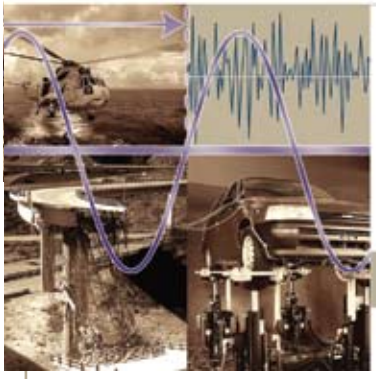


# ERI News

your reliability newsletter

February 2009 | Equipment Reliability Institute | Volume 34


In this issue...



Wayne Tustin

Voice of the President

## Lessons learned at JPL

*by Wayne Tustin*

Considerable newspaper and technical publication coverage was given to an overly-severe March 21, 2000 vibration test in Room 144 of Building 100 at the Jet Propulsion Laboratory, Pasadena, California. The over-test caused significant damage (over $1,000,000) to the High Energy Solar Spectroscopic Imager (HESSI) satellite built by the University of California at Berkeley (UCB). A Mishap Investigation Board (MIB) was convened. The principal source for this article is a prerelease version of the MIB report, which will eventually appear at http://www.gsfc.nasa.gov.

My intent here is to help readers (who are in any way involved in testing) appreciate the possibly disastrous consequences of actions that are taken or not taken in seemingly routine procedures.

**Event Sequence**

Earlier on March 21, at 13:39 hours, the spacecraft had passed a nominally sinusoidal 0.25g survey test, Run #2. (I say nominally because records later investigated by the MIB showed that there had been significant waveform distortion.) The spacecraft also passed a random vibration test at 17:50 hours. Run #9 utilized force limitations and spectrum notches. (Other records investigated by the MIB showed that this test also had unusual characteristics.) In retrospect, both of these tests had revealed symptoms of trouble, symptoms that unfortunately were ignored on March 21.

The MIB Report mentions aborts on Runs 1, 5, 6, 7 and 8. These are blamed on various overloads, but these overloads are not explained in the Report. I've been told of solar array panel rattling, with acceleration peaks causing limit channels to clip.

At 18:13 hours (Run #10) the 13:39 sine survey test was repeated. The third test of the day, Run #11, was to be a 7.5g open-loop sine burst vibration test.

Plans called for six bursts at -12 dB or 1.88g peak, one burst at -6 dB or 3.75g and (after a review of input and responses) a single burst at full level, 7.5g peak. Unfortunately, the first -12 dB (1.88g) check, at 18:43 hours, was much too severe. The test was aborted manually. Records showed that acceleration reached 21g for 4+ cycles. Solar panel arrays were damaged.

## How Many BSMEs had Practical Lab Courses?

The most common university degree, among participants in my short courses dealing with vibration and shock measurement and testing, is BSME. When I ask those BSME-holders to describe their university vibration or shock courses, most describe them as heavy on math, light on practical, hands-on. I'd like to identify, and praise, the relatively few mechanical engineering departments that offer practical, hands-on, experimental, training in dynamics. One that I'll praise is California State University at San Luis Obispo, California. Will readers please identify others?


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**What had happened?**
The Board prepared a lengthy list of all possible causes for the mishap. One by one, most of the possible causes were exonerated.

- Endevco 2271A/A20 accelerometers
- Trig-Tek 1273A charge amplifier
- m + p VCP9000 vibration control system
- LDS power amplifier driving the Ling A-249 shaker
- Shaker internals (flexures and bearings and other possible mechanical and electrical difficulties).
- Spacecraft response instrumentation is not discussed here ... only the mechanical input to the spacecraft.

Attention soon focused on the oil film slip plate (magnesium alloy) to which the spacecraft was attached via an adapter ring which was connected by 24 Kistler 9251A force sensors (to measure force input to the spacecraft) to an aluminum fixture plate. (After the event, several of the mounting ring-to-slip plate bolts were found to be loose. See log at 18:53 hours.) The slip table, supporting granite block and shaker armature were found to be misaligned, not parallel. The magnesium slip table had evidently been rubbing on the granite block for some time, generating considerable heat. Magnesium had transferred from the underside of the plate to the granite surface. Considerable evidence from the earlier tests that day indicated that the resulting stiction (greater than normal coefficient of static friction) had been present throughout the day's testing and was the root cause of the mishap.

*MIB found that the granite block itself had not shifted, but that the shaker body had moved, misaligning the moving system (consisting of shaker armature, flexures, bearings, bullnose and slip plate) and creating stiction.*

This author asks: were records of tests from March 13-17 and from March 20 reviewed? Yes, and there is some evidence that the stiction problem had existed.(but not been recognized) before March 21.

Concerning the pressurized oil film slip table, the question was raised: had oil pressure been turned on? General agreement: yes, but no documentation and (false economy) no system interlocks.

MIB found that the granite block itself had not shifted, but that the shaker body had moved, misaligning the moving system (consisting of shaker armature, flexures, bearings, bullnose and slip plate) and creating stiction. Two 1 inch diameter bolts that had secured the shaker "saddle" to the shaker base were broken with holes misaligned approximately 0.5 inch. Upon disassembly of the shaker supporting base, one of the two trunnion support needle bearings was found to have a broken outer race. Some rollers were loose; others were missing. Replacement parts will be taken from a surplus A-249 shaker being shipped from Huntsville, Alabama.

**When did the shaker base fail?**
I've been told that the shaker had been used in the vertical attitude for "a long time" prior to March 21. During rotation of the shaker body into the horizontal attitude, the soon-to-fail (or already failed) trunnion bearing must have emitted loud noises. Why did no one hear that noise? Careful realignment of slip plate to shaker followed that rotation.

**How did stiction cause the overtest?**
MIB reconstructs the events thus: upon initiating the sine-burst test, the shaker control computer had (at much reduced

## Upcoming "open" courses

Wayne and several ERI specialists will teach "**Fundamentals of Random Vibration and Shock Testing, measurement, analysis, calibration, HALT, ESS and HASS"** at the following locations:

February 16-18, 2009, Santa Barbara, California

March 3-5, 2009, Mississauga, Canada

*(presented by Steve Brenner)*

April 1-3, 2009, College Park, Maryland

April 14-16, 2009, Fullerton, California

May 11-13, 2009, Dayton, Ohio

June 1-3, 2009, Boxborough, Massachusetts

July 14-16, 2009, Hillsboro, Oregon

Herb Lekuch will be teaching "**Isolating COTS Equipment aboard military vehicles**" at:

March 3-5, 2009, Fullerton, California
(3-day course)

September 22-24, 2009, San Jose, California
(3-day course)

September 29 - November 17, 2009, College Point, New York

***(new course format: once a week on Tuesdays)***

*☞ Take advantage of our early-bird discounts and save up to $200 when your enrollment and*

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level) developed and stored a drive signal. Unfortunately, that drive signal was incorrect (much too high) due to slip plate stiction. Excessive force had been required to obtain the required low level of slip plate motion. The computer poorly estimated the drive signal which would be needed for the -12 dB check. Unfortunately, no procedure required the operator to run the sine burst test before mounting the spacecraft.

When the -12 dB check occurred, that excessive force not only overcame stiction but created excessive motion. That's what damaged the spacecraft.

**Evidence of stiction**

MIB found evidence of stiction in acceleration vs. time plots taken during the earlier 0.25g sine sweep, Run #10. Large amplitude "glitches" occur immediately after the zero velocity points. This author surmises that the accelerometer signals leading to those plots were available to test personnel in Room 104 during the several sine sweeps. Subsequent question brought assurance that an oscilloscope was provided and is always turned on. Those charged with watching the oscilloscope blamed distortion on "shaker-spacecraft interaction and electrical noise". It seems to me they should have been instructed to stop the test if motion was not sinusoidal.

Observers in Room 100 had noticed a "different" low frequency sound during the control computer's equalization process, prior to the earlier random vibration tests (Runs 3 through 9). MIB found indications that stiction had affected equalization, particularly in the low frequency, large displacement spectral region. This was confirmed by reviewing control accelerometer PSD from the self-check at 18:43 hours. This author now asks: 1. Had no one said to all present in Shaker Room 100 and Control Room 104, something like "Listen up, folks. This is an important test upon a very valuable satellite. If you should observe any anomalies, holler so we can investigate."? 2. Why did no one shout "Stop the test."?

**Schedule requirements**

This author asks: Why was the sine-burst test initiated, in the face of this evidence that all was not right? One of the investigators opines that the misalignment was not sudden but rather was a degradation to which the operators had become accustomed. Perhaps. But might we not ascribe some blame to pressure from above? Tests, coming late in any program, always seem to commence behind schedule. Page 23 of the MIB Report mentions "tight schedule". Was any individual afraid to stop the test?

How long had that test crew been working? 18:13 hours is 6:13 pm. 10 hours? Pressure to finish testing so all could go home to dinner is certainly understandable. Was there another "hurry up" test inflexibly scheduled for that facility next morning? One of the investigators told me privately that testing for 12 hours would not be unusual or unsafe and that project personnel are used to even longer hours. I've learned that commercial testing laboratories sometimes work their people 18 hour shifts. Accident-investigation psychologists tell us that judgment lessens when people are tired, and that quite often the people involved in an accident will later deny having been tired.

**Contributing factors**

- Misalignment caused the slip table to bind at low force levels. MIB recommends checks for routinely assessing the mechanical "health" of shaker and slip table system.
- Test personnel did not know that quality data was available prior to initiating the sine-burst test. MIB recommends additional procedure steps, to review such data.
- No facility validation test was performed. MIB recommends simulating tests before the test article arrives.
- The shaker base failure. This was also identified as the root cause. MIB

*payment reach ERI one month before the course starts. Sign up now!*

## Military Standard 810

Many organizations around the world are affected by Military Standard 810. It is cited in many USA military and some commercial contracts. Rather than make their own environmental measurements, some organizations copy numbers from 810. Many of the 810G changes will, in the next few years, be reflected in IEC Specifications and other European test Standards.

Many potential users of 810 are unaware of the details and impacts of these changes. That's why ERI offers to bring these short courses to your facility:

- Military Standard 810G Climatics Test Interpretation,
- Military Standard 810G Dynamics Test Interpretation
- Transition from MIL-STD-810F to MIL-STD-810G

Which Army Arsenal or Proving Ground, which Naval Command or Center or which Air Force Base will be the first US military agency to obtain ERI's 810G training? ERI plans to hold "open" or "public" courses at various USA cities, commencing with ERI's home city of Santa Barbara, California.

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recommends refurbishing or replacing the shaker.

- Too-low an amplitude self-check. MIB recommends self-checks at appropriate levels.

*The MIB came up with some excellent steps to prevent recurrence of these events. All dynamics labs should copy these six points and post them prominently.*

To MIB's five, I would like to suggest a sixth and seventh. I'm told there has been considerable test personnel turnover in the JPL test organization. Much experience has been lost. Possibly the year 2000 staff had had little formal precautionary training on this specific shaker system.

Much of the shaker equipment at JPL is 30 or more years old. In generating vibratory force, shaker internals and externals gradually deteriorate with each test. Anticipate failure. Treat your shaker at least as well as you treat your automobile.

**Observations**
MIB offers nine very thoughtful observations, accompanying each with recommendations.

**Lessons learned**
The MIB came up with some excellent steps to prevent recurrence of these events. All dynamics labs should copy these six points and post them prominently. Here is Section 10 of the prerelease report. (I have added numbers and slightly changed wordings.)

- Test facilities must be maintained with test equipment in good working order. Metrics that assess the mechanical health of the systems must be developed and tracked.
- "Canned" tests should be developed (and used periodically) to provide a trended database for test systems' responses. Any deviations in any system response should be investigated.
- Critical control system response data such as (a) the transfer function or (b) inverse transfer functions, and (c) calculated drive voltage must be evaluated real-time during testing to ensure that they are reasonable and do not indicate system maladies.
- A facility validation test should be done for each planned test series, before flight or critical hardware is mounted. This should represent actual test conditions.
- Run self-checks that provide a representative response for the forcing range of the planned test. For higher force shock tests, shaker systems and test fixtures often do not respond in a linear fashion. Don't assume that test facilities are always in perfect working order.
- Define all test requirements (for a particular test) in the test plan. Provide test operators with adequate data. Require complete (system) verification testing before testing critical hardware. To those six, I would like to add six more to make a dozen:
- Run self-checks at approximately test intensities.
- Don't operate shaker systems "open loop".
- Supplement your shaker system with an independent "soft shutdown" system protector that derives its signal from an additional redundant (safety) accelerometer.
- Encourage anyone in the lab, whether part of the test team or observing, to call out "Question" if he/she suspects something is not right.
- Display unfiltered accelerometer time histories on at least one old-fashioned

## Readers of Your Reports Do THEY understand your message?

You've measured vibration and/or shock in flight, over-the-road, on shipboard, in the test lab, and tried to communicate your measurements. You've described how you conducted environmental vibration or shock tests.

But the readers of your reports, your supervisor, department head, company president, customer ...do THEY understand what you've told them?

In many cases, no, you're aware that they don't understand. Any more than Dilbert's pointy-headed haired? boss understands Dilbert.

Is it important that those important readers understand you?

Can ERI assist?

Send us the individuals' names, phone numbers and e-mail addresses. Tell us what you suspect they don't understand. Perhaps, tell why it's important. If you wish, don't identify yourself. We promise to forget how we learned that the need exists.

The subject of our e-mail message will be "Some technical information you need." It will commence "We promised someone that we'd not reveal how we got your name, phone and e-mail. He asked us to tell you about ....."

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analog oscilloscope. During a sine vibration test, fully investigate any departures from a sine waveform.

- Listen to your shaker. It may be trying to tell you something. If, as at JPL, the operators cannot hear the shaker from their control room location, place a microphone near the shaker and a loudspeaker that is always turned "on" in the control room.

Thanks to several people who commented upon drafts of this article: Guido Bossaert, Dan Worth, Bob Newton, Bob Mercado.

*Wayne Tustin, ERI's president, can be reached by e-mail or phone (805) 564-1260.*

## Who Needs Shock & Vibration Isolation?

*by Herb Lekuch*

1. Engineers who install delicate electronic and other equipment (often COTS equipment) aboard military vehicles.

2. Packaging specialists who protect delicate electronic and other equipment during shipment.

There is considerable similarity between these situations. And considerable similarity between the shock and vibration isolators used and the engineering involved.

**Aiming at the first need**, in October 2008, Herb LeKuch initiated ERI's short course "Isolating COTS Equipment aboard Military Vehicles." Herb aims this course at engineers who attach sometimes delicate electronic and other hardware onto

- helicopters and other aircraft, onto
- ships that have to survive combat and onto
- hard-riding land vehicles such as tanks.

Often the equipment was designed for commercial (not military) applications. (COTS stands for Commercial Off-The-Shelf.) But this equipment is often used on military vehicles. As in Figure 1.


*Figure 1*

How can we protect this equipment against shock and vibration? That's the job of vibration and shock isolators. Herb teaches his students how to select the right isolators for a given application. And where, in between the hardware and vehicle, they should attach their isolators.

**Aiming at the second need**, Herb offers "Isolating COTS Equipment within Shipping Containers," When delicate equipment has to be shipped, when it becomes cargo, it's usually placed in some kind of shipping container to protect it against natural environments: heat, cold, moisture, sand-and-dust, sunlight, etc. Against theft. And against dynamic

### "Ground Loop" problems?

Within your organization, are small-electrical-signals from accelerometers, from strain gages, etc. (millivolts down to microvolts) measurements (in the field or in your lab) complicated by electrical interference? By unwanted 60 Hz and multiples (50 Hz and multiples in much of the world) signals?

In many instances those complications can be overcome by proper instrumentation electrical grounding.

Let us know of your need so we can help. An associate firm offers to assist your metrologists with their "ground loop" problems. ERI may offer a short course at your facility, regarding your specific problems. ERI may also offer "open" short courses at major cities.

### Have new people joined your test lab?

New hires in your environmental test activity are probably somewhat overwhelmed by unfamiliar test equipment and test activity.

Quite likely the "old timers" are (1.) too busy to assist the newcomers, (2.) lacking in introductory-level teaching materials or (3.) just possibly not too sure that they fully understand everything they do.

Don't be embarrassed. None of us learned this material

or man-made environments: shock and vibration.

Let's look inside the container, at the delicate cargo. Is it pushed up tight against the shipping container? No. It's protected, it's softly-suspended within the shipping container. It's able to move, perhaps move quite a bit, when the vehicle and container move. There will be motion. Count on it. Bump! The container is set down hard on the loading dock. Bump! The container is set down hard on the truck bed. Bump! Bump! Jiggle! Bump! Bump! Jiggle! Bump! Down the road. Into the driveway. Bump! Against the receiving dock. Bump! Offload. Bump! Final destination.

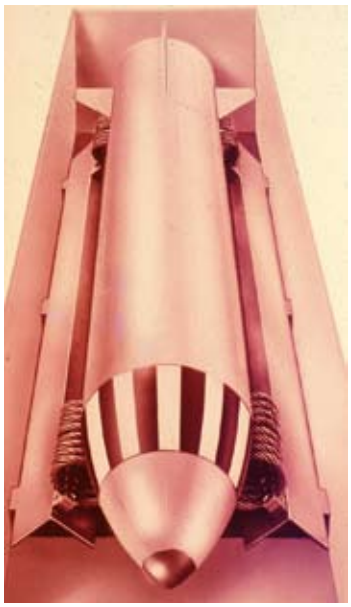

*Figure 2*

But our delicate cargo is ok. It was protected from all those bumps and jiggles. It came through the trip just fine. Unpacked and installed, it's ready to serve its new owner for years.

Isolation requires the shipping container to be oversize, as in Figure 2 (Figure 5-22 from Wayne's book) as to permit the cargo some relative motion.

In class, Herb talks kind of technical, using words like static deflection, stiffness, natural frequencies, forcing frequencies, acceleration, displacement, force, etc. Most of his students have a little mechanical engineering in their backgrounds. They are getting ready to deal with professional packaging engineers, with container manufacturers and with testing laboratories.

Does some reader have a question for Herb? E-mail him at *specialist@equipment-reliability.com*.

*Herb is a consultant to Shock Tech Corp and to 901D, LLC. He has extensive experience in mechanical design, shock and vibration isolation, test and analysis, sales and marketing for military, space and industrial projects.*

*Herb is also an ERI specialist. Ask ERI (or Herb) about his upcoming short courses that fill the first need and those that fill the second need described above.*

in engineering school.

Tell the "new hire" to visit ERI's website, pick out an upcoming course and tell "the boss" you need to attend. He may well surprise you by instantly agreeing.

## EMI/RFI/EMC Teacher Needed

ERI needs an electromagnetic interference/ radio frequency interference/ electromagnetic compatibility teacher for occasional short (typically 3 days) courses. Please phone or e-mail Wayne Tustin.

## NDT instructor needed

Does some reader specialize in Non-Destructive Testing (NDT)? Which of the following? liquid penetrant testing, radiographic (X-ray) testing, computed tomography, ultrasonic testing, magnetic acoustic testing, electromagnetic testing, e ddy-current testing, acoustic emission testing, hardness testing, magnetic resonance imaging, etc.

Would you be interested in teaching a few days, several times per year? If so, please communicate with Wayne.

## Sample Lesson

Do you know someone who is just getting started in vibration testing? In

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## Test Lab Musings (part 23)

*by Robert L. Renz*

- Taking digital photos of your test setups and the UUT (Unit Under Test) for reports is probably standard operating practice for virtually every test lab, and hopefully for your lab. But before you snap a shot, consider the background. Be sure

  (1) that it's clean and orderly, and also

  (2) that it doesn't show anything that isn't part of the test you're conducting (like maybe a fixture for someone else's test).

  (3) After taking the photo, verify that it's in focus.

  (4) Before you use it or send or give it to your customer, take a moment to clean it up with photo editing software - correct exposure and colors, and

  (5) crop it appropriately.

  (6) Some compression (such as jpg} will lessen storage and e-mail transmittal times.

- Keeping a spool of RG-58 coax and connectors on hand will let you assemble exact length cables as needed. For best results, purchase a good quality crimp-type connector instead of a wrench-assembled connector. I prefer Amphenol connectors and crimping tools, supplied by Newark Electronics.

- We purchase ready-built cables in various lengths.

*Robert L. Renz of General Dynamics - Advanced Information Systems at Bloomington, Minnesota.*

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understanding vibration measurements?

Suggest that your friend look at the free sample vibration lesson out of Wayne's Distance Learning (home study) vibration course.

### Does your employer require that you participate in training?

Many organizations have that requirement, but immediate supervisors sometimes forget to implement the rule. In a way, you might be doing your immediate boss a favor if you sign up for a short course. Several are suggested at our website.

### Draft Message to our Training Director

Joe, some of us test engineers seek your assistance in obtaining training in vibration and shock testing, measurement, analysis and calibration. Not so much theory as practical information. Senior test lab people don't seem to have the time nor the teaching tools.

Many of our designers need this also, so that we "speak the same language".

Can the needed training meet here at our facility? Alternately, a few of us, at a time, can travel to a course location.

Joe, you'll find such training offered at www.equipment-reliability.com.

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