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# Space solar array reliability: A study and recommendations

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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. Furthermore, solar arrays are exposed to the harshest environment of virtually any satellite component. In the past 10 years 117 satellite solar array anomalies have been recorded with 12 resulting in total satellite failure. Through an in-depth analysis of satellite anomalies listed in the Airclaim's Ascend SpaceTrak database, it is clear that solar array reliability is a serious, industry-wide issue. Solar array reliability directly affects the cost of future satellites through increased insurance premiums and a lack of confidence by investors. Recommendations for improving reliability through careful ground testing, standardization of testing procedures such as the emerging AIAA standards, and data sharing across the industry will be discussed. The benefits of creating a certified module and array testing facility that would certify in-space reliability will also be briefly examined. 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.


## 1. 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 10 years Airclaim's Ascend SpaceTrak database has documented 117 satellite solar array anomalies, 12 of which resulted in total satellite failure. Through an in-depth analysis of satellite anomalies it is clear that solar array reliability is a serious, industry-wide issue. To make matters worse, solar array claims are more costly than any other power system element. They result in almost half the value of all insurance claims. Although these anomalies have decreased in the last few years, the consequences of previous failures still affect the industry through high insurance rates. For the future of the satellite industry, it is imperative to increase solar array reliability. Factors affecting satellite reliability including the type of anomaly, what manufacturers were involved, the average time after launch that an anomaly occurred, and how many of these anomalies proved fatal will be presented and discussed. Recommendations for improving reliability through careful ground testing, standardization of testing procedures such as the emerging AIAA standards, data sharing across the industry, and others will be discussed. The benefits of creating a certified module and array testing facility that would certify in-space reliability will also be briefly examined. 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.

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## 2. Solar array anomalies

### *2.1. Overview of solar array anomalies*

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. Most satellite incidents occurring in space today are tracked by Ascend's database which is the space industry's leading events-based launch and satellite database [1]. This database separates anomalies into four types to address the impact of the anomaly on the satellite and further separates anomalies into the general subsystem of the satellite where the anomaly occurred. This paper focuses on solar array anomalies which are a sub-set of all power anomalies. Fig. 1 depicts the solar array anomalies that have occurred on orbit in the past 10 years. The anomalies are separated by year and orbit showing that the number of satellite failures in GEO is significantly greater than any other orbit. This is 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.

### *2.2. Insurance issues associated with anomalies*

Solar array anomalies made up 33% of all insurance claims in the last 10 years as seen in Fig. 2. However, solar arrays made up 49% of the value of all insurance claims in Fig. 3 [2]. Premiums are directly related to industry claims and past performance. One insurer reports that recent on orbit failures have exhausted the premium pool that had been established for such losses ($800M) [3]. The consequences of previous failures affect the industry though high insurance rates (∼ 50% of the satellite cost) and 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. Past insurance claims also decrease the confidence of new investors.

### *2.3. Permanent impact of anomaly*

To address the impact of solar array anomalies, it is important to understand the significance of an anomaly. Fig. 4 shows a graph of solar array anomalies for the last 10 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

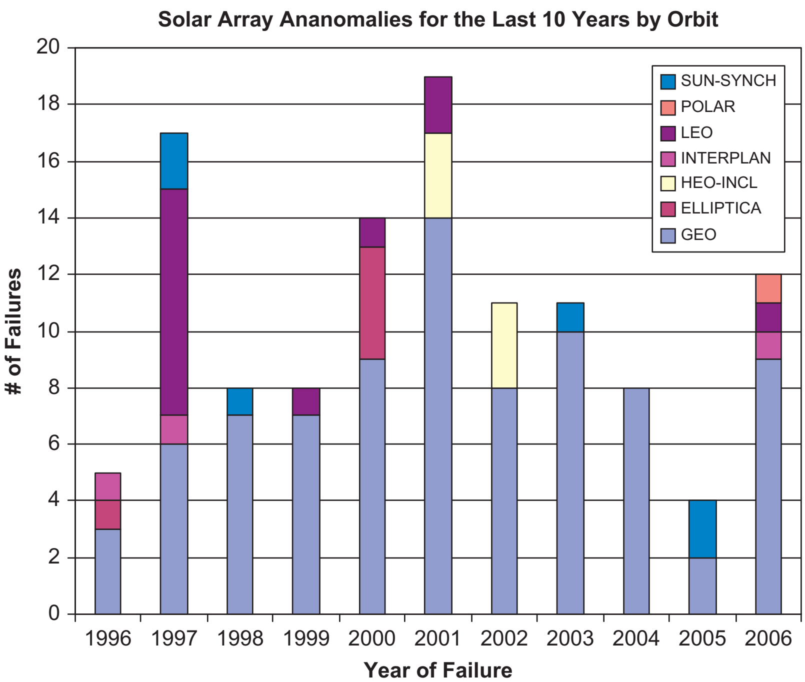


Fig. 1. Solar array anomalies by orbit.

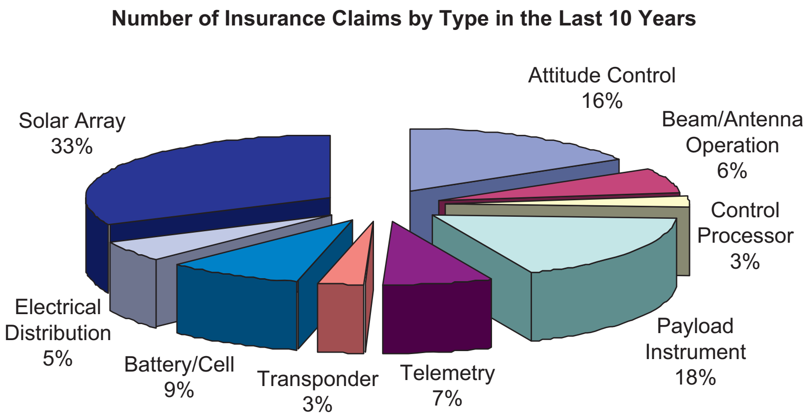


Fig. 2. Insurance claims from anomalies.

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 60% of all solar array anomalies are type II which results in a permanent impact on the operation.

### 2.4. *Time between launch and anomaly*

The time between satellite launch and the occurrence of a solar array anomaly coincides with the classic infant mortality trend as depicted in Fig. 5. 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 as shown in Fig. 6. All satellite manufactures have had anomalies and failures. Fig. 6 shows the top 10 manufactures by the number of insurance claims issued. This list does not compare market share to the number of failures; so actual names have been left off so that 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 10 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.

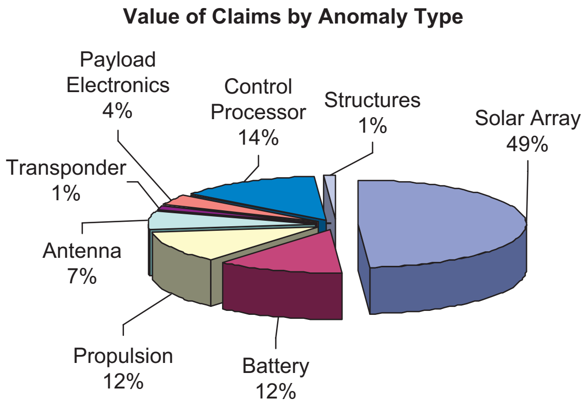


Fig. 3. Value of insurance claims for 2004.

## 3. Solar array reliability recommendations

### 3.1. *Data sharing across industry*

A common database on orbital failures can become an integral part of overcoming such failures. More feedback is essential to face the challenge of solar array failures on orbit. 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.

### 3.2. *Increasing diagnostic instrumentation on space arrays*

Another area that must be addressed simultaneously is to equip satellites with enough on-orbit diagnostic

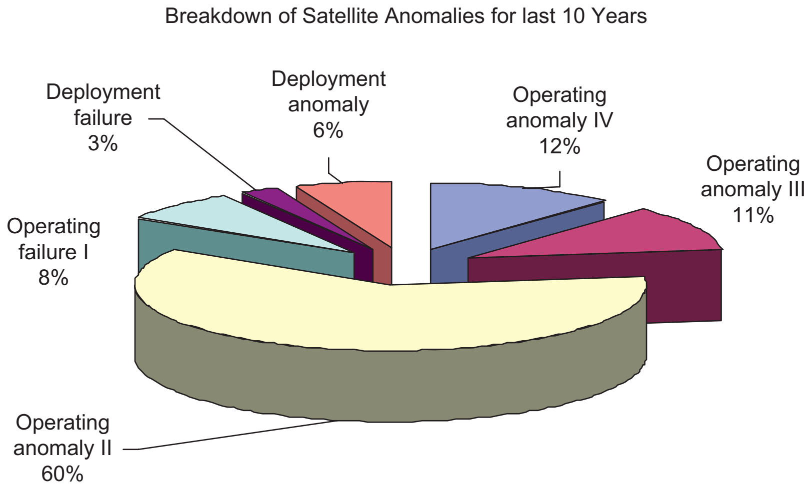


Fig. 4. Satellite anomaly breakdown.

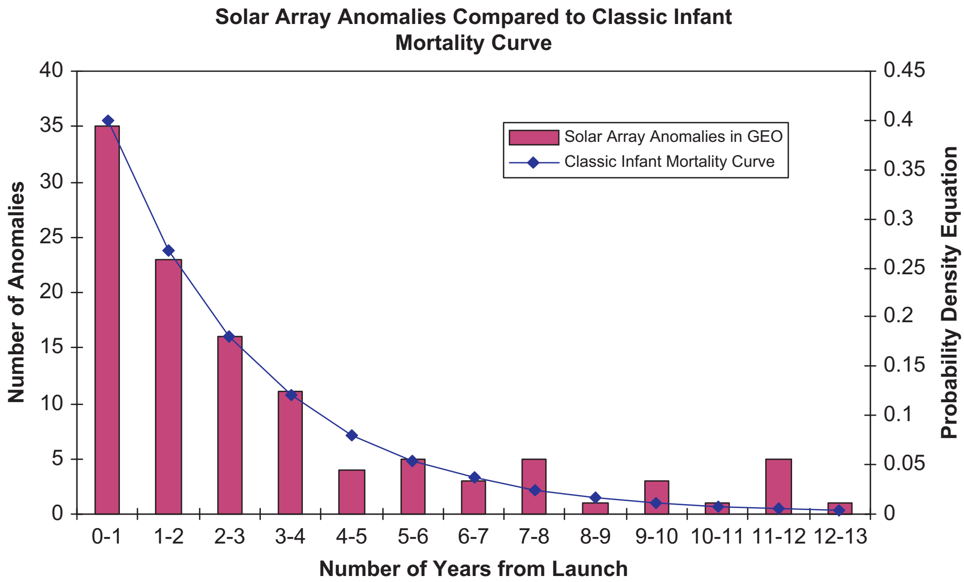


Fig. 5. Infant mortality curve relation to solar array anomalies.

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. Often the only information available is that the solar array string failed open or shorted. The root cause must be accurately known before a viable solution can be determined. More diagnostic instrumentation should be added. 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.

### 3.3. Automation of cell and module fabrication

Increased automation for manufacturing, assembly, and testing of the arrays is another potential approach to lower costs and increase reliability. This is in conjunction with the use of a standardized module design. Automating the entire process increases quality and reliability by having repeatability at a module level. The

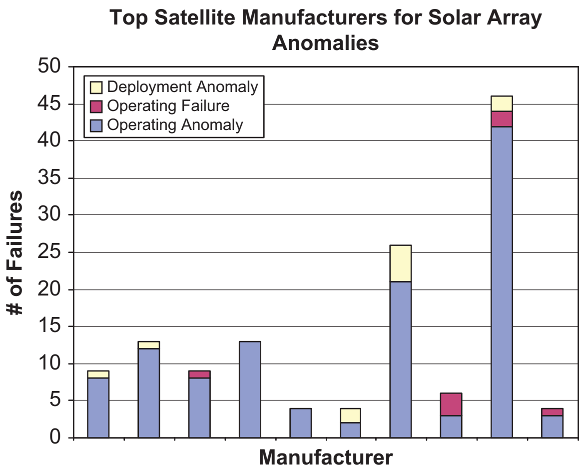


Fig. 6. Top satellite manufactures for anomalies.

concept of modularity is not new, but it has not been readily accepted by the satellite industry due to some obstacles such a single module being able to handle a variety of different space environments from LEO, to GEO, to deep space planetary missions. Modularity, standardization, and automation can produce long-term benefits and need to be considered.

### 3.4. Embracing new technology

Better designs that will improve solar arrays and eliminate current failures need to be tested and flown. 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.

An example of a new technology that should be embraced is the stretched lens array (SLA) developed by ENTECH Inc. in Keller, TX. The SLA is a refractive concentrator with efficiencies greater than 27%. It can be super insulated and super shielded with minimal mass penalty due to its 8× concentration. Ground testing has shown its resistance to electrostatic discharge and micrometeoroid bombardment. This makes it an optimal candidate for GEO missions which have previously been shown to be the most susceptible to anomalies. The reduced mass of the SLA also allows for the potential of more transponders. Better designs, such as the SLA, need to be tested and flown. They provide a way to improve the reliability of solar arrays and eliminate current anomalies.

### 3.5. Standardization of testing procedures

Solar array reliability can also be improved through careful ground testing. The 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". There are mixed feelings in the industry about incorporating these standards due to anticipated cost increases. However, if they serve to ameliorate failures, it will lead to a much more substantial cost saving. Also, because solar array failures on orbit are an international issue, extensive discussion and meetings are being held world wide to seek agreement on an international set of standards. Thus, the attention of the world's satellite producers is being focused on real, legitimate, costly issues whose solution will benefit all satellite suppliers.

### 3.6. Certified testing facility

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. 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.

## 4. Conclusion

The reliability of solar arrays has a huge effect on the satellite industry though increased insurance premiums and lack of confidence by investors. The known anomalies have been analyzed to determine the most hazardous orbit, the period of time before an anomaly occurs, the manufacturers of the flawed satellites, the impact the anomaly had on the life and power of the satellite, along with the value of associated insurance claims. These data have been presented and can be used by the industry to focus attention on the most serious areas effecting solar array anomalies on orbit.

Recommendations to increase the reliability of solar arrays have been outlined and briefly discussed. The first recommendation is to have a network available for disseminating data between manufacturers and forming a joint effort to determine solutions to common problem areas. Increasing the on-orbit diagnostic instrumentation on solar arrays will help determine root causes of anomalies and allow for newer arrays to be designed to withstand these problem areas. Embracing new technology that is inherently designed to be durable and reliable is a necessity. Standardization of testing procedures to make sure all arrays are tested the same and can withstand the known variables of the space environment is another potential solution to raising reliability. Automation of cell and module fabrication has potential benefits and should be explored in greater depth. The creation of an international committee on satellite failures through an underwriters' agency is also a suggestion that would help validate appropriate testing methods and create testing uniformity across the industry.

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. The recommendations presented in this paper are just a start, but work must begin immediately to help bring confidence back to the industry and continue the success of the space satellite industry.

## References

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