

☒ Mitigation Techniques & Missions

## DEVELOPMENT OF AN ASTEROID MISSION DESIGN SOFTWARE TOOL FOR PLANETARY DEFENSE

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Traditional trajectory and mission optimization tools (such as Mystic, MALTO, Copernicus, SNAP, OTIS, and GMAT) are all rather high-fidelity computer programs [1]. One of the common denominators of all these tools is that they primarily look at the intermediate stage of a mission, the spacecraft trajectory from one target to another. The other two mission stages are more or less overlooked in comparison to the spacecraft's mission trajectory. Meanwhile, Dr. Nahum Melamed at The Aerospace Corporation is currently developing an on-line mission design tool, which has hopes of incorporating several specific design variables and limitations to allow for only feasible mission designs [2].

The Asteroid Mission Design Software Tool (AMiDST) being developed at the Asteroid Deflection Research Center (ADRC) at Iowa State does not yet have the high fidelity as many existing optimization-based packages. However, it focuses on the launch and terminal phase of a near-Earth object (NEO) mission. Looking into several launch vehicle and spacecraft configurations to complete a given mission design to a designated target NEO, the mission design software evaluates the possible combinations based upon several evaluation criteria such as space in the launch

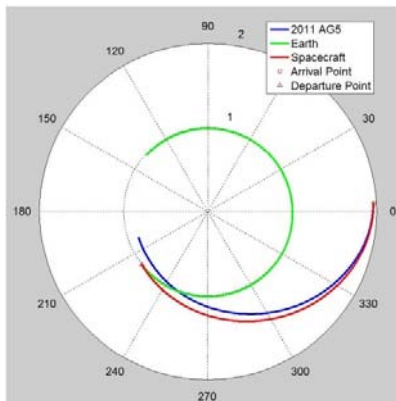


Figure 2. Plot of the proposed mission orbit from Earth to asteroid 2011 AG5.

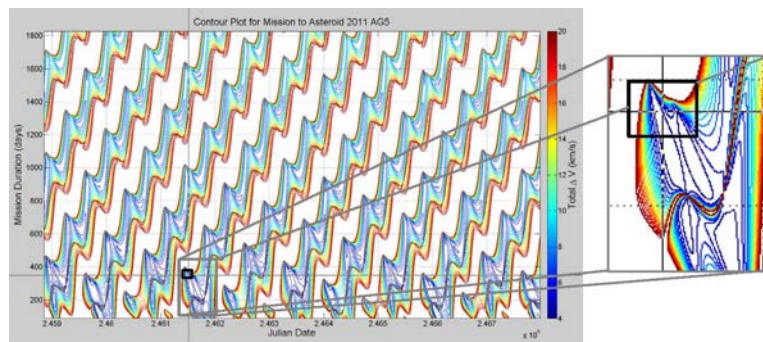


Figure 1. Depiction of the graphic-user interface (GUI) to select launch date and mission duration parameters for analysis by AMiDST.

vehicle fairing, mission  $\Delta V$  requirements, and excess launch vehicle  $\Delta V$ . Figures 1 and 2 show some of the features and outputs of the AMiDST computer program [3].

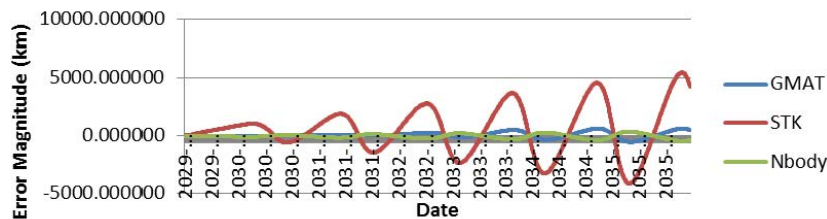
The two main mission types analyzed using the AMiDST are nuclear disruption and kinetic impacts. Given the absolute nature of a disruption mission, the terminal phase of a NEO mission currently is limited to kinetic impact perturbations to a target's orbital trajectory. Using the impact angle and arrival velocities of both the spacecraft and target

NEO, along with both masses, the trajectory of the perturbed asteroid is tracked, using high-precision N-body simulation, in order to find how much the trajectory is altered from its previous unperturbed state.

Beyond just basic orbit determination of the kinetic impact, the use of high-precision N-body simulation allows for the impact probability of an asteroid to be determined both before and after a perturbation is applied to the body, as a way to gauge its threat to Earth. Using the so-called Standard Dynamical Model (SDM) of the form:

$$\frac{d^2\vec{r}}{dt^2} = -\frac{\mu}{r^3}\vec{r} + \sum_{k=1}^{np} \mu_k \left( \frac{\vec{r}_k - \vec{r}}{|\vec{r}_k - \vec{r}|^3} - \frac{\vec{r}_k}{r_k^3} \right) + \vec{f}$$

where  $\mu = GM$  is the gravitational parameter of the Sun,  $np$  is the number of perturbing bodies,  $\mu_k$  and  $\vec{r}_k$  are the gravitational parameter and heliocentric position vector of perturbing body  $k$ , respectively, and  $\vec{f}$  represents other non-conservative orbital perturbation accelerations - a highly accurate orbit track can be found for any NEO. Figure 3 shows preliminary results from a study done to compare the capabilities of



STK, GMAT, and the ADRC's in-house N-body simulator versus JPL's Horizons [3].

Figure 3. Position error of asteroid Apophis for STK, GMAT, and the ADRC's N-body simulator with respect to JPL's Horizons [3].

Beyond modeling the motion of a (un)perturbed NEO, it would be desirable to know if it

poses any future threat to the planet. Through the use of keyhole theory, coupled with N-body simulation, that question can be quickly and accurately answered. Keyholes are regions in a planet's B-plane where if the encountering body were to pass through, it would be on a resonant return trajectory to impact the planet in the future. Using the parameters from the NEO on its approach towards Earth, including their associated errors, the corresponding gravitational keyhole would be calculated on Earth's B-plane from the nominal data. The NEO data would continue to be propagated through the B-plane using N-body gravity to see if it would pass through the keyhole and what the miss distance would be. The process would continue until the NEO is no longer considered a threat or until a significant chance of a collision arises. All together the various components of this software program provide a good basis for understanding the motion of bodies in the solar system, along with mitigation techniques and strategies to counter-act any dangers.

## References

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