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Forensic Engineering Investigation of a Fatal Farm Tractor Incident

By Daniel P. Couture, PEng (NAFE 951M)

Abstract

A farm owner was found unresponsive with crushing head injuries on his property in rural Ontario. His small farm tractor was found 60 meters away down a small incline with the engine running and transmission in neutral. The owner's son alleged that when the parking brake was engaged (with the engine running and transmission in neutral), this tractor's parking brake would "pop out," allowing the tractor to move. Field tests were conducted on the tractor to attempt to duplicate the scenario and to determine if the alleged sequence of events was plausible. Components of the parking brake and one exemplar were assessed with specialized metrology to determine whether they were within the manufacturing specifications on the blueprint. A 3-D CAD model of fit was created, and several variances were identified between the parts and the factory drawing. The results of the analysis concurred with the scenario that these variances led to the disengagement of the parking brake and operator fatality.

Keywords

Tractor, parking brake, disengagement, 3-D modeling, laser scan, forensic engineering

Background

In 2016, there were 43 farm-related deaths in Canada, according to statistics from the Canadian Agricultural Safety Association (CASA), including 11 in Ontario, which is home to the largest farming population in Canada. Some recent facts are shown in **Figure 1**. There were 19 on-farm deaths in Ontario in 2013, while Saskatchewan was second with eight. These facts set the context for the incident described in this paper.

It was reported that the 83-year-old victim (referred to as "Mr. W" for the purpose of this paper) was found lying on the ground by the shed on the farm in the rural Ontario township where he lived. He died at the scene from his injuries, and there were no witnesses to the accident.

The Ontario Provincial Police conducted a homicide investigation into the sudden death of Mr. W, and foul play was ruled out. The autopsy revealed that the victim had fatal crushing injuries to the head, leading investigators to presume he had been run over by the tractor, which was found with its engine idling and transmission in neutral some distance away from the shed against a fence post at the bottom of a small hill, as shown in **Figures 2** through **4**. Mr. W had significant farm operator experience. It was believed by his son, "Mr. AW," that his father had been operating the tractor to pull a riding lawn mower out from within the shed. Mr. AW suspected involvement of the parking brake, which had unexpectedly "popped out" when AW had operated this tractor.

The author's original scope of involvement was to inspect the tractor's parking brake mechanism and provide

Farm Injury/Fatality Statistics in Canada	
+ Agriculture ranks as Canada's third most hazardous industry	
+ In terms of absolute numbers of fatalities, there is no more dangerous occupation	
+ 1769 agricultural fatalities in Canada from 1990-2005: 2 per week	
+ Agricultural machines were involved in 70.9% of fatalities	
+ 91.6% of those fatally injured from this work were male	
+ For children under 14, the following were the most predominant causes of farm-related fatalities:	
Machine runovers	41.9%
Drownings	15.2%
Machine rollovers	11.1%
Animal-related	6.5%
Crushed under an object	5.1%

Figure 1
Recent Canadian agricultural injury and fatality details.

Daniel P. Couture, 352 Consumers Road, Toronto, ON M2J 1P8, daniel.couture@arconforensics.com

Figure 2
View downhill from shed at farm site.

a report on its condition. As the investigation progressed, the forensic engineering firm was subsequently engaged to quantify the differences between the blueprint design of the parking brake mechanism, an unused exemplar of the parts purchased from stock, and the actual involved components from the tractor. The objective was to gain insight into the circumstances of the fatality and possibly determine the root cause(s).

Investigation

The fact-gathering and analysis portions of the investigation were executed in three distinct phases over a period of four years.

First Phase: Elements and Observations

The original fact-finding phase of the investigation incorporated the following elements:

- During attendance at the incident site in December 2006, the tractor and parking brake mechanism were inspected and documented;

- Mr. AW was briefly interviewed about the circumstances of the incident; and

- The neighbor's ("Mr. R") farm was visited to inspect the parking brake mechanism of an identical model tractor owned by Mr. R.

The small tractor, which had a 55-hp engine and a bale spear attachment accessory, had been purchased new by Mr. W in the fall of 2004 from the local brand distributor. At the time of the incident, it reportedly had about 63 hours on the operation clock. When inspected in December 2006, the clock read 132.6 hours. This would be characterized as occasional use of about one hour per week.

The Parking Brake Mechanism

The tractor braking system comprised independent mechanical wet disc brakes for the right and left traveling brakes. Separate pedals were provided for the right (outboard side) and left (inboard side). Depressing the pedals and pulling the parking brake lever locks the traveling brakes, and results in the same state as that obtained when the brake pedals are pressed. The inboard and outboard pedals can be split, but only the inboard pedal is required to be depressed to engage the parking brake, as shown in **Figure 5**.

The brake was engaged by depressing the pedal with the right foot and simultaneously pulling up and back on a hand lever at approximately even elevation with the right knee of a sitting operator. The hand lever was solidly fixed to a flat chisel-like bar such that, as the lever was raised,

Figure 3
View uphill to shed from path.

Figure 4
Final position of tractor with engine running.

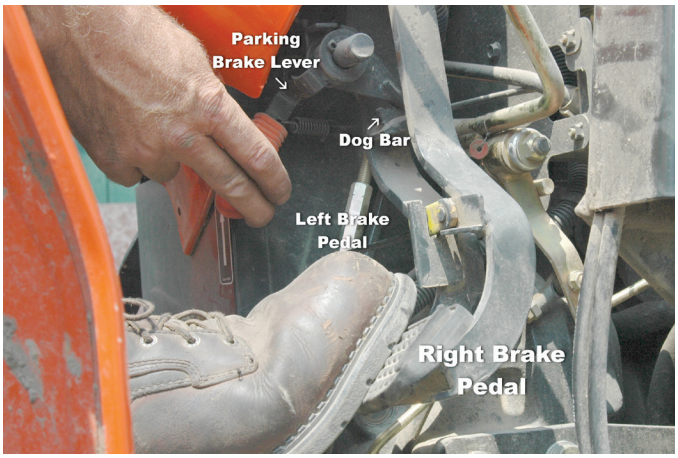

Figure 5
Parking brake configuration.

the end tip of this bar dropped at an acute angle into one of a series of transverse tooth-shaped slots (**Figure 6**) cut across another bar ("dog bar") welded horizontally to the upper side of the inboard pedal.

The dog bar grooves were shaped such that the pedal return action engaged the flat bar tip edge, catching it and locking the brake pedal at that position. There were eight slots in the dog bar over its length from leading to trailing ends. The dog bar and the flat bar were composed of steel, and appeared to have been painted dark grey originally. The paint on the front leading edge of the flat bar had been worn away, and the underlying metal had rusted.

Parking Brake Operation Test

The parking brake on the W tractor was operated at idle. When throttling up the engine, the following characteristics were observed:

a) The flat bar tip in the first slot position at the leading tooth of the dog bar would not hold the brake pedal, and the parking brake would disengage immediately at idle;

b) The flat bar tip in the second slot position would not hold the brake pedal in locked position, when the engine was throttled up with a person sitting on the seat;

c) The brake held with the flat bar tip in the third slot position;

d) The brake pedal remained depressed, and the parking brake remained fully engaged while the flat bar tip was in the fourth slot position of the dog bar, at idle and when the engine was throttled up.

During the interaction between the flat bar and the grooves, it could be seen that the shape of the upper portion of the dog bar at the first and second slots was rounded, rather than sharp. Furthermore, the depth of the grooves appeared insufficient to provide contact forces to reliably engage the brake pedal and hold it depressed.

Testing the W Tractor Roll under Local Conditions

The tractor transmission was set in neutral with the engine running, without the parking brake engaged, at the edge of the shed, as shown in **Figure 7**. With the rear tires on a projected line on the ground below the eaves, the tractor was witnessed creeping backward out of the shed into the driveway. The 3.5-meter-long tractor backed out, gradually increasing in speed, and exited the shed in about 15 seconds. Further tests demonstrated that creeping would occur even with the engine stopped and the transmission in neutral.

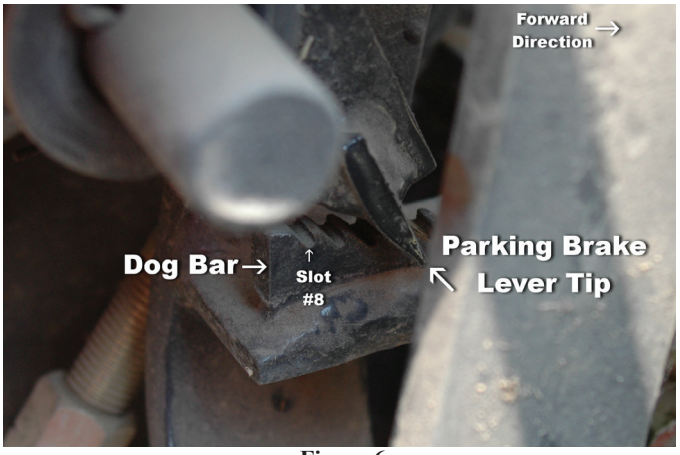

Figure 6
Dog bar and tip interaction.

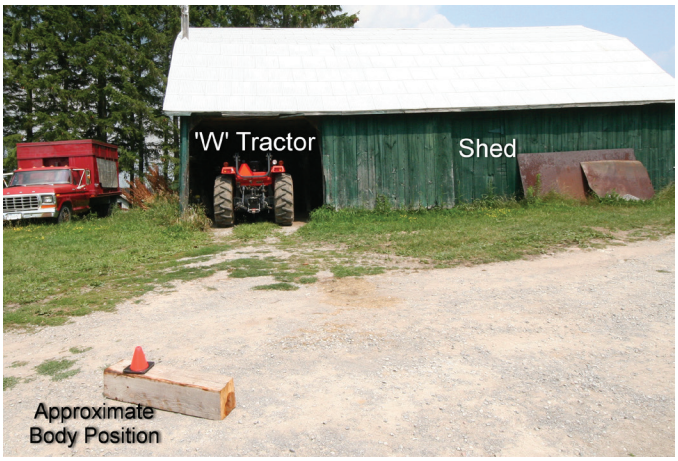

Figure 7
Position of the tractor for neutral drifting test.

The R Exemplar Tractor and Parking Brake

The authors compared notes with observations made on an identical model tractor of similar age owned by Mr. R, which had about 750 hours on its operating clock. The R tractor parking brake comprised the identical components. When tested, the brake handle remained engaged, even on the first slot of the leading edge of the dog bar. The parking brake could not be made to disengage, even when the engine was throttled up. It was tested in the R barn where it was parked.

Summary of First-Phase Findings

These results generated immediate concerns about the variation of performance between the parking brakes of these two tractors with identical model and similar manufacturing dates. The service hours could not account for the disengagement issue, since the newer one did not work — but the older one worked correctly.

The first two positions on the W tractor would not hold the parking brake engaged when parked with the transmission in neutral and the engine running. This would have presented an operating hazard, since an operator could move the hand lever, and may have falsely perceived that the parking brake was engaged when it was not.

Recalling that the tractor transmission was found after the incident in neutral (with the engine running), it was inferred to have been that way at the time of the incident. With the local slope conditions contributing to creep of the tractor backward, the tractor parking brake was either not engaged at the time of the incident involving Mr. W, or it was engaged and had become disengaged. The possibility of the latter provided the impetus to continue the second phase of the investigation.

Second-Phase Elements and Observations

Further detailed analysis of the involved components was warranted in order to reveal whether they fell within the specified range in the manufacturer's guidelines. The authors wrote to the manufacturer in January 2007, disclosing the potential issue with the parking brake and requesting that a detailed physical inspection be arranged.

A field inspection was proposed to be carried out in the presence of representatives of the tractor manufacturer and other parties. The inboard brake pedal and hand-release lever would be removed for detailed inspection by all parties. A further suggestion was that exemplar parts be obtained from stock — and that they be used to compare the surface geometry and slot morphology of the dog bar. The suggestions were accepted by the other parties.

The second inspection and testing of the tractor was arranged at the W farm in July 2007. The second phase incorporated the following elements:

- An inspection protocol was discussed prior to the activities, and proceeded after agreement on the suggested steps;
- The parking brake lever operation was demonstrated by AW;
- The tractor was placed in neutral with the engine running, and allowed to travel from the tool shed down the path to the fence;
- The tractor's brake system was tested by a manufacturer's technical service supervisor;
- The cover on the right side of the tractor was removed for closer inspection of the operation of the parking brake lever and pedal combination;
- The involved parking brake mechanism was removed from the W tractor; and
- The involved and exemplar components were retained in the author's secure evidence facility to maintain the chain of custody.

Total Station Survey of the Site

A Total Station Survey of the site identified the slope at the south entrance to the tool shed, where the tractor had allegedly been prior to the collision, as between 5.6% and 6.1% downward to the west. The slopes were independently confirmed as being between 6% and 10% with a 24-inch-long (60-cm-long) smart level.

Brake System Component Observations

The tractor's brakes were properly adjusted and functioned correctly, according to the technical service representative who test drove the tractor around the site. The range of free movement of the brake pedals was about 50 mm (2 inches), and another expert report cited 36 mm as the norm, although the workshop manual contains a value of 40 to 45 mm. The range of movement is shown in **Figure 8** and **Figure 9**. The parking brake adjustment turnbuckle had not been altered by servicing since the incident.

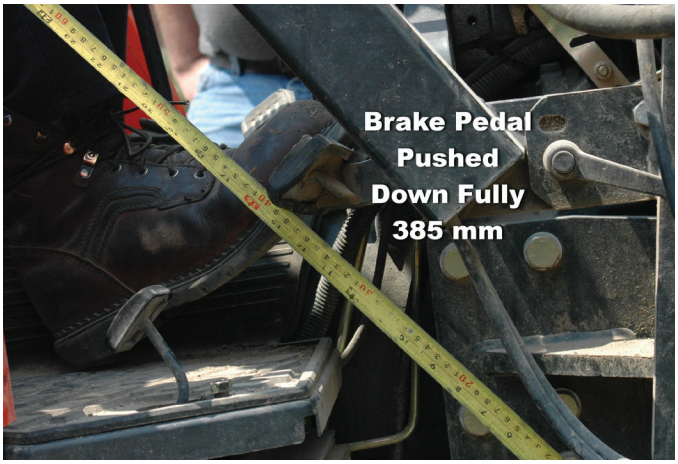

Figure 8
Brake pedal pushed down fully.

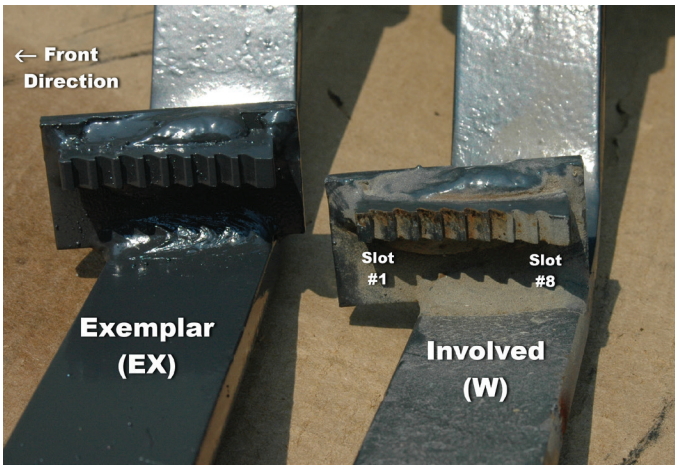

Figure 10
Exemplar (EX) and involved (W) dog bars.

The exemplar and the W (hence forward referred to as "EX" and "W," respectively) brake pedal dog bar welded positions were visibly different (**Figure 10**), when the front edge of the brake pedal was used as a reference point. On the W dog bar, the wear pattern was concentrated on one side — and on the first six teeth only — as shown in **Figure 11**.

As shown in **Figures 12** and **13**, there was a trapezoidal shape of the wear pattern to the paint on the W parking brake lever tip, while on the obverse the paint coating was missing on the W lever tip, covering about three quarters of the width to a depth of 1.5 mm. The uneven wear pattern seen in **Figures 12** and **13** at the tip was suggestive of a lateral offset between the tip and the teeth, matching the uneven pattern as seen in **Figure 11**, possibly indicating incorrect fit.

The uneven wear pattern seen at the tip was suggestive of a lateral offset between the tip and the teeth of the dog bar, as seen in **Figure 10**.

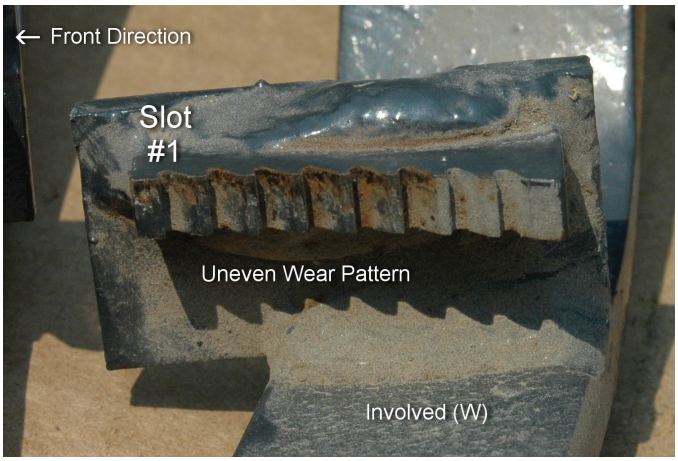

Figure 11
The wear pattern on the involved dog bar was uneven.

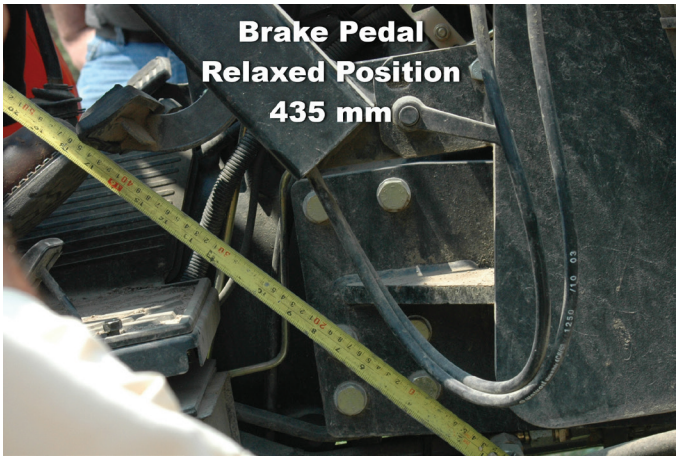

Figure 9
Brake pedal in relaxed position.

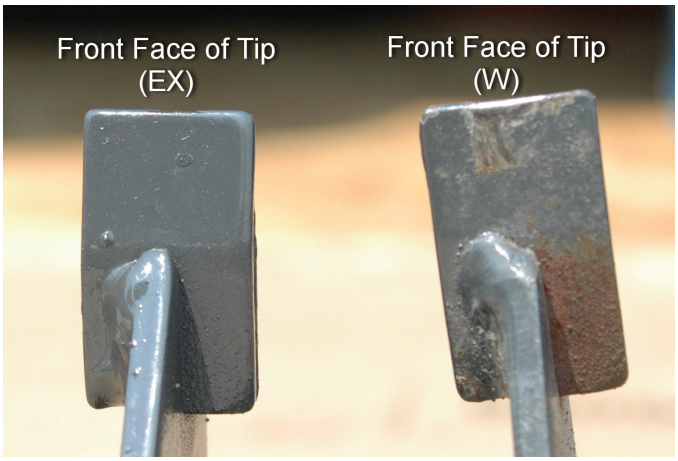

Figure 12
Front faces of the tips of the exemplar (EX) and involved (W).

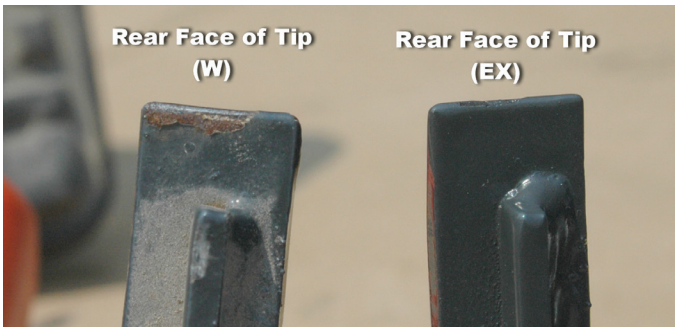

Figure 13
Rear faces of the tips.

Demonstration of Disengagement of the Lever

During the second inspection, the operation was tested in front of the assembled group. The videograph* of the operation of the parking brake lever and dog bar combination demonstrated that the lever would not stay safely engaged in the first three slots, which confirmed the findings of the first parking brake operation test.

Third-Phase Elements and Observations

The third phase of the investigation was designed to gather specific characteristics of the components, and included:

- Laser scanning of the exemplar and involved components at a specialty contractor;

- Analyzing the resulting data with modelling software to determine relevant similarities and differences; and

- Presenting the data and comparisons in 2-D and 3-D formats.

Geometric Evaluation of Involved and Exemplar Assemblies

The forensic engineers evaluated the geometric issues associated with the brake assembly. Two assemblies were made available — one specimen from the involved W tractor and the exemplar from the manufacturer's stock (EX). The assembly consisted of two parts: 1) brake-lever with the integrated chisel-like flat bar and 2) a brake-arm with an integral foot pedal and a slotted teeth set machined out of a block (dog bar). Both parts were designed to rotate about different axes of rotation. The flat bar tip was designed to engage the separate teeth of the dog bar in eight successive positions.

Tooth-Profile Examination

The tooth profiles of the dog bar(s) were assessed for differences. Close-up digital SLR photographs of each profile were performed using a 50-mm macro lens (**Figure 14**). In Adobe Photoshop, the photographs were superimposed by overlaying a transparency of EX over top of W — the EX profile was uniformly scaled until both EX and W dog bar lengths were equal. The profiles were subjectively assessed and found to be identical.

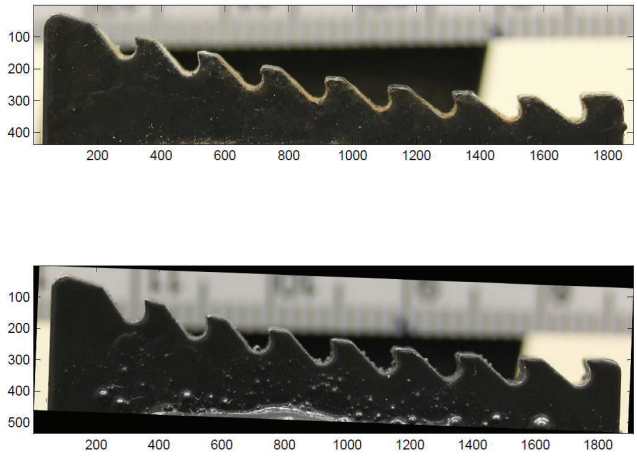

Figure 14
Tooth profiles for W (top) and EX (bottom) dog bars.

3-D Scans and Model Development in Rhino Software

The local service provider performed 3-D scans (high-resolution 175 microns, lower resolution 520 microns) of both EX and W brake-arm specimens using a laser scanner. The 3-D data of these scans were supplied in IGES format.

Rhino 3D software (v3.0, Robert McNeal & Associates) was used under license to create 3-D models of the brake-lever and brake-arm parts. Using the 3-D scans, the solid IGES brake-arm parts were imported into a 3-D workspace. Blueprints (scaled engineering drawings disclosed in the affidavit of documents of the manufacturer) of the brake-lever and brake-arm components were transferred to digital format. As scans were only performed on the brake-arm parts, the blueprints were used to create a 3-D model of the brake-lever in Rhino. From the blueprint, the relative position of the two rotation axes was calculated to accurately place the two parts in 3-D space.

Three brake assemblies were then constructed in Rhino to geometrically analyze brake engagement and sub-assembly (dog bar) placement: EX (exemplar); W (involved); and Y (blueprint).

* A videograph is the physical record made by a video device that describes movement captured in a scene over time. It is derived from Latin videre "to see" and Greek grapho "to describe."

Brake Engagement Assessment

For each of the three brake assemblies, 2-D flat-bar tooth engagement was quantified for the eight different gear engagement positions. The amount of tooth engagement (i.e., locking) was related to both the relative positions and orientations of the flat bar and dog bar. Eight locking positions were made possible by the eight slots in the dog bar. For example, Position 1 for EX is shown in **Figure 15**.

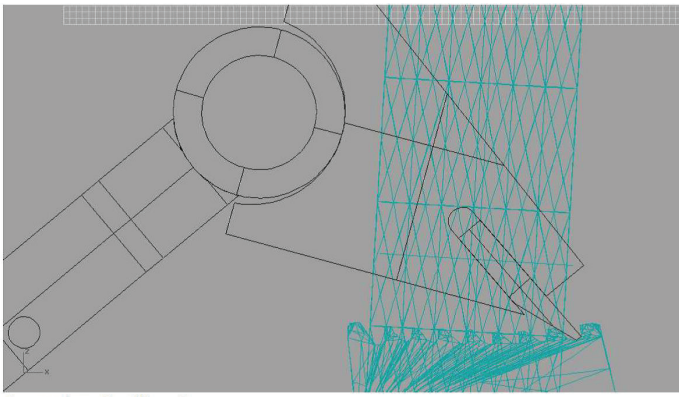

Figure 15
Position 1 for EX in two dimensions.

Comparison of Tooth Contact Depth and Tooth Contact Angle at Brake Lever Positions
Blueprint (Y); Involved (W); Exemplar (EX)

	Tooth Contact-Depth mm				Tooth Contact Angle			
Position	Y	EX	Delta mm		Position	Y	EX	Delta degrees
1	1.4	1.8	-0.4		1	9.7	29.5	-19.8
2	1.2	1.2	0.0		2	9.6	28.6	-19.0
3	1.3	1.1	0.2		3	9.2	29.8	-20.5
4	1.4	1.1	0.3		4	7.8	30.7	-22.9
5	1.5	1.4	0.1		5	8.5	23.9	-15.4
6	1.5	1.3	0.2		6	8.2	31.3	-23.0
7	1.4	1.2	0.1		7	8.0	33.7	-25.7
8	1.3	2.2	-0.8		8	7.7	22.0	-14.3
mean	1.4	1.4	0.0		mean	8.6	28.7	-20.1
std dev	0.1	0.4	0.4		std dev	0.8	3.9	3.9
Position	Y	W	Delta mm		Position	Y	W	Delta degrees
1	1.4	1.5	-0.2		1	9.7	30.5	-20.8
2	1.2	1.2	0.0		2	9.6	29.8	-20.2
3	1.3	1.0	0.3		3	9.2	32.7	-23.5
4	1.4	0.7	0.8		4	7.8	30.4	-22.5
5	1.5	1.2	0.3		5	8.5	25.5	-17.0
6	1.5	1.0	0.5		6	8.2	31.6	-23.4
7	1.4	1.0	0.4		7	8.0	33.3	-25.3
8	1.3	1.9	-0.6		8	7.7	23.3	-15.6
mean	1.4	1.2	0.2		mean	8.6	29.6	-21.0
std dev	0.1	0.4	0.4		std dev	0.8	3.5	3.3
Position	EX	W	Delta mm		Position	EX	W	Delta degrees
1	1.8	1.5	0.2		1	29.5	30.5	-0.9
2	1.2	1.2	0.0		2	28.6	29.8	-1.2
3	1.1	1.0	0.1		3	29.8	32.7	-2.9
4	1.1	0.7	0.4		4	30.7	30.4	0.4
5	1.4	1.2	0.2		5	23.9	25.5	-1.6
6	1.3	1.0	0.3		6	31.3	31.6	-0.4
7	1.2	1.0	0.2		7	33.7	33.3	0.4
8	2.2	1.9	0.3		8	22.0	23.3	-1.4
mean	1.4	1.2	0.2		mean	28.7	29.6	-1.0
std dev	0.4	0.4	0.1		std dev	3.9	3.5	1.1

Figure 16
Comparison of tooth contact depth and contact angle for Y, W, and EX.

Two measures of tooth engagement were established to indicate the amount of potential interference contributing to locking: the angle between the flat bar top surface and the dog bar slot top surface and the engagement depth between the tip of the flat bar tooth and the top surface of the dog bar. These measures were calculated for all three assemblies in all eight positions (**Figure 16** and **Figure 17**).

Comparison of Relative Positions and Angles of the Brake Lever Sub-Assemblies
Blueprint (Y); Involved (W); Exemplar (EX)

W to Y	value	units	EX to Y	value	units
offset	6.3	mm	offset	4.2	mm
rotation (side)	1.8	deg	rotation (side)	0.2	deg
rotation (top)	2.6	deg	rotation (top)	0.4	deg
rotation (front)	5.8	deg	rotation (front)	0.2	deg

Figure 17
Comparison of relative positions and angles for Y, W, and EX.

3-D Dog Bar Position Comparison and Assessment

The relative positions of the dog bar with respect to the blueprint position and orientation were computed in both side- and top-planes. The accompanying **Figures 18** through **23** for Y, EX, and W depict the positions in 2D snapshots — a more convenient form for viewing. The 3-D versions were distributed on a DVD included with report to counsel, and could be opened with the accompanying MYRIAD viewing software.

Analysis

The data scans of the components were compared and contrasted in the plane of action in 2-D and 3-D space.

When compared in three dimensions, using a common reference origin with respect to the blueprint dog bar orientation and dimensions, it was determined that W dog bar had an offset of 6.3 mm, and rotation of its side, top and front by 1.8, 2.6 and 5.8 degrees, respectively. The

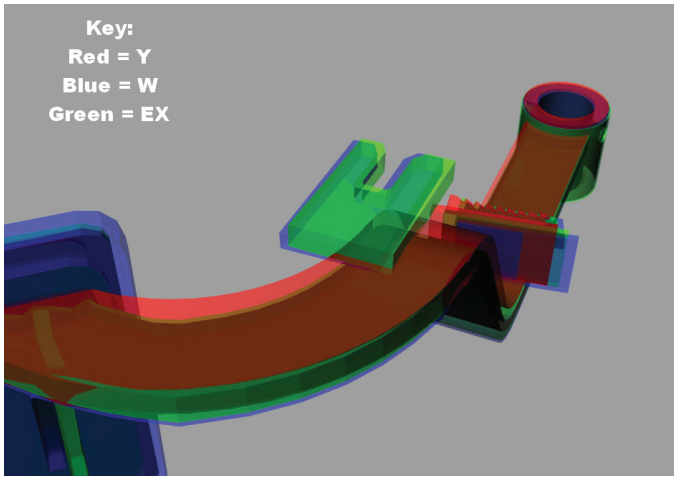

Figure 18
3D color overlay comparison #1.

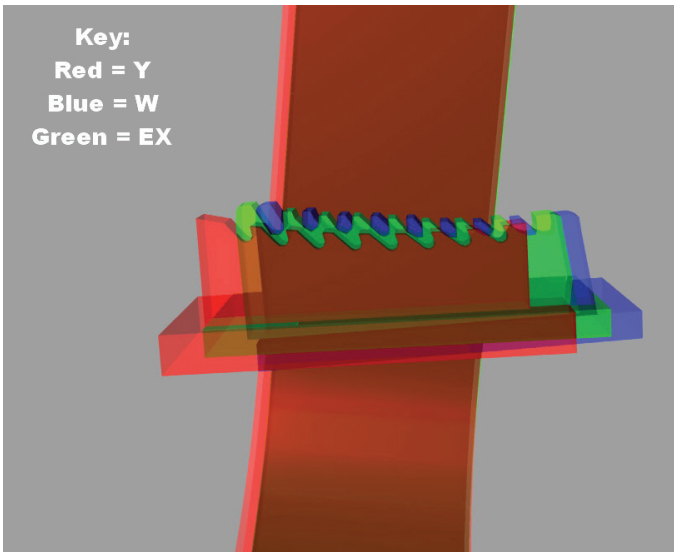

Figure 19
3D color overlay comparison #2.

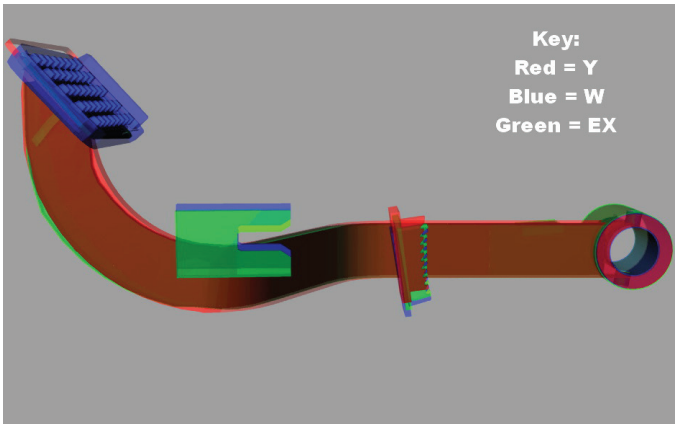

Figure 20
3D color overlay comparison #3.

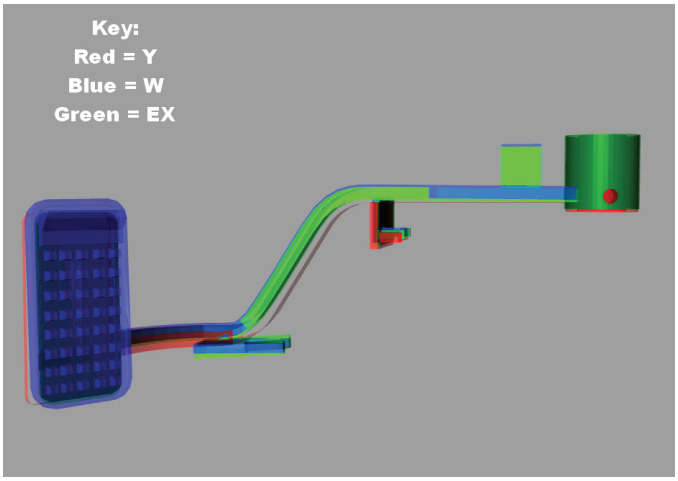

Figure 21
3D color overlay comparison #4.

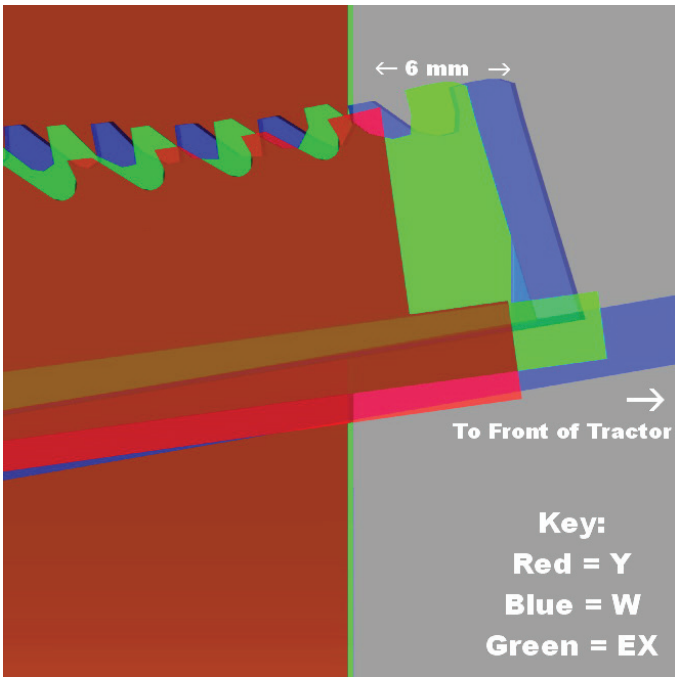

Figure 22
3D color overlay comparison #5.

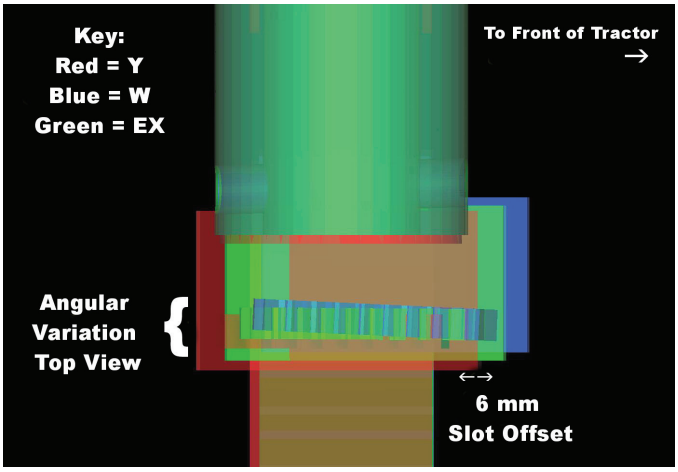

Figure 23
3D color overlay comparison #6.

EX dog bar had an offset of 4.2 mm, and rotation of its side, top and front by 0.2, 0.4, and 0.2 degrees, respectively.

When the three are set at the common center of rotation and overlaid in color (red for Y, blue for W, and green for EX), the positions and orientations are very different, as depicted in **Figure 22** and **Figure 23**. The blue portion lies at an angle to the red, and at the forward edge, the separation between the supposed position of the first tooth on Y and that of the W is about 6 mm (about $^{1}/_{4}$ inch). This offset is 133% of the 4.5-mm slot center-to-center

distance on the dog bar toward the front of the tractor.

In summary, the tooth contact-angle was much smaller for the blueprint (Y) than both EX and W. The tooth contact-depth was slightly larger and more consistent across all positions for Y than found in both EX and the W parts. These characteristics indicated that for the manufactured parts the amount of engagement varies significantly across all eight positions. Parking brake locking was less consistent than that shown on the blueprint.

Discussion

Tractor Starting and Final Positions

The starting position of the tractor was assumed to be within the tool shed, at the south edge of the door, with its engine running and the transmission in neutral. The tractor could not have been driven backward and down the hill to its final position 60 meters away. If the engine had been off at the time of the incident, it would not have restarted on the way down the hill. In police photographs, the parking brake lever was in the relaxed state on the tractor at the position of rest.

Contact Mismatch Between Dog Bar Tooth and Flat Bar Tip

The software models and part imaging showed that there were measurable differences between the master blueprint directing production of the parts on one hand and the unused exemplar and the involved component on the other.

In a 2-D analysis, which did not take into account out-of-plane orientation, the differences appeared to be minor. In a 3-D analysis, which did account for out-of-plane orientation, the variations would change the interaction between the dog bar and the slot bar edge because the dog bars lay in different positions on the expected arc of travel of the brake pedal. The slot bar edge tip should have met and engaged each of the eight teeth independently and firmly, transferring the force from the return spring through the dog bar against the slot bar of the handle.

The tip-to-tooth engagement went from a defined area (the width of the tip times its thickness held against the inner surface of a tooth in the dog bar) to a fraction of this area because the faces of the tooth and tip were no longer parallel.

The angular variations affected the interaction of the edge of the bar and the tooth, in particular at positions 1, 2, and 3 of the W, which were displaced forward by 6 mm. The intersection of the arc of travel of the lever tip and the dog bar no longer lay at the expected location in space after assembly, as shown in **Figure 24**.

The direct observations during the first phase provided the impetus for the detailed investigation; to wit, that the parking brake lever edge would not catch in the dog bar's teeth in the first two and possibly three positions on the W tractor, whereas it fit and held correctly on the neighbor's similar tractor.

Efforts were taken to explain the different behavior, by evaluating brake setting, parking brake adjustment, and field performance of the brakes during a dynamic test during the second instance of examination. No performance variations from the specified parameters for the brake system were noted except for the parking brake lever disengagement as captured in the videographs.

More detailed scrutiny of the components in the third stage, using (newly) available laser-scanning technology was judged to be the most effective route to quantify the existence of variations between the drawings for making the parts (the blueprint, Y) and the two components (EX and W).

The 6 mm ($^1/_4$ inch) displacement and relative rotation of the W components accounted for the change of behavior noted during the first and second phases of the investigation, in which the slot bar edge tip would not remain within the teeth of the dog bar. As mentioned, this distance was 133% of the slot center-to-center distance on the dog bar — a misalignment of more than one tooth.

Specifically, this safety component — the parking brake — had been intended to lock with the lever tip in each and every tooth of the dog bar, per the service

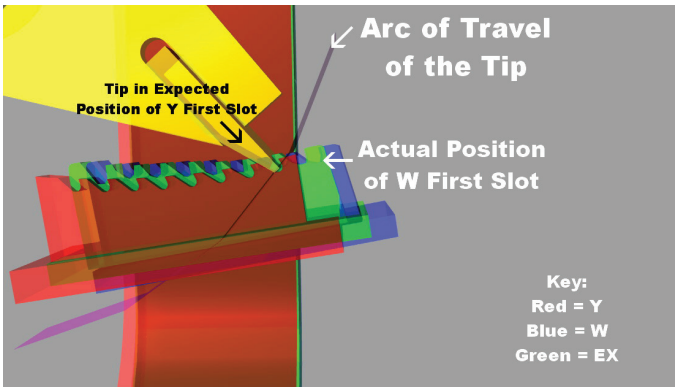

Figure 24
Expected and actual positions of the tip at dog bar first slot.

instructions. In the small tractor's Workshop Manual, under the heading "Parking Brake Lever Free Play," it states, "Pull the parking brake one notch and make sure the parking brake shaft is activated." The parking brake lever did not lock in the first notch on the W tractor.

The positional variations were found in an area of critical safety to the operator of the tractor, and for which he would rely intuitively to function each and every time it was deployed.

The parking brake malfunction was a plausible root cause of the fatal farm tractor incident, given the reported circumstances. The tractor began moving away from the shed, and the incident was consistent with Mr. W falling beneath the bale spear attachment. This explanation of the sequence of events was accepted by Mr. AW.

Conclusions

The proven hypothesis was that, due to the welded orientation of the W dog bar on the pedal, the first, and second slots could not have met the lever edge tip, and therefore could not have acted to distribute the load across sufficient area to develop the required binding force. On the third slot, the binding force was shown to be inadequate to secure the engagement during local vibration caused by the running engine. This had the potential to allow a sudden unexpected release of the parking brake lever, which would disengage the brake.

The comparison illustration set in color, highlights the difference when the parts (red = Y; blue = W; green = EX) are placed in a common reference orientation.

These variations formed the basis of a reasonable explanation for the symptoms observed in the first instance, as well as reported by AW when he had operated the tractor on several prior occasions, when the lever tip failed to stay engaged in the dog bar on the W tractor. The author's analysis showed that the mating position of the first slot lay beyond the circle of contact for the lever bar tip, such that it could have never correctly met and sat within the first tooth.

Given that the design appears intended to facilitate reliable engagement between the lever edge tip and all slots of the dog bar, the fact that the subject parts did not adequately engage in three of the eight positions reveals that there were design and/or manufacturing errors that could foreseeably have led to unreliable engagement of the parking brake. The subject parts were undamaged compared to new condition, did not have appreciable amounts of wear on the contacting surfaces (see **Figures 10** to **13**), and had been maintained by the owner.

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