Comm sats quality problems need

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Suddenly nothing seems to be going right with new satellites. Failures are being discovered at the beginning of life during the in-orbit-tests. This article looks for clues to the reasons and then suggests potential ways to improve the quality of commercial communications satellites.

Background

Historically satellites, automobiles and people follow a similar failure (or death) curve with age. Figure 1 shows the standard 'bathtub curve'. Infant mortalities claim many babies and many new cars, etc. have factory defects. In recent years pre-natal care has reduced the infant mortality rates for children. Could the same work for satellites to reduce the failures during the initial in-orbit-tests? After the birth period both people and equipment enter a long period with few deaths. Accidents (for equipment these are called random failures) take place. For electronics the failure rate can be predicted using handbooks. The curve rises again at old age. Most satellites have run out of stationkeeping fuel before this happens.

It seems as though new satellites have parts failing during the in-orbit-test (IOT) or far before the anticipated end of life (EOL). Why is this happening?

Review of problems

Table I lists recent problems. Several observations can be made.

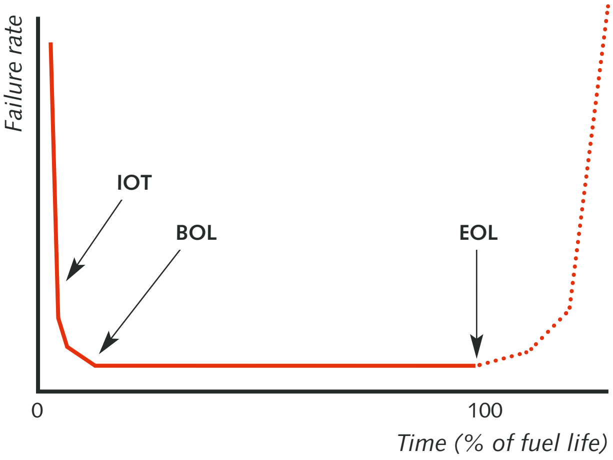
First, the problems are widespread. They infect every Western manufacturer. In addition Russian and Asian manufacturers have had their share of problems. While Hughes shows up frequently, it is not alone.

Secondly, the same types of problem are also evident inlaunch vehicles and again

Table I – Satellites with Problems

Spacecraft Name	Manufacturer	Model	Launch Date
JCSat 3	Hughes	HS 601	29 Aug 1993
Palapa C1	Hughes	HS 601	1 Feb 1996
Intelsat 801	Lockheed Martin	LM 7000	1 Mar 1997
Tempo 2	SS/Loral	FS 1300	8 Mar 1997
BSat 1A	Hughes	HS 376	12 Apr 1997
Thor 2	Hughes	HS 376HP	20 May 1997
PAS 6	SS/Loral	FS 1300	8 Aug 1997
Kupon 1	NPO L (Russia)	Kupon	12 Nov 1997
EchoStar IV	Lockheed Martin	A2100AX	7 May 1998
Afristar	Alcatel	Eurostar	28 Oct 1998
PAS 8	SS/Loral	FS 1300	4 Nov 1998
JCSat 4	Hughes	HS 601	17 Feb 1 997
Galaxy Si	Hughes	HS 601HP	8 Dec 1997
EchoStar IV	Lockheed Martin	A2100AX	7 May 1 998
Sirius 2	Aerospatiale	SB	12 Nov 1997
PAS 5	Hughes	HS 601HP	28 Aug 1 997
Kupon 1	NPO L (Russia)	Kupon	12 Nov 1997
Insat 2D	ISRO	Insat 2	6 Mar 1997
HGS 1	Hughes	HS 601HP	24 Dec 1997
GE 3	Lockheed Martin	A2100	4 Sep 1997
Palapa C1	Hughes	HS 601	1 Feb 1 996
Telstar 401	GE	LM 7000	16 Dec 1 993
Galaxy IV	Hughes	HS 601	25 Jun 1 993
DBS 1	Hughes	HS 601	18 Dec 1993
Solidaridad 1	Hughes	HS 601	20 Nov 1993
Galaxy Vll	Hughes	HS 601	28 Oct 1992
Eutelsat 2F4	Aerospatiale	SB2000	9 Jul 1992

Figure 1 – Failure rates



more than just buzz words

are sidtributed geographically.

Thirdly, the root cause of the problems can generally be traced back to materials, processes or mishandling (including commands from the ground). Many of these may seem mundane at the time but result in big problems later. See Table II.

Fourthly, some satellite operators are either very lucky or are doing something right because their satellites are not listed in Table I.

What is the common denominator that is causing these problems and producing the successes?

Potential theories

The conventional wisdom is that satellites are being built too fast. This may have been true for Iridium that at its peak was producing 14 buses per month (roughly one every other day).

For the geostationary satellites, we carefully researched the time between the contract signing and the launch of the satellite. Less

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Table II – Key parts problems

Power	
Solar cells	Adhesives and materials
Array deployments	Materials
Battery cells	Amount of electrolyte
Single-string batteries	Single point of failure
Short circuits	Insulation and protection of cables from abrasion
Communications	
TWTAs and SSPAs	Connections
Limiters	Design
Output multiplexers	Contamination
Attitude control/Propulsion	
Valves	Cleanliness
SCPs	Tin plate

KEY: **T** = Total failure **P** = Partial failure **R** = Redundancy reduction **M** = Minor

Problem Date	Age at Problem Years	Design Life Years	Percent of Life	Subsystem	Degree of Failure See key	Effect	Cause
29 Oct 1993	IOT	12	0%	Power	M	Bent solar panel	Ground command
13 Feb 1 996	IOT	14	0%	Power	P	Battery charging	Battery charger
18 Mar 1997	IOT	10	0%	Power	P	Bent solar panel	Ground command
11 Apr 1 997	IOT	12	0%	Power	P	DC power loss	High voltage array
30 Apr 1 997	IOT	12	0%	Comm	P, R	TWTA & spare	Loss of transponder
30 May 1 997	IOT	11	0%	Comm	M	Cross polarization	Antenna polarization
30 Aug 1997	IOT	15	0%	Power	P	DC power loss	High voltage array
18 Nov 1997	IOT	6	0%	Power	P	Mispointed array	Sensor
19 May 1998	IOT	12	0%	Power	P	DC power 8 stability	Array deployment
30 Oct 1998	IOT	15	0%	Power	P	RF power reduction	North PIU
4 Nov 1998	IOT	15	0%	Comm	P	Patterns off markets	Antennas reversed
April 1997	0.1	12	0.8%	Comm	P	Connectivity loss	Switch matrix
Feb 1998	0.2	15	1.3%	Power	P	Eclipse power loss	Battery cell failure
July 1998	0.2	15	1.3%	Comm	P	Loss of TWTAs	TWTA open circuit
1 Sep 1998	0.2	12	1.7%	Power	P	DC power loss	High voltage array
2nd Q 1998	0.7	15	4 7%	Power	P	Eclipse power loss	Battery cell failure
17 Mar 1998	0.3	6	5.7%	Command	T	Total loss	Command lost
4 Oct 1 997	0.6	10	5.8%	Power	T	DC power loss	Short circuit
15 Dec 1998	1.0	14	7.0%	Power	P	Power reduction	Battery cell failure
11 Mar 1 999	1.5	14	10.8%	Attitude	M	6 hour outage	Loss of a gyro
21 Nov 1998	2.8	14	20.0%	Power	T	DC power loss	Battery cell failure
11 Jan 1997	3.1	12	25.6%	Power	T	Sudden death	Short circuit
19 May 1998	4.9	14	35.0%	Attitude	T	Sudden death	Both SCPs failed
4 Jul 1998	4.5	12	37 9%	Attitude	R	Loss of redundancy	One SCP failed
26 Apr 1999	5.4	14	38.8%	Attitude	R	Loss of redundancy	One SCP failed
13 Jul 1998	5.7	12	47.5%	Attitude	R	Loss of redundancy	One SCP failed
30 Mar 1999	6.7	9	74.7%	Attitude	M	4 hour outage	Entered Sun mode

than half of the dates were available, especially for in-house purchases (like Hughes Galaxy from Hughes Space & Communications). Several surprises came from this study: first, delivery dates were generally not met. There could be many reasons for this (financing, market readiness, changes by the customer, manpower or test facility restrictions, etc.). The second surprise was that many of the satellites in Table I took a long time to build (34 to 61 months). To be fair we only considered the first satellite in a series. This says the conventional wisdom that speed is the problem may not be that wise.

Customers continue to ask for 12 to 18 month deliveries instead of two to three years. This type of shortened schedule can only be met by cutting something out. Testing takes time and money and is a candidate, especially when it can be automated so multiple tests can be done simultaneously instead of sequentially. But the low-failure operators like SES, Intelsat and GE have insisted on more, not less, test time.

The other place to shave time is in the design cycle. Computers can speed up this process and avoid many of the breadboard and brassboard steps. But do computers know about the growth of tin whiskers or interactions between materials?

The competition for commercial satellite (and launch vehicle) contracts is fierce. As a result the profit margins for the manufactures are razor thin. Last year Hughes Space & Communications (HSC) reported profits of only 8.7%, but PanAmSat, its operating arm, earned 42%. Many of HSC's competitors have profit margins in the 0 to 10% range.

Low profits

With the low profits, the economics allow little room to do extra work. This situation will not change until the profits improve, thus it may take a while before the present situation changes. The changes may have to come from the buyers, not the sellers. Most satellite operators would prefer to have an operable satellite earning revenues than to take a full or partial loss payment from an insurance company, thus they have the incentive to demand better satellites even if it means paying a premium and waiting a few weeks longer for delivery.

Unfortunately, the buzzwords today seem to be 'satellite production line', 'quicker, cheaper, better' and 'in-orbit-delivery'.

NASA has certainly learned that 'quicker, cheaper, better satellites' sounds great in front of Congress but it is not reality.

Others suggest the delivery incentives are wrong. These provide bonus payments to meet milestones and delivery dates. They sound good, but when the bonus gets too big the employee's focus may shift from long-term quality to short-term monetary gains from the bonus.

This is compounded by the employment instability in the United States, Europe, Russia and now, Asia. Are long-term employees going to be a thing of the past? Are management changes, mergers & acquisitions and relocations coming too rapidly to have the needed stability to make high quality products?

What is the average age of the design and management staff? Have critical skills been retired? To cut costs will a manufacturer retire one experienced hand and hire two right out of college or six in an underdeveloped country to do design and programming?

In the period from the late 1950's to the early 1990's, there was prestige in being involved in the design of satellites. With all of the changes has this become just another 8 am to 5 pm job? As job security eroded did it silently take its toll in the form of lower quality?

A test of theories

Long delays in a satellite delivery can come from many sources (see above). In all cases they may lead to a start-stop-restart flow. During each stop, key people will be moved off the project onto other, funded or moving, jobs. Many will not return because of their new responsibilities and the ensuing reorganizations. Can this lead to discontinuities in the flow of knowledge? Does this lead to special work-arounds to restaff and reschedule the satellite? Do these discontinuities result in quality reduction? Without detailed internal case studies (that would not be open to outsiders) this theory cannot be tested.

If too long is bad, if too short is bad, is their a happy medium? Apparently the Societe Européenne des Satellites, GE Americom and Intelsat feel that by stationing personnel at the manufacturer's plant(s) and insisting on extra testing they will get a better product. So far they have been right. This costs extra money and time.

Many small startup operators do not want to pay the extra price or have the logistics of a large staff. The plan is to buy a satellite under a delivery-in-orbit contract. The manufacturer arranges everything, establishes the

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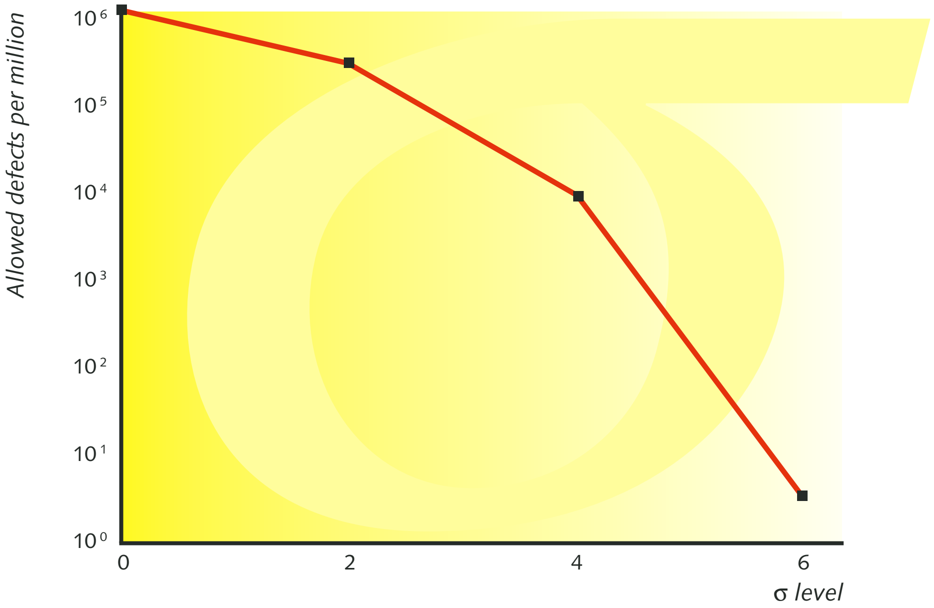
Figure 2 – Sigma performance



specifications, the design, production, test, selects a launch vehicle from its bulk-buy inventory and arranges for the insurance, all for a price plus a fee. If the satellite does not pass the in-orbit-tests a partial loss payment is made from the insurance.

One manufacturer was concerned that the lack of uniform requirements (a standardized product) was leading to lower quality as each spacecraft needed to be customized to the customer. It seemed that because customers focused on different market segments or regions, they were to blame for the quality problems. If this is the case, why are there satellite production lines for custom spacecraft? Commercial aircraft generally are customized for the airline but have a high reliability. Non-customized automobiles seem to have factory defects that need attention during the warranty period. Unlike autos or planes, a factory recall does not work for in-orbit satellites but we have seen several spacecraft being reworked at the launch site or being returned to the factory.

It would be interesting to compare the in-orbit performance of satellites built under "delivery in orbit" contracts, those with in-orbit incentives, those with vendor financing and conventional contracting. Material for a future paper.

Potential answers

Is more management needed? Simply adding more layers of management will not solve the little problems that create in-orbit failures. In some cases the extra layers simply insulate the top brass from the truth. The best answer seems to be a small, talented, and diligent oversight staff resident at the manufacturer provided by the customer. Their skills can be augmented by special consultants on an as-needed basis. Operators need to show their presence and interest almost on a daily basis throughout the manufacturer's organization. If the customer rarely shows up for tests or uses an inexperienced third party there may be a temptation to take shortcuts.

Eventually, insurers are asked to pay the bill for poor quality. Should they be more involved in this process? In the United States, electrical equipment is certified by the Underwriters Laboratory (UL) before being marketed. Faulty items can lead to fires and electrocutions, hence insurance claims. Should there be a UL for spacecraft?

The builder's management needs to be more inquisitive and be ready to allocate resources to solve little problems as they arise. Most big problems and failures come from a simple little error. This extends down to the selection of materials and finishes, the amount of electrolyte, etc.

The delivery date in the bid and actual delivery are often far apart. Does this add stress to an impossible schedule? Do bidders lie about the schedule because they think everyone else lies?

Has quality become a set of buzz-words? Has ISO-9000 helped? Did 'Zero Defects' succeed? Is 'Six Sigma' applicable to small quantity production runs?

At six sigma there should be less than four defects per million opportunities. In spacecraft there are many opportunities for problems in the design, hardware and software steps. At four sigma the number of permitted defects rises to 6,210. See Figure 2. Translated into probability of success terms, the four sigma is about 99%. Many spacecraft have a 80% success expectation at the end of their design life (excluding fuel exhaustion).

At the start of this paper I posed the question about applying pre-natal care to satellites. One way this could be done is for the manufacturer to employ outside teams to staff a design review rehearsal using former employees that still carry the experience from on-the-bench failures and fixes. This would balance the current dependance on computer-aided designs that may miss the subtleties that seem to be bedeviling the industry.

As indicated earlier, there seems to be a tie between customer involvement and in-orbit success.

Finally, the engineers should be satisfied when the satellite fully meets its specifications and avoid the temptation to redesign it to make it slightly better, to add a little more electrolyte, etc. These innocent attempts, generally unknown to management and perhaps undocumented, can be the seeds of future problems.

Conclusion

In the end it all comes down to a few simple items: the attitudes and fulfilling of responsibilities by all involved. In particular this applies to the manufacturers (and its suppliers), the buyers (operators) and the insurers. SBi