
Role of Interpolation in Airflow Induced Vibration in Hard Disk Drive Enclosures

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Fluid-structure interaction is vital for the study of airflow induced vibrations, a cause of hard disk drive failure. With the loose fluid-structure coupling, there is a need for an accurate exchange of information at the fluid-structure interface. This work looks at two variations of the Shepard's interpolation method to assess their accuracy in such an exchange and their application in simulating the airflow induced vibration on the actuator arm of a small one-inch form factor.

1 Introduction

As airflow induced vibrations is one of the primary causes of hard disk drive (HDD) failure, it is important to understand the airflow characteristics and fluid-structure interactions for the optimal design of the HDD. While researchers [WC02] have performed experiments on simple rotating disks within a casing, it still remains a challenge to perform experiments on the actual hard disk drives. To this end, simulation is an efficient and economical tool in the early design stages of the HDD. Coupling a Computational Fluid Dynamics (CFD) code and a computational structural dynamics (CSD) code to address the fluid-structure interaction problem, as studied by [TTM01, DAD05], assumes that the accuracy of the information exchanged depends on the accuracy of the interpolation algorithm used. In the present study, Shepard's interpolation method [She68] is used in conjunction with several neighbouring point selection techniques to evaluate the accuracy of these techniques in exchanging the information for the airflow induced vibration studies for a one-inch HDD.

2 Models and Algorithms

Based on the studies conducted by Goh et. al. [GDN05], the airflow within the one-inch HDD as shown in Figure 1(a) can be modeled by the incompressible Navier-Stokes equations with no-slip boundary conditions while the structural

deformation is assumed to be elastic. Only pressure forces are imposed on the structural domain at the interface since the viscous forces on the structure are assumed to be much smaller than the pressure forces. The current fluid-structure interaction considers only a one-way coupling from the CFD (*Fluent* [Flu05]) to the CSD solver (*Abaqus* [ABQ05]) due to the very small deflections of the structures with the exchange of information facilitated by Shepard’s interpolation method [She68].

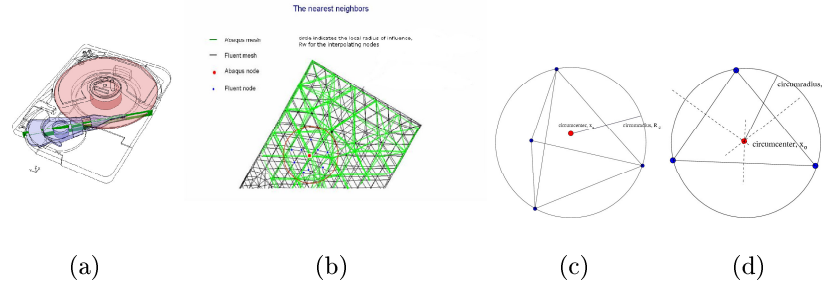


Fig. 1. (a) HDD enclosure configuration and construction of the (b) local region of influence via (c) circumsphere and (d) circumcircle methods.

Shepard’s interpolation method [She68], also known as the inverse distance weighted method, can be expressed as $F(\mathbf{x}) = \sum_{k=1}^N w_k(\mathbf{x})f_k / \sum_{k=1}^N w_k(\mathbf{x})$ for a given scattered data, $f(\mathbf{x}_k)$ and weights, $w_k(\mathbf{x}) = (d_k)^{-n} = \|\mathbf{x} - \mathbf{x}_k\|_2^{-n}$, where usually $n = 2$, which takes into consideration the influence of all of the data. An improvement to the weighting functions could be found by selecting nearby data points, thus limiting the influence of the scattered data to a local subset of data points [She68, FN80] where the weights should be dependent on a local radius, R_w centered at \mathbf{x} as shown in Figure 1(b).

In the present study, two techniques for obtaining R_w and the variations of the weighting function based on the information on the non-matching fluid and structural meshes are proposed. The techniques assume that the meshes are tetrahedral meshes and estimate the associated circumspheres and circumcircles. Similar methods could be derived for hexagonal or wedge elements. The first technique constructs a circumsphere for each element of the coarser mesh as shown in Figure 1(b) and the second technique constructs a circumcircle for each surface element of the coarser mesh as shown in Figure 1(c). The choice of the coarser mesh is to ensure that the local radius obtained will be large enough to include the nodes of both meshes. In the construction of circumsphere, the circumcenter, \mathbf{x}_0 , and the circumradius R_c could be obtained using the equations given in the *MathWorld* website [Wei99] utilizing the four nodes of the tetrahedral elements. For the circumcircle, \mathbf{x}_0 is found by the intersection of the three perpendicular bisectors of the edges of each

triangular face. The circumradius, R_c , is then obtained as $R_c = \|\mathbf{x}_0 - \mathbf{x}_i\|_2$ where i denotes one of the three nodal points of the triangular face element. Having obtained the circumcenter and circumradius for each element, the new weights for Shepard’s interpolation for any node, \mathbf{x} , within the radius R_c of each coarse mesh element can be established as follows:

$$w(\mathbf{x}) = \begin{cases} G & : d_k \leq \epsilon \\ (d_k)^{-n} & : \epsilon < d_k \leq R_c \\ 0 & : d_k > R_c \end{cases} \quad (1)$$

for some big number G and small tolerance, ϵ . The first criterion for Equation 1 is selected to avoid discontinuity of $w(\mathbf{x})$ t \mathbf{x}_k .

3 Results and Discussion

The HDD enclosure in Figure 1 consists of a single disk rotating at 3600 rpm, a latch, and an actuator arm with sliders. The material used for the actuator arm is aluminium which has a density of 2700 kg/m³, Young’s Modulus of 70 GPa and a Poisson ratio of 0.33.

In order to compare the performance of the various weighting functions, two test functions have been adapted from Gantovnik et. al. [GGW04], i.e.

$$f_1(\mathbf{x}) = 1 - 2/3(|x_1 - 0.001| + |x_2 - 0.02| + |x_3 - 0.003|) \quad (2)$$

$$f_2(\mathbf{x}) = \begin{cases} 2/3(x_1 + x_2 + x_3) & , \sum_{i=1}^3 x_i \leq 0.03 \\ -2/3(x_1 + x_2 + x_3) + 0.05 & , \sum_{i=1}^3 x_i > 0.03 \end{cases} \quad (3)$$

For assessing accuracy, the approximation error is characterized by the maximum relative error, e_{max} , and the mean relative error, \bar{e} . The errors of Shepard’s original method [She68], Franke-Nielson’s method [FN80], the circumcircle and circumsphere methods are tabulated in Table 1. Based on Table 1, the circumcircle and circumsphere techniques seem to out-perform Shepard’s and Franke-Nielson methods in their interpolation results when comparing the mean relative error for the given test functions.

Table 1. Interpolation errors for the test functions (%)

Test functions	Errors	Shepard	Franke-Nielson	Circumsphere	Circumcircle
1	e_{max}	0.8	0.4	0.05	0.04
	\bar{e}	0.3	0.1	0.005	0.005
2	e_{max}	26.4	28.3	33.3	33.3
	\bar{e}	6.6	2.0	0.2	0.2

Modal analysis has been performed on the actuator arm to compute its natural frequencies prior to the fluid-structure interaction. Figure 2(a) and

(b) show the first bending and sway modes contributing to the on-track and off-track displacements respectively. The on-track displacement is the displacement along the plane in Figure 1(a) (in green) while the off-track displacement is the displacement perpendicular to the plane.

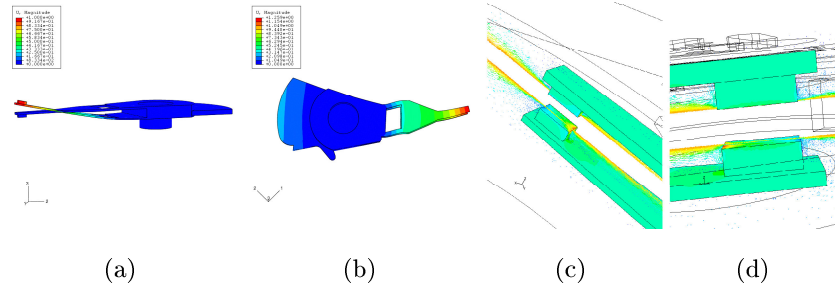


Fig. 2. First (a) bending (mode 1 = 2.066kHz) and (b) sway modes (mode 5 = 17.917kHz) and the initial flow characteristics (c) Gauge static pressure and (d) Velocity Vectors in the vicinity of the sliders

First the steady flow field corresponding to a fixed disk rotational speed in the HDD enclosure are computed and used as the initial flow conditions for the study of the unsteady flow field associated with fluid structure interactions. Figure 2(c) and (d) show that the highest and lowest pressures are located on these slider surfaces as well as the formation of several recirculation flow regions in the vicinity of the sliders. Random fluctuations are then added to the steady velocity field to evaluate the response of the CFD and CSD models. A global time step size of $50 \mu s$ based on flow physics consideration is used to advance the solution to model the unsteady flow, utilizing Shepard's method, the circumcircle and circumsphere techniques to transfer information from the CFD model to the CSD model.

The computed time variation of the computed on-track and off-track displacements of the lower slider based on the three interpolation methods for the first $10 ms$ are shown in Figure 3(a) and (b) respectively. Figure 3 shows that the displacement amplitudes from the circumcircle and circumsphere techniques are much larger than those from the Shepard's method. The off-track displacement amplitudes of the circumcircle and circumsphere techniques are similar as observed in Figure 3(a) while the on-track displacement amplitudes of the two techniques differ by a factor of ten as shown in Figure 3(b). The larger displacement amplitudes could be attributed to the ability of these two techniques in capturing the actual pressure distribution on the actuator arm.

Based on the displacement amplitudes of Figure 3(a) and (b), the accuracy of the interpolation results affects the on-track displacements more than the off-track displacements. The mean relative errors shown in Table 2 clearly

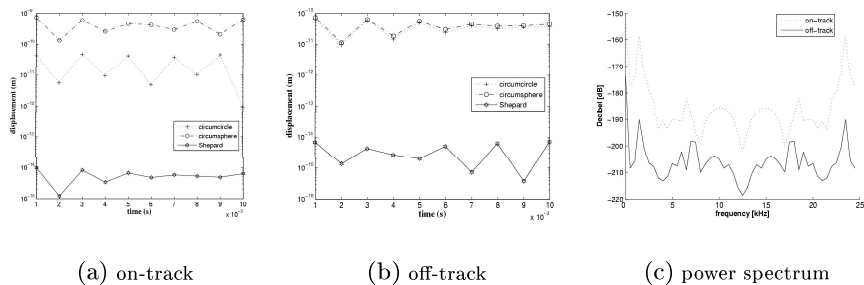


Fig. 3. (a)On-track and (b)Off-track displacement amplitudes (in meters) of the lower slider and (c) the corresponding vibration power spectrum using circumcircle technique.

Table 2. Percentage mean relative errors of pressure

Time (ms)	1	2	3	4	5	6	7	8	9	10
Circumsphere	2.92	3.16	2.49	9.22	5.75	4.53	2.73	2.64	2.45	3.94
Circumcircle	1.06	1.14	1.08	4.50	1.12	2.09	1.11	1.14	1.07	1.85

indicate that the results from the circumcircle technique are relatively more accurate than those from the circumsphere technique. This difference in accuracy could be attributed to the size of the coarser mesh elements in relation to the thickness of the actuator arm. The inaccuracy of the interpolation results of circumsphere technique arises from the inclusion of pressure values from both the upper and lower surfaces of the arm as opposed to those of the circumcircle technique due to the size of the coarse mesh spanning both surfaces. However, the mean relative interpolation errors shown in Table 2 for both techniques based on pressures from the nearest neighbouring fluid nodal points are less than ten percent of the actual pressure values of these neighbouring points. These figures give some assurance on the accuracy of the two techniques in capturing the pressure distribution.

Using Discrete Fourier transformation on the displacements determined from *Abaqus* for the circumcircle technique, the frequency analysis is plotted in Figure 3(c). Though offsetted by about 30 dB, the off-track and on-track power spectrum patterns are similar with several peaks. The first peak could be found at 2 kHz which is close to the natural frequency of the actuator as shown in Figure 2(a) and similarly, the peak at 18 kHz is close to the natural frequency of the fifth mode as shown in Figure 2(b). These close proximities to the natural frequencies are likely to lead to the problem of vibrational resonance and affect the integrity of data being written or retrieved by the actuator arm. However, this analysis is still incomplete due to the lack of experimental data validation and the fact that the slider to disk gap used for the present study is around $9 \mu\text{m}$ which is much larger than the nano-sized gap of the actual HDD assembly.

4 Conclusions

The role of interpolation methods in ensuring the accuracy of the information passed between the CFD and CSD solver is explored in this paper and it is found that the displacement amplitudes are sensitive to the difference in interpolation results. The two techniques greatly improve on the interpolation results of the Shepard's method by enforcing selection rules for the local subset of the data points with the circumcircle technique observed to be more accurate. As fluid-structure interactions are applied to smaller structures, the accuracy of the interpolation methods used in the loose-coupling approach play an increasingly important role in ensuring the accuracy of the results.

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