Engineering Ethics Cases with Numerical Problems

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Electrical Engineering Case 6

Missile Explosion

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Physics II, E-M I

Level:

Freshman & Sophomore

I. Narrative

On a very cold dry winter morning in West Germany a group of American servicemen were removing a solid-state-fueled missile from its packing case, using a hoist. They had some difficulty with the hoist and had to raise the missile from its cradle several times and lower it back in before they were finally successful. Shortly after the missile was finally lifted from its cradle it was moved close to a grounded metal antenna. The fuel in the missile ignited, burned through the side of the rocket motor and killed several of the servicemen.

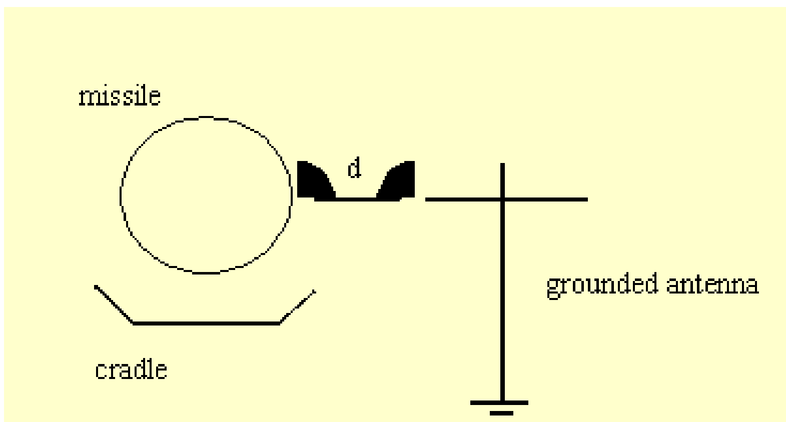
Subsequent analysis and testing pointed to electrostatic charge build-up and sparks resulting from that charging as the culprit.

The course of events was probably as follows. When the missile was lifted from the cradle, the friction caused tribo-electric charging of both the cradle which was grounded, and the surface of the motor casing. The casing was not grounded, moreover, a very good insulator. The charge on the casing was not able to spread out because of the insulating nature of the casing and was not able to bleed off through the air because the air was so dry. (You must have noticed how much more aggravating sparks from your fingers are during cold, dry weather.)

As the missile was lifted, the cradle and the missile casing acted like the plates of a capacitor. Because the separation of the plates was increasing, the value of the capacitance decreased. The total charge on the plates remained unchanged, as discussed above, so that the voltage on the capacitor increased. The voltage became greater than the break-down voltage of the air and a spark was drawn from the missile casing to the grounded metal antenna. (The exact mechanism by which the spark ignited the fuel is complicated and involves the removal of polarization electric fields produced inside the fuel by the charge on the casing.)

II. Numerical and Design Problems

Problem 1. Calculate the separation d between the missile and the antenna when the spark occurred. See figure.



Assume that the missile and the cradle formed a parallel plate capacitor with an effective area of 4.0 square feet and a plate separation of 6.0 inches. The average surface charge density σ is 1.0×10^{-9} Coulombs per square meter. The breakdown electric field strength of cold dry air is 3.0×10^{6} V/m.

Problem 2. What modification to the missile and/or cradle would prevent electrostatic discharge in the future?

III. Questions on Ethics and Professionalism

Consider the following scenario:

A few years before the accident occurred, and before the missile went into production, an engineer, who was working on the project, conceived the idea that a missile might be ignited by just the mechanism we have been discussing. He approached his supervisor and raised his concern.

The supervisor said that he thought, (a) that electrical breakdown of the air was unlikely and (b) that even if it did occur, there was only a very remote possibility that it would cause any problem. They both agreed that there was no data that would help them evaluate the probability that an accident could occur. Although there was nothing in the specifications about the matter, they decided to approach the military procurement officer about the issue.

The military officer agreed with them that the mechanism was possible, but unlikely. Moreover, he said that any design changes then would seriously delay the deployment of the missile. Anyway, he added, the people working with the missile would be military personnel, and they couldn't expect everything they had to do to be absolutely safe.

Question 1. What professional and ethical responsibilities do you think the engineer and his supervisor had in this case?

Question 2. Does it make any difference to your views that no accident of this type had been recorded at the time they thought of the problem? Why?

Question 3. What do you think of the procurement officer's views about the deployment delay? What about his views on safety and military personnel? What alternative views would you suggest?

IV. Solutions

Problem 1. Model the system as a pair of parallel-plate capacitors as follows. Let C_1 be the capacitor formed by the missile and the cradle, and let C_2 be the capacitor formed by the missile and the antenna. The two capacitors are in parallel as suggested by the figure. Calculate Q, the charge on C_1:

$$Q = \sigma A = (3.5 \times 10^{-6}\ C/m^2)(4\ ft^2)(0.3048\ m/ft)^2 = 1.3\ \mu C$$

Now the two parallel plate capacitors values can be calculated from

$$C = \frac{\varepsilon_0 A}{d}$$

The effective area A of C_2 is much smaller than that of C_1, so the parallel combination of $C_1 + C_2$ can be approximated as just C_1 alone.

$$C_1 = (8.85 \times 10^{-12}\ F/m)(4\ ft^2)(0.3048\ m/ft)^2/(0.15\ m) = 21.9\ pF$$

Now express the charge Q in terms of the breakdown voltage and the unknown separation d between the missile and the antenna, then solve for d.

$$Q = C_{Tot} V_b \approx C_1 (E_b d)$$

$$\therefore \quad d = \frac{Q}{C_1 E_b} = \frac{1.3\ \mu C}{(21.9\ pF)(3.0\ MV/m)} = 19.8\ mm$$

The missile was about 2 cm away from the antenna when the spark occurred.

Problem 2. No technical design is provided. This is an open ended design problem involving the addition of grounding.

1. **to Questions on Ethics and Professionalism**

1. The IEEE code (Canon1) requires its members to "accept responsibility in making engineering decisions consistent with the safety, health, and welfare of the public, and to disclose promptly factors that might endanger the public or the environment." The National Society of Professional Engineers (NSPE) code (Rules of Practice 1) requires engineers to "recognize that their primary obligation is to protect the safety, health, property and welfare of the public." It goes on to say: "If their professional judgment is overruled under circumstances where the safety, health, property and welfare of the public are endangered,…[engineers] shall notify their employer or client and such other authority as may be appropriate."

The engineer in question made the required notification and so fulfilled this minimal obligation, as prescribed by the codes. Both the engineer's supervisor and the military officer recognized the problem, but concluded that the danger was remote and did not warrant design changes. the question now is whether the engineer or his supervisors had any further obligation. The NSPE code does require the engineer to "protect" safety and welfare of the public. Does this require more than simply notifying superiors of a danger? If not, does the personal ethics of the engineer enter the picture and supplement the strictly professional obligations, perhaps requiring the engineers to do more?

In order to decide whether he should do more, the engineer must get the answers to certain factual questions, such as: How serious is the risk? What could he do (if anything) that might lead to a change? How much damage would stronger action on his part inflict on his career or his family? How much more or less influence might a protest have because it relates to a military operation?

In making his recommendations for a design change, the engineer should have attempted to ascertain what design change might solve the problem, what they would cost, and how much time they would take. In making unpopular suggestions, professionals should always be as specific in their suggestions as possible.

2. The fact that no accidents of this type had been recorded at the time they thought of the problem almost certainly would affect the engineer's judgment of the extent of his obligations. Since there are no documented cases of harm due to the missile design, the engineer's conviction that there is likelihood of harm is bound to be diminished. There is simply less evidence that there is a likelihood of harm. Insofar as the conviction of the likelihood of harm is diminished, the obligation to take action is also diminished.

3. The procurement officer should take into account the delays in deployment that might be caused by a design change, especially if crucial military reasons can be given for avoiding the delay. Still, the safety of the operators of the missiles must also be taken into consideration. The argument that military personnel are expected to take greater risks than civilians has only limited validity. First, some of the personnel might have been in the military involuntarily. Second, the requirement for free and informed consent for unusual risks is not entirely invalidated, just because one is in the military. The procurement officer's statements give evidence of an unjustifiably cavalier attitude toward the lives of military personnel.

The procurement officer might, instead, have asked for specific suggestions as to what design changes might eliminate the problem, how much they would cost and how much delay they might cause. As already indicated, the engineers who discovered the problem should have come with such estimates.