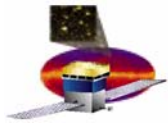


GLAST Large Area Telescope:

I&T Particle Test - Airplane

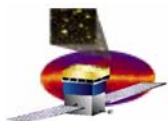
Elliott Bloom, Gary Godfrey, Tune Kamae

Presentation to GLAST Engineering Meeting
October 29, 2002



Purpose of LAT Airplane Test

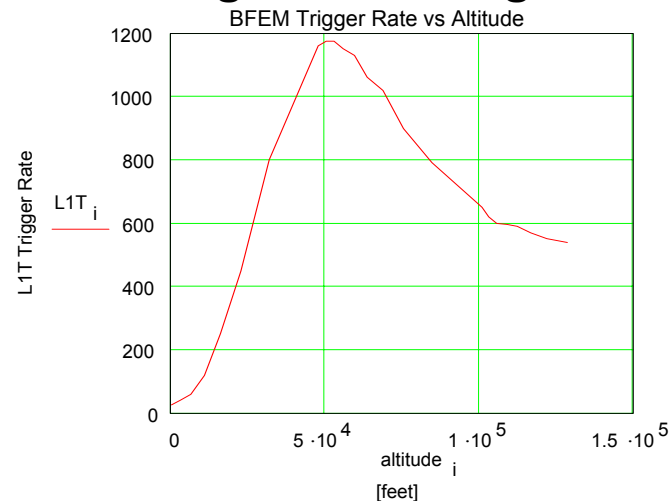
- **Expose the LAT to charged particle fluxes similar to those in orbit. Do an End-to-End test of the LAT in as close to orbital environment as practical.**
 - **Demonstrate the complete LAT system functionality at in-orbit cosmic rates and higher. Our only other chance for a similar test will be in-orbit.**
 - **See LAT-TD-00550 “LAT Test Plan for Airplane”.**



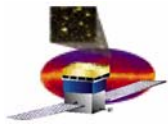
End-to-End Test in Airplane (using Cosmic Rays)

- Full LAT in an airplane (during airplane ride to/or back from NRL environmental test).
- L1T trigger rate measured in single tower during Balloon Flight.

Alt [feet]	L1T [Hz]	Notes
0	25	Ground
25,000	540	Same rate as in orbit
35,000	900	Airplane flight
50,000	1175	Pfotzer max
127,000	540	~Orbital rate



- At 25,000 feet verify the flight hardware
 - The BFEM was 1/25 of a full LAT.
 - Scales by MC to $\sim 17 \times 540 = 9.2$ kHz of L1T (over Palestine, Texas).
 - Test LAT End-to-End performance
 - Live time is reasonable for the trigger rate.
- At 35,000 feet test the flight hardware at $>$ orbital L1T rates
 - ~ 22 kHz saturates the LAT trigger
 - Test LAT End-to-End performance

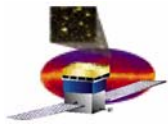


“Success” Criteria for the LAT Airplane Test

Success will be the timely completion of the following two classes of tests with satisfactory (TBD) results:

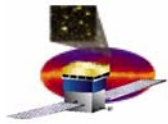
- 1. General hardware tests for the complete LAT system at high particle rate:**
 - a) DAQ stability at orbital rates.**
 - b) Events contain good data (e.g., no scrambled bits, no unsync'd events, data from all subsystems, ...).**
 - c) Trigger rate in the various trigger modes as expected from MC.**
 - d) Livetime/Realtime in the various trigger modes as expected from MC.**

- 2. Detailed comparison of analyzed events (from standard 3-in-row trigger) to GEANT 4 as was done for the BFEM.**



Schedule

- **Flight from SF Bay Area airport to Environmental Tests (NRL)**
- **1 day (24 hours +) allotted for flight in P3 schedule**
- **Could do this on the way from NRL back to SLAC or Spectrum Astro.**

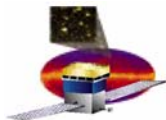


Airplane Acceleration Environment

- **DOT/FAA/AR-98/28**
 - **Statistical Loads Data for Boeing 737-400 Aircraft in Commercial Operations**
- **DOT/FAA/AR-00/10**
 - **Statistical Loads Data for Boeing 767-200ER Aircraft in Commercial Operations**
- **Both documents show the Probability per Nautical mile of exceeding a particular acceleration. At any acceleration, the vertical acceleration is more probable than a horizontal one.**
- **Assume we are willing to accept a 1% chance of exceeding our tested acceleration during the flight. The data says:**

**Probability of >0.6 vertical g during cruise of 3000 Naut miles = 0.01.
Horizontal accelerations are less.**

This data consisted of 8 acceleration measurements/sec and thus represents the acceleration environment at < 4 Hz.



Example Transfer Function of the LAT Mounting within the Shipping Box

Acceleration of the LAT within the Transport Box

Gary Godfrey
Oct 14, 2002

The LAT of mass "m" is mounted on springs with a combined spring constant "k". The springs + LAT have a resonant frequency $\omega_0 = \sqrt{k/m}$.

One end of the spring is connected to the aircraft (or the box wall). This end of the spring is driven by 1) Vibration and airpockets through contact with the airplane, or 2) Acoustics through pressure on the Transport Box wall.

1) Consider the airplane floor moving with some $x_{floor}(t)$ irrespective of the mass m. The floor acceleration has a Fourier spectrum of $a_{floor}(\omega) = x_{floor}(\omega) \cdot \omega^2$. Assume the floor acceleration amplitude is independent of freq (as it would be for a narrow delta function acceleration of amplitude a_{floor_vib0}). Let $x_{lat}(t)$ be the position of the LAT mass m. The differential eqn for the system is:

$$\frac{d^2}{dt^2} x_{lat} + \gamma \frac{d}{dt} (x_{lat} - x_{floor}) + \frac{k}{m} (x_{lat} - x_{floor}) = -a_{floor} \quad \omega_0^2 := \frac{k}{m}$$

$a_{floor_vib0} = .6 \cdot 9.8$ [m/sec²] Vibration acceleration amplitude

$\omega_0 := 1.2 \cdot \pi$ [rad/sec] Resonant freq of spring + LAT

$Q := .1$ Q of the spring (very low to suppress the resonance)

$\gamma := \frac{\omega_0}{Q}$ Damping constant

$$x_{floor_vib}(\omega) := \frac{a_{floor_vib0}}{\omega^2}$$

$$x_{lat_vib}(\omega) := \frac{\omega_0^2 + i \cdot \gamma \cdot \omega}{\omega^2 - \omega_0^2 + i \cdot \gamma \cdot \omega} \cdot x_{floor_vib}(\omega) \quad a_{lat_vib}(\omega) := \omega^2 \cdot x_{lat_vib}(\omega)$$

2) Consider a flat spectrum acoustic pressure wave acting on one side (the floor) of the box with force F(t). Assume the acoustic force on the wall is independent of frequency (db is the same at all frequencies).

$$\frac{d^2}{dt^2} x_{lat} + \gamma \frac{d}{dt} x_{lat} + \frac{k}{m} x_{lat} = \frac{F(t)}{m} \quad a_{floor_acoustic}(\omega) := \frac{F(\omega)}{m}$$

db := 100 [decibels] Sound pressure relative to 2×10^{-5} Newtons/m²

A := 2.3 [m²] Area of side of box

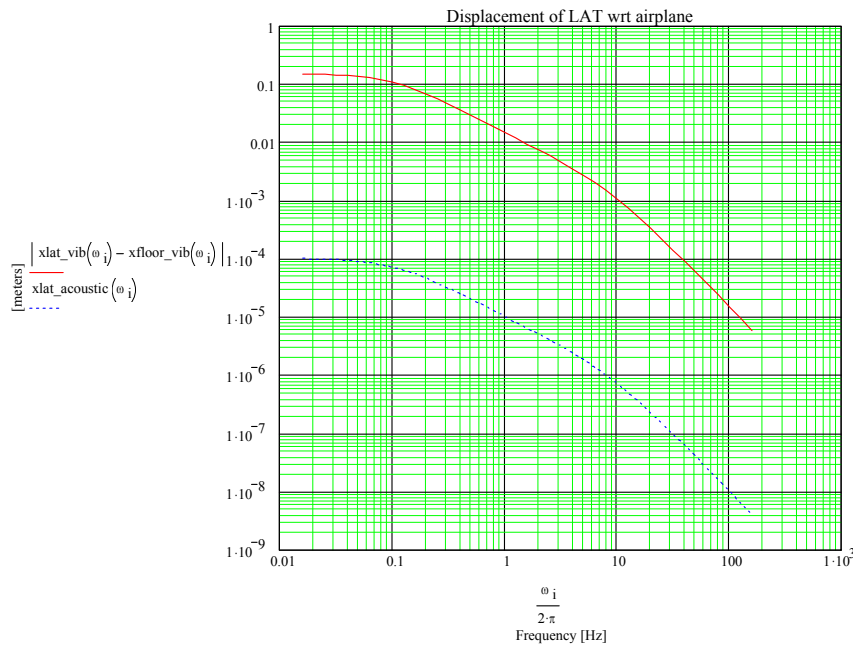
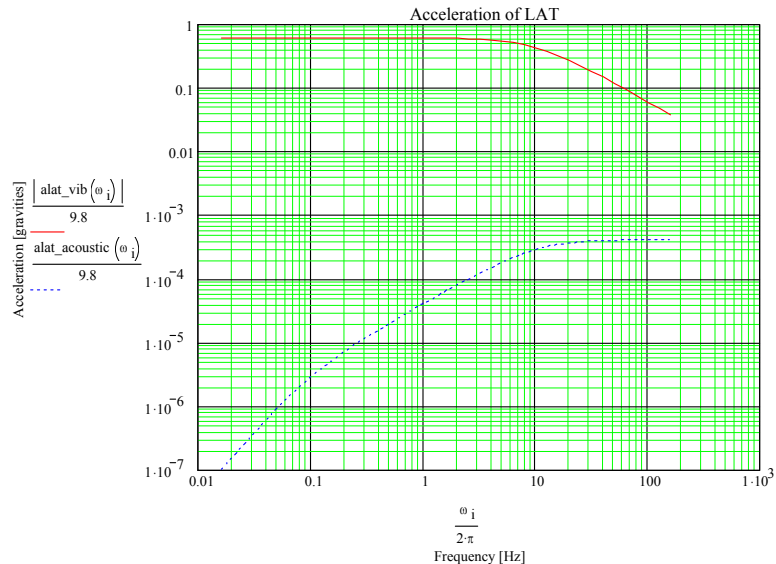
m := 3000 [kg] Mass of LAT

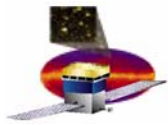
$$a_{floor_acoustic0} = \frac{A \cdot 2 \cdot 10^{-5}}{m} \cdot 10^{\frac{db}{20}}$$

$a_{floor_acoustic0} = 4 \cdot 10^{-3}$ [m/sec²] Acoustic acceleration amplitude

$$x_{lat_acoustic}(\omega) := \frac{a_{floor_acoustic0}}{\sqrt{(\omega_0^2 - \omega^2)^2 + (\gamma \cdot \omega)^2}} \quad a_{lat_acoustic}(\omega) := \omega^2 \cdot x_{lat_acoustic}(\omega)$$

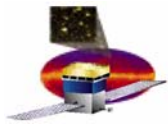
$$i := 0.40 \quad \omega_i := 10^{\frac{i}{10} - 1}$$





Anticipated Impact on Subsystems

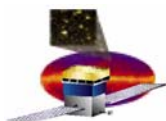
- **Electronics**
 - Test electronics while powered ON at the highest expected airplane acceleration. If this acceleration is exceeded, LAT will be switched off.
 - Power conversion from airplane power (e.g., 24 VDC to 120 VAC)
- **I+T**
 - Plan for and operate LAT in flight.
 - Understand flight environment.
 - Analyze data and quantify LAT performance.
- **Mechanical Systems and I&T**
 - Thermal/mechanical analysis of test environment.
- **Flight Software**
 - New(?) trigger modes: throttled, ACD-damaged, and wide open trigger modes.
- **Science Analysis Software**
 - Process additional ~6 hours of data.



What Might we Learn

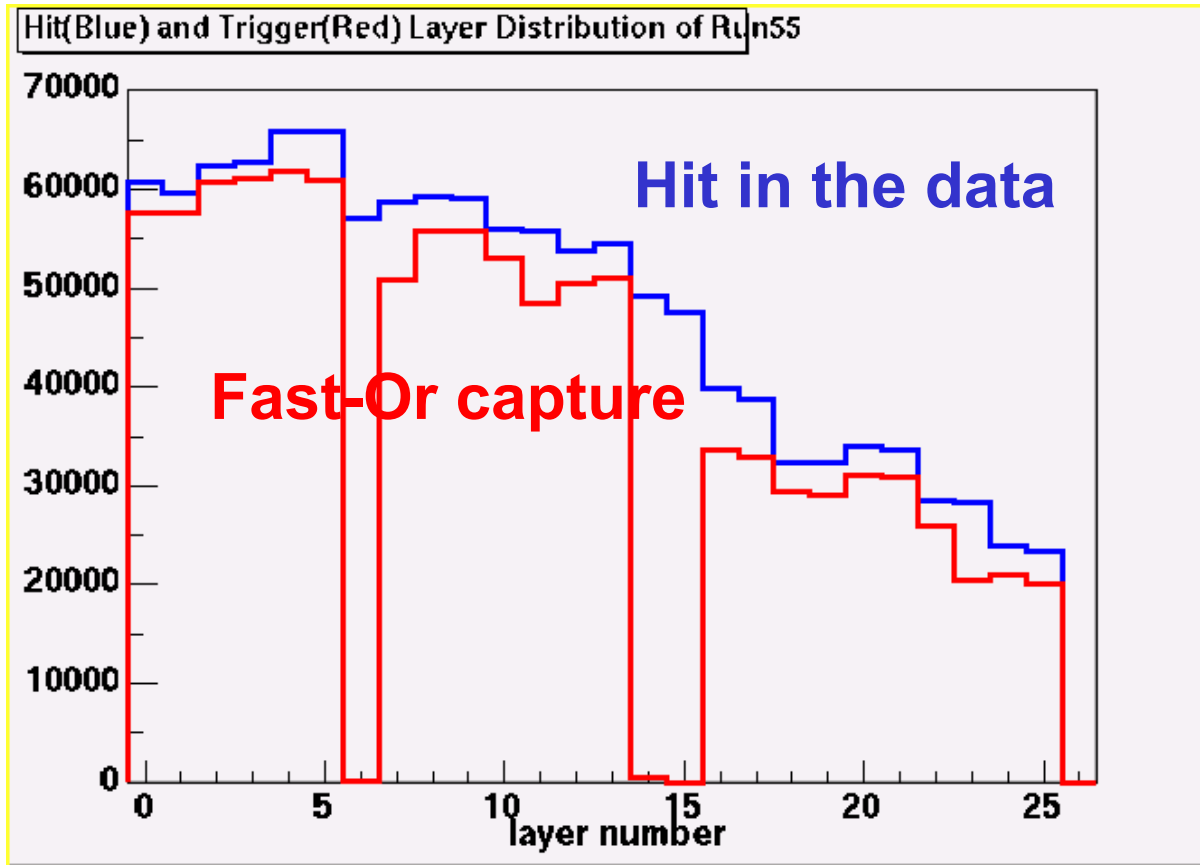
Two examples where our BFEM data analysis revealed instrumental problems that were not captured by electronic tests nor on-ground cosmic-ray tests.

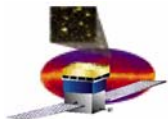
- 1) Fact that 3 layers were disconnected from the trigger was overlooked because cosmic-ray muons reach the Earth surface mostly from the zenith and penetrate many layers. Detecting cosmic-rays with large polar angles was essential to uncovering this instrumental failure. (See Slide #10)
- 2) Fact that propagation delay through the daisy chain of LSI (GTFE chips) took ~4 times longer than calculated. Capture efficiency of Fast-OR was dependent on the distance from the first LSI to the struck LSI. (See slide #11 and #12). Spice-based prediction of the total delay was only ~20-40ns. When measured the delay was about ~140ns.



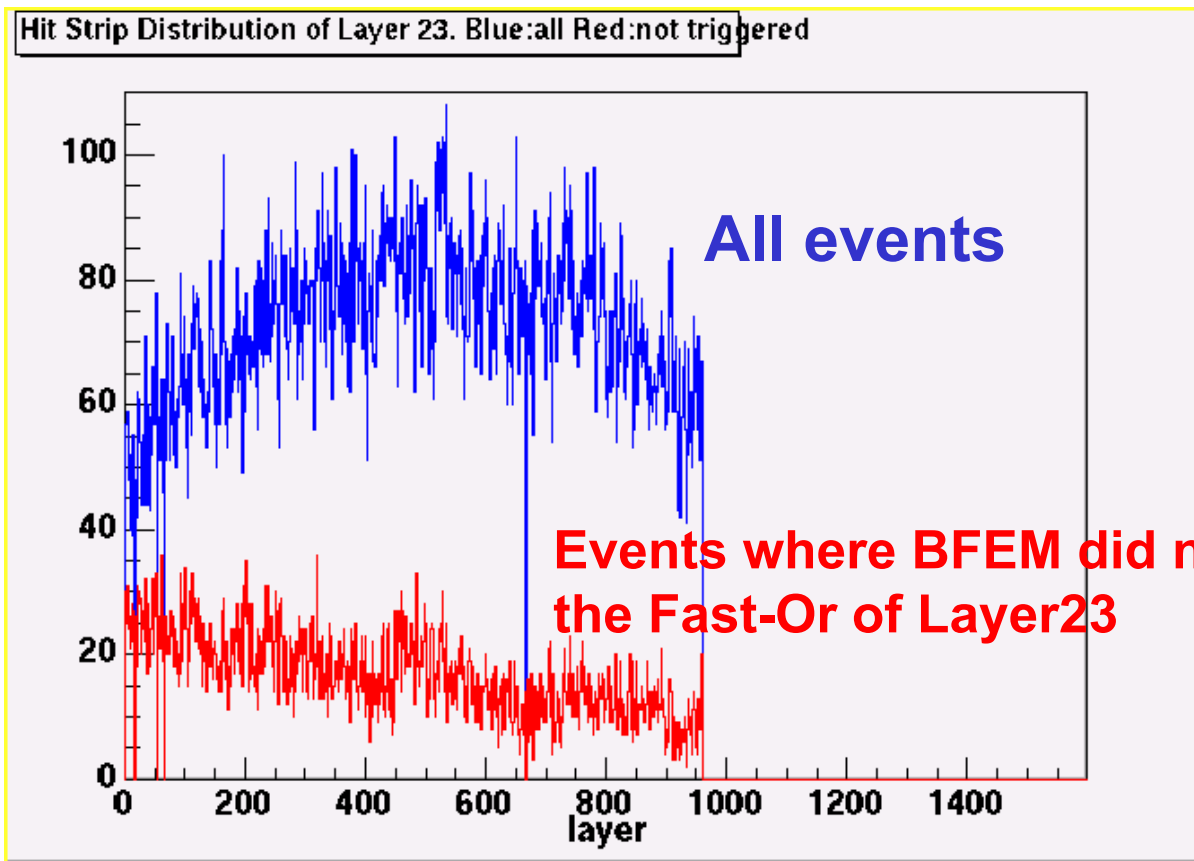
1) Trigger Inefficiency in 3 Layers

- We discovered using in-flight data that three layers did not participate in the trigger as shown below. This was detected because there was an “inefficiency” in near-by layers compared with Geant4 predictions.
- The **Blue histogram** (counts read into data) and the **Red one** (counts in Fast-Or capture) disagree with each other.



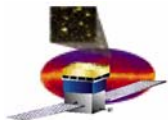


2) Hit Strip Distribution of Layer23

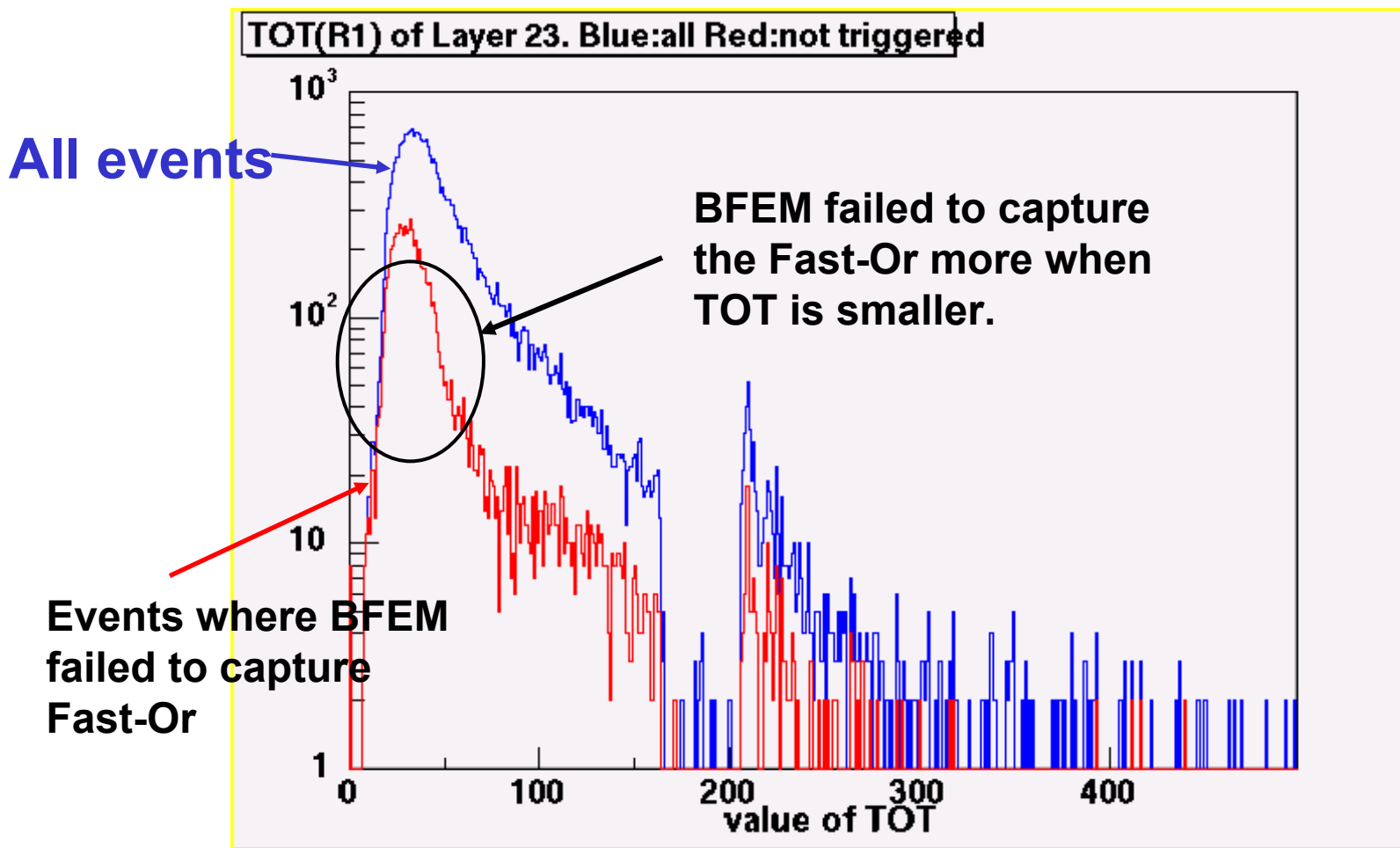


Distance from the readout chip

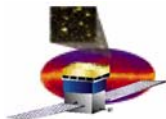
One readout chip failed in Layer23 and all data were readout from the other end. We detected that the Fast-Or capture efficiency depended on the distance from the readout chip. Later measurement revealed that the propagation delay was under-calculated by a factor $\sim 4-5$.



2) TOT Distribution of Layer23

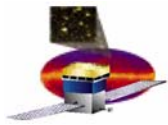


TOT=5 corresponds to width of about 1us

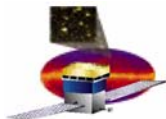


Conclusions

- **I&T and other collaborators believe that it is crucial for the success of GLAST performance on orbit that we perform an End-to-End test of the LAT in as close to orbit particle flux conditions as practical.**
- **We believe that the proposed Airplane test is an excellent candidate for such a test.**
- **Past experience has shown that testing an instrument's pieces separately, and the full instrument in an environment far from the orbital data environment, is frequently insufficient to yield a properly operating instrument on-orbit. Such an approach has high risk.**
- **In our opinion, the risk of losing the LAT in a properly engineered airplane test is very low compared to not doing the proposed airplane LAT End-to-End test (or an equivalent test).**

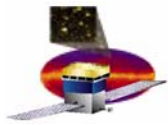


Backup Transparencies



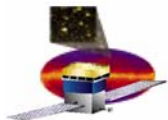
Data Taking Modes

- **The aircraft will be in one of 3 states**
 - 1) **Sitting on the ground, climbing, or descending**
 - 2) **Level flight at ~25,000 feet for ~2 hours (cosmics~orbit)**
 - 3) **Level flight at ~35,000 feet for ~2 hours (cosmics~2 X orbit)**
- **LAT Trigger Modes**
 - **A) Standard 3-in-row with software filter for gammas**
 - **B) Throttled (~2 modes)**
 - **Cal energy requirement in coincidence with 3-in-row**
 - **ACD veto of L1T**
 - **C) Damaged (~2 modes)**
 - **Turn off one ACD tile**
 - **Turn off one tower**
 - **D) Wide open trigger (3-in-row with no software filtering)**
- **Cycle through the triggers (10 min runs or 1 Gbyte files)**
 - **Trigger A when in state 1**
 - **Cycle through 6 trigger modes A,B,C,D when in states 2,3**



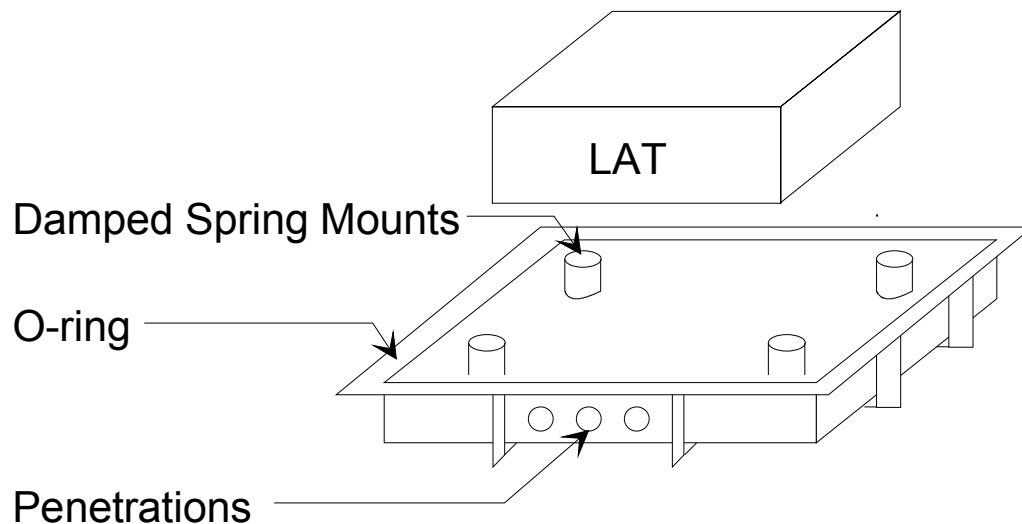
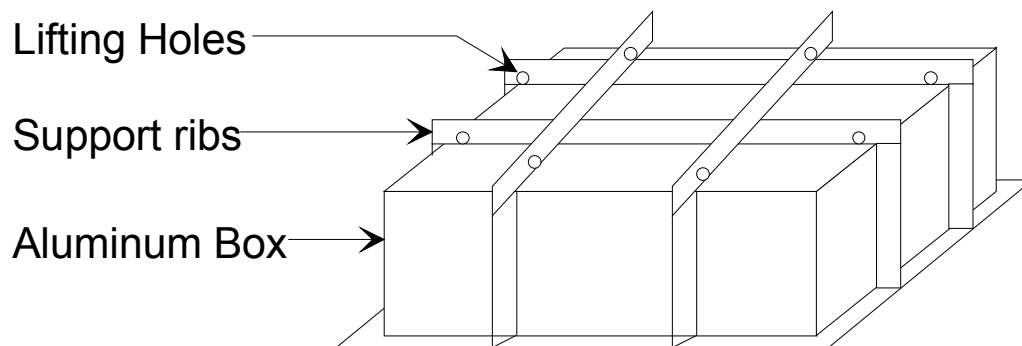
Existing Plans (even if no data in airplane)

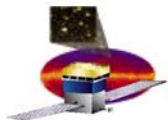
- **Shipping box**
 - The box already is designed for shipping.
 - LAT shipping accelerations < (6.6 g vert, 4.0 g horiz) (LAT-MD-00649)
 - Damped spring mounts to support points on grid
 - Box thermal insulation. Temperature stabilized.
 - MicroDAQ (3 of them) Monitors (Temp, Press, Hum, 3 axis accel)
 - Flow dry air from a portable dehumidifier (~1 Kw)
 - Cable, coolant tubes, dehumidified air penetrations.
 - Box is already designed for operating the LAT for the Bldg 33 thermal tests.
 - Liquid cooled heat exchangers bolted to grid
 - Portable 1-2 Kw liquid chiller (<0° C for SLAC thermal cycling tests TBR)
 - Pseudo solid state recorder on the 30 Mbit/sec data cable
 - Cat 5 cable to the GSE computer (=Laptop computer in plane)
 - Power supply to convert 110 VAC to 28 VDC for the LAT.
- **Airplane ride (even if we don't take data !)**
 - Expectation value of \$ loss in truck accident > cost of airplane flight
 - $(10^{-2} \times \$200 \text{ M}) = \$2 \text{ M} \gg \$200 \text{ K}$
 - Saves ~1 week trucking time in schedule.



LAT Shipping Box Conceptual Drawing

LAT Transport and Environmental Test Box





Boeing 737-400 (DOT/FAA/AR-98/28)

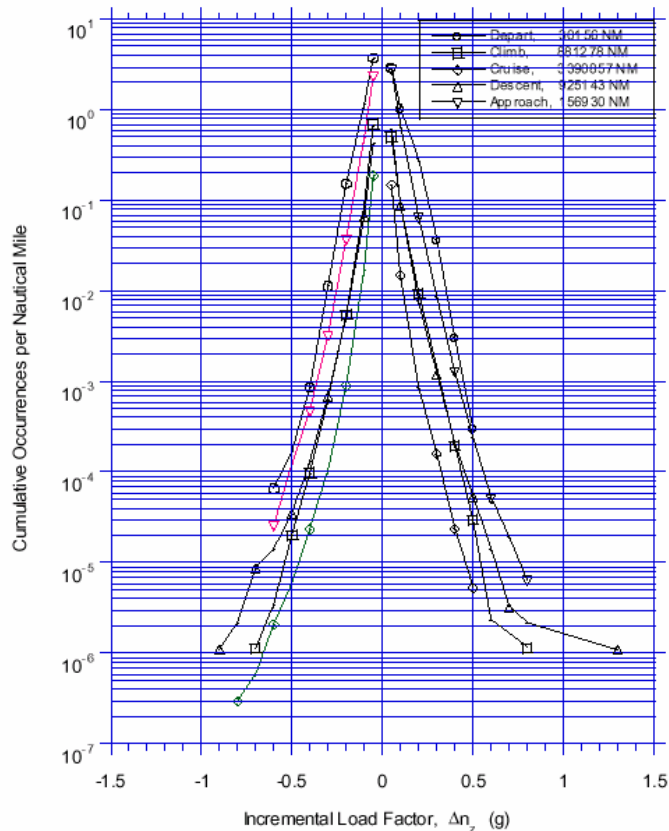


FIGURE A-60. CUMULATIVE OCCURRENCES OF VERTICAL LOAD FACTOR PER NAUTICAL MILE BY FLIGHT PHASE

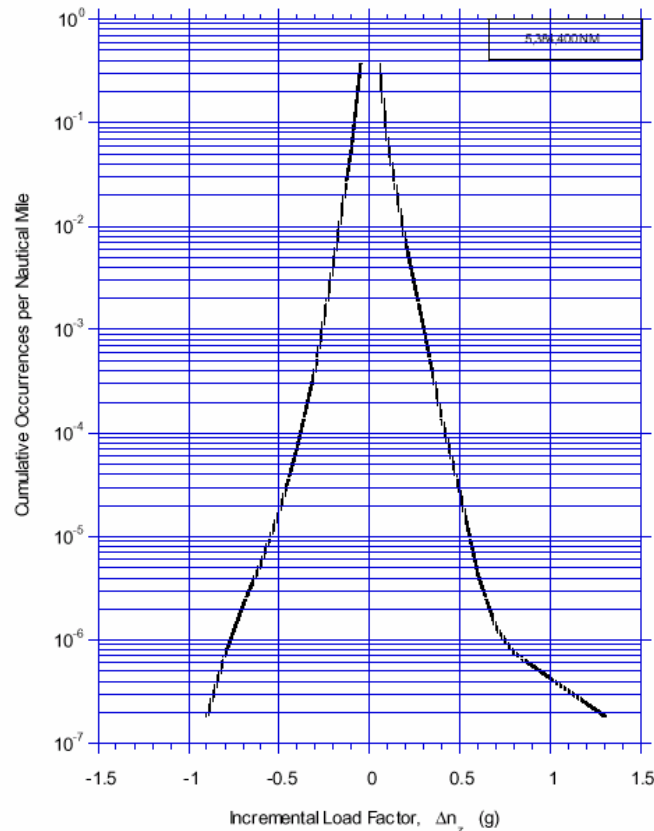
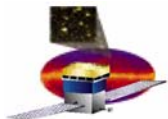


FIGURE A-61. CUMULATIVE OCCURRENCES OF VERTICAL LOAD FACTOR PER NAUTICAL MILE, COMBINED FLIGHT PHASES



Boeing 737-400 (DOT/FAA/AR-98/28)

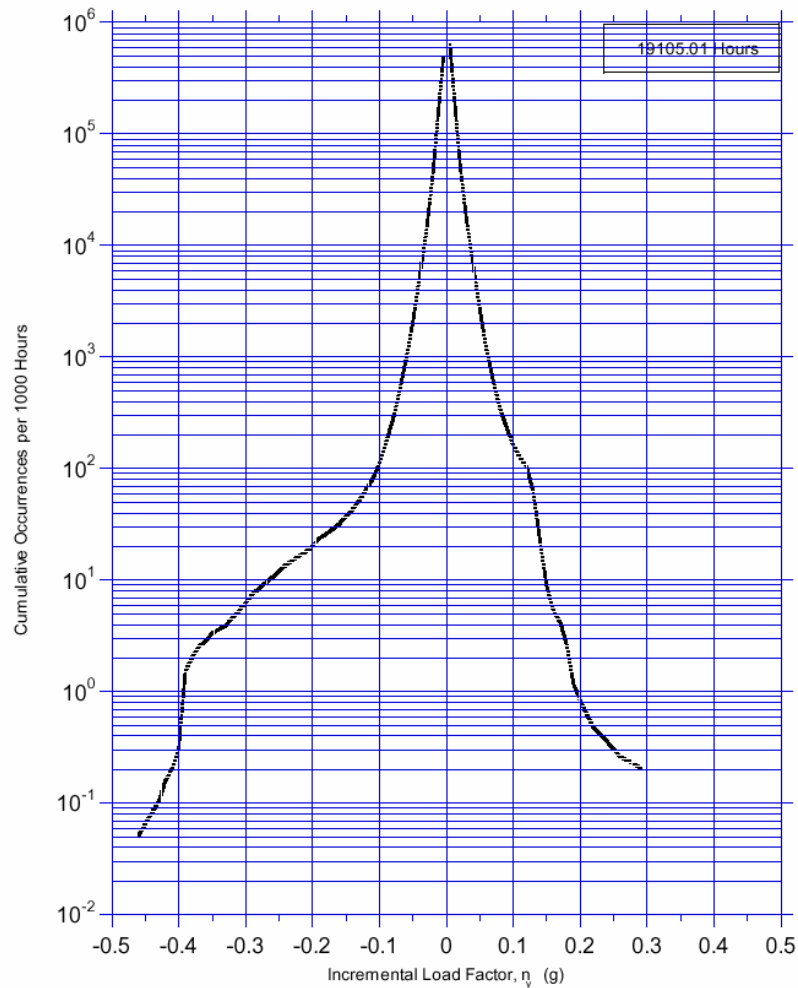
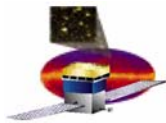


FIGURE A-62. CUMULATIVE OCCURRENCES OF LATERAL LOAD FACTOR PER 1000 HOURS, COMBINED FLIGHT PHASES



Boeing 767-200ER (DOT/FAA/AR-00/10)

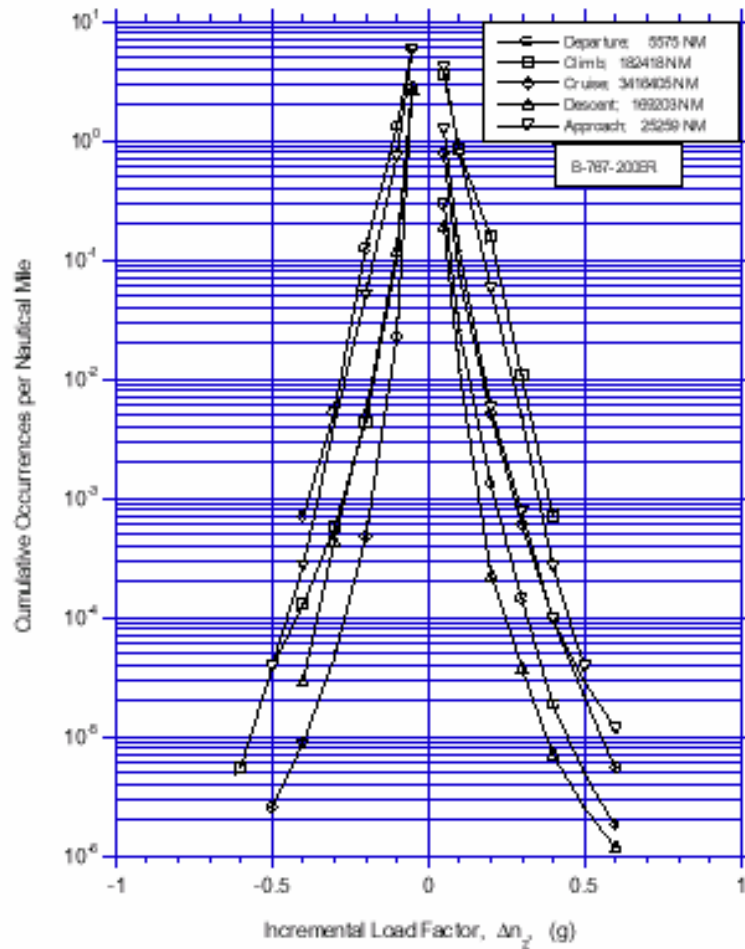


FIGURE A-61. CUMULATIVE OCCURRENCES OF INCREMENTAL VERTICAL LOAD FACTOR PER NAUTICAL MILE BY FLIGHT PHASE

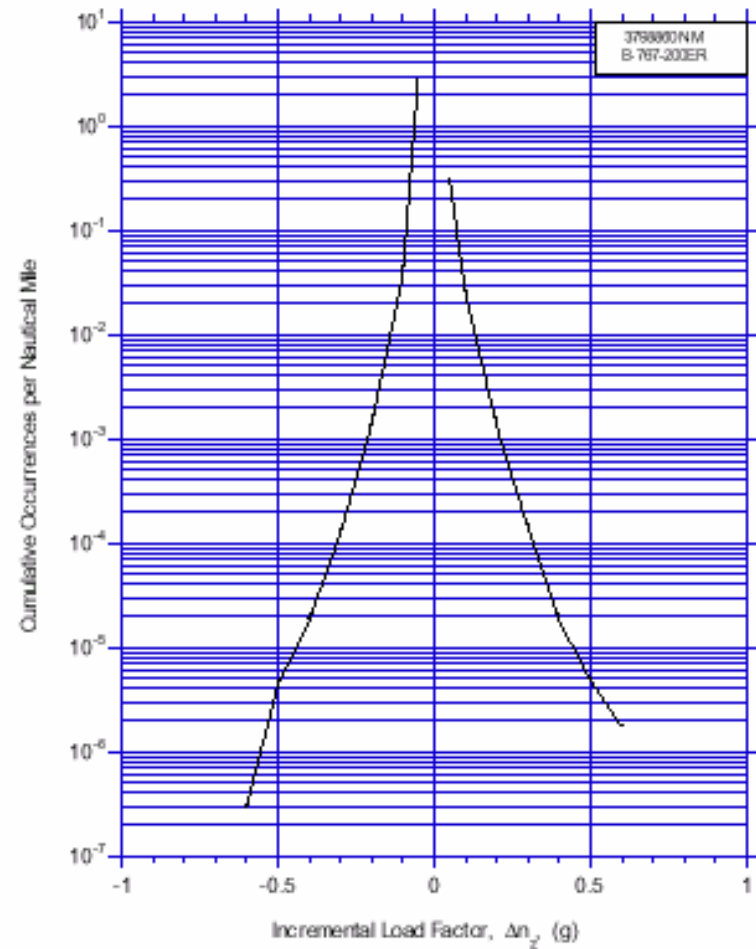
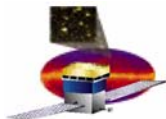


FIGURE A-62. CUMULATIVE OCCURRENCES OF INCREMENTAL VERTICAL LOAD FACTOR PER NAUTICAL MILE, COMBINED FLIGHT PHASES



Boeing 767-200ER (DOT/FAA/AR-00/10)

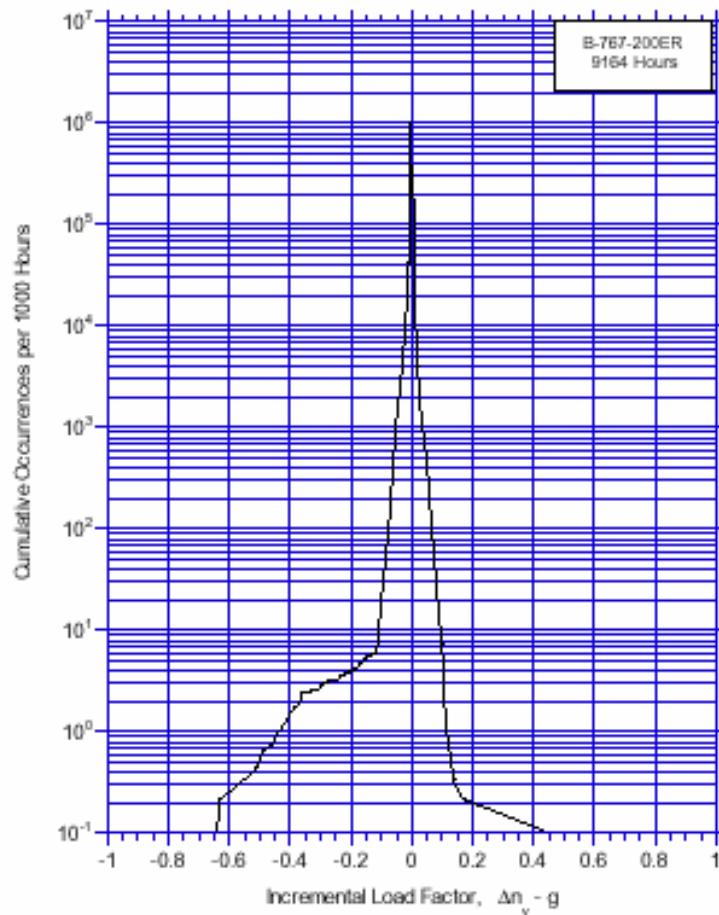


FIGURE A-63. CUMULATIVE OCCURRENCES OF LATERAL LOAD FACTOR PER 1000 HOURS, COMBINED FLIGHT PHASES