جامعة الدوحة
للعلوم والتكنولوجيا
UNIVERSITY OF DOHA
FOR SCIENCE & TECHNOLOGY

AEMA2113 Hydraulics & Pneumatics-2

Spring Semester 2024

Project- Automotive Brake System

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Abstract

This report presents a comprehensive design analysis of a hydraulic brake system for automotive applications. The hydraulic brake system operates based on Pascal's Law, which states that pressure applied to a confined fluid is transmitted equally in all directions. This principle is crucial in ensuring that the force applied by the driver on the brake pedal is effectively and evenly distributed to all wheels, resulting in a reliable and efficient braking performance. In this report, we detail the theoretical calculations for selecting appropriate hydraulic components, such as the diameters of the master cylinder, caliper pistons, and brake lines, ensuring minimal pressure loss and adequate fluid flow. We also calculate the required capacity of the brake fluid reservoir to maintain system functionality, accounting for fluid volume in the system, brake pad wear, and an additional safety margin. This design analysis ensures that the hydraulic brake system is effective and provides optimal performance and safety for automotive applications.

Design and analysis of system

Brakes are essential in vehicles for controlling speed, ensuring safe stopping, and maintaining vehicle stability. The sequential mechanism of a hydraulic brake system involves the conversion of the mechanical force applied on the brake pedal into hydraulic pressure, which then actuates the brake calipers to create friction against the brake rotors, thereby slowing down or stopping the vehicle.

Master Cylinder: Converts the mechanical force from the brake pedal into hydraulic pressure. When the brake pedal is pressed, the force applied by the driver is transmitted to the master cylinder, which then pressurizes the brake fluid initiating the entire braking process by sending hydraulic fluid through the brake lines to the calipers. The master cylinder was selected based on its ability to generate sufficient pressure. The calculation involved assuming a force of 90 lbs. and a pressure of 300 psi, which led to a required diameter of 0.618 inches. The chosen master cylinder has a diameter of 5/8 inches (0.625 inches), closely matching the calculated requirement and ensuring efficient pressure generation.

Caliper: It receives hydraulic pressure, converts it into mechanical force in the pistons within the calipers and pushes the brake pads against the rotor. This action creates the necessary friction to slow down or stop the vehicle. The calipers were selected for their clamping force, piston size, and durability under high temperatures and pressures. The selection process involved calculating the required braking force for a vehicle mass of 2500 lbs., with a stopping distance of 150 feet and an initial velocity of 75 ft/s. Using a pressure of 300 psi, the required area was found to be 1.25 in^2, and the selected caliper piston area is 1.58 in^2, providing a robust and reliable braking force.

Reservoir: Maintains an adequate supply of brake fluid within the hydraulic brake system. It ensures that the master cylinder always has enough fluid to generate the necessary hydraulic pressure. For the reservoir design, an assumed velocity of 12 in/s and a diameter of 0.1 inches were used to calculate the flow rate, then multiplied it with 2 minutes to determine the minimum reservoir. The calculated reservoir volume is 12 in^3, and the selected reservoir has a slightly larger volume of 12.6 in^3. This ensures there is always enough brake fluid to compensate for any loss due to leaks or pad wear, maintaining the system's reliability and performance.

Hydraulic Fluid: It is the medium in which the hydraulic pressure from the master cylinder travels to the calipers. The selected brake fluid, Wilwood Brake Fluid No.: 290-0632, was chosen for its stability under extreme temperatures and pressures. This ensures consistent braking performance and prevents vapor lock, which can occur when the fluid boils and creates gas bubbles, leading to brake failure. The high-quality brake

fluid ensures that the system remains responsive and effective under all operating conditions.

Hydraulic Hose: Serves as the pathway for hydraulic fluid between the master cylinder and the calipers. It is designed to withstand high pressures and temperatures while maintaining flexibility for suspension movement and steering. The selected hose was chosen for its high-pressure rating, flexibility, and durability, ensuring minimal pressure loss and consistent fluid flow.

Proportioning Valve: Adjusts the brake pressure between the front and rear brakes to prevent rear-wheel lockup during heavy braking. It is designed to regulate the pressure to the rear brakes, ensuring balanced and stable braking performance. The selected proportioning valve was chosen for its precise control.

Residual Pressure Valve: The residual pressure valve maintains a small amount of pressure in the brake lines to ensure that the brake pads stay close to the rotors. This reduces the response time of the brakes and ensures that they are always ready to engage. The selected residual pressure valve was selected for its ability to maintain constant pressure.

The total cost of the hydraulic brake system is $596.57, which converts to QR 2,173.73. Each component was selected for its performance and compatibility, with consideration of cost-effectiveness. The selected master cylinder and calipers are the costliest due to their critical role in the braking process and their need for high durability and performance. The hydraulic hose and brake fluid were selected for their quality and reliability, ensuring minimal maintenance and long-term performance. The proportioning and residual pressure valves were selected to improve braking dynamics.

References

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https://www.wilwood.com/mastercylinders

https://www.wilwood.com/Calipers

https://www.wilwood.com/BrakeFluid

https://www.wilwood.com/LineKits

https://www.wilwood.com/itemno=260-10922

https://www.wilwood.com/itemno=260-13783

https://www.researchgate.net/publication/323522310

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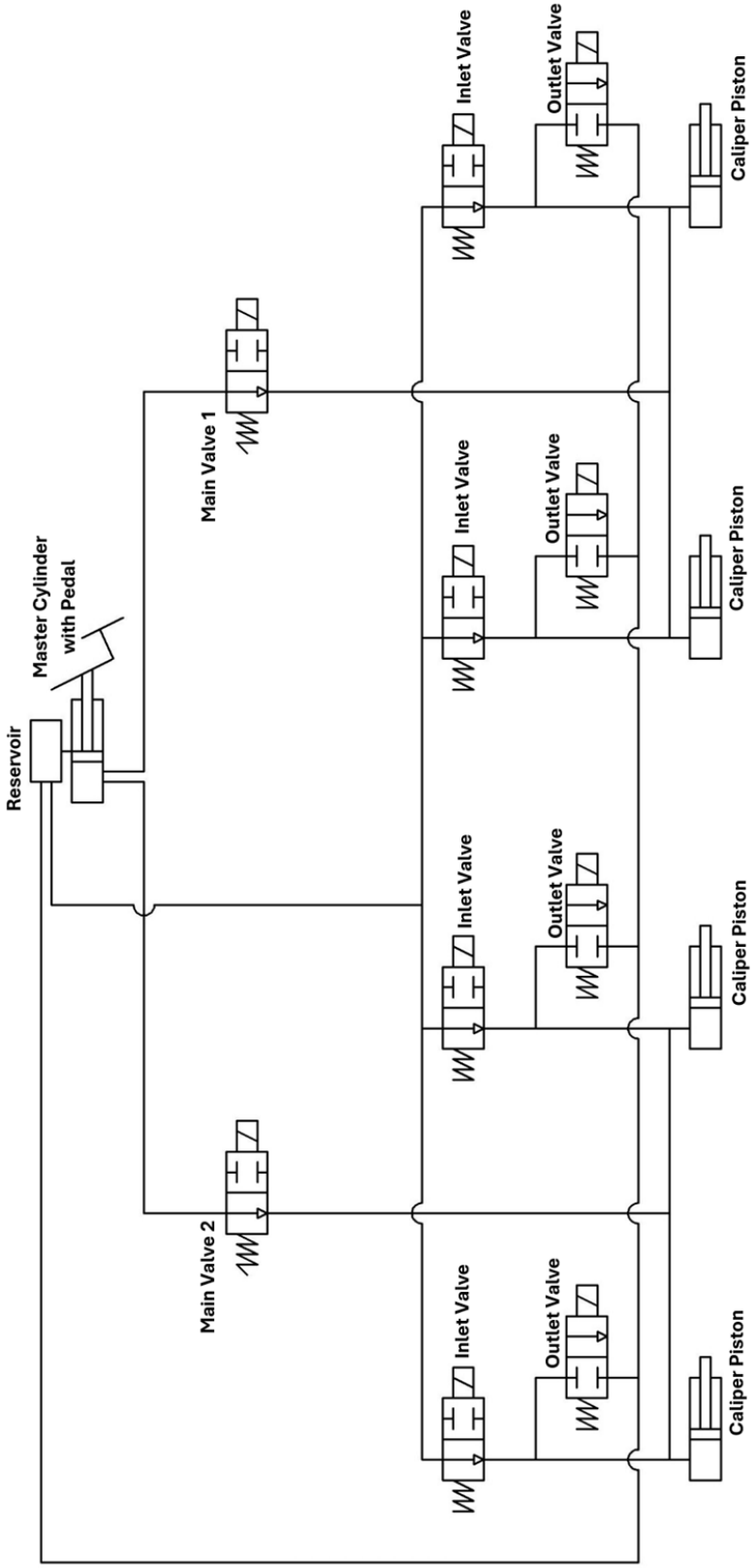
Appendix - System Schematic



University of Doha for Science and Technology
Mechanical Engineering Department
AEMA2113 Hydraulics & Pneumatics
Project Automotive Brake System
Section 2
10/06/2024

Appendix - Detailed calculations

Brake Caliper

Assuming
stopping distance $s = 150\ ft$
Initial velocity $u = 75\ ft/s$
Final velocity $v = 0\ ft/s$

$v^2 = u^2 + 2as$

$\Rightarrow 0 = (75\ ft/s)^2 + (2 \times a \times 150\ ft)$

$\Rightarrow 0 = 5625\ ft^2/s^2 + (300\ ft \times a)$

$\Rightarrow a = \dfrac{-5625\ \frac{ft^2}{s^2}}{300\ ft} = -18.75\ ft/s$

Deceleration $a = 18.75\ ft/s$

Average mass of car $m = 2500\ lbs \times \frac{1}{32.174\ ft/s^2}$

$m = 77.7\ slugs$

Breaking force $F_b = ma$

$= 77.7\ slugs \times 18.75\ ft/s$

$F_b = 1456.92\ lbs$

$F_b \approx 1500\ lbs$

Assuming a pressure $P = 300\ psi$

Selecting a caliper with 4 pistons

∴ Total area of caliper with 4 piston = A_c

$\therefore A_c = \dfrac{F_B}{P} = \dfrac{1500\ lbs}{300\ psi} = 5\ in^2$

Area of single piston of caliper = $\dfrac{A_c}{\text{No. of pistons}}$

$A_p = \dfrac{5\ in^2}{4}$

$A_p = 1.25\ in^2$

∴ Minimum piston area $= 1.25\ in^2$
selected piston area $= 1.58\ in^2$

Master Cylinder

Assuming a force $F_m = 90$ lbs
and pressure $P = 300$ psi

$\therefore$ Area required $A_m = \frac{F_m}{P} = \frac{90 \text{ lbs}}{300 \text{ psi}}$

$$A_m = 0.3 \text{ in}$$

Cylinder diameter $d_m = \sqrt{\frac{4A_m}{\pi}} = \sqrt{\frac{4 \times 0.3 \text{ in}}{\pi}}$

$$d_m = 0.618 \text{ in}$$

Selected cylinder diameter $= \frac{5}{8}'' = 0.625 \text{ in}$

Reservoir

Assuming Velocity $V = 12\ in/s$
Diameter of Intake line $d = 0.1\ in$

Area of Intake line $= \frac{\pi}{4} d^2 = \frac{\pi}{4} \times 0.1^2 = 0.0079\ in^2$

$$A \approx 0.008\ in^2$$

Flow Rate $Q = AV$

$$\Rightarrow Q = 0.008\ in^2 \times 12\ in/s$$

$$\Rightarrow Q = 0.096 \frac{in^3}{s} \times \frac{60 s}{1 min}$$

$$\Rightarrow Q = 5.76\ in^3/min$$

$$Q \approx \underline{6\ in^3/min}$$

∴ Minimum Reservoir Volume $(V_R) = Q \times 2 min$

$$V_R = \frac{6\ in^3}{min} \times 2 min$$

$$V_R = 12\ in^3$$

Selected Reservoir Volume $= 12.6\ in^3$

Appendix - Bill of material

Component	Product Number	Cost
Master Cylinder with Reservoir	MasterCylinder No: 260-10371	$104.70
Caliper	Caliper No: 120-9706	$296.86
Hydraulic Fluid	Brake Fluid No.: 290-0632	$15.42
Hydraulic Hose	Flexline No: 220-10879	$102.61
Proportioning Valve	Prod #: 260-10922	$52.32
Residual Pressure Valve	Prod #: 260-13783	$24.66
		Total - $596.57 QR 2,173.73

Appendix - Component Catalog Sheets

MasterCylinder No: 260-10371

Master Cylinder Dimensions	
Bore Size	5/8"
Area (in²)	0.310
Stroke	1.12
Volume (cu in)	0.34
Master Cylinder Description	
Type	Single Outlet
Outlets	1
Material	Aluminum / Plastic
Finish	Black E-coat
Reservoir	
Res Type	Remote
Res Size (oz)	10.0 or 7.0
Res Size(cu in)	18.0 or 12.6
Rate	
UPC Number	
UPC	889545066555

General Information and Installation Instructions (Continued)

Ordering Information:

5/8" Combination Master Cylinder Kit (1.12 stroke)	260-10371	5/8" Combination Rebuild Kit	260-10513
3/4" Combination Master Cylinder Kit (1.12 stroke)	260-10372	3/4" Combination Rebuild Kit	260-10514
13/16" Combination Master Cylinder Kit (1.12 stroke)	260-10373	13/16" Combination Rebuild Kit	260-10515
7/8" Combination Master Cylinder Kit (1.12 stroke)	260-10374	7/8" Combination Rebuild Kit	260-10516
15/16" Combination Master Cylinder Kit (1.12 stroke)	260-14784	15/16" Combination Rebuild Kit	260-14920
1" Combination Master Cylinder Kit (1.12 stroke)	260-10375	1" Combination Rebuild Kit	260-10517
1-1/8" Combination Master Cylinder Kit (1.12 stroke)	260-10376	1-1/8" Combination Rebuild Kit	260-10518

If after following the instructions, you still have difficulty in installing or bleeding your Wilwood master cylinder, consult your local chassis builder, or retailer where the kit was purchased for further assistance.

Exploded Diagram

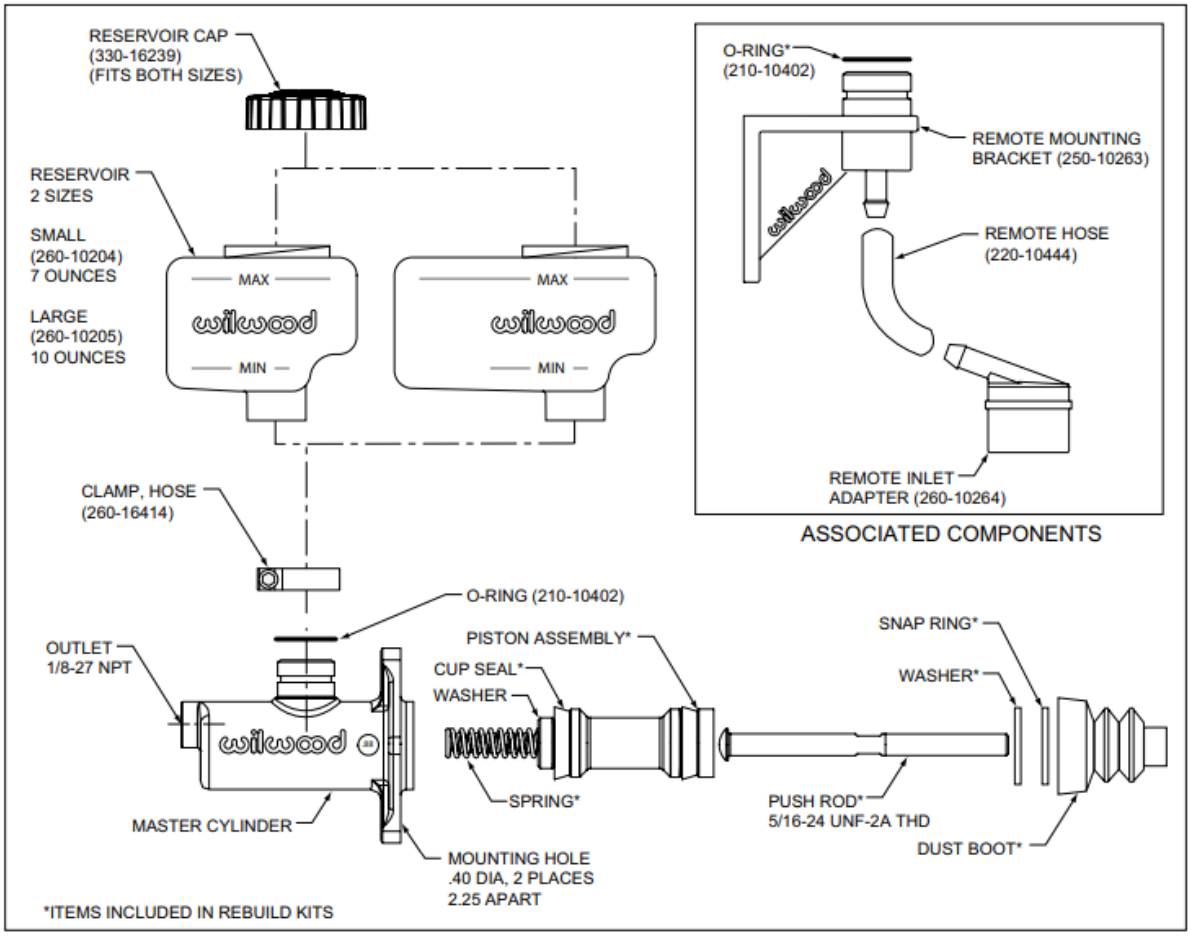
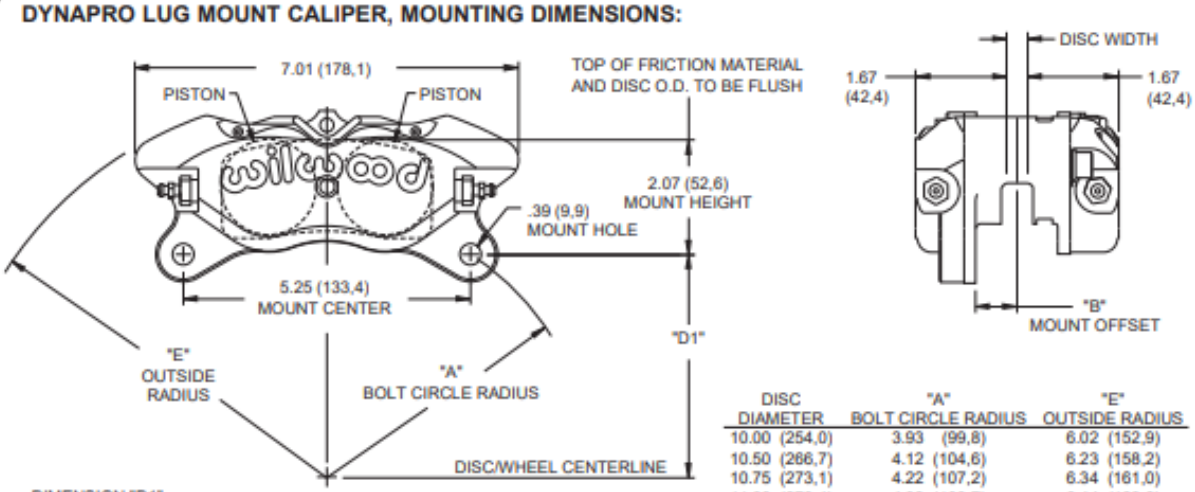


Figure 4. Master Cylinder and Associated Components

Caliper No: 120-9706

Pistons	
Piston Count	**4**
Piston Area (in²)	**1.58**
Piston Type	**Stainless**
Dust Boot	**No**
Rotor Dimensions	
Rotor Width (in)	**0.81**
Rotor Diameter(in)	**13.06**
Pad Dimensions	
Pad Area (in²)	**6.36**
Pad Volume (in³)	**2.1**
Duty Rating & Material	
Material	**Forged Aluminium**
Weight(Lbs)	**3.8**
Colors & Finish	
Color	**Black**
Finish	**Black Powder Coat**

DYNAPRO LUG MOUNT CALIPER, MOUNTING DIMENSIONS:



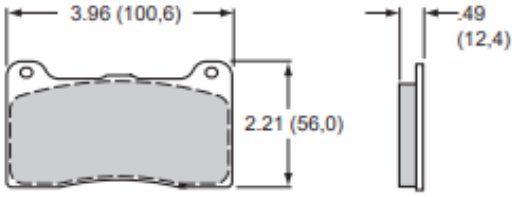
DIMENSION "D1" =
(DISC DIAMETER/2) - 2.07 (52,6)

INLET FITTING: 1/8-27 NPT

DISC WIDTH	"B" MOUNT OFFSET
.38 (9,7)	.76 (19,3)
.50 (12,7)	.82 (20,8)
.81 (20,6)	.98 (24,9)
1.00 (25,4)	1.08 (27,4)
1.25 (31,8)	1.20 (30,5)

DISC DIAMETER	"A" BOLT CIRCLE RADIUS	"E" OUTSIDE RADIUS
10.00 (254,0)	3.93 (99,8)	6.02 (152,9)
10.50 (266,7)	4.12 (104,6)	6.23 (158,2)
10.75 (273,1)	4.22 (107,2)	6.34 (161,0)
11.00 (279,4)	4.32 (109,7)	6.44 (163,6)
11.44 (290,6)	4.50 (114,3)	6.63 (168,4)
11.75 (298,5)	4.63 (117,6)	6.76 (171,7)
12.19 (309,6)	4.81 (122,2)	6.97 (177,0)
12.88 (327,2)	5.06 (128,5)	7.21 (183,1)
13.00 (330,2)	5.11 (129,8)	7.27 (184,7)
13.06 (331,7)	5.14 (130,5)	7.31 (185,7)

DYNAPRO LUG MOUNT CALIPER, TYPE 7812 PAD DIMENSIONS AND ORDERING INFORMATION:



AXLE SET P/N	PAD TYPE / COMPOUND
15A - 9835K	7812 A PolyMatrix
15B - 9836K	7812 B PolyMatrix
15E - 9837K	7812 E PolyMatrix
15H - 10644K	7812 H PolyMatrix
15Q - 10385K	7812 Q PolyMatrix
150 - 9136K	7812 10 BP-10 Smart Pad
150 - 9418K	7812 20 BP-20 Smart Pad
150 - 11735K	7812 30 BP-30 Smart Pad
150 - 12247K	7812 40 BP-40 Smart Pad
150 - 10020K	7812 CM For Titanium Rotor

ORDERING INFORMATION, USER SERVICEABLE COMPONENTS:

CALIPER PART NO.	PISTON	SQ RING (4 PK)	BLEED SCREW KIT (4 PK)	BODY SEAL (EA)	BRIDGE WEAR PLATE (EA)	PAD RETAINER CLIP PIN (EA)	BRIDGE BOLT KIT (EA)
120-9691	200-7528 (1.75")	130-2655	220-0627	210-2582	300-5875	300-9638	230-10119
120-9692	200-7528 (1.75")	130-2655	220-0627	210-2582	300-5875	300-9637	—
120-9693	200-7528 (1.75")	130-2655	220-0627	210-2582	300-5875	300-9636	230-10118
120-9694	200-7528 (1.75")	130-2655	220-0627	210-2582	300-5875	300-9635	—
120-9695	200-7528 (1.75")	130-2655	220-0627	210-2582	300-5875	300-9634	230-10117
120-9701	200-7518 (1.38")	130-2658	220-0627	210-2582	300-5875	300-9638	230-10119
120-9702	200-7518 (1.38")	130-2658	220-0627	210-2582	300-5875	300-9637	—
120-9703	200-7518 (1.38")	130-2658	220-0627	210-2582	300-5875	300-9636	230-10118
120-9704	200-7518 (1.38")	130-2658	220-0627	210-2582	300-5875	300-9635	—
120-9705	200-7518 (1.38")	130-2658	220-0627	210-2582	300-5875	300-9634	230-10117
120-9706	200-6979 (1.00")	130-4320	220-0627	210-2582	300-5875	300-9636	—

Brake Fluid No.: 290-0632

HI-TEMP Brake Fluid

Prod #: **290-0632**

290-0632 — Product Summary	
Dry Boiling Point	**573 °F**
Wet Boiling Point	**313 °F**
Quantity	**1 each**
Size	**12 oz bottle**
UPC	**889545069426**

Product Documents	
DATA SHEET	SAFETY DATA SHEET
Click To View	Click to View

ORDERING INFORMATION: PH: 805.388.1188 • FAX: 805.388.4938 • wilwood.com • info@wilwood.com

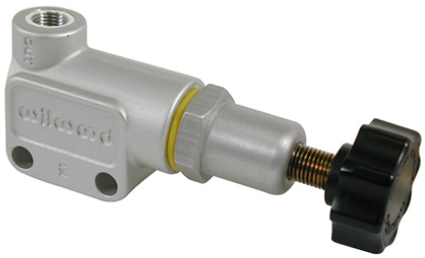
PART NUMBER	DESCRIPTION
290-0632	Hi-Temp 570 Bottle, 12 fluid ounces (1 Bottle)
290-2210	Hi-Temp 570 Six Pack, 12 fluid ounces (6 Pack Bottles)
290-0633	Hi-Temp 570 Case, 12 fluid ounces (24 Pack Bottles)

Flexline No: 220-10879

Size & Fittings	
Length	16.00
Size	-3
Chassis Fitting Size	-3 to M10 x 1 BF
Inlet Fitting	-3 Female
Inlet Fitting Angle	90 Degree
Outlet Fitting	-3 Female
Outlet Fitting Angle	Straight
Caliper Fit Angle	Banjo 0 De
Caliper Fit Thread	10mm Banjo
Additional Info	
Weight (lb)	0.80
Qty Each	1
Qty per Kit	2
Chassis Clip	300-15780
Line Bracket	
UPC Number	
UPC	889545044577

Proportioning Valve

Prod #: **260-10922**



Master Cylinder Dimensions	
Bore Size	N-A
Area (in²)	
Stroke	
Volume (cu in)	
Master Cylinder Description	
Type	
Outlets	0
Material	Aluminum / Steel
Finish	Clear Anodize
Reservoir	
Res Type	
Res Size (oz)	
Res Size(cu in)	
Rate	0 to 57%
UPC Number	
UPC	889545066715

wilwood DISC BRAKES

ADJUSTABLE PROPORTIONING VALVE

PART NUMBER: 260-10922

SPECIFICATIONS

MAX PRESSURE REDUCTION	57%
INLET / OUTLET PORTS	3/8-24 I.F.
MOUNTING HOLE DIAMETER	.250 INCH
MOUNTING HOLE SPACING	1.00 INCH
WEIGHT	5.2 OUNCES

Residual Pressure Valve

Prod #: **260-13783**

Master Cylinder Dimensions	
Bore Size	
Area (in²)	
Stroke	
Volume (cu in)	
Master Cylinder Description	
Type	
Outlets	
Material	**Aluminum**
Finish	**Blue Anodize**
Reservoir	
Res Type	
Res Size (oz)	
Res Size(cu in)	
Rate	**2 lbs**
UPC Number	
UPC	**889545074789**

DISC BRAKES wilwood

RESIDUAL PRESSURE VALVE

This package contains **ONE** of the following:

- 2 lb. (P/N 260-13706 • Blue)
- 2 lb. (P/N 260-13783 w/fittings)
- 4 lb. (P/N 260-15365 • Gold)
- 4 lb. (P/N 260-15366 w/fittings)
- 10 lb. (P/N 260-13707 • Red)
- 10 lb. (P/N 260-13784 w/fittings)