The Nebraska Tractor Test Laboratory: 100 Years of Service

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Abstract. *The history of the Nebraska Tractor Test Laboratory is presented, describing changes for tractor technology and globalization. The current tractor test and interpretation of test reports are included. Recent research supporting testing procedures is discussed, including the method to verify tractor power when a full power PTO (power take-off) is not present, a method of evaluating the fuel efficiency of continuously variable tractor transmissions, revisions to three-point lifting results, and development of a dynamic ROPS test for large tractors. Future testing challenges are described, such as those presented by electric tractors, electric power delivery to implements, and multi-mode testing.*

Keywords. *Nebraska Tractor Test Laboratory, history.*

History of Tractor Testing

In order to understand the history of tractor testing, one must first understand the history of tractors. The first commercially viable internal combustion engine was introduced by Otto in 1876. In the late 19th century, the internal combustion engine found use on farms to power water pumps and other stationary agricultural equipment, typically through the use of flat belt drives. Steam tractors, then known as traction drives, also appeared in the latter 1860s; by the early days of the 20th century, traction drives powered by internal combustion engines were commercially available. Davidson and Chase (1908) note that some of the advantages of the internal combustion engine over steam engines were:

1) internal combustions engines could work immediately rather than after the typical one-hour time period required to produce steam in a boiler,

2) large amounts of thermal energy were wasted at shutdown by steam engines, and

3) steam engines required near constant attention to maintain the correct amount of water in the boiler and to be almost constantly fueled.

The marketing for tractors in the early days was quite different from modern times. Although at one point there were as many as 200 separate tractor manufacturers, the primary competition for tractors was with animals. As an example, the Little Bull tractor (manufactured from 1914 to 1918) advertising claimed "The tractor sensation—does the work of five good horses for the price of two poor ones. Is light and can travel anywhere." (Vossler, 2001). The end of significant animal power in agriculture in the United States did not occur until after World War II.

The first documented tractor testing occurred in 1908 at the Winnipeg Plowing Contest (figure 1). This event, held from 1908 to 1913, allowed tractors and animals to compete in plowing contests. Early agricultural engineers such as L. W. Chase served as judges and in 1913 Chase served as the director of the event. Results from the Winnipeg plowing contests were used to inform producers about tractors and the test methods developed were a starting point for the Nebraska Tractor Test Laboratory (NTTL). With the advent of World War I, the Winnipeg Plowing contests were discontinued; however, Chase continued to conduct the event in Nebraska through at least 1917.

The NTTL had its beginnings in the number of producers who found the tractors they had purchased were not satisfactory and did not perform as advertised. In 1916, Wilmot F. Crozier, a Polk County, Nebraska, farmer, bought a Minneapolis Ford Model B tractor. He found this tractor to be unreliable and also found difficulty procuring service and parts as there were no such services available in Nebraska. In his dealings with the Minneapolis Ford company, he traded the 1916 model for an improved 1917 model but found this tractor also to be unreliable. The third tractor he purchased was a used Little Bull. This tractor was a top seller at the time but it still did not work properly and was unreliable. Finally, Crozier acquired a Rumely Oil Pull Tractor that worked with no trouble (Vossler, 2001). In 1919, Crozier was elected to the Nebraska Legislature as a representative (the Nebraska Unicameral was not instituted until 1937). Crozier teamed up with Nebraska senator Charles Warner to write the first Nebraska Tractor Test Law. Crozier and Warner were aided in this task by L. W. Chase, then the chair of the Agricultural

Figure 1. The Winnipeg plowing contest.

Engineering Department at the University of Nebraska. The bill passed the legislature easily and was enacted into law in 1919. At the time, both Missouri and North Dakota were considering similar legislation; however, Nebraska acted first causing other states to abandon their efforts. An excellent description of the need for the law may be found in the article "Father Of Nebraska's Tractor Law Explains It" by Rep. W. F. Crozier, published in the Implement & Tractor Trade Journal, September 9, 1919.

The original law contained several provisions that have lasted largely unchanged to the present, such as:

1) the University of Nebraska's Agricultural Engineering Department (now the University of Nebraska—Lincoln (UNL), Biological Systems Engineering Department) is responsible for testing advertised claims;

2) at least one parts warehouse is required in Nebraska;

3) at least one repair facility is required in Nebraska;

4) permits to sell tractors are issued by the State Railway Commission (now the Nebraska Department of Agriculture);

5) a board of engineers under the control of the University is to review test results and develop new test procedures.

Subsequent to the law's enactment, the NTTL was established as separate entity within the then-Agricultural Engineering Department and a temporary building was constructed to house the NTTL. It was equipped with the necessary tools, offices, and dynamometer for belt testing. Further, a clay and cinder test track was constructed for drawbar testing. L. W. Chase convinced a former student, Claude Shedd, to establish the lab and serve as the first chief engineer. Since the earliest days, UNL students, primarily majoring in agricultural engineering, have done much of the work at the NTTL.

As required by the law, a board of tractor engineers was established from departmental faculty to approve testing procedures and tractor testing results. The initial board members were Oscar W. Sjogren, Elmer E. Brackett, and Chauncey W. Smith. The board and Shedd worked together to properly establish the NTTL. Although completed by the end of 1919, tractor testing did not begin until the spring of 1920. Test number 1, the John Deere Waterloo Boy Model "N" was completed on April 9, 1920.

In the early days, tractor testing consisted of validating the manufacturer's claims for drawbar horsepower and belt horsepower. In each of these tests, fuel consumption was also measured. For belt horsepower measurements, the flat belt drive on the tractor under test was connected to an electric resistance dynamometer which provided load. The precise dynamometer used in 1920 has been lost to history; however, Bill Splinter's history of the UNL Biological Systems Engineering (BSE) Department claims it was a Sprague 150 HP unit (Splinter, 2012). Such a dynamometer was used in the 1930s and is shown in figure 2; however, there are various other references to dynamometers as small as 40 HP which would have been a better match for the belt horsepower available in 1920-era tractors.

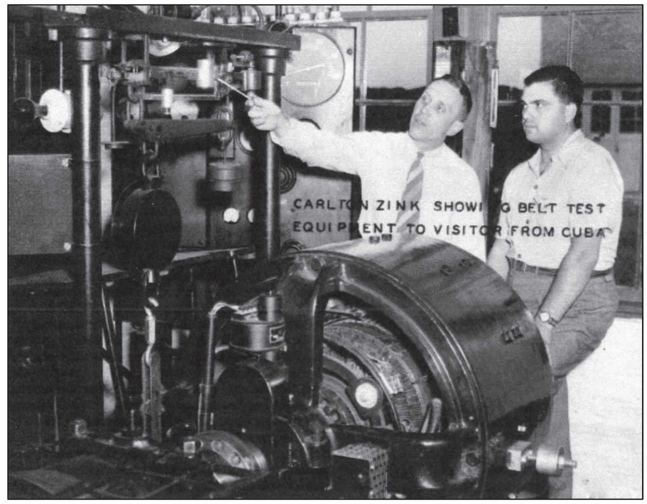

Figure 2. Sprague 150 HP dynamometer.

For drawbar testing, the first load car (see figure 3) is believed have been built by adding a Gulley traction dynamometer to the chassis of an Illinois tractor frame, which was pulled in reverse. Splinter states, "The load car was attached to the tractor drawbar by a hydraulic piston with an internal spring. As it was compressed by the pull of the tractor, the increased hydraulic pressure was measured by a pressure gage of the type used to measure steam pressure. The pressure actuated a pen that moved across a strip chart driven by a ground wheel so that the pressure was recorded as the tractor moved down the test track. The pressure recorded on the strip chart was then measured with a planimeter and draft was determined from the area under the curve" (Splinter, 2012). A mechanical integrator was later used to replace the need for a planimeter.

During the 1920s there were a number of rapid changes in leadership as well as in tractor testing technology and procedures. The first such change occurred during the 1920 testing season when Chief Engineer Claude Shedd (NTTL Tests 1-44), having completed his task of starting up the lab, resigned to pursue other interests. During the remainder of the 1920 test season and into 1921 (NTTL Tests 45-79), Fred Novacek served as the chief engineer. During the first season of 1920, 65 tractor models were tested.

It was soon realized that the original tractor test law did not address funding for the NTTL. A change to the law was made, effective for the 1921 testing seasons, that allowed the NTTL to collect fees from entities submitting tractors for test to cover the cost of operating and maintaining the NTTL. Power to set fees was delegated to the University by the Legislature and initial fees were set at $250 per tractor model tested.


Figure 3. First load car.

Figure 4. Early belt testing.

The Fall 1921 test season began with a new chief engineer, Elmer E. Brackett (NTTL Tests 80-118), who was one of the founding members of the Nebraska Board of Tractor Test Engineers. Brackett would serve in this role through the 1925 testing season after which he assumed department head responsibilities. During the remainder of the 1920s, Lew Wallace (NTTL Tests 119-172) served as the chief engineer.

Various changes in tractor testing technology also occurred in the 1920s. As noted above, the dynamometers used for measuring belt horsepower in the 1920s are not precisely known. There are references to 40 HP, 120 HP and 150 HP dynamometers. Further, a period photograph exists (figure 4) of a tractor undergoing belt testing using a Prony Brake dynamometer outside the test lab. It is clear that by 1930, a 150 HP electric resistance dynamometer was in use. Other changes involved the drawbar tractor test. It was found that use of the cinder and clay test track caused the cinders and clay to separate with simply clay on the top surface, so the track was remade using only clay. Equipment was acquired to allow the track to be restored after use so that the consistency of the pulling surface could be maintained from test to test and year to year. This practice continued until 1956 when a concrete track was installed. In addition, several test cars and load units were developed for drawbar testing. Figure 5 shows what is believed to be the second test car. A steam tractor is acting as a load unit, most probably acting as a compressor for additional drawbar loading (Splinter, 2012). Measuring the drawbar force by measuring the pressure in a hydraulic cylinder was an excellent choice and this method of drawbar force measurement was used successfully until 2011. Evidence suggests that at some point a load car that provided resistive load by use of a wheel driven oil pump existed and was also used; however, for this paper's purpose, it appears that the second load car, with attached load units, was used until 1938.

Figure 5. The second test car using a load tractor that is in turn pulling a steam tractor.

With the appointment of Lew Wallace as the fourth chief engineer in 1926, stability in lab personnel, testing equipment, and testing procedures began to be reached.

Testing of tractors required long hours and meals were eaten when time permitted. In 1929, Wallace developed a stomach ulcer and did not survive the operation to correct the ulcer. In 1930, Carlton Zink (NTTL Tests 173-378), the first of several long-serving chief engineers was appointed. Future chief engineer Lester Larsen recalled that Zink, an instructor in the department, became scarce to his students (which included Larsen) as he unexpectedly assumed his new role.

The Tractor Test Law had the intended effect of largely eliminating disreputable tractor manufacturers. Even outside of Nebraska where the law did not apply, lack of a successful test at the NTTL became a significant barrier to sales. Further, the advent of the depression in the 1930s caused further consolidation of agricultural machinery manufacturers and elimination of some resulting in fewer manufacturers.

Changes in tractor technology drive changes in tractor testing procedures and equipment, and there were many in the 1930s. A major change in tractor technology occurred in 1934 when the first rubber tired tractor, the Allis Chalmers WC, was introduced. For the next several years, it was common for the NTTL to test the same model of tractor on both steel wheels and rubber tires, but in 1937 the last test of a tractor equipped with steel wheels was conducted. A new load car (figure 6) was designed in 1937 by Charlie Adams, implemented in 1938, and (although heavily modified over time) used until 2003. This, the third load car, was equipped with precision pressure gages that monitored the pressure in the hydraulic cylinders used for measuring drawbar loading.

Figure 6. The Adams test car.

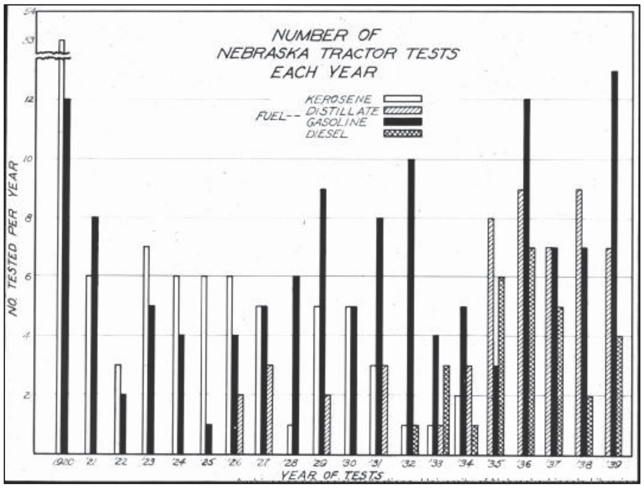

Figure 7. Fuel type by tractor, 1920-1939.

A mechanical tachometer was used to count wheel revolutions of an un-powered tire that was used for wheel slip calculations. Early wheel counters mounted to the tractor drive wheels used the core of automotive distributors to count tractor tire revolutions. Each rotation of the tractor tire would cause the points to make contact allowing wheel revolutions to be determined.

A glimpse of one of the questions of the day can be found in a study of the tractor fuels used as seen in figure 7. Note both the decline of kerosene and the start of the rise of diesel fuel, which ultimately supplanted other fuels. In 1932, a tractor known as the "Caterpillar Diesel" was the first diesel tractor tested at the NTTL (Test No. 208). For several decades, data from the NTTL was used in extension publications to help producers with tractor and fuel selection. An extension circular from 1954 included a nomograph that allowed producers to use tractor data from NTTL reports with expected annual use to estimate annual fuel costs (Kitchen and Larsen, 1954).

With the US entry into World War II, the lab discontinued operations, as tractor manufacturing was converted to war production. Carleton Zink spent the first years of the war instructing Nebraska farmers on techniques to keep agricultural equipment running. He left the University in 1943 to work first for Firestone and then later at Deere (from which he retired in 1968). At Deere, Zink became known as a pioneer and champion for the development and application of roll-over protective structures (ROPS) to agricultural tractors (Zink, 1990).

In 1946, the NTTL resumed tractor testing operations. The new chief engineer was Lester Larsen (NTTL Tests 379-1178). Larsen, a Nebraska native from Brunswick, graduated from the agricultural engineering program at the University of Nebraska in 1932. After graduation, Larsen worked for the International Harvester Company for a few years before returning to Nebraska for his M.S. degree, which he received in 1939. Larsen then joined the agricultural engineering faculty of the South Dakota State College of Agriculture and Mechanic Arts (now South Dakota State University). In 1943, Larsen came back to Lincoln as an extension agricultural engineer before leading the NTTL (Larsen, 1992). He served as the chief engineer of the NTTL until 1976, a period that saw much tractor development.


Figure 8. Test 449—the Choremaster, 0.7 drawbar HP.

Following World War II, the pace of mechanization of agriculture in the US greatly increased with tractors almost fully displacing animal power. Several changes in 1956 had a particularly large impact on the NTTL. One such change was made to the Nebraska Tractor Test Law to refine the definition of a tractor. In 1919, when the law was originally enacted, the machinery industry had not yet differentiated between agricultural tractors and construction equipment. Further, by 1956 a lawn and garden machinery market was emerging. An example of an early lawn and garden tractor undergoing drawbar testing is shown in figure 8, illustrating the need for a change in tractor definition. The change in the law created a more modern definition of an agricultural tractor, quite similar to the one today found in the ASABE Standard S390 (ASABE, 2017). Another notable change in this period is that although steel tracked tractors were once used in agriculture, by 1956 tractors used in agriculture were exclusively rubber tired. Concurrent with the change in the law, the NTTL received a new concrete test track that allowed more consistent drawbar testing conditions and far less effort to maintain the track. The cost of this track in 1956 was $30,000.

By 1960, the Adams test car required either replacement or a significant modification to handle the higher horsepower tractors in the market. The original Adams test car was mounted on the first of three Oliver tractor chassis. The new arrangement allowed the load car to handle up to 10,000 lb of drawbar loading, which could be further increased through the use of load units. Resistive load was applied by restricting the tractor exhaust. A coarse adjustment was through a gate valve in the exhaust system with the fine control provided by a secondary valve that could be controlled within the cab of the original Adams test car. The new load car arrangement was developed under the direction of Larsen by John Carlisle and is pictured in figure 9. While the Oliver tractor was replaced twice, this test car arrangement was used into 2003 for drawbar testing. The final configuration still exists and may be seen in the Larsen Tractor Test and Power Museum at UNL.

Figure 9. Test 953, Minneapolis Moline G1000 diesel using the revised load car.

The NTTL has always solicited opinions from producers and tractor manufacturers to improve the tractor tests. In the late 1960s producers suggested sound measurement be added to help producers select quieter tractors. This test was instituted in 1971 with Test 1063. It determined noise at the operator ear to be 97.0 dB(A). Interestingly, as soon as sound numbers began to be published in NTTL tractor test reports, manufacturers began to compete with each other to produce quieter tractors. While such changes would likely have taken place at some point, perhaps the introduction of the sound test at the NTTL acted as a catalyst to cause sound reduction to occur sooner than it otherwise might have. The development of the first sound measurement system and testing procedure was conducted by Ned Meier, as a part of his master's research project (Meier, 1970). Meier, who joined Caterpillar following his time at the NTTL and UNL was sent in the early 1970s to an agricultural farm show by Caterpillar to gain understanding of new features of agricultural tractors. Meier's report indicated that agricultural tractors were much quieter than construction machines. This caused Caterpillar to also produce quieter machines leading the rest of the construction industry to follow suit.

Lester Larsen retired in 1976 and was replaced as chief engineer by Lou Leviticus (NTTL Tests 1179-1743). During Leviticus's time, further changes occurred. The depression in the agricultural industry during the 1980s resulted in some tractor manufacturers going out of business and some consolidating with others. As an example, Allis Chalmers went out of business while International Harvester consolidated with Case.

Also during the 1980s, globalization played a larger role. In 1957, the Organization for Economic Cooperation and Development (OECD), Tractor Test Codes and Schemes first formed. Initially, OECD wrote protective structure test codes to validate designs of ROPS. The methods OECD used were incompatible with US methods, often causing tractor manufacturers to conduct two tests of the same ROPS. During Larsen's tenure, the NTTL collaborated with OECD to furnish the information required to write tractor performance codes. OECD first published a tractor performance code in 1973. By the 1980s, cost cutting efforts by manufacturers resulted in much greater pressure on the NTTL to accept performance tests conducted at OECD test stations for validating advertising claims rather than require these tractors to be tested at both the NTTL to meet the Nebraska Law and at OECD test stations overseas to meet European requirements. In 1986, the tractor test law was changed to recognize testing at other OECD test stations. Simultaneous to this change, the US decided to formally join the OECD Tractor Test Codes and Schemes. A memorandum of understanding (MOU) was reached between the NTTL, the Farm and Industrial Equipment Institute (FIEI; now, the Association of Equipment Manufacturers, AEM), and the US Department of Commerce. Under the MOU, the NTTL was appointed the Official US Third Party Review Agency for OECD Tractor Testing. This designation allowed the NTTL to submit and approve OECD test reports. Further, the MOU established a committee, normally led by one of the tractor manufacturers, to decide the US position on OECD matters. The structure of this committee provided for equal voting representation between the tractor manufacturers and the UNL Tractor Test Program. One additional vote could be cast by the US Department of Commerce. This arrangement represents the modern relationship between the tractor manufacturers and the industry. The lead author of this paper has been associated with this committee since 2002 and in his time, the number of votes taken can be counted on one hand. In almost all cases, decisions are reached through consensus.

Adoption of OECD testing procedures led to several additional activities at the NTTL. The OECD Code 2 performance test was essentially the NTTL's established testing procedure that was embodied in several standards, most recently SAE J708. In the most modern version, OECD Code 2 requirements are nearly 90% traceable to the NTTL. OECD also supports protective structure testing of tractors for ROPS and Falling Object Protection (FOPS) in OECD Codes 3, 4, 6, 7, 8, 9, and 10. While protective structure testing is not conducted at the NTTL, NTTL engineers typically witness and direct 25-35 protective structure tests each year. Completed test reports are checked and approved by the OECD coordinating center and are used as a third party certification by tractor manufacturers where required in the world. Additionally, OECD Code 5 details sound measurement procedures and is used for sound testing at the NTTL.

As tractors continued to evolve, tractor testing also changed. In 1984, hydraulic lift testing was added to the testing procedures and in 1988 the NTTL began measuring and documenting hydraulic power of tractors. A new challenge was the larger size of tractors. The new tractor test lab was built with overhead doors 24 ft wide, but the existing drawbar track was only 15 ft wide. A consequence of this was the need to occasionally move tractor testing to the Lincoln airport to have a paved surface sufficiently wide enough for the largest tractors.

More recent changes have been related to regulation. In 1996, the EPA introduced Tier 1 emission standards for off-road compression ignition engines. Prior to 1996, these engines were not regulated. Over the course of the next generation, new emission standards generally caused new tractor models to be introduced every 3-5 years, greatly increasing the demand for tractor testing. This trend continued through 2017 when the last Tier 4b models were tested.

At the beginning of 1998, Leviticus retired and Leonard Bashford (NTTL Tests 1744-1882) assumed leadership. At this time, the title was changed from chief engineer to director. Bashford was no stranger to the NTTL, having served many years as both a member and chair of the Nebraska Board of Tractor Test Engineers. A major change that occurred during Bashford's tenure was the first significant upgrading of the drawbar load car since the 1960s. A new load car was acquired from Caterpillar and placed in service in 2003. It was based on an articulated dump truck chassis, with the main dump body removed and replaced with a fixed structure. A custom drop gear box was completed that allowed the rear tires to drive a separate transmission. The output of the transmission drove a shaft attached to three Telma driveline retarders. Also included were fuel tanks for both the truck and tractor under test and two separate generators, one to provide excitation for the driveline retarders and one to provide electrical power for the computers and instrumentation systems. A front yoke supported the same hydraulic cylinders as used previously to determine drawbar force. A fifth wheel was also attached to give true distance travelled and true speed for power and wheel slip calculations.

While the new load car had greatly increased capacity, the most significant change for the NTTL was the amount and granularity of data now available. Rather than simply getting one set of numbers for each 500 ft test run, keyed into an Excel program on a laptop in the old load car, data were available for virtually every 0.1 inch of the test run. This was the NTTL's first experience with massive amounts of data, and extracting and processing the data proved burdensome. In those days, Excel was limited in the number of rows of data allowed so a full day's drawbar data required three separate Excel files to hold it all. Development of both the load car's control and data acquisition systems had been outsourced, which proved to be problematic initially.

Bashford retired in 2006 and Roger Hoy (NTTL Tests 1883-present) was induced to leave Deere and assume the role of NTTL director. Hoy first encountered a need to replace the current drawbar test track. The existing track had been in use since 1956 and the surface was badly deteriorated. Initial planning for the track replacement had been performed under Bashford's tenure. During the summer of 2007, the track was replaced with a new track, slightly longer and with a width increased from 15 to 22 ft. The new track was wide enough to test even the largest tractors and interestingly was designed by the same engineering firm (HWS) that had designed the 1956 drawbar track. One of the most important decisions made by the NTTL was the surface finish for the track. To meet the goal of matching the previous track's surface finish and to gain experience working with the stiff concrete mixture specified, the contractor, TCW of Lincoln, poured and finished several subdivision streets in Lincoln with different surfaces that allowed the NTTL to choose the one most appropriate. It is noteworthy that the most likely failure of the concrete does not come from normal stresses associated with axle weight but from the shear stresses imposed from drawbar loads: the design standard drawbar load was 100,000 lbs.

Also in 2007, the controller on the load car suffered a failure. The controller was no longer supported as the manufacturer had exited the business. A new controller was obtained from Dyne Systems. It essentially was a modified eddy current dyno controller. This system proved much better and more reliable and is still in use today. In 2009, the NTTL developed the hardware and skills required to implement a new data acquisition system for the load car. National Instruments hardware running Labview® software were used. One issue with the Dyne Systems controller was its reliance on a PID algorithm for control. The result of using a PID controller was that different PID values were needed for each tractor tested to achieve appropriate control. Tractors tested on the drawbar track range from as low as 80 HP to as high as 620 HP. In 2011, a further modification was performed to use a fuzzy logic control algorithm. This proved to be an effective solution. Also in 2011, the hydraulic cylinders used to measure drawbar load were replaced with 100,000 lbf capacity load cells. Concurrent with this change, the connection to the tractor drawbar was changed from a chain attached to the drawbar to a direct connection. The change took much of the excitement out of starting and especially stopping on the drawbar track. The new front hitch of the load car featured a hydraulically raised and lowered hitch that could be set to maintain a proper height, applying no tongue weight to the tractor drawbar. In the same timeframe, the antiquated dynamometer control and data acquisition system was replaced. A modern Interloc V (Dyne Systems) digital dynamometer control system was installed. A National Instruments data acquisition system was also introduced.

Current Tractor Testing

At the present time, the current tractor performance test is conducted according to OECD Code 2 (OECD, 2019). This test code is freely available to the public. OECD Code 2 consists of both mandatory and optional test procedures. An OECD test report can be achieved simply by completing only the mandatory test procedures. The mandatory portion of the OECD Code 2 consists of:

1) power take off (PTO) performance testing;
2) hydraulic flow testing;
3) three point linkage testing, and
4) drawbar power testing.

These tests are discussed in the following paragraphs.

Testing of tractors is further constrained by decisions of the Nebraska Board of Tractor Test Engineers. Decisions of the board are communicated through Board Actions which are publicly available on the Tractor Test website (tractortestlab@unl.edu). Since the OECD codes only provide a testing procedure, many Board Actions relate to verifying actual performance claims. Board Action No. 18, for example, details the procedure to be used to determine the conditions required to meet PTO and Drawbar Performance Claims (NTTL, 2019). Other Board Actions detail additional constraints that must be observed. As examples, Board Action No. 32 specifies the method to be used to determine what fuel temperature must be maintained at the inlet to the engine fuel system. Board Action No. 34 (NTTL, 2019) specifies that OECD Code 2 optional tests documenting reagent consumption and fuel used during regenerations of diesel particulate filters (DPF) must be conducted. OCED Code 2 requires in all cases that the tractor be operated in a manner specified by the manufacturer.

PTO Tests. These tests consist of documenting PTO performance at rated engine speed (RES), standard PTO speed, and maximum PTO power, each for a period of one hour. Additionally, a lug curve is established for a range of engine operating speeds between RES and either ½ of RES or to the engine speed that is 15% less than the engine speed which produces maximum torque, whichever is lower. Normally this test is conducted before the maximum power test as the lug curve identifies the engine speed that produces both maximum power and maximum torque. Several other points under the lug curve are collected. For both RES and standard PTO speed, the dynamometer is set to torque control and a torque of 85% of the torque at RES or standard PTO speed, is supplied. Throttle settings are adjusted as necessary to maintain RES and standard PTO speed. Additional points are collected at 75%, 50%, 25%, and 0% of the 85% torque value. Lastly, five additional data points are collected that represent various loads from heavy drawbar work to light drawbar or PTO work at reduced engine speeds. The points are determined based on the power achieved during the RES test and are 80% of the power obtained at RES (heavy drawbar work), 80% of power at RES at 90% RES (heavy drawbar or PTO work at standard speed), 40% of RES power and 90% RES (light PTO or drawbar work), 60% of RES power and 60% RES (heavy drawbar work or PTO work at economy PTO speeds or automatic engine speeds near the most economical operating range of the engine), and 40% of RES power at 60% RES (light drawbar or PTO work at reduced engine speeds). For all PTO tests, the following measurements are made: PTO torque; PTO speed; engine and cooling fan speeds; fuel consumption; atmospheric temperature, pressure, and humidity; engine coolant, engine oil, fuel, and air intake temperatures. Additional requirements for permitting purposes include the measurement of reagent for all operating points for tractors equipped with selective catalyst reduction systems and the observation of three regenerations of tractors equipped with DPF systems to measure fuel used during regenerations.

Hydraulic Power Tests. During these tests, OECD Code 2 requires the hydraulic oil temperature to be maintained at 65° ± 5°C. A test fixture is connected to the tractor's auxiliary service couplings that consists of pressure transducers located at each coupler pair, a flowmeter, and a restrictor valve that can be manually adjusted to restrict flow and increase pressure. During testing, the engine is maintained at full throttle and engine speed is recorded continuously during the test. Data reported are the maximum hydraulic pressure that can be maintained, the hydraulic power available at a single service coupler pair at the flow rate produced when the pressure is 90% of the maximum hydraulic pressure, the maximum hydraulic power available at a single coupler pair and the maximum hydraulic power available through multiple coupler pairs (two or more pairs to ensure maximum flowrate is available).

Figure 10. Hitch lift test 610 mm behind hitch balls.

Hydraulic Lift Tests. These tests consist of measuring the lifting ability of the three-point hydraulic lift both at the hitch locations and at a point 610 mm (24 in.) rearward of the hitch locations. The tractor is supported so that the tires do not bear weight and the tractor is secured to the hitch fixture so that the tractor may not lift during the test. A vertical downward force is applied at the hitch locations and the vertical force the hitch can exert is measured for at least six points from the lowered position to the raised position. For the second part of this test, a lift fixture is attached to the hitch so the vertical downward force is applied at a point 610 mm rearward of the hitch locations and the test is repeated. The hitch fixture is constructed so that the center of gravity of the fixture is centered on the point of load application (see figure 10). One of the weaknesses of this test is that the force exerted by the hitch may exceed the force required to lift the front of the tractor during actual use. Melotz studied the required front axle force required to maintain adequate tractor steering control and developed equations to calculate the maximum usable lifting force that preserved adequate steering (Melotz, 2016). As a result of this research, a change to the OECD test codes has been approved for the 2020 edition of the codes that will also report the maximum force the hitch can exert while still maintaining at least 20% of the tractor's mass on the front axle to allow for steering control for wheeled tractors and 0% for two-track tractors (which remain steerable as long as the tracks remain in contact with the ground). This lifting force is a calculated value based upon the tractor mass and geometry and multiple values may be included at the manufacturer's choice for typical ballasting configurations.

Drawbar and Fuel Consumption Tests. These tests document pulling performance at the drawbar at typical speeds. Drawbar testing must be conducted on either a level good quality concrete or tarmacadam surface. While the tractor maybe ballasted at the request of the manufacturer, the compulsory test requires the tractor to be unballasted. Tires and rubber tracks need not be new but must have at least 65% of their tread height present. Further, Board Action No. 11 (NTTL, 2019) limits drawbar testing to ambient temperature between 40°F and 80°F, one of the reasons for limiting tractor testing to the spring and fall months. All gears which give field travel speeds must be tested. For NTTL purposes, testing is conducted in all gears that give an unladen travel speed between 3 and 17 kph with the tractor at full throttle. In the case of "stepless" (CVT) transmissions, at least seven speed settings must be chosen between 2.5 and 17.5 kph. Further, if the tractor employs an automatic mode for fuel consumption, the tractor may operate in this mode for each speed setting. For each gear or speed setting, drawbar force is applied to find the maximum sustainable drawbar power. For wheeled tractors, slip may not exceed 15%. In most cases, maximum drawbar power is achieved at no higher than 12% slip. The control system of the NTTL load car allows for speed control based on either engine speed or ground speed as well as force control. In practice to find the maximum drawbar pull in each gear, ground speed control is used with progressively lower speeds selected until either equilibrium is reached or the maximum allowable slip is reached. This results in a negative feedback system where as the tractor reaches its ability, ground speed drops causing the load controller to reduce the load since it is acting to maintain a set groundspeed. Data collected besides drawbar pull include travel speed, left and right rear axle wheel slip, engine speed, fan speed, fuel consumption, several temperatures, and atmospheric conditions.

The NTTL employs a permanent weather station that provides ambient temperature, barometric pressure, and relative humidity and records conditions during each data run. The NTTL track is an oval-pattern track with the straight sections aligned in the east-west direction. Normally for each required set of data, two straight passes with the tractor traveling west are averaged with two straight passes with the tractor traveling east to minimize the effect of any wind speed. Additionally during this testing, the gear which gives maximum drawbar power must be identified. Additional testing is completed in this gear/speed setting with the drawbar force reduced to 75% and 50% of the pull force that was documented during the maximum power run. The tractor is then shifted to a higher gear/speed setting and the 75% and 50% pull forces are replicated. The engine throttle is reduced as necessary to maintain the same travel speed as the 75% and 50% runs in the gear that produced maximum drawbar power. These data runs illustrate the value to users of the shift up and throttle back practice to reduce fuel usage. In the case of tractors with either no PTO or a limited power PTO, additional testing is performed to produce a lug run and to demonstrate the ability of the tractor to operate at maximum power output for one hour. It is generally advisable to conduct drawbar testing at the lowest tire pressure available. A load per tire is calculated based on the tractor axle weights. Data from the Rim and Tire Association is used to calculate the minimum acceptable tire pressure for the load. Tire pressures must be set at or above this value for testing.

Current Tractor Test Law

The original tractor test law was passed by the Nebraska Legislature in 1919. This law established the tractor testing requirements, appointed the University of Nebraska's Agricultural Engineering Department as the body responsible for testing tractors to insure that they performed as advertised, established the Nebraska Board of Tractor Test Engineers with authority to determine tractor testing requirements, to review tractor testing reports and to recommend to the State Railway Commission the issuance of sales permits. The Railway Commission was empowered to enforce the tractor test law. The tractor test law has been changed several times since its initial enactment. The first change occurred in 1920 to allow the University to recoup fees for testing, an oversight in the original law. In 1956, a modern definition of a tractor was established, eliminating the need to test construction and lawn and garden products. In 1967, the State Department of Agriculture replaced the State Railway Commission as the permit issuing and enforcement body. In 1986, the law was changed to allow full participation in OECD and allow tractor manufacturers to utilize reciprocity between OECD test stations. The most recent change to the law, which occurred in 2012, made testing of tractors advertised at less than 100 PTO HP optional. This change also removed the agricultural sales tax exemption for non-permitted tractors. The effect of this change was that manufacturers of smaller tractors who want to sell those models to agricultural customers continue to test and obtain permits. This last change also brought to an end the opposition to tractor testing from the Iowa-Nebraska Equipment Dealer's Association, which opposed the law due to the number of dealers targeting non-agricultural customers who were required to permit such tractors. The current tractor test law may be found in Nebraska Statutes 2-2701 through 2-2711 (Nebraska Department of Agriculture, 2017).

Board Actions

The Nebraska tractor test law established the University of Nebraska Board of Tractor Test Engineers (Board) and assigned to the Board of Regents of the University of Nebraska the power to adopt and promulgate rules and regulations for the official testing of tractors. One of the main functions of the Board of Tractor Test Engineers is to compare tractor test results with the manufacturer's advertised values for power and fuel consumption. The law gives the Board the option to test advertised claims at other than the customarily used tractor power outlets. In order to meet these duties, the Board has made decisions regarding technical details not specifically addressed in the law. The Board refers to these decisions as Board Actions (NTTL, 2019), and makes them publicly available. These Board Actions are mostly of interest to the tractor manufacturers, and are currently available on the tractor test lab's website (https://tractortestlab.unl.edu). As an example, Board Action No. 27 provides a definition of what constitutes a tractor model for the purposes of the law. As tractor technology or testing procedures have changed, some Board Actions have been rescinded or superseded. At the present time, 12 of the 38 Board Actions have been rescinded or superseded and 26 are in force.

DEF Consumption and DPF Fuel Use

Increasingly strenuous emission standards cause tractor and engine technology to change, which in turn causes changes to tractor testing procedures. Two emission mitigation techniques were employed to allow tractors to meet the Tier 4 interim and final emission standards, which went into effect in 2011 and 2014, respectively, for most tractors. One technique to reduce NOx emissions is to employ a selective catalytic reduction process that introduces an aqueous urea solution known as diesel exhaust fluid (DEF) into the exhaust stream of a diesel engine. DEF reacts with the NOx compounds in the exhaust gases, converting them through chemical reactions into nitrogen, water, and carbon dioxide. The urea in the DEF quickly breaks down into ammonia, which is the oxidizer used. From a tractor user's perspective, DEF is a consumable fluid that must be replenished and therefore is a cost of tractor ownership just as fuel is. As such, the NTTL testing procedures were modified to document DEF usage.

DEF dosing systems differ between manufacturers. Since the dosing injector is located in the exhaust gas stream, cooling the injector is required, so it is normal for some of the DEF to be injected and some to circulate to keep the injector cool. Normally, two flow meters are employed to measure the supply and return flowrates with the difference being the DEF expended. As NOx formation is related to temperature, higher torque settings create higher exhaust gas temperatures and more DEF is required. DEF rates can be as high as 16% of the fuel rate on some tractors.

The second primary mitigation technique is to employ a diesel particulate filter (DPF). A DPF collects particulate matter that is not fully combusted from the exhaust stream and stores the particulates. When exhaust gas temperatures are high, some of the stored particulate matter is fully combusted and released as gas. This is known as passive regeneration. Periodically, the DPF requires active regeneration. During an active regeneration, diesel fuel is combusted in the exhaust stream to increase the exhaust gas temperature sufficiently to combust the stored particulate matter. Active regenerations can last up to one hour. During an active regeneration, the tractor normally remains usable and the event occurs in the background. The fuel consumed during an active regeneration can vary considerably depending on the operating mode of the tractor and is dependent on engine speed (more or less exhaust gas to heat) and loading (lower or higher exhaust gas temperatures). As such, three regenerations are observed during the PTO tests. One occurs at full load with the tractor operating at rated engine speed (4.1.2.1.1 of OECD code 2). The second occurs at 40% power and 90% of rated engine speed (4.1.2.1.4 of OECD code 2), and the third occurs at the 40% power and 60% of rated engine speed (4.1.2.1.5 of OECD code 2) (OECD, 2019). The development of these test procedures within OECD was led by the US. With the DPF procedure, especially, the procedure was drafted at a time that tractor manufacturers were still gaining experience with such systems. The NTTL remains grateful to the outstanding cooperation of the tractor manufacturers, which included visits to some manufacturers' design and testing facilities and the review of not-yet-in-production systems that allowed these procedures to be developed successfully. In practice, while OECD code 2 considers this testing to be optional, Board Action No. 34 requires these optional tests to be performed in order to obtain a Nebraska Sales Permit (NTTL, 2019).

Verifying Power of Tractors Without a PTO

One example of the effect changes in technology have had on tractor testing is the development of large tractors without a PTO, as these tractors are primarily used to pull large draft implements. The primary method the Board has used to verify advertised power claims over the years has been the PTO power test. The OECD Code 2 test procedure provides options that tractors without a PTO, or without a full-power PTO, can be tested for drawbar power, or by pulling the engine from the tractor and conducting an engine power test. Manufacturers are reluctant to advertise drawbar power as, of all the means tractors have to output power, drawbar power is the most variable, and therefore most difficult to verify. Manufacturers and test labs are reluctant to pull the engine to conduct an engine test because it is time consuming (reducing the rate at which the test lab can complete tests, as well as increasing the cost of testing), and raises reliability and warranty concerns from the disassembly and reassembly work. The Board used data from 18 years of tests to establish relationships between maximum drawbar power at rated engine speed with the tractor unballasted and advertised engine power (Kocher et al., 2011) for rubber-tracked tractors, four-wheel drive tractors, and large front-wheel assist tractors. Board Action No. 31 makes those relationships publicly available and describes the method used by the Board to verify the advertised engine power claims of these tractor models.

Testing Fuel Efficiency of CVT Transmissions

Since about the time of the fuel crisis in the 1970s, people have been studying means to reduce tractor fuel consumption. A concept that was developed has been called shift-up and throttle-back (SUTB) or gear-up and throttle-down (GUTD) when full tractor power is not required. In the early 2000s manufacturers began producing tractors with engine and transmission controllers (generically referred to in this paper as CVT for continuously variable transmission) that utilized this concept to reduce fuel consumption. Reports of tests of tractors with these engine-transmission controllers provided only minimal information about their fuel savings capability since almost all of the required drawbar testing is done at full power. A few manufacturers asked the Nebraska Tractor Test Lab to develop a test procedure that could demonstrate the fuel savings capability of these engine-transmission controllers. Bart Coffman, an undergraduate honors student who worked at the lab, initiated the first effort at developing this test. Coffman et al. (2010) tested a single CVT tractor with 17 different drawbar loads and a 9 km/h travel speed. Three different randomizations of the order of application of the loads were used in this work, and results showed that the order in which the loads were applied did not significantly affect the fuel consumption for the steadystate portion of the loads. Graduate student Christopher Howard continued the work by comparing fuel consumption of two tractors of the same model with two transmissions, one a standard gear transmission, and the other a CVT (Howard et al., 2013). This test was conducted with three travel speeds (approximately 6, 8, and 11 km/h) and six loads at each speed (30, 40, 50, 60, 70, and 80% of pull at maximum power for each speed). The fuel consumption model used in Howard et al. (2013) had fuel consumption as a linear function of drawbar power, with separate equations for each travel speed. One result of this work was the addition of Section 4.4.5 Fuel consumption test at varying drawbar loads to the OECD Code 2 as an optional test. The method of reporting the fuel consumption in this part of the OECD Code uses the approach presented in Howard et al. (2013) as it has not yet been updated to the approach presented in Kocher et al. (2017). A second graduate student, Bryan Smith, tested eight tractor models with three speeds (approximately 7.5, 10, and 13 km/h) and seven loads (30, 40, 50, 60, 70, 75, and 80% of pull at maximum power for each speed). The fuel consumption model preferred in Kocher et al. (2017) has fuel consumption as a linear function of drawbar power and travel speed. The advantage of this model is that one equation can be used to estimate fuel consumption over travel speeds ranging from 7.5 to 13 km/h.

Interpretation of Test Reports

A test report is issued for a tractor model, as defined in Board Action No. 27. There are currently three general categories of test reports. A "Nebraska OECD test report" is published for a tractor model that was tested according to the OECD Code 2 at the NTTL. An "OECD test report" is published for a tractor model that was tested according to the OECD Code 2 at an OECD test station other than NTTL. A "Nebraska test report" is published for a "limited" test including all portions of the OECD Code 2 test procedure except for drawbar tests. Board Action No. 28 describes tractors eligible for the limited test as small tractors (power ratings from 40 up to and including 100 PTO hp) that may be more of a utility tractor than one used for draft work. These limited tests must be conducted at NTTL, as OECD has no approval process for a Code 2 test that does not include the drawbar tests required by that code.

It is not uncommon to be asked a question like "which of these tractors is better?" Our standard answer is "read the whole reports." Each tractor has its strong points and weak points. The individual users should know best what functions and loads are most important for their applications, so they should know best which results are of more importance to them, and which are of less importance. Users can compare the results on the reports for the different tractors, giving more weight to the results of more importance to them, and less weight to the results of lesser importance.

The heading (or title block) of a tractor test report includes the test number and Nebraska summary number (if applicable), and the manufacturer's model and transmission designation. A basic test report has eight sections including: 1) a general description of the test, consumable fluids, engine, chassis, repairs and adjustments, notes, and remarks; 2) power take-off performance; 3) fuel consumption characteristics for drawbar work; 4) drawbar power; 5) sound; 6) tires, weight, and dimensions relevant to the drawbar; 7) hydraulic power and three-point hitch lift; and 8) three-point hitch dimensions. As the "limited" Nebraska test does not include drawbar tests, these reports do not include sections 3 and 4 from the above list. Manufacturers may request additional optional tests so the reports may include additional information in some of these sections. As one example, manufacturers sometimes request additional drawbar tests with ballast added to the tractor, which adds information to sections 4 and 6 from the above list.

The first section is most often located in a column on the right-hand side of page 1, continuing on in the right-hand column on page 2. This section describes the location (OECD test station) and dates the tractor was tested, the manufacturer's name and location, technical details about the consumable fluids (fuel, DEF, engine oil, hydraulic and lubricant fluids), technical details about the engine, technical details about the chassis, a list of any repairs or adjustments that were made to the tractor while undergoing the official test, any notes about any electronic engine control features, active regenerations for the exhaust system, etc., and remarks that indicate any of the manufacturer's performance claims that either were not met, or not tested. At the end of this first section are the report numbers and the date the report was signed by the board and published, along with the names of the NTTL director and Board members who reviewed and approved the report.

The second section on the power take-off performance, located in the upper left-hand corner of page 1, begins with results from maximum power test runs, each one hour long, at rated engine speed, standard PTO speed (if this does not occur at rated engine speed), and maximum power. The Board considers the manufacturer's PTO power claim to be met when the PTO power at either rated engine speed, or at rated PTO speed, exceeds or is equal to the advertised PTO power claim. Fuel and DEF consumption rates are reported along with power and engine speed for each of these test runs. Unless otherwise specified by the manufacturer, the Board considers the manufacturer's fuel consumption claim to be met when the fuel consumption rate for the test run at maximum power and rated engine speed is less than or equal to the advertised fuel consumption rate. The last part of this section includes results from PTO power measurements taken at full throttle and six load points specified in the OECD Code 2 test procedure. These results typically give the reader information about the consumable fluid consumption and engine speed with the engine at full throttle, over the range from no load to full load at rated engine speed.

The third section is the drawbar performance fuel consumption characteristics section, usually located in the lower left-hand corner of page 1. This section gives the reader some information about the potential for fuel savings from shift up and throttle back operation of the tractor during drawbar work at as close to the chosen travel speed as possible. The first three lines of these results give fluid consumption information for the tractor at full throttle with drawbar loads of: line 1, maximum power at rated engine speed; line 2, 75% of the pull in line 1; and line 3, 50% of the pull in line 1. The last two lines of results in this section come from operation of the tractor in shift up and throttle back mode as the transmission is shifted up a selected number of gears and the throttle setting is reduced to achieve the same travel speed as in lines 1 through 3 with drawbar loads of: line 4, 75% of the pull in line 1, and line 5, 50% of the pull in line 1. The difference in fuel consumption between the lower gear with full throttle and the higher gear with reduced throttle at the same drawbar power level gives an indication of the fuel savings rate. As an example, a John Deere 6230R traveling at 5.86 mph on the drawbar track with 75% of pull, speed setting 9, and full throttle (drawbar power of 140.3 hp), has a fuel consumption rate of 0.454 lb/hp·h. That same tractor at 75% of pull, speed setting 11, and reduced throttle (drawbar power of 138.0 hp), has a fuel consumption rate of 0.420 lb/hp·h. The difference in fuel consumption rate is 0.034 lb/hp·h, which when multiplied by the average drawbar power level of 139 hp translates to a fuel savings rate of 4.7 lb/h.

The fourth section is the drawbar performance maximum power section, usually beginning at the left-hand side of the top of page 2. This section presents tables of drawbar results with the tractor transmission in each gear (or speed) setting from at least one gear lower than the gear at which maximum pull is achieved, to at least one gear higher than the gear at which maximum drawbar power is achieved. The first of these tables is from the compulsory drawbar test with the tractor unballasted, front drive engaged, and at rated engine speed, or possibly another engine speed specified by the manufacturer. Additional tables of optional drawbar results may have been obtained at other engine speeds and/or ballast conditions requested by the manufacturer. These results show the drawbar pull, travel speed, drawbar power, slip, and fuel and DEF consumption achieved by the tractor in each of the gears tested. Occasionally conditions occur that require limiting drawbar loading, such as excessive bouncing of the tractor, or excessive slip, etc., and footnotes are added to the tables to indicate these conditions. The results in these tables show that as the gear (speed) increases, the drawbar pull decreases. Users who have some knowledge of the drawbar pull required for an operation can review these tables to determine the range of gears and travel speeds at which a tractor can potentially provide that drawbar pull. Results in the tractor test reports are from tests done with the tractor on a hard-surfaced track, so the user must use judgement from their experience to determine what reduction in drawbar pull, increase in slip, and reduction in speed they can expect for operations conducted with the soil types and conditions in their fields.

The fifth section of typical Nebraska tractor test reports, frequently located below the drawbar results, is the sound test results. Exposure to high noise levels over periods of time can result in hearing loss and other health effects. The noise to which the tractor operator is exposed is measured using a microphone held in position close to the operator's ear. Sound measurements are reported for the tractor operating on the drawbar test track either under load, or unloaded, in the gear giving the nominal speed closest to 7.5 km/h, and may also be reported for the tractor operated at maximum travel speed. The sound level is measured in decibels on the A curve (dB(A)). Sound measurement for a bystander is sometimes also reported. As a reference for sound level, OSHA's time weighted average permissible exposure limit for all workers for an 8 hour day is 90 dB(A) (U.S. OSHA, 2019). The decibel scale is a logarithmic one, so an increase of approximately 3 dB(A) represents a doubling of the sound power. OSHA also requires that the amount of time a person can be exposed to a sound level is cut in half when the sound level increases by 5 dB(A). As an example, if the sound level to which a worker is exposed increases from 90 to 95 dB(A), the worker can only be exposed to that sound level for 4 hours per day (8 hours per day ÷ 2).

The sixth section, generally located below the drawbar test results and the sound results, is the tires and weight section. This section presents information about the numbers and size designations of tires (or tracks) on the tractor that was tested. Tire pressure information is also included, although the reader is reminded that the tire pressures used for testing the tractor on a hard-surfaced track may not be appropriate for use in agricultural fields. This section also includes the height of the drawbar above the ground, and static weights of the tractor with the operator (at the front axle, rear axle, and total). If the manufacturer requested optional drawbar tests with additional ballast weights, the tires and weights section includes the tires and weight information for the tractor as ballasted, as well as unballasted. A recent addition to the test reports, usually located above the tires and weight section, is information about the location of the hitch point holes in the drawbar.

The seventh section, usually located at the top of the last page of the report, is the hydraulic performance section, which includes information about the three-point lift, and hydraulic system for providing power through the hydraulic remote outlets. The three-point lifting force reported is the maximum force that the three-point lift can exert throughout its full range of motion from the lowest to the highest position of the hitch. Unfortunately, prior to the 2020 version of the OECD Codes, this lifting force has been measured with the tractor chained down, so while the three-point hitch is capable of exerting the reported force, in many cases, the tractor would tip backwards before the three-point hitch would lift that heavy a load. Beginning in February 2020 with the revised OECD Code, as discussed above in the Hydraulic Lift Tests section of this paper, the hydraulic performance section of test reports will also include a calculated maximum usable lifting force that maintains adequate steering (and won't tip the tractor backwards). Manufacturers sometimes provide options of different lift cylinders with the three-point lift, so when three-point lifts with the different lift cylinders have been tested, these results are also included in this section.

The seventh section also presents information about the power the tractor hydraulic system can deliver through the remote outlets. The manufacturer may provide multiple pump options with the hydraulic system, so this section includes results from all pump combinations that were tested. Hydraulic power is a function of pressure and flow rate, so values for these three quantities are presented. Hydraulic power may be delivered to implements through one or more pairs of remote outlets, so test results are often presented for flow through a single pair of outlets, and multiple outlet pairs. Flow rates are presented both for flow at minimum pressure, and at the pressure and flow rate combination resulting in the maximum hydraulic power delivery. Use of tractor hydraulic systems to deliver power to implements has been increasing, with implements such as air planters including specifications for the flow rates and pressures required for their operation. Readers may review the hydraulic power section of tractor test reports to determine which tractors meet or exceed the pressure and flow requirements of their implements.

The eighth section of tractor test reports presents a diagram of the geometry of the rear wheel and axle and three-point hitch (with lower lift arms in the lowest, horizontal, and highest positions) and PTO shaft. Lines and labels on the diagram refer to various dimensions relevant to these components and the rear of the tractor. A table of the dimension lengths referenced by the labels in the diagram is also included, and this table may include lengths for more than one hitch category, if the tractor is offered and tested with more than one hitch category (e.g. Category 3 and Category 3N), or if the hitch dimensions were obtained according to more than one test procedure (SAE test and OECD test). This section is useful when the reader has implements with specific hitch and connection geometry and needs to determine if the tractor and implement connections are compatible.

The last two items that may be on the report are a recommended format for citing the report, and a picture of the tractor. The recommended format for citing the report was added to the reports beginning with Nebraska OECD Test 2179 in October of 2017. If the tractor was tested at NTTL, a picture of the tractor is also located at the end of the report. Nebraska reports for tractors tested at other OECD test stations generally do not have a picture of the tractor because no picture was received by NTTL with the report from the OECD Coordinating Center.

Other Activities

The NTTL routinely conducts and supports research with regards to tractor testing. The NTTL also offers testing services other than official tractor testing. As an example, the NTTL worked with Lubrizol to test improved transmission/hydraulic fluid for off-road machinery. Results of this work were published through SAE (Stackpole et al., 2018). In field tire/track performance was studied through a proprietary field performance study. Ethanol and water injection of a diesel engine via fumigation was studied by Janousek with promising results for NOx mitigation (Janousek, 2010). Additional engine testing of propane engines have supported cost analyses for the use of propane as an irrigation engine fuel. Whole vehicle testing has been performed at numerous times on motor graders, crawlers, skid steer loaders and ATVs. Perhaps the most unique test completed was an evaluation of the hydraulic system on a fire truck.

An upcoming issue facing the tractor industry is to develop new methods of proving that ROPS have cold weather embrittlement properties. The current practice for ROPS is to construct the ROPS of steels that have been pretested to demonstrate resistance to failure at low temperature impact loads. The future introduction of non-ferrous structural materials necessitates a different approach. One method is to return to using the dynamic ROPS test conducted at low temperatures which provides impact loading; however, this test is currently restricted to tractors of less than 6000 kg reference mass. Lindhorst recently proposed new ROPS energy equations for tractors of higher mass and new heavier pendulums (Lindhorst et al., 2018). Future work is planned to validate the new equations by comparing results with the currently employed static ROPS test.

Future Challenges

The use of electric power on tractors will present future testing changes for the NTTL. In 2017, the NTTL evaluated two electric tractors manufactured by Solectrac as seen in figure 11. These tractors were designed for orchard and vineyard work, a niche market. While this tractor was not officially tested, the evaluation did provide useful information to both Solectrac and the NTTL. One clear question to be answered is how to document the useful work that can be obtained from a fully charged battery. A second question might be how to document the time required to fully charge the batteries. Another foreseeable tractor technology change is the delivery of electric power directly to attached implements. Such power may be produced by a flywheel generator or even possibly a diesel electric power train. Since such power is intended to be supplied to implements, electric power becomes another power outlet available to end users as hydraulic, PTO, and drawbar power currently are.

An additional challenge is to better relate the current tractor test to implement power requirements. Field implements

Figure 11. Solectrac utility tractor on test at the NTTL.

typically consume tractor power through more than one power outlet. An air seeder may be using both drawbar and hydraulic power, for example. Roeber developed measurement systems for drawbar, PTO, and hydraulic power (Roeber et al., 2016, 2017a,b). These systems can be employed in the field to collect actual implement power requirements. CANBUS data can also be collected that measures engine operating parameters such as speed and engine power. Such data collection will allow a library of typical load cases to be collected. In the future, CANBUS data can be collected for the same parameters during official tractor testing essentially establishing the efficiency of power transmission from the tractor's engine to the various accessible power outlets. Such data will allow several benefits. First, additional drawbar or PTO loading points could be used in official testing that correlate to expected implement power requirements. Such data could be used by end users of the reports to estimate fuel use during known applications. In fact, it is foreseeable that a simple app could be created to input expected implements and operating hours and an output could be tractor models that are well matched to the expected uses for the tractor. The ability to correlate CANBUS data with actual power delivered during official testing would enable CAN logging hardware to be used to evaluate tractor efficiency in the field. The end result would be a tool that allows producers to select the tractor best matched for their intended uses. At present, the NTTL is operating with researchers funded by the USDA to begin the process of understanding in field implement power requirements.

Conclusions

The NTTL has been in place for a century since its first test in 1920. During this period of time, tractor technology has changed significantly. The staying power of the NTTL can be perhaps explained by its consistency in supplying accurate, unbiased, and relevant tractor performance data. Had the NTTL not displayed the high integrity it has, it would not have survived long. Had the NTTL not adopted new tractor testing procedures and testing technology appropriate for the changes in tractor technology it would not have survived long. As the NTTL begins its second century, continuing these two trends remains just as necessary. The agricultural tractor is much evolved from the early 1920s tractor that competed with horses. It seems reasonable to assume that agriculture by 2120 will be much evolved from today. The NTTL serves a secondary mission in the education of agricultural engineering and agricultural mechanization students. During a given semester, 20-30 students are employed part time and provide much of the labor required in tractor testing, anything from operating the computer on the load car (a great job) to cleaning up the occasional 20 gallon oil spill (a not-so-great job). Students work alongside NTTL staff and testing engineers from the companies testing tractors and gain valuable experience that is an excellent complement to their formal education. Former NTTL students have worked and are working today at all levels of the agricultural industry.

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