

BiTMICRO Release  
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MASS BODY DATA COLLECTION SYSTEM

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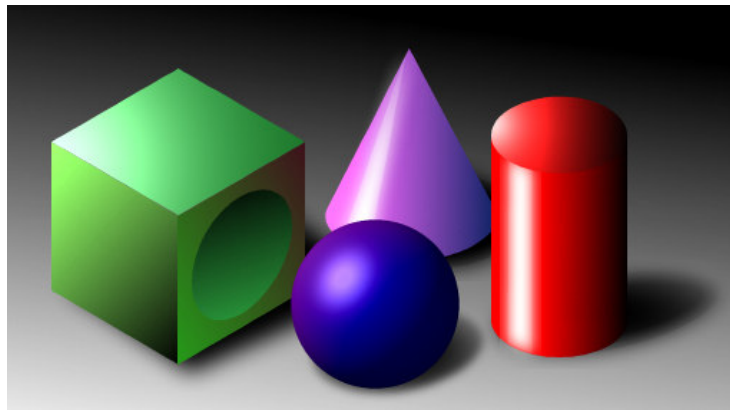
Linthicum, MD 21090

## Abstract

In designing a new system for a modern fighter aircraft, our team was tasked with characterizing the vibration environment in the nose of the fighter. This system would have to be small, light, and have as little interaction with the aircraft as possible. Time constraints necessitated using a collection of Commercial Off The Shelf (COTS) systems that still had to operate in a fighter aircraft environment.

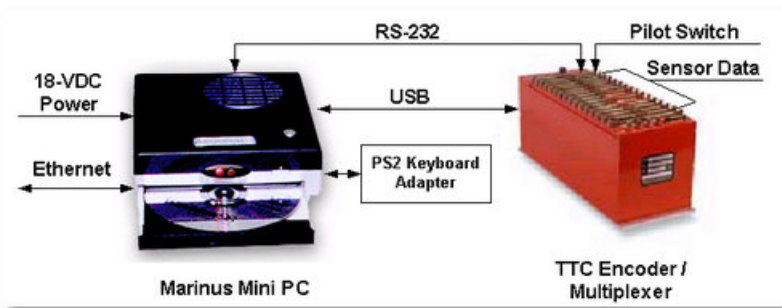
## System Objective

The Mass Body Data Collection System collects vibration data from tri-axial accelerometers mounted on a mass body at selected points. The mass bodies can be any shape and are formed to reflect actual equipment that is yet to be designed. The mass bodies are then mounted in the test vehicle and stressed as the finished equipment would be stressed.



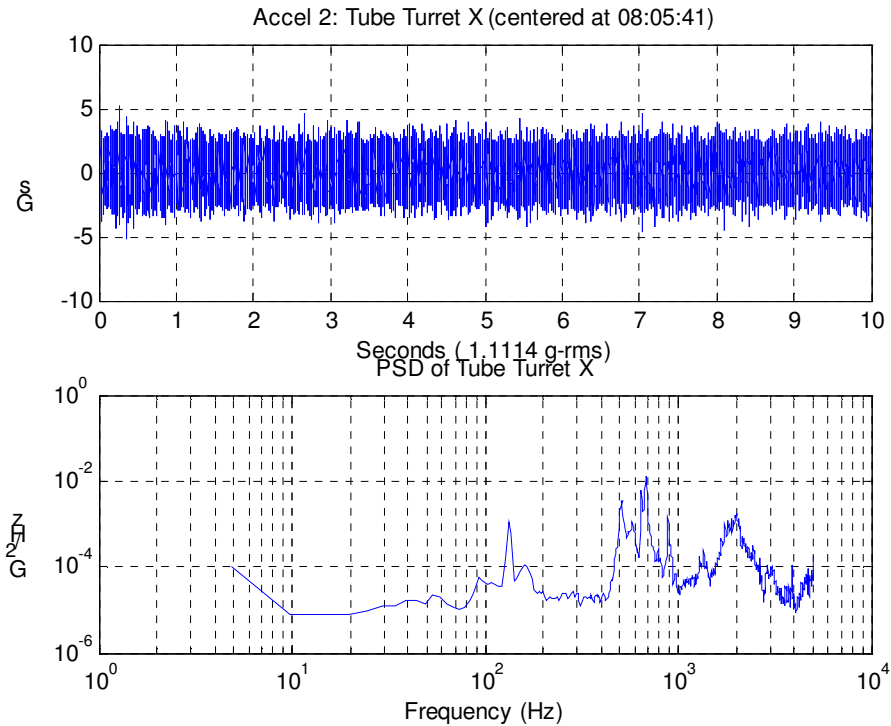
Basic Mass Bodies

Collected data is stored in an inexpensive COTS mini PC mounted along with the mass body during a vibration test. A mass body is defined as an object that has the same mass and size as the actual final production equipment that will be mounted on a test vehicle. The tests are done as a part of an early risk reduction program that reduces or eliminates problems created by vibrations generated by equipment in actual use. In the system below uses a Marinus Argonaut mini computer and a Teletronics Technology Corporation (TTC) encoder / multiplexer chassis to gather sensor accelerometer data into buffered data blocks passed over a USB connection.



Basic Mass Body Collection System

A typical use for this system is to record accelerometer data and process it through a Fast Fourier Transform (FFT) filter to generate frequency response plots for a given test period of time.



Sample Accelerometer and Processed Vibration Data

Analysis of the collected three-dimensional accelerations provides a characterization of the vibration environment of the equipment represented by the mass body.

## General Hardware Description

### ***Marinus Mini PC***

The Marinus COTS computer is small enough and rugged enough to fly along with the mass body during flight test. The Marinus computer saved space by not having a (Peripheral Component Interconnect) PCI bus and card slots. All I/O was conducted through the standard USB and Ethernet connections. A shareware program called VNC was used to remotely operate the Marinus computer from an Ethernet connection when the test unit was being prepared for a test. During testing, the Marinus computer ran without outside intervention from power up to power down.

The computer is a standard Pentium III, 1.3 GHz processor with 512 megabytes of RAM. The system is able to withstand the irregularities of ground and aircraft power sources and was able to record gigabytes of data without loss as the test body moved through various rigorous test points. The computer is fast enough to support two Analog to Digital (A/D) converters running at a 100 kilo Samples/second rate.



Marinus PC

The Marinus BIOS was reconfigured to boot on power up without a password and the keyboard connection was patched to allow for its absence during boot up. This novel approach allowed using a non-ruggedized COTS notebook PC that was fast enough to keep up with the data sample rates. Using USB I/O devices allowed the PC to be small since the PCI bus and associated cards were not used. USB plus Ethernet connections provided all the I/O capability needed to control, collect, record, and off load captured data for analysis.

### ***BiTMICRO Solid State Flash Disks***

To ensure test vibration would not affect the recording of data, the PC mechanical hard drive was removed and a BiTMICRO 17-gigabyte flash solid state hard drive was installed. The BiTMICRO drive could sustain a bit rate of 28 Mbytes per second with a burst rate up to 166 Mbytes per second. The rated G force is 1,500 Gs.

The solid state flash disk did not require additional drivers and fit into the same form factor as the original mechanical hard drive rectangular dimensions and electrical connections for IDE connection and power. The height of the drive was taller than the mechanical drive requiring the removal of the PC top cover. No other modifications were needed such as special drivers, to make the solid state disk operational.

Because the PC top cover was removed, the cooling fan, CPU reset switch and power on buttons were also removed. Cooling had to come from the test fixture cooling system. The BIOS Automatic Power Management (APM) feature was set to allow the CPU to reboot on initial application of power.



BitMICRO Solid State Flash Hard Drive

### **USB A/D Converters**

Data collection systems that used either USB or RS-232 are less expensive than converters mounted on a PCI bus. This gives the versatility to use adaptable I/O devices for different applications. Avoiding the PCI bus interface allows the PC to be much more compact.



Data Translation A/D Acquisition USB Module

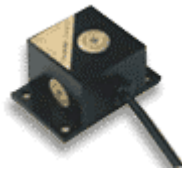
The A/D converters used in this application allowed eight channels of differential +/- 10 V bipolar, 2-wire analog inputs with a resolution of 12 bits. The maximum sample rate for the DT9801 is 100 kilo Samples/second. The sample rate had to be time shared between the eight channels. In the mass body study, the time sharing between channels was on an equal basis with the eight channels plus the one discrete channel. The discrete channel was used to monitor the pilot's RECORD ON/OFF switch.

### **Anti-Aliasing Filters**

Anti-Aliasing filters were used on each differential channel to limit the vibration frequency response to the range of frequencies of interest for each mass body test. This keeps higher frequencies from being sampled at a lower rate and appearing in the data erroneously. One filter was required for each analog channel being sampled. The cutoff frequency is the frequency represented by the Nyquist rate of the time shared sample rate for an individual channel. (i.e.  $100,000 \text{ samples} / 9 \text{ channels} = 11,111 \text{ samples}$ . Divide by 2 (the Nyquist rate) equals 5,555 Hz.)

### **Test Sensors**

The mass body study used accelerometers to provide differential analog signals on three axis in one package. The output voltage of each accelerometer is +/- 10 volts.



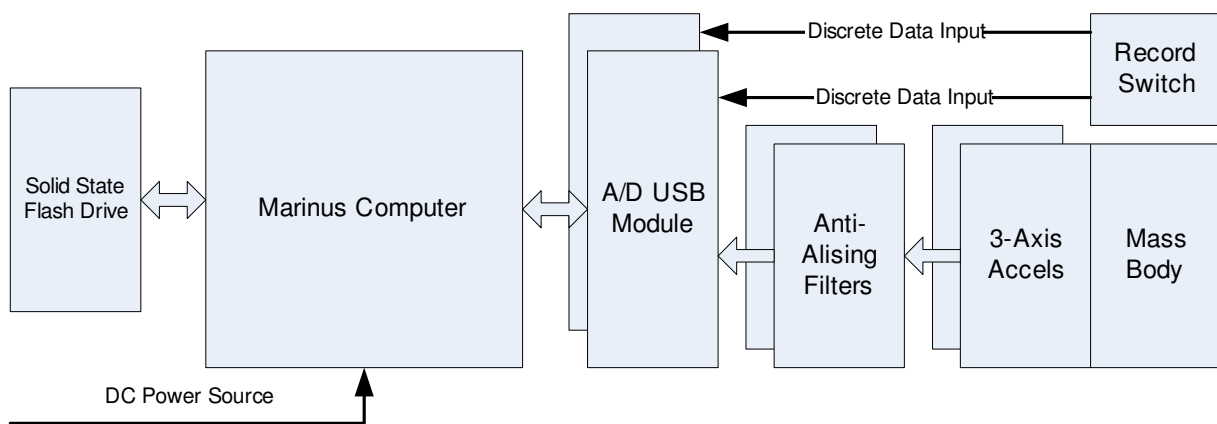
3-Axis Accelerometer

The accelerometers were simply glued onto the mass body with epoxy glue before the test. The glue was susceptible to a solvent so the sensors could be removed from the mass body after the test.

## **Detailed Hardware Design**

### **Sensor and Control Signals**

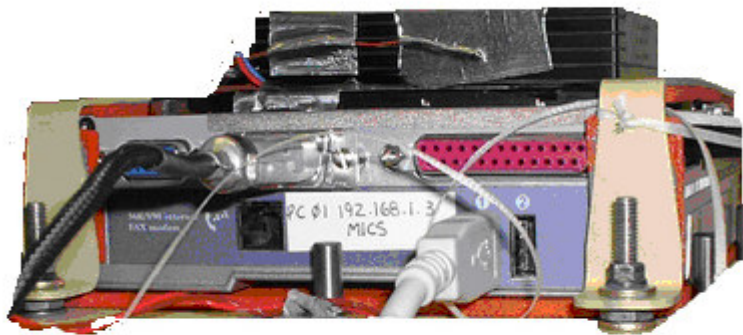
The Marinus computer has two USB sockets allowing for two A/d Converters and associated accelerometers. The Marinus computer is fast enough to download the data buffers from each



Mass Body Overall Block Diagram

A/D converter and store the data in separate files for analysis. In actual practice, only one data acquisition program was written and associated to a unique A/D USB driver. The second instance of the program was associated to the second A/D USB driver. This allowed both instances of the data collection programs to write independent data to the BiTMICRO flash solid state hard drive with different file names. Both A/D converters monitored the same RECORD On/OFF switch.

The mass body sensor system major components are all approximately the same size and operate off of a single power source from the test fixture. This allows the mass body data collection system to occupy a small area and to operate with a minimal number of control lines (power and RECORD ON/OFF switch) to the outside.

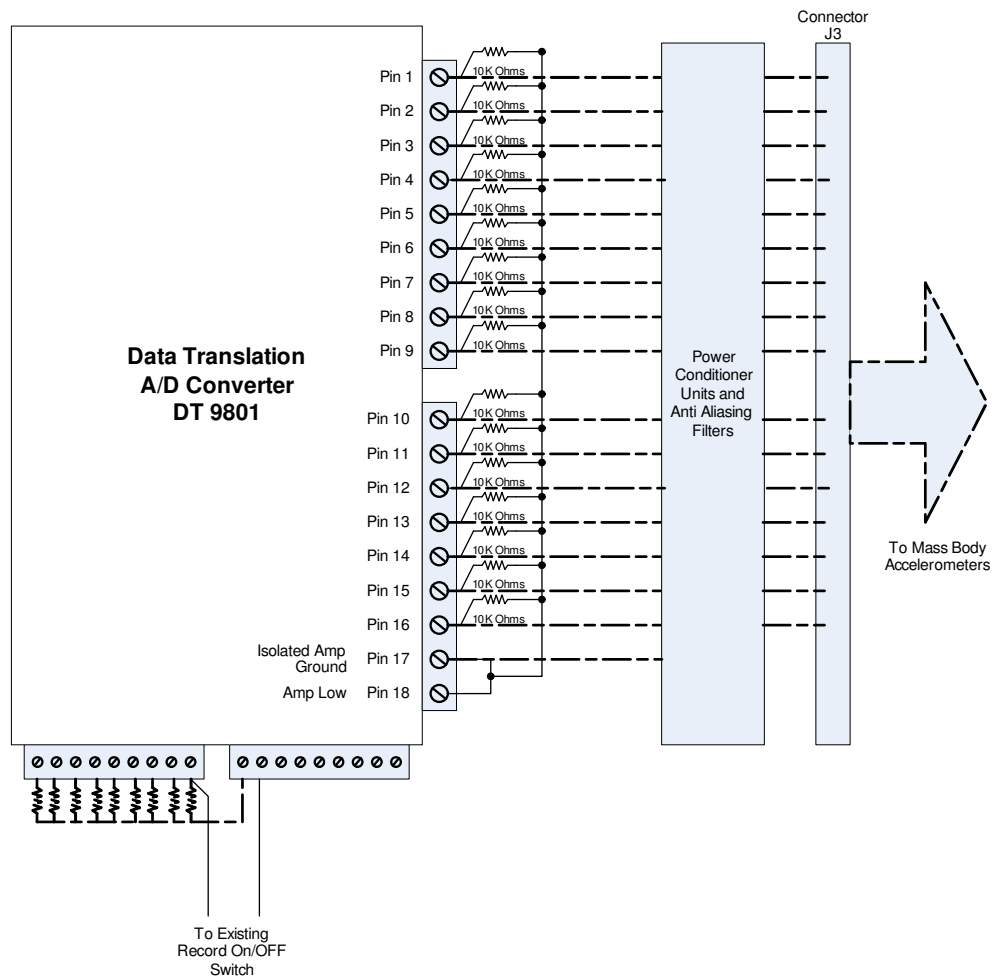


Marinus Computer Mounted in Mass Body

In the above figure, the Marinus top cover which included the speaker, power-on switch, and reset switch, has been removed to allow for the mounting of the BiTMICRO solid state flash drive. The remaining PC chassis is shock mounted to the mass body frame in such a way to allow for the connection of the Ethernet cable for control and downloading of data after a test.

The A/D converters are mounted separately and as close as possible to the accelerometers and aliasing filters. Care must be taken to ensure a good solid connection from the accelerometer cables through any connectors to the A/D converter inputs. Loose connector pins will cause noise in the sensor line that will be interpreted as vibration in the mass body.

Each of the discrete input lines from the accelerometer lines are further conditioned with a 10K ohm resistor to common ground. This greatly eliminated noise on the line and in the data.



A/D Converter Signal Lines

The discrete digital inputs are also held to ground with 10K resistors. This keeps the discrete lines from “floating” high during normal operation. The Record On/Off switch functions by changing the data on the discrete inputs from FF (all inputs high) to FE (record on input low). The data acquisition software continuously reads the input buffers from the A/D converters and looks for the FE value on the discrete channel. When found, the software writes the data buffer to disk. When not found (Record Off), the data from the A/D buffer is read but discarded. Therefore, the data is constantly being read from the A/D converters keeping their buffers up to date. Data is discarded or saved with the time code depending on the status of the Record switch inputs.

### ***PC Automatic Operation***

The computer must be able to start from a power-off condition and initialize the operating system without human intervention. This means the operating system has to be set to not ask for a user name and password as well as autostart the data collection programs.

Unless it is selectable in the BIOS, the Windows 2000 operating system will check for a coherent response from the keyboard over the PS2 interface. This signal exchange must be created with a PS2 module designed to eliminate the presence of the keyboard during the boot sequence.

Also, the BIOS must also be set to allow the Marinus computer to defeat the APM (Automatic Power Monitor) function thus allowing the computer to start initializing when power is applied. This feature keeps the Marinus rebooting after each power cycle on the test body fixture.

## **Software Description**

### ***Initialization***

Each type of A/D converter has an associated API set of functions that control the converter operation. The functions control the number of storage buffers used, sample rates, channel assignments for unique sample rates, and methods of acquiring and downloading sample data. PCs with a newer BIOS can be set to boot without the presence of a keyboard.

The analog inputs were set for 2- wire differential inputs with a +/- 10V range. Since the same frequencies were of interest on each sensor, the sample rates for each input including the discrete inputs were the same. Therefore, each input was sampled at 1/9<sup>th</sup> of the total sample rate capacity of 100 kS/s. If higher vibration frequencies of interest on some sensors, then a higher sample rate for that input are needed.

### ***Buffer Control and Data Storage***

The A/D converters each used four buffers to rotate the input data to different buffers allowing others to be downloaded without missing sample data. During the mass body study, data was continuously sampled and each buffer was downloaded into the Marinus. This keeps the converter buffers current and downloaded. The size of the buffers depend on the number of channels sampled and the sample rates. The software API sets an interrupt to trigger the data acquisition software to download a buffer load of data.

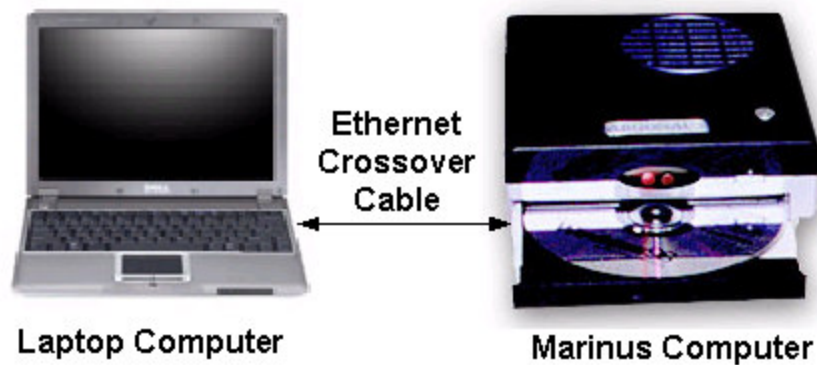
Each buffer download was pre-pended with a marker bit pattern (DEAD BEEF in Hexadecimal) along with the time from the PC down to milliseconds. The PC time is also used to form the last part of the data file name. The first part of the name is the A/D converter designation. The file name is formed when the first data block is written to disk. This file name is kept throughout the test until the next time the power is cycled on the PC. This keeps the data file names unique and relevant to the testing done on a certain day and time.

Since power interruptions are always possible during a test, the data acquisition program always closed the data file after each data block save. The file was then reopened again at the start of the next data read. This action kept the hard disk directory current and kept the file available and readable if the test was prematurely terminated due to a power failure. The Marinus PC had plenty of time to write buffers from two A/D converters opening and closing each file during each read for the duration of the testing.

### ***Data Retrieval***

After each test, the power was removed from the Marinus PC leaving the accumulated buffers on the BiTMICRO flash solid state hard disk. A laptop computer with an Ethernet crossover cable

was used to connect the Marinus PC to a network. The hard drive was previously set to Shared status so an external PC could access the drive and using the standard Copy command to copy the data to a remote location for analysis.



For intermediate testing during development, a copy of VNC (Virtual Network Computing) remote access software was placed on the laptop and the Marinus PC to allow control and program development from a remote computer while the unit was assembled in the mass body test fixture. This technique eliminated the need to use a separate monitor and keyboard for the Marinus PC while enabling software developers the ability to program the unit while it was still installed in the mass body.

## **Data Analysis**

### ***Numerical Analysis***

There is one data file for each test series (power on to power off sequence) Each recorded accelerometer data file containing the header and sensor data is recorded in binary format and can be read with a customized data analysis program such as MatLab. The program was written to analyze a brief time period (10 seconds) centered on a time associated with the test body motion for a sensor of interest.

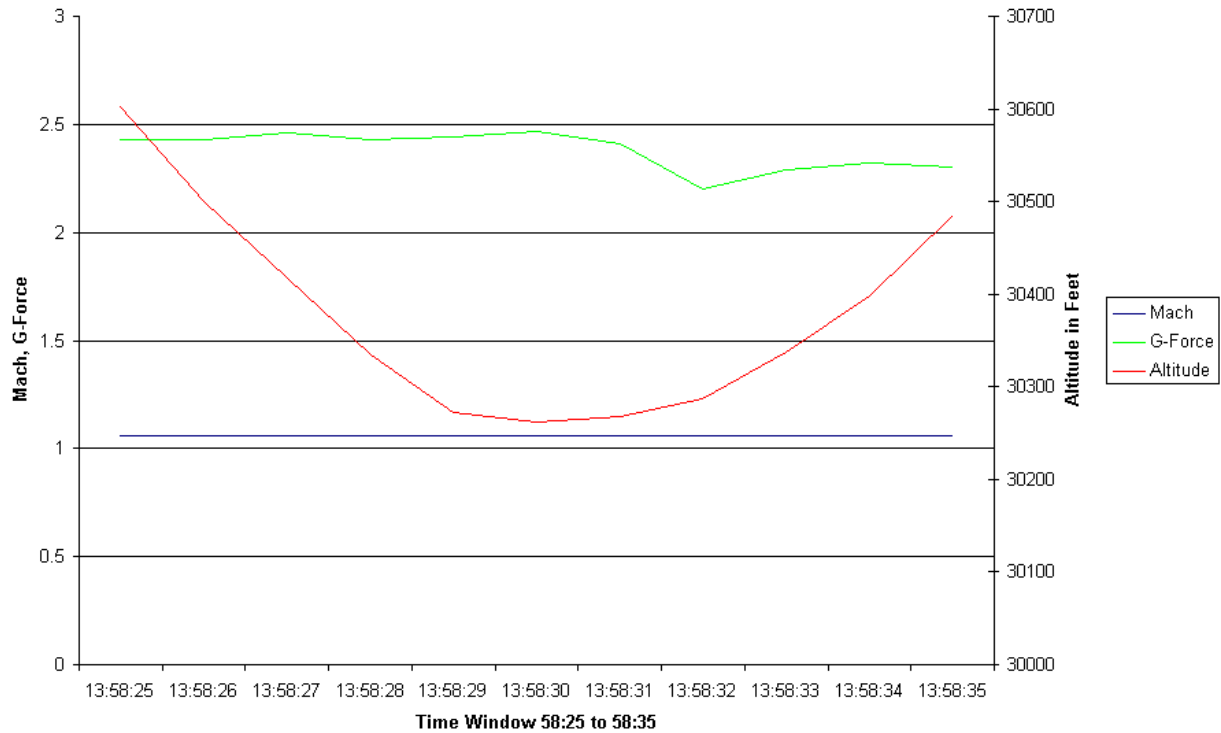
By performing an FFT analysis in MatLab, the accelerometer values are converted from the time domain to the frequency domain yielding a vibration frequency response for the processed time period.

Although not performed in this testing, time alignments from a standardized calibrated source such as GPS or IRIG time standards could be incorporated into the data stream header to more closely coordinate the motion of the test body and the sensor data.

### ***Test Body Motion Analysis***

The movements of the mass body as it progressed through a motion test must be recorded by an external measurement system. Items such as speed, G force, altitude, depth, temperature, humidity, etc need to be tracked in time and compared with the accelerometer data.

### 359 Flight Test 05\_08\_02

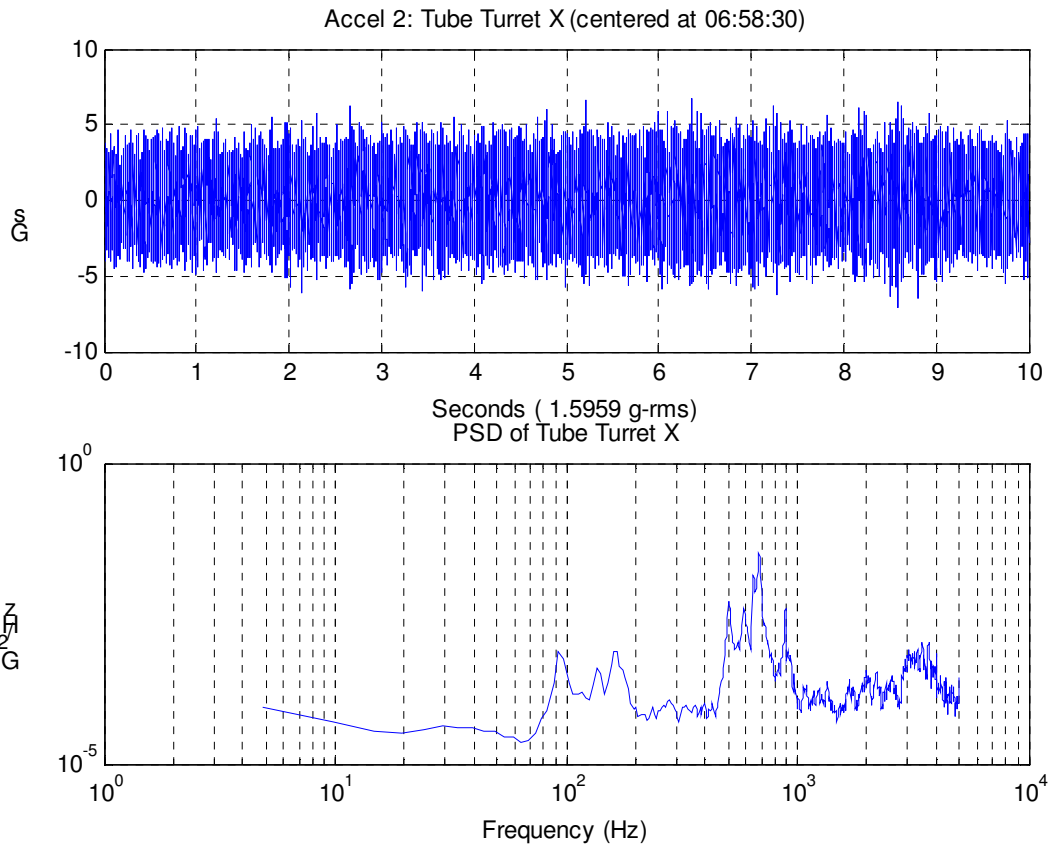


#### 10 Seconds of Mass Body Motion as Recorded From Test Vehicle Data Bus

The above chart shows the mass body movement in speed, G force, and altitude for a 10-second time period. The figure below shows the same 10-second time period recorded accelerometer data and the associated frequency response spectrum. The data indicates vibrations from 100 Hz up to approximately 1 kHz with the peak vibration at 700 Hz. The frequency spectrum ends at 5 kHz because the anti-aliasing filter cuts the response of at that point.

The analysis shown is for one axis on one 3-axis accelerometer. Similar plots are available from the other axis on the sensor as well as other sensors on the mass body. The number of sensors times and the number of time periods of interest generates a large amount of data. The analysis from one mass body test must be subdivided into time slices selected for both time position in the test and the duration of the data for the FFT analysis.

It was found that giving the designer the ability to select sensors and time values in a graphical user's interface simplified the task of data analysis. Working from plots of the mass body external speed and position test data the designer easily selected sensor and time periods for analysis. The MatLab program and user's interface generated all the frequency response charts as indicated below on demand quickly and easily.



10 Seconds of Accelerometer Data Centered at 6 hours, 58 Minutes, 30 Seconds

## Summary

Using inexpensive COTS hardware and some creative programming, mass body studies can be automated and designed to accompany the hardware in the test environment. The system takes a minimal amount of intervention from the test operator. A typical test requires only the DC input power and a simple Record On/Off switch.

Variations in temperature, humidity, G forces are all possible with a standard COTS mini computer equipped with a BiTMICRO flash solid-state drive. The custom written software along with the Windows 2000 operating system are robust enough to operate through several power interruptions during testing. Over months of testing on several projects, this system always returned a full measure of data after each test.

## Biography

John Cooper ([john.cooper@ngc.com](mailto:john.cooper@ngc.com)) is a principal engineer who originally came to work for Westinghouse/Northrop Grumman in 1982 from the Bendix Corporation. He has a masters of science degree in computer engineering from Loyola College in Baltimore. Presently he works in systems integration and test developing data acquisition and control software. In the past, Mr. Cooper, has worked in technical training where he developed training courses and automated training simulations for ground based radars.

Buddy Sinor ([buddy.sinor@ngc.com](mailto:buddy.sinor@ngc.com)) is a managing engineer who has been working for Westinghouse/Northrop Grumman since 1981. He has a masters of science degree in computer engineering from Loyola College in Baltimore. He presently manages flight test programs for airborne radar systems.