LAT Vibration and Acoustic Testing

Martin Nordby 21 May 01

Goals of Vibration Testing

Goals

The LAT vibration test plan is intended to:

Qualify all new designs and processes used in the LAT
Verify workmanship of all flight hardware.

Part of the qualification process involves developing analytical models (mostly finite-element analysis (FEA) models), then validating them by comparing their predictions with test results.

While GEVS defines many of the tests needed to fully qualify and verify a proto-flight, one-off instrument like the LAT, it leaves much open to interpretation and to personal and project preference. Thus, it is incumbent on the LAT team to develop a suitably conservative test program that we, and the GLAST project, are comfortable with its results.

General Test Plan

The general plan of attack in qualifying and verifying the LAT is to start from the lowest logical level of assembly and work up:

1. Module-level vibration qualification and workmanship verification testing
2. LAT system-level prototype qualification testing
3. LAT system-level flight qualification and verification testing
4. Observatory level verification testing

In planning this set of tests, we need to keep the following in mind:

1. All new designs must be qualified. We need to make sure that nothing "falls between the cracks."
2. All interfaces must be qualified, and their final flight configuration must be verified for workmanship. However, the means by which this is done is open to discussion.
3. We need to balance the gain of the test against the expected cost: increased technical and schedule risk, increased cost, and cycle life reliability concerns.

<u>Summary of LAT Subsystem Vibration Testing</u>

Qual Modules for TKR, CAL, Elec

Tests: sine sweep, modal survey(?), random vibration, sine burst. All at PFQ levels.

Qualifies:

- Module design and fabrication processes
- Subsystem side of interface design. This is a partial qualification, since it does not include Grid-induced distortions. Should this be approximated in SS vibe test?

Validates:

- Subsystem FEA models. This is a partial validation, since it does not include distortion of Grid. It should validate model in that model can be fully checked with respect to results.

Does NOT do:

- Does not qual subsystem for Grid-induced loads. Can this be done using FEA-predicted loads and physically distorting the interface?
- Does not validate LAT FEA predictions of subsystem loads, although it validates that part of it due to body motion of the subsystem module.

Flight Modules for TKR, CAL, Elec

Tests: random vibe, modal survey. All at Acc levels.

Verifies:

- Workmanship on all modules

Does NOT do:

- Does not verify calbe free-end connections and free part of cable harness.
- Does not verify workmanship on interface joint connection to Grid.

Flight Units for ACD, Cable Harness

Tests: sine sweep, modal survey(?), random vibration, sine burst. All at PFQ levels.

Qualifies:

- Module unit and fabrication processes
- Subsystem side of interface design. This is a partial qualification, since it does not include Grid-induced distortions. Should this be approximated in SS vibe test?

Validates:

- Subsystem FEA models. This is a partial validation, since it does not include distortion of Grid. It should validate model in that model can be fully checked with respect to results.

Does NOT do:

- Does not qual subsystem for Grid-induced loads. Can this be done using FEA-predicted loads and physically distorting the interface?
- Does not validate LAT FEA predictions of subsystem loads, although it validates that part of it due to body motion of the subsystem module.

Flight Grid

Tests: pull-out test on tapped holes, static load test on Grid deflection. All at Proof levels.

Qualifies:

Grid tapped hole design.
Structural design of Grid.
Grid fab method.

Verifies:

Grid fabrication workmanship

Validates:

Can be used to validate response of Grid part of FEA model.

Does NOT do:

Does not qualify Grid and interfaces to distortion-induced loads at interfaces. Although un-validated FEA model is used to set max loads for proof testing.

Does not validate LAT FEA model, in total. Grid distortion test plus subsystem dynamic tests does a nearly complete job in validating LAT FEA model.

Flight Radiators

Tests: Random vibe, sine burst, sine sweep, modal survey (?). All at PFQ levels.

Qualifies:

Radiator design and fabrication processes.
Radiator side of Grid and SC mount.
Radiator for amount of relative motion predicted by Observatory CLA.

Verifies:

Radiator fabrication workmanship.

Validates:

Radiator FEA model.

Does NOT do:

Does not qualify Grid side of Radiator joint, or interaction with Grid.
Does not validate LAT FEA model of Radiator mount.

Summary of Missing Qualification, Verification, and Validation activities

Missing Verification

TKR tower collision
CAL-Grid-TKR cable interaction
Elec box bolted connections to CAL
Actual flight cable connections
Actual flight bolted interfaces

Missing Validation

Effect of Elec on CAL
Elec response to CAL
Subsystem response to Grid distortion
LAT FEA model, in total

Missing Qualification

Elec response to CAL distortion
CAL response to Elec piggyback
Grid response to subsystem stiffness
Subsystem response to Grid distortion
Grid response to Radiator mounting

LAT Vibration Testing

(+) = higher perceived risk
(-) = lower perceived risk

		Level	Verification					Validation				Qualificatior				
			TKR tower collision	CAL-Grid-TKR cable interaction	Elec box bolted conn. To CAL	Actual flt cable connections	Actual flt bolted interfaces	Effect of Elec on CAL	Elec response to CAL	SS response to Grid distortion	LAT FEA model, in total	Elec respons to CAL distortion	CAL response to Elec piggyback	Grid response to SS stiffness	SS response to Grid distortion	Grid response to Radiator mount
A	***Qual Grid + SS mass/stiffness models***															
	Modal survey, static proof test	Qual								X	X					
	Sine burst, random vibe, sine sweep	Qual										O	O	X	X	
	Flight LAT, fully integrated															
	Random vibe, modal survey	Acc	X	X	X	X	X	X	X							
	Risks															
	+: Doesn't qual Elec/CAL struc interface. Poses largest schedule risk relating to over-taxing resources and slippage due to availability of vibe facilities.															
	-: Flight config is fully verified. LAT FEA validation is early. This poses the least risk relating to late discovery of a problem.															
B	***Static test qual modules and distort base***															
	Static proof test	Qual										O	O	O	X	
	Flight LAT, fully integrated															
	Random vibe, sine sweep	Acc	X	X	X	X	X			X	X					
	Modal survey							X	X		X					
	Risks															
	+: LAT FEA validation comes just before delivery, raising schedule risk. Qual is incomplete, not dynamic. Mitigated by good validation of all subsystems. May be able to do simple mass model modal test to validate model.															
	-: Flight config is fully verified. Eliminates need for mass model and flight spare Grid.															
C	***Flight LAT, fully integrated***															
	Sine burst, sine sweep	PFQ								X	X	X	X	X	X	
	Random vibe, modal survey	Acc?	X	X	X	X	X	X	X	X	X					
	Risks															
	+: LAT FEA validation, full qual comes very late. All modules see PFQ, raising risk for subsystem problems.															
	-: Flight configuration is fully verified															
D	***Qual Grid + SS mass/stiffness models***															
	Modal survey, static proof test	Qual								X	X					
	Sine burst, random vibe, sine sweep	Qual										O	O	X	X	
	Flight LAT, during integration															
	Load test joints under static load	Proof			X		X									
	Observatory															
	Random vibe, modal survey or acoustic	Acc	X	X	X	X	X	O	X							
	Risks															
	+: Verification is done on Obs. Qual/val is not dynamic															
	-: Schedule and damage risk to LAT is reduced, since it is not vibe'd.															

Definitions from GEVS

Miscellaneous Definitions

Qual Qualification level testing. Done at a standard level over design level.

PFQ Proto-Flight Qualification test. Test done at nearly qualification levels and durations, on hardware that will be used for flight.

Acc Acceptance level testing. Done at the design limits. This is the level used for workmanship testing.

Proof Proof level testing. Done at a fixed level over design, depending on the particular application being tested (typically 10-25%).

Performance Verification

"Determination by test, analysis, or a combination of the two that the payload element can operate as intended in a particular mission; this includes being satisfied that the *design* of the payload or element has been *qualified* and that the particular *item* has been *accepted* as true to the design and ready for flight operations."

Design Qualification Tests

"Tests intended to demonstrate that the test item will function within performance specifications under simulated conditions more severe than those expected from ground handling, launch, and orbital operations…The design qualification tests may be to either "prototype" or "protoflight" test levels."

Test does two things. First, it is used to validate the FEA model. This is especially important for modal survey testing, since the test results are used to validate the load limits to which components and subsystems must be designed. This type of Qual test is typically done at the instrument level.
Second, it shows that the planned designs and processes for a given assembly are adequate to meet the expected loads (with safety factor).

Acceptance Tests (a.k.a.: Verification Test)

"The verification process that demonstrates that hardware is acceptable for flight. It also serves as a quality control screen to detect deficiencies…"
This verifies that the designs and processes were actually done right, and that the resulting assembly can actually take the loads it will see, and perform as specified. This is for actual flight hardware.

Workmanship Tests

"Tests performed during the environmental verification program to verify adequate workmanship in the construction of a test item…"
A workmanship can also be an acceptance test, but not necessarily. Example of this is vibration testing a TKR tray. This is a workmanship test, but is not part of a formal acceptance test (that is only done at the module level).

Modal Test
Modal test is required to validate the FEA model of the LAT. This can be done with accelerometers and a hammer, and will should validate modal frequencies and shapes for all modes up to 70 Hz.

GEVS 2.4.1 Structural Loads Qualification: "…A modal test shall be performed for each payload (at the subsystem/instrument or other appropriate level of assembly) to verify that the analytical model adequately represents the dynamic behavior of the hardware. The test-verified model shall then be used to predict the maximum expected load for each critical loading condition…"

Modal Survey
Modal survey is not required for the LAT, since all modes are above 50 Hz.

GEVS 2.4.1.2 Modal Survey: "A modal survey test will be required for payloads and subsystems, including instruments, that do not meet requirements on minimum fundamental frequency." Therefore, modal survey of LAT is not needed.

Design Qualification Tests (a.k.a.: "Strength Tests")
Qual testing. This is required. Usually at instrument level, but not mandatory. Does not need to be sine burst. Can be static. Composites must be qualified using actual flight hardware (not prototypes).
Acceptance testing (a.k.a: "workmanship," "proof test"): Not needed, unless Qual testing used prototype hardware.
Realistically, strength qualification testing will be better done at the subsystem level, where loads can be applied in a more uniform, consistent manner.

GEVS 2.4.1.3 Design Strength Qualification
"The preferred method of verifying adequate strength is to apply a set of loads equal to 1.25 times the limit loads, after which the hardware must be capable of meeting its performance criteria (see 2.4.1.3.1 for special requirements for beryllium structure). As many test conditions shall be applied as necessary to subject the hardware to the worst-case loads.
a. Selection of Test Method – "The qualification load conditions may be applied by acceleration testing, static load testing, or vibration testing (either transient, fixed frequency or swept sinusoidal excitation). Random vibration is generally not acceptable for loads testing. The following questions shall be considered when the method to be employed for verification tests is selected:"

(1) Which method most closely approximates the flight-imposed load distribution?
(2) Which can be applied with the greatest accuracy?
(3) Which best provides information for design verification and for predicting design capability for future payload or launch vehicle modifications?
(4) Which poses the least risk to the hardware in terms of handling and test equipment?
(5) Which best stays within cost, time, and facility limitations?

Sine Sweep Test
Low-level, 5-50 Hz vibration test, “to verify its ability to survive the low-frequency launch environment. The test also provides a workmanship vibration test for payload hardware which normally does not respond significantly to the vibroacoustic environment at frequencies below 50 Hz, but can experience significant responses from the ELV low-frequency sine transient vibration and any sustained, pogo-like sine vibration.”
In general, the LAT should not be sensitive to low-frequency transients. Since this is generally a workmanship test, it can be done at the subsystem level. Biggest exposure would then be: cable harnesses on integrated LAT; details of thermal shield and its attachment to Grid. These would still be tested at Observatory sine sweep, but risk is increased.

GEVS 2.4.3.1 ELV Payload Sine Sweep Vibration Tests – “At the payload level of assembly, ELV prototype/protoflight hardware shall, when practicable, be subjected to a sine sweep vibration design qualification test to verify its ability to survive the low-frequency launch environment.” Sine sweep is done at payload level, usually.

GEVS 2.4.3.2 ELV Payload Subsystem (including Instruments) and Component Sine Sweep Vibration Tests – “As a screen for design and workmanship defects, these items (per Table 2.4-1) shall
be subjected to a sine sweep vibration test along each of three mutually perpendicular axes.” Sine sweep at instrument level is usually for workmanship testing, not for qualification. Table 2.4-1 says that this is required at instrument level, unless it is decided not to do it.

Random Vibration
Instrument-level random vibe and acoustic testing is not mandated, but is typical. This is true at the Observatory level, also, where size and mass can make such a test impractical. In broad terms, the LAT is not very sensitive to structure-borne random vibration. Most of these sensitivities can be tested at the module level. In general, sub-system response to structure-borne vibration is separable, largely because fundamental modes occur at different frequency, and have different mode shapes.

GEVS 2.4.2.4 Subsystem/Instrument Vibroacoustic Tests – “If subsystems are expected to be significantly excited by structure-borne random vibration, a random vibration test shall be performed…. The levels shall be equal to the qualification level as predicted at the location where the input will be controlled…. A random vibration test is generally required for instruments.”

GEVS 2.4.2.5 Component/Unit Vibroacoustic Tests — “As a screen for design and workmanship defects, components/units shall be subjected to a random vibration test….”

Acoustic
Acoustic testing follows the same guidelines as random vibe testing.

GEVS 2.4.2.4 Subsystem/Instrument Vibroacoustic Tests – "…Subsystem acoustic tests may also be required if the subsystem is judged to be sensitive to this environment or if it is necessary to meet delivery specifications…."

GEVS 2.4.2.5 Component/Unit Vibroacoustic Tests - "…In addition, when components are particularly sensitive to the acoustic environment, an acoustic test shall be considered.

Notes

In broad terms, the LAT is not very sensitive to structure-borne random vibration. Most of these sensitivities can be tested at the module level. In general, sub-system response to structure-borne vibration is separable, largely because fundamental modes occur at different frequency, and have different mode shapes.

Grid: fundamental is vertical drum-head vibration. F(Grid) = 60 Hz. This is excited by LV vertical vibrations.

Radiators: fundamental is panel vibration, which cannot be excited by the Grid. Transverse vibration of the SC can excite this, but f(rad) ~ 70 Hz, and f(SC) <35 Hz, so there should not be strong coupling.

Tracker: fundamental is cantilever tower tipping. f(TKR) > 120 Hz. This is just not driven by the Grid vertical vibration. The Grid is stiff transversely, so it could couple transverse oscillations into the TKR, but the SC and interface structure will have a fundamental transverse mode of 12-20 Hz. This will have no affect on the TKR.

Calorimeter: fundamental is transverse shear distortion of the module, and crystal "sloshing". Expected f(CAL) = 70-100 Hz. This is close to the Grid fundamental, but mode shape is transverse to Grid's. As with TKR, there is little coupling to LV oscillations at the frequency, since SC acts as a base-isolator for transverse motions.

ACD: fundamental is vertical drumhead mode of top of ACD. f(ACD) ~ 100 Hz. This poses the biggest risk of coupling with the Grid oscillation. Also, the large ACD panels pose the largest sensitivity to acoustic loading.