Acoustics • Shock • Vibration • Signal Processing **July 2001 Newsletter**

GREETINGS

This is the inaugural issue of the Vibration Data Newsletter. The purpose of this newsletter is to provide useful articles and information for anyone interested in acoustics, shock, vibration, and signal processing.

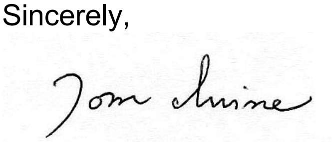
For this issue, I have enclosed an article about Pegasus shock and vibration environments. I recently completed a twelve-year career at Orbital Sciences Corporation. In this position, I had the opportunity to perform shock and vibration testing on the initial Pegasus vehicle. I also analyzed flight accelerometer data for several Pegasus and Taurus flights.

For future issues, I highly encourage readers to submit their own articles, announcements, advertisements, interesting web links, etc. Readers may also submit questions and suggestions for topics.

Hopefully, we can build a sense of community.

Thank you for your support.

Sincerely,



Tom Irvine
Email: tomirvine@aol.com

FEATURE ARTICLE

This month's issue features an article about Orbital Sciences Corporation's Pegasus launch vehicle. The article begins on Page 3.

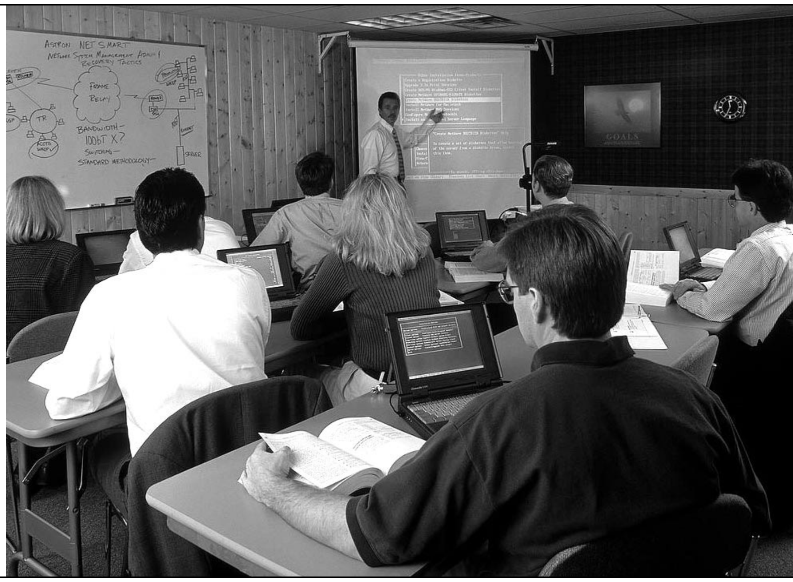
USEFUL LINKS

NASA/JPL Documents
http://standards.jpl.nasa.gov/jpl-nasa/

Engineering Message Boards
http://www.eng-tips.com/

Wayne Tustin's Directory of Shock and Vibration Equipment
http://www.equipment-reliability.com/link.htm

Shock & Vibration Handbook
http://www.vibrationdata.com/SVhandbook.htm



Vibrationdata Announces

Shock & Vibration Response Spectra & Software Training Course

Course Benefits

This training will benefit engineers who must analyze test data, derive test specifications, and design isolation systems, with respect to shock and vibration environments.

Engineers in the aerospace, automotive, medical, and semiconductor industries can apply the course materials to solve real-world vibration problems.

Course Description

- The course includes viewgraph presentations as well as hands-on software training.
- Each student will receive a licensed copy of MIT's EasyPlot software, in addition to software programs which perform the following calculations: power spectral density (PSD), Fast Fourier Transforms (FFT), shock response spectrum (SRS), and digital filtering.
- Students will receive data samples so that they can practice using the software programs. Students are also welcome to bring their own data samples.

Dates for 2001 Courses

July 10-12
September 11-13
October 9-11
November 6-9

Location

Mesa Commerce Center
1930 S. Alma School #B-219
Mesa, Arizona 85210

Students may also arrange for onsite training.

For Further Information Please Contact

Tom Irvine
Course Instructor
Vibrationdata
Email: tomirvine@aol.com
http://www.vibrationdata.com/course.htm

Voice: 480-820-6862
Fax: 240-218-4810

The Pegasus Launch Vehicle: A Shock and Vibration Perspective

By Tom Irvine

Figure 1. Pegasus Carried underneath the L-1011 Aircraft

INTRODUCTION

In the mid 1980s, Orbital Sciences Corporation and Hercules Aerospace began design work on an innovative, air-launched, delta-winged rocket vehicle called Pegasus.

The goal was to develop a launch vehicle that could insert small satellites into low-Earth orbit. For example, a 600 lb (270 kg) payload could be inserted into a 200-nmi (370 km) circular orbit.

The Pegasus propulsion design consisted of three solid rocket motors. Carbon fiber/epoxy was chosen as the material for the motor cases and most of the structural components.

The delta wing provided aerodynamic lift for Pegasus. The three movable fins on the stage 1 aft skirt provided steering control.

The original carrier aircraft was a B-52, one of the same B-52s used for the X-15 program some thirty years earlier.

The first Pegasus launch was on April 5, 1990. The Pegasus vehicle successfully deployed the Pegsat and GLOMAR satellites on this mission.

Pegasus and the enhanced Pegasus XL version have conducted a combined total of 30 missions as of May 10, 2001.

Note that the L-1011 aircraft shown in Figure 1 replaced the B-52 as the carrier aircraft in June 1994.

MISSION SCENARIO

The carrier aircraft cruises at an altitude of nearly 40,000 feet (12.2 km) and at a speed of Mach 0.80.

The Pegasus vehicle is then released from the aircraft. It experiences a free-fall for five seconds before the first stage ignites. The vehicle then experiences

- Stage 1 separation
- Stage 2 burn
- Fairing separation
- Coast period
- Stage 2 separation
- Stage 3 burn
- Payload separation

The mission scenario creates some unique shock and vibration environments for the payload.

POWERED FLIGHT VIBRATION

A distinct advantage is that the Pegasus vehicle experiences virtually none of the launch acoustic effects that are a challenge for ground-launched vehicles.

The initial launch altitude also minimizes the buffeting vibration as the vehicle accelerates past the speed of sound.

In fact, the Pegasus launch vehicle experiences very benign vibration levels during its powered flight. The powered flight levels at the payload mounting location are typically below an overall level of 0.5 GRMS, over the frequency domain from 0 to 2000 Hz.

The Pegasus stage 1 motor burn produces a brief pressure oscillation in its cavity, which excites the vehicle's longitudinal axis. The oscillation frequency for a Pegasus XL stage 1 is approximately 60 Hz. The resulting sinusoidal vibration at the payload mounting location may reach a peak level of 0.2 G during this pressure oscillation, but this event is considered as benign.

KEY ENVIRONMENTS

The powered flight vibration is benign. Nevertheless, the Pegasus launch vehicle and its payload must withstand three particular shock and vibration environments:

1. Captive Carry Vibration
2. Drop Transient
3. Staging Shock

In addition, the vehicle and payload must withstand quasi-static structural loads, as discussed in Reference 1.

CAPTIVE CARRY VIBRATION

The Pegasus vehicle experiences a narrowband vibration from 40 Hz to 50 Hz as it is carried underneath the L-1011 aircraft to the cruising altitude. The vibration occurs in the lateral axis.

Pegasus engineers have learned to mitigate this vibration by specifying a benign takeoff and ascent trajectory for the L-1011.

The Pegasus captive carry vibration environment is discussed in References 1 and 2.

DROP TRANSIENT

The most significant event for the payload is the drop transient from the carrier aircraft. In fact, this is event is the sole focus of the coupled-loads analysis.

The Pegasus vehicle is mounted to the L-1011 aircraft by four load bearing hooks. The aircraft hooks attach to fittings on the topside of the Pegasus wing.

In this configuration, the Pegasus vehicle bows downward due to the effects of gravity. In addition, the Pegasus vehicle is subjected to aerodynamic drag forces during captive carry. These loads thus induce initial strain energy in the Pegasus vehicle.

In some sense, the Pegasus vehicle is like a free-free beam subjected to an initial displacement that varies along its length.

During the five-second free-fall interval, the initial strain energy is released, causing the Pegasus vehicle to experience a damped, transient oscillation. The oscillation frequency is typically 9 Hz to 10 Hz, depending on the payload mass. The oscillation occurs in the vertical axis. It is the fundamental body-bending frequency of the vehicle with its payload.

A sample drop transient time history is shown in Figure 2. The time history is measured data from a typical Pegasus XL mission. The amplitude is left unscaled for proprietary reasons. The data has an idealized, textbook quality.

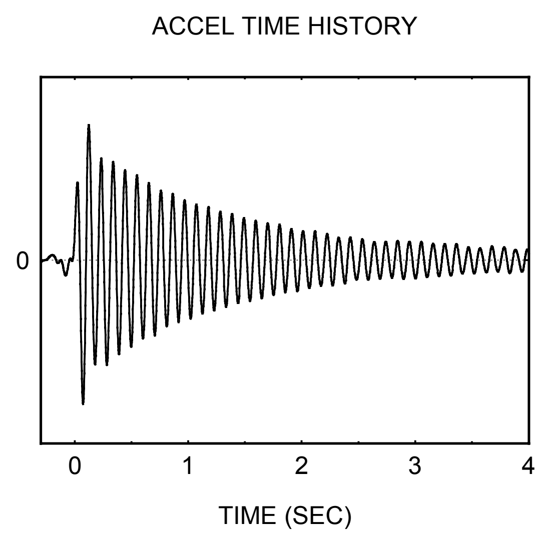


Figure 2. Drop Transient

Reference 1 states that the payload's individual fundamental lateral frequency should be above 20 Hz in order to minimize coupling with the vehicle's first bending mode. This recommendation satisfies the "octave rule."

STAGING SHOCK

The payload must withstand a series of staging shock events. The fairing separation and the stage 2/3 separation events are particularly critical. Reference 1 gives a payload base excitation level in terms of a shock response spectrum that has a plateau of 3500 G.

These staging events are also critical for the Pegasus vehicle's avionics components.

CONCLUSION

The Pegasus launch vehicle has achieved several milestones. Among other distinctions, it is the world's first privately developed space launch vehicle.

Pegasus' unusual design and launch trajectory minimize many of the shock and vibration environments encountered in ground launched vehicles.

On the other hand, Pegasus presents some unique shock and vibration environments for its payloads.

REFERENCES

1. Pegasus® User's Guide Release 5.0, Orbital Sciences Corporation, August 2000.
2. Isam Yunis, KSC Engineering Review Board ELV-Pegasus-1999-03 Decision on Pegasus Captive Carry Random Vibration Testing Requirements, NASA Kennedy Space Center, Florida, 2000.