Proceedings of IMECE 2006
2006 ASME International Mechanical Engineering Congress and Exposition
November 5th – 10th, 2006, Chicago, Illinois, U.S.A.

IMECE2006-13305

"FIRE AND EXPLOSION INVESTIGATIONS; WHY HEAVY TRUCKS MAY BURN"

Christopher W. Ferrone
ARCCA, Inc.
550 W. Van Buren, #1220
Chicago, Il 60607
312.386.2300
cferrone@arcca.com

Charles Sinkovits
CES Consulting
8039 W. Leland
Norridge, IL 60706
708.724.3347
cesconsulting@comcast.com

ABSTRACT

There is a basic misconception that diesel fuel does not explode and/or ignite upon a collision or impact. This particular chain of events, in fact, does occur. However, it is not always thoroughly investigated or understood.

The purpose of this paper, through mechanical analysis and accident reconstruction, is to inform truck manufacturers and operators of this hazard. In addition, it will supply design alternatives that will aid in mitigating and/or preventing injuries altogether.

INTRODUCTION

On January 9, 2001 on U.S. 49 in the State of Louisiana, a tractor trailer was maneuvering into a driveway to make a delivery. During the process, the tractor was struck by another truck which was attempting to pass. (Fig. 1) The impact was to the driver's side area of the first tractor, specifically, to the

Photo 1

location where the fuel tank and battery box reside (Photo 1).

A witness reported that the first tractor burst into flames upon impact. The driver was trapped and perished as a result of the fire.

DISCUSSION

Over the past two years we have investigated four similar accidents. In each case a truck tractor was involved in a collision which resulted in an explosion and/or fire. In each of these incidents, the fact pattern was similar, the battery box and fuel tank area were impacted simultaneously or in close sequence. A full scale fire arose destroying the equipment (Photo 2) (Appendix A).

Photo 2

HYPOTHESIS

In the event of this type of collision, most cars' front bumper will contact the fuel tank of a truck tractor on or about the tank's longitudinal center line (Photo 3). The same goes for pickup trucks, S.U.V.'s and other trucks/tractors front bumpers. This event may then lead to a fuel spill. Additionally, the placement of the battery box in such close proximity to the fuel tank can become an ignition source for the potentially spilled and/or atomized (spray) diesel fuel.

Photo 3

Automotive bumpers range in height from approximately 13" – 23" from the ground.

- Tractor fuel tank centerline approximately 24" from ground
- Tractor battery tray/bracket distance to fuel tank approximately 2"
- Tractor battery tray approximately 25" from ground

A study of various truck tractor battery box and fuel tank locations was conducted. As stated earlier, the contention is that in most cases the battery box resides within inches from the fuel tank. This package of components is not unique to any one manufacturer (Photo 4).

Photo 4 – Mack R-Model

In some cases the battery box can be as close as 2 ½ inches from the fuel tank (Photo 5).

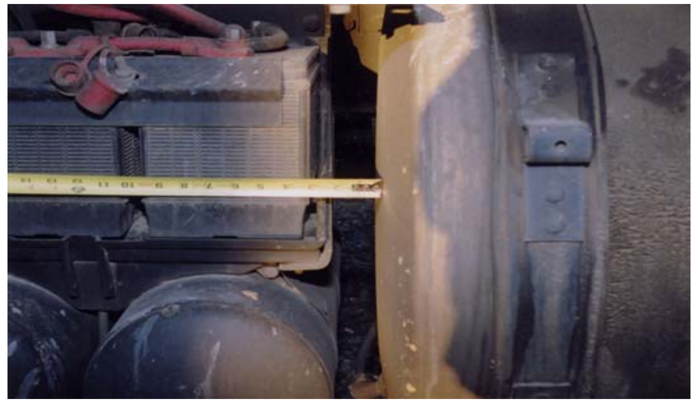

Photo 5

Therefore, the two hypotheses are:

i) Truck tractor battery box and fuel tank are too close

ii) The location of the truck tractor battery box and fuel tank are exposed and coincident with automotive bumper heights

BASIS FOR HYPOTHESES

Various measurements and photographs were taken of automobiles and truck tractors interacting along side another truck tractor (Photo 6 & 7). These measurements and photographs clearly show that there is a high likelihood that if a collision was to occur with a truck tractor on the left-hand side near the batteries and fuel tank area that a fuel spill and ignition source (battery) would be present.

Photo 6

Photo 7

IF HAZARD EXISTS, USE SAFETY HIERARCHY (National Safety Council)

Since we know a hazard exists, the safety hierarchy must be employed so that an alternate system design can be made available and able to replace the current, hazardous design. The hierarchy asks the designer to;

- Design out hazard
- Guard against hazard
- Warn of hazard
- Instruct/train
- Use personal protection

In this instance, designing out the fuel tanks (relocating them) would be overly cumbersome for the manufacturer deeming it impractical. The next logical step, however, is to limit the ignition source. This can be done by relocating the battery box; a much more practical solution.

The most practical and beneficial approach to this is to relocate the battery box to inside the frame rails in the already clear/free space just behind the cab.

A drawing of this clear/free space within the frame rails of a typical tractor has been supplied and labeled. (Fig. 2a, 2b)

The reader must realize that relocating the battery box to within the frame rails, as suggested, in not novel to the author. Freightliner Corporation currently employs this design scheme on their Century, Coronado and Columbia tractors. Photograph 8 and dimensional drawings (Fig. 3) of a typical Century Class tractor are included showing the design scheme today. This design dates back to 1996 when it was introduced on the Century Class tractor.

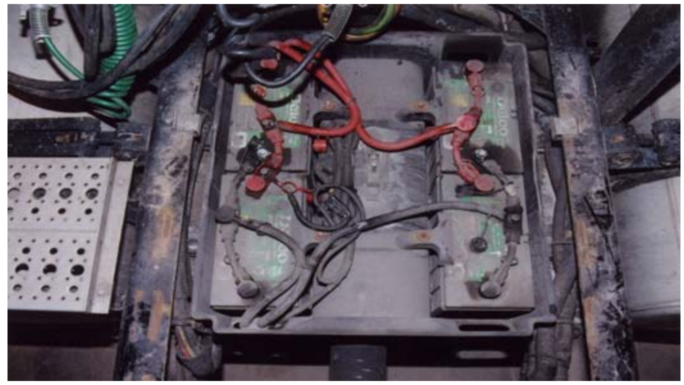

Photo 8 – Batteries Inside Frame Rails, Freightliner Century Class

WHAT IS REQUIRED FOR A FIRE

Three elements are needed to create a fire: air, fuel and an ignition source. Air is all around us; making for an abundant supply of the first element. Fuel, the second element, is the diesel fuel in the trucks' fuel tank which, in this scenario, is located right next to the third element, the ignition source. In this case, the ignition source is the battery box. Along with air, fuel and an ignition source, atomization of the fuel must occur in order to satisfy the stoichiometric requirement (14:l) to burn. The atomization increases the surface area of the fuel by creating small spheres or droplets. This increase in surface area is what allows the air to properly mix with the fuel for the stoichiometric ratio to be satisfied. Once this ratio has been met, a fire can occur. The atomization comes from the impact of the fuel tank as a result of the volumetric shape change and breaching that the tank goes through during the collision. Additional ignition sources are abundant but should be carefully analyzed prior to selection. In these accidents, the battery boxes were impacted directly, or in coincidence with the fuel tank. Upon impact, the batteries themselves or a cable (system element) can be damaged creating the ignition source. Since the batteries can create a large sustained spark, it can, in some cases, be the ignition source of the fire.

THE SIGNATURES

An explosion and fire of this type leaves many mechanical and fire related signatures.

- Impact to the battery box and fuel tank area (Photo 9).

Photo 9

- Battery tray and support structures are damaged (Photo 10).

Photo 10

- Fuel tank supports are damaged or reoriented (Photo 11).

Photo 11

- The companion fuel tank (passenger side) of the truck tractor is usually uninvolved from an explosion/fire point of view.

Photo 12

- An uninvolved fuel tank usually shows a volumetric "fuel level line" indicating how much fuel was in the tank at the time of the fire (Photo 12).

- In some cases there was evidence of the battery box being pushed into the fuel tank towards the rear of the tractor (Photo 13).

Photo 13 – Battery Box Moved Rearward

OTHER IGNITION SOURCES

In all of these investigations alternate sources of ignition were evaluated. In each one, the bullet vehicle was inspected and concluded not to be an independent ignition source of these fires. Specifically, the striking vehicle was inspected to see if any signatures were present that would determine that it was the ignition source. In each of the four investigations, the striking vehicle was ruled out as the ignition source (Photos 14 & 15).

Photo 14 – Striking Vehicle (no fire signatures)

Photo 15 – Striking Vehicle (no fire signatures)

These alternate ignition sources may be; auto-ignition contact and electrical in nature, to name a few.

A SOLUTION

Freightliner Corporation has employed a design scheme since 1996 which, in most cases, precludes this hazard.

On many of their tractors Freightliner installs the batteries inside the frame rails (Fig. 4). The battery cables are nested inside the frame rails along with the batteries. This design, assuming this area is not intruded upon, provides protection from impact in most cases. The fact that the battery is now no longer adjacent to the fuel supply, significantly reduces the fire hazard. In other words, it takes the potential ignition source out of play from the fuel source, thus reducing the risk of the fire/explosion hazard. This design scheme has been installed on tractors with a wheel base as short as 162" (see Appendix B), as well as long wheelbase sleeper tractors. As a result, packaging typically is not a design constraint.

PROOF TEST ALTERNATIVE DESIGN

Relocating the batteries and/or battery box must be examined for acceptability. That is to say, is it technically feasible, economical, does it have engineering acceptance, and is accepted by the user base?

I. Technically Feasible:

Since the alternative only proposes moving the battery box to inside the frame rails, in a nested orientation, there are no technical hurdles which would need to take place. Moving the batteries simply consists of fabricating steel brackets and forming a plastic/composite box to fit around the drive shaft. To further make this point, the author has inspected other brands of class 8 truck tractors with batteries inside the frame rails (Photo 16) (Appendix C).

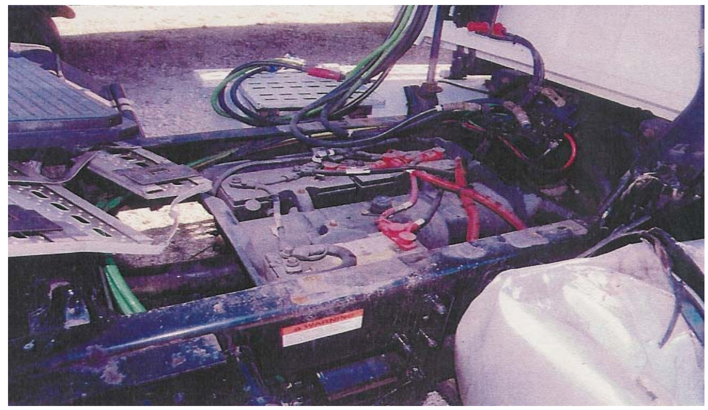

Photo 16 – Sterling Truck/Tractor

Interestingly enough Sterling[1], a division of Freightliner, has a model with the batteries located within the frame rails. This may not appear very impressive but the point to be taken away from this is this tractor appears to be generally the same as the original design by Ford Heavy Truck but with the Freightliner battery location/design. The initial implication of this is that this design can be employed into other truck tractors with minimal design efforts.

As far as any concern for voltage/amperage drop associated with longer cables, the author investigated this topic and concludes the following. Typical truck tractors use four (4) batteries totaling (625x4) 2500 CCA. This energy is passed through cables that are 5/8” in diameter.

The Freightliner Century Class tractor, with batteries in the frame rails uses four (4) batteries totaling (700x4 CCA) 2800 CCA. This energy is passed through the same diameter cables as other tractors of 5/8”. The difference in size from a 625 A battery to a 700 A battery is not consequential.

II. Economics

An examination of proposed part costs was conducted. However, it must be realized that this analysis was done with (retail) pricing. Therefore, an exact cost offset is not possible by the author due to not knowing what the % markup of either the analysis tractor or Freightliner parts are. A comparison analysis of parts required for the present system to the proposed Freightliner system concludes that the Freightliner system is approximately $229.00 additional (differential) above the system parts requirement at present day. However, the $229.00 is present day value. The analysis truck was produced in 1998. Therefore, the actual cost differential is less than the $229.00 in 1998 dollars. The analysis truck purchased new was valued at $58,000.00. Considering that $229.00 is less than 1% of the value of the truck, economics should not be a concern.

III. Engineering Acceptance

Here the concerns are whether or not the alternative design possesses a hazard itself, creates any type of operational interference, actually works and resolves the issue at hand.

a.) Hazard Itself

Moving the battery box to within the frame rails does not create new hazards. This task is simply comprised of re-routing the battery cables along with providing a compartment for the batteries in which to reside. Individuals adverse to this position will suggest that a frontal collision will drive the power train rearward into the batteries if relocated here.

If this was to happen, all that would likely occur is a battery/electrical "failure" minus the ignitable fuel source, therefore, no fire would occur.

If this was a concern a barrier could be developed to assist in the defection of the power train if it did move rearward so much that it could contact the batteries.

In 17 years of investigating heavy truck accidents the author has witnessed various "heavy" collisions. However, the power train is typically thrown from its mounts and/or the engine breaks away from the transmission at the bell-housing. A power train rearward migration, of this magnitude, is far less likely than the more frequent side impact with the unprotected battery/fuel tank combination.

Considering Freightliner has employed this design since 1996, it is reasonable to suggest that the Freightliner engineers have considered the "hazard" of the power-train migrating rearward in the direction of the nested batteries and dismissed it as a non-issue.

b.) Operational Interference

Moving the battery box to inside the frame rails will not create any operational problems or maintenance interference. Drivers typically do not interact with the batteries frequently. If the need to jump-start the truck arises, remote jump-posts (already in use) can be contemplated for installation in a safe location (Photo 17). As for maintenance, the

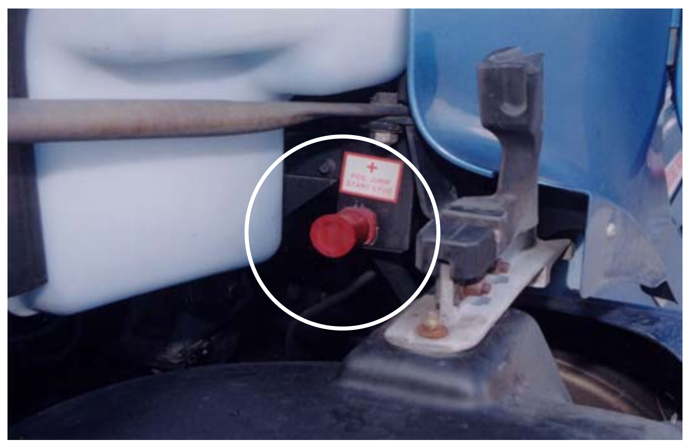

Photo 17 –Engine Compartment Jump Post

current location on a typical truck tractor requires work by the mechanic to remove the fiberglass fering to access the batteries. The Freightliner design has immediate access by removing an expanded metal “cat-walk” (Photo 18). In the unlikely event the Freightliner design was too difficult for a mechanic, one would think that:

i) The design would have changed since 1996, **but has not**.

ii) Freightliner would have discontinued it since its inception; **they have not.**

Photo 18 – Battery Access Covers, Freightliner Century Class

Therefore, all claims for operational interference are not an issue.

c.) Actually Works

Moving the batteries to inside the frame rails will not cause any problems with the electrical system and will allow the vehicle to function as expected. This comes with the one minor exception of using (4) four 700 CCA batteries instead of 625 CCA batteries.

d.) Solves Issue At Hand

Moving the batteries to inside the frame rails would have, in many instances, eliminated the ignition source of the fire. There is overwhelming physical evidence that shows that the batteries were in fact contacted during these collisions in at least the four investigations conducted by the authors. Furthermore, there is no physical evidence that suggests that the proposed location was intruded on at all.

Further methodology analysis shows that this design is tested. Both in the field since 1996 and most likely prior to that at the Freightliner proving grounds.

In addition, the fact that this concept/design has been subjected to peers and has been in existence since 1996, without major design changes or recalls, positions it as a viable solution to the issue at hand. Furthermore, thorough investigations have been conducted for recalls on this design; to date, none have been found.

e.) System Concerns

Others in the industry have resisted this design scheme by proposing utility downsides, maintenance concerns and packaging problems. Some of the utility downsides advanced are excessive voltage drop, poor start ability and additional wiring. We have investigated and tested these ideas and have concluded that none of these concerns are valid from an engineering or operational aspect. With respect to voltage drop, tests were conducted to compare the voltage drop of a truck tractor with in-rail batteries and a truck tractor with batteries located in the classic location. The classic location had a voltage drop of .54V and the in-rail truck had .74V. The difference of .20V is negligible and will not create any unwanted results (See Appendix D for test data). As far as the ability to jump-start a dead battery, remote jump posts are employed to facilitate this concern.

ADDITIONAL ADVANTAGES

The inner frame-rail mounted battery configuration has other advantages in addition to fire prevention. Weight/balance of the tractor is enhanced since the batteries are now symmetrically located about the longitudinal center line of the frame rails. Cantilever battery box support failures are eliminated since the brackets holding the batteries in the Freightliner design are loaded symmetrically. With batteries located between the frame rails you can expect prolonged battery life, easier access for replacement, no box corrosion (due to composite box), weight reduction and reduced shorting due to cable arcing[2, 3].

OTHER ALTERNATIVES

As a further alternative, based on the truck tractor configuration and application, a fuel tank and battery box location matrix is suggested if locating the batteries inside the frame rails is not possible.

- If short fuel tanks (dual), move battery box away from fuel tank creating a larger gap (same side).
- If only one fuel tank, locate battery box to opposite side of tractor.
- If dual tanks are required, make one large (long range) and one smaller, while mounting the battery box on the side with the short tank, creating a greater gap.

- If the truck tractor is C.O.E. configured the batteries may be located symmetrically on top of the frame rails (Photo 19 &20).

Photo 19 – Freightliner C.O.E

Photo 20 – Navistar C.O.E

CONCLUDING REMARKS

The purpose of this paper is to bring to the attention of truck manufacturers, owners and drivers that a solution does exist which can mitigate this type of accident. The design scheme described is not novel to the authors and is specifically to the credit of Freightliner Corporation.

Furthermore, it is to assist the investigator in conducting fire-cause and origin analysis of heavy trucks involved in collisions as well as to show the mechanical finger prints which are associated with this type of accident.

Results of this investigation indicate that there are unique fire-cause and origin fingerprints to this type of occurrence. Furthermore, there is a technically feasible, economical and practical design alternative that does exist which can mitigate this type of occurrence.

REFERENCES

[1] Sterling is a member of the Freightliner group. Freightliner LLC is a DaimlerChrysler Company.

[2, 3] Freightliner Web Pages: www.freightlinertrucks.com/trucks/find-by-model/features-benefits.asp?id=2;

www.selectrucks.com/inside-selectrucks/magazine/archive/tried-true.asp.

ACKNOWLEDGEMENTS

The authors would like to thank Dr. Mike James of Stress Dynamics, College Station, Texas for his expert accident reconstruction in this study.

APPENDIX A:

Make:	Volvo
Model:	VNL64T
Class:	8
Year:	1998
VIN:	4VG7DBRFOWN761068
Wheel base:	164”

APPENDIX B:

Make:	Freightliner
Model:	Columbia
Class:	8
Year:	2005
VIN:	1FUJFOCV35LN77629
Wheel base:	162”

APPENDIX C:

Make:	Sterling
Model:	AT 9513
Class:	8
Year:	08/02
VIN:	ZFWJA3AS53AK82003

APPENDIX D:

VOLTAGE/AMPERAGE TESTING DATA

Testing was conducted to show that that voltage drop is not a concern with in-frame batteries.

Volvo tractor (exemplar)

Penske unit:	# 5509726
VIN:	4V4MD2AF2YN241481
Voltage drop:	.74 volts (during cranking) (battery to starter solenoid)
Amperage draw:	1426 max, 900 steady state (during cranking)
Alternator output:	38A idle/26A stabilized 26A max rpm 44A idle/max rpm (full electrical load)
Cable length:	50" approximately d=5/8"

Freightliner Columbia

Penske unit:	#274271
VIN:	1FUJA6CG81PJ9597
Year:	01/01
Voltage drop:	.74 volts (during cranking) (battery to starter solenoid)
Amperage draw:	1200 max, 800 steady state (during cranking)
Wheel base:	170”
Cable length:	90”, d=7/8”

Fig. 1

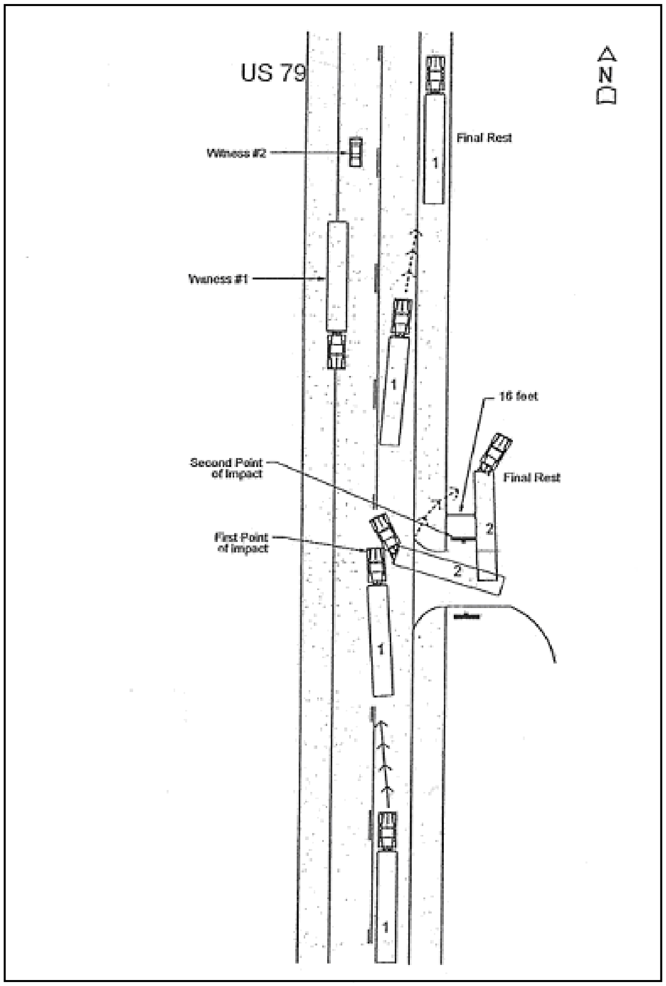

Fig. 2A

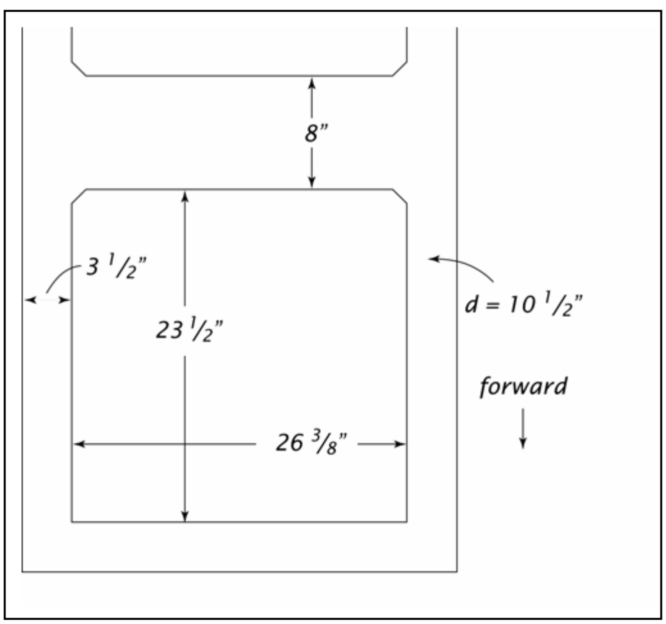

Fig. 2B

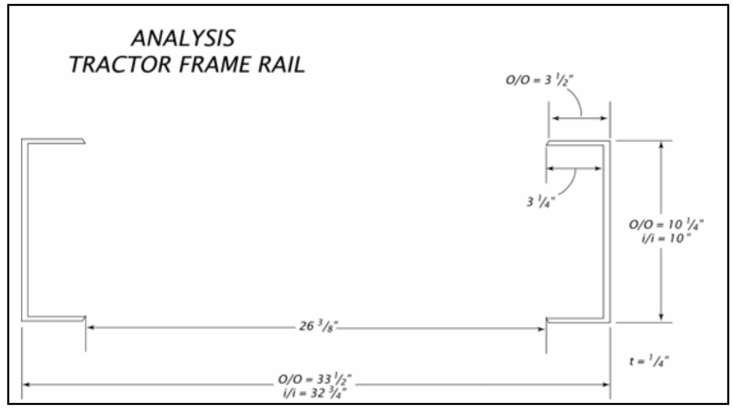

Fig. 3

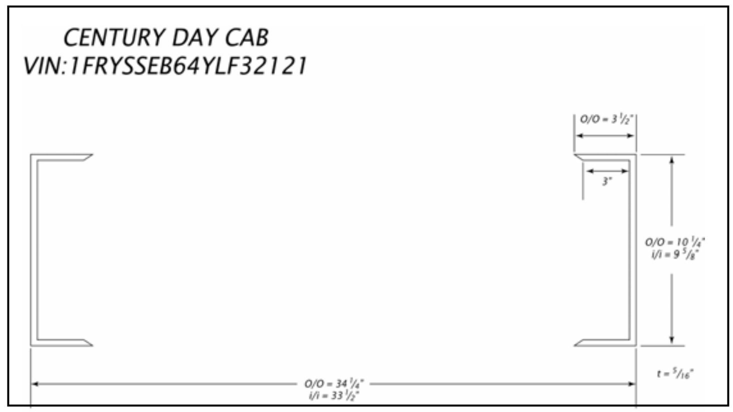

Fig. 4