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Analysis of the Temperature Dynamics in General Aviation Brake System

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by

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Abstract

Title: Analysis of the Temperature Dynamics in General Aviation Brake System

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As aircraft brakes are subjected to intense heat generation during landings and braking maneuvers, comprehending the temperature dynamics is essential for ensuring optimal performance, longevity, and, most importantly, the safety of flight operations. This paper dives into understanding heating and cooling in the brake systems of the Piper Aircraft PA-28.

In order to investigate the thermal behavior of aircraft brake components, this study evaluates a variety of general aviation braking scenarios, from light to heavy braking, including stop-and-go landings, full-stop taxi backs, and continuous braking while taxiing. It was noticeable that light braking exhibits slight temperature increases and cooling rates. Moderate braking demonstrates an intermediate thermal response, offering adequate stopping distance without excessive temperature rise. Heavy braking resulted in the highest temperature increases and cooling rates.

Thermal inertia is evident during stop-and-go situations, where heat generation from friction may outpace cooling effects. Continuous braking during taxiing had the highest risk, with temperatures exceeding recommended limits for prolonged durations, especially when combined with heavy braking for landings. However, the brakes tended to return near ambient temperature during flights, proving that multiple stop-and-go operations are unlikely to overheat the brakes. Wind direction is related to cooling rates, with the windward side cooling faster. These findings underscore the importance of braking techniques and management to mitigate thermal stress on aircraft brakes.

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Chapter 1 Theory

Introduction

The aviation industry, and general aviation, in particular, highly relies on the efficient performance of its components. Among these, the brake system is critical in ensuring safety during landings and ground operations. The brake system plays a vital role in decelerating the aircraft during operations. However, the operational efficiency of these brake systems is profoundly influenced by temperature variations, posing a significant challenge for engineers and aviation experts.

In general aviation, where smaller aircraft cater to a diverse range of missions, understanding the temperature dynamics of brake systems is essential. The Piper Aircraft PA 28 series is known for multiple missions, such as training, recreational flying, and light transport. This paper provides an analysis of the thermal dynamics of the brake system of the Piper Aircraft PA 28 by analyzing the temperature dynamics during light, moderate, and heavy braking for stop and gos and full stop taxi back, in addition to continuous braking while taxiing. The paper contributes valuable knowledge that can be analyzed to enhance the safety and efficiency of the brake systems across various general aviation platforms.

Brake System Design

There can be two types of braking systems: direct-contact braking and contactless braking. In a direct-contact braking system, a stationary frictional material is pressed against the rotating rotor. In the stationary frictional material, there is a frictional force against the rotor direction of motion. This opposing force is responsible for the aircraft's deceleration (Kumar et al., 2021).

In a contactless braking system, there is no direct contact between the moving device and the braking system. Electro-magnetic devices are used for braking operation without any physical connection with the rotating device. When magnetic flux is applied across a conducting device, there is a generation of eddy current in the conducting material. Eddy current applies an opposing force hence there is an eddy current heating in the material. In this way, the rotating device's kinetic energy is converted into heat energy, and as a result, the rotating device stops (Kumar et al., 2021).

The Piper Aircraft PA 28 has a direct contact standard brake system comprising dual toe brakes connected to the rudder pedals, along with a hand lever and master cylinder. Each of the toe brakes and the hand brake is equipped with its brake cylinders while sharing a common reservoir ("Piper Pilot PA-28-181 SN 28020001 AND UP With Garmin," 2020). See Figure 1. The process of braking within the aircraft entails the pilot applying force to the top of the pedal, which starts the hydraulic process. The master cylinder that is linked to the brake pedal propels hydraulic fluid through hoses and rigid lines to a brake caliper on the landing gear strut. The brake caliper, a segment of the brake disc, houses pistons that respond to the hydraulic pressure, moving and exerting force on the pressure plate. The caliper and linings align centrally with the disc as pressure is exerted. The lining is riveted to the back plate and the pressure plate this ensures even pressure on both sides of the disc. Figure 2 shows an exploded view of the brake assembly. This action generates friction to decelerate the airplane. This integrated system in Piper aircraft enhances control and safety during ground operations.

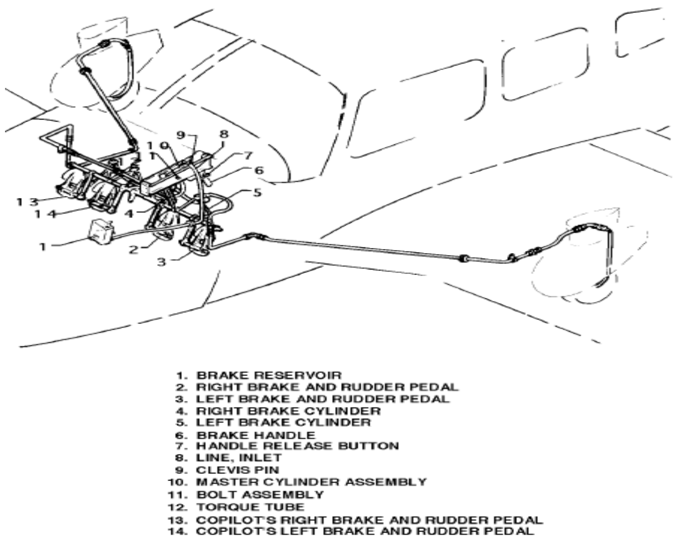


Figure 1 Brake system schematics.("Piper Aircraft," 2020)

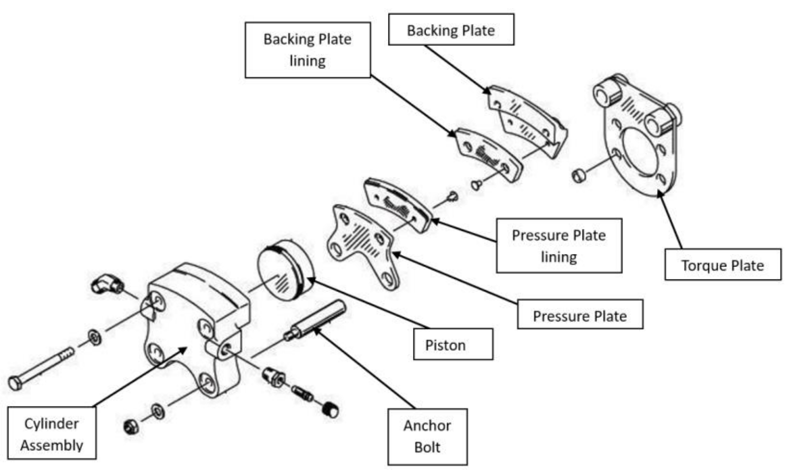


Figure 2 An exploded view of a single-piston Cleveland brake assembly.("Parker Hannifin Corporation," 2007)

One major component that the aircraft needs to decelerate is the brake cylinders. They are a crucial linkage between the pilot's input on the pedals and the mechanical action to decelerate the plane as a pilot applies force. This force is translated using the Pascal

Principle, which is defined as a change in pressure applied to an enclosed fluid that is transmitted undiminished to all portions of the fluid and the walls of its container (Lumen Learning, 2021). The formula P=F/A is used where P represents the hydraulic pressure, F is the force applied to the piston, and A represents the area of the master cylinder piston. When a pilot applies force to the brake pedals, the cylinders convert this mechanical input into hydraulic pressure. This pressure is then transmitted through the brake fluid within the hydraulic system, initiating a series of events that result in the application of the brake pads on the aircraft's wheels. This relationship is fundamental in determining the braking force applied to the aircraft's wheels.

The hydraulic pressure the brake cylinders generate is a crucial factor influencing the heat generated during braking. As the hydraulic pressure is transmitted to the brake components, such as calipers or wheel cylinders, friction is induced, converting kinetic energy into thermal energy. Consequently, this heat must be managed effectively to prevent deterioration of braking performance and ensure the safety and reliability of the entire system.

Brake System Dynamics

A crucial aspect of brake system dynamics is the torque generated by the brake disc, a factor integral to achieving the necessary deceleration rates during landing and rejected take-offs. Interestingly, 40% of the aircraft's kinetic energy during landing is dissipated in the wheel and brake system. The remaining energy is dissipated between aerodynamics. (Meunier et al., 2022). As an aircraft undergoes the landing, it carries significant kinetic energy that must be dissipated to come to a complete stop safely. Extensive analysis has been conducted on the impact of the aircraft's speed and the duration of braking. It was found that it is crucial to effectively dissipate the heat generated during this process to ensure the proper functioning of the braking system and overall aircraft performance (Towoju, 2019). The brake system is central in this operation, converting a substantial portion of kinetic energy into thermal energy. The calculation of kinetic energy for each main wheel with brakes involves factors such as design landing weight, brakes-on speed, and the number of main wheels with brakes. Notably, the square of the brakes-on speed emerges as a significant variable, underscoring the importance of careful considerations in approach speeds and landing scenarios.

The consultation of the kinetic energy rating of the wheel and brake assembly becomes necessary to ensure its compatibility with the aircraft and the intended operational conditions. Should the brake disc possess an undersized heat sink, the generated heat may elevate brake linings' temperatures, potentially leading to "brake fades," which is particularly relevant in lightweight aircraft using organic brake linings. The choice of metallic linings introduces a trade-off, altering the critical temperature for brake fade but requiring greater system pressure, contributing to increased disc wear, and introducing potential operational issues such as grabbing and squeaking.

Brake Fade

Brake fade, a critical concern in general aviation, arises from the excessive heat generated during braking, compromising the braking system's effectiveness. As an aircraft's brakes engage, converting kinetic energy into heat through friction, prolonged or intense braking can lead to heat accumulation beyond the system's designed thermal capacity. As the sliding interface's temperature increases, the friction coefficient varies. This variation is unpredictable, and no general trend exists except that at extremely high temperatures, the coefficient may become very low (<0.15) (Jacko & Rhee, 2000). In particular, brake fade can be exacerbated by inadequately sized heat sinks within the braking system or the use of organic brake linings prevalent in general aviation, which are susceptible to reduced friction and braking efficiency. Symptoms of brake fade include a noticeable reduction in braking effectiveness, a spongy pedal feel due to compromised brake fluid integrity, and increased stopping distances. Mitigation strategies involve allowing for cooling periods between demanding operations, employing proper braking techniques to manage heat generation, conducting regular maintenance checks, and considering operational factors such as approach speeds to minimize the risk of brake fade. By implementing these preventive measures, pilots and maintenance personnel can enhance the safety and reliability of general aviation aircraft operations, where efficient braking is essential for safe landings and ground operations.

Chapter 2 .Test Article and Flight Test Plan

Test Article

The aircraft chosen for the brake system test is the Piper Pilot 100i, a training-focused model equipped with a Lycoming IO-360-B4A engine and from the PA 28 family of Archer . This aircraft has a maximum cruise speed of 128 knots and a recommended landing approach speed of 66kts. This stripped-down version of the Piper Archer features avionics situated only on the pilot's side. With only pilot and co-pilot seats, the airplane has a maximum Takeoff Weight of 2550 lbs. The weight and balance sheet can be found in Appendix 1. The Piper Pilot 100i adopts a tricycle landing gear configuration. The aircraft's practical design, weight specifications, and brake configuration make it well-suited for evaluating the performance of the Parker brake system in various flight conditions and training scenarios.

Figure 3 Piper 100i Test Article

Instrumentation

To accurately record the temperature of the brakes, it was necessary to install thermocouples within the brake system. The selected thermocouple was specifically designed for brake pads. It is a K-type thermocouple with a copper cap (see Figure 4). The thermocouple had an accuracy of +/- 0.4% and a 500ms response time. Small holes were carefully drilled in both the backing plate (see Figure 3) and the pressure plate (see Figure 4). The thermocouples were then securely pressed into these holes. Once the plates were reattached to the brake calipers (see Figure 5), the thermocouple wires were carefully routed and taped to the aircraft's structure, leading them to the Data Acquisition System (DAS) mounted inside the aircraft. The table below shows the calibration of each thermocouple.

Standard	Left-Hand Pressure Plate	Right-Hand Pressure Plate	Right-Hand Back Plate	Left-Hand Back Plate
0°C	0.13°C	0°C	1°C	1°C
25°C	26.6°C	24.4°C	26.6°C	25.3°C
50°C	50.1°C	49.4°C	50.4°C	50.3°C
75°C	77.0°C	75.8°C	77°C	75.7°C
100°C	100.6°C	100.2°C	100.5°C	100.6°C
125°C	127.1°C	124.5°C	127.7°C	125.8°C
150°C	150.1°C	148.7°C	150.3°C	148.9°C
175°C	174.3°C	173.9°C	174.3°C	174.1°C

Table 1 Calibration table of each thermocouple

Figure 4 Shows K type thermocouple used to measure temperature of the back and pressure plate.

The aircraft is equipped with a Garman Avionics GDU 460 system featuring a Multi-Function Display (MFD). The MFD has the capability to transfer and record over 80 parameters onto an SD card. However, for this specific test, the required parameters include time, airspeed, altitude, Outside Air Temperature (OAT), and GPS data."

Figure 5 Pressure plate with thermocouple installed.

Figure 6 Backing plate with thermocouple installed.

Figure 7 Backing plate and pressure pate thermocouple wires.

Test Location and Meteorological Conditions

The airplane was based at Vero Beach Regional Airport (KVRB), Vero Beach, Florida however, the test was conducted at Airglades (21S) Airport, Clewiston, Florida (Figure 8). This decision was made after consideration of various factors, including the need to minimize potential disruption from air traffic and to capitalize on the favorable meteorological conditions. The absence of sea breeze provided a more stable atmospheric environment, allowing the pilot to conduct repeatable, precise, and reliable tests, especially during landing.

The Test location (Figure 9) is Runway 31 at Airglades. The airport was also ideal for its exceptional quality and dimension, aligning perfectly with the test requirements of well-maintained, durable asphalt. The dimensions of 5902 feet in length and 75 feet in width provide ample space for conducting the test safely and effectively. With the Pilot 100i requiring a landing distance of 1400 feet and a takeoff distance of 1608 feet, there was more than enough runway to accommodate light, moderate, and heavy braking during landing, followed by a successful takeoff. (“Piper Pilot PA-28-181 SN 28020001 AND UP With Garmin,” 2020). Using Automated Weather observation system the wind was 090

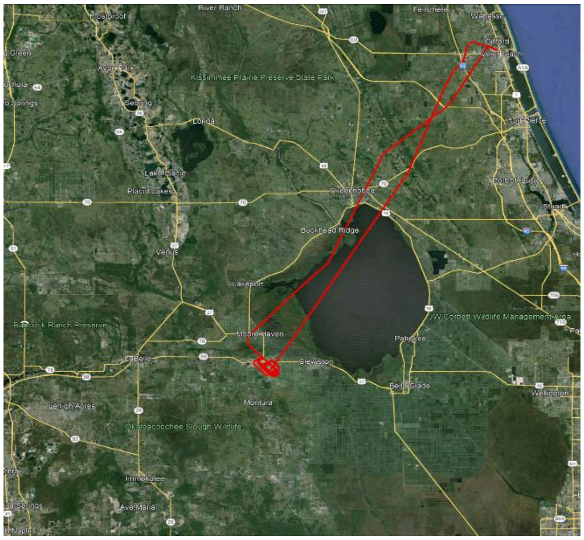


Figure 8 Flight path

Figure 9 Test location and flight path for each traffic pattern at 21S in Florida

Test Matrix

Tables 1, 2 and 3 below describe the procedural steps for conducting each test point. The test is divided into 3 different test matrices: Landings with full-stop taxi back (refer to Table 2) and landings with stop and go (refer to Table 3), both incorporating light, moderate, and heavy braking. These landings are common during pilot training, especially for private pilot licenses. The test points are structured to give insights into the change in temperature subsequent to each landing with varying brake pressure. Additionally, to have a more detailed understanding of the temperature dynamics of the brakes, the test matrix also has the pilot extending the pattern by 3 minutes therefore, the pilot had to use landmarks while maintaining consistent airspeed in the pattern.

Lastly, Table 4 shows the third test matrix, where a pilot applies continuous pressure on the brake during taxiing, which is common among many pilots, particularly those with limited experience. During testing, the pilot must maintain a consistent traffic pattern time and ensure the aircraft doesn't bounce upon touchdown, thus having smooth and controlled landings. The pilot was able to maintain +/- 7kts indicated airspeed during the testing.

Test Title		Regulations	Test Objectives
1	Brake Temperature	N/A Company Test Only	Provide data for master's degree thesis

Test Procedures	Pass/Fail Criteria
1. Minimize brake application during initial taxi 2. Record fuel quantity 3. Record wind direction/speed 4. Perform normal takeoff 5. Record time takeoff roll begin 6. Fly airport's traffic pattern 7. Perform normal landing per POH procedure 8. Record touchdown time 9. Apply brakes 10. Record time brakes are applied 11. Wait 3 seconds after full stop before taxiing back to runway Note: Establish a baseline traffic pattern time by calculating the time difference between step 8 and step 5 All test points are full stop taxi backs	Brake temperature data gathering only

Test Point	Risk	Flight Conditions		Aircraft Configuration			Test Condition
		Altitude	Speed	Power	Flap	WT/CG	
01	LOW	AR	66KIAS	AR	DN	HVY/OPT	Light braking, Baseline traffic pattern time
02	LOW	AR	66KIAS	AR	DN	HVY/OPT	Moderate braking, Baseline traffic pattern time
03	LOW	AR	66KIAS	AR	DN	HVY/OPT	Heavy braking, Baseline traffic pattern time
05	LOW	AR	66KIAS	AR	DN	HVY/OPT	Light braking, Baseline traffic pattern time +3 minutes
06	LOW	AR	66KIAS	AR	DN	HVY/OPT	Moderate braking, Baseline traffic pattern time +3 minutes
07	LOW	AR	66KIAS	AR	DN	HVY/OPT	Heavy braking, Baseline traffic pattern time + 3 minutes
08	LOW	AR	66KIAS	AR	DN	HVY/OPT	Cool brake temperature, Baseline traffic pattern time + 3 minutes

Table 2 Full Stop Taxi Back brake cooling data test matrix

Test Title		Regulations	Test Objectives
1	Brake Temperature	N/A Company Test Only	Provide data for master's degree thesis

Test Procedures	Pass/Fail Criteria
1. Perform normal takeoff 2. Record time takeoff roll begin 3. Fly airport's traffic pattern (76kts on climb, 90kts for downwind, 80kts for base leg 66KIAS for final) extend upwind and downwind time as specified) 4. Record touchdown time 5. Apply brakes 6. Record time brakes are applied 7. Wait 3 seconds after full stop Note: Establish a baseline traffic pattern time by calculating the time difference between step 8 and step 5 All test points are stop and go	Brake temperature data gathering only

Test Point	Risk	Flight Conditions		Aircraft Configuration			Test Condition
		Altitude	Speed	Power	Flap	WT/CG	
01	LOW	AR	66KIAS	AR	DN	HVY/OPT	Light braking, Baseline traffic pattern time
02	LOW	AR	66KIAS	AR	DN	HVY/OPT	Moderate braking, Baseline traffic pattern time
03	LOW	AR	66KIAS	AR	DN	HVY/OPT	Heavy braking, Baseline traffic pattern time
04	LOW	AR	66KIAS	AR	DN	HVY/OPT	Light braking, Baseline traffic pattern time +3 minutes
05	LOW	AR	66KIAS	AR	DN	HVY/OPT	Moderate braking, Baseline traffic pattern time +3 minutes
06	LOW	AR	66KIAS	AR	DN	HVY/OPT	Heavy braking, Baseline traffic pattern time + 3 minutes
07	LOW	AR	66KIAS	AR	DN	HVY/OPT	Cool brake temperature, Baseline traffic pattern time + 3 minutes

Table 3 Stop and go braking cooling data test matrix

Test Title		Regulations	Test Objectives
1	Continuous Braking	N/A Company Test Only	Provide data for master's degree thesis

Test Procedures	Pass/Fail Criteria
1. Taxi airplane in straight line while holding the brakes for 1 minute. 2. Record highest observed temperature 3. Allow brakes to cool 20ºC below highest observed temperature	Brake temperature data gathering only

Test Point	Risk	Flight Conditions		Aircraft Configuration			Test Condition
		Altitude	Speed	Power	Flap / Gear	WT/CG	
01	LOW	Field	AR	AR	Up	HVY/AFT	1. Maintain consistent groundspeed of 10kts make note of airspeed.

Table 4 Test matrix for the effects of riding the brakes

Chapter 3 Results and Analysis

Light Braking

The first test point conducted involved light braking full stop taxi back. As depicted in the graph, the outside air temperature that the aircraft was experiencing was at 23°C during takeoff, dropped to 19°C in flight, and then rose back to 23°C upon landing this is because of the change in altitude and airspeed. During the takeoff roll, the left-hand (LH) brake pressure plate and backing plate temperatures were 77°C and 105°C, respectively, while the right brake pressure plate and backing plate temperatures were 71°C and 93°C, respectively. These elevated temperatures were due to the necessity for a normal landing to assess the runway condition for the safe completion of all test points. Rates of temperature were calculated with Equation 1 and 2. Ten seconds after the takeoff roll, the temperature of the left backing plate decreased at a rate of 0.37°C/sec and the pressure plate at 0.44°C/sec, while the right backing plate decreased at a rate of 0.37°C/sec and the pressure plate at 0.23°C/sec.

Equation 1 Heat accumulation rate

Heat accumulation rate=$\frac{Brake\ Temperature\ After\ Braking - Brake\ Temperature\ before\ brake}{Time}$

Equation 2 Cooling Rate

Cooling Rate=$\frac{Brake\ Temperature\ before\ cooling - Brake\ Temperature\ after\ cooling}{Time}$

At the point of touchdown, the left pressure plate and backing plate had a temperature of 26°C, and the right pressure plate and backing plate had a temperature of 24°C. This temperature was consistent for 2 minutes before touchdown. This could have resulted from factors such as outside air temperature (OAT), as OAT slightly increased as the plane descended. However, there was still airflow over the brakes. After the pilot applied light braking at 62kts groundspeed, the RH and LH backing plate and pressure plate started increasing. Three seconds after touchdown, the brakes were applied, and the temperature of the LH pressure plate increased at a rate of 0.4°C/sec, and the LH backing plate increased at a rate of 0.5°C/sec. The RH pressure plate and backing plate also increased at the same rate of 0.4°C/sec and 0.5°C/sec respectively. This consistency in temperature increase suggests that the braking system components on both sides of the aircraft were made of materials with similar thermal capabilities and characteristics.

Although this rate was calculated while the brake was being applied, the temperature continued to rise after the pilot released the brakes to exit the runway.

Thermocouple location	Temp 3 seconds after full stop	Time of applied brake (secs)
LH PP	43°C	156
LH BP	49°C	156
RH BP	48°C	156
RH PP	40°C	156

Table 5 Brake temperature after light brake

To conduct the landing checklist, the pilot taxied off the runway and braked again therefore, the temperature increased, as seen in Table 6. While taxing back to the runway due to limited airflow, minimal cooling was shown. The temperature slowly increased except for the RH backing plate (see Table 7); interestingly, after decelerating and coming to a full stop to enter RWY 13, the brake temperature only increased by approximately 1°C as there was minimal braking required by the pilot, except for the RH BP plate that increased 5°C.

Thermocouple location	Temp after taxiing to exit runway
LH PP	49°C
LH BP	60°C
RH BP	59°C
RH PP	47°C

Table 6 Temperature after taxiing to exit the runway and applying brakes

Thermocouple location	Beginning of taxi	End of taxi before brakes were applied
LH PP	49°C	58°C
LH BP	66°C	70°C
RH BP	66°C	63°C
RH PP	49°C	55°C

Table 7 Temperature change from the beginning of taxiing to the end before brakes were applied.

The cooling of the brakes started on takeoff roll, occurring at approximately 40kts indicated airspeed. The LH pressure plate cooled at a rate of 1.3°C /sec, and the LH backing plate cooled at a rate of 2.0°C /sec. The RH backing and pressure plate cooled at similar rates to the LH backing and pressure plate with rates of 2.1°C /sec and 1.4°C/sec respectively. The backing plate has a higher thermal mass because it is thicker than the pressure plate; therefore, it can store more heat (Shafigh et al., 2018). Consequently, because the backing plate stores heat longer. The backing plates cooled at a higher rate than the pressure plate due to the temperature gradient between the outside air temperature and the temperature of the plate. The temperature then remained constant for 1 minute until touchdown.

Sensor Location	Starting temperature	Lowest Temperature observed	Time brakes to cool to lowest temperature (secs)
LH PP	57°C	25°C	274
LH BP	70°C	23°C	274
RH BP	66°C	21°C	274
RH PP	56°C	21°C	274

Table 8 Temperature change after0 light braking.

The extended 3-minute brake cooling rate pattern exhibited behavior comparable to that found during light braking operations. Interestingly, the rate at which the pressure plate or backing plate temperatures remained same for both the RH and LH brake plates for regular pattern during the extended pattern cooling phase. This temperature decrease rate resulted in the graph line appearing suddenly truncated from the extended 3-minute segment(see Figure10).

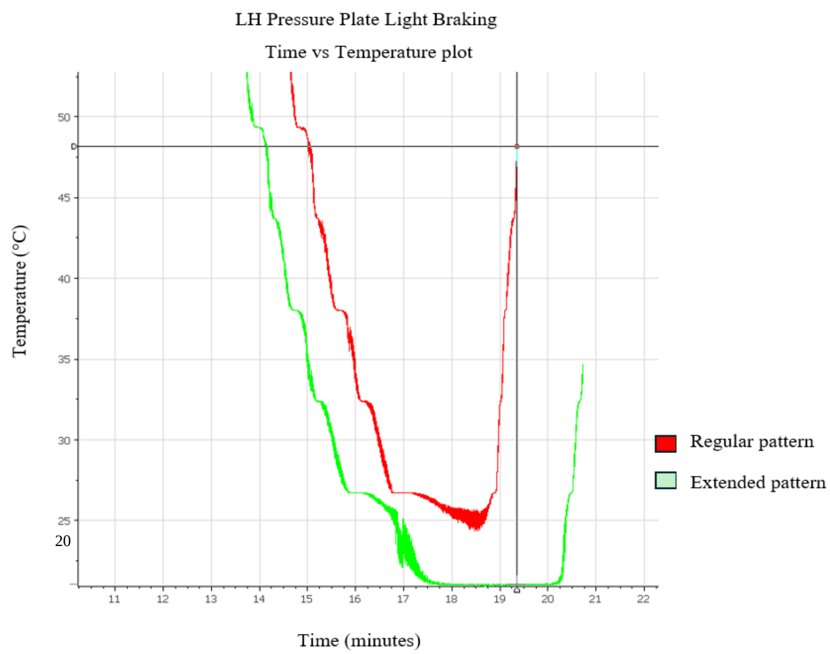


Figure 10. LH Pressure plate light braking: Temperature vs time for the regular pattern and extended pattern brake cooling

The temperature profiles of all four plates showed a clear distinction between the extended and regular traffic patterns. All four plates had lower temperatures during the extended traffic pattern than the regular pattern. The extended pattern allows more efficient heat transfer techniques like conduction, convection, and radiation. As a result, the plates may lose heat more efficiently, resulting in lower temperatures when compared to the regular pattern. The LH pressure and backing plates maintained the same temperature of 21°C. The RH brake assembly, on the other hand, showed a minor difference in pressure plate and backing plate temperatures. The RH pressure plate recorded a temperature of 19°C, one degree lower than the backing plate's temperature of 20°C.

The last test conducted with light braking was stop and gos. As seen in Table 9, the backing plate and pressure plates of the RH and LH were very close. Although, they are on opposite sides, the rate of heat accumulation remained the same as light brake, full stop taxi back. Three seconds after touchdown, the brakes were applied, and the temperature of the LH pressure plate increased at a rate of 0.3°C/sec. The LH backing plate increased at a rate of 0.5°C/sec. The RH pressure plate and backing plate also increased at the same rate of 0.3°C/sec and 0.5°C/sec respectively. The consistent rates of heat accumulation observed in both the LH and RH brake suggest that there was minimal influence from external factors such as prevailing winds.

Stop and go light braking heat accumulation.			
	3 seconds after touch down temperature	Temp 3 seconds after full stop	Duration of brake application
LH PP	26°C	40°C	46 secs
LH BP	26°C	49°C	46 secs
RH BP	24°C	49°C	46 secs
RH PP	23°C	39°C	46 secs

Table 9 Heat accumulation for light braking.

Interestingly, the temperature continued rising during the takeoff roll for all the plates. The LH pressure plate temperature rose to 48°C, which took thirty seconds. This suggests that the rate of heat generated due to frictional forces surpasses the airflow cooling effects. The peak temperature of 48°C occurred while the airplane was in the takeoff roll at 32kts ground speed. Furthermore, there was an equilibrium between the production and dissipation of heat as temperature remained constant at 48°C. Cooling started after takeoff at approximately 193 ft 75 kts indicated airspeed (68kts ground speed), and the LH pressure plate decreased to a minimum temperature of 22°C for forty seconds. It increased back to 23°C upon touchdown as there was an increase in OAT, and ground heat had an effect. The LH pressure plate decreased from 48°C to 26°C at a rate of 0.2°C/sec however, it 1 minute to decrease from 25°C to 22°C at a rate of 0.06°C/sec. One effect of this was because the temperature gradient between the brakes and OAT started to decrease as OAT ranged from 22°C to 19°C. A reduced temperature gradient results in a decelerated heat transfer rate. The LH backing plate also had a similar thermal dynamics pattern where there was an increase in temperature up to 54°C during the takeoff roll, and then temperature remained constant; Cooling did not start until the airplane was 233ft high. The cooling rate started at 0.2°C/sec from 55°C to 27°C. The rate then slowed down to 0.06°C/sec when the temperature reached 24°C. The LH backing plate and pressure plate were at 26°C for forty-five seconds and then decreased to a minimum temperature of 21°C and 22°C, respectively, for ten seconds but gradually increased as the airplane approached the landing.

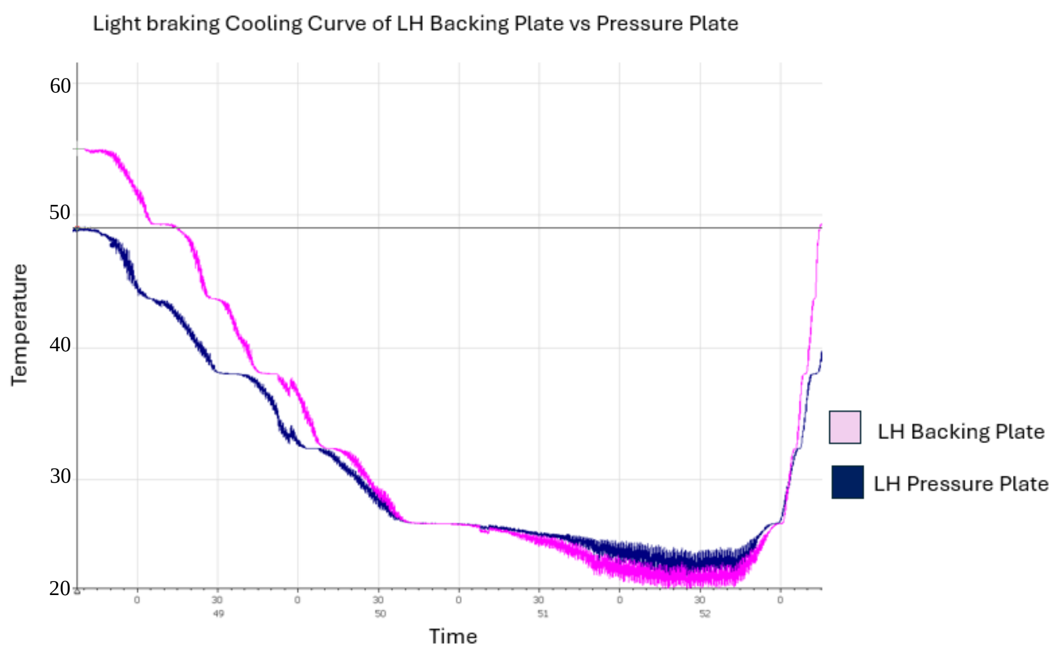


Figure 11 Light braking cooling curve for LH backing plate vs pressure plate

The RH plates temperature had both similarities and differences to the LH plates. After waiting three seconds after full stop to begin takeoff, the temperature continued to increase until 65kts right at takeoff, with a peak temperature of 57°C. Unlike the LH side, the RH side peak temperature did not remain constant because the prevailing winds were coming from the RH side. As soon as the plane took off, cooling started. Both backing plate and pressure plate reached a minimum temperature of 22°C and 21°C respectively. The extended pattern light braking was the same, except that the temperature stayed at a minimum for a longer period.

Moderate braking

Moderate braking was consistent throughout the test. After each landing, the accumulated heat was in the middle of light and heavy braking. The first test point was full stop taxi back moderate braking with normal pattern. From this landing, the backing plate had a rate of heat accumulation of 0.6°C/sec for the RH and LH, while the pressure plates had 0.5°C/sec for the RH and LH See. Table 10 for the temperatures. The rate of heat accumulation and the corresponding temperatures observed during moderate braking were found to be slightly higher than those observed during light braking but lower than those recorded during heavy braking.

Full stop taxi back moderate braking heat accumulation			
	3 seconds after touch down, the temperature	Temp 3 seconds after full stop	Duration of brake application
LH PP	25°C	48°C	42
LH BP	24°C	60°C	42
RH BP	22°C	61°C	42
RH PP	21°C	45°C	42

Table 10 Heat accumulation for moderate braking

While taxiing at 15kts for 1 minute to the runway, there was no cooling and the temperature continued to increase until the pilot was about to reenter the runway where the temperature remained constant see Table 11. While many factors could cause this, one could be that intermittent application of the brakes while taxiing may result in continual heating instead of cooling. The pilot could have applied the brakes, which would have produced extra thermal energy or there could have been as a result of ground heat. Cooling started during takeoff roll at approximately 53 kts groundspeed for pressure plates on both RH and LH. While the RH and LH the backing plate cooling started at 21 kts groundspeed. This is because backing plate cooling started at 21 kts groundspeed. This is because the backing plate had a higher temperature and a higher temperature gradient. The LH and RH pressure plate cooled at a rate of 2°C/sec while the LH and RH backing plate cooled at a rate of 3°C/sec. Table 12 shows the lowest temperature was again observed on the RH side for both the backing and pressure plates due to the prevailing wind direction.

Thermocouple location	Temp after taxiing to enter the runway
LH PP	72°C
LH BP	94°C
RH BP	89°C
RH PP	66°C

Table 11. Temperature of the brakes after taxiing back to the runway.

Moderate Braking Cooling			
Sensor Location	Starting temperature	Lowest Temperature observed	Time brakes to cool to lowest temperature (secs)
LH PP	72°C	25°C	250
LH BP	94°C	24°C	250
RH BP	87°C	22°C	247
RH PP	66°C	21°C	245

Table 12. Moderate braking cooling and lowest observed temperature

The extended 3-minute pattern for moderate braking also showed that the temperature cooling rate did not change. Figure 9 shows that the temperature remained constant for a period of time; this was on long final at approximately 75 kts and below. The major difference is that the pressure and backing plates' temperatures decreased to a lower temperature compared to the regular pattern (see Table 13).

Sensor Location	Regular pattern lowest temperature	Extended pattern lowest temperature
LH PP	25°C	21°C
LH BP	24°C	21°C
RH BP	22°C	20°C
RH PP	21°C	19°C

Table 13 Extended pattern and regular pattern lowest temperature.

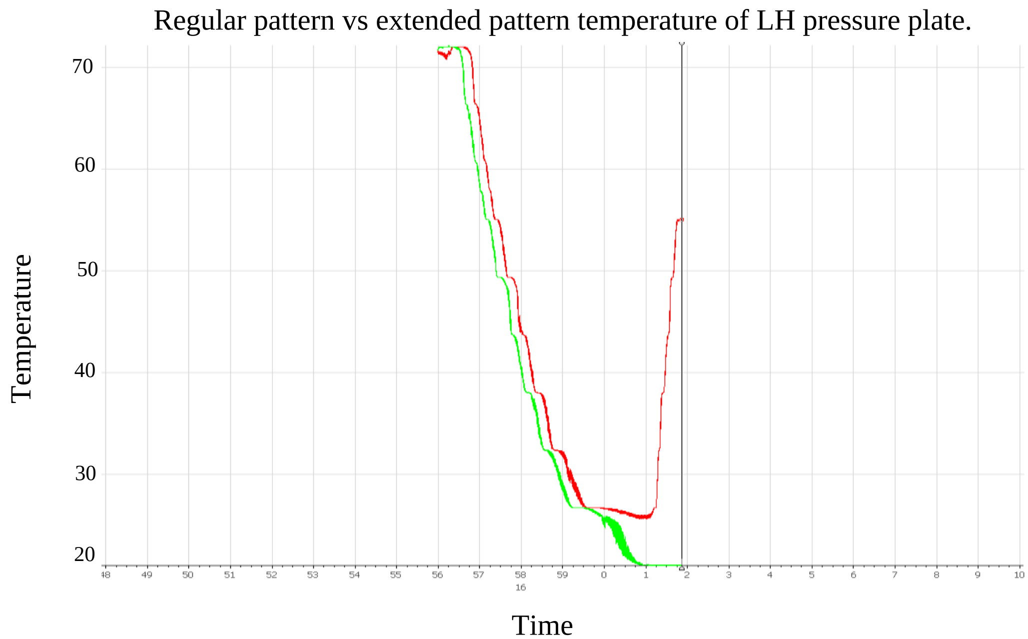


Figure 12 Regular pattern vs. extended pattern temperature of the LH pressure plate.

The stop-and-go regular pattern temperature three seconds after touch down for LH pressure and backing plates were 24°C and 22°C respectively, while the RH pressure and backing plates were 21°C and 22°C. The rate of heat accumulation was relatively close to moderate braking full-stop taxi back. three seconds after touchdown, the brakes were applied, and the temperature of the LH pressure plate increased at a rate of 0.5°C/sec, and the LH backing plate increased at a rate of 0.8°C/sec. The RH pressure plate and backing plate also increased at the same rate of 0.5°C/sec and 0.8°C/sec respectively.

Stop and go moderate braking heat accumulation.			
	3 seconds after touch down, the temperature	Temp 3 seconds after full stop	Duration of brake application
LH PP	24°C	41°C	36 secs
LH BP	23°C	53°C	36 secs
RH BP	22°C	54°C	36 secs
RH PP	21°C	41°C	36 secs

Table 14 Heat accumulation after moderate brake

The temperature continued rising during the takeoff roll for all the plates. The LH pressure plate temperature took twenty-nine seconds to rise to 53°C. However, the peak temperature of 53°C occurred just after takeoff at 68kts ground speed. This temperature remained constant, and there was no cooling during the takeoff roll. Cooling started after takeoff at approximately 177ft for the LH pressure plate. As the airplane turned on final and slowed down to approximately 70kts groundspeed the cooling rate decreased, it took 1 minute to drop 2°C to the minimum temperature of 25°C for thirty-four seconds. The LH backing plate also had a similar temperature pattern where temperature increade up to 65°C during takeoff roll and remained constant cooling did not start until the airplane was 130 ft high, then the temperature decreased at a rate of 0.3°C/sec from 65°C to 27°C. The rate then lowered as the airplane decreased altitude and airspeed; the LH backing plate and pressure plate decreased to a minimum temperature of 26°C.

Although the LH plates remained rather stable, the RH plates experienced a gradual decline in temperature, reaching minimal values of 22°C and 23°C for the RH pressure plate and RH backing plate, respectively (see Figure 13). The observed variation in temperature patterns can be linked to the prevailing wind direction, which exerted more influence on the RH in comparison to the left-hand. The RH exhibited a higher degree of direct airflow, facilitating accelerated heat dissipation and allowing it to reach thermal equilibrium more efficiently.

On the other hand, the LH side had reduced direct airflow because of the prevailing wind direction, leading to a slower decline in temperature. The RH side exhibited similar thermal behavior during the takeoff roll as observed after waiting three seconds after full stop to begin takeoff. The temperature continued to increase, the RH backing plate had a temperature increase of up to 64°C during the takeoff roll. Cooling started at 95 ft high, and the temperature decreased at a rate of 0.3°C/sec from 52°C to 26°C. The RH pressure plate had a temperature increase of up to 52°C during the takeoff roll. Cooling started at 99 ft high, then the temperature decreased at a rate of 0.2°C/sec from 52°C to 26°C The temperature then lowered to 23°C.

In the extended 3-minute pattern of moderate braking, the RH plates showed similar behavior, with the temperature staying at the minimum temperature for longer time than the regular pattern.

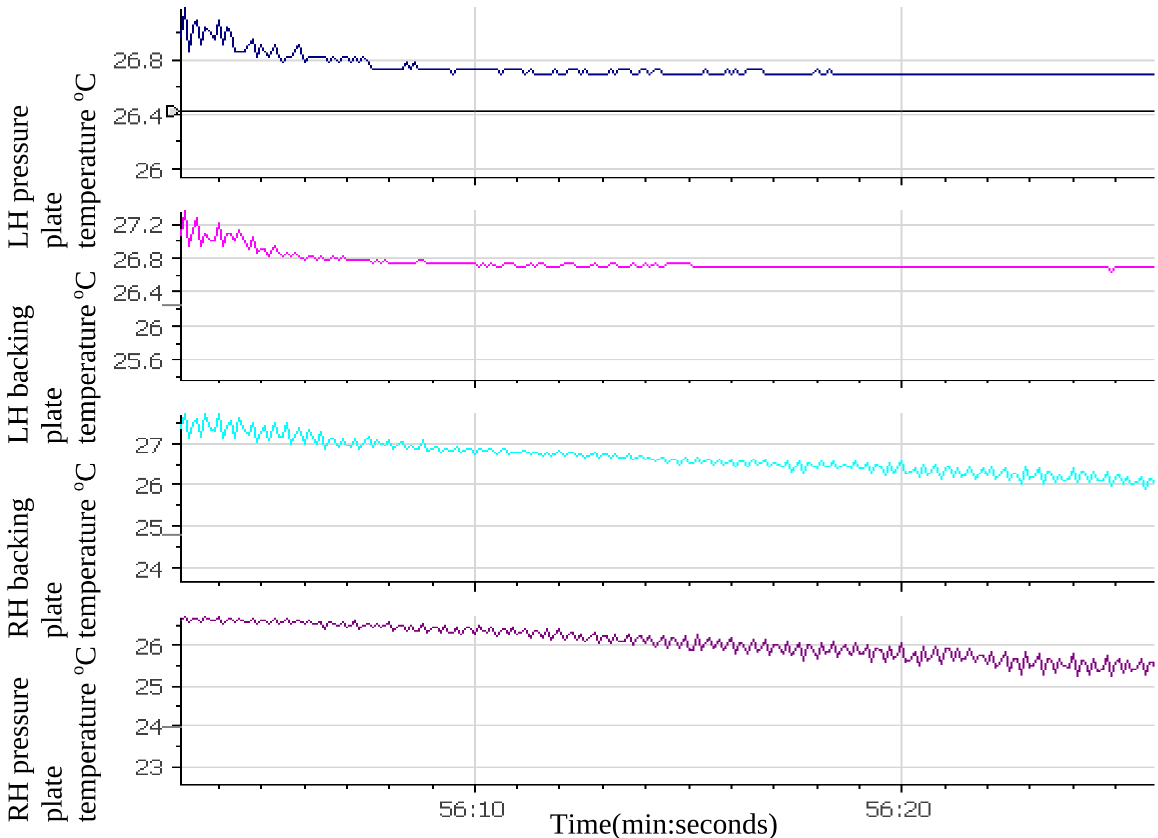


Figure 13 RH and LH plates cooling over time.

Heavy braking

Heavy braking was the highest risk of all the test points for multiple reasons. The first test point conducted was heavy braking full stop taxi back. The pilot was instructed to apply heavy braking without skidding the tires. Before touchdown, the temperature of the plates were 25°C for the LH pressure plate, 24°C for the LH backing plate, and 22°C and 21°C for the RH backing plate and pressure plate, respectively. After the pilot applied brakes at 62kts groundspeed the RH and LH backing plate and pressure plate started increasing. three seconds after touchdown, the brakes were applied, and the temperature of the LH pressure plate increased at a rate of 0.6°C/sec, and the LH backing plate increased at a rate of 0.7°C/sec. The RH pressure plate and backing plate also increased at the same rate of 0.6°C/sec and 0.7°C/sec, respectively, higher than the moderate braking. As expected, after the pilot released the brakes to exit the runway, the temperature continued to rise. Furthermore, as the pilot taxied back to the runway, the airplane reached a maximum groundspeed of 20 kts, yet there was still an increase in temperature. Beyond 20 kts, the temperature remained constant until the pilot had to apply light brakes again to taxi onto the runway for takeoff see table 15.

Thermocouple location	Beginning of taxi	End of taxi before takeoff
LH PP	65°C	86°C
LH BP	96°C	117°C
RH BP	88°C	94°C
RH PP	61°C	74°C

Table 15 Increase in temperature while taxiing.

As a result of the higher temperature gradient, the cooling rate during heavy braking exceeded moderate and light braking, with cooling starting around 46 kts indicated airspeed. The LH pressure plate cooled at a rate of 2°C/sec, while the LH backing plate cooled at a faster rate of 3.1°C/sec. Similarly, the RH pressure plate cooled at a rate of 2.1°C/sec, and the RH backing plate cooled at 3.1°C/sec. Following this, the temperatures remained constant for thirty seconds until touchdown.

At the beginning of the extended 3-minute pattern, the LH pressure plate started at 80°C, and the LH backing plate at 111°C. While the RH pressure plate began at 90°C, and the RH backing plate at 70°C. The extended pattern resulted in cooler brakes compared to the regular pattern while maintaining the same cooling rate as depicted in figure 15 as if they were truncated. This is because the thermal inertial did not change for the plate additionally, the pilot was instructed to maintain a certain airspeed on each leg therefore, airflow was relatively close.

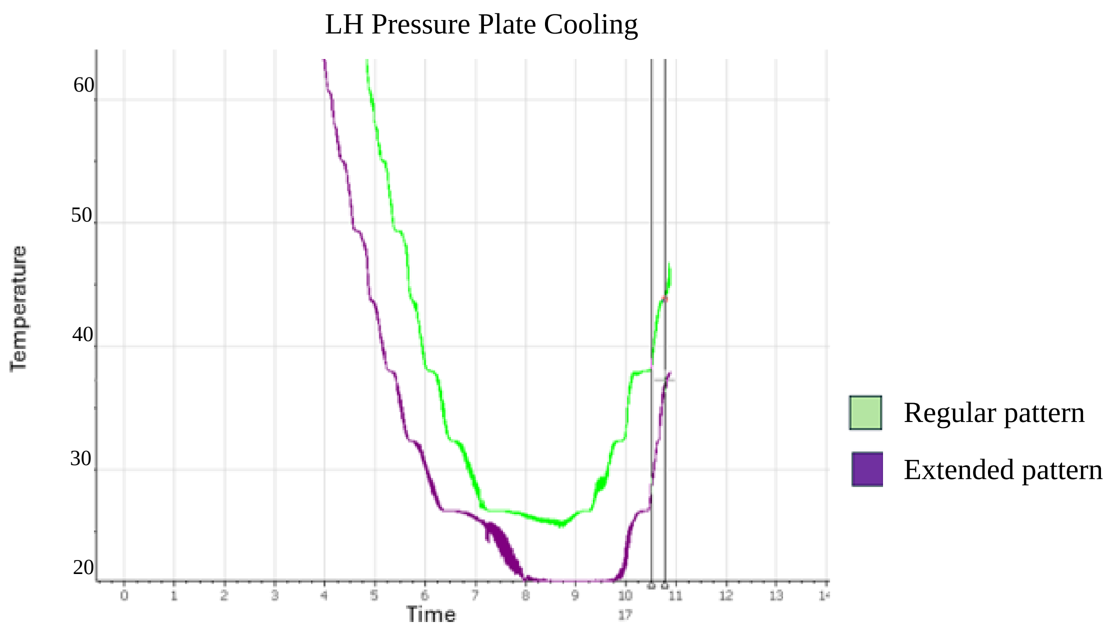


Figure 15 LH pressure plate extended pattern and regular pattern cooling

In the final test point involving heavy braking, which included stop-and-go maneuvers, Table 16 illustrates that the LH and RH backing plates and pressure plates were close despite being on opposite sides (LH and RH). This indicates that the pilot was applying relatively equal force on the brakes. During the stop-and-go maneuvers, the rate of heat accumulation remained consistent with that of heavy braking full stop.

The brakes were applied three seconds after the touchdown, increasing the temperature. The LH pressure plate temperature rose at a rate of 0.5°C/sec, while the LH backing plate temperature increased at a faster rate of 1.1°C/sec. Similarly, the RH pressure plate and backing plate had temperature increases, with rates of 1.3°C/sec and 0.6°C/sec, respectively.

Stop and go heat braking heat accumulation.			
	3 seconds after touch down, the temperature	Temp 3 seconds after full stop	Duration of brake application
LH PP	25°C	40°C	27 secs
LH BP	24°C	54°C	27 secs
RH BP	22°C	57°C	27 secs
RH PP	21°C	38°C	27 secs

Table 16 Stop and go heavy braking heat accumulation.

During the takeoff roll, the temperature continued to rise for all plates. The LH pressure plate temperature increased to 57°C, which took twenty seconds. However, the peak temperature occurred during takeoff at 122 ft. Cooling began at approximately 204 ft for the LH pressure plate, reducing to 25°C for thirty seconds. It took 1 minute and fifty-eight seconds for the LH pressure plate to decrease from 27°C to 24°C. The LH backing plate temperature's behavior differed from any other braking scenario. It peaked at 72°C at 44 kts ground speed during takeoff roll and remaining constant. Cooling did not start until the airplane reached an altitude of 233ft. The cooling rate started at 0.2°C per second, from 55°C to 27°C, then slowed to 0.02°C per second.

The RH plates temperature had both similarities and differences. After waiting three seconds after full stop to begin takeoff, the temperature continued to increase until 70kts right at takeoff with a peak temperature of 57°C for the pressure plate and 72°C for the backing plate. Unlike the LH side, the RH side peak temperature did not remain constant. As soon as the plane took off, cooling started, drastically changing the cooling rate. Both plates reached a minimum temperature of 21°C at approximately the same time and remained constant until touchdown. In the case of extended pattern light braking, there was no notable phenomenon the temperature stayed at the minimum for a longer period. In contrast to moderate and light braking, heavy braking produced a greater temperature gradient. Heat is produced in the brake components rapidly due to the significant conversion of kinetic energy into heat produced by the strong friction created during heavy braking.

Continuous braking

After performing a normal landing per the Pilot's Operating Handbook (POH) procedure with moderate braking, the temperatures three seconds after full stop landing were 39°C and 53°C for the LH pressure plate and backing plate, respectively, while the RH pressure plate and backing plate increased to 43°C and 62°C, respectively. As the pilot began taxiing, the temperatures continued to rise. After stabilizing for twenty seconds, they reached 49°C and 69°C for the LH pressure plate and backing plate, respectively, while the RH pressure plate and backing plate increased to 56°C and 81°C, respectively. The pilot then increased power to 1670 RPM and started applying brakes to maintain a speed of 10 kts ± 1 kts for 1 minute. This increased the temperature to 83°C for the LH pressure plate and 106°C for the LH backing plate. The RH temperatures were even higher, with a backing plate temperature of 139°C, higher than the maximum recommended temperature for forty seconds (Parker Hannifin Corporation [Aircraft Wheel & Brake Division], 2023). The RH pressure plate temperature of 95°C. As the plane taxied back to the tent, which took two minutes and thirty seconds, the temperatures slowly changed to 77°C and 94°C for the LH pressure plate and backing plate, respectively. The backing plate temperature for the RH was 125°C, and the pressure plate temperature was 101°C.

Remaining stationary for 2 minutes resulted in little to no change in temperature, with the LH pressure plate at 79°C and the LH backing plate at 94°C. The RH backing plate temperature was 102°C, and the pressure plate temperature was 89°C. Figure 12 shows how riding the brakes can cause elevated temperatures, especially after landing.

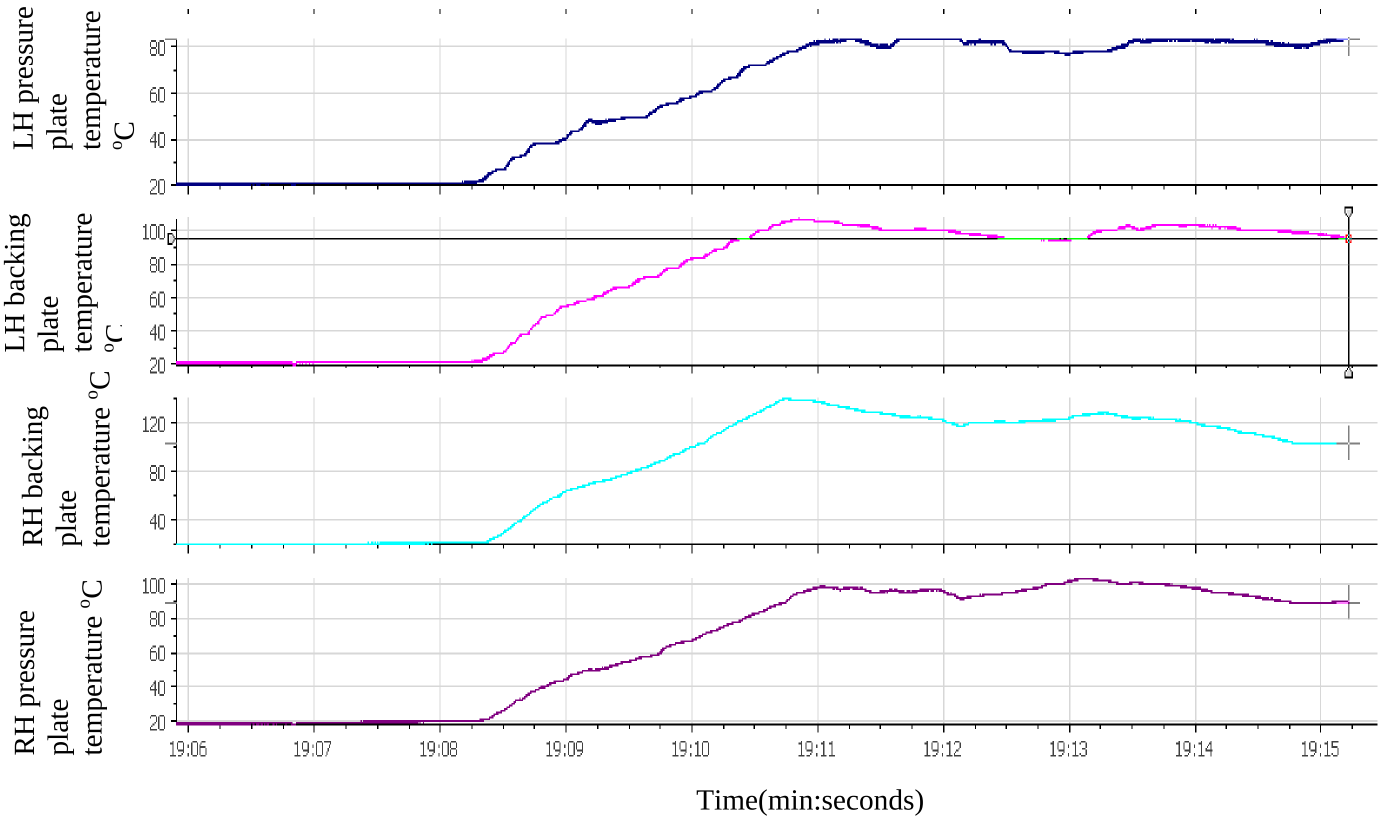


Figure 16 RH and LH pressure plate and backing temperature for continuous braking.

Chapter 4 Conclusion

The analysis of different brake scenarios from light to heavy braking, including stop-and-go landings, full-stop taxi back, and continuous braking, offers information about the thermal behavior of aircraft brake parts. Compared to moderate and heavy braking, light braking is defined by applying minimal brake force, which shows smaller temperature increases and cooling rates. Light braking caused only slight temperature variations linked to outside influences such as airflow dynamics and ambient temperature.

The relationship between brake force and thermal dissipation was evident in moderate braking, which, on the other hand, showed in between temperature increases and cooling rates. The extended cooling pattern during light braking led to lower temperatures than the regular pattern. Heavy braking resulted in the highest temperature increases and cooling rates of all the scenarios. Temperature increased quickly due to the substantial friction created during heavy braking. The recommended braking technique for landing would be moderate braking, as this provides adequate stopping distance and does not cause the temperature to rise too much. The highest temperature recorded during heavy braking testing was 117°C during the takeoff roll. However, the max recommended temperature for 30-55 brake used on the piper aircraft assembly is 133°C for a short period of time(Parker Hannifin Corporation [Aircraft Wheel & Brake Division], 2023).

One major limitation that was encountered was the fact that the light moderate and heavy braking was based on the pilot judgment which can be trusted as the pilot has over 3000 hours as PIC and is very familiar with the testing environment. The data also was very evident that the pilot did maintain light moderate and heavy braking as seen in the temperature results.

No matter what the temperature was, there was heating during taxiing. This could have resulted from ground heat transferring some of the thermal energy to the brake components. There could also be unconscious application of the brakes. However, the pilot has over 3000 hours of PIC and is used in different testing environments.

Especially during the stop-and-go, it was evident that thermal inertia played an important role in the heat generation rate from frictional forces and may outpace any potential cooling effects from airflow.

The most critical test was continuous braking while taxiing. It is important for pilots not to ride the brakes while taxing as it can be concluded that riding the brakes for a long period causes higher temperatures to increase higher than heavy braking landing. As seen in the result, the temperature exceeded the maximum recommended temperature for forty seconds for moderate and continuous braking. The worst-case scenario is if a pilot conducts heavy braking and then continuously rides the brakes. Combining these two would cause the brake to go above the recommended max operating temperature of 133°C for a long time.

It was also evident that no matter what the temperature of the brakes was, the brake components consistently reverted to near or even ambient temperature, while the speed remained approximately at 90 knots. Therefore, it can be concluded that multiple stop and gos would not overheat the brakes. However, the side where the prevailing wind is flowing over directly would cool first.

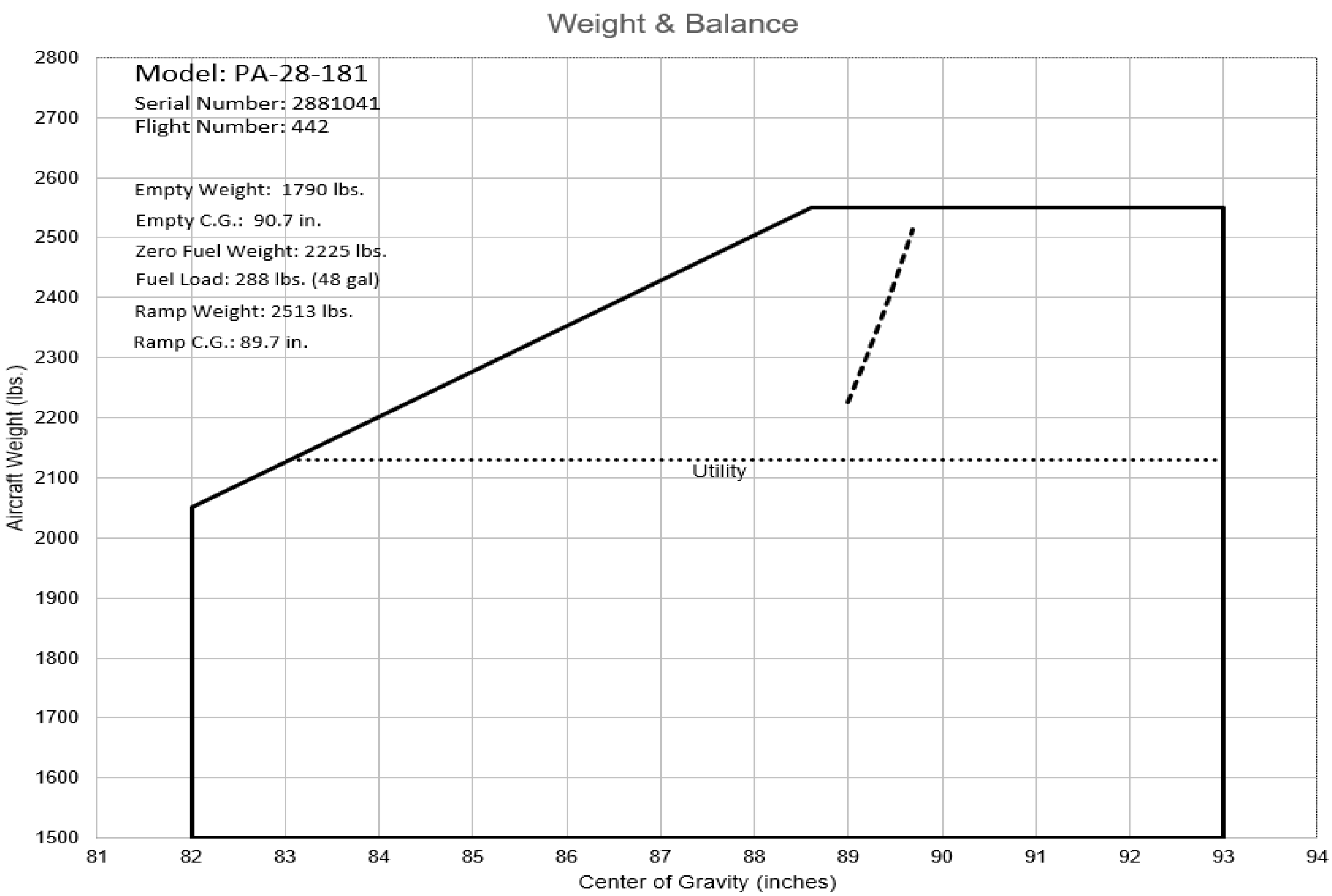
References

1. Jacko, M. G., & Rhee, S. K. (2000). Brake linings and clutch facings. Kirk-Othmer Encyclopedia of Chemical Technology. https://doi.org/10.1002/0471238961.0218011110010311.a01
2. Kumar, N., Bharti, A., Goyal, H. S., & Patel, K. K. (2021). The Evolution Of Brake Friction Materials: A Review. Materials Physics & Mechanics, 47(5). pp. 799
3. Lumen Learning. (2021, June 1). *Pascal's principle*. Pressbooks. https://pressbooks.nscc.ca/heatlightsound/chapter/11-5-pascals-principle/
4. Meunier, C., Bauzin, J., Laraqi, N., Gapin, A., & Diebold, J. (2022). Thermal characterization of an aircraft brake's braking and cooling stages using identification techniques and a life-size experimental test bench. *International Journal of Heat and Mass Transfer (Print)*, *196*, 123277. https://doi.org/10.1016/j.ijheatmasstransfer.2022.123277
5. Parker Hannifin Corporation [Aircraft Wheel & Brake Division]. (2023). Technician's Service Guide. Parker Vault, AWBTSG0001-25/USA(25).
6. Piper Pilot III PA-28-181 SN 2843001 AND UP With Garmin. (2020). Pilot Operating Handbook, VB-2960.
7. Shafigh, P., Asadi, I., & Mahyuddin, N. (2018). Concrete as a thermal mass material for building applications - A review. *Journal of Building Engineering*, *19*, 14–25. https://doi.org/10.1016/j.jobe.2018.04.021

8. Towoju, O. A. (2019). Braking Pattern Impact on Brake Fade in an Automobile Brake System. *Journal of Engineering Sciences*, *6*(2). https://doi.org/10.21272/jes.2019.6(2).e2

Appendix

Appendix 1: Aircraft weight and balance



Appendix 2 Test Cards

Model: PA -28-181 N28PP A
Flight: 442

ENGINE START

Set Up	Config. Notes
Altitude: FIELD	Flaps: UP
Airspeed: AR	Gear: DN
Power: AS REQUIRED	

1. MFD Card: ___x___
2. G5 Standby Instrument Card: _____x__
3. DAS:___x
4. Engine Start Time: 10:33 LCL

   Hobbs : 676.3 Fuel L/R: 24 / 24

Airport Weather Conditions

ATIS H Time 1553 Wind 360153G23

Sky10SM BKN041 Temp/Dew:19/11

Baro 3012 inHg Rwy 30l/30r

Notes

Model: PA -28-181 N28PP 1
Flight: 442

Brake Temperature Evaluation 94.300

Set Up	Config. Notes
Altitude: AR ft AGL	Flaps: FULL
Airspeed: 66 KIAS	Gear: DN
Power: AR	Weight/C.G: HVY/OPT

TP 01
Full Stop Taxi Back Brake Cooling

- Minimize brake application during initial taxi
- Perform normal takeoff
- Fly airport's traffic pattern (76kts for climb, 90kts for downwind, 80kts for base leg, 66KIAS for final)
- Perform normal landing per POH procedure
- Perform Light Braking
- Remain stationary 3 seconds after full stop before taxiing clear of the runway
- Taxi back to runway
- Perform normal takeoff
- Fly airport's traffic pattern (76kts for climb, 90kts for downwind, 80kts for base leg, 66KIAS for final)

Notes

Fuel: L/R 21 / 23

Wind speed:100@09

Takeoff roll time: 16:39UTC

Touchdown time:16:43

Time Taxi back began:16:45:25

Traffic Pattern time : 4 minutes

Highest temperature observed 69

Model: PA -28-181 N28PP
Flight: 442

2

Brake Temperature Evaluation 94.300

Set Up	Config. Notes
Altitude: AR ft AGL	Flaps: FULL
Airspeed: 66 KIAS	Gear: DN
Power: AR	Weight/C.G: HVY/OPT

TP 02
Full Stop Taxi Back Brake Cooling

- Perform normal landing per POH procedure
- Perform Moderate Braking
- Remain stationary 3 seconds after full stop before taxiing back to runway
- Taxi back to runway
- Perform normal takeoff
- Fly airport's traffic pattern (76kts for climb, 90kts for downwind, 80kts for base leg, 66KIAS for final)

Notes

Traffic Pattern time : 4 minutes

Touchdown time: 16:53:23

Highest observed temperature: LH BP 88 °C RH BP 89 °C

Time Taxi back began:16:54:12

Takeoff roll time:16:56:33

Model: PA -28-181 N28PP
Flight: 442

3

Brake Temperature Evaluation 94.300

Set Up	Config. Notes
Altitude: AR ft AGL	Flaps: FULL
Airspeed: 66 KIAS	Gear: DN
Power: AR	Weight/C.G: HVY/OPT

TP 03
Full Stop Taxi Back Brake Cooling

- Perform normal landing per POH procedure
- Perform Heavy Braking
- Remain stationary 3 seconds after full stop before taxiing back to runway
- Perform normal takeoff
- Taxi back to runway
- Fly airport's traffic pattern (76kts for climb, 90kts for downwind, 80kts for base leg, 66KIAS for final)

Notes

Touchdown time: 17:01:03

Highest observed temperature: LH BP 99 °C RH BP 88 °C

Time Taxi back began:17:02:00

Takeoff roll time:17:04:14

Traffic Pattern time : 4 minutes

Model: PA -28-181 N28PP

Flight: 442

4

Brake Temperature Evaluation 94.300

Set Up	Config. Notes
Altitude: AR ft AGL	Flaps: FULL
Airspeed: 66 KIAS	Gear: DN
Power: AR	Weight/C.G: HVY/OPT

TP 04

Full Stop Taxi Back Brake Cooling

- Perform normal landing per POH procedure
- Perform light braking
- Remain stationary 3 seconds after full stop before taxiing back to runway
- Taxi back to runway
- Perform normal takeoff
- Fly airport's traffic pattern extend **3 minutes of baseline**

Notes

Touchdown time: 17:08:40

Highest observed temperature: LH BP 49 °C RH BP 42 °C

Time Taxi back began:17:10:15

Takeoff roll time:17:13:50

Traffic Pattern time : 7 minutes

Model: PA -28-181 N28PP
Flight: 442

5

Brake Temperature Evaluation 94.300

Set Up	Config. Notes
Altitude: AR ft AGL	Flaps: FULL
Airspeed: 66 KIAS	Gear: DN
Power: AR	Weight/C.G: HVY/OPT

TP 05
Full Stop Taxi Back Brake Cooling

- Perform normal landing per POH procedure
- Perform moderate braking
- Remain stationary 3 seconds after full stop before taxiing back to runway
- Taxi back to runway
- Perform normal takeoff
- Fly airport's traffic pattern extend **3 minutes of baseline**

Notes

Touchdown time: 17:19:15

Highest observed temperature: LH BP 75 °C RH BP 55 °C

Time Taxi back began:17:22:55

Takeoff roll time:17:23:20

Traffic Pattern time : 7 minutes

Model: PA -28-181 N28PP

Flight: 442

6

Brake Temperature Evaluation 94.300

Set Up	Config. Notes
Altitude: AR ft AGL	Flaps: FULL
Airspeed: 66 KIAS	Gear: DN
Power: AR	Weight/C.G: HVY/OPT

TP 06

Full Stop Taxi Back Brake Cooling

- Perform normal landing per POH procedure
- Perform heavy braking
- Remain stationary 3 seconds after full stop before taxiing back to runway
- Taxi back to runway
- Perform normal takeoff
- Fly airport's traffic pattern extend **3 minutes of baseline**

Notes

Touchdown time: 17:30:11

Highest observed temperature: LH BP 93 °C RH BP 88 °C

Time Taxi back began:17:31:50

Takeoff roll time:17:33:04

Traffic Pattern time : ~7 minutes

Model: PA -28-181 N28PP
Flight: 442

7

Brake Temperature Evaluation 94.301

Set Up	Config. Notes
Altitude: AR ft AGL	Flaps: FULL
Airspeed: 66 KIAS	Gear: DN
Power: AR	Weight/C.G: HVY/OPT

TP 01
Stop and Go Brake Cooling

- Perform normal landing per POH procedure
- Perform light braking
- Remain stationary 3 seconds after full stop before takeoff
- Perform normal takeoff
- Fly airport's traffic pattern (76kts for climb, 90kts for downwind, 80kts for base leg, 66KIAS for final)

Notes

Touchdown time: 17:39:53

Aborted takeoff 17:41:21

Takeoff roll time: 17:43:43

Highest observed temperature: LH BP 53 °C RH BP 52 °C

Takeoff roll time:17:47:41

Traffic Pattern time : 5 minutes

Model: PA -28-181 N28PP
Flight: 442

8

Brake Temperature Evaluation 94.301

Set Up	Config. Notes
Altitude: AR ft AGL	Flaps: FULL
Airspeed: 66 KIAS	Gear: DN
Power: AR	Weight/C.G: HVY/OPT

TP 02
Stop and Go Brake Cooling

- Perform normal landing per POH procedure
- Perform moderate braking
- Remain stationary 3 seconds after full stop before takeoff
- Perform normal takeoff
- Fly airport's traffic pattern (76kts for climb, 90kts for downwind, 80kts for base leg, 66KIAS for final)

Notes

Touchdown time: 17:52:53

Highest observed temperature: LH BP 61 °C RH BP 60 °C

Takeoff roll time:17:53:50

Traffic Pattern time : 4 minutes

Model: PA -28-181 N28PP
Flight: 442

9

Brake Temperature Evaluation 94.301

Set Up	Config. Notes
Altitude: AR ft AGL	Flaps: FULL
Airspeed: 66 KIAS	Gear: DN
Power: AR	Weight/C.G: HVY/OPT

TP 03
Stop and Go Brake Cooling

- Perform normal landing per POH procedure
- Perform heavy braking
- Remain stationary 3 seconds after full stop before takeoff
- Perform normal takeoff
- Fly airport's traffic pattern (76kts for climb, 90kts for downwind, 80kts for base leg, 66KIAS for final)

Notes

Touchdown time: 17:57:53

Highest observed temperature: LH BP 66 °C RH BP 65 °C

Takeoff roll time:17:58:26

Traffic Pattern time : ~4 minutes

Model: PA -28-181 N28PP
Flight: 442

10

Brake Temperature Evaluation 94.301

Set Up	Config. Notes
Altitude: AR ft AGL	Flaps: FULL
Airspeed: 66 KIAS	Gear: DN
Power: AR	Weight/C.G: HVY/OPT

TP 04
Stop and Go Brake Cooling

- Perform normal landing per POH procedure
- Perform light braking
- Remain stationary 3 seconds after full stop before takeoff
- Perform normal takeoff
- Fly airport's traffic pattern extend 3 minutes of baseline

Notes

Touchdown time: 18:03:08

Highest observed temperature: LH BP 64 °C RH BP 51 °C

Takeoff roll time:18:03:59

Traffic Pattern time : ~7 minutes

Model: PA -28-181 N28PP
Flight: 442

11

Brake Temperature Evaluation 94.301

Set Up	Config. Notes
Altitude: AR ft AGL	Flaps: FULL
Airspeed: 66 KIAS	Gear: DN
Power: AR	Weight/C.G: HVY/OPT

TP 05
Stop and Go Brake Cooling
- Perform normal landing per POH procedure
- Perform moderate braking
- Remain stationary 3 seconds after full stop before takeoff
- Perform normal takeoff
- Fly airport's traffic pattern extend 3 minutes of baseline

Notes

Touchdown time: 18:10:10

Highest observed temperature: LH BP 54 °C RH BP 56 °C

Takeoff roll time:18:10:50

Traffic Pattern time : ~7 minutes

Model: PA -28-181 N28PP
Flight: 442

12

Brake Temperature Evaluation 94.301

Set Up	Config. Notes
Altitude: AR ft AGL	Flaps: FULL
Airspeed: 66 KIAS	Gear: DN
Power: AR	Weight/C.G: HVY/OPT

TP 06
Stop and Go Brake Cooling

- Perform normal landing per POH procedure
- Perform heavy braking
- Remain stationary 3 seconds after full stop
- Perform normal takeoff
- Fly airport's traffic pattern extend 3 minutes of baseline

Notes

Touchdown time: 18:17:26

Highest observed temperature: LH BP 58 °C RH BP 58 °C

Takeoff roll time:18:18:10

Touchdown time: 18:24:40

Traffic Pattern time : ~7 minutes

Model: PA -28-181 N28PP
Flight: 442

13

Brake Temperature Evaluation 94.302

Set Up	Config. Notes
Altitude: AR ft AGL	Flaps: UP
Airspeed: 10 KTS	Gear: DN
Power: AR	Weight/C.G: HVY/OPT

TP 01
Heavy Braking

- Taxi airplane in straight line while holding the brakes for 1 minute to maintain specified ground speed
- Stop and record highest observed temperature
- Allow brakes to cool 20ºC below highest observed temperature before shutdown

Notes

Time brakes were applied 19:10 – 19:11

Highest observed temperature:105 °C

Model: PA -28-181 N28PP B
Flight: 442

Engine Shutdown

Set Up	Config. Notes
Altitude: FIELD	Flaps: UP
Airspeed: AR	Gear: DN
Power: AR	

1. Engine Shutdown Time 13:30 LCL

   Hobbs : 678.9 Fuel L/R:11/13

Airport Weather Conditions

ATIS _J__ Time _1753____ Wind 070@5

Sky 10V Scatter 4600 Temp/Dew 23/12

Baro 3022 inHg Rwy 12R

Notes