# Improving Space Utilization by Increasing Solar Array Reliability

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**Reliable power delivery over the mission life is critical to all satellites; therefore solar arrays are one of the most vital links to satellite mission success. However, in the last ten years, the Ascend Division of Airclaims has documented 117 satellite solar array anomalies, 12 of which resulted in total satellite failure, making solar array reliability a serious issue. This paper will discuss satellite power system issues with the focus on solar array reliability issues. Suggestions for next steps that could be taken by the satellite industry to improve the reliability of the solar arrays will be included. Ways to improve solar arrays for high power and geosynchronous power will also be discussed in an effort to address some of the main failure trends seen in the satellite anomaly analysis. Solar array reliability is an issue that must be addressed to take space utilization to the next level.**

## I. Introduction

RELIABLE power delivery over mission life is critical to all satellites; therefore solar arrays are one of the most vital links to satellite mission success. However, in the last ten years, the Ascend Division of Airclaims has documented 117 satellite solar array anomalies with 12 resulting in total satellite failure. These failures make solar array reliability a serious issue. Solar array anomalies account for the majority of satellite power system anomalies. In addition, solar array claims are much more costly than any other power system claims, resulting in almost half of insurance claim payouts. It is no wonder that satellite manufactures have faced criticism over these problems that has resulted in a negative perception and impact on the space industry as a whole. Thus it is imperative that the industry address these issues affecting the quality and services provided by satellite operators. 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. These factors combine to create the view that satellites are no longer a reliable commodity. For the future of the satellite industry, it is imperative to increase solar array reliability.

To better face the challenge of solar array failures on orbit, more feedback throughout the industry is essential. The types of anomalies seen in satellites over the past ten years need to be examined and trends analyzed. With access to the Ascend SpaceTrak database, many factors of satellite reliability have been queried and analyzed to determine which 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 time after launch that an anomaly will occur, and how many of these anomalies prove fatal to the satellite. Finally, the integration of this information makes it possible to determine trends in satellite reliability.

Another issue associated with satellite failures that must be considered is failure prior to launch. Over-testing the satellite is a prime example. Quality testing versus acceptance testing is an emerging issue. There is a need for standardization of testing procedures and setting limits as to what tests can be done on the flight hardware. In many cases, tests are done on engineering hardware that does not duplicate flight hardware. Based on our analysis, solar array anomalies show the classic infant mortality trend. 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.

This paper will discuss power system issues with the focus on solar array reliability issues. Suggestions for the next steps that could be taken by the satellite industry to improve the reliability of the solar arrays are included. These recommendations include the creation of an international committee on satellite failures through an underwriters' agency. Also ways to improve solar arrays for high power and geosynchronous orbit power will be

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discussed in an effort to address some of the main failure trends seen in the satellite anomaly analysis. Solar array reliability is an issue that must be addressed to take space utilization to the next level.

## II. 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. These failures can cause serious implications on the space industry as a whole by increased insurance premiums and a lack of confidence by investors. 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. This lack of knowledge is generally caused by lack of sensors and telemetry channels on the satellite for this purpose.

Most satellite incidents occurring in space today are tracked by Ascend's SpaceTrak database which is the space industry's leading events-based launch and satellite database. This database separates anomalies into four types to address the impact of the anomaly on the satellite. 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 cause of failure can be inexact leading to the need for more instrumentation that should be added to satellites to help determine the root causes of these anomalies.

### A. Power System Issues

Not only are anomalies broken down into the four types that determine the extent of damage caused by the anomaly; they are also broken down into the general subsystems of the satellite where the anomaly occurred. These include: attitude control, telemetry, mechanical structure, and power. This paper focuses on power anomalies with an emphasis on solar array 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 as shown in Fig. 1. 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 as shown in Fig. 2. Of this 47%, solar arrays have been at fault in 69% of the cases. More importantly, Frost and Sullivan published Fig. 3 which shows solar arrays made up 49% of the value of all claims by anomaly type in 2004.[1] Battery claims made up 12%, so in conjunction with solar arrays, power anomalies made up 61% of the value of all insurance claims in that year. This trend has continued in recent years. Thus it is no wonder that solar array manufacturers have faced criticism that has resulted in negative perceptions and impact on the space industry as a whole. This has affected the quality and services provided by satellite operators. The

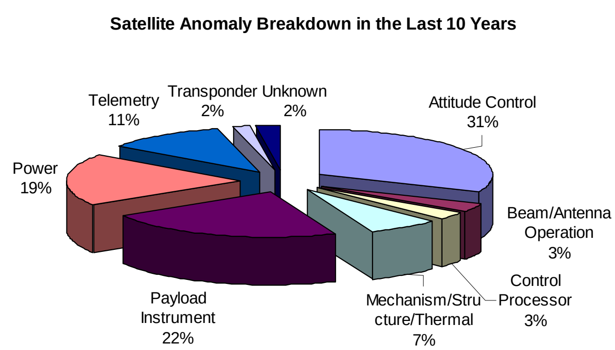


**Figure 1. Satellite anomaly breakdown last 10 years**

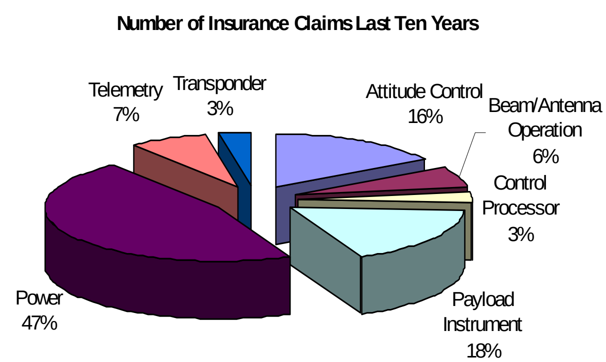


**Figure 2. Number of insurance claims in last 10 years**

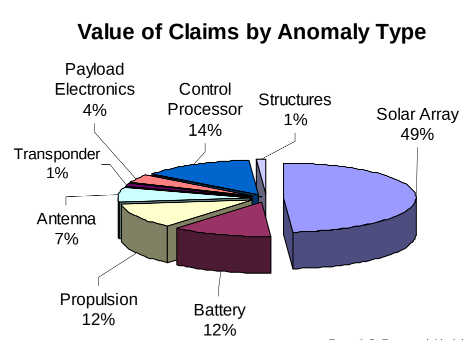


**Figure 3. Value of insurance claims for 2004**

consequences of these failures affect the industry through high insurance rates, approximately 50% of the cost of the satellite, along with new technology no longer being embraced due to increased fear of failure. Thus satellites are no longer seen as commodities. Power anomalies, with a focus on solar arrays, are a serious issue that must be understood and alleviated for the future of the satellite industry.

## B. Solar Array Issues

Solar arrays are exposed to the harshest environment of virtually any satellite component. In the last ten years 117 solar array anomalies have been documented. Sixty percent of these anomalies are type II anomalies meaning they are non-repairable and affect the operation on a permanent basis. Figure 4 shows the number of anomalies by orbit for the last ten years. The number of satellite anomalies in GEO is significantly greater than any other orbit for the last ten years. The general belief is that most, if not all of these anomalies, are due to electrostatic discharge. Unfortunately, without adequate monitoring channels, exact causes can be somewhat speculative. The number of launches in the last ten years by final orbit is presented in Fig. 5. These two graphs show conclusively that GEO is the most hazardous orbit for solar arrays. The charts also make it clear that this failure rate is not due to GEO having a higher launch rate. 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.

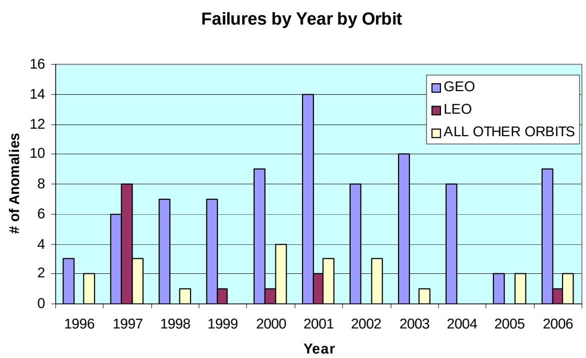


Figure 4. Solar array anomalies by year and orbit

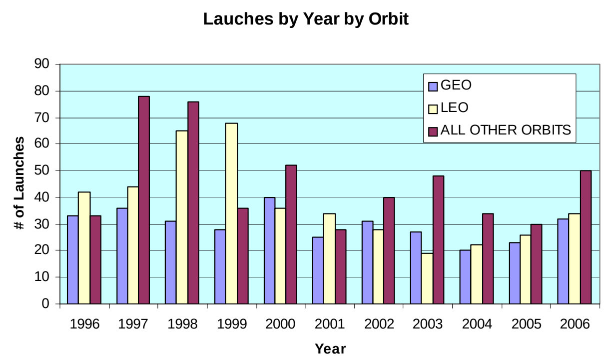


Figure 5. Launches by year and orbit

Solar array anomalies show the classic infant mortality trend as depicted in Fig. 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. It has also been determined from the SpaceTrak data base that no single manufacturer is having all the problems. These failures are a worldwide phenomenon; therefore, defects in construction are an unlikely cause. However, as noted before, new solar array designs are usually not considered 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. However, more pre-launch testing can lead to over testing resulting in additional failures.

## C. Failures Prior to Launch

Over-testing is a prime example of procedures that lead to satellite failures prior to launch. Quality testing versus acceptance testing is an emerging issue in the industry today. There is a need for standardization of testing procedures and providing a limit to what tests can be done on the actual flight hardware. Ground testing needs to accurately reflect the expected space flight conditions and not test the array to extremes that will not be observed on orbit. Past over-testing has introduced failures on orbit.[2] Unfortunately, the Ascend SpaceTrak database is not able to distinguish if over-testing is a cause of orbital failures. From discussions with representatives in all areas of the satellite industry it has been recognized as a problem.[2]

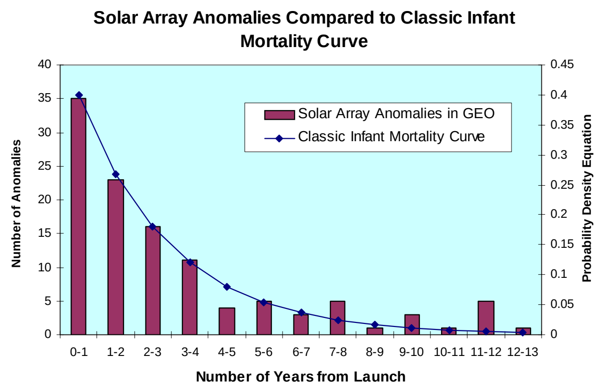


Figure 6. Infant mortality trend with respect to solar array anomalies

"Test as you fly and fly as you test" should be the accepted industry-wide procedure. Improper testing of a design occurs by failure to accurately recreate all the spacecraft's environments or by placing overly cautious margins on environments. Such instances can lead to testing failures of a design that would have been perfectly adequate for a mission. AIAA has taken steps to develop new, universal testing requirements for cells ("Qualification and Quality Requirements for Space Solar Cells" S-111-2005) and arrays ("Qualification and Quality Requirements for Space Solar Arrays" S-112-2005) that should help alleviate these problems. However, the entire industry must embrace these procedures in order to improve array quality.

## III. Steps for Improvement

### A. Diagnostic Instrumentation and Data Dissemination

To better face the challenge of solar array failures on orbit, more feedback is essential. Currently there is lack of communication about the types and numbers of failures occurring in the satellite industry. Open disclosure of anomalies and industry group strategizing in overcoming them is essential. This communication can occur without disclosing 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. Another area that must be addressed simultaneously is to equip satellites with enough on-orbit diagnostic instrumentation to more accurately determine the cause of an anomaly. The root cause must be accurately known before a viable solution can be determined. Solar arrays are poorly instrumented now, making it difficult, if not impossible, to uncover the root cause of on-orbit failures. More diagnostic instrumentation should be added. Often the only information available is that the solar array string failed open or shorted. The new AIAA standard S-121-2006 "Electric Power Systems for Unmanned Spacecraft" includes a requirement for full I-V curve instrumentation that should improve data collection capability for launches 4-6 years in the future.

### B. Underwriters' Laboratory for Solar Arrays

Another suggestion for improving the reliability of solar arrays is the creation of an international committee on satellite failures through satellite insurance underwriters and their parent organizations. 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. The facility would need to be equipped with appropriate test chambers and the expertise to perform array certification to agreed-upon testing protocols. This independent entity would validate existing and emerging solar array designs and technologies, and ensure that arrays made with these technologies would function as designed in their intended orbital location. This facility would also conduct studies to increase solar array reliability, would strive to determine factors to reduce array cost, and would help develop new testing protocols. 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. A reduction in the insurance claims due to solar array failures would lead to a substantial benefit to the insurance underwriting industry. A standardization of testing protocols and procedures by a single entity would also help eradicate failures prior to launch due to over-testing of the flight hardware.

### C. High Voltage and Geosynchronous Satellite Power System Improvements

As is well known, 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 from Fig.4. Ground testing of solar arrays at high voltages can determine potential charging issues that need to be addressed prior to launch. Testing should include corona discharge and hypervelocity particle impact tests, but standardized testing procedures currently do not exist. It is well known that exposed solar arrays can collect large currents from the space plasma. While there are documents that aid in these designs, they do not appear to be routinely used.[3] In addition, corona testing can detect the emergence of defects in the insulation system that occur over time due to the voltage stress across the insulation layer(s) which could subsequently lead to catastrophic failure. These failures may take more than a decade to emerge. It is well-known that to reduce the occurrence of arcing, the potential of the cell or interconnect and the cover glass should be kept the same, especially in GEO.[4] Through extensive ground testing, an understanding of charging effects has been obtained which enables design of reliable high voltage solar arrays for the future. Solar array power levels will continue to increase as lunar bases, solar electric propulsion missions, and higher power communication satellites are developed. 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 shown in Fig. 7. Because of the inherent design of the concentrator system, the small-area cells and interconnects are completely encapsulated.

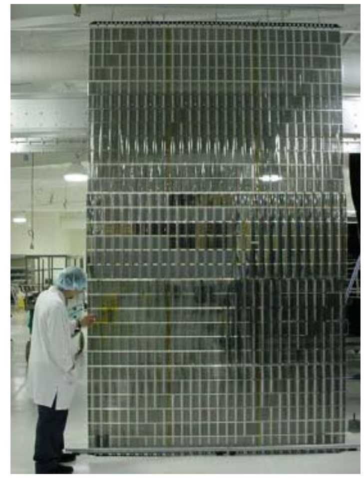

**Figure 7. 3.75 kW Stretched lens array on a SquareRigger platform**

### D. Embracing New Technology

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 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.

## IV. Conclusion

Solar arrays are vital to satellite mission success; however, solar array anomalies continue to occur, thus making them unreliable and costly liabilities. Analysis has shown that GEO is the most hazardous orbit for solar arrays with 71% of anomalies occurring there. Power anomalies made up 61% of the value of all insurance claims one year with solar arrays making up 49% of the claims. Satellite failures prior to launch due to over testing, has been another blow to solar array reliability. The consequences of failures affect the industry though high insurance rates and a negative perception on the space industry as a whole. Steps that could be taken by the satellite industry to improve the reliability of the solar arrays include the creation of an international committee on satellite failures through an underwriters' agency, more diagnostic instrumentation on the satellites, anomaly data dissemination across the industry, and a standardized testing regime that will accurately test the solar array but will not over-test actual flight hardware. Improvements to the design of solar arrays for GEO orbits will be needed to protect against electrostatic discharge and better testing regimes will need to be instigated. New technology needs to be embraced to contend with the hazardous space environment and increased voltage demands for future satellite missions. 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 to take space utilization to the next level.

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