Acoustics • Shock • Vibration • Signal Processing **August 2010 Newsletter**

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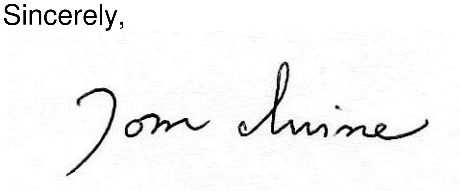
Currently I am serving as an industry representative for NASA. I have the opportunity to review structural dynamics and vibroacoustic analyses and test results for a variety of programs, including the space shuttle, the International Space Station, sounding rockets, and the Constellation program. I also provide mentoring and training to engineers performing these analyses for NASA.

I am sharing some information on a few of these projects in this month's newsletter. Note that the data presented is not ITAR sensitive.

NASA was established by the National Aeronautics and Space Act of 1958.

The founding document declared "The Congress hereby declares that it is the policy of the United States that activities in space should be devoted to peaceful purposes for the benefit of all mankind."

Sincerely,



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Feature Articles

ISS Solar Panel Vibration by Tom Irvine

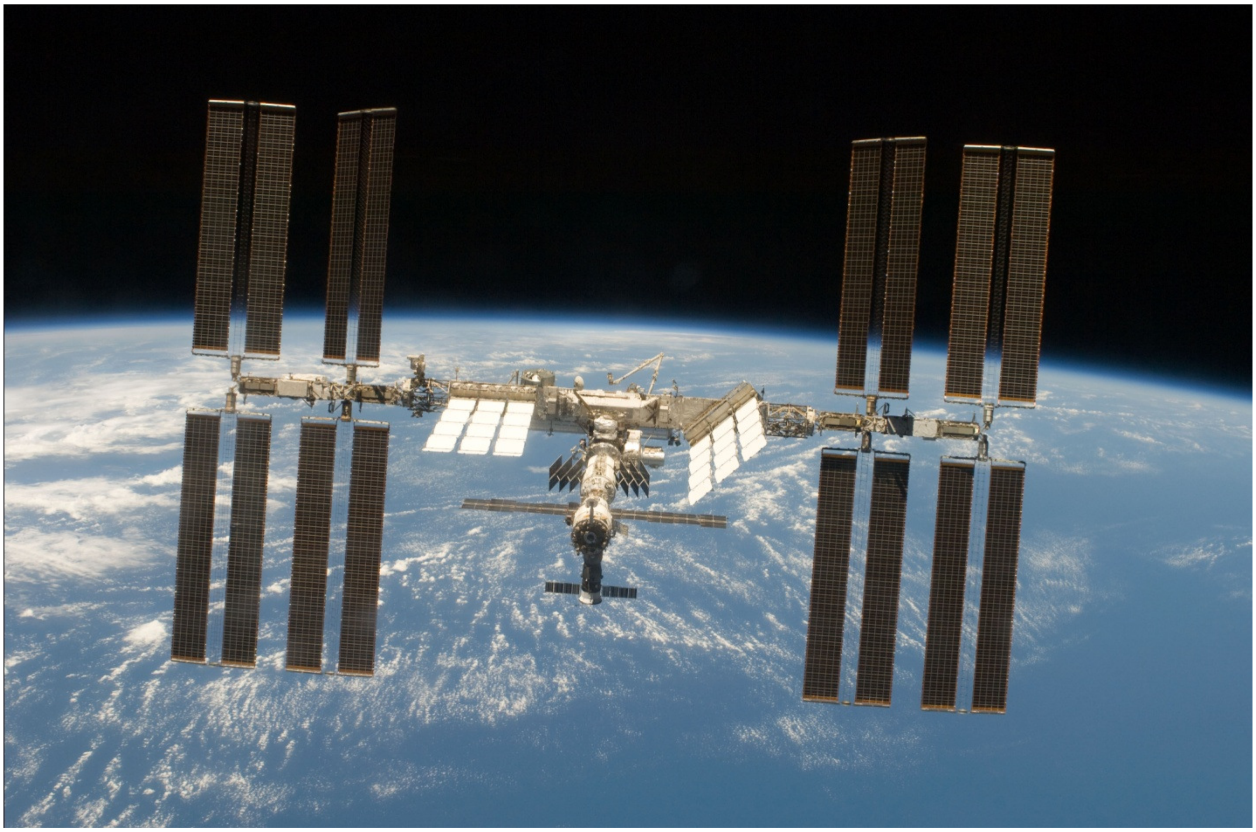

Figure 1. International Space Station

The International Space Station is seen from Space Shuttle Discovery as the two spacecraft begin their relative separation. Earlier the STS-119 and Expedition 18 crews concluded 9 days, 20 hours and 10 minutes of cooperative work onboard the shuttle and station. Undocking of the two spacecraft occurred at 2:53 p.m. (CDT) on March 25, 2009.

Introduction

The International Space Station (ISS) orbits above the Earth with a nominal apogee of 360 km (194 nmi). The on-orbit construction of the station began in 1998 and is scheduled for completion by late 2011.

Solar panels have been gradually added to the ISS. The panels now provide 110 kW of power available for all uses. That is enough to run a small village of 50 to 55 houses, according to David McKissock, a NASA power management systems analyst.

This solar power is used to created breathable oxygen by splitting water molecules using electricity. The power is also used for lighting, pumping liquids for recycling, warming meals, and running computers and experiments. Furthermore, some of the solar power is used to recharge batteries on-board the ISS. The battery power is then used when the ISS is in the Earth's shadow.

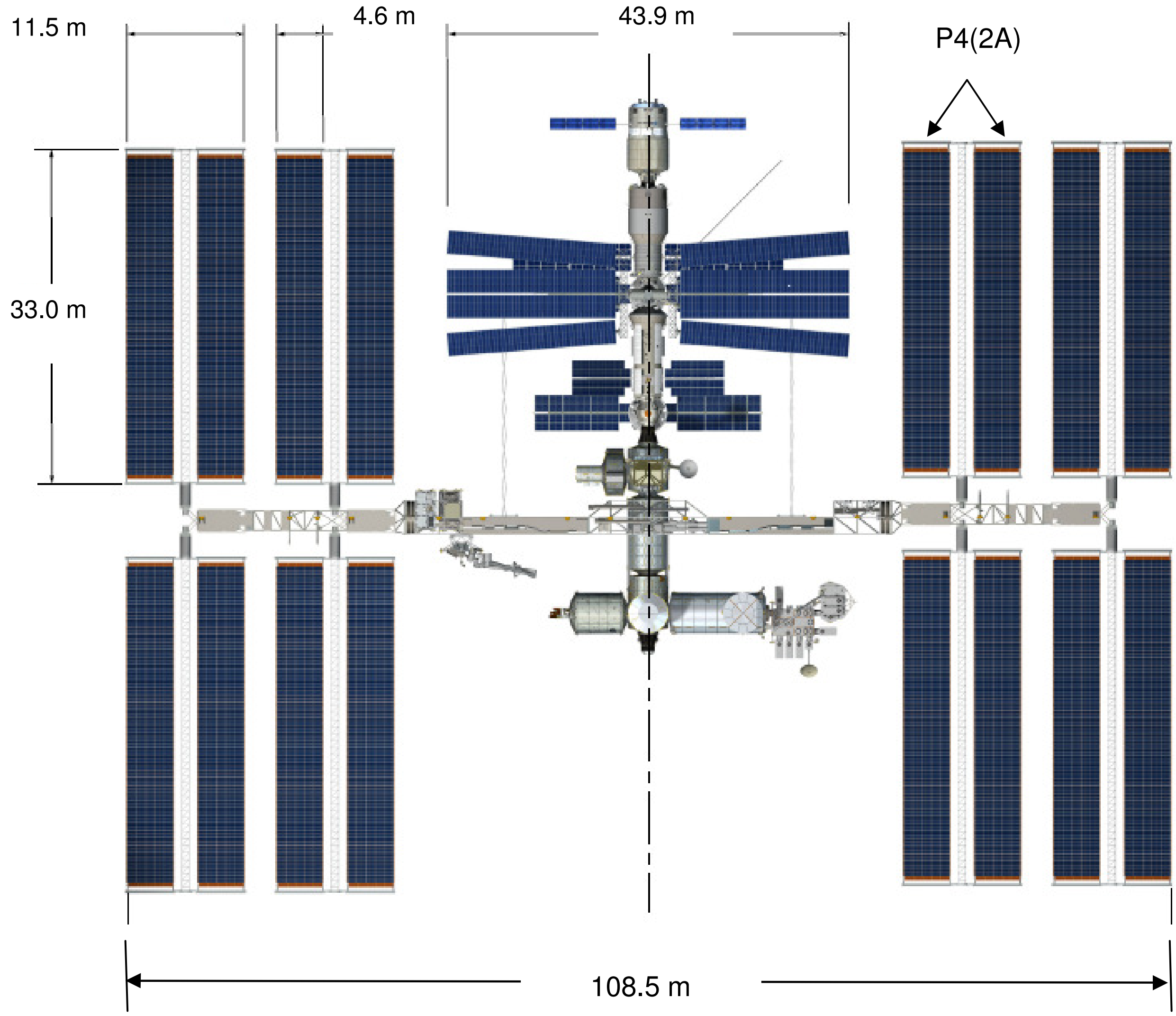

Figure 2. ISS Solar Panels

The dimensions are in meters.

Solar Panel Design and Configuration

The solar panels are sometimes referred to as "blankets." They are composed of paper-thin Mylar with a layer of photovoltaic cells on one side.

The sixteen large rectangular panels are grouped together in eight pairs. Each pair is connected to a mast, located between the pair. A clearer view of the mast is given in Figure 3.

The pair of panels designated P4(2A) are of particular interest in this article.

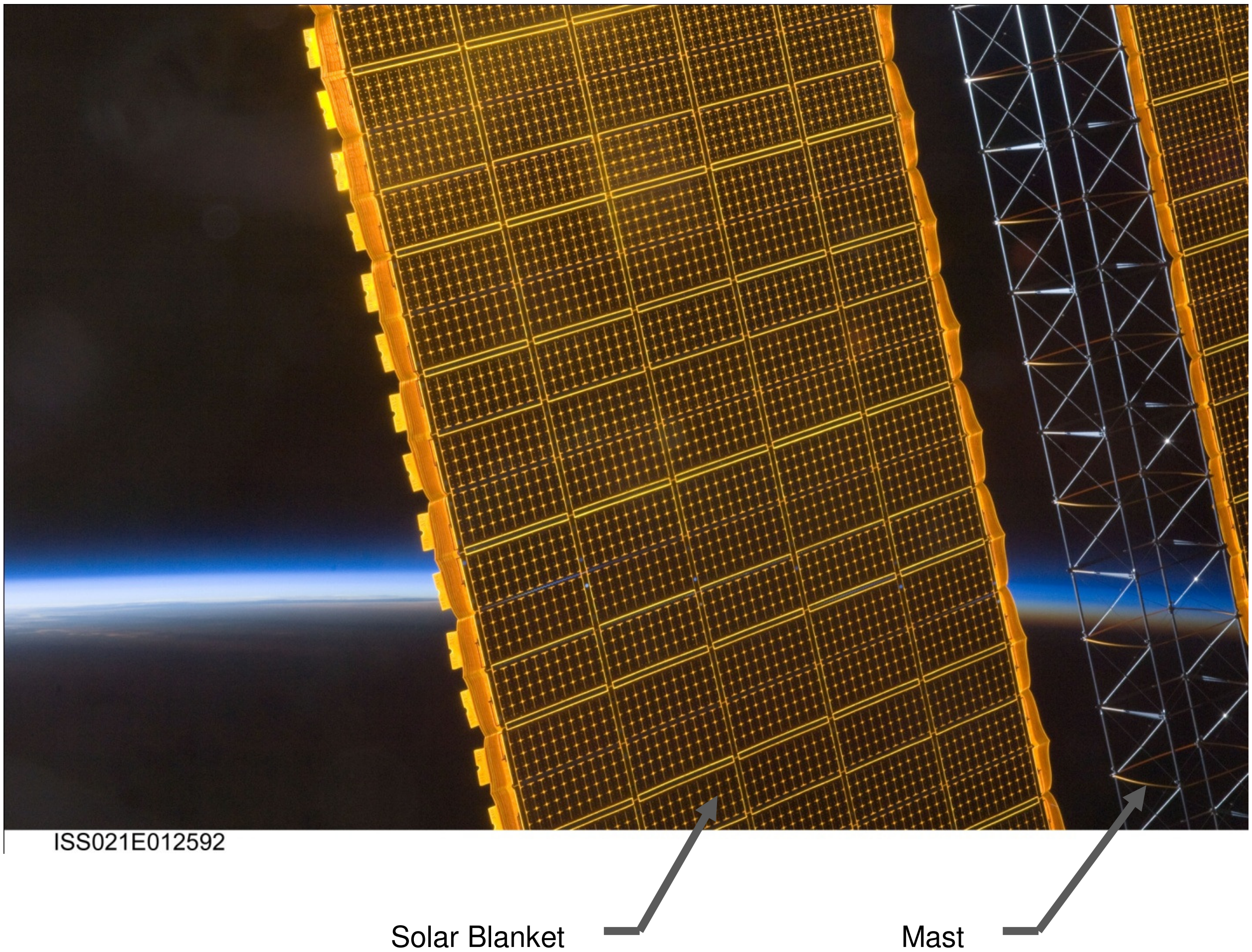

Figure 3. ISS Solar Blankets and Mast

This is an actual photograph taken by the Expedition 21 crew member aboard the station.

Structural Dynamics

The solar panels have very low natural frequencies, as shown for the P4(2A) set in Table 1.

Table 1. P4(2A) Solar Panel Natural Frequencies			
Mode	Frequency (Hz)	Period (sec)	Mode Shape
1	0.06	16.7	Out-of-plane, bending
2	0.08	12.5	In-plane

Mechanical vibration is normally measured by an accelerometer or some other type of transducer. The natural frequencies of the ISS solar panels are so low, however, that they can be measured by a *photogrammetric* method instead. This is a technique whereby the position of an object is measured from a series of photographic images. The data in Table 1 was thus measured by photogrammetry. The data was taken during a reboost event.

The solar panels undergo benign oscillations during reboost events with the exception of the anomaly discussed in the next section.

2009 Reboost Event

The orbital altitude of the ISS over the Earth varies between 320 to 410 kilometers. The altitude gradually decreases with time due to aerodynamic drag from the tenuous atmosphere. Thus the space station needs an occasional reboost, sometimes referred to as orbital altitude maintenance.

Furthermore, the altitude of the ISS must sometimes be adjusted so that the ISS can avoid colliding with space debris. The ISS also undergoes orbital changes so that it can rendevouz with the space shuttle or cargo resupply modules.

The station's *Zvezda* service module has a rocket propulsion system for the needed orbital maneuvers.

An ISS reboost was conducted on January 14, 2009. The *Zvezda* rocket engines were thus fired for 2 min 22.4 sec. This the first of two reboosts used to set up phasing for rendezvous with the space shuttle STS-119/15A and Progress-M1 32P vehicles.

However, an incorrect command sequence software parameter caused an error in the propulsion gimbal control system. As a result, a dynamic frequency control filter malfunctioned during the reboost maneuver. The engines thus cut off abruptly instead of gradually ramping down, causing the ISS and its solar panels to oscillate excessively.

The oscillations became a subject of engineering evaluation due to concerns about potential fatigue cracks and other damage which would reduce the longevity of the ISS.

NASA spokesman Kelly Humphries explained "Anytime you impart a vibration to the station it has potential implications" for the station's solar panels and the connections between the station's parts.

NASA's on-orbit daily status reports stated on January 29 that "As of now, evaluation of the external video survey conducted over the last weekend and a review of subsystem data have not shown any off-nominal results" from the higher oscillations. The station was built with extra structural strength, Humphries said, and the current analysis is "just making sure we haven't eaten into that margin." Engineers also want to make sure the abrupt stop by the engines won't occur again.

Note that this event is also referred to as the "1/14 reboost anomaly."

Solar Dynamics Observatory by Tom Irvine

The purpose of this article is to introduce some background information for the following Terrier-Black Brant Flight Vibration article.

Figure 1. Solar Dynamics Observatory Satellite, Artist Rendering

The Solar Dynamics Observatory is a NASA mission which will observe the Sun for over five years. It was launched via an Atlas V rocket on February 11, 2010. An image recorded by this satellite is shown in Figure 2. Astronomers are using the satellite's data to study the Sun's magnetic field and the solar wind.

The Extreme Ultraviolet Variability Experiment (EVE) is one of three instrument suites on SDO. EVE measures the solar extreme ultraviolet (EUV) irradiance energy which impacts the Earth's atmosphere.

The other instruments are the Atmospheric Imaging Assembly (AIA) and the Helioseismic and Magnetic Imager (HMI).

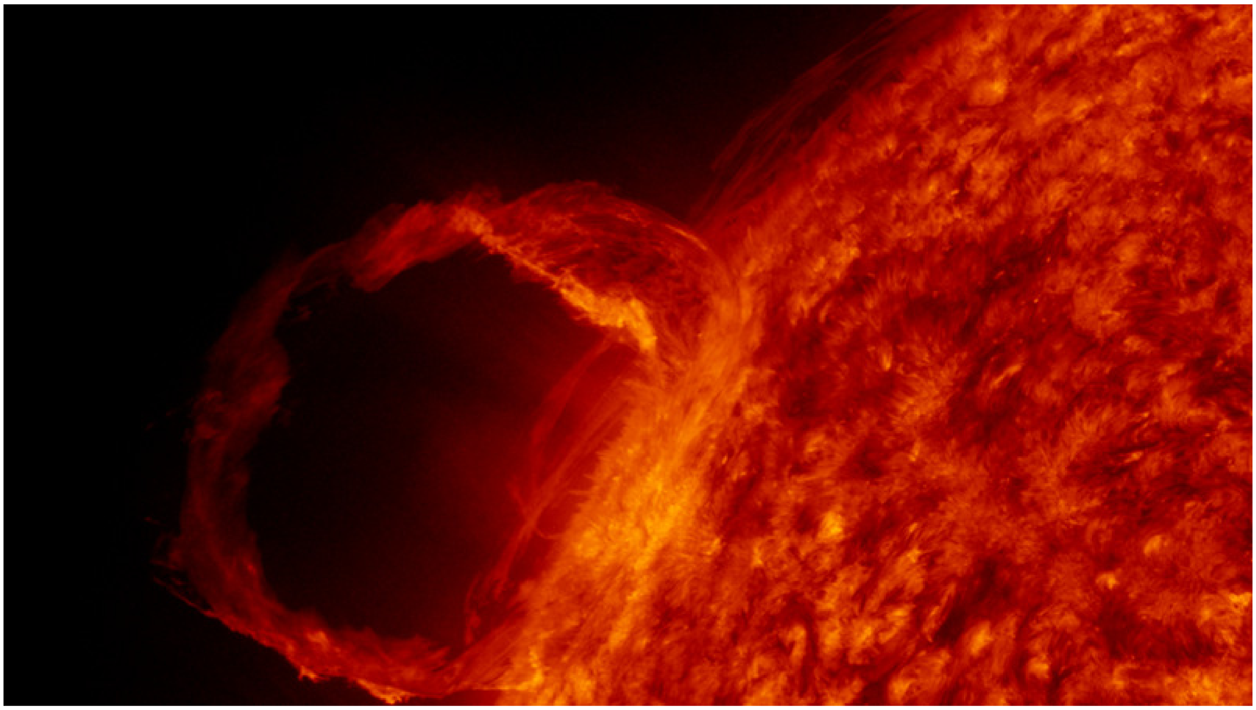

Figure 2. First Light image from the SDO showing a solar flare

A solar flare is an enormous explosion of hydrogen and helium above the sun's surface. Most flares occur in active regions around sunspots.

The flares emit energetic protons and electrons which form the solar wind. These particles are funneled down and accelerated along the Earth's magnetic field lines. The solar particles collide with the Earth's oxygen and nitrogen molecules. Photons are released from the molecules thus generating the *Aurora Borealis* and the *Aurora Australis*.

The flares also emit X-rays and ultraviolet radiation which can affect Earth's ionosphere and disrupt long-range radio communications.

The solar radiation is also a concern for astronauts. The Earth's protective magnetosphere helps shield the ISS from high-speed solar particles. But radiation exposure is a serious concern for astronauts on any future Mars or deep space missions.

As an aside, the Sun's magnetic field reverses itself about every 11 years. The number of sunspots varies according to this cycle.

Terrier-Black Brant Flight Vibration by Tom Irvine

Figure 1. Mission 36.258 Launch via a Terrier-Black Brant

The Terrier and the Black Brant are first and second stages, respectively. The total vehicle length is 670 inches. The purpose of this mission was to provide a calibration under-flight for the Solar Dynamics Observatory (SDO) satellite which had been launched three months earlier.

Introduction

The Terrier-Black Brant is a two-stage, solid propellant, rail launched, guided, fin-stabilized sounding rocket. It is used for unmanned, suborbital missions.

NASA's Mission 36.258 was launched via a Terrier-Black Brant from White Sands Missile Range, NM, on May 3, 2010, as shown in Figure 1.

The purpose of the mission was to provide a calibration under-flight calibration for the SDO satellite's Extreme Ultraviolet Variability Experiment.

The Terrier-Black Brant vehicle was instrumented with two accelerometers, which were mounted on a ring that was attached to the front of the Black Brant motor.

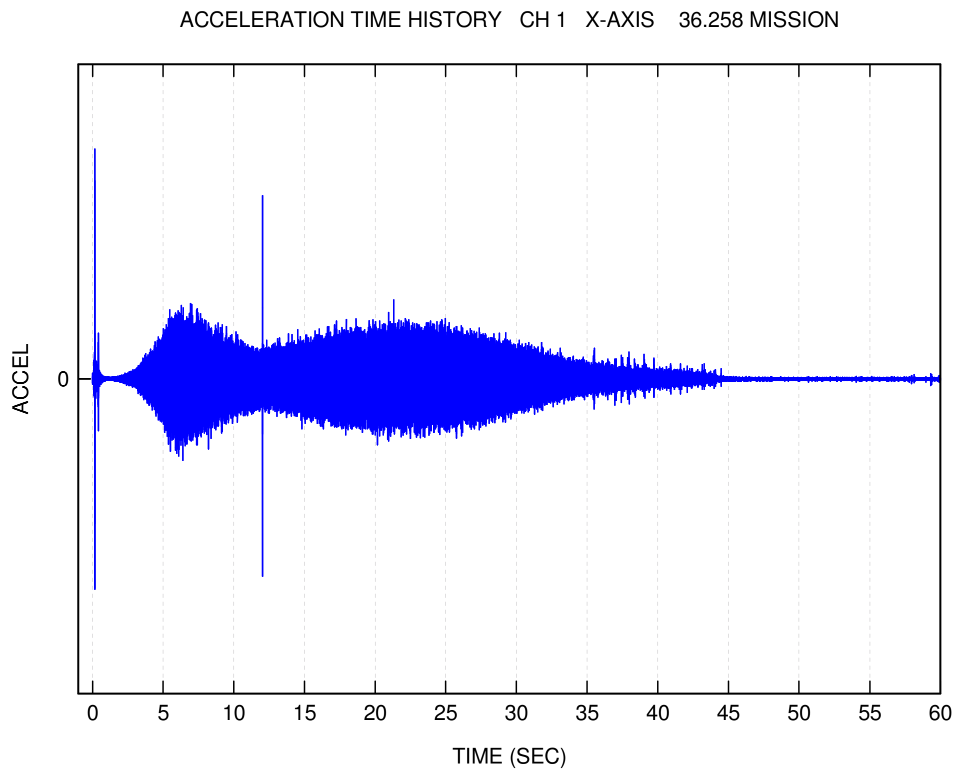

Figure 2.

The instantaneous time history for the X-axis accelerometer is shown in Figure 2. The amplitude is left unscaled on the plot but is available on a “need-to-know” basis.

The launch shock is apparent at time zero. The Stage 1 Terrier motor burns out at 6.2 seconds, but the vibration persists due to aerodynamic flow excitation. Note that the vehicle speed is Mach 1.7 at Terrier burn-out.

The Stage 2 Black Brant ignition occurs at 12 seconds. The Black Brant burn-out occurs at 45.5 seconds. The Black Brant motor may have experienced some rough combustion beginning at 35 seconds.

Fundamental Body Bending Mode

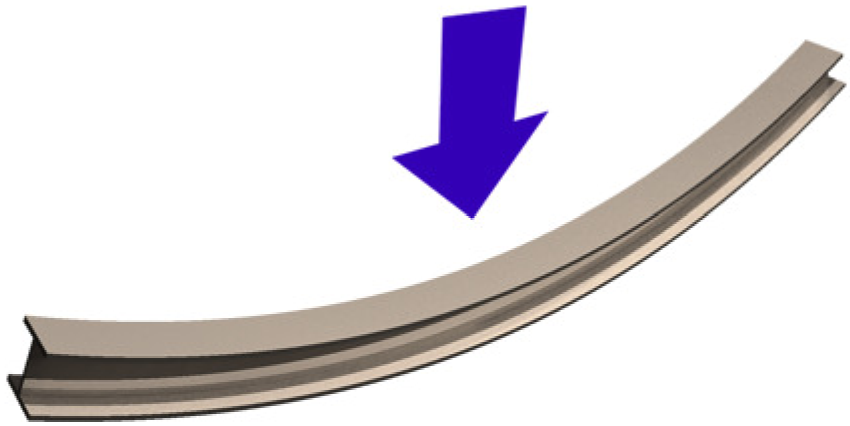

Figure 3. Free-Free Beam, Fundamental Bending Mode

A rocket vehicle in flight is conceptually similar to the beam in Figure 3 in terms of structural dynamics. The beam is unconstrained, with free boundary conditions.

Both the beam and the rocket vehicle have a fundamental body bending mode which oscillates back and forth. The vehicle's bending natural frequency must be determined via analysis and test data prior to flight so that the autopilot control system can be designed accordingly.

Note that this vehicle's bending mode may be excited in flight by thrust offsets, maneuvers, wind gusts, etc.

Unlike the beam, the launch vehicle's bending frequency changes with time. The vehicle's frequency increases as the propellant mass is expelled.

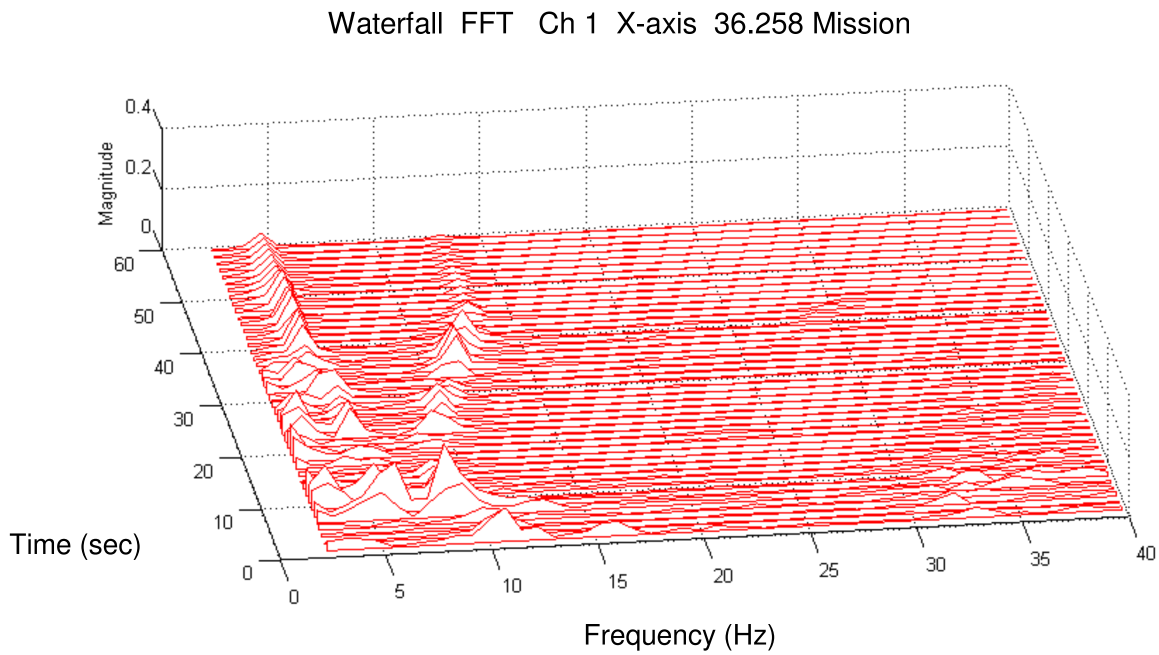

Figure 4.

The X-axis accelerometer data reveals the fundamental bending mode frequency. The frequency begins at about 8 Hz and then sweeps up to 13.2 Hz as propellant mass is expelled. This is shown more clearly in Figure 5.

The spectral peaks at 5 Hz are due to vehicle imbalance at the induced roll rate. This spin-stabilization is clearly visible in the video posted at:

http://www.youtube.com/watch?v=ULlUfSoGIPw

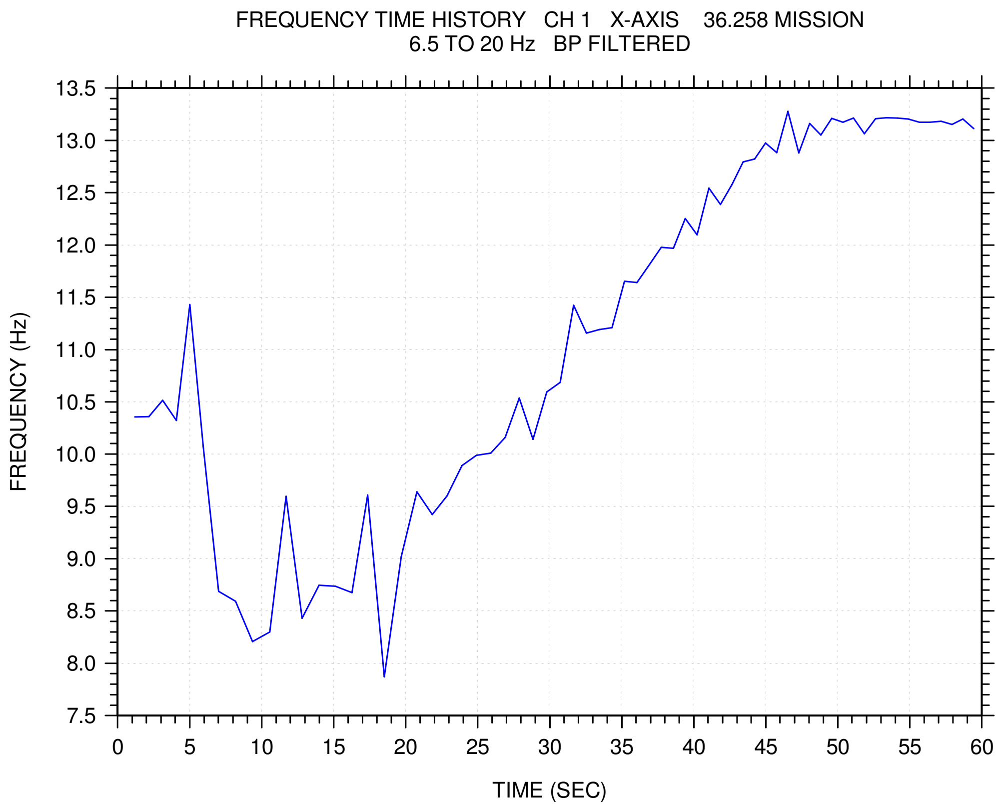

Figure 5.

The data is somewhat erratic prior to 18 seconds. The fundamental body-bending mode may not have been readily exited during this duration.

Thereafter, a consistent pattern emerges. The frequency reaches a plateau after 45 seconds because the mass remains constant after Black Brant burn-out.