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Overview of a New NASA Activity Focused on Planetary Defense

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OBJECTIVE & APPROACH

OBJECTIVE: Develop Predicted Impact Assessment tools to support decision makers in the event of discovery an impact by a Potentially Hazardous Asteroid (PHA)

APPROACH: Characterize PHAs, modify NASA codes to conduct physics-based simulations of meteor entry/breakup, surface damage and bound associated risks

TASK 1: PHA CHARACTERIZATION

- Collect physical properties of PHAs from literature and from in-house study of meteorites, ground-based observations, and eventually, *in situ* measurements.
- Focus is on needs for simulation of entry/breakup, risk assessment and kinetic mitigation (impact and nuclear stand-off – collaboration with LLNL)
- Modeling of PHAs as they exist in the space environment

TASK 1: PRODUCTS

- Test cases for simulations of entry/breakup and surface damage. Cases range from simple, homogeneous boulders to complex rubble piles composed of stones with heterogeneous properties and ranges of cohesive binding
- Observed data needed for validation of simulations: Deceleration, light curves, videos of fragmentation/airburst, surface damage and entry state
- Web based catalog of PHA properties with focus on needs for Planetary Defense and associated bibliography

See companion papers by:

Sears, *et al., Planetary Defense: A Meteorite Perspective*

Dobrovolskis & Korycansky, *Internal Gravity, Self Energy and Disruption of Asteroids*

Test cases

TASK 2: ATMOSPHERIC ENTRY & BREAKUP

- Modify re-entry codes: Flow solver (DPLR), Radiation solver (NEQAIR) for conditions up to 20 km/s and 300 bar stagnation pressures.
- Modify materials response codes FIAT and TITAN to account for meteor ablation; these codes are routinely used for entry capsule thermal protection system design
- Apply thermal-structural code MARC to fragmentation of meteors
- Expand input databases to account for meteor ablation species
- Develop models for fragmentation and airburst
- Modify "fast" engineering code (TRAJ) to capture results of high fidelity simulations along flight paths accounting in "real time" for ablation, shape change, fragmentation and airburst
- Validate simulations by comparison to observed meteor entries : light curves, decelerations, and deduced near-field energy deposition
- Validate by comparison to ground test following of re-entry capsule design approach, e.g., arcjet tests that mimic "physics" involved in meteor entry and comparison to pre-test predictions

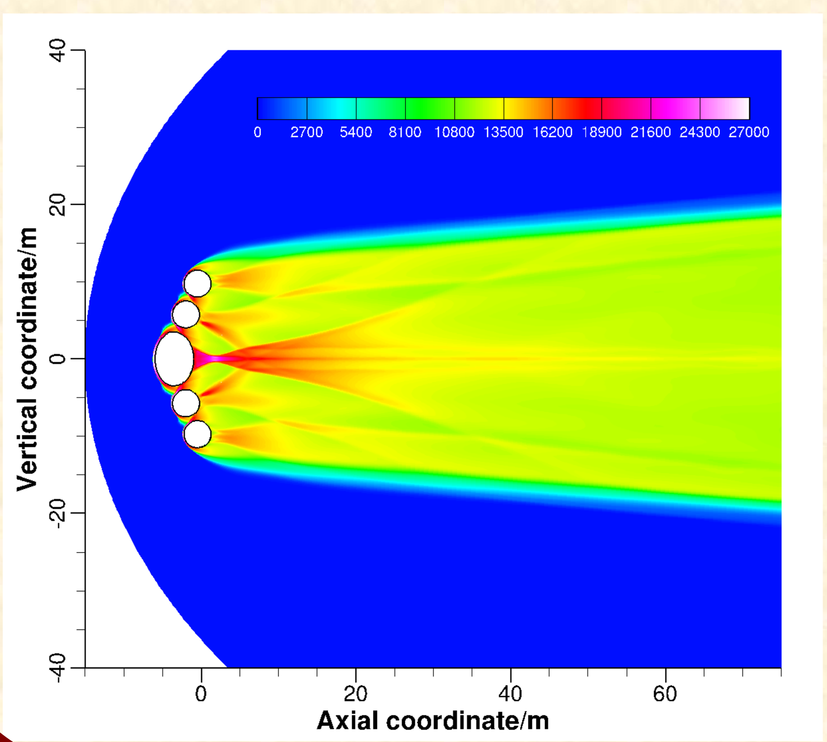
See companion paper by:

Prabhu, *et al., Physics-Based Modeing of Meteor Entry and Breakup*

Sim. codes

TASK 2: ENTRY & BREAKUP PRODUCTS

- Validated, near-field energy deposition curves from high-fidelity simulations as a function of altitude or time
- Results bounded by best and worst case scenarios in terms of PHA property uncertainties and surface damage/casualties



Preliminary DPLR flow solver result for objects of revolution flying in formation at 20 km/s

See companion paper by:

Mathias, *et al., Sensitivity of Ground Damage Predictions to Meteroid Breakup Modeling Assumptions*

Near field energy f(z)

To Task 3

Near field energy

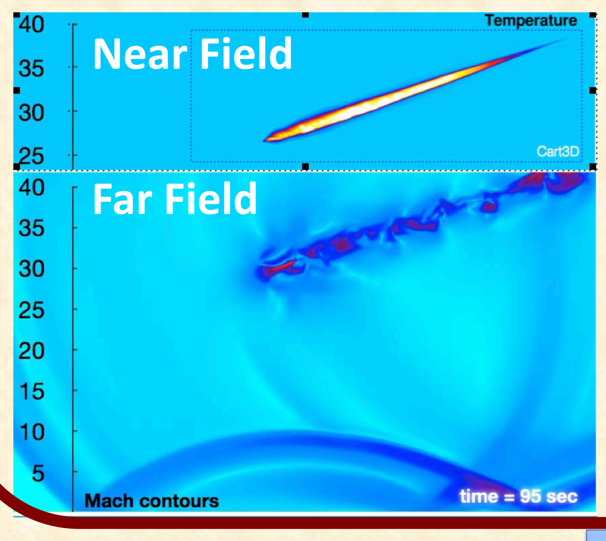
TASK 3: PROPAGATION OF NEAR-FIELD ENERGY DEPOSITION TO SURFACE

- Modify NASA Flow Solver Cart3D to account for exponential atmosphere, hydrostatic equilibrium and subroutines to capture surface overpressures and wind profiles.
- Entry/breakup predictions from Task 2 used as basis for near-field energy deposition along the trajectory. Disturbance is propagated in the atmosphere with Cart3D
- Surface damage for land impacts based on Cart3D overpressures and winds. Outputs from Cart3D will be coupled to GEOCLAW code and models of ocean topography to predict damage tsunamis created by PHAs
- Future applications will include simulations of damage from crater formation and ejecta

Sim. codes

TASK 3: PRODUCTS

- Computationally propagate the near field shock front to the far field accounting for transfer of mass, energy and momentum through the exponential atmosphere. Products are surface damage (land/tsunami)



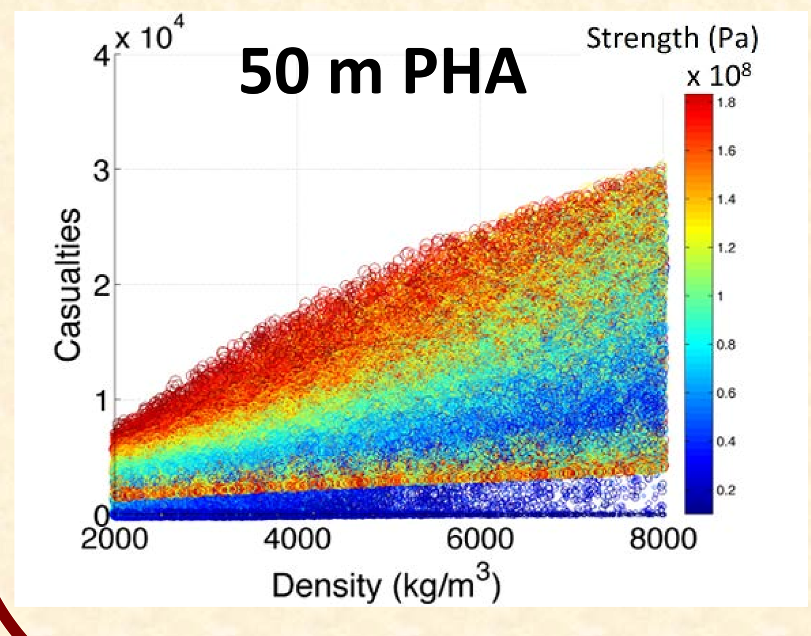
Preliminary Cart3D blast propagation results.*

*Near field energy deposition from Popova, et al., *Chelyabinsk Airburst, Damage Assessment, Meteorite Recovery, and Characterization*, Science Express, 2013

Surf. damage

TASK 4: RISK ASSESSMENT

- Apply NASA Risk Assessment modeling code to analyze PHA threats
- Select (via Monte Carlo) a sets of test cases from Task 1 with uncertainty in characterization data specified by Task 1.
- Calculate casualties based on damage area simulated from Task 3 for either the average world population or gridded population data set
- Evaluate relative sensitivity of input data and levels of simulation fidelity. Use results to guide re-focus levels of effort in Tasks 1, 2 and 3
- Generate bounds on PHA threat and quantify uncertainty



Preliminary result showing casualties as effected by PHA strength ranging from 2 to 200 MPa. Color banding shows expected trend that as PHA strength increases, casualties do as well.

For a 157 m PHA, banding is not apparent, meaning that for this case, strength is not an input driver

FINAL PRODUCT

Predictive Impact Assessment Tools to support decision makers of mitigation approach

July 7/8/9 Workshop at NASA Ames

The NEO Program Office is sponsoring multi-lateral workshop July 7–9, 2015 at NASA Research Park, Ames Research Center. The purpose of the workshop is to foster, through international collaborations, advancement in the state-of-the-art in these topic areas. The program includes invited speakers, posters and student attendance (limited to 75 participants). For more information, see workshop announcement distributed at this conference or web site (www.planetarydefenseworkshop2015), or talk to workshop organizers Ethiraj (Raj) Venkatapathy or David Morrison.

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