National Aeronautics and Space Administration

Mission Design and Optimal Asteroid Deflection for Planetary Defense

Bruno V. Sarli / CUA

Jeremy M. Knittel / GSFC

Jacob A. Englander / GSFC

Brent W. Barbee / GSFC

NAVIGATION & MISSION DESIGN BRANCH

www.nasa.gov

Code 595

MESA Code 590 MISSION ENGINEERING AND SYSTEMS ANALYSIS DIVISION

Outline

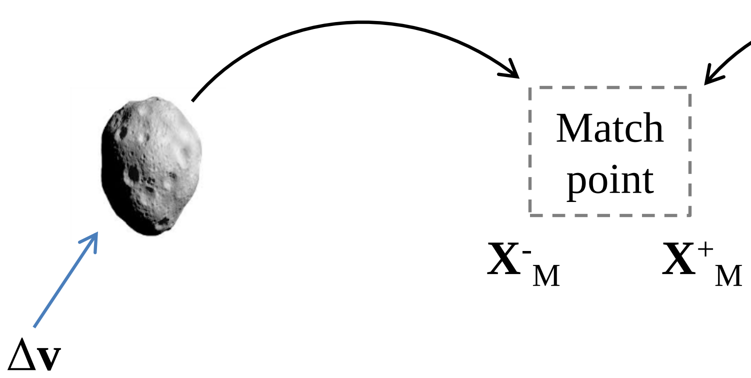
- Optimal solutions for PD
- Problem Structure and Modeling
- Correctors
- The 2017 PDC scenario
- Peak Solutions for 2017 PDC
- Mission Constraints
- Mission Trade Study Options
- Mission Design Solutions

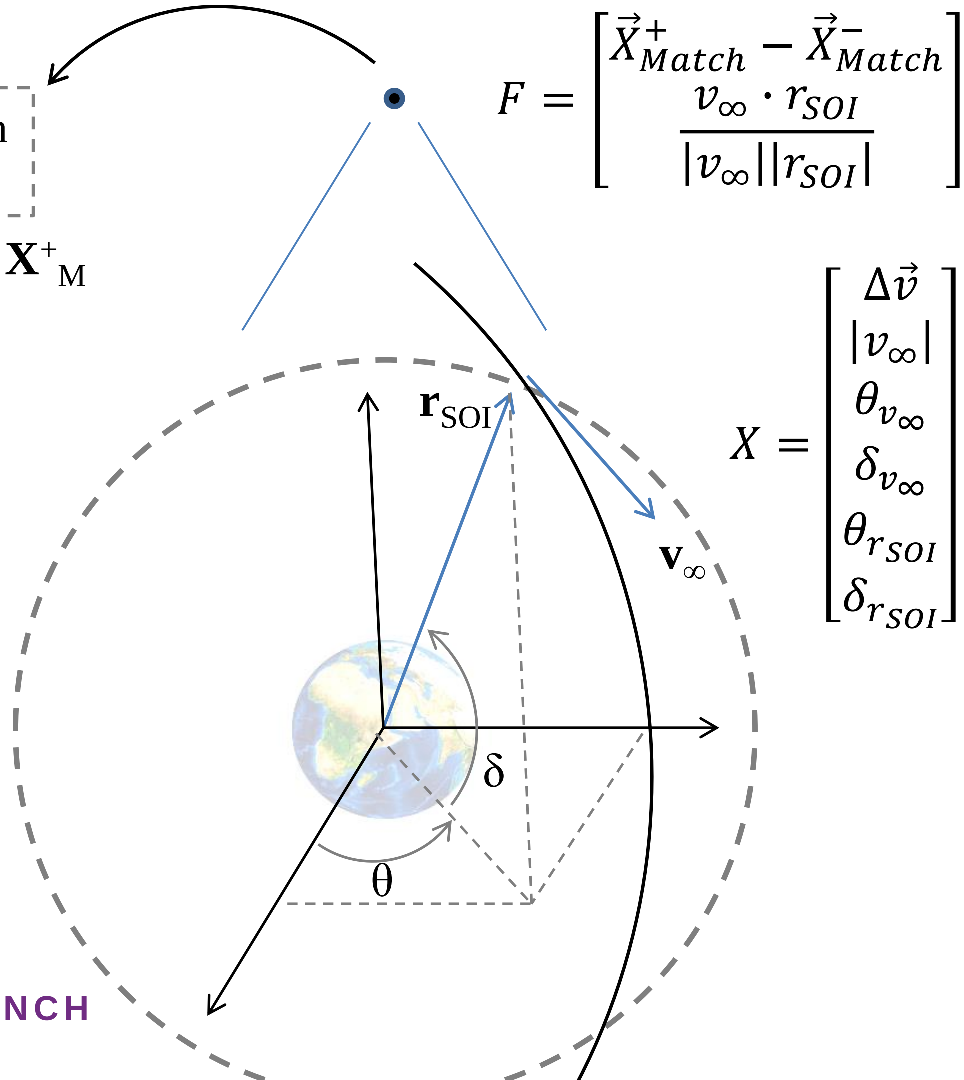
Optimal solutions for PD

- Simulation time and precision are key factors for PD missions
  - Asteroid post impact orbit (change in the order of cm/s)
  - Mission design trade (thousand optimizations)
- Previous research:
  - Analytical approximations on the close encounter conditions; or
  - Heavy n-body propagation of the asteroid's orbit
- This method: incorporates the trajectory design of the spacecraft with a simple set of two-body propagations to define the asteroid's post-deflection path. This provides a fast and cheap approximation with medium accuracy, suitable for preliminary mission design.
  - Kinetic impactor
  - Nuclear deflection

Target orbit	Calculation	Speed
Real ephemerids (fully propagated model)	No analytical approximations	Fast

Problem Structure and Modeling





- This structure:
  - Leverages the optimization code structure
  - Gives direct control over the objective function

$$r_p = -a(1-e)$$

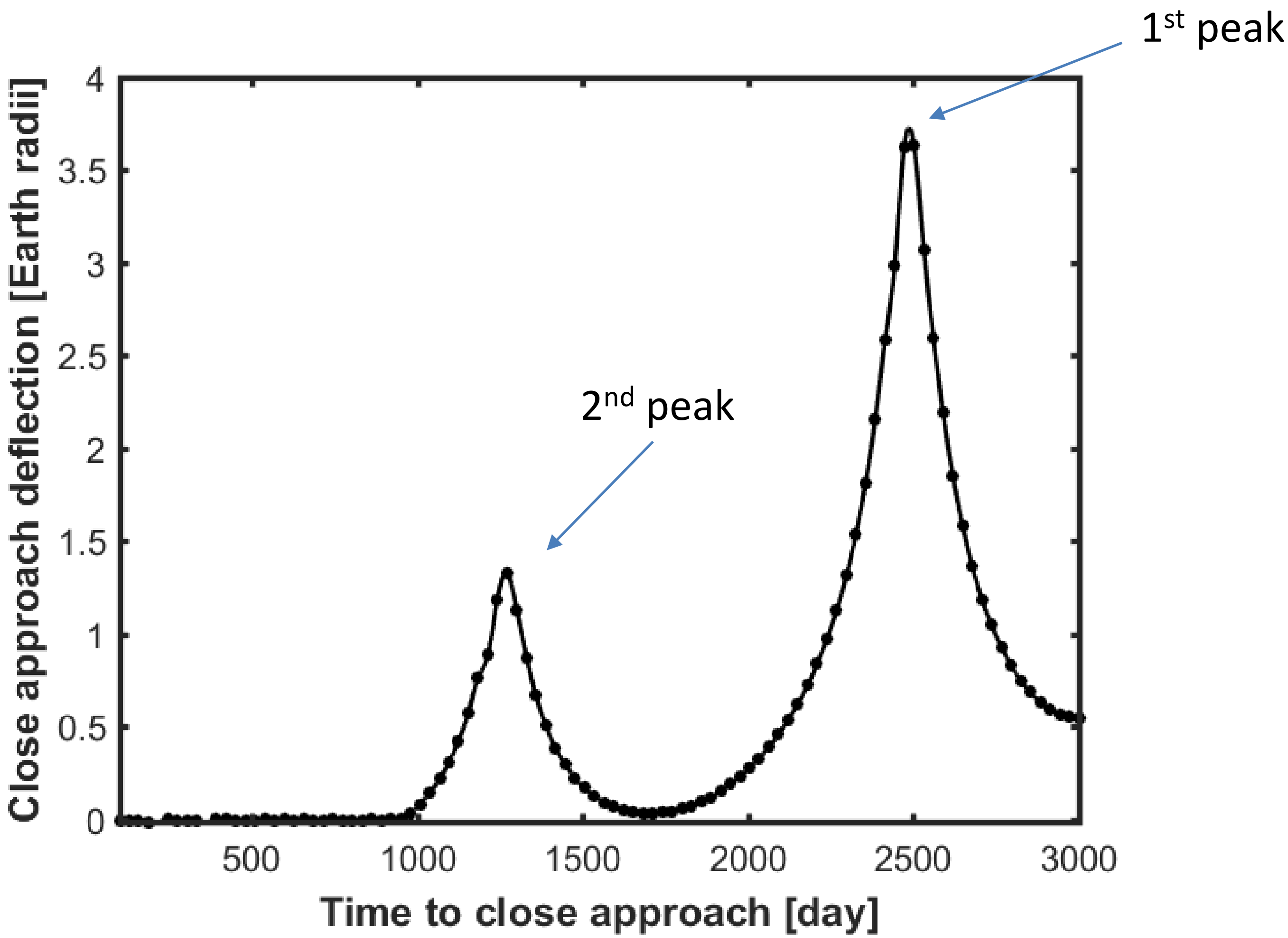
Correctors

- A Kepler propagation of the asteroid's orbit is NOT representative for PD
  - Lambert fit on the asteroid's velocity at the point of deflection
- The new time of the SOI crossing is unknown
  - Single shoot search combine with a bisection to find the deflected orbit crossing time
- Radius of the perigee of the corrected orbit is different from the ephemerids
  - Lambert fit on Earth's velocity at the SOI crossing

The 2017 PDC Scenario

- The 2017 PDC
  - Hypothetical asteroid impact scenario developed by NASA CNEOS
- The impact scenario:
  - An asteroid has been discovered on March 6, 2017.
  - First estimate of an Earthly impact is about 1 out of 40,000.
  - After an observation campaign the impact probability rose to 1%.
  - Latter confirmation of a Earth impact on July 21, 2027.
- Physical characteristics:
  - Asteroid is assumed to have 385 m in diameter with a density of the 2.6 g/cm^3 (mass is $7.768804e^{10}$ kg)

Peak Solutions for 2017 PDC



Mission Constraints

Constraint	Value	Reason
Launch date	after Aug. 1, 2019	2 years after the asteroid's probability of Earth impact rises to 10%.
Launch declination	± 28.5	Declination bounds for the Kennedy launch complex.
Asteroid encounter phase angle	≤ 120	Upper limit to have enough of the asteroid illuminated for the spacecraft's terminal guidance system.
Sun minimum distance	0.7 A.U.	Lower limit for the spacecraft design to handle the more aggressive thermal and radiation environments.
Sun maximum distance	3.5 A.U.	Upper limit to design a large spacecraft (complicated) enough to handle power generation and Earth communications at greater distances.
Earth Angle at asteroid encounter	≥ 3	Lower limit for the Deep Space Network to guarantee a viable RF link with the spacecraft.

Mission Trade Study Options

Launcher
- Atlas V (551)
  - Min dry mass: 1900 kg
  - Max. mass 5000 kg
- Delta IV Heavy
  - Min dry mass: 1900 kg
  - Max. mass 5000 kg

Number of S/C
- Single
- Double

Encounter type
- Rendezvous
- Flyby
- Combined with EGA

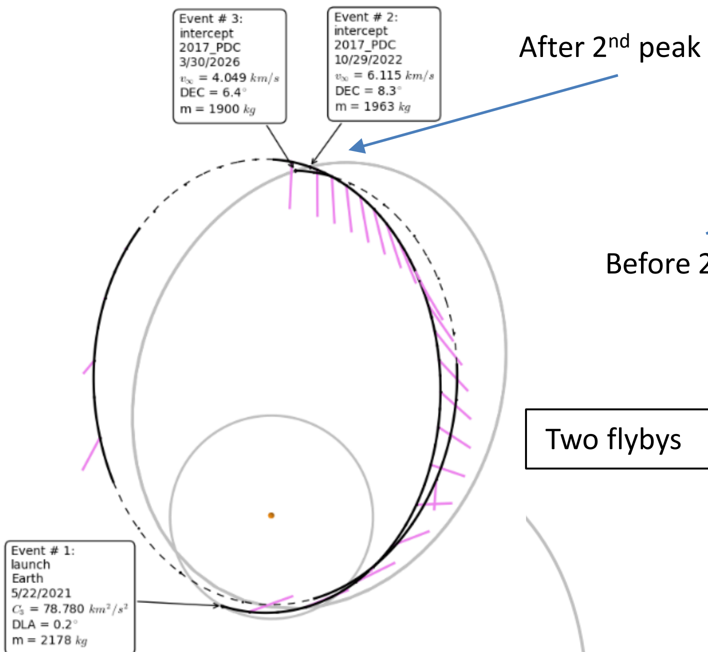
Deflection type
- Nuclear
  - $|\Delta v| = \sigma$(cm/s)
- Kinetic

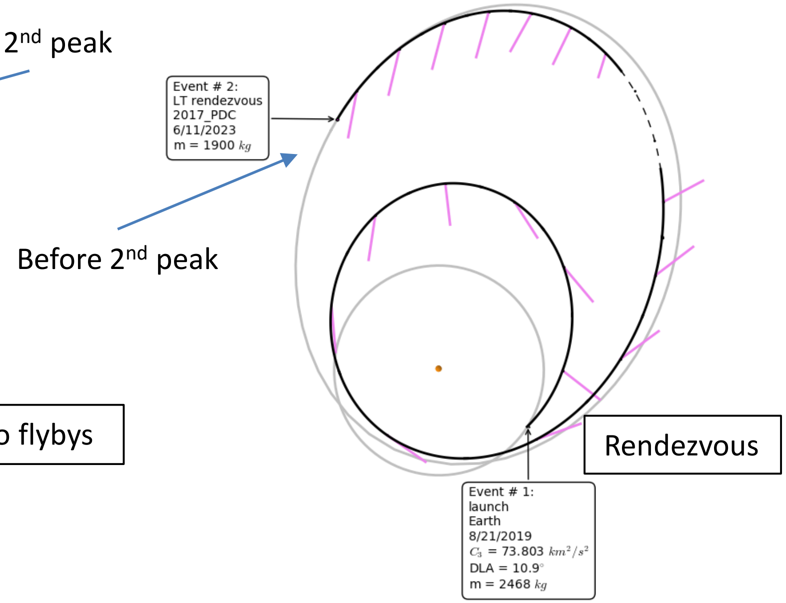
Propulsion system
- Ballistic
- SEP
  - Number of thrusters: 2
- Chemical
  - 1 DSM

Engine
- NEXT TT11
  - Duty cycle: 90%
  - Power at BOL: 20 kW
  - S/C power: 0.8 kW
  - Throttle logic: min. number of thrusters

Mission Design Solutions

Single S/C
- Survey + Deflection





Double S/C
- Survey
- Deflection