25, 2021	2.89 km/s	10 days
4	Asteroid to LEO	Feb 04, 2021	4.2 km/s	2.58 years
5	LEO to Earth surface	Apr 15, 2021		
	Total		**10.83 km/s**	**125 days**

The propellant requirements for this trip will be more than 4,000 kg, which will cost more than $45M to ship to LEO at the current rate of $10K/Kg.

Stages of the mission

There are 6 stages in the mission:

1. Earth surface to LEO
2. LEO to Asteroid
3. Get into Asteroid orbit
4. Mine the Asteroid
5. Leave Asteroid and depart for LEO
6. Deliver payload to LEO or Earth surface

Stage 1: Earth surface to LEO

This stage will likely be done by a commercial space launch company like SpaceX or Vector, which have figured out how to launch payload to LEO. These companies charge by $/kg of the payload. Currently, that price is: $10,000 per Kg, though it is expected to go down in the future.

- **Total Payload weight of the first stage**: 1,294 Kg
    - Dry Mass: Mass of the Ship and the mining robots: 400Kg
    - Propellant for this stage: N/A
    - Propellant for all the following stages: 894Kg
- **Total cost to launch**: $12.9 Million

Stage 2: LEO to Asteroid

Once in LEO, using the Hohmann transfer maneuver, the ship needs to shift to an elliptical orbit that takes it to the orbit of the Asteroid Ryugu. The details are as follows:

- Δv requirement: 4.01 km/s
- Propellant used: 774Kg
- Total payload weight: 520 Kg
    - Dry mass: 400 Kg
    - Propellant for following stages: 120 Kg

- Time to reach Asteroid: 1.05 years

Stage 3: Get into Asteroid orbit

Once the ship has reached the Asteroid, it needs to get out of the elliptical orbit and get into the Asteroid's orbit around the Sun. This is the second step in the Hohmann transfer maneuver. The details are as follows:

- Δv requirement: 0.304 km/s
- Propellant used: 35 Kg
- Total payload weight: 486 Kg
  - Dry mass: 400 Kg
  - Propellant for following stages: 86 Kg

Duration of orbit around the Asteroid: 128 days.

Stage 4: Mining the Asteroid

Now to do, what we really came here to do: mine the Asteroid. Mining an Asteroid presents its own challenges as it is very different than mining on Earth. The following factors need to be taken into account:

- Microgravity
- No atmosphere
- Ore Collection
- Location of Ore Processing unit
- Transportation of Ore from the Asteroid to Processing unit
- Processing
- Transportation to the Earth return ship

These issues are addressed in another document that describes how a mining robot can operate.

The mission as planned allocates about 128 days to do the mining. This should be sufficient time.

Stage 5: Leave Asteroid and depart for LEO

Now that we have mined the Asteroid, we need to do the reverse to set on a path to the LEO. This requires a Hohmann transfer maneuver, where the ship shifts to an elliptical orbit that takes it towards LEO. The details are as follows:

- Δv requirement: 0.303 km/s
- Propellant used: 86 Kg
- Total payload weight: 1,200 Kg
  - Dry mass: 200 Kg (the robot is left on the Asteroid)
  - Mass of the Ore/mineral: 1,000 Kg
  - Propellant for following stages: 0 Kg
- Time to reach LEO: 2.58 years

Stage 6: Deliver payload to LEO or Earth Surface

This stage depends on the payload itself. There are two options:

- **Bring the payload to Earth in a capsule**: if the mined product from the ore is a source of metal like Platinum or something similar which has a large $/kg value on Earth, it may make sense to bring it down to Earth and sell it.
- **Keep the payload in LEO**: this may be better if the payload is actually water or another source of propellant. Since the current cost of shipping propellant to LEO is $10,000/kg, this may make more financial sense

Ship Design parameters

This section only deals with the required capacity on the ship. Additional factors like maneuverability, power, etc. which would apply to spaceships in general are not addressed here. The Ship needs to have sufficient cargo space to bring back the mined material. Some design parameters are:

- **Weight capacity**: The ship needs to be able to carry 1,000 – 10,000 Kg of cargo.
- **Volume capacity**: 10,000 Kg of ice would need about 10 m^3 of volume, so the cargo portion of the ship can be in the shape of a rectangular prism with sides: 5m x 2m x 1m.

This section obviously needs a lot of work…

Economic Rationale

This is a for-profit mission and we need to make sure that we can do the entire mission profitably.

Potential Revenue Opportunity per mission

The goal is that the mission can mine enough quantity of valuable minerals from the Asteroid to generate sufficient revenue which exceeds the cost of the operation. There are two possible mineral options:

Precious metals

Many of the asteroids have abundant quantity of precious metals like Platinum. The retail value of Platinum on Earth is: $30,000 Kg. For a payload of 1,000 Kg, with a yield of 20%, the potential economic value is: up to $6 Million dollars.

Propellant

Many of the C-type asteroids have water. Water can be converted to H_2 and O_2 via electrolysis. This is a great source of rocket propellant. Currently, it costs $10,000/ Kg to send propellant to LEO. If the mission finds water, it is reasonable to assume that it can be sold for $10,000 / Kg in LEO. For a net payload of 1,000 Kg, the potential economic value is: $10 Million dollars.

Total Revenue opportunity:

- $6 Million, if mining metals, or
- $10 Million, if mining water

Expected costs

- **Cost of payment to a LEO launch company** (SpaceX or Vector).
    - Size of payload to LEO: 1,294 Kg
    - Cost at $10,000 / Kg: $12.9 Million
    - Cost at $5,000 / Kg: $6.4 Million
- **Cost to build the mining robot**:

  - Estimated cost of building one robot: $50,000
  - Number of robots on the mission: 4
  - Total Cost: $200,000.
- **Cost of propellant**: 894Kg of propellant (Liquid Oxygen + Liquid Hydrogen) is needed. At $10/Kg, the cost is $8,940, rounded to $10,000.
- **Cost to build the ship** for journey from LEO to Asteroid and back to LEO
  - Estimated cost of building the ship: Unknown, estimated to be $1 million. This ship is expected to be reused, so the entire cost will not apply to a single mission.

Majority of the cost is for the mission is the payment to an LEO launch company, which can range from $6.4 Million to $13 Million, depending on the $/Kg price.

Profitability

Currently, the mission is not profitable as there are several hurdles to profitability:

- **Cost**: At a cost of $13 Million per launch, the mission is not profitable. If the launch costs can be reduced to less than $5,000 / Kg, ideally in the range of $1,000 - $2,000 / Kg the mission can be profitable.
- **Capacity constraint**: The ship is limited in how much mined material it can bring back, because it significantly increases the propellant requirements, which increases the cost. If the propellant for the return trip can be sourced on the asteroid, instead of carrying from Earth, that can make the mission profitable.
- **Duration**: currently, the duration for the entire trip is almost 4 years. It is tough to build a profitable business if the revenue generation takes 4 years. It would help if the duration can be reduced. A shorter trip of 125 days is possible, but it would require a lot of propellant and increase the costs significantly. If the launch costs per Kg can be reduced significantly, the additional propellant requirements can be met.
- **Use another technology like Ion Thrust Engine**: this may increase the trip duration, but will probably require less propellant and reduce the cost of launching.

As can be seen, the biggest hurdle to profitably mine the asteroids is the cost to ship propellant to LEO. If that cost be can be reduced, the mission can be profitable.