The Pegasus® Launch Vehicle: Shock & Vibration Environments

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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. A diagram of the Pegasus vehicle is shown in Appendix A.

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 insert 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, a coast period, stage 2 separation, stage 3 burn, and finally payload separation and orbital insertion.

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.

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."

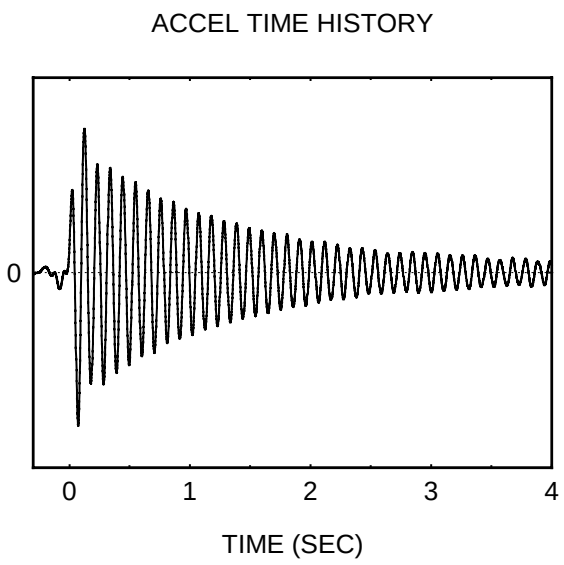

Figure 2. Drop Transient

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.

AUTHOR BIOGRAPHY

Tom Irvine is the president of Vibrationdata, which offers shock and vibration training courses.

He worked as an engineer for Orbital Sciences Corporation from 1988 until 2001. He developed the shock and vibration environmental test levels for the initial Pegasus launch vehicle, and he reduced flight accelerometer data for a number of Pegasus missions.

APPENDIX A

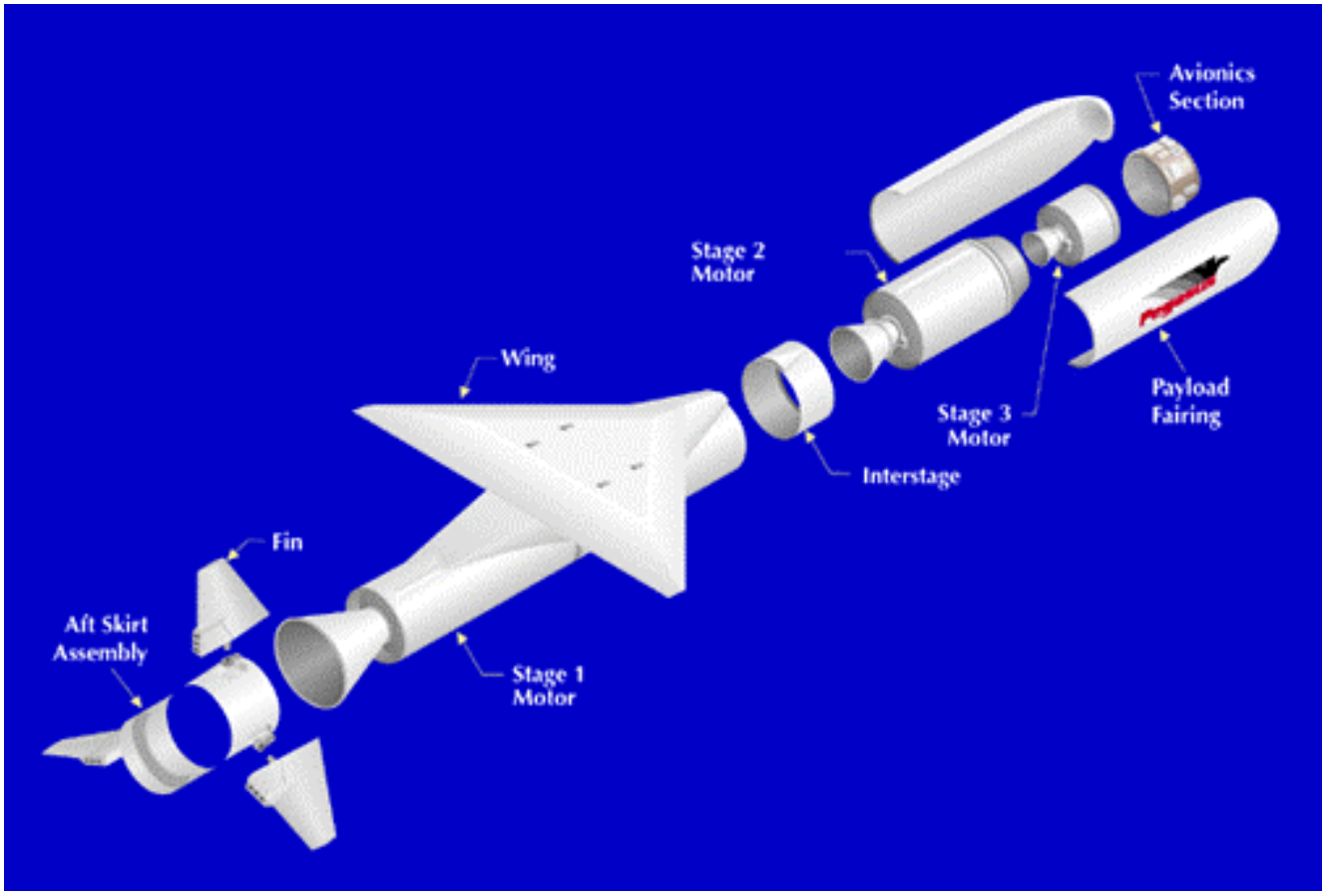

Figure A-1. Diagram of the Pegasus Launch Vehicle

The payload mounts to the forward end of the avionics section.