Electronics

Optimising storage server chassis design with aeroacoustic simulations

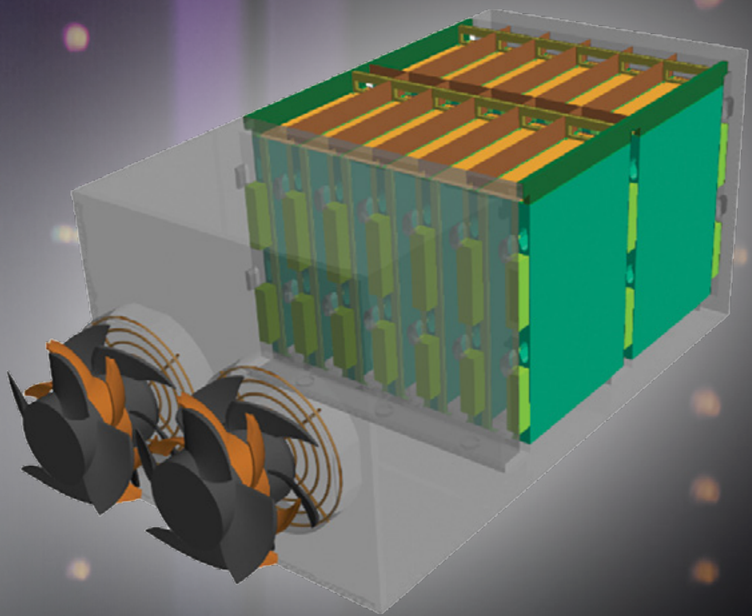
By Kanwardeep Bhachu, Optimisation Engineer at Meta (Facebook)

Meta

Introduction

In the digital age, data makes the world go round. Every day, billions of internet users are generating more and more data, which companies and platforms store on large data centres containing millions of hard drives. These hard drives are similar to what an ordinary person has in their personal computer, but at a larger scale. Multiple drives are arranged in server chassis that are stacked in racks to provide access to the data in the fastest and most reliable way possible. Hard drives are sensitive to vibrations that can cause a loss in the throughput performance or even failure. An analysis by the cloud storage company Backblaze has revealed that of their 200,000 installed drives, about 1% failed during 2021, amounting to about 2,000 drives! Of course, companies that store data like Google and Meta (the parent company of Facebook) have contingency plans with multiple redundancies to avoid data loss. Still, hard drive performance degradation can significantly impact their business, so companies want to ensure smooth operation by design with as little vibration and disturbance as possible.

At Meta, in an effort to maximise the performance of hard drives, a team is working on identifying vibration mechanisms, establishing the importance of such vibrations, developing possible mitigation techniques and optimising chassis design for minimal vibration of the hard disks. “Typically, we relied on a lot of testing. We would prototype a chassis and work with our vendors to find solutions. What we wanted to do was to find out if we could predict hard drive vibrations through simulation early in the design cycle and identify what we could change to control the vibration levels”, says Kanwar Bhachu, the optimisation engineer leading the project. A simulation-based multi-disciplinary optimisation (MDO) approach is deployed to save time and resources, which enables faster iterations than a purely testing approach. Another benefit of this simulation-based approach is that it can give the designer or analyst a clear direction to move towards by identifying what to change and by how much. “This approach could give us this insight in a very powerful way that makes it very efficient to go through a design cycle”, adds Mr. Bhachu.



Challenge

Meta has very high requirements when it comes to their hard drives. One of the most important ones is the hard drive throughput, which is how quickly you can transfer data in a very reliable way.

To understand the impact of vibration on hard drive performance, we first need to understand how a hard drive works. To read and write data, a hard drive must rapidly and accurately position the read/write head –imagine the cartridge and stylus of a vinyl record player – slightly above narrow tracks on rapidly spinning platters. Vibration can have a significant impact since the movements of the head are rapid and precise, and any disturbance can lead to erroneous data read or write.

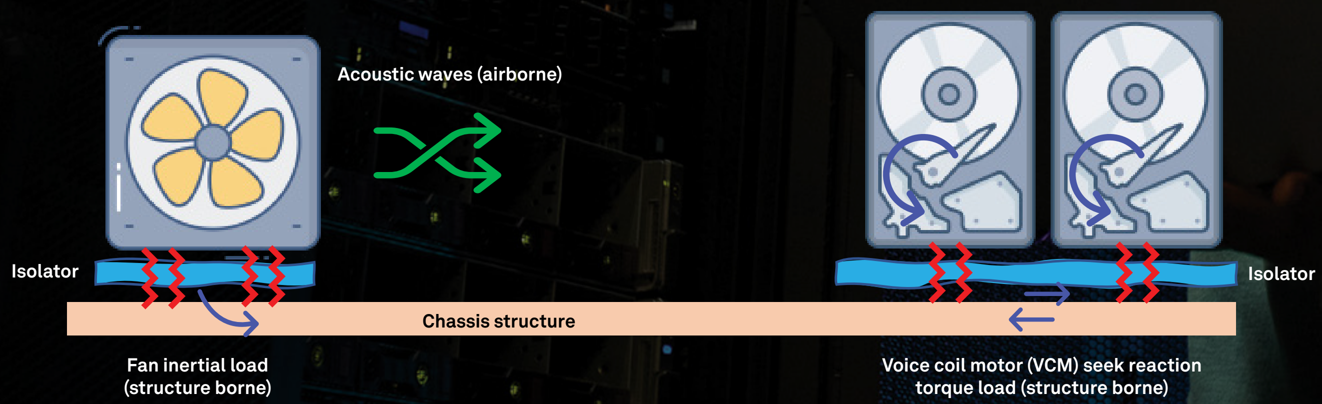
The vibration needs to be evaluated at nominal conditions as well as certain special conditions such a fan failure. Fans are critical to the operation of the storage units that host the hard drives because the main consideration is thermal management or cooling of the electronic components.

There are three main sources of vibration that can contribute to hard drive performance loss: (1) Acoustic loading from the cooling fans, (2) vibration loading from the fans that is transmitted through the chassis of the storage unit and (3) vibration loading from the hard drives themselves.

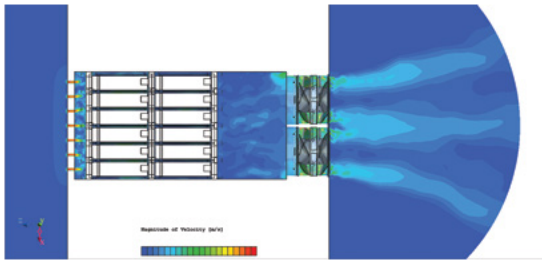
The primary purpose of a fan in a storage chassis is thermal management. However, as the fan rotates and air moves around, aeroacoustic sources create acoustic pressure waves. These acoustic waves are transmitted through the air and upon impacting the lateral faces of the drives, can cause vibration. This source of vibration is typically neglected in the literature, but it can have a significant impact on the overall loading of the hard drives, especially the rows closest to the fans.

Fans are also responsible for the second source of vibration as they are mounted to the walls of the server chassis. Often, they are not perfectly balanced, and this can cause vibrations that can propagate all the way to the hard disks causing them to vibrate.

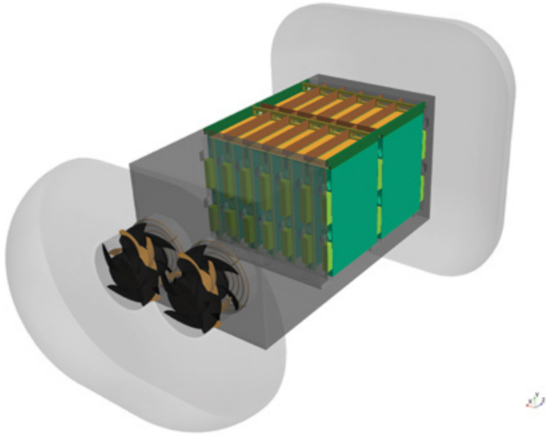
The final source of vibration can come from the hard drives themselves. When the head of a hard drive moves very quickly to go to different places to read the data, the arm that supports the head must accelerate quickly. A rapid acceleration requires a large force, and each action has an equal and opposite reaction which causes rotational vibrations of the hard drive that is then transmitted to the neighbouring drives through the chassis structure.



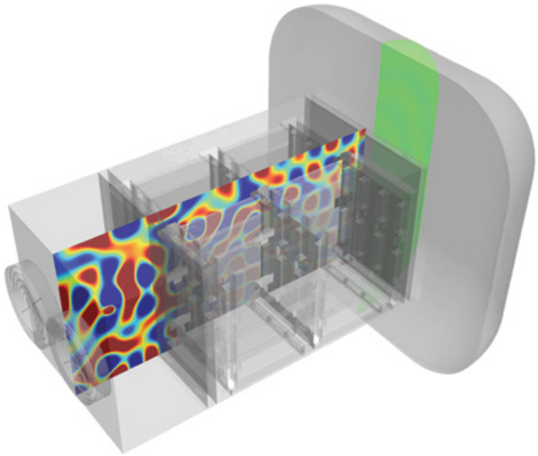
Building trust on an innovative process



After Meta had established that simulation and optimisation could lead to a faster design result for reducing vibrations, the next step would be building upon the main sources of vibration and calculating their impact. A literature study showed that little work had been done on simulating the effect of the mechanical vibrations from the fans and hard drives themselves and none had looked at the aeroacoustic excitation. Following along this unique dimension, Meta approached Hexagon due to its expertise in acoustic and aeroacoustic simulations.

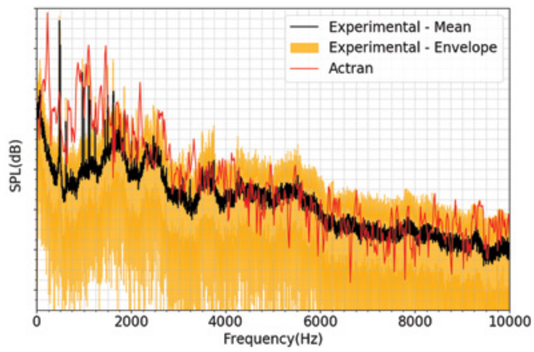


As a first step, a project was created to validate scFLOW, Actran and the team's expertise in fan aeroacoustics. The goal was to simulate a chassis and compare results with measurements, and high-fidelity, resource-intensive simulations based on Large Eddy Simulation (LES) were performed. The flow simulation was run with scFLOW and the acoustic simulation with Actran. "We had made measurements where we put the acoustic sensors inside the hard drives and measured the data. When we compared the prediction versus what was happening in measurements, I would say that predictions correlated well. That was one of the confidence boosters for us to see that.", says Mr. Bhachu.

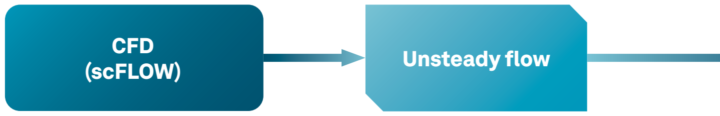


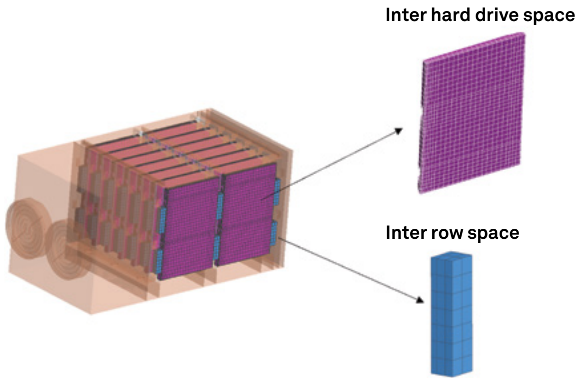
As part of the optimisation strategy, further studies to reduce the computational cost of simulation were performed. One approach utilised duct modes in an effort to validate a reduced model for identifying and evaluating mitigation techniques. With the help of the Hexagon team's expertise, Meta was able to explore further improvements such as: introducing channels for provoking visco-thermal losses, allowing for lower acoustic pressure levels on the drive, integrating honeycomb panels commonly used in aircraft engine liners, and quarter-wavelength Helmholtz resonators which could help with noise cancellation.

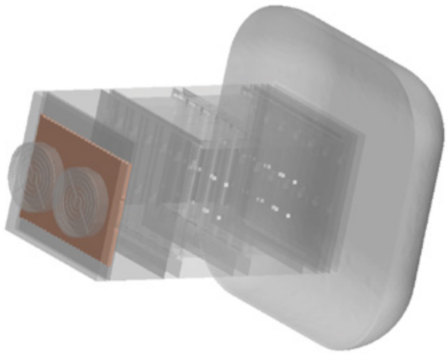
A lot of analysis went into evaluating the different design options, and the solution that was chosen for further exploration and optimisation was the inclusion of vertical channels for visco-thermal effect, a unique proposal by the Hexagon team. These vertical channels were placed between hard drives to dampen the waves in the higher frequency range, which was of primary interest. "These channels managed to reduce the acoustic pressure levels in the order of six decibels, which was a significant reduction", adds Mr. Bhachu.

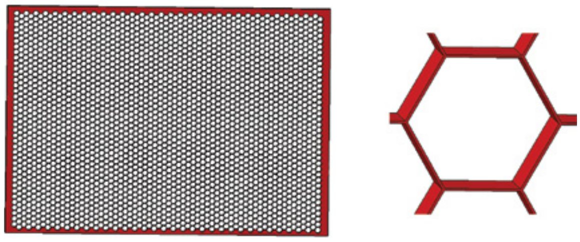


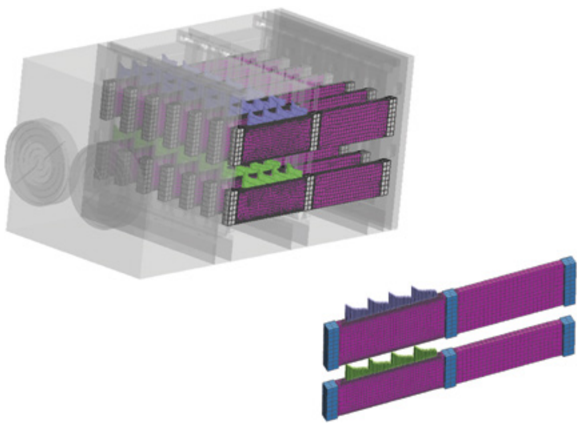
An advantage of the aeroacoustic process with scFLOW and Actran is that the flow simulation, which is the most computationally demanding part of the process, only needs to be run once. After that, modifications in the channels can be simulated without rerunning the flow simulation, resulting in faster turnaround times.











Optimisation

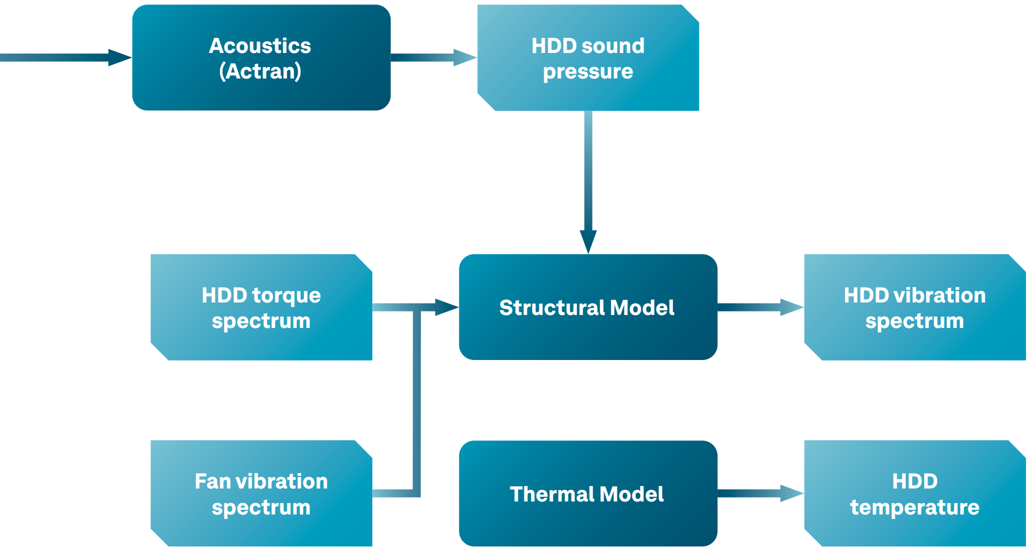
The main objective of the optimisation process was to reduce the vibration while keeping the thermal management efficiency intact. After building confidence in the models, it was important to identify the design variables for the optimisation process. Initially, thirteen design variables could help minimise the vibrations across different sources. For the acoustic source, this involved the visco-thermal channels and specifically, the number of channels and their width. In addition, acoustic foams were also added to target the lower frequency range, and the sound absorption coefficient of the foams was also a design variable. There is a trade-off between reduction in sound pressure levels and thermal efficiency; if the number of channels is increased or the space between the channels is decreased, the sound pressure level on the hard disks would fall. At the same time, however, the airflow is restricted which is undesirable for thermal management. As a result, the surface temperature of the hard disks provides a constraint to the optimisation process.

The simulation workflow has four parts: three based on the sources that need to be evaluated including the acoustic loading from the fans, the mechanical loading from the fans and the mechanical loading from the hard drives themselves, as well as the thermal management model for calculating the hard drive temperature.

Interestingly, the optimisation process features input from both simulation and measurements. The acoustic part of the process and the resulting structural model are both simulation-based. The excitations from the fan imbalance and the hard drive head vibration are measurement-based.

For the simulation-based part of the process, different tools were used for the flow, structural and acoustic analysis. The flow simulation is relied on to generate the unsteady flow that is required to calculate the acoustic response. The average acoustic pressure on the hard drive panels is then mapped onto the structure surface as a function of frequency and solved in a different software package. The fan vibration spectrum and the hard drive torque spectrum both were retrieved from measurements performed by the suppliers. With all the inputs available, the structural model was evaluated to provide the resulting vibration spectrum which served as the objective function of the process. In parallel, the thermal model was run to provide the surface temperature constraint.

During the optimisation process, a machine learning model was used to generate the value of the objective function based on the inputs. Simulations may take a large amount of time to run and for each evaluation of the objective function, a set of

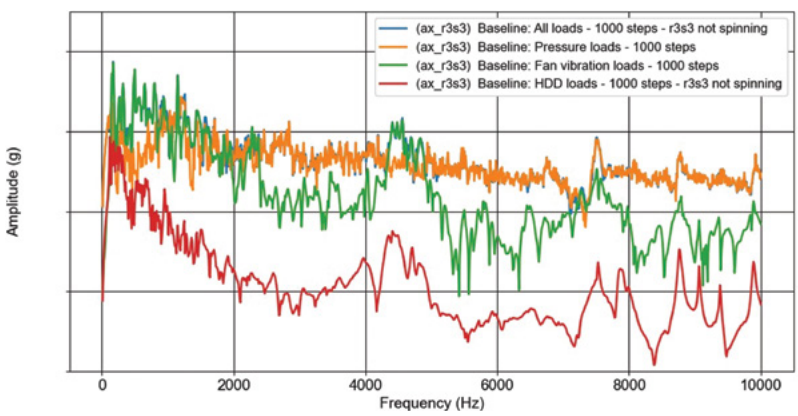


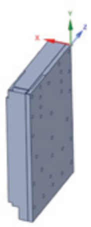
simulations needs to be performed. In order to avoid this time-consuming process, simulations were run at certain points in the design space as defined by a design of experiments technique. A machine learning model was then fit to the data, which was used by the optimisation process to evaluate the objective function value; thus, the overall process was sped up significantly. The whole optimisation process was handled by OpenMDAO, an open-source multidisciplinary optimisation tool built by NASA.

The impact of each design variable on the hard drive vibration was evaluated. Since the model accuracy depends on the proper representation of the design space – meaning the number of simulations required depended on the number of design variables used – the initial thirteen design variables chosen were reduced to six based on this sensitivity analysis.

Overall, the optimisation process led to a total vibration reduction by 50%, a significant amount for the performance of the hard drives, while keeping the thermal management at the same levels as before.

A test surrogate of a hard drive disk was designed for comparing simulations and the optimisation results with measurements. The surrogate housed both accelerometers and pressure sensors into one body, something unique in the industry currently. The trends predicted by the simulation models were reproduced in the measurements and the team at Meta identified ways to improve correlations, such as more complex damping models and more accurate mapping between the acoustic and structural simulation.





Conclusions - the value of a simulation-based design process

A simulation-based optimisation process was performed that resulted in a 50% reduction in vibrations for the hard disks. This approach aimed to supplement a previous workflow that relied completely on testing. Kanwar Bhachu, the optimisation engineer responsible for the project notes on the value of simulation: "If we were to do this only with testing, we would need to go through a limited number of iterations because a prototype needs to be constructed each time. We could only do 5 or 10 different options and then, pick the one that works best, but that did not guarantee that this is the optimal configuration. With the simulation models, we can actually do hundreds of thousands of calculations very quickly." Testing would still be used but only for verification purposes.

Another benefit of building a machine learning model is that what-if scenarios can be run almost instantaneously. This can really speed up discussions with vendors on possible solutions since solution evaluation can be done immediately by querying the machine learning model.

A key enabler for this project was the collaboration with Hexagon. "The team was very helpful in guiding us and helping us choose the right variable and right direction to move on before we thought of fixing an architecture. They were also extremely flexible and accommodating when working on the project which was a very professional way of handling things", concluded Mr. Bhachu.