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***A Comparative Analysis of Drum, Cast Iron, Carbon–
Ceramic, and Regenerative Braking Systems and
their effectiveness in motorsport.***

Academic and Laboratory skills (ACHA4032)

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November /2025

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1 Abstract

This report compares drum brakes, cast-iron discs, carbon-ceramic brakes, and regenerative systems in motorsport. It evaluates their performance, thermal efficiency, and suitability for racing applications. Disc brakes outperform drums, while carbon-ceramics offer superior heat resistance, lower weight, and durability. Regenerative braking recovers energy and supports hybrid systems. Overall, modern braking technologies enhance performance, consistency, and efficiency in competitive motorsport.

2 Introduction

Brakes are a fundamental component of every vehicle, providing both safety and control while allowing drivers to push the limits by braking later and gaining valuable time. In motorsports, efficient braking enables stable corner entry and maximises cornering speed, directly correlating to faster lap times. Achieving this requires advanced braking technology capable of storing and dissipating heat as effectively as possible.

Braking systems have evolved significantly over time, from inefficient drum brakes to cast iron rotors, to lightweight carbon-ceramic assemblies and now to regenerative systems that simultaneously decelerate the vehicle and recharge hybrid batteries. These technologies are especially critical in motorsports such as World Endurance Hypercar and Formula 1, where braking efficiency, thermal management and energy recovery are vital to both performance and reliability.

This report compares four major braking technologies used in motorsports: drum brakes, steel disc brakes, carbon-ceramic disc brakes and regenerative systems. This report will evaluate their design principles, performance benefits, and engineering trade-offs. The report will also focus on their historical developments, current applications and current innovations that are driving the industry forward.

3 Background

3.1 Drum Brakes

According to Hu (2023), drum brakes were invented in the early 1900s and were the first brakes used in automobiles. Hu identify five types of drum brakes, Simplex, Duplex, Uni-Servo, Duo-Servo, and Duo-Duplex. All of these have two brake shoes but differ in features such as the number and arrangement of wheel cylinders. Hu (2023, p.109) states that: “when the driver presses on the pedal, the hydraulic pressure in the drum brakes increases, the piston pushes the brake shoe outward, and the friction material on the brake lining is pressed against the brake drum and creates friction to slow down

the vehicle. When keeping the brake pad free, the brake shoe returns to its original position, and the wheel rotates normally.”

One of the main advantages of drum brakes is their low manufacturing cost compared to disc brakes. The design also benefits from its enclosed construction, which provides better protection from dust, debris and water making them durable and reliable in basic applications. Additionally, they are also convenient for integrating the parking brake mechanism within the same assembly.

Due to the enclosed design, drum brakes are often attributed with poor heat dissipation which can lead to fading during heavy braking scenarios. This is not ideal for high performance or racing conditions. Despite this, drum brakes have found a place in low cost and light duty vehicles, playing to their strengths of being cheap and relatively low maintenance.

3.2 Disk Brakes

V. Yadav and P. Yadav (2020, p. 1763) state that: “A disc brake is a type of brake that uses the callipers to squeeze pairs of pads against a disc or ‘rotor’ to create friction. This action slows the rotation of a shaft, such as a vehicle axle, either to reduce its rotational speed or to hold it stationary.” The main components of a disk brake are the brake pads, rotor, calliper and calliper support. Modern brakes are ventilated, “Ventilated discs have passages or an air vent that helps pass air through the disc. Thus, it provides cooling and prevents fading” V. Yadav, P. Yadav (2020, p.1765).

Cast iron has historically been the dominant material for brake discs due to its excellent thermal conductivity, strength, and cost-effectiveness. It provides reliable performance under repeated braking cycles and can withstand high temperatures without significant warping. However, cast iron discs are considerably heavy, increasing unsprung mass and reducing handling responsiveness. They are also susceptible to corrosion and can experience thermal cracking or distortion under extreme motorsport conditions, which limits their performance compared to newer composite or carbon-ceramic alternatives.

3.3 Carbon Ceramic Discs

Carbon-ceramic brakes are high-performance discs made from carbon fibres and ceramic materials, primarily used in racing and luxury sports cars (Tech-9, 2025). They operate like standard disc brakes, with callipers pressing pads against a rotor to create friction.

Their main advantages include excellent heat management, preventing brake fade under heavy use, and low weight, which improves handling by reducing unsprung mass. They are also very durable, lasting over 100,000 miles, and produce minimal brake dust (Tech-9, 2025). However, they are expensive to manufacture and repair, and performance can be reduced when cold (Tech-9, 2025). Despite these drawbacks, carbon-ceramic brakes are a key technology in motorsport and high-performance vehicles.

3.4 Regen Braking

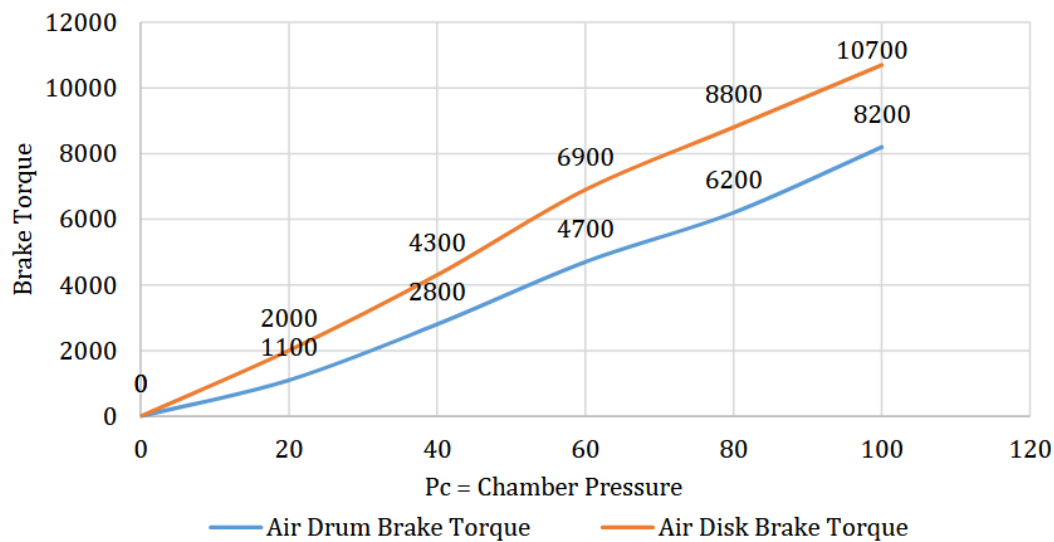
Regenerative braking decelerates a vehicle by using the electric motor instead of traditional friction brakes. The motor's rotation is reversed, generating resistance that slows the car while simultaneously converting kinetic energy into electrical energy, which is then stored in the battery for later use. It allows electric vehicles and hybrids a way to regenerate energy without charging outright.

4 Analysis

A study by Ampadu et al. (2023) used data from Dunn (2003) to compare braking pressure between drum and disc brakes. Although the original tests were conducted on trucks, Ampadu et al. consistently found that disc brakes produced greater braking torque than drum brakes at the same hydraulic pressures. They found that the higher

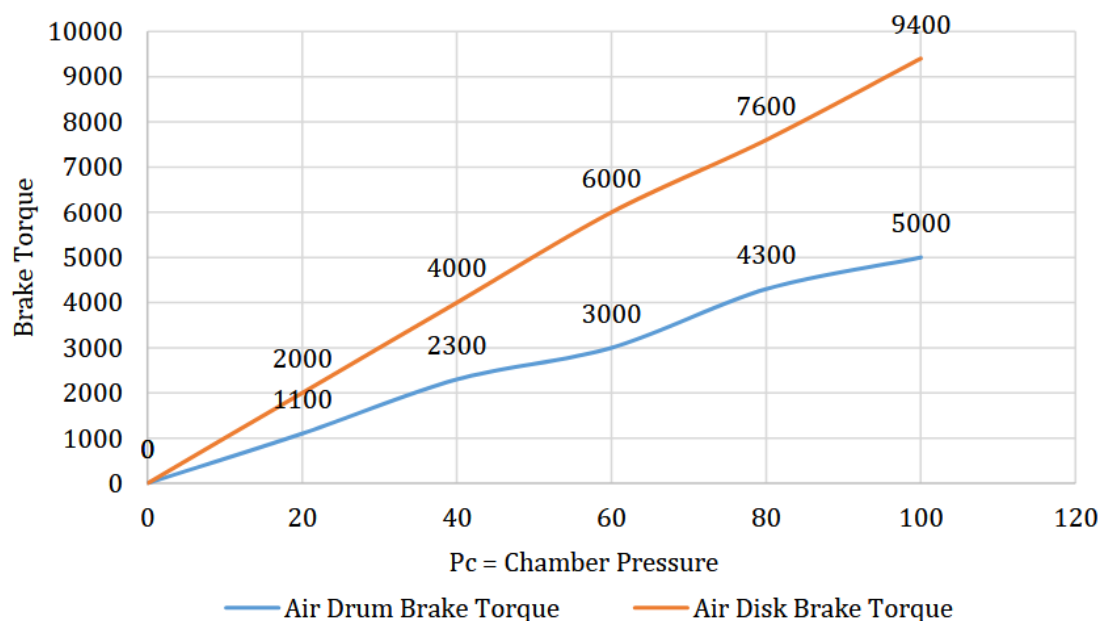
the speed, the greater the delta in brake torque was.

Figure 3: Steer Axle Air Drum Brake & Air Disc Brake Torque vs. Pressure at 32 km/h



Source: Dunn, 2003

Figure 5 Steer axle air drum brake & air disc brake torque vs. pressure at 97 km/h



Source: Dunn, 2003

At 32 km/h, the mean braking torque of disc brakes was approximately 30% higher than that of drum brakes. However, at 97 km/h, this difference increased to around 46%. The data also showed that the performance gap widened further at higher chamber pressures, particularly at higher speeds. This demonstrates that disc brakes maintain

superior performance compared to drum brakes under more demanding conditions. This finding aligns with their universal adoption in modern motorsport, where all competitive racing vehicles now employ disc brake systems due to their higher thermal efficiency and braking consistency.

Carbon-ceramic brakes offer major advantages over cast-iron discs. According to Motor1 (2024), they weigh up to 50% less, reducing unsprung mass and improving acceleration, handling and responsiveness. They also perform consistently at temperatures exceeding 500 Celsius where cast-iron brakes typically fade due to heat buildup. Carbon-ceramic rotors resist corrosion and can last the vehicle's lifetime, while cast-iron ones wear and warp over time. However, their high cost at around 9000 dollars per set plus their reduced cold performance make them impractical for everyday use. Overall, cast-iron brakes remain cost-effective, but carbon-ceramics deliver superior performance and durability for high-end or motorsport applications.

According to Gumbrell (2024), regenerative braking allows a vehicle to recover kinetic energy during deceleration and store it in the battery instead of wasting it as heat. He states: "regenerative braking slows down the car by turning its forward motion into electrical energy, which can then be stored in the battery" (Gumbrell, 2024). In addition, regenerative braking reduces wear on traditional friction brakes, thereby lowering maintenance requirements.

Gumbrell (2024) also outlines several limitations: although the system operates seamlessly in many vehicles, drivers may require adjustment time to adapt to its behaviour. He notes that the main disadvantage is "its learning curve, some drivers may find that they have to adapt their driving style to suit the system" (Gumbrell, 2024). Furthermore, regenerative braking alone cannot fully handle emergency stops, thus traditional hydraulic brakes remain essential (Gumbrell, 2024).

5 Conclusion

In motorsport, braking performance directly influences lap time, consistency, and driver confidence, making brake technology a critical differentiator. Drum brakes, while historically significant, are completely unusable for motorsport due to heat buildup, fade, and poor modulation under sustained load. Cast-iron discs, although heavier, deliver reliable and predictable braking, making them ideal for entry level or endurance applications where cost and ease of maintenance are key. Carbon-ceramic systems represent the current pinnacle of motorsport braking, offering unmatched thermal resistance, weight reduction, and consistency under extreme temperatures are crucial advantages in top tier motorsports such as Formula 1 and endurance racing in the Hypercar class. Finally, regenerative braking has become integral in the aforementioned racing series' both of them make good use of this system. Regenerative braking contributes not only to deceleration but also to energy recovery and strategic deployment.

Overall, the evolution of braking systems in motorsport reflects a balance between raw stopping power, thermal control, and energy efficiency. Cast-iron and carbon-ceramic systems dominate conventional racing, while regenerative braking helps to further improve performance and sustainability of hybrid systems.

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