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DISK BRAKE REPORT

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EXECUTIVE SUMMARY

The disk brakes on a small aircraft were reverse engineered at the owner's request. The existing brakes are not capable of holding the aircraft stopped during a full-power engine runup. From both measurements and calculations, approximately three times the existing braking power will be required to do this. At the owner's request the existing brakes will be replaced with Matco disk brakes that claim an improvement of more than 2.5 times the existing braking. The calculations herein show an existing braking torque of 764 inch-pounds per wheel, which closely agrees with Matco's figure of less than 800 inch-pounds.

STATIC THRUST

Static Thrust, the pounds of push on the airplane while standing still with the propeller turning and the brakes applied, is difficult to calculate accurately, as there are too many fuzzy variables. Static thrust is roughly 50% of maximum airborne thrust because the propeller is designed to work best while the aircraft is moving forward through the air. The most accurate way to determine static thrust is to tie the aircraft to a tree (with a chain) and measure the pull with an inline scale having at least 2000 pounds maximum reading. This could be risky. I don't know what part of the aircraft could hold the chain without bending or breaking.

From http://www.rcuniverse.com/forum/m_608127/tm.htm
For a 2-blade propeller, Static Thrust = $2.83 \times 10^{-12} \times RPM^2 \times D^4 \times$ AirDensityFactor x CFValue. As thrust is proportional to the square of propeller RPM then so is the required braking power. The braking power required at 5500 RPM will be $(5500 / 3000)^2 = 3.36$ times that required at 3000 RPM. The air density factor at sea level is 1.0 and decreases with increasing altitude. D is the propeller diameter in inches. The CFValue is a number close to 1.0.

The aircraft is equipped with:

- WarpDrive, 4-blade, ground adjustable pitch propeller of 1.65-meters (65-inches) overall diameter. Pitch is set to 13.75 degrees.
- Rotax 912 motor has 2:1 reduction gear to propeller. At 5500 RPM the prop turns at 2750 RPM.

Using the Static Thrust Calculator downloaded from http://www.bmaps.net/ , Static Thrust is $4.8 \times 10^{-12} \times (2750)^2 \times (65)^4 \times 1 \times 1 = 649$ pounds for the WarpDrive 4-blade propeller.

MEASURED EXISTING BRAKING

From measurements made in May 2006 by my son and myself:

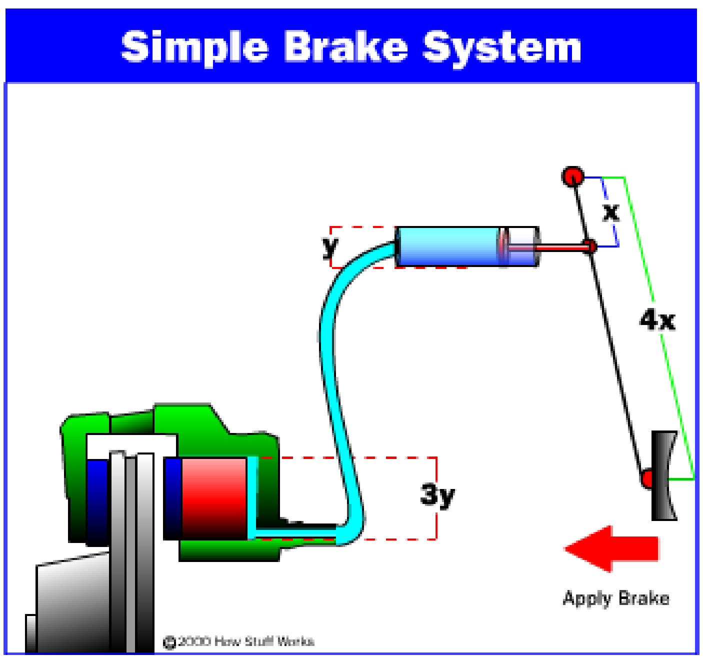
- One person on the brakes can hold the aircraft stopped up to 3000 engine RPM.
- Two people on the brakes can hold the aircraft stopped up to 4000 RPM.
- The aircraft cannot be held stopped from 4000 to 5500 RPM.

The above measurements were made pushing as hard as humanly possible on the brakes while seated in the aircraft.

The Disk Brake Tutorial at http://auto.howstuffworks.com/brake5.htm will be used to explain the calculations that follow it.

A Simple Brake System

"Before we get into all the parts of an actual car brake system, let's look at a simplified system:



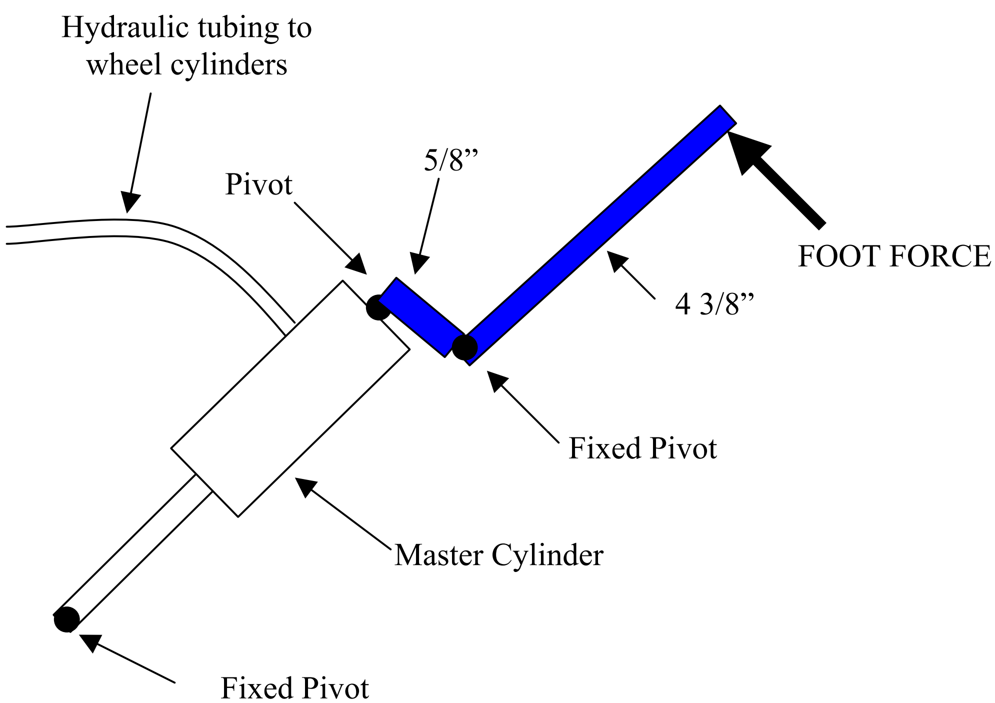
A simple brake system

You can see that the distance from the pedal to the pivot is four times the distance from the cylinder to the pivot, so the force at the pedal will be increased by a factor of four before it is transmitted to the cylinder.

You can also see that the diameter of the brake cylinder is three times the diameter of the pedal cylinder. This further multiplies the force by nine. All together, this system increases the force of your foot by a factor of 36. If you put 10 pounds of force on the pedal, 360 pounds (162 kg) will be generated at the wheel squeezing the brake pads. "

DISK BRAKE SYSTEM CALCULATIONS

Based on the automotive example above, here is how the existing aircraft disk brake system compares. The pilot's foot presses on the brake pedal with a (4 3/8) / (5/8) or 7:1 mechanical advantage. The mechanical lever presses on the Master Cylinder which forces hydraulic fluid out the tubing toward the Wheel Cylinder.



The fixed pivots are mounted to the rudder pedals so the whole brake assembly shown above acts the same regardless of position of the rudder pedals.

The ¾" OD Master Cylinder has an (unmeasured) estimated inner diameter of ½" and a cylinder area of 0.196 square inches. The Wheel Cylinder lies within a rectangle of 1 ¼" x 1 ½" has an (unmeasured) estimated piston diameter of 1" with an area of 0.785 square inches. The hydraulic force multiplier is 0.785 / 0.196 = 4.

The total force multiplier is the mechanical advantage of 7 times the hydraulic advantage of 4 = 28.

Thus, for example, 25 pounds of pilot foot pressure would result in 25 x 28 = 700 pounds of force on the disk brake pads on each wheel squeezing them against the brake disk on each wheel.

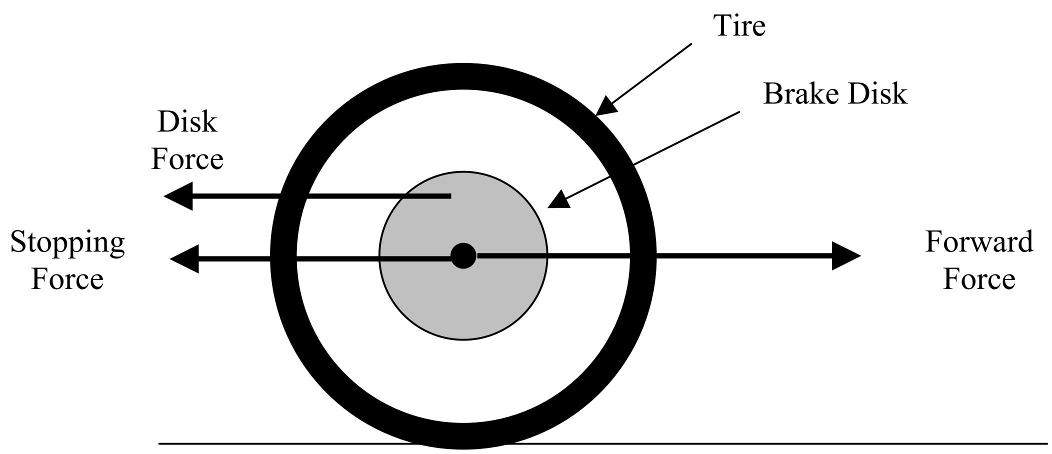
The coefficient of friction between the brake pads and the disk depends on the pad material, the rotational speed of the disk, and the force applied to the pad. The coefficient of Friction (μ) typically decreases with:

- Higher speed
- More clamp force
- More heat

We will use a typical number of 0.35.

The disk is about 7" maximum diameter and the contact area on the disk is about 1 ½" wide so the center of the pad contact area is about 7 – (1.5 / 2) or 6 ¼ inches. The wheel and tire assembly has a measured overall diameter of 15-inches.

The push on the aircraft, whether from rolling momentum or push from the propeller, is applied to the wheel axle with a moment arm of the wheel radius or 15 / 2 = 7.5 inches. The moment arm of the disk brake is from the axle to the center of the pad contact area, or about 3.12 inches.



The example of 25 pounds of pilot foot pressure puts 700 pounds of pressure on the brake pads against the disk on each wheel. If the brake pad coefficient of friction is 0.35, then 700 x 0.35 = 245 pounds of pressure is available as stopping force on each brake disk. This is 245 x 3.12 = 764 inch-pounds of torque. Translated to the wheel this is 764 / 7.5 = 102 pounds of stopping force on each of the two braked wheels, or a total of 204 pounds of stopping force on the aircraft.

If the propeller pushes on the aircraft with a Static Thrust of 649 pounds (calculated above), and the brakes can only provide 204 pounds of stopping power, then the braking must be increased by 649 / 204 = 3.18 times.

MATCO DISK BRAKE SYSTEM

The Matco disk brake claims 1990 inch-pounds of stopping torque versus the existing brake torque of less than 800 inch-pounds. Above I calculated 764 inch-pounds of stopping power. The claimed Matco performance is at least 2.5 times the present stopping power.

CONCLUSIONS

- The Static Thrust was calculated at 649 pounds of push on the aircraft at the maximum 5500 engine RPM.
- The existing brakes on were calculated to provide 204 pounds of maximum stopping push. From this a braking improvement of 649 / 204 = 3.18 times is needed.
- The measured maximum stopping power of the existing brakes occurs at about 3000 engine RPM. From this a braking improvement of 3.36 times is needed.
- The measured 3.36 times improvement needed and the calculated 3.18 times improvement needed are very close in agreement.
- The Matco brake claims to offer an improvement of over 2.5 times.
- The Matco brake will offer significant improvement over the existing brakes.