Dynamic Concepts, Inc.
Huntsville, Alabama

THE NASA ENGINEERING & SAFETY CENTER (NESC)

SHOCK & VIBRATION TRAINING PROGRAM

By
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- NESC is an independently funded program with a dedicated team of technical experts
- NESC was Formed in 2003 in response to the Space Shuttle Columbia Accident Investigation
- NESC's fundamental purpose is provide to objective engineering and safety assessments of critical, high-risk NASA projects to ensure safety and mission success
- The National Aeronautics and Space Act of 1958
- NESC is currently expanding its services to benefit United States:

  Military
  Government Agencies
  Commercial Space

- NESC Engineers Provide a Second Pair of Eyes
- Design and Analysis Reviews
- Test Support
- Flight Accelerometer Data Analysis
- Tutorial Papers
- Perform Research as Needed
- NESC Academy

We already have a charge number.

NESC Sample Projects

NASA/Wallops

Terrier-Black Brant Flight

Orion LAS PA-1 Test

NASA/Stennis A-3 Test Stand

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The authors have prepared self-study course units for:

- Shock
- Vibration
- Acoustics
- Structural Dynamics
- Signal Processing

These taxpayer-funded materials are available upon request to U.S. civil servants and contractors working on NASA, commercial space, and military projects.

Students learn best by doing!

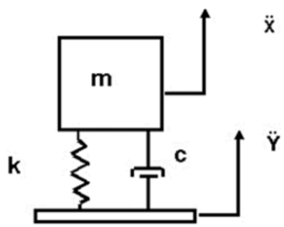
These NESC course units contain

- Slide presentations
- Software exercises using actual accelerometer data samples & synthesized time histories
- Software is mainly written in Matlab with some visual C++ programs
- Students keep software for use on their own projects, including source code

Challenges

- Most engineering students do not take a vibrations course in college
- College-level vibration courses focus on theory rather than on practical applications
- *Pedagogy . . .*

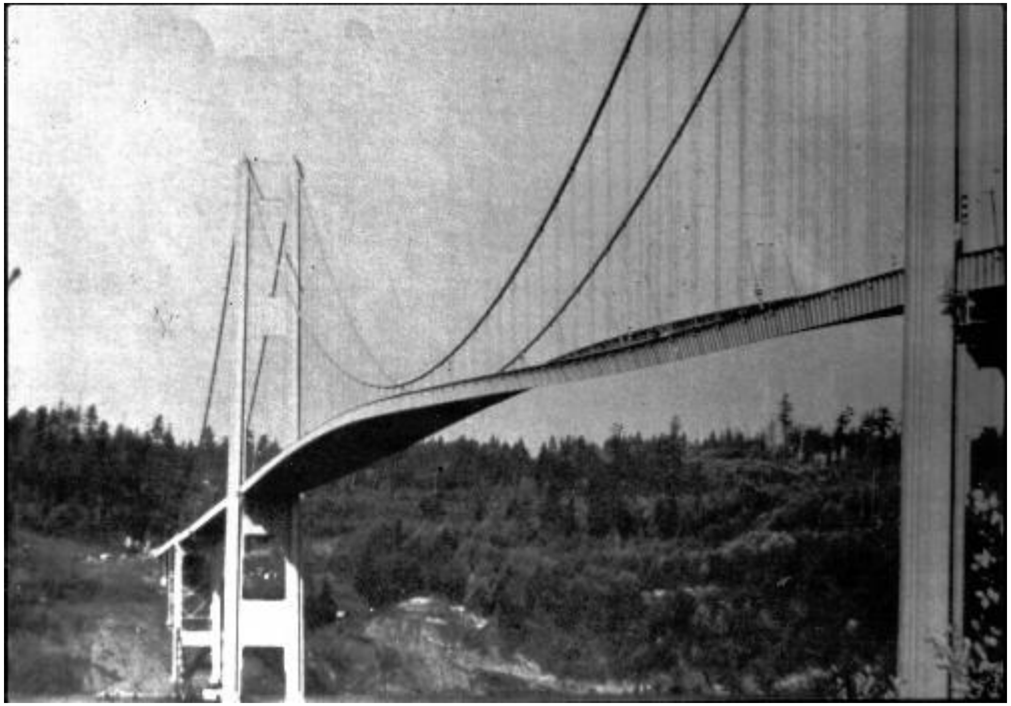
Topics (planned or completed)



- Signal Identification, Natural Frequencies, and Damping Ratios
- Structural Dynamics, Rods, Beams & Plates
- Avionics Isolation
- Octave Rule
- Sine & Sine Sweep Vibration
- Random Vibration
- Fourier Transforms
- Power Spectral Density
- Shock Response Spectra
- Vibration Response Spectra
- Fatigue, Miners Rule, Rainflow
- Steinberg Electronic Formulas
- Aliasing, Nyquist Frequency
- Digital Filtering
- Sound Pressure Levels
- Finite element methods

Work-in-Progress . . . 18 Units completed, hundreds more to go!

Tacoma Narrows Bridge 1940



Wind speed of 42 miles per hour

Torsional vibration mode at 0.2 Hz.

The two halves vibration 180° out-of-phase.

Torsion mode response due to aerodynamic self-excitation.

<u>Not</u> due to resonance.

Strouhal frequency

$$f_s = S\ U/D$$

$$f_s = 0.84 \text{ Hz at } 42 \text{ mph}$$

0.2 Hz oscillation sinusoidal with an amplitude up to 28 feet.

Acceleration = ω^2 Displacement

0.5 (336 in peak-to-peak) [2π 0.2 Hz]^2 (1 G /386 in/sec^2)
= 0.69 G

Sine Vibration: Gemini Program Titan II Pogo

Astronaut Michael Collins wrote:

The first stage of the Titan II vibrated longitudinally, so that someone riding on it would be bounced up and down as if on a pogo stick. The vibration was at a relatively high frequency, about 11 cycles per second, with an amplitude of plus or minus 5 Gs in the worst case.

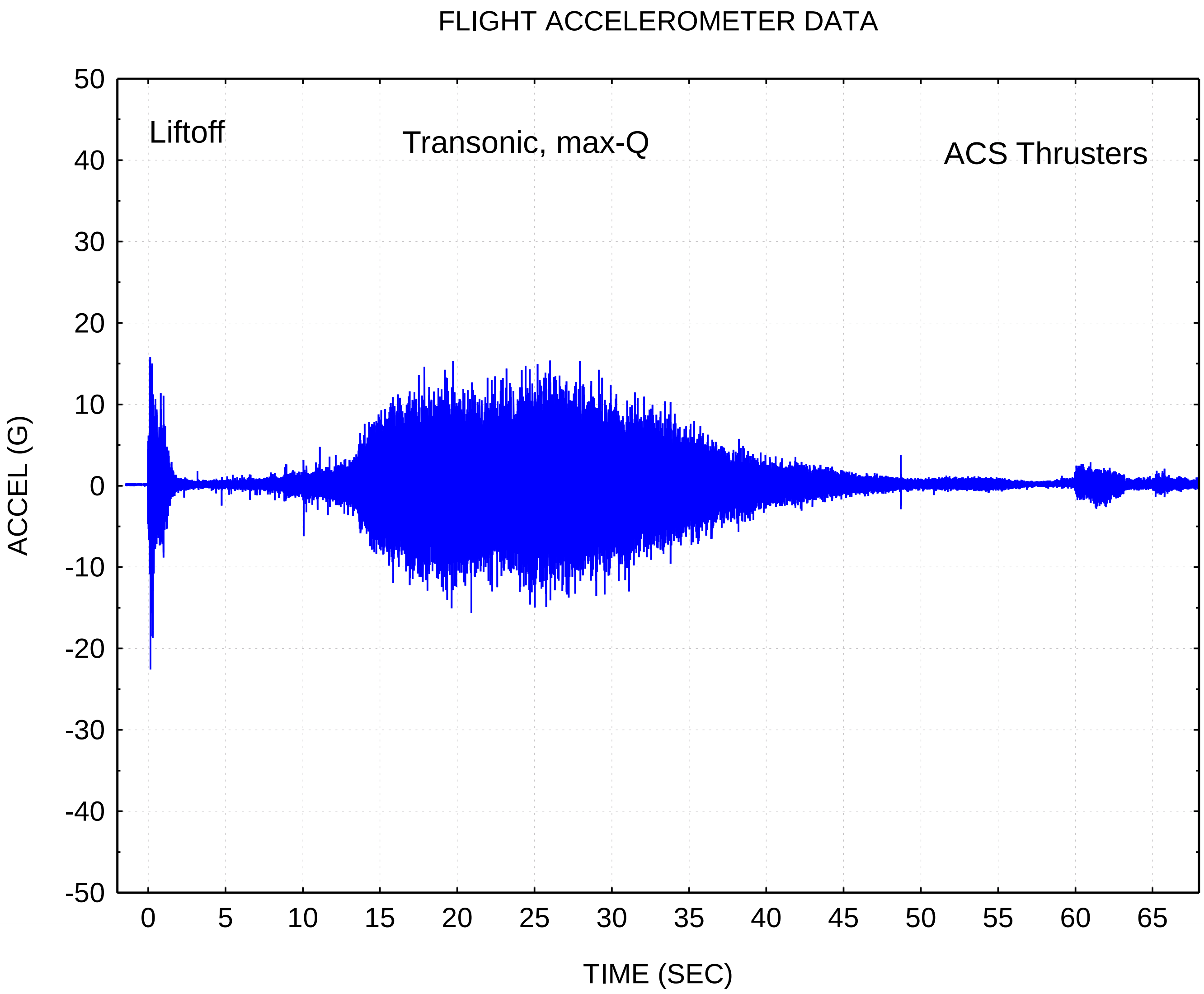
$$X_{peak} = \frac{1}{\omega^2}\ddot{X}_{peak}$$

$$X_{peak} = \frac{1}{[2\pi(11\text{ Hz})]^2}\,[5\text{ G}]\left[\frac{386\text{ in/sec}^2}{\text{G}}\right]$$

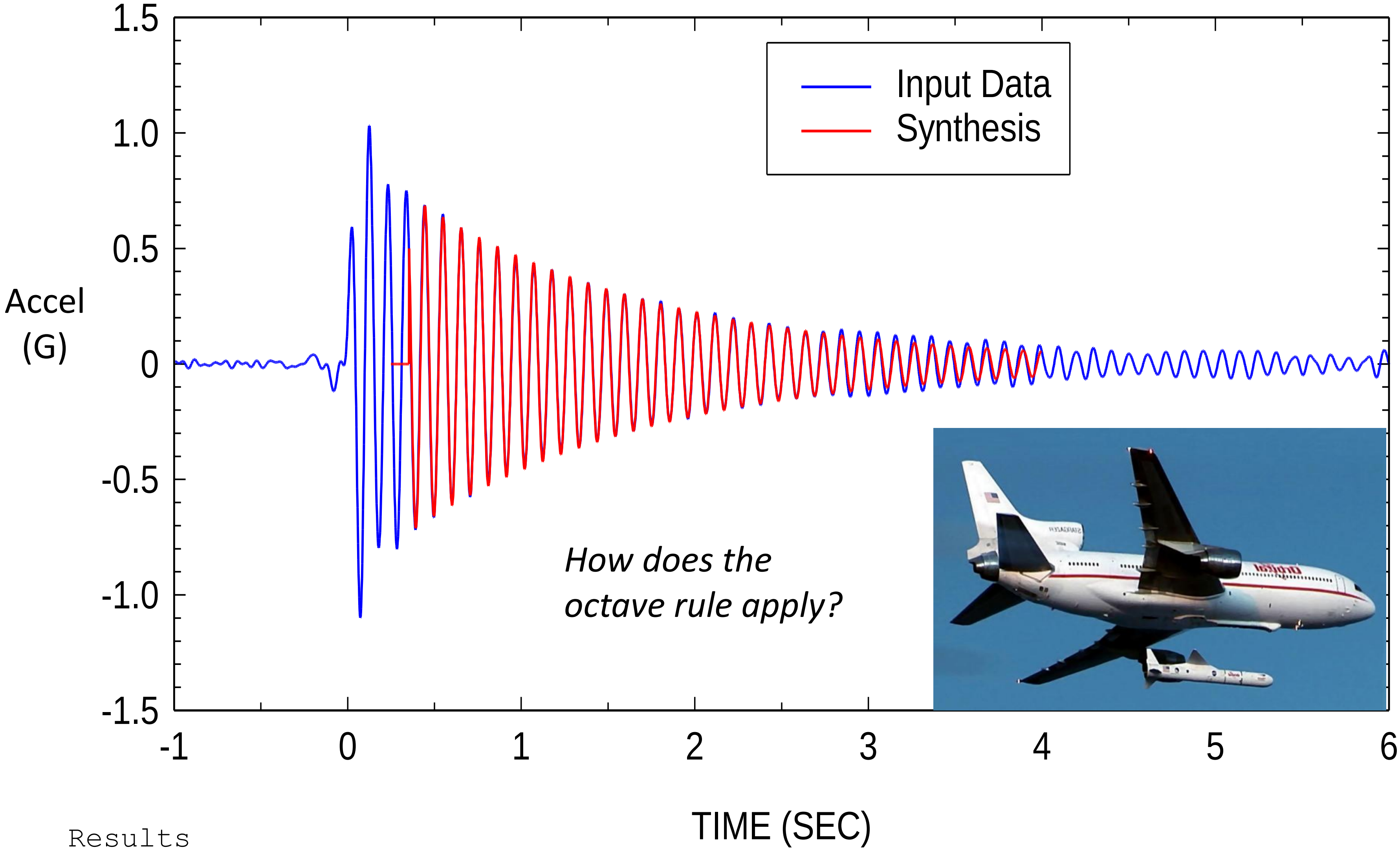
$$X_{peak} = 0.404 \text{ inch zero-to-peak}$$

$$X_{peak} = 0.81 \text{ inch peak-to-peak}$$

Suborbital Launch Vehicle Flight Accelerometer Data



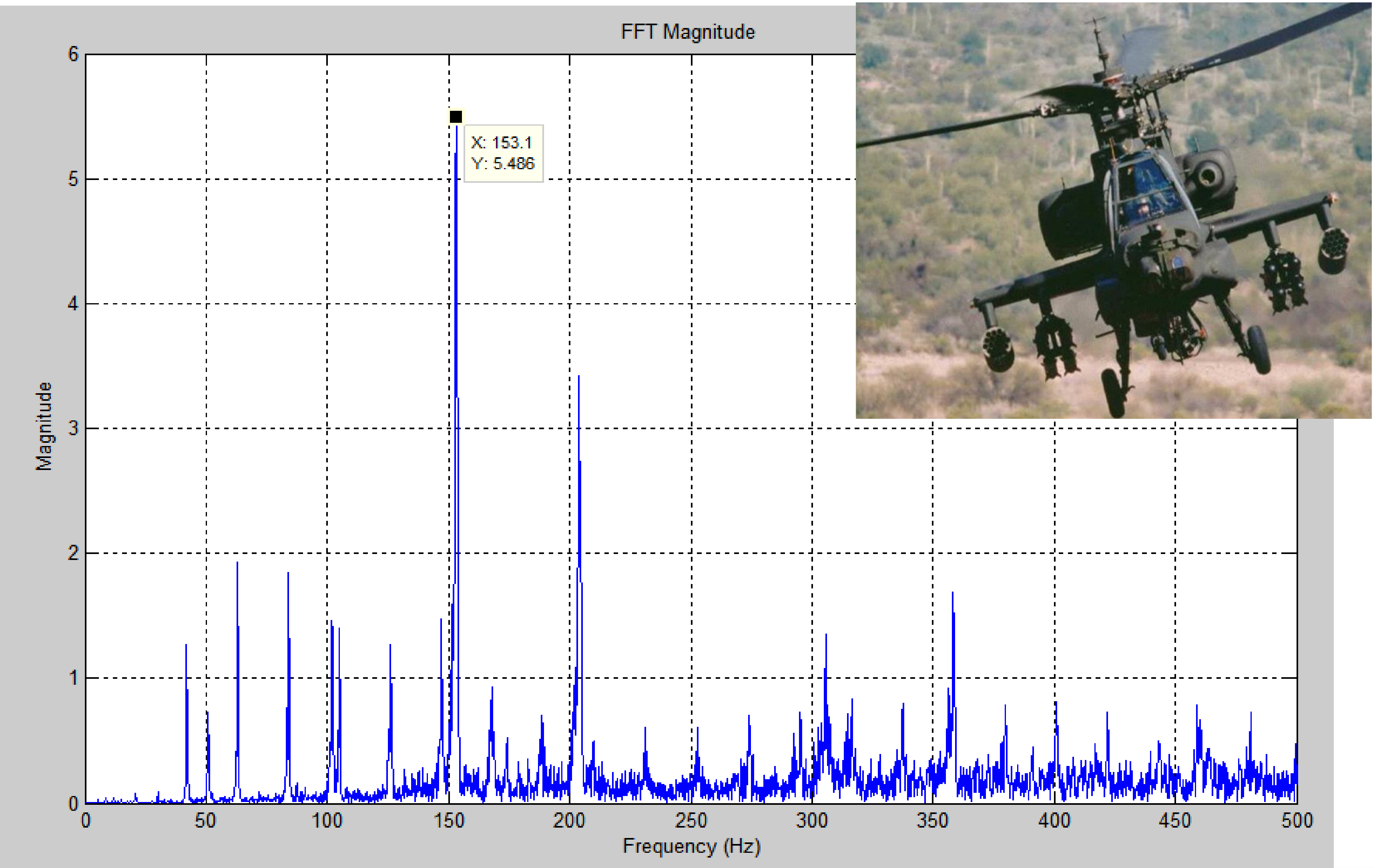
Pegasus Drop Transient – Damped Sinusoid



Results

Case	Amplitude	fn(Hz)	damp	Phase(rad)	Delay(sec)
1	0.7306	9.5715	0.0118	3.8999	0.1055

FFT Sound Pressure from an Apache Helicopter Fly-over

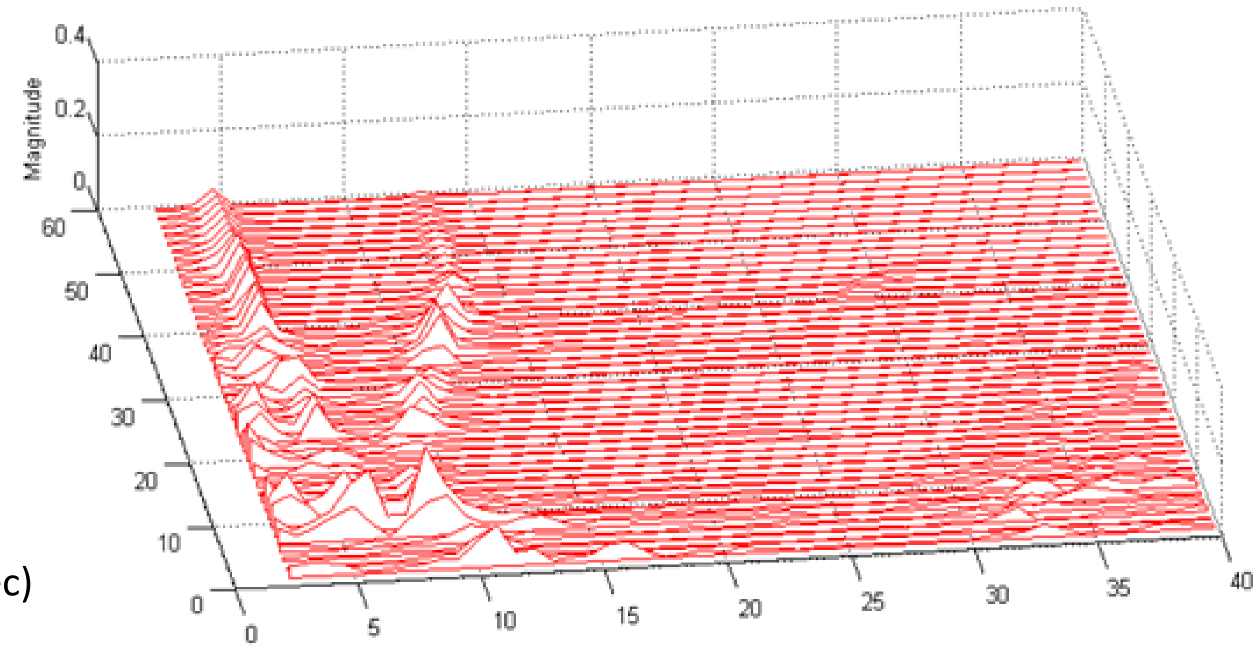


Main rotor hub frequency = 5.25 Hz & BPF = 21 Hz (Doppler shifted)

Sounding Rocket Flight Accelerometer Data

Terrier-Black Brant

Waterfall FFT Ch 1 X-axis 36.258 Mission



Waterfall FFT 3D Plot - Time, Frequency, Magnitude

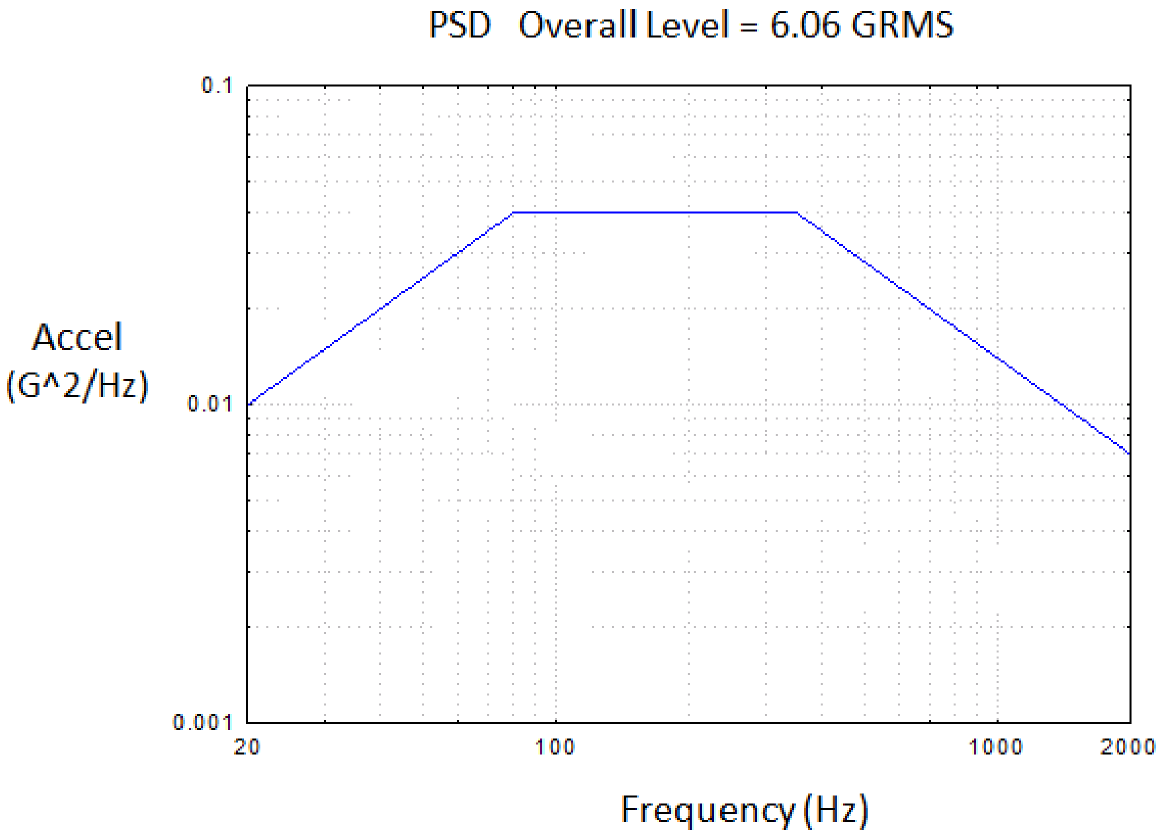
Fundamental body-bending frequency 10 to 13 Hz.

Rigid-body rotation frequency at 4 Hz.

Power Spectral Density

NAVMAT P9492 level

Learn how to calculate the overall GRMS level

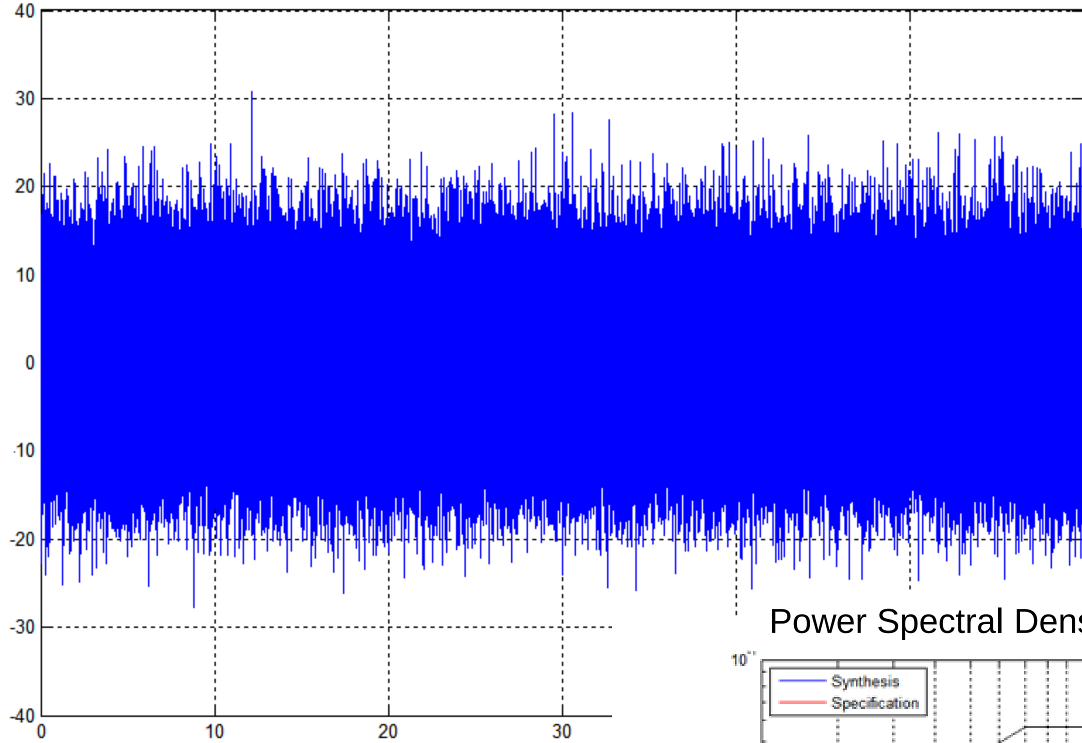


Frequency (Hz)	Accel (G^2/Hz)
20	0.01
80	0.04
350	0.04
2000	0.007

G^2/Hz is really GRMS^2/Hz

Synthesized Base Input

Accel (G)



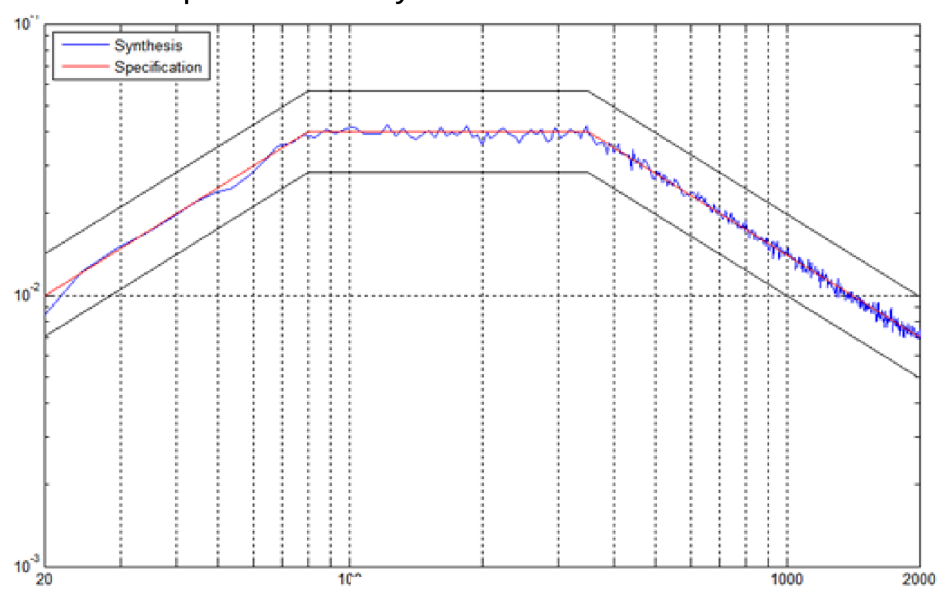
Time (sec)

Synthesize time history to satisfy NAVMAT P9492 level

Also take histogram to verify normal distribution (histogram plot omitted for brevity)

Power Spectral Density Overall Level = 6.06 GRMS

Accel (G^2/Hz)

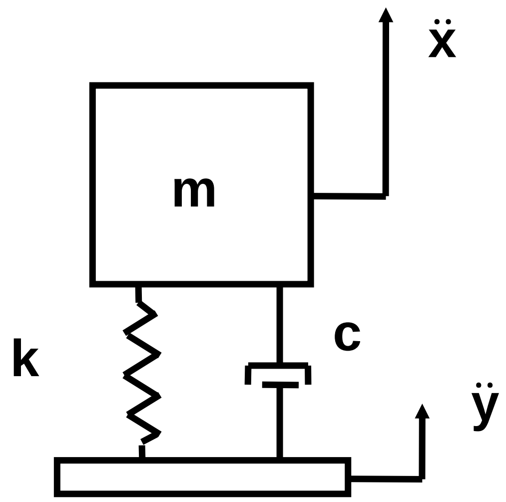


Frequency (Hz)

Useful for

- Understanding how a vibration control computer generates a signal for a PSD
- Performing modal transient and rainflow cycle fatigue analysis

SDOF System Response to Base Input



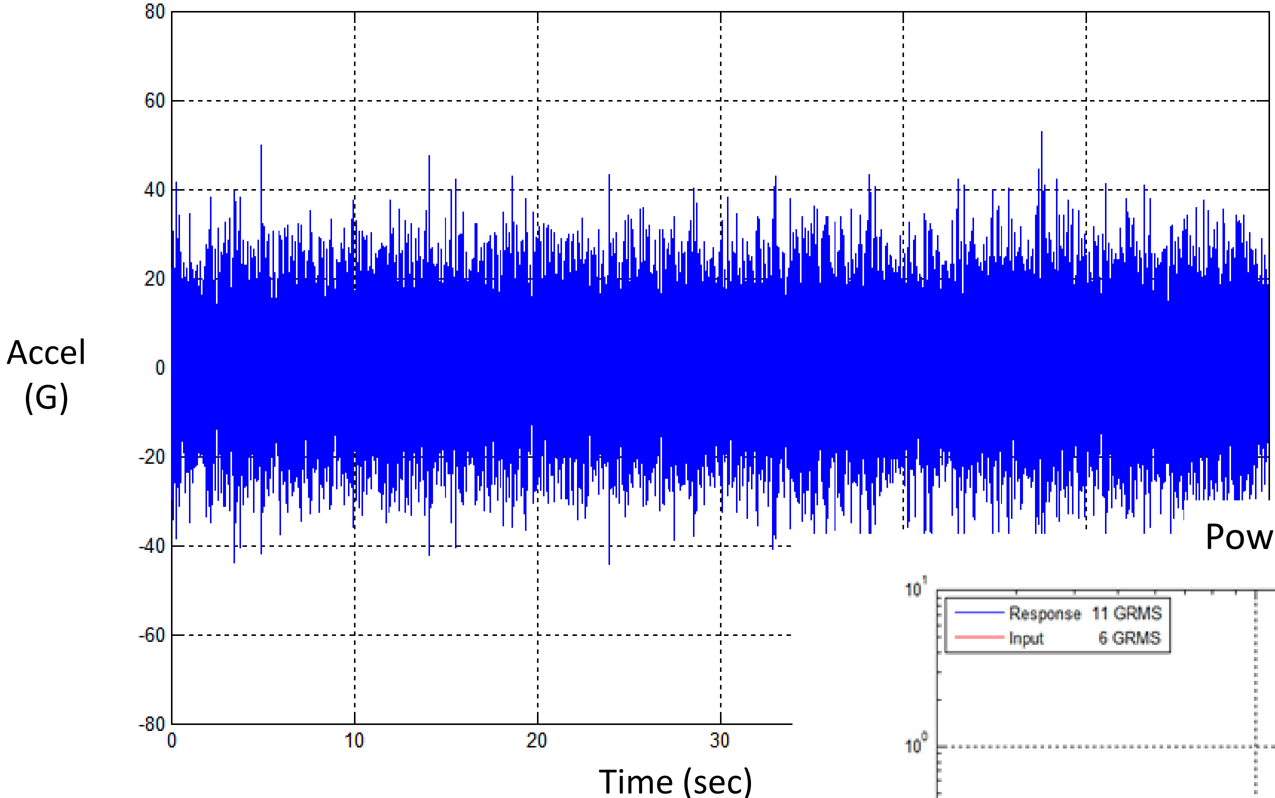
m	mass
c	damping coefficient
k	stiffness
$\ddot{x}$	acceleration of mass
$\ddot{y}$	base acceleration

Useful for

- Apply synthesized time history as base input to SDOF system
- Calculate modal transient response using a *Digital Recursive Filtering Relationship*
- Same numerical engine as used in the SRS calculation

SDOF System Response to NAVMAT Time History

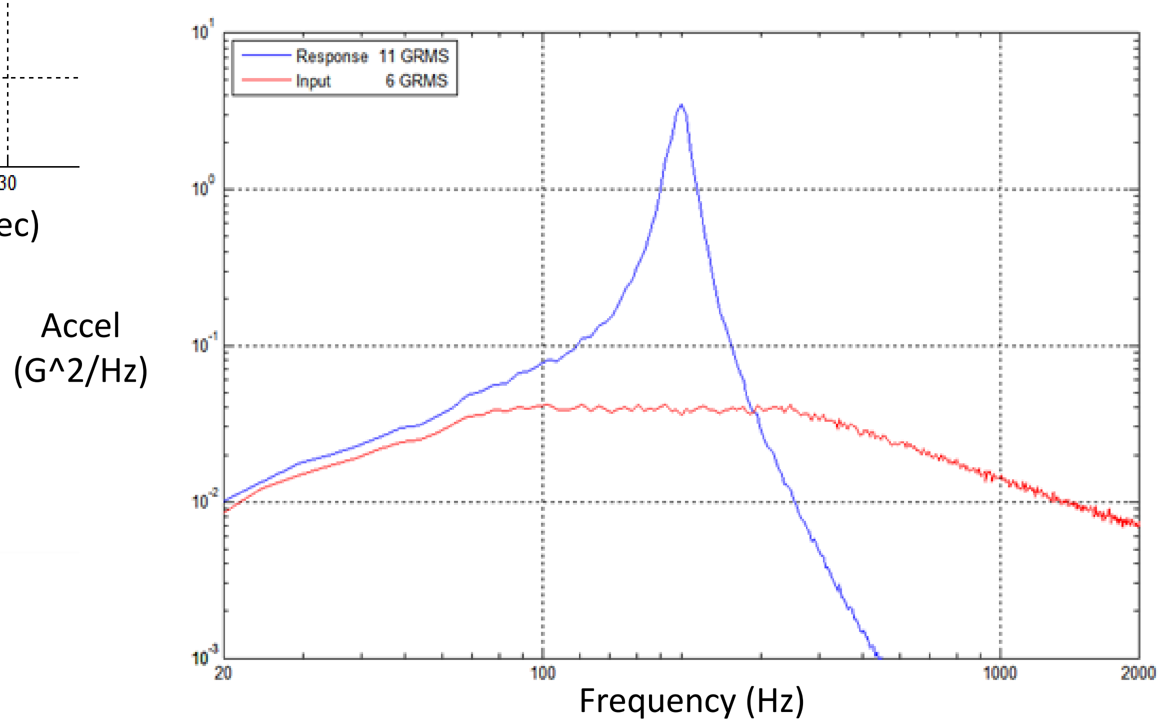
SDOF Acceleration Response, fn=200 Hz, Q=10, 11 GRMS



Response is narrowband random.

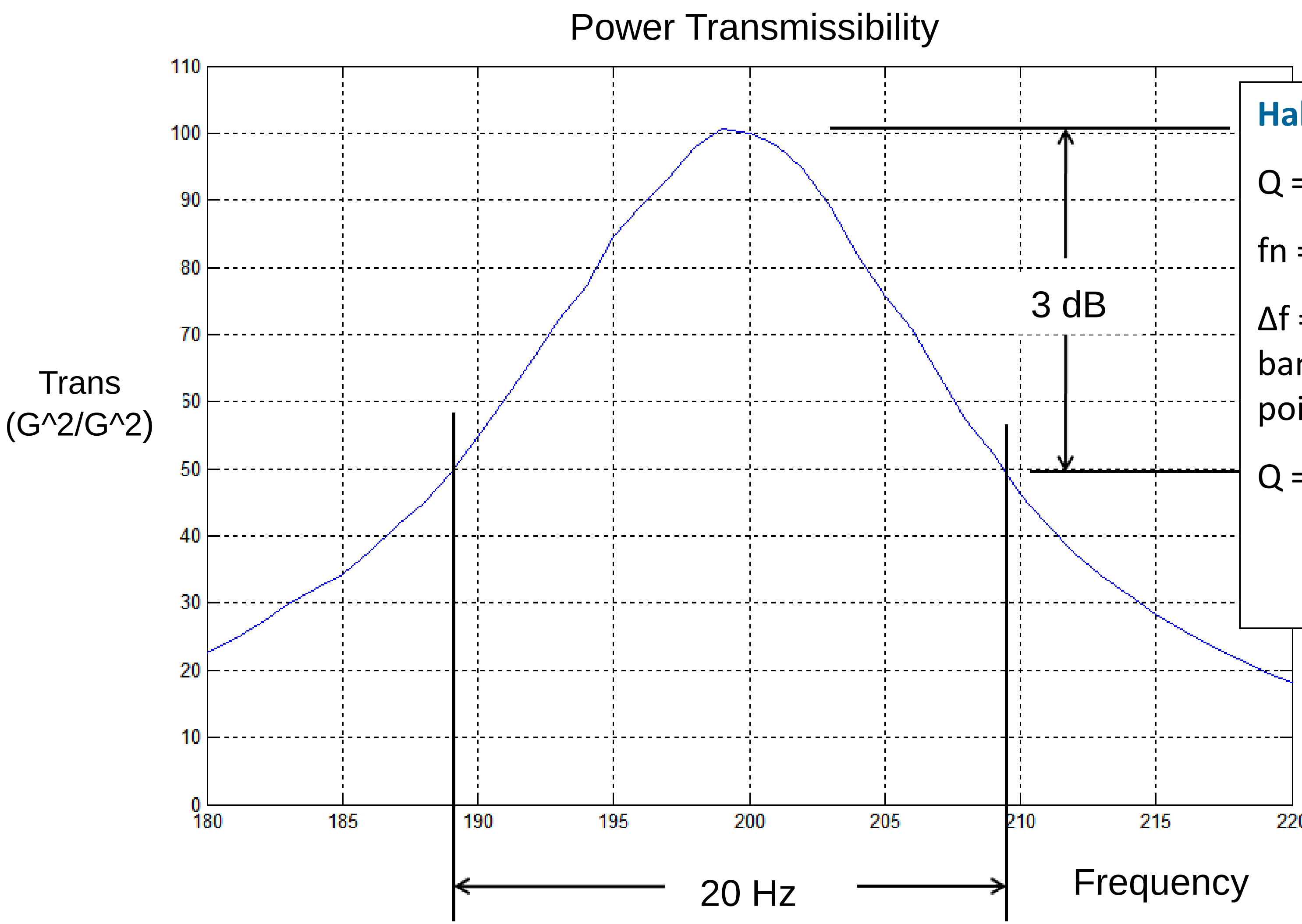
Take histogram to verify normal distribution (histogram plot omitted for brevity)

Power Spectral Density



Take PSD of input and response.

Show that overall response GRMS can also be calculated via Miles equation.



Half-power Bandwidth

$Q = f_n / \Delta f$

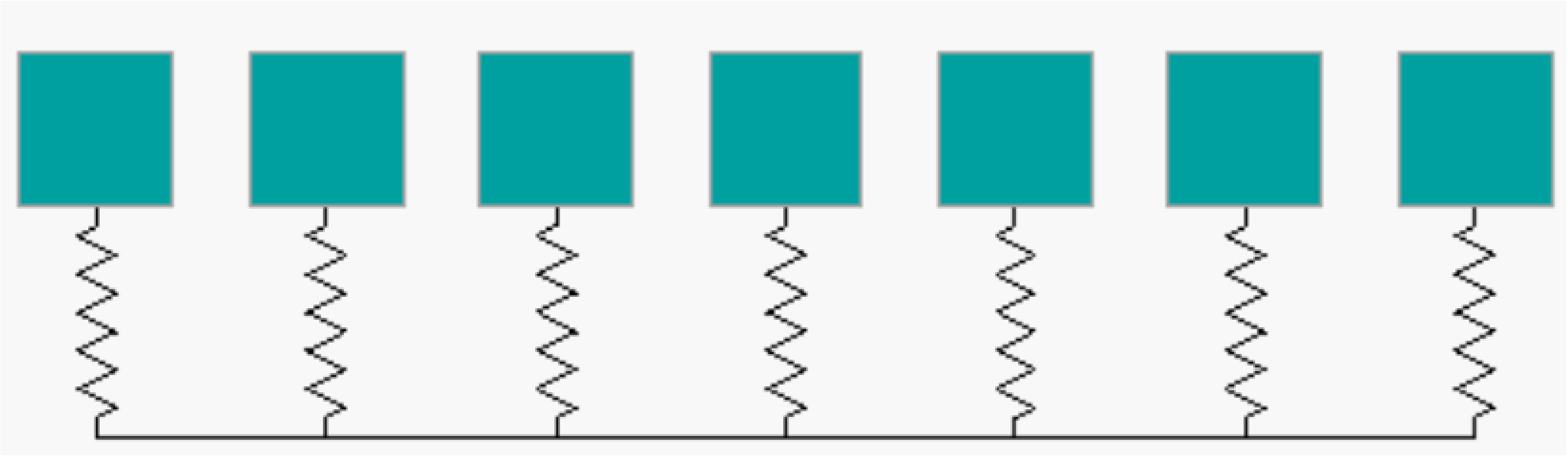
fn = natural frequency

Δf = frequency bandwidth for -3 dB points

Q = 200 Hz / 20 Hz

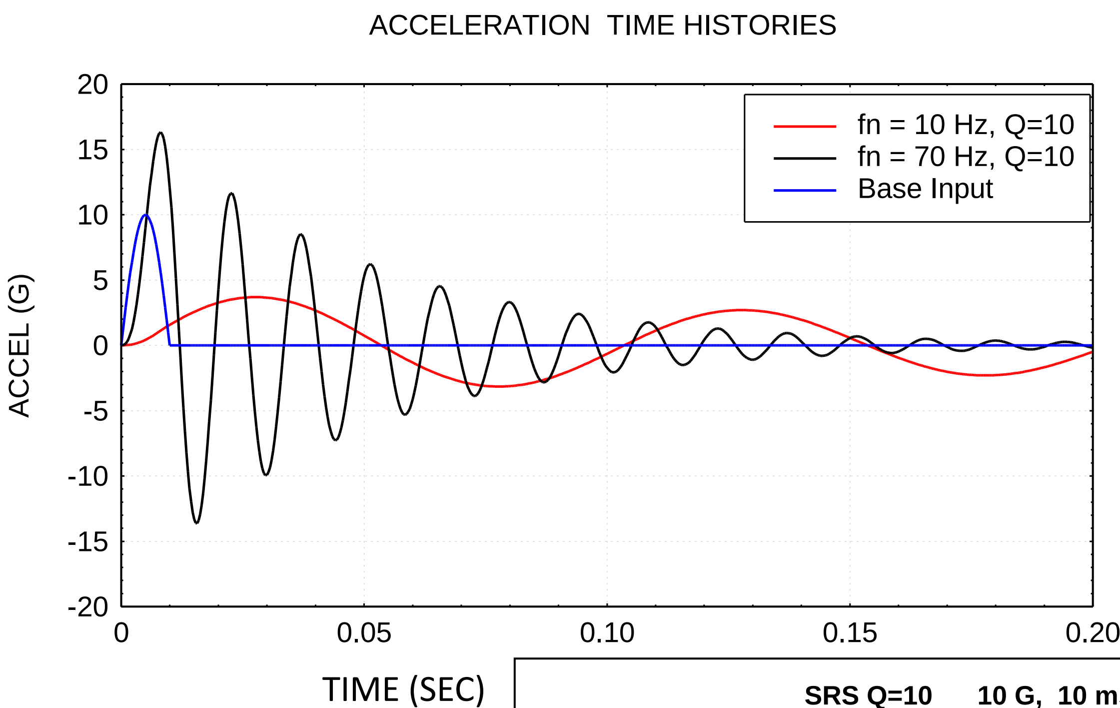
= 10

Shock Response Spectrum



$fn_1 \quad < fn_2 \quad < fn_3 \quad < \quad \ldots \quad < fn_L$

Subject a system of independent SDOF systems to a common base input

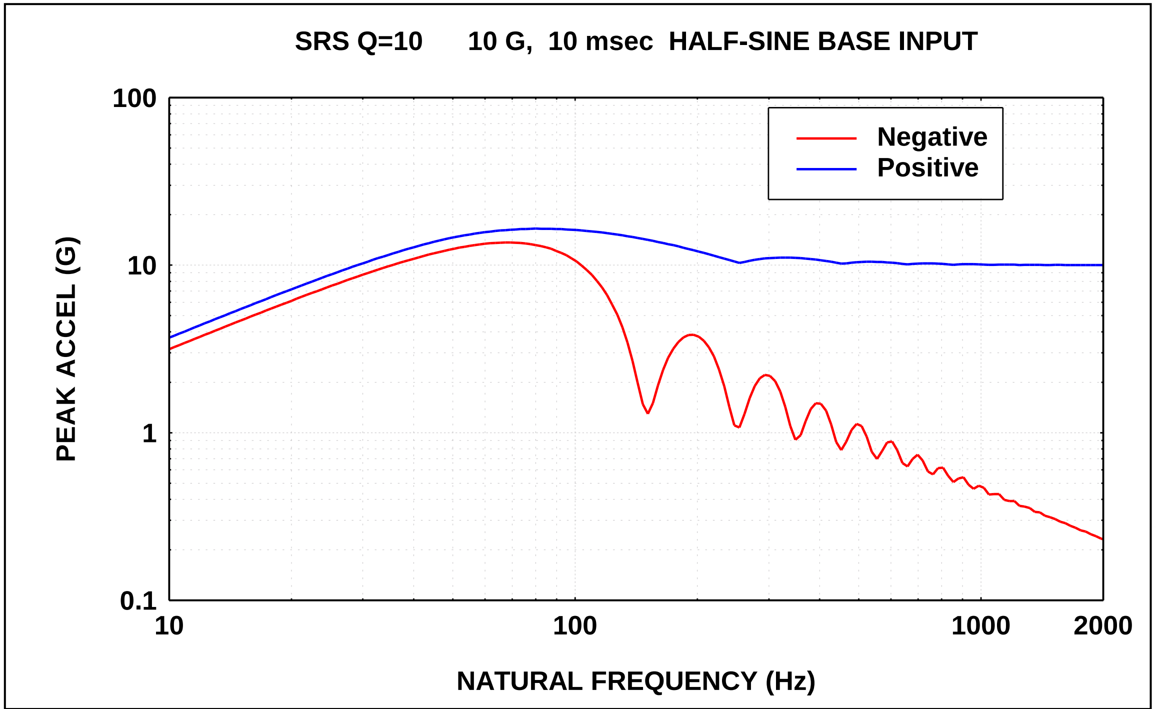


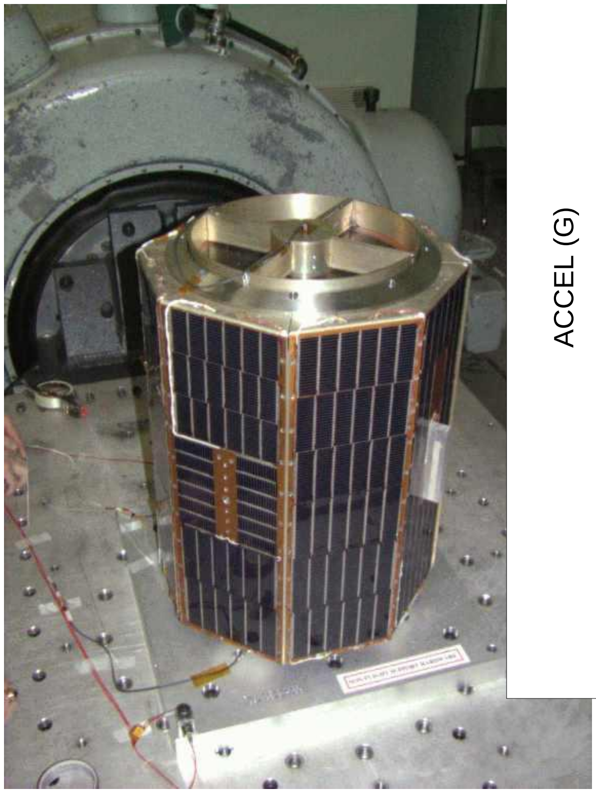
Shock Response Spectrum

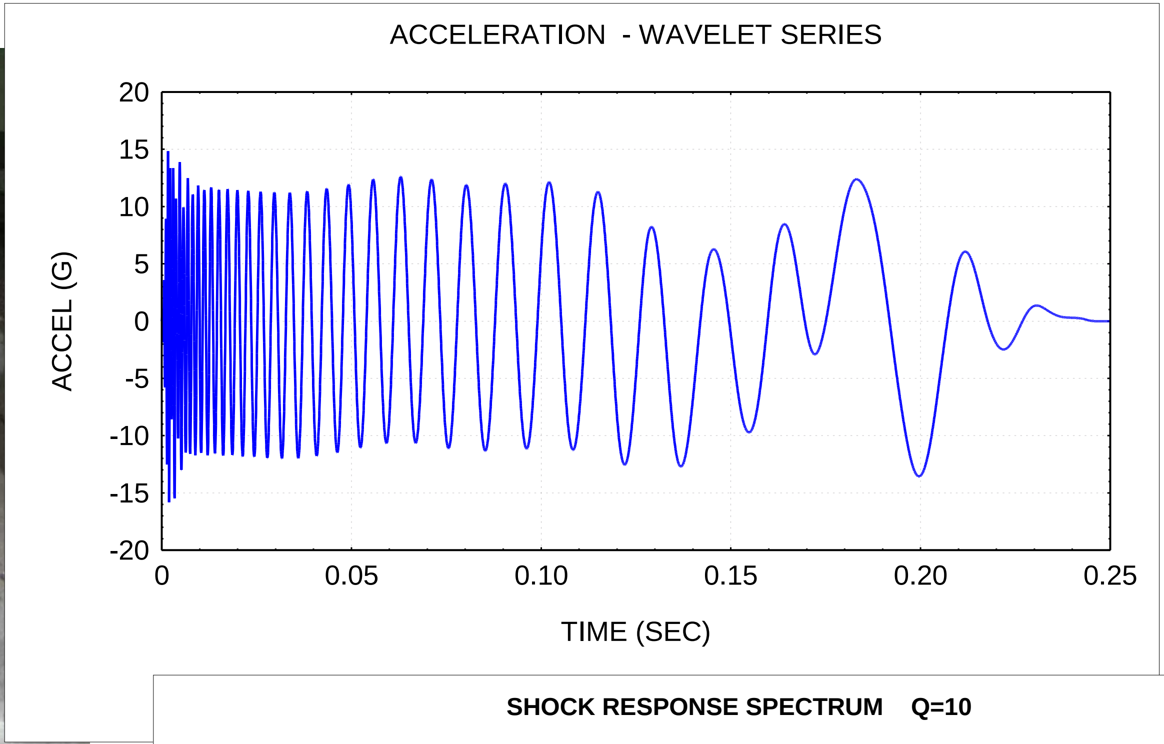
Calculate family of response curves with natural frequency as an independent variable.

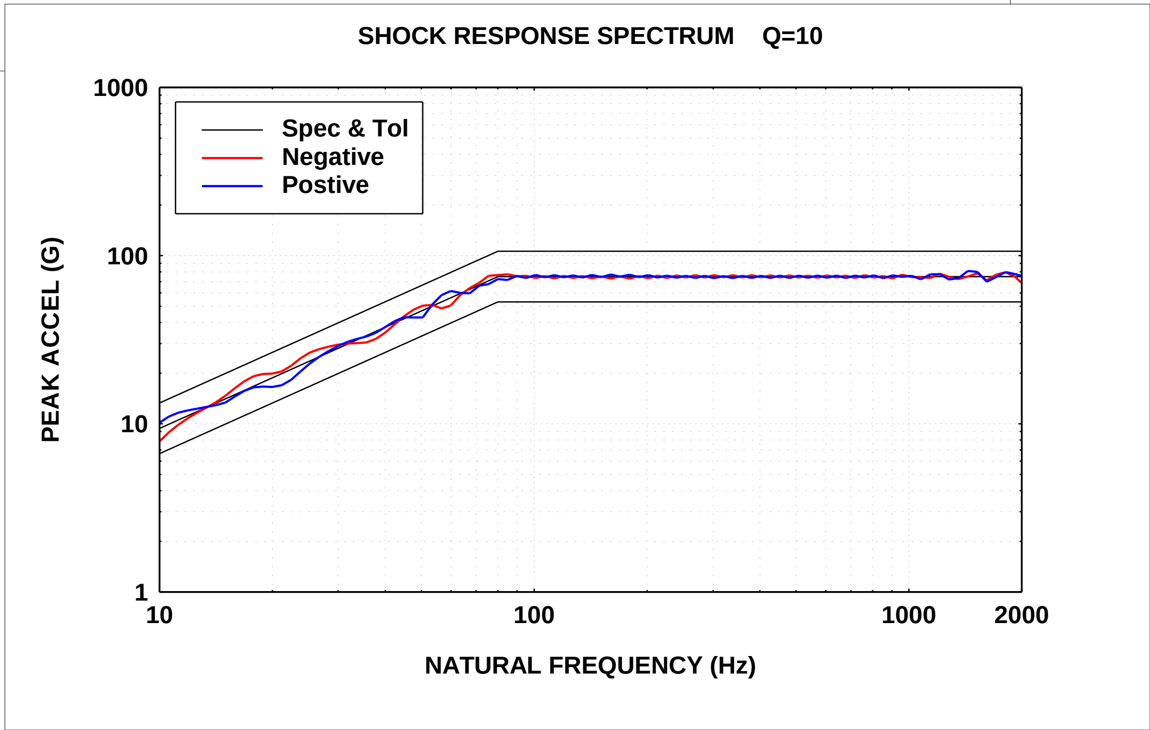
Pick off maximum and minimum peaks for each response curve.

Make table. Plot SRS.









Shaker Shock using Wavelets

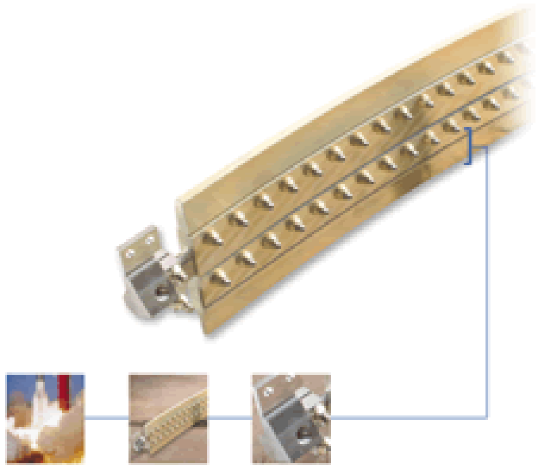
Optimized to Minimize Displacement, Velocity & Acceleration

Damped Sine Synthesis to Satisfy an SRS

Frangible Joint, 26.25 grain/ft

SRS Q=10   For Reference Only

fn (Hz)	Peak (G)
100	100
4200	16,000
10,000	16,000

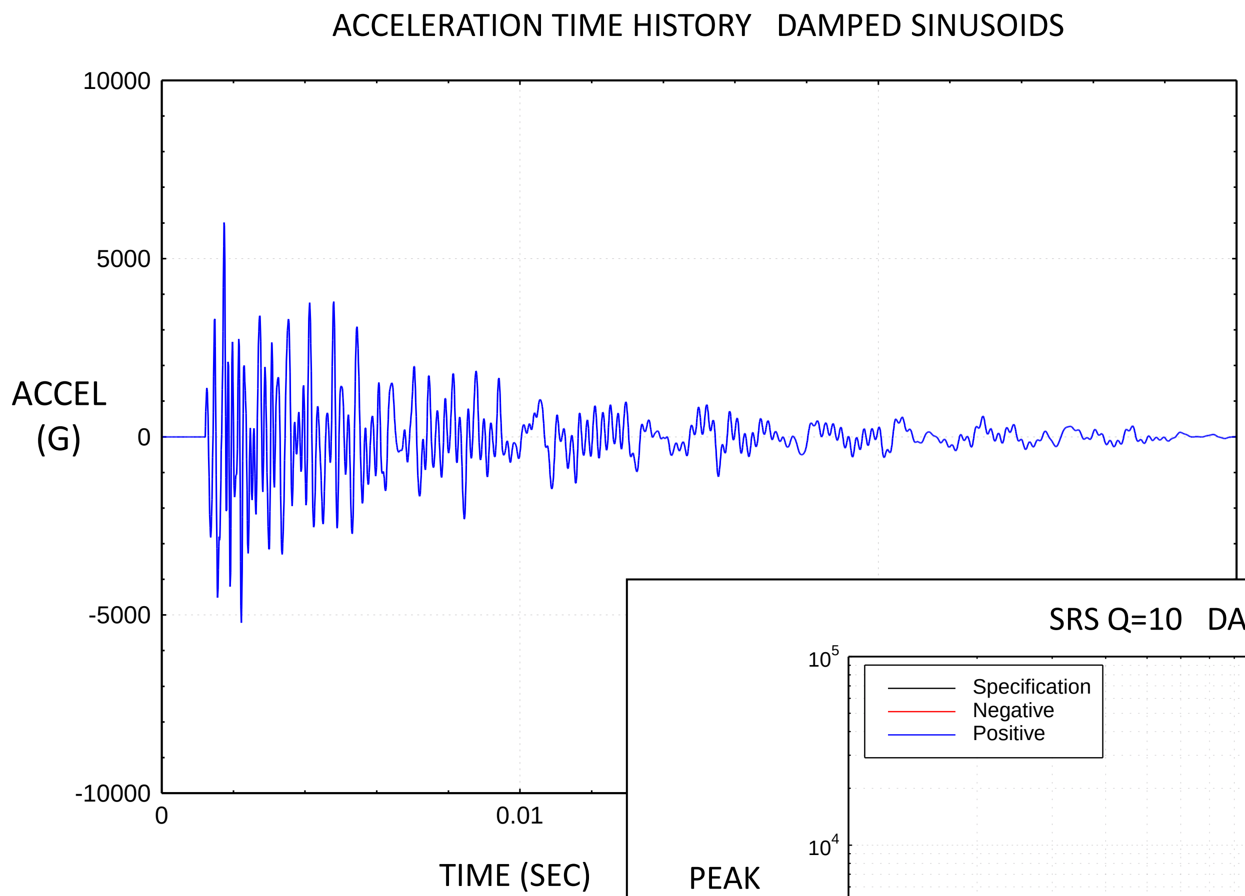


Note that the specification is log-log format.

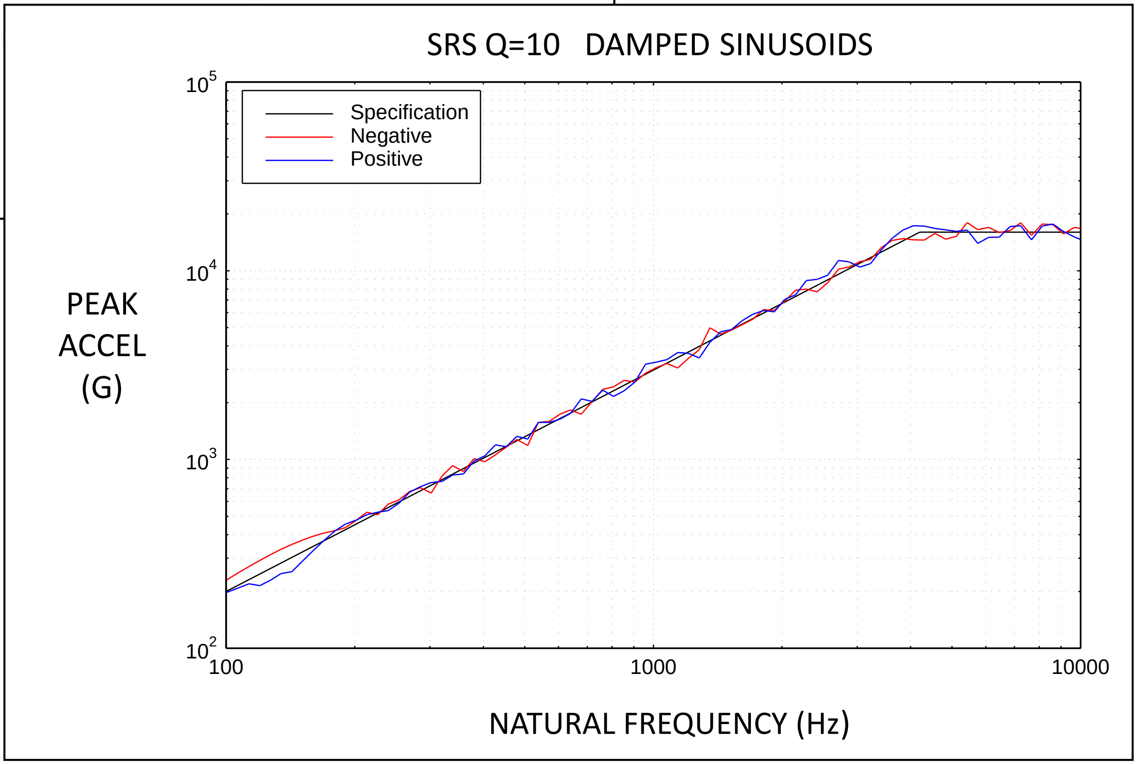
Modal transient analysis to determine response of component.

Need to synthesize a time history to satisfy the SRS.

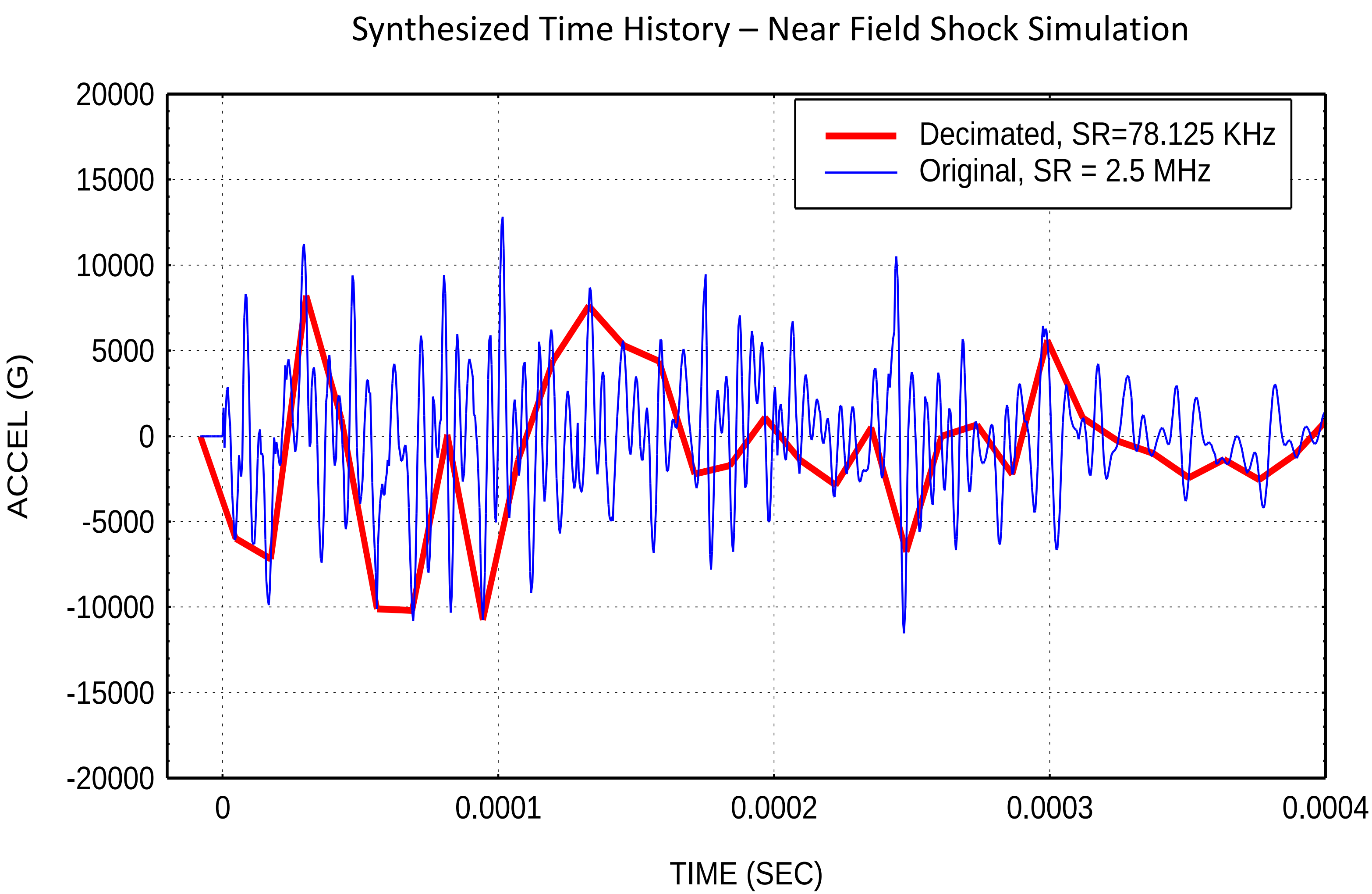
But the time history will not be unique.



Pyrotechnic Shock Simulation for Modal Transient Analysis

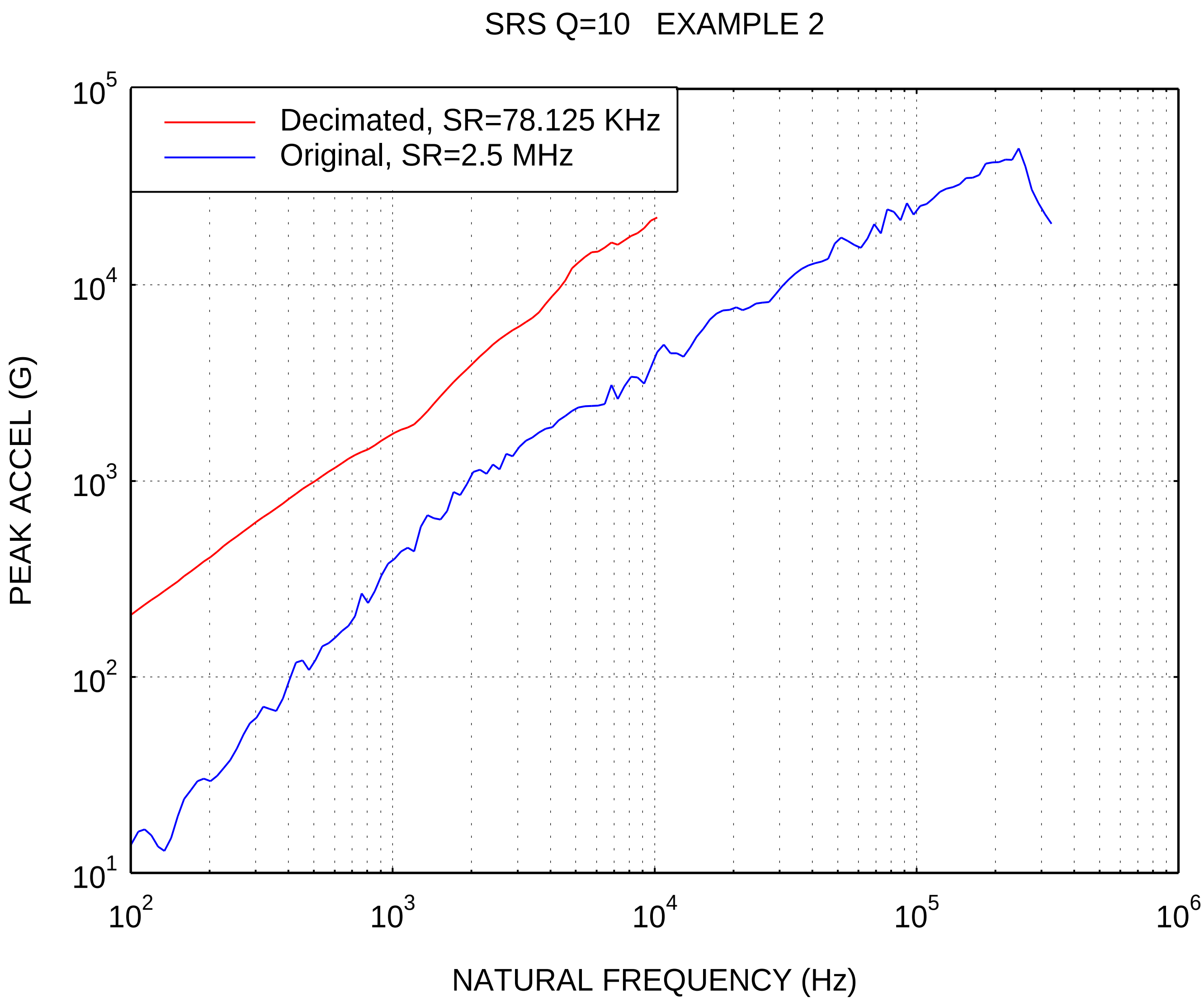


Aliasing Errors in Signal Analysis - Numerical Experiment



Aliasing occurs in the Decimated time history.

Aliasing Errors in Signal Analysis



The Decimated SRS is approximately 10 to 20 dB higher than the Original SRS. The source of the error is aliasing.

Conclusions

- NESC engineers are available to help with design reviews, test support, research projects, flight accelerometer data reduction, etc.
- NESC is independently funded
- NESC offers shock & vibration training units, which include software programs

How may we serve you?

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