Artemis I Liftoff Measurements Issues and Corrections

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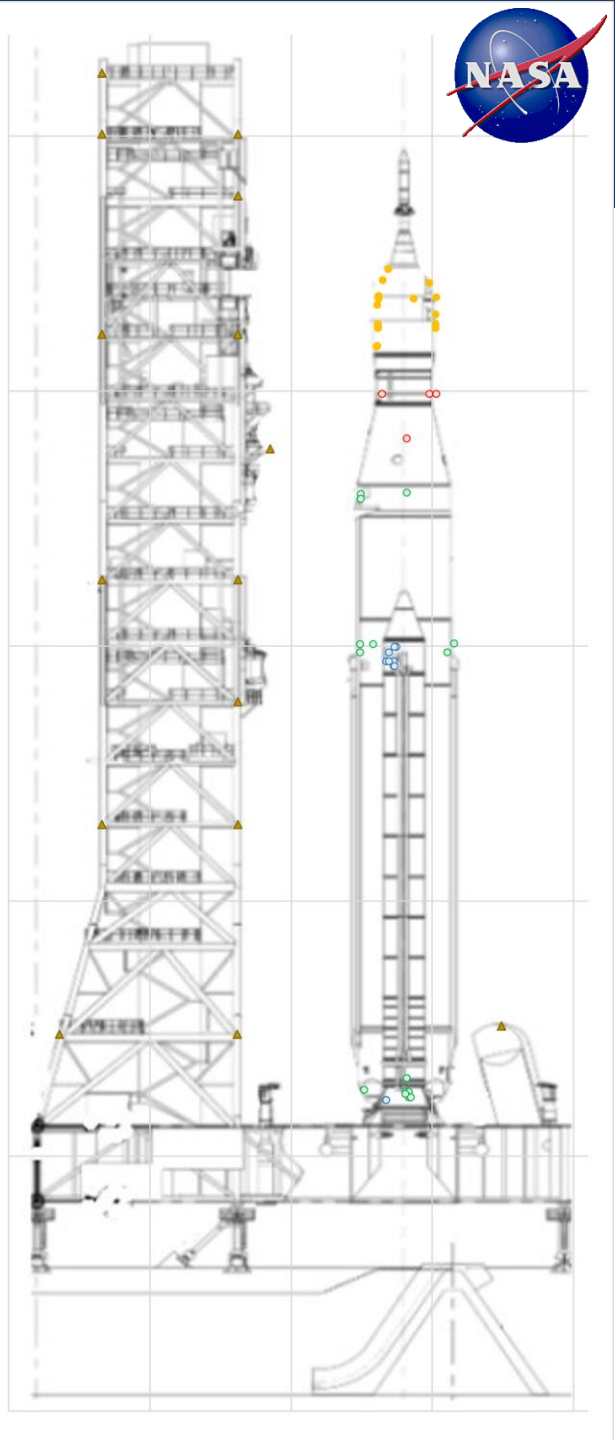
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Introduction

- The first Space Launch System, SLS, rocket was launched on November 16, 2022 (Artemis I mission)
- Measurements were made of liftoff environments
  - 45 vehicle measurements were deemed ‘good’ for assessment of liftoff environments
  - Of these, most Booster and Core Stage measurements required corrections to data
  - Some Multi-Purpose Crew Vehicle data also required correction
- This presentation describes the data issues, correction methods, and correction results



Background

- In preparation for Artemis I flight, characteristics of combined data collection hardware were analyzed to determine sense port effect, and time delays
- Methods were devised to correct for sense port resonance and software was developed to account for predetermined time delays, *i.e.*, a timestamp validation algorithm

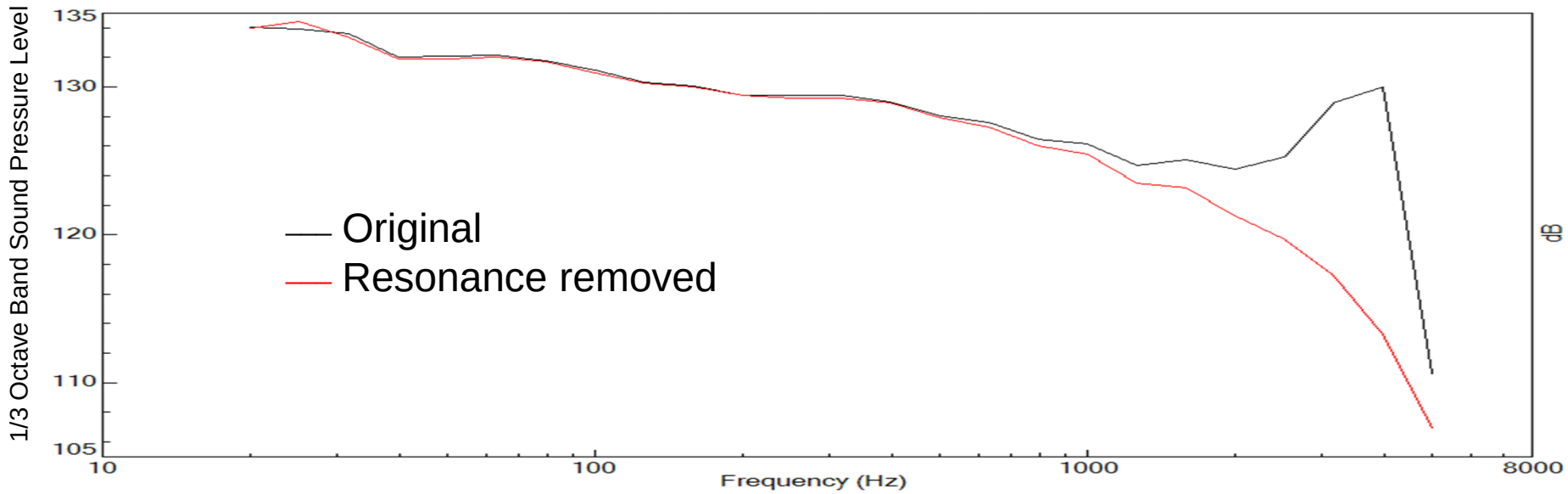
Overview

- Liftoff environments include transient events and time averaged events
- These events occur in the five seconds preceding liftoff and first ten seconds of flight
- Measurement issues occurred during these times requiring corrections to the data

Overview

- The data corrections included port resonance removal, trend removal, time alignment, and data gap and spike zeroing
  - Port resonance removal is required to prevent erroneously high amplitude data
  - Trend removal eliminates a time changing bias in the data
  - Time correction synchronizes measurements to the correct flight time
  - Zeroing data gaps removes erroneous high-amplitude low-frequency spectral content introduced by interpolation across the gap
  - Zeroing data spikes removes a high-amplitude transient that introduces a significant distortion to spectral content

Sense Port Resonance Removal

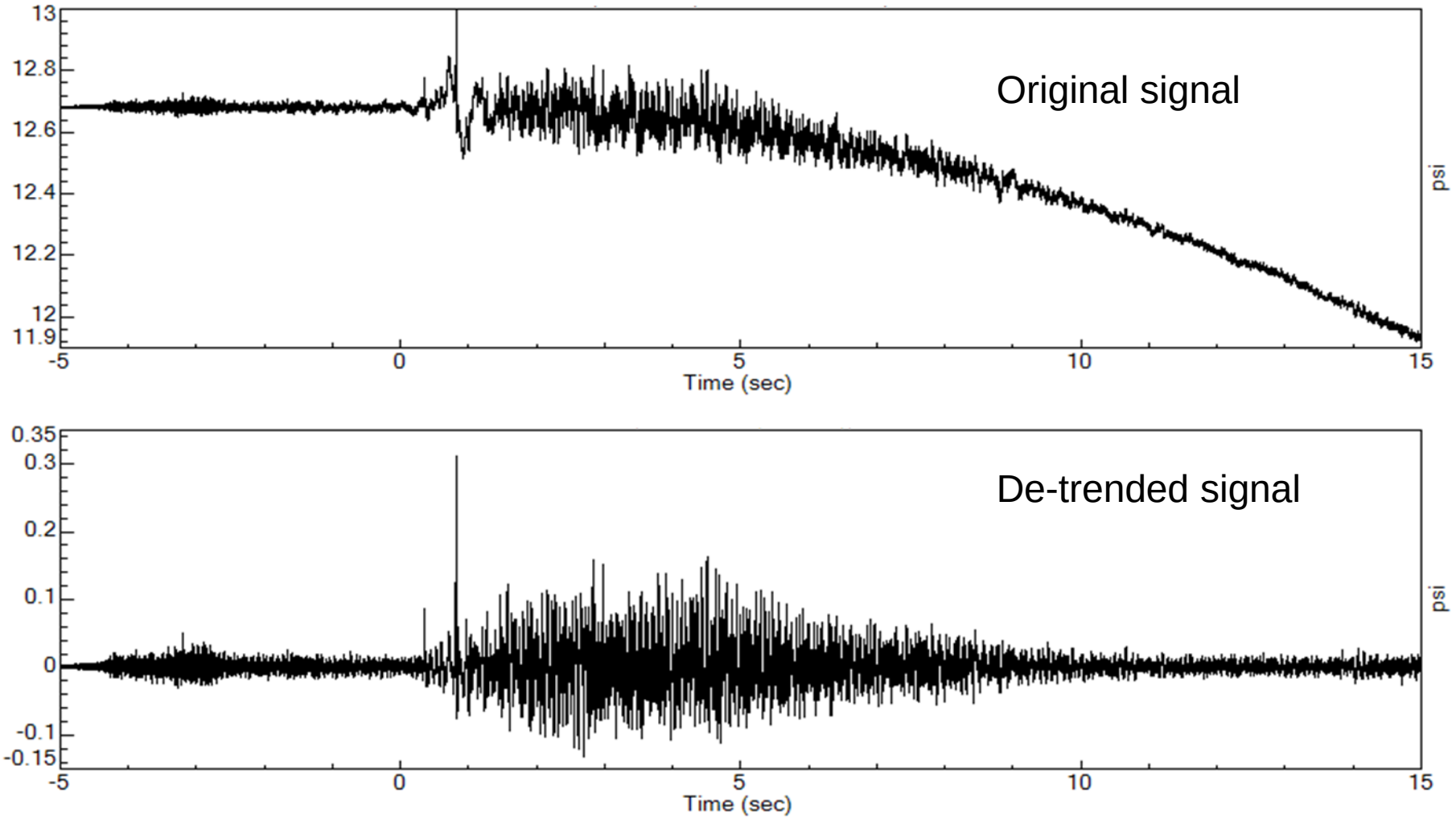


- Some transducers were recessed in small cavities
- The cavity acoustic resonance erroneously amplified data
- A single-degree-of-freedom model was used to remove the resonance effect

Trend Removal

- Some measurements showed a bias and slow drift in the mean pressure
- This drift has been attributed to gradual changes in temperature or changes in mean pressure during flight
- For the acoustic environment, which is from 20 to 5000 Hz, the bias, slow trend and very low frequencies can be removed from the data without affecting the 20 to 5000 Hz content of the signal

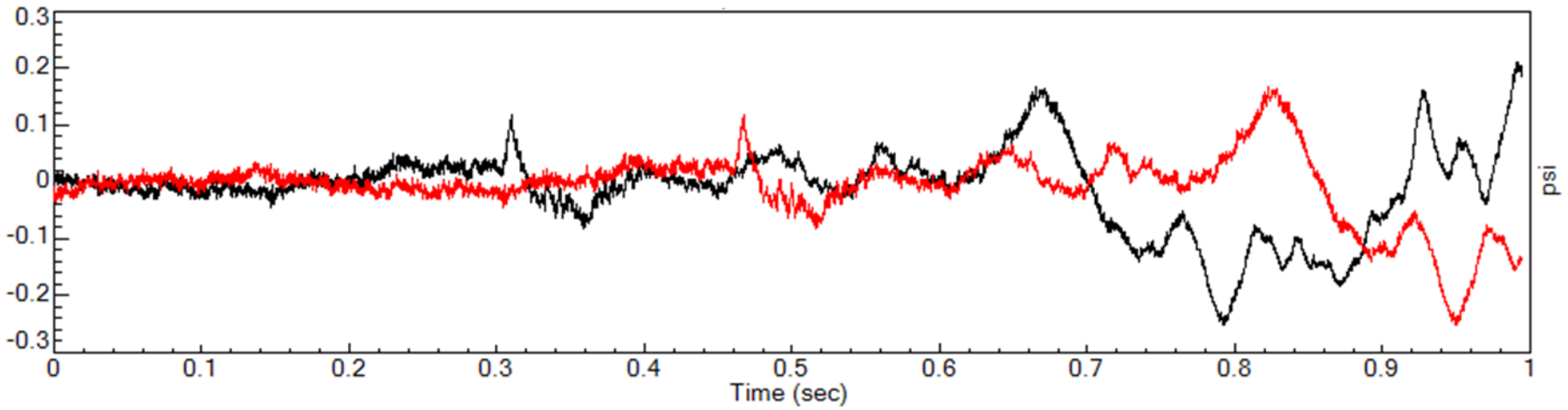
Trend Removal



‘Reconstruction Algorithm’ Time Delay

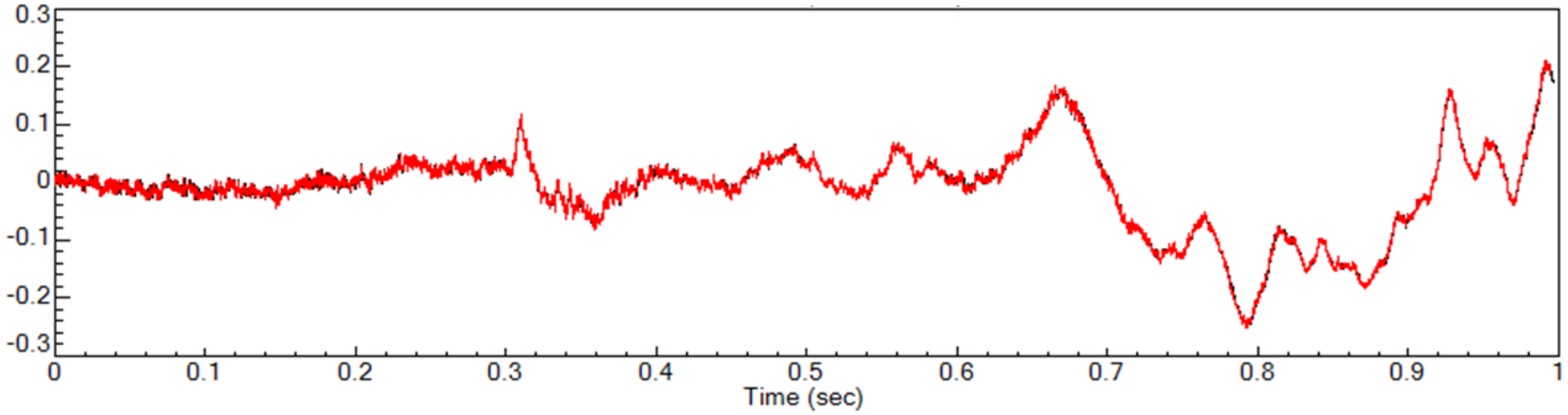
- Except for on the MPCV and tower, measurements were sampled, packeted, and telemetered to ground receiving stations during Artemis I launch
- Data from receiving stations was then reconstituted into its original form using two different software algorithms
- The first algorithm assigned time sequentially to each data point referencing the beginning packet time which is included in the data stream
- A second algorithm provides each data point with time that has timestamp validation based on known clock drift and biases from flight telemetry
- This second algorithm provides time values that are more accurate than the sequential algorithm … with exceptions to be illustrated in the following slides
- Un-anticipated problems with both reconstruction processes led to time alignment issues and/or data gaps

Time Delay Between Algorithms



- Examination of all the data showed that there was an erroneous time delay for data from the sequential algorithm (red) to the validation algorithm (black)
- A similar delay occurred on most measurements

Time Shift Correction



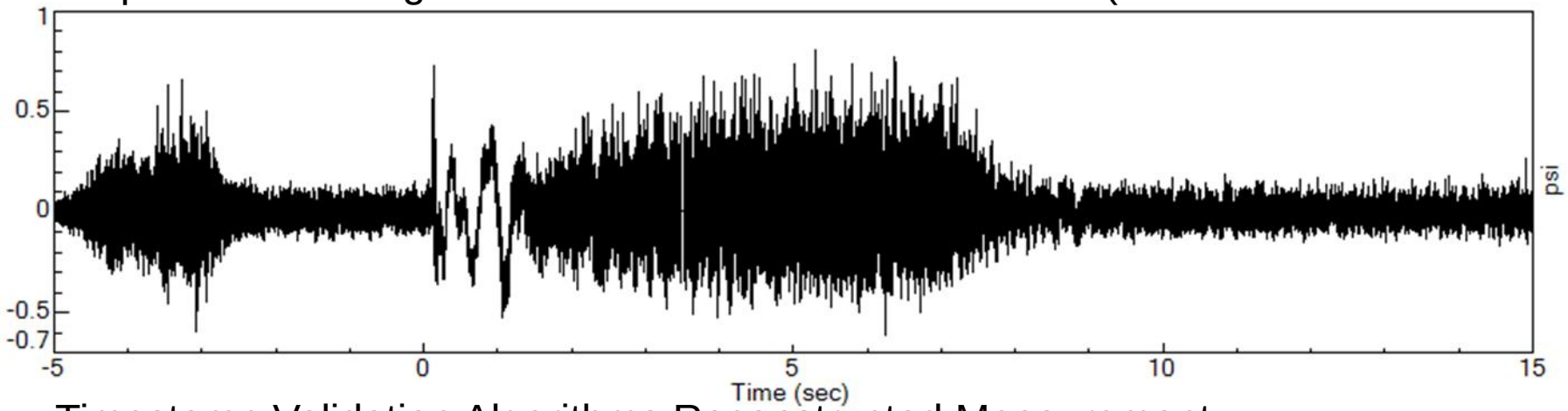
- By shifting the measurement start time, the sequential algorithm data was aligned to the data that was reconstructed with the time validation algorithm
- This results in a close reconstruction from both sets of data (red overlays black)

Data Gaps

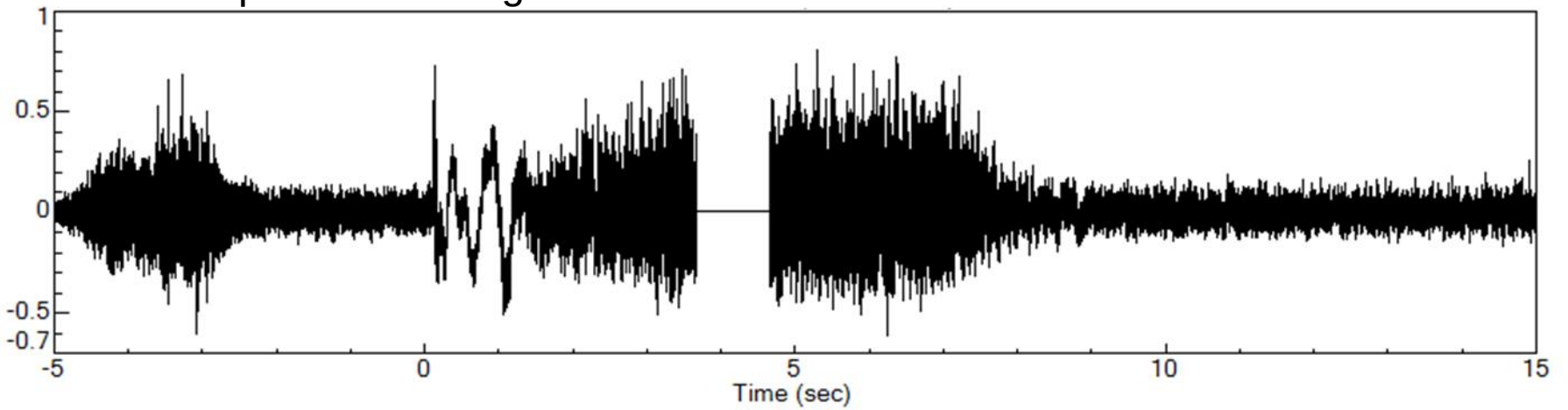
- The next problem, after the time alignment is mitigated, is that there were significant gaps in the data beginning a few of seconds after liftoff
- The timestamp validation algorithm, while able to adjust for small data gaps, creates a period of erroneous data when it encounters large data gaps
- The sequential reconstruction algorithm shows the data gaps in the sequence that they occur, but no erroneous data

Data Gaps

Sequential Time Algorithm Reconstructed Measurement (after time shift correction)



Timestamp Validation Algorithms Reconstructed Measurement

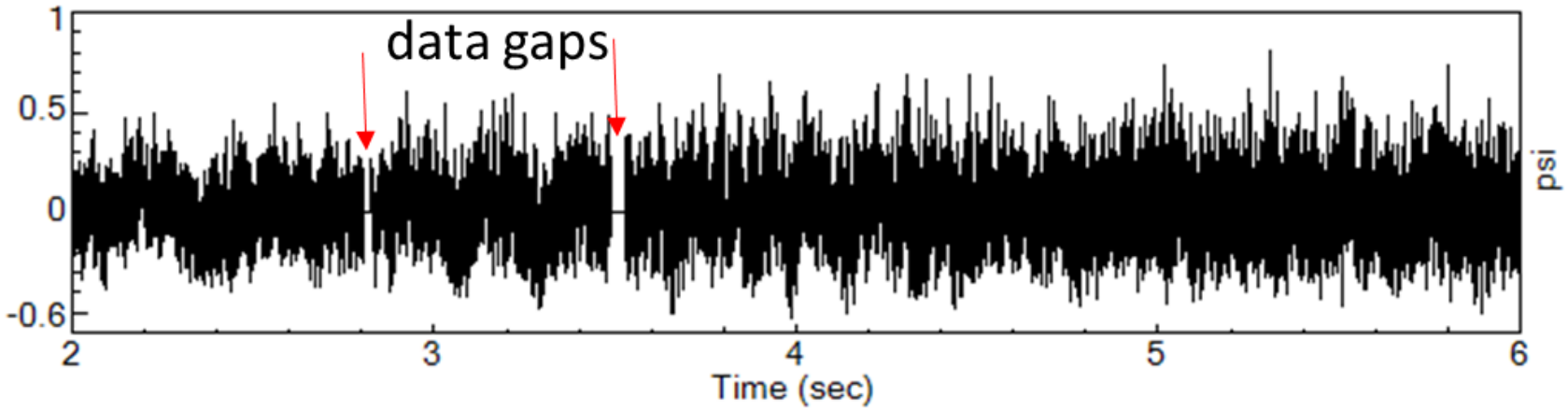


Data Gaps

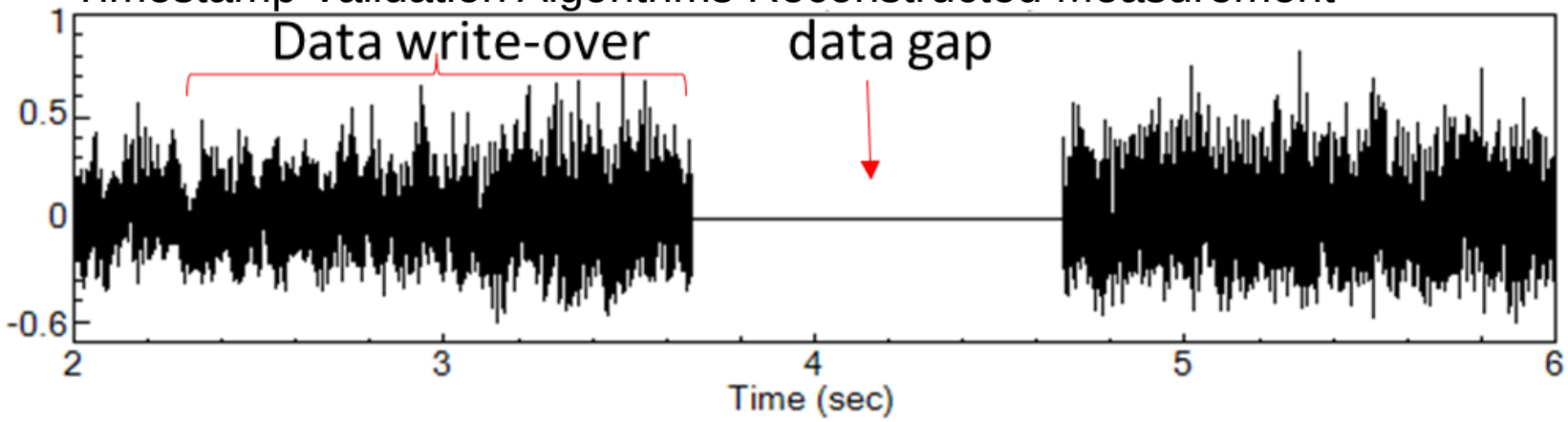
- By careful examination of the data, it was determined that timestamp validation algorithm erroneously incorporates negative time markers which cause a re-write over existing data; and in this example also producing a lengthy data gap
- After a short time of erroneous data, the timestamp algorithm begins to provide accurate data again
- The gaps are set to zero in the figures, but later we will show that the reconstructions use interpolation which creates other problems

Data Gaps and Write-over

Sequential Time Algorithm Reconstructed Measurement (after time shift correction)



Timestamp Validation Algorithms Reconstructed Measurement



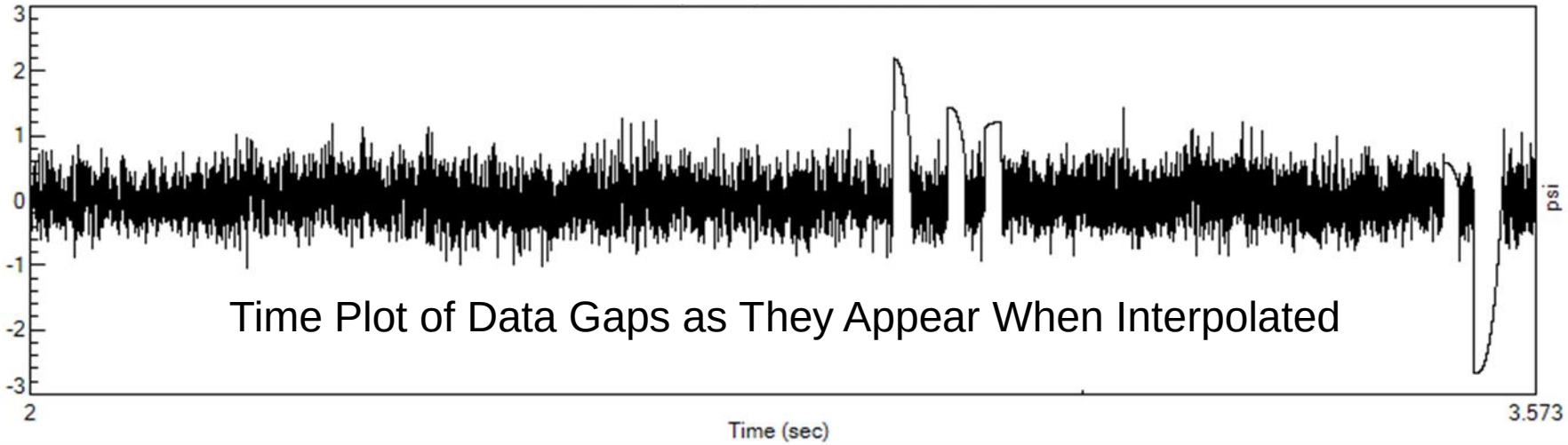
Data Gaps and Write-over

- The data write-over invalidates a crucial portion of the timestamp validation algorithm data
- For this reason, the time-shift corrected data from the sequential algorithm was used for the ten seconds after liftoff

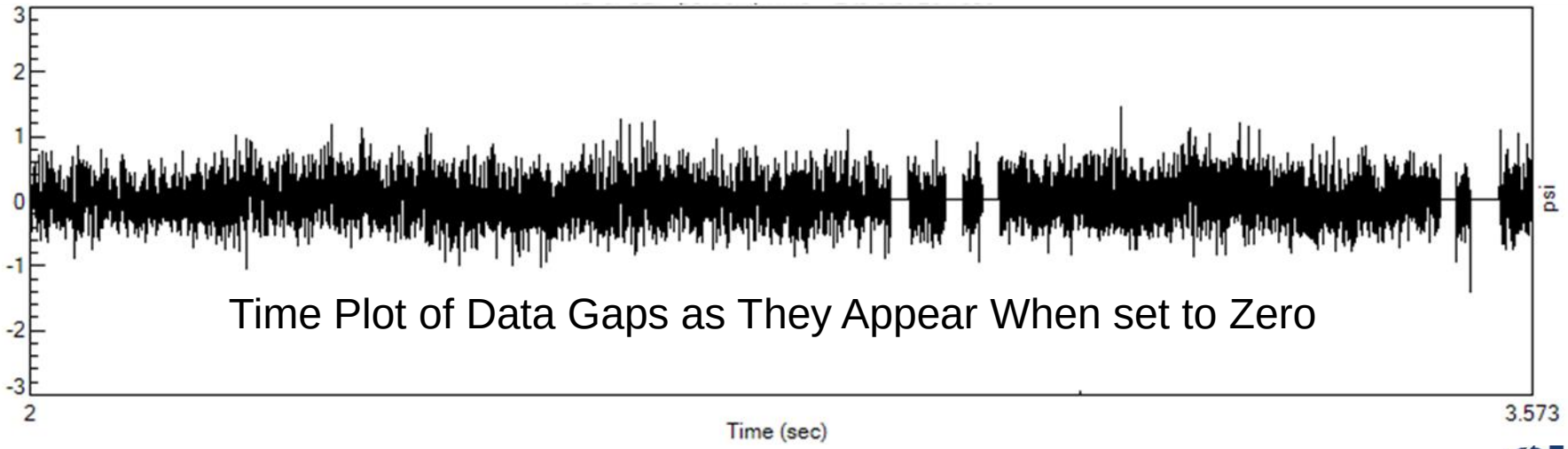
Gap Interpolation

- All 45 liftoff environment measurements were examined, and data gaps were identified in 22 of those measurements
- A major problem with the data gaps is that the internal software tool that reconstructs the acoustic measurements linearly interpolated across the data gap interval
- This is sound practice for a data gap of one or two data points; however, much larger gaps were found in the liftoff environment measurements

Gap Interpolation/ Zeroing



Time Plot of Data Gaps as They Appear When Interpolated

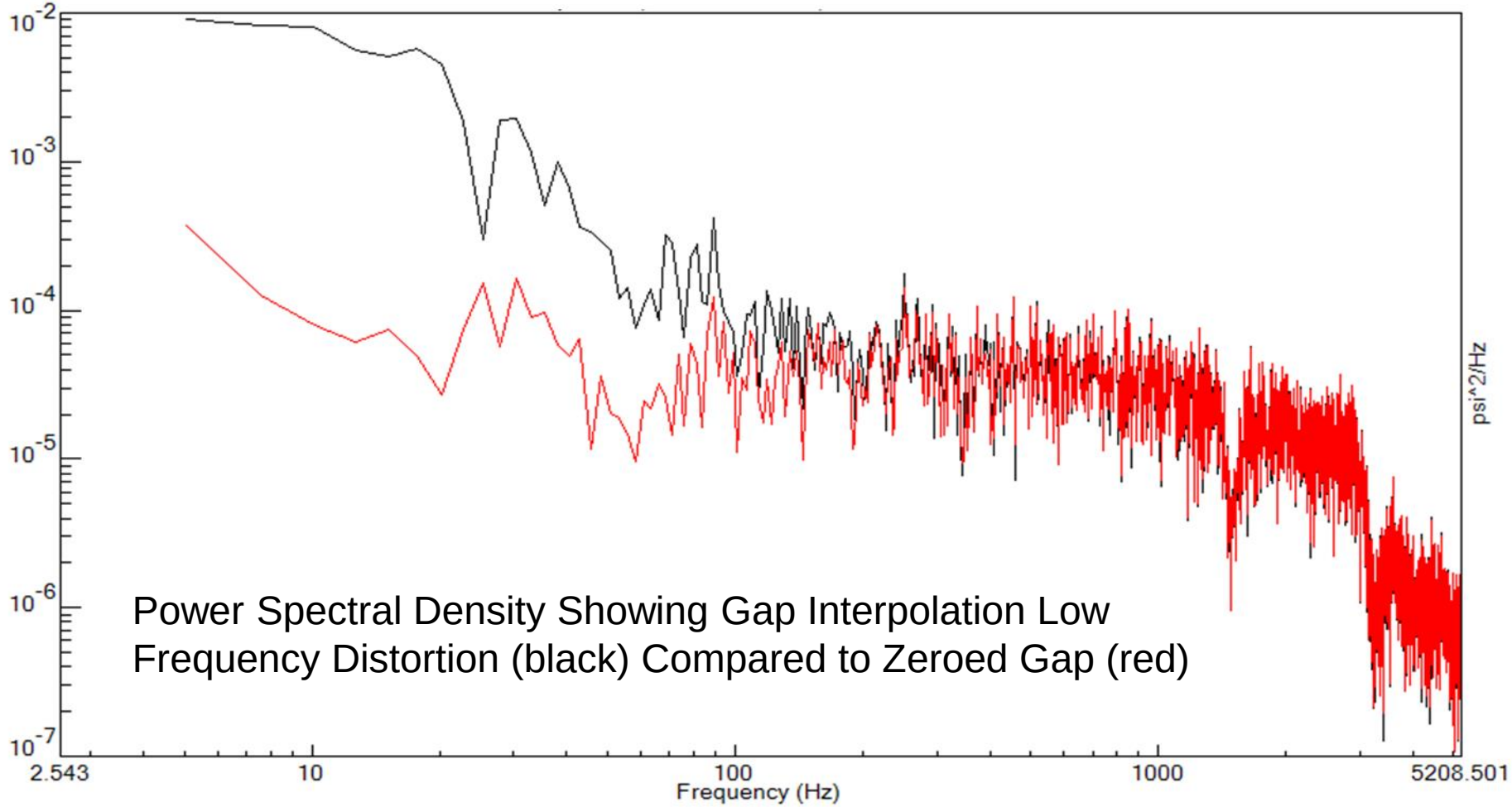


Time Plot of Data Gaps as They Appear When set to Zero

Gap Interpolation/ Zeroing

- Gap interpolation led to excessively biased ‘steps’ in the data which show up as erroneous high-amplitude low-frequency spectral values
- By zeroing the gap data, this error is mitigated and results in periods of no-data in some spectral analysis windows
- The period of no-data is small compared to the block size and can be shown to reduce spectrum amplitude by only a fraction of a dB

PSD of Interpolated vs Zeroed Gap Data

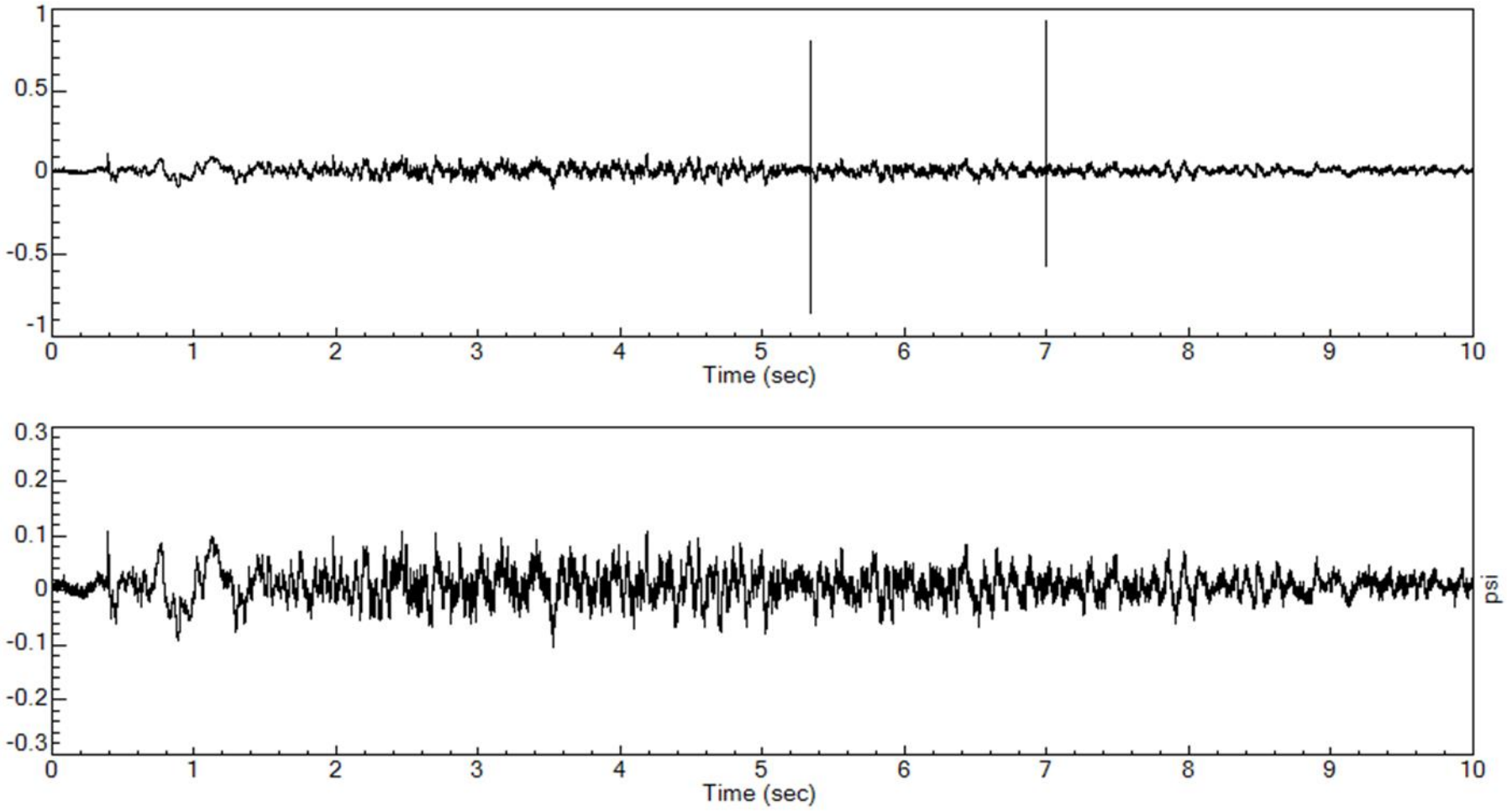


Power Spectral Density Showing Gap Interpolation Low Frequency Distortion (black) Compared to Zeroed Gap (red)

Data Spike Zeroing

- The liftoff environment measurements were examined, and data ‘spikes’ were identified in 3 of those measurements
- These were large-amplitude, short-duration spikes
- Time history plots on the next slide show a typical signal with spikes and then with spikes set to zero

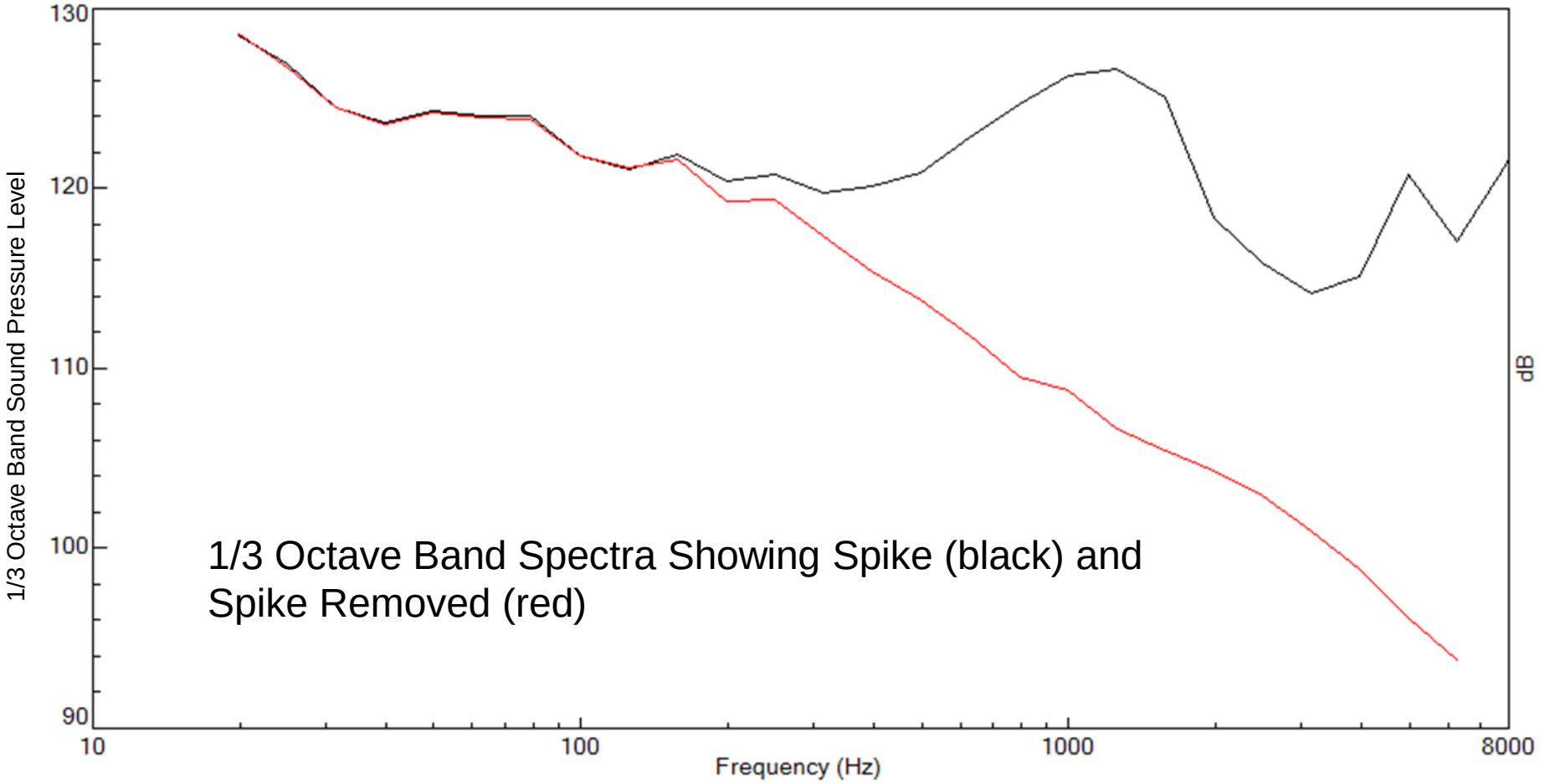
Data Spike Zeroing



Data Spike Zeroing

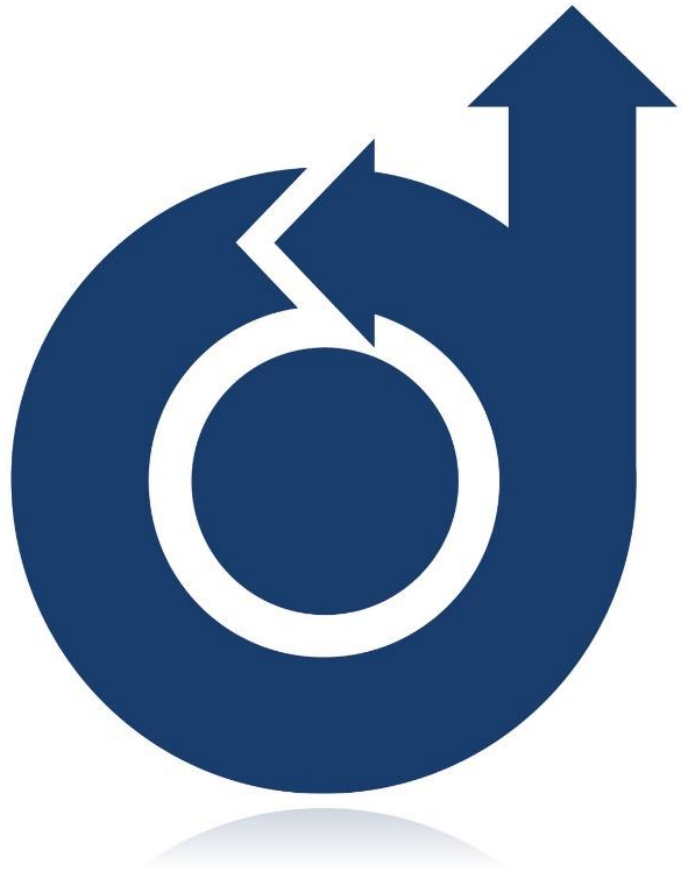
- The effect of one of these spikes on a 1 second duration 1/3 Octave Spectrum is significant
- The figure on the next slide shows a 1/3 Octave Spectrum plot of the T0+5 to T0+6 second time window of data from the previous slide
- In this figure, the 1/3 Octave Spectrum of data with a spike (black) is compared to the 1/3 Octave Spectrum of the same time window with the spike set to zero (red)

1/3 Octave Spectrum Illustrating Spike Zeroing



1/3 Octave Band Spectra Showing Spike (black) and Spike Removed (red)

- In summary, 45 liftoff environment measurements were selected as ‘good’ and a series of corrections applied to provide time alignment, senseport resonance removal, trend removal, and gap and spike zeroing.



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