# Are we shaking too much?

## An inquiry into environmental random vibration testing margins

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# *Background*

**Problem Statement:** The conventional, MIL-STD-810 approach to vibration environment derivation is perhaps too conservative, leading to unnecessary failures during acceptance & qualification vibration testing of Armstrong's one-off flight equipment.

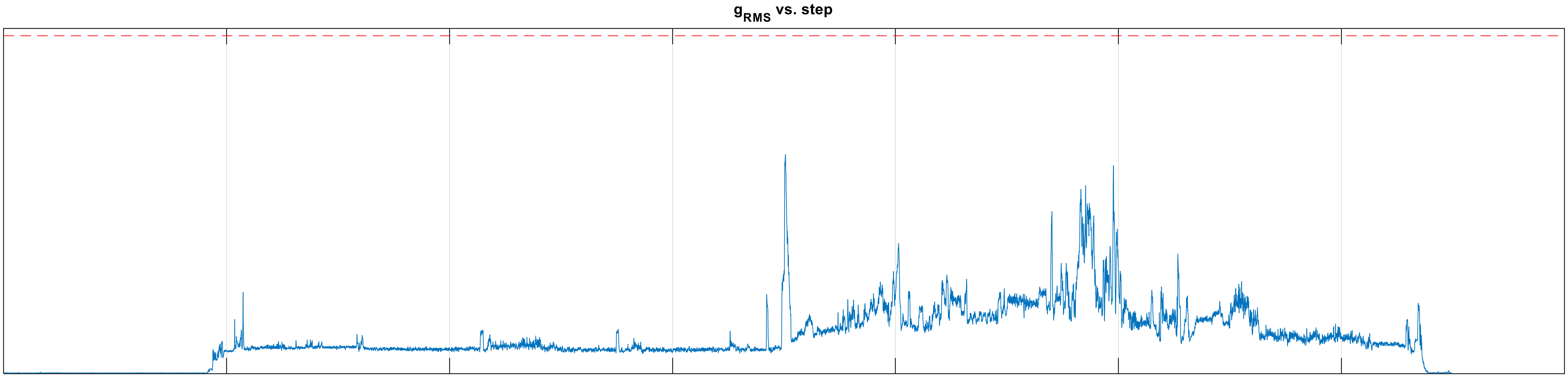
**Objective:** This presentation explores some alternative understandings of the distributions of vibration severity in non-stationary environments. Proposed methods of sorting and adding appropriate margin are explored.

# Background – High Performance AC Stores

To develop instrumentation for experimental aeronautics program, several power supply units were to be fitted inside the storage bay of a NASA high-performance jet aircraft. During a random vibration test of the power unit, several electro-mechanical breakers tripped.

To see if the 1990's era environmental book included 'too severe' of a vibration environment, the program instrumented and flew the aircraft with Slamsticks – self-contained environmental data recorders.

# *Accelerometer Time History of a Flight with Slam Stick*

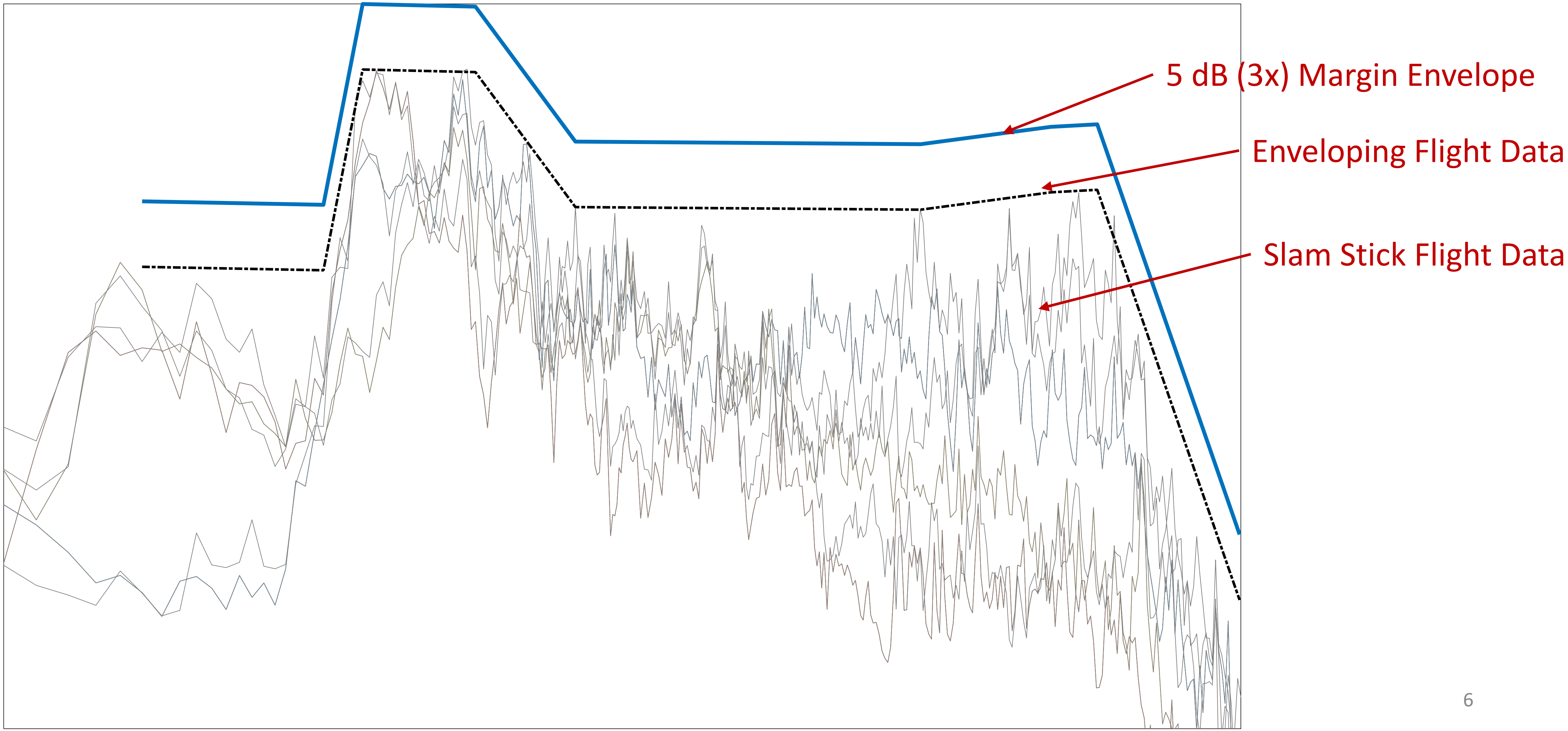



Looking at the $g_{RMS}$ level chronologically can be quite informative

# *How much margin is necessary?*

After the flight data was collected, so called ‘peak’ or ‘ensemble’ Auto-Spectral Densities (ASDs) were calculated for the anticipated most-severe flight environments, specifically Wind-Up Turns (WUT). There was concern that the limited data (3 flights with one maneuver) was not statistically significant enough. We added about 5 dB (3x) margin, after underfitting the envelope.

# *Underfitting the Envelope*



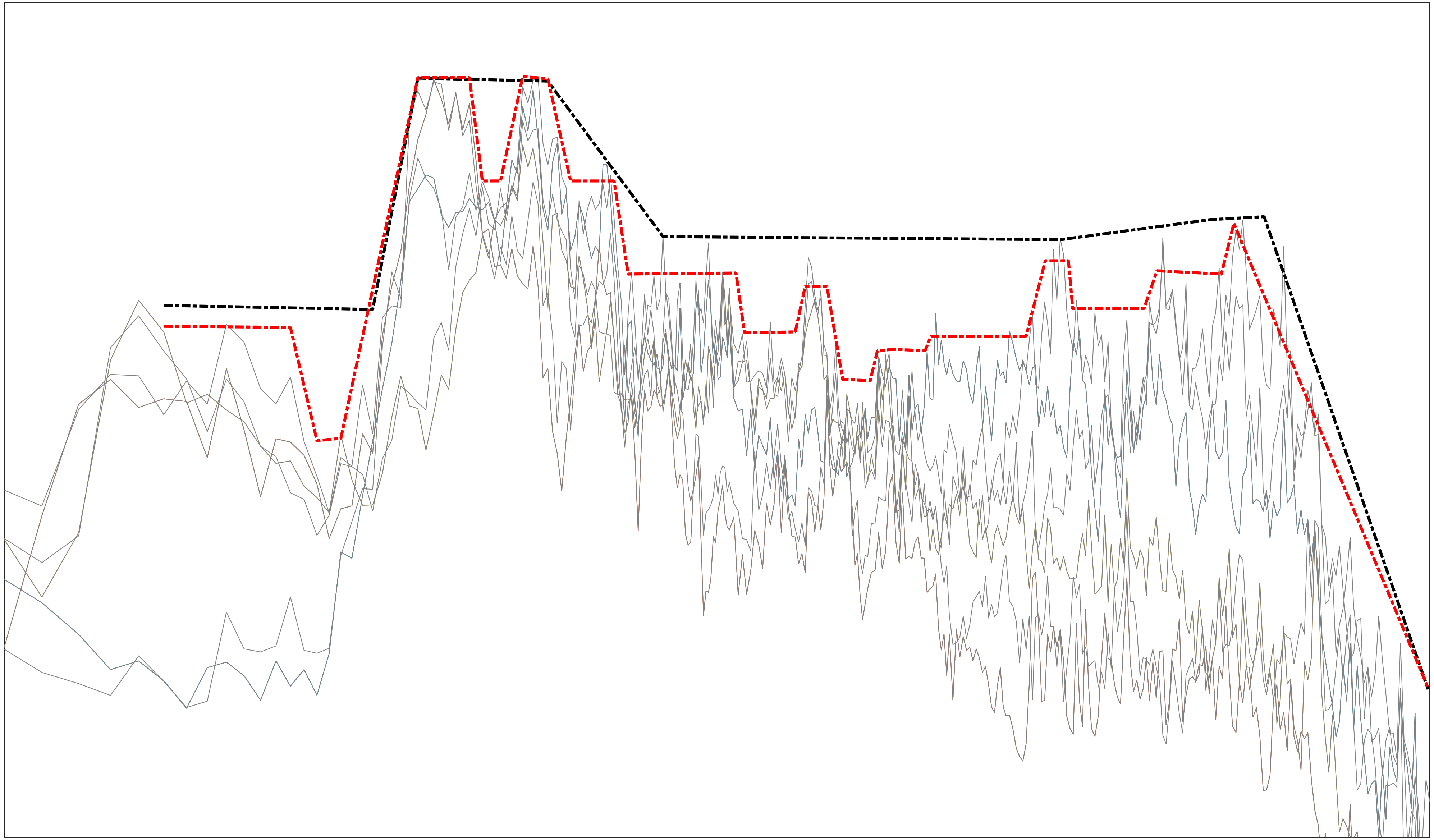
# *Antiquated enveloping rules*

The Finite Element Modeling Continuous Improvement (FEMCI) handbook, published by Goddard Space Flight Center (GSFC), has guidance for developing a test specification from measured ASDs. For instance, it recommends:

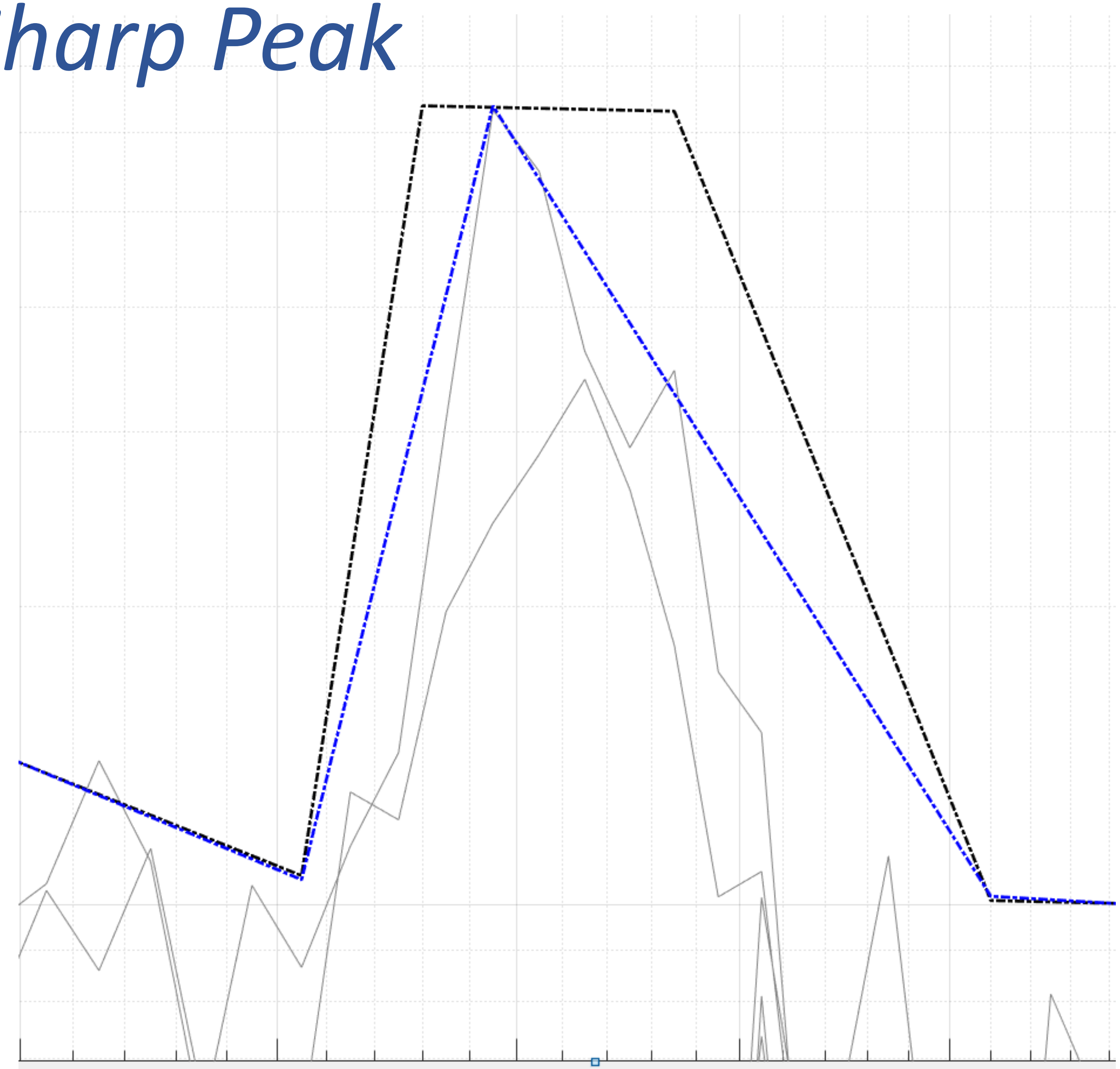
- Slopes are no steeper than +25 decibels/octave.
- No more than 20 breakpoints are typical
- Peaks must have mesas

Working with the Armstrong Environmental Lab, I found many of these rules had not been updated to reflect better control systems that vibration tables had. Breakpoint tables can be loaded electronically (rather than typed in), freeing the analyst to use as many points are needed, with ‘odd’ numbers and steep peaks. Thus, test specifications could more closely match the measured data.

# Fitted vs. Underfitted Curve



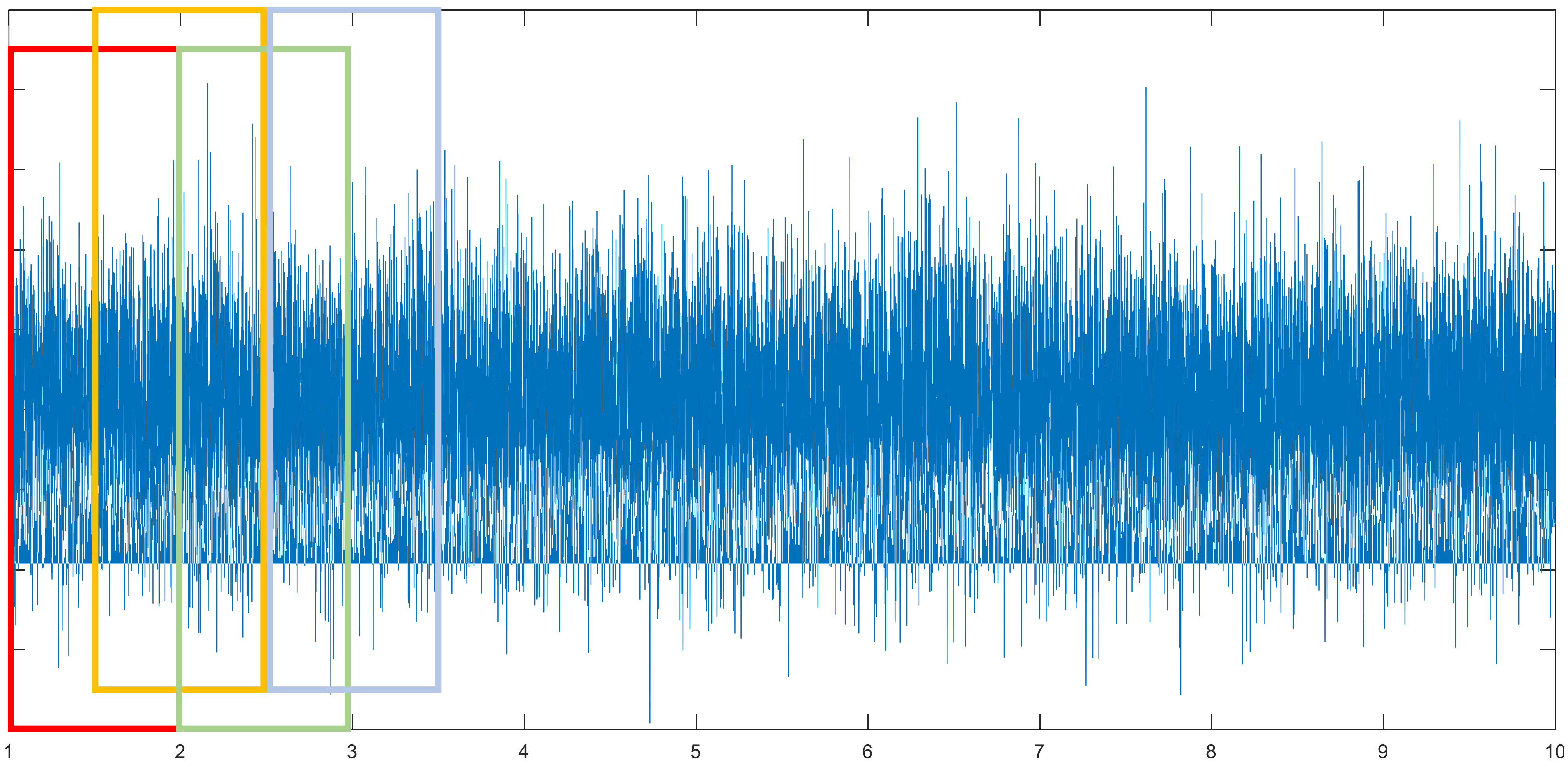
# *Mesa vs. Sharp Peak*



# *MIL-STD-810 Approach*

Conventional 810 processing indicates that if the vibration environmental data are non-stationary, ASDs for 1 second windows, with 50% overlap should be calculated. These one-second ASDs should be super imposed, with the higher $g_{RMS}$ level for each bandwidth determining the shape of the peak ASD. The newest versions of the standard (810H) includes a lengthy appendix describing various averaging methods, breaking out different events, and recombining them.

# *One second windows with 50% overlap*



# *How much of the flight is that bad, anyway?*

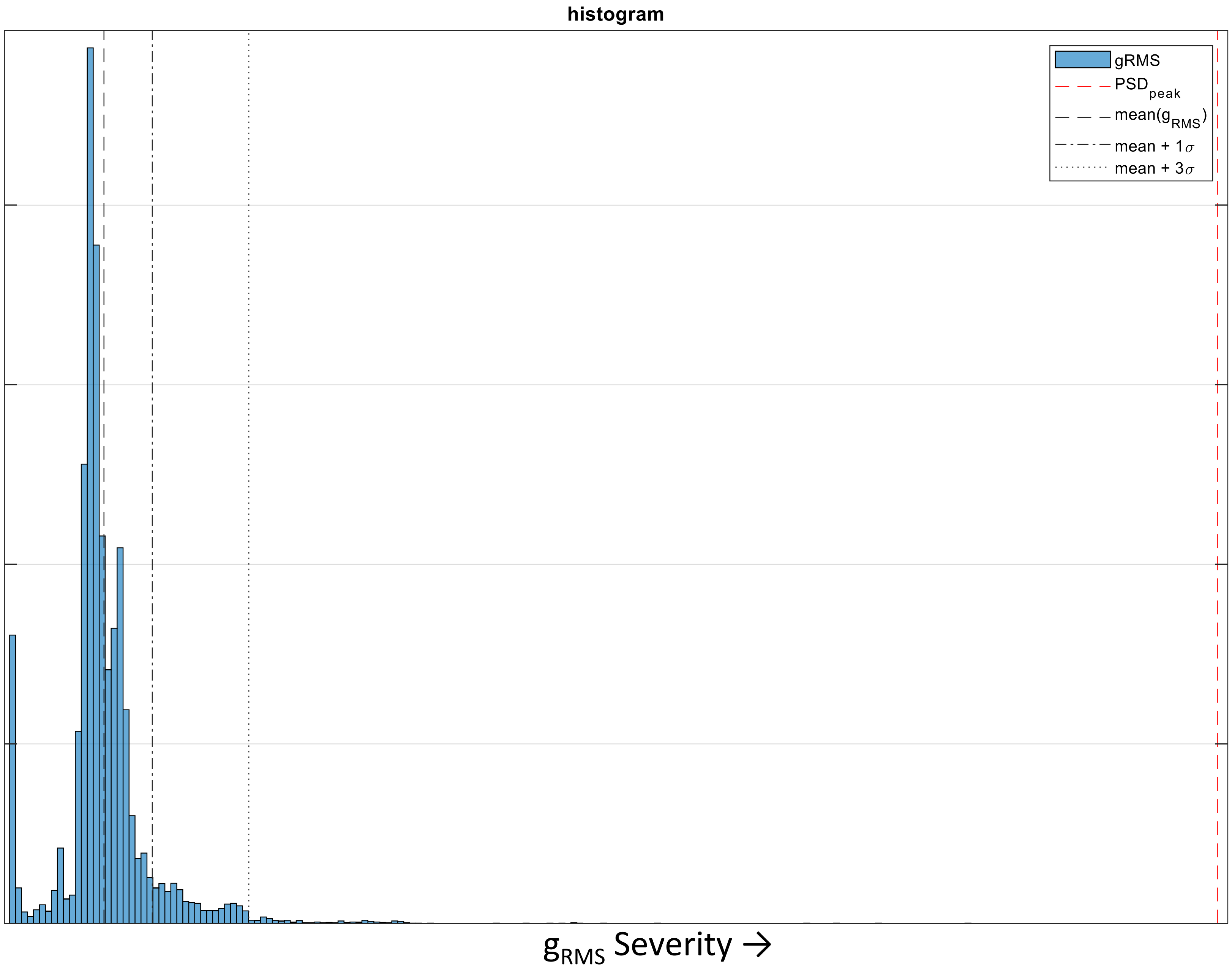
Early in the program, I had a small set of data. As the program progressed and acquired more data, I started wondering, how bad was the typical flight second, anyway?

The standard practice for testing aircraft equipment was to shake it in three axes for 30 minutes per axis – different from my prior experience with missiles.

## *Distribution of $g_{RMS}$, Histogram, As a function of time*

Eventually, I found time to write a MATLAB script to look at the $g_{RMS}$ level of each window, and plot it as a function of time, as well as a histogram. I am generally not a fan of relying solely on the RMS level of the entire bandwidth, but for developing an intuition of the severity levels of the flight, it was a good metric.

*Histogram of a typical flight. Several 'near normal' distributions can be identified. The flight population is highlighted in blue, The peak ASD is the red dotted line on the far right. The 'average' severity of flight is the black dotted line. The peak ASD has considerable margin (~10x) over the flight. Is additional margin needed?*



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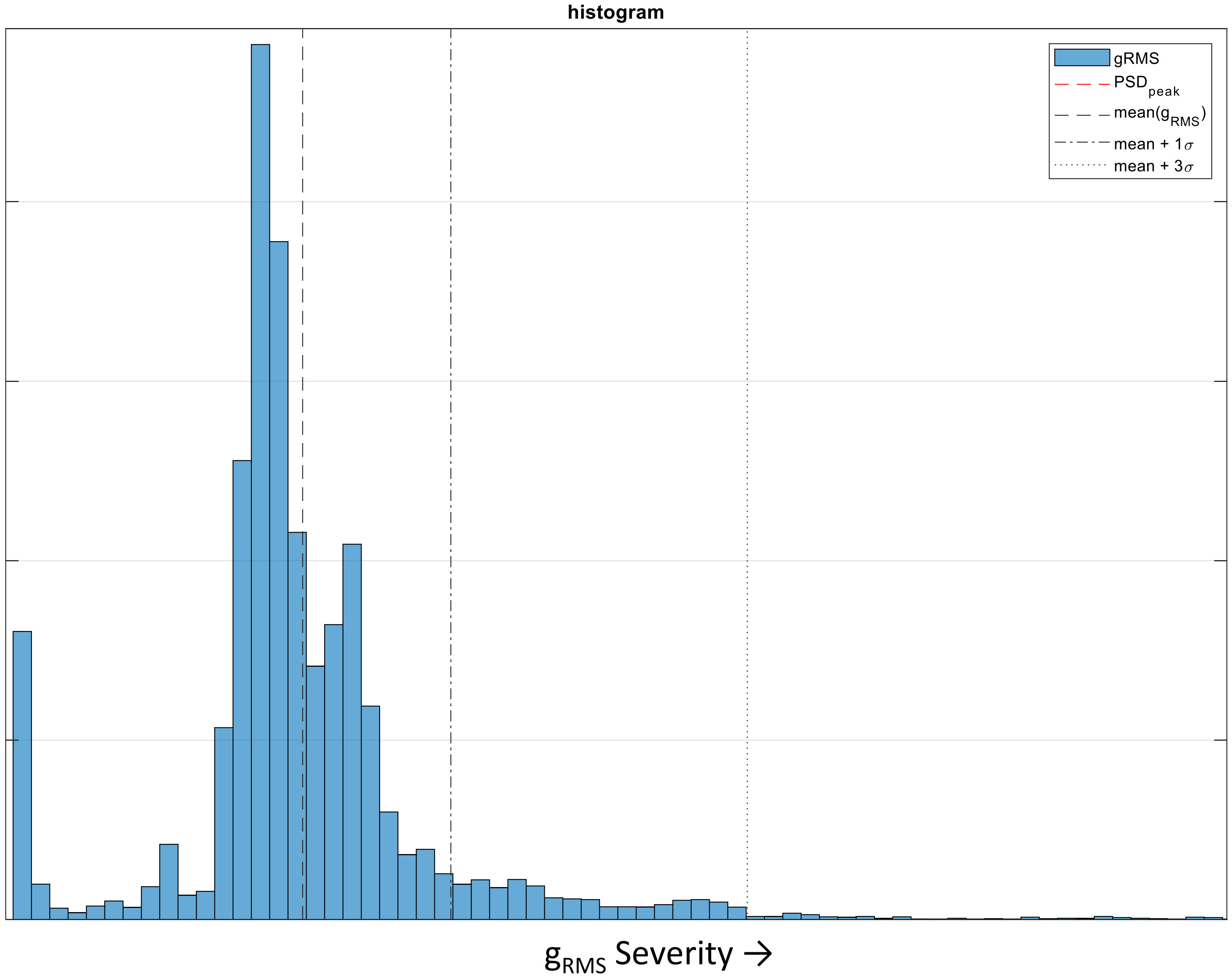
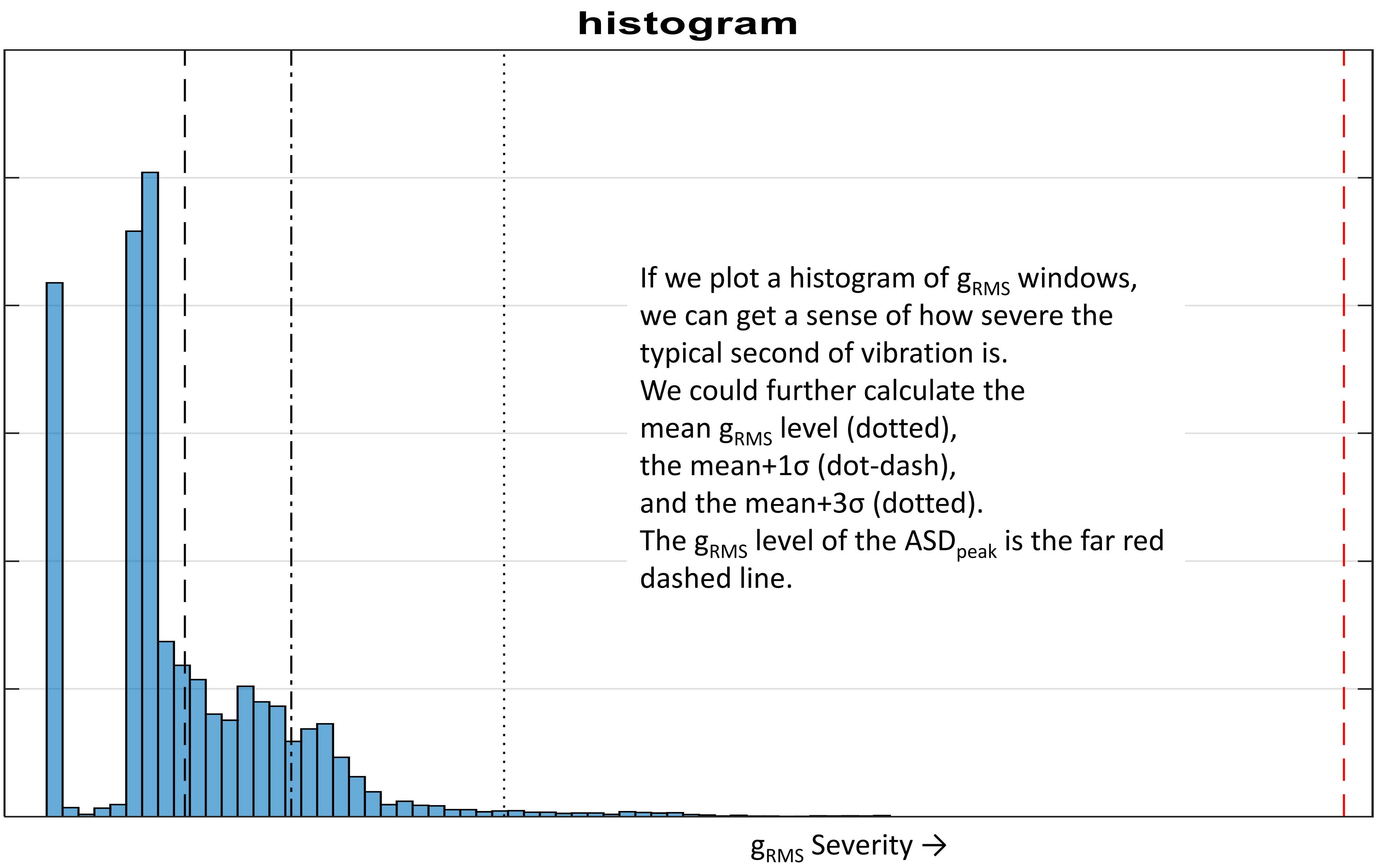
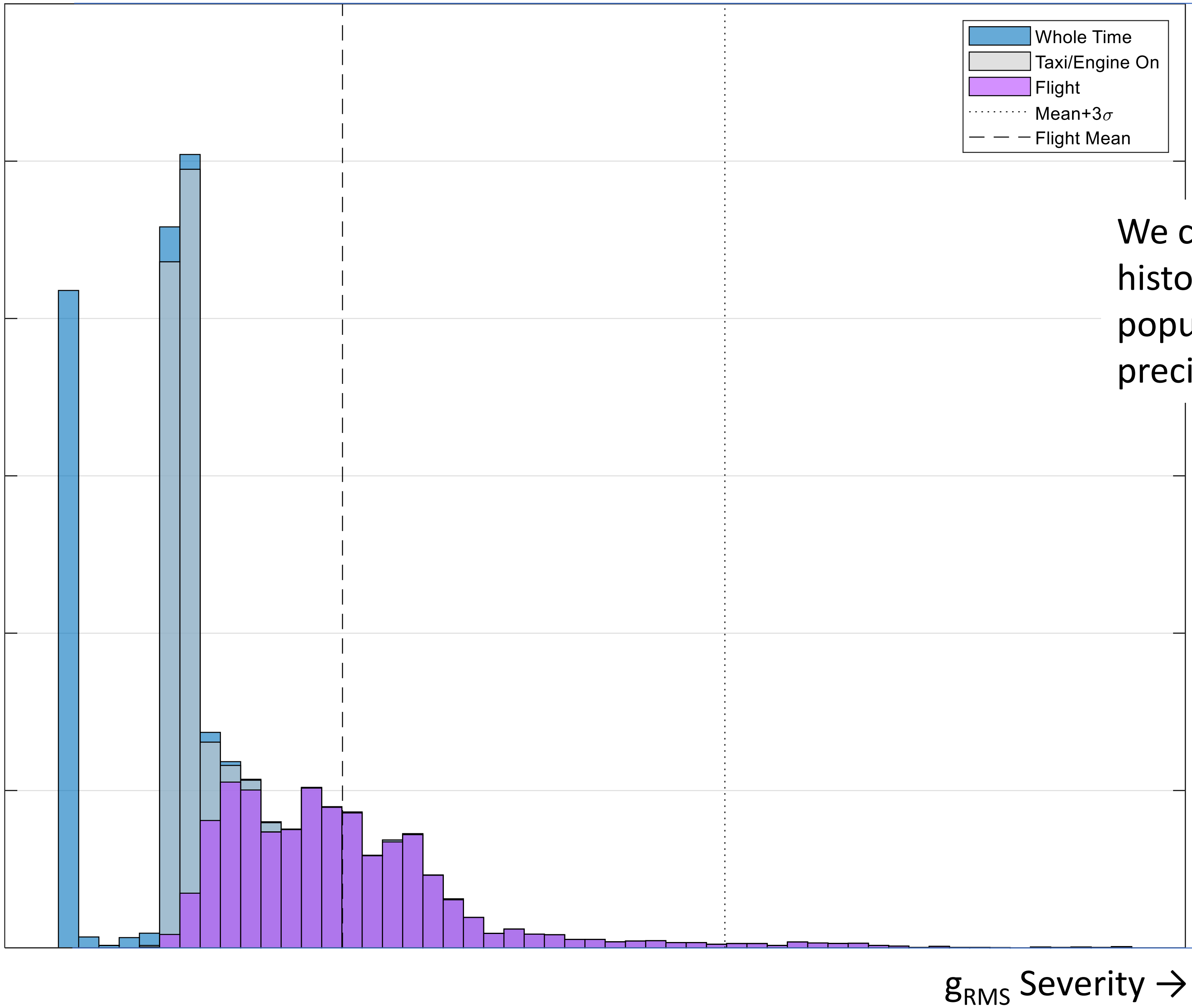
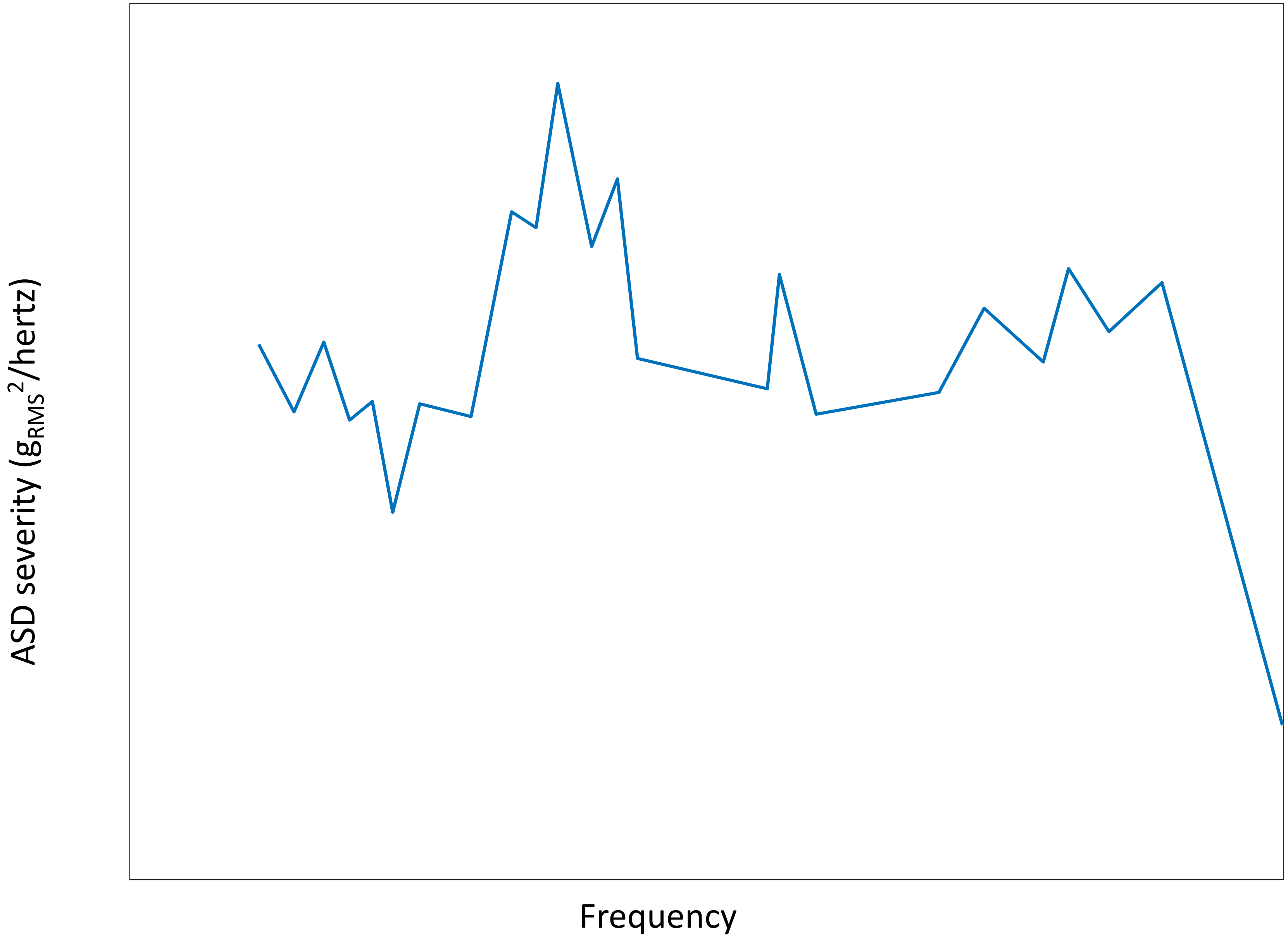


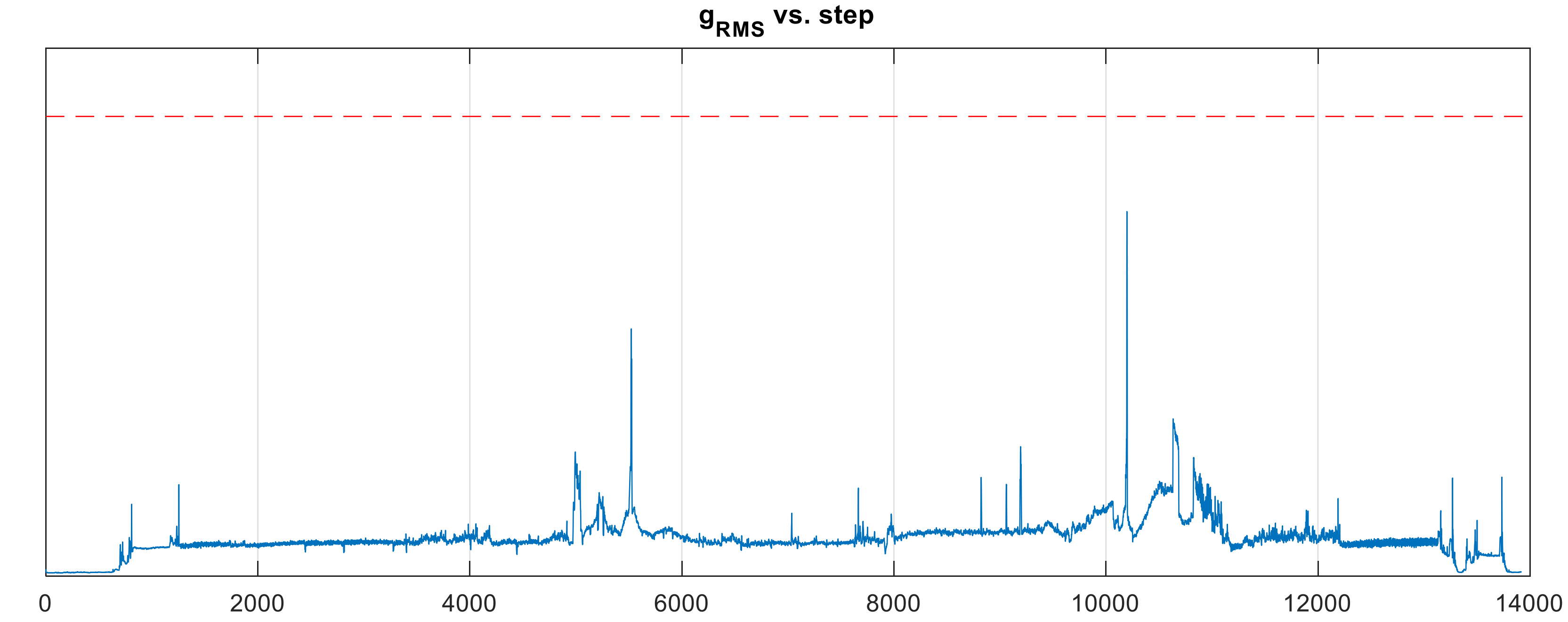


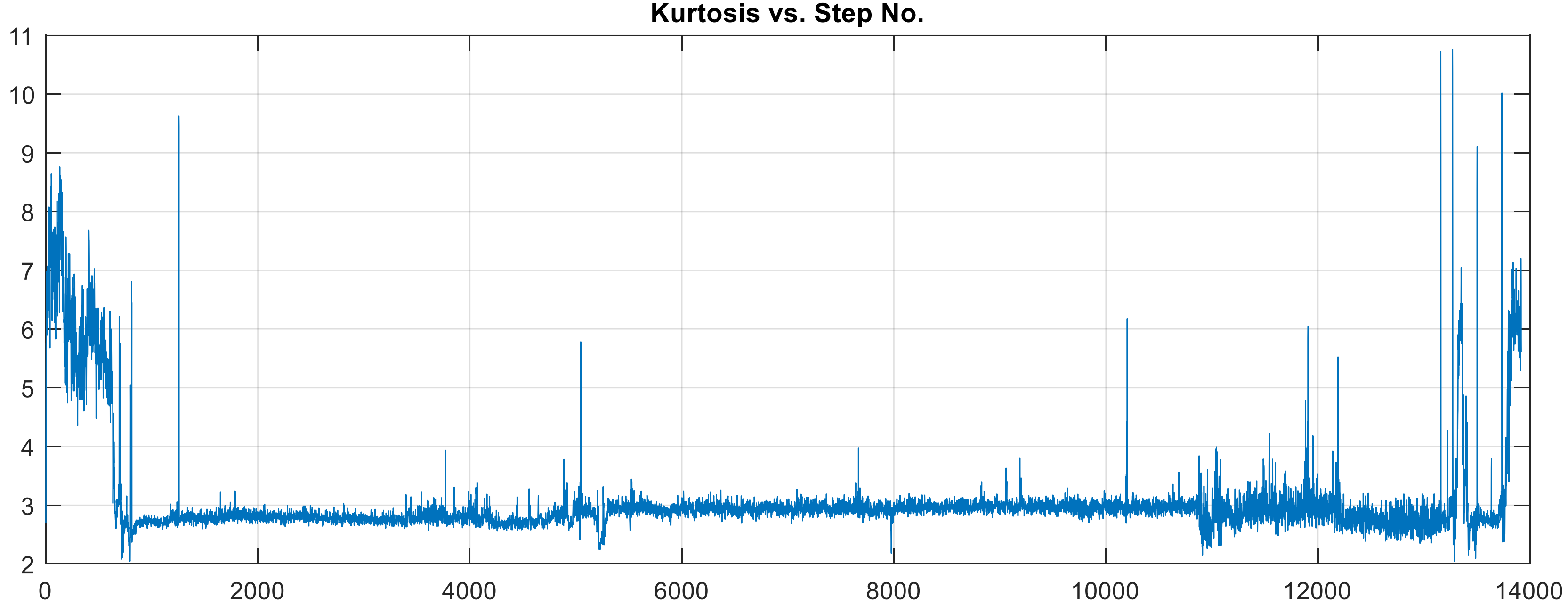

If we plot a histogram of $g_{RMS}$ windows, we can get a sense of how severe the typical second of vibration is.
We could further calculate the mean $g_{RMS}$ level (dotted),
the mean+1σ (dot-dash),
and the mean+3σ (dotted).
The $g_{RMS}$ level of the $ASD_{peak}$ is the far red dashed line.



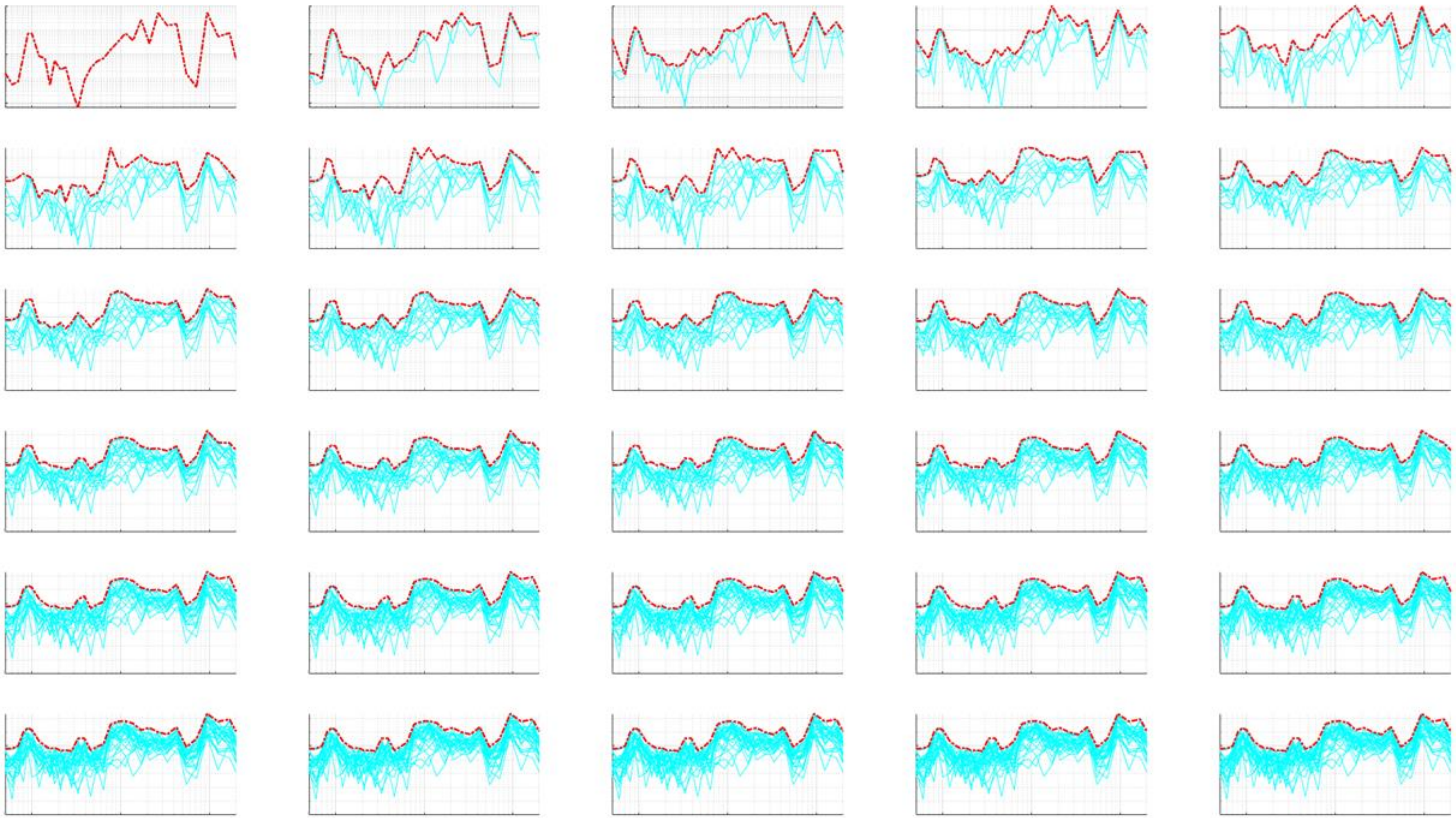

We could also separate the time history into ‘on’, ‘taxi’, and flight populations and be a bit more precise

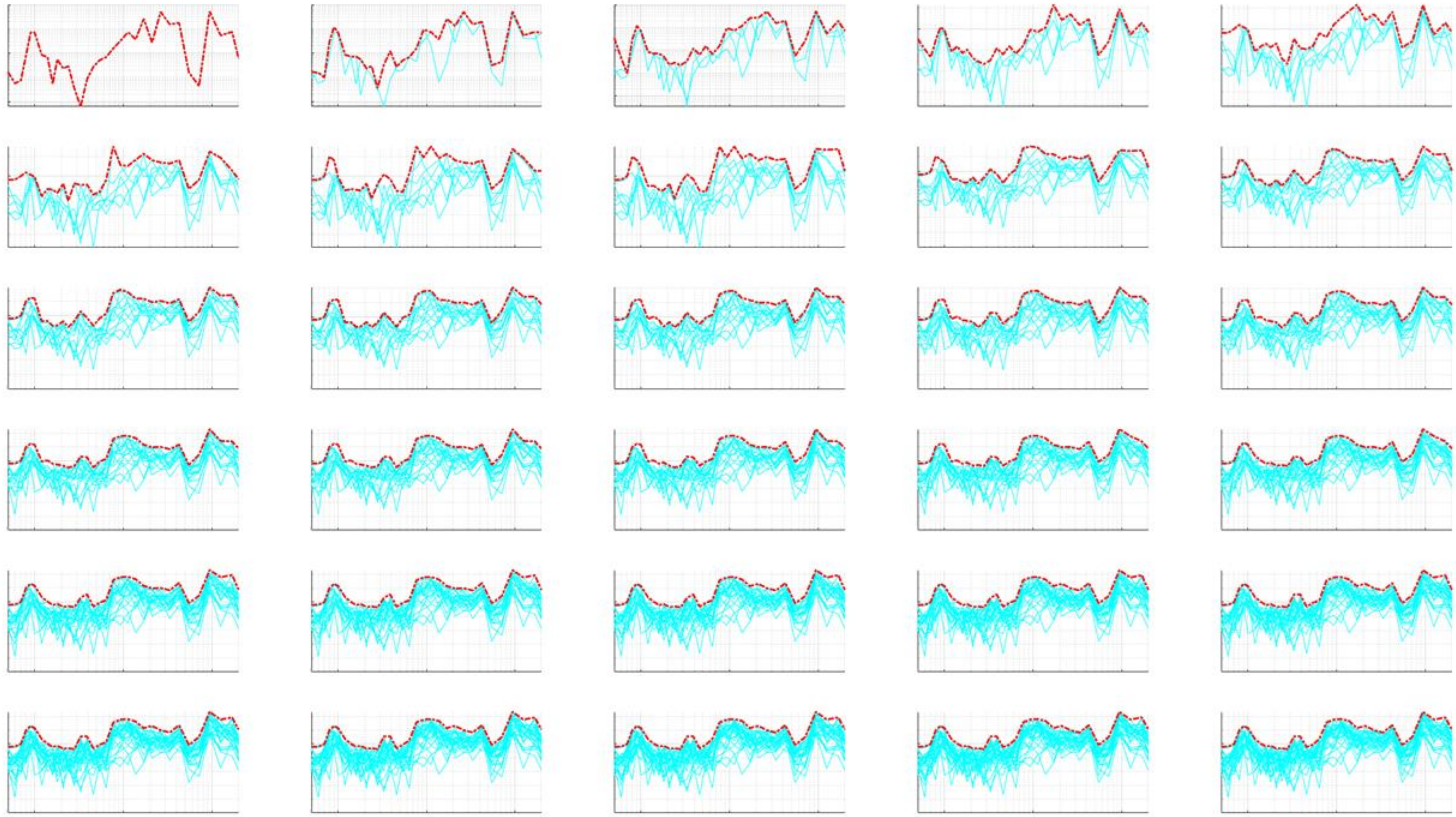

ASD severity ($g_{RMS}^2$/hertz)
Frequency


$g_{RMS}$ vs. step
0
2000
4000
6000
8000
10000
12000
14000


Kurtosis vs. Step No.
11
10
9
8
7
6
5
4
3
2
0
2000
4000
6000
8000
10000
12000
14000

# *How is an ensemble ASD (ASDpeak) calculated?*





# *Conclusions*

This seems to have a great potential for quantification of random vibration margin.

Better enveloping techniques can reduce unwanted conservatism

(talk to your local environmental lab!)

## **Looking for feedback:**

- Does this make sense?
- Is this an intelligent way to better manage margin?
- Thoughts?