Common Measurement Errors in Weighing

Abstract

Trucks, planes, boats, and many other cargo or passenger vessels rely on getting the proper weights of their cargo. When the weight of shipments are off, catastrophic events can happen. For example, an overloaded airplane may not be able to climb correctly and crash during take-off. If take-off is achieved, excessive wear and tear on engine parts, increased fuel consumption, and a reduced range will likely occur.

An overloaded truck can pose safety hazards to the road it drives on. The increased weight will wear down the tires and breaks, the risk of rollover increases, and in poor weather conditions, the probability of a crash increases. On an overloaded boat, instability and the risk of swamping and capsizing increases.

Other industries rely on equipment to weigh fuel, chemicals, or agricultural, pharmaceutical, and construction equipment. Many industries rely on measuring equipment to ensure safe and consistent operation. Getting a proper measurement from equipment such as scales, dynamometers, load cells, tension links, force gauges, and more are essential for our overall safety.

End-users of these force-measuring devices do not always do things properly, which results in unsafe conditions, product recalls, production overruns, fines, or scrapped products. At Morehouse, our purpose is to create a safer world by helping companies improve their force and torque measurements. This extends into the weighing industry because force measurements should be a more common practice than weighing the equipment in mass, which results in significant measurement error.

Our discussion will focus on the top measurement errors we have commonly helped many customers correct. These errors include

- Using the wrong size pins
- Applications where side loading occurs
- Using mass instead of force
- Not using the appropriate adapters to simulate the tire for truck scale (fixed scales that are driven on) and aircraft scale (wheel pad) calibration

We hope that anyone reading this will learn something new, which will help improve your measurements.

Tension Link Calibration Errors – Using the Wrong Size Pins

Tension Clevis Adapters for Tension Links, Crane Scales, and Dynamometers

Imagine you are out in the field with a tension link, load link, or some digital dynamometer to use for a weighing application. Of course, it would be best if you had the proper adapter to engage the unit. However, what happens if you do not? Do you not perform the lift, or do you use what you can find?

Maybe you use one pin with one diameter on one end and another pin with a different diameter on the other end. If the fixtures are safe to hold the load, it should not matter, right? Unfortunately, a large percentage of the time we see people using whatever is available. The problem with this method is that there is a high probability of significant error.

Manufacturers know this, and many of them have published specifications detailing the appropriate pin size if one was not purchased with the unit. Many reputable manufacturers agree on the following:

- Using correctly sized pins is critical.
- Do not use pins that are worn or bent.
- If the links are damaged, highly used, or worn, then decrease the time between calibrations.
- The same size and style of shackle and pin used during operation should be used for calibration.

A picture is worth a thousand words, so below is an example and a potential solution for a calibration laboratory that needs to calibrate these devices. We loaded a tension link in our Morehouse deadweight machine to demonstrate the pin size error with an accuracy of better than 0.002 % of applied force and loaded to 50,000 lbf with two different size load pins. When loaded with a smaller pin of 1.85 inches, the device read 49,140 lbf compared to a 2-inch pin that read 50,000 lbf.

Figure 1Tension Link Difference in Output with Pin Size

Knowing these issues, Morehouse has designed patent pending clevis assemblies for use with our Quick-Change Tension Adapters. These assemblies cross-reference the manufacturer's recommended pin size and allow the calibration laboratory to calibrate hundreds of tension links, crane scales, dynamometers, and rod-end load cells, all using the identical clevis. Not only does this simplify the logistics of having the proper adapter, but it improves cycle time and standardizes the calibration process.

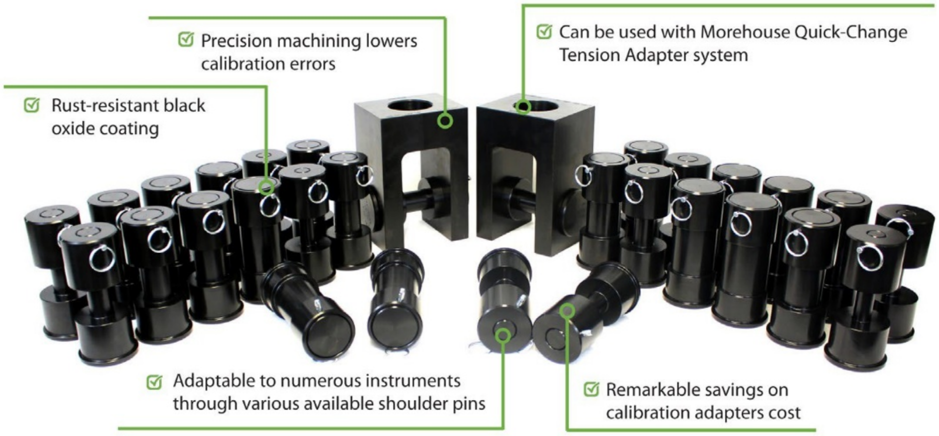


Figure 2 Solution to Having the Proper Calibration Adapters, Morehouse Clevis Kits

Side-Loading – Too Many Adapters

The key to almost all measurements involving force is keeping the line of force pure. Thus, we want to keep the line of force free from eccentric loads. When an eccentric or side load occurs, the load is not centered. Then the lifting mechanism, which in weighting is often a crane, pulls vertical and a horizontal force is applied. When this happens, the center of gravity is not directly under the lifting mechanism. Therefore, the equipment used to make the measurement will not read correctly.

Figure 3 S-Beam Load Cell with Six Adapters

In this example, every time we add another adapter to a load cell setup, we increase the likelihood of introducing additional horizontal forces or a side load. Different load cells will have specifications for side loading that ultimately determine how much additional error is observed. However, how do you know how much additional error you might have?

The error can be difficult to test for, unless you have test weights for your setup or the lab that performs the calibration uses the exact same equipment. Another problem is that all these adapters and joints can be very inconsistent. This means that at each lift different interactions can occur, which creates a non-repeatable process.

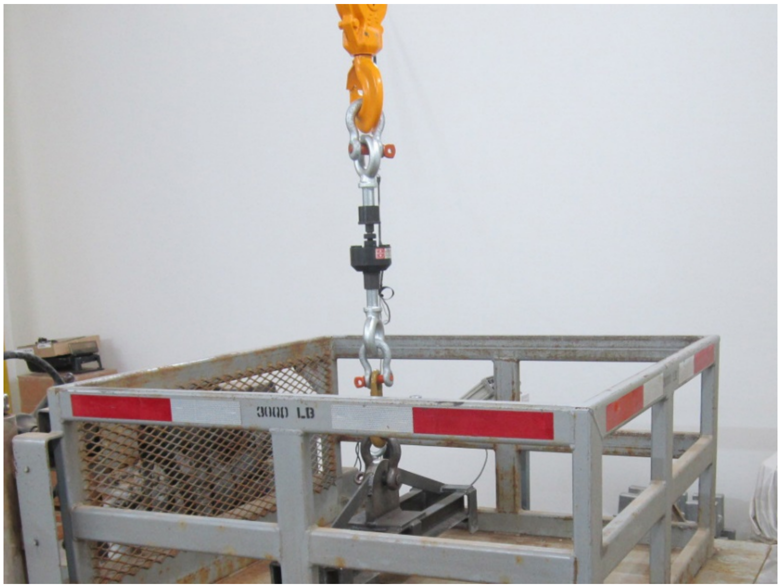


Figure 4 Morehouse Precision Calibration Load Cell with Custom Adapters

We solved this problem for a state lab that had an issue with not getting reproducible results. Our team designed custom adapters for a Morehouse shear web load cell, which replaced the S-beam, which had poor side load sensitivity specifications. The specifications on the shear web cell are found under side load sensitivity and are much better than S-type cells. We reduced the number of adapters needed, replaced the indicator with our 4215, and calibrated the load cell in force per ASTM E74 with deadweight standards accurate to <0.002 %.

In the example above, it would have been even better to replace another two adapters with a more expensive option with two ball nuts and two ball cups. If budget were not an option, that would have been the best solution. The solution above is a more economical approach to the too many adapters problem. We always strive to operate within a budget when we provide solutions.

This brings us to the issue of using mass reference standards versus force reference standards.

Local Gravity Error – Using Mass instead of Force

When metrologists talk about measurement error, we talk about the difference between the nominal value and what the instrument is reading. If 10,000 lbf is applied to a force-measuring device and the readout displays 10,002 lbf, then the device has a 2 lbf bias. If we load the same force measuring device to 10,002 lbf, we will have applied 10,000 lbf. This is a measurement error, and there can be many different causes.

After speaking with several professionals inside the weighing industry, it has come to my attention that some labs use mass weights to calibrate force devices. These include dynamometers, crane scales, hand-held force gauges, and others. This can result in significant measurement errors.

There is a difference between mass and force. Mass, under almost every terrestrial circumstance, is the measure of matter in an object. Measuring force takes additional factors into account: air density, material density, and gravity. It is the effect of gravity that can produce significant errors when comparing mass and force measurements.

Gravity is not constant over the surface of the earth. The most extreme difference is 0.53% between the poles and the equator (983.2 cm/s2 at the former compared to 978.0 cm/s2 at the latter). A force measuring device calibrated in one location using mass weights then deployed somewhere else will produce different strains on the physical element.

The resulting measurement errors can be significant on devices with specifications that are likely 0.1 % of applied force. Since many of these instruments are used for measuring loads of 0.1 tons through 300 tons, it is impractical to have the mass weights necessary to calibrate on-site, and calibrating using force may be the only practical method to certify the device.

Instruments calibrated using force can be used anywhere globally, knowing the force value will not change. If using mass, you may need additional adjustments or a complete calibration at the location where the device is being used. Simply put, it is much easier to calibrate in force.

$$Force = \frac{Mg}{9.80665}\left(1 - \frac{d}{D}\right)$$

Figure 5 Formula for Force

M = true mass of the weight (not to be confused with conventional mass)

g = local acceleration due to gravity, m/s2

d = air density (approximately 0.0012 g/cm3)

D = density of the weight in the same units as d (approximately 8.0 g/cm3)

If we want to solve for Mass, then the formula would be Mass = Force x 9.80665/(local gravity*(1-d/D)

If someone wanted to make corrections, NOAA's website has a tool for predicting local gravity (ngs.noaa.gov/TOOLS/Gravity/gravcon.html).

Here is an example of how local gravity impacts mass weights. Morehouse's gravity in York, Pennsylvania is 9.801158 m/s^2. If we compare that to the gravity of Houston, TX (9.79298 m/s^2), the difference is -0.00084 ((9.79298 m/s^2 - 9.801158 m/s^2) / 9.79298 m/s^2). As a percentage, that is -0.084%.

If a lab in Houston calibrated a force-measuring device with mass weights for use at Morehouse, then we could expect anything we weigh to be heavier by 0.084%. This can have a lot of consequences. If we were shipping steel by the tonnage, we would ship less steel, reducing our cost but possibly upsetting our customer. Reversing the scenario, if a scale calibrated in York with mass weights is used in Houston without correction, then the steel supplier in Houston would ship more steel per ton.

These types of errors can make people a lot of money and cost them a lot. We started the article by discussing airplanes, trucks, and boats. Weighing these vehicles using force has become standard in several organizations. Though these scales can have large errors if not calibrated correctly. The next section will deal with other errors for scales.

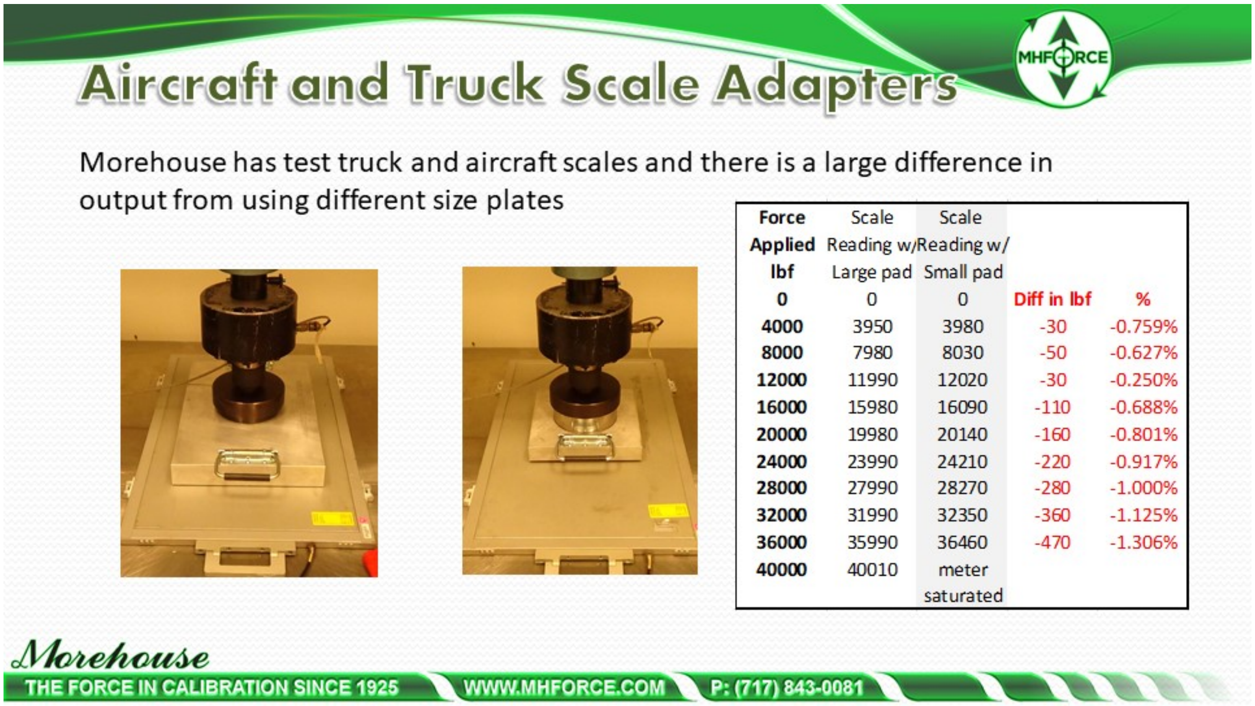
Measurement Errrors - Adapters that Don’t Simulate the Tire for Truck and Aircraft Scale Calibration

To achieve proper calibration, equipment should be used that is plumb, level, square, and rigid. Pictured in Figure 6 is a Morehouse Aircraft and Truck Scale Calibrator. This machine was designed to minimize bending of the top beam and load bearing table, which had occurred in older Morehouse models and in several non-Morehouse products.

Figure 6 Morehouse Aircraft and Truck Scale Calibrator

The plates are designed to be square and level with custom machining processes and ground to maintain a level surface. If there is an increase in bending or uneven surfaces, the strain elements in the scale will vary. These errors could easily be a magnitude from two to ten times the tolerance. The right equipment is also stable, with enough resolution to not impact the overall uncertainty significantly. The Morehouse machine can generally apply forces within 0.5 lbf, which can be limited if the proper load cell and indicator combination are not used.

Controlling the force application is critical because the best that the measurement can be known by is the Calibration and Measurement Capability (CMC) of the system. CMC Uncertainty includes the uncertainty of the calibration by the reference laboratory, the reference standard calibration uncertainty, repeatability studies, reproducibility, the resolution of the reference or stability of the system, stability or drift of the reference standard, environmental factors, and other errors. Many of these errors we can control by purchasing the right equipment and adapters. Therefore, we will examine how adapters that simulate the tire impact the calibration of truck and aircraft scales.



Aircraft and Truck Scale Adapters

Morehouse has test truck and aircraft scales and there is a large difference in output from using different size plates

Force Applied lbf	Scale Reading w/ Large pad	Scale Reading w/ Small pad		
0	0	0	**Diff in lbf**	**%**
4000	3950	3980	-30	-0.759%
8000	7980	8030	-50	-0.627%
12000	11990	12020	-30	-0.250%
16000	15980	16090	-110	-0.688%
20000	19980	20140	-160	-0.801%
24000	23990	24210	-220	-0.917%
28000	27990	28270	-280	-1.000%
32000	31990	32350	-360	-1.125%
36000	35990	36460	-470	-1.306%
40000	40010	meter saturated		

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Figure 7 Difference in Adapters

Aircraft (wheel pad) and truck scale (fixed scales that are driven on) calibration often requires special adapters to simulate a tire contact area with the scale. Scales come in a variety of sizes and have specific tolerances. The problem is that not many calibration laboratories use the right adapters. Not using the proper adapters can result in significant measurement errors.

When an adapter is different from the tire footprint on the scale, we have found substantial errors. Figure 7 shows a digital scale with a tolerance of 0.1 % of full scale using two different size adapters. The adapter on the left better simulates the tire of a truck; the adapter on the right simulates that of an airplane.

The difference between the adapters is over 1.3 %. It quickly becomes apparent that this scale, like several others, will not be within the specification if different size tires are used that vary from the footprint of the adapter used during calibration. We have performed this test and have several examples.

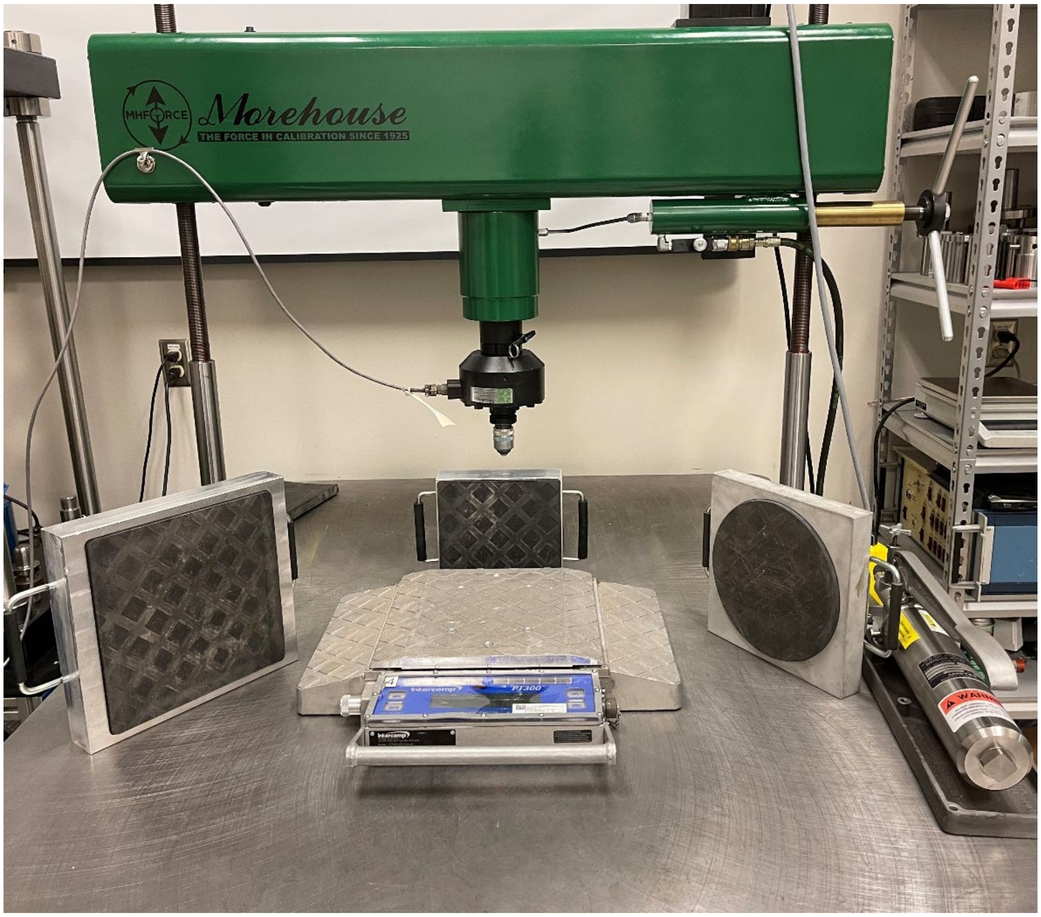

Figure 8 PT300 Scale Tested with 3 Different Size Adapters

The test shown in Figure 8 shows various adapters that Morehouse makes. We decided to test three different adapters that closely matched the 8 x 8 recommended footprint on the same scale. The adapters, which are made by Morehouse, are shown from left to right: 10 x 10-inch pad, 8 x 8-inch pad (recommended by the manufacturer), and a 9" round pad Morehouse designed to replicate a tire footprint closely.

The test was performed, and the output is shown in Figure 9. Any point in green is within the manufacturer's specification of 1 % of the applied load.

PT 300 Example					
FORCE APPLIED	10 X 10 PAD READINGS	8 X 8 PAD READINGS	9" ROUND PAD READINGS	Maximum Difference	% Maximum
2000	2000	2000	2000	0	0.00%
4000	4040	3990	4000	50	1.25%
6000	6090	5990	5990	100	1.67%
8000	8130	7990	8000	140	1.75%
10000	10170	10000	10010	170	1.70%
12000	12190	12010	12000	190	1.58%
14000	14210	14010	14000	210	1.50%
16000	16230	16010	15990	240	1.50%
18000	18230	18010	17980	250	1.39%
20000	CAP	20000	19980	N/A	N/A

Figure 9 Data from Using the Pads in Figure 8

When using the recommended size adapter, we met the manufacturer's specification because we were using the adapter that we designed to match the tire footprint. When using a 10 x10 rubber footprint, the numbers in red show a noticeable difference outside of the allowable tolerance. This further supports the principle that any scale calibration should be done with the proper size adapter.

Conclusion

We have described the four common sources of measurement error found within the general industry. All these errors can directly impact the measurement result, and many can profoundly affect safety. The errors associated with not using the proper equipment, units, or adapters can make achieving tolerances impossible.

However, I suspect that many in the industry continue to make these errors. Fortunately, you are now part of the solution to help us make the world a safer place. You now know some common errors; you can take the necessary steps to correct them and help others make better measurements. If you want to contact us or read more articles (we have over one hundred), please visit us at mhforce.com.