HEAVY AIR BRAKED VEHICLE ACCIDENT RECONSTRUCTION

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DETERMINING WHEN A WHEEL IS CAPABLE OF LOCKING AND ESTIMATING AIR LAG TIME BASED ON VEHICLE WEIGHT

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Abstract

Investigation of heavy air braked vehicle collisions and controlled emergency brake testing often reveal irregularities in tire marking from locked wheels. It is not uncommon to find trucks loaded to near full axle capacity with brakes in proper mechanical condition, leaving little or no tire marking on the pavement. If marking does occur, a delay seems apparent.

Another irregularity confronting the accident investigator occurs when clear tire marking is apparent from wheels that are later inspected and found to be beyond adjustment limits so much so the vehicle is declared in an “Out Of Service” condition due to defective brakes.

This paper will discuss a methodology to determine if a brake is capable of locking on a given road surface, and will further discuss adjusting “air lag” time based on the condition of the brakes and wheel axle weight.

Discussion

Heavy air braked vehicles are designed to meet the Federal Motor Vehicle Safety Standard (FMVSS 121), 49 CFR, Part 571.121 braking and deceleration standard. The vehicle must be tested, loaded to its gross vehicle weight rating (the manufacturers GVWR, **not** the highway “bridge formula” statutory weight limits) and its unloaded vehicle weight plus 500 pounds (including driver and instrumentation).

No wheel lock up is required of this standard and steerable axles may not lock up at speeds above ten mph.. Wheel lockup means 100 % wheel slip and would not include tire / surface brake “shadowing”. The certification test standard is conducted on a Skid No. 81 surface (f = 0.81) dry and Skid No. 30 (f = 0.30) wet. The stopping distances specified in TABLE II of 571.121, S5.3.1.1 compute to an average deceleration factor for speeds of 20 mph of f = 0.38 and 30 mph to 60 mph of f = 0.40 to 0.41.

Federal Motor Carrier Safety Regulation (FMCSR) 49 CFR Part 393.52 specifies: upon application of service brakes at 20 mph vehicles with a manufacturers GVWR in excess of 10,000 pounds, must under any condition of loading, be capable of developing a braking force at least equal to 43.5% of its gross weight (f = 0.435 or rate of 14 fps/s).

The standard applies to a surface that is hard, essentially level, dry, smooth, clear of loose material and the vehicle may not deviate from a twelve-foot lane.

While there would appear to be a conflict between these two federal regulations, in fact, they are consistent. The FMCSR 393.52 standard further indicates the deceleration of 14 fps/s, (f = 0.435) must be achievable **sometime** during the deceleration, but not as an average. The stopping distance specified in both the FMVSS & FMCSR tables at the 20 mph test is 35 feet from application which computes to an average f = 0.38 as a minimum standard on dry surface.

This clearly shows a heavy vehicle can meet the minimum deceleration standard without wheel lock up. When driving heavy vehicles, especially articulated vehicles, drivers are taught to avoid full wheel lock up whenever possible to maintain maximum lateral stability and steering control. Commercial Driver's License manuals and driver training instruct drivers to avoid wheel lock up by "controlled" (threshold) braking or "Stab" braking which minimized wheel lock up.

A commonly accepted practice is to reduce an automobile or drag sled drag factor to 70% and apply the adjusted drag factor to a heavy, air-braked vehicle. These have been based on many old, car versus truck tests on the same surface. Many explanations have been put forth to justify the difference, which generally fall back to the tires relative to hardness of truck tires compared to car tires. In fact testing a drag sled made from a truck tire and one from a car tire on the same surface, results in a relative difference much closer to 85% to 90%.

One problem is the high tire pressures (90 - 110 psi) and firm platform of the truck tire can not be duplicated with a drag sled. Although the hardness of the truck tire creates a firm slip platform, a series of factors further add to the differences between overall stopping ability of heavy trucks versus cars.

In skid testing air-braked vehicles under various conditions of loading and speed, it is rare to find all of the brakes locking or locking at the same time. The lag may be explained by variations in the load on a given axle end, surface friction differences, brake adjustment, foundation brake components and variations in air brake valves, limiting valves and air brake timing.

Brake Force Calculation

Manufacturers of heavy air braked vehicles developed a series of brake force calculations (commonly known of as "A / L Factoring") to determine proper sizing of air brake components. The calculations are intended to achieve the customers' needs and meet FMVSS requirements. The "A" refers to the size (Type) of the air brake chamber and "L" refers to the length of the slack adjuster. The formula assumes Gross Axle Weight Rating (GAWR) load and brakes operated within the adjustment limits.

As part of the National Transportation Safety Board (NTSB) Heavy Air Braked Vehicle Study - 1992 (Ref. 1) this formula was used but was modified to allow adjustment for variations in conditions of road surface, loading, brake application pressure and brake adjustment levels.

Validation testing was conducted by NTSB and Stopper in June 1990 at TEEX, Texas A & M University. This methodology has since been taught at Northwestern Traffic Institute and Institute of Police Technology and Management.

The formula developed by NTSB (Ron Heusser - Ref. 2) requires acquisition of certain data on the mechanical components of each wheel's foundation brakes. This includes:

- **Size (Type) of air chamber (Types: 9, 12, 16, 20, 24, 30, 36)**

- **Effective length of the slack adjuster (measure center of cam shaft to center of clevis pin; 5", 5.5", 6", 6.5" 7").**

- **Push rod stroke (the distance the push rod extends from the air chamber under 80-90 psi brake application).**

- **Brake drum radius (most steer axles are 7.5", most drive & trailer axles are 8.25").**

- **Brake block "Edge Code". most are "EF" or "FF" friction rating. These have a friction range of 0.35 - 0.45.**

- **Rolling radius of tire measured center of axle to ground**

- **Weight on each axle end**

Establishing these values will allow calculation of the brake force attempted at each brake. The brake force calculation developed by Heusser is:

$$\text{Brake force} = \left[\frac{2 \times PRF \times SA \text{ x } Lf \times D\ Rad}{CamR \times \text{Tire Radius}}\right] \times 0.6$$

where:

2 = leverage ratio
PRF= Push rod force (from charts)
SA = Slack adjuster length
Lf = lining friction
DRad = drum radius
CamR = S cam effective radius (normally 0.5)

Using this calculation for each brake, a total brake force and subsequent potential deceleration rate can be calculated for an entire air braked vehicle at a given application pressure.

Algebraic rearrangement of this formula and addition of weight vs. force (brake force - "BF") of a suspect wheel allows calculation of push rod force (PRF) required to lock the wheel. The PRF formula is:

$$PRF = \frac{(BF \times CamR \times \text{Tire Radius})}{(2 \times SA \times Lf \times DrumR \times 0.6)}$$

First, calculate the BF (brake force) at the wheel in question. First think of each axle end as a drag sled.

If:
f = Force / Weight
then:
Force = Weight × f

The maximum available brake force at each axle end at 100% slip will be the weight on that axle end multiplied by the friction of the tire on that surface.

Heavy truck tires at 100% slip have been found to develop 80% - 85% of the friction value of a car tire on the same surface. As previously indicated, other factors, such as front wheel non lock up, air valve timing, smaller front brakes, etc. will usually show a lower adjustment factor when running side by side tests comparing an automobile to a heavy truck. In very low friction conditions, **if all the wheels lock**, the heavy truck will typically develop the 80% - 85% values.

Heavy motorcoaches (buses), unlike most heavy trucks, usually show these higher values as the front axles often have larger brakes, similar to the rear brakes and the weight is more evenly distributed for maximum brake effort. Dry pavement testing of motorcoaches and transit buses have shown they will rarely leave locked wheel marks, as they tend to be balanced and achieve more threshold braking.

First establish the weight on the axle end.
Typical weight values:

Loaded truck tractor & semi trailer:

Steer axle: 10,000 - 12,000 pounds
(5,000 - 6,000# per wheel)
Drive axles 32,000 - 34,000 pounds
(8,000 - 8,500# per wheel)
Trailer axles: 32,000 - 34,000 pounds
(8,000 - 8,500# per wheel)
Loaded: 74,000 - 80,000 pounds

Empty truck tractor & semi trailer:

Steer axle: 8,000 - 9,000 pounds
(4,000 - 5,000# per wheel)
Drive axles: 10,000 - 15,000 pounds
(2,500 - 3,750# per wheel)
Trailer axles: 7,000 - 8,000 pounds
(1,750 - 2,000# per wheel)

Empty weight: 25,000 - 32,000 pounds

Bobtail truck tractor:

Steer axle: 8,000 - 9,000 pounds
(4,000 - 4,500# per wheel)
Drive axles: 6,000 - 7,000 pounds
(1,500 - 1,750# per wheel)

Empty weight: 14,000 - 16,000 pounds

Note: Cab Over Engine (COE) truck tractors usually carry a larger percentage of their weight over the front axle than conventional cabs.

The best method to establish the axle end weight is to weigh the vehicle or an exemplar vehicle with similar load on portable scales. Axle end weights can also be reconstructed using weight and balance formulas. (These are taught as part of the Advanced Commercial Vehicle Reconstruction course at TEEX, but are to lengthy to discuss within this topic).

Establish the weight of the axle end in question and the drag factor of the road surface of the braking. Then adjust the road surface friction for a 100% slip truck tire:

Adjusting drag factor & calculating brake force (BF)

Example (loaded truck):

Road surface test: f = 0.80
Axle end weight 8,500 pounds
85% adjustment factor

0.80 × 0.85 = 0.68

Truck tire at 100% slip f = 0.68
(Tt f)

BF = Tt f × Weight

BF = 0.68 × 8,500

BF = 5,780 pounds

Now enter the BF into the formula to establish the PRF required to achieve 100% slip on that wheel.

Example:

Mechanical data:

Slack adjuster:	**5.5”**
Air Chamber:	**Type 30**
PRS:	**1.75”**
DRad:	**8.25”**
Tire Radius:	**21”**
Lf (brake block):	**.35**
CamR:	**.5**

Calculation

$$PRF = \frac{(BF \times CamR \times Tire\ Radius)}{(2 \times SA \times Lf \times DrumR \times 0.6)}$$

$$PRF = \frac{(5780 \times 0.5 \times 21)}{(2 \times 5.5 \times .35 \times 8.25 \times 0.6)}$$

$$PRF = \frac{60690}{19.0575}$$

PRF = 3184.57 pounds

The PRF (push rod force) required to achieve 100% slip of the subject wheel on this surface is 3,184 pounds.

Now reference air chamber push rod force charts **Appendix C** taken from reference documents 1 & 2. Locate the **Type 30** chamber chart and check the force developed at a **1.75” push rod stroke**. Find at **90 - 100 psi** application pressures, the chamber develops **2,530 - 2,850 pounds of PRF.**

Although the brake will develop significant deceleration force, it is very unlikely to achieve 100% slip. As an example, cases exist where a braking loaded truck leaves no marks or light shadowing up to a wide painted stop bar at an intersection but leaves dark marks after the stop bar. As the wheel is near lock up, shadowing may occur. If the wheel does lock due to a low friction area, it may remain locked or begin rotating again if the roadway friction level increases. Using the same mechanical data, we will now calculate an empty truck or trailer brake.

Example (empty truck or trailer):

Road surface test: f = 0.80
Axle end weight 2,500 pounds
85% adjustment factor

0.80 x 0.85 = 0.68

Truck tire at 100% slip f = 0.68
(Tt f)

BF = Tt f × Weight

BF = 0.68 × 2,500

BF = 1,700

$$PRF = \frac{(BF \times CamR \times Tire\ Radius)}{(2 \times SA \times Lf \times DrumR \times 0.6)}$$

$$PRF = \frac{(1700 \times 0.5 \times 21)}{(2 \times 5.5 \times .35 \times 8.25 \times 0.6)}$$

$$PRF = \frac{17850}{19.0575}$$

PRF = 936.63

Returning to the same chart we find that with a PRS of **1.75"** the **Type 30** chamber develops **730 - 1,010 pounds** of force between **30 and 40 psi** application pressure. This wheel will easily achieve 100% slip on this surface. On low friction surfaces, an empty or lightly loaded air braked vehicle can lock wheels with under 20 psi application pressure.

100% slip with an out of adjustment brake

Using the previous example of an empty air braked vehicle it can be established that a brake that has a **dynamic** PRS of 2 ½" (1/2" beyond the adjustment limit) can still develop enough PRF to achieve 100% slip with an application pressure of 60 psi (PRF = 1070 pounds). **Note:** The static PRS should be adjusted as follows to account for **dynamic** increase as follows:

Speed at braking / add to PRS

30 mph = 0.13"
40 mph = 0.16"
50 mph = 0.19"
60 mph = 0.22"

If there is evidence of excessive heat (such as braking on a long downhill grade or stop & go traffic) additional PRS adjustment for heat may be necessary. This calculation is available in the Heusser paper (Ref. 2).

Do not use the dynamic and / or heat increase PRS for the FMCSR "Out Of Service" or "Appendix G - Minimum Inspection Requirements" when inspecting for compliance with those regulations. Those have been established as proper static PRS in accordance with manufacturers' maintenance recommendations and adopted by the USDOT/ Office of Motor Carrier Safety and the Commercial Vehicle Safety Alliance (CVSA) for enforcement purposes.

Limiting and proportioning valves

When evaluating application pressure, you should also consider limiting and proportioning valves. From the late 1960's through 1992 approximately 40% of trucks and truck tractors were equipped with Automatic Limiting Valves (ALV's). These valves cut front axle brake pressure 50% at application pressures of 0 - 40 psi and "catch up" at a 2:1 ratio from 40 - 60 psi. Above 60 psi full pressure is delivered to the front axle. The most common valve of this type is designated as the LQ-3 & LQ-4.

In 1987 in response to the need for better brake balance on truck tractors when operating without trailers, The BP-1, BPR-1 & LQ-5 were marketed and are very popular today. These can also be found incorporated with ABS systems.

These "proportioning valves" help balance the system when there is no weight on the rear of the "bobtail" tractor. The front brakes receive 100% application pressure while the drive axle brakes only receive 25% of application pressure. This compensates for the severe over braking on the rear when bobtailing. The LQ-5 also functions the same as the LQ-3 & LQ-4 when a trailer is attached.

They are actuated by sensing supply line pressure between the tractor and the trailer (red hose).

The LQ-3, LQ-4, BP-1 & LQ-5 valves are usually found under the front radiator of the truck. The BPR-1 valve replaces the standard relay valve and is usually found under the fifth wheel plate, mounted to a frame rail. Exception: Many older Mack™ trucks have the LQ-4 valve mounted on the frame rail behind the cab.

Validation testing

TEEX, NTSB, Heusser & Stopper have conducted tests as a standard part of the training and course curriculum. Vehicles include 2 axle dump trucks, 10 wheel trucks, truck tractors with semi trailers, turnpike doubles and buses in a variety of load, brake adjustment and surface conditions since 1990 finding the methodology quiet reliable. Controlled tests include weighing of the test vehicles on portable scales brake inspection and recording of the mechanical components. A bumper gun has been attached to the truck tractor for several of these tests to help establish first movement of the brake pedal. A variety of friction testing of the road surfaces with vehicle test skids, drag sleds, G-Analyst™, Vericom™ & Mu-Meter™ have accompanied these tests.

Application pressure tests have been conducted using a Gooch™ M-600 Air Brake Analyzer which monitors air pressures to 0.001 second and ½ psi increments. Sensors are set at the service brake chambers, on the steer axle, drive axle and trailer axle. Pressure to the service "glad hand" (blue hose connecting the truck tractor to the semi trailer) is also monitored.

A highly representative test (**Appendix A & B**) was conducted August 23, 1996 by the Advanced CVAI class at TEEX. The test truck tractor was a 1995 Kenworth™ Model T-800B equipped with 4 channel anti lock brakes towing a 1991 Fruehauf™ MC-306 aluminum tanker semi trailer.

The steer axle was equipped with Type 20 air chambers and 5.5” slack adjusters. All other axles were equipped with Type 30 chambers and 5.5” slack adjusters. All brakes were within adjustment limits.
The test track tested to a drag factor of 0.70 to 0.74

When emergency brakes were applied at approximately 50 mph with the combination unloaded, the semi trailer brakes locked and the drive axles began to lock at 33 psi in 0.26 seconds (**Appendix A**). As the ABS continued to function, threshold braking was maintained at approximately 28 psi.

The tanker was filled with water to a weight of approximately 80,000 pounds and tested again (**Appendix B**). Only the right rear semi trailer brake locked (axle 5 - right) but did not lock until after 1 second of brake application. The ABS never functioned, as the truck tractor wheels never achieved lock up. Brake application pressures of 79 - 90 psi took 0.81 seconds from first movement of the brake pedal.

This illustrates brake lock up can occur at low application pressures in short time if the vehicle is lightly loaded or empty. More time was required to approach full application pressure.

Air lag time

It is well recognized that air lag must be considered when calculating the total stopping distance of a heavy air braked vehicle.
The two most common **misconceptions** I have encountered is “air brakes must lock in 0.45 seconds” and “trailer wheels are designed to lock first”.

The 0.45 seconds actually is misquoted for the FMVSS 571.121, S5.3.3.1(a) which states:

> ***“With the initial service reservoir system air pressure of 100 psi, the air pressure in each service brake chamber shall, when measured from the first movement of the service brake control, reach 60 psi in not more than 0.45 second in the case of trucks and buses, 0.50 second in the case of trailers other than trailer converter dollies, designed to tow another vehicle equipped with air brakes, 0.55 second in the case of converter dollies, and 0.60 second in the case of trailers designed to tow another vehicle equipped with air brakes.***

The time specified is the time to achieve 60 psi at the air chamber, which may or may not be enough to lock the brakes. One second or more of brake application may occur before achieving 100% slip of a wheel on a fully loaded heavy air braked vehicle. In some cases, wheels may never lock on a fully loaded truck, truck tractor and semi trailer or bus. Empty air braked vehicles can achieve 100% slip in 0.2 to 0.3 seconds.

Release times (0.55 second for trucks up to 1.20 seconds for trailers) are based on a drop from 95 psi to 5 psi from first release of the brake pedal. (FMVSS 571.121, S5.3.4.1(a)).

Appendix D is an illustration of apply and release time from the FMVSS 571.121 standard.

The FMVSS 571.121 manufacturing standard as well as testing of numerous truck tractors and semi trailers with the Gooch™ Air Brake Analyzer reveal semi trailers consistently achieve full application pressure **last.**

It is true that the semi trailer will often leave the longest identifiable mark. When in doubt, due to overlapping tire marks this is the most conservative approach, however it is not a valid assumption in all cases. The first tire to mark on an air braked vehicle (if it does mark) is more a function of weight and balance, brake adjustment and application pressure.

For many years, ½ second has been widely accepted as a reasonable estimate of air lag time. However, using the brake force formulas, a more accurate estimate of air lag time to first tire marking can be reasonably estimated by establishing the minimum psi required to lock the wheel that left the tire mark.

Testing conducted by TEEX have shown results reasonably consistent with time versus pressure chart example published in the FMVSS 571.121 standard (Appendix D). Using that chart as a reference, if lock up is achievable at 40 psi, 0.25 second air lag time is appropriate, at 80 psi, 0.53 second and 95 psi 0.80 second.

ABS tire marking

Most truck tractors that are equipped with ABS systems do often leave visible intermittent marks. First, the algorithms, of the air brake ABS are much slower than that of an automobile which allow more time to leave intermittent marks. Another factor affecting the air braked vehicle's ABS function and efficiency is the number of channels (sensors and control valves) are on the system. The most common system in use today is the "**4 channel**" ABS. This system has sensors on the front steer axle wheels and usually the last axle of a three-axle truck tractor. The second axle then is a "slave" to the third axle brake. Some are crossed and some are on the same side.

Another ABS valve design operates all four drive axle brakes from one relay valve with sensors to both rear (#3) axle brakes.

A "**two channel**" system only has ABS sensors on either the second or third drive axle. It has no ABS valves or sensors on the steer axle.

You must trace the service brake lines to the control valve to establish the type of valve(s). If the second axle locks under full braking, it won't receive a pulsing ABS command until the third axle wheel locks and then begins to cause an ABS pressure fluctuation. In this case the second axle may leave a very strong tire mark that fades as the ABS functions. In a few of my tests, the second axle has left a mark to final rest even though the other axles left no discernible mark.

Currently, very few semi trailers are equipped with ABS. Those that are, do not communicate with the truck tractor's ABS ECM. It will function on its own without consideration to the truck tractor ABS function.

Full brake application with an ABS truck tractor that is pulling a non ABS semi trailer can often result in full control of the tractor while the trailer wheels lock and the trailer then swings laterally. Trailer swing can be brought back under control by releasing and modulating the brakes, which unfortunately, defeats the ABS advantage.

ABS air brakes do not always result in shorter stopping distances, however the trade off in controlled stopping far outweighs the possible disadvantage of stopping in a shorter distance without control.

Advances in technology and new FMVSS 571.121 ABS requirements will result in safer commercial motor vehicle environment, however this change will not be overnight. Trucks, truck tractors and semi trailers are expensive and have long operating lives, if properly maintained, therefore natural attrition and change to the newer technology in air brake systems will take time.

Summary

- **Depending on application pressure, surface condition and weight, a properly adjusted and maintained air brake can function without achieving 100% slip.**
- **Limiting valves can change brake balance.**
- **Fully loaded air braked vehicles are not required to achieve 100% slip on all wheels when under full braking.**
- **Depending on application pressure, surface condition and weight, a brake that is beyond the recommended adjustment limits can achieve 100% slip.**
- **Air lag time estimates can be adjusted depending on brake force required to achieve 100% slip**
- **Trailer brakes are not designed to lock first.**
- **ABS air brakes may leave measurable tire marks. Examination of system type is necessary.**
- **Air braked vehicles take longer to stop than automobiles due to a combination of factors beyond tire composition.**
- **ABS equipped truck tractors can allow trailer swing under hard braking when towing non ABS equipped semi trailers.**

References

1) **National Transportation Safety Board, *Heavy Air brake Performance- Safety Study,* (NTSB/SS - 92/01)**

2) **Ronald B. Heusser, *Heavy Truck Deceleration Rates as a Function of Brake Adjustment,* SAE 910126, ISSN 0148-7191, 1991**

3) **Code of Federal Regulations, *Federal Motor Vehicle Safety Standards, 49 CFR, Part 571.121, Air Brake Standards,* U.S Government Printing Office**

4) **Code of Federal Regulations, *Federal Motor Carrier Safety Regulations, 49 CFR, Part 393.52 & Appendix G to Subpart B - Minimum Periodic Inspection Standards,* U.S Government Printing Office**

5) **Horn, Walter B.; *Highway Safety and Automobile / Truck Tire Friction Capability;* Joint ASTM F9 / E-17 Technical Program, Nittany Lion, State College, PA May 4, 1994**

6) **Commercial Carrier Journal, *The Air Brake Book, Fifth edition***

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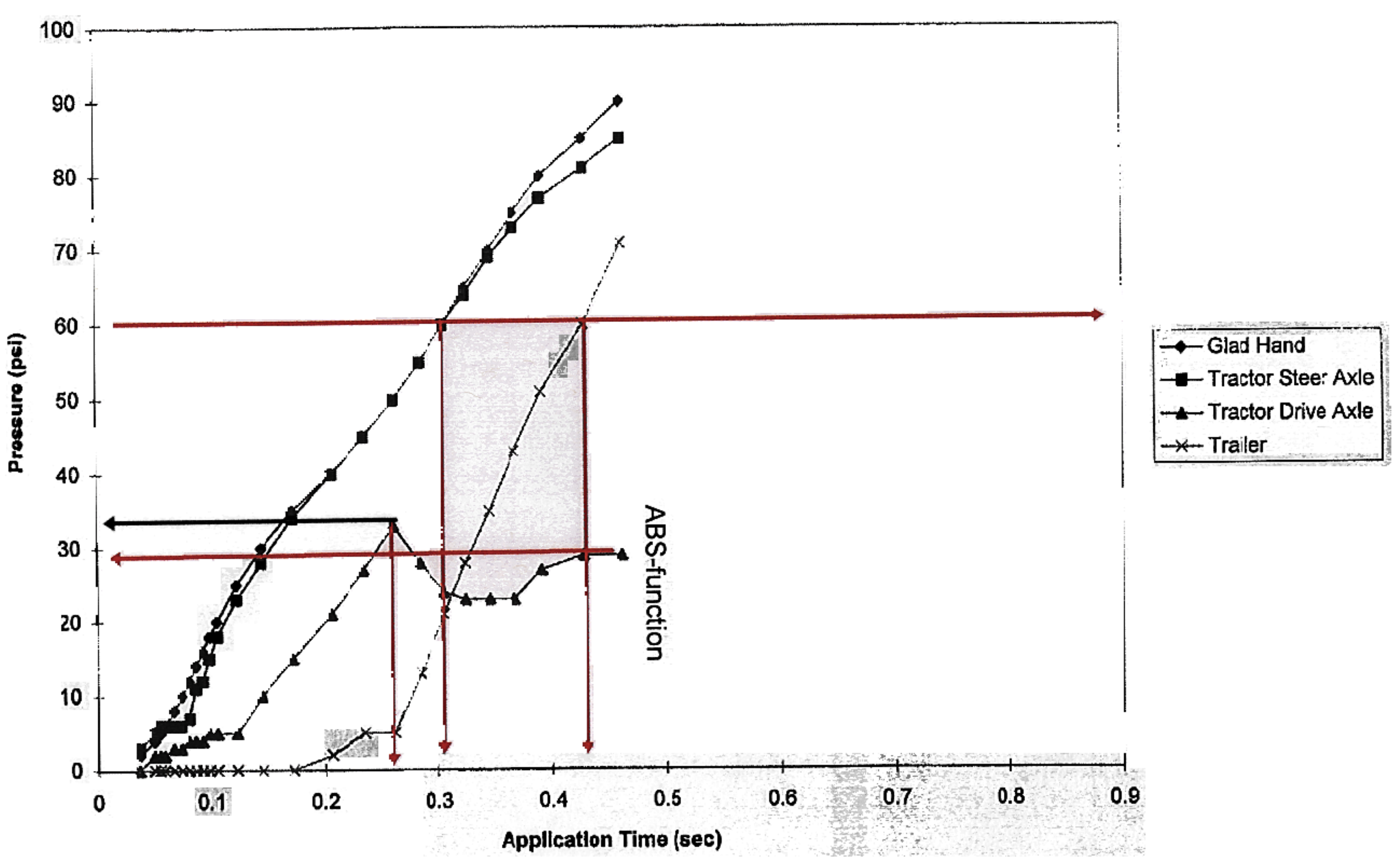
Presented at:

National Association of Traffic Accident Reconstructionists and Investigators Annual Conference, Allentown, PA, October, 1999.

WREX 2000 – World Reconstruction Exhibition. College Station, TX September, 2000

Dynamic Test--Unloaded

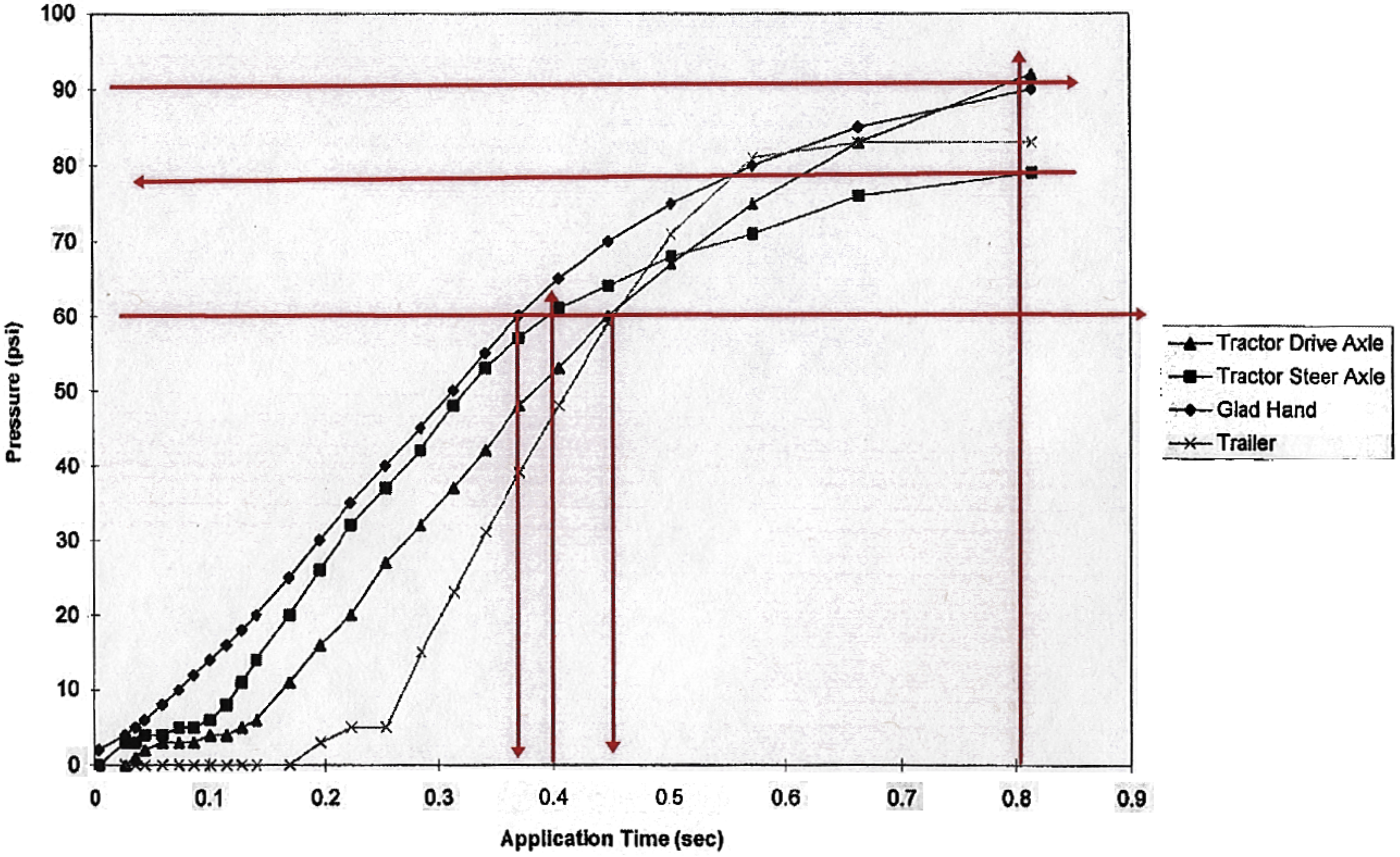


APPENDIX A

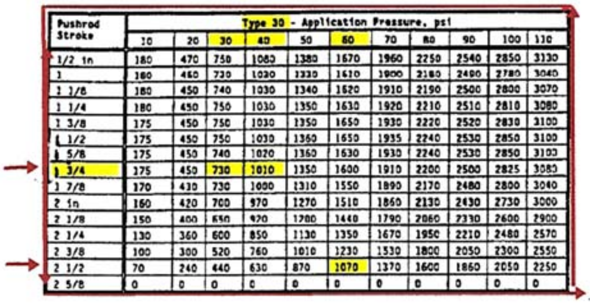
Advanced Commercial Vehicle Accident Investigation
TEEX--Bryan, TX

8/23/96

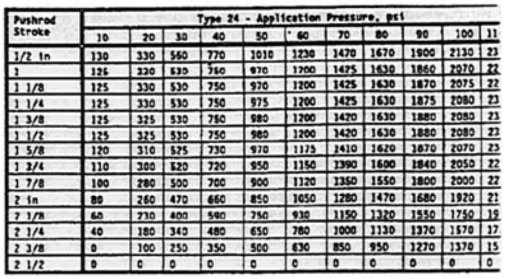
Dynamic Test--Loaded



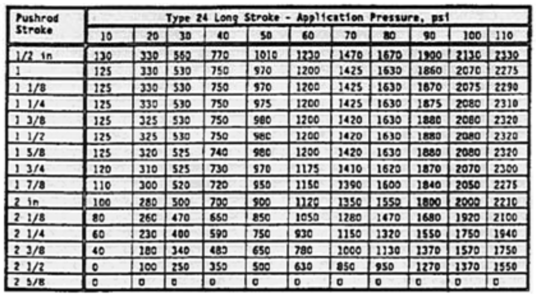
APPENDIX B



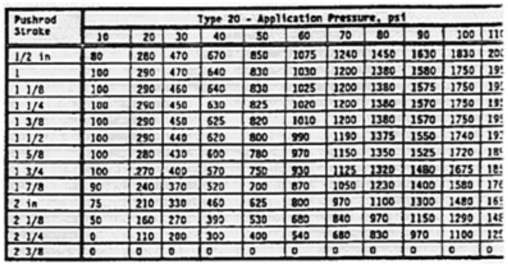
Pushrod Stroke	Type 30 - Application Pressure, psi										
	10	20	30	40	50	60	70	80	90	100	110
1/2 in	180	470	750	1080	1380	1670	1960	2250	2540	2850	3130
1	180	460	730	1030	1330	1610	1900	2180	2490	2780	3040
1 1/8	180	450	740	1030	1340	1620	1910	2190	2500	2800	3070
1 1/4	180	450	750	1030	1350	1630	1920	2210	2510	2810	3080
1 3/8	175	450	750	1030	1350	1650	1930	2220	2520	2830	3100
1 1/2	175	450	750	1030	1360	1650	1935	2240	2530	2850	3100
1 5/8	175	450	740	1020	1360	1630	1930	2240	2530	2850	3100
1 3/4	175	450	730	1010	1350	1600	1910	2200	2500	2825	3080
1 7/8	170	430	730	1000	1310	1550	1890	2170	2480	2800	3040
2 in	160	420	700	970	1270	1510	1860	2130	2430	2730	3000
2 1/8	150	400	650	920	1200	1440	1790	2060	2330	2600	2900
2 1/4	130	360	600	850	1130	1350	1670	1950	2210	2480	2570
2 3/8	100	300	520	760	1010	1230	1530	1800	2050	2300	2550
2 1/2	70	240	440	630	870	1070	1370	1600	1860	2050	2250
2 5/8	0	0	0	0	0	0	0	0	0	0	0



Pushrod Stroke	Type 24 - Application Pressure, psi										
	10	20	30	40	50	60	70	80	90	100	11
1/2 in	130	330	560	770	1010	1230	1470	1670	1900	2130	23
1	125	330	530	750	970	1200	1425	1630	1860	2070	22
1 1/8	125	330	530	750	970	1200	1425	1630	1870	2075	22
1 1/4	125	330	530	750	975	1200	1425	1630	1875	2080	23
1 3/8	125	325	530	750	980	1200	1420	1630	1880	2080	23
1 1/2	125	325	530	750	980	1200	1420	1630	1880	2080	23
1 5/8	120	310	525	730	970	1175	1410	1620	1870	2070	23
1 3/4	110	300	520	720	950	1150	1390	1600	1840	2050	22
1 7/8	100	280	500	700	900	1120	1350	1550	1800	2000	22
2 in	80	260	470	660	850	1050	1280	1470	1680	1920	21
2 1/8	60	230	400	590	750	930	1150	1320	1550	1750	19
2 1/4	40	180	340	480	650	780	1000	1130	1370	1570	17
2 3/8	0	100	250	350	500	630	850	950	1270	1370	15
2 1/2	0	0	0	0	0	0	0	0	0	0	0



Pushrod Stroke	Type 24 Long Stroke - Application Pressure, psi										
	10	20	30	40	50	60	70	80	90	100	110
1/2 in	130	330	560	770	1010	1230	1470	1670	1900	2130	2330
1	125	330	530	750	970	1200	1425	1630	1860	2070	2275
1 1/8	125	330	530	750	970	1200	1425	1630	1870	2075	2290
1 1/4	125	330	530	750	975	1200	1425	1630	1875	2080	2310
1 3/8	125	325	530	750	980	1200	1420	1630	1880	2080	2320
1 1/2	125	325	530	750	980	1200	1420	1630	1880	2080	2320
1 5/8	125	320	525	740	980	1200	1420	1630	1880	2080	2320
1 3/4	120	310	525	730	970	1175	1410	1620	1870	2070	2300
1 7/8	110	300	520	720	950	1150	1390	1600	1840	2050	2275
2 in	100	280	500	700	900	1120	1350	1550	1800	2000	2210
2 1/8	80	260	470	650	850	1050	1280	1470	1680	1920	2100
2 1/4	60	230	400	590	750	930	1150	1320	1550	1750	1940
2 3/8	40	180	340	480	650	780	1000	1130	1370	1570	1750
2 1/2	0	100	250	350	500	630	850	950	1270	1370	1550
2 5/8	0	0	0	0	0	0	0	0	0	0	0



Pushrod Stroke	Type 20 - Application Pressure, psi										
	10	20	30	40	50	60	70	80	90	100	11
1/2 in	80	280	470	670	850	1075	1240	1450	1630	1830	20
1	100	290	470	640	830	1030	1200	1380	1580	1750	19
1 1/8	100	290	460	640	830	1025	1200	1380	1575	1750	19
1 1/4	100	290	450	630	825	1020	1200	1380	1570	1750	19
1 3/8	100	290	450	625	820	1010	1200	1380	1570	1750	19
1 1/2	100	290	440	620	800	990	1190	1375	1550	1740	19
1 5/8	100	280	430	600	780	970	1150	1350	1525	1720	18
1 3/4	100	270	400	570	750	930	1125	1320	1480	1675	18
1 7/8	90	240	370	520	700	870	1050	1230	1400	1580	17
2 in	75	210	330	460	625	800	970	1100	1300	1480	16
2 1/8	50	160	270	390	530	680	840	970	1150	1290	14
2 1/4	0	110	200	300	400	540	680	830	970	1100	12
2 3/8	0	0	0	0	0	0	0	0	0	0	0

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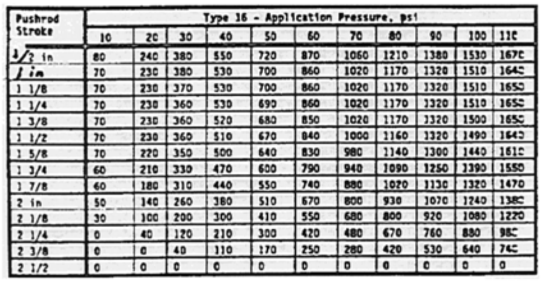
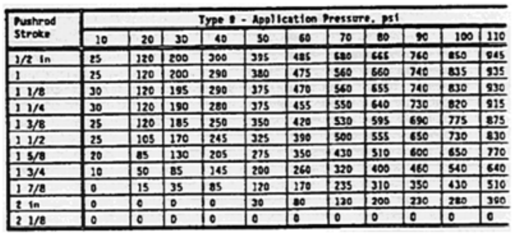
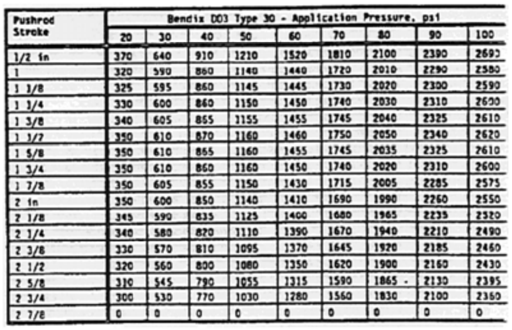


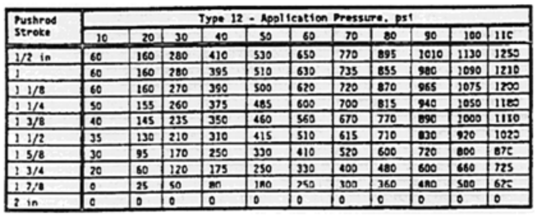
Pushrod Stroke	Type 16 - Application Pressure, psi										
	10	20	30	40	50	60	70	80	90	100	110
1/2 in	80	240	380	550	720	870	1060	1210	1380	1530	1670
1 in	70	230	380	530	700	860	1020	1170	1320	1510	1640
1 1/8	70	230	370	530	700	860	1020	1170	1320	1510	1650
1 1/4	70	230	360	530	690	860	1020	1170	1320	1510	1650
1 3/8	70	230	360	520	680	850	1020	1170	1320	1500	1650
1 1/2	70	230	360	510	670	840	1000	1160	1320	1490	1640
1 5/8	70	220	350	500	640	830	980	1140	1300	1440	1610
1 3/4	60	210	330	470	600	790	940	1090	1250	1390	1550
1 7/8	60	180	310	440	550	740	880	1020	1130	1320	1470
2 in	50	140	260	380	510	670	800	930	1070	1240	1380
2 1/8	30	100	200	300	410	550	680	800	920	1080	1220
2 1/4	0	40	120	210	300	420	480	670	760	880	980
2 3/8	0	0	40	110	170	250	280	420	530	640	740
2 1/2	0	0	0	0	0	0	0	0	0	0	0



Pushrod Stroke	Type 9 - Application Pressure, psi										
	10	20	30	40	50	60	70	80	90	100	110
1/2 in	25	120	200	300	395	485	580	665	760	850	945
1	25	120	200	290	380	475	560	660	740	835	935
1 1/8	30	120	195	290	375	470	560	655	740	830	930
1 1/4	30	120	190	280	375	455	550	640	730	820	915
1 3/8	25	120	185	250	350	420	530	595	690	775	875
1 1/2	25	105	170	245	325	390	500	555	650	730	830
1 5/8	20	85	130	205	275	350	430	510	600	650	770
1 3/4	10	50	85	145	200	260	320	400	460	540	640
1 7/8	0	15	35	85	120	170	235	310	350	430	510
2 in	0	0	0	0	30	80	130	200	230	280	390
2 1/8	0	0	0	0	0	0	0	0	0	0	0



Pushrod Stroke	Bendix DD3 Type 30 - Application Pressure, psi								
	20	30	40	50	60	70	80	90	100
1/2 in	370	640	910	1210	1520	1810	2100	2390	2690
1	320	590	860	1140	1440	1720	2010	2290	2580
1 1/8	325	595	860	1145	1445	1730	2020	2300	2590
1 1/4	330	600	860	1150	1450	1740	2030	2310	2600
1 3/8	340	605	865	1155	1455	1745	2040	2325	2610
1 1/2	350	610	870	1160	1460	1750	2050	2340	2620
1 5/8	350	610	865	1160	1455	1745	2035	2325	2610
1 3/4	350	610	860	1160	1450	1740	2020	2310	2600
1 7/8	350	605	855	1150	1430	1715	2005	2285	2575
2 in	350	600	850	1140	1410	1690	1990	2260	2550
2 1/8	345	590	835	1125	1400	1680	1965	2235	2520
2 1/4	340	580	820	1110	1390	1670	1940	2210	2490
2 3/8	330	570	810	1095	1370	1645	1920	2185	2460
2 1/2	320	560	800	1080	1350	1620	1900	2160	2430
2 5/8	310	545	790	1055	1315	1590	1865	2130	2395
2 3/4	300	530	770	1030	1280	1560	1830	2100	2360
2 7/8	0	0	0	0	0	0	0	0	0



Pushrod Stroke	Type 12 - Application Pressure, psi										
	10	20	30	40	50	60	70	80	90	100	110
1/2 in	60	160	280	410	530	650	770	895	1010	1130	1250
1	60	160	280	395	510	630	735	855	980	1090	1210
1 1/8	60	160	270	390	500	620	720	870	965	1075	1200
1 1/4	50	155	260	375	485	600	700	815	940	1050	1180
1 3/8	40	145	235	350	460	560	670	770	890	1000	1110
1 1/2	35	130	210	310	415	510	615	710	830	920	1020
1 5/8	30	95	170	250	330	410	520	600	720	800	870
1 3/4	20	60	120	175	250	330	400	480	600	660	725
1 7/8	0	25	50	80	180	250	300	360	480	500	620
2 in	0	0	0	0	0	0	0	0	0	0	0

Appendix C

Nat'l Highway Traffic Safety Admin., DOT § 571.121

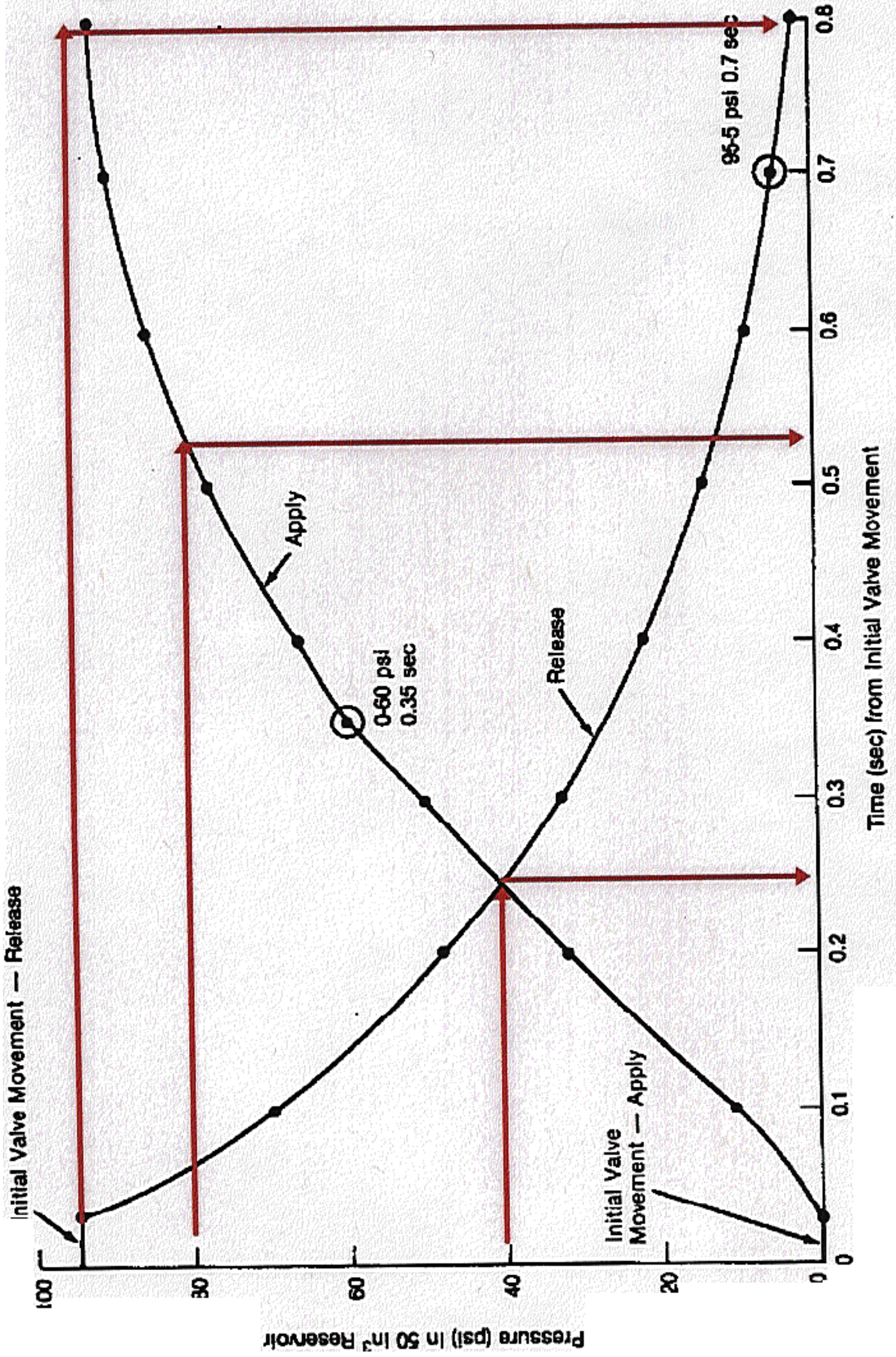


Figure 3. Pressure vs. Time for 50 in³ Test Reservoir.

395

APPENDIX D