

Roscommon Equipment Center Program

Newsnote #3

GUIDELINES FOR DESIGNING WILDLAND FIRE ENGINES

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Northeast Forest Fire Supervisors

In Cooperation with

Michigan's Forest Fire Experiment Station

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INTRODUCTION

Each year state and local fire agencies fabricate many pieces of equipment to meet their wild fire control needs. This is especially true because of the availability of military rolling stock through the Federal Excess Personal Property (FEPP) Program. FEPP based equipment has become a familiar sight at rural fires in the United States. This guide discusses important references and design concerns to help agencies fabricate efficient engines for their fire control needs.

PLANNING AN ENGINE¹ DESIGN

RESOURCES:

The first step in any plan is to determine your needs; designing an engine for wildfire use is no different. Based on your preferred strategy and tactics, decide how much water capacity, the type of pumping system and what miscellaneous storage system you need. These needs will determine the size and type of cab and chassis that you obtain. There are several resources available to help you plan the engine. The Fire Equipment Working Team (FEWT) of the **National Wildfire Coordinating Group** publishes the *Water Handling Equipment Guide* (WHEG) every few years. This publication presents photographs and data about a variety of engines from many of the state and federal agencies in the United States. It can be useful for determining how much water capacity is reasonable for a chassis, what types of storage could be utilized and which pumps are popular for wildfire control tasks. Each entry provides an address for obtaining more information. The *Water Handling Equipment Guide* sells for about \$3.00 and can be obtained at the address found in the Resource List at the end of this report.

FEWT also published the *Wildland Fire Engine Component Guide*, also listed in the Resources List. This guide discusses a variety of engine components from tanks to pumps to winches to chemical delivery systems and how to choose what is right for you. If a military vehicle is desired, check for **Roscommon Equipment Center** (REC) designs.

Table 1 lists REC design publications that show how to fabricate engines for wildfire control. The table also shows the water capacity as determined by that design project. The WHEG, Component Guide and REC publications were published to help you save time and fabricate a safer vehicle.

The **National Fire Protection Association** (NFPA) publishes *Standard 1906; Wildland Fire Apparatus*. This is intended as a purchasing standard and sets minimum performance characteristics as recognized by that body. Several other resources may

¹ "Engine" is the Incident Command System term used to describe ground based wildfire tankers and pumpers. The latter terms being more common in some regions in the past.

be useful. If you buy a new cab and chassis from a truck manufacturer, you will receive with it an *Incomplete Vehicle Document*. This document tells which *Federal Motor Vehicle Safety Standards* (FMVSS) need to be added by you, the body manufacturer, before the vehicle can be used on the highway. Most of these requirements will concern lighting such as stop, tail and turn lights, side marker lights and clearance lights. If you need detailed information about meeting any of these requirements you can refer directly to the FMVSS codes. For these, access the **U.S. National Highway Traffic Safety Administration** internet web page at www.nhtsa.dot.gov. The codes are an extremely lengthy and unwieldy publication that should be unnecessary if you ask questions of the truck manufacturer.

Each truck manufacturer also produces a *Body Builder's Book*. This publication details critical dimensions important to truck body manufacturers. Other information in the *Body Builder's Book* includes the location of components such as exhaust systems, transmission power-take-offs and frame crossmembers. It also has spring deflection curves that will help you calculate the height of the frame with and without a load, enabling you to design adequate wheel clearance for the body that you build. Obtain the book through your truck dealer.

If the vehicle will see at least some role in structure fire control, reading through other standards might be appropriate. NFPA also has Standard 1901 which concerns structure fire engines. **The Occupational Safety and Health Administration** (OSHA) also has safety regulations for structure fire vehicles. Lastly, **The Society of Automotive Engineers** (SAE) *Standards Book* has a wealth of information concerning the components on your truck.

TABLE 1, REC Engine Publications:

Military Model*	Payload	Tank Capacity	Project No.
M-38 Jeep	1/4 Ton	66 gal.	4
M-37	3/4 Ton	150 gal.	34
M-715	5/4 Ton	200 gal.	33
M-880 Dodge	5/4 Ton	200 gal.	40
M-561 Gamma-Goat	5/4 Ton	200 gal.	53A
M-998, HMMWV	Variable	100-300 gal.	56, 56B
M-135, M-211	2-1/2 Ton	1000 gal.	22
M-39, M-809	5 Ton	1500 gal.	39

* Sample model number for one model of the military series.

VEHICLE LOADING

GROSS VEHICLE WEIGHT RATINGS:

The gross vehicle weight rating (GVWR) is the single most important information that the truck manufacturer provides its' customer. It is the maximum design weight of the vehicle. This includes its' payload, the occupants, and the weight of the vehicle itself. **This weight should not be exceeded.** Note that for many trucks the GVWR is less than the sum of its' individual Gross Axle Weight Ratings (GAWR). Be careful! In these cases you can be within the limits of the GAWRs but exceed the load capacity of the vehicle. This is because the weight ratings take into account the load capacity of a variety of components, including the tires, suspension and frame. Any one of these, or other factors, may limit the weight rating.

Commercial trucks are designed primarily for use on paved highways. The GVWR is based on this use. If you plan to use these vehicles a good percentage of the time off-road, the GVWR should be reduced to account for the rough use. Commonly a value of 80 percent of the GVWR is used when designing wildfire vehicles from commercial cab and chassis. For most military vehicles, like those obtained from FEPP sources, the GVWR has already been reduced to account for a large percentage of off-road use. Check the data plate located on the dash of a military vehicle. It will tell you the GVWR and axle weight ratings. Older military vehicles will give these values for highway use and for cross-country use. Use the cross-country figures. Newer military vehicles provide only the cross-country GVWR.

CURB WEIGHT:

The curb weight is the weight of the vehicle without payload or occupants. If you purchase a new cab and chassis and it is delivered with its' fluid levels at "full", the vehicle would be at curb weight. Take the incomplete unit to a scale and weigh it². Weigh the total vehicle and at least one axle. The difference between the total weight and the axle weight will be the second axle's weight. Sand and gravel pits, highway truck scales and many wood processing companies will do this for you free or for a nominal charge.

DETERMINING THE PAYLOAD:

The manufacturer has given you the GVWR in the *Incomplete Vehicle Document*, or the military truck's data plate, and you have taken the bare cab and chassis to the scales to determine curb weight. With this information you can determine the vehicle payload and maximum weight that can be place on each axle. The payload is the difference between the GVWR and the curb weight (Figure 1). The maximum payload of each axle is the difference between the GAWR and the amount of curb weight on the axle.

² The truck manufacturer often provides the curb weight data, but modifications and options made to the vehicle just before delivery may change the weight making it advisable to check it at the scales.

To obtain a rough estimate of the weight of water, tank and apparatus mounted on the truck frame, use 11 pounds per gallon³. Water weighs about 8.3 pounds per gallon and typically the tank material, pump, hose reel and plumbing average 2.5 pounds for each gallon of water capacity. REC's web site has a "[quick and dirty calculator](#)" for finding this estimate or follow these directions. For commercial vehicles reduce the rear GAWR by 20 percent for off-road use. Subtract the rear axle curb weight from the rear axle gross axle weight rating. This will yield the payload allowable on the rear axle. Divide this figure by 11 pounds per gallon and you can estimate the vehicle's tank capacity in gallons. It is good to reduce this estimate by 5 or 10 percent to give yourself a margin of error.

Remember, you want to get full value out of your truck, but in rugged off-road settings the addition of too much payload on a vehicle will increase the frequency and cost of repairs and could cause safety problems.

Trucks are designed to have their load centered upon, or slightly forward of, the rear axle. Weight centered on an axle will be translated directly to that axle. These factors might help:

- Weight placed behind the rear axle will increase the load on the rear axle and reduce the weight on the front axle.
- Weight put forward of the front axle will increase the load to the front axle and reduce the total load on the rear axle.
- Weight placed between the axles will be translated proportionally to the front and rear axles.

Details on balancing all the loads that may be placed on your fire vehicle are beyond the scope of this booklet. If in doubt, consult an engineer or someone who has experience in vehicle body design. REC's web site also has a [more precise load calculator](#). It requires that you provide accurate weights of components and their distance from the front axle. If used correctly, it should give reasonably precise estimates prior to fabrication.

WEIGHING THE COMPLETED VEHICLE:

After the vehicle body has been fabricated and the apparatus has been placed, load the vehicle with water and full complement of occupants and gear, and take it to a scale to be weighed. Check the weight on each axle. The sum should be the total vehicle weight. Compare with the GVWR and GAWRs to make sure that none have been exceeded. For commercial vehicles, compare to 80 percent of the GVWR and GAWRs to determine suitability for off-road use. If the GVWR has been exceeded, take corrective action. In most cases this can be done by making a modification to reduce

³ Experience has shown that 11 pounds per gallon provides a reasonable estimate of the weight of a wildfire vehicle's apparatus package full of water. Tank material, storage needs and pump type are factors that will affect this estimate.

tank capacity or by limiting the amount of gear stored with the vehicle. Take the vehicle for a test drive; get a feel for the load balance, both with and without water. You should be able to answer “yes” to these questions:

- Is the vehicle easy for the driver to control?
- Is the center of gravity low enough to handle curves and side slopes well?
- Do the brakes stop the vehicle well without brake fade?

Find an area to safely test your new vehicle and make sure there are no problems before it goes on an emergency run.

TABLE 2, Determining Allowable Loads:

-
1. Find the Weight Rating
Military Vehicle – Dash Plate
Commercial Vehicle – Incomplete Vehicle Document
 2. Weigh the Bare Chassis
 3. Calculate the Difference between GVWR and Bare Chassis
 4. Estimate Weight of the Tank, Water and Accessories
approximately 11 pounds per gallon of water capacity
 5. Center the Water Load and Tank on or Slightly Ahead of the Rear Axle
 6. Weigh the Completed Vehicle Fully Loaded – Make Sure the Weight Ratings are not Exceeded
-

OTHER DESIGN CONSIDERATIONS

The previous section discussed vehicle weight ratings and their importance to basic designs of the apparatus for the finished wildfire engine. There are many other components of a safe and efficient design.

CAB AND CHASSIS SPECIFICATIONS:

Besides determining the vehicle by its’ weight ratings, certain other needs should be defined before ordering the vehicle. One of these is wheelbase. The wheelbase is the distance between the centers of the front and rear axles (Figure 1). A shorter wheelbase vehicle will give you more maneuverability and smaller turning radius. This will be helpful if you are planning to use the vehicle off-the-road and need to steer it

around objects. The cab to axle (CA) dimension is partially dependent on the wheelbase. This is defined as the horizontal distance between the back of the vehicle's cab and the rear axle or rear suspension. Most truck manufacturers use standard CA distances, this helps truck body manufacturers to fit their products on many truck models. If you plan on using a premade truck body as part of your finished wildfire tank, make sure that your truck's cab to axle distance is suitable.

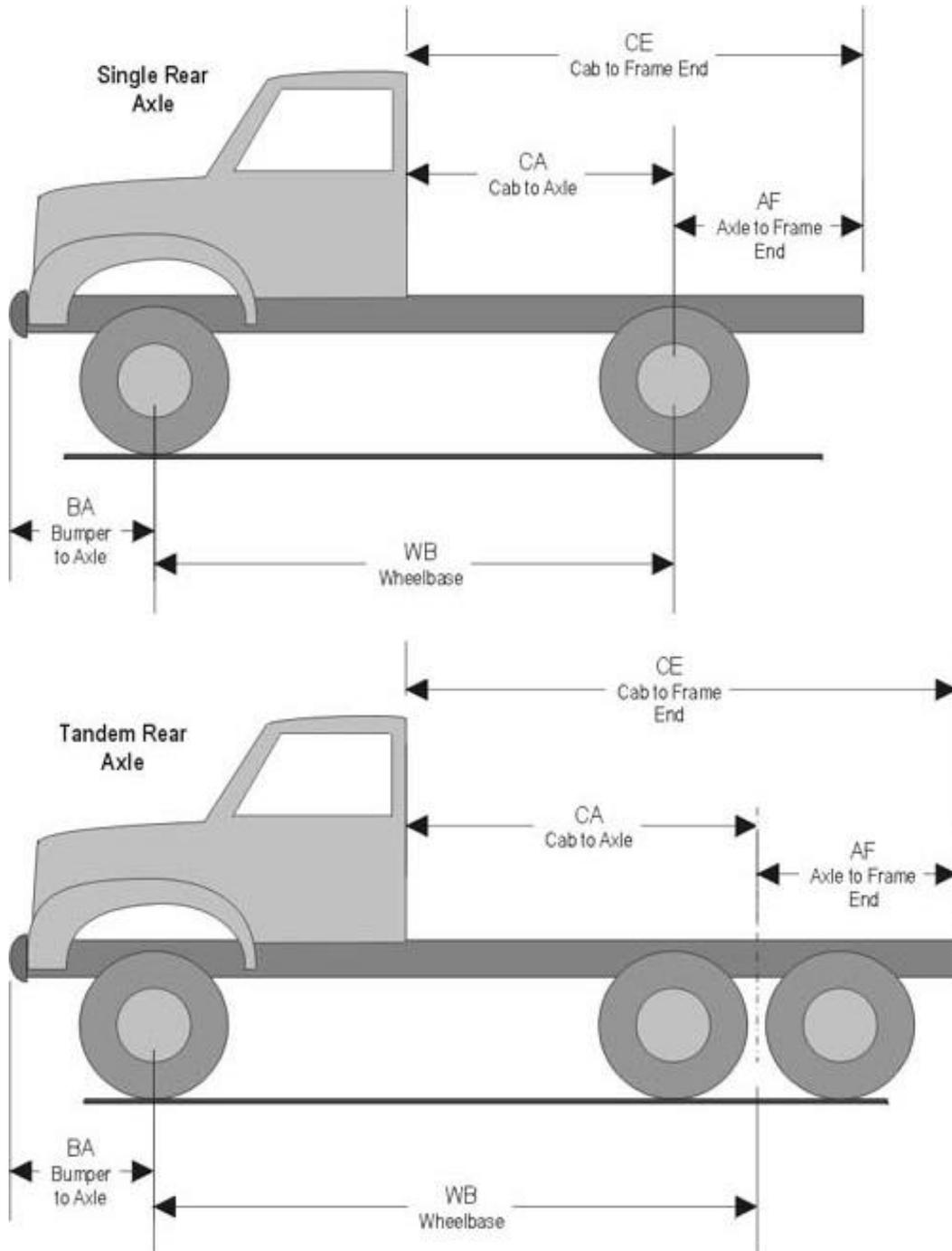


Figure 1 – Common Cab and Chassis Abbreviations

If off-road use is necessary, you may wish to consider all-wheel drive. Light duty (pickup) class trucks have this as an available option. Although it is getting better, in today's commercial market few all-wheel drive models are available for vehicles greater than 11,000 GVWR. There are some secondary manufacturers who will modify a vehicle by installing a front driving axle.

Another consideration for off-road use is the vulnerability of components located underneath the vehicle. Stumps, rocks and moguls can easily take a wildfire engine out of service. With some vehicles brake and fuel lines, tie rods, oil pans and exhaust components are very vulnerable to being damaged by objects that the vehicle might drive over. Some of these components can be protected by skid plates, but it is best to look for a vehicle that comes with adequate ground clearance and a minimum of exposed components.

You may wish to use a pump or winch that drives from a transmission power-take-off. Consult your truck dealers to see what is available and to make sure the power-take-off is matched to the components you wish to drive. Many of today's trucks have very limited space for routing drive shafts from the power-take-off. Make sure the clearance is adequate before you order the vehicle.

The number of electrical components used on today's wildfire vehicles seem to be increasing daily. Sirens, rotating beacons, electrical hose reel rewinds, pump starters and work lights all can impose heavy electric loads. Dual batteries and high amperage alternators merit consideration.

TANK:

Center of Gravity

The proper tank design can contribute greatly to the safety of the fire vehicle. For wildfire use it is important to keep the vehicle's center of gravity low. This means low profile, rectangular style tanks are preferred. These provide better stability on all side slopes and while cornering. If the tank height is below the bottom of the rear cab window, you usually can be assured that the center of gravity is low. Keeping the tank below the rear cab window also provides increased visibility for easier maneuverability and greater safety. In no case should an off-road fire unit have a vertical center of gravity higher than 3/4 of the vehicle track (Figure 2).

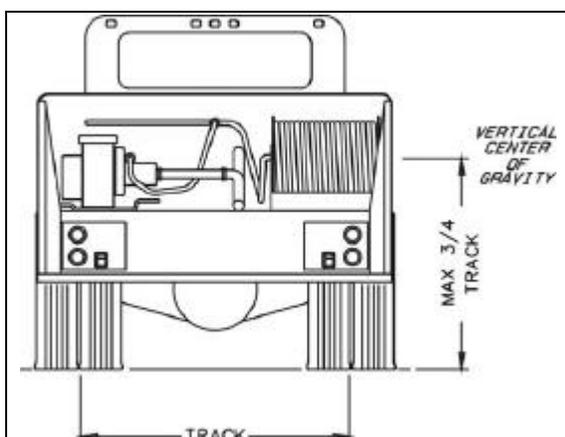


Figure 2 - Keep the vertical center of gravity (CG) low for stability and visibility. The CG should not be higher than 3/4 times the vehicle tire track.

Baffles

Essential to any water tank design is the addition of baffled sections inside the tank

(Figure 3). Baffles prevent massive water shifts when encountering slopes, going around curves or braking. Without baffles, large changes in water momentum occur that could cause rollover of the vehicle or failure of the tank. Design and placement of baffles are determined by safety and ease of construction. Each section may contain as much as 150 gallons for a heavy truck with a tank of 1000 gallons or more. Small vehicles will need smaller sections (usually 50 to 75 gallons). Check the REC design publication for a vehicle close to the size you are using. The tank design drawings will give ideas about placement. Make sure that there are adequate openings for water flow at the bottom of each baffle and adequate openings for air flow at the top.

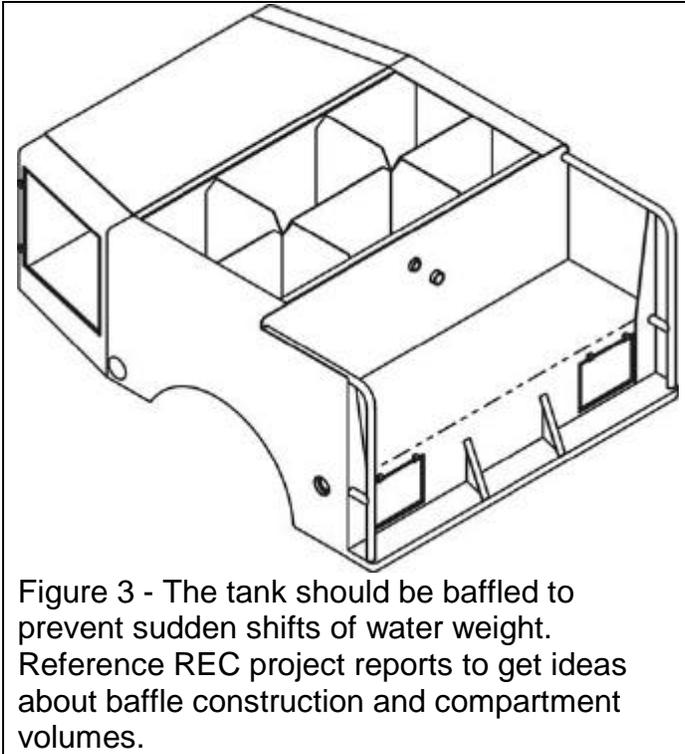


Figure 3 - The tank should be baffled to prevent sudden shifts of water weight. Reference REC project reports to get ideas about baffle construction and compartment volumes.

Materials

Water tanks are commonly constructed of mild steel, stainless steel, fiberglass, polyurethane and sometimes aluminum. The choice of material is usually based on a compromise between cost, ease of manufacture, corrosion resistance and tank weight. Stainless steel is relatively free of corrosion problems but it is costly and heavy. Using mild steel reduces the initial cost considerably. Mild steel tanks should be protected from corrosion (see REC Publication #11), but they are durable in other ways and generally easy to fabricate.

Aluminum may be suitable for small tanks, but is prone to weld failure.

Fiberglass provides a lighter weight and is generally more costly to build than mild steel tanks. Relatively corrosion free, fiberglass is generally most suitable for smaller slip-on tanks.

Polyurethane is a recent addition to materials used for tanks. Free of corrosion problems, its' initial cost, like fiberglass, is somewhat higher. Fabrication using polyurethane is best left to the experienced manufacturers which usually offer a very good warranty.

Tank Mounting

A truck's frame is designed to be flexible. When a tire hits a bump, or the vehicle rocks over uneven terrain, the frame rails and crossmembers that tie it together must flex to prevent an overload of forces that could damage or weaken the frame components. Because of this, it is extremely important to secure the water tank to the frame in a manner that allows the frame to flex as designed. A common and highly recommended

method of securing a tank to a truck is by a single bolt through each frame rail at the rear of the vehicle (see Figure 4). The mounting holes should be located near the neutral axis – normally the vertical centerline of the frame rail. Flanges should be located near the front of the tank that will serve as guides to prevent the tank from moving from side to side. Hardwood mounting strips should be placed between the tank and frame rails. Spring loaded tie-downs can be used at the front. Never weld directly to a truck's frame rail without consulting the truck manufacturer. The heat from the welding can severely weaken the steel.

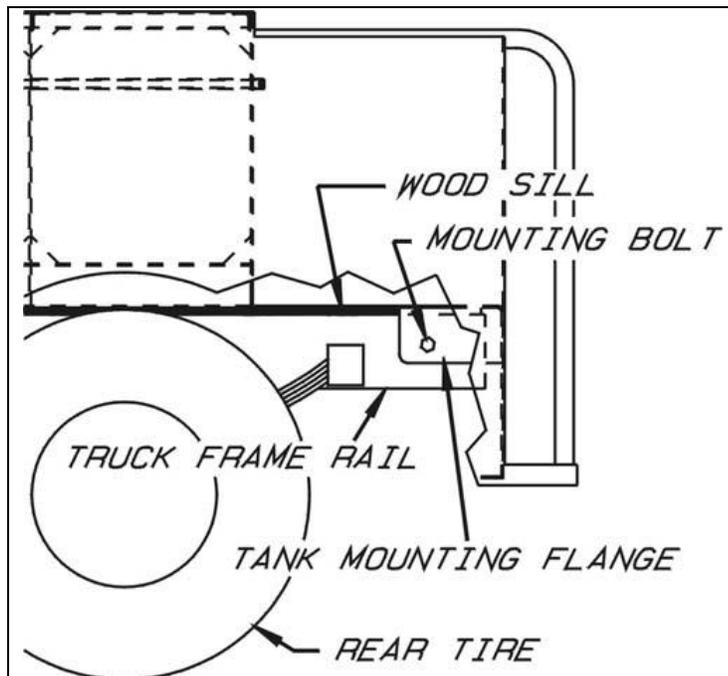


Figure 4 - Unitized tanks should be attached so that the truck frame can flex. A common method is to lay the tank on hard wood strips, to prevent metal to metal contact. Then use a single bolt at the end of each frame rail to secure the tank.

Plumbing

Be sure to plan areas for the pump and hose reel. Consider having a sump area that will drain easily for winter storage. If it is a large tank you may wish to have a "quick dump" so the vehicle can be used to shuttle water. REC Project #39 shows how a sump, "quick dump" and tank drainage can be cleanly designed together. In most cases you will want a top for the tank that can be completely removed for inside the maintenance and tank cleaning. The simplest way to do this with a steel tank is to tap threads and bolt the top onto the main tank body. Be sure that the tank has a filler port of adequate size to be filled by a portable pump or other engine. It is also essential to have an air vent of a size that will prevent the tank being

pressurized if the tank is filled with a high volume of water in a short time.

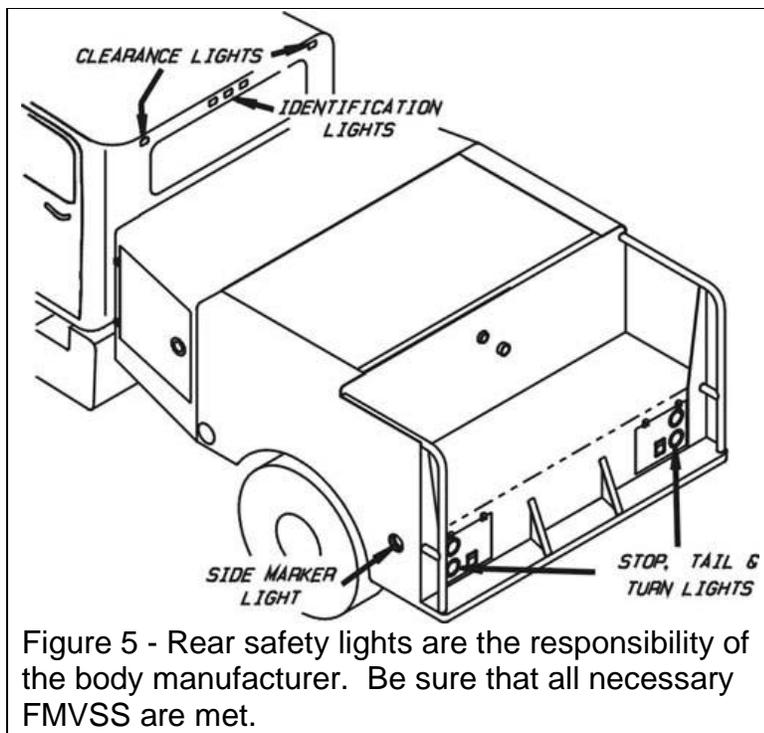
Chemicals

The use of fire chemicals has been increasing. Some of these chemicals are highly corrosive. Wet Water and Foaming Agents will deteriorate galvanized coatings, leading to premature corrosion of the mild steel underneath. Long-term phosphate based retardants will also attack galvanizing. Be careful when using dissimilar metals such as carbon steel with aluminum in direct contact with each other. Galvanic corrosion cells can be set up that might quickly deteriorate one of the components.

Safety Needs

Before the vehicle is finished consider these safety concerns:

- Slippery surfaces – make sure the areas where personnel will step, such as bumpers or pump operating areas, have abrasive surfaces or anti-skid plates to prevent personnel from slipping under wet conditions.
- Look for areas that may need grab rails to help personnel climb up to operating areas.
- Often, visibility is poor to the rear of fire vehicles and backup alarms are advised; in some cases they may be required.
- Night work will require lighting so the operator can adequately see pump controls in the area they are working.
- Make sure all Federal Motor Vehicle Safety Standards are met (www.nhtsa.dot.gov/cars/rules/standards). Some that are often overlooked include the series of five clearance lights, front and back (for vehicles over 80 inches in width, see Figure 5), and side marker lights, both front and rear. Check the truck's lighting. Make sure it is visible to public.



Safety and efficiency are the two goals of wildfire engine design. The above information is provided to give the potential user an idea of some important elements that should go into the vehicle needed for the task. In the design and fabrication process mistakes can be costly. There is no substitute for tested professional designs. This publication has listed many sources in which you can obtain those designs. You will save time and money by utilizing them whenever possible.

RESOURCE LIST

REC, ENGINE RELATED PROJECTS:

- REC #2 Wiring Conversions on Military Vehicles
- REC #4 Jeep Tanker Handbook
- REC #11 Rustproofing Treatment for Steel Water Tanks
- REC #22 1000 Gallon 6x6 Tanker Handbook
- REC #25 Protective Cabs for 6x6 Trucks – GMC & REO
- REC #33 Tanker Handbook, Military 1-1/4 Ton, 4x4 Cargo Truck
- REC #34 Tanker Handbook, Military 3/4 Ton, 4x4 Cargo Truck
- REC #39 Tanker Handbook, Military 5-Ton 6x6, 1500 Gallon Low Profile Tanker
- REC #40 Tanker Handbook, Military 880 Series 1-1/4 Ton, 4x4 Cargo Truck (Dodge W-200)
- REC #56A Evaluating the HUMMER and HMMWV Series Chassis for Wildland Engine Use
- REC #56B Hard Cab Design for HMMWV
- REC #60 M548/M1015 Track Vehicle

Order REC Project Reports From

Roscommon Equipment Center
c/o Forest Fire Experiment Station
P.O. Box 68
Roscommon, MI 48653-0068
email: info@RoscommonEquipmentCenter.com

ENGINE DESIGN REFERENCES:

[Water Handling Equipment Guide, NFFS #1275](#)

[Wildland Fire Engine Component Guide, NFFS #1871](#)

Order: National Interagency Fire Center, Attn: Great Basin Cache Supply Office
3833 South Development Avenue
Boise, ID 83705

www.nwcg.gov/pms/pubs/puborderform2001.pdf

Body Builders Design Books

These can be obtained from the Truck Sales Representative or Dealer.

[Society of Automotive Engineers Handbook](#)

400 Commonwealth Drive
Warrendale, PA 15096

www.sae.org

National Fire Codes

National Fire Protection Association

1 Batterymarch Park

Quincy, MA 02269-9101

www.roproc.nfpa.org

Thomas Register of American Manufacturers

Thomas Publishing Company

Five Penn Plaza

New York, NY 10001

www.thomaspublishing.com

Federal Motor Vehicle Safety Standards (FMVSS)

NHTSA Information

400 Seventh Street, S.W.

Washington, DC 20590

www.nhtsa.dot.gov/cars/rules/standards