Calculating Halyard Loads

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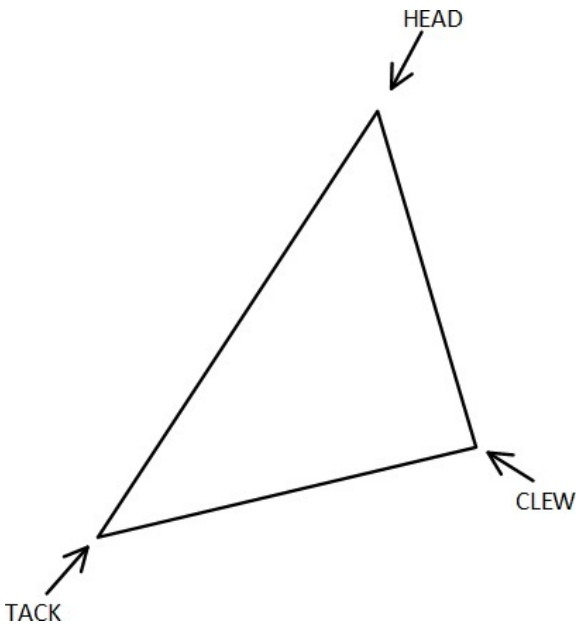
Running Rigging

Last time, we talked about calculating Sheet Loads. Now we will look at the loads placed on the Halyards and why they are so difficult to calculate! If you look online, it won't be easy to find a resource on calculating halyard loads because of the legal ramifications. If a halyard breaks because it wasn't strong enough when it was calculated to be strong enough, legal consequences can follow. Because of this, everyone seems to keep a tight lip with regards to halyard loads.

In a similar fashion, I will begin with a disclaimer:
The loads calculated here are calculated with formulas that are discussed in college physics and math classes. They are the formulas for calculating the tension on a line. They are theoretical values, not real world values. In the real world, shocks and freak weather systems can greatly stress a system in ways far more extensive than originally calculated. In other words, always oversize by a significant margin of safety. To be on the safest side, I would follow the recommended size given by New England Ropes in their calculator, and then choose a line with at least that breaking strength.

http://www.neropes.com/InteractiveLineSelector/Sailing_Type.html



The halyard pulls against the head to keep the luff under tension. While there are many formulas and online calculators available to figure out the clew loads, halyard calculators are not as plentiful.

This is because halyard tension can be extremely variable. If you simply raise your sail all the way and let it hang without applying any tension, the halyard load will be equivalent to the weight of the sail hanging from it.

Then you begin to tighten the halyard by cranking a winch or tightening the Cunningham. These actions along with the force of the wind pressure on the sail add up to an immense load on the halyard.

The most reliable way to calculate the halyard tension would be to sail with a tension meter mounted between the halyard and winch. This would be the only way to know exactly how much force is being exerted on that line.

Installing a tension meter inline is not practical, so other methods must be utilized to estimate the loads. One of the least involved methods is to calculate halyard tension based off of the force exerted on a 10" winch handle. The winch is simply a device that acts as a force multiplier. The number on the top of the winch corresponds to the number of times your effort is multiplied (not taking friction into account). For example, a 24 winch simply multiplies the force you put in by 24. If you apply 1 pound of force, it will apply 24 pounds of force to the halyard; if you apply 20 pounds of force, it will apply 480 pounds of force. By estimating the amount of force you are applying to the handle, you can get a ballpark figure of the halyard tension.

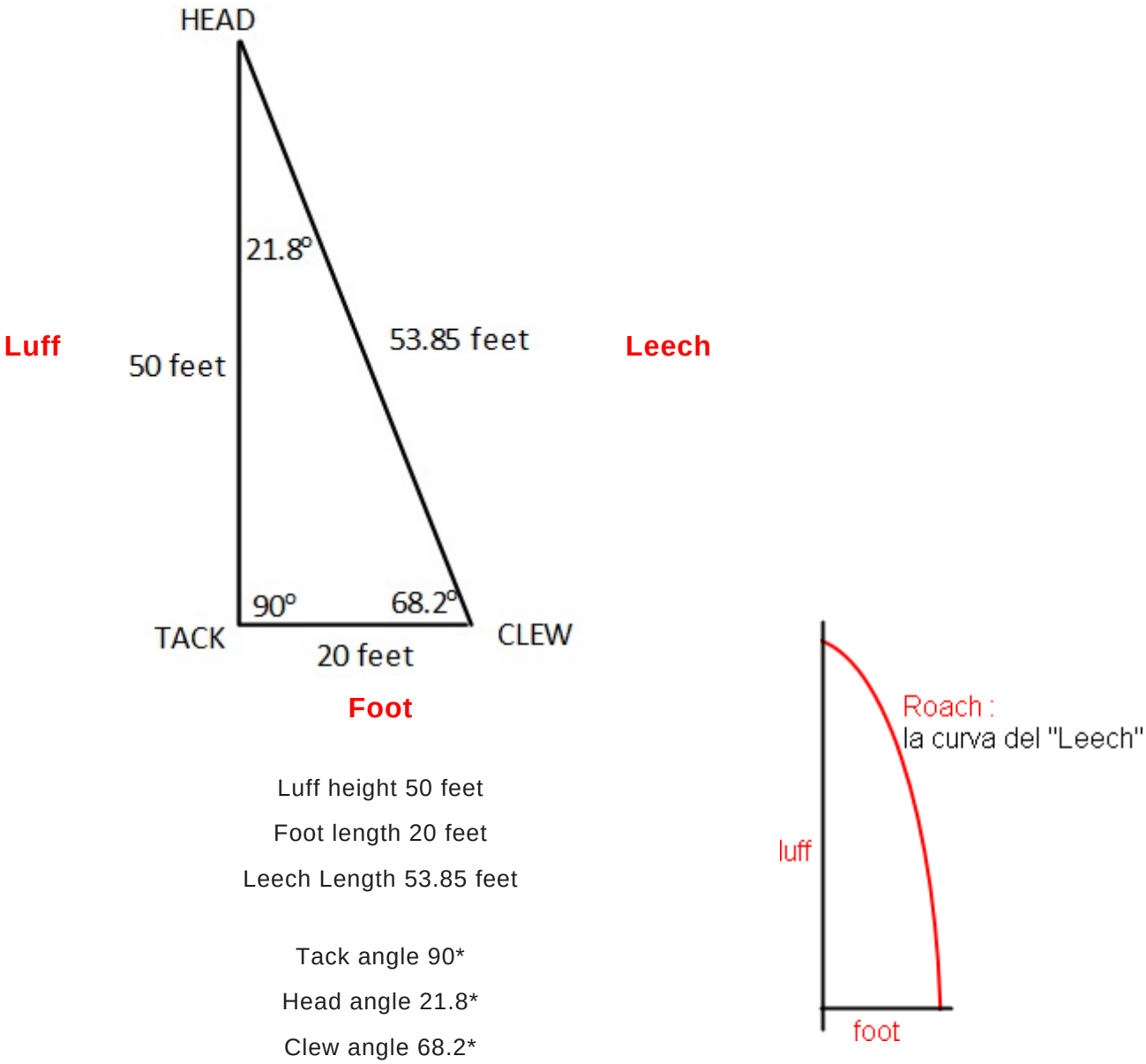
The safest way to decide what size halyard to use is to follow the advice given by New England Ropes on their interactive line selector.

http://www.neropes.com/InteractiveLineSelector/Sailing_Type.html

The line selector will tell you a specific line for the job, you can then look at the breaking strength of the line and use that as your minimum breaking strength requirement. Say it gives a size for Sta-Set X, you want to use a smaller or lighter line. Simply take the minimum breaking strength for the size of line they list and select an equally strong alternative.

Lastly, if you really want to do the math to calculate the loads exerted on the halyard because you are curious, please read on. I did well in Physics, so I believe I have correctly calculated all the values. I personally use the line selector from New England Ropes or the factory recommendations as my starting point. I have no problem installing a "stronger than necessary" halyard on a boat, but do veer away from the thought of installing a line with less breaking strength.

For our example, we will use a 500 square foot mainsail. The measurements of this sail are as follows:



Luff height 50 feet

Foot length 20 feet

Leech Length 53.85 feet

Tack angle 90*

Head angle 21.8*

Clew angle 68.2*

If this is starting to look like Trigonometry class, it's because it is Trig.

From here, we can calculate the wind pressure that will be exerted on the sail, which in our example would be

Wind Pressure per SqFt = 0.00256 x Wind Speed^2 in mph

0.00256 x 25^2 = 1.6 lbs per SqFt

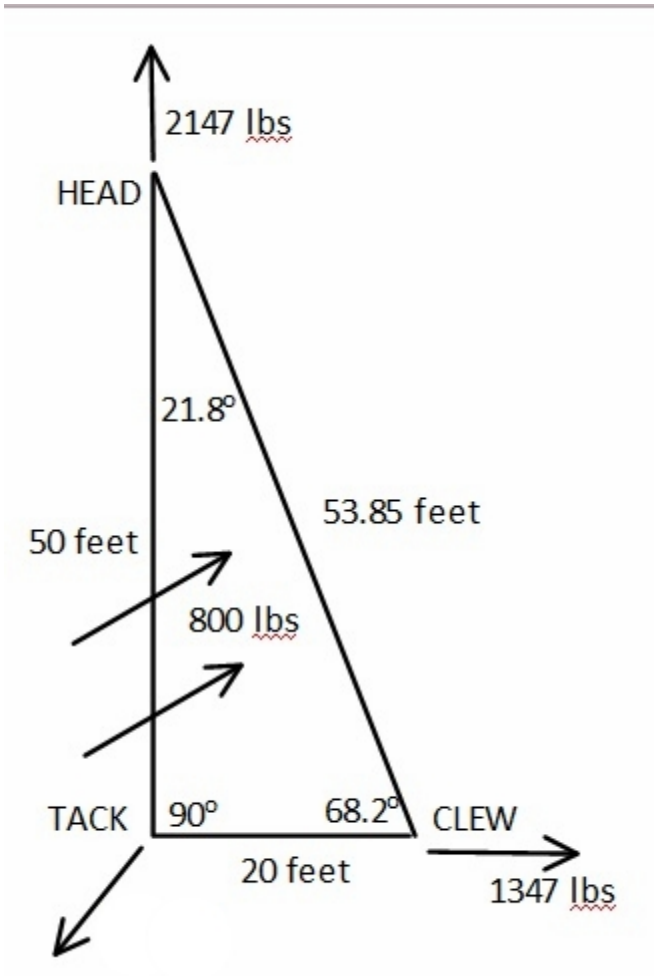
1.6 x 500 square feet = 800 pounds in 25mph of wind.

So in winds of 25mph, we can estimate that 800 pounds of pressure will be exerted on the mainsail.

To convert our wind pressure into halyard load, we need to calculate the forces involved using a vector diagram.

The force on the clew is:

0.00431 x 25^2 x 500 = 1,346.875 pounds on the clew



The force on the head is roughly the sum of the wind pressure on the sail pulling the sail down, and the load on the clew of the sail pulling back and down. In our example, with 800 pounds of wind pressure on the sail and 1347 pounds of clew load, we arrive at around 2147 lbs of load on the head.

Big picture points to take away when sizing your halyard:

- Online calculators exist that will tell you roughly what size line you need. I strongly recommend using them and following their guidance.
  http://www.neropes.com/InteractiveLineSelector/Sailing_Type.html
- If you wan't to know a rough estimate of the loads involved, look at the force multiplier number on your winch and guestimate how many pounds you are pushing on a 10" handle. Multiply your guestimated work with the number on the winch and that is a very rough estimate of luff tension while the sail is being raised.
- You can do all the math involved to figure out a rough estimate for the halyard load. This information is only useful for those who would sit at the helm and wonder "how much tension is the halyard under?" I would not choose a halyard that has a breaking strength anywhere near the calculated load. The safety margin on the halyard should be tremendous. If this line should snap, the sail comes down and it will be a lot of work to replace this line (this is the same reason you should replace your halyard when it begins to show signs of wear).
- Make sure the halyard is comfortable in your hands.
- There is a nifty graph that will tell you the halyard loads based on boat size on page 372 of "The Complete Riggers Apprentice" by Brion Toss. It is the only place I have ever seen any information on how much load is on a halyard. To give an idea of how elusive this information is, the graph is only a small portion of the page with no caption or explanation in the back of the book, past where most people would have stopped reading. I do not have permission to reproduce the image, so the best I can do is reference the specific page in the book.

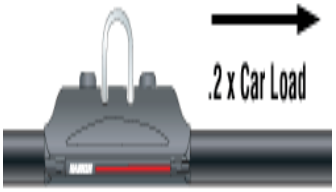
$$SL = SA \times V^2 \times 0.02104$$

SL	Sheet load in kilograms (Sheet = Escota)
SA	Sail area in square meters
V	Vind speed in knots

Mainsheet Loading Calculator

The formula for mainsheet loading is not as widely accepted as that for genoa sheet loads and should only be used as a rough guide for offshore boats from 30 ft to 60 ft (9 m to 18 m).

Traveler car adjuster load is generally considered to be .2 times car load.



$$ML = \frac{E^2 \times P^2 \times 0.02104 \times V^2}{(\sqrt{P^2 + E^2}) \times (E - X)}$$

ML	Mainsheet load in kilograms
E	Foot length of main in meters
P	Luff Length of main in meters
V	Wind speed in knots
X	Distance from aft end of boom to mainsheet attachment point in meters.

Formulas are for typical cruising monohulls with fixed keel and Dacron sails, sheets, and halyards. Assumes standard roach of 7.5%. For large roach sails such as “flattops” multiply calculated load by the percentage of the mainsail roach. If a sail has 25% roach, multiply the calculated load by 1.25.

ROACH : a curve, in or out, in the edge of a sail, especially in the leech of a fore-and-aft sail