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Satellite mission to study the Van Allen belts

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ABSTRACT

The Van Allen belts are said to be a pack of highly energetic particles which are extremely fatal to electronic systems and living beings. Very little information is known about them. Besides the data from past missions, it's still not enough to draw any conclusion regarding the phenomenon of its shape, size, and density. The paper talks of a cost-effective satellite mission named Vansat to study the Van Allen belts in depth. The project aims to study the energetic particles, magnetic fields, and plasma waves in the radiation belts. The mission also focuses on having environment-friendly concepts demonstrated through the technologies along with a reduction in the complexity of the devices and instruments. Vansat consists of a dual satellite system-one satellite to study the inner belt and the other to study the outer belts. The octagonal geometry of the satellite along with wings and solar panels ensure aero dynamicity, energy saving as well as radiation shielding.

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1. INTRODUCTION

Cosmic radiation can be threatening to living beings and proper information is very crucial. Hence, to investigate further, this paper aims to examine the behavior of the Van Allen belts [1], [2]. It could be the best option to perform such experiments because the radiation level of Van Allen belts is 1,000 times higher than other parts of space [3]. This paper discusses what could be helpful for developing a proper understanding of the behavior of radiation belts as well as a few space weather phenomena. The main problem that arises here is the insufficient data about the radiation belts which hinders the launch of any satellite or even upcoming space missions [4]. The instability of solar flares may expand the density of the Van Allen radiation. Vansat is a satellite mission to study the Van Allen belts. It uses a dual satellite system-one for studying the inner belts and the other for studying the outer belts. Several devices namely-emsim, radspect, protspect, and magnodet. have been developed. Efficient yet cost-effective satellites and launch vehicles have been designed [5]. Efforts have been made to establish the relationship between space weather and events on earth. The later part of the paper discusses the safety measures taken and the costs required to implement this mission.

To date, there have been several space missions to study the Van Allen belts regions [6]. The first such mission was explorer 1 in 1958 which led to the discovery of these belts by a cosmic ray experiment using a geiger counter and tape recorder. Several follow-up missions such as explorer 3, explorer 4, and pioneer 3 continued. Some complex features of the belts were found. Certain parts of the belts had less radiation than the others and humans, spacecraft would require lesser radiation protection in those areas. This paper discusses certain devices and instruments which could specifically identify which parts have the mentioned features. The

Van Allen probes launched in 2012 was the most successful mission in studying the radiation belts as the electronics also lasted far more than expected. Hence few devices used in Van Allen probes have been taken as an inspiration and modifications have been made to their designs to increase efficiency, the primary objective of this mission is to reduce costs and increase efficiency. Efforts have been made in this direction by reducing the complexity of instruments and developing a radiation-proof satellite case, among other things. Various studies were conducted on space weather and its effects on earth's atmosphere, as well as on factors such as soil index and vegetation index. These studies established relationships between space weather events and factors such as satellite imagery analysis and built index. Technologies used in other space missions have also been adapted for this mission, along with modifications to existing technologies.

Investing the behavior of the Van Allen belt with the space weather and using the existing data of the space weather, finding the anomalies and cause by the same. The mission discussed in this paper is to study the number of particles absorbed by the satellite under harsh conditions, observe how much it can sustain from its journey, from the given state of the Van Allen belt; to discover plasma-waves having different wavelengths at the different places, which contribute to the loss of electrons from the belts; and to create an understanding of the changes in the magnetic fields due to change between the two belts-inner radiation belt and outer radiation belt. The section 1 discusses the goals and approaches regarding the problem. The section 2 shows the components used in this paper which are presented in a detailed manner. The section 3 highlights the precautions and problems which are assumed to be faced by the Vansat satellite as well as the benefits of the technologies used. The section 4 here we are estimating the necessary calculation for the orbit transformation section 5 demonstrates Maxar satellite imagery analysis which done by manipulating the color spectrum. It was done to establish relationships between space weather events and events occurring on earth. The section 6 takes up the cost and finances which are done by observing the market at a particular time indeed.

2. METHOD

The satellite system aims to synchronize the data of both inner and outer Van Allen belts and find out the effects of excessive protons, electrons, and radiation. It also fosters the objective and importance of Van Allen belts on our planet earth. Devices such as electric and magnetic fields (EMF) detector energy management simulator (EMSIM), magnetometer magnodet, proton spectrometer protspect, relativistic particle detector reldet and electron spectrometer radspect have been used. New technologies have been implemented in this paperwork. The implementation of the most advanced renewable and durable propulsion system i.e. ion-propulsion system. The outer case of the satellite ensures maximum shielding and cost reduction. The proposed case could be used for future space missions as well. EMSIM is a new simple device that uses embedded systems to detect EMF. This will also accomplish the mission of detecting plasma waves. The different spectrometers have been designed to tolerate extreme conditions. The Van Allen probes and the MeRit missions inspired us to design a satellite mission in order to explore the Van Allen belts. This work gives an idea about space weather and its relationship with factors on earth; radiation-proof material technologies; satellite communications; remote sensing; analog and digital electronics; embedded systems; systems engineering analyzing satellite data; additive manufacturing; and software's-GMAT, Blender, Dust-3D, Photoshop, QGIS, Visio, Tinkercad.

2.1. Materials

Maximum utilization of 3D printing [6], [7] has been done in the structure of the launch vehicle because of its advantages over traditional manufacturing methods. Certain modifications were planned for this application, including the use of an aerospike engine and its complex geometries being printed using additive manufacturing [8]. Internal insulation was also considered, as well as using carbon foams to reduce vibration due to internal pressure and metal tanks to prevent reactions with liquid oxygen [9].

2.2. Propulsion, communication, and power amplifier

The propulsion system will be an ionic thruster propulsion system. In this electron will bombard neutral atoms and release electrons and positively charged atoms will be created. Ion-drives containing Xe atoms will be carried. The satellite will operate in the microwave spectrum in the Ku band at a frequency of 15 GHz [10], [11]. The satellites are equipped with microwave transmitters. Both satellites have a reflector microwave antenna with a parabolic surface. The antenna diameter is 0.5 m, the gain is 34.88709318 dB and the efficiency are 50%. The dual spacecraft systems of Vansat are tuned to communicate with the ground station. Gallium nitride (GaN) high electron mobility transistors (HEMT) based solid-state power amplifiers having parallel cascaded balanced configurations are used to add 53% of power-added efficiency. It will be operated in class AB mode.

2.3. Outer design of satellite

The outer design of the satellite includes an octagonal geometry, having 4 winglets on alternatively on top and bottom to ensure no shadow formation on the winglets. The wings will be made of kevlar to protect them from space debris [12]. Each of these wings will have four solar panels with fused silica panel coverings to reduce efficiency loss and save energy. The material of the body will be polylactic acid nylon material to further reduce the cost and increase durability. The proposed geometry will ensure much-increased aero dynamicity and effectiveness than the design used usually in space missions.

2.4. Antennas and power

For the antenna shape memory, alloy nitinol will be used and will be trained at 455ºC to 565ºC. All the different devices will be powered using Li-ion solar powered [13], [14]. The fuel properties are: fuel mass 750 kg, fuel density 1260 kg/m^3, temperature 20ºC, reference temperature 20ºC, pressure 1500 kPa. The tank properties are volume 0.75 m, pressure model pressure regulated. The specifications obtained from the propellant tank have been found after simulating the entire mission on GMAT (refer to GMAT report [15]).

3. DEVICES

3.1. Magnodet

Magnodet will detect the magnetic field in the radiation belts using an upgraded triaxial fluxgate magnetometer. To improve sensitivity, the fluxgate sensor's core is electroplated with permalloy (Ni80Fe20) and its geometry is circular. Cold-rolled coils are formed into thin foils and moulded to the desired geometry and have been subjected to multi-step heat treatments [16]. The proposed device has low noise and a square wave has been chosen for the excitation of the core. A 2 kHz square wave is employed, and a microprocessor 8,085 is used to generate a square wave with twice the frequency, i.e., 4 kHz [17]–[20].

3.2. Emsim

Emsim will be deployed to detect the electromagnetic field in the Van Allen belts. It can be referred to as one of the simplest and most cost-effective devices. It uses an embedded board, i.e., Arduino Uno powered by solar energy to plot a graph of the electromagnetic fields. A resistor of a high resistance value (i.e., 9 MΩ) has been chosen to increase the sensitivity. A copper antenna having a spherical probe (10 cm diameter) and a length of 1m has been used. The major changes in EMF (as read from the graph) will also indicate the motion of plasma and hence the presence of plasma waves [3], [21]–[23]. From the experiment, the graph is expected to be plotted showing the variations in EMF with time. It will have EMF along the Y axis and time along the X axis. The major changes in EMF (as read from the graph) will also indicate the motion of plasma and hence the presence of plasma waves.

3.3. Radspect

Radspect is a low-mass, low-volume, low-strength GaAs electron spectrometer coupled to custom preamplifier electronics. It is tolerant of excessive temperatures and severe radiation due to the huge bandgap of GaAs [14] provides [24], [25]. It will be coated with P layer, i layer, n+layer, n+substrate [26]. The layers will be sandwiched between Ti and InGe material. This spectrometer is cylindrical in shape and is mounted inside another covering that has a door mechanism, a bit similar to the one used in the Van Allen probes. It acts as a barrier to particulate contamination. The door's surface is made of dicronite to reduce friction. A multipurpose tang at the door ensures proper movement of the door and serves as a handle for manual reset.

3.4. Protspect

Protspect will be used to detect the protons in the radiation belts. This proton spectrometer contains a sensor box and an electronics box connected to a cable [27]–[29]. The sensor box includes a telescope and a pre-amplifier board. The electronics box includes an analog board, a digital signal processing board (DSP), a central processing unit board (CPU), an input/output board, and an electricity converter board. It uses a combination of gadolinium silicate (GSO) crystal scintillators to detect the protons and measure their energy. The sensor has four thin silicon detectors and three scintillators including one veto scintillator. PIN photodiodes are used to measure the light emitted by the scintillators, which is proportional tothe amount of energy lost by protons in that material [5]. The box is made of aluminum. The sensor also includes passive shielding, a collimator to reduce the flux from outside the nominal aperture, and a copper degrader to reduce the flux of low-energy electrons and protons.

3.5. Reldet

Inspired by the Van Allen probes, reldet is a miniature and low-power version of REPT. It will detect the relativistic particles in the Van Allen belts. Each detector is placed in a flexible connection kapton type

PWB. The detectors are layered cathode-to-cathode in the stack to prevent arcing and limit cross-talk [23], [30]. Tungsten (W) and aluminum (Al) shielding surround a stack of silicon solid-state detectors. A 2 mm thick beryllium (Be) window is present at the back of the collimator to block lower energy electrons (i.e less than 1 MeV) and protons (i.e., less than 14 MeV).

4. SYSTEM ENGINEERING

Due to the different purchasing prices of components, it may be possible to save money by using different components-for example, less expensive, similar parts-in areas where a component would be much more expensive [31]. To be able to use resources efficiently the rockets will be reusable. For the purpose of reusability in future missions, two satellites will be used at one time. The inner belt satellite will be available for 38min maximum for the data transfer but it will gradually pass through the ground station which will keep the satellites up-to-date on the current missions quickly [32]. For the orbit transfer “hohmann transfer orbit” method will be used for the outer satellite. Data sent majorly via inner satellite and outer satellite data will only be used for the verification of the data to avoid bit-flips occurrence.

5. MAXAR SATELLITE IMAGERY ANALYSIS

This study has demonstrated a link between earth’s vegetation index, soil index, constructed index, and the occurrence of space weather events [33], [34]. These elements, nonetheless, are comparable to the conclusions reached thus far. The QGIS software has been used to do deep colour band analysis on a chunk of the Indian map. For the calculations, the inner satellite orbital radius (Ri=2Re) is 9556.5 km and the outer satellite orbital radius (Ro=5Re) is 31855.5 km. From the hohmann transfer orbit formula:

$$\Delta V1 = \sqrt{\frac{\mu}{Ri}}\left(\sqrt{\frac{2Ro}{Re} + Ro} - 1\right) \tag{1}$$

$$\Delta V2 = \sqrt{\frac{\mu}{Ro}}\left(1 - \sqrt{\frac{2Ri}{Re} + Ro}\right) \tag{2}$$

where $\mu \sim 3.986 \times 10^{14} m^3 s^{-2}$. Therefore, the total V=V1+V2=1,868.5651 m/s.

5.1. Soil index

Analysis of the soil index over the period of 2019-2021 has been depicted in Figure 1. It is observed that in 2019 the bottom-left side of the field had a lower density of soil than other parts. A very steep curve from the bottom is seen in the raster histogram, which indicates a change in slope. However, since 2019 there has been an increase in the average density of soil index all over the map which suggests vegetation health and growth. However, it can be seen from the raster histogram that the average soil index has decreased further since 2020.

5.2. Vegetation index

The analysis of the vegetation index over the period of 2019-2021 has been depicted in Figure 2. As already observed 2019 had a proper soil index. Since the vegetation index and soil index are proportionally related to each other, the observations are theoretically justified. The drastic change in vegetation index occurs in 2020 compared to 2019. This image has a very minute difference from the previous image. However, the raster histogram shows some unusual changes in the vegetation index of this area. The vegetation index has increased significantly and is the highest among the three compared years.

5.3. Built index

Analysis of the builtindex over the period of 2019-2021 has been depicted in Figure 3. Human-made buildings and road progress can be seen. The raster histogram also shows a high built index. It indicates urbanization and hence 2019 was a year of great development. From the above image, it can be observed that the built index has little or no changes. The progress rate is almost the same as that of 2019. From the imagery as well as the raster histogram of 2021, changes in the build index seem to be frozen or have taken very little step. It could be the influence of Covid protocols taking place at this particular place also.

The image was taken in New Delhi, India, at 28.60795875290435 and 77.27740546485825. It was provided by Maxar technologies. The image was used to create a digital elevation model (DEM) from landsat satellite images. The DEM is used to calculate the soil index and is calculated using band 3-band 4/band 3 +band 4 (35). In May 2019, when a surprise geomagnetic storm took place despite the unusually high soil index in 2019 compared to previous years. However, there is still uncertainty about the impact of geomagnetic storms on soil index due to their inconsistent nature. The vegetation index is an important measure of the health of vegetation on earth. Space weather events can affect the amount of solar radiation reaching earth, which in turn affects the amount of vegetation present on the planet. The vegetation index is calculated using landsat-8 images with band 6 replaced by band 4 and band 6+band 4 replaced by band 4+band 5. We found that almost no change was seen in either built or vegetation indices after space weather events took place on earth between May 2021 and May 2023.

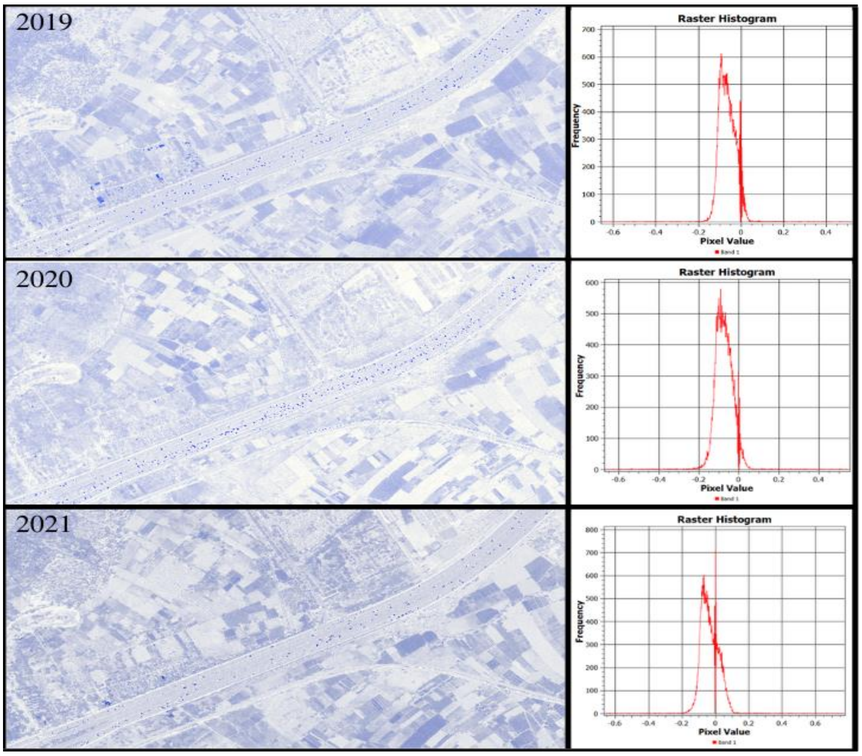

Figure 1. Analysis of the soil index over the period of 2019-2021

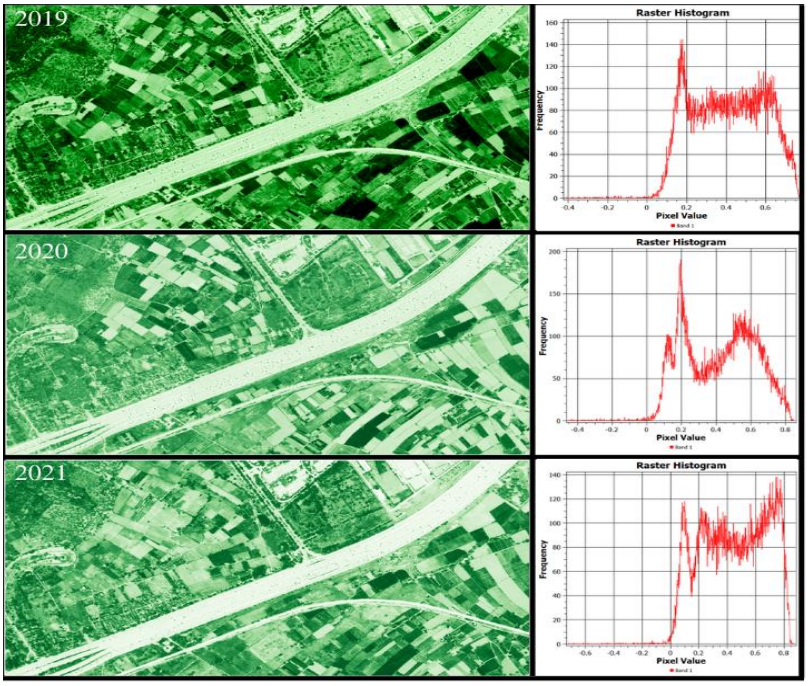

Figure 2. Analysis of the vegetation index over the period of 2019-2021

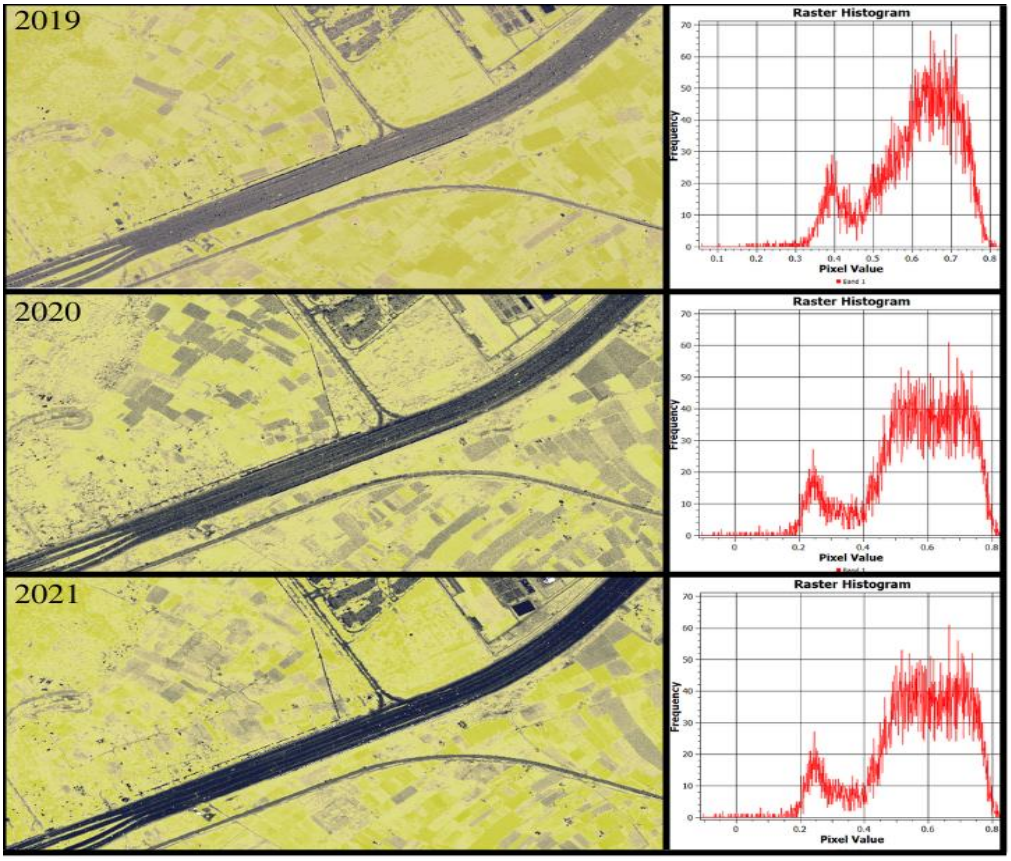

Figure 3. Analysis of built index over the period of 2019-2021

6. FINANCING

According to data, some countries have the opportunity to purchase components that are both affordable and of high quality. The cost for the body material of the satellite is $5,400,000 (weight of satellite =270 kg). Ground station communication cost is approximately $2,064.67. Insurance for 15-25 years is $11,250. The approximate cost for each device is-radspect [$415.7], protspect [$459,8787], container or box [$91.72], emsim [$6,078.60], reldet [$4,231], magnodet [$21,600]. Accessories are layers [$81,749.56], li-ion battery [$66], solar panels [$331.58], aluminum tank [$411], thrusters [$1,500,000]. Here, the grand total would be $7,425,793.02.

7. CONCLUSION

A satellite mission has been designed to study the energetic particles, magnetic fields, and plasma waves in the Van Allen belts. An outer case of a satellite having a new cost-friendly and effective design; and modifications that can be brought to rockets to utilize the advantages of 3D printing have been developed. They can be useful for future space missions too. The possibility of bit flip has been taken as an example to show the significant hazards the satellite might face during its journey. The paper has also covered the financing part to demonstrate the esteemed cost that such a big project may require. The images which are used in the paper are created in such a way that they can be taken as blueprints for every component. Efforts have been made to shield all components from radiation. Risk management, backup, and environmental effects have been taken care of. Satellite imagery analysis of Maxar satellite has also been done to establish relationships between space weather events and events occurring on earth. This analysis has led to peculiar findings which may be a vast topic for future research.

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