THE VIABILITY OF USING WEIGHT SAVING MATERIAL FOR FUTURE LONG TERM SPACE VEHICLES (I.E. SATELLITES)

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Abstract

The potential hazards of the natural space environments to a composite structure and to the systems within the structure are compared to an all conductive (metal) structure. Low Earth Orbit (LEO) will be the focus of the evaluation. The natural space environments comprise a multitude of risks, with a primary concern being the natural space plasma and the resulting spacecraft charging. Various other aspects of the environment and their impacts on a composite structure will also be examined.

The evaluation of spacecraft charging demonstrates a high probability of electrical overstress (EOS). The majority of space vehicles are made of a combination of metal and composites, indicating a concern of EOS (arcing) between the materials. To avoid EOS, you must have the entire vehicle at the same potential. Different materials will not have the same discharge voltage, allowing one to charge at a higher voltage than the other. This causes a potential difference and allows for EOS. The composite is not a good conductor and has a dielectric constant associated with it. The rate of charging and the distribution of charge will vary non-linearly, causing a non-uniform distribution of charge. EOS allows degradation of the on board systems, leading to possible mission failures. EOS may cause physical damage to composites, which can lead to a loss of structural integrity.

Introduction

With the advancement of man's presence in space, the cost and weight of objects being launched have become major concerns; as a result, composite materials are being widely used for space travel. The cost to launch a spacecraft into space is predicated by weight; as composites are generally more lightweight than traditionally used metals, they are cheaper to launch. Also when considering the cost of building a spacecraft, the cost of the material has to be taken into consideration. Not only are launch costs made lower by lighter material the cost of the material itself is also lower than commonly used metal, making both launching and building composite spacecrafts more attractive in an economic sense.

Along with composites being financially more attractive, the mechanical properties of composites often are more appealing. Due to the longevity required of spacecraft, mechanical strength is a major concern for designers. The mechanical strength of a composite can be stronger than a lot of the commonly used metals, thus composites are appealing to make a successful mission. Also due to the manner in which composites structures are composed (via computer), all the boltholes and apertures are built into the structure when it is wound, unlike its metal counterpart, which needs drilling and boring to complete the structure. This, from a mechanical standpoint, makes a composite vehicle easier to work with.

The third major reason for using composites is the thermal properties. Composites have been proven to provide good thermal conductivity, thus they have the ability to adjust to high temperature variations. Due to the nature of the space environment, structures will have to undergo numerous temperature differentials when traveling into and out of the sunlight. Due to the thermal properties of composites this constant changing is easily handled.

The above thermal and mechanical properties and cost effectiveness are three reasons why composites are being widely used in long-term space missions. There are, however, some consequences of using composites. The natural space environment is made up of 9 components: the neutral thermosphere, the thermal environment, plasma, meteoroids and orbital debris, the solar environment, ionizing radiation, the magnetic field, the gravitational field, and the mesosphere[1]. The environment of primary concern for spacecraft charging is plasma. Plasma exists in the ionosphere and is caused by the interaction of the gas in the ionosphere and solar particles. In the ionosphere the electron and ion densities are equal and as a rule vary depending on the location in the ionosphere. Due to this the altitude will make a difference in the amount of plasma flux a spacecraft encounters. Low Earth Orbit (LEO) will be of primary concern in this discussion.

While reviewing the environments for space travel it is obvious that there are more considerations than the cost and the thermal and mechanical properties. Along with mechanical and thermal considerations, electromagnetic considerations have to be evaluated as well. All of the systems being launched currently are using very sophisticated electrical devices and these devices are very susceptible to the electromagnetic space environment. To protect these devices there needs to be adequate shielding provided by the body of the craft. Typically, a method of shielding these devices is to provide a metal (conductive) enclosure referred to as a faraday cage. This also ties into the grounding scheme as a faraday cage provides the ground to prevent arcing between pieces of the spacecraft. When a composite is used this faraday cage becomes impossible to achieve as the composite is not, in general, a good conductor. This leaves an opening anywhere there is composite thus exposing sensitive electrical devices to a hostile electromagnetic environment. Also if there are any metal structures the composite between them will act as a dielectric, thus creating a capacitor.

Existing information

Spacecraft charging and its effects are widely known and discussed in various papers and conferences. Many failures have been documented and blamed on spacecraft charging. For

[1] NASA Reference Publication 1350

example, the Telsat, Canada's Anik E-1 communications satellite began to spin out of control on 20th January 1994. Within two hours Anik E-2 also lost control[2]. This caused over $50 million in recovery, repair, and lost revenue costs. It has been determined that this anomaly was caused by ESD from a build up of charge from a solar flare. Other various spacecraft anomalies have been blamed on spacecraft charging or the electromagnetic environment in general with more that have not been identified. Much is understood about the natural space environment and its possible effects on spacecraft, first studied in detail by SCATHA. The following figure from NASA Reference Publication 1350 outlines the issues that are faced in the natural space environment.

Natural Space Environments

	DEFINITION	PROGRAMMATIC ISSUES	MODELS/DATABASES
NEUTRAL THERMOSPHERE	Atmospheric density, Density variations, Atmospheric composition (Atomic Oxygen), Winds	GN&C system design, Materials degradation/ surface erosion (atomic oxygen fluences), Drag/decay, S/C lifetime, Collision avoidance, Sensor pointing, Experiment design, Orbital positional errors, Tracking loss	Jacchia/MET, MSIS< LIFTIM, upper atmospheric wind models
THERMAL ENVIRONMENT	Solar radiation (albedo and OLR variations), Radiative transfer, Atmospheric transmittance	Passive and active thermal control system design, Radiator sizing/material selection, Power allocation, Solar array design	ERBE database, ERB database, NIMBUS database, ISSCP database, Climate models, General Circulation Models (GCM's)
PLASMA	Ionospheric plasma, Auroral plasma, Magnetospheric plasma	EMI, S/C power systems design, material determination, S/C heating, S/C charging/arcing	International Reference Ionosphere Models, NASCAP/LEO NASCAP/GEO, POLAR
METEOROIDS AND ORBITAL DEBRIS	M/OD flux, Size distribution, Mass distribution, Velocity distribution, Directionality	Collision avoidance, Crew survivability, Seconary ejecta effects, Structural design/ shielding, Materials/solar panel deterioration	Flux models
SOLAR ENVIRONMENT	Solar physics and dynamics, Geometric storms, Solar activity predictions, Solar/geomagnetic indices, Solar constant, Solar spectrum	Solar prediction, Lifetime/drag assessments, Reentry loads/heating, Input for other models, Contingency operations	EL Laboratory model, NOAA prediction data, Statistical models, Solar database
IONIZING RADIATION	Trapped proton/electron radiation, Galactic cosmic rays (GCR's), Solar particle events	Radiation levels, Electronics/parts dose, Electronics/single event upset, Materials dose levels, Human dose levels	CREME, AE-8MIN, AE-8MAX, AP-8MIN, AP-8MAX, Radbelt, Solpro, SHIELDOSE
MAGNETIC FIELD	Natural magnetic field	Induced currents in large structures, Locating South Atlantic Anomaly, Location of radiation belts	IGRF85, IGRF91
GRAVITATIONAL FIELD	Natural gravitational field	Orbital mechanics/tracking	GEM-T1, GEM-T2
MESOSPHERE	Atmospheric density, Density variations, Winds	Re-entry, Materials selection, Tether experiment design	Earth-GRAM 90, UARS database, "science" GRAM

MSFC EM & Environments Branch/EL54

Figure 1. Table outlining space environments and their concerns

As can be seen from the above table, there are numerous concerns due to the space environment and these concerns are identified and understood. Much is understood about composites and how they react in certain environments as can been seen in the "Handbook of Composites" and NASA's "Design Guidelines for Shielding Effectiveness, Current Carrying Capability, and the Enhancement of Conductivity of Composite Materials". What is not completely understood, however, are the interactions of composites and the natural space electromagnetic environments. Since the composite has a conductive and dielectric component, it is necessary to identify when each is dominant.

[2] NASA Reference Publication 1375

Current Work

Spacecraft charging has been a primary concern for the aerospace and defense industries since the launch of the first spacecraft. Numerous analyses have been conducted to determine the possibility of spacecraft charging and the effects this would have to a vehicle within the LEO environment. These analyses have focused on an all metal structure and approximated it to be a sphere thus allowing the use of probe theory[3]. This is a reasonable assumption due to the fact that the spacecraft is immersed in the natural space plasma. The primary method of charging is particle collisions within the metal structure. The source of this charging is primarily the electrons that are released from the sun in the form of solar winds. Solar winds have a 50:1 ratio of electrons to protons and have a measured charging rate of 10V/s and up to 1MV/s during high solar flare activity. Other effects that contribute to charging are secondary electrons, back scattered electrons, and photoelectrons.

There are two major components of spacecraft charging. The first is surface charging. Spacecraft charging has the possibility to build up enough difference in potential to cause ESD (arcing). The second is internal dielectric charging. Once a surface is charged there is only a matter of time before it discharges. Discharges can exceed 40 amps and last longer than 150 nanoseconds. Due to the severity of this effect it needs to be fully understood and analyzed.

The surface charging, attributed to the aforementioned sources, has various effects on the vehicle. The phenomenon and severity of charging is dependent on the materials of the spacecraft. For dielectrics the electrons are absorbed or captured until sufficient numbers are present. The material then discharges in the form of an arc to neighboring material or to the surrounding space. Arcing can occur as low as 300V in Low Earth Orbit (LEO).

Another concern is coronal discharging. A corona is most likely to occur at sharp points or when a circulating current is induced. A corona discharge is a potential breakdown (not total or arcing) and occurs when arcing potential is not met. Coronal discharge is the ionization of the space plasma and comes in various forms. The ionized plasma fluoresces causing a “glow” or, if unstable, streamers. Corona discharge is looked at in more detail in section 3.0.

The third concern is internal dielectric charging. Internal dielectric charging occurs when there are energetic electrons in the plasma. The electrons can penetrate the surface of the satellite, thus charging an internal surface. When the surface has sufficiently charged with electrons captured, a discharge will occur. This internal discharging can couple directly to subsystems, exposed circuits and cables in a pulse-like manner causing major problems with the internal systems of the satellite, thus has a higher potential of damage.

Surface Charging

Surface charging will occur when a vehicle is immersed in space plasma. To calculate the potential on the surface of a vehicle in space, probe theory is used. Probe theory is when a sphere is placed in plasma, and the resulting cloud of electrons and ions is a function of the particles energies and densities and the surface potential. This is reasonable due to the fact that

[3] Handbook of geophysics

the satellite is immersed in the natural space plasma. The potential on the surface is calculated in two steps: 1) finding the currents to the surface of the vehicle, which are based on functions of ambient conditions and the vehicle geometry. 2) the vehicle potential is then based on the current balance (this also includes sheath particles trapped close to the vehicle). Current balance theory is based on the assumption of charging a sphere of radius r and capacitance C_0 (capacitance at infinity, $C_0 = 4\pi\varepsilon_0 r$) using certain time scales. The following derivation is based on the "Handbook of Geophysics". The time for charging the sphere relative to space is given by:

$$\tau_s = \frac{C_0 V}{4\pi r^2 J} = 2x10^{-3} \sec \qquad (1)$$

where r = 1 meter, V = 1 kV and J = 0.5nA/cm^2 (the ambient current).

The time for charging a dielectric of area A is given by: $\tau_s = \tau_D = \dfrac{C_D V}{AJ}$ (2)

where A is the area and C_D is the dielectric capacitance, leading to τ_D, the charging time for a dielectric. For example, the dielectric constant of composites without metal mesh is between 2 - 10, thus the charging time of the sphere is less than the charging time of the dielectric, therefore the dielectric will charge. The probe method as outlined in The Handbook of Geophysics is commonly used in various computer codes such as NASCAP. It should be noted however, that the computer codes assume either a pure conductor or a pure insulator; composites have properties of both, thus putting the results in question. Also, all of the data on the electrical properties treat composites primarily as conductors, such as the Composite Handbook and NASA's "Design Guidelines for Shielding Effectiveness, Current Carrying Capability, and the Enhancement of Conductivity of Composite Materials."

Corona

An aspect of discharging that is a possible concern is that of a coronal discharge. A coronal discharge is the ionization of a surrounding gas which occurs when that potential gradient exceeds the ionization potential of the gas but is not sufficient to cause arcing (arcing begins at 300V in LEO). A corona is caused by a build up of electrons on a surface, thus when enough electrons are collected, they cause a "glow" by means of discharging into an inhomogeneous electric field. If these currents are circular, charge build up becomes possible at various points. Some examples of where this can happen are antennas and bore sights. In these cases build up of charge can lead to ionization of the surrounding area leading to corona discharge. Corona discharge at the end of a cylindrical tube can seriously impact the performance of electro-optic devices due to the fact that a corona may be luminescent. Also, communications equipment can be severely interfered with when a corona forms around antennas.

Corona discharge is a partial breakdown of the plasma. There are various methods used in the investigation of corona discharge[4]. The first is using coaxial cylinders assuming the center

[4] Electrical Breakdown of Gasses

cylinder is a cathode and the outer cylinder is an anode. From this assumption the electric field intensity between the coaxial cylinders is given by the following:

$$E = \frac{V}{r \ln\left(\frac{r_c}{r_a}\right)} \tag{3}$$

where E is the electric field intensity at a point r in between the two cylinders, V is the potential on the electrode (cathode), r_c is the radius of the cathode, and r_a is the radius of the anode. The electric field accelerates electrons toward the anode and if enough electrons start to accelerate there can be an avalanche of electrons leading to a breakdown or corona.

Another way to evaluate the possibility of coronas is to assume a radial current distribution around a disk. From the current, magnetic flux can be found by:

$$B = \frac{b\mu_0 I}{2\pi a^2} \tag{4}$$

where B is the radial magnetic flux, b is some point inside the cylinder, μ_0 is the permeability of free space, I is the current, and a is the radius of the cylinder. Given that $B=\mu H$, the magnetic field intensity is found by:

$$H = \frac{bI}{2\pi a^2} \tag{5}$$

From H, and given E=377H in free space, the electric field can be solved for:

$$E = 377\frac{bI}{2\pi a^2} \tag{6}$$

This electric field is then compared to known values for breakdown.

Internal Dielectric Charging

Along with the importance of investigating surface charging, internal charging is also of great concern. Internal charging has the potential to be more damaging than surface charging as it is within the satellite itself. Internal dielectric charging is due to high-energy electrons (E > 100eV) that penetrate though diffusion, into the satellite and build up on internal structures, including inside the satellite. These high-energy electrons are present in the natural space plasma the surrounds the satellite. High-energy electrons are more common in polar orbits, like the orbit of this vehicle, due to aural events. Diffusion is the mechanism in which charge that is built up on the outside of the space vehicle will diffuse though the outer vehicle and build up on the inner surface thus creating the possibility of arcing. Once the initial diffusion has taken place it becomes a continuous process whereby allowing a current to pass though from the outer surface to the inner wall. Thus internal charging and discharging will be a continual occurrence.

The internal electric field can build up when the charge leakage rate is less than the charge collection rate. The time it takes to charge is thus related to the dielectric leakage rate, however given enough time sufficient charging will occur resulting in arcing. This arcing will appear as a pulse to the internal systems, cables, exposed circuits, etc. Pulse's usually last approximately 10's nanoseconds. The likelihood for a discharge to occur is a function of both the voltage potential and the electric field. But first before the electric field is calculated the range of the energetic electrons has to be calculated to see if there would indeed be a charge build up. The range that the electrons penetrate is given by Weber's equation (1),

$$R = 0.55\frac{E}{\rho}\left[1 - \frac{0.9841}{(1+3E)}\right] \tag{7}$$

where R is the maximum range an electron with energy E can travel in cm, E is in MeV, and ρ is the density of the material. The electrons within the dielectric are not all distributed at R but spread throughout the material, and there is a fall-off in the current as the range is approached. Sorensen (1) estimated that fall off was linear, though a gaussian might fit better the improvement is too small for the additional computation, thus the linear approach is used,

$$a(g/cm^2) = 0.238xE \tag{8}$$

where a is the fall off distance.

The electric field also needs to be calculated this can be done with the use of the dielectric current density,

$$J = \phi\, q \tag{9}$$

where J is in A/cm^2, ϕ is the electron flux, and q is the charge of an electron. Just to note that a capacitor plate behavior is assumed, and thus the electric field buildup may be determined from the conductivity of the material,

$$E(t) = \frac{V(t)}{d} = \frac{J}{\sigma}\left(1 - e^{-t/\tau}\right) \tag{10}$$

where σ is the dielectric conductivity, τ is the time constant, and d is the thickness of the material. The time constant is a function of the material,

$$\tau = \frac{\varepsilon}{\sigma} \tag{11}$$

where ε is the dielectric constant. The above electric field can be calculated and then compared to the breakdown strength of the dielectric to determine if arcing will occur.

Arcing

Arcing occurs between either different metals or two pieces of metal at different potentials separated by a gap. Due to the fact that various areas of the craft are made up of different materials there could be arcing from one material to another. The vehicle will have a net potential induced by the plasma that will be the same for all the materials, however the current balance for each material will not be the same due to the differences in conductivity, thus arcing will occur. A simple form of Ohm's law can be used to calculate this imbalance,

$$I = \frac{V}{Z} \tag{12}$$

where V is the potential and Z is the impedance. Let I_1, I_2 and I_3 be the currents for 3 materials the potential across each material can be found by the following. Given the definition of current,

$$dq = Idt \tag{13}$$

and then the fact that,

$$C = \frac{\varepsilon_0 A}{d} \tag{14}$$

where d is the distance between the materials and A is the area of the material. Thus the potential is given by,

$$\begin{aligned} q &= CV \\ \Delta q_1 - \Delta q_2 &= C\Delta V \end{aligned} \tag{15}$$

where ΔV is the voltage across the imbalance and C is the capacitance between the two. Given that the internal discharging also acts like a capacitor it will discharge in the same manner.

Charging of a Composite

Charge build up and arcing

The outlined effects of being in the natural space plasma are also evaluated with a composite structure in mind. It is determined that surface charging and internal dielectric charging are greater concerns when composites are used in conjunction with metal for the structure of the space vehicle this is due to the electrical properties of composites. As previously mentioned composites are a concern due to the fact that they are poor conductors and have dielectric matrix associated with them. Due to the poor conductivity, the rate the composite can charge and the distribution of charge vary non-linearly, causing a non-uniform distribution of charge. This allows for areas of the composite to charge differently from other areas, thus punch through or flash over[5] may occur. Also as various materials have different discharge voltages, there can be

[5] Spacecraft Charging by Dr. Holbert

a potential difference reached before the discharge occurs. Thus a metal will charge to a different potential than a composite, allowing for a potential difference between the two materials and in essence creating a capacitor and allowing for arcing.

If the charge builds up faster than current moves then the charge will “stack up” eventually building up enough charge to arc or corona. The time for current to move is dependent on the material under question; this is known as the relaxation time. The relaxation time is determined by the resistivity and the dielectric constant of the material. For any material, if the charging time is less than the relaxation time, charge has the opportunity to build up leading to corona or arcing. This can become a major concern when composites are being taken into account as the relaxation time is commonly higher than the charging time as shown with the dielectric time constant (equation 2). The following table lists the electrical properties for some common materials including some composites.

Table 1. Typical Resistivity and Conductivity Values[6]

MATERIAL	THICKNESS		RESISTIVITY			CONDUCTIVITY		
			Volume		Surface			
	mil	cm	ohm-meter	ohm-centimeter	ohm/square	mho/meter	mho/cm	relative
Copper		0.100	1.72E-08	1.72E-06	1.72E-03	5.81E+07	5.81E+05	1.00E+00
Aluminum		0.100	2.87E-08	2.87E-06	2.87E-03	3.48E+07	3.48E+05	6.01E-01
Cold rolled steel		0.100	1.01E-07	1.01E-05	1.01E-02	9.90E+06	9.90E+04	1.71E-01
Stainless steel		0.100	8.62E-07	8.62E-05	8.62E-02	1.16E+06	1.16E+04	2.00E-02
Steel filaments in plastic		0.100	2.00E-03	2.00E-01	2.00E+02	5.00E+02	5.00E+00	8.62E-06
10% stainless filaments		0.320	8.20E-03	8.20E-01	2.56E+00	1.22E+02	1.22E+00	2.10E-06
Zinc plating	1	0.003	5.70E-08	5.70E-06	1.90E-03	1.75E+07	1.75E+05	3.02E-01
GFRP (typ.)		0.100	1.80E-05	1.80E-03	1.80E+00	5.56E+04	5.56E+02	9.58E-04
GFRP (meas.)		0.360	8.64E-05	8.64E-03	2.40E-02	1.16E+04	1.16E+02	2.00E-04
40% Carbon fiber	70	0.178	1.00E+00	1.00E+02	5.62E+02	1.00E+00	1.00E-02	1.72E-08
5% Ni coated graphite in polycarbonate	125	0.318	3.40E+02	3.40E+04	1.07E+05	2.94E-03	2.94E-05	5.07E-11
10% "	125	0.318	5.20E-01	5.20E+01	1.64E+02	1.92E+00	1.92E-02	3.32E-08
15% "	125	0.318	1.60E-03	1.60E-01	5.04E-01	6.25E+02	6.25E+00	1.08E-05
20% "	125	0.318	1.10E-03	1.10E-01	3.46E-01	9.09E+02	9.09E+00	1.57E-05

As can be seen from the above table the resistivity is considerable higher for the composite materials than for the metal materials (it should also be noted that the GFRP typical value is greater than the measured value, as the means of measurement is not know the typical value will be of most curiosity). This leads to a longer relaxation time and the possibility of charge build up. To calculate the relaxation time equation 2 is used.

$$\tau_c = RC = \frac{CV}{AJ}$$

[6] NASA Contractor Report 4784

where τ_c is the relaxation time, R is the resistance and C is the capacitance. Then using the following equations,

$$R = \frac{\rho d}{A} \qquad C = \frac{\varepsilon A}{d} \tag{16}$$

the relaxation time becomes,

$$\tau_c = \rho\varepsilon \tag{17}$$

where ρ is the resistivity and ε is the relative permittivity given by $\varepsilon = \varepsilon_0 \kappa_\varepsilon$.

The following table shows the resistivity, for those materials listed above when calculated for a thickness of 0.5cm (a typical body tube thickness).

Table 2. Resistivity at 0.5 cm

Material	Surface Resistivity (Ω-square)	Volume Resistivity (W-m) (based on 0.5 cm thickness)
Copper	1.72E-03	8.60E-06
Aluminum	2.87E-03	1.44E-05
Cold rolled steel	1.01E-02	5.05E-05
Stainless steel	8.62E-02	4.31E-04
Steel filaments in plastic	2.00E+02	1.00E+00
10% stainless filaments	2.56E+00	1.28E-02
Zinc plating	1.90E-03	9.50E-06
GFRP (typ.)	1.80E+00	9.00E-03
GFRP (meas.)	2.40E-02	1.20E-04
40% Carbon fibor	5.62E+02	2.81E+00
5% Ni coated graphite in polycarbonate	1.07E+05	5.35E+02
10% "	1.64E+02	8.20E-01
15% "	5.04E-01	2.52E-03
20% "	3.46E-01	1.73E-03

From the above table it can be seen that the resistivity is much higher for the composite material as expected. Due to the fact that the dielectric matrix is non-linear for composites it can be determined that with a charging mechanism of up to 1MV/s during auroral conditions the composite will charge in a non-linear manner until arcing potential is reached. The material will then arc or corona and charge again, repeating this process. As can be inferred from above, composite materials will have the time to build up enough charge to arc more rapidly than metal.

It should be noticed that the above analysis talks about arcing, however does not talk about different materials. This is due to the fact that composite materials charge differentially as well as non-linearly. With this differential charging parts of the composite will charge at a different rate than other parts thus allowing for different potentials to build up and allowing for surface arcing or arcing through the material in a channel like manner.

Along with surface charging and arcing there is a concern with internal arcing. Internal arcing occurs when the internal surface of the composite (assuming a tube) becomes charged enough to arc (internal dielectric charging). This arcing can occur between different parts of the composite as previously mentioned, or to equipment located inside the composite. Charge will build up on the inside of most composite materials due to the fact that there is little to no shielding effectiveness provided by the material, thus a current on the outside of the composite will be on the inside also, due to short diffusion time of composite materials. This will be looked at in more detail in the next section.

Spacecraft Charging with Composite Materials

As is discussed previously the natural space environment is such that if not protected against is of great concern. Also as previously mentioned, spacecraft charging is even more concerning with the use of composites. Surface charging is calculated in the same manner as before using probe theory, however that composite will charge at a faster rate than metal because of the longer relaxation time. Also due to the nonlinear dielectric properties of the material, the material will not all charge to the same potential. This differential charging allows for the possibility of punch though and flashover as mentioned in section 4.1. Both of these effects are of concern with composites due to their destructive manner. With both punch through and flashover there is the possibility of physical damage to the vehicle in the form of holes and degradation of the composite. Due to the make up of the composite it is possible to melt during one such arc.

Again like metals there is also a threat of corona. Coronas can occur when enough electrons are deposited on a surface and then discharge into the surrounding environment causing “glow” or “streamers”. Composites will have a larger “stack up” of charge thus there is a higher probability of a corona. As opposed to the physical damage that can occur with surface arcing, a corona can interfere with sensors, receivers, and antennas or anything on the outside of the vehicle. For example if an electro-optic detector has a corona “glow” around it, it will make it almost impossible to obtain any reliable data. This corruption of data could possibly result in failure. The best way to avoid corona is to minimize sharp points and use metals to negate charge buildup.

Finally internal dielectric or bulk charging is most likely when using composites. This is due to the lack of conductivity. Composites typically have little to no shielding thus impinging electrons will drive straight through the material deeper than if the material was metal. This leads to a build up of charge on the inside of the vehicle. Not only can arcing occur within the vehicle, but due to the magnetic field within the vehicle, caused by the moving charge, there is the possibility of inductive coupling to cables, wires, and internal systems. The electrons built up on the inside of the vehicle will arc as they do on the outside surface. When arcing inside occurs, the arc will go to the internal systems or to other parts of the composite. As is shown above, spacecraft charging is a major concern in general and even more so with composites.

Conclusion

With composites becoming more prevalent in today's and tomorrow's aerospace industry, the effects of natural space environment and other extreme electromagnetic environments have to be evaluated. The electromagnetic properties of composites must be understood to provide an integrated design which provides protection of electronic equipment from the external hostile environments. As previously mentioned, composites have good thermal and mechanical properties, and these are well understood in the community. But the electromagnetic properties of composites are incomplete. Most analyses treat composites as conductors. However, the literature reports that composites have dielectric properties. This makes the response of composites to the mentioned environments a dispersive or non-linear material. This has been discussed in this paper by the fact that composites not only act as conductors, but also dielectrics-they charge!!

Due to the fact that composites have dielectric components implies a dielectric matrix is associated with them. With this knowledge the internal charging of composites becomes a major issue in the analysis of the material. To thoroughly understand the interaction of the composite to the space plasma and other extreme electromagnetic environments this dielectric matrix along with the accompanying conductivity matrix must be studied. The response of the material is directional and complex. To provide complete protection of the internal systems, this knowledge needs to be acquired. With future missions into space looking to survive longer and at the same time be cost conscious, composite material usage will grow. Therefore, the electromagnetic analysis and testing of these materials becomes a major program issue in order to insure mission success.

References

1. Ryden, K. A., D. J. Rodgers, and G. L. Wrenn, "Engineering Tools for Internal Charging", Establishment of Engineering Specification for Internal Charging, England 1999.

2. Jursa, A. S. ed., "Handbook of Geophysics and the Space Environment", Air Force Geophysics Laboratory, USAF Systems Command, 1985.

3. Meek, J. M. and J. D. Craggs, ed., "Electrical Breakdown of Gases", John Wiley & Sons, New York, 1978.

4. Leach, R. D. and M. B. Alexander, ed., "Failures and Anomalies Attributed to Spacecraft Charging", NASA Reference Publication 1375, NASA Marshall Space Flight Center, August 1995.

5. Vaughan, W. W., K. O. Niehuss, and M. B. Alexander, ed., "Spacecraft Environments Interactions: Solar Activity and Effects on Spacecraft", NASA Reference Publication 1396, NASA Marshall Space Flight Center, November 1996.

6. James, B. F. Coordinator, "The Natural Space Environment: Effects on Spacecraft", NASA Reference Publication 1350, NASA Marshall Space Flight Center, November 1994.

7. Herr, J. L., M. B. McCollum, "Spacecraft Environments Interactions: Protecting Against the Effects of Spacecraft Charging", NASA Reference Publication 1354, NASA Marshall Space Flight Center, November 1994.

8. Leach, R. D. and M. B. Alexander, ed., "Electronic Systems Failures and Anomalies Attributed to Electromagnetic Interference", NASA Reference Publication 1374, NASA Marshall Space Flight Center, July 1995.

9. Bedingfield, K. L., R. D. Leach, M. B. Alexander, ed., "Spacecraft System Failures and Anomalies Attributed to the Natural Space Environment", NASA Reference Publication 1390, NASA Marshall Space Flight Center, August 1996.

10. Casper, Jeffrey E., ed., "High Power Microwave Harding Design Guide for Systems Volume I: HPM and Interpreting Harding Requirements", Final Design Guide, US Army Laboratory Command Harry Diamond Laboratories Adelphi, April 1992

11. "Avoiding Problems Caused by Spacecraft On-Orbit Internal Charging Effects", NASA Technical Handbook 4001, NASA, February 1999

12. Evans, R. W., "Design Guidelines for Shielding Effectiveness, Current Carrying Capability, and the Enhancement of Conductivity of Composite Materials", NASA Contractor Report 4784, NASA Marshall Space Flight Center, August 1997

13. Sorensen, J., “Engineering Tools for Internal Charging”, ESA Final Report, ESA, January 1999

14. Peters, S. T., ed., “Handbook of Composite 2nd ed.”, Chapman and Hall, New York, 1998

15. Gaier, James R., “Intercalated Graphite Fiber Composites as EMI Shields in Aerospace Structures”, IEEE Transactions on Electromagnetic Compatibility, Vol. 34, No. 3, August 1992

16. Whittlesey, Albert and Dr. Henry B. Garrett, “NASA’s Technical Handbook for Avoiding On-Orbit ESD Anomalies Due to Internal Charging Effects”, 6th Spacecraft Charging Technology Conference, AFRL-VS-TR-20001578, September 2000

17. Holbert, Dr., “Spacecraft Charging”, Retrieved 8 May 2003, Online: http://www.eas.asu.edu/~holbert/eee460/spc-chrg.html

18. Sorensen, J., “An Engineering Specification of Internal Charging”, ESA, Retried 22 January 2003, Online: www.estec.esa.nl/conferences/96a09/Abstracts/abstract35/paper/

19. Holbert, Dr., “Space Radiation Environmental Effects”, Retrieved 16 May 2003, Online: http://www.eas.asu.edu/~holbert/eee460/spacerad.html