Ride quality and noise in high speed elevators

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Abstract

Ride quality in an elevator is the latest "hot topic" in elevator design and construction. In skyscrapers being built in Asia, Dubai and the US, the new elevators travel close to and beyond 10m/s. The rides to the highest floors will last well over one minute. From a comfort point of view, it is important that the ride be as smooth and quiet as possible. There are many factors that influence the vibration of the elevator and the concomitant noise. In this paper we will examine the sudden forces that the elevator experiences as it passes each floor. The side forces on the elevator are caused by the asymmetric flow field about the elevator cab. The pressure and streamline flow field was evaluated by using the CFD code FLUENT. Comparison between the numerical and the measured results are given and the pressure disturbances caused by the passage of the elevator and its appendages are discussed together with some solutions to alleviate the pressure disturbances.

1 Introduction

In the world we are now building taller and taller buildings. Some of the skyscrapers under construction are on the order of 500 meters while future planned skyscrapers are going to reach 1000 meters. In order to reach the upper floors in reasonable amount of time, higher speed elevators are being studied. The upper floor elevators will be express and will bypass all the lower floors. As the elevator travels in the hoistway, it passes the doors that separate the hoistway with the particular floor. Figure 1 shows a typical layout of the hoistway elevator configuration.

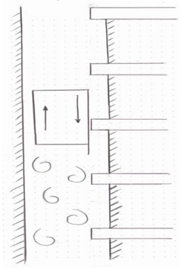


Figure 1-Typical hoistway-elevator cab geometry- 2D

For clarity the cavity produced by recessed floor door has been exaggerated. Also note that the gaps between the hoistway walls and the front and the back of the elevator cabin are not symmetric. As the elevator moves up (or down) it will experience an unsteady flow field as it passes through each floor. This unsteadiness will result in a side force that will be felt as a vibration and/or a noise. For competitive reasons the elevator designer has to provide a very smooth and comfortable ride.

This study has analyzed the flow field about the elevator has it moves in the hoistway. Most of the analysis has been performed with two dimensional modeling, however a few three dimensional systems have also been studied. The commercially available CFD software FLUENT has been utilized in this study. The flow field is treated as an incompressible fluid. The computer system that was utilized was an 8 processor SGI Altix 350 with a Silicon Octane 2 graphics workstation. Typical runs have taken from one/six days depending upon the Reynolds number that and the geometrical complexity of the problem. The three dimensional systems have taken from two to three weeks to run.

Figure 2 shows the two dimensional model that has been employed. Note that the elevator has a toe guard at the floor that extends about 50-80 cm below.

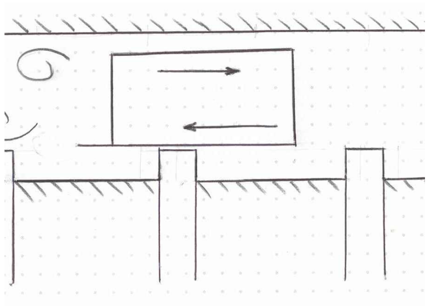
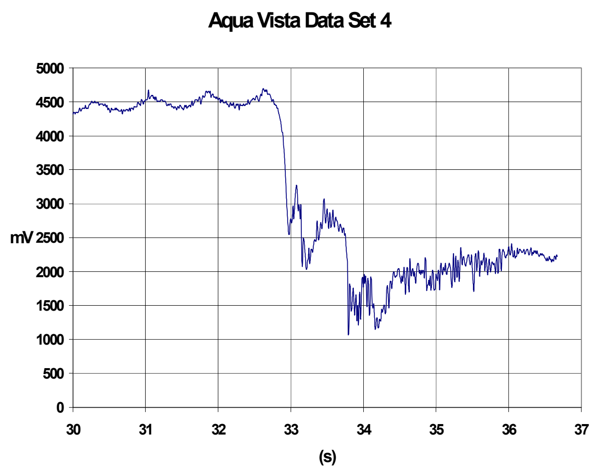


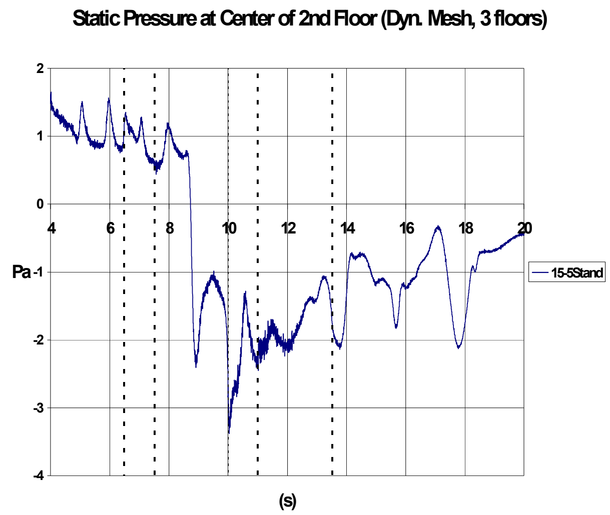
Figure 2- Two Dimensional elevator-hoistway modeling

2 Numerical Analysis

To verify the accuracy of the model and the numerical procedure a validation process was investigated. A full scale elevator operating in a ten story building was instrumented with pressure transducers. One of the transducers was placed on the inside of a floor door on three separate floors. The pressure was then recorded as the elevator passed in the up and down mode. The elevator geometry was then modeled and the numerical results consisted of evaluating the pathlines of the flow field and the pressure field at every point on the elevator surface and at selected points on the cavity surface. A comparison was then made with the experimental results. Figure 3 shows this comparison



a-Experimental Data



b-Numerical Data from Fluent

Figure 3- Validation of the CFD Fluent Program

On the experimental results note how a relatively small periodic pressure signal is felt inside the cavity before the elevator enters the cavity. As the cab moves through the cavity a sudden pressure drop is felt, a partial pressure recovery is obtained and then a further drop is seen before a gradual recovery is obtained. The numerical results representing the pressure on the inside of the floor door are seen to behave very closely to the actual case, even the pre pressure signal is seen.

3 Results

Three numerical schemes have been employed in the analysis. The "Fixed mesh" has the walls and the elevator fixed in space while the flow field passes by the elevator at a constant speed. This model is the most time efficient and the most numerically accurate; however it does not properly model the hoist-way-wall-elevator interaction. The "Sliding mesh" scheme has the elevator fixed in space while the walls and the fluid pass by at a constant speed. This second model has the correct relationship between the fluid and the hoistway walls; however the flow field in the door cavity is not correct. The third scheme is the "Dynamic mesh" where the walls and the fluid are at rest while the elevator starts to move at a constant speed. This last scheme has the correct physical modeling, however it is more numerically laborious and the scheme is only a first order accurate while the other two schemes utilized are of second order accuracy.

Figure 4 shows the flow pattern about the standard elevator geometry at the beginning of the flow field and at a later time. It is interesting to note that the flow field on the upper elevator-hoistway gap is very much time dependent and it creates vortices that eventually detach themselves from the leading edge and then flow downstream to join the wake of the elevator. This run corresponds to a model flow field speed equal to 2.75 m/sec for the model elevator whose length dimension is 0.425 m.

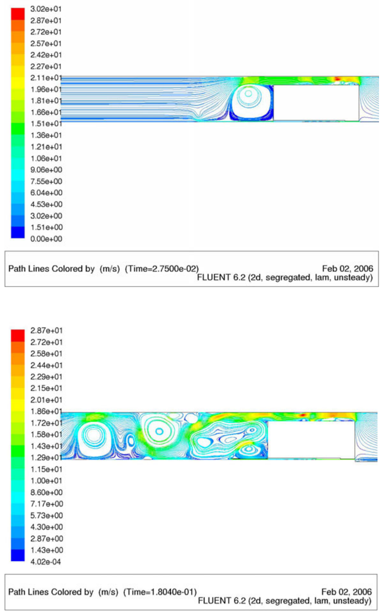


Figure 4- Pathline of flow field about standard elevator cab. Two dimensional model. Re=$3.5x10^5$

This correspond to a Reynolds number of $3.5x10^5$. The maximum flow speed occurs at locations on the upper gap or in the wake of the cab. The maximum speed is of the order of 25-30 m/sec. This value is an order of magnitude larger than the incoming free field flow. The flow field is two dimensional and thus the entire flow field ahead of the elevator cab has to pass through an area equal to the size of the gap between the elevator wall and the rear wall of the hoistway, however the two boundary layers present on the upper gap will shrink the effective width more. The effective width of the gap is then reduced to an order of magnitude smaller than the height of the channel. The equation of continuity is satisfied! The magnitude of the unsteady side force acting on the elevator is a function of this maximum fluid speed. One way of reducing the magnitude of this force is to streamline the flow by attaching a nose cone. The nose cones considered were of three types. The three options are: (1)quarter circle nose cones symmetric in forward and rear section of cab, (2)quarter circle nose cones with antisymmetry in the front and the rear, (3) bullet shaped nose cones both in front and in rear. Of all the cases investigated, the most advantageous is the symmetric quarter circle nose cones systems. Figure 5 shows the comparison of the time varying lift coefficient (equal to the side forces acting on an elevator) between the standard geometry and the elevator with the symmetric quarter nose cones. Note that the variation in the values of the C_l go from a delta of 175 to a value of 45. This is a reduction in the forces by a factor of four

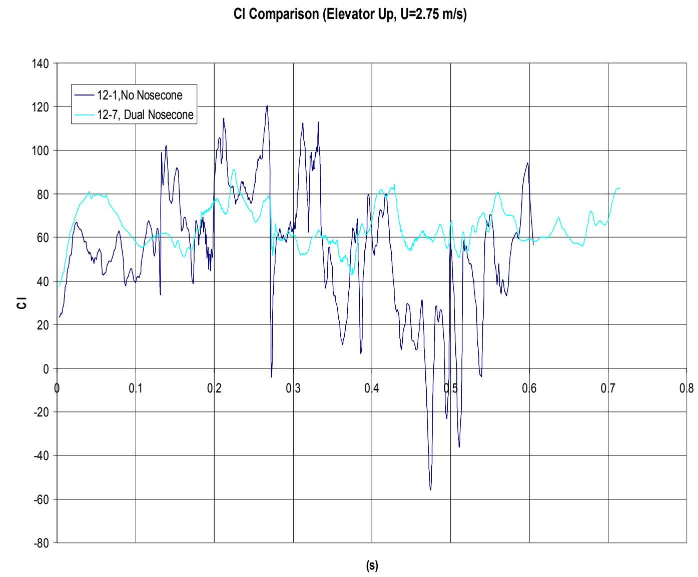


Figure 5-Comparison of Side force due to vortex shedding around the elevator cab

A factor of four in the magnitude of the side force will produce considerable improvements in the ride quality. Figure 6 shows a comparison of typical flow field results for a standard and a dual nose cone elevator cab. As expected the flow field above and behind the elevator is much smoother and it results in considerable reduction of the maximum flow speed.

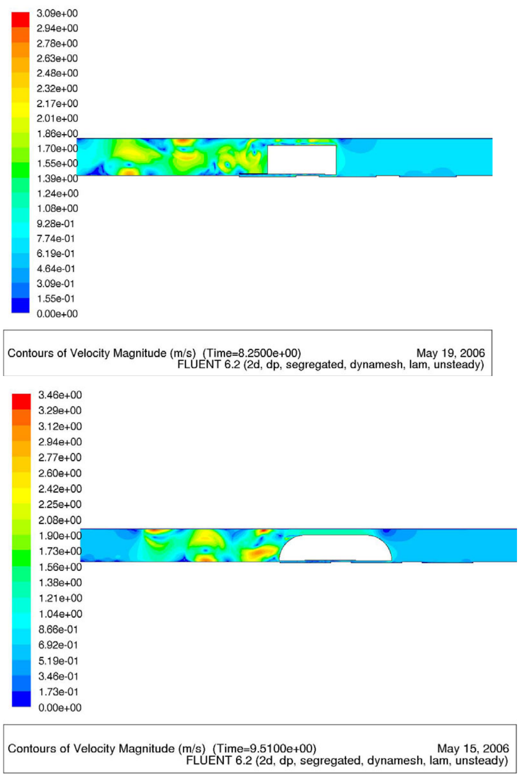


Figure 6 Flow path line field on standard elevator design and with dual nose cones

Figure 7 compares the pressure distribution in the cavity for the standard, front nose cone only, rear nose cone only and dual nose cone for the case presented in figure 6. Again as expected the pressure variation in the cavity is much smoother for the double nose cone case. The double nose cone case which is shown by the red curve (corresponding to the only curve that does not have a sudden pressure impulse drop) is seen to have a smooth decline in the value of the pressure as the elevator cab enters and exits the cavity. No sudden pressure impulse is seen in the results. The other three cases are seen as having sudden pressure drops of anywhere from 2 to 3.5 pascals.

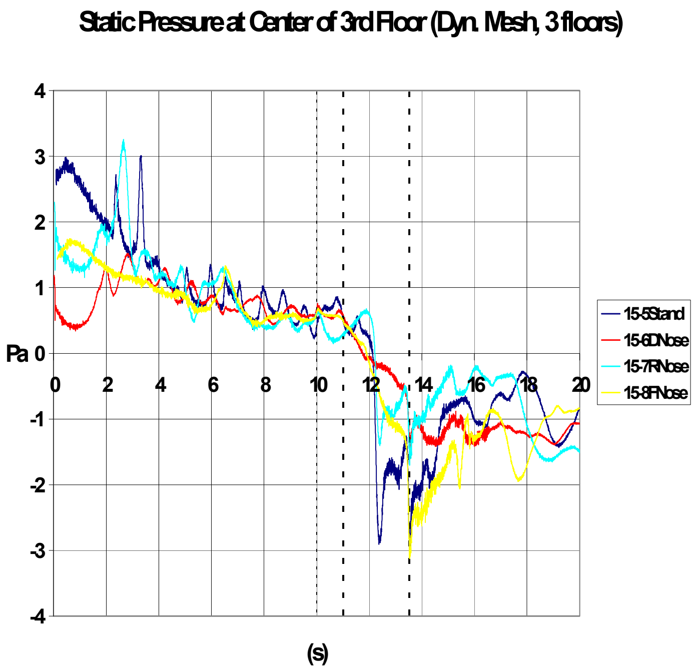
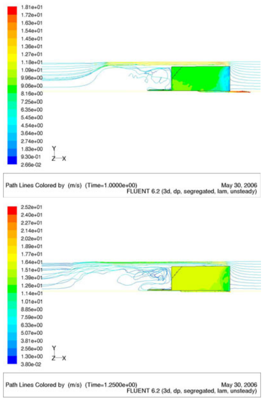


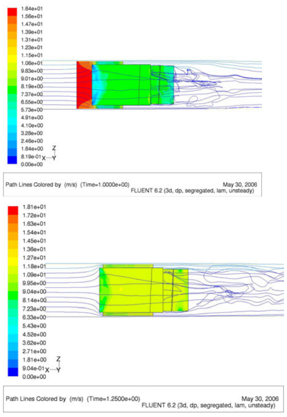
Figure 7- Comparison of cavity pressure due to the flow produced by a standard elevator and with nose cones

All of the results presented to this point correspond to a two dimensional elevator model. Due to the time required to run three dimensional cases, we were able to run only a few cases. I would like now to present one typical result that seems to validate the two dimensional results that we have already discussed.

Figures 8 and 9 show typical side and top view of the pathlines of the flow field for the standard elevator cab design. The effect of dual nose cones has also been investigated and they are shown for comparison. The nose cones considered were of two types. The simplest nose cone consisted of a quarter section of a circular cylinder attached to the front and the rear of the cab. This type of nose cone has curvature in only two dimensions. This nose cone was then modified by including curvature in the nose cone in the other dimension so that it becomes more pointed. This is referred to as the modified nose cone. Both figures show the pathlines at two different times. The first time corresponds to a time close to the starting time while the second time corresponds to the time when the cab closes off the cavity.



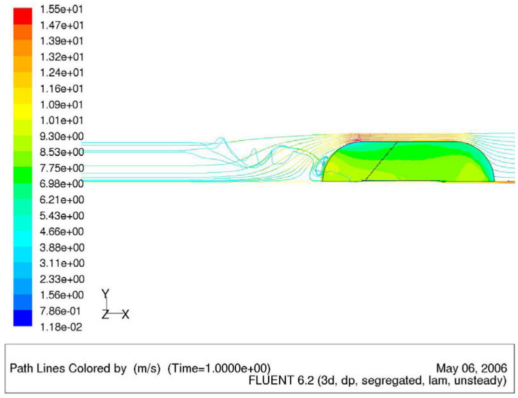
(a)



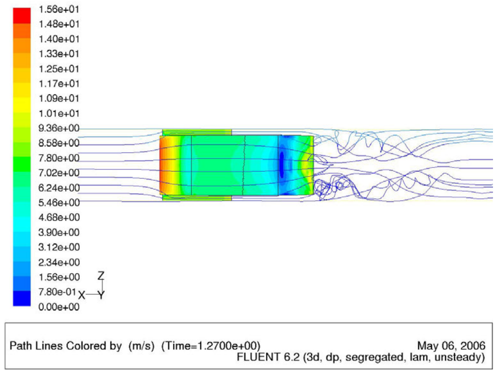
(b)

Figure 8- Flow field about a three dimensional standard elevator. (a) side view (b) top view

Figure 10 presents the results of this series of study where the lift coefficient (equivalent to the side force on the elevator) variation is presented for the standard 3D shape, single nose cone forward only, single nose cone rear only, dual cylindrical nose cone and modified dual nose cones.



(a)



(b)

Figure 9 Pathlines about 3D elevator cab model with dual nose cone. (a) side view (b) top view

In figure 10 the standard elevator cab model result is the second curve from the bottom while the modified nose cone model is the third curve from the bottom.

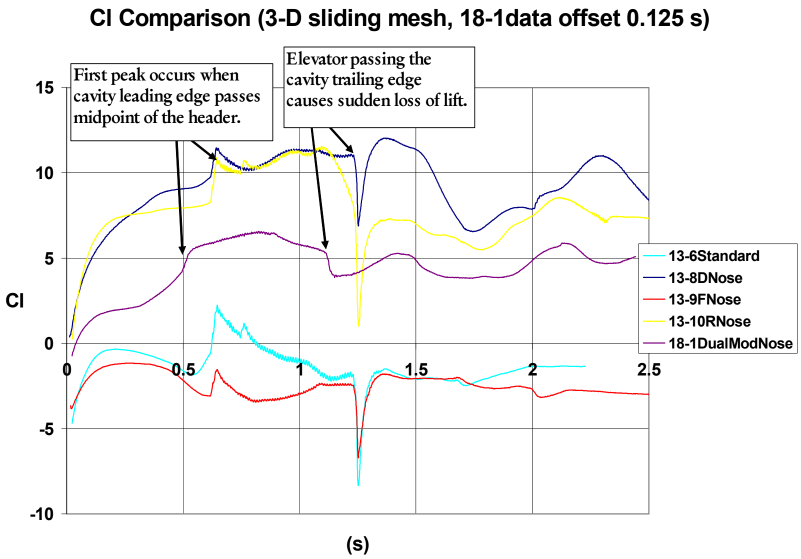


Figure 10- Comparison of side forces of a 3D elevator cab model with different types of nose cones

Note that the inclusion of a simple double nose will decrease the pressure jump from 11 to 7, not as large as for the two dimensional case presented above, but still substantial. Modifying the design of the nose cones produces a smooth pressure variation with a pressure jump that is barely visible on the figure.

4 Conclusions

The results presented show that it is possible to modify the shape of the elevator to reduce the vibrations and the noise inside the elevator. The proposed modification consist of a dual nose cone for the two dimensional model and a modified cylindrical nose cone for the three dimensional model.