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Overview of the Risks of Vehicle Conversions and Overweight Vehicles

Emergency vehicles, regardless of type, make, model, or year built, all have some common characteristics. They are subject to severe use; have multiple drivers; are heavy; and many have a high center of gravity. These last two items, weight and the high center of gravity, may cause problems with regard to the vehicle's handling characteristics. Too much weight or weight that is improperly distributed may cause steering and braking problems that could result in component failure. A high center of gravity, in addition to having an impact on steering and stopping the vehicle, plays heavily into the risk of vehicle rollover. Improper weight distribution or too much weight also influence the rollover potential.

There are three types of vehicles that are operated by emergency service organizations (ESOs) that VFIS would like to bring additional attention to:

1. **vehicles being considered for conversion for fire department use;**
2. **vehicles already converted; and**
3. **overweight vehicles.**

Vehicles Being Considered for Conversion

Unlike if you were to purchase custom-built fire apparatus, rebuilds and conversion vehicles are often manufactured or converted without any formal engineering applied to the vehicle design or modification. Any vehicle that is not being used for its original design use or that is being considered for modification should be regarded as a conversion vehicle. Examples include a commercial cab and stripped chassis, a commercial vehicle such as a beverage truck, milk tanker, or a military surplus vehicle.

Reconfiguring and building an emergency vehicle is not something that just anyone can or should attempt. Even those with a mechanical background and the tools to accomplish the physical modifications and installations (or well-meaning emergency service personnel attempting to do this) may be building something very dangerous to operate without the proper engineering being completed first. ***VFIS strongly discourages the modification of any vehicle without proper engineering.***

Vehicles Already Converted or Overweight Vehicles

If your organization already has converted vehicles or has vehicles that are known to be overweight, the same safety issues exist as with a vehicle being considered for conversion. Without a proper engineering evaluation, conditions may exist that may cause the vehicle to be overweight on one or all axles, have an unsafe center of gravity, or have component parts (e.g., brakes, springs, shocks, tires, etc.) that are undersized or otherwise inappropriate. VFIS strongly recommends that you have any converted vehicle (or one you suspect might have been converted or overweight) weighed to assure that the manufacturer's designed gross vehicle weight rating is not exceeded.

If you have a vehicle that has not been built or designed with the benefit of engineered specifications or converted from its original intended use, it is strongly suggested that you have the vehicle evaluated by an engineer with expertise in vehicle design to determine whether the vehicle is roadworthy. There are steps that can be taken to help make these vehicles safer to operate. These include, but are not limited to, the following:

Technical Advice

The first step you should take in evaluating your vehicles or a vehicle to be purchased should be to seek out qualified technical advice. This includes finding qualified individuals and a review of appropriate, written technical advice. An automotive engineer and the vehicle manufacturer are two good resources. Another resource is the most recent version of NFPA 1912, The Standard for Fire Apparatus Refurbishing. Persons who are qualified to recommend or make mechanical changes to the vehicle should be familiar with the standard and its requirements and recommendations. Copies of this and all NFPA standards may be obtained from NFPA by visiting their website at ***www.nfpa.org/catalog.***

Vehicle Weight Definitions

In your discussions with qualified persons who can evaluate your vehicle or conversion properly, there are a number of definitions from the U.S. Department of Transportation and NFPA regarding vehicle weight that you may find helpful. They include, but are not limited to:

- **Base Curb Weight:** The weight of the vehicle, including standard equipment, oil, lubricants and a full tank of fuel. It does not include the weight of the driver, passengers, cargo or any optional or aftermarket equipment.
- **Cargo Weight:** Any weight added to the base curb weight, including tools, equipment, water, and optional vehicle equipment. The tongue weight of any trailer attached to the vehicle for towing should be added as well.
- **Center of Gravity:** The point on an object at which the weight is distributed equally in every direction. It is the point at which an object is in balance.
- **Gross Axle Weight Rating (GAWR):** The value specified by the manufacturer as the loaded weight of a single axle.
- **Gross Vehicle Weight Rating (GVWR):** The maximum allowable weight for a fully loaded vehicle (base curb weight + payload).
- **Gross Combination Weight Rating:** The maximum combination of base curb weight + cargo weight + payload + trailer weight that the vehicle can safely carry/tow.
- **Gross Vehicle Weight:** The actual weight for a fully loaded vehicle (base curb weight + payload).
- **NFPA 1912 - Standard for Fire Apparatus Refurbishing:** This standard specifies the minimum requirements for the refurbishing of automotive fire apparatus utilized for firefighting and rescue operations, whether the refurbishing is done at the fire department, municipal maintenance facilities, or the facilities of private contractors or apparatus manufacturers.
- **Payload:** Maximum payload is defined as the weight of all passengers, optional equipment and cargo; net payload is defined as the weight that can be placed in the truck after subtracting for the driver, passengers, and optional equipment.

- **Safety Compliance Certification Label:** A label or plate affixed to the vehicle by the manufacturer detailing all of the weight capacities and restrictions for the vehicle. This includes axle weights, tire size and inflation pressure, and vehicle weight limits.
- **Tongue Weight:** The maximum amount of weight permitted to be carried on the trailer hitch.
- **Towing Capacity:** The combination of the amount of tongue weight capacity and total trailer weight that the vehicle is designed to safely tow.

Chassis and axle ratings

The qualified individual evaluating your vehicle will need to know the chassis and axle ratings to help determine how much weight the vehicle can safely carry and where the weight should be placed. This information may be found by:

- Reviewing printed information from the manufacturer regarding the original design of the vehicle.
- Locating the Federal Safety Compliance Certification Label (typically located on the inner door frame of the cab). This label may provide you with information including:
  - Gross Vehicle Weight Rating
  - Payload rating
  - Front axle weight rating
  - Rear axle weight rating
  - Wheel base measurements

Modifying the Vehicle

The qualified individual that designs and completes the modifications must have an understanding of and evaluate how each change WILL impact the physical dynamics of the vehicle post-modification. Consider that:

- ***Lengthening or shortening the frame changes weight distribution on the axles and the horizontal center of gravity.***
- ***Changing springs or modifying tire and wheel size can change the angle of the driveshaft and the relationship to the transmission and rear differential. This can also redistribute weight. The weight ratings of any component change should also be obtained.***
- ***Raising the vehicle body height will raise the vertical center of gravity.***
- ***Mounting cabinets, pumps and accessories will not just add to overall weight, but will add front-to-rear and side-to-side weight. Pre-planning for placing equipment on the vehicle and in cabinets with regard to weight is an often-overlooked part of vehicle modification. This may also affect the center of gravity and change the base curb weight of the vehicle.***
- ***The balance of the vehicle weight is as important as overall weight. Side-to-side balance is of particular concern. Since many roads are designed with crowns in the middle, the vehicle doesn't sit level often, which means there is usually more weight riding on the right side of the vehicle. If the vehicle has significantly more weight on the right side when it is level this will be exaggerated when the vehicle is moving on a road with a high center crown or when moving around a right-to-left curve or corner.***
- ***Nothing impacts vehicle safety and performance of fire apparatus more than the size, weight and location of the water tanks.***

Only after being armed with the correct vehicle information should a qualified person begin to determine what and where you may add onto the chassis safely. The qualified person should understand that, if the frame of the vehicle is going to be modified,

A Word about Water Tanks

Weight and Capacity

As mentioned before, nothing impacts vehicle safety and performance of fire apparatus more than the size, weight and location of water tanks. Simply because there is enough chassis length and width to mount a tank doesn't mean that it is an appropriate size or configuration for that vehicle. Water weighs approximately 8.34 pounds per gallon, or approximately 62.4 pounds per cubic foot. Consider the following chart to see the impact of various tank sizes:

Tank Size	500 gal.	750 gal.	1,000 gal.
Cubic Feet	66.85	100.27	133.69
Water/lbs.	4,171 lbs.	6,257 lbs.	8,342 lbs.

For every 100 gallons of water, you either add or subtract nearly ½ ton of weight. And remember, it is not just the weight of the water. With the water comes the weight of the tank itself, the mounting hardware, welds, valves and baffles, which must be factored into the design.

If the vehicle you are placing into service was originally designed with a tank to carry another type of fluid, be aware that the same volume of water will likely weigh considerably more, as illustrated in the chart below.

Water	Fuel Oil	Gasoline	Jet Fuel
7.48 gal./cu. ft.	7.48 gal./cu. ft.	7.48 gal./cu. ft.	7.48 gal./cu. ft.
x 8.34 lbs./gal.	x 7.14 lbs./gals.	x 6.10 lbs./gal.	x 6.84 lbs./gal.
62.40 lbs./cu. ft.	53.40 lbs./cu. ft.	45.63 lbs./cu. ft.	51.16 lbs./cu. ft.

So if the vehicle you are thinking of converting was designed to carry fuel oil, for example, by simply converting the tank over to carry water you've added considerable weight, as shown in the chart below:

Tank Size	500 gal.	750 gal.	1,000 gal.
Cubic Feet	66.85	100.27	133.69
Water/lbs.	4,171 lbs.	6,257 lbs.	8,342 lbs.
Fuel Oil/lbs.	3,570 lbs.	5,354 lbs.	7,139 lbs.
Difference	+601 lbs.	+903 lbs.	+1,203 lbs.

Configuration and Location

The shape and size of the tank also have an effect on the weight distribution and significant impact on the vertical center of gravity.

The configuration of the tank should be evaluated to determine what shape (round, elliptical, rectangular), length and width are appropriate for the application. Keep in mind that the higher off the ground the vehicle frame is to begin with, the higher the vertical center of gravity will be. The higher the vertical center of gravity is, the greater rollover potential the vehicle will have.

The length and width, as well as where the tank is physically mounted on the frame, impact the horizontal center of gravity. The mounting location is a major determining factor in the weight distribution between the front and rear axles and side-to-side. Placing tanks, bodies and loads in the proper place on the chassis will help ensure that the axles are loaded correctly.

Tank Baffles

All fire apparatus equipped with a water tank must have the water tank properly baffled. Baffles are critical to vehicle stability since they greatly reduce water slosh (inertia caused by the movement of water within the tank). Water-carrying apparatus that are contracted to the U.S. Forestry Service are required to have properly installed tank baffles.

A properly baffled tank reduces water slosh in all directions, not just front to back. Traditional baffling is done by welding physical baffle plates into the tank to divide the tank into chambers. This is referred to as the Containment Method of water control. This method is effective as long as the baffles are specifically designed and installed for the size and configuration of the tank and the liquid being carried.

The other acceptable method of water slosh control is known as the Dynamic Method. This method uses either staggered baffles or drop-in-style water displacement forms. The person designing the baffling system should check with the tank manufacturer (if known) and the baffle manufacturer to make certain that the style selected will be effective in the particular tank being used or considered.

Water Weight Reduction

If you have a vehicle that is found to be over the gross vehicle weight rating, or overweight on either the front or rear axle, reduction of the water tank capacity may be the best way to address the overweight condition. Recalling that for every 100 gallons of water you remove you can eliminate 834 pounds of weight, it is easy to see the impact that water volume reduction will have.

Another benefit of water weight reduction is that there may be options for where within the tank weight may be reduced. You can:

- Reduce the water volume in the front of the tank, reducing front end weight.
- Reduce the volume in the center of the tank or through the middle of the tank, reducing overall weight.
- Reduce water volume in the rear of the tank, reducing rear axle weight.
- Displace the water volume across the top of the tank, lowering the center of gravity.

An initial objection to reducing water volume is often that "If I reduce the amount of water my truck can carry, I am reducing my fire fighting capability." While there is some validity to that, you need to look at the bigger picture. If your truck doesn't make it to a scene because it is overweight and either rolls over or has a mechanical failure, you've lost your firefighting capability completely.

Options that may be considered to reduce the volume of water include filling one or more chambers in a traditionally baffled tank, and/or using products that will displace water volume. It bears repeating that you can remove or redistribute a lot of weight on the vehicle with only a relatively small loss of water volume.

Tires

Having the proper tires on every vehicle is very important. This doesn't mean just the proper size of the tires, but the specific ratings. In addition to the size and profile measurements, tires also have maximum load and speed ratings. The load rating is a standard index that indicates the maximum load and cold tire pressure under which a tire should operate. Speed ratings indicate the maximum safe speed at which a tire should be operated. You should check with the manufacturer of the tires on your vehicle to determine whether they are adequately rated for the type of use.

Overloading tires can cause them to weaken or overheat during use, causing them to fail. Even if a tire doesn't fail, the handling characteristics of an overloaded tire will change. Sidewall flexibility in particular can be negatively impacted by being overloaded. If the tire cannot flex under side load conditions as designed could result in a loss of traction when cornering. If the sidewall is flexed too greatly, the sidewall could come into contact with the road surface, possibly causing a blowout. If it is determined that a particular tire meets the load-carrying capacity but is close to the maximum for the rating, serious consideration should be given to replacing it with a tire from the next load index factor. Consult your tire dealer or manufacturer for recommendations.

In addition to the tire ratings, tires are also labeled with a date of manufacture. Many tire and vehicle manufacturers, as well as the Federal DOT, acknowledge that age may also be a tire safety issue. Several tire manufacturers have determined that tires that are over 6 years old, regardless of wear, may need replacement. As part of the conversion or evaluation process, the tires on the subject vehicle should be examined to determine the date of manufacture. The manufacturer or distributor should be contacted to determine the recommended action for the continued use or replacement of the tires.

Brakes

Regardless of the type of braking system (drum brakes, disc brakes, hydraulic or air-operated), the front brakes typically are tasked with having to provide the most stopping power. The braking efficiency of any braking system can be greatly diminished by too much weight on the front end, and stopping will be adversely affected, as will steering.

Weight issues related to braking can come from two different sources, static weight and dynamic weight. Static weight overload is simply having too much weight while the vehicle is at rest. What may not be as obvious or as easy to evaluate is the dynamic weight. Dynamic weight is a shift in weight caused from the vehicle in motion trying to overcome the resistance of braking. In simple terms, the weight of the back of the truck is trying to keep moving (momentum) while the front of the vehicle is trying to decelerate. This causes a weight transfer to the front axle. It may only be for a brief period of time, but it can be significant, especially during panic braking. Depending on several factors—where weight is located on the vehicle, how

fast the vehicle is traveling, the adequacy or inadequacy of the suspension (springs & shocks) and how hard the brakes are applied—a temporary increase in front end weight can easily exceed 20% or 30%. This not only affects the brakes but also steering, tires and suspension…all of which can be adversely affected or fail under the stress of dynamic weight transfer.

Cab and Personnel Safety

The driver and passenger compartments of any emergency vehicle should be designed with safety in mind. Some items that need to take priority in the design are:

- Visibility
- Mirror location
- Interior accessory location
- Cab integrity during a rollover (rollover protection)
- Seat style and adjustability
- Seat belts

Seat belts not only need to be installed but used 100% of the time. A review of emergency vehicle fatality crashes indicates that many of those killed were not wearing seatbelts. Seatbelts do two important things:

1. For the driver of the vehicle, the seatbelt will help keep the driver in contact with the steering wheel and brake by holding him/her in the seat.
2. Seat belts also keep the occupants inside of the vehicle. Many of the fatalities in emergency vehicle rollovers occur from the occupant being thrown out of the vehicle, often times being rolled onto by the vehicle, in an otherwise survivable accident. A visit to the NIOSH website can provide you examples of numerous investigative reports on emergency vehicle fatalities and reinforce the need to wear seat belts.

Vehicle Warranty

If your ESO has purchased a new vehicle or chassis with plans to convert it for emergency vehicle use, you should check with the dealer or manufacturer to determine whether the changes you are planning for the vehicle will void the new vehicle warranty.

For example, your modification replaces the rear springs or changes the rear end, and these modifications change the angle at which the drive shaft now meets the transmission. Will the manufacturer challenge whether the premature breakdown of the transmission at 18,000 miles was caused by the modification? As most people are aware, a non-covered item under a warranty can be very costly to repair out of pocket. A review of your modification plans with the dealer or manufacturer could help tremendously.

Driver Training

After an organization has completed the evaluation of an existing vehicle or has completed modifications on the apparatus, give consideration to the person at the controls. Determine who is qualified to drive the vehicle and the appropriate training the selected individuals will receive. Regardless of the amount of experience a driver may have, when a new vehicle is introduced to the fleet, his or her driving skills should be formally evaluated. This is particularly important with tankers and brush vehicles…tankers because of the overall size, weight and rollover potential, and brush vehicles because of the off-road use.

VFIS has a number of driver training programs available that address many specific aspects of driving. These programs are available to VFIS clients at no charge and are available online at www.vfis.com.

Summary

Modifying a vehicle requires more than just a toolbox and a torch. Give serious consideration to the issues contained in this document and in NFPA 1912, The Standard for Fire Apparatus Refurbishing. Obtaining professional advice from equipment or vehicle manufacturers or designers/engineers can be invaluable and may save your life.

Failure to properly evaluate how the changes and the components will impact the safety and handling of the post-modified vehicle can have disastrous results. To help prevent component failure, improper braking, handling, and rollovers, take the time to evaluate all of the parts and modifications as a whole. Weight and weight distribution should be at the top of this checklist.

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If you require additional information or if you have questions, please contact VFIS Risk Control Services at 800-233-1957.