Welcome to Vibrationdata

Acoustics • Shock • Vibration • Signal Processing **May 2005 Newsletter**

Hello!

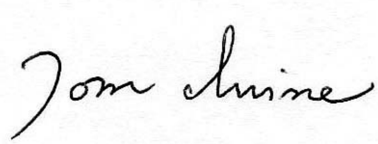
My family and I recently visited Independence Hall. Delegates of the Continental Congress signed the Declaration of Independence in this historic building on July 4, 1776. George Washington presided over the Constitutional Convention in this hall as the delegates debated the Constitution, from May to September 1787.

The noble principles of freedom set forth by men such as Benjamin Franklin, Thomas Jefferson, James Madison, and George Washington provide an illuminating beacon to a world burdened with terrorism and tyranny.

This month's newsletter pays tribute to the Founding Fathers by providing an engineering discussion of the Liberty Bell, as well as measured acoustical data from the Centennial Bell.

As an unrelated aside, the third article gives measured data for elevator jerk and acceleration.

Sincerely,



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Feature Articles

Independence Hall, Philadelphia
(Photo courtesy of Yi Su)

The Liberty Bell by Tom Irvine

History

The Liberty Bell symbolizes early America's struggle for independence and freedom. The bell is a bronze alloy composed of 70 percent copper and 25 percent tin, along with other trace metals. It has a 12-foot circumference. It is currently located in a museum adjacent to Independence Hall in Philadelphia. This hall was originally the Pennsylvania State House.

The Pennsylvania Assembly ordered the bell in 1751 to commemorate the 50-year anniversary of William Penn's 1701 Charter of Privileges. It was cast in 1752 by the Whitechapel Bell Foundry in London, England. It cracked, however, in March 1753.

The bell was recast by John Pass and John Stow of Philadelphia, but the tone of the recast bell proved unsatisfactory. Pass and Stow recast the bell once again. The third bell was hung in the steeple of the State House in June 1753. The names of Pass and Stow are inscribed on the bell.

Declaration of Independence

The Second Continental Congress publicly read the Declaration of Independence on July 8, 1776. The bell was rung to summon citizens for this historic event.

The bell was temporarily moved to a secure location in Allentown, Pennslyvannia in 1777, when the British were advancing on Philadelphia.

It was later moved back to the State House.

Naming

The bell was officially named the Liberty Bell in 1837, when it became a symbol of the abolistionist movement because of its cast inscription from Leviticus 25:10:

"Proclaim Liberty throughout all the land unto all the inhabitants thereof."

Tuning

The strike note of the Liberty Bell is E flat.

Crack Formation and Repair

The Liberty Bell was rung on every July 4th and on every state occasion until 1846. There is a lack of consensus as to when the first crack formed in the Liberty Bell.

The crack eventually reduced the sound quality so that a repair was required in 1846. The goal was to repair the bell for celebration of Washington's Birthday on February 23, 1846.

The Liberty Bell could have been recast for a fourth time.

A much less effective repair method was used instead. The method, known as stop drilling, required drilling along the hairline crack to prevent the sides of the fracture from vibrating against each other. Two rivets were inserted in this slot to control the vibration of the two sides and restored the bell's tonal quality.

The repaired bell was rung on Washington's Birthday, but the crack propagated to the crown of the bell rendering it unusable.

Crack Theories

The initial crack in the Liberty Bell formed due to some combination of brittleness, residual stress, and vibration fatigue.

As an oversimplification, a brittle failure would be due to a single event overload, whereas a fatigue failure would be due to accumulated stress reversal cycles.

Clapper Impact

One theory is that the clapper always struck the same spot inside the bell. George R. Meneely later patented a bell rigging that allowed the clapper to rotate freely inside a bell, thus significantly reducing the potentials for crack formation. Meneely's foundry cast a replacement bell in 1876 to celebrate America's centennial. This Centennial Bell still sits in the Independence Hall belfry today.

Another concern is that the Liberty Bell was designed so that the entire bell would be swung. Instead, the bell was actually rung by swinging a rope which was attached to the clapper. This method is called clappering.

Clappering is used for stationary bells such as Big Ben in Westminster. Nevertheless, the clapper impact must be as light and as well-controlled as possible to avoid excessive stress. Some mechanical control method is thus necessary. Big Ben indeed has a control mechanism, but the Liberty Bell did not.

Brittleness

The tin content near the crack initiation point may have been too high, resulting in brittleness. Brittle materials may fracture if the impact force is too high.

Residual Stress

Furthermore, casting of bells requires great metallurgical precision. Rapid cooling can make a bell prone to crack. In particular, the casting may induce "residual stress."

Material had been chipped away from the Liberty Bell's lip or rim, so that its natural frequency would be tuned to E flat. This process may have induced further residual stress. In addition, the resulting jagged material in the bell's lip may have had high "stress concentration factors."

Conclusion

Eventually, any given bell will develop cracks, whether due to fatigue or to a single overload impact. Even Big Ben has a crack, which is 180 degrees from the point of the striker impact, according to Reference 1.

The Liberty Bell should thus be considered in historical perspective.

The Liberty Bell recast by Pass and Stowe provided 83 years of service, ringing in the birth of a free nation. It continues to serve as powerful symbol of freedom today.

Reference

1. A. R. Rosenfield, "A Crack in the Liberty Bell," International Journal of Fracture, December 1976.

The Centennial Liberty Bell by Tom Irvine

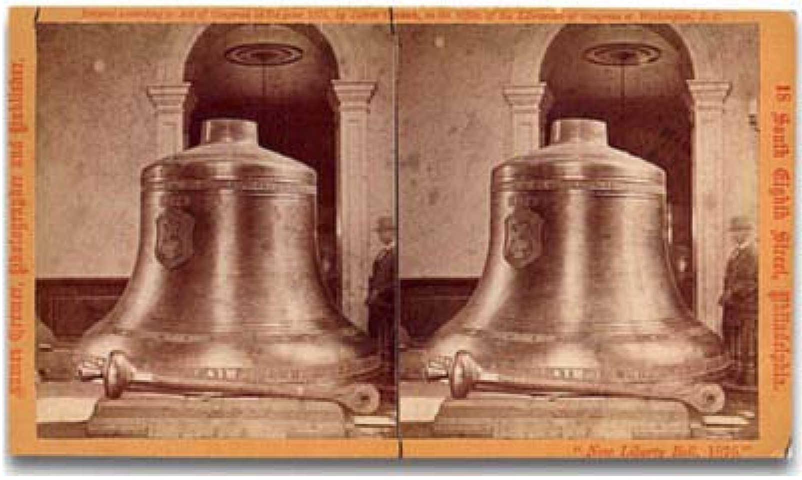

Figure 1. Henry Seybert's Centennial Liberty Bell

<u>History</u>

The Centennial Liberty Bell is the current bell in the Independence Hall tower in Philadelphia. It replaced the Liberty Bell which had become unusable after 83 years of service.

Henry Seybert donated a new bell and a large clock for the tower of Independence Hall in 1873.

Seybert commissioned the Meneely and Kimberly Bell Foundry to cast the bell and install it in the steeple by July 4, 1876, in time for the Centennial anniversary celebration.

The bell was cast using a mixture of 80% copper and 20% tin.

A British and American cannon from the battle of Saratoga and a Union and Confederate cannon from the battle of Gettysburg were added to the casting mixture.

The bell weighs 13,000 pounds representing 1,000 pounds for each of the 13 original states and bears the following inscriptions:

Around the crown: "Glory to God in the highest and on earth peace, good will toward men - Luke, chapter II, verse 14."

Around the lip: "Proclaim liberty throughout all the land unto all the inhabitants thereof - Leviticus, chapter XXV, verse 10."

Henry Seybert did not approve of the tonal quality of the first casting. The bell was recast following the Centennial. The recast bell had greatly improved tonal quality.

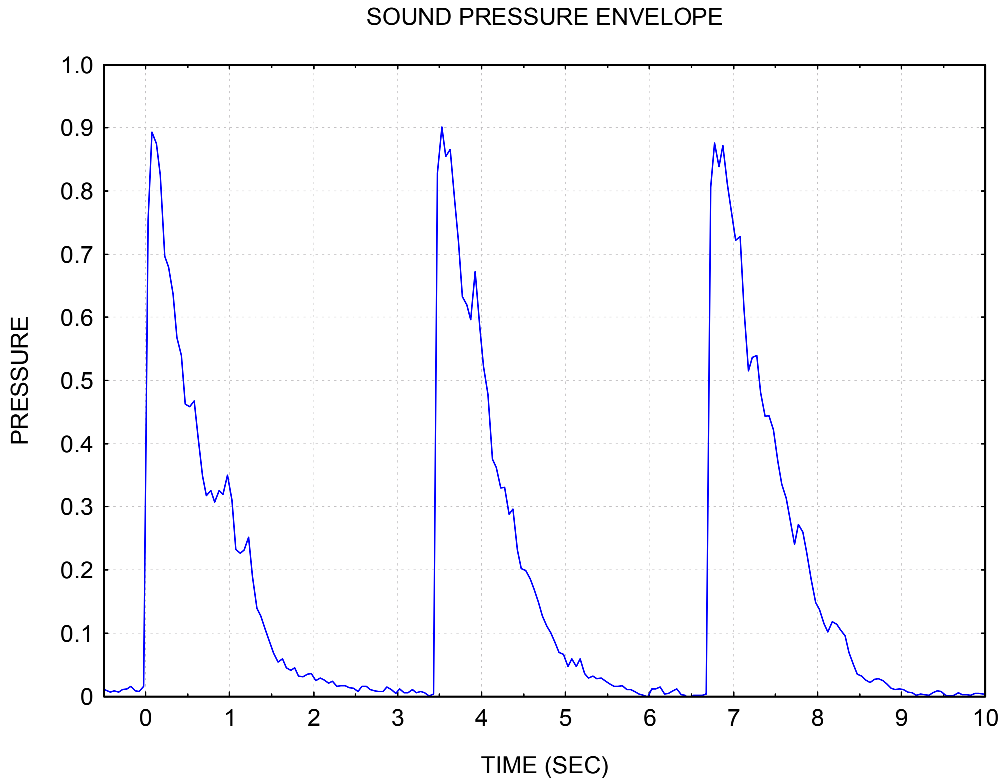

Figure 2.

Measurement

A recording was made of the Centennial Bell as is tolled three times at 3:00 PM on April 30, 2005.

The envelope of the sound pressure signal is shown in Figure 2.

The delay from one strike to the next is about 3.4 seconds.

Each envelope decays at an approximate rate of 11 dB/sec.

A waterfall FFT is shown in Figure 3. The music notes corresponding to the spectral peaks are identified in Table 1.

Sound Pressure Waterfall FFT

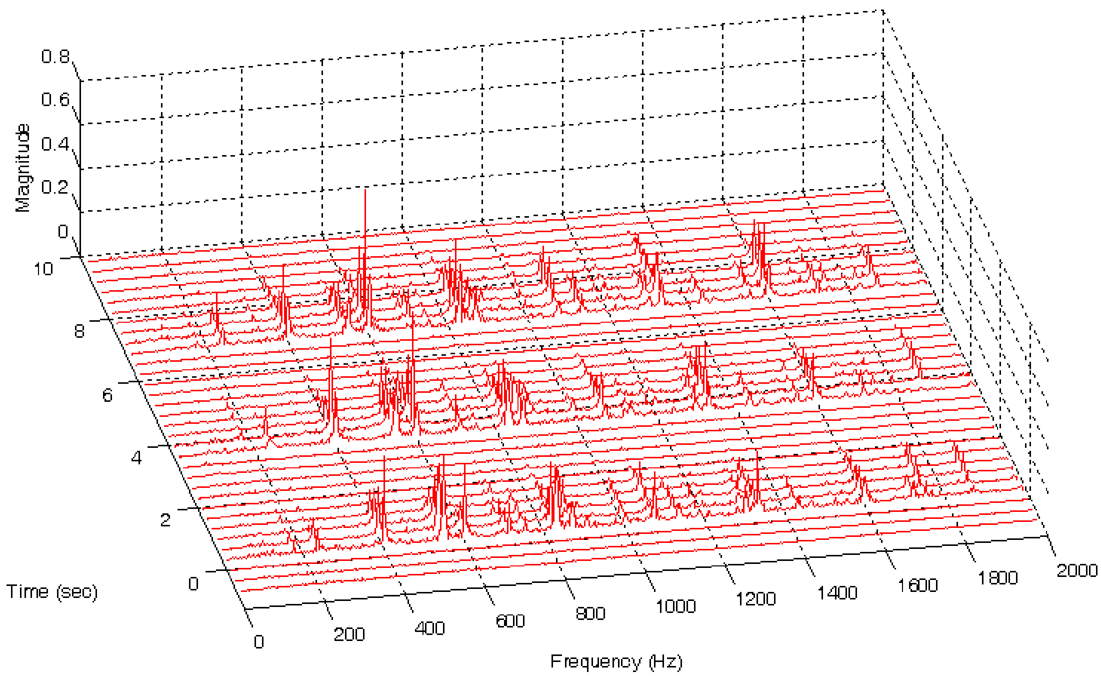

Figure 3.

Table 1. Centennial Bell Tones		
Frequency (Hz)	Nearest Musical Note	Tone Description
236	A	Hum
403	G	_
550	C#	Fundamental, Prime, or Strike Note
604	D	_
830	G#	Quint, 3:2 ratio with respect to the Prime
1076	C	Nominal, one octave above Prime
1334	E	_
1600	G	_

Elevator Jerk by Tom Irvine

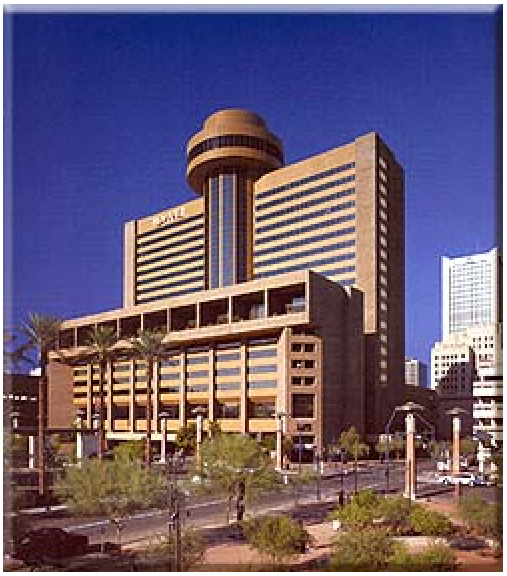

Figure 1. Hyatt Regency Hotel, Phoenix

Downtown Phoenix, Arizona

Phoenix lacks the distinctive skyline of other major cities. There are two reasons. One is that the downtown area is in the flight path of Phoenix Sky Harbor airport. Another reason has been the preference to build outward rather than upward given the availability of inexpensive land.

The 40-story Bank One Center in Phoenix is the tallest building in the state of Arizona. It is 483 feet (147 meters) tall. It was built in 1972 for Valley National Bank, which Bank One acquired in 1994.

Hyatt Building

The Hyatt Regency has the most distinctive geometry of the downtown buildings with its revolving Compass restaurant on the 24th floor. The Hyatt was built in 1976. Its total height is 318 feet (97 meters).

Furthermore, the Hyatt's glass elevator shaft is located on the outside of the building. The elevator travels at a brisk rate. The purpose of this report is to evaluate the elevator's speed, acceleration and jerk in terms of industry standards.

Elevator Standards

The elevator industry has developed the following physiological limits which standing elevator riders can tolerate without feeling discomfort.

Table 1. Recommended Limits

Parameter	Limit
Vertical acceleration/ deceleration	≤ 1.0 - 1.5 m/sec^2
Speed	≤ 7.0 m/sec
Jerk rates	≤ 2.5 m/sec^3
Sound	≤ 50 dBa
Ear-pressure change	≤ 2000 Pa

All of the physiological elevator design parameters can be regulated by proper equipment design except for ear-pressure changes.

Ear pressure changes do not usually affect elevator riders, unless the descent speeds exceed 7.0 m/sec and the vertical travel exceeds 300 m. Elderly persons, those with colds, flu or allergies, or those who cannot rapidly clear their ear passages are more at risk of discomfort or pain. In extreme cases, a passenger may suffer a broken eardrum.

The middle ear is like a balloon that expands as exterior pressure decreases during ascent and contracts as exterior pressure increases during descent.

The expanding air in the middle ear pushes the normal Eustachian tube open as the elevator-cab pressure decreases during ascent. This allows the increased pressure to escape down into the nasal passages until the pressure in the inner ear and the cab level is equalized.

However, during rapid decent, the passenger must consciously open the Eustachian tube by swallowing, yawning or tensing muscles in the throat, or by closing the mouth, pinching the nose closed and blowing through the nose to equalize the pressure.

Hyatt Elevator Data

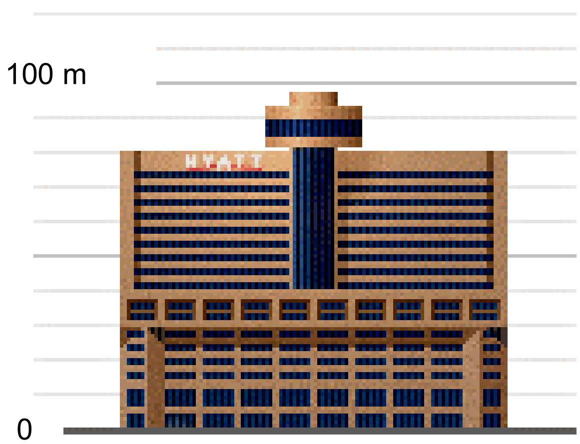

Figure 2. Hyatt Hotel Diagram

(Courtesy of skyscraperpage.com)

Accelerometer data was taken for non-stop trips from the lobby to the Compass restaurant, for both ascent and descent. The accelerometer was mounted on the floor in the vertical axis.

The accelerometer time history for the ascent is shown in Figure 3. Positive acceleration corresponds to the upward vertical direction. Zero corresponds to standing still.

The peak acceleration value is 1.1 m/sec^2. The measured peak reasonably complies with the 1.5 m/sec^2 limit. The measured peak is equivalent to 0.11 G. A passenger's apparent weight would thus change by 11% for a few seconds during the starting and stopping transients.

Note that a 1.3 Hz vibration is apparent from 5 to 21 seconds, when the elevator is moving at a constant velocity.

The velocity is shown in Figure 4, as obtained by integrating the acceleration time history. The peak is 3.7 m/sec. This is less than the recommended 7.0 m/sec limit.

The integration process is analogous to lowpass filtering. Thus, the appearance of the 1.3 Hz ripple is diminished in the velocity plot.

The area under the velocity curve yields a travel distance of about 82 meters. Note that the distance from the top floor to the highest point on the building is about 15 meters.

The jerk is shown in Figure 5, as obtained by differentiating the acceleration curve. The peak value is just within the 2.5 m/sec^3 limit.

Note that the jerk amplitude is very sensitive to the lowpass filter value.

The descent data was similar to the ascent data except with an opposite polarity. The descent data is omitted for brevity.

Conclusion

The measured parameters for the Hyatt elevator complied with the recommended limits in Table 1. Nevertheless, my son and I both experienced some minor ear popping during the ride. Perhaps this could be mitigated by programming the elevator for at least one intermediate stop.

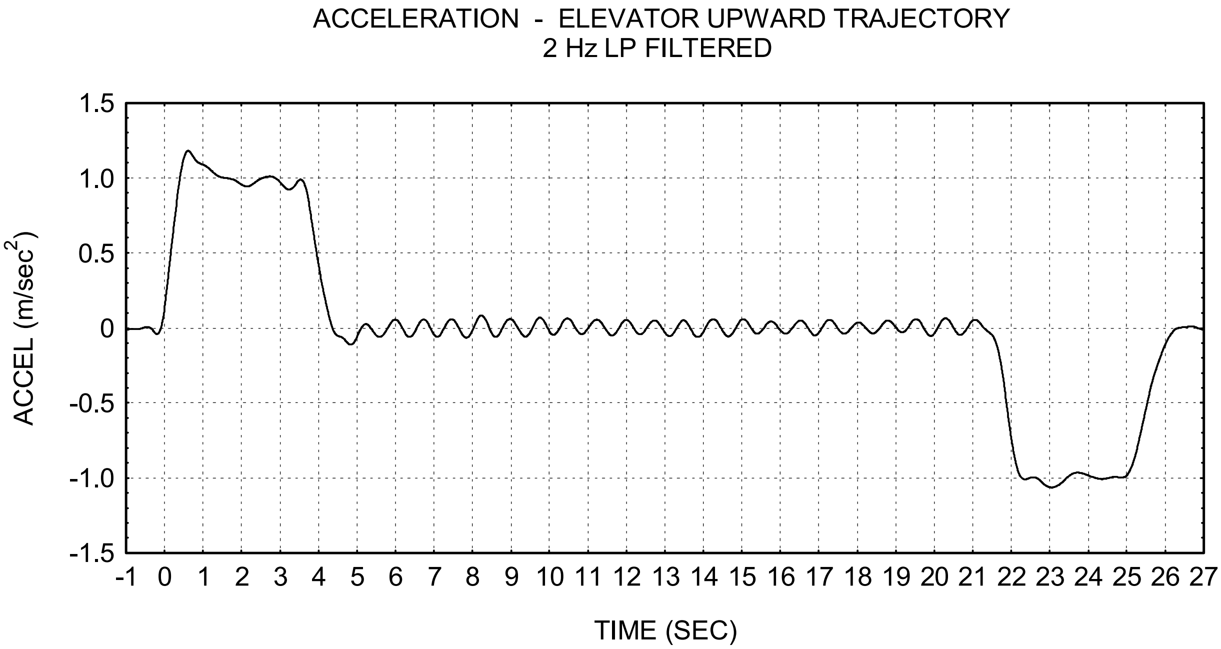

Figure 3.

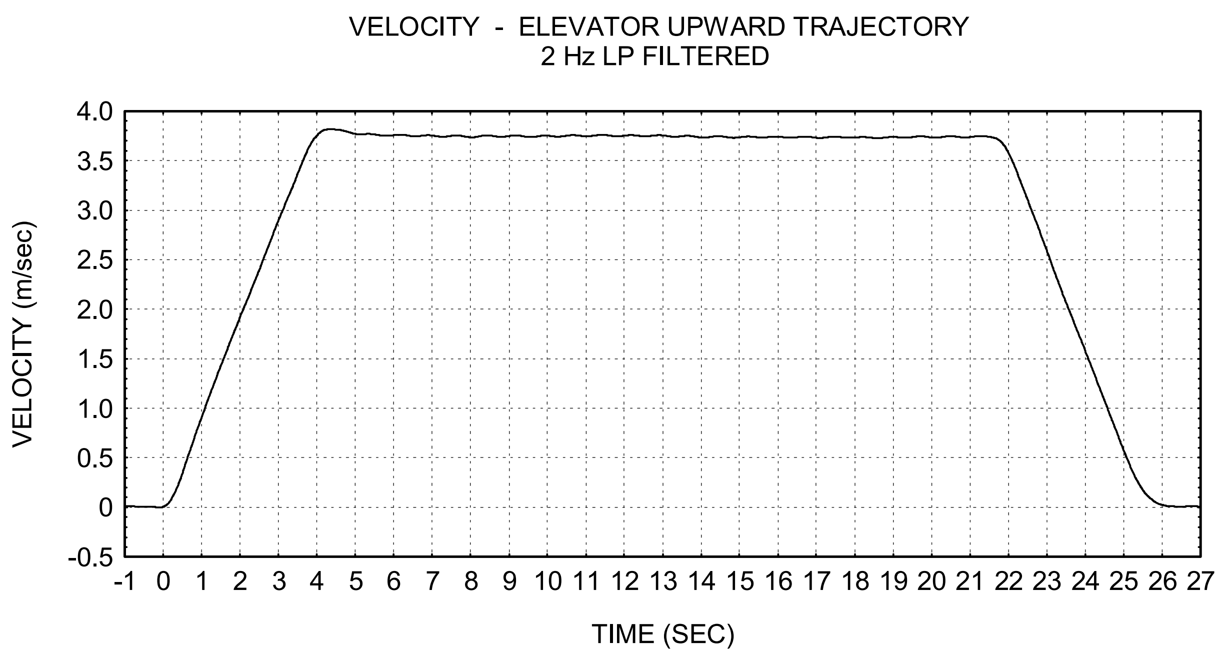

Figure 4.

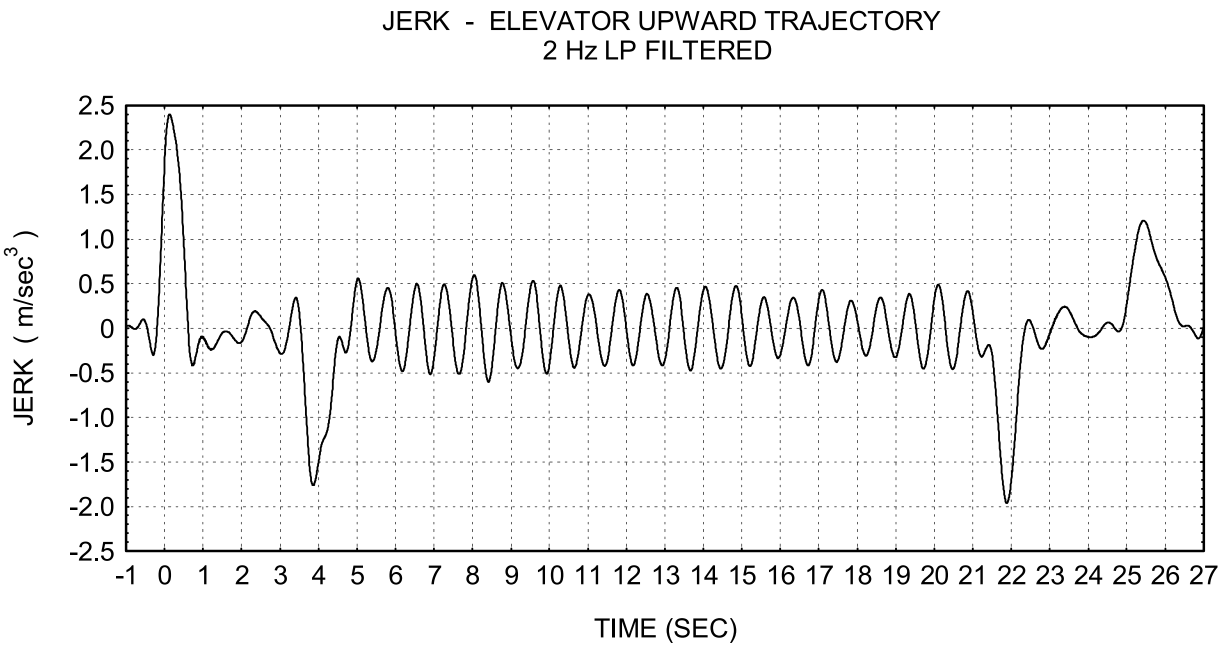

Figure 5.

Reference

1. Physiological Problems Associated With High-Speed Lifts, Elevator World, Issue: 07/01/95. Posted at: http://www.gmu.edu/departments/safe/mega.html