WITH SPACE RESEARCH FOR MORE LOVABLE PHYSICS CLASSES

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ABSTRACT

In this paper, I discuss how one can motivate students with the results of space research, and make them more interested in the subject of physics. In Hungary the MaSat-1, which is the first Hungarian satellite, presents an excellent opportunity for this. This spacecraft was designed and made by students of the Budapest University of Technology and Economics for educational purposes. Not only the MaSat-1, but the satellites in general provide opportunity for motivation in many topics in our teaching of physics. I attempt to prove in my presentation that not only in the traditional areas (for example laws of Kepler) can we refer to satellites, but also in other topics, such as thermodynamics or electrostatics.

INTRODUCTION

The fact that students do not like physics as a subject is a problem in teaching physics all over Europe. Although in the media we can learn about all the latest remarkable results of research done in physics, most of which are also available for anyone online, physics classes are not the students' most favoured classes. In my paper I intend to show how we could motivate students by integrating the results of space research into physics classes.

There has been a recent opportunity to make use of the results of space research in physics education in Hungary by means of MaSat-1, the first Hungarian satellite [1], see Fig.1.

Fig.1. MaSat-1 (source: https://masat.bme.hu)

This orbital vehicle was designed and constructed by the students of the Budapest University of Technology and Economics for educational purposes within the confines of the CubeSat programme of the European Space Agency (ESA). Some important data of MaSat-1: its mass was 1 kg, with an edge of 10 cm and there was no propulsion. This small satellite was functioning for almost three years, far exceeding its planned 3-month lifespan. Covering MaSat-1 in physics classes in secondary schools is an outstanding opportunity to motivate students as it is an exceptionally successful implementation of a student experiment. MaSat-1 itself as well as CubeSats in general can be used in an astonishing number of educational topics. In the present paper I will show their application not only in the traditional areas (e.g. Kepler's Laws), but also in branches of physics which may first sound astounding, e.g. in electrostatics and thermodynamics.

THE ORBIT OF MASAT-1

First of all, let us take a look at an otherwise common task, but this time using the real data of MaSat-1. Given the furthest and closest point of the elliptic orbit of MaSat-1 from the Earth, we can calculate its geometrical parameters, its orbital period and its lowest and highest speed of motion:

point closest to Earth (perigee): r_{min}=300 km,

point furthest from Earth (apogee): r_{max}=1450 km.

The geometrical parameters of the elliptical orbit are as follows ('*a*' being the semi-major axis of the ellipse, '*b*' its semi-minor axis, '*c*' half of the distance of its focal points and '*e*' its numerical eccentricity):

$$a = \frac{r_{\min} + r_{\max}}{2} = R + \frac{h_{\min} + h_{\max}}{2} = 6371 + \frac{300 + 1450}{2} = 7246\,(km)$$

$$c = \frac{r_{\max} - r_{\min}}{2} = \frac{h_{\max} - h_{\min}}{2} = \frac{1450 - 300}{2} = 575\,(km)$$

$$\mathrm{e} = \frac{c}{a} = \frac{575}{7246} = 0,079$$

$$b = \sqrt{a^2 - c^2} = \sqrt{7246^2 - 575^2} = 7223\,(km)$$

With the help of Kepler's Third Law we can calculate the orbital period. Since the mass of MaSat-1 is only 1 kg, we can simplify with it. It is fortunate if students have the opportunity to deal with more and more tasks in which they meet the notions of commensurability or incommensurability so that we can discuss when we can leave out a term. The gravitational constant is: $G = 6,67 \cdot 10^{-11} \frac{m^3}{kg \cdot s^2}$, the mass of the Earth is: $5,97 \cdot 10^{24} kg$.

The orbital period:

$$\frac{a^3}{T^2} = \frac{G \cdot (M + m)}{4\pi^2}$$

$$T = 2\pi \cdot \sqrt{\frac{a^3}{G \cdot (M + m)}} \approx 2\pi \cdot a \cdot \sqrt{\frac{a}{G \cdot M}} = 6,28 \cdot 7246 \cdot 10^3 \cdot \sqrt{\frac{7246 \cdot 10^3}{6,67 \cdot 10^{-11} \cdot 5,97 \cdot 10^{24}}} =$$

$$= 6,14 \cdot 10^3\,(s) \approx 102\ \mathrm{min}$$

It reaches the highest and lowest speed in its perigee and apogee which can be calculated based on the following formula:

$$v^2 = G \cdot M \cdot \left(\frac{2}{r} - \frac{1}{a} \right)$$

$$v_{close} = \sqrt{6,67 \cdot 10^{-11} \cdot 5,97 \cdot 10^{24} \cdot \left(\frac{2}{6371+300} - \frac{1}{7246} \right) \cdot 10^{-3}} = 0,13 \cdot 10^5 = 13000 \left(\frac{m}{s} \right)$$

$$v_{far} = \sqrt{6,67 \cdot 10^{-11} \cdot 5,97 \cdot 10^{24} \cdot \left(\frac{2}{6371+1450} - \frac{1}{7246} \right) \cdot 10^{-3}} = 0,068 \cdot 10^5 = 6800 \left(\frac{m}{s} \right)$$

We have this formula from the energy integral and the fact that in the two-body problem we obtain the relation a=-m/2E where ‘a’ is the semi-major axis of the ellipse, ‘m’ is the reduced mass, and ‘E’ is the total energy [2].

MECHANICAL VIBRATIONS

When teaching vibrations, we may call the students’ attention to the fact that in reality mechanical vibrations are not predominantly harmonic vibrations. For instance, MaSat-1 in the rocket was mostly exposed to irregular vibrations when being launched and put into orbit. For this reason, it was tested on a vibrating platform (see Fig.2 and Fig.3) during qualification procedures in order to make sure that the parts would survive in the extreme conditions it was going to face in the rocket. The test was carried out after having the parameters of the launch vehicle called Vega set. We can say that statistical methods are used to describe random vibration loads because there is no inherent mathematical way to describe a random vibration time history. In Fig.2. we can see a CubeSat on the vibration platform, and in Fig.3. the vibration platform on which the Hungarian CubeSat was tested.

Fig.2. Vibration platform (Source: [3])

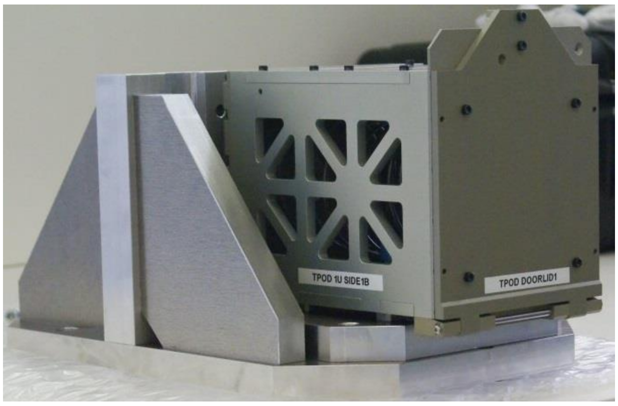

Fig.3. Vibration platform (Source: [1])

MASAT-1 AND OTHER CUBESATS IN THERMODYNAMICS

When introducing thermodynamics in class, first we discuss the notion of temperature and then we continue with the principles of thermal expansion. After doing experiments on thermal expansion in the classroom, we can look out to space. We can make the students calculate how much the earthbound geometrical data (edges, surface and volume at room-temperature, i.e. 20 °C) of the CubeSat were reduced when its internal temperature fell to 5 °C. At this point we can mention that the internal temperature of the CubeSat was not allowed to drop below 5 °C in order to protect the battery it contained and we can also tell the students that the metal plate of MaSat-1 was made of special aircraft aluminium. With the help of this exercise we can show our students one of the problems of spacecraft design, namely, that in the secondary school handbooks we find the value of the thermal expansion coefficient in normal atmospheric pressure. We may tell them there exists a separate space technology, where engineers take the special circumstances in space into account. It may be interesting for the students to find out that the discovery of Teflon coating for pans as well as hook and loop fasteners are both the results of the development of space technology.

In its simplest form, the First Law of Thermodynamics states that neither matter nor energy can be created or destroyed. The amount of energy in the universe is constant. This law will be better understood if we give a wider range of examples. Let us look at satellites to see how we can prove the validity of this law. Consider a satellite in its orbit. Why does this 'perpetual motion' not contradict this law? The students will probably give the right answer immediately that the satellite does not stay in its orbit forever; sooner or later it enters the Earth's atmosphere due to friction, and it burns away afterwards.

See Fig.4 which shows that the apogee of MaSat-1 in its final months was continuously getting closer to the surface. The blue line shows the decrease of apogee, and the pink one shows the altitude of perigee. The satellite was destroyed at an altitude of about 130 km. It is interesting to note that the orbit had gradually become circular in shape.

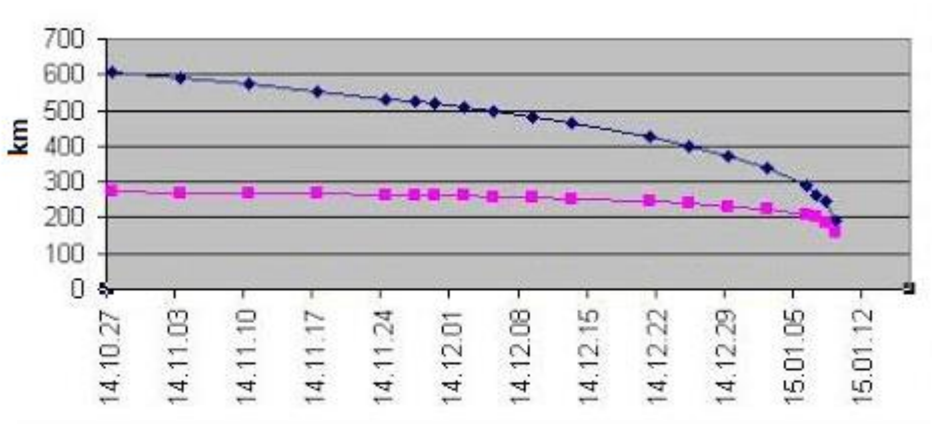

Fig.4. The last months of MaSat-1 (source: http://www.ha5mrc.hu/hamsat/sats.html)

The satellite's return into the atmosphere and its annihilation, however, can be a very long process. Therefore, there may be satellites which no longer function but might stay in orbit for years, even decades. An interesting example of this is the ENVISAT, an Earth-monitoring satellite of ESA, which will be a ghost in space for 150 years. This problem is a new challenge for space research in the twenty-first century; it is necessary to deal with the increasing number of space debris.

ELECTROSTATICS

In the topic of electrostatics we can demonstrate a Faraday Cage in real-life practice. A Faraday Cage protected the central computer in the control room of MaSat -1 from lightning strikes. In the picture on the left we can see this room under construction, in the picture on the right we can see my students attending a lecture on MaSat-1 in the same room. (see Fig.5).

Fig.5. Control Centre of MaSat-1 - Faraday Cage (Source: [4])

ELECTRICITY AND PHENOMENA IN CONDUCTIVITY

In the topic of semiconductors we mention the solar cells since they carry significance not only on Earth but also in space. The energy from solar radiation transformed into electric energy with the help of solar cells is a determining factor for spacecrafts. Thus solar cells were placed on all six sides of MaSat-1 as well, for they served as its basic energy source. Once again using the original data of the device, we can make our students do calculations.

In the case of MaSat-1 a subsidiary power supply system was also needed in the form of a single-cell Lithium-Ion battery. One third of the cube contained the battery itself, and it took a great proportion of its mass as well. By means of the battery the CubeSat had sufficient energy supply even when it was orbiting the dark side of the Earth. Energy distribution was controlled by an on-board computer. With our students we can discuss that the Lithium-Ion battery is the most dynamically developing of all battery types. It has optimal figures regarding its mass and the proportion of its volume to the energy supplied. It is becoming more and more widespread in space industry; however, it is extremely sensitive to changes in temperature.

ELECTROMAGNETIC WAVES

Due to international frequency allocations, the CubeSat was operating on two different frequencies, i.e. on 437 and 145 MHz amateur radio frequencies. Therefore, its life could be tracked by radio amateurs and valuable information was forwarded to the control centre on the appointed website. We may also tell our students that three days after its launch, it was given the OSCAR number: MO-72, indicating that MaSat-1 is the 72^{nd} radio amateur satellite. The first was launched in 1961 from private funds. OSCAR is a mosaic word meaning **O**rbiting **S**atellite **C**arrying **A**mateur **R**adio. In the reference given one can consult the conditions of giving out OSCAR numbers.

The antenna of MaSat-1 is also worth mentioning, it was not made of space-qualified material, yet it functioned impeccably. The antenna is a 17-cm-long part of a metallic tape-measure, available in all do-it-yourself stores (see Fig.5). Again we have a calculation exercise at hand: namely if the frequency of the wireless receiver is 437 MHz then what proportion of the wavelength is the 17 cm?

SPACE WEATHER

Space weather is an interesting new field of research which may attract our students' attention. Let us discuss with the students that by space weather we mean phenomena taking place in the ionosphere, magnetosphere and the interplanetary space near the Earth. The most important effects influencing space weather are solar wind, mass transfer from the Sun and magnetic phenomena in interplanetary space. Satellite damage may occur in the cases of intensive solar magnetic activity. In MaSat-1 each subsystem was monitored by a network of signal relays providing overcurrent protection against incidental particle radiation [4].

CONCLUSIONS

My in-class experience reveals that including a significant number of references related to space research makes physics classes more attractive for students. Since I started to use this method, several students of my classes have done research in the topic of space technology and have taken part successfully in the 'Physics in Science and Arts Competition', in spite of the fact that they study to be professional musicians. It is also important to note that as the list of references below shows, all the data referred to in this article are available online. This means that one way to make our physics classes more engaging for our students could be collecting this information from professional online material. At the same time we can also teach our students how to recognize which websites are reliable. Apparently they may come across inaccuracies this way as well, but the probability of mistakes is also there in the case of printed sources.

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- National Conference of Physics Teachers in Italy (October 2015, Trento, Italy).

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