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The Causal Factor of Bus Wheel Injuries and a Remedial Method for Prevention of These Accidents

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Introduction

The accident statistics for injuries caused by pedestrians or cyclists being injured, or killed, by U.S. transit buses have typically been categorized simply as either fatalities or serious injuries[1]. Although anecdotal information from police accident investigators and Forensic Engineers have indicated that certain types of accidents with transit buses are more prevalent than other types, definitive data has been lacking. Recent risk management efforts at various transit authorities[2] have revealed a prevalent type of accident from transit vehicles interacting with either cyclists or pedestrians. The predominant accident type seems to be pedestrians or cyclists being pulled into the bus-wheel, as opposed to individuals being struck by the vehicle body[3]. Further questioning of transit personnel indicates that, in most cases, the accidents occur from the rotating bus transit wheel on the bus as it passes the individual as opposed to the cyclist or pedestrian running into the stationary transit vehicle or tire. Surprisingly, the type of accident where the bus strikes the cyclist or pedestrian in an area other than on the rotating wheel is almost negligible.

While statistical reporting and analyses of this data has not been accomplished to a high degree of engineering certainty, most risk managers for metropolitan transit authorities will admit to a surprisingly high number of these rotating wheel type of accidents[4]. By whatever analysis method that is used, there is a clear problem with these types of accidents. Of particular interest is the fact that most points of impact onto the bus body appear to occur at the point of the rotating wheel in the bus wheel well.

The analysis in this paper is focusing on Transit Authority Buses since risk assessment managers have identified high incidents of injury at the site of the rotating wheel for these vehicles. More probably than not, other types of motor vehicles, such as trucks, would also tend to have a high degree of cyclist or pedestrian accident prevalence at wheel wells. Currently the Engineering, and related literature, does not contain valid statistics on wheel well accidents other than Transit Authority vehicles. As a result, this analysis centers on these vehicles, but can be applied to other heavy-duty vehicles as well.

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Bernoulli's Principle

Since transit authority personnel agree that there is a problem with pedestrians and cyclists being impacted in the proximate vicinity of the wheel well, an explanation is needed for this set of data. If Bernoulli's Principle is defined in terms of pressure, the equation becomes:

$$\frac{1}{2}pV^2 + p + pgy = \text{constant}$$

where: p = pressure

g = acceleration due to gravity

y = elevation.

V = velocity

If y does not change, then an increase in V means a decrease in p. This basically means that as a transit authority bus passes a cyclist or pedestrian at a higher speed, there will be a decrease in pressure between the two entities. Since the bus is at a much higher mass, the pedestrian or cyclist will be drawn toward the vehicle.

This does not explain why most points of impact occur on or near the rotating wheel. If we assume that elevation (y) and the constant (k) are both 1 and the equation is unitless[5], then the relationship between pressure and velocity becomes:

Solving For P

$$P = \frac{1}{\frac{3}{2}V^2 + 33.3}$$

The plot of P^{-1} versus V is shown in Figure 1. If a bus passes a pedestrian or cyclist at 10 MPH or 14.7 ft/second, the rotating wheel of an assumed 6 ft of circumference will rotate approximately 2.5 revolutions/second[6]. Therefore, regardless of the units used, if you compare the different speeds of the rotating wheel at 10 MPH, there is a ratio of 2.5/1 of wheel velocity to bus speed. For comparison purposes, the inverse pressure (p^{-1}) from Figure 1 is 183 at 10 MPH while the inverse pressure for the increased speed of the bus wheel is 971. From this unitless analysis, it is obvious that regardless of the method used, the rotating wheel of the bus, or any large vehicle, will create a low pressure between the cyclist or the pedestrian that is vastly different than just the motor vehicle passing the individual. As a result, there is a greater potential for the cyclist or pedestrian to be pulled into the motor vehicle body. This lower pressure resulting from

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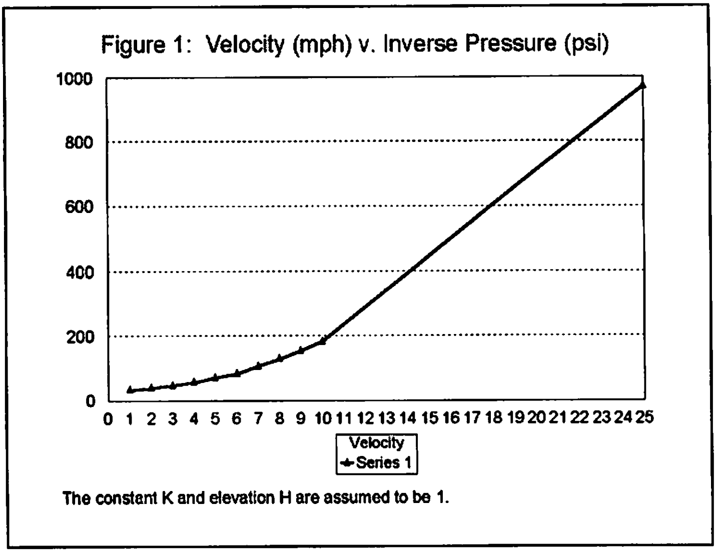

Figure 1

the higher rotational velocity of the motor vehicle wheel explains the greater grouping of the points of impact at the wheel well of transit authority buses.

An increase in velocity means a decrease in pressure and accounts for the fact that passing ships run the risk of a sideways collision. This is due to the fact that water flowing between ships travels faster than water flowing past the outer sides. Therefore, water pressure acting against the hulls is reduced between the ships. Unless the ships are steered to compensate for this, the greater pressure against the outer sides of the ships forces them together.

In order to design a remedial measure to prevent the inordinate amount of accidents at transit bus wheels, Bernoulli's principle must be utilized.

A Practical Design for Preventing Wheel Well Accidents

There are two problem areas in designing a remedial measure to prevent wheel well accidents.

The first area of concern is the description of the low-pressure gradient between the rotating high velocity bus wheel and the pedestrian or cyclist. The second area of design application is the prevention of the physical entrapment of the cyclist or pedestrian from a bus turning into the path of travel of either entity. In this second area, physical entrapment can also occur from the low-pressure gradient pulling the cyclist or pedestrian to the physical proximity of the rotating wheel.

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Bernoulli's Principle can be applied to disrupt the low-pressure gradient that can pull a cyclist or a pedestrian into the high velocity-rotating wheel by considering the lifting force of the airplane wing. The airfoil of a curved airplane wing adds considerably to lift and results in a greater difference in pressure between the lower and upper wing surfaces. This net upward pressure multiplied by the surface area of the wing gives the net lifting force. By having a curved wheel guard at the forward leading edge of the transit bus wheel well, a net outward pressure away from the direction of travel of the bus is produced. This results in the complete elimination of the low-pressure gradient that would draw the cyclist or pedestrian into the high velocity-rotating wheel. More importantly, the curvature of the guard would act like an airplane wing and literally be able to push the cyclist or pedestrian out of the path of travel of the transit bus.

As noted in Figure 2, a wheel well guard with a leading edge capable of lifting the air outward from the bus's path of travel is shown. By utilizing this curvature, the cyclist or pedestrian is actually pushed away from the leading edge of the wheel well by the outward change in air gradient. The strength of materials of the guard should also be capable of actually pushing a pedestrian or cyclist away from the path of travel of the transit bus if the individual falls into the path of the rotating wheel.

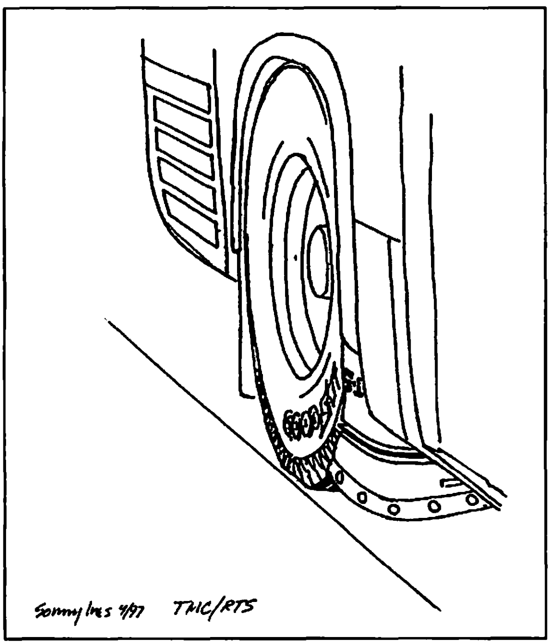

Figure 2

As noted in Figure 2, field trials do support the ability of this design to physically move a subject from the path of travel. This is helpful in instances where Bernoulli's principal is not a causal factor, as when transit buses turn into pedestrians or cyclists. In those instances, the guard must act much like the cowcatcher on a train and physically move the individual from the path of the rotating wheel.

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Conclusion

As described in the Bernoulli analysis, and from the field data, the causal factor of most cyclist-pedestrian accidents with transit buses are from the individuals either being dragged into the rotating wheel by the lower pressure gradient or from the physical impacting of the bus during a turning radius.

When investigating these types of accidents, the Forensic Engineer should realize that Bernoulli's Principal could be a definite causal factor. Also, the bus physically turning into the path of an accident victim should be considered. Of equal importance in the analysis is the fact that remedial measures are easily available to prevent these accidents. The illustrated S-1 Gard (generic name), see Figure 2, has been implemented in several municipality's. Thus far, in those municipalities that have initiated this program the accident rate has decreased from several incidents per year to zero.

Case studies are being developed at: Washington D.C., Los Angeles, California, Miami-Dade County, Florida, and San Diego, California. Ferrone has accomplished a field evaluation of the effectiveness of the S-1 GARD[7]. In that effort, the emphasis was on the physical effectiveness of the S-1 GARD in moving a stunt man out of the path of the rotating wheel. The experimental runs, as expected, showed that the physical properties of the S-1 GARD did successfully remove the individual from the path of the rotating wheel.[8]

Additional case studies are being planned. The effectiveness of the S-1 GARD[9] to eliminate the low-pressure gradient at wheel wells as a function of speed is needed. Theoretically, the effectiveness of the S-1 GARD should increase as velocity increases. An additional study to determine the effectiveness of the S-1 GARD on heavy-duty vehicles should also be considered.[10]

The use of a guard on the rear wheel wells of transit authority buses as well as heavy-duty vehicles is in its infancy. The initial evaluations clearly show a dangerous problem exists. Field studies conducted thus far yield excellent preliminary results in utilizing the S-1 GARD, the only guard currently on the market, to completely eliminate wheel well accidents. Hopefully, the release of this paper into the Forensic Engineering community will enable the reason behind these accidents to be acknowledged as well as the remedial measure needed to eliminate the problem.

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Reference

1. US Department of Transportation, National Highway Traffic Safety Administration, "Traffic Safety Facts," for Pedacyclists (DOT HS 808 957) and Pedestrians (DOT HS 808 95).

2. See Bus Wheel Injury Study, San Diego Transit Corporation, DART, G. Transit Richmond 1989-1993.

3. Ibid Although Risk Managers at these transit authorities have not applied statistical analyses, the predominant, and in most cases, total accident rate is by the rotating transit vehicle wheel.

4. Most reconstruction projects that I have had with accidents involving buses, pedestrians and cyclists did, in fact, involve rotating bus wheels. In my own interviewing of transit personnel, this type of accident is definitely the most common.

5. We are interested in making a comparison of the increased velocity of the bus wheel versus the body of the bus passing a cyclist or pedestrian. The important issue here is the inverse relationship between pressure and velocity.

6. 14.7/6 = 2.45 rps.

7. Ferrone, Christopher W. "A Field Evaluation of the S-1 Gard: Transit and Shuttle Bus Applications", Society of Automotive Engineers, Inc., Paper No. 982775, 1998.

8. Public Transportation Safety International Corporation, US Patent #5,462,324 WO 95/28300, S-1 GARD, Pacific Center, 523 West 6th Street, Suite 1222, Los Angeles, Ca., 90014, Office phone = 1-213-689-7763, Fax= 1-213-689-7765, e-mail= s1pts@aol.com, www.s1gard.com

9. Currently the S-1 GARD is the only device being sold to eliminate the accidents that occur at large vehicle wheel wells.

10. I have personally reconstructed accidents on garbage trucks operating in high-density population neighborhoods. The Forensic Engineering evaluation of these accidents did show that the victims where impacted at the well of the rotating rear wheel.