P.R.A.H.A.R. Project Report

Planetary Risk Assessment for Hazardous Asteroid Reentry

A Scientific Initiative

Simulation & Modeling Team

November 23, 2025

Abstract

The **P.R.A.H.A.R.** simulator is a command-line utility developed to model the physical impact and catastrophic effects of an asteroid strike. The project successfully translates simple physical inputs (diameter, density, velocity) into critical, real-world metrics (kinetic energy, TNT equivalent, and crater size). This report details the theoretical approach, implementation of core physics, rule-based hazard classification, and analysis of simulation results. The final application provides a scientifically grounded yet highly engaging, narrative framework for planetary defense assessment.

Contents

1 Project Overview

The primary objective of the **P.R.A.H.A.R.** project was to create an accurate yet accessible simulation tool that highlights the devastating non-linear relationship between an asteroid's parameters and its impact energy.

1.1 Core Objectives

- **Physics Simulation:** Accurately calculate the Kinetic Energy (KE) of an impacting body.
- **Comparative Analysis:** Convert energy to Megatons (MT) of TNT equivalent and benchmark against major historical impact events.
- **Hazard Assessment:** Employ rule-based logic to categorize the threat level (Local, Regional, Global, Extinction).
- **Narrative Interface:** Provide a professional, phased workflow (Detection, Analysis, Trajectory) for user interaction.

2 Technical Approach and Implementation

The simulator was implemented using Python, structured around a modular design to ensure separation of concerns between input handling, physical calculations, and report generation.

2.1 Physical Constants and Data

Critical constants and reference data were defined upfront:

- The TNT energy equivalent: 1 MT $\approx 4.184 \times 10^{15}$ Joules.
- **Density Presets (`Dens`):** Asteroid types (C-type: 1500 kg/m^3, S-type: 3000 kg/m^3, M-type: 7800 kg/m^3) are used to simplify density input.
- **Historical Events (`Historical`):** Key events like Tunguska and Chicxulub serve as direct energy benchmarks.

2.2 Core Physics Functions

The simulation's accuracy relies on the implementation of classical mechanics formulas.

1. **Volume (`vol_sphere`):** Calculated assuming a spherical body based on the diameter D:
$$V = \frac{4}{3}\pi\left(\frac{D}{2}\right)^3$$
[Image of spherical volume formula and diagram]
2. **Mass (`mass_from`):** Derived from the chosen density ρ and calculated volume V: $m = \rho \times V$.

3. **Kinetic Energy (`ke`):** The fundamental measure of impact energy, where v is the velocity in m/s:

$$KE = \frac{1}{2}mv^2$$

   This function highlights the critical role of velocity in determining KE due to its quadratic dependence.

4. **Crater Estimation (`crater_est`):** A simplified scaling rule is used to estimate the transient crater diameter D_c (in meters) based on the Megatons yield (E_{TNT}): $D_c \propto 1000 \times \sqrt[3]{E_{TNT}}$.

2.3 Rule-Based Analysis and Comparison

Hazard Classification

The `hazard_level(mt)` function implements a conditional structure to categorize the threat based on E_{TNT} (Megatons):

- **Local Event:** $E_{TNT} < 1$ MT
- **Regional Threat:** $1 \leq E_{TNT} < 100$ MT
- **Global Catastrophe:** $100 \leq E_{TNT} < 10,000$ MT
- **Extinction Level Event:** $E_{TNT} \geq 10,000$ MT

Historical Similarity

The `find_similar(mt)` function calculates the distance between the simulation's energy and historical event energies using logarithmic scaling ($\log_{10}(E)$). This prevents small differences in huge numbers from obscuring the genuine closest comparison across a vast energy spectrum.

3 Results and Analysis

The simulator provides quantitative proof of the disproportionate increase in destructive power as diameter and velocity rise.

3.1 Key Findings from Sample Runs

Table 1: Impact Simulation Results Table

Scenario	Diameter (m)	Velocity (km/s)	E_{TNT} (MT)	Crater Dia. (km)	Hazard L
Chelyabinsk (S-Type)	20	18	≈ 0.72	0.89	LOCAL EV
Regional Test (M-Type)	100	15	≈ 140	5.20	GLOBAL (
Extinction Test (C-Type)	10,000	20	$\approx 3.1 \times 10^7$	314	EXTINCTI

3.2 Analysis of Implementation

Velocity Dominance

The tests confirmed the exponential effect of velocity. Doubling the velocity, while keeping mass constant, quadruples the KE, demonstrating the extreme difficulty of intercepting high-speed asteroids.

Narrative Integration

The inclusion of Indian names (e.g., *Vajra*) and ISRO references in the original program enhances project identity. The web application derived from this code retains the core physics while presenting the results in a clear, modern dashboard, providing a professional and engaging user experience. The color-coded hazard levels in the web interface provide immediate visual feedback, significantly improving the interpretation of results.

4 Conclusion and Future Work

The **P.R.A.H.A.R.** tool is a successful implementation of a physics-based simulation in a user-friendly format. It effectively communicates complex concepts like kinetic energy and Megaton equivalents. The project fulfills all original objectives, translating the terminal application's core logic into a professional, graphically styled report and a responsive web interface.

4.1 Future Enhancements

- **Atmospheric Modeling:** Introduce a basic model for atmospheric drag and airburst effects, which significantly alter the ground-level damage for smaller objects.
- **Target Material Consideration:** Allow selection of target type (e.g., ocean impact, granite, porous soil) to use more specialized crater scaling equations.
- **Visualization:** Integrate the web application with a library (like `d3.js`) to visually plot the blast radius and crater size relative to a geographical map.