



Rail Applications Design Guide



AIRAIL 0105

Firestone

World's Number 1
Air Spring.



FIRESTONE INDUSTRIAL PRODUCTS COMPANY





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PLEASE NOTE

The information contained in this publication is intended to provide a general guide to the characteristics and applications of these products. The material, herein, was developed through engineering design and development, testing and actual applications and is believed to be reliable and accurate.

However, Firestone makes no warranty, express or implied, of this information. Anyone making use of this material does so at his own risk and assumes all liability resulting from such use. It is suggested that competent professional assistance be employed for specific applications.

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HISTORY

In the early 1930's, the Firestone Tire and Rubber Company began experiments to develop the potential of pneumatic springs. In 1938, the country's largest manufacturer of motor coaches became interested in using air springs on a new design bus they were developing. Working with Firestone engineers, the first buses were tested in 1944 and the inherent ride superiority of air suspensions was clearly documented.

In the late 1940's, Firestone engineers, encouraged by the success of the bus application, turned their attention to the passenger rail market. They saw an opportunity to use an air spring in the secondary suspension of the rail truck or bogie. Working closely with rail truck manufacturers, the engineers at Firestone were able to perfect the double convoluted style of air spring for rail applications; consequently, this style became the standard for the next several years.

Development continued into other vehicular applications.

Firestone made huge in-roads into the automotive, heavy truck and trailer markets.

With the invention of the reversible style air spring, significant improvements were made to the performance of the air springs in these applications. Eventually the passenger rail car manufacturers desired the benefits of the reversible style air spring as well. Continuing in the spirit of joint development, Firestone worked with rail truck engineers to perfect and finalize a reversible style air spring system for rail applications.

Firestone Industrial Products continues to supply and develop convoluted and reversible style air springs to passenger rail markets all over the world.

ADVANTAGES

Passenger Comfort

Suspension systems designed with Airail™ springs provide a uniformly smooth ride for passenger comfort. The rail car is cushioned by air springs from the jolts and vibration experienced by the rail truck. By incorporating an auxiliary air reservoir, the frequency and spring rate characteristics of the air spring can be modified to the exact specifications of the suspension designer. Utilizing Firestone's extensive computer modeling programs, the effect of orifice damping can be determined for controlled shock absorption.

Constant Floor Height

With the use of a leveling system, the air springs can be used to keep the car floor at a constant height. When passengers enter, exit or change positions in the rail car, the air springs and leveling system are used to maintain a level floor during operation and at station platforms to insure passenger safety and comfort.

Performance Benefits

Due to the overall construction, air springs are virtually noise free and therefore are able to meet the demands of rail operators for noise reduction.

Another added benefit is a proven service life. Airail™ springs are constructed of highly engineered materials to reduce the effects of abrasion, heat build-up and ozone attack, making them capable of service life up to and exceeding ten years.



TERMS – AIR SPRINGS & SUSPENSIONS

PRESSURE & PROCESS TERMS

Absolute Pressure. The pressure in a vessel located in a complete vacuum. Usually determined by adding 14.7 pounds per square inch (psi) to the gauge pressure. Absolute pressure=gauge pressure+atmospheric pressure.

Adiabatic Process. All the calculation variables (volume, pressure, and temperature), change without any heat transfer (not often a real life situation).

Atmospheric Pressure. The average atmospheric air pressure measured at sea level. Normally accepted to be 14.7 pounds per square inch (psi).

Constant Volume With Airflow Process. Volume and temperature constant, pressure changes. This condition applies when load is added or removed from above the air spring over a period of time.

Gauge Pressure. Gas or liquid pressure in a vessel, which is higher than atmospheric pressure. Usually measured by a Bourdon tube gauge in pounds per square inch (psi).

Polytropic Process. All the calculation variables (volume, pressure, and temperature), change with heat transfer to the air spring structure. To account for this, air spring dynamic operation is calculated by the use of what is known as the polytropic exponent (n). $n=1.38$ is the generally accepted value for air springs.

AIR SPRING COMPONENT TERMS

Bead. A part of the flexible member that locks the cord structure to an inside reinforcing metal ring and provides a means of sealing the joint between the flexible member and the adjacent structure.

Bead Plate. A metal plate closing the top end of the flexible member. It is attached to the flexible member with a clamp ring. It has studs, blind nuts, brackets, or pins to facilitate its attachment to the vehicle structure. A means of supplying air to the assembly is provided as a separate fitting or in combination with an attachment stud. Convoluted type springs incorporate a second bead plate on the bottom to create an air tight unit and to provide a means of fastening the unit to the suspension.

Bead Ring. A metal ring incorporating a shaped cross-section that grips the bead of the flexible member and provides a means of attaching and sealing the bead to a plate or other structure.

Bead Skirt. A bead ring (see above description) that has a profile such that it controls the lateral movement of the spring. A bead skirt is used in reversible style air springs to give specific lateral spring rates as required by the car manufacturer.

Bumper. Usually, these are made of rubber, rubber and fabric, or steel and rubber materials. They are used to support the vehicle when there is no air in the air springs, when the vehicle is not in use, or when there is a system failure on the track. They will also, to some degree, cushion the shock of very severe axle force inputs to prevent damage to both the Airail™ spring assembly and to the vehicle.

Clamp Ring. A metal hoop that is used to secure a bead plate to the flexible member.

Flexible Member. The fabric-reinforced rubber component of the air spring assembly or component of the air spring.

Piston. A metal component of the air spring assembly usually placed at the lower end of the flexible member and used to both support and provide a surface for the flexible member to roll on. It also provides a means for attaching the assembly to the mounting surface. Pistons with tailored contours may be used to obtain air spring characteristics to meet special performance requirements.

AIR SPRING TERMS

Assembly. This includes the flexible member, which may include an upper bead plate, piston, or lower bead plate with an internal bumper. See illustration on pages 7-9.

Assembly Volume. The internal working air volume, exclusive of any external working volume.

Bumper Volume. The space taken up inside the air spring assembly by the bumper.

Compression Stroke (Jounce). The reduction in height from the normal design height of the spring as it cycles in dynamic operation.

Design Load. This is the normal maximum static load the air spring suspension is expected to support. It is the rated axle load divided by the number of air springs working with the axle and adjusted according to any suspension lever arm ratio incorporated.

Design Height. The overall height of the air spring as selected from the characteristics chart design position range. The air spring selected should provide for adequate jounce and rebound travel for the proposed suspension. The design height would be the starting position for calculating the spring and suspension dynamic characteristics.

Dynamic Force. The instantaneous supporting force developed by the air spring during vehicle motion. It is this constantly changing force that creates the spring rate, suspension rate, and in combination with the normal vehicle load on the spring, creates the suspension system's natural frequency.

Effective Area. The actual working area perpendicular to the output force of the spring. It is not the diameter of the spring. This working area, when multiplied by the gauge pressure in the spring, produces the correct output force. Conversely, dividing the measured output force of the spring by the measured internal gauge pressure obtains the correct effective area. In many cases, this is the only practical way to obtain it.

Extension Stroke (Rebound). The increase in height from the normal design height of the spring as it cycles in dynamic operation.

Reservoir Volume. Any working air volume located externally from the air spring assembly, but functioning with the spring.

SUSPENSION RELATED TERMS

Height Sensor. An electronic device that senses the position of a suspension or other mechanical device. The output signal from this device is sent to a control circuit which then exhausts or adds air to the air spring through a solenoid valve.

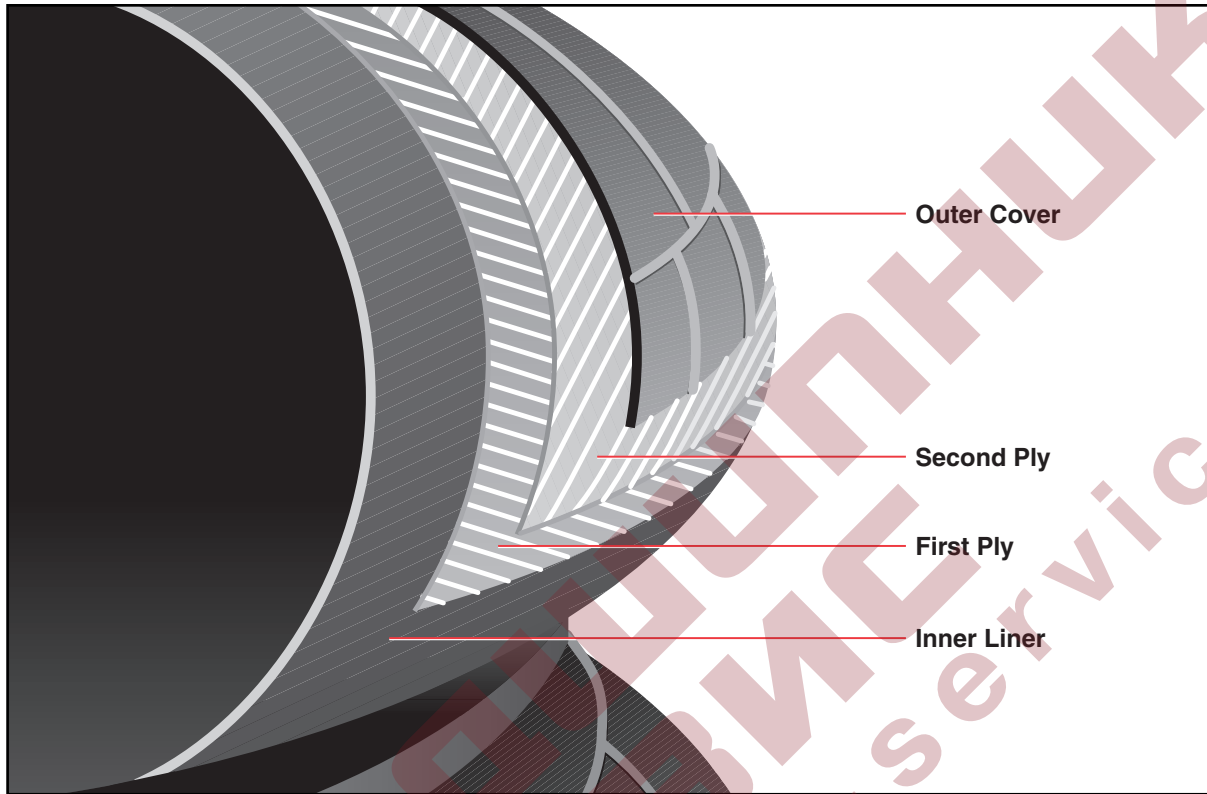
Leveling Valve. A pneumatic valve that senses the distance between the vehicle frame and the axle via a mechanical linkage which adds or exhausts air pressure to maintain a constant vehicle height.

Sprung Mass Natural Frequency. The speed of vertical oscillations of the suspended vehicle sprung mass. Can be expressed in cycles per minute (cpm) or cycles per second (hertz).

Sprung Mass (Weight). That part of the vehicle structure and cargo that is supported by the suspension.

Unsprung Mass. That part of the suspension that is not supported by the spring (e.g., axle wheels, air spring, etc.).

CONSTRUCTION OF AIR SPRINGS



FLEXIBLE MEMBER CONSTRUCTION

An air spring is a carefully designed rubber and fabric flexible member which contains a column of compressed air. The flexible member itself does not provide force or support load; these functions are performed by the column of air.

Firestone air springs are highly engineered elastomeric flexible members with specifically designed metal end closures. The two-ply version is made up of four layers:

- **Inner Liner.** An inner liner of calendared rubber.
- **First Ply.** One ply of fabric-reinforced rubber with the cords at a specific bias angle.
- **Second Ply.** A second ply of fabric-reinforced rubber with the same bias angle laid opposite that of the first ply.
- **Outer Cover.** An outer cover of calendared rubber.

Although the two-ply air spring is available, most Firestone air springs for rail applications are built with four-ply rated construction.

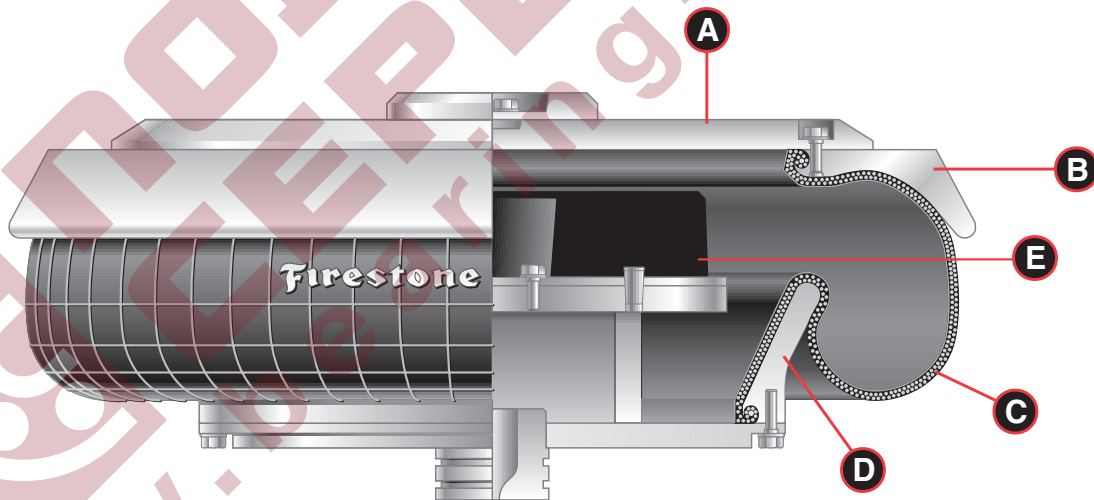
Each air spring's flexible member is identified by a style number, which is molded-in during the curing (vulcanization) process. Examples would be 29, 218, 1T60, etc. This identifies only the rubber/fabric flexible member . . . not the complete assembly.

STYLES OF AIR SPRINGS

REVERSIBLE STYLE AIR SPRING WITH BEAD SKIRT

- A Bead Plate.** A metal component, typically steel, plated for corrosion resistance, bolted to the bead skirt to create an airtight assembly that allows for leak testing before the unit leaves the factory.
- B Bead Skirt.** A metal component, typically aluminum, plated for corrosion resistance that is used to attach the flexible member to the bead plate and also to control the lateral movement of the spring.

- C Flexible Member.** See page 6 for flexible member construction information.
- D Piston.** A metal component, typically aluminum, plated for corrosion resistance whose profile, along with the bead skirt, can further influence the vertical and lateral characteristics of the spring per the designer's requirements.
- E Bumper.** An internal component made of rubber, rubber and fabric or rubber and steel that is used to prevent damage to the air spring or rail car during times when no air is in the system.



CONVOLUTED AIR SPRINGS – ROLLED PLATE ASSEMBLIES

Convoluted parts are available with bead rings or permanently attached plates called “rolled plates.” Rolled plate assemblies may offer an advantage over bead ring parts because installation is much easier.

When installing rolled plate parts, a backup plate, as large in diameter as the bead plate, must be used. This plate should be a minimum of .50” thick.

The blind nut and air entrance locations of rolled plate assemblies are available from Firestone.

A Air Inlet. 3/4” NPT is standard.

B Blind Nut. 1/2”-13 UNC thread x .75” deep.
Studs or pins can be used in place of blind nuts.

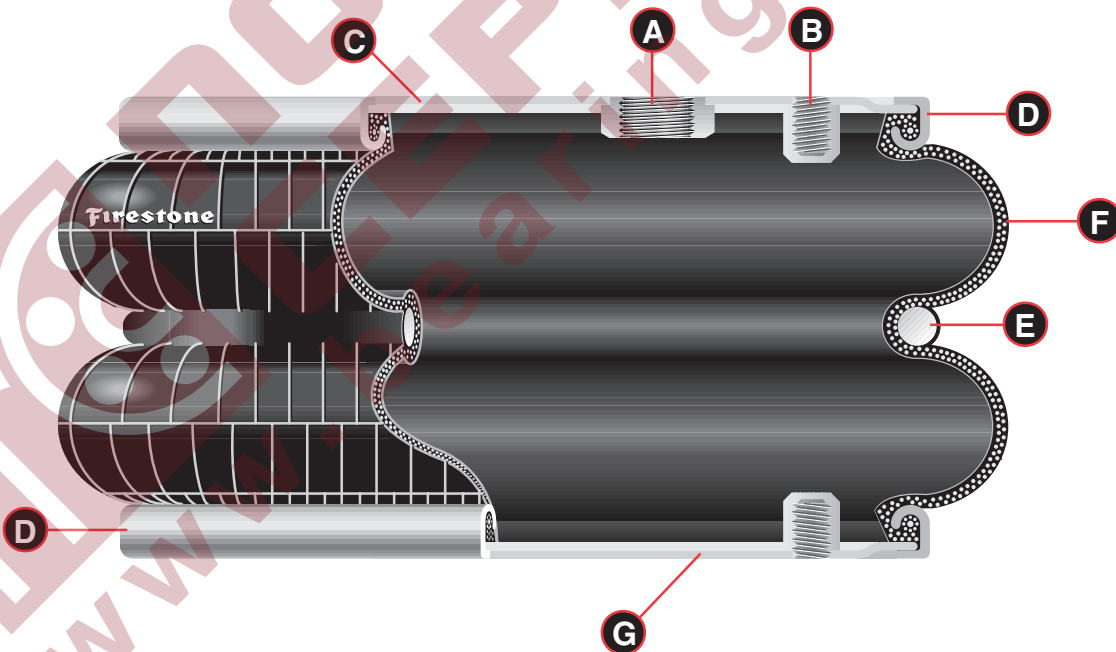
C Upper Bead Plate. 6-gauge (.194”) carbon steel, plated for corrosion resistance. Permanently attached to the flexible member with a clamp ring (D) to form an airtight assembly. Allows for leak testing before the assembly leaves the factory.

D Clamp Ring. This ring is crimped to the bead plate to permanently attach it to the flexible member. It is also plated for rust protection.

E Girdle Hoop. Solid type shown, molded into the flexible member between the convolutions.

F Flexible Member. See page 6 for flexible member construction information.

G Lower Bead Plate. Usually the same as the upper bead plate, except without the air inlet.



CONVOLUTED AIR SPRINGS – BEAD RING ASSEMBLIES

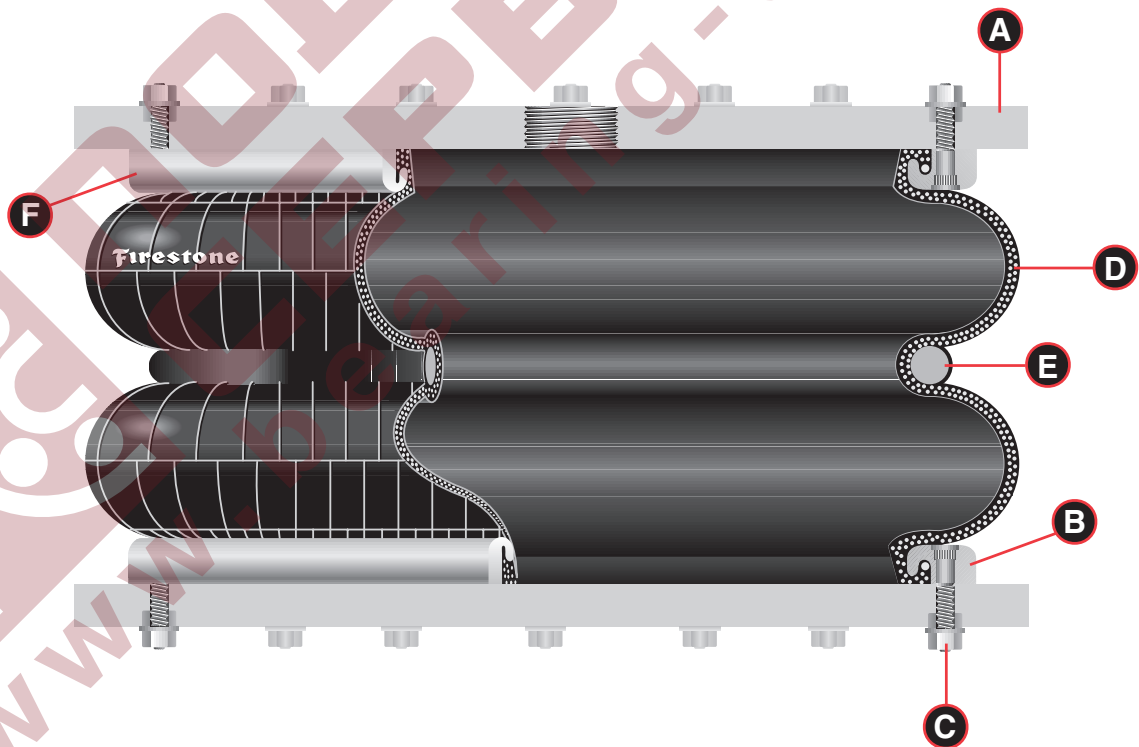
- A Mounting Plate.** Not included. See page 10 for material, machining recommendations and installation instructions.
- B Bead Ring Bolt.** Some assemblies may include one of three varieties included with air spring assemblies. See chart on page 10.
- C Nuts & Lock Washers.** Included with air spring assembly.
- D Flexible Member.** See page 6 for flexible member construction information.
- E Girdle Hoop.** Solid type shown, molded into the flexible member, between the convolutions.

- F Bead Ring.** Aluminum ribbed neck type shown. May also be of a second stamped steel variety or made of aluminum (see page 10).

SERVICE ASSEMBLY

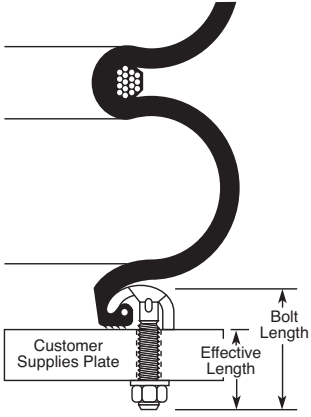
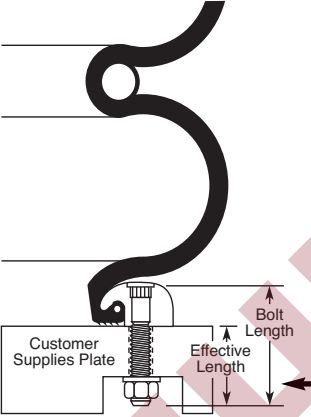
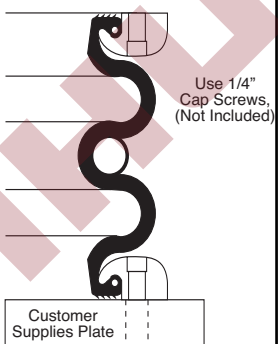
The flexible member is available separately as a replacement on convoluted bead ring assemblies.

Note: No convoluted bead ring assemblies are shown in the following product data sheets. All convoluted air springs shown are available in bead ring assemblies.



BEAD RINGS

THREE TYPES OF BEAD RINGS

STEEL COUNTERSUNK BEAD RING	ALUMINUM RIBBED NECK BEAD RING	ALUMINUM SOCKET HEAD BEAD RING*
		
Standard Bolt Length (in) 1%	Standard Bolt Length (in) 1%	Standard Bolt Length (in) 1 1/4
Standard Effective Length (in) 1.22	Standard Effective Length (in) 1.28	Optional Effective Length (in) 0.66
Standard Order Number (bolt only) WC1-358-3625	Standard Order Number (bolt only) WC1-358-3620	Optional Order Number (bolt only) WC1-358-3618
Thread 5/16-24UNF	Thread 3/8-24UNF	Thread 3/8-24UNF
Tightening Torque (ft-lb) 17 to 22	Tightening Torque (ft-lb) 28 to 32	Tightening Torque (ft-lb) 28 to 32

INSTALLING AIR SPRINGS WITH BEAD RINGS

When using bead rings, you will need to fabricate your own mounting plates. Hot or cold rolled steel provides satisfactory mounting surfaces with finishes of 250 micro inches, if machined in a circular fashion, or 32 micro inches when ground (side-to-side). The thickness of mounting plates depends upon the application. The plates must be strong enough and backed by structural members to prevent bowing of the plates when subjected to the forces or loads involved. The flexible member provides its own seal, so "O" rings or other sealants are not required.

INSTALLATION

Follow this technique for assembling a bead ring style flexible member to the mounting plate:

1. Insert the bolts into the bead ring, which has already been attached to the flexible member.
2. Slip all of the bolts, which protrude through the bead ring, into the mating holes of the mounting plate and attach the lock washers and nuts. Finger

tighten all nuts to produce a uniform gap between the bead ring and mounting plate all the way around. The bolts will be pulled into place by the action of tightening the nuts. When using *aluminum* bead rings, it may be necessary to lightly tap the ribbed neck bolts with a small hammer to engage the splined portion into the bead ring.

3. Make certain that the flexible member bead is properly seated under the bead ring. *Please note that uniform successive tightening of the nuts is important to seat the rubber bead properly to the mounting plate around its full circumference.*
4. Tighten all nuts one turn each, moving around the circle until continuous contact is made between the bead ring and mounting plate.
5. Torque all nuts to the torque specifications shown in the chart above, going at least two complete turns around the bolt circle.

Note: Consult Firestone for proper selection of bead ring type.

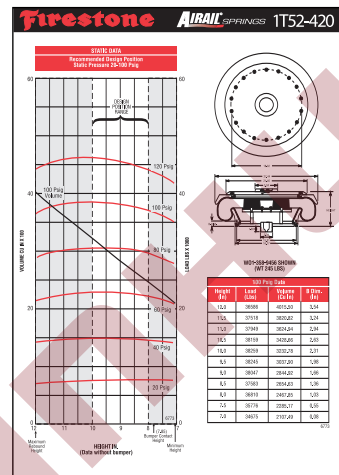
HOW TO USE THE PRODUCT DATA SHEETS

INTRODUCTION

This section is a guide to using the Product Data Sheets which Firestone Industrial Products Company publishes for Airail™ air springs.

These sheets show the mounting configuration, physical limitations and technical characteristics of the air spring. With this information, the suspension designer can accurately calculate the overall performance of an air suspension system.

The Product Data Sheets can also serve as a guide for selecting a particular air spring for a new suspension system.



A The part description is shown in the upper right corner.

B Bead plate diameter.

C Bead plate mounting arrangement.

D Bead skirt diameter, or on convoluted air spring data sheets, the maximum rubber part diameter at 100 psig and minimum height.

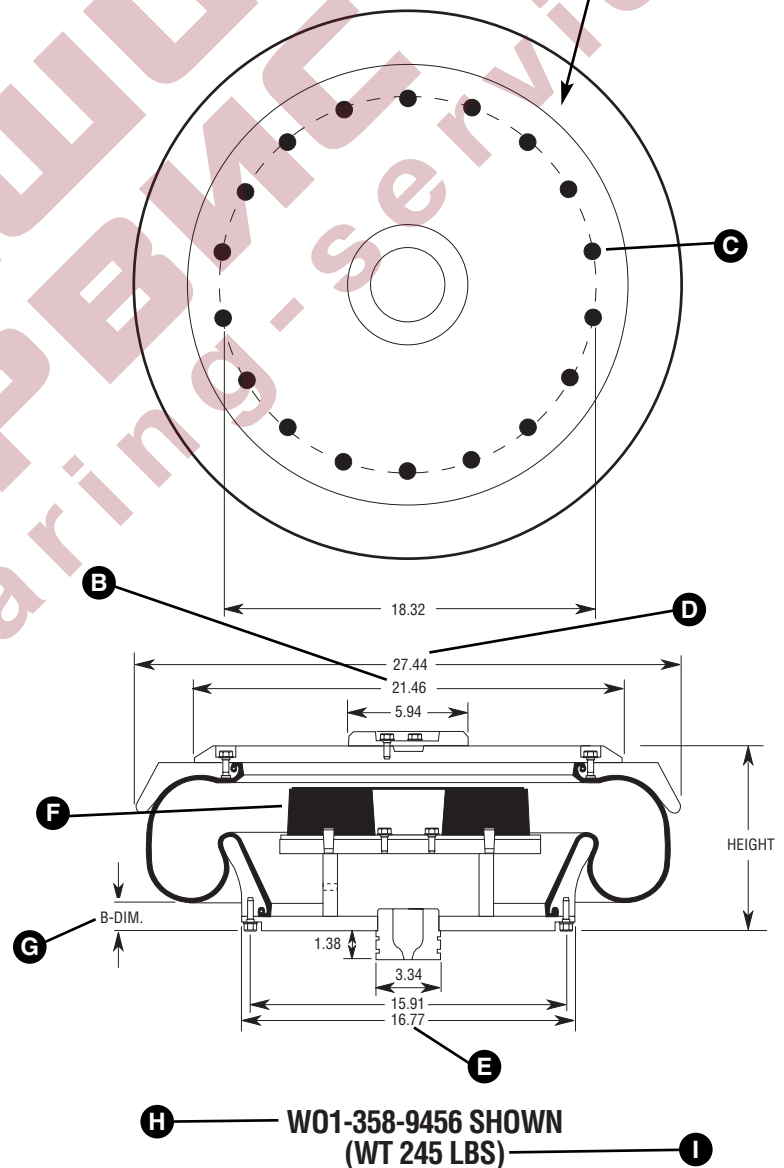
E Piston body diameter.

F Bumper.

G "B" dimension. The distance from the piston base mounting surface to the bottom of the loop of the flexible member.

H The assembly Order Number, W01-358-9456.

I Approximate weight of the assembly.

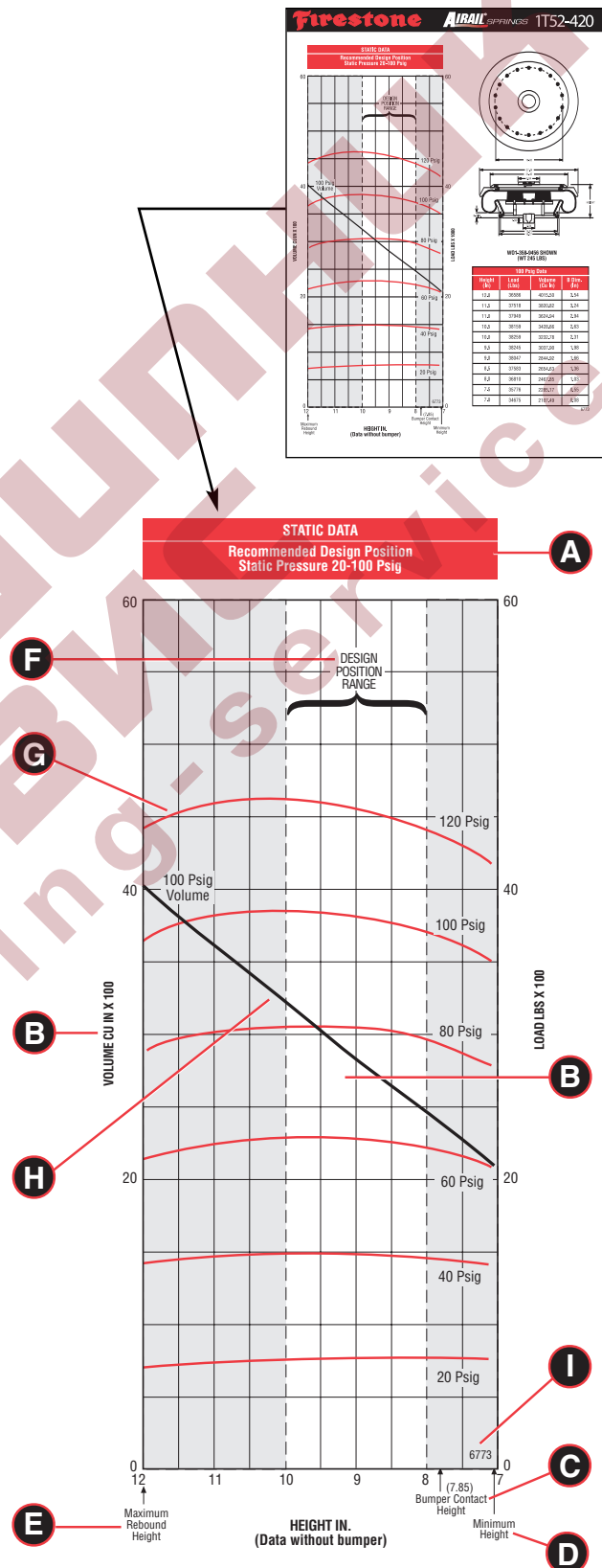


STATIC DATA CHART

This chart is referred to as the *Static Load Deflection Curve* for an air spring. The following parameters are displayed:

- A Recommended Design Position Static Pressure.** The recommended static operating pressure range is shown at the top of the chart. This is 20 to 100 psig for most air springs. The minimum pressure is required to prevent internal damage to the air spring.
- B** The **Load** is given on the right-hand axis vs. the air spring **Height** along the bottom axis. The internal **Volume** is also given along the left-hand axis vs. the **Height**.
- C** The **Bumper Contact** shows the compressed height of the air spring when the bead plate comes in contact with the internal bumper as shown on the air spring drawing.
- D** The **Minimum Height** shows the lowest compressed position of the air spring before internal contact. In many instances, an external positive stop may be required to prevent internal damage to the air spring.
- E** The **Maximum Rebound Height** is the maximum extended position of the air spring before the flexible member is put in tension. Some means of preventing the suspension extending the air spring past this height must be provided to prevent damage to the air spring. Shock absorbers are typically used, however chains, straps, and positive stops may also be used.
- F** The **Design Position Range** shows the recommended operating range of static heights. This range is 8 to 10 inches for the 1T52-420, as shown on the chart. Use outside range may be possible, however, Firestone should be consulted.
- G** The **Constant Pressure Curve** is the Load trace obtained as the part is compressed from the maximum height to the minimum height while maintaining a regulated constant pressure in the part. A series of constant pressure curves, 20 psig through 120 psig are shown at 20 psi increments. The 120 psig curve is shown for reference only, as most parts are limited to static design pressure of 100 psig.

(continued on page 13)



STATIC DATA CHART (continued)

- H** The **Volume Curve** is a plot of the data points obtained by measuring the volume of exhausted liquid as the part is compressed from maximum to minimum height while maintaining a regulated pressure of 100 psig in the air spring. (This is the volume without a bumper).
- I** The number, 6773, is the **Test Request Reference Number**.

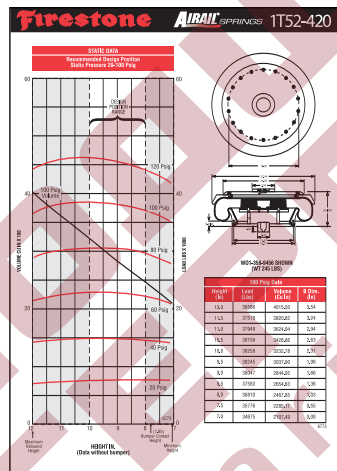
100 PSIG DATA TABLE

This is a table of static data on the 100 psig constant pressure curve with loads, volumes and "B" dimensions shown.

The Static Data Table contains the following information:

- Height at each .50" increment.
- Load at each .50" increment.
- Volume at each .50" increment.
- "B" dimension (the distance from the piston base mounting surface to the bottom of the loop of the flexible member) at each .50" increment.

All data is calculated without a bumper.



100 Psig Data			
Height (in)	Load (lbs)	Volume (in³)	B Dim. (in)
17.00	30715	4263.80	
16.50	31183	4109.72	7.32
16.00	31666	3951.81	7.04
15.50	32062	3790.89	6.79
15.00	32317	3627.78	6.46
14.50	32412	3463.29	6.15
14.00	32345	3298.24	5.80
13.50	32122	3133.45	5.48
13.00	31753	2969.72	5.12
12.50	31243	2807.89	4.71
12.00	30600	2648.76	4.38
11.50	29834	2493.14	4.00
11.00	28965	2341.86	3.62
10.50	28036	2195.73	3.25
10.00	27124	2055.56	2.90

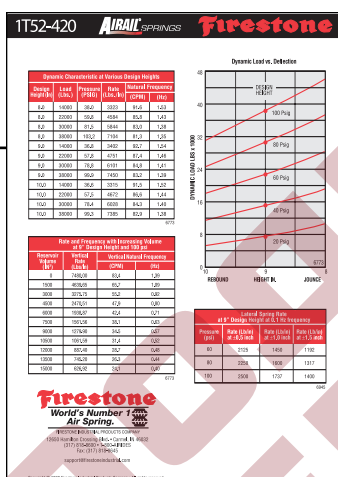
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DYNAMIC CHARACTERISTICS TABLE

The Dynamic Characteristics Table consists of the following calculated characteristics:

- Data for three design heights within the design position range: minimum, midrange and maximum.
- Four loads at each design height.
- Pressure, Rate, and Frequency for each design height and load condition.

All data is calculated without a bumper.

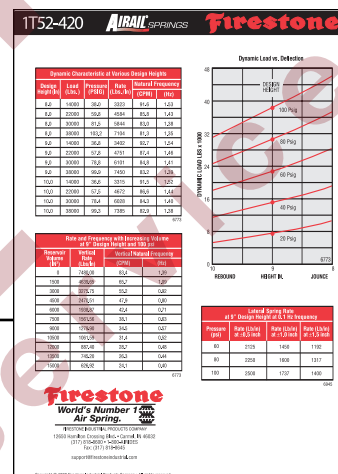


RATE AND FREQUENCY WITH INCREASING VOLUME

This chart shows the change in the air spring's vertical rate and natural frequency with the addition of external reservoir volume.

The data is calculated at a mid-range design height and at 100 psig internal volume.

All data is calculated without a bumper.



Dynamic Characteristic at Various Design Heights					
Design Height (in)	Load (lbs)	Pressure (psig)	Rate (lbs/in)	Natural Frequency	
				(CPM)	(Hz)
8.00	14000	38.0	3323	91.6	1.53
8.00	22000	59.8	4584	85.8	1.43
8.00	30000	81.5	5844	83.0	1.38
8.00	38000	103.2	7104	91.3	1.35
9.00	14000	36.8	3402	92.7	1.54
9.00	22000	57.8	4751	87.4	1.46
9.00	30000	78.8	6101	84.8	1.41
9.00	38000	99.9	7450	83.2	1.39
10.00	14000	36.6	3315	91.5	1.52
10.00	22000	57.5	4672	86.6	1.44
10.00	30000	78.4	6028	84.3	1.40
10.00	38000	99.3	7385	82.9	1.38

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Rate and Frequency with Increasing Volume at 9" Design Height and 100 psi			
Reservoir Volume (in³)	Vertical Rate (lbs/in)	Vertical Natural Frequency	
		(CPM)	(Hz)
0	7480.00	83.4	1.39
1500	4639.65	65.7	1.09
3000	3275.75	55.2	0.92
4500	2470.51	47.9	0.80
6000	1938.87	42.4	0.71
7500	1561.56	38.1	0.63
9000	1279.90	34.5	0.57
10500	1061.59	31.4	0.52
12000	887.40	28.7	0.48
13500	745.20	26.3	0.44
15000	626.92	24.1	0.40

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DYNAMIC LOAD VS. DEFLECTION CHART

This chart shows the variation in **Dynamic Load vs. Deflection** for the 1T52-420.

The curves are obtained by extending (rebound) or compressing (jounce) the air spring with captured air.

The *starting* point for each curve is at a design height of 9 inches, which is the mid-design position, and *starting* pressures of 20, 40, 60, 80 and 100 psig.

As you can see on the DYNAMIC LOAD axis, the load is approximately 38,000 lb at the design height of 9 inches and pressure of 100 psig.

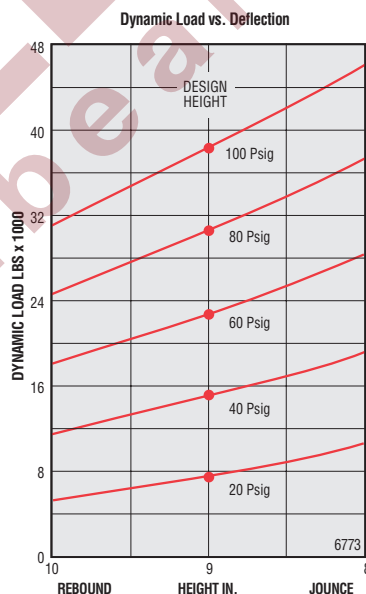
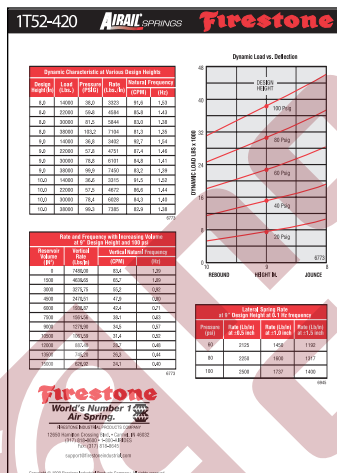
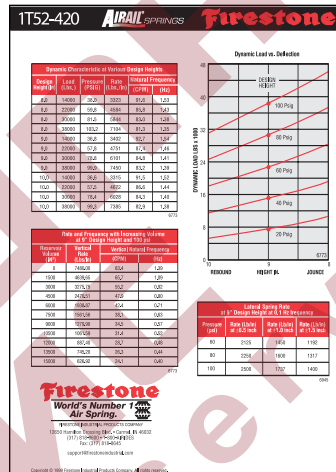
When the air spring is compressed one inch to an 8 inch height, the load increases to approximately 46,000 lb, (with a corresponding increase in pressure to 125 psig).

When the air spring is extended one inch to a 10 inch height, the load is reduced to 31,000 lb, (with a corresponding reduction in pressure to 78 psig).

LATERAL SPRING RATE

This chart shows the calculated lateral spring rate of the air spring.

The lateral rates are calculated at a mid-range design height and an input frequency of 0.1 Hz.



Lateral Spring Rate at 9" Design Height & 0.1 Hz frequency			
Pressure (psi)	Rate (lbs/in) at ± 0.5 in	Rate (lbs/in) at ± 1.0 in	Rate (lbs/in) at ± 1.5 in
60	2125	1450	1192
80	2250	1600	1317
100	2500	1737	1400

6945

FASTENER TIGHTENING SPECIFICATIONS

Description	Size	Torque (ft-lb)
• Bead ring nuts on bolts	$\frac{5}{16}$ -24	17-22
• Bead ring bolts and nuts	$\frac{3}{8}$ -24	28-32
• Bolts in blind nuts in bead plates	$\frac{3}{8}$ -16	15-20
• End of adapter studs in blind nut	$\frac{3}{8}$ -16	15-20
• Nut on end of adapter studs	$\frac{1}{2}$ -13	25-30
• Studs on bead plates or blind nuts	$\frac{1}{2}$ -13 or $\frac{1}{2}$ -20	25-30
• Bolt to attach piston base to lower mounting surface	$\frac{1}{2}$ -13	25-30
• Nut on air entrance stud	$\frac{3}{4}$ -16	40-45
• NPT air supply fitting	$\frac{1}{4}$ & up	17-22
• Nut on end closure lower mounting	$\frac{3}{4}$ -10	45-50

OPERATIONAL CAUTIONS

Air spring failure can be caused by a variety of situations, including internal or external rubbing, excessive heat and overextension.

TEMPERATURE RANGE

The normal ambient operating temperature range for standard vehicular air springs is -65°F to +135°F.

BUMPERS

In general, bumpers are used to support the vehicle weight to prevent damage to the flexible member during times when no air is in the system. In applications that require frequent bumper contact, consult Firestone. There are a variety of bumpers available for use in Airail™ springs. Firestone has developed a line of progressive springs under the trade name Marsh Mellow™. These springs have been used extensively in rail springs because of their unique performance characteristics. Due to the Marsh Mellow™ spring's greater deflection capabilities and load carrying influences of the fabric reinforcement, it can carry a greater load when compared to an all rubber part of the same modulus and dimensions.

Firestone also offers molded rubber bumpers that are manufactured by Firestone along with the Marsh Mellow™ springs, if required bumpers can be purchased from outside vendors for use inside the Airail™ springs.

INTRODUCTION

The fundamental concept of an air spring is a mass of air under pressure in a vessel arranged so that the pressure exerts a force. The amount of static force developed by the air spring is dependent on the internal pressure and the size and configuration of the vessel. The vessel is defined in this manual as the Airrail™ spring by Firestone or air spring.

Dynamic force is the result of internal pressure changes and air spring effective area changes as height decreases (compresses) or increases (extends).

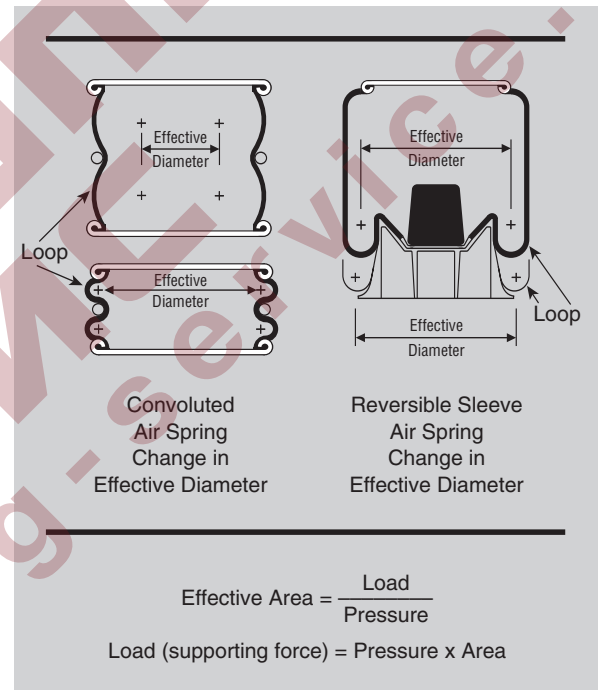
The amount of pressure change for a stroke depends on volume change compared to total volume at equilibrium position. For the convoluted type, effective area change for a stroke depends on where in the total travel range the motion takes place. For the reversible sleeve type, the shape of the piston, size of the piston related to the flexible member diameter, and cord angle built into the flexible member all have an influence on effective area.

The effective area can be arrived at by taking the longitudinal static force developed at a specified assembly height and dividing this force by the internal pressure (psig) existing in the air spring at that height. This method is used to develop the static effective areas used in dynamic rate and frequency calculations.

EFFECTIVE AREA

Effective area is the load carrying area of the air spring. Its diameter is determined by the distance between the centers of the radius of curvature of the flexible member loop. The loop always approximates a circle because the internal air pressure is acting uniformly in all directions, so that only the area inside the centers is vertically effective. For a convoluted air spring, the effective area increases in compression and decreases on extension. For a reversible sleeve air spring, the effective area is constant while operating on the straight side of the piston, increases when working on the flare of the piston in compression, and decreases when the rubber part lifts off the piston in extension.

When a vehicle having air springs in its suspension is at rest, and then load is added or removed, the height control valve operates to add or remove sufficient air in the air spring to maintain the set air spring overall height. This then increases or decreases the pressure in the air spring the amount needed to provide the required lifting force to match the current downward force created by the new load condition, and equilibrium is again reached.



SPECIAL CHANGES OF STATE FOR IDEAL GASES

Non-flow process, specific heats assumed constant. Subscripts 1 and 2 refer to the initial and final states, respectively.

P = Absolute Pressure
T = Absolute Temperature
V = Total Volume

1 Constant Volume (Isochoric)

$$\frac{P_2}{P_1} = \frac{T_2}{T_1}$$

This is an unattainable process due to the nature of the flexible member; however, at static conditions, the change in pressure may be calculated for a change in temperature.

2 Constant Pressure (Isobaric)

$$\frac{V_2}{V_1} = \frac{T_2}{T_1}$$

Dynamically, the only way to maintain constant pressure is in combination with infinite volume and is generally not useful.

3 Constant Temperature (Isothermal)

$$\frac{P_2}{P_1} = \frac{V_2}{V_1}$$

This requires very slow movements not normally applicable to air spring operation.

4 Reversible Adiabatic (Isentropic)

$$P_1 V_1^k = P_2 V_2^k$$

And:

$$\frac{T_2}{T_1} = \left(\frac{V_2}{V_1}\right)^{k-1} = \left(\frac{P_2}{P_1}\right)^{(k-1)/k}$$

This is defined as a process with no heat transferred to or from the working fluid. This is a

theoretical process not attainable with pneumatic springs, however, for rapid deflections, it is closely approached. $k=1.404$ for air.

5 Polytropic

$$PV^n = \text{Constant}$$

This process usually represents actual expansion and compression curves for pressures up to a few hundred pounds. Assuming the specific heat of the gas is constant, "n" may be changed for special cases of the polytropic process.

Thus for:

$n = 1$, $PV = \text{Const.}$ (Isothermal)
 $n = k$, $PV^k = \text{Const.}$ (Isentropic)
 $n = 0$, $P = \text{Const.}$ (Constant Pressure)
 $n = \infty$, $V = \text{Const.}$ (Constant Volume)

The principal formulas for air compression up to a few hundred pounds pressure where $1 < n < k$ are:

6 Reversible Adiabatic (Isentropic)

$$P_1 V_1^n = P_2 V_2^n$$

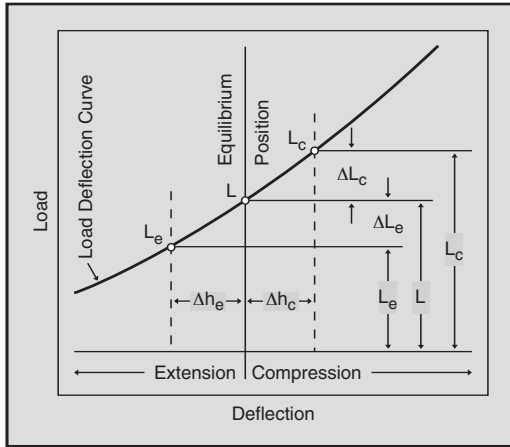
And:

$$\frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{n-1} = \left(\frac{P_2}{P_1}\right)^{(n-1)/n}$$

During air spring dynamic operation, the pressure, volume and temperature change instantaneously. The air spring flexible member structure also changes depending upon the specific configuration. As a result, air springs operate in the range $1 < n < k$, however, a generally acceptable value for "n" is 1.38 for normal vehicle operation.

Note: Red boxes are used to designate important formulas.

DYNAMIC AIR SPRING RATE



Rate is the slope of the tangent at the equilibrium position. For small increments of deflection, rate equals the load change per unit deflection.

(The slope of the chord line through L_c and L_e is parallel to the tangent at L for small deflections.)

$$[1] K = (L_c - L_e) / (\Delta h_c + \Delta h_e)$$

Where:

K = Rate (Load per unit deflection)

L_c = Load at compression travel

L_e = Load at extension travel

Δh_c = Height change, compression

Δh_e = Height change, extension

$$[2] \begin{aligned} L_c &= P_{gc}(A_c) \\ L_e &= P_{ge}(A_e) \end{aligned}$$

Where:

P_{gc} = Gauge Pressure at L_c

P_{ge} = Gauge Pressure at L_e

A_c = Effective area at L_c

A_e = Effective area at L_e

substituting [2] in [1] and setting $\Delta h_c = \Delta h_e = .5$ inch

$$[3] K = P_{gc}(A_c) - P_{ge}(A_e)$$

$$[4] \begin{aligned} P_{gc} &= P_{ac} - 14.7 \\ P_{ge} &= P_{ae} - 14.7 \end{aligned}$$

Where:

P_{ac} = Absolute Pressure at L_c

P_{ae} = Absolute Pressure at L_e

14.7 = Atmospheric Pressure in pounds per in²

$$[5] \text{ Now using the polytropic gas law and } n=1.38$$

$$P_{ac} = P_{a1} \left(\frac{V_1}{V_c} \right)^{1.38}$$

$$P_{ae} = P_{a1} \left(\frac{V_1}{V_e} \right)^{1.38}$$

Where:

P_{a1} = Absolute Pressure at equilibrium position

V_1 = Volume at equilibrium position

V_c = Volume at L_c

V_e = Volume at L_e

substituting [5] in [4]

$$[6] P_{gc} = P_{a1} \left(\frac{V_1}{V_c} \right)^{1.38} - 14.7$$

$$P_{ge} = P_{a1} \left(\frac{V_1}{V_e} \right)^{1.38} - 14.7$$

substituting [6] in [3]

$$[3] K = P_{gc}(A_c) - P_{ge}(A_e)$$

$$[7] K = \left[P_{a1} \left(\frac{V_1}{V_c} \right)^{1.38} - 14.7 \right] A_c - \left[P_{a1} \left(\frac{V_1}{V_e} \right)^{1.38} - 14.7 \right] A_e$$

Then, grouping terms, this becomes the general rate formula for air springs.

$$[8] K = P_{a1} \left[A_c \left(\frac{V_1}{V_c} \right)^{1.38} - A_e \left(\frac{V_1}{V_e} \right)^{1.38} \right] - 14.7(A_c - A_e)$$

NATURAL FREQUENCY

Since the air spring has a variable rate and essentially a constant frequency, it is helpful to calculate the natural frequency when evaluating characteristics.

When considering a single-degree-of-freedom system (undamped), the classical definition of frequency is as follows:

Note: The period of free vibration (which is the reciprocal of frequency) is the same as the period of a mathematical pendulum, the length of which is equal to the static deflection of the spring under the action of load W.

$$f = \frac{\omega}{2\pi} \text{ and } \omega^2 = \frac{K}{m}$$

Where:

f = Frequency, cycles per second
 ω = Circular frequency, radians per second
 K = Rate, pounds per inch
 m = Mass, pound seconds² per inch

Then:

$$f = \frac{\sqrt{\frac{K}{m}}}{2\pi} = \frac{1}{2\pi} \sqrt{\frac{K}{m}}$$

Also:

$$m = \frac{W}{g}$$

Where:

W = Weight, pounds
 g = Acceleration of gravity, 386 inches per second²

Substituting:

$$f = \frac{1}{2\pi} \sqrt{\frac{Kg}{W}} = \frac{\sqrt{386}}{2\pi} \sqrt{\frac{K}{W}} \text{ cps}$$

$$f = \frac{60 \sqrt{386}}{2\pi} \sqrt{\frac{K}{W}} \text{ cpm}$$

This is normally rounded to:

$$f = 188 \sqrt{\frac{K}{W}} \text{ cpm}$$

Where:

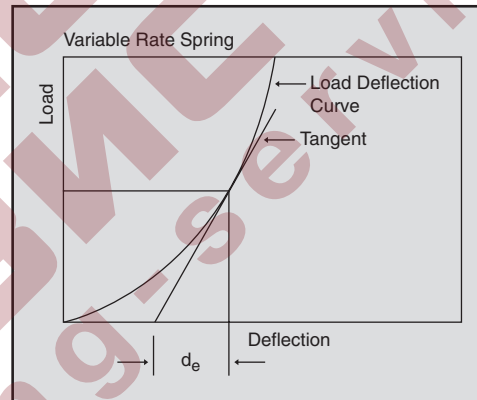
K = Rate
 W = Weight (load)

Also since:

$$\frac{W}{K} = d_e \text{ (effective deflection)}$$

$$f = \frac{188}{\sqrt{d_e}} \text{ cpm}$$

Effective deflection (d_e) has no physical significance, however, it has mathematical meaning. It is defined as load divided by rate and is graphically explained below.



$$d_e = \frac{\text{Load}}{\text{Rate}}$$

$$\text{Load} = \text{Rate} \times d_e$$

Note: For a constant rate spring, d_e and the deflection from free height are equal.

SUMMARY OF IMPORTANT FORMULAS

Polytropic Gas Law

$$P_1 V_1^n = P_2 V_2^n$$

Dynamic Air Spring Rate

$$K = P_{a1} \left[A_c \left(\frac{V_1}{V_c} \right)^{1.38} - A_e \left(\frac{V_1}{V_e} \right)^{1.38} \right] - 14.7(A_c - A_e)$$

Natural Frequency

$$f = 188 \sqrt{\frac{K}{W}} = \frac{188}{\sqrt{d_e}} \text{ cpm}$$

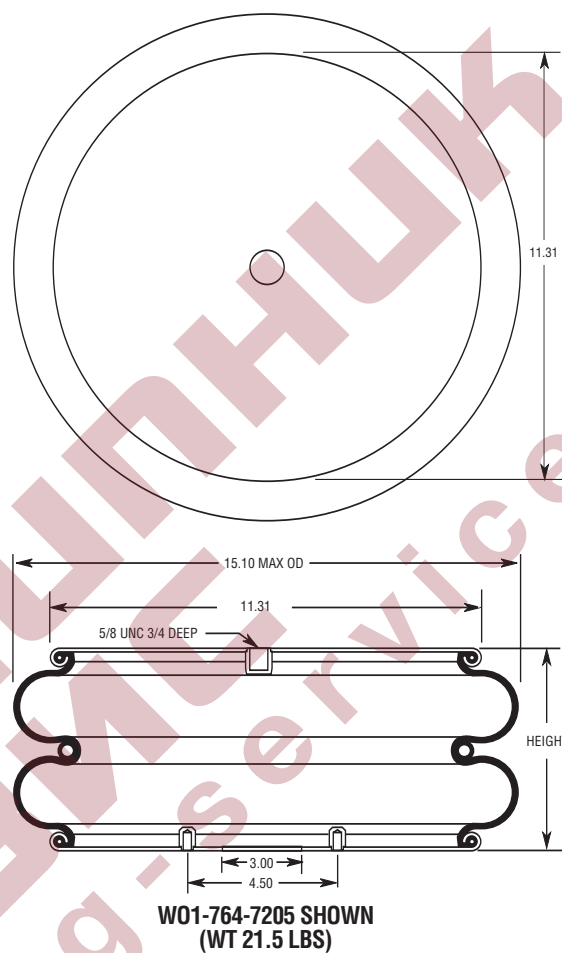
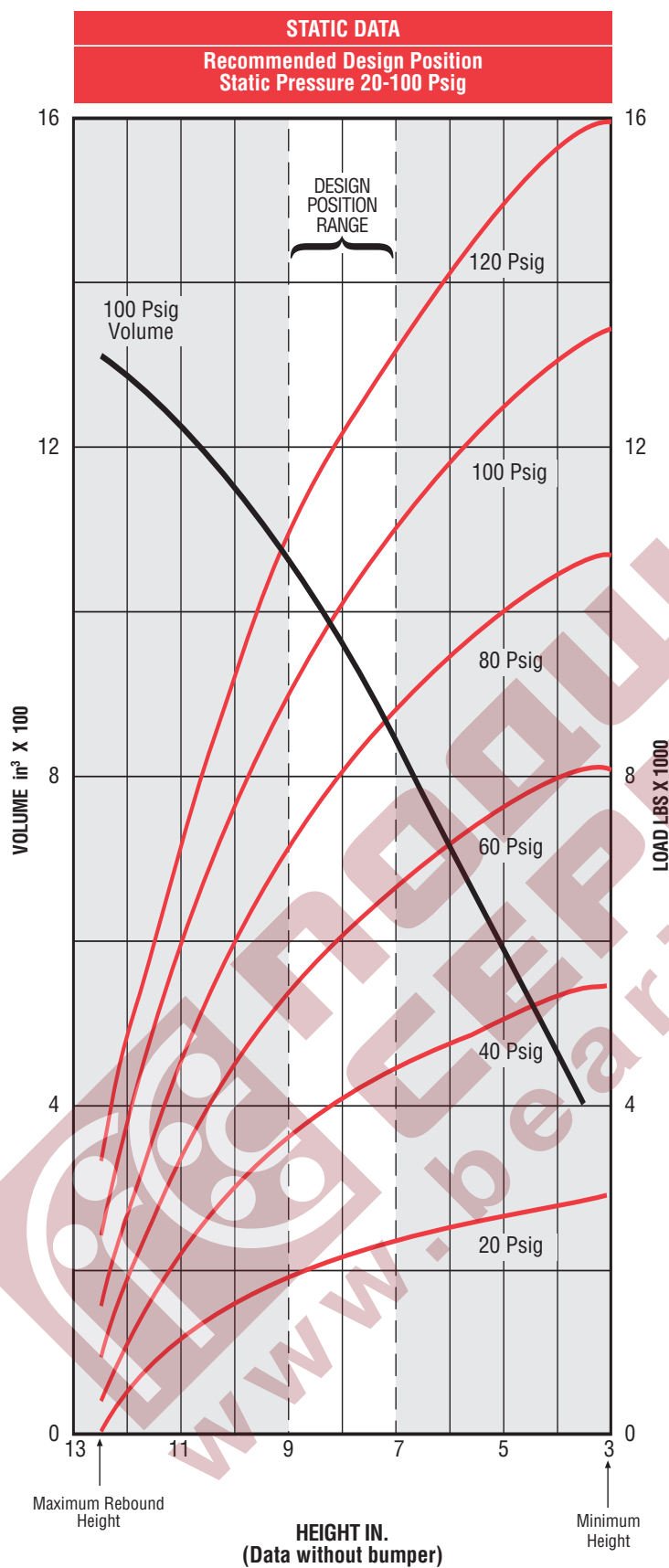
TECHNICAL DATA SHEETS

Firestone

*World's Number 1
Air Spring.*



FIRESTONE INDUSTRIAL PRODUCTS COMPANY



100 Psig Data		
Height (in)	Load (lbs)	Volume (in ³)
12.50	2222	1304.47
12.00	3571	1279.87
11.50	4790	1250.87
11.00	5879	1217.88
10.50	6840	1181.08
10.00	7684	1140.69
9.50	8422	1096.99
9.00	9067	1050.09
8.50	9636	1000.30
8.00	10142	947.81
7.50	10602	892.91
7.00	11028	835.72
6.50	11430	776.62
6.00	11815	715.73
5.50	12183	653.33
5.00	12531	589.74
4.50	12847	524.95
4.00	13113	459.35
3.50	13300	393.26

9914

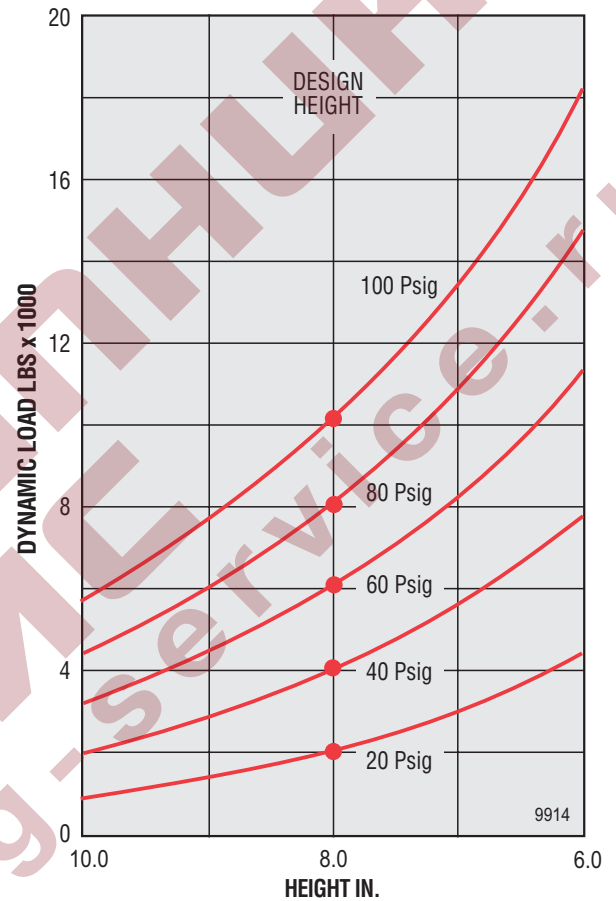
Dynamic Characteristic at Various Design Heights					
Design Height (in)	Load (lbs)	Pressure (psig)	Rate (lbs/in)	Natural Frequency	
				(CPM)	(Hz)
7.00	4000	36.3	1393	110.9	1.85
7.00	6000	54.4	1931	106.7	1.78
7.00	8000	72.5	2470	104.5	1.74
7.00	10000	90.7	3009	103.1	1.72
8.00	4000	39.4	1248	105.0	1.75
8.00	6000	59.2	1754	101.6	1.69
8.00	8000	78.9	2260	99.9	1.67
8.00	10000	98.6	2766	98.9	1.65
9.00	4000	44.1	1218	103.8	1.73
9.00	6000	66.2	1742	101.3	1.69
9.00	8000	88.2	2266	100.1	1.67
9.00	10000	110.3	2790	99.3	1.66

9914

Rate and Frequency with Increasing Volume at 8.0" Design Height and 100 psi			
Reservoir Volume (in³)	Vertical Rate (lbs/in)	Vertical Natural Frequency	
		(CPM)	(Hz)
0	2782.73	98.5	1.64
500	2162.41	86.8	1.45
1000	1853.65	80.4	1.34
1500	1671.64	76.3	1.27
2000	1551.60	73.5	1.23
2500	1466.47	71.5	1.19
3000	1402.96	69.9	1.17
3500	1353.75	68.7	1.14
4000	1314.51	67.7	1.13
4500	1282.48	66.9	1.11
5000	1255.84	66.2	1.10

9914

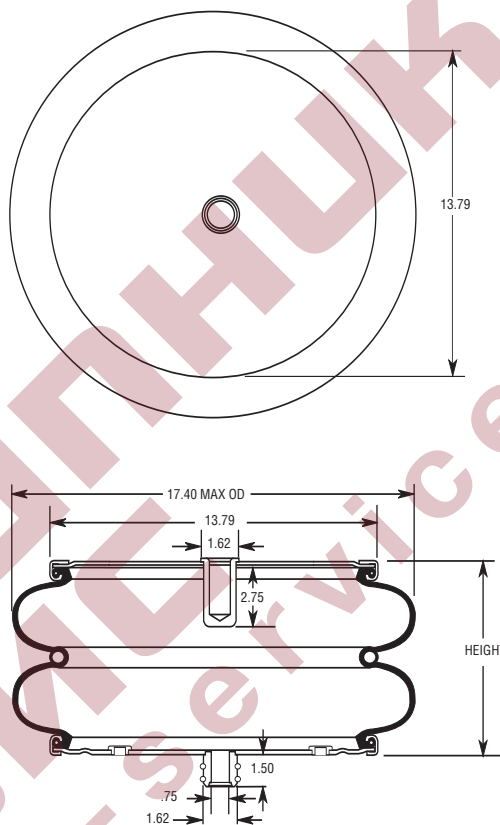
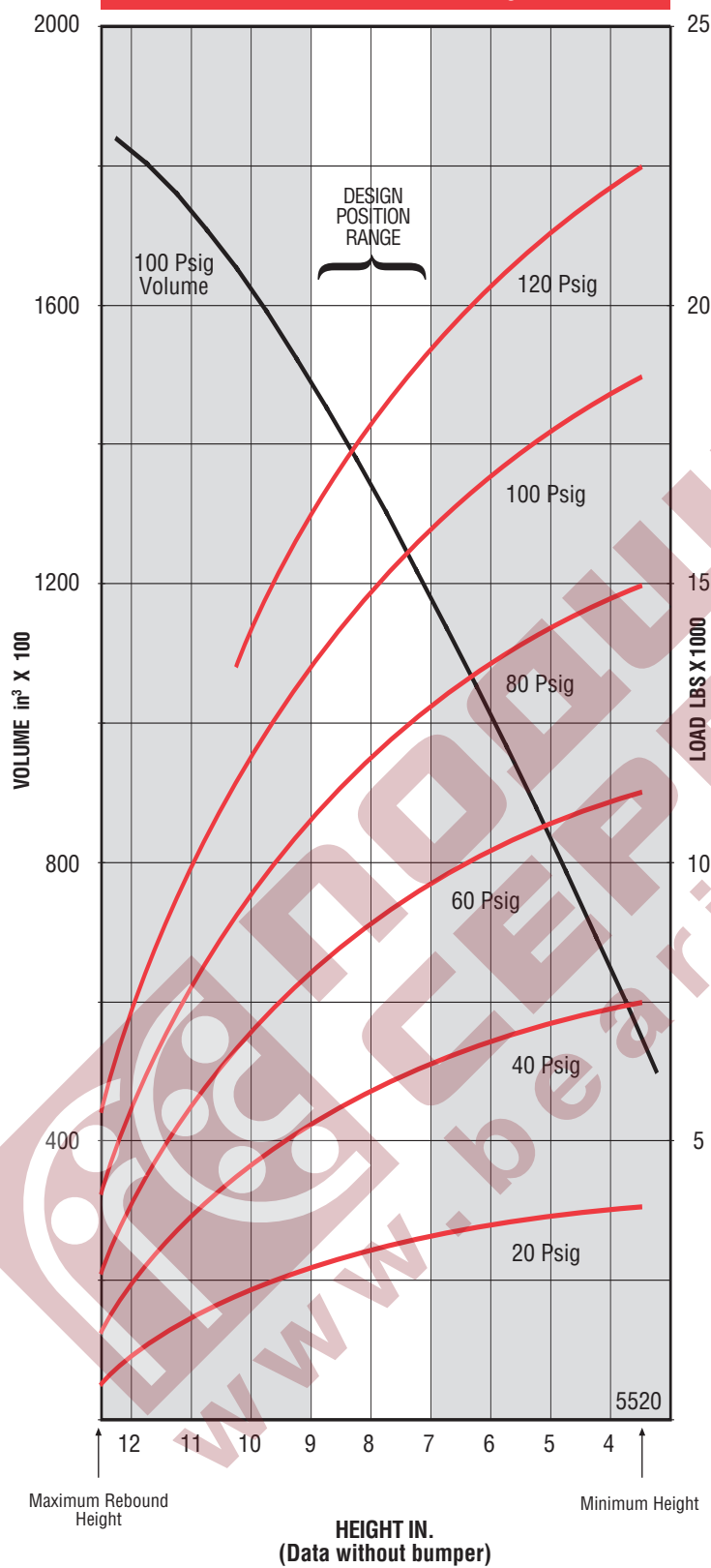
Dynamic Load vs. Deflection



Lateral Spring Rate at 8.0" Design Height & 0.1 Hz frequency			
Pressure (psi)	Rate (lbs/in) at ± 0.5 in	Rate (lbs/in) at ± 1.0 in	Rate (lbs/in) at ± 1.5 in
20	222	175	153
40	345	260	215
60	390	300	248
80	400	325	267
100	410	330	275

6978

STATIC DATA

Recommended Design Position
Static Pressure 20-100 PsigW01-358-7285 SHOWN
(WT 30.0 LBS)

100 Psig Data		
Height (in)	Load (lbs)	Volume (in³)
12.50	5500	1835.00
12.00	7272	1799.00
11.50	8694	1756.00
11.00	9925	1705.00
10.50	10909	1649.00
10.00	11893	1587.00
9.50	12689	1519.00
9.00	13484	1449.00
8.50	14166	1375.00
8.00	14810	1298.00
7.50	15394	1216.00
7.00	15977	1134.00
6.50	16428	1050.00
6.00	16917	963.00
5.50	17293	874.00
5.00	17727	783.00
4.50	18068	689.00
4.00	18409	596.00
3.50	18712	498.00

5520

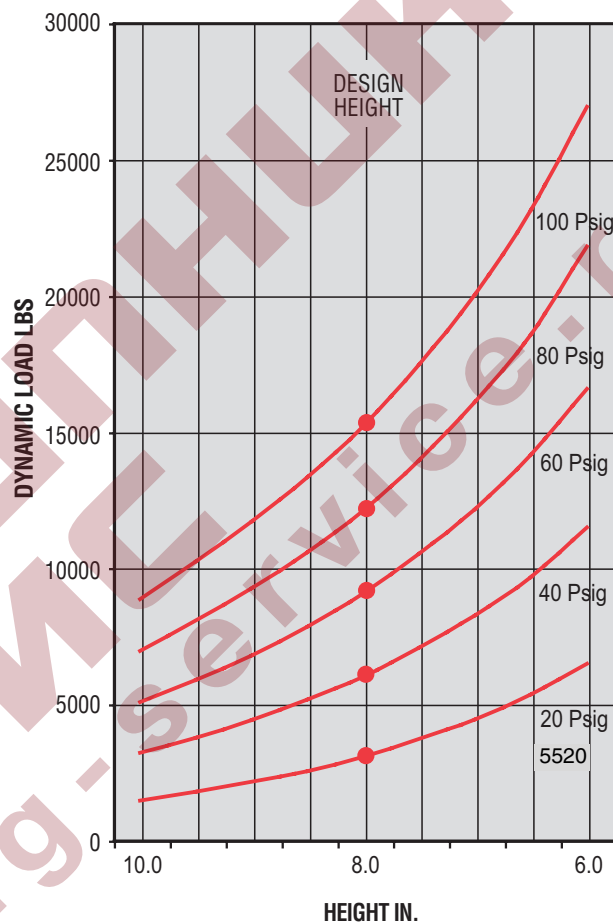
Dynamic Characteristic at Various Design Heights					
Design Height (in)	Load (lbs)	Pressure (psig)	Rate (lbs/in)	Natural Frequency	
				(CPM)	(Hz)
7.00	6000	37.5	2035	109.3	1.82
7.00	9000	56.7	2837	105.4	1.76
7.00	12000	74.4	3606	102.9	1.72
7.00	15000	92.8	4341	100.9	1.68
8.00	6000	40.3	1895	105.5	1.76
8.00	9000	60.3	2670	102.2	1.70
8.00	12000	79.8	3367	99.4	1.66
8.00	15000	99.2	4049	97.5	1.63
9.00	6000	44.3	1803	102.8	1.71
9.00	9000	66.0	2484	98.6	1.64
9.00	12000	87.6	3167	96.4	1.61
9.00	15000	108.7	3950	96.3	1.61

5520

Rate and Frequency with Increasing Volume at 8.0" Design Height and 100 psi			
Reservoir Volume (in³)	Vertical Rate (lbs/in)	Vertical Natural Frequency	
		(CPM)	(Hz)
0	4123.00	97.9	1.63
500	3287.00	87.4	1.46
1000	2818.00	80.9	1.35
1500	2518.00	76.5	1.28
2000	2310.00	73.3	1.22
2500	2157.00	70.8	1.18
3000	2039.00	68.8	1.15
3500	1946.00	67.3	1.12
4000	1871.00	65.9	1.10
4500	1809.00	64.8	1.08
5000	1756.00	63.9	1.07
5500	1712.00	63.1	1.05
6000	1673.00	62.4	1.04
6500	1639.00	61.7	1.03

5520

Dynamic Load vs. Deflection

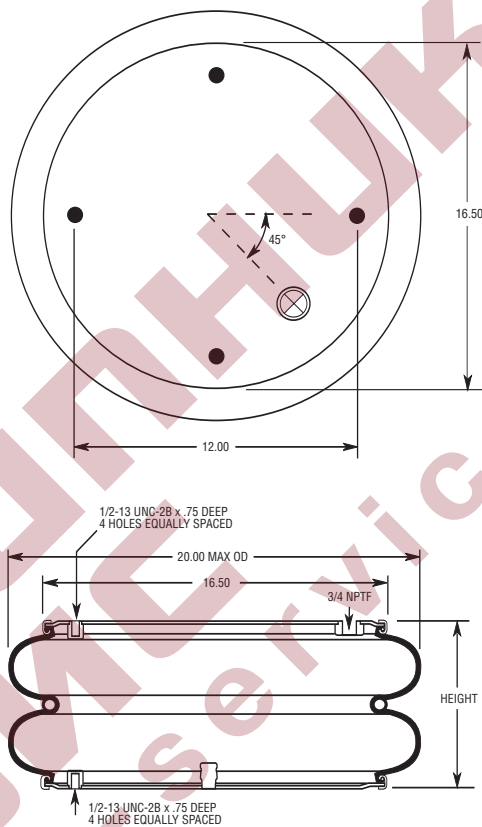
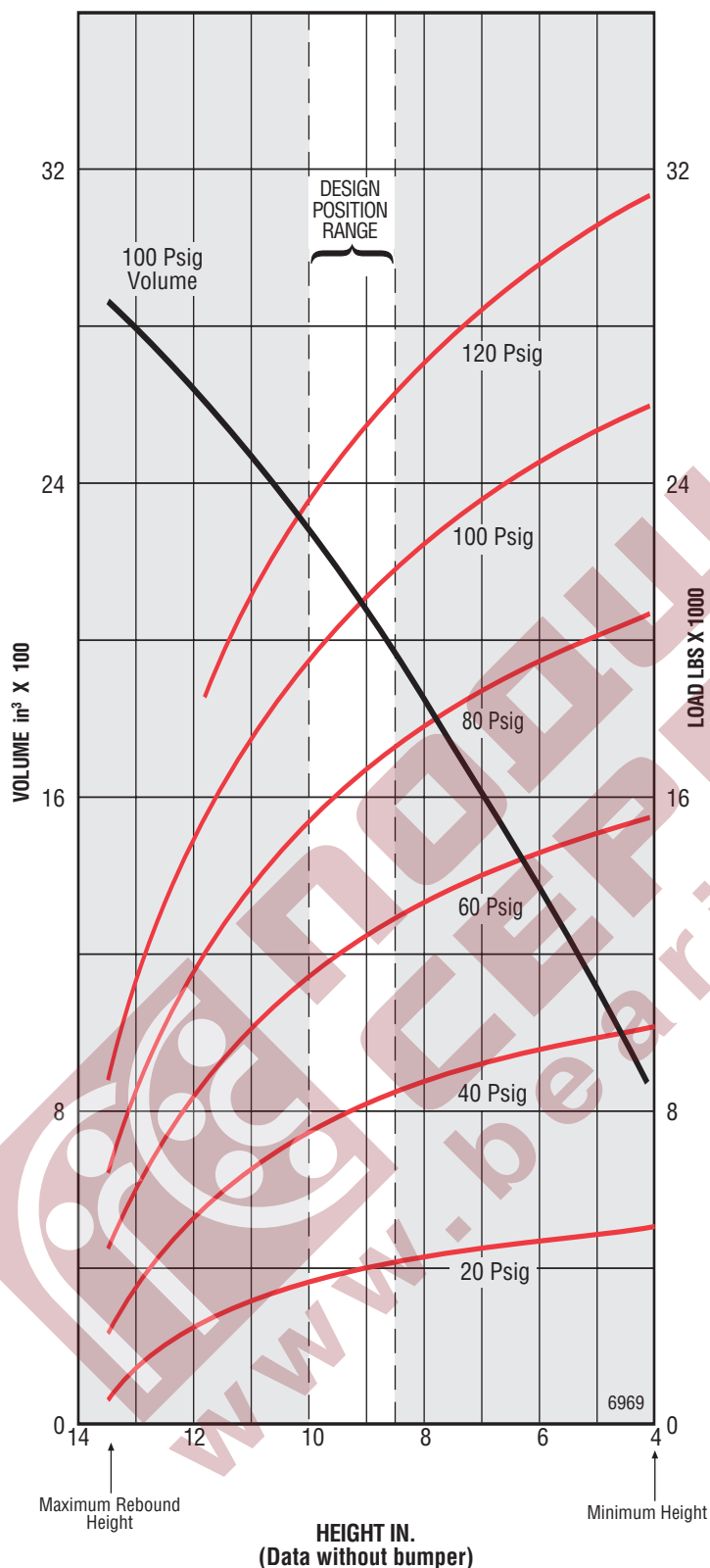


Lateral Spring Rate at 8.0" Design Height & 0.1 Hz frequency			
Pressure (psi)	Rate (lbs/in) at ± 0.5 in	Rate (lbs/in) at ± 1.0 in	Rate (lbs/in) at ± 1.5 in
20	375	300	272
40	625	467	396
60	750	606	492
80	825	656	542
100	875	737	608

5519

STATIC DATA

Recommended Design Position
Static Pressure 20-100 Psig



W01-358-7273 SHOWN
(WT 45.2 LBS)

100 Psig Data		
Height (in)	Load (lbs)	Volume (in ³)
13.50	9456	2878.51
13.00	11599	2813.22
12.50	13393	2741.43
12.00	14927	2663.43
11.50	16264	2579.64
11.00	17450	2490.35
10.50	18517	2395.86
10.00	19483	2296.57
9.50	20363	2192.78
9.00	21163	2084.89
8.50	21888	1973.20
8.00	22544	1858.11
7.50	23133	1739.83
7.00	23663	1618.74
6.50	24139	1495.25
6.00	24571	1369.56
5.50	24968	1242.18
5.00	25337	1113.39
4.50	25686	983.50
4.00	26014	852.91

6969

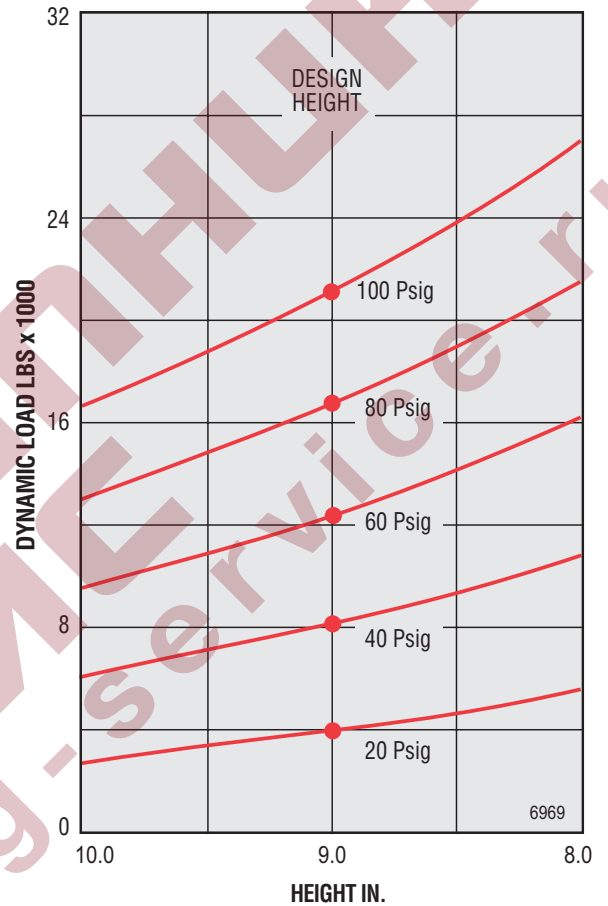
Dynamic Characteristic at Various Design Heights					
Design Height (in)	Load (lbs)	Pressure (psig)	Rate (lbs/in)	Natural Frequency	
				(CPM)	(Hz)
8.50	8000	36.5	2297	100.7	1.68
8.50	12000	54.8	3189	96.9	1.62
8.50	17000	77.7	4303	94.6	1.58
8.50	21000	95.9	5195	93.5	1.56
9.00	8000	37.8	2203	98.6	1.64
9.00	12000	56.7	3076	95.2	1.59
9.00	17000	80.3	4168	93.1	1.55
9.00	21000	99.2	5042	92.1	1.54
10.00	8000	41.1	2092	96.1	1.60
10.00	12000	61.6	2962	93.4	1.56
10.00	17000	87.3	4050	91.8	1.53
10.00	21000	107.8	4920	91.0	1.52

6969

Rate and Frequency with Increasing Volume at 9.0" Design Height and 100 psi			
Reservoir Volume (in³)	Vertical Rate (lbs/in)	Vertical Natural Frequency	
		(CPM)	(Hz)
0	5053.23	91.9	1.53
1000	3917.89	80.9	1.35
2000	3329.48	74.6	1.24
3000	2973.49	70.5	1.17
4000	2734.86	67.6	1.13
5000	2563.76	65.4	1.09
6000	2435.06	63.8	1.06
7000	2334.75	62.4	1.04
8000	2254.36	61.4	1.02
9000	2188.49	60.5	1.01
10000	2133.53	59.7	0.99

6969

Dynamic Load vs. Deflection

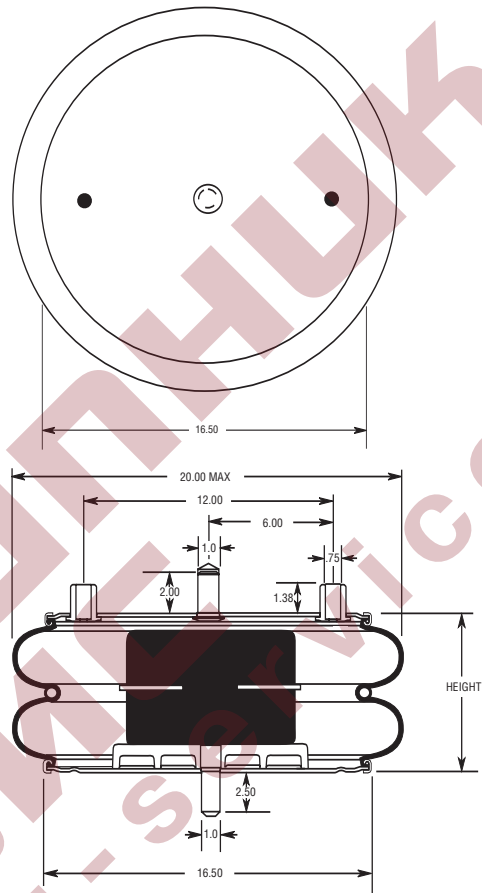
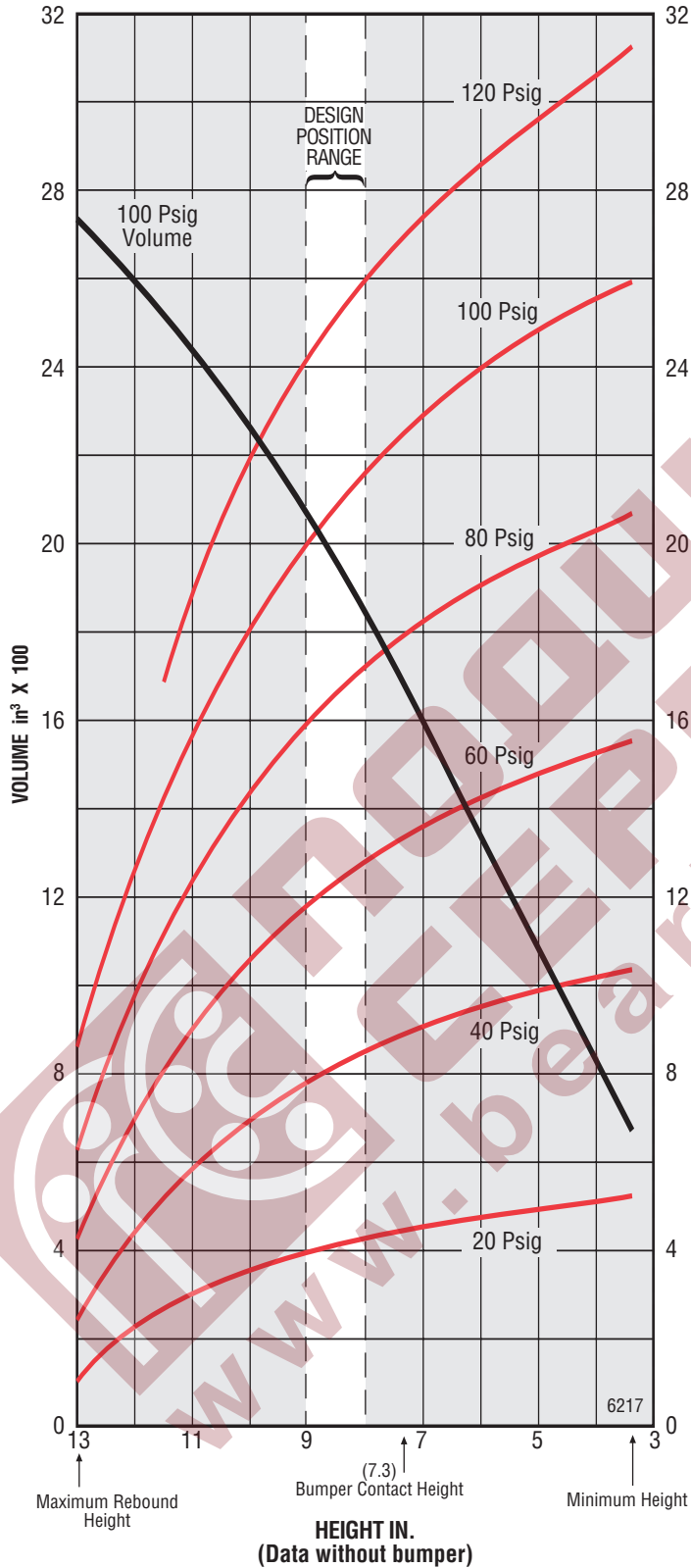


Lateral Spring Rate at 9.0" Design Height & 0.1 Hz frequency			
Pressure (psi)	Rate (lbs/in) at ± 0.5 in	Rate (lbs/in) at ± 1.0 in	Rate (lbs/in) at ± 1.5 in
20	365	287	250
40	500	405	337
60	515	450	388
80	525	481	417
100	587	494	437

6927

STATIC DATA

Recommended Design Position
Static Pressure 20-100 Psig



W01-764-7221 SHOWN
(WT 79.1 LBS)

100 Psig Data

Height (in)	Load (lbs)	Volume (in³)
13.00	8597	2737.23
12.50	10505	2674.53
12.00	12353	2604.54
11.50	14071	2527.75
11.00	15623	2444.56
10.50	16996	2355.36
10.00	18196	2260.67
9.50	19240	2160.78
9.00	20149	2056.29
8.50	20948	1947.51
8.00	21657	1834.82
7.50	22296	1718.73
7.00	22878	1599.74
6.50	23410	1478.05
6.00	23895	1354.36
5.50	24337	1228.88
5.00	24737	1102.09
4.50	25101	974.40
4.00	25448	846.32
3.50	25808	718.33

6217

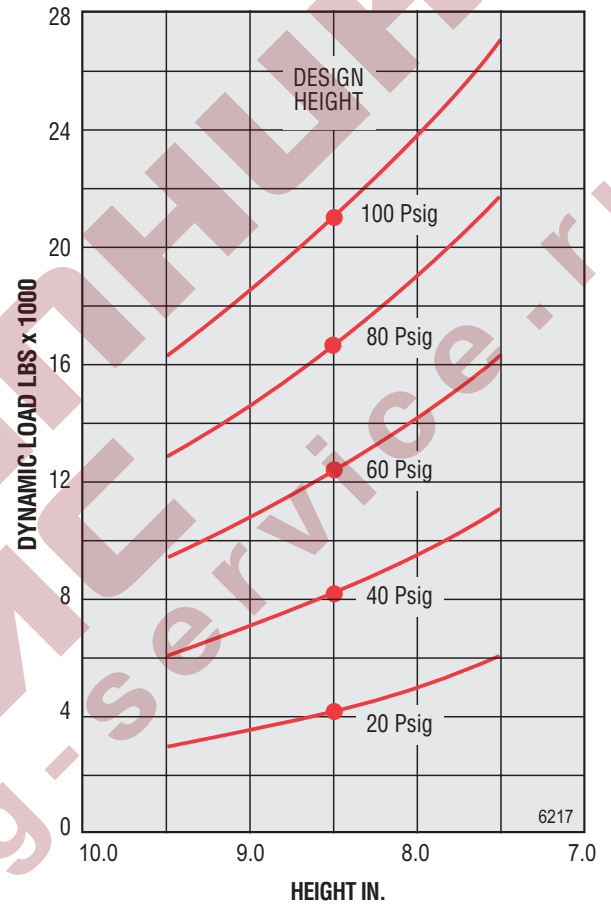
Dynamic Characteristic at Various Design Heights					
Design Height (in)	Load (lbs)	Pressure (psig)	Rate (lbs/in)	Natural Frequency	
				(CPM)	(Hz)
8.00	8000	36.9	2439	103.8	1.73
8.00	12000	55.4	3382	99.8	1.66
8.00	17000	78.5	4561	97.4	1.62
8.00	21000	97.0	5504	96.2	1.60
8.50	8000	38.2	2328	101.4	1.69
8.50	12000	57.3	3249	97.8	1.63
8.50	17000	81.2	4399	95.6	1.59
8.50	21000	100.2	5320	94.6	1.58
9.00	8000	39.7	2258	99.9	1.66
9.00	12000	59.6	3173	96.7	1.61
9.00	17000	84.4	4318	94.7	1.58
9.00	21000	104.2	5233	93.9	1.56

6217

Rate and Frequency with Increasing Volume at 8.5" Design Height and 100 psi			
Reservoir Volume (in³)	Vertical Rate (lbs/in)	Vertical Natural Frequency	
		(CPM)	(Hz)
0	5275.44	94.3	1.57
1000	4008.49	82.2	1.37
2000	3372.01	75.4	1.26
3000	2993.98	71.1	1.18
4000	2743.49	68.0	1.13
5000	2565.29	65.8	1.10
6000	2432.03	64.1	1.07
7000	2328.60	62.7	1.04
8000	2246.01	61.6	1.03
9000	2178.52	60.6	1.01
10000	2122.34	59.8	1.00

6217

Dynamic Load vs. Deflection



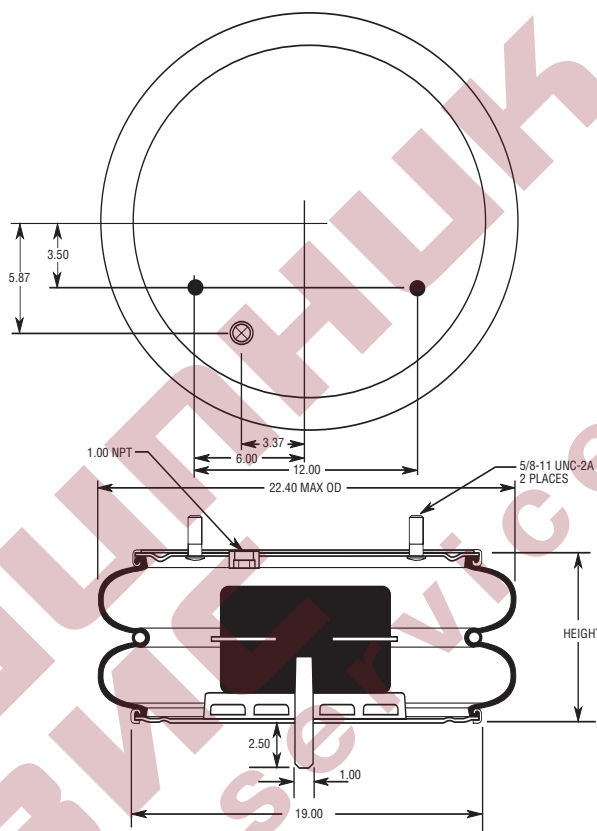
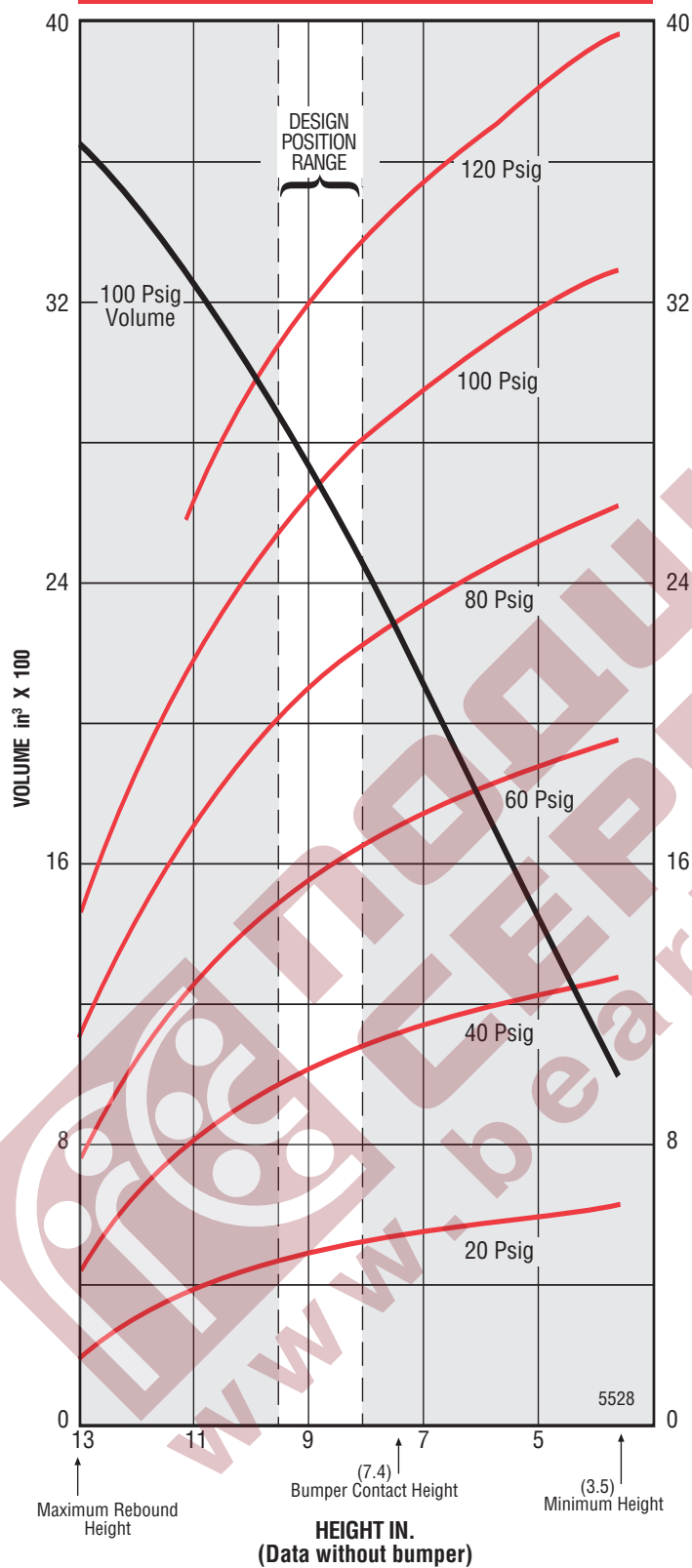
6217

Lateral Spring Rate at 8.5" Design Height & 0.1 Hz frequency			
Pressure (psi)	Rate (lbs/in) at ± 0.5 in	Rate (lbs/in) at ± 1.0 in	Rate (lbs/in) at ± 1.5 in
20	370	300	278
40	600	437	371
60	700	519	419
80	794	600	419
100	800	638	500

6559

STATIC DATA

Recommended Design Position
Static Pressure 20-100 Psig



W01-764-7229 SHOWN
(WT 86 LBS)

100 Psig Data		
Height (in)	Load (lbs)	Volume (in³)
13.00	14618	3651.23
12.50	16611	3557.44
12.00	18468	3456.15
11.50	20182	3347.77
11.00	21744	3232.78
10.50	23152	3111.39
10.00	24407	2984.20
9.50	25516	2851.51
9.00	26491	2713.73
8.50	27349	2571.14
8.00	28108	2424.36
7.50	28793	2273.57
7.00	29424	2119.19
6.50	30022	1961.80
6.00	30601	1801.52
5.50	31168	1638.94
5.00	31715	1474.45
4.50	32218	1308.27
4.00	32629	1140.99
3.50	32876	972.90

5528

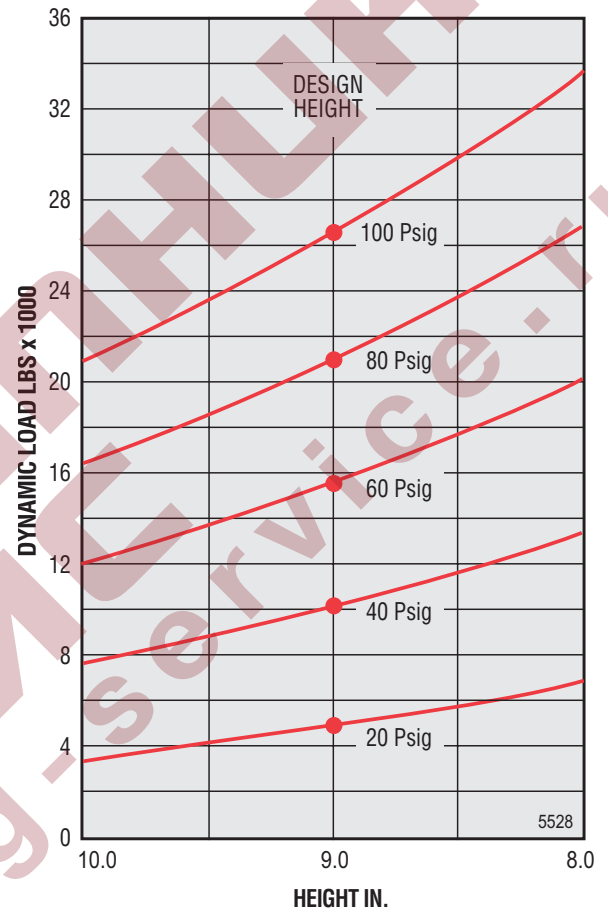
Dynamic Characteristic at Various Design Heights					
Design Height (in)	Load (lbs)	Pressure (psig)	Rate (lbs/in)	Natural Frequency	
				(CPM)	(Hz)
8.00	10000	35.6	2927	101.7	1.70
8.00	16000	56.9	4259	97.0	1.62
8.00	21000	74.7	5370	95.1	1.58
8.00	27000	96.1	6702	93.7	1.56
9.00	10000	37.7	2685	97.4	1.62
9.00	16000	60.4	3961	93.5	1.56
9.00	21000	79.3	5024	92.0	1.53
9.00	27000	101.9	6300	90.8	1.51
9.50	10000	39.2	2627	96.4	1.61
9.50	16000	67.0	3907	92.9	1.55
9.50	21000	82.3	4973	91.5	1.52
9.50	27000	105.8	6253	90.5	1.51

5528

Rate and Frequency with Increasing Volume at 9.0" Design Height and 100 psi			
Reservoir Volume (in³)	Vertical Rate (lbs/in)	Vertical Natural Frequency	
		(CPM)	(Hz)
0	6157.81	90.6	1.51
1000	5009.50	81.8	1.36
2000	4332.21	76.0	1.27
3000	3893.16	72.1	1.20
4000	3585.40	69.2	1.15
5000	3357.67	66.9	1.12
6000	3182.34	65.2	1.09
7000	3043.19	63.7	1.06
8000	2930.06	62.5	1.04
9000	2836.27	61.5	1.03
10000	2757.26	60.7	1.01
11000	2689.79	59.9	1.00
12000	2631.50	59.3	0.99
13000	2580.64	58.7	0.98

5528

Dynamic Load vs. Deflection



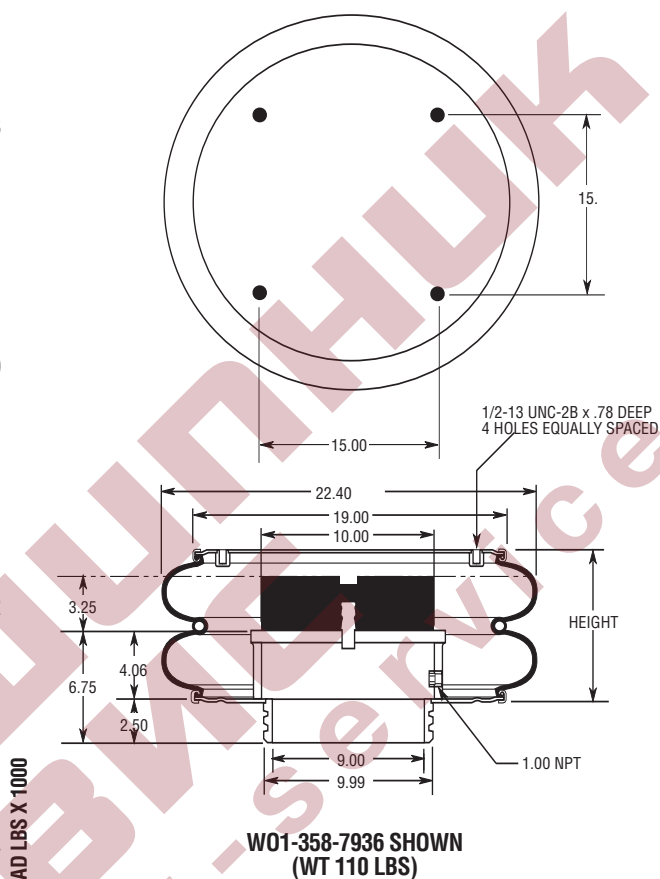
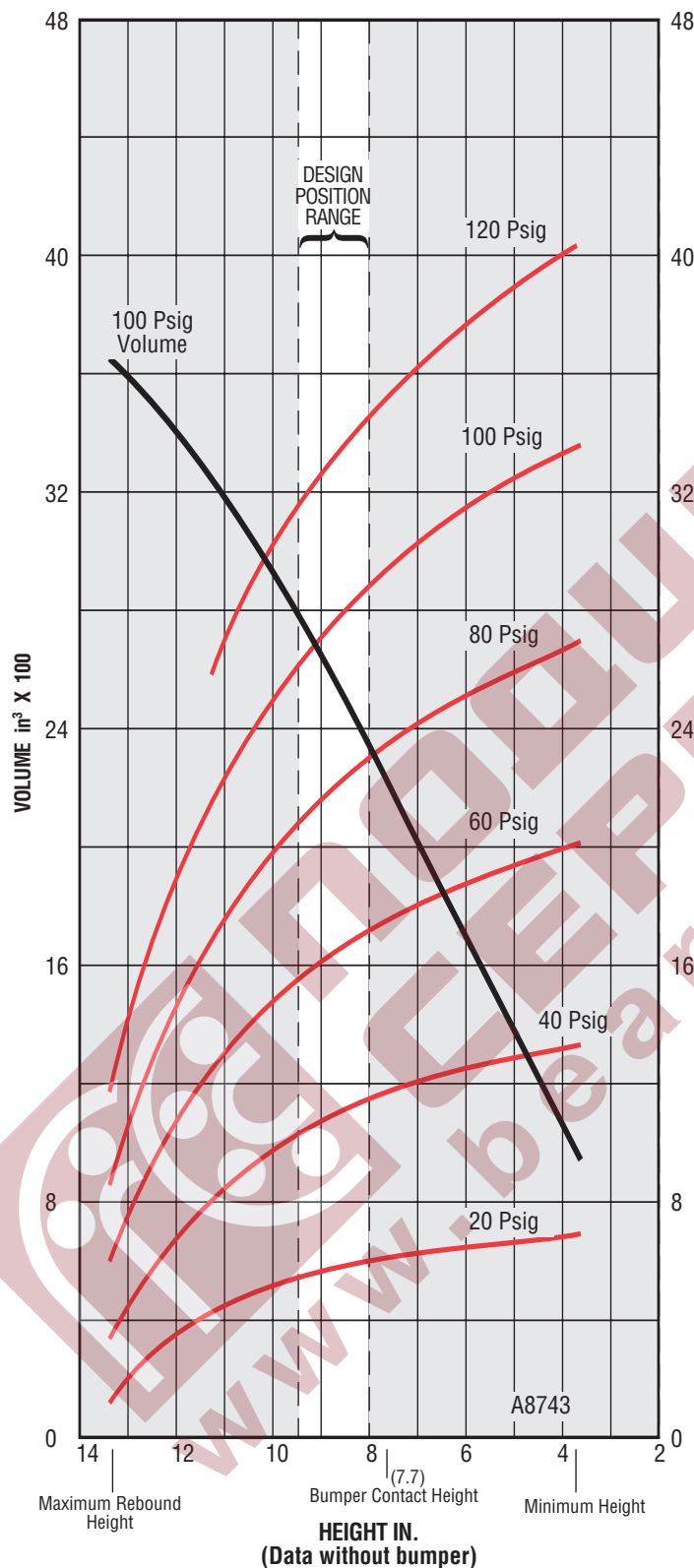
5528

Lateral Spring Rate at 9.0" Design Height & 0.1 Hz frequency			
Pressure (psi)	Rate (lbs/in) at ± 0.5 in	Rate (lbs/in) at ± 1.0 in	Rate (lbs/in) at ± 1.5 in
20	500	406	334
40	750	562	458
60	812	631	550
80	875	750	625
100	900	756	658

5527

STATIC DATA

Recommended Design Position
Static Pressure 20-100 Psig



100 Psig Data

Height (in)	Load (lbs)	Volume (in³)
13.50	11585	3653.83
13.00	14357	3570.14
12.50	16768	3478.05
12.00	18876	3377.96
11.50	20726	3270.27
11.00	22353	3155.48
10.50	23783	3034.10
10.00	25040	2906.51
9.50	26145	2773.12
9.00	27115	2634.54
8.50	27971	2491.05
8.00	28733	2343.27
7.50	29418	2191.48
7.00	30048	2036.30
6.50	30638	1878.11
6.00	31204	1717.33
5.50	31752	1554.44
5.00	32281	1389.86
4.50	32778	1224.08
4.00	33214	1057.59
3.50	33538	890.81

A8743

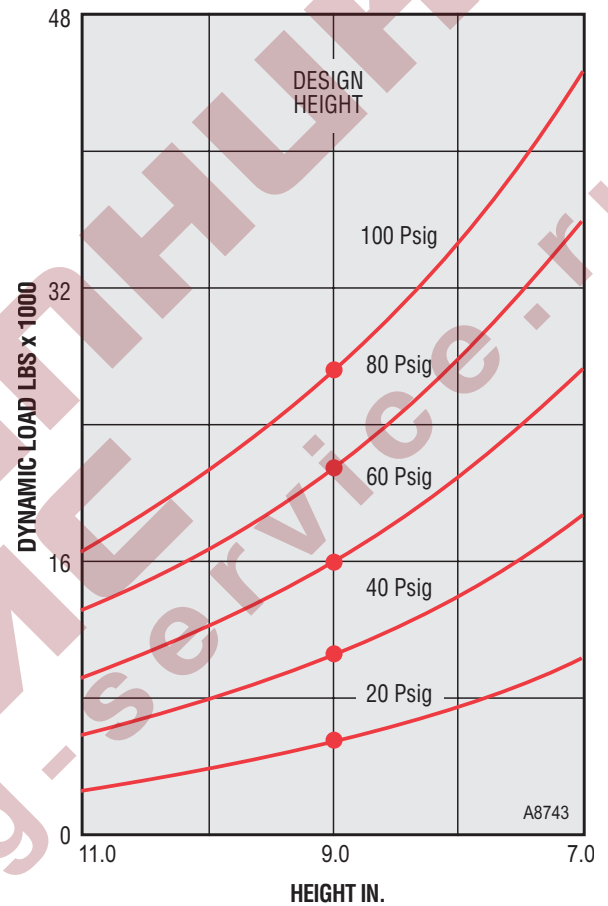
Dynamic Characteristic at Various Design Heights					
Design Height (in)	Load (lbs)	Pressure (psig)	Rate (lbs/in)	Natural Frequency	
				(CPM)	(Hz)
8.00	10000	34.8	3034	103.6	1.73
8.00	16000	55.7	4404	98.6	1.64
8.00	22000	76.6	5774	96.3	1.61
8.00	26000	90.5	6687	95.3	1.59
9.00	10000	36.9	2754	98.7	1.64
9.00	16000	59.0	4050	94.6	1.58
9.00	22000	81.1	5347	92.7	1.54
9.00	26000	95.9	6211	91.9	1.53
9.50	10000	38.2	2678	97.3	1.62
9.50	16000	61.2	3972	93.7	1.56
9.50	22000	84.1	5265	92.0	1.53
9.50	26000	99.4	6127	91.3	1.52

A8743

Rate and Frequency with Increasing Volume at 9.0" Design Height and 100 psi			
Reservoir Volume (in³)	Vertical Rate (lbs/in)	Vertical Natural Frequency	
		(CPM)	(Hz)
0	6414.53	91.4	1.52
500	5707.13	86.3	1.44
1000	5169.23	82.1	1.37
1500	4762.48	78.8	1.31
2000	4444.07	76.1	1.27
2500	4188.02	73.9	1.23
3000	3977.63	72.0	1.20
3500	3801.68	70.4	1.17
4000	3652.34	69.0	1.15
4500	3524.01	67.8	1.13
5000	3412.53	66.7	1.11

A8743

Dynamic Load vs. Deflection



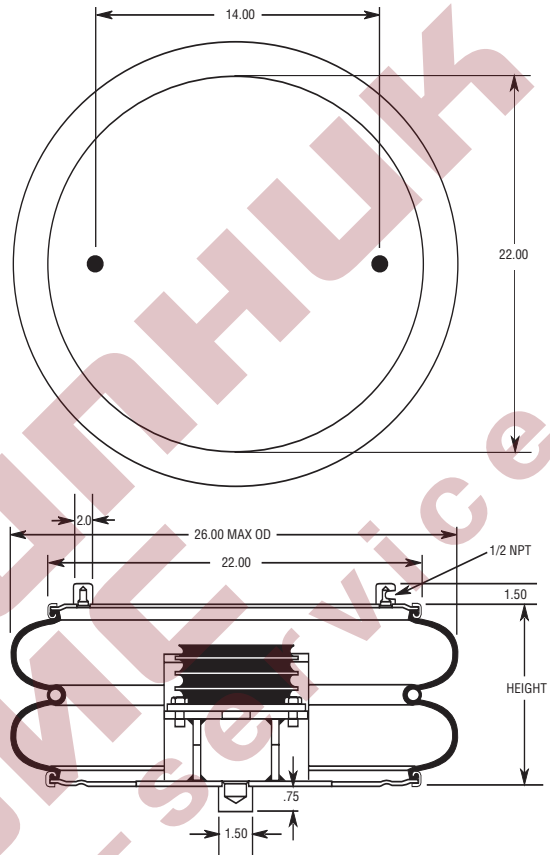
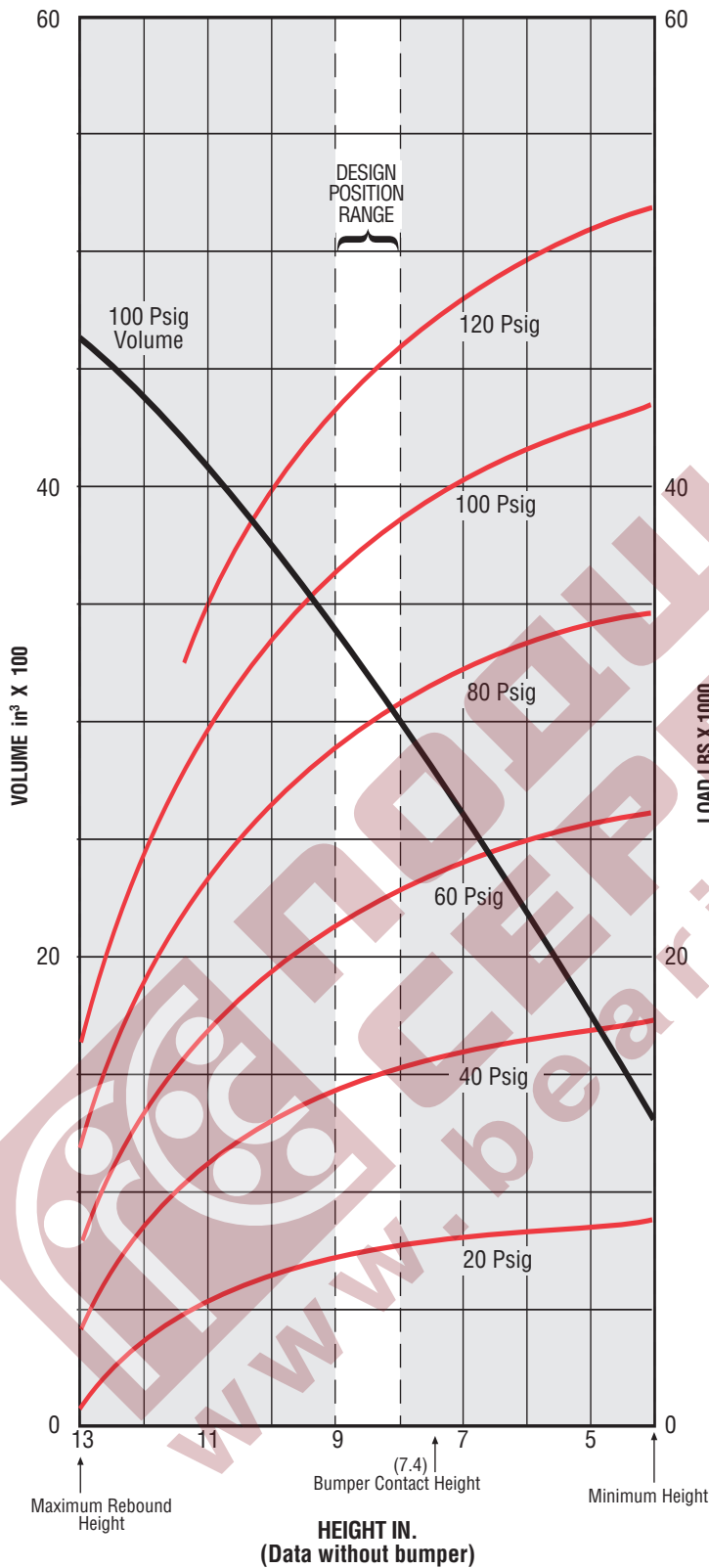
A8743

Lateral Spring Rate at 9.0" Design Height & 0.1 Hz frequency			
Pressure (psi)	Rate (lbs/in) at ± 0.5 in	Rate (lbs/in) at ± 1.0 in	Rate (lbs/in) at ± 1.5 in
20	625	500	425
40	900	687	571
60	1137	875	708
80	1200	981	812
100	1287	1062	904

5529

STATIC DATA

Recommended Design Position
Static Pressure 20-100 Psig



W01-358-7780 SHOWN
(WT 154 LBS)

100 Psig Data		
Height (in)	Load (lbs)	Volume (in ³)
13.00	15727	4652.27
12.50	20013	4535.43
12.00	23596	4406.24
11.50	26617	4265.53
11.00	29180	4114.12
10.50	31364	3952.81
10.00	33231	3782.43
9.50	34826	3603.80
9.00	36191	3417.73
8.50	37360	3225.04
8.00	38367	3026.54
7.50	39244	2823.06
7.00	40023	2615.41
6.50	40730	2404.41
6.00	41386	2190.88
5.50	42000	1975.62
5.00	42564	1759.47
4.50	43047	1543.25
4.00	43384	1327.75

B6173

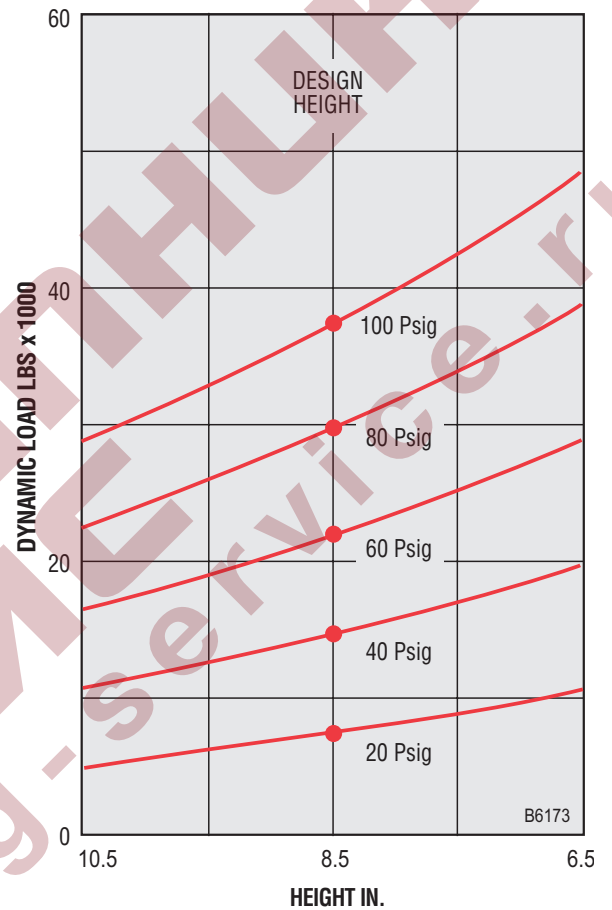
Dynamic Characteristic at Various Design Heights					
Design Height (in)	Load (lbs)	Pressure (psig)	Rate (lbs/in)	Natural Frequency	
				(CPM)	(Hz)
8.00	15000	39.1	4552	103.6	1.73
8.00	22500	58.6	6306	99.5	1.66
8.00	30000	78.2	8061	97.5	1.62
8.00	37500	97.7	9816	96.2	1.60
8.50	15000	40.1	4330	101.0	1.68
8.50	22500	60.2	6031	97.3	1.62
8.50	30000	80.3	7733	95.4	1.59
8.50	37500	100.4	9435	94.3	1.57
9.00	15000	41.4	4179	99.2	1.65
9.00	22500	62.2	5858	95.9	1.60
9.00	30000	82.9	7538	94.2	1.57
9.00	37500	103.6	9218	93.2	1.55

B6173

Rate and Frequency with Increasing Volume at 8.5" Design Height and 100 psi			
Reservoir Volume (in³)	Vertical Rate (lbs/in)	Vertical Natural Frequency	
		(CPM)	(Hz)
0	9343.08	94.0	1.57
2000	6615.84	79.1	1.32
4000	5381.67	71.4	1.19
6000	4684.72	66.6	1.11
8000	4236.79	63.3	1.06
10000	3924.63	60.9	1.02
12000	3694.61	59.1	0.99
14000	3518.09	57.7	0.96
16000	3378.33	56.5	0.94

B6173

Dynamic Load vs. Deflection



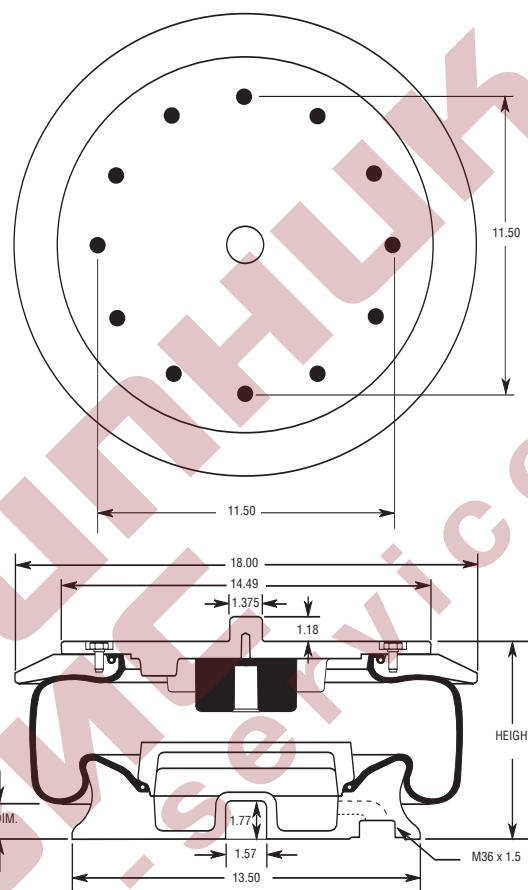
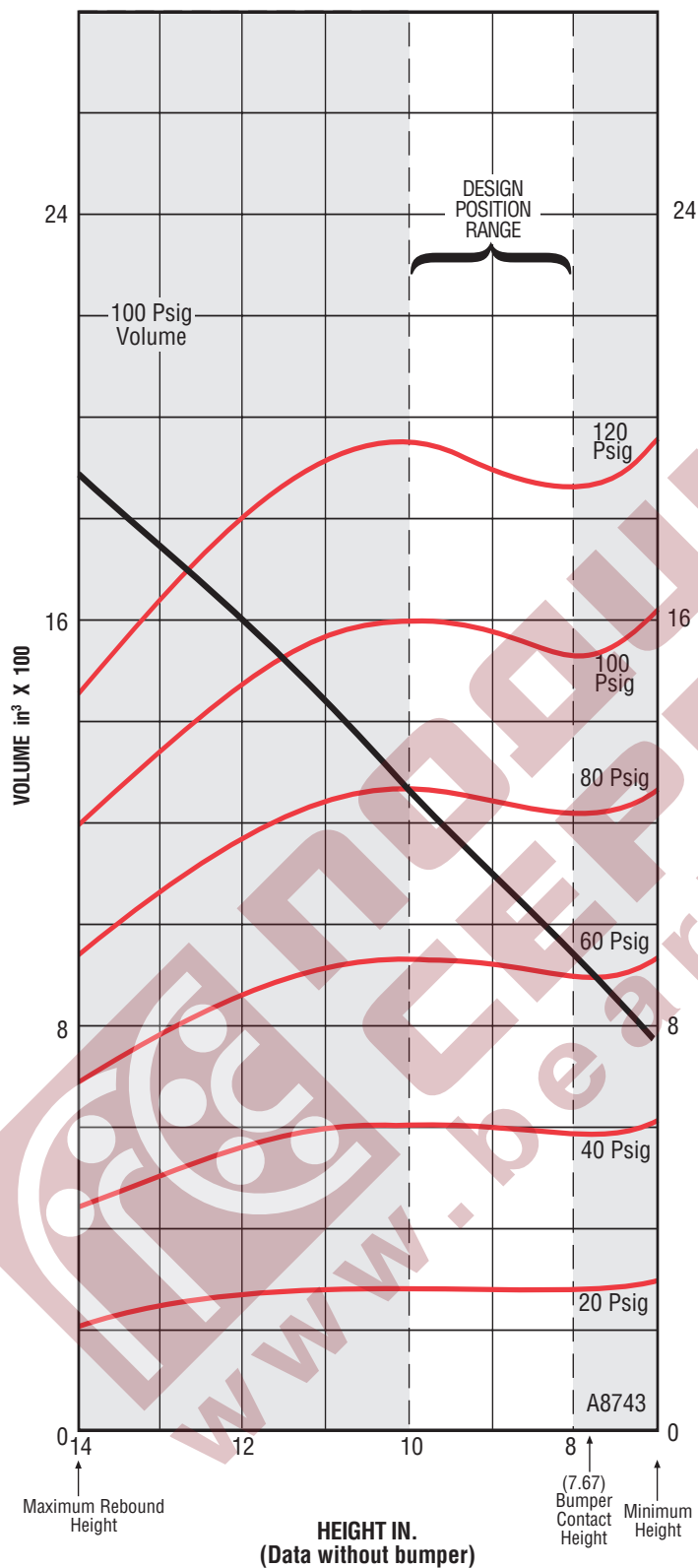
B6173

Lateral Spring Rate at 8.5" Design Height & 0.1 Hz frequency			
Pressure (psi)	Rate (lbs/in) at ± 0.5 in	Rate (lbs/in) at ± 1.0 in	Rate (lbs/in) at ± 1.5 in
60	1750	1312	1167
80	1937	1437	1187
100	2187	1625	1312

A9278

STATIC DATA

Recommended Design Position
Static Pressure 20-100 Psig



W01-358-6700 SHOWN
(WT 92 LBS)

100 Psig Data

Height (in)	Load (lbs)	Volume (in³)	B Dim. (in)
14.00	12085	1893.71	
13.50	12813	1827.12	
13.00	13525	1756.22	3.45
12.50	14213	1681.83	3.45
12.00	14847	1604.14	3.17
11.50	15385	1523.95	2.97
11.00	15785	1441.76	2.74
10.50	16016	1357.96	2.45
10.00	16070	1273.27	2.14
9.50	15963	1188.08	1.80
9.00	15746	1102.99	1.44
8.50	15508	1018.60	1.08
8.00	15376	935.41	0.74
7.50	15521	853.91	0.49
7.00	16400	775.02	0.29

5579

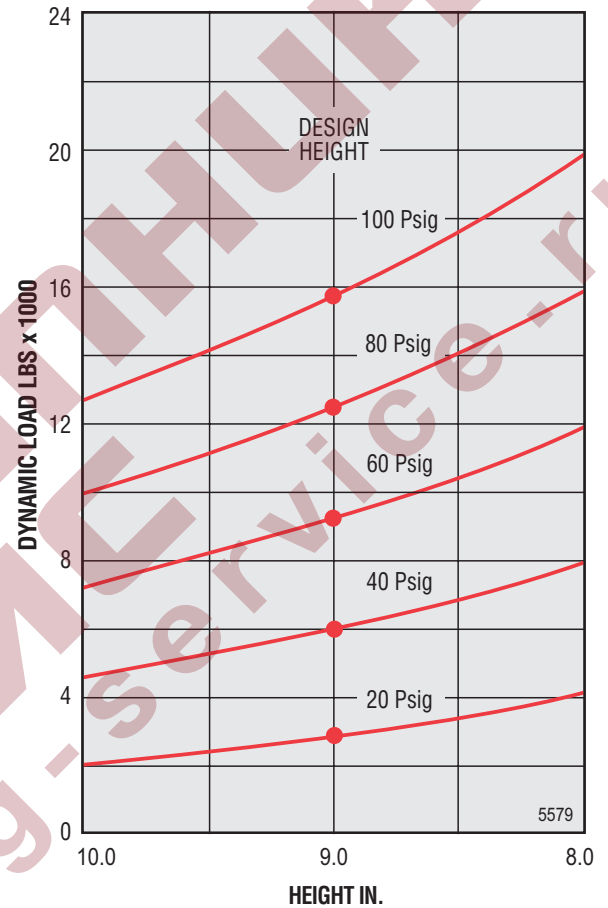
Dynamic Characteristic at Various Design Heights					
Design Height (in)	Load (lbs)	Pressure (psig)	Rate (lbs/in)	Natural Frequency	
				(CPM)	(Hz)
8.00	6000	39.0	2047	109.8	1.83
8.00	9000	58.5	2791	104.7	1.74
8.00	12000	78.0	3535	102.0	1.70
8.00	16000	104.1	4527	100.0	1.67
9.00	6000	38.1	1599	97.1	1.62
9.00	9000	57.2	2152	91.9	1.53
9.00	12000	76.2	2705	89.3	1.49
9.00	16000	101.6	3442	87.2	1.45
10.00	6000	37.3	1522	94.7	1.58
10.00	9000	56.0	2065	90.1	1.50
10.00	12000	74.7	2608	87.6	1.46
10.00	16000	99.6	3333	85.8	1.43

5579

Rate and Frequency with Increasing Volume at 9.0" Design Height and 100 psi			
Reservoir Volume (in³)	Vertical Rate (lbs/in)	Vertical Natural Frequency	
		(CPM)	(Hz)
0	3343.81	86.6	1.44
500	2184.77	70.0	1.17
1000	1554.70	59.1	0.98
1500	1167.79	51.2	0.85
2000	905.93	45.1	0.75
2500	716.90	40.1	0.67
3000	573.99	35.9	0.60
3500	462.17	32.2	0.54
4000	372.28	28.9	0.48
4500	298.44	25.9	0.43
5000	236.70	23.1	0.38
5500	184.32	20.3	0.34

5579

Dynamic Load vs. Deflection



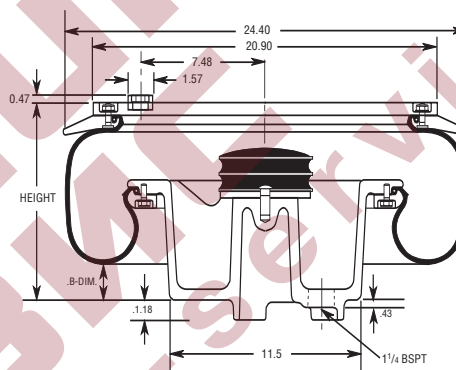
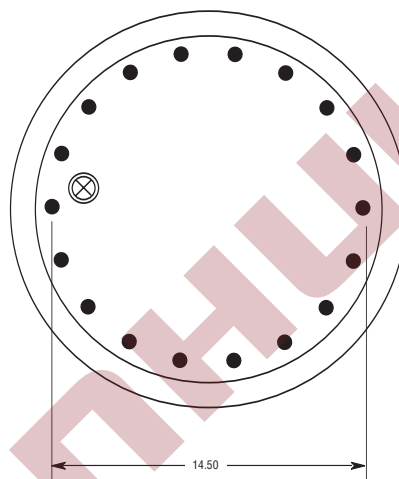
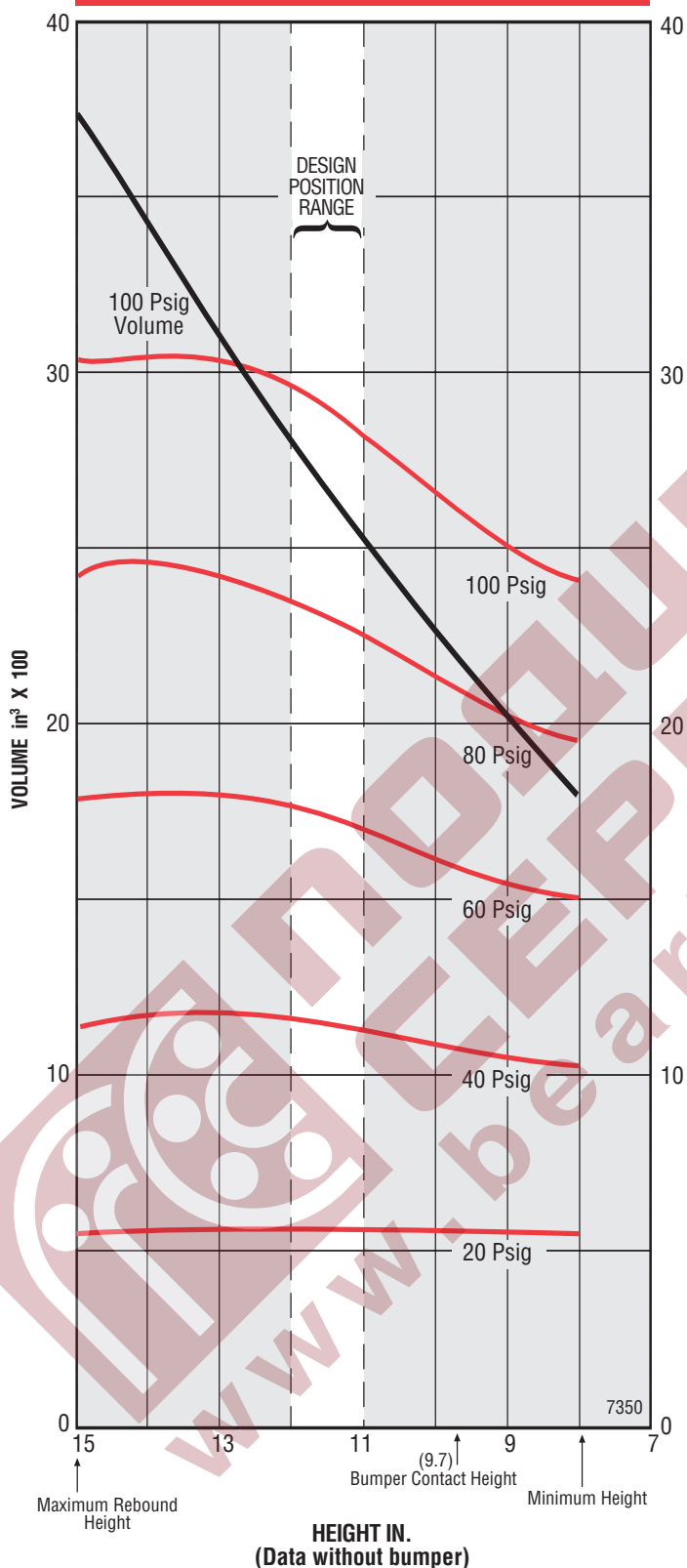
5579

Lateral Spring Rate at 9.0" Design Height & 0.1 Hz frequency			
Pressure (psi)	Rate (lbs/in) at ± 0.5 in	Rate (lbs/in) at ± 1.0 in	Rate (lbs/in) at ± 1.5 in
40	400	225	225
60	400	175	167
80	400	132	92
100	375	68	9

5581

STATIC DATA

Recommended Design Position
Static Pressure 20-100 Psig



W01-358-8995 SHOWN
(WT 109 LBS)

100 Psig Data

Height (in)	Load (lbs)	Volume (in³)	B Dim. (in)
15.00	30401	3749.20	
14.50	30284	3590.08	4.92
14.00	30365	3432.03	4.33
13.50	30421	3275.50	4.33
13.00	30332	3120.97	3.69
12.50	30049	2968.91	3.34
12.00	29574	2819.80	3.00
11.50	28938	2674.09	2.63
11.00	28188	2532.28	2.26
10.50	27373	2394.81	1.85
10.00	26542	2262.18	1.47
9.50	25741	2134.86	1.07
9.00	25012	2013.30	0.67
8.50	24407	1897.99	0.31
8.00	23993	1789.39	-0.04

7350

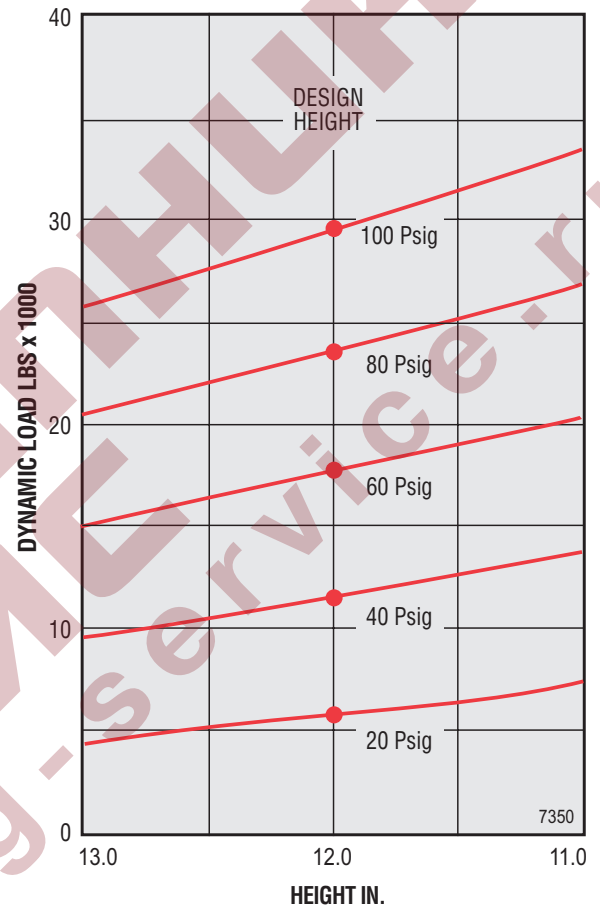
Dynamic Characteristic at Various Design Heights					
Design Height (in)	Load (lbs)	Pressure (psig)	Rate (lbs/in)	Natural Frequency	
				(CPM)	(Hz)
11.00	12500	44.3	1838	72.1	1.20
11.00	17500	62.1	2321	68.5	1.14
11.00	23000	81.6	2852	66.2	1.10
11.00	30000	106.4	3528	64.5	1.07
11.50	12500	43.2	1885	73.0	1.22
11.50	17500	60.5	2386	69.4	1.16
11.50	23000	79.5	2938	67.2	1.12
11.50	30000	103.7	3640	65.5	1.09
12.00	12500	42.3	1958	74.4	1.24
12.00	17500	59.2	2490	70.9	1.18
12.00	23000	77.8	3076	68.8	1.15
12.00	30000	101.4	3822	67.1	1.12

7350

Rate and Frequency with Increasing Volume at 12.0" Design Height and 100 psi			
Reservoir Volume (in³)	Vertical Rate (lbs/in)	Vertical Natural Frequency	
		(CPM)	(Hz)
0	3772.77	67.1	1.12
1000	2493.31	54.6	0.91
2000	1744.56	45.7	0.76
3000	1253.61	38.7	0.65
4000	906.79	32.9	0.55
5000	648.75	27.8	0.46
6000	449.24	23.2	0.39
7000	290.38	18.6	0.31
8000	160.88	13.9	0.23
9000	53.29	8.0	0.13
10000	37.50	6.7	0.11

7350

Dynamic Load vs. Deflection

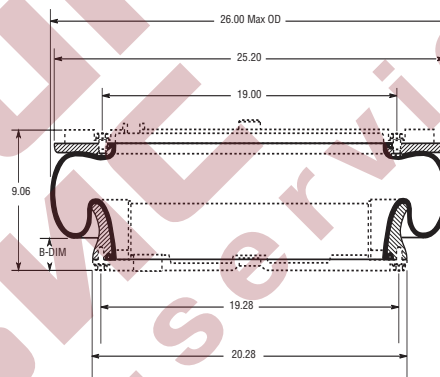
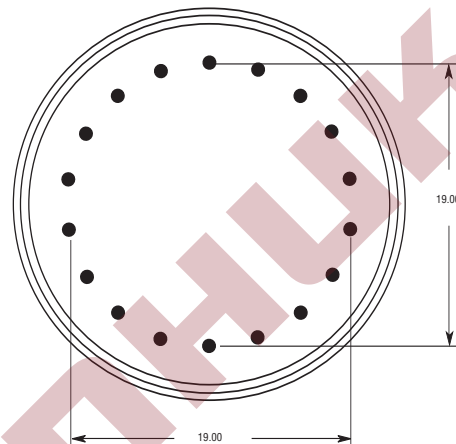
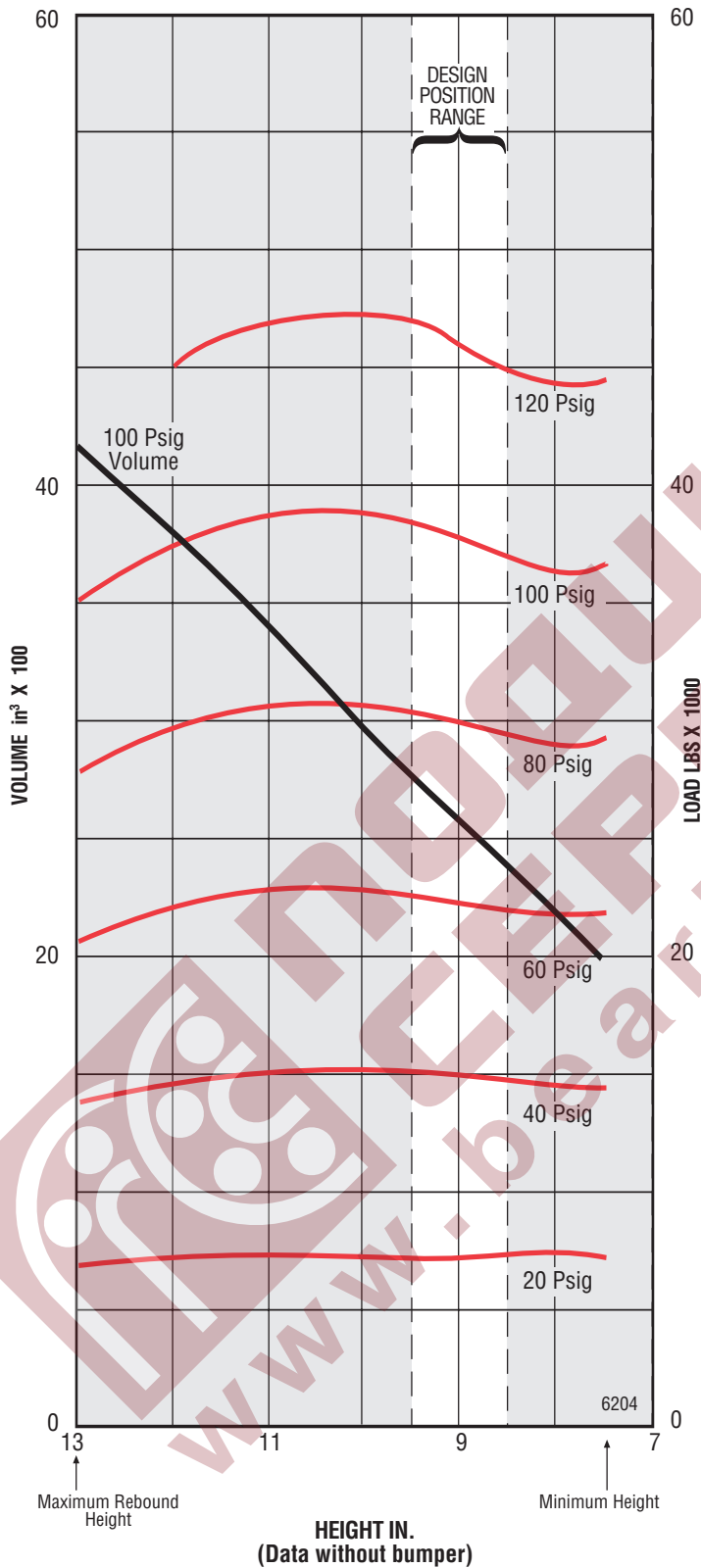


Lateral Spring Rate at 12.0" Design Height & 0.1 Hz frequency			
Pressure (psi)	Rate (lbs/in) at ± 0.5 in	Rate (lbs/in) at ± 1.0 in	Rate (lbs/in) at ± 1.5 in
20	662	662	667
40	562	625	646
60	475	519	579
80	337	425	500

7883

STATIC DATA

Recommended Design Position
Static Pressure 20-100 Psig



W01-358-9009 SHOWN
(WT 63 LBS)

100 Psig Data

Height (in)	Load (lbs)	Volume (in³)	B Dim. (in)
13.00	35184	4189.48	4.57
12.50	36347	4000.50	4.57
12.00	37346	3805.32	4.23
11.50	38165	3605.34	4.23
11.00	38746	3401.86	3.74
10.50	39016	3196.38	3.46
10.00	38927	2990.10	3.14
9.50	38480	2784.42	2.76
9.00	37760	2580.84	2.36
8.50	36971	2380.56	1.94

6204

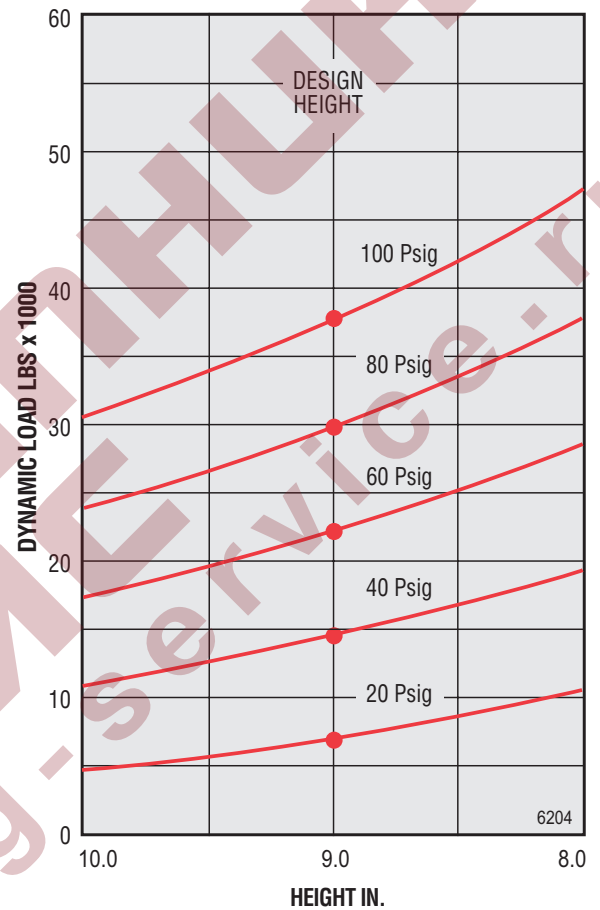
Dynamic Characteristic at Various Design Heights					
Design Height (in)	Load (lbs)	Pressure (psig)	Rate (lbs/in)	Natural Frequency	
				(CPM)	(Hz)
8.50	15000	40.6	4204	99.5	1.66
8.50	22500	60.9	5677	94.4	1.57
8.50	30000	81.1	7150	91.8	1.53
8.50	37500	101.4	8623	90.2	1.50
9.00	15000	39.7	3857	95.3	1.59
9.00	22500	59.6	5183	90.2	1.50
9.00	30000	79.4	6510	87.6	1.46
9.00	37500	99.3	7836	85.9	1.43
9.50	15000	39.0	3741	93.9	1.56
9.50	22500	58.5	5038	89.0	1.48
9.50	30000	78.0	6334	86.4	1.44
9.50	37500	97.5	7630	84.8	1.41

6204

Rate and Frequency with Increasing Volume at 9.0" Design Height and 100 psi			
Reservoir Volume (in³)	Vertical Rate (lbs/in)	Vertical Natural Frequency	
		(CPM)	(Hz)
0	7767.25	85.3	1.42
1000	5239.38	70.0	1.17
2000	3760.34	59.3	0.99
3000	2814.00	51.3	0.86
4000	2156.19	44.9	0.75
5000	1672.29	39.6	0.66
6000	1301.34	34.9	0.58
7000	1007.92	30.7	0.51
8000	770.01	26.8	0.45
9000	573.20	23.2	0.39
10000	407.69	19.5	0.33
11000	226.56	15.8	0.26
12000	144.80	11.6	0.19
13000	38.67	6.0	0.10

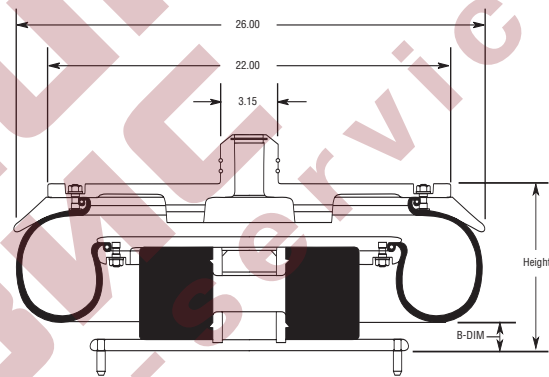
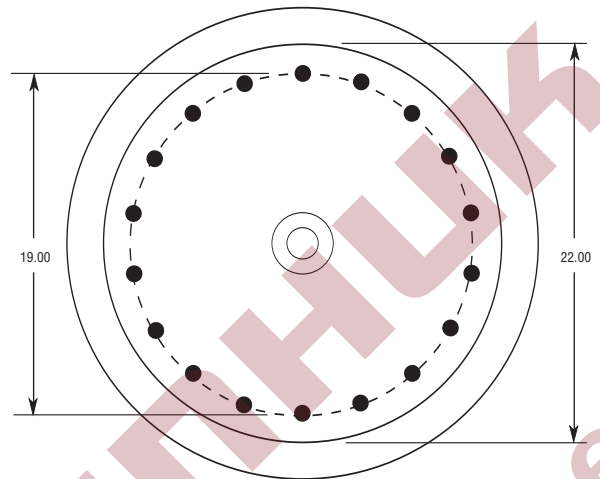
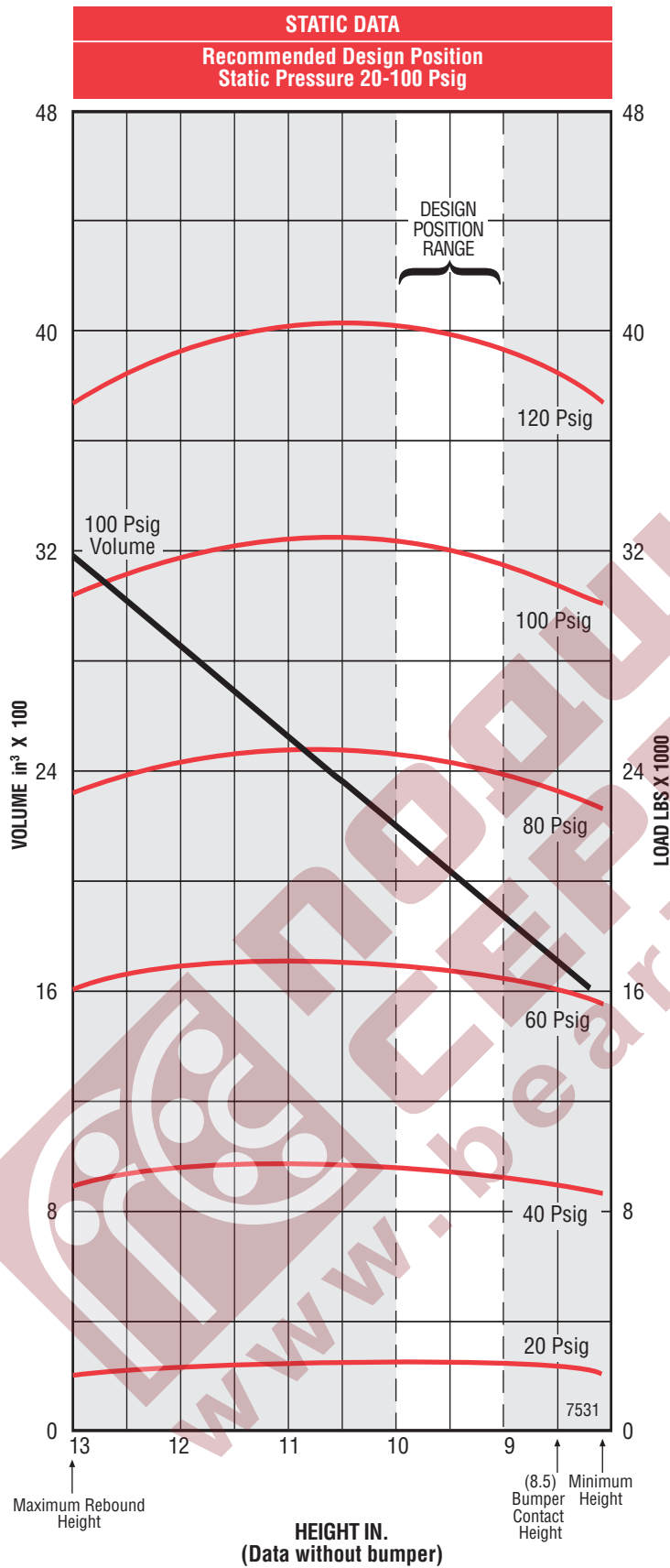
6204

Dynamic Load vs. Deflection



Lateral Spring Rate at 9.0" Design Height & 0.1 Hz frequency			
Pressure (psi)	Rate (lbs/in) at ± 0.5 in	Rate (lbs/in) at ± 1.0 in	Rate (lbs/in) at ± 1.5 in
20	1133	1153	1172
40	1440	1326	1269
60	1500	1345	1272
80	1435	1280	1164

7380



W01-358-8999 SHOWN
(WT 190 LBS)

100 Psig Data

Height (in)	Load (lbs)	Volume (in³)	B Dim. (in)
13.00	30533	3192.78	3.67
12.50	31382	3036.60	3.44
12.00	31982	2875.91	3.17
11.50	32335	2711.63	2.88
11.00	32503	2544.95	2.56
10.50	32538	2376.76	2.23
10.00	32445	2208.08	1.88
9.50	32174	2039.90	1.52
9.00	31658	1873.11	1.16
8.50	30870	1708.93	0.78
8.00	29930	1548.25	0.52

7531

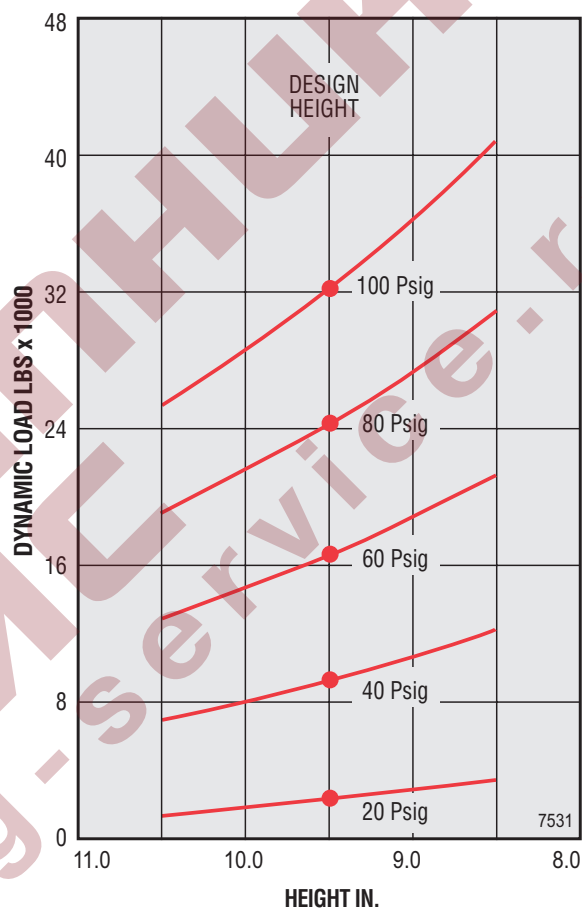
Dynamic Characteristic at Various Design Heights					
Design Height (in)	Load (lbs)	Pressure (psig)	Rate (lbs/in)	Natural Frequency	
				(CPM)	(Hz)
9.00	9000	28.4	2967	107.9	1.80
9.00	17000	53.7	4593	97.7	1.63
9.00	25000	79.0	6219	93.8	1.56
9.00	32000	101.1	7642	91.9	1.53
9.50	9000	28.0	2901	106.7	1.78
9.50	17000	52.8	4524	97.0	1.62
9.50	25000	77.7	6148	93.2	1.55
9.50	32000	99.5	7568	91.4	1.52
10.00	9000	27.7	2810	105.1	1.75
10.00	17000	52.4	4412	95.8	1.60
10.00	25000	77.1	6014	92.2	1.54
10.00	32000	98.6	7416	90.5	1.51

7531

Rate and Frequency with Increasing Volume at 9.5" Design Height and 100 psi			
Reservoir Volume (in³)	Vertical Rate (lbs/in)	Vertical Natural Frequency	
		(CPM)	(Hz)
0	7606.63	91.4	1.52
1000	4818.98	72.8	1.21
2000	3425.36	61.3	1.02
3000	2587.48	53.3	0.89
4000	2027.92	47.2	0.79
5000	1627.66	42.3	0.70
6000	1327.10	38.2	0.64
7000	1093.13	34.7	0.58
8000	905.79	31.5	0.53
9000	752.42	28.7	0.48
10000	624.54	26.2	0.44

7531

Dynamic Load vs. Deflection



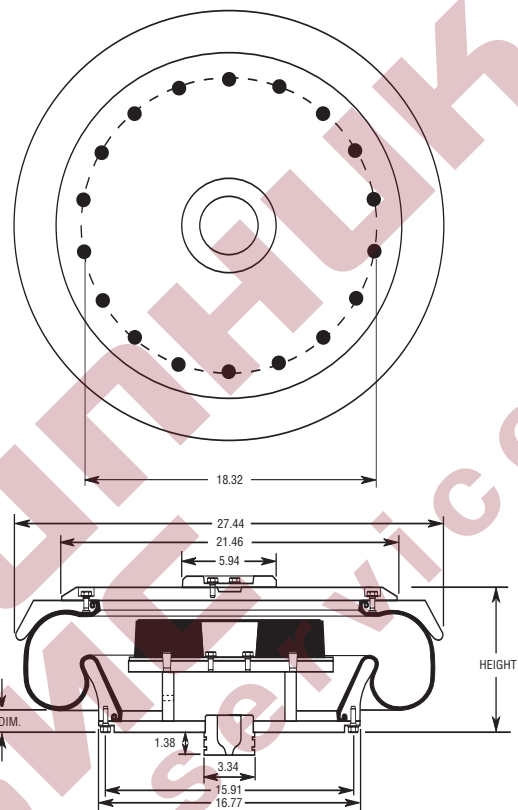
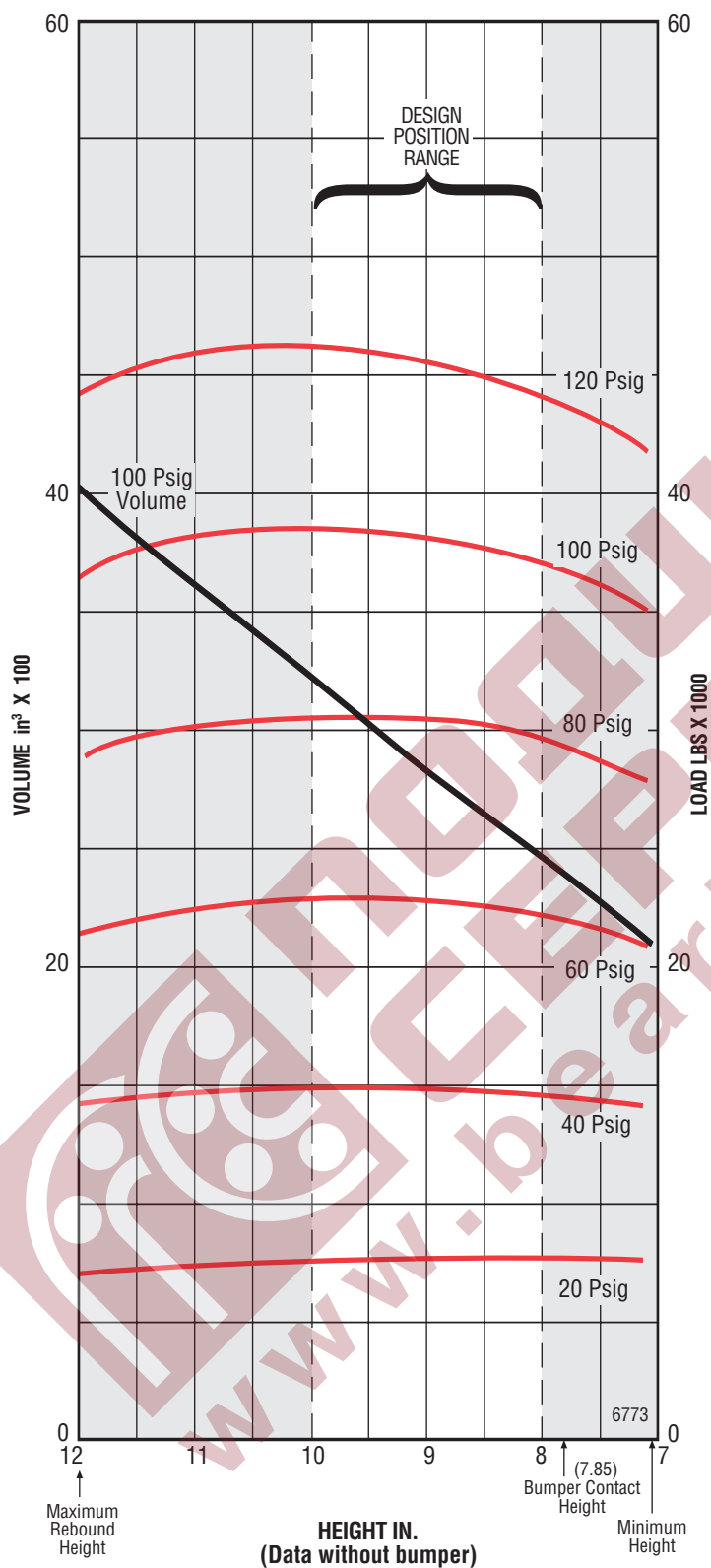
7531

Lateral Spring Rate at 9.5" Design Height & 0.1 Hz frequency				
Pressure (psi)	Rate (lbs/in) at ± 0.5 in	Rate (lbs/in) at ± 1.0 in	Rate (lbs/in) at ± 1.5 in	Rate (lbs/in) at ± 2.0 in
40	1125	1019	1000	984
60	1250	1125	1104	1103
80	1325	1187	1137	1125
100	1612	1312	1267	1250

7545

STATIC DATA

Recommended Design Position
Static Pressure 20-100 Psig



100 Psig Data

Height (in)	Load (lbs)	Volume (in ³)	B Dim. (in)
12.00	36586	4015.50	3.54
11.50	37518	3820.82	3.24
11.00	37949	3624.94	2.94
10.50	38159	3428.66	2.63
10.00	38259	3232.78	2.31
9.50	38245	3037.90	1.98
9.00	38047	2844.92	1.66
8.50	37583	2654.63	1.36
8.00	36810	2467.85	1.03
7.50	35776	2285.17	0.55
7.00	34675	2107.49	0.08

5773

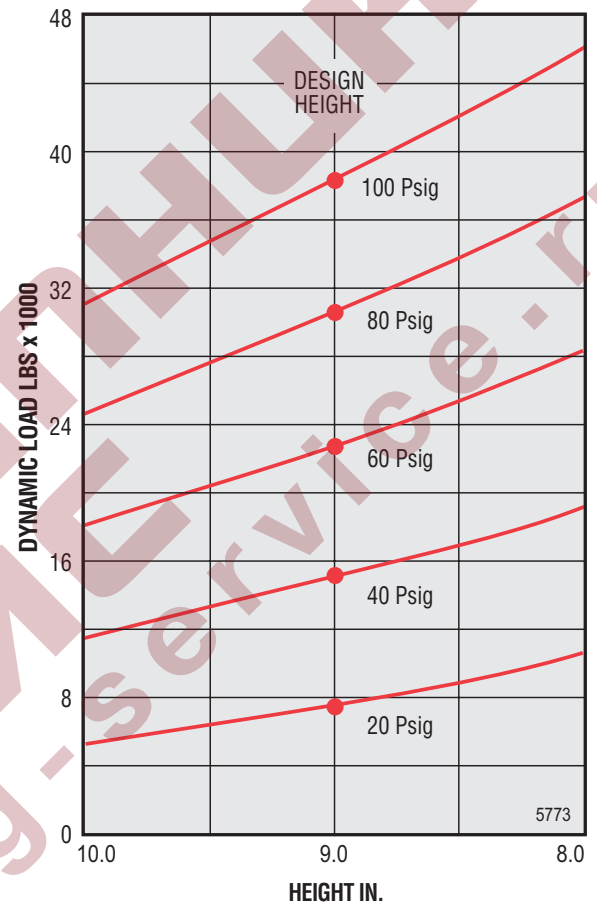
Dynamic Characteristic at Various Design Heights					
Design Height (in)	Load (lbs)	Pressure (psig)	Rate (lbs/in)	Natural Frequency	
				(CPM)	(Hz)
8.00	14000	38.0	3323	91.6	1.53
8.00	22000	59.8	4584	85.8	1.43
8.00	30000	81.5	5844	83.0	1.38
8.00	38000	103.2	7104	91.3	1.35
9.00	14000	36.8	3402	92.7	1.54
9.00	22000	57.8	4751	87.4	1.46
9.00	30000	78.8	6101	84.8	1.41
9.00	38000	99.9	7450	83.2	1.39
10.00	14000	36.6	3315	91.5	1.52
10.00	22000	57.5	4672	86.6	1.44
10.00	30000	78.4	6028	84.3	1.40
10.00	38000	99.3	7385	82.9	1.38

5773

Rate and Frequency with Increasing Volume at 9.0" Design Height and 100 psi			
Reservoir Volume (in³)	Vertical Rate (lbs/in)	Vertical Natural Frequency	
		(CPM)	(Hz)
0	7480.00	83.4	1.39
1500	4639.65	65.7	1.09
3000	3275.75	55.2	0.92
4500	2470.51	47.9	0.80
6000	1938.87	42.4	0.71
7500	1561.56	38.1	0.63
9000	1279.90	34.5	0.57
10500	1061.59	31.4	0.52
12000	887.40	28.7	0.48
13500	745.20	26.3	0.44
15000	626.92	24.1	0.40

5773

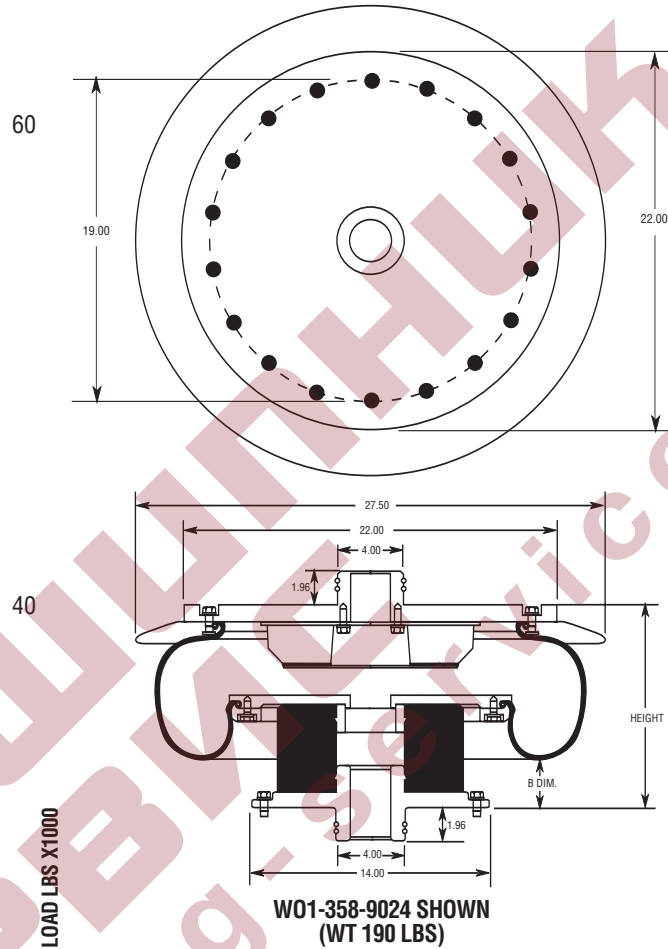
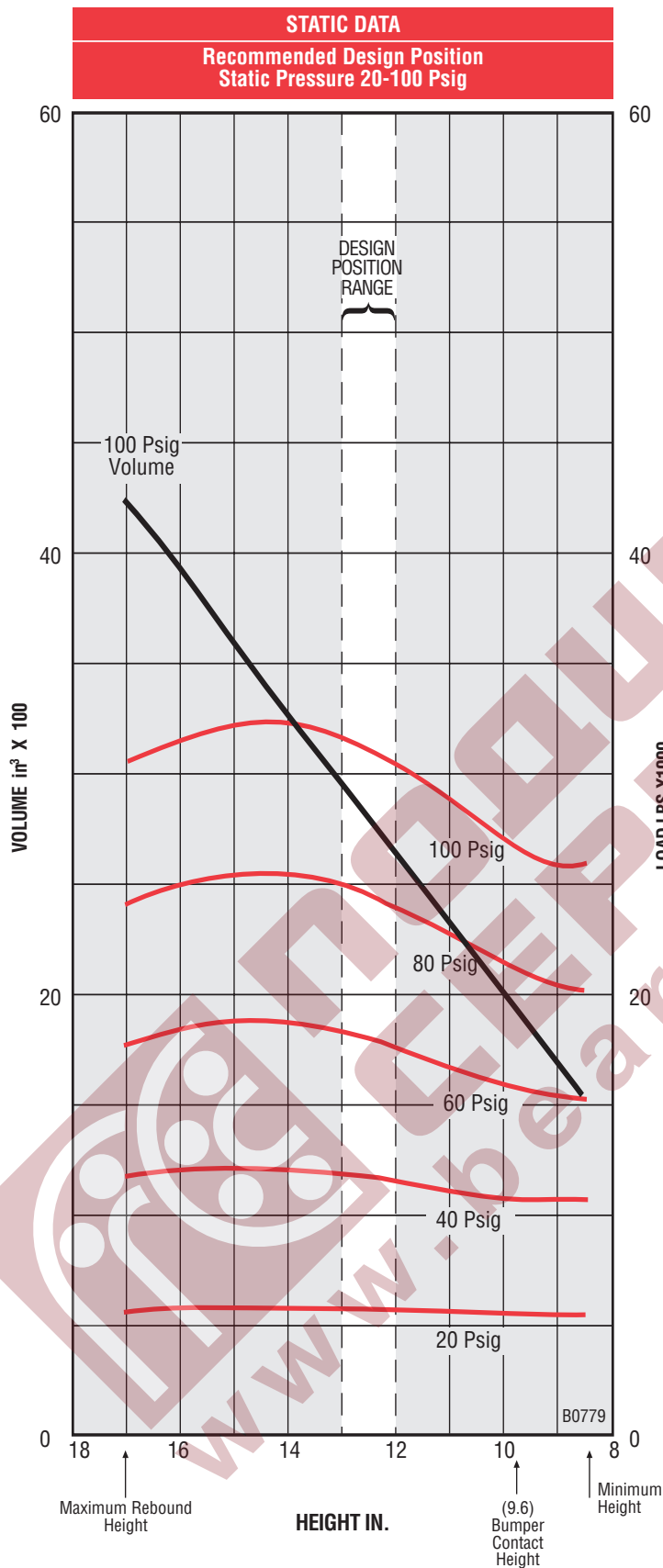
Dynamic Load vs. Deflection



5773

Lateral Spring Rate at 9.0" Design Height & 0.1 Hz frequency			
Pressure (psi)	Rate (lbs/in) at ± 0.5 in	Rate (lbs/in) at ± 1.0 in	Rate (lbs/in) at ± 1.5 in
60	2125	1450	1192
80	2250	1600	1317
100	2500	1737	1400

6945



100 Psig Data			
Height (in)	Load (lbs)	Volume (in ³)	B Dim. (in)
17.00	30715	4263.80	
16.50	31183	4109.72	7.32
16.00	31666	3951.81	7.04
15.50	32062	3790.89	6.79
15.00	32317	3627.78	6.46
14.50	32412	3463.29	6.15
14.00	32345	3298.24	5.80
13.50	32122	3133.45	5.48
13.00	31753	2969.72	5.12
12.50	31243	2807.89	4.71
12.00	30600	2648.76	4.38
11.50	29834	2493.14	4.00
11.00	28965	2341.86	3.62
10.50	28036	2195.73	3.25
10.00	27124	2055.56	2.90

B0779

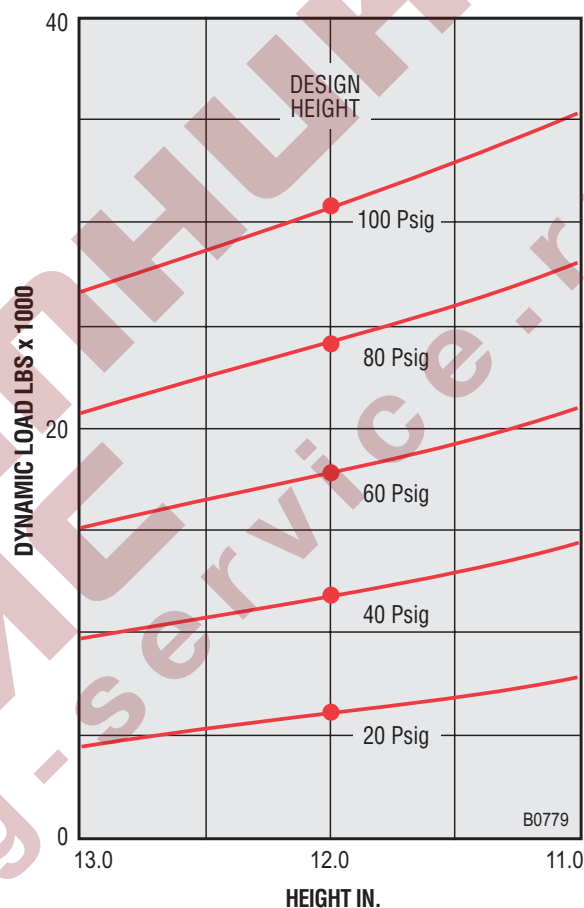
Dynamic Characteristic at Various Design Heights					
Design Height (in)	Load (lbs)	Pressure (psig)	Rate (lbs/in)	Natural Frequency	
				(CPM)	(Hz)
12.00	12000	39.2	2152	79.6	1.33
12.00	18000	58.8	2860	74.9	1.25
12.00	24000	78.4	3567	72.5	1.21
12.00	31000	101.3	4392	70.8	1.00
12.50	12000	38.4	2175	80.0	0.18
12.50	18000	57.6	2900	75.5	1.33
12.50	24000	76.8	3625	73.1	1.26
12.50	31000	99.2	4471	71.4	1.22
13.00	12000	37.8	2190	80.3	1.19
13.00	18000	56.7	2932	75.9	1.34
13.00	24000	75.6	3674	73.6	1.26
13.00	31000	97.6	4539	71.9	1.23

B0779

Rate and Frequency with Increasing Volume at 12.0" Design Height and 100 psi			
Reservoir Volume (in³)	Vertical Rate (lbs/in)	Vertical Natural Frequency	
		(CPM)	(Hz)
0	4347.20	70.9	1.18
1000	2762.61	56.5	0.94
2000	1863.81	46.4	0.77
3000	1283.99	38.5	0.64
4000	878.82	31.9	0.53
5000	579.69	25.9	0.43
6000	349.77	20.1	0.33
7000	167.52	13.9	0.23
8000	19.50	4.7	0.08

B0779

Dynamic Load vs. Deflection



B0779

Lateral Spring Rate at 12.0" Design Height & 0.1 Hz frequency				
Pressure (psi)	Rate (lbs/in) at ± 0.5 in	Rate (lbs/in) at ± 1.0 in	Rate (lbs/in) at ± 1.5 in	Rate (lbs/in) at ± 2.0 in
40	1250	1042	1042	833
60	1250	1042	1042	833
80	750	750	667	713
100	750	750	667	750

B0780





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