PREFERRED RELIABILITY PRACTICES

SPACECRAFT THERMAL CONTROL COATINGS DESIGN AND APPLICATION

Practice:

Select and apply thermal coatings for control of spacecraft and scientific instrument temperatures within required ranges and for control of spacecraft charging and RF emissions.

Benefit:

This practice enhances the probability of mission success by controlling temperatures of flight hardware as well as spacecraft charging and RF emissions over the life of the mission.

Programs That Certified Usage:

Most flight hardware requires thermal control coatings. The specific requirements are developed as flight programs are

Center To Contact For More Information:

Goddard Space Flight Center

Implementation:

Spacecraft and scientific instruments usually contain hardware, including sensitive detectors, which require that temperatures be maintained within specified ranges. A good thermal design is therefore essential to a successful mission. Thermal control coatings is one of several systems, such as thermal blankets and electric heaters, that are used to control temperatures.

In space, the operating temperature of a spacecraft is determined by the heat input from the sun, the reflected solar energy from the earth, the background temperature of space, the internal heat generated by the spacecraft and by the emittance and absorptance of spacecraft coatings. Predicting the operating temperature of the spacecraft therefore requires a knowledge of the thermal properties (absorptance and emittance) of the coatings used. In addition to these basic requirements, it is usually necessary to be cognizant of other spacecraft requirements such as spacecraft charging and particulate and molecular contamination requirements in order to choose the proper thermal control coating. It is also important to know how those properties are going to degrade throughout the life of the spacecraft due to exposure to UV, high energy protons and electrons, low energy solar wind protons, and contamination from other parts of the spacecraft. The practice for the selection and application of thermal control coatings includes the following key elements in the selection and application of thermal coatings:

1) The absorptivity and emissivity of particular thermal control coatings are determined and verified by testing. When possible, test measurements are made with the test sample subject to actual flight conditions such as vacuum, temperature, etc.

Electromagnetic theory can give useful insights into the absorption and emission of electromagnetic energy from thermal control coatings and how the absorption and emissivity vary as a function of angle, temperature, and wavelength. Maxwells equations can be used to show a theoretical description of the interaction of electromagnetic radiation with spacecraft coatings if one knows the optical constants of conductivity, permittivity, and permeability of the coating. However, In a number of cases, it has been shown that predicted reflectivity and emittance do not agree with test measurements. This can be due to lack of precise data and also due to the fact that electromagnetic theory does not always account for factors that can cause irregularities in the actual performance. Therefore, the absorptivity and emissivity of particular thermal control coatings are determined and verified by testing.

2) Effects of surface roughness and coating thickness are primary considerations in applications of coatings.

The surface roughness and the thickness of thermal coatings can have a significant effect upon the emittance and absorptance of the coating. The absorption and emittance will begin to change when the surface is no longer optically smooth; that is when surface defects are much smaller than the wavelength of radiation being absorbed or emitted. When the wavelength becomes comparable to the size of the imperfections, multiple reflections and diffraction effects can occur resulting in changes in the absorption and emittance. Also, if the coating is too thin, the coating becomes partially transparent in the infrared or visible part of the spectrum. This makes the effective emittance or absorption of the coating the sum of the emittance of the coating plus some portion of the emittance of the substrate. It is important to test samples analogous in roughness ans thickness (same coating processes and substrate) as used in the space application. Thickness is also a consideration for optimum adhesion and stability during thermal cycling.

3) Flight data is researched and laboratory testing is performed to determine a thermal coating's susceptibility to space radiation and the amount of degradation that can be expected during the lifetime of a mission.

Degradation of thermal control coatings in space can manifest itself as changes in emittance, solar absorptance, loss of adhesion, changes in specularity, or changes in electrical conductivity. These changes can be caused by absorption of electromagnetic photons, contamination of the coating by outgassing from other parts of the spacecraft, and by thermal effects on the coatings. The degree to which thermal coatings degrade also depend upon the energy and total contamination that the coatings receive during the mission. It is therefore, necessary to assess the mission radiation environment. This includes the energy fluency at each energy level of protons, the total UV exposure and atomic oxygen exposure level over the life of the mission. From this data, a test program is devised to determine the susceptibility of the coating to each form of radiation as well as to assess the synergistic effects of multiple radiation sources.

4) A detailed analysis of the contamination of the spacecraft is performed in order to determine the amount and type of contaminates expected to develop on surfaces of the spacecraft.

Chemical contaminants on surfaces including oxide layers deposited either by absorption or through a chemical reaction with the surface can cause significant changes to the absorptance, emittance and conductivity. These surface contaminants can change the chemical composition of the outer layer and the electrical conductivity thereby increasing the emittance of most metals. Particulate surface contaminates can also affect the thermal properties of coatings. This effect though is usually much less than that caused by chemical contaminants. Particulates tend to scatter incident radiation but since the total area coverage is small they generally do not greatly affect the absorption or emittance unless the contamination becomes excessive. In addition, very thin layers of particulate contamination can have an effect on the emittance of a coating and must be taken into account.

5) Electrical properties are primary considerations used in the selection of thermal control coatings.

Electrostatic discharges (ESD) can occur in space between various parts of a spacecraft due to differential charging of the spacecraft caused by energetic charged particles. This ESD is a source of electromagnetic interference (EMI) which can be coupled to electronic circuits and devices. Sensitive ICs can be damaged by several micro-joules (uJ) of ESD and circuits can be upset with only several nano-joules (nJ). This charging phenomena has been blamed for arcing that has caused blown fuses and loss of data transmission on several spacecraft. ESD can also cause electronic parts failure, operational anomalies, degradation of thermal control surfaces, and can also render low energy particle detectors useless. It is recommended that the energy stored by each electrical nonconductive surface be less than milli-joule (3mJ) and that ESD should not be allowed to occur near receivers or antennas operating at frequencies less than 8 GHz or near sensitive circuits. This implies that the spacecraft must be immune to 3 mJ ESD.

Differential spacecraft charging is primarily the result of low energy electron flux. High energy electrons penetrate the thin thermal coatings and therefore do not contribute to the differential charging process. The relatively few high energy protons encountered do not penetrate the coatings and therefore contribute to the charging although to a much less extent than the low energy electron flux. This is because the mass of electrons is much less than the mass of protons and they must travel much faster than protons in order to reach the same kinetic energy and hence thermodynamic equilibrium. This means that the total number of electrons passing a given point in a fixed amount of time is greater than for protons, therefore the spacecraft receives a much greater electron flux than proton flux.

Finding a coating which satisfies both thermal and electrical conductivity requirements is sometimes difficult to achieve, particularly if a low absorptance high emittance coating is needed. The conductivity of coatings can depend upon a number of factors. First, the length of time the coating has been exposed to vacuum can cause outgassing of volitales and water vapor which can alter the conductivity. Second, the energy of the electron flux can have a bearing on the extent to which a coating will charge since the conductivity is a function of particle energy. And thirdly, the temperature of the coating can also play a significant role in the charging process. Therefore the measurement and the verification of the conductivity of space flight coatings is performed under as close to actual conditions as is possible in a laboratory.

In those cases where a coating is applied over a nonconductive substrate, charge control is achieved through the conductivity of the coating. Provisions are made for grounding the edges of the coating. In some cases the substrate is coated with a conductive medium before the thermal coating is applied in order to alleviate a high charge with respect to ground. Refer to the following Figures 1 and 2 for methods for grounding conductive coatings to spacecraft ground.

> *6) Specific, detailed, and written GSFC approved methods and procedures have been prepared for the selection, handling, and application of each thermal coating used on GSFC instruments and spacecraft.*

These procedures have been prepared for both paint and tape coatings. The procedures include general considerations on the use and applications of the coatings, formulation where applicable, and complete procurement and acceptance inspection and testing requirements. Acceptance testing includes outgassing tests, electrical charging and erosion characteristic measurements as applicable, adhesion, and optical measurements and degradation. Materials and equipment lists for handling and applying the coatings are provided including safety and toxic considerations and equipment such as air filtration and ventilation hoods etc. Formulation and blending procedures are detailed where applicable as well as surface preparation and cleaning procedures including post coating operations and cleaning and touch up. The application of the coating whether bybrush, spraying, or by applications of strips of tape are defined. The procedures require monitoring samples for inspection and testing and in some cases require that monitoring

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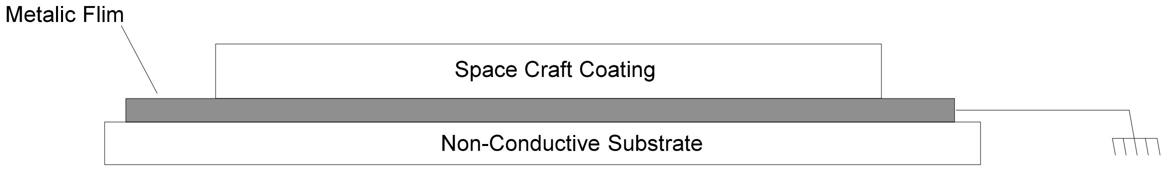

Figure 1. Method for grounding spacecraft coating to a nonconductive substrate

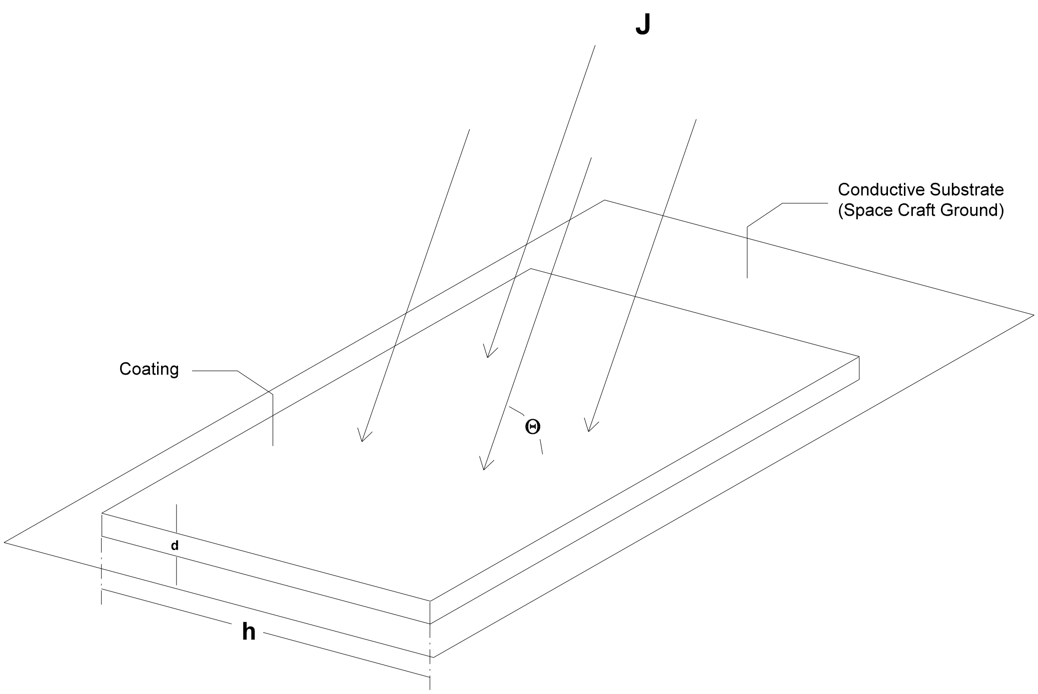

Figure 2. Space Craft Coating on a Conductive Substrate

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samples be maintained for inspection and testing throughout the life of the coating in space. Storage requirements and shelf life limitations of coating materials must be observed. Curing times can be a factor to be considered in the selection of coatings due to interference with other testing or hardware activities.

Complete documentation is maintained of the coating material from delivery to launch of the spacecraft. A procurement log of delivery date, manufacturer's batch and lot numbers, expiration of shelf life date, etc. and incoming inspection and testing data including monitor samples are maintained. A processing work order document is filed in the coating facility to provide a description of the specific coating requirements including required tests and test samples. A complete log of the coating process including any problems and test failures is maintained.

Technical Rational:

The reliable operation of a spacecraft and its complement of scientific instruments and equipment require thermal controlcoatings to maintain temperatures within specified ranges. In addition, these coatings must also control spacecraft charging and ESD. This practice ensures good thermal coating design and application procedures to reliably meet a wide variety of thermal design and ESD requirements.

Impact of Nonpractice:

If this practice is not followed, thermal control may not be maintained and spacecraft and their instruments and equipments may be damaged and fail due to exposure to temperature ranges beyond operating and failure limits. Also, ESD could occur which can cause damage and failures to hardware.

Reference:

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10) NASA Reference Publication 1121 Entitled "Solar Absorptance and Thermal Emittance of Some Common Spacecraft Thermal Control Coatings" Prepared by John Henniger
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