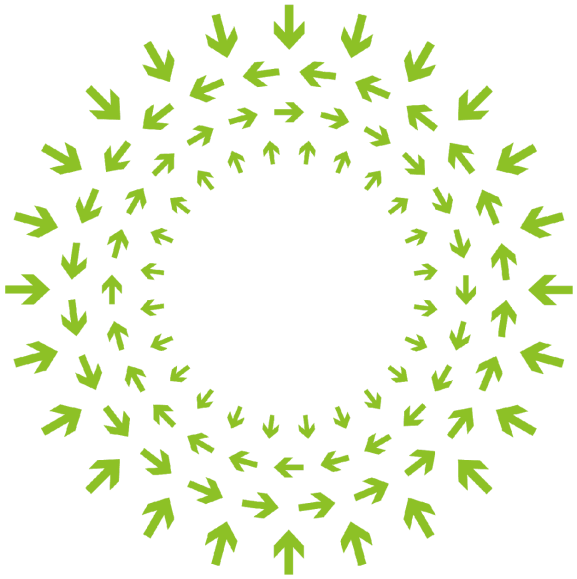

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Compute Project

HDD Dynamics Common Language and Tool: Phase 1 – Acoustical HDD Surrogate White Paper

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1.

2. Scope & Overview

Hard disk drive (HDD) throughput performance, often provided in terms of Input / Output per second (IOps), is disrupted when a HDD is shaken. Steady state or transient disturbances cause the HDD head to miss its target on the HDD platters during read/write, and sufficient amplitude and/or duration of disturbance can incur significant latency and potentially damage the platters. Historically drive to drive vibration transmission resulted in rotational vibration interference (RVI) that was < 2kHz, and HDD manufacturers developed servo mechanisms to account for it.

Over the past decade, the following two technological vectors have provided for a greater challenge to HDD throughput performance. One is the pursuit of higher capacity thus more data per platter and smaller targets for the head. The other is escalation in air mover speed to cool components that are increasing in power and density in the enclosures that also house the HDDs. Specifically sound pressure from air movers scales with 5^{th} power and vibration with 2^{nd} power of air mover speed. Moreover, sufficient acoustic energy to agitate a HDD exists up to 20kHz. Such a span is generally beyond the HDD servo capability. Other events such as shock from a drop, noise from expulsion of gases from fire suppression systems, and yelling at HDD enclosures can provide enough disturbance to degrade HDD throughput performance or damage the HDD. The term dynamics is thus implemented to embody to the various physics mechanisms. The acoustical contributor is described in the following 2019 ASHRAE paper: http://tc0909.ashraetcs.org/documents/ASHRAE_TC0909_Hard_Disk_Drive_Performance_Degradation_Susceptibility_to_Acoustics_9_September_2019.pdf

Recognizing that dynamics data measured by various methods and tools from different companies could yield confusion, HDD manufacturers and HDD enclosure designers have identified the need to define common communication tools. With these in hand, they could collaborate in order to find solutions the physics of which are compatible between sensitivity of HDDs and output of enclosures. Although each individual party is responsible for their designs best to correspond with the other's product, a measurement tool and communication scheme could facilitate compatibility.

Harnessing contributing companies' experience and understanding of the dynamics challenge, the authors listed above, in conjunction with the OCP Storage Project Community, embarked on this paper to specify an industry standard for HDD Dynamics acoustical surrogate and means to communicate characterization data collected with it. A HDD surrogate has similar size, shape, and mass to a HDD but it is instrumented with one or more sensors to measure relevant HDD dynamics. Phase 1 of the OCP effort is described in this paper and introduces the HDD Dynamics acoustical surrogate, which uses microphones to sense acoustic signals. In Phase 2 of the OCP effort addition of accelerometers is intended to be evaluated, in order to add vibration signals to the measurement. The focus of Phase 2 will be standard tools and language extensions associated with structural vibration interference. Viability of tools and language extensions that combine these two surrogate types into one unified device are intended for Phase 3.

In this paper, HDD Dynamics acoustical surrogate test hardware construction, analysis parameters, and terminology are specified for a standard means of expressing and exchanging physics characterizations of Hard Disk Drives (HDDs) with relation to disturbance that can result in performance degradation. A communication structure is provided for alignment on expectations among HDD manufacturers, component vendors, and system enclosure designers in order to accommodate highest capacity HDDs and enable Industry to optimize storage TCO.

3. HDD Surrogate Usage Models

Below is a non-comprehensive list, capturing the motivations for interest in HDD surrogates among the authors listed above, in conjunction with OCP Storage Project Community.

1. Enclosure designers may use HDD surrogates to iteratively improve and evaluate mechanical (or, not in scope of this paper, thermal characteristics) design.
2. HDD manufacturers may use HDD surrogates to characterize their HDD designs and test their designs' dynamics sensitivity in a given enclosure.
3. Enclosure designers and HDD manufacturers may use HDD surrogates to determine acoustical from vibration influences and degree of confluence of the effects.
4. Component suppliers may use HDD surrogates in mockup testing to help develop and tune devices like air movers, acoustic absorption materials, and vibration damping materials with the goal of minimizing dynamics at enclosure HDD locations.

4. Hardware Requirements

4.1 3.5" HDD Acoustical Surrogate

The 3.5" HDD Acoustical Surrogate consists of three parts: Base, Top cover, and Bottom cover. All parts are made of Aluminum 2011 (if Aluminum grade 2011 is not available, then any grade suffices). The hardware specifications are described in a later section and CAD is provided at the OCP Storage Project Community site, https://www.opencompute.org/wiki/Storage. A port hole in the top cover and another in the bottom cover accommodate two flush mount microphones described in the following section. HDD acoustical surrogates with additional mic locations were studied, and although the signals from them may provide additional information, the frequency content and the sound pressure level at the top cover port hole was found to be representative of that of the surface and spectral average.

The location of the port holes corresponds with that of the spindle of the HDD. Care should be taken to ensure microphones are snug and slightly recessed from a purely flush mount condition, in order to reduce the chance of damage to the microphones and also to reduce introduction of wind noise around the microphone. Sufficient clearance should be provided for microphone cable pass through holes so that cables are neither crushed nor sliced. Glue or adhesive may be added to provide strain relief. The approximate cost of the materials for hardware for the Base, Top cover, and Bottom cover is ~1500 USD.

Design Notes: Use of certain drive carriers may require modification to allow the microphone cables to pass through to the outside of the system, usually achieved by snipping some front grids of carrier.

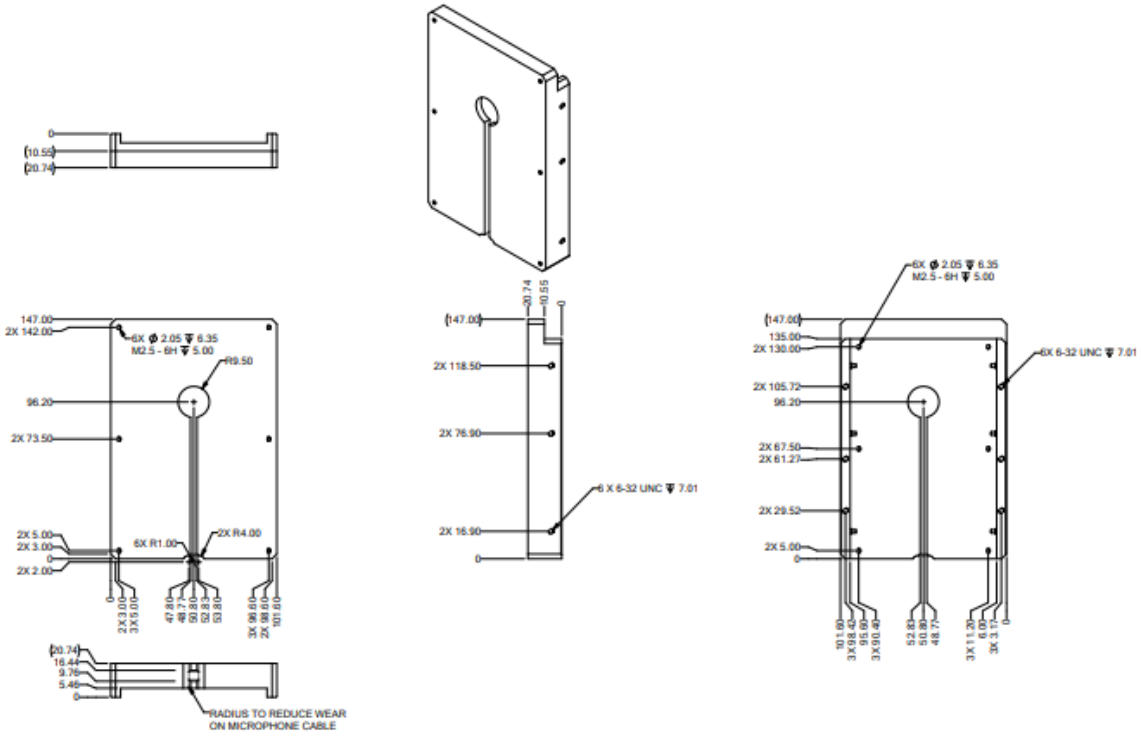


Figure 1: Excerpt from CAD for 3.5” HDD Acoustical Surrogate Base

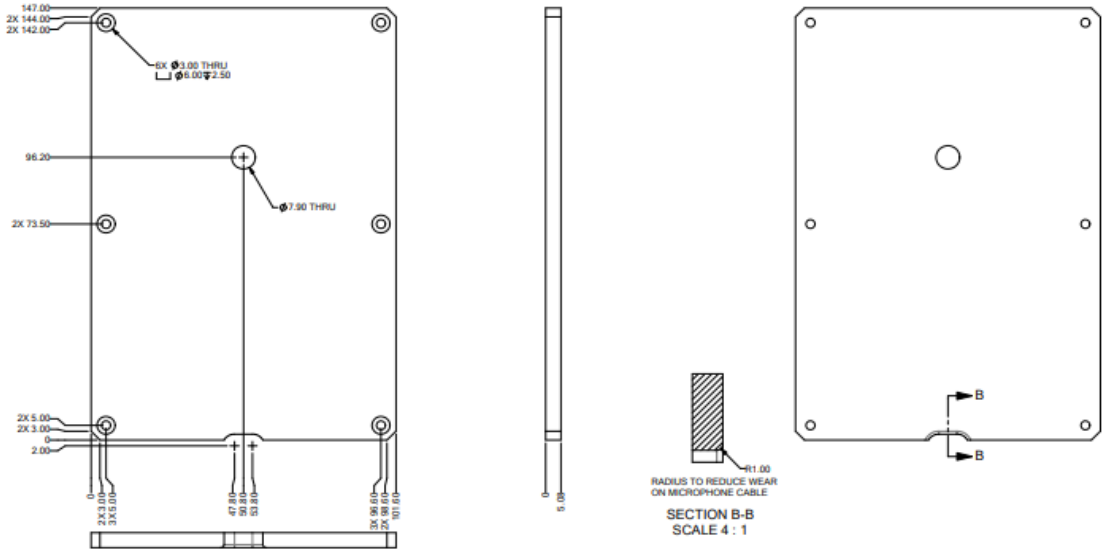


Figure 2: Excerpt from CAD for 3.5” HDD Acoustical Surrogate Top Cover

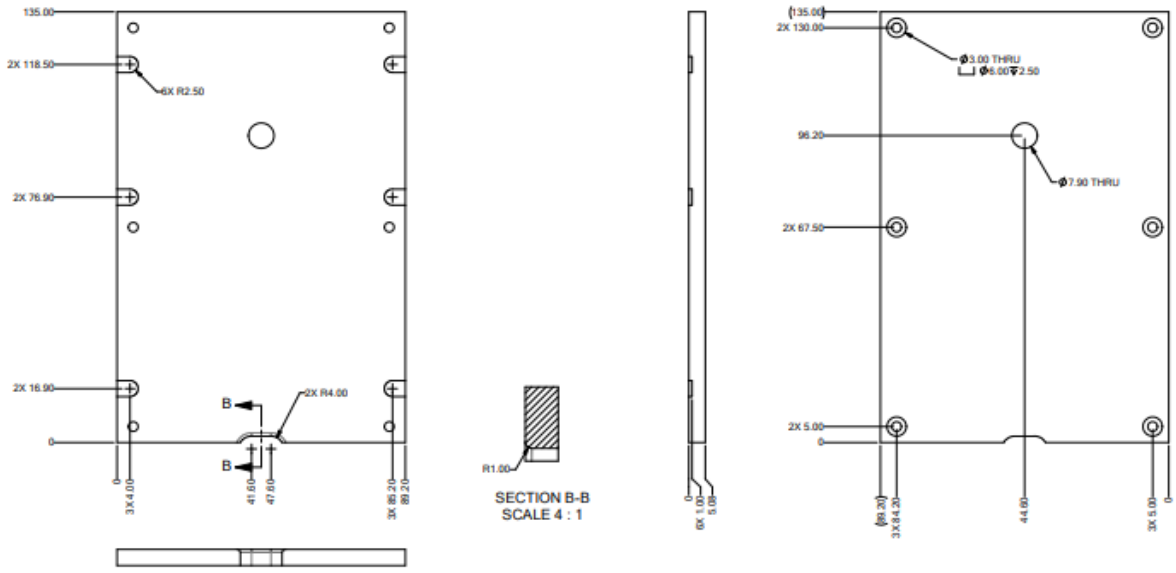


Figure 3: Excerpt from CAD for 3.5” HDD Acoustical Surrogate Bottom Cover

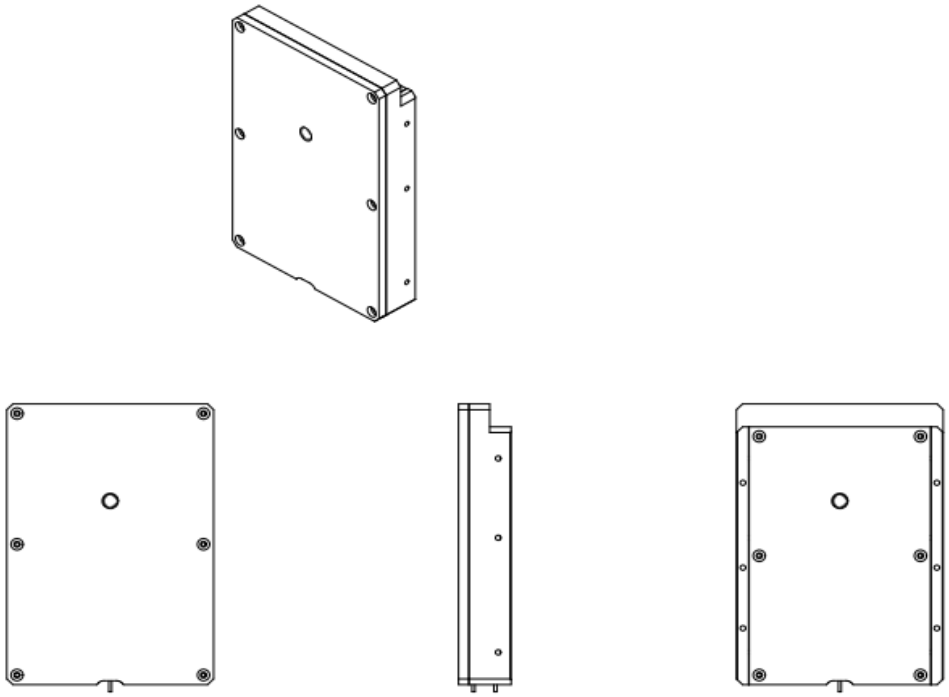


Figure 4: Excerpt from CAD for 3.5” HDD Acoustical Surrogate Full Assembly

4.2 Microphones

Because disturbances up to 20 kHz have been demonstrated to result in HDD throughput degradation, a Class-1 microphone is required with flat response at least up to 20 kHz. It must be a ¼" diameter flush-mounted style and installed internally to the surrogate hardware. The placement of the microphone is such that the grill above the diaphragm is slightly recessed from flush to the surface of the surrogate, in order to reduce the chance of damage to the microphone. A total of two microphones is standard, whereby one is installed in the Top plate and another in the Bottom plate. As discussed in a previous section, the signal at the top port hole microphone has been shown to correlate with HDD throughput degradation. The bottom port hole microphone may be used to attain greater understanding of acoustic propagation or effects. Corresponding parties may agree to use just one, either at top or bottom location. The approximate retail cost of such a microphone is ~2000 USD each for a total of ~4000USD.

One example of a microphone that meets these requirements is the GRAS 47BX. Care must be taken not to damage the cables under normal usage. Some provisions may be required in larger systems to safely pass the microphone cables from HDD slots to data acquisition gear located outside the chassis.

4.3 Data Acquisition System

Based on the OCP's storage working group data review, experience, and focus on intended usage, any data acquisition system selected must accept a minimum of two channels of input, support 24-bit, provide ≥ 40kHz resolution per channel, and take an Integrated Circuit Piezoelectric (ICP) supply. A non-exhaustive survey of some data acquisition systems currently on the market and meeting the minimum requirements is provided in Table 1. The range of approximate retail cost is ~2000 – 8500 USD.

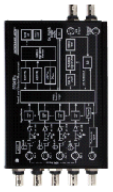
	HEAD Acoustics	Data Physics	Data Translation	National Instruments	National Instruments
Model Hardware	SQobold	Quattro DP240	DT DT9837B	NI 9234	NI 9250
Retail Price (Hardware)	$ 7,064.95	$ 4,350.00	$ 2,080.00	$ 2,400.00	$ 1,320.00
Analysis Software	Need to purchase	Need to purchase	User need to create in-house program for analysis (e.g. Matlab, LabView)	User need to create in-house program for analysis (e.g. Matlab, LabView)	User need to create in-house program for analysis (e.g. Matlab, LabView)
Cost (Software)	$ 1,368.55	$ 3,950.00	$ -	$ -	$ -
Framework/ Chassis	N/A	N/A	N/A	$ 1,595.00	$ 700.00
Total	$ 8,433.50	$ 8,300.00	$ 2,080.00	$ 3,995.00	$ 2,020.00
# Channels	4 Channel/ 24 bit	2 Channel/ 24 bit	4 Channel/ 24bit	4 Channel/ 24bit	2 Channel/ 24bit
Resolution/ Channel	51.2kHz	40kHz	105.4kHz	51.2kHz	51.2kHz
Votage Range/ Auto Range	+/-5.0V (Auto Range)	+/-0.1V, 1.0V, 10.0V (Fixed Voltage)	+/-1.0V, 10.0V (Fixed Voltage)	+/-5.0V (Fixed Voltage)	+/-5.0V (Fixed Voltage)
Dynamic Range	97dBA	120dB		102dB	102dB
SNR (signal-noise ratio)			95dB	97dB	97dB
ICP supply	YES	YES	YES	YES	YES
Power	Battery-6hr (Portable)	USB Power (Portable)	USB Power (Portable)	USB Power (Portable)	USB Power (Portable)
Picture					

Table 1: Examples of Data Acquisition Systems for Acoustical Surrogate

5. Measurement & Communication Process

5.1 Test Environment & Setup

The enclosure hosting OCP-conforming HDD dynamics acoustical surrogates may be mounted in a rack or placed on a bench. If the host system is on a bench, it shall be placed on mounts that physically isolate the bottom of the host chassis from the benchtop and provide damping of sonically-induced vibration.

Broadband sound pressure levels (SPL) that result in sufficient disturbance in performance degradation generally exceed 100 dB, re 20 µPa, at the HDD. (For readers unfamiliar with acoustical terminology, a brief search will show that sound pressure level is given in units of decibels and in terms of the logarithm of the ratio of acoustic pressure to a reference pressure, which in air, is 20 micro Pascals.) If your ear were at the location of the HDD undergoing performance degradation, what you hear might be as loud as a jack hammer or a chain saw. The test environment therefore need not be quiet and moreover, an acoustical test chamber is generally not required. Sensitivity may increase with frequency, however, and so background

levels must be validated for each test as described in the section below. Limiting background may also aid in correlation of the acoustic frequency signature observed at the surrogate to specific sound sources internal or external to the host enclosure.

5.2 Measurement & Output

The HDD slots of interest should be agreed on between the generators and consumers of data from the HDD Dynamics acoustical surrogate. If the HDD slot requires a carrier, then it should be attached to the surrogate. The surrogate should be installed into each HDD slot while air movers, if present, are run at speeds of interest.

Measurement time should be at least ten seconds. Analysis output from the time signal should be 1/3rd octave unweighted sound pressure level from 100Hz to 20kHz and rounded to the nearest integral decibel. The top and bottom microphone data should be saved independently, i.e., not combined, averaged, etc. Retaining the ten-second time history for each microphone allows for post-processed through whatever analyses may be desired for development investigation, i.e., outside the requirements of this standard.

Each 1/3rd octave unweighted sound pressure level must be at least 10 dB above the background. In order to validate this, a test must be conducted with the host system powered down. If the difference is smaller than 10 dB, then the test environment must be changed. This can be done by moving to a quieter space, placing barriers around the host chassis, turning off equipment that is contributing to the background frequency content of concern, etc.

5.3 Recommended Report Template & Communication Flow

The recommended report template is shown in Table 2. Important information includes description of microphones, data acquisition system, host system variables, HDD slot(s) tested, background levels, and test levels. The recommended communication flow between HDD designers and enclosure designers is shown in Figure 5, and the recommended communication flow between enclosure designers and component suppliers is shown in Figure 6.

Parties may choose to provide additional information that may include target thresholds or engineering areas of concern. One such example is shown in Figure 7, whereby the 1/3rd octave unweighted sound pressure levels measured with the OCP HDD Dynamics acoustical surrogate for two cases (and background) in a company's test system are plotted over ranges that indicate risk by a coloration scheme (red = high risk, yellow = medium risk, and green = low risk) to a sample HDD manufacturer's disturbance rejection scheme. Sample data correspond with those in Table 2.

Microphone Type A, Data Acquisition System B, Test Date, Test Contact

	1/3rd Octave Band SPL, dB, at Top cover microphone location		
Center Frequency, Hz	Background	Enclosure X1, Fan Y1 at Z1 RPM, Slot W1	Enclosure X2, Fan Y2 at Z2 RPM, Slot W2
100	74	86	84
125	74	87	84
160	74	89	84
200	74	89	88
250	71	90	89
315	74	92	88
400	70	89	89
500	69	86	88
630	62	85	87
800	62	98	97
1000	62	93	96
1250	69	94	96
1600	71	103	96
2000	68	93	91
2500	64	94	93
3150	61	97	93
4000	58	95	93
5000	54	97	93
6300	54	94	94
8000	50	91	85
10000	52	87	81
12500	48	85	78
16000	44	81	73
20000	40	76	69

Table 2: Recommended report template and sample data.

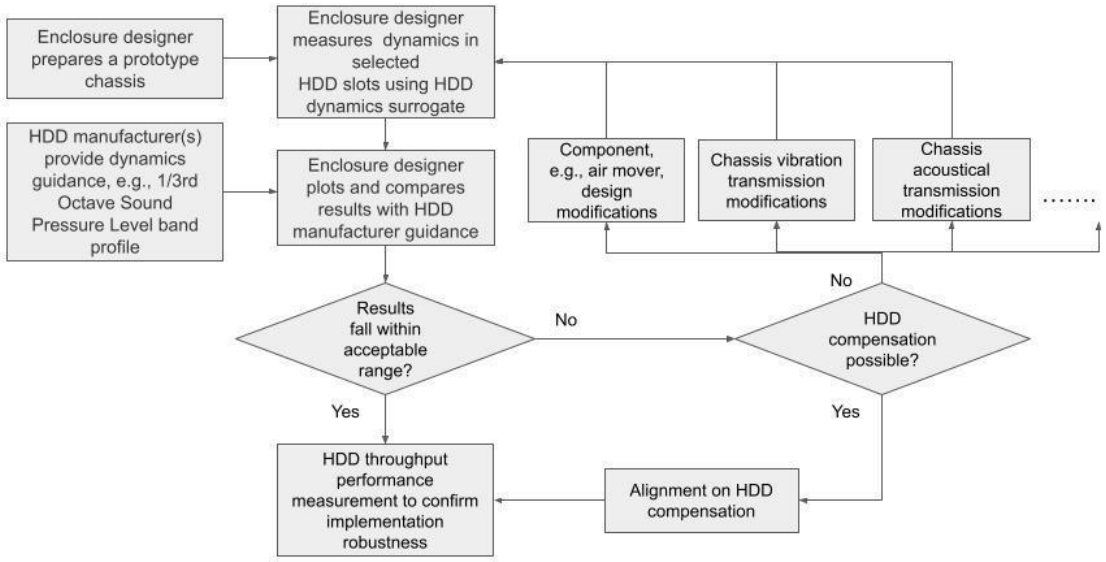


Figure 5: Recommended communication flow between HDD manufacturer and enclosure designer

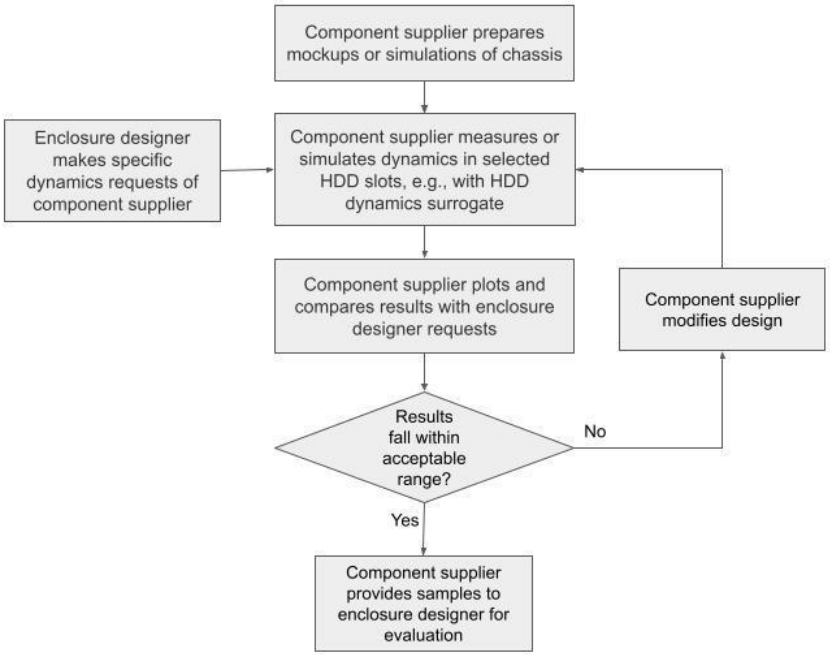


Figure 6: Recommended communication flow between enclosure designer and component supplier, e.g., air mover supplier

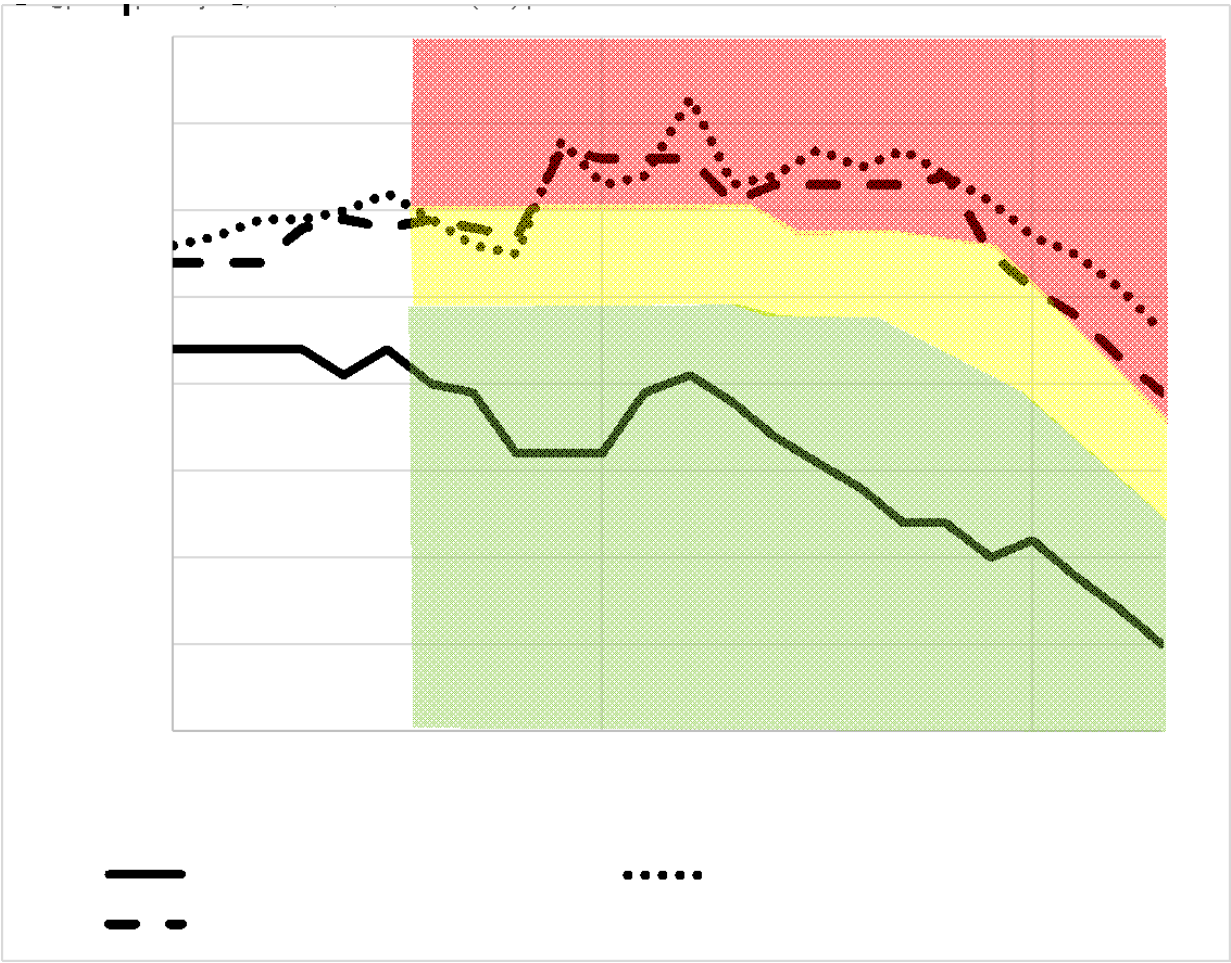


Figure 7: Plot of sample test data overlaid on risk coloration scheme of sample guidelines. The 1/3rd octave band sound pressure level data represented by the dashed and dotted lines reside mostly in the red or high risk zone. Guidelines may vary by HDD manufacturer, model, etc.

6. Conclusion & Future HDD Dynamics Surrogate Development

The authors in conjunction with the OCP Storage Project Community have described hardware and communication tools to facilitate communication among companies on acoustical disturbances to HDD dynamics. A part that resembles a simplified HDD is made of Aluminum and contains microphones at specific locations. Means for testing and acquiring signals relevant to the disturbances are detailed. Finally, a template and examples are provided for interchange of data for assessment of HDD Dynamics acoustical risk.
Future work is proposed to provide guidance for mount impedance and structural vibration for future HDD dynamics and to develop a single surrogate that contains sensors and thus may provide synchronous information for vibration and acoustical disturbance.