Killer Asteroids: How Engineers Will Save the Earth

An Online Continuing Education Course for Engineers

Course Number: M-3076

Credit: 3 Hours / 3 PDH / 3 CPD

Killer Asteroids: How Engineers Will Save the Earth

Neil Weisenfeld, P.E.

Introduction

Asteroid impacts are among the most consequential natural hazards Earth faces—rare enough that they are easy to discount, yet energetic enough to produce local, regional, or even global disruption. With respect to risk, engineers view asteroid risk through a hazard spectrum with two variables: probability (of impact) and consequence. Engineers would classify asteroid hazards as low probability, high-consequence events, with uncertainty dominating the early stages of decision-making. Most near-Earth objects (NEOs) pass the Earth harmlessly. Still, the combination of high velocities and large masses means that even a relatively small object can release enormous energy if it enters the atmosphere or strikes the surface. The fundamental challenge is not only the physics of impact, but the fact that the risk is dynamic: new objects are discovered over time, their predicted paths change as observations accumulate, and response options depend heavily on how much warning time is available.

Several historical events illustrate why planetary defense deserves engineering attention. The Chelyabinsk airburst (2013) demonstrated that objects on the order of tens of meters—far smaller than "dinosaur killer" asteroids—can still cause widespread damage, including broken glass injuries across a major city, primarily from shock waves rather than direct impact. The Tunguska event (1908) remains the key example of a large atmospheric explosion flattening a vast forested area, underscoring the potential risk. At the far end of the spectrum, the Chicxulub impact (about 66 million years ago) provides a baseline to demonstrate that large impacts can reshape climate and ecosystems on a planetary scale. Together, these events teach engineers three important lessons: (1) damage is not limited to ground impact—airbursts and fragmentation can be damaging; (2) size alone does not determine consequences—material strength, density, and trajectory shape outcomes; and (3) uncertainty is inherent—we often must act before all key parameters are fully known.

Because of these uncertainties and interdependencies, planetary defense is fundamentally an engineering systems problem. It is not the focus of a single technology or one heroic mission; it is an end-to-end chain of capabilities—sensing, data processing, modeling, decision support, launch readiness, guidance and navigation, and post-intervention verification—integrated into a coordinated global response.

Each link in the chain has its own performance requirements and failure modes, and improvements in one area can be wasted if another area is weak. For example, highly accurate deflection technology is of limited value without early detection and reliable tracking; conversely, accurate detection is insufficient if deflection cannot be executed in the available time window. Engineers will recognize this as a classic system-of-systems challenge: requirements flow down from a risk objective ("reduce impact probability below a threshold”), and technical design must account for constraints, interfaces, uncertainty, and reliability.

This course is organized around the end-to-end planetary defense chain: detect, track, assess, and intervene:

- Detect focuses on how NEOs are discovered in the first place, including the practical limits of ground-based and space-based sensing, observation frequency, and the realities of finding small, dark objects against complex backgrounds.
- Track addresses how repeated observations convert “a point of light” into an orbit with quantifiable uncertainty, and how improved data rapidly changes predicted trajectories and impact probabilities.
- Assess covers consequence modeling, risk thresholds, and decision-making under uncertainty—how engineers and agencies interpret probability distributions, evaluate potential outcomes (airburst vs surface impact), and determine whether action is warranted.
- Intervene examines mitigation options from an engineering standpoint, including how warning time, targeting accuracy, asteroid structure, and mission reliability drive the choice among deflection methods.

By the end of this course, it should be clear to the reader that killer asteroids are not an abstract cosmic threat, but a manageable engineering risk—one that can be reduced through systems engineering, robust modeling, and well-designed, testable technologies.

Historical Events - Why Asteroids Matter (Chelyabinsk, Tunguska, Chicxulub)

Asteroid impact events are infrequent on human timescales, but consequences can be severe. The three events discussed here—Chelyabinsk (2013), Tunguska (1908), and Chicxulub (~66 million years ago)- cover a wide range of outcomes, from injuries and building damage to regional destruction, to global environmental change.

A key theme across these cases is that the outcome depends strongly on where the object’s energy is released. Some objects break apart and release most of their energy in the atmosphere (an airburst). Others reach the surface and release energy at impact, forming a crater and causing broader second-order effects. The same basic inputs —object size, speed, entry angle, and strength—can produce very different results depending on how the object breaks apart during entry and where the energy ends up.

Chelyabinsk (2013): A small object with widespread, real-world damage

On February 15, 2013, a bright fireball crossed the sky over the southern Ural region of Russia, and an object exploded in an airburst over Chelyabinsk Oblast. The source was a stony near-Earth object roughly 18 meters across, which approached undetected before entry and fragmented at high altitude.

The explosion occurred at roughly 30 km altitude, producing a shock wave that traveled to the ground and across populated areas. After the initial flash of light, the shock wave followed seconds to minutes later, depending on location, and broke windows across a wide area.

Chelyabinsk meteor fireball over Russia on February 15, 2013. Image courtesy of NASA

The main human impacts came from indirect effects, especially shattered glass. About 1,491 people sought medical treatment, mostly for cuts and injuries caused by broken glass after the shock wave arrived. No deaths were reported. Property damage was extensive, with roughly 7,200 buildings reported damaged across the region, including the collapse of a factory roof.

Key insights from Chelyabinsk start with the fact that “small” does not mean “safe.” An object tens of meters across is not a civilization threat. However, it can still cause injuries and widespread damage if the airburst occurs at an altitude that produces strong overpressure at the surface. Chelyabinsk also shows how short the warning time can be for smaller bodies, especially when approach geometry makes detection difficult (in this case, the approach direction was close to the Sun). This event also shows that consequences can be caused by secondary damage mechanisms such as glass failure, façade damage, and nonstructural damage.

Tunguska (1908): Regional devastation from an airburst, with major uncertainty in the details

The Tunguska event is the best-known historical case of a powerful atmospheric explosion causing major regional damage without leaving a clear impact crater. It occurred on June 30, 1908, near the Podkamennaya Tunguska River in central Siberia (now in Krasnoyarsk Krai, Russia). Eyewitness reports describe a bright fireball and a powerful explosion, and later investigations documented a vast area of downed trees consistent with a high-energy airburst rather than a ground impact. The most common explanation is an airburst caused by a small asteroid (sometimes discussed as possibly a comet), with the explosion occurring at an altitude between 5 and 10 km.

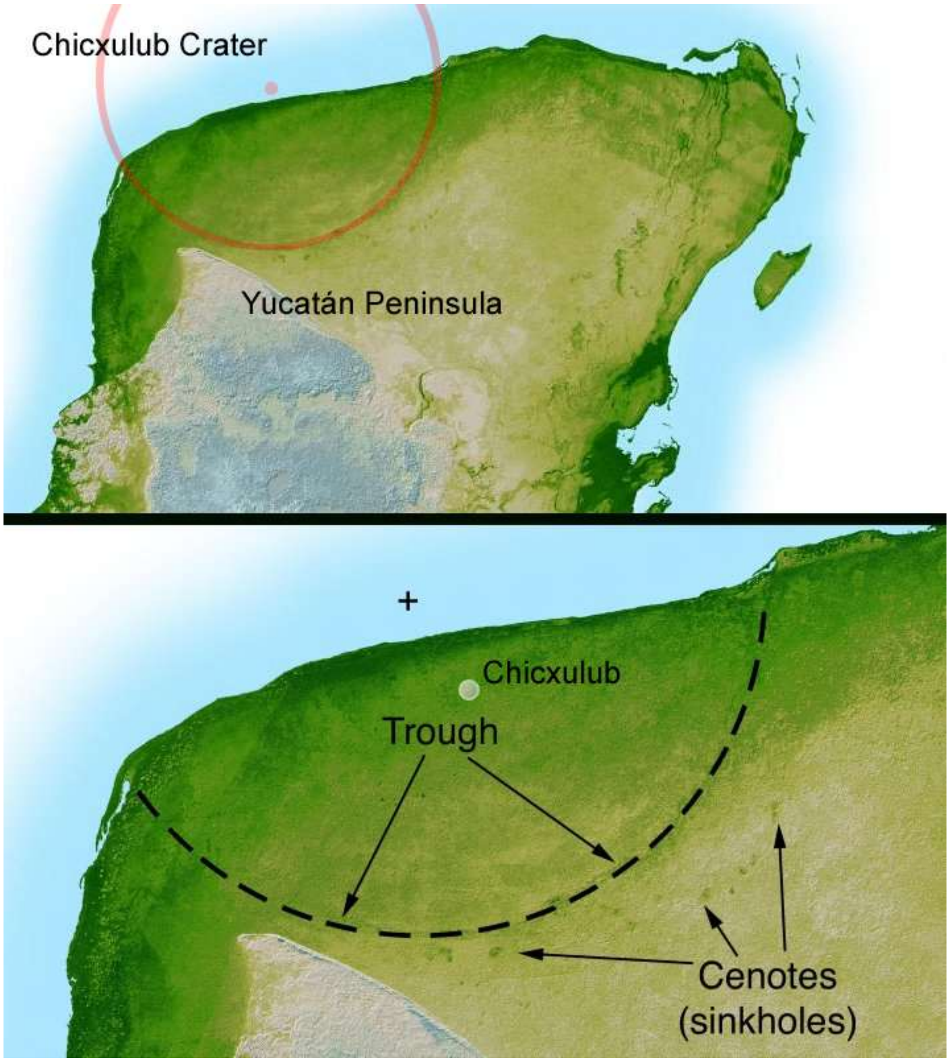
Tunguska event aftermath (Kulik expedition). Trees knocked down and burned near the Podkamennaya Tunguska River, Siberia, June 30, 1908. Source: Leonid Kulik (Kulik expedition), "Tunguska Ereignis-1," via Wikimedia Commons (public domain).

The outcome of the Tunguska event was extreme landscape damage with roughly 2,150 km² (830 square miles) of forest being flattened. Energy estimates vary across sources and methods, often described as multiple megatons of TNT equivalent, which reflects uncertainty in the limited measurements available at the time. Human fatalities were low mainly because the region was sparsely populated; some sources mention up to three possible deaths, though the count is not certain.

A key insight from the Tunguska event is that a large airburst can produce a footprint that would be catastrophic if it occurred over a modern city. Tunguska also highlights uncertainty when instrumentation is absent, and data comes from indirect evidence and eyewitness reports. This matters because early assessments of any new threat can face similar uncertainty: object size, strength, fragmentation behavior, and burst altitude may not be well known until later, yet decisions often must be made early.

Chicxulub (~66 million years ago): A surface impact with global after-effects

Chicxulub is the reference case for very large impacts and global consequences. The Chicxulub crater lies beneath and partly offshore of the Yucatán Peninsula in Mexico and is about 180–200 km in diameter. It formed about 66 million years ago, when an asteroid roughly 10 km across struck Earth at the end of the Cretaceous period. The impact is thought to have caused a mass extinction that eliminated a large fraction of species, including some dinosaurs.



Source: NASA/JPL-Caltech, modified b – Modified NASA image to increase contrast,
Original: http://photojournal.jpl.nasa.gov/catalog/PIA03379

Unlike Chelyabinsk and Tunguska, where the main impacts are tied to blast effects and damage was local, Chicxulub is important because the largest consequences were global and long-lasting. The impact injected enormous amounts of dust, soot, and aerosols into the atmosphere, reducing sunlight and causing major cooling ("impact winter"), along with additional effects such as widespread fires and long-term disruption to ecosystems. Even with extensive research, some aspects of the post-impact climate response remain uncertain, including how long the most severe cooling and darkness lasted.

A key insight from the Chicxulub events is the impact of cascading effects over the initial blast footprint. In a Chicxulub-class event, the greatest harm comes not only from the immediate impact area but from the atmospheric and climate consequences that spread globally. Chicxulub also sets the "tail risk" end of the hazard spectrum: extremely rare, but with outc so large that the ong-term thinking about detection and prevention.

Putting t ce range, and uncertain

Chelyabinsk, Tu of event types and outcomes. Sma f an airburst occurs at an alti rsts are rarer but can create region nd burst altitude can be significant npacts can cause global environme

Across all three typ ze, structure, entry angle, and the s, or reaches the ground, and tho ould need to be made. This is why , assess, and intervene, so that obs v data arrives, and interventi

To view the remainder of the course material and to take the quiz for PDH credit, you must purchase the course.

Close this window and click "Add to cart" on the product page.

Historical Conte

A bolide is a small asteroid or meteoroid that enters Earth's atmosphere and produces a bright flash and a rapid release of energy as it travels at high speed. Most bolides are relatively small, typically meters to a few tens of meters in diameter, and deposit the majority of their energy in the atmosphere, fragmenting or exploding as airbursts rather than striking the ground. Because these events are detected by satellites and other sensors, they can be plotted globally and mapped. Bolide maps illustrate small objects interacting with Earth's atmosphere, not the locations of surface impact craters. The map below shows the global distribution of detected bolide airbursts, indicating where Earth's atmosphere has absorbed energy from incoming cosmic objects over the observation period.