Aerial Apparatus Operations

THE AERIAL APPARATUS:

There are many different types of aerial apparatus used in the fire service today. However, many share the same basic characteristics. NFPA 1901 requires that an aerial device should consist of two or more ladder sections that reach to a vertical height of at least 50 feet. The ladder should be rated at a minimum of 250 lbs with the ladder fully extended at a horizontal position. In addition to the aerial ladder, the apparatus should have a full complement of tools and equipment, including ground ladders. The ground ladders should total 115 feet, with at least one attic, 2 straight, and 2 extension ladders.

There are 3 main types of aerials; the Straight Ladder (Fig. 1), the Elevated Ladder Platform (Fig. 2), and the Elevated Platform (Fig. 3). The Straight Ladder consists of multiple ladder sections with an open style tip. The Elevated Ladder Platform is similar to the Straight Ladder but has a working platform at the tip. The Elevated Platform does not have a ladder, rather a boom. This boom can be articulated or straight. All of these aerial ladders / platforms are either a rear mounted or tillered (tractor drawn aerial, above).

Aerial apparatus are used in a variety of applications. Some operations include general egress, access, rescue, ventilation, and elevated streams. Some aerials are better than others in certain operations. For example, Platforms can handle non-ambulatory victims easier than Straight Ladders. However, ambulatory victims can get down a Straight Ladder quicker.
AERIAL APPARATUS DESIGN:

The basic design of an Aerial Ladder Apparatus (Ladder Truck) consists of the Chassis and the Aerial. The Chassis deals with the main driving unit of the truck and includes the motor, breaking, electronics, etc. The Aerial component can be further broken down into four areas. The first part is the structural component of the ladder, which includes the shape, material, and capacity of the ladder. Often if there is a failure in this component, the entire ladder will fail. The second component is mechanical and includes the bushings, rollers, cables, and pulleys. These parts can be considered general consumables and should be checked and replaced periodically. The hydraulic system is the third part of the Aerial. This component consists of the hydraulic fluid, hoses, pumps, manifolds, valves, etc. Often if there is a failure in this area, the ladder will not fail; yet cease movement. Lastly is the electrical system. This component consists of all the wires, connections, and other devices to send the signal from the operator to move the ladder. Again, a failure here often only stops the ladder.

Fig. 4 – Basic Aerial Design

AERIAL APPARATUS FAILURE:

Aerial Ladders are fairly safe, but accidents happen. Failure of Aerial Apparatus occurs because of three reasons. The first reason is the easiest to remedy. Wear on vital parts due to normal use can cause a catastrophic failure of the ladder. NFPA 1911 outlines inspection, maintenance, and testing of Fire Service Apparatus. Departments should be aware of their manufactures maintenance schedule and adhere to it closely. Abuse and overloading is another cause for ladder failure. Again, apparatus operators should be aware of the ladder capacity of their apparatus. Ladders should never be side-loaded or used to break out windows, as that is not their intended design. Lastly, poor design or manufacturing flaws can cause failure. Looking at a typical failure curve, all ladders are destined to fail. That is why NFPA 1901 recommends non destructive testing. In any case, it is always important to follow the manufactures recommendations for use. Department SOP’s should coincide with these manufacture recommendations.
AERIAL APPARATUS STABILIZATION:

Apparatus stabilization is of the utmost importance to reduce the risk of failure. All ladder trucks have their own recommendations for spotting and stabilizing the apparatus. Some trucks recommend jackknifing the tiller, some recommend keeping the truck inline. Some manufactures recommend lifting the wheels off the ground, some recommend just taking the bubble out. Do you know what’s right? Know your manufactures recommendations prior to stabilizing your ladder truck. When setting the outriggers always use the outrigger plates on a firm surface. NFPA requires the use of outrigger plates. The outrigger shoe does not provide adequate distribution of weight.

CONSIDERATION #1:

While operating an aerial ladder at full extension and 45 degree angle, the outriggers on the opposite side come off the ground (fig. 7). Do you continue working? NFPA recommends that the ladder truck must remain stable. But what is stable? They define stability as:

“The truck is considered to be in a state of stability when no sign of overturning is evident with the aerial ladder or elevating platform in operation. The lifting of a tire or stabilizer on the opposite side of the vehicle from the load does not necessarily indicate a condition of instability. Instability occurs when an aerial device can no longer support a given load and overturning is imminent.”

If we look at the forces acting on each outrigger, then we can argue that if the outrigger on the opposite side were to leave the ground then the truck would still be stable. Let us consider Newton’s third law. If the weight of the aerial is pushing down on the outrigger; let’s assume 5,000 lbs; then the ground must push back at the same force. The force that the ground is pushing up is actually in the same direction as to the ladder weight on the opposite side. That force would actually want to make the truck roll over. If the outrigger is not in contact with the ground, then there is 5,000 less lbs of force wanting to make the truck roll over. So, what is the answer? Again, it depends upon your departments SOP’s and the manufactures recommendations, which should be the same. How many departments carry the apparatus manual in the apparatus, where it should be?
Outrigger Force Test:

Truck: 2003 KME Tiller Truck  
Aerial: 100ft 4 section straight ladder

<table>
<thead>
<tr>
<th>Aerial Orientation</th>
<th>Driver’s Side Outrigger (lbs)</th>
<th>Passenger’s Side Outrigger (lbs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ladder bedded</td>
<td>8500</td>
<td>8600</td>
</tr>
<tr>
<td>Elevated to 75 degrees</td>
<td>8800</td>
<td>9000</td>
</tr>
<tr>
<td>Fully extended at 75 degrees</td>
<td>9200</td>
<td>9600</td>
</tr>
<tr>
<td>Rotate to 90 degrees to truck</td>
<td>6700</td>
<td>12800</td>
</tr>
<tr>
<td>Lower angle to 60 degrees</td>
<td>2600</td>
<td>16500</td>
</tr>
<tr>
<td>45 degrees</td>
<td>200</td>
<td>19700</td>
</tr>
<tr>
<td>30 degrees</td>
<td>0 - Lifted</td>
<td>22000</td>
</tr>
<tr>
<td>15 degrees</td>
<td>0 - Lifted</td>
<td>24000</td>
</tr>
<tr>
<td>0 degrees</td>
<td>0 - Lifted</td>
<td>24600</td>
</tr>
<tr>
<td>With a 200 lb load added to tip</td>
<td>0</td>
<td>25600</td>
</tr>
</tbody>
</table>

AERIAL APPARATUS POSITIONING:

Aerial Apparatus placement is very important on an incident. It is important for all arriving companies to determine and leave free ideal positions for the truck. The truck company must consider multiple issues, which include overhead wires or other obstructions, collapse zones, width of the street, location of victims, and the height of the building (fig. 8). Once the aerial is up, it is time consuming to retract and reposition the apparatus. A good rule of thumb for a first in truck company, is to drive past the incident location (fig. 9). This will allow the company officer a look at all three sides of the building.

When spotting apparatus, keep in mind the collapse zone. The collapse zone should be 1 ½ times the height of the building. Often this will limit the height in which the aerial apparatus may reach. To combat this issue, truck companies will often spot on the corner of the building less than 1 ½ times the height. If a collapse were to occur, the apparatus is positioned at the strongest part of the building and should not be affected by the collapse. The corner also allows the apparatus operator the option to reach two sides of the building instead of just limited to one (fig. 10).

Street conditions also play an important role on apparatus positioning. In some instances the street may be too narrow for the apparatus and outriggers may need to be “short-jacked”. Always follow the manufactures recommendations on short-jacking. Short jacking should never be done on the same side as the ladder is positioned. Some streets have “crowns” or high points in the middle of the street. For large buildings, this crown may give the apparatus the added height it needs. If the building is located on a steep incline, positioning the apparatus on the downhill side will maximize the angle of the ladder, but may decrease the reach (fig. 11).
Once the apparatus is positioned, the next important step is spotting the aerial. When using elevated ladder platforms for roof rescue, place the bottom of the platform just above and over the roof edge (fig. 12). This will allow victims to crawl into the platform. When this same platform is used for rescue from a window, the platform rail should be placed even with the windowsill so that victims have access directly into the bucket (fig. 13). It is a good idea to shoot above your target and work down. If there is a firefighter in the bucket and the bucket is coming from below the level of the victim, the victim may jump prematurely and injure the firefighter in the bucket and/or shock load the ladder. For straight ladders, the aerial should extend past the roof line so that firefighters have access from either side of the ladder. It is very difficult and sometimes intimidating to get on and off of the ladder from the tip. In some instances, a roof ladder may also be used to gain access to the roof from large parapets (fig. 14).

CONSIDERATION #2:

There are many different ideas of why or why not to support the ladder on the roof. Some say that by supporting the ladder on the roof, the ladder is more stable and is easier to climb because it does not bounce. Some ladders are not able to be supported due to a pre-plumbed waterway under the ladder. Newer aerials have the option of “ladder pipe” or “rescue” mode. With the position of a pin, the waterway and nozzle either stay with the tip of the ladder or stay with the bed or one of the lower sections. To answer the question of whether or not an aerial should be supported or not, lets look at its construction. Aerial ladders are constructed much like open web bar joists. The top cord is held in tension, while the bottom cord is held in compression (fig. 15).

When unsupported, an overloaded aerial will fail in compression. As it extends the ladder will bow downward. When the ladder is supported the loads invert. By inverting the loads the ladder is more susceptible to buckle because it is easier to fail in tension then compression. To help illustrate this idea, take a tape measure and extend the tape as far as possible while only holding the base of the tape. The tape begins to bow until the point that it finally breaks. Now flip the tape measure over and repeat. By inverting the loads, we made the tape measure weaker and it does not extend as far.
AERIAL LOADS:

**Dead Load**: (NFPA 1901) The weight of the aerial device structure and all materials, components, mechanisms, or equipment permanently fastened thereto.

**Live Load**: (NFPA 1901) Forces acting on the aerial device from personnel, portable equipment, water, and nozzle reaction.

**Rated Capacity**: (NFPA 1901) The total amount of weight of all personnel and equipment that can be safely supported at the outermost rung of an aerial ladder or on the platform of an elevating platform with the waterway uncharged.

NFPA 20.20.1- All structural load supporting elements of the aerial device that are made of a ductile material shall have a design stress of not more than 50 percent of the minimum yield strength of the material based on the combination of the rated capacity and the dead load. This is equivalent to a 2:1 safety factor.

Abuse and overloading are the most common causes of aerial ladder failures. It is important to understand the loads or forces that act on an aerial ladder and the forces that counteract these loads. Stress is defined as the applied force to an object. Strain is how much the object responds. All materials have some form of elasticity to stress. To illustrate this idea, imagine a spring. Place a small weight at the end of the spring and the spring will elongate. If that weight is not more than the spring’s weight capacity, the spring will return to its original length when the weight is removed. Now if we overload the spring, the spring loses its elasticity and becomes permanently deformed when the weight is removed. This deformity actually causes plasticity in the material. If the spring is continually overloaded, the plasticity of the spring cannot compensate for the load and it will break. What holds true to the spring, holds true to the aerial ladder.

The ways loads are applied are also important. Loads can be applied as either static (or semi-static) and dynamic (shock loads). Static loads are loads that are at rest or not moving; or forces that are slowly applied. Dynamic loads are loads in motion or quickly applied. Here are a few simple formulas:

\[ \text{Acceleration} = \text{initial velocity} - \text{final velocity} \]

\[ \text{Force} = \text{mass (weight)} \times \text{acceleration} \]

If a firefighter walking up the aerial ladder creates a 1 ft/s acceleration down then there is a rebound force of 1 ft/s up. This equals a total acceleration of 2 ft/s. If we take a basic 250 lb firefighter as our mass (weight) and multiply by the acceleration of 2 ft/s then we come up with 500 lbs. Knowing that we have a NFPA rated aerial at least at 250 lbs with a 2:1 safety factor, with one firefighter on the ladder, we have reached that limit due to bouncing (dynamic) forces. However, many ladders are now rated well above 250 lbs at certain angles. It is important to understand how these angles will affect loads. For ladders that are rated above 250 lbs, NFPA requires load charts (fig. 17).
AERIAL APPARATUS FOR RESCUE:

Now that we understand the importance of tip loads and forces, let’s look at using the aerial ladder for rescue. The benefit of using an aerial ladder for rescue is it allows us to utilize the reach capability as well as the height of the aerial to reach areas that would otherwise be difficult. However, it is important to understand how the tip forces affect the ladder. Let’s look at a basic ladder rescue set up. We have a weight in the litter stokes basket of 240 lbs tied off with a mainline running through and pulley at the tip of the ladder and down to a mechanical advantage. For purposes of the illustration, no belay line is shown. Belay lines should always be used. The force of the litter stokes is pulling down at 240 lbs, so in order to raise the litter stokes we need the same force pulling it. Assuming our pulley angle is less than 30 degrees, then the combined forces on the aerial tip will equal between 500 – 550 lbs with friction (fig. 18). Now if we increase the pulley angle, we decrease the load on the tip (fig. 19). An important factor to remember is the load must always stay within the beams of the ladder. If the load shifts outside the ladder beams, the ladder will be side-loaded. This can cause failure of the ring gear or the ladder itself. Another important safety issue is to use smooth hauling techniques. Fast or jerking pulls cause a change in velocity at the tip and can more than double the tip loads. NFPA and most manufactures do not condone using the aerial device like a crane. If using the aerial device for rescue, the safest technique is thorough rope and mechanical advantage, pulled manually.

RESCUE SET UP:

Some apparatus manufactures do not condone the use of their aerial apparatus as a high pick point for rescue. Other manufactures do, and their procedures should be adhered to. The following is an example of a set up for an American LaFrance Tractor Drawn Aerial (TDA). First, all personnel should be trained in utilizing the apparatus as a high pick point and understand the forces involved. The apparatus operator should communicate with the other crew members what the rated tip loads are at the operating angle (via the Aerial Load Chart discussed earlier). American LaFrance, like most manufactures approve their aerial for a high pick point anchor only, and it should not be used as a crane. For the American LaFrance TDA all rigging attempts shall be made off the sides of the turntable from 30% forward to the cab through 30% towards tiller trailer (fig. 20).
The most common mechanical advantage rope systems used for high pick points are the 4:1 “Ladder Rig” or the 3:1 “Z-Rig” or “RPM”. The 4:1 gives the user more mechanical advantage than the 3:1, but has two main disadvantages. The first disadvantage is rope consumption. For a basic 300 foot rope bag, the user only has about 75 feet of working line. Also, the tip load of the TDA must be set at 1000lbs at all times. Therefore, the 3:1 “Z-Rig” is the most common mechanical advantage used in this operation.

Some manufactures have anchors set at the tip of the ladder to attach a high pick point pulley to (fig. 21). Notice that American LaFrance provides two anchors at the tip in which an orange webbing or anchor strap in tied between. The pulley must be attached to both anchors via the webbing. Since each individual anchor is not centered between the rungs, if the pulley were only attached to one anchor, the ladder may be side loaded and can fail.

The main line rope is then ran through the pulley on the high pick point anchor (fig. 22). The running line of the rope follows down the bottom of the ladder, between the beams. The next connection to make is at the bottom side of the base section of the aerial. This cross brace is located approximately 5 feet from the turn table. Note its location in the center of ladder (fig. 23, 24).

A third anchor is then tied at the tractor wheels (fig. 25). A change of direction pulley is attached in which the rope runs through. The rope continues to the 3:1 “Z-Rig” attached to an anchor (fig. 26).
All loads, whenever possible, should be belayed. Using an aerial apparatus as a high point is no exception. The difference comes in forces applied in a dynamic situation (i.e. main line failure). Even the best belayer will have some slack in the belay rope. This slack, during a main line failure, translates into force. Aerial ladders are not designed to handle shock loads. Whenever possible the belay should be positioned to minimize swing, pendulum and/or drop of the rescue package and minimize or eliminate force on the aerial.

Scenario #1: If the aerial was being used as a high pick point to remove a patient from the roof of a structure the aerial’s ladder should be positioned so that, when the patient is lowered, the litter is as close to the building as possible. The belay line should be attached to a suitable anchor on the roof of the structure and go directly over the edge of the building. In this scenario #1 the belay line is never attached to the aerial.

Scenario #2: A below grade vault, manhole, etc. Once again the green line is the main rope and red line is the belay. Again note that the belay is independent of the aerial. It is also worth noting that the patient should only be lifted high enough to clear the hole. Once the belay is above the level of the hole, main line failure will result in a large dynamic event.

It is important to remember that when selecting any belay anchor you must remember that the load will be dynamic (falling due to main line failure). A one foot drop can magnify 5 - 7 times its force on the anchor depending on the length of the drop.

It is also worth noting that, due to the angle the rope forms at the top of the aerial, the load can be as high as twice the load at the tip of the aerial. Due to the forces created it is recommended that when running the belay along the aerial that the aerial should be as closed to a climbing angle (70 degrees) as possible. This configuration loads the rams not the ladder itself.

NOTE: Using the aerial as a high pick point should be considered a last option. The forces created can easily exceed the manufactures recommendation. It is also worth noting that when using the aerial as a high pick point that option 1 and 2 above are considered optimal. Only as a last resort should the belay be run along the aerial ladder (fig. 29).

In this scenario the belay line should be run along the top of the aerial, over the tip, across the built in rope roller and down to the load.
REFERENCES:

