Reliability and Cost Reduction of Solar Arrays for GEO Satellites

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(Tracking Number = 80782)

Solar array reliability has become a serious issue over the past decade. From AirClaims's Ascend SpaceTrak database, more than 117 solar power system anomalies have been reported from 1996 to 2006. Eighty-three (71%) of these have occurred in GEO. This paper will discuss power system issues with the focus on solar array reliability issues in GEO. Recommendations from the Prospector XII – Space Solar Array Cost Reduction Workshop on how to decrease solar array costs by increasing reliability will be addressed.

I. INTRODUCTION

Power delivery over the mission life is critical to all satellites; therefore solar arrays must be reliable and live up to predicted on-orbit performance. Space satellite insurance claims were particularly high from 1998 to 2001. This has caused both a negative perception and a financial impact on the satellite industry as a whole due to increased insurance rates. These factors then affect the quality and services provided by commercial satellite operators. In reality, solar arrays are the cause of a large percentage of these satellite anomalies. This is especially true in GEO missions as can be seen in Figure 1 where solar array anomalies reach a level as high as 33% of the total anomaly reports. In GEO, the anomaly often occurs when the satellite comes out of an eclipse period, yet over the years, no effective solution for this problem has been implemented.

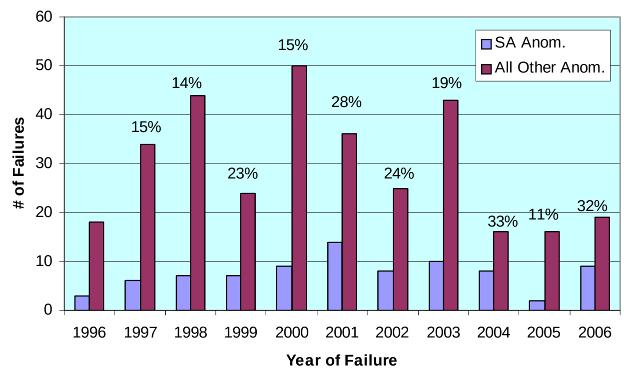

Figure 1: Solar array anomalies vs. all anomalies in GEO

Solar array costs and reliability issues were recently discussed at Prospector XII – Space Solar Array Cost Reduction Workshop. It was made clear that the solar cell suppliers have been under extreme pressure to continually reduce costs. However, the array anomalies are not due to the cells themselves, but are array related. Thus cost reduction strategies have to lead to significant increases in solar array reliability. Recommendations from the workshop included steps that could be taken to implement changes across the industry to reduce these solar array-related costs and some of these will be presented.

In addition, the types of anomalies seen in GEO satellites in the past ten years will be examined and trends will be shown. With access to the Ascend SpaceTrak database many factors of satellite reliability have been queried and analyzed to determine which type of anomaly occurs most often, which anomaly has the greatest insurance loss, what manufacturers are involved in the majority of anomalies, what anomalies are industry wide, what is the average timeframe after launch that an anomaly will occur, and how many of these anomalies prove fatal. In addition, it is possible to determine if the reliability of satellites is getting better or worse.

Suggestions for next steps that could be taken by the satellite industry to improve the reliability of the solar arrays in GEO will be included. It will also be shown that increasing the reliability of solar arrays will also reduce their cost and will help put the space satellite industry back in good standing with the insurance underwriters.

II. SOLAR ARRAY ANOMALY ISSUES

Solar arrays are arguable the most critical component to satellite success because they are responsible for supplying reliable and predictable power to the satellite over the entire mission life. However, solar array reliability has become a serious issue over the past decade. From AirClaims's Ascend SpaceTrak database, more than 117 solar power system anomalies have been reported from 1996 to 2006. Eighty-three (71%) of these have occurred in GEO. To better face the challenge of solar array anomalies on orbit, more feedback and dissemination of the data to the entire industry is essential. The goal is to do a detailed statistical analysis of satellite anomalies to find out what is reality versus what is perception. This paper examines trends in the types of anomalies seen in satellites in the past ten years by using information from the SpaceTrak database. This database is the space industry's leading events-based launch and satellite database and reports events as they occur.

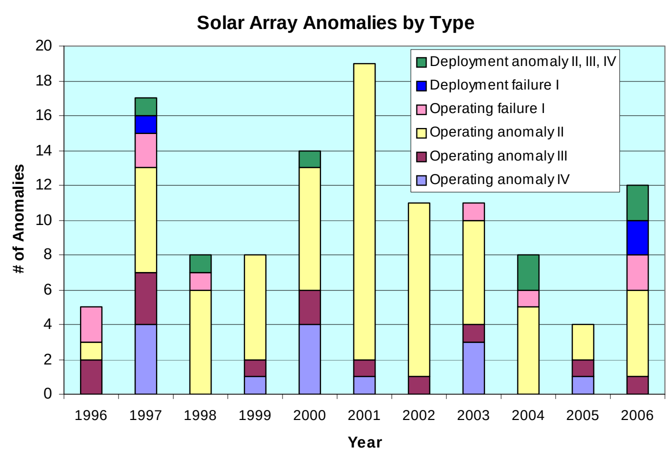

Figure 2: Solar Array Anomalies by Type

To address the impact of solar array anomalies, it is important to understand the significance of an anomaly. Figure 2 shows a graph of solar array anomalies for the last ten years separated into anomaly type. 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 and that is why more instrumentation must be added to determine root causes of these anomalies.

Prospector XII, a space solar array cost reduction workshop was help last September to determine the major drivers of spacecraft solar array-related costs and make recommendations of steps to reduce these solar array-related costs. Addressing the causes and/or drivers of higher-than-expected solar array costs and eliminating them is essential for the industry as a whole. It is important to note that two of the main concerns with the satellite industry are that there is not open disclosure of failures/anomalies or the actual costs. Another area of great concern that surfaced is that there is not enough monitoring available for solar arrays on orbit to ascertain the root cause of the problem when an anomaly occurs. It is impossible to increase reliability and reduce costs without knowing the facts behind the anomalies such as who, what, where, when, and why.

III. GEO SATELLITE ANOMALY STATISTICS

The GEO environment is especially dangerous for solar arrays. Spacecraft charging in geosynchronous orbit is a reality that can be destructive and thus negatively affect the satellite industry as a whole. Figure 3 shows that the number of satellite anomalies in GEO is significantly greater than any other orbit for the last ten years. In the last ten years only 25% of satellite launches went to GEO. However, 41% of all anomalies and failures occurred in GEO including 71% of all solar array anomalies. To better understand the importance of this figure it is essential to know the percentage of satellites being launched to GEO compared to other orbits, as seen in figure 4. The percentage for recent years is below 30% however, the rate of failure for that orbit is much higher. Figure 5 shows the ratio of anomalies to launches per year in both GEO and LEO which are the two most used orbits. This is not necessarily the best comparison since the anomalies do not just occur on the satellites that are launched that year but it does prove that anomalies in GEO are a serious issue. The majority of these anomalies can be traced to electrostatic discharges that often occur when the satellite emerges from an eclipse period into a solar storm. Yet over the last decade, no effective solution for this problem has been implemented. The consequences of spacecraft charging have ranged from intermittent

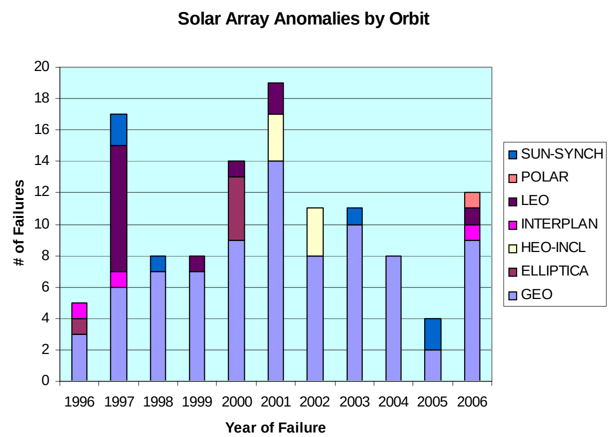

Figure 3: Satellite failures by orbit

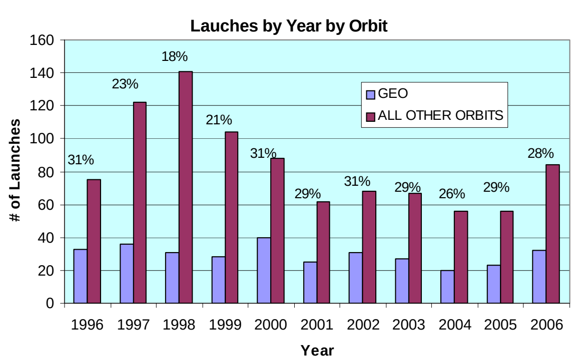

Figure 4: Launches by year by orbit

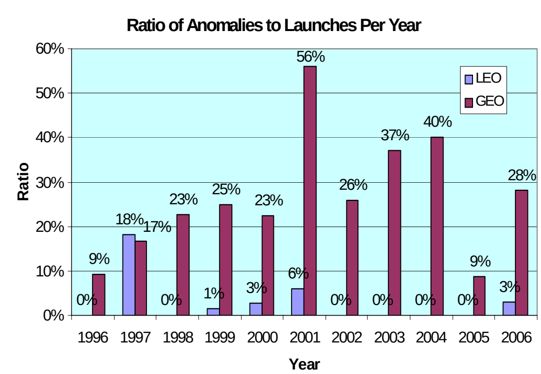

Figure 5: Ratio of anomalies by year by orbit

anomalous behavior up to catastrophic satellite failure.
As is well known, operating spacecraft buses at 100 V and above has led to arcing in GEO communications satellites, so the issue of spacecraft charging and solar array arcing remains a serious design problem. The number of solar array anomalies in satellites in GEO coincide quite well with the classic infant mortality curve as can be seen in Figure 6. 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. Nearly all manufacturers have this problem; therefore defects in construction are an unlikely cause. However, new designs are usually rejected due to the belief that flight heritage is the best proof of performance.

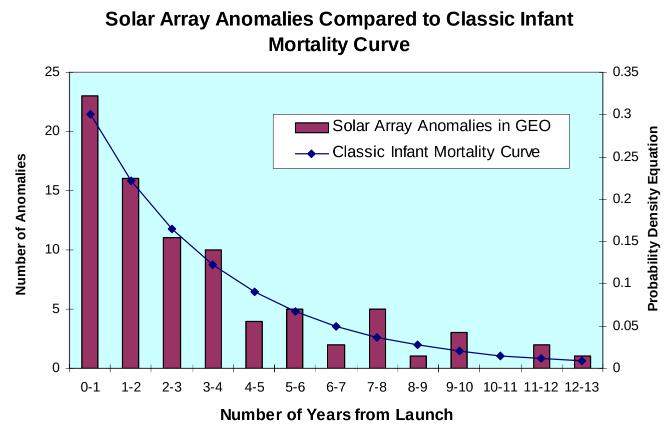

Figure 6: Years between launch and anomaly

Satellite insurance claims have had a very serious impact on the cost of insurance for commercial satellites. Over the period of 1999-2003, insurance claims made to one insurer exceeded $800M. Overall in the insurance industry, claims exceeding $2B have resulted from satellite losses over the past six years. Figure 7 shows the number of insurance claims by type of anomaly in GEO for the last ten years. Solar array anomalies make up 37%. Insurance premiums are directly related to industry claims and past performance. This results in not only increases in future insurance premiums, but the requirement by the insurance industry to design additional margin into power budgets before even issuing a policy is considered. This ultimately increases the cost of the solar array which now must be designed to provide additional power due to reduced performance reliability, whether it is justified or not. It is important to note that solar array anomalies are not occurring to just one or two manufactures. It is an industry wide problem.

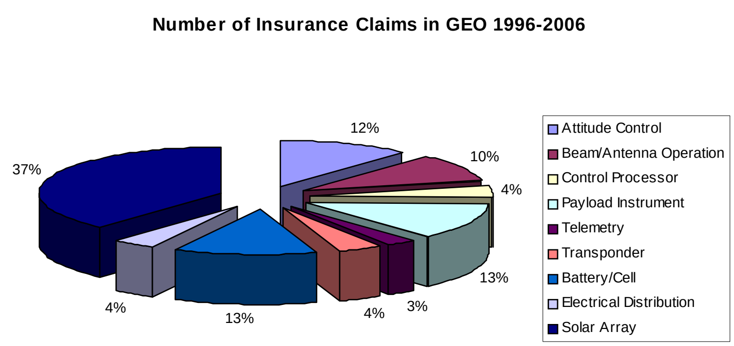

Figure 7: Number of Insurance Claims in GEO in last ten years

IV. **PROSPECTOR XII RECOMENDATIONS**

Prospector attendees quickly came to the consensus that cost reduction strategies must lead to significant increases in solar array reliability verses cost cutting in the design and fabrication of solar arrays and cells. Suppliers are already under continuous pressure to reduce costs by the competitive commercial satellite industry and profits are slender at best. The approach for making major cost reductions is best achieved by reliability improvements and subsequently demonstrated solar array durability in ground testing.

One major observation from the Prospector XII workshop is the lack of communication about the types and numbers of failures occurring in the satellite industry. Open disclosure of anomalies and group strategizing in overcoming them is essential. This can occur without disclosing proprietary information. There also needs to be a working relationship between satellite manufacturers and insurance companies with no penalties for disclosure of potential problem areas. Another area that must be addressed simultaneously is equipping satellites with enough on-orbit diagnostic instrumentation to accurately determine the cause of an anomaly. The problem must be accurately known before a solution can be determined.

Other discussions included standardization of facilities and procedures, implementation of the new testing requirements by AIAA, the philosophy of test-as-you-fly fly-as-you-test, misuse of "heritage", and the creation of a <u>certified</u> module and array testing laboratory akin to the Underwriters Laboratory for electrical appliances that would certify reliability of anyone's design in confidence and use the best ground test facilities and approaches.

V. CONCLUSIONS

Solar array reliability has become a serious issue over the past decade especially in GEO. Sharing of data across the industry for unclassified missions would be a meaningful step forward and more diagnostic instrumentation should be added to satellites. Major solar array cost reductions are best achieved by making array reliability improvements and examining new concepts that both reduce cost and may be inherently more reliable by design. In addition, new array designs and theoretical modeling have shown several ways of rendering GEO solar arrays much more resistant to arcing and similar plasma-induced failures. Emerging array designs need to be seriously examined. Some appear to offer the potential for lower cost and increased reliability for LEO to GEO applications. They need to be demonstrated in relevant orbits but there are limited opportunities at this time. Improvements in these areas will lead to cost savings through cost avoidance. Improvements to the reliability and quality of satellites will help put the space satellite industry back in good standing.