Armageddon

Like many films in the science fiction/apocalyptic disaster movie genre *Armageddon* is based on a reasonable premise. Scientists have discovered that a large asteroid "the size of Texas" is on a direct collision course with Earth. If the asteroid hits, it will destroy all life on the planet. It is generally believed that several large (although no nearly as big as Texas) asteroids have in fact collided with Earth over its lifetime. In fact, one of the major theories of why dinosaurs became extinct 65 million years ago is that an asteroid of about 6 miles in diameter landed in the Gulf of Mexico and released enough energy to raise a tremendous dust cloud into the atmosphere. The dust sufficiently obscured sunlight (perhaps for months or even years) so that not only the dinosaurs, but also more than 80% of the plant and animal species that lived on Earth at the time, were killed.

1. The head of NASA and his governmental support staff are aware of the impending disaster, and have to come up with some way to divert the asteroid before it hits. The solution involves flying a space shuttle out to the asteroid, carrying a bomb. What type of bomb?

2. The bomb will be placed in a hole that the crew is going to drill into the asteroid, and then detonate it. We are told that an explosion on the surface won't break up the asteroid, and so the bomb must be placed **inside.** We are also told (many times) that the hole must be 800 feet deep to blow the asteroid in half, where each half will be deflected to either side of Earth.
    a. Remember that we are told the asteroid is the size of Texas, which means it has a diameter of about 700 miles, or 1,100,000 meters. Draw a figure to scale, approximating the asteroid as a sphere, and show the relative depth of the hole to the size of the asteroid.
    (Hint: Use 1 cm = 100,000m)

b. Compare the depth of the hole with the size of the asteroid?
c. Are they really **inside** the asteroid? Explain.

3. Later in the movie, the drill crew is told that they will place the bomb along a “fault line”.
   a. They mention early on that only 10 telescopes in the world can even detect the asteroid, and they wouldn’t yield a particularly detailed image. Therefore, how would they know that there is a “fault” on the asteroid?

   b. Furthermore, why would asteroids have faults? (Note: Asteroids are too small for tectonic activity (even though there is an “earthquake” in one of the dozens of climactic moments that *Armageddon* bombards us with every minute or two)

   c. Nevertheless, even if there is some fault or fracture running a significant length along the asteroid, and even if the bomb is capable of exploiting this feature, do they drill this site later in the movie? Explain. (Note: They overshoot the landing by 26 miles)

4. We are told that once the asteroid is within 3 hours and 56 minutes of impacting Earth, if it hasn’t been split yet, it will be too late for the pieces to miss hitting the Earth’s surface. Let’s say that the asteroid with a radius of 550,000 meters (which may or may not contain a tectonic fault) is broken into two pieces due to the exploding bomb at the bottom of 250 meter deep hole. Does the bomb have enough energy to insure that the fragments won’t hit the Earth?
   a. Because it takes just under 4 hours (or about 14,000 seconds) from the time the asteroid is blown apart until the fragments will arrive in the vicinity of Earth, each fragment must move a minimum distance of one earth radius perpendicular to its original line of motion in order to avoid a collision with Earth. To demonstrate this, show with a sketch below:

b. In a best case scenario, when the bomb blows up, it will need to exert forces only perpendicular to the trajectory. This will allow the fragments to be pushed as far off their original line of motion as possible before arriving at Earth. Do you think that this possible? (Note: The shock wave from the explosion will radiate outwards in all directions) Explain.

c. In a best case scenario, we have to assume that all of the energy of the bomb goes into Kinetic Energy of the asteroid fragments. Do you think this is possible? (Note: Thermal Energy and Electromagnetic Energy) Explain.

d. Let us assume the best possible outcomes mentioned above, calculate the minimum perpendicular velocity imparted to each fragment for a near miss:

(Use the following equation: Perp. Velocity = v= $\frac{r_{earth}}{t}$ where r_{earth} = 6,400,000 m)

e. Assume the asteroid is roughly spherical in shape, calculate the volume?

(Use the following equation: $V = \frac{4}{3}\pi r^3$)

f. An asteroid has a significant amount of iron. The Density of Iron is 5,000 kg/m^3. Calculate the mass of the asteroid? (Use the following equation: D = $\frac{Mass}{Volume}$)

g. Calculate the amount of kinetic energy that must be added to the asteroid: (Use the following equation: K.E. = $\frac{1}{2}$ m v^2) where m = mass of the asteroid and v = Perp. velocity [Note: 1 kg m/s = 1 Newton & 1 Newton meter = 1 Joule]

h. The biggest bomb ever made had a yield of about 100 megatons. Using the fact that $4.1X10^{15}$ Joules = 1 Megaton , how many Joules is this?

i. Compare part (g) with part (h):

j. Assuming we can convert all the energy of a nuclear bomb into kinetic energy of the assuming that 100% of the force generated by the bombs are in a direction perpendicular to the original line of motion of the asteroid, how many bombs are needed to accomplish this task required to miss the earth from the split asteroid?

5. Apparently, NASA for years has been unsuccessfully trying to put together a drill designed by the "world's best" oil rig driller Harry Stamper. Being egg-headed scientists and engineers they just can't seem to get it right. Therefore, the governmental authorities decide that when it comes to drilling, real practical know-how is what you need. So instead they bring in Harry and his crew of colorful roughneck misfits to fix the drill and save the world. What is your opinion on the lack of knowledge for NASA on how to work a work a rock drill?

6. Astronauts have been trained nonstop for years to perform important missions in outer space. However, in *Armageddon,* oil rig guys are the only ones that can do the job. So the oil rig workers are going to be trained up for space flight **in a week or two,** because there isn't much time. They may be out of shape, have drinking and/or psychological problems, and a criminal record or two, but why not give them a chance? NASA mission control apparently can ignore the opinion of the general who questions the choice of crew when he suggests, "The fate of the planet is in the hands of a bunch of retards who I wouldn't trust with a potato gun!" What is your opinion on this?

7. Before heading off to the asteroid, the courageous crew must stop at the Russian space station to refuel. The station is set into rotation to create artificial gravity so that the shuttle crew can work more easily, by the wacky Russian cosmonaut, Lev. We see the obligatory shot of the rotating station, with Lev walking around the perimeter of the circular floor/ceiling under full artificial gravity conditions. In this scene, the filmmakers attempt to apply physics to show how rotation is used to create artificial gravity on a space station.
   a. Look at the diameter of the rotating object. What is your estimate of the diameter in feet and meters?
   b. Let's assume it is at least 9 feet (or 2.8 m). That means that Lev's head is on the other side of the center of the circle that his feet. Draw a sketch:

   c. Note that although the centripetal forces acting on his head and feet are acting towards the center of the circle, the inertia of his head and feet give him the sensation of being pulled towards the outside of the circle. Would make Lev feel like he is being pulled apart? Explain.

   d. Determine the rotation rate (w) in rad/sec from what's happening at Lev's feet:
      Use the following formula: $v = (g\ r)^{\frac{1}{2}}$ where $g = 9.8\ m/s^2$ and r = Diameter/2 = 1.4 m.

      Note: $v = w\ r$

   e. Calculate the acceleration acting on Lev's head, which is 0.4 meters from the center:
      Use the following formula: $g = w^2 r$

   f. This acceleration is opposite in direction to that experienced by his feet. Describe what he would actually feel like after awhile.

8. Right after coming around the far side of the moon, the shuttles have to land on the asteroid. The interesting thing is that in real life the space shuttle slow down for a landing on Earth by using atmospheric drag (air resistance) as a braking mechanism. Because there is no atmosphere on the asteroid, the shuttles will be approaching with a relative velocity of several hundred miles per hour.
    a. How would you decelerate your space-shuttle?

    b. With the large torques and decelerations that the crew will experience as they impact various obstacles, will they survive? Explain.

    c. To be fair, the shuttle captain does say something about initiating “reverse thrust” upon landing. However, because the shuttles use rocket engines on the back for thrust, what would they have to do for slowing-down?

9. It’s really irritating to see exhaust being expelled from the rocket engines as they approach the asteroid, because this is going to speed them up. Probably the filmmakers fall for the usual misconception that a force is required to maintain a constant velocity. Explain why this is an inexcusable violation of Newton’s first and second laws.

10. For some reason these shuttles are equipped with large machine guns. A.J. uses one to blast his trapped crewmates out of the cargo bay. Even Rockhound goes a little space crazy and starts shooting one off near the drill site.
    a. Do you really think automatic weapons are standard shuttle issue? Explain.

b. Nevertheless, what happened to the third law and conservation of momentum? What would actually happen if you attempted to shoot a machine gun on an asteroid with very little gravity and friction? (Note: Friction requires a Normal force which requires gravity).

11. Using the information about the size and density of the asteroid given in #4, calculate the acceleration due to gravity, g: Use the formula: $g = \frac{GM}{r^2}$ where M = mass of the asteroid; G = 6.67 X 10^{-11} Nm^2/kg^2 and r = the radius of the asteroid.

12. How long will an object fall to reach 1 m/s, under the calculated acceleration of #11. Use the formula v_f = g t

13. When the riggers are drilling, the rocks falling into the hole seem to be accelerating at a rate of 9.8 m/s^2. Is this consistent with your answers in #11 and #12?
14. How do the crew members walk around on the asteroid in a very comfortable surface-of-the-Earth-type way? Is this consistent with your answers in #11 and #12?
15. In *Armageddon* the surface of the killer asteroid is covered with jagged spires, yawning fissures, and other scary features. Real asteroids don't have these features. Asteroid surfaces look a lot like the surface of the moon---a lot of craters and maybe some rock fragments. What geologic process could cause long pointed spires in space?

16. *Armageddon* has one of the two shuttles crash, but, of course, all hands are not lost. The surviving crew member set out in a rover hoping to join up with members of the intact shuttle. Faced with crossing a deep chasm, they simply rev up the rover and roar over to the other side. With the low gravity and no air resistance, the rover supposedly goes into a close-to-surface orbit, easily crossing the chasm without falling into it. [Note: If an object close to the surface has no horizontal velocity and is dropped, it will fall straight down. Give it enough horizontal velocity, and it will "fall" in a stable circular orbit. There are two critical velocities related to

gravity that determine how and if an object orbits a celestial-spherical body. ***Lowest Circular Orbit Velocity and Escape Velocity***]. By the way, in one of the crashes, we see fire with the debris. Is this possible? Why?

a. An object could conceivably orbit a planet a fraction of a millimeter off the surface, if the planet were perfectly spherical, uniform in density, and had no air resistance to slow the object's speed. The horizontal velocity required for the lowest possible circular orbit defines the first critical velocity. This velocity is perpendicular to a radial line drawn from the center of the celestial body. If a spacecraft attempts to take off in a horizontal direction on a celestial body that has no atmosphere, the craft's velocity will have to exceed the first critical velocity. Without a lengthy well-maintained runway, a horizontal takeoff is next to impossible, which is why missions to asteroids, moons, or planets with thin atmospheres will require vertical takeoffs and landings. In a circular orbit, the force of gravity acting on an object acts as the centripetal force. The velocity required for a circular orbit is calculated as follows: $V_1 = (GM/r)^{\frac{1}{2}}$

Use $G = 6.67 \times 10^{-11}$ N m^2/kg^2 ; M = Mass of the asteroid from #4; and

r = the distance from the center of the asteroid from #4.

Calculate the velocity required for the rover to go into circular orbit.

b. Convert the "m/s" to "miles/hr":

c. Is this a reasonable speed for the rover to go?

d. Escape velocity is the second critical velocity value. This is the minimum velocity required to escape from the gravitational pull of the celestial body. If an object is moving with a tangential velocity between the first and second critical speeds, it will move in an elliptical orbit. The escape velocity is derived from energy equations. The work required to move an object from a planet's surface to infinity is set equal to the object's kinetic energy. This results in the following expression:

$$V_2 = (2G\,M/r)^{\frac{1}{2}}$$

[Note: Although the escape velocity is derived in a different manner, it's simply the circular orbit velocity multiplied by the square root of 2. When a space vehicle slingshots around a planet, moon or asteroid, it has to be going at or above the escape velocity to avoid being captured in an orbit or worse---crashing into the surface (if the vehicle is below the circular orbit speed).

Using the formula above calculate the escape velocity for the asteroid using the same data used in part (a).

e. Convert from “m/s” to “miles/hr”.
f. It looks like all hope is lost when Max and the drill rig are blasted off of the asteroid and into space.
   i) From the scene estimate their speed just after the explosion.
   ii) From part (d); is Max moving fast enough to escape permanently? If not, how long until he crashes back to the surface? (Fortunately, A.J. arrives with the backup rig just in time to finish the job.)

17. In the next scene, a large meteorite destroys Paris.
    a. Assuming it has an impact velocity of 22,000 miles per hour and an energy equal to a 50-megaton nuclear bomb, determine how massive it is. [Note: Refer to #4(g)]

    b. It is significant to note that the three meteorite showers that hit the Earth in advance of the asteroid all strike major urban centers. In this case New York, Shanghai, and Paris are the unfortunate recipients, and poor Paris is destroyed completely by a particularly violent impact. The thing is this: big cities comprise such a small percentage of the total land mass, that the odds of these meteors landing in a city are monumentally small. Where do you think are the most likely places for meteorites to land?

18. It comes as no surprise that, at the last moment, the crew is able to detonate the bomb, and the surviving members are able to escape, except for Harry, who, in an act of great heroism and self-sacrifice, stays behind to detonate the bomb himself because. Why did he need to do this?

19. After saying a teary goodbye to his daughter Grace at mission control, Harry blows the asteroid in half—and just in time. The fragments miss the Earth by only 400 miles on either side.
    a. Tides are normally created by shifting gravity forces that the Moon and, to a lesser extent, the Sun exert on the oceans. From #4 (f), what is the mass of ½ of the asteroid?
    b. If the mass of the Moon is 7×10^{22} Kg; how many times more is this from the mass of ½ of the asteroid?
    c. Gravity forces are directly proportional to mass. If they were the same distance away; how many times more would the tidal effect of the Moon have on the asteroid?

d. How many meters are in 400 miles?

e. If the Moon-Earth distance is 3.8×10^8 m away, how much closer are the asteroids?

f. Unfortunately, the gravity force is also inversely proportional to the square of the distance between the centers of mass of the objects causing them. Taking into account all of the differences, estimate the number of times the gravity-force of the asteroid is greater than the gravity-force of the moon on the tides. [Note: Subract the mass effect calculated from part (c).]

g. But there are two of these forces, one acting on each side of Earth. From the standpoint of tides these tend to reinforce each other. Keep in mind that ordinary tides caused by the Moon are around 3 meters and take several hours to rise. Estimate how much higher the asteroid-produced tides are than the Moon-produced tides.

h. The oceans would have sloshed out of their basins and sent walls of salt water smashing across the world's coastal areas. The water walls would be so heavy they would destabilize fault lines, setting off earthquakes, and volcanic eruptions. What other factors would change near coastal areas? Name cities that would be highly devastated?

i. Water, however, is only one source of devastation. There's also wind. Normally the atmospheric tides created by the Moon are so small that they have almost no effect on weather. But increase these forces by the factor you calculated in part (g), on opposite sides on the globe, what would be the results?

j. The asteroid pieces would pass around Earth and collide back together on the other side in about a half a day. They would then fly off into the cosmos. The gravitational pull of the asteroid mass would diminish quickly as it moved away form Earth. Within just a few hours the pull would be negligible. Unfortunately, the disastrous problems on Earth would persist for some time. The back and forth sloshing action of the ocean would last for hours if not for days. How do you think this episode would affect the global climate for years or decades to come?

k. Do you think that the orbits of the Earth-Moon be affected? How?