Weighing a Trailer

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We have had a travel trailer for a number of years. I've never had it weighed, so I don't know if we've ever overloaded it. As it's so easy to just stick stuff in the trailer, I suspect we have been overloaded before. I've also not been able to measure the tongue weight.

Figure 1

While I could go to a local truck stop and get the trailer weighed, I'd rather be able to do it at home. The ideal tool would be a hydraulic cylinder of appropriate area connected to an analog pressure gauge or a digital pressure sensor. However, that would mean finding a gauge, buying some material, and machining a device. I will eventually do this, as it would easily fit on our hydraulic jack and make it easy to weigh things. However, I needed something more quickly and wondered if I could do it with a lever. It turns out I could; see Figure 1.

I used a 12 foot long 4x4 (3.5 inches square in actual cross section). I lag-screwed a steel plate onto the 4x4 for where the fulcrum would rest. The fulcrum was a piece of 1" steel pipe, about 1.3 inches in diameter. The short lever arm was 4.8 inches and the long lever arm was 136.75 inches. This gave a leverage of 28.5 times. I used a bathroom scale to measure the force I applied at the long end. I removed a wheel from the trailer because the 4x4 would not fit between the wheels. The jack stand is holding the left axle. A close-up of how things worked is on the next page.

There's a piece of 1" pipe under the springs, which is where the lifting force was applied. The fulcrum is at the red mark on the 4x4. The fulcrum pipe is resting on a 4x4x8 block of steel, supported on three pieces of plywood. This allowed the beam to be horizontal when the two axles were lifted off the ground.

My wife verified that the tire came off the ground and the axle came off the jack stand when I applied the lifting force. Using the scale and a 2x4, I applied 90 pounds 1.5" from the end of the beam. This translates into a lifting force of 2560 pounds. A quick sensitivity analysis shows that if the short lever arm were 0.5 inches longer, the weight would drop by about 250 pounds. A 5 pound scale error translates into about a 150 pound error. The scale was "calibrated" by setting the zero level so that the scale read the same weight for me as measured by my doctor's scale. Taking both types of errors into account, I estimate the uncertainty of the measurement is about ±200 pounds.

I made a 1/4 scale layout on paper prior to making the lever. This let me get a good idea of how things would work. I originally wasn't going to remove the wheel, but rather shave about 5 mm off the 4x4. However, this would have forced the fulcrum point to be at 15 inches and would have required a lot more weight on the other end.

I lag-screwed a steel plate onto the 4x4 for the fulcrum to rest against. This wasn't really necessary, as the 1" pipe supporting the load of the trailer showed -- it only dented the wood fiber slightly. If I were to do this again, I would cut a shallow vee slot cross-ways in the 4x4 to accurately locate the fulcrum. I bolted another of the steel plates to the end of the 4x4 to register the lever against the pipe being lifted. I might forgo this next time; instead, I'd cut another transverse vee channel to index the pipe. This would reduce the uncertainty of length of the lever arm on that end.

Figure 2

I'd also cut a corresponding transverse vee channel in the other end and cut a mating vee shape on a piece of wood, which would then get screwed to the bottom of a piece of plywood. The scale would push on this plywood, which would then index in the vee. This would allow for accurately measuring the lever arms to within 1 mm or less.

If the 4x4 could be spared, this suggests making a "weighing" lever dedicated to this type of task. I'd lay out a number of transverse vee notches at various locations, both for the lifting part of the lever as well as the side to apply the force. I'd also put a corner-rounding bit in the router and round off the sharp edges, as otherwise it's easy to get splinters. Finally, a coat or two of a finish would keep the thing in good shape. It won't be needed very often, but it will prove handy when it is needed.

If you're not familiar with the mechanics of a lever, the distance from the fulcrum multiplied by the force applied at that distance (assuming it's at a right angle to the beam) is the same on both sides of the fulcrum. Thus,

$$WM = Lw \quad \text{or} \quad W = \frac{L}{M}w$$

where

> W = weight of trailer being lifted = unknown
> w = downward force I apply to lift the other end = 90 pounds
> L = distance from my force to the fulcrum = 136.75 inches
> M = distance from trailer weight to fulcrum = 4.8 inches

In other words, since this is a statics problem, the sum of the torques around the fulcrum must be zero, as there is no rotational movement.

Since L/M = 28.49, the trailer weight is 28.49×90 or 2560 pounds. Let's look at the sensitivity:

$$dW = \frac{w}{M}dL - \frac{Lw}{M^2}dM + \frac{L}{M}dw = 18.75\,dL - 534\,dM + 28.49\,dw$$

Let's assume my distance measurements are in error by 2 mm, so that dL = dM = 0.08 inches. If we also assume dw = 5 pounds (scale error), then

$$dW = 1.5 - 43 + 142 \approx 100$$

The scale uncertainty is the biggest contributor and is where I'd spend effort first to improve the measurement. Of course, in the above differential, we really should put the absolute value around each term unless we're sure of the sign of the error.

With a carefully constructed lever so that dL = dM = 1 mm = 0.04 inches and dw = 1 pound, we see that the estimated uncertainty would be around

$$\begin{aligned} dW &= \left|\frac{w}{M}\right|dL + \left|\frac{Lw}{M^2}\right|dM + \left|\frac{L}{M}\right|dw \\ &= 18.75(0.04) + 534(0.04) + 28.49(1) \\ &= 0.75 + 21 + 28.5 \approx 50 \text{ pounds} \end{aligned}$$

This means it's a (50/2500)(100%) = 2% measurement. Not bad for essentially no cost.

Update 27 Jun 2020: A linear uncertainty analysis can be done with the python uncertainties library. We'll use the above differentials as the type B estimated standard uncertainties.

```
from uncertainties import ufloat
L = ufloat(136.75, 0.08)   # inches
M = ufloat(4.8, 0.08)      # inches
w = ufloat(90, 5)          # pounds
print("Weight of trailer =", L*w/M)
```

This results in

```
Weight of trailer = (2.56+/-0.15)e+03
```

which means the calculated trailer weight is 2560 pounds with a standard uncertainty of 150 pounds. Expressing the uncertainty as a percentage of the calculated weight gives about 6%.

For the best case values given above, the results would be 2560 pounds with a standard uncertainty of 40 pounds, giving a percentage of 1.6%.