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Design Notes...

Loading Pressures for Rockets

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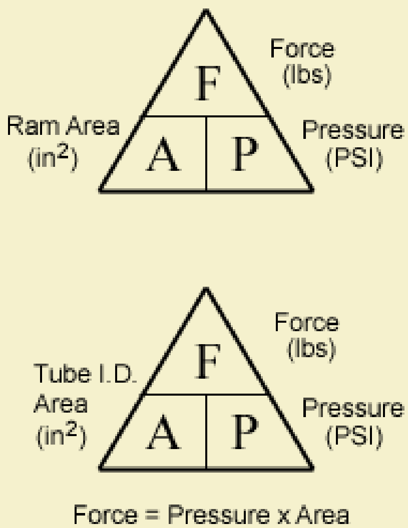

Figure 1: Pascal's law for finding the force generated from pressure over a given area.

Introduction:

This article explains how to calculate loading pressures based on the pressure reading of a hydraulic press, the surface area of the press piston and the surface area of the rammer being used to compress the fuel. An automated calculator is provided for making these calculations easier, but the reader should be aware of the relationship between pressure, force and surface area in order to have a better understanding of the variables involved.

For the solid fuel type propellants used in most hobby rocket engines, the following variables will determine the performance for a given type of fuel: the burning surface area, the nozzle or choke dimensions and the density of the fuel. The surface area is the area of burning composition at any given time during the combustion of the rocket engine. This parameter is controlled by the geometry of the tooling, so it is not an easy parameter to adjust. The length, diameter and exhaust geometry of the nozzle is controlled by both the tooling and the size of the clay increment used to make the nozzle. Because the tooling is difficult to change, the most common variables that are tweaked when developing rockets are the fuel composition and the loading pressure used to produce the engine.

To assure consistency in rocket performance, it is important to keep the powder increment size as well as the loading pressure constant. The loading pressure, combined with the amount of powder added for each pressing, determines the density of the propellant “grain," which is the name given to the solid chunk of fuel that is pressed into rocket motors. Whether one rams or presses rockets, differences in loading pressure can mean the difference between a rocket that worked during testing but then blew up on the pad during competition.

The "increment size" refers to the amount of fuel that is added for each pressing. The increment is usually measured by volume instead of weight, since it must be measured out quickly and frequently when loading a rocket. A general rule of thumb for the correct increment size is an amount of powder that compresses to a height equal to the inside diameter of the rocket you are making. Smaller increments result in more dense powder grains for a given loading pressure, while larger increments result in less density. Since a given density can be achieved through a range of increment size and loading pressure combinations, increment sizes can vary between rocket builders based on preference. However, the increment size must be noted and controlled in the same way loading pressure is controlled for producing consistent results. Any blueprint for reproducing a given rocket engine must include increment size as well as loading pressure.

While the use of pressure gauges and accurate measurements of pressures has made consistent reproduction of rocket motors easy, there are still those who practice the art and skill of ramming rockets by hand. The importance of loading force remains the same whether one rams rockets by hand, by hydraulic press or with an arbor press. Obviously, the degree of artisanship and craftsmanship required to make consistently performing devices by hand ramming is considerably greater. One does, however, after years of experience, get a “feel” for loading pressures.

Various fuels have either narrow or wide ranges of loading pressures at which performance can be assured. There is no single “correct” loading pressure for a fuel system. Rather, there is a range over which the fuel system will perform successfully. As an example, for whistle fuel, if the loading pressure is too little and the fuel is not compressed into a homogeneous grain, the imperfections in the loose material will result in its exploding. If the loading pressure is too high, the material may become brittle and crack, resulting in an explosion. Over the range of useful loading pressures, the burning characteristics will vary.

Black powder rockets also have a wide range of useful loading pressures. Greater loading pressures may increase performance by loading more fuel in the rocket. However, overly compressed black powder may burn too slowly to provide the thrust desired. Some fuels, such as strobe fuels and some color fuels, may be “dead-pressed.” In this case, once the maximal loading pressure needed to compact the grain is achieved, there is nothing further to be gained by increasing the loading pressure.

More...

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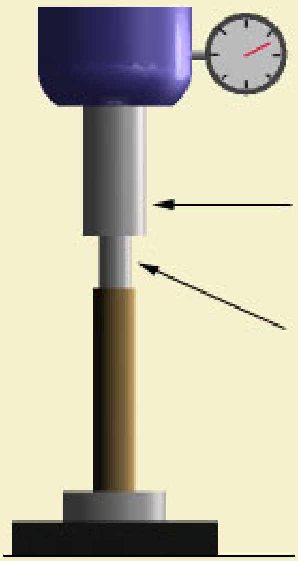

Gauge (PSI)
1588

Piston Dia. (inches)
1.77

Rammer Dia. (inches)
.875

Loading Pressure (PSI)
6500

Loading Pressure Calculator
Changing any value will recalculate all other values as you type. Gauge pressure is always solved for except in the case where the gauge pressure is being manually specified. In this case the loading pressure is solved for based on the gauge pressure specified. Note that piston and rammer dimensions indicate diameters and not cross sectional areas, allowing you to simply measure these dimensions from your tooling using a caliper and entering them directly into the calculator.

The single most important number one needs to know to manufacture a rocket is the loading pressure. The loading pressure will not, for most sizes of rocket motors, vary as the size of the rocket motor varies. For most whistle and strobe rockets (with cored propellant grains), a loading pressure of 6500 PSI may be used. For end-burning hybrid rockets, a loading pressure of 8800 PSI serves as a useful and successful approach. “End-burning,” means that the burning surface is the same as the cross-section of the rocket motor tube: there is no core in the propellant. “Hybrid” in this usage refers to the propellant composition: whistle mix with added airfloat charcoal, a hybrid fuel mix less energetic than pure whistle and more energetic than black powder.

One exception to this general rule is that for rocket motors that are smaller than 3/4" I.D., slightly higher loading pressures may be needed for best performance. For rocket motors larger than this, the loading pressures should remain the same whether one is pressing one-pound (3/4” ID), two-pound (7/8” ID), three-pound (1” ID), four-pound (1-1/4” ID), or six-pound (1-1/2” ID) rockets.

Once a new rocket system is developed for one specific size engine diameter, loading force calculations will enable one to successfully duplicate their efforts with a variety of different motor sizes. It also allows different builders using a variety of different press setups to obtain similar results regardless of differences in press sizes.

A simple formula known as Pascal's Law may be used to determine the loading pressure, as seen in Figure 1. The variables in this formula, which equate Force to Pressure multiplied by Area, are often arranged into a triangle to illustrate their relationship. One simply places a finger over the variable he wishes to solve for, and the visible part of the triangle shows the math to be performed. Variables above one another are to be divided, while variables next to each other are to be multiplied. For example, if you want to determine the Force, covering that part of the triangle leaves you with A x P. Likewise, solving for Pressure (covering P) leaves you with F/A.

An important thing to remember when working with several variables like this is to use the correct units. If pressure is being measured in Pounds per Square Inch (PSI), then the Area must be specified using square inches as well, and the resulting force will be in pounds. Do not make the mistake of using square feet or, even worse, mixing metric and English units!

The pressure gauge on your press gives you the pressure being applied to the piston head of the press, not the rammer in contact with the powder charge. Because the piston head does not have the same surface area as the rocket drift in most cases, it is necessary to perform two calculations in order to arrive at the true loading pressure applied to the powder grain. The first calculation converts the pressure on the piston head to a force value, then the second calculation converts this force back into the final desired pressure value. The following two formulas show the necessary calculations to arrive at the loading pressure:

$$\text{Force (piston)} = \text{Pressure (gauge)} \times \text{Area (piston)}$$

$$\text{Pressure (loading)} = \frac{\text{Force (piston)}}{\text{Area (rammer)}}$$

Note that these can be combined into one single formula to give the loading pressure as follows:

$$\text{Pressure (loading)} = \frac{\text{Pressure (gauge)} \times \text{Area (piston)}}{\text{Area (rammer)}}$$

Another way to think of this calculation is multiplying the gauge pressure by the ratio of piston area to rammer area, thus bypassing the need for any intermediate force calculation. The most common scenario is likely to be a rocket builder who already knows the loading pressure he wants and thus needs to calculate the gauge pressure on his press required to achieve this desired loading pressure. The equation above can be rearranged to solve for gauge pressure in this situation:

$$\text{Pressure (gauge)} = \frac{\text{Pressure (loading)} \times \text{Area (rammer)}}{\text{Area (piston)}}$$

Finally, an example from the real world to show how this all works. Using the twelve ton Harbor Freight hydraulic press, which is a popular press used by many rocket builders, the loading force calculation for a two pound rocket (7/8" I.D.) would be calculated as follows:

Desired loading pressure = 6500 PSI
Piston Area = 2.461 square inches
Rammer Area = 0.601 square inches

Gauge Pressure = 6500 x (.601 / 2.461) = 1588 psi

From this calculation one can see that 1584 psi on the press gauge results in over four times as much pressure on the motor itself! The smaller your rammer is, the more loading force you will be able to apply with your press. This is the reason small presses such as arbor presses can be used to create small rockets, even though the loading pressures are the same as for the larger rocket engines.

Now that you understand the basic relationship between pressure, force and surface area, the interactive calculator above can help you solve for the pressure values you need without ever reaching for a calculator. Simply measure the piston and rammer diameters from your tooling and enter these values into the calculator fields. Then typing in one of the two pressure values will automatically calculate the other!

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