MIDÉ

SLAM·STICK™
HIGH SPEED • PORTABLE • RECHARGEABLE • DATA LOGGER

FEATURES

- Free Analysis Software - click here for web page
- Simple and Easy to Use
- Small and Lightweight
- High Speed - 3.2 KHz Sampling Rate
- Rechargeable
- Characterizes Vibration Profile for Energy Harvesting Applications
- Dust Proof Enclosure
- Simple Analysis & Configuration Software (Included)

APPLICATIONS

- Characterizing Energy Harvesting Vibrations
- Equipment Installation Verification
- Vibration Characterization for Damping Purposes
- Condition Based Maintenance
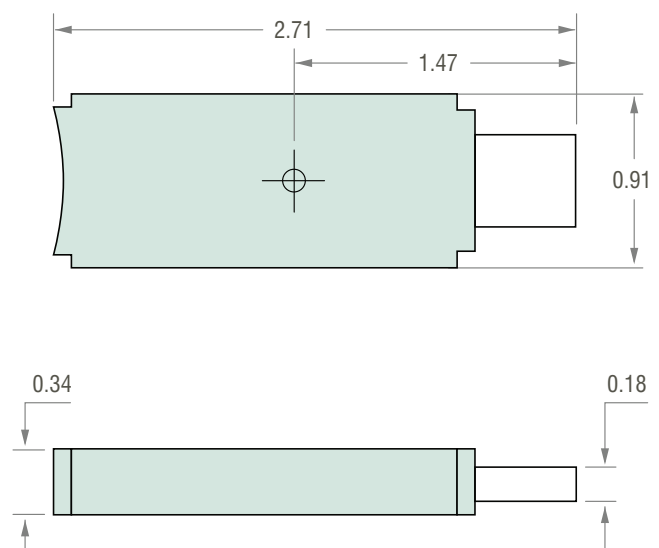- Equipment Monitoring
- Bearing Monitoring

DESCRIPTION

The Slam Stick™ is a high speed ultra portable rechargeable data logger capable of measuring acceleration in all three axes. The device uses a USB Port for on the fly configuring, charging and downloading of data. Simple configuration software allows users to tailor the device to their specific needs. The configuration options include an adjustable delay time before each measurement, different measurement durations, and a trigger based on a pre-determined acceleration level. Free analysis software allows for complete vibration characterization enabling the user to determine the frequency content of their given vibration.

The Slam Stick™ can be used for many different applications including energy harvesting vibration characterization, modal surveys and equipment monitoring. Simply configure the device for your application, mount the device on your vibrating structure, hit the button and download the data to your computer.
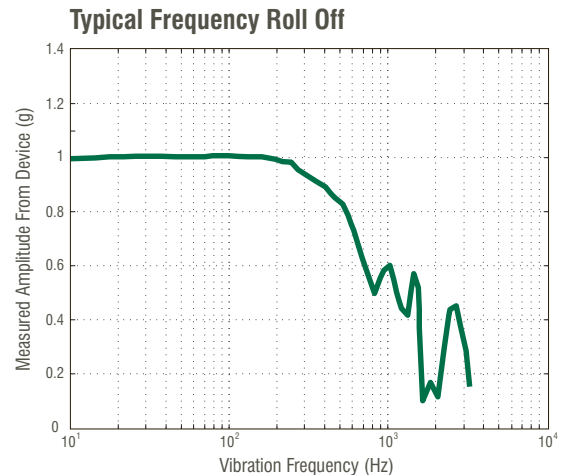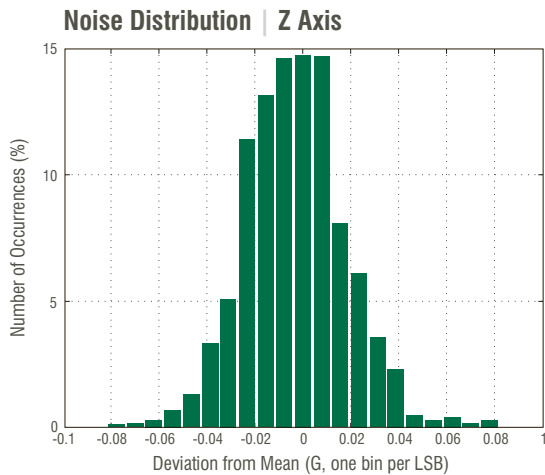
Contact Midé by emailing: slamstick@mide.com.

SPECIFICATIONS

Specifications	Value	Units
Axes Measured	X,Y,Z	NA
Max Acceleration (each axis)	16	g
Sampling Rate (each axis)	3.2	kHz
X,Y axis RMS noise	0.016*	g
Z axis RMS noise	0.022*	g
Max Recording Time at 3.2 kHz	220	Seconds
Min Operating Temperature	-40	C
Max Operating Temperature	80	C
Length	2.71	in
Width	0.91	in
Thickness	0.34	in
Mass	14	gram

ᵗSee noise histogram data in Testing section

PRODUCT DIMENSIONS

* Dimensions in Inches

SLAM·STICK

PERFORMANCE PLOTS

Noise Distribution | X Axis

Noise Distribution | Y Axis

Noise Distribution | Z Axis

Typical Frequency Roll Off
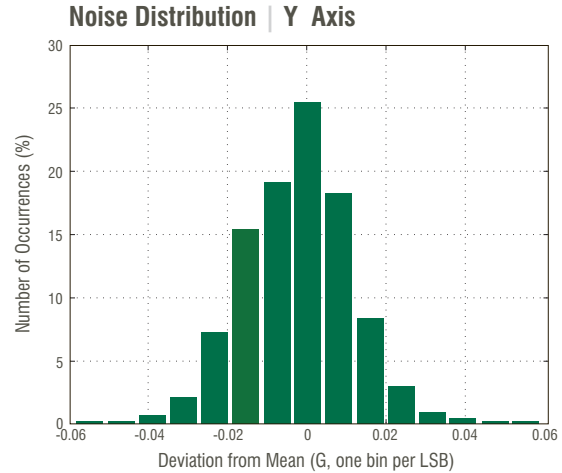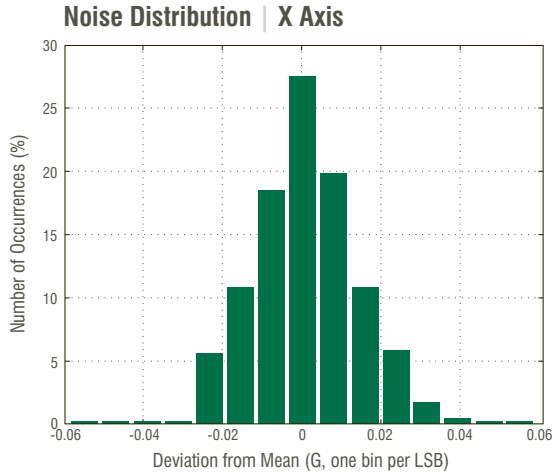
"Noise" in this document refers to sample-to-sample deviations of the measured signal from the actual value due to internally-generated electrical interference, thermal effects and other factors (not acoustic sounds). Random noise is statistical in nature and follows a Gaussian (bell-curve) distribution, thus a histogram is normally used to quantify its distribution in a given signal.

For the noise measurement, a sample Slam Stick recording was taken at room temperature with no vibrations present. The plots above represent the distribution of noise in the recorded data for each axis. This distribution is approximately Guassian, with the majority of samples falling very close to the correct value and less frequent outliers falling further from the correct value. This distribution is typical of random noise present in any measurement.

Each bin represents one LSB (Least Significant Bit, or the minimum G-level difference that can be represented, by a 1-bit change, in the recorder's digital output), while the X axis shows the corresponding error in Gs and the Y axis value indicates the percentage of

PERFORMANCE PLOTS

samples which contain this amount of error. The RMS error (or standard error) is the error value at which 68.2% of samples (one standard deviation) have an error lower than the RMS value.

Frequency roll off data was taken by exciting the Slam Stick at a constant amplitude (1 gee in this case) over a range of frequencies from 10 Hz to 3200 Hz. The measured vibration amplitude from the Slam Stick was then plotted versus frequency. Note that the roll off is severe after ~240 Hz. Different devices performed differently after this frequency and amplitude data should not be trusted when above this frequency. Frequency data is not impacted by this roll-off. For example if a vibration source was providing a 3 gee amplitude at 500 Hz, the Slam Stick would properly provide the relevant frequency information, however the gee level would be inaccurate, most likely providing a lower than 3 gee amplitude reading.

OPERATION

To Charge your Slam Stick™

Leave the device plugged into the USB port for charging. A green LED will signify that the device is charging. The LED will go out when a full charge has been reached. A full charge will take 1 to 2 hours.

To Configure your Slam Stick™

The following parameters can be configured for your device.

- Pre-delay in seconds before recording
    - ‣ Values between zero and 86,400
    - ‣ Time after the button is pressed before the recording starts
- Number of samples recorded
    - ‣ Values between zero and 65535
    - ‣ Hit enter or zero if you would rather enter the time of the recording
- Recording time in seconds
    - ‣ Values between 1 and 220 seconds
    - ‣ How long the device will record data after the pre-delay has ended
    - ‣ Hit enter or zero for no limit
- G-Level Trigger
    - ‣ See Special Trigger Modes section for more detail

To change settings such as recording pre-delay and recording time, you can use either the ss_config.exe program or (for Matlab® users) the 'ss_config.m' Slam Stick Matlab script. Make sure any recordings you wish to keep have been downloaded before you change settings.

Whether using the .exe or Matlab, after asking a few questions, the program will output a new 'config.dat' file in the current working directory. Copy this file onto the Vibration Recorder over the original. When you unplug the device, an automatic erase will be performed.

The Slam Stick™ will be delivered with a standard configuration including a 10 second delay with a 30 second recording time. The g-level trigger will not be enabled.

Multiple Recordings

Two methods are available to limit the size of each recording, allowing you to continue taking recordings until the flash memory is full. The recommended method is to specify the number of seconds to record for; however, the number of samples to record can also be specified. If both settings are entered, recording will stop if either condition is met. Please note that because the recorder saves data in complete sectors (512 bytes) at a time, actual recording length may vary slightly from the setting you enter.

Special Trigger Modes

Normally, recording or pre-delay begins immediately after pressing and releasing the button. In some cases it may be desirable to trigger recording only when a certain G-level is exceeded. There are two G-level trigger modes, depending on the nature of the event to be measured and battery life required:

- 'Nap' sample rates (1-8Hz)

This is the lower power (longer battery life) trigger mode and consumes ~ 60uA current. This mode is best suited for sustained vibration events where it is not necessary to record the beginning of the event. Since the sample rate is very low, a brief G-level spike may fall 'in between' samples and go unnoticed. In this mode, the accelerometer is in a low-power idle mode, the CPU is asleep and the Flash memory is powered off. Thus, there will be a short delay between the first recognized G-level exceedance and the start of recording as the Flash memory is re-initialized.

SLAM·STICK

OPERATION

- 'Full' sample rate (up to 3200Hz)

'Full' leaves the accelerometer in active mode and the Flash memory powered, and uses the same sample rate as the actual recording. This mode consumes more power (~300uA @ 3200Hz), but will trigger even on brief G-level exceedances. In addition, this mode will record the 32 pre-trigger samples leading up to the trigger event. This is the recommended mode of operation for recording impacts and other transient events.

Note that in either mode, a button press is still required to arm the G-level trigger between recordings. The G-level trigger will arm approximately 1 second after pressing the button (plus any user-set time delays) to prevent nuisance triggering due to the button recoil. To minimize nuisance triggers, avoid setting a trigger level at or near the noise floor (0.1 ~ 0.2g). For DC triggering, the contribution of gravity (up to 1G +/- any offset error), if any, must be added to this value.

To Erase data the device

DO NOT DELETE FILES FROM THE Slam Stick™!!! To erase data (the configuration file will not be erased), hold down the white button while unplugging the USB connection. Keep the white button pressed down until the orange LED starts flashing. At this point you can remove pressure from the button. The device is done erasing when the flashing LED stops. This will clear any previous recordings from the device so it will be ready for more testing.

To Install on Your Vibration Structure

Attach the Slam Stick™ to the vibration source using any means that will ensure a high quality vibration energy transfer with minimal damping. Ensure that the mounting method also allows for easy removal of the Slam Stick™ after the test. Ensure that the user still has access to the operating button after installation, or

delay is long enough to permit installation. Ensure that the axes orientation of the Slam Stick™ is suitable for the desired measurement (see figure below). It is suggested to take a picture of the device for later confirmation of mounting position. Suggested mounting options include bee's wax, thin double sided tape, duct tape and/or mechanical brackets. If mechanical brackets are used be careful not to over load the plastic enclosure. Please note that the enclosure is only dust proof and should not be submerged or subjected to any direct fluid spray.

To Record

To begin the vibration measurement press and release the white button on the Slam Stick™. An amber LED near the rear end of the device will indicate the recording progress. If a pre-recording delay has been set, the LED will flash briefly, about every 2 seconds, during the delay period. During active recording, the LED will blink rapidly, then stop when the recording completes.

During recording, the button can also be pressed during the delay period (if any) to skip the delay and begin recording, or during the active recording period to terminate the recording early.

SLAM·STICK

OPERATION

Downloading and Analyzing the Data

For technical performance reasons, the Slam Stick™ stores its data in a raw binary format, which requires additional software to interpret or convert to a more accessible format. There are currently two ways to do this: use a standalone PC/Windows program, or use the Matlab scripts (preferred if available) to view the data graphically.

> PLEASE NOTE: The data.dat file (approx. 4Mbytes) and config.dat file will always appear on the device, even if it has been "erased" and no new recordings have been taken. Because date and time information is not available to the Slam Stick™, the file timestamps will contain a default value (e.g. 1/1/2000) regardless of the date the recording was taken. This is normal operation, and not a cause for concern.
>
> Do not perform file management directly on the Slam Stick™ (such as deleting, moving or creating new files on the device, or reformatting) using your PC, as this may cause any currently recorded data to be lost. If such file management has been performed, or your PC does not correctly recognize the disk, please erase it by holding down the button while unplugging. This will recreate the internal file system and associated files.

To download a permanent copy of the recording data, plug the device into a USB port and copy the data.dat file to a desired location. You can rename it with a more descriptive name if desired.

If it is not important to save the data permanently, you can instead point your analysis software at the data file on the device, rather than copy it to your hard disk. Please note that reading from the USB stick is much slower than reading from your hard disk, so the analysis software may take some time to finish reading the file.

Viewing Data and Analysis Using Slam Stick Viewer

Slam Stick Viewer is a GUI application for viewing and exporting data from the Slam Stick™portable vibration recorder and configuring the recorder. It's written in the Python programming language, and can be used either stand-alone, as part of your own data analysis s scripts, or interactively with SciPy's IPython shell. Click here for specific details (PDF)

Exporting data to spreadsheet (.CSV) format using ss2csv.exe

For Windows users*, the included ss2csv.exe program can be used to convert recording files from the vibration recorder's native format to a plaintext .CSV (Comma Separated Value) file that can be used with many common software packages.

> PLEASE NOTE: MS-EXCEL or OpenOffice will not completely read a .CSV file which contains more than 65,535 lines (approx. 20 seconds of data at 3200Hz). If such a file is opened, only the first 65,535 lines will be read. This is a limitation of MS (and compatible) spreadsheet software.
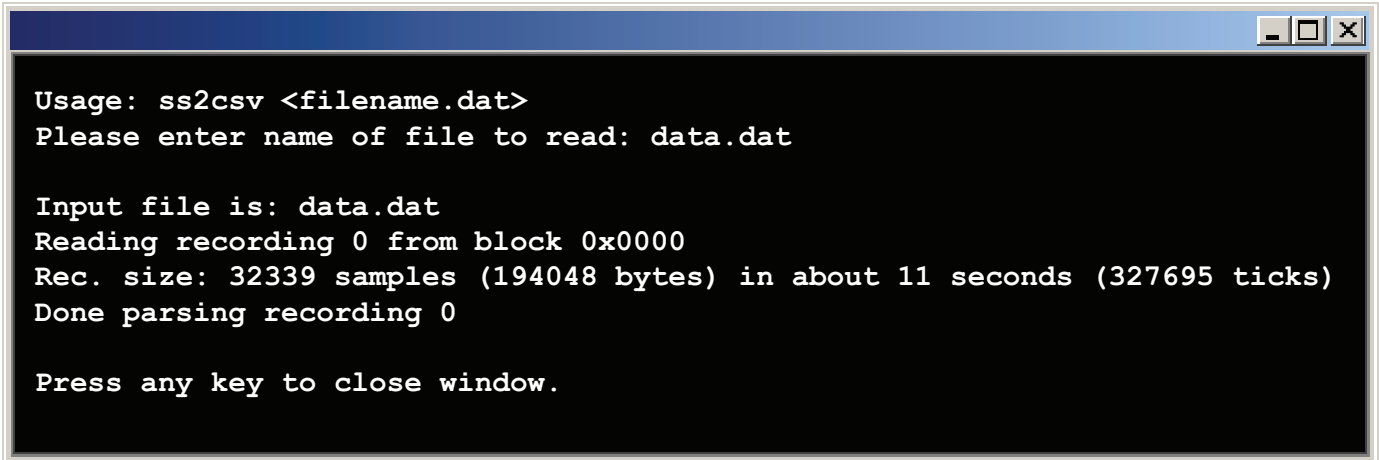
If more than a quick 20-second preview is needed, other software/script language must be used to plot the data.

* Users of other operating systems, please refer to section non-windows platforms for information on building the included source code on other platforms.

Interactive mode (prompt for user input)

To run the program interactively, run ss2csv by double-clicking on its icon. When prompted, enter the path and filename of the data file to be converted (if the data file is in the same directory as the program, only the filename needs to be entered). The recordings will be output as files named VIB0000.CSV, VIB0001.CSV, etc., in the directory the program was run from, one file per recording. The output files will always be numbered in the order they were recorded.

SLAM·STICK

OPERATION

```
Usage: ss2csv <filename.dat>
Please enter name of file to read: data.dat

Input file is: data.dat
Reading recording 0 from block 0x0000
Rec. size: 32339 samples (194048 bytes) in about 11 seconds (327695 ticks)
Done parsing recording 0

Press any key to close window.
```

The program's output window will remain onscreen to review for any errors/warnings. When finished, press a key to close it.

> **WARNING:** If old files with the same name are present, they will be overwritten without warning. Move, or rename old files if you want to keep them!

Noninteractive

This program can also be called from the command line or from other programs, etc., or by dragging a data file onto its icon. In this case, the first and only command line argument is the path/filename of the file to be converted. When run in this manner, the user will not be prompted for a file name, and the program will exit immediately when finished rather than waiting for a key press.

```
C:\stuff\> ss2csv J:\data.dat
```

> **WARNING:** If old files with the same name are present, they will be overwritten without warning. Move, or rename old files if you want to keep them!

Viewing and data analysis using MATLAB

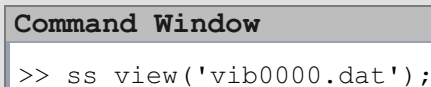MATLAB is a popular numerical analysis software package commonly used in science, engineering and educational settings. If you have access to MATLAB, you can use the included scripts to view and analyze recording data interactively, or import recording data into the MATLAB environment for use with your own scripts.

Viewing recordings is currently a two-step process. First, run the script 'ss_split.m' on the multi-recording 'data.dat' file to generate individual (binary) recording files:

```
Command Window
>> ss_split('data.dat');
```

The output will be a series of files named 'vib0000.dat', 'vib0001.dat', etc., depending on the number of recordings available. The file numbering will match the order in which the recordings were taken, from earliest to latest.

```
Command Window
>> ss_view('vib0000.dat');
```

Next, use the script 'ss_view.m' to view individual recording files:

SLAM·STICK

OPERATION

The following Figure windows will be displayed:
1) Time history (x, y, z)
2) Fourier Transform (X)
3) Fourier Transform (Y)
4) Fourier Transform (Z)
5) 2-D Fourier Transform (X)
6) 2-D Fourier Transform (Y)
7) 2-D Fourier Transform (Z)

The 2-D Fourier windows will slice the complete recording into shorter time segments and display the frequency content over time as a 3-D surface. This may help provide a clearer picture of vibration events over time, for example, differentiating constant or repeating shock/vibe events from high-amplitude but nonrepetitive events, even though they may produce similar amplitude peaks in the 1-D Fourier results.

Figure 1: Time Domain

Figure 2: Z Frequency (1-D)

SLAM•STICK

OPERATION

Figure 7: Z Frequency 2D
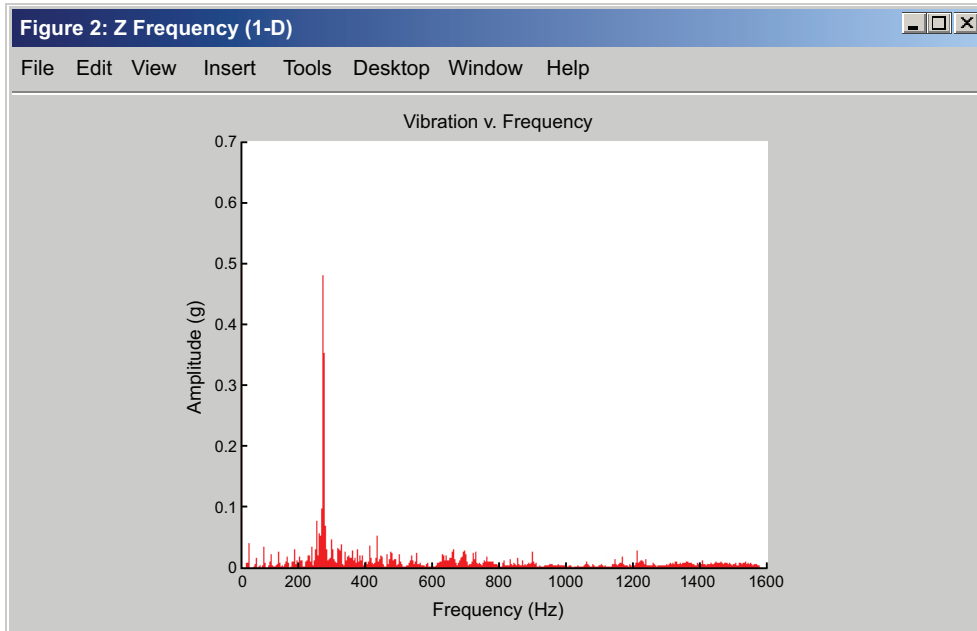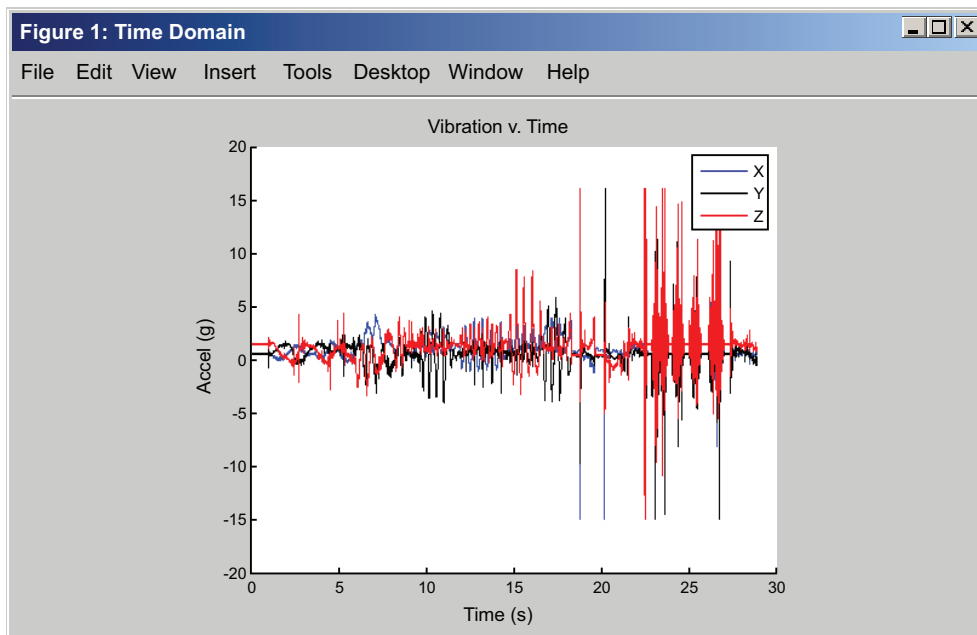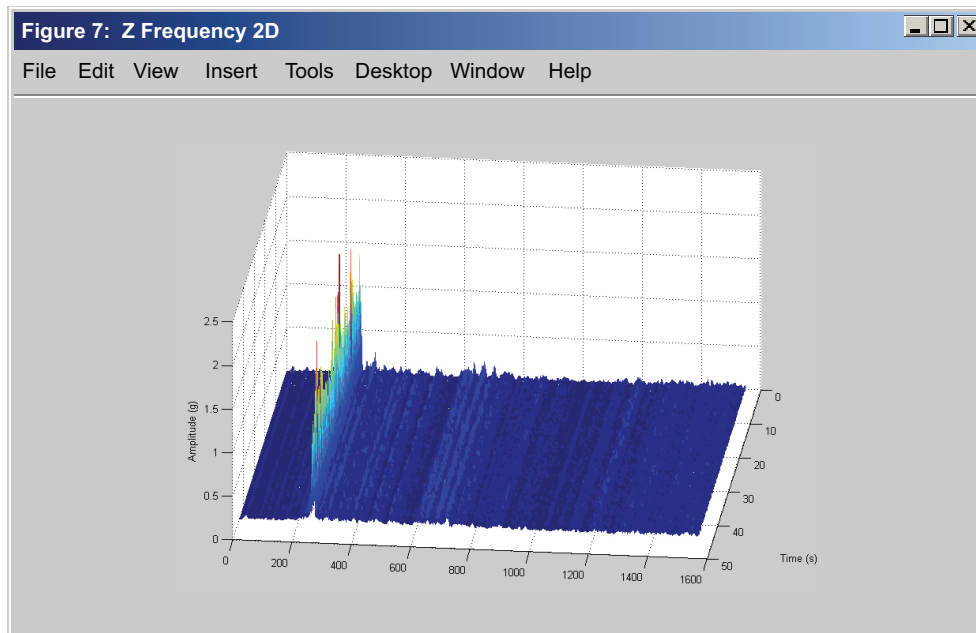
2-D Frequency options

The 2-D Fourier graph splits frequency data into small time 'slices' to visualize time-dependent trends in the frequency data. By default, the full frequency range is shown on the 2-D Fourier graphs, and the data are segmented into 4 slices per second (this can be adjusted by editing the script). Since the FFT implementation requires each slice to be of equal length, the data will be reshaped into equal-length slices, and (if necessary) up to one slice of trailing data will be discarded to maintain equal slice lengths.

Unlike a 2-d plot, Matlab's 3d surface plot cannot easily be zoomed or panned to show only a specific region of interest. To more easily view a specific data feature, optional parameters can be input to constrain the contents of the 2-D Fourier graphs. The parameters accepted are:

Command Window
```
ss_view('filename', startfreq,
endfreq, ceiling);
```

The startfreq and endfreq parameters will constrain the frequency range displayed, and the ceiling parameter will constrain the maximum height (ceiling) of the plot by cutting the tops off peaks above that value. For example:

Command Window
```
ss_view('vib0000.dat', 100, 500);
```

will show only the frequency range between 100 and 500 Hz.

Command Window
```
ss_view('vib0000.dat', 100, 500, 0.5);
```

will show the frequency range between 100 and 500 Hz, and also ceiling the amplitude to 0.5g so that small features can be seen.

To provide a ceiling value without entering frequency constraints, you can pass an empty string (two single

OPERATION

quotation marks with nothing in between) for startfreq and endfreq. For example:

```
Command Window
ss_view('vib0000.dat', '',  '', 0.5);
```

will ceiling the surface plot to 0.5g without affecting the range of displayed frequencies.

Non-Windows platforms

Pre-compiled binaries are provided for Win32, but for customers using other platforms, these tools must be compiled from source. The source code included is mostly OS-neutral and should compile without significant changes under Linux, etc. Unfortunately, there is not a true platform-neutral way to detect keypresses, so the getch() function used in Midé's code may need to be replaced. Additionally, this code assumes a little-endian system and directly uses the little-endian data received from the device – users of big-endian processors must add code to temporarily switch the CPU to little-endian (if supported, e.g. PowerPC), or modify the appropriate sections.

This code is supplied under the GNU General Public License, which allows you to freely use, modify, and create derivative works of the software. It also allows you to redistribute your modifications, provided the source code is included. Please see the comments at the beginning of the code for additional details.

The Windows version was compiled with gcc and the MinGW/msys package (http://www.mingw.org/).

SLAM·STICK

APPLICATIONS INFORMATION

Aliasing

Any complex waveform, such as Slam Stick vibration traces, can be expressed as the sum of sinusoidal frequency components.

Per Shannon's Sampling theorem, in any sampled data such as that produced by the Slam Stick, the maximum frequency that can be reliably identified is limited to half the sampling frequency. This limiting frequency is known as the Nyquist frequency, critical frequency or folding frequency. Any frequency content at or above

Sampling devices such as the Slam Stick include a lowpass filter at the folding frequency to minimize the appearance of such aliases (see the Frequency Response Graph in performance plot section); however, no filter can completely eliminate unwanted signals, so a very strong signal above the folding frequency may still produce a visible alias. The best course of action is to recognize that this can occur and take steps to identify aliasing if it occurs. For example, if the frequency content of the system is known to be (or found to be) dependent on an external parameter
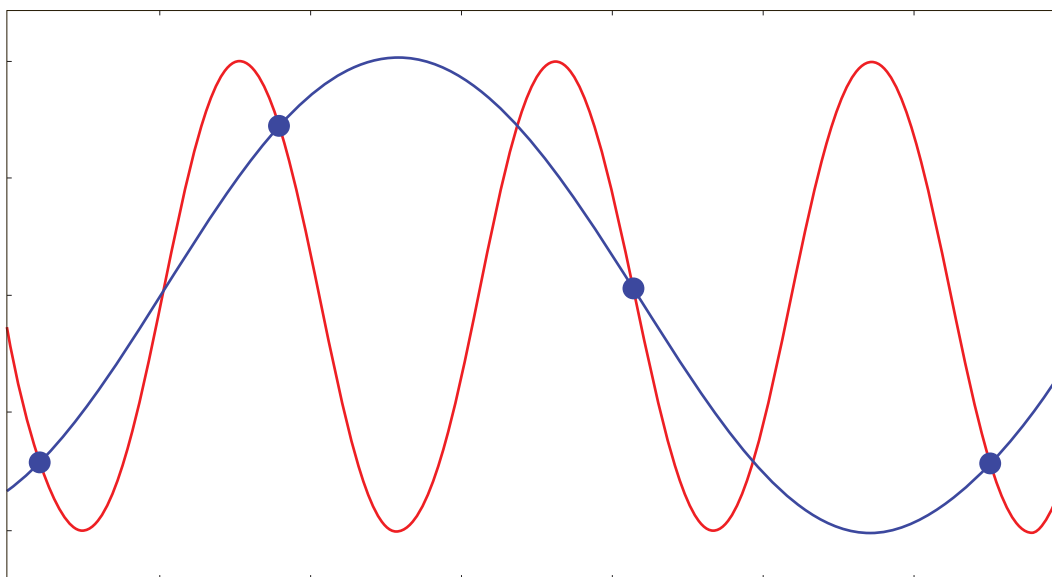

Figure 1: Aliasing occurs when the real signal frequency exceeds the Nyquist frequency, resulting in there being not enough data points to correctly reconstruct the signal.

this limiting frequency will produce an alias, or false signal appearing at a lower frequency. This alias will appear as the reflection of the high frequency signal over the folding frequency. For example, if the folding frequency is 1600Hz (half of the Slam Stick's 3200 Hz sampling frequency), an 1800Hz signal would appear as an alias at 1400Hz, and a 1900Hz signal would appear at 1200Hz, etc. Figure 1 shows an example of a real signal exceeding the folding frequency, and the apparent (aliased) signal that results.

such as engine RPM, observing the response as this parameter is varied can help in identifying spurious signals.

Commercial Aircraft Vibration Characterization

The following shows a brief example of using the Slam Stick data to identify specific features in a recording. This example uses the included MATLAB script for data visualization.

SLAM•STICK

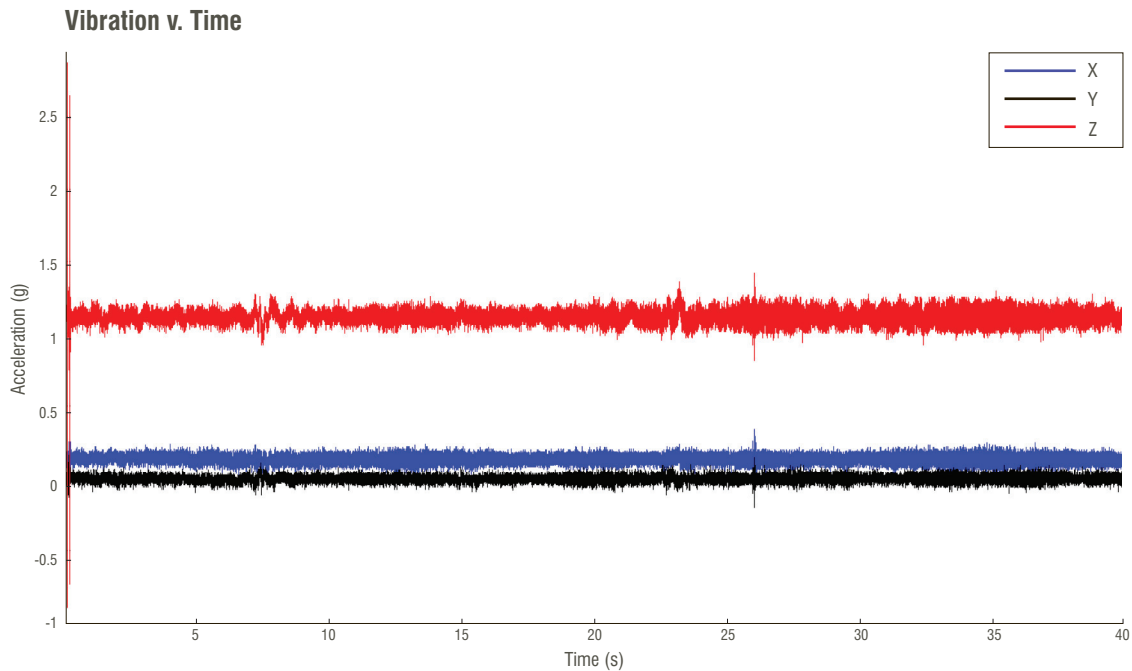## APPLICATIONS INFORMATION

Vibration v. Time

Figure 2: Time domain response of a commercial jumbo jet during taxiing.

A series of vibration recordings were taken during a flight on a commercial jumbo jet. The first was taken during taxiing; the second taken during active flight. In each case, the recorder was placed on the floor of the craft with the button facing upward (Z-axis normal to the ground). The time-domain result is shown in Figure 2.

Vibration v. Frequency

Figure 3: 1-D FFT of the time domain data shown in Figure 2.

Unsurprisingly, the greatest energy is seen in the Z direction. The 1-D FFT result for this axis, shown in Figure 3, shows several features that may be of interest. The first is a comparatively strong peak at around 920Hz, some extremely low-frequency components (1.5Hz and 5Hz), and a broad swath centered around 260Hz or so. What's producing these features, and are these consistent? Would any of them be useful in an event triggering or energy harvesting application?
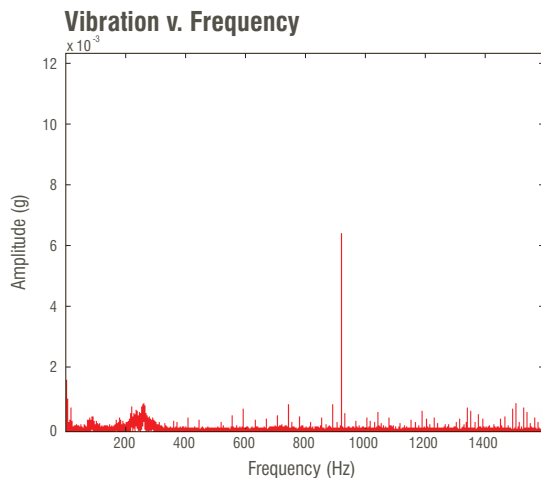
For a more detailed look at the vibration profile, the 2-D FFT was plotted with a low ceiling value (~ 0.05) in order to clearly show each feature of interest. For this Figure, the surface plot was rotated so that it is viewed directly from the top. Some of the identifiable features have been labeled.With this image, the contributors become more clear. The 920Hz peak is extremely consistent both in time and frequency, most likely contributed by the aircraft Auxiliary Power Unit (APU). Although it appears to have the highest amplitude in the 1-D result by far, it is not the highest amplitude signal after all – those in the 150-375Hz range have higher
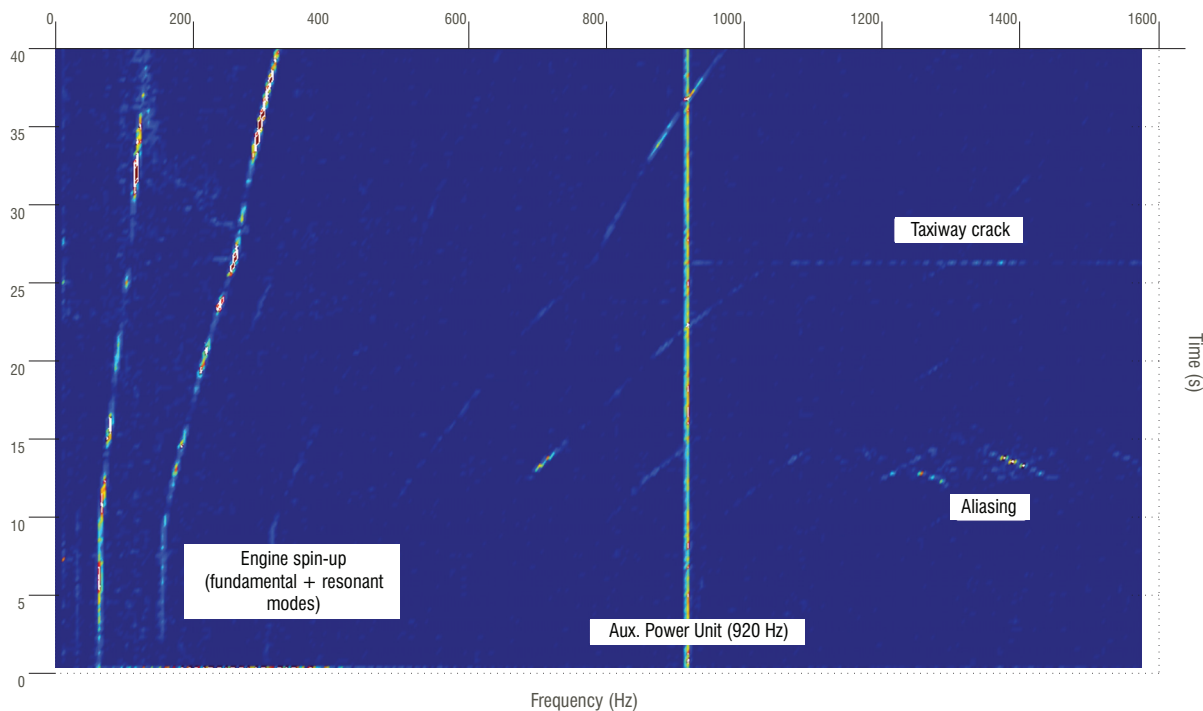
SLAM·STICK

APPLICATIONS INFORMATION

Figure 4: 2-D FFT of the time domain data shown in Figure 2. Salient features have been labeled.

peak amplitudes, but appear negligible in the overall 1-D result since this energy is spread out over a wide frequency range. A closer look at the 150-375Hz signals, along with the similarly-shaped features at higher frequencies, shows that they all start off at multiples of approximately 64Hz and 156Hz. That is, 64, 128, 156, 312, … . Note that not all of these overtones are visible at t=0; the higher modes are visible mainly as they cross fixed resonant modes in the aircraft structure itself. Some examples of these mode crossings are near 750Hz, 900Hz, 1050Hz and 1200-1300Hz. The 150-375Hz signals are most likely the n/rev contributions of one engine being spun up, meaning they are engine-speed dependent and may not be reliable for e.g. energy harvesting, but may be useful to estimate engine RPM remotely.

A couple other features are of note in this plot: At approximately 28 seconds, a brief horizontal 'broadband' feature is evident, most prominently from

920Hz all the way up to 1600Hz. This is the impulse response as the craft crosses a large crack or other discontinuity in the taxiway, creating a mild mechanical impact. Other sudden mechanical shock or impacts will produce a similar response. Finally, note the signal between 1200-1450Hz at approximately 13-15 seconds. As the engine speed continues to increase, frequency features in the inverse (decreasing) direction are evident. This is a good example of an aliasing artifact caused by a very strong signal beyond the maximum measurable frequency of the device. As mentioned in the Aliasing appnote, any signal energy remaining beyond the Nyquist (folding) frequency will be mirrored over this frequency and appear as a spurious signal below the Nyquist frequency.

The next series of plots shows data taken from the same location during flight at cruising altitude. The APU contribution is still visible in the Z axis, but the response is now dominated by "wind noise" at 400-600Hz (Y

APPLICATIONS INFORMATION

axis) and a similarly wide band centered around 380Hz (Z axis). The X axis shows contributions from both of these sources. Unlike the previous case, all of the peak frequencies are stable over time, making these more suitable energy harvesting frequencies.
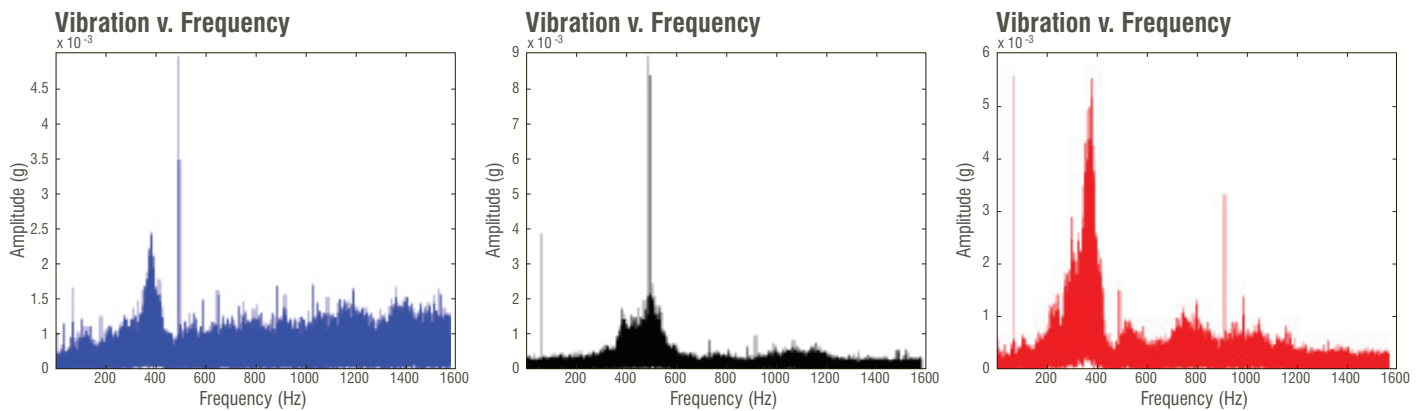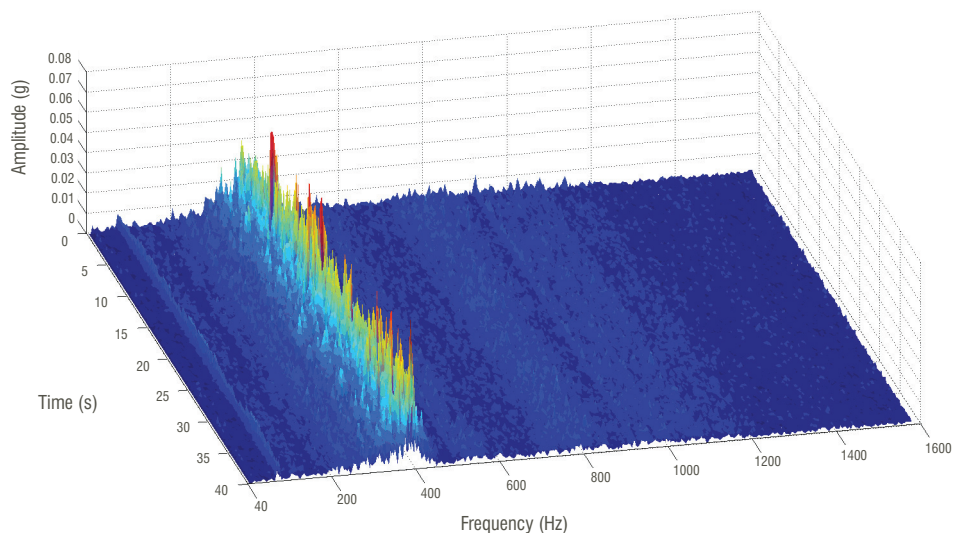

Figure 5: 1-D FFTs of vibration data during cruise

Figure 7: 2-D FFT of vibration data during cruise (X axis)

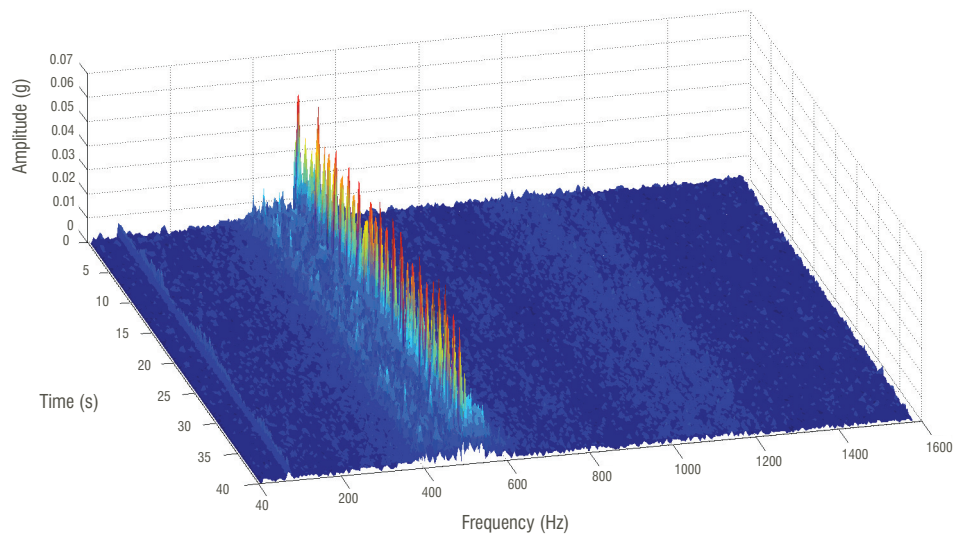# SLAM•STICK

APPLICATIONS INFORMATION

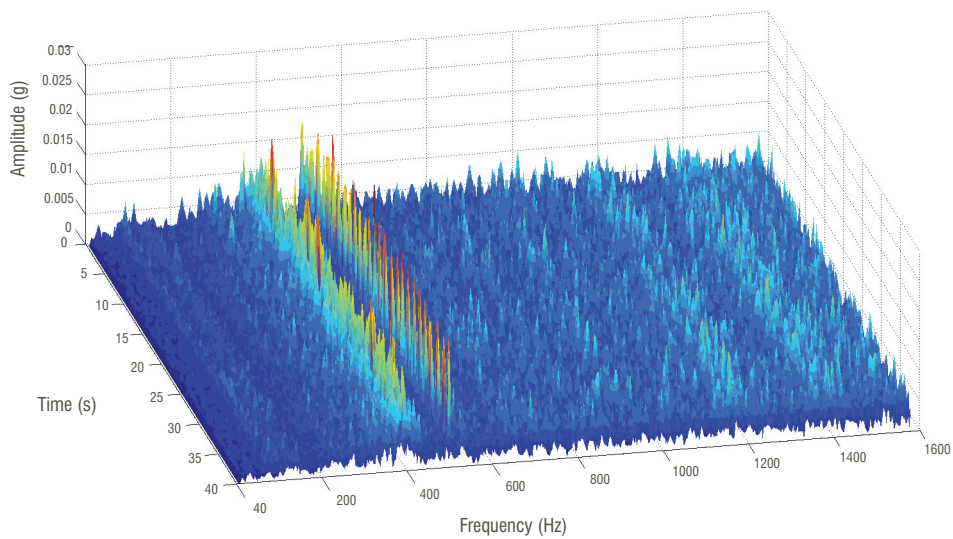**Figure 8: 2-D FFT of vibration data during cruise (Y axis)**

Figure 6: 2-D FFT of vibration data during cruise (Z axis)