Presentation of Team 8

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I. Consideration on the Cost Function

$$J = m_f \left| \boldsymbol{U}_f \cdot \mathbf{V}_{af} \right|$$

m_f : final mass of the spacecraft

V_{af} : velocity of the asteroid at the impact time

V_{sf} : velocity of the spacecraft at the impact time

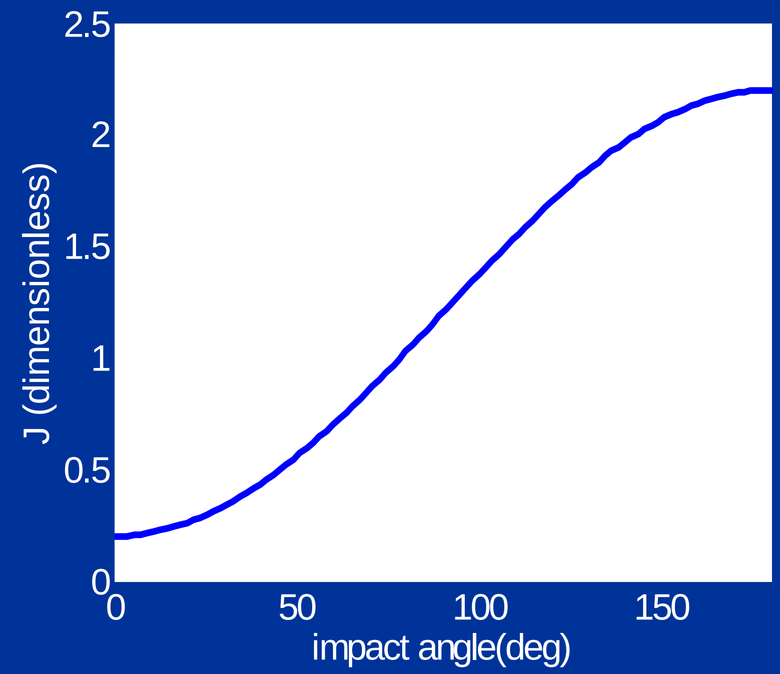
U_f : $V_{sf} - V_{af}$

From the cost function we can guess that to get a higher J:

1. Decrease the consumption of fuel (Increase m_f)
2. Impact near the perihelion of the asteroid (Increase V_{af})
3. Increase the angle α between V_{sf} and V_{af} (see next slide)

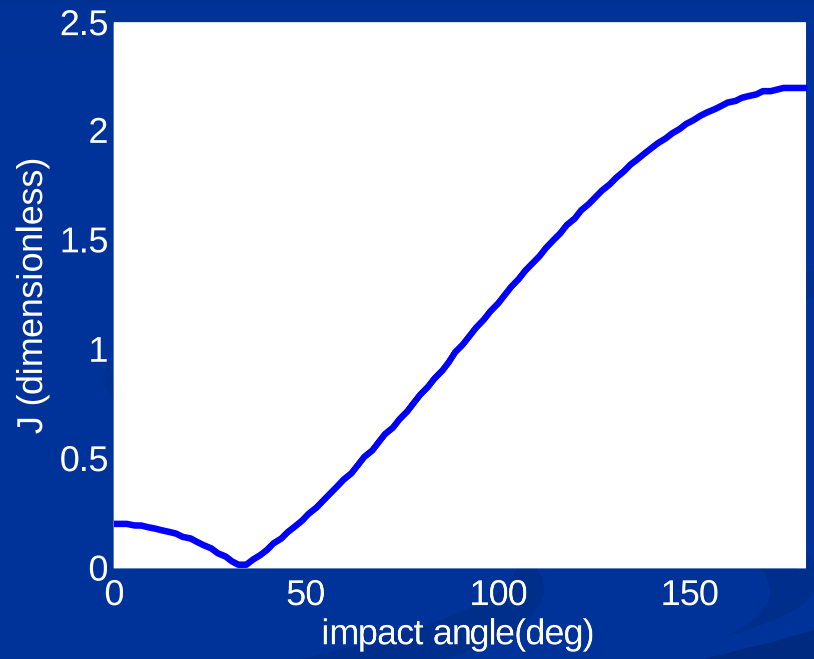
Relationship between α and J

- To get the relationship between α and J , if m_f , V_{af} and V_{sf} fixed, α-J plots are



(a) when $V_{af} > V_{sf}$

(e.g. V_{af} =1.2 , V_{sf} =1)



(b) when $V_{af} < V_{sf}$

(e.g. V_{af} =1 , V_{sf} =1.2)

II. Strategy of Flying and Control

- As the first step to impact the asteroid, we only aim for a basic solution to the mission, which is using Genetic Algorithms (GA) to optimize the cost function under a direct earth-to-asteroid trajectory
- some significant simplifications are made to reduce the workload of the optimization, which may lead to the lower value of J

Simplifications

- Try to impact the asteroid in the ecliptic plane, so the thrust is always in the ecliptic plane
- The direction of thrust are fixed along the tangent of the trajectory
- The propulsion system always works at the maximum thrust level, and On and Off

Basic Flying and Control Strategy

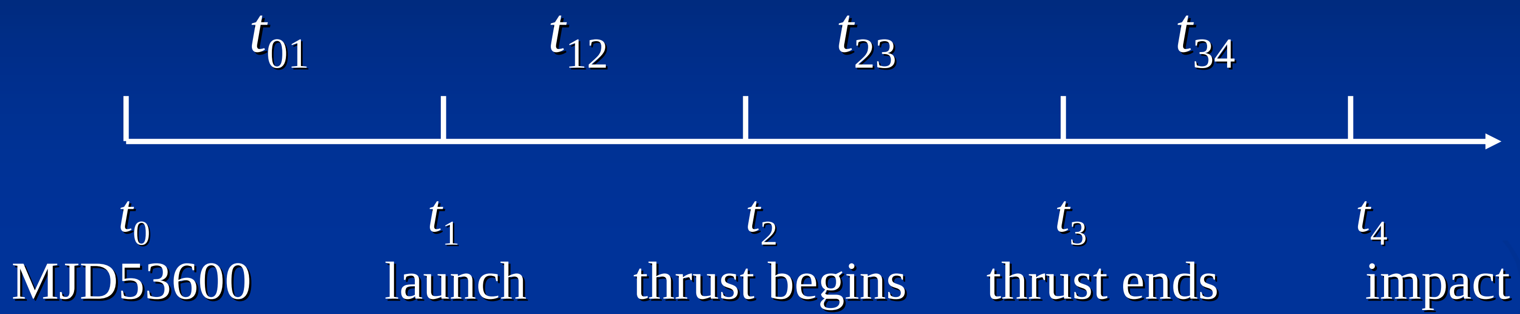
- The method can be described as

1. Search a optimal date to launch the spacecraft
2. Launch the spacecraft into an escape orbit, with the escape velocity along the tangent of the earth orbit
3. Let the spacecraft coast (without thrust) along the escape orbit for a certain optimal time
4. Start up the propulsion system for an optimal time
5. Shut down the propulsion and let the spacecraft coast until impact

Explanations on the strategy

- We employ this **co-planar strategy** because maneuver between planes costs a large amount of fuel
- The strategy confines the **impact point** on the intersection of the asteroid orbit and the ecliptic plane
- **More thrust-and-coast arcs** can be added between steps 3 and 4 of the previous slide, which may lead to a better solution, but increase the optimizing time as well. We split the time into 4 interval only (see the next slide).

III. Formulation and Implement of GA



- Variables to optimize

t_{01}: time from MJD53600 to launch date

t_{12}: duration of coasting along the escape orbit

t_{23}: duration of thrusting

t_{34}: duration of coasting along the final orbit

Object Function of GA

$$J_{GA} = -J + k \cdot d_f$$

d_f : the distance between spacecraft and asteroid at time t_4 , it is introduced as a penalty term

J: the mission objective function

k: coefficient of the penalty term

Explanations on the algorithm

- A solution to the mission can be obtained By MINIMIZING J_{GA}
- To get a desirable solution, the algorithm should be implemented several times, each time the penalty coefficient k should be increased
- A good initial guess can greatly cut down the optimizing time

GA Parameters

Population Size:	20
Fitness Scaling:	Rank
Selection Operator:	Stochastic Uniform
Reproduction Rate:	0.8
Mutation:	Gaussian
Crossover:	Heuristic
Stop Criteria:	d_f < 0.001AU /1500 generations

IV. Results and Conclusion

- Results of one-thrust arc strategy (see the table below)

  Launch about Mar 2017

  Coasting about 6 years and 2 months

  Thrust is applying about 6 years and 8 months

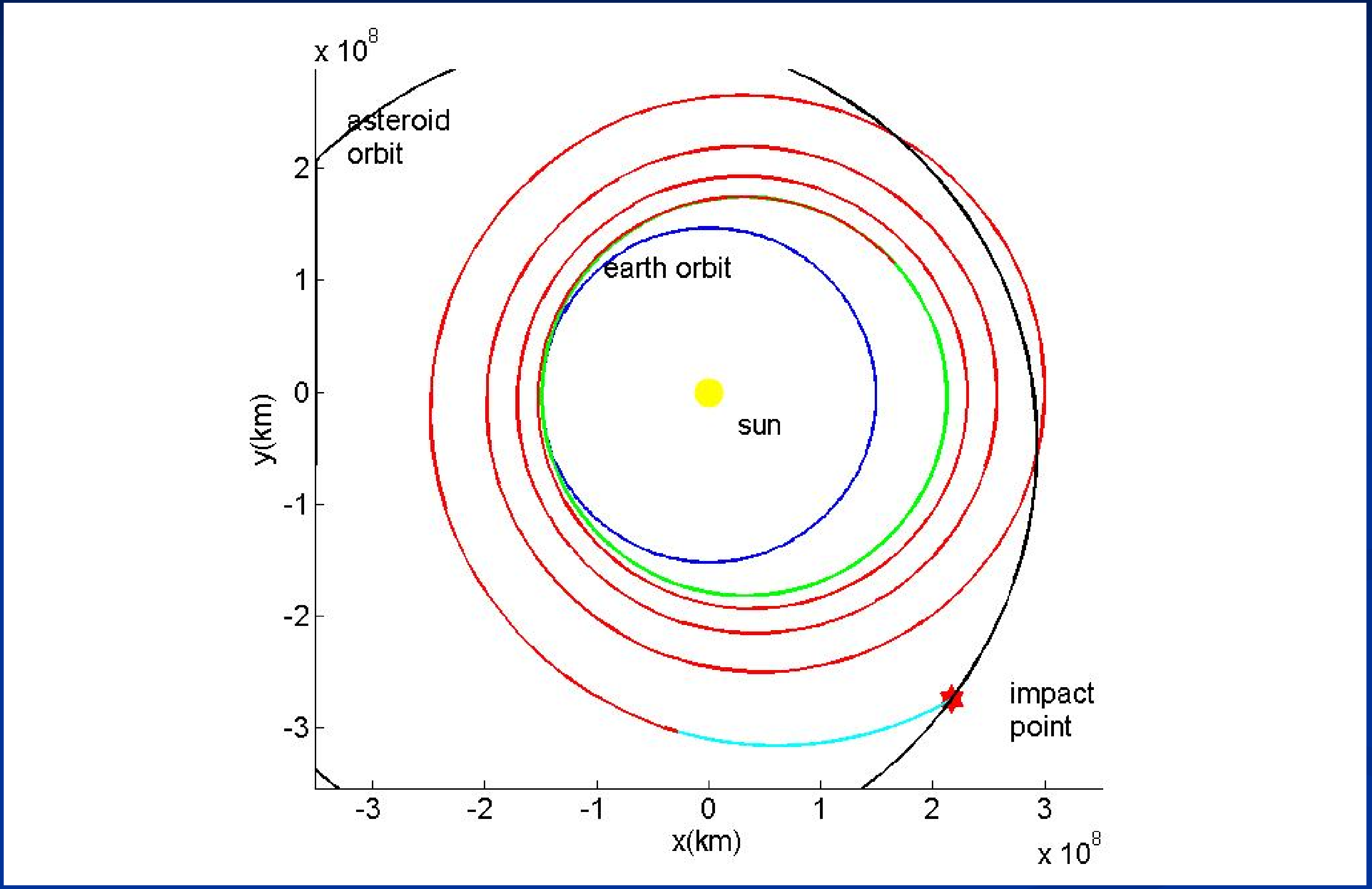
  Impact on June 2030, flying about 13 years and 3 mouths

t_{01} (day)	t_{12} (day)	t_{23} (day)	t_{34} (day)
4232.1334	2263.3690	2424.5472	149.8079
$\boldsymbol{m_f}$ (kg)	$\boldsymbol{d_f}$ (km)	$\boldsymbol{J}$ (10^9jol)	α(deg)
1157.9904	2026	89.0498	24.2

Explanation of Result

- The optimizing time on a Pentium IV 1.7G PC is about 50min (for 3 implements of the algorithm)
- Multi-thrust strategy can increase ***J*** but also greatly increase the optimizing time. For a 3-thrust strategy, we got a value **J**=118×109(J) when optimizing time=140min

Trajectory Illustration



Green curve is coasting phase,

Red curve is thrust phase, and Cyan is coasting again

Conclusion

1. Our strategy, especially the one-thrust-arc strategy cannot attain a highly eccentric final orbit. This limitation leads to a low impact angle α, which cause a low J
2. Because the spacecraft flies to the asteroid directly, not swings-by other planets, so its flying time is relatively short but the energy increment is limited that leads to a low J

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