Suborbital Asteroid Intercept and Fragmentation For Very Short Warning Time Scenarios

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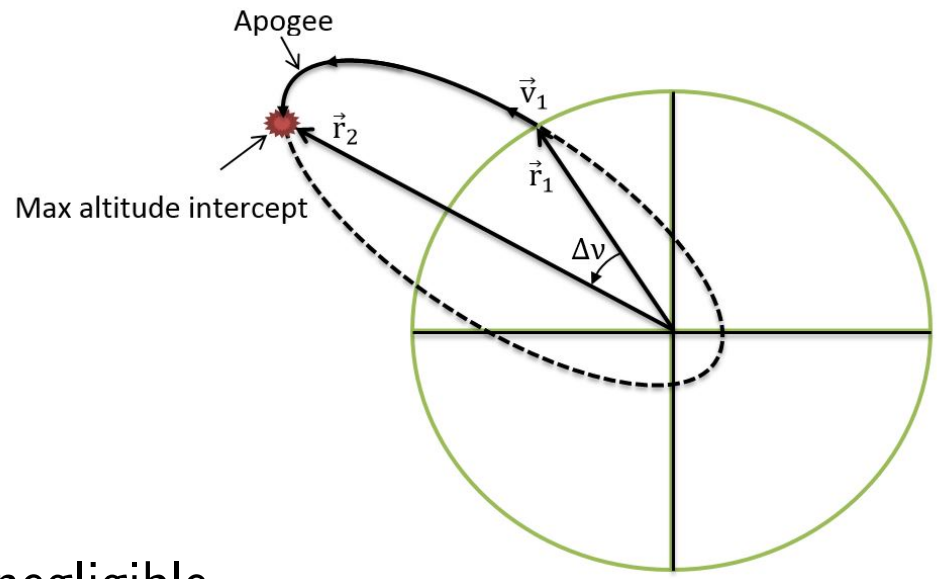
Introduction

- We are motivated to develop, test, and deploy operational Planetary Defense systems (long before discovery of an actual incoming near-Earth object (NEO))
  - Earth has a well-documented NEO impact history
  - At least $\sim 10^4$ undiscovered NEOs $>$100 m in size
  - $\sim$Several million undiscovered NEOs $<$100 m in size
  - Chelyabinsk impact in February 2013
- Our previous Phase 2 NIAC project examined the design of a Hypervelocity Asteroid Intercept Vehicle (HAIV)
  - Two-body vehicle: blended kinetic impactor and Nuclear Explosive Device (NED) payload delivery
  - Robust hypervelocity (i.e., 5–30 km/s) intercept of NEOs as small as 50 m

Introduction

- In the study described herein we investigate very short warning time scenarios
  - These may well arise in practice (ATLAS: 2 days to 3 weeks warning; Chelyabinsk (no warning); currently we have no space-based NEO survey)
  - We focus on hypothetical assessment of what could be done against incoming NEOs with only a few hours or a few days of warning time
- Suborbital (but high altitude) intercept of NEOs
  - Nuclear Explosive Device (NED) payload for NEO fragmentation
  - Could ICBMs (such as the Minuteman III), carrying a HAIV, be used for suborbital NEO intercept?
  - Full neutralization of NEO not feasible; goal here is to reduce impact damage

Analysis Assumptions



- Given a fixed launch site on Earth's surface, determine optimal suborbital intercept trajectory
  - Maximize intercept altitude
- Missile performance limited to total available Δv
- Earth treated as rotating sphere with negligible atmosphere
- Missiles launch with a single impulse
- Restricted two-body orbital dynamics
- Example NEO:
  - Trajectory impacts east coast of US
  - Incidence angle of 53.73°, impact velocity of 14.933 km/s
  - Discovered less than 11 hours before Earth impact

Methodology

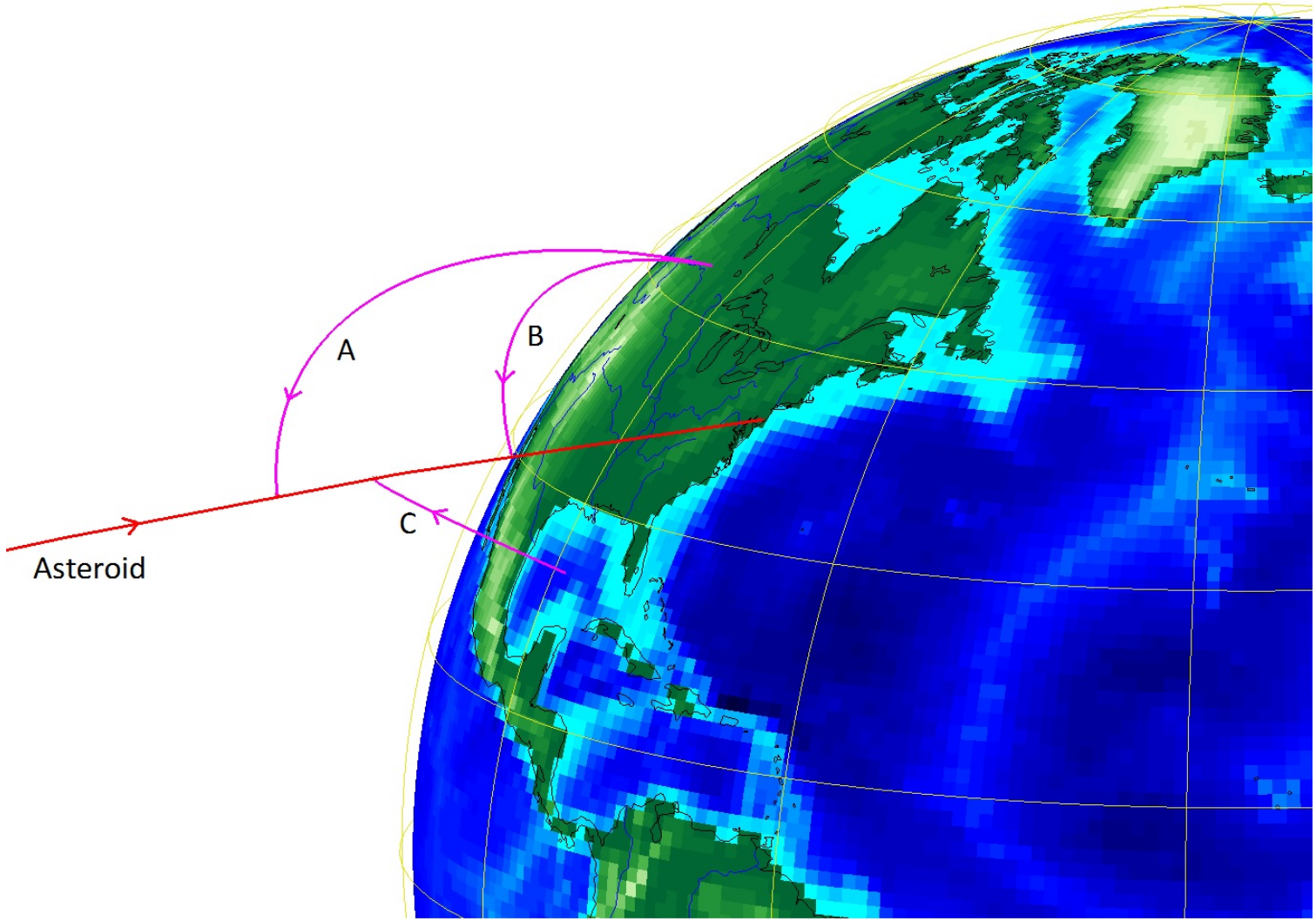
- Compute optimal suborbital intercept (maximize intercept altitude), using full available Δv of launch vehicle
  - Maximize intercept altitude $\rightarrow$ minimize/limit effects on Earth
- Δv augmentation from Earth's rotation is included in the calculations
- Two free variables: Time-of-intercept (TOI), time-of-flight (TOF)
- Required initial velocity for interceptor is found with Lambert solver
- `fmincon` in MATLAB® used to solve for TOI and TOF of optimal solution
- There is a unique optimal solution

Example Cases and Results

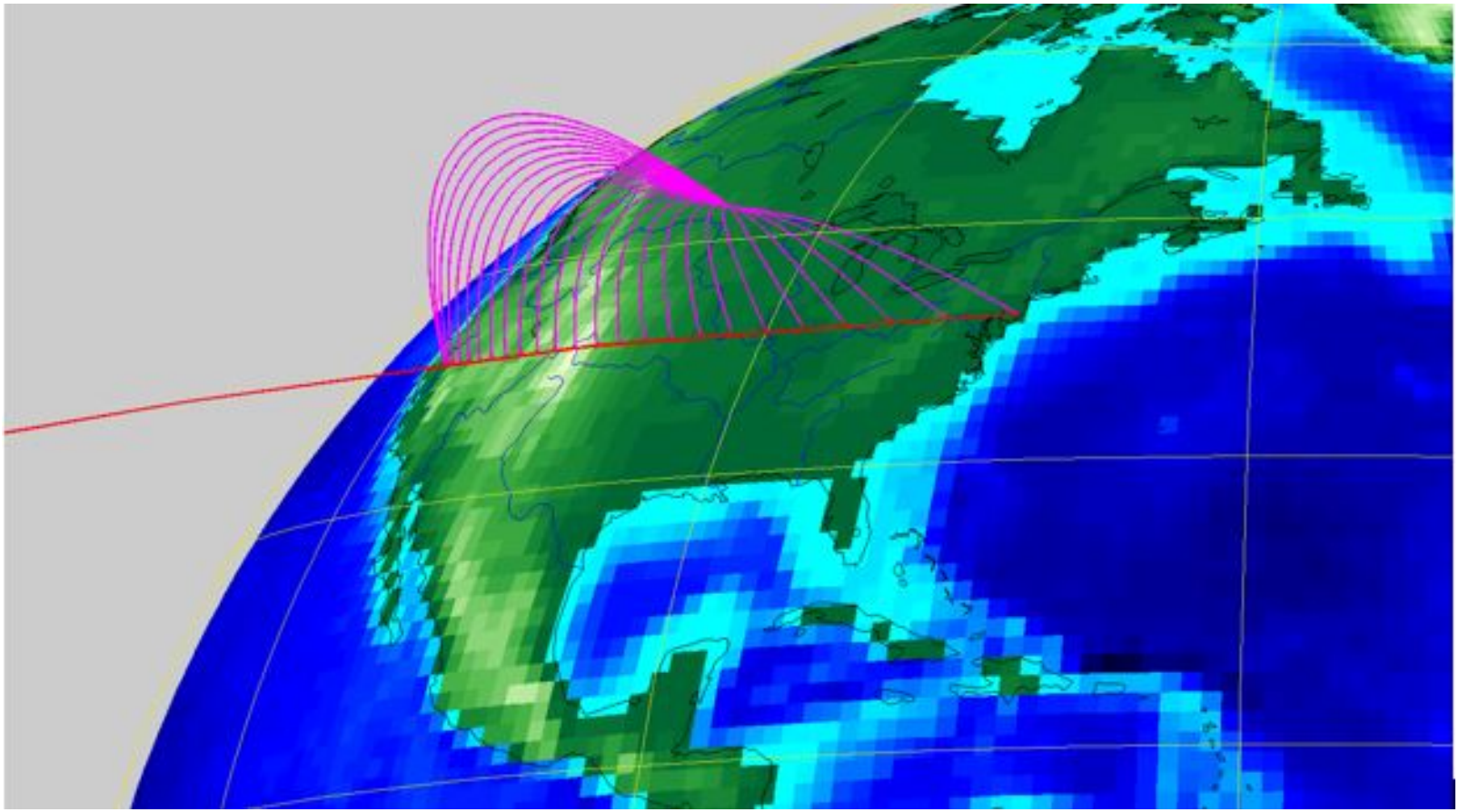
Interceptor	A	B	C
Vehicle	Minuteman III	SM-3 IIA	SM-3 IIA
ΔV (km/s)	6.6	5.5	5.5
Launch Site	48.5°N 101.5°W (North Dakota)	48.5°N 101.5°W (North Dakota)	25°N 90°W (Gulf of Mexico)
Intercept Altitude (km)	2,625	1,269	2,044
Time Until Impact at Intercept (s)	264	133	209
Time of Flight (s)	1341	971	817
Intercept Closing Speed (km/s)	14.2	14.4	13.7

- Putting launch site beneath NEO's path can increase intercept altitude, all else being equal
- 16.7% increase in Δv results in a 50% increase intercept in intercept altitude

Example Optimal Trajectories



Post-Optimal Trajectories



Leftmost trajectory is the best sub-optimal solution
Rightmost trajectory is the "last chance" solution

Higher Δv Interceptors

Vehicles	Minotaur-V	Fictional Booster
ΔV (km/s)	9.5	11.12
Launch Site	$48.5°$N $101.5°$W	$48.5°$N $101.5°$W
Impact Altitude (km)	15,101	393,620
Time Until Impact at Intercept (s)	1,388	38,623
Time of Flight (s)	5,779	414,030
Time of Flight	1.6 hrs	4.79 days

- A small improvement in Δv leads to a large increase in intercept altitude
  - Intercept altitude increases exponentially with increasing launch Δv
  - Δv increase can be achieved by using a larger booster or reducing payload mass
- Minotaur-V can intercept NEO at an altitude nearly 5 times higher than Minuteman III
- Fictional booster can intercept NEO 10 hours before Earth impact, but launch must occur 5 days before impact

Additional Considerations

- NED yield sizing for properly fragmenting ∼50–150 m NEOs of various types
- Limiting cases: sizes/types of NEOs for which a suborbital disruption attempt would make sense
- Examination of all high-altitude NED detonation effects on Earth and satellite infrastructure
- How quickly a dedicated launcher (e.g., silo-based) could actually be made ready
- How quickly a non-dedicated launcher (e.g., spacecraft launch vehicle) could be made ready
- Precision guidance for ascent and the terminal phase of intercept (∼14 km/s closing velocity)
- Effects of realistic navigation and orbit determination errors
- Assessment of performance when interceptor begins in Earth orbit rather than on the surface

Conclusions

- Within the assumptions and limitations of our analysis framework, we find that current silo-launched booster vehicles have sufficient burnout velocities to deliver a payload to intercept a NEO approaching Earth impact, when the NEO is very near Earth.
- If more warning time than several hours is provided (e.g., >1 week), then an interplanetary (i.e., far from Earth) intercept/fragmentation becomes feasible, but will require an interplanetary launch vehicle.
- In principle, preparing for and executing Planetary Defense missions need not be prohibitively expensive (i.e., some existing hardware may be directly applicable).

When a hazardous NEO on a collision course with Earth is discovered we will not have the luxury of designing, testing, and refining our systems and plans. We will need to be fully prepared at that time to take effective action on relatively short notice with a high probability of success. That level of preparedness can only be achieved through proper design and testing of systems now.

Acknowledgments

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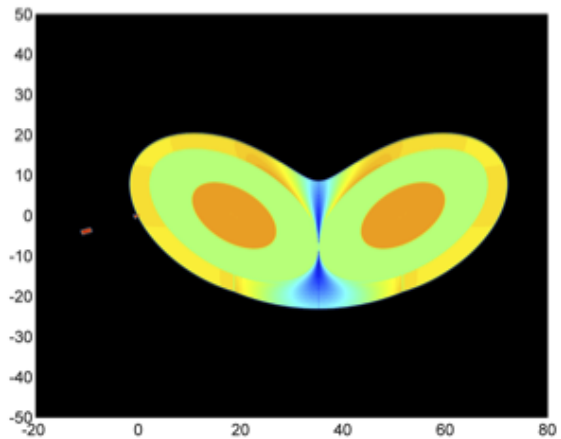

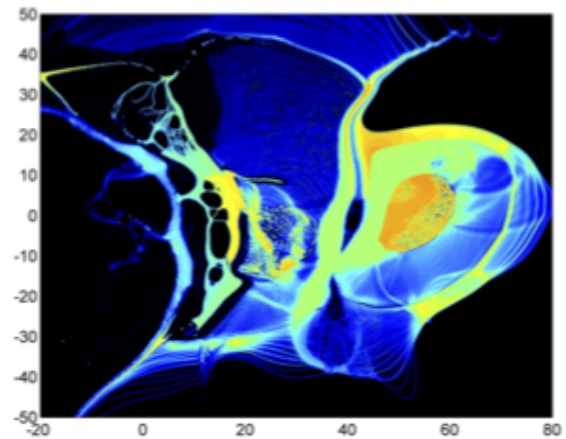

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