SOLAR ARRAY RELIABILITY IN SATELLITE OPERATIONS

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ABSTRACT

Providing reliable power over the anticipated mission life is critical to all satellites; therefore solar arrays are one of the most vital links to satellite mission success. Solar arrays are exposed to the harshest environment of virtually any satellite component causing a significant amount of documented anomalies. It is clear that solar array reliability is a serious, industry-wide issue. This paper will document a statistical analysis that was undertaken to deduce the factors affecting satellite reliability. Suggestions to improve the reliability of the solar arrays will be included. Solar array reliability is an issue that must be addressed to both reduce costs and ensure continued viability of the commercial and government assets on orbit.

INTRODUCTION

Providing reliable power over the anticipated mission life is critical to all satellites; therefore solar arrays are one of the most vital links to satellite mission success. Furthermore, solar arrays are exposed to the harshest environment of virtually any satellite component. Over the last ten years Airclaims has documented 117 satellite solar array anomalies, 12 of which resulted in total satellite failure. Thus it is clear that solar array reliability is a serious, industry-wide issue.

To better face the challenge of solar array failures on orbit, more feedback is essential. A statistical analysis has been completed through the use of Ascend's Airclaims SpaceTrak database which is the space industry's leading events-based launch and satellite database [1]. Factors affecting satellite reliability including type of anomaly, what manufacturers are involved in these anomalies, the average time after launch that an anomaly will occur, how many of these anomalies prove fatal, and if the reliability of satellites is improving will be presented and discussed.

Suggestions for the next steps that could be taken by the satellite industry to improve the reliability of the solar arrays will be included. Solar array reliability is an issue that must be addressed to both reduce costs and ensure continued viability of the commercial and government assets on orbit.

SATELLITE ANOMALIES

The space environment consists of many hazards such as radiation, micrometeoroids, and thermal extremes that can lead to the degradation and even failure of satellites. It is well known that anomalies and failures of satellites are occurring, but the reality is that few people know the exact cause and conditions surrounding these failures. With access to the Ascend's Airclaims SpaceTrak database, many factors of satellite reliability have been queried and analyzed. The integration of this information makes it possible to determine trends in satellite reliability. The solar array anomalies that have occurred on orbit in the past ten years have been categorized by year and orbit showing that the number of satellite failures in GEO is significantly greater than any other orbit (see Fig. 1). This failure rate is not due to GEO having a higher launch rate, in fact, LEO has the highest launch rate but is associated with much lower levels of anomalies. This information allows manufacturers to focus on the issues in GEO that are causing failures and modify their solar array designs to withstand the environmental conditions present in this orbit. GEO failures are believed to be attributed to electrostatic discharge caused when an array comes out of an eclipse. By analyzing the known anomalies it is possible to pinpoint key issues where attention needs to be placed to find solutions.

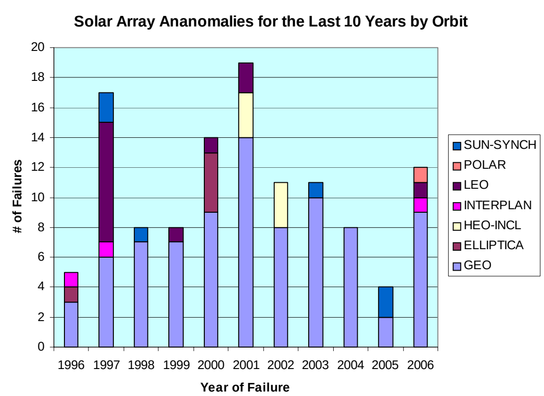

Fig. 1. Solar array anomalies by orbit

Solar array anomalies show the classic infant mortality trend (see Fig. 2). Infant mortality generally indicates that the design is poor and/or there are defects in construction. This observation raises fundamental questions about solar array designs, construction, and testing prior to launch. It has also been determined from the SpaceTrak database that no single manufacturer is having all the problems (see Fig. 3). All satellite manufactures have had anomalies and failures. Figure 3 shows the top ten manufactures by the number of insurance claims issued. This list does not compare market share to the number of failures, so actual names

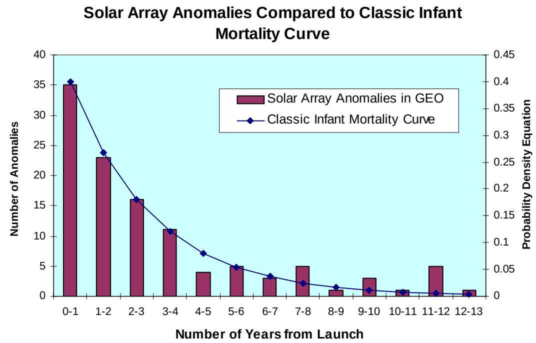

Fig. 2. Infant mortality curve relation to solar array anomalies

have been left off so assumptions are not made on the reliability of certain manufacturers. The most important detail of this figure is that six different countries are represented in the top ten manufactures in relation to number of anomalies. Failures are a worldwide phenomenon; therefore, defects in construction are an unlikely cause of the relation to infant mortality. Unfortunately, new solar array designs are usually not considered for flight due to the conservative belief that flight heritage is the best proof of performance and that requiring more pre-launch testing will resolve the problems. Most stringent testing will not correct an inherent design flaw.

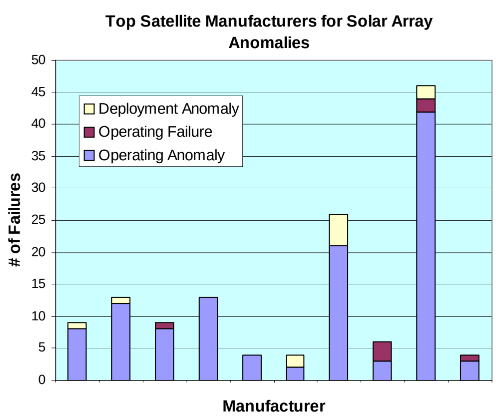

Fig. 3. Top Satellite Manufactures for anomalies

Solar array anomalies account for the majority of satellite power system anomalies. In the last ten years, power anomalies have ranked third in number of anomalies at 19% of the total; attitude control and payload instrumentation subsystems are the lead causes. Because of this, the emphasis for improvement is not focused on power issues. The significance of power anomalies is not readily seen until past insurance claims are analyzed. In the same time period that power anomalies made of 19% of incidents, power anomalies made up 47% of insurance claims (see Fig. 4). Of this

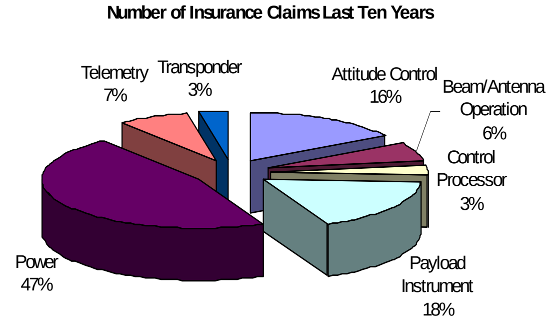

Fig. 4. Number of insurance claims in last 10 years

47%, solar arrays have been at fault in 69% of the cases. More importantly, Frost and Sullivan published a pie chart (see Fig. 5) which shows solar arrays made up 49% of the value of all claims by anomaly type in 2004 [2]. Solar array anomalies are the costliest insurance claims. This has caused increases in insurance rates and a negative perception by investors. Although anomalies have decreased in the last few years, the consequences of previous failures still affect the industry though high insurance rates, up to about 50% of the cost of the satellite. In addition there is a resistance to using new technology due to increased fear of failure.

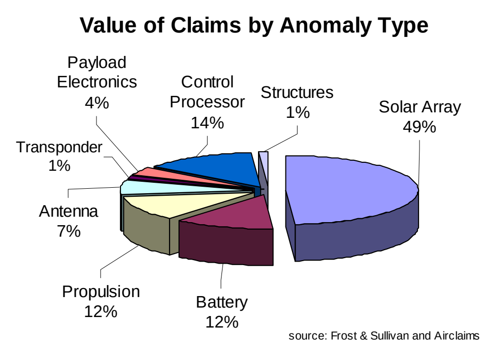

Fig. 5. Value of insurance claims for 2004.

To address the impact of solar array anomalies, it is important to understand the significance of an anomaly (see Fig. 6). A type 1 anomaly indicates a complete failure for either deployment or operation of the satellite. A type II operating anomaly is non-repairable and affects the operation on a permanent basis. Type III anomalies are non-repairable failures that cause lack of redundancy to the operation on a permanent basis. Type IV anomalies are temporary or repairable and do not have a significant permanent impact on operation. The actual failure cause can be inexact but it is of great importance to note that 71% of all solar array anomalies are type I or II which results in a permanent impact on the operation.

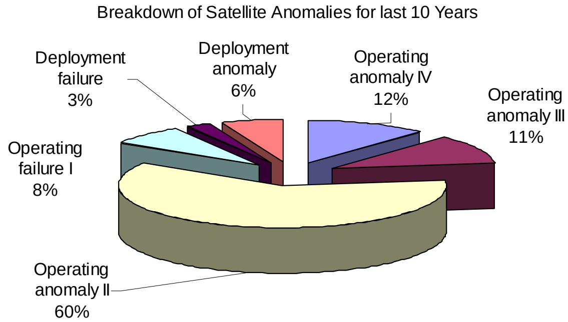

Fig. 6. Satellite Anomaly Breakdown

RECOMMENDATIONS

Obtaining more information on existing anomalies is the most important step in eradicating future failures. Open disclosure of anomalies and industry group strategizing in overcoming them is essential and can be done without exposing proprietary information. Another desirable process is to establish a working relationship between satellite manufacturers and insurance companies that has no penalties for disclosure of potential problem areas. Satellites also must be equipped with enough on-orbit diagnostic instrumentation to more accurately determine the cause of an anomaly. Solar arrays are currently poorly instrumented making it difficult to accurately determine the root cause of a failure. The new AIAA standard S-121-2006 “Electric Power Systems for Unmanned Spacecraft” includes a requirement for full I-V curve instrumentation. This standard should improve data collection capability for launches 4-6 years in the future.

Other emerging AIAA standards address the issue of standardization of testing procedures. These three standards documents are AIAA S-111-2005 “Qualification and Quality Requirements for Space Solar Cells”, AIAA S-112-2005 “Qualification and Quality Requirements for Space Solar Arrays”, and AIAA S-121-2005 “Electric Power Systems for Unmanned Spacecraft”. Standardization of testing procedures will help facilitate the philosophy of test-as-you-fly fly-as-you-test. This should help to alleviate anomalies associated with over-testing along with addressing issues seen in on-orbit failures. However, the entire industry must embrace these procedures in order to improve array quality.

Another recommendation that has the potential to increase solar array reliability is the creation of an international committee on satellite failures through an underwriters’ agency. This could take the form of a certified module and array testing facility (somewhat akin to the Underwriters’ Laboratory for terrestrial electrical appliances) that would be able to certify in-space reliability. Each manufacturer currently has their own facilities for testing, but all yield different results. This often leads to tests which are too extreme which can in turn lead to orbital failures. Uniformity across the industry would help to validate appropriate testing methods. An underwriters’ laboratory would be the center for design validation and would be available to all satellite manufacturers. A working relationship between this entity and the satellite insurance underwriting industry is vital to help lower rates according to testing practices and certification results.

Solar array power levels will continue to increase as lunar bases, solar electric propulsion missions, and higher power communication satellites are developed. As power levels continue to increase more durable arrays that can operate in high voltage operations must be incorporated. Operating spacecraft buses at 100 V and above has led to arcing in GEO communications satellites. Thus the issue of spacecraft charging and solar array arcing remains a serious design problem as shown by the high occurrence of anomalies in GEO (see Fig.1). Ground testing of solar arrays at high voltages can determine potential charging issues that need to be addressed prior to launch. Finding solar array designs to withstand the GEO environment will lead to arrays that will match the requirements for future high voltage mission success. An optimal candidate would be an array that encapsulates the entire cell and cell edges providing a sealed environment without incurring a significant mass penalty. One example of this type of array is the Stretched Lens Array (see Fig. 7). Because of the inherent design of the concentrator system, the small-area cells and interconnects are completely encapsulated. However, new technology is usually not embraced due to the increased fear of failure. Satellite owners and manufactures would rather “stick with what they know” than to take any additional risks. This limits the opportunities to make major increases in solar array reliability. Newer designs are often engineered and built to withstand known

Fig. 7. A 3.75 kW Stretched lens array on a SquareRigger platform

anomalies, yet "heritage" is deemed more worthy. However, in retrospect, oftentimes sufficient changes have been made in the design to eliminate its heritage status. Accepting the risks and flying improved technologies that have been thoroughly tested will be required to overcome the challenges of the hazardous space environment and increased voltage demands for future satellites.

CONCLUSION

Solar arrays are vital to satellite mission success; however, solar array anomalies continue to occur, thus making them unreliable and costly liabilities. A statistical analysis of past documented anomalies has revealed that GEO is the most damaging orbit, the majority of anomalies occur in the first two years of solar array service, solar array insurance claims occur most often of all power anomalies and are the costliest, and 60% of all solar array anomalies are of a type II affiliation which results in a permanent impact on the operation. Recommendations to increase the reliability of solar arrays include obtaining more information on existing anomalies through open disclosure of anomalies and industry group strategizing, along with equipping satellites with enough on-orbit diagnostic instrumentation to better understand the cause of the anomalies. Emerging AIAA standards address the issue of standardization of testing procedures in an effort to facilitate the philosophy of test-as-you-fly. Embracing new technology that is engineered and built to withstand known anomalies is a necessity in improving satellite reliability. The industry will always have to contend with some anomalies but these steps will lessen the degree to which the industry is affected overall. Solar array reliability is an issue that must be addressed.

REFERENCES

[1] Airclaims Ascend SpaceTrak Database www.ascendspacetrak.com/Home

[2] P.Lecointe, "Satellites failures in orbit Focus on power systems," Hiscox Syndicates Ltd. @ Lloyd's, *Space Power Workshop,* 2005.