NAVAL HISTORY STEM-H LESSON PLAN

LESSON PLAN: Newton's 2nd Law Revisited: Sea vs. Air, Fast Attack Submarine vs. Airborne Laser
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OBJECTIVE: Review and Practice calculations involving Conversions, Kinematics, Newton's Second Law, Energy, Non-Conservative Forces and Power

MATERIALS: None

INSTRUCTIONS:

Today we compare a Navy Los Angeles (688) class Submarine with the Air Force Airborne Laser (a Boeing 747 airliner).

- Thoughts to ponder...
- Which has the more powerful propulsion system?
- Does one speed up more quickly than the other? ...why?

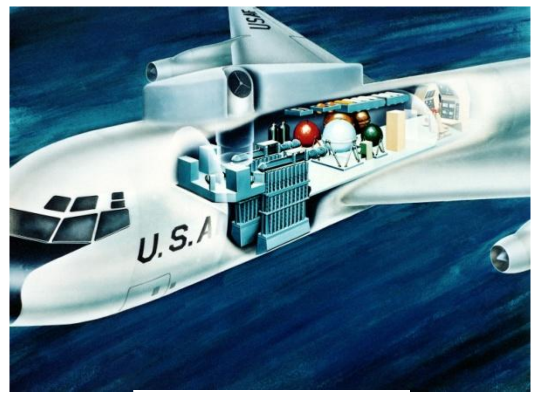
- 688 Class Submarine
  - Los Angeles (688) Class Submarines were designed as Fast-Attack submarines because their main purpose was to hunt down and kill other submarines. Among other things, they needed to be able to accelerate quickly to evade enemy torpedoes.
  - They were also designed to be able to keep up with fast moving Aircraft-Carrier Battle Groups, so they could sprint out in front of the carrier and make sure the path was clear of enemy ships and submarines.
  - mass = 7.00 million kg
  - Shaft horsepower = 34850 hp or 26 MW
  - Speeds up from 0 to 20.0 knots in one minute

- Air Force Airborne Laser (Boeing 747) – program cancelled in 2010

- Aims a basketball width laser beam, able to destroy a large incoming missile
- Weight = 875,000lbs
- 4 engines
- Each engine generates 432300 horsepower
- Speeds up from 0 to 175mi/hr (290km/hr) in 30.0sec

- Show your work for conversions and calculations used to complete the table. You will need to make conversion factors out of many of these helpful conversion equalities. There are others that you will need, but you should have memorized them by now, or you can look them up. :)

  - 1 knot = 1.151 miles per hour
  - 1 horsepower (hp) = 746 Watts
  - 1 m = 3.281 feet 1mi = 5280 ft
  - 1 pound (lb) = 4.45 Newton



1. Assume that the acceleration is constant during these problems.
2. Use the speeds and the time to calculate the acceleration.
3. Using the acceleration and the vehicle's mass, calculate the net horizontal force exerted during this time period.
4. Calculate the power of the propulsion plant (for the 747, the power for all 4 engines combined)
5. Using Kinematics, calculate the distance travelled during the period of acceleration
6. Using the rated power of the vehicle's propulsion plant, calculate the amount of energy wasted... expended by the propulsion system, but not converted into KE of the vehicle.
7. Using the wasted energy and the distance, calculate the average fluid friction force experienced during the period of acceleration. How does this force compare with the weight of the vehicle?
8. Calculate the factor by which the airliner value compares to the 688 value, e.g. $mass_{plane}$ / $mass_{sub}$

688 Class Submarine Calculations:

- Convert 20 kts to m/s:
  - 20kts [(1.15mi/hr) / kt] (5280ft / mi) (1m / 3.281 ft) (1hr / 3600sec) = 10.289m/s
- Initial velocity = 0 m/s
- Final velocity = 10.289 m/s
- $a = \Delta v / \Delta t = (10.289 - 0) / 60\text{sec} = .171\ \text{m/s}^2$
- $\Sigma F = ma = (7.0\text{x}10^6)(.171) = 1.197 \times 10^6$ N

- $\Delta x = \frac{1}{2}(v_o + v_f)\, t = \frac{1}{2}(0 + 10.289)(60) = 308.7\text{m}$

- $\Delta KE = \frac{1}{2} m v_f^2 - \frac{1}{2} m v_f^2 = \frac{1}{2}(7\text{x}10^6)(10.289)^2 - 0 = 3.705 \times 10^8$ Joules
- Energy Provided by the Propulsion Plant = Pwr * Time = $2.6\text{x}10^7$ Joules/sec (60 sec) = $1.56\text{x}10^9$ J
- Mechanical Energy is NOT conserved ☺
- $E_{final} = E_{original} - W_{non\text{-}Conservative\ Forces}$
- $W_{non\text{-}Conservative\ Forces} = E_{final} - E_{original}$

- “Wasted” energy = 3.705×10^8 Joules – 1.56×10^9 Joules = – 1.190×10^9 Joules
  - The fact that the work is negative indicates that the friction is in the opposite direction of the direction of motion of the submarine, which makes sense, since…
  - The main non-conservative force causing this difference in energy is fluid friction

- Work = Force * Distance moved in the direction of the force
- Force = Work / distance = 1.19 x 109 J / 308.7m = 3.85×10^6 N,
  - ~25% of the submarine’s weight

Airborne Laser (Boeing 747) Calculations:

- Convert 290 km/hr to m/s:
  - 290km/hr (1000m / 1km) (1hr / 3600sec) = 80.5556m/s
- Initial velocity = 0 m/s
- Final velocity = 80.5556m/s
- $a = \Delta v / \Delta t = (80.5556 – 0) / 30\text{sec} = 2.685\ m/s^2$

- Convert 875,000 lbs to Newtons: 875000 lbs (4.45 N/lb) = 3.894×10^6 N
- Use weight to determine the plane’s mass:
  - W = mg → m = W/g = 3.894×10^6 N / $9.8 m/s^2$ = 3.973×10^5 kg
- $\Sigma F = ma = (3.973\times10^5)(2.685) = 1.0668 \times 10^6$ N

- $\Delta x = ½(v_o + v_f)\, t = ½ (0 + 80.5556)(30) = 1208.3$m …thus the need for a long runway ☺

- $\Delta KE = ½\, mv_f^2 – ½\, mv_f^2 = ½\, (3.973\times10^5)(80.5556)^2 – 0 = 1.289 \times 10^9$ Joules

- 4.323×10^5 hp * 4 engines = 1.72922 hp
- Convert hp to Watts: 1.729×10^6 hp (746W / hp) = 1.290×10^9 Watts
- Energy Provided by the Propulsion Plant = Pwr * Time = 4.300×10^7 Joules/sec (30 sec) = 1.290×10^9 J
- Mechanical Energy is NOT conserved ☺
- $E_{final} = E_{original} – W_{non\text{-}Conservative\ Forces}$
- $W_{non\text{-}Conservative\ Forces} = E_{final} – E_{original}$
- “Wasted” energy = 1.289×10^9 Joules – 1.290×10^9 Joules = – 1.000×10^6 Joules
  - The fact that the work is negative indicates that the friction is in the opposite direction of the direction of motion of the submarine, which makes sense, since…
  - The main non-conservative force causing this difference in energy is fluid friction

- Work = Force * Distance moved in the direction of the force
- Force = Work / distance = 1.000×10^6 J / 1208.3m = 827.6 N,
  - ~ .02% of the plane’s weight.

Solutions:

Characteristic	688 Class Submarine	747 Airborne Laser	Factor
mass (kg)	7.00×10^6	3.973×10^5	.057
weight (lbs, AKA Pounds)	1.542×10^7	8.75×10^5	.057
weight (N)	6.86×10^7	3.894×10^6	.057
acceleration (m/s^2)	.171	2.685	15.0
net horizontal force (N)	1.197×10^6	1.068×10^6	.890
power (Watts)	2.6×10^7	1.29×10^9	49.6
energy wasted (J)	1.19×10^9	1.000×10^6	.000840
distance travelled (m)	308.7m	1208.3	3.91
average friction force (N)	3.85×10^6	8.276×10^2 N	.000215