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solar array reliability concerns and possibilities for improvement

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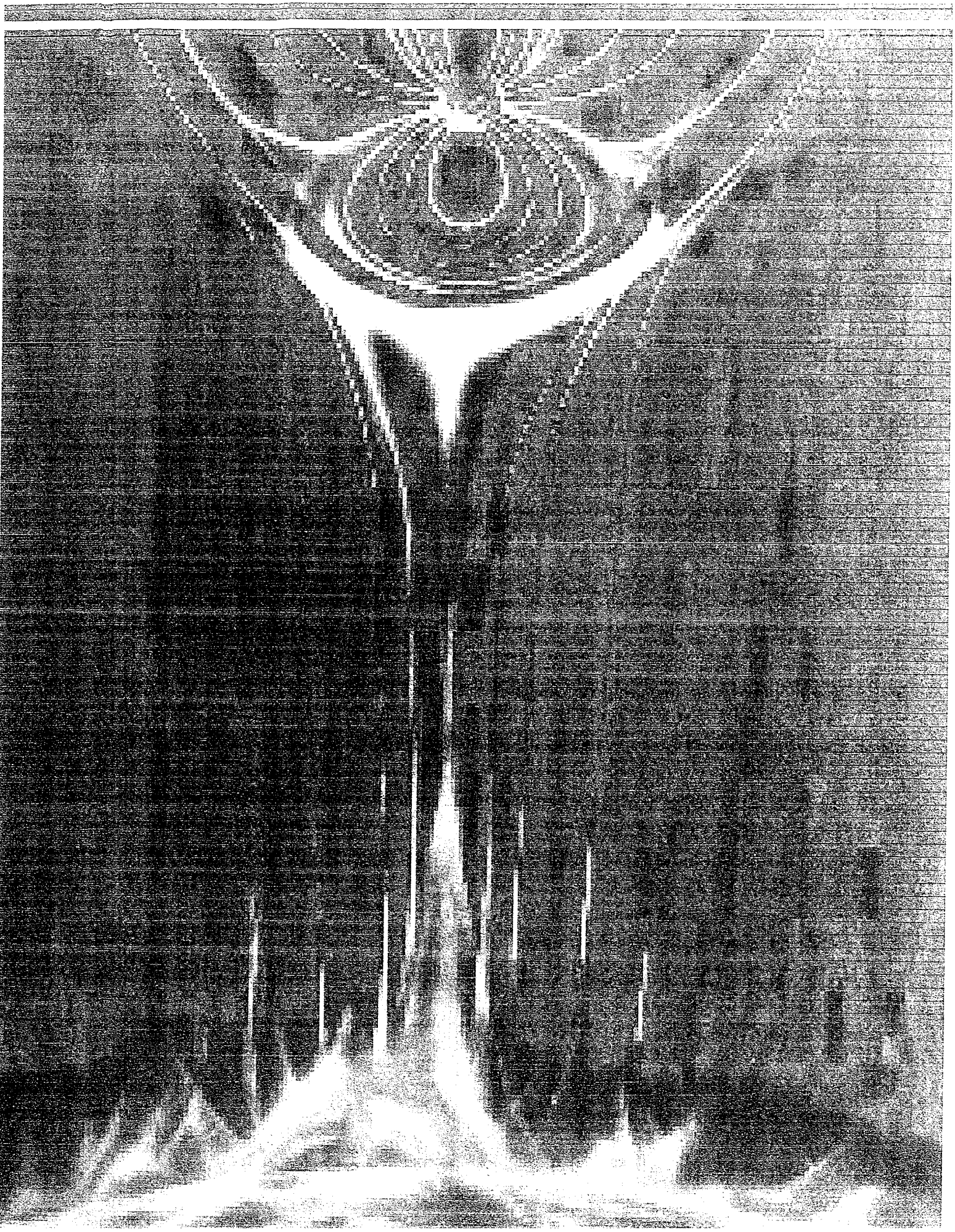

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agenda

- gsfc recent missions
- gsfc array failure rate
- industry concerns
- gsfc on-orbit problems
- gsfc test problems
- repeaters
- a thought or two
- some improvements
- a real challenge
- peace at last

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recent gsfc missions

• GALEX	April 28, 2003
• SORCE	January 25, 2003
• CHIPSat/ICESat	January 12, 2003
• ADEOS II - SeaWinds	December 13, 2002
• TDRS-J	December 4, 2002
• CONTOUR	July 3, 2002
• NOAA-M	June 24, 2002
• Aqua	May 4, 2002

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recent gsfc missions

- GRACE — March 17, 2002
- TDRS-I — March 8, 2002
- RHESSI — February 5, 2002
- TIMED/Jason — December 7, 2001
- STS-108 — December 5, 2001
- MAP — June 30, 2001
- GOES-M — July 23, 2001

significant gsfc on orbit array failures

- **overall significant failure rate <1%**
- **only array failure having a significant impact on a gsfc spacecraft was landsat 4, launched in July 1982**
  - approximately 50% of array output was lost after about 6 months on orbit
  - thermal cycles fatigue cracked solithane potted wires on a connector
  - operated thru august, 1993 until transmitter failures rendered it useless

the array failure that isn't counted

- **the first hst array had a mechanical fault that shook the spacecraft out of its pointing requirement on entry into and exit from shadow**
  - the roll out array had a mechanism used to help unfurl the kapton blanket on the array tip
  - the mechanism was not designed to compensate for the difference in thermal expansion between the bi-stem booms and the kapton, but it did (another mechanism was designed to do this)
  - the mechanism was rough in operation
  - the fault was serious. i don't count it against gsfc as the hst was fabricated under marshall contracts. gsfc gained responsibility for hst after launch.

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array reliability concerns

- **solar array reliability is an industry concern**
  - well publicized failures
    - matra failures due to coating problems on the covers
    - tempo failures due to arcing between cells
    - hughes 702 failures due to outgassing onto concentrators
    - lockheed satellite failure due to cell shorting
  - several indications that array failures have caused the majority of insurance payouts on commercial spacecraft

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gsfc concerns

- numerous on-orbit nuisance problems
- repeated significant difficulties getting product thru qualification testing

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on orbit nuisanceproblems with gsfc spacecraft

- **xte: power loss up to 12.5%, average < 5%**
  - due to cracks in silicon solar cells on an aluminum substrate
  - cause: cell cracking from tap testing
  - omitted test: obtain iv curve at the array's highest operating temperature
- **trmm: power anomalously down 25% (more than a nuisance, except that we knew it might happen before launch and could handle the possible degradation)**
  - due to cell cracking or cell shunting
  - probable cause of cracking: too rough handling in manufacture, possibly cells were prone to cracking
  - test omitted: none. cracking was known prior to launch and computation indicated the maximum loss would be 28%
  - prior to launch it was known that the loads were about 25 % less than expected.

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more on orbit nuisance problems

- **hst: loss of four strings**
  - strings shorting to substrate
  - cause unknown: contractor believes the problem to be meteorite impact. however, computations predicting the rate of failure due to meteorites are too low to explain the problem.
  - test omitted: unknown

more on orbit nuisance

- **aura: loss of part of the array (so far a nuisance, could turn into significant difficulty)**
  - a connector is possibly opening
  - cause: possibly that contractor made small changes to improve connector reliability that had the opposite effect
  - test omitted: none
- **terra: stage 1 deployment not indicated**
  - cause: microswitch failure or failure of associated electronics
- **euve: deployment not indicated**
  - failure of several microswitches
- **hst first array: deployment not indicated**
  - failure of several microswitches

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gsfc test problems

- fast: cracked solar cells, substrate delaminations
- xte: substrate delaminations on flight, interconnect cracking on qual
- trmm: cracked solar cells in qual and on flight
- terra: delamination of kapton in qual and on flight, cell contact bubbling on soldering on flight
- noaa: weld failures on the rear of solar cells in qualification testing (only found by hi temperature test)
- aqua: solder failures from string terminations to wire on qual
- aura: weld failures on string terminations to wire on flight

more gsfc test problems

- glast: open weld to bypass diodes on qual (only at hi temperature)
- goes: open solder joint to bypass diodes on qual (only at hi temperature)
- hst 1st array: open welds on qual
- smexLight: cracked cells (caught by hi temperature test)
- map: osr deterioration prior to launch

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some repeaters

- numerous microswitch failures on orbit. none on ground test.
- several weld failures
- several solder failures
- several delaminations
- several instances of cracked cells
- many problems only occur at hi temperature
- several problems caught by test at high temperature

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a thought or two

- most spacecraft electronic equipment are acceptance tested by operating for tens of hours at hi and low temperature in vacuum.
- flight solar arrays, one of the least reliable of spacecraft parts, are acceptance tested by operating for 12 milliseconds at ambient temperature and pressure.

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some improvements

- **institute hi temperature acceptance flash testing of solar arrays, not just solar panels, prior and subsequent to mechanical and thermal vacuum exposure.**
  - most other spacecraft components have these tests run. the arrays have escaped it because of the expense and difficulty . . . except that it when compared to other equipment it is cheaper and less difficult to test the arrays.
- **customers to assist the array contractors in using the same processes, procedures, parts and materials from program to program.**
  - in this regard, the aiaa and the aerospace corporation are leading an industry wide effort to craft cell and qualification specifications that will lead to a better and more accepted products.

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some more improvements

- **institute deming ideas, a sampling:**
  - provide supervision with knowledge of statistical methods; encourage use of these methods to identify which nonconformities should be investigated for solution
    - an example is weld pull strengths where the production pulls can be running an average of over 1,000 grams with a standard deviation of 50 grams. meanwhile,
    - if the pulls are over 300 grams, everything is deemed ok. it's a tradition.
    - this means the process can change all over the place and the pull strength indicate this; but no action will be taken
    - change to: if it's more than 3 sigma off the average, investigate.
  - discard the old philosophy of accepting nonconforming products and services
    - every solar panel made has cell cracks. that's the way it is.
    - change to: investigate what's doing it and eliminate it.

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more improvements (somewhat reliability related)

- **inventory is evil**
  - the government's method of payment encourages overly early production and purchase of equipment
    - somebody is paying interest on it even if your company isn't
    - it's gotta be warehoused
    - it's not getting any better as it ages
    - it's going obsolete
    - it has to be protected against out-of-control forklifts
    - the roof might spring a leak and get it wet
    - you gotta keep track of it
- **quit producing product too early to get your revenues up for the quarter**
- **quit buying product to protect against shortages**

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a real challenge

- cease dependence on inspection to achieve quality. eliminate the need for inspection on a mass basis by building quality into the product in the first place
- consistency is a hobgoblin

some more

- **to do: keep track of problems and their cause on an industry wide basis**
  - gsfc to do, aerospace to do?
  - hampered by proprietary concerns