Tabulation of Power-Related Satellite Failure Causes

Conference Paper · July 2013

DOI: 10.2514/6.2013-3736

Geoffrey A. Landis
NASA

CAUSES OF POWER-RELATED SATELLITE FAILURES

Geoffrey A. Landis[1], Sheila G. Bailey[1], and Renee Tischler[2]

[1]NASA Glenn Research Center
21000 Brookpark Road
M/S 302-1
Cleveland, OH 44135

[2]Parma Senior High School
6285 W. 54th Street
Parma, OH 44129

ABSTRACT

Satellite on-orbit failures are rare, but costly. Failures cumulatively account for losses that total many billions of dollars. In order to understand the causes of power-system related failures, publicly-available data sources were analyzed to determine the origin of power-system related failures of spacecraft. Data from reported failures and anomalies of commercial and scientific satellites from the period 1990-2006 were analyzed. Military, GPS, and reconnaissance satellites were not included in the data set. The major failures were divided into nine primary categories: Impact or collision induced failures, battery failures, solar array mechanical failures, attitude control failures, failures due to plasma-discharge events, cell failures, other array failures, darkening of glass or solar reflectors, and cell interconnect failure. These failures account for a reported cumulative loss of 4.4 billion dollars. These data were analyzed to show the cause of each type of failure as a percentage of the total number of failures, and the net cost of each type of failure.

INTRODUCTION

Satellite on-orbit failures are rare, but costly. Failures cumulatively account for losses totaling many billions of dollars. Understanding causes of failures has benefits to commercial, government, and military satellite customers.

Typical commercial satellite launches are covered by insurance, which covers both launch and operation. Insured values for geosynchronous satellites range from \$150 M to \$300M. The premium for this coverage is typically about 20% of the value for the launch and first year of operation, and about 2.5% of the insured value for subsequent years of operation. Over the life of the satellite, insurance costs total about 33% of the total project cost [1]. According to data from Frost and Sullivan [2], half of the insurance claims for satellites in orbit are power-system related; 50% related to the solar arrays; 12% related to the battery. Understanding the causes of power-system related failure is a key to reducing the costs.

In order to understand the causes of power-system related failures, publicly-available data sources were analyzed to catalog anomalies and failures of spacecraft in orbit due to power-system related failures. Data from reported failures of commercial and scientific satellites from the period 1990-2006 were analyzed.

These failures account for an average loss of \$300 M per year over fifteen years. These data were analyzed to show the cause of each type of failure as a percentage of the total number of failures, and the net cost of each failure, both in dollars and as a percentage of the total cost of all failures.

METHOD

A database was assembled incorporating publicly available (unclassified) information on degradation and failures of satellites related to the power system. This incorporates commercial and civil satellite systems, but does not include data from military, GPS, or reconnaissance satellite systems. Where possible, multiple sources were consulted to verify details of the failure modes. Some of the major data sources are listed in references [3-10].

For the purposes of the database, "failures" were broadly defined to include degradation in performance with a significant impact on power system performance. In many cases these failures resulted in loss of performance without loss of the mission; in several cases full mission success was achieved despite the failure, and in other cases, the power-related failure occurred after the end of the nominal mission lifetime. In these cases where the full mission lifetime was achieved, the failure was tabulated in the database, but the associated value loss was listed as zero.

The dollar value of the failure was tabulated from available data. Where there was an insurance payment associated with the failure, the value of the payment was used as the value of loss; in other cases, where a dollar value for lost revenue was quoted, this value was used. For satellites that were not insured, the dollar value of a total failure was the cost of the satellite (including launch).

If the satellite retained partial function, this value was multiplied by a fraction to account for the revenues associated with partial function.

RESULTS

A total of 64 incidents were tabulated, of which roughly two thirds were commercial satellites. The total value lost in power system-related failures tabulated here was 4.4 Billion dollars. We categorized the cause of these incidents into nine top-level categories:

1. Array mechanical failure
2. Array wiring, short circuit, and cell interconnect failure
3. Solar cell failures
4. Battery failure
5. Darkening of glass or reflectors
6. Plasma discharge events
7. Attitude or computer failure
8. Impact events
9. Array failures (other)

Grouping of failures into categories (and even the selection of categories to group them into) is a process that necessarily has some element of subjectivity. The categories were chosen to be most useful to our analysis of root causes. Plasma discharge events were divided out into a separate category, for example, although the actual failure manifests in the form of a short-circuit or solar cell failure.

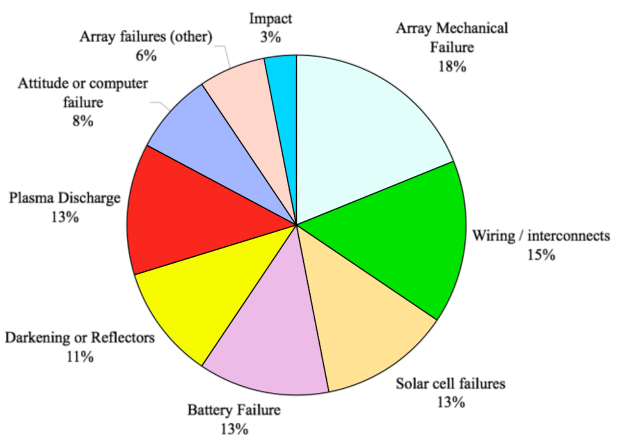

Figure 1. Number of power-related failures, by cause

Cause	Loss $
Array mechanical failure	552M
Wiring / interconnect failure	1097.5M
Solar cell failures	23M
Battery Failure	514M
Darkening or optical contamination	972M
Plasma Discharge	1070.5M
Impact events	22M
Attitude or computer failure	77.1M
Array failures (other)	76.8
Total	*4,404.9M*

Table 1: Failure costs, by category

Figure 1 shows the number of each type of incident as a fraction of the total number of failures. Table 1 tabulates the cost of the failures broken down by cause.

It is instructive to examine the failures by cost. The summary data is shown in Table 1, and graphed by failure type in Figure 2. Figure 3 shows the total lost value attributed to each failure type as a percentage of the total.

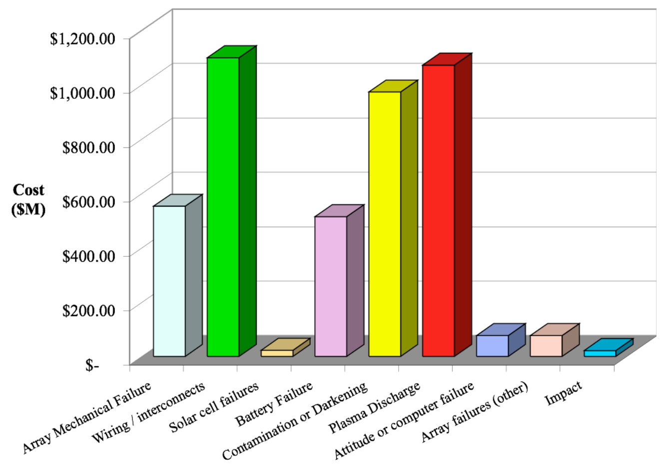

Figure 2: Cost by failure cause

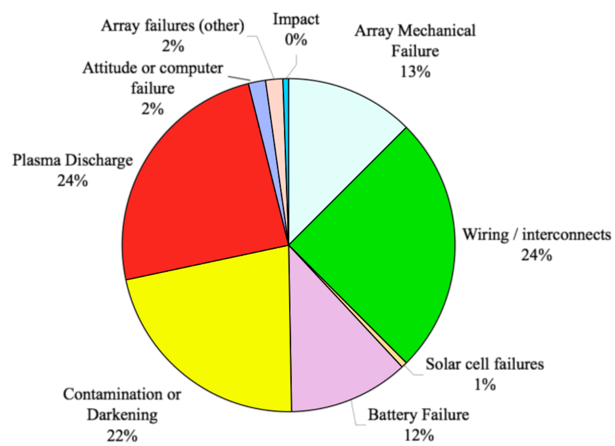

Figure 3: Cost of power-related failures, by cause.

Discussion

By numbers, the most common category of failure comprises solar array mechanical failures. By cost, however, short circuits and wiring failures are the most costly failure type. This is because the operations team of many of the satellites that experienced array mechanical failures were able to salvage all of part of the value of the satellite, while a larger fraction of failures due to wiring failures and short circuits in the power system resulted in loss of mission.

Some of these failure types were rare. Impacts, for example, accounted for only two power-related incidents;

both on the Russian "Mir" space station. (One of these failures, the impact of a Progress Spacecraft with the station in 1997, resulted in significant damage to the station. Only the damage to the solar arrays was counted as power-system related failure cost.)

Failure or degradation of the photovoltaic cells themselves, although 12% of the incidents by number, accounted for only 1% of the value lost. Some of these were incidents of unexpectedly high radiation-induced degradation, produced by an unusually energetic solar flare or coronal-mass ejection; others incidents were due to defective manufacturing. In general, however, since solar arrays are sized for end-of-life power, the array design includes a large enough margin to mitigate the cost impact of degradation.

The category of darkening of glass and contamination of optical reflectors accounts for an unusually large percentage of the total. This is primarily due to a single design that affected six commercial communications satellites in orbit, as well as incurring costs due to replacing the arrays and delaying the launch of several additional satellites. In this case, introduction of a new solar-array design incorporating lightweight reflective concentrating mirrors had a design-related flaw resulting in contamination of the array reflectors and subsequent loss of array power. Although the resulting degradation in performance did not cause any of the satellites to fail, the reduced performance resulted in insurance payments. This array design is no longer in use, and the factors involved in this degradation are now believed to be well understood [11,12].

Failures relating to plasma discharge caused 13% of the failures, and 24% of the monetary loss, a total loss of 1.07 Billion dollars. These failures are typically the result of solar coronal mass ejections and subsequent geomagnetic storms causing spacecraft charging, often resulting in short-circuits in the power system [4-9, 13]. (Geomagnetic storm events also often cause spacecraft to lose orientation; this is usually a temporary disturbance, resulting in temporary loss of service but not permanent damage.)

CONCLUSIONS

Power-system related failures are a significant cause of failures and nomalies in spacecraft, including many loss of vehicle events. Over the last fifteen years, such failures have resulted in over 4.4 billion dollars worth of failures.

A small number of categories of failure have resulted in the largest amount of monetary losses. Two of the most important causes of such failure are wiring and interconnect failures, and plasma discharge events.

REFERENCES

[1] P. Limonite, "Satellites Failures in Orbit: Focus on power systems," *Space Power Workshop 2005*, Los Angeles, CA, April 2005.

[2] Frost and Sullivan, *Commercial Communications Satellite Bus Reliability Analysis*, August 2004 . Available at http://www.satelliteonthenet.co.uk/white/frost3.html

[3] L. Rains (ed.), *Space News,* Imaginova Co., Springfield, VA. See http://www.space.com/spacenews

[4] P. C Klanowski, "Satellite Outages and Failures," *Satellite News Digest,* http://www.sat-index.com/failuresl

[5] H. C. Koons, *et al.,* "The Impact of the Space Environment on Space Systems," Report. No. TR-99(1670)-1, Aerospace Corp., 1999.

[6] D. C. Wilkinson, "National Oceanic and Atmospheric Administration's Spacecraft Anomaly Data Base and Examples of Solar Activity Affecting Spacecraft," *J. Spacecraft and Rockets, Vol. 31,* No. 2, March-April 1994, pp. 160-165.

[7] R. D. Leach and M. B. Alexander, "Failures and Anomalies Attributed to Spacecraft Charging," *NASA Reference Publication RP-1375,* Aug 1, 1995.

[8] S. T. Lai, "A Survey of Spacecraft Charging Events," *paper AIAA-1998-1042, 36th Aerospace Sciences Meeting and Exhibit,* Reno NV, 12-15 January, 1998.

[9] R. Gabby and J. Evans, "Space Weather Anomalies on Telecast Satellites & Related Design Issues," NATO Advanced Study Institute, *Space Storms & Space Weather Hazards,* Crete, Greece, June 19-29, 2000.

[10] The American Distance Education Consortium, "Summary of Changes, Domestic GEO Satellite Inventory," Jan. 29, 2004. Available at http://www.adec.edu/tag/change-l.sat.200401.pdf

[11] M. Bordeaux, "Root-Cause of the 702 Concentrator Array Anomaly," *Space Power Workshop 2003,* Redondo Beach, CA, April 2003.

[12] M. Ashkenazi, A. Jones and R. K. Jain, "Cellsaver Qualification Testing and Contamination Analysis," *paper AIAA 2003-6084, 1st International Energy Conversion Engineering Conference,* Portsmouth, VA, 17 - 21 August 2003.

[13] H. Garrett, "Future Directions in Spacecraft Charging - 2001 and Beyond," *paper AIAA-2002-0624, 40th AIAA Aerospace Sciences Meeting & Exhibit,* Reno NV, 14-17 January 2002.