

THE COMPELLING CASE FOR AIR DISC BRAKES IN HEAVY TRUCK BRAKING: A WHITE PAPER



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THE EVOLUTION OF AIR DISC BRAKES

While already highly utilized in Europe and in select North American applications, air disc brakes are experiencing continued growth in popularity on North American highways with commercial vehicle fleets and owner-operators. Previously considered a niche technology for bus, coach, fire trucks, and other special applications, air disc brakes are becoming increasingly sought out for over-the-road applications. The growth in this braking technology is being driven by several factors, including:

- the critical demand for brakes to respond to higher speeds and lower natural retardation;
- the increasing expectation for safety and performance;
- the need for reduced maintenance, longer service intervals, and longer lining life;
- reduced stopping distance requirements in the United States; and
- reliability improvements in disc brake technology.



In 2010, Peterbilt Motors became the first North American heavy truck manufacturer to offer air disc brakes as standard equipment on a heavy truck. At the 2010 MidAmerica Truck Show, Peterbilt announced that the Bendix ADB22X™ air disc brake would become standard equipment on the steer axle of its Model 587.

To have a full appreciation of the evolution of foundation brakes, we must first understand their physics.

A fundamental rule of physics, the **Law of Conservation of Energy**, asserts that the total amount of energy in the universe remains constant over time. A corollary to this law is that energy can neither be created nor destroyed; it can only be transformed from one state to another. This fundamental rule also applies to heavy truck engines and brake systems. In the case of the diesel engine, the potential energy – energy stored in a body – is the diesel stored in the fuel tank. This potential energy is converted to kinetic energy – energy associated with motion – by the engine and drive train. While the drive train's key role is to move the vehicle, it is the primary responsibility of the braking system to bring it to a stop.

Energy Equation

The role of the foundation brake is to reduce the velocity of the vehicle – to slow it down. The heavier the load and higher the speed, the greater the kinetic energy and, subsequently, the greater the braking demand.

Kinetic energy is defined by the equation:

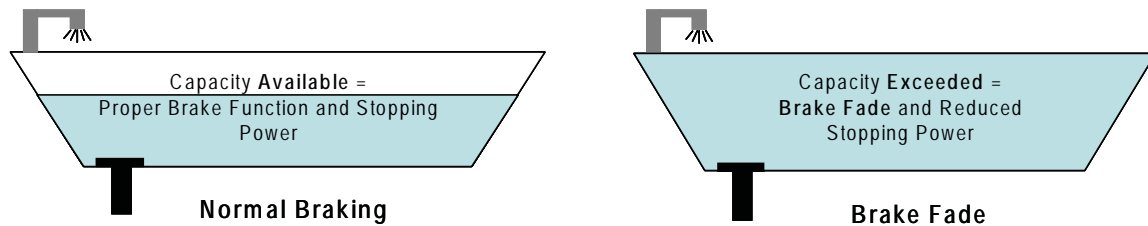
$$KE = \frac{1}{2}MV^2$$

In this equation, KE is kinetic energy, M is mass or load, and V is velocity or speed.

When considering this equation, two things are clear: (1) the impact of vehicle weight on braking demand is significant, but linear; and (2) the impact of speed on brake demand is exponential. When factoring in the **Law of Conservation of Energy**, the kinetic energy of the moving vehicle must somehow be transformed as the vehicle slows and eventually stops. In the case of the braking system, this energy is transferred into work and heat. *The brake systems' ability to generate the required torque to slow the vehicle, and then dissipate this heat into the atmosphere, becomes the most important aspect of any vehicle braking system.*

Heat Dissipation and Thermal Capacity

As the brake system converts energy into heat, two factors become important: (1) the amount of heat the system can retain – commonly referred to as thermal capacity; and (2) the rate at which it releases that heat into the atmosphere, known as the heat dissipation rate. To illustrate this point, we can use the analogy of a common bathtub.



In the bathtub illustration, the amount of water the tub can hold is its **capacity**. In the case of the braking system, **thermal capacity** is largely dependent upon the size, shape, and material of the drum or rotor. Drum and rotor materials are primarily made of cast iron, an economic material that provides the needed thermal capacity. Lighter-weight drum designs use less cast iron – or a combination of iron and steel – to achieve reduced weight. Unfortunately, this weight reduction comes at the expense of the system's thermal capacity.

Continuing with the bathtub analogy, the rate at which water is added to the tub by the faucet is similar to the rate at which the braking system adds heat to its capacity as it **transforms energy into heat** during active braking. As the brakes are applied, the temperature increases.

In this example, as water continues to fill the tub, the drain simultaneously removes water, preventing it from overflowing. In a steady-state condition, the tub must drain *faster* than the faucet adds water. The function of the drain is similar to the brake system's objective to **dissipate heat**. An example of how this analogy applies to the braking system is illustrated in sustained downhill braking. In this situation, the brakes are used constantly, adding heat to the system over a sustained period of time without the luxury of a complete cool down.

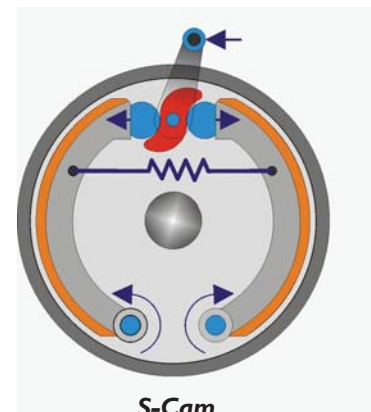
Going back, once again, to the bathtub illustration, we analyze what will happen if the drain is unable to keep pace with the rate at which water is being added. In this scenario, the tub will overflow. Overflowing water means that the capacity of the system has been exceeded. This is parallel to the braking phenomena known as **fade**. Fade is the condition in which the **thermal capacity** of the braking system has been exceeded and the **system operates at reduced effectiveness**.

TYPES OF COMMERCIAL VEHICLE FOUNDATION BRAKES

Foundation Drum Brakes

S-Cam Brakes

The most common type of foundation drum brake is the **S-Cam Brake**, commonly referred to simply as **Cam – or Drum – Brakes**. Cam Brakes are actuated by applying input force from an **air chamber or actuator**. This force acts against a lever arm, which doubles as a slack adjuster to turn the camshaft. The head of the camshaft actuates both brakes' shoes and resembles the letter "S." It is this feature that gives the S-Cam Brake its name. Because of their simple design, relatively light weight, and economic cost, S-Cam Brakes are currently used on approximately 95 percent of all North American Class 5-8 air-braked vehicles.



S-Cam

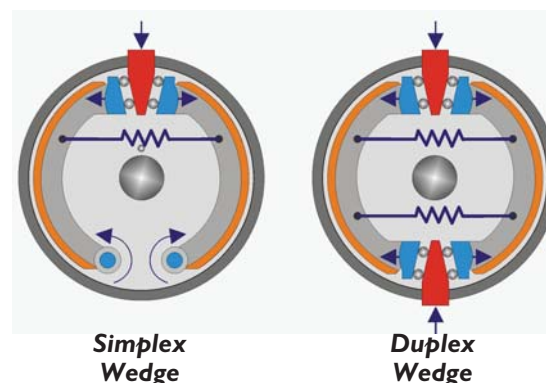
Since 1995, all air-brake equipped vehicles in the United States and in Canada have been required to use **automatic slack adjusters**, commonly referred to as **ASAs** or simply "**slack adjusters**." The ASA keeps the brake in constant adjustment by advancing the camshaft forward as the friction material wears. As the slack moves to and from its reference point, it advances its position as the specified brake application stroke is exceeded. This helps the vehicle maintain a reasonable brake stroke as the brake lining wears. The ASA is integrated into the brake lever and is generally mounted toward the inboard side of the chassis, along with the air chamber and parking brake.



Automatic Slack Adjuster (ASA)

Wedge Brakes

Although no longer common in North American applications, the other major drum brake design is the **Wedge Brake**. There are two types of Wedge Brakes: **Simplex** (single actuation) and **Duplex** (dual actuation). With greater complexity, cost, and relatively high **hysteresis** (release responsiveness), Wedge Brakes have been relegated to specialty and niche applications where their robust sealing, compact packaging, and durability warrant the added weight and cost. Unlike the S-Cam Brake, the Wedge Brake's adjusting mechanism is incorporated into the housing of the brake itself.



Simplex Wedge

Duplex Wedge

As a result of their design, all drum brakes – S-Cam and Wedge – incorporate a varying internal amplification, which is expressed by the brake factor “C*.” This parameter defines the relationship between the brake’s braking (output) force and actuating (input) force. The brake factor “C” is determined by the friction coefficient of the friction material used and the mechanical advantage of the brake design. Because the friction coefficient, brake stroke, lining, and drum condition can all vary slightly between wheel-ends, the variation is amplified by the mechanical advantage of the brake design. This factor results in a greater sensitivity to variation in drum brakes. The heightened sensitivity can result in moderate levels of torque output variation between like brakes on either side of the axle. These phenomena – coupled with its susceptibility to fade – represent the general shortcomings of drum brakes.

Air Disc Brakes

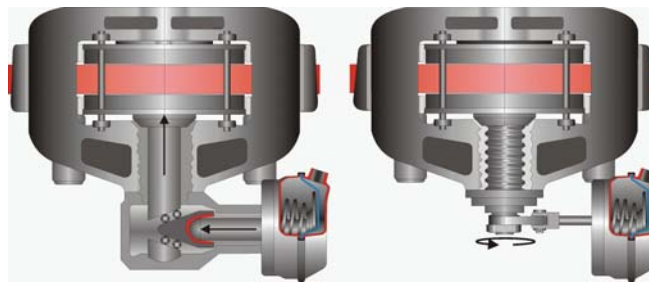
Air Disc Brakes – often referred to as ADBs or disc brakes – offer an alternative to drum brake designs. When compared to drum brakes, air disc brakes have a number of advantages, including:

- **No exaggeration of friction coefficient differences:** This results in improved side-to-side consistency between left and right brakes.
- **Reduced fade:** Consistent contact between the friction surfaces remains, even with brake disc warm-up and radial expansion.
- **High thermal load:** Heat dissipation is efficient for internally vented brake discs. As such, it is possible to maintain high braking performance, even in demanding conditions.
- **Minimal and consistent hysteresis:** This is due to the high efficiency of the actuating mechanism.
- **Servicing ease when changing brake pads:** When compared to drum brakes, disc brakes require only a fraction of the service time.

These advantages – coupled with an increasing demand for higher performance, safety, and less frequent maintenance – have resulted in the growing acceptance of conventional air disc brake designs.

Early Air Disc Brake Designs

Air disc brakes have been used on North American air-braked vehicles since the early 1980s. Early designs were actuated by either a single power screw or a wedge. Although relatively lightweight and economical, these initial designs were used primarily in heavy trucks and specialty vehicles. While greeted enthusiastically by fleets and end users that desired the improved performance and safety they could deliver, early air disc brake designs were plagued by a number of design shortcomings, as well as difficulties with maintenance and service.



Early air disc brake designs featuring wedge and power screw actuation

Design Shortcomings of Early Air Disc Brakes

Initial air disc brakes were earmarked by a number of shortcomings in their design, including:

- a power screw design that had good apply but poor release characteristics (Hysteresis ~ 30 percent);
- slide pins that were chrome plated and unprotected, making them subject to flaking, corrosion, and seizing;
- pads that were attached to the brake caliper, making the caliper subject to clamp load and brake torque;
- a single-piston design, which did not provide uniform pad wear; and
- brake rotors that were undersized (typically 15 inches) and not optimally designed, increasing their potential for cracking.

Maintenance and Service Challenges of Early Air Disc Brakes

The first air disc brake designs also came with inherent maintenance and service challenges, including:

- designs that were not sealed, meaning they required regular lubrication;
- pad changes that were both time consuming and difficult, adding substantial cost to overall maintenance expense;
- exposed slide pins that often became corroded, causing caliper seizure and unequal inner-to-outer pad wear; and
- pad-to-rotor clearance that was dependent upon rotor vibration for proper return and clearance.

CURRENT GENERATION AIR DISC BRAKES

Lessons learned from prior technologies have enabled an evolution to the modern, effective designs that have overcome the shortcomings of both drum brakes and the early offerings of disc brakes. Today's air disc brake offers maximum stopping power, passenger car-like feel, longer pad life, reduced fade, and faster service time than their predecessors. To the delight of a rapidly growing customer base, the air disc brake of today is an engineering achievement. It is rapidly moving away from its roots as a brake for specialty and niche applications and emerging as a viable option for everyday use.

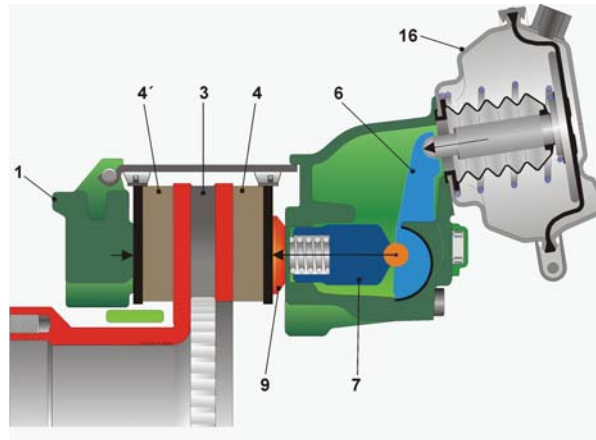
Due to its wheel-end packaging, limited space inside the wheel, the valve stem location, and the axle and suspension system, special consideration must be given to the positioning of the air disc brake on the axle. It should be assumed that the size of the brake is dependent upon the wheel size. In addition, the floating caliper design dictates that the brake must move as it actuates.



Wheel-end Packaging

Understanding Air Disc Brake Operation

To understand the intricate operation of the air disc brake, it is beneficial to first become familiar with the fundamentals of air disc brake actuation.



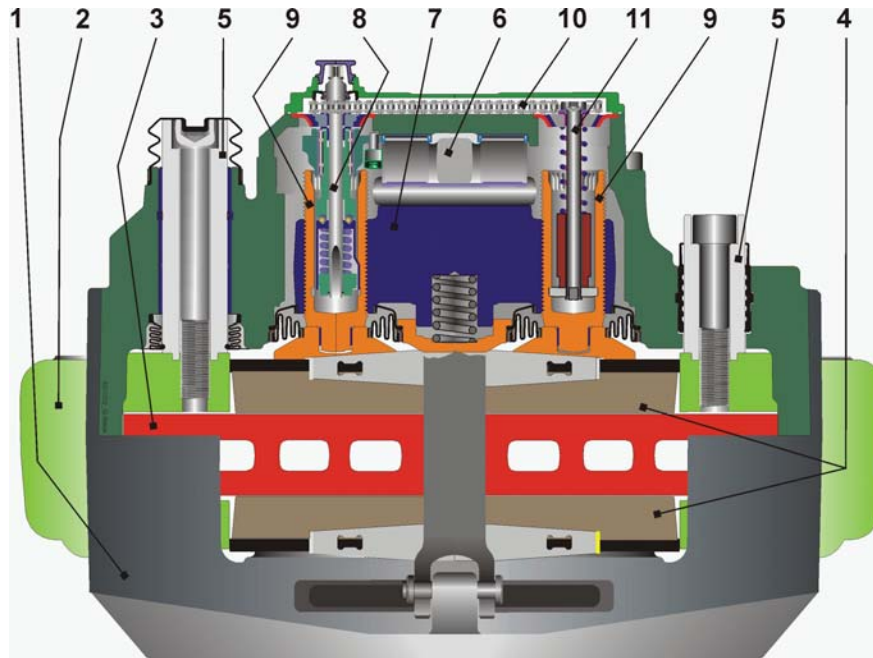
The Actuation System

First, the actuation system of today's air disc brake consists of the brake actuator (item 16, above) directly screwed to the brake, as well as the brake lever and the pressure piston – both located within the brake itself. The brake lever (6) amplifies the actuating force produced by the brake actuator. The brake lever is supported by roller bearings on the brake caliper's back plate, which minimizes friction and hysteresis.

Next, when pressurizing the brake actuator (16), the eccentrically supported lever (6) is actuated by the brake actuator's piston rod. The brake actuator force is amplified according to the lever multiplication in relation to the piston force. It is transmitted to the brake pad (4) via the bridge (7) and the screwed-on, threaded spindles on the piston (9). As a result of this transmission, the brake pad (4) is pressed onto the brake disc (3).

Finally, the reaction force that is created at the brake caliper is transferred to the opposite brake pad (4), pressing it onto the brake disc with the same force. The brake actuation force produced by this action depends upon the brake pressure applied by the brake actuator (16), the brake actuator size, and the brake lever multiplication ratio.

The Floating Caliper Design



Air disc brake cutaway view

The floating caliper air disc brake consists of two main components: the caliper (item 1, above) and the carrier (2).

The brake caliper, which includes the actuating system and the adjusting mechanism, holds the brake actuator and applies the clamping force to the brake pads (4) on both sides of the brake rotor (3).

The brake carrier (2) is rigidly mounted to the axle and carries the brake caliper (1), enabling the caliper to be axially displaced via the slide pins (5). The carrier holds the brake pads (4) and absorbs the circumferential load exerted by the application of the brakes, transferring this load to the axle. The reaction force resulting on the actuation side during each brake application causes the displacement of the brake caliper (1). This displacement is so significant that the air gap is overcome on the brake disc side where no brake actuation takes place. The clamping force compensates for the elastic deformations of the brake caliper (1) and brake pad (4). When the brake actuation has been completed, the brake caliper (1) returns to its initial zero-force position.

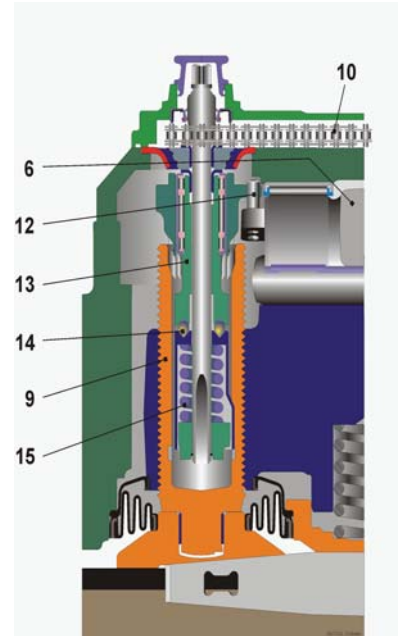
In the event of wear, the wear adjusting system gradually moves the brake caliper (1) from its initial position so that a constant – and small – air gap between the brake pad (4) and the brake disc (3) is always on the side where no brake actuation takes place.

The Internal, Automatic Adjuster

Unlike most drum brake designs that have a separate, external automatic slack adjuster, air disc brakes are equipped with an internal, automatic, wear-adjusting system. The basic function of these adjusting mechanisms is the same as that of both the drum brake and first-generation disc brake designs: **to maintain brake stroke and compensate for wear of the friction material.**

To comprehend this concept, it must first be understood that the amount of adjustment is independent of the brake force, but dependent upon the amount of the brake stroke or travel. Clearance is defined to ensure that the initial travel of the brake lever occurs at the beginning of each brake application without any unintentional adjustment. The piston stroke covered during this idle movement is described as the **design clearance** and is defined by geometric values in the adjuster drive mechanism. The mechanism only adjusts when its defined brake stroke has been exceeded.

To guard against the tapered lining wear that plagued early air disc brake designs, modern ADBs feature dual – or twin – **pistons**, which are also referred to as **tappets**. To ensure even adjustment across both tappets, each is synchronized by a chain (1). The adjuster (2) is installed in the driving tappet and connected to the driven tappet by the chain (1). This guarantees the synchronization of both tappets.



Adjuster Mechanism

The Friction Couple: The Brake Pad & Rotor

When specifying brake systems, the importance of the brake pad and rotor are often overlooked. In fact, because of this oversight, end users often select replacement parts that are not recommended by the brake manufacturer, which can lead to a variety of problems later in the vehicle cycle. The non like-for-like components they select are often attractively priced, but fail to meet the high standards set by the original equipment manufacturers of the vehicles and brakes. The resulting problems can include: noise, lack of stopping power, shorter pad life, rotor cracking, and uneven wear. To address these concerns and maintain the intended performance level of the foundation brake system, **end users should always use original equipment as replacement parts.**

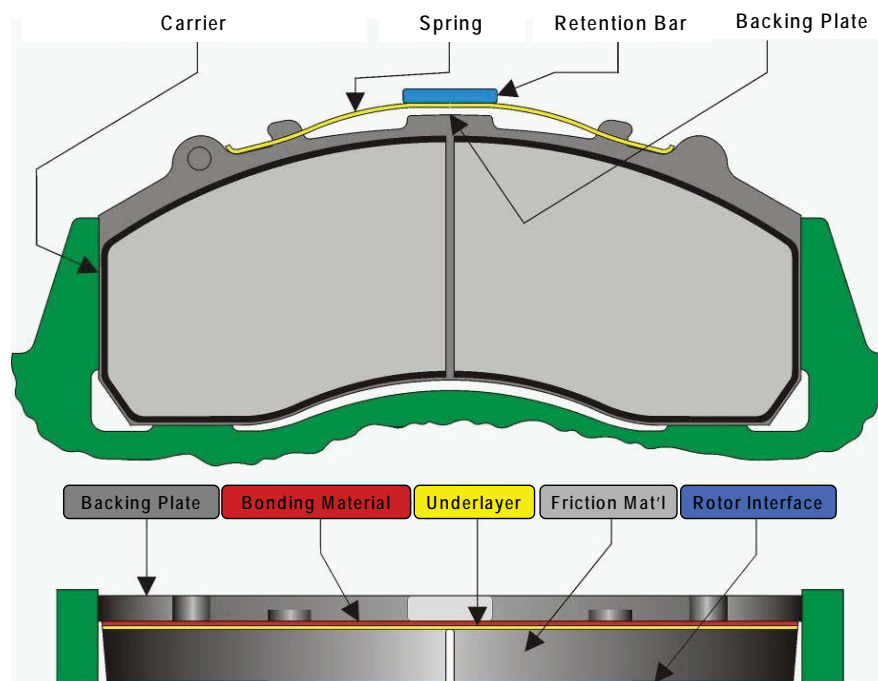


Illustration of Air Disc Brake Pad and Hardware

The Brake Pad

The **brake pad's** basic function is to provide the primary means of applying the friction material to the rotor, retain that material in the brake assembly (also known as controlled erosion), and provide a rigid surface (backing plate) for the tappets to apply the necessary force for the application of the friction material to the rotor. Because of the critical nature of the support the brake pad provides to braking activity, the friction material is an extremely important aspect of the brake assembly and its function. The brake pad helps ensure:

- **High compressibility:** Compressibility (= low E-module) results in even pressure distribution. As a result, the required working stroke of the brake actuator is increased and brake vibrations are damped.
- **Thermal transmission:** Good heat dissipation can relieve the thermal increases within the rotor, but results in high temperatures of the surrounding brake components.
- **Thermal expansion:** This defines the brake's required minimum air gap. The gap, in turn, defines the response behavior and the stroke requirement of the brake.
- **Elastic recovery:** Elasticity is required, even when pressure has been applied to the brake (e.g., parking brake) over a long period of time. An undesirable reduction of the air gap can result when the brake pads slowly return to their initial thickness (the memory effect). This reduction is caused by the activation of the adjusting mechanism during the actuation time of the brake.

The Brake Rotor (Disc)

Along with the brake pads (friction material), the **rotor** has the task of producing the braking torque necessary to slow or stop the vehicle. As discussed on page four of this paper in “***The Physics of Foundation Brakes***,” during braking, **kinetic energy** is transformed into **work** and **heat**. As the braking action takes place, torque is transmitted from the rotor to the hub, from the hub to the wheel, and from the wheel to the tire. Ultimately, stopping occurs where the tire and the

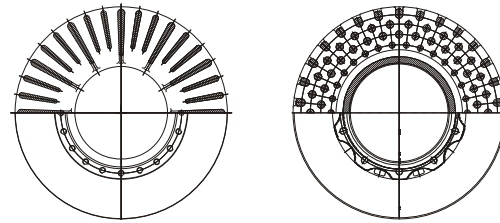
road surface connect. It is important to understand that only a small amount of the heat generated during the stopping action is absorbed by the brake pads. This is advantageous to the brake system, as it helps provide protection to the brake and its internal components. The majority of the heat generated during stopping is absorbed – and temporarily stored – by the rotor. As illustrated in the bathtub example on page five, the rotor's capacity to absorb heat is finite. To maintain proper brake function,



Bendix® Splined Disc Rotor

the rotor also has the task of acting as a heat exchanger, quickly dissipating the heat created when braking into the surrounding air. Solid rotors have limited heat dissipation characteristics. As a result, they are rarely used in heavy truck applications.

Similar to most passenger car designs, most commercial vehicle rotors are vented. These vents create a significantly larger surface area for improved heat dissipation. In these designs, two iron braking surfaces are connected via webs, which are in the form of ribs (also referred to as veins) or nubs. Ventilation is produced when the rotor turns, venting the heat into the surrounding air.



**Examples of Rotor
Veins and Nubs**

For some time in the United States and Canada, there has been a desire to reduce the gap between the stopping capability of passenger cars and that of heavy trucks. Over the past five years, the drive to achieve such a reduction was the primary impetus for the increased focus on reduced (shorter) stopping distances. As a means to reach this goal, in the summer of 2009, the **National Highway Traffic Safety Administration (NHTSA)** issued new braking standards for commercial truck tractors. The organization's new reduced stopping distance (RSD) requirement is defined by a series of updates to the **Federal Motor Vehicle Safety Standard (FMVSS) 121**. These updates reduce the required stopping distance of tractors traveling at 60 miles per hour (MPH) from today's 355 feet to 250 feet – a 30 percent reduction.

The transition to the new RSD requirement will be completed in two phases from 2011 to 2013. Phase one – which focuses on standard 6x4 tractors, takes effect August 1, 2011. It will address approximately 70 percent of all new heavy tractors built after that date.

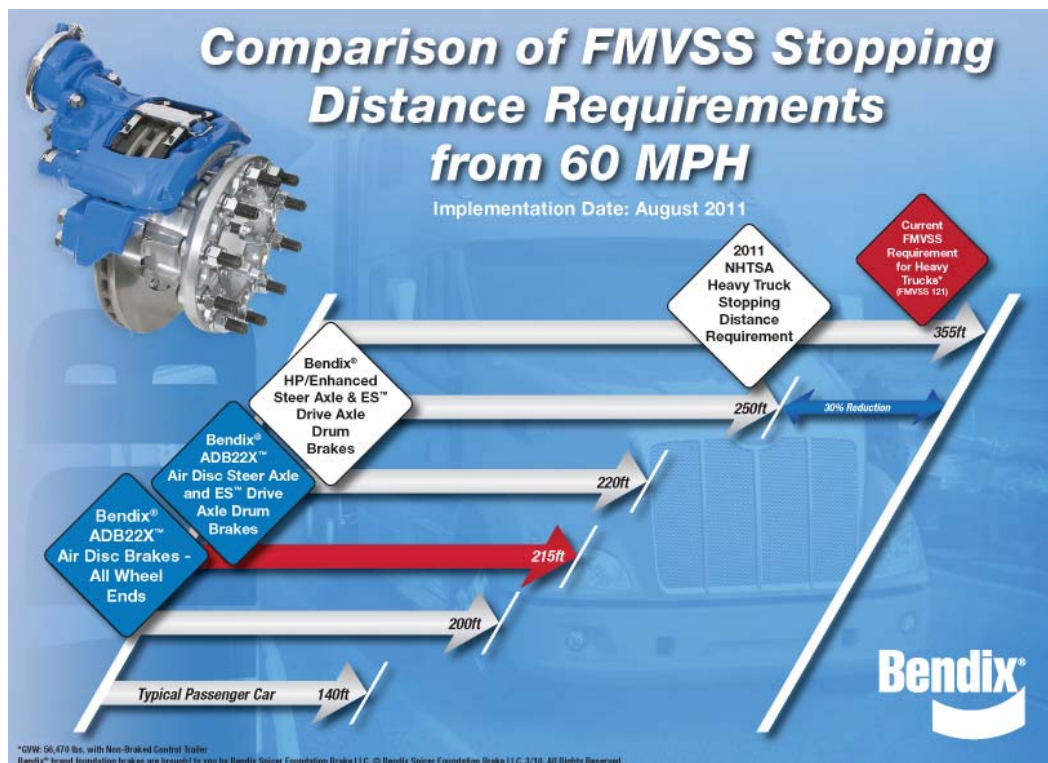
The remaining new truck tractor production, which includes 6x4 severe service tractors, as well as all 4x2 tractors, will take effect in August 2013. All vehicles in use before that date, including straight trucks, buses, and trailers, will be considered exempt.

New Heavy Truck Tractor Stopping Rules

Phase	Axle Configuration	GVWR	New Requirement	Compliance Date
Phase 1	Standard 6x4	Below 59,600 lbs.	250 feet	Aug 2011
Phase 2	6x4 Severe Service	59,600 – 70,000 lbs.	250 feet	Aug 2013
	6x4 Severe Service	Above 70,000 lbs.	310 feet	Aug 2013
	All 4x2 Heavy Tractors	All	250 feet	Aug 2013

Source – U.S. Code of Federal Regulations 2009. Title 49: Transportation Section 571.121 - Air brake systems.

The impact of these new requirements is significant. They will play an integral role in driving the need for larger, more powerful brakes and friction materials, particularly on the steer axles, where the typical brake sizes are considerably smaller and less powerful. **It is important to understand that the launch of the new RSD rules will not require air disc brakes.** Instead, the new mandate **will bring larger, more powerful brakes into the forefront, making them the norm within the industry.** As air disc brakes become more common, the corresponding price and weight delta, which in the past served as barriers to faster acceptance of the technology, will decrease.



THE GROWING POPULARITY OF AIR DISC BRAKES ON TODAY'S HEAVY TRUCKS



End users consistently expect specific outcomes from their heavy truck braking systems. In addition to achieving shorter stopping distances, fleets and owner operators have an ongoing desire to reduce operating costs, improve braking stability and feel, and decrease fade – all the benefits that air disc brakes decidedly provide. The chart below provides an overview of the features – and corresponding benefits – that air disc brakes offer to meet end user needs.

Superior Performance	Shorter Stops	Stops 42 feet shorter than today's drum brakes** from 60 MPH
		Stops 100 feet shorter than today's drum brakes** from 70 MPH
	Better Braking Feel	Passenger car like feel
		Improved side to side brake consistency
Lower Maintenance	Safety	Greater braking power can result in fewer accidents
	Longer Lining Life	Typically twice the lining life of drum brake applications
	Sealed Design	Sealed design, no periodic lube required
		Sealed reliable, integrated automatic brake adjustment
Light Weight	Quick Pad Changes	Quick change pads – 15 minutes per brake (with wheels off)
	Design Optimization	Weight comparable to high performance larger (16.5") front drum brakes
		Patented splined rotor design with Aluminum Hubs for optimized weight
		Lightwest dual piston air disc brake available

**Standard drum brakes compared to all wheel disc brakes on a 6x4 Tractor, 59,470 pounds GVW, un-braked trailer

With continued advancements in technology and increasing demand for improved safety and performance, the growth of air disc brakes is just beginning. Their superior performance, ease of maintenance, and lighter weight make air disc brakes a viable option for everyday applications, as well as the ideal solution for meeting new RSD requirements.



**Bendix Spicer
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