PDC 2017
Tokyo, Japan

- [ ] **Key International and Political Developments**
- [ ] **Advancements in NEO Discovery**
- [ ] **New NEO Characterization Results**
- [ ] **Deflection & Disruption Modeling and Testing**
- [x] **Mission & Campaign Design**
- [ ] **Impact Consequences**
- [ ] **Disaster Response**
- [ ] **The Decision to Act**
- [ ] **Public Education and Communication**

Spacecraft Mission Design For The Mitigation Of The 2017 PDC Hypothetical Asteroid Threat

Brent W. Barbee[a,1,*], Paul W. Chodas[b,2], Jacob A. Englander[c,1], Joshua Lyzhoft[d,3], Daniel W. Mattern[e,4], Sean W. Napier[f,5], Bruno V. Sarli[g,6]

[a] *NASA/Goddard Space Flight Center, Code 595, 8800 Greenbelt Road, Greenbelt, MD, 20771, USA, 301-286-1837*
[b] *Jet Propulsion Laboratory, California Institute of Technology, Solar System Dynamics Group, 301-121, Pasadena, CA, 91109, USA, 818-354-7795*
[c] *NASA/Goddard Space Flight Center, Code 595, 8800 Greenbelt Road, Greenbelt, MD, 20771, USA, 301-286-4710*
[d] *NASA/Goddard Space Flight Center, Code 595, 8800 Greenbelt Road, Greenbelt, MD, 20771, USA*
[e] *NASA/Goddard Space Flight Center, FDF, 8800 Greenbelt Road, Greenbelt, MD, 20771, USA, 301-286-3486*
[f] *Omitron, Inc., 7051 Muirkirk Meadows Dr Suite A, Beltsville, MD, 20705, USA, 301-286-0517*
[g] *Catholic University of America, 620 Michigan Ave NE, Washington, DC, 20064, USA, 301-286-0353*

Keywords: planetary defense, asteroid deflection, mission design, astrodynamics

---

In this paper we present detailed mission design analysis results for the 2017 Planetary Defense Conference (PDC) Hypothetical Asteroid Impact Scenario, documented at http://neo.jpl. nasa.gov/pdc17/. We are designing mission campaigns for both reconnaissance (flyby or rendezvous) of the asteroid (to characterize it and the nature of the threat it poses to Earth) and mitigation of the asteroid, via kinetic impactor deflection, nuclear explosive device (NED) deflection, or NED disruption.

We vary relevant scenario parameters within a range of values, to assess the sensitivity of the design outcome to input values, including asteroid bulk density, asteroid diameter, momentum enhancement factor (β), spacecraft launch vehicle, and mitigation system type.

We examine a range of spacecraft trajectory types in our analysis, from purely ballistic to those involving optimal midcourse maneuvers, planetary gravity assists, and/or low-thrust solar electric propulsion. We optimize trajectories using grid search, non-linear numerical techniques, and genetic algorithms, and we constrain parameters including Earth departure date, launch declination, space-

*Corresponding author
Email addresses: brent.w.barbee@nasa.gov (Brent W. Barbee), paul.w.chodas@jpl.nasa.gov (Paul W. Chodas), jacob.a.englander@nasa.gov (Jacob A. Englander), joshua.r.lyzhoft@nasa.gov (Joshua Lyzhoft), daniel.w.mattern@nasa.gov (Daniel W. Mattern), sean.napier@nasa.gov (Sean W. Napier), bruno.victorinosarli@nasa.gov (Bruno V. Sarli)
[1] Flight Dynamics Engineer, Navigation and Mission Design Branch (Code 595)
[2] Manager, Center for Near-Earth Object Studies (CNEOS)
[3] Pathways Intern, Navigation and Mission Design Branch (Code 595)
[4] Aerospace Engineer, Flight Dynamics Facility
[5] Flight Dynamics Engineer
[6] Research Fellow, Navigation and Mission Design Branch (Code 595)

craft/asteroid relative velocity and solar phase angle, spacecraft dry mass, minimum/maximum spacecraft distances from Sun and Earth, and Earth/spacecraft communications line of sight.

The following are brief descriptions of some preliminary results, assuming asteroid diameter and density of 385 m and 2.6 g/cm^3, respectively. Figure 1 presents an example solution space involving pre- and post-deflection flyby reconnaissance spacecraft launched on Atlas V (401) rockets and a deflection of the asteroid via 3 kinetic impactors, each launched by a NASA Space Launch System (SLS) 2B launch vehicle, with a total mass of 32,000 kg.

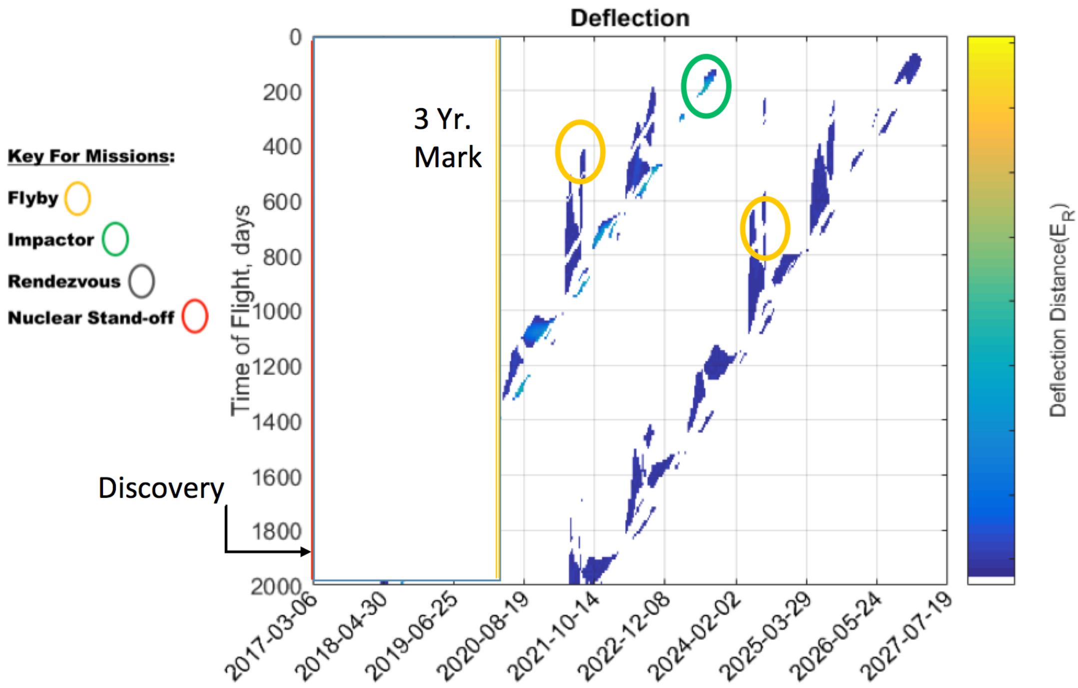

Figure 1: Example mission solution space for asteroid deflection.

Figure 2 depicts an alternative in which a single spacecraft launched aboard an Atlas V (551) or Delta IV Heavy rocket achieves pre- and post-mitigation flyby reconnaissance, as well as deflection via standoff NED detonation. Figure 3 shows a low-thrust solution in which a spacecraft launches on an Atlas V (401) rocket and uses a NEXT solar electric propulsion system with 15 kW of power[7] to rendezvous with the asteroid in July of 2023, early enough to support some candidate deflection mission solutions.

We will analyze various combinations of mission options, identify those that appear best for the hypothetical threat scenario, and generalize design principles that could be applied during any actual planetary defense scenario. We will also discuss the following:

- The number of redundant mitigation mission spacecraft that should be deployed to ensure sufficient mission reliability. We prefer solutions that achieve mission success with only a single mitigation spacecraft, such that several copies of that spacecraft can be deployed, to provide robust redundancy.
- What particular asteroid characterization data are needed from the reconnaissance missions, e.g., to inform subsequent mitigation activities and predictions of Earth impact effects.
- What asteroid characterization data is obtainable by a spacecraft during a hypervelocity asteroid flyby.
- The requirements on spacecraft absolute and relative navigation, sensor performance, etc.
- Issues associated with terminal GNC for hypervelocity asteroid intercept.
- Constraints on asteroid/spacecraft range sensing and timing performance for standoff NED detonation during hypervelocity intercept.

[7]Beginning of life power at 1 au from the Sun.

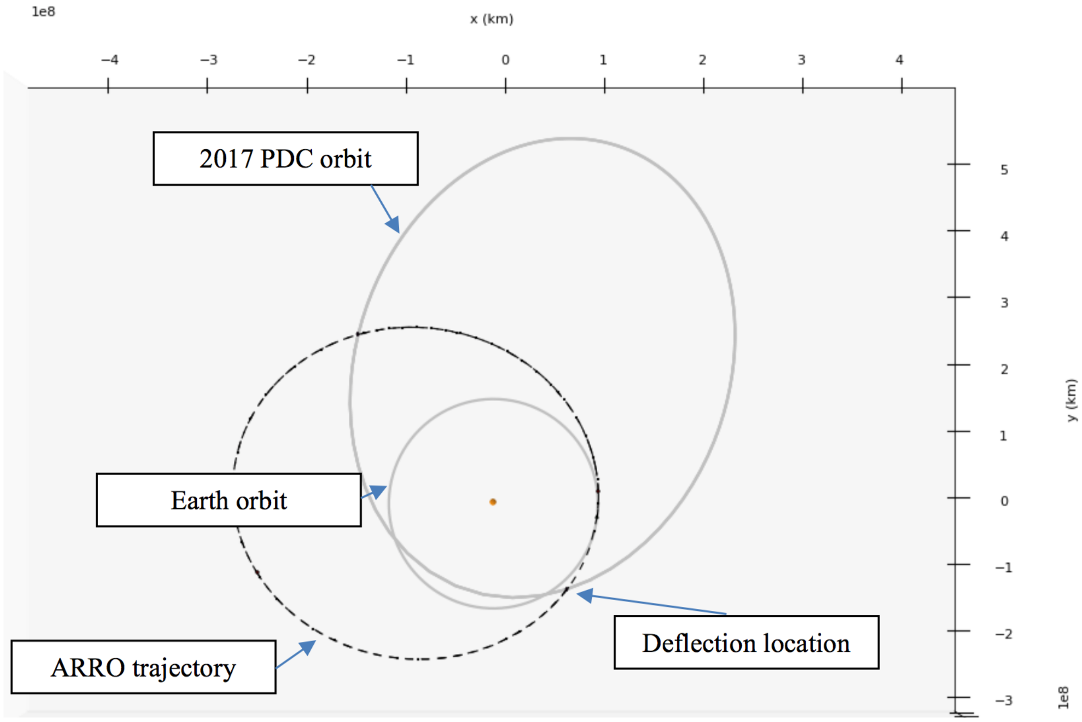

Figure 2: **Asteroid Reconnaissance Resonant Orbiter trajectory.**

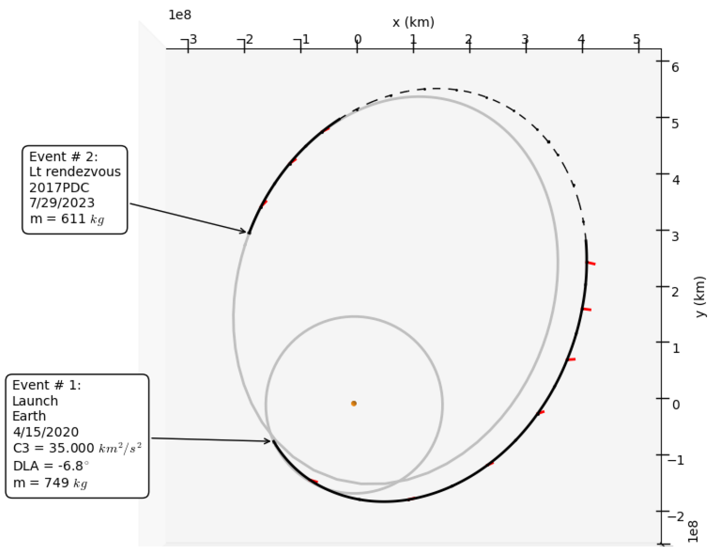

Figure 3: **Low-thrust trajectory for a rendezvous observer arriving at 2017 PDC on July 29, 2023.**

Acknowledgments: **This research was supported in part by NASA ROSES grant NNH14ZDA001N-SSO.**

Comments:
We believe this paper to be appropriate for an oral presentation.