Kinetics Noise Control, Inc.
6300 Irelan Place
Dublin, OH 43017-0655
www.kineticsnoise.com

The Effects of the Air Space on the Natural Frequency of an Acoustical Floating Floor

Richard Sherren P. E.[1]

Introduction:

Floating floors are used to reduce vibration and sound transmission between rooms. Typically the source room is the one above, and the floating floor is intended to reduce the sound and vibration that passes to the receiver room below. The floating floor is typically supported on the structural floor by an array of discrete resilient isolators. There will be an air space between the floating floor and the structural floor surrounding the discrete isolators. For the floating floor to be effective in reducing the sound transmission between the two rooms, it must be completely sealed around its perimeter to prevent the movement of air, and thus sound, between the rooms. Further, the structural floors and the interface with any walls are also sealed to prevent the passage of air and sound, flanking, around the structural floor. The sealing of the floors and walls creates a sealed air chamber between the floating floor and the structural floor. Any vertical displacement of the floating floor due to walking, aerobics, dancing, and etc. will compress and decompress the air in the air space causing it to act like a spring. The entrapped air between the two floors will have a stiffness that must be accounted for when determining the overall stiffness of the floating floor system in order to assess its effectiveness in mitigating the vibration transmission from the source room to the receiver room. This paper will present the current theory and assumptions used to compute the stiffness of the entrapped air and its effect on the natural frequency of the floating floor system.

Basic Theory for Estimating the Stiffness of the Entrapped Air:

A section through a basic floating floor is shown in Figure 1 below. The isolators actually support the dead load of the floating floor and any objects that are resting on it. The floor is

[1] Richard Sherren is Chief Mechanical Engineer for Kinetics Noise Control in Dublin, Ohio. He holds a B.S.M.E. and an M.S.M.E. both from West Virginia University. He is a member of ASHRAE, and an Allied Professional Member of the AIA.

shown deflected to the static operating height of the isolators. Any motion of the floating floor due to activities in the source room will be about this static operating height.

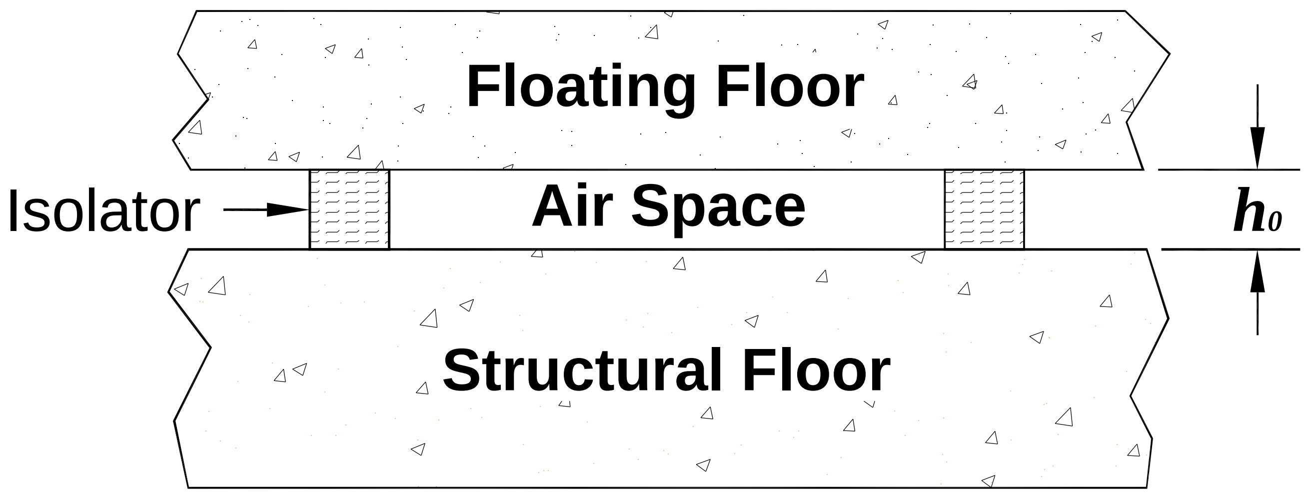

Figure 1; Section through a Typical Floating Floor

This paper will concentrate on the stiffness of the entrapped air in the air space between the two floors. Some basic assumptions will need to be made in order to start the investigation.

1. The floating floor is an acoustical floor, and thus is sealed so that the air is entrapped between the floating floor and the structural floor.
2. The isolators will be assumed to provide support for the dead weight load of the floor only, and have a stiffness that is much less than the stiffness of the entrapped air. For the purposes of this paper, the stiffness of the isolators will be ignored.
3. If the floating floor is rigid, such as a concrete slab, the entire floating floor will be evenly displaced under the excitation applied to the floor. If the floating floor is somewhat flexible such that only the area surrounding the excitation point is displaced, the resistance to the movement of air radially outward away from the excitation point will be assumed to be high enough to maintain the spring like action of the entrapped air.

Further assumptions will be made and noted as required as the investigation proceeds. The expression for the stiffness of the entrapped air has been performed elsewhere by Vér[2] and Ungar[3]. The approximation of the stiffness of the entrapped air between the floors will begin with the polytropic gas equation from thermodynamics.

$$pV^{\gamma} = Constant$$ **Equation 1**

Where:

p = the pressure of the entrapped air between the floors at any given time (psi). This will be the absolute pressure rather than the gage pressure.

V = the volume of the air space between the two floors at any time (in^3). This can be the total volume between the two floors, or the volume beneath the area of the floor supported by a single isolator in the array.

γ = the ratio of the specific heat of the air at a constant pressure to the specific heat of the air at a constant volume.

And;

$$\gamma = \frac{C_P}{C_V}$$ **Equation 2**

Where:

C_P = the specific heat of the entrapped air between the floors at a constant pressure.

C_V = the specific heat of the entrapped air between the floors at a constant volume.

The initial state of the entrapped air between the floors may be related to its state at any other time by Equation 1 as follows.

---

[2] Vér, Istán L., *Acoustical and Vibration Performance of Floating Floors*; Bolt, Beranek, and Newman; BBN Project 135250, Report No. 1830; July 29, 1969

[3] Ungar, Eric E.; *Design of Floated Floors to Avoid Stiffness Effects of Entrapped Air*; Noise Control Engineering, July – August 1975, Vol. 5, No. 1; pp12 – 16

$$p_0 V_0^{\gamma} = pV^{\lambda}$$ **Equation 3**

Where:

p_0= the initial pressure in the air space (psi). This will be assumed to be atmospheric pressure. Even though the floor is sealed, no seal that can be installed in a structure is going to be perfect, and over time the "dead load" pressure in the air space will equalize with the outside atmospheric pressure. For the purposes of this paper, $p_0 = 14.7\,psi$.

V_0= the initial volume of the air space (in3). This will take into account the static deflection of the isolators if they are nonadjustable.

The pressure at any given time in the air space from Equation 3 will be;

$$p = p_0 \left(\frac{V_0}{V} \right)^{\gamma}$$ **Equation 4**

When the floating floor is excited, the volume of the sir space will change with time as it is compressed and then allowed to expand. The dynamic pressure component may be determined by differentiating Equation 4 with respect to the volume of the air space.

$$\frac{dp}{dV} = -\gamma p_0 V_0^{\gamma} \left(\frac{1}{V^{\gamma+1}} \right)$$ **Equation 5**

Rearranging Equation 5, the dynamic pressure fluctuation will be;

$$dp = -\gamma p_0 V_0^{\gamma} \left(\frac{dV}{V^{\gamma+1}} \right)$$ **Equation 6**

If the isolators are properly specified and sized, it is reasonable to assume that for excitation frequencies down to as low a 1 Hz to 3 Hz the displacement of the floating floor will be small with respect to the static operating height of the air space. Thus the changes in the volume of the air space over time will be very small. Therefore, it may also be assumed that the volume of the air space when the floor is displaced during excitation is approximately equal to the initial volume of the air space, or $V \approx V_0$. The Equation 6 may be simplified and rewritten as;

$$dp = \left(-\frac{p_0 \gamma}{V_0} \right) dV \qquad \textbf{Equation 7}$$

The following substitutions will be convenient.

$$V_0 = A_F h_0 \qquad \textbf{Equation 8}$$

$$dV = A_F dh \qquad \textbf{Equation 9}$$

$$dp = \frac{dF_A}{A_F} \qquad \textbf{Equation 10}$$

Where:

A_F = the area covered by the floating floor (in^2). This may also be taken as the area of the floor supported by a single isolator in the array.

h_0 = the initial operating height of the air space (in).

dh = the change in the height of the air space which is also the displacement of the floating floor (in).

h = the height of the air space at any given time (in).

dF_A = the dynamic component of the force exerted on the floor by the entrapped air in the air space (lbs).

F_A = the force exerted on the floor by the entrapped air in the air space (lbs).

Substituting Equations 8, 9, and 10 into Equation 7 will yield the following result.

$$dF_A = -\left(\frac{p_0\gamma}{h_0}\right)A_F\,dh$$ **Equation 11**

It will be convenient to let the displacement of the floating floor to be expressed as follows.

$$dh = -x_F$$ **Equation 12**

Where:

x_F = the displacement of the floating floor from the static condition (in).

Then;

$$dF_A = \left(\frac{p_0\gamma}{h_0}\right)A_F\,x_F$$ **Equation 13**

Equation 13 follows the form of that for a linear spring such that;

$$F = Kx$$ **Equation 14**

Where:

F = the force acting on the linear spring (lbs).

K = the spring rate, stiffness, of the linear spring (lb/in).

x = the displacement of the linear spring under the force F (in).

Using this analogy of a linear spring depicted in Equation 14 with Equation 13, the spring rate, or stiffness, of the entrapped air in the air space between the two floors will be;

$$K_A = \frac{p_0 A_F \gamma}{h_0}$$ **Equation 15**

Where:

K_A = the spring rate, or stiffness, of the entire air space covered by the floating floor (lb/in).

It is not uncommon for a request to be made for an evaluation of a floor system without prior knowledge of the exact area to be covered by the floating floor. For cases like this it will be convenient to normalize the stiffness of the air space with respect to the area of the floating floor. The normalized form of Equation 15 will be;

$$k_A = \frac{p_0 \gamma}{h_0}$$ **Equation 16**

Where:

k_A = the spring rate, or stiffness, of the air space normalized with respect to the area of the floating floor, or the area supported by a single isolator in the array (lb/in^3) or (psi/in).

The value of γ will depend on the type of thermodynamic process which the entrapped air is undergoing, typically $1.0 \le \gamma \le 1.4$. For a reversible adiabatic process, $\gamma = 1.4$. If the process is isothermal, $\gamma = 1.0$. Under the adiabatic process the excitation frequency is such that the entrapped air is heated as it is compressed and cools as it expands, the pressure fluctuations are magnified by the increase in the temperature of the air under compression making the "air spring" appear to be stiffer. For an isothermal process, the compression and expansion happen slowly enough that the there is no appreciable change in the temperature of the entrapped air. The transition point between isothermal and adiabatic behavior is thought to be at an excitation frequency of less than 0.01 Hz[4]. Both Vér[2] and Ungar[3] indicate that if adequate heat transfer away from the entrapped air can occur, then up to around 50 Hz, the process may be considered to be adiabatic. Also, both Vér[2] and Ungar[3] suggest that filling the air space with a loose fibrous material, e.g. fiberglass, rock wool, or etc., will provide this additional heat transfer area, providing a buffer to slow the flow of air, and thus produce a

[4] Rothbart, Harold A. Editor-in-Chief; Mechanical Design and Systems Handbook, McGraw-Hill Book Company, 1964; Section 36, Schuder, Charles B.; *Pneumatic Components*, pg 36-12

situation where the compression and expansion of the floor under excitation will be isothermal. So;

$\gamma = \mathbf{1.0}$ For an air space that is filled with loose fibrous material.

And;

$\gamma = \mathbf{1.4}$ For an air space that is empty, or not filled with loose fibrous material.

To evaluate the effects of the air space on the natural frequency of an acoustical floating floor it will be necessary to define the natural frequency in terms of the normalized stiffness of the air space. Also, the floating floor will be assumed to be a single degree of freedom system without damping. The natural frequency of such a system has been shown by Ungar[3] to be;

$$f_N = \frac{1}{2\pi}\sqrt{\frac{gk_A}{w_F}} \qquad \textbf{Equation 17}$$

Where:

f_N = the primary natural frequency of the floating floor system (Hz).
w_F = the weight of the floating floor normalized with respect to the area of the floating floor, or the area supported by a single isolator in the array (lb/in^2) or (psi).
g = the acceleration due to gravity (386.4 in /sec^2).

Using Equation 16, Equation 17 may be more conveniently expressed as;

$$f_N = \frac{1}{2\pi}\sqrt{\frac{gp_0\gamma}{h_0 w_F}} \qquad \textbf{Equation 18}$$

The results from Equation 18 are shown in Tables 1 and 2 and plotted in Figures 2 and 3.

Table 1; Natural Frequency of the Floating Floor Based on the Entrapped Air Stiffness vs. Floating Floor Load – No Loose Fibrous Material Fill in the Air Space.

Air Space Operating Height (in)	Floor Load (psf)						
	5	10	20	30	40	50	60
0.25	152.3	107.7	76.2	62.2	53.9	48.2	44.0
0.50	107.7	76.2	53.9	44.0	38.1	34.1	31.1
0.75	87.9	62.2	44.0	35.9	31.1	27.8	25.4
1.00	76.2	53.9	38.1	31.1	26.9	24.1	22.0
2.00	53.9	38.1	26.9	22.0	19.0	17.0	15.5
3.00	44.0	31.1	22.0	18.0	15.5	13.9	12.7
4.00	38.1	26.9	19.0	15.5	13.5	12.0	11.0
5.00	34.1	24.1	17.0	13.9	12.0	10.8	9.8
6.00	31.1	22.0	15.5	12.7	11.0	9.8	9.0

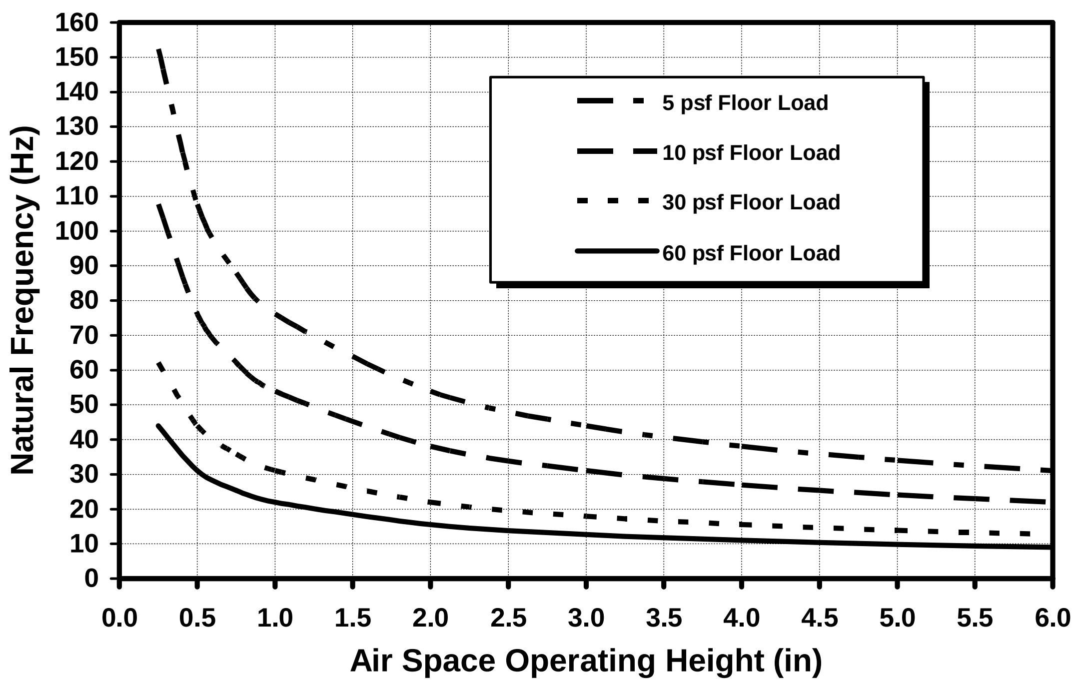

Figure 2; Plot of the Natural Frequency of the Floating Floor Based on the Entrapped Air Stiffness vs. Floating Floor Load – No Loose Fibrous Material Fill in the Air Space.

Kinetics Noise Control, Inc.
6300 Irelan Place
Dublin, OH 43017-0655
www.kineticsnoise.com

Table 2; Natural Frequency of the Floating Floor Based on the Entrapped Air Stiffness vs. Floating Floor Load – With Loose Fibrous Material Fill in the Air Space.

Air Space Operating Height (in)	Floor Load (psf)						
	5	10	20	30	40	50	60
0.25	128.7	91.0	64.4	52.6	45.5	40.7	37.2
0.50	91.0	64.4	45.5	37.2	32.2	28.8	26.3
0.75	74.3	52.6	37.2	30.3	26.3	23.5	21.5
1.00	64.4	45.5	32.2	26.3	22.8	20.4	18.6
2.00	45.5	32.2	22.8	18.6	16.1	14.4	13.1
3.00	37.2	26.3	18.6	15.2	13.1	11.8	10.7
4.00	32.2	22.8	16.1	13.1	11.4	10.2	9.3
5.00	28.8	20.4	14.4	11.8	10.2	9.1	8.3
6.00	26.3	18.6	13.1	10.7	9.3	8.3	7.6

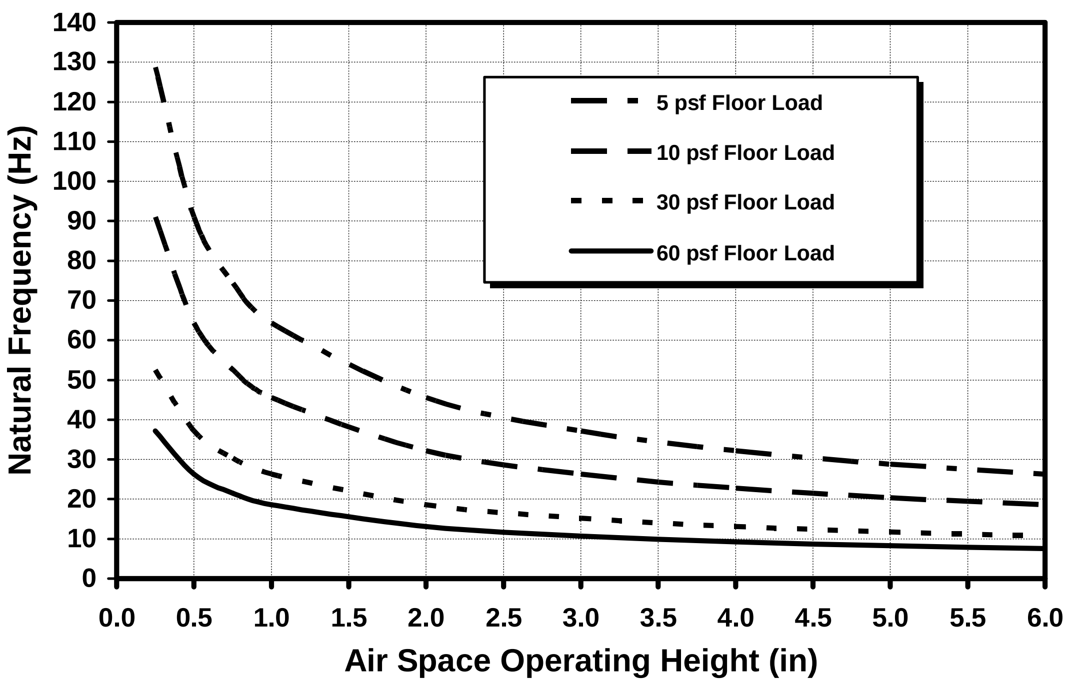

Figure 3; Plot of the Natural Frequency of the Floating Floor Based on the Entrapped Air Stiffness vs. Floating Floor Load – With Loose Fibrous Material Fill in the Air Space.

Discussion:

In each case, as one would expect, the natural frequency of the floating floor decreases with increasing air space operating height and increasing floor load. Regardless of the type of isolator used to support the floating floor, these results represent the minimum possible natural frequency for the floating floor system for each combination of air space operating height and floor load. For most floating floor applications, a 2″ air space operating height is the maximum that may be used due to the amount of vertical room available for the floating floor. From Table 2, with a 2″ air space operating height and a loose fibrous fill material in the air space, the lowest possible natural frequency for the floating floor system will be ~13.1 Hz, and that is with a 60 psf floor load.

When the stiffness of the isolators is considered, it will be added directly to the stiffness of the entrapped air. This is because the isolator and the entrapped air are each subjected to the total displacement of the floor, and thus behave as if they are springs acting in parallel.

It is apparent that the stiffness of the entrapped air between the floors of an acoustical floating floor system has a significant impact on the primary natural, or resonance, frequency of the floor system. This must be taken into account when recommending floating floor systems for specific applications.

The use of a floating floor system that includes a loose fibrous material fill in the air space will greatly improve the performance of the floating floor system in the lower frequency ranges. With the proper selection of isolators, the systems with the loose fibrous material fill in the air space should perform quite well in high impact applications such as aerobics, basketball courts, dance floors, exercise centers, and etc.