ISSUE 47

APOGEE

PEAK OF FLIGHT

NEWSLETTER

Piston Launchers Explained

By Scott Johnsgard Jr.

"How do those crazy piston launchers work anyway? Where does the performance gain come from? And what is the difference between the zero-volume piston launchers that I've seen and the floating-head piston launcher people keep talking about? What precisely happens when it 'pops'? "

Certainly a controversial part of hobby rocketry lies in the topic of piston launchers. Most of the debate centers on exactly how such devices work and where the performance gains come from. In this article, I will explain the true action behind piston launchers, as I see it!

Howard Kuhn invented the zero-volume piston launcher (ZVPL) in the early 1970s. Rocketeers were excited because:

a. It increased rocket performance.
b. It eliminated launch lugs.
c. It was far easier to use than most other performance enhancing launch devices at the time.

Technically speaking, ZVPLs consist of three parts: the breach, the head, and the termination device (these are illustrated in Figure 1.

You may know these as the piston tube, the piston head, and the little ring in the bottom of the piston tube. (We'll call them the common names.)

The piston head sits on top of some kind of a support rod, usually a brass tube or wooden dowel. The piston tube is a typical body tube. The head is carefully turned or sanded so that it sits inside of the piston tube and can slide up and down inside. The ring in the bottom of the piston tube stops the head from being pulled out of the bottom of the piston tube. The piston launcher is effectively one sliding unit.

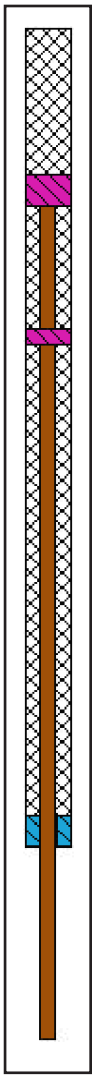

Figure 1: Anatomy of a piston launcher

When ready for flight, the exposed end of the rocket is fitted into the top of the piston tube (Figure 2). The igniter wires are either dangled over the side or routed internally. The piston tube and rocket are pushed down so that the top of the piston head is against the bottom of the rocket motor. The rocketeer then proceeds with the launch and countdown.

The result is a loud "pop", almost like a gun. Assuming the rocket is fairly light, anyone hoping to follow the rocket at this point has lost it.

Most competitive rocketeers set about using ZVPLs in contests with altitude events. They found that the promised performance increase could be had -- but it was kind of unpredictable.

The curious set about to find out what caused this variable performance. This analysis can be done in one of several ways: tinkering, scientific observation and mathematical analysis. The last two options are most always avoided when something else can be done, so folks began tinkering with piston launchers.

The first question on hand was "What causes this increase in performance?" The answer seemed to involve several changes that piston launchers

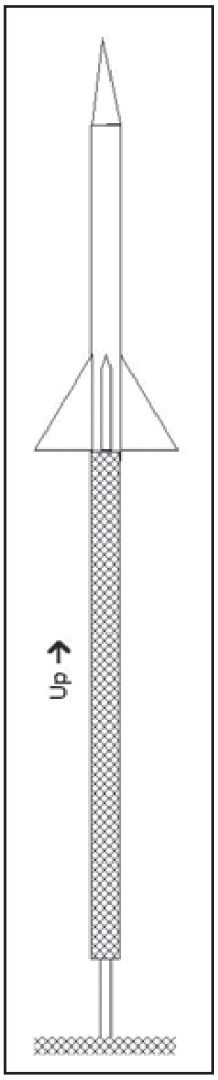

Figure 2: The rocket installed on top of the piston launcher.

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cause.

Common knowledge indicated simply that the elimination of launch lugs increased performance a good deal. The piston launchers definitively add something more than that, though. The piston must create an additional force.

Of course, a piston launcher certainly does. Since it is trapping the exhaust gases in the piston tube, it is creating an increased pressure. This additional force is described by the equation:

$$F_{piston} = A_{pistonhead} (P_{inside} - P_{outside})$$

Where the force generated by the piston is equal to the area of the piston head times the pressure difference between the inside of the piston tube and the outside.

If the pressure inside of the piston was, say, twice that of the atmosphere, then a large force could be generated.

This leads to the next question on hand, which is: "How do these things work?", or: "What are the precise details of their operation?" I will not delve into how the answers were uncovered, but here is the answer:

When the rocket is first ignited, the gases from the very beginning of the motor thrust fill the tiny space between the piston head and the rocket motor. This space is probably less than one milliliter. Because of the weight of the rocket and piston tube, and also a strong friction force, the piston does not move. The result is a very rapid rise in pressure. (Technically, this is known as the "static phase.")

Within probably about 0.000004 seconds, one of two things will have happened: the piston will have overcome these forces and begun to move upward, or the rocket will have been blown off the top of the piston launcher.

If the second option has happened, the rocket will have experienced little or no performance increase. It will be basically starting from rest.

If the piston is moving, and the rocket is still attached, it has now begun what is technically known as the "dynamic phase". The velocity of the piston/rocket assembly increases, slowly at first, more rapidly later. As it travels upward, the volume inside of the piston tube will begin to increase. The inside pressure will peak early in this phase, and then begin falling towards atmospheric pressure as volume increases. (This peak occurs at about 0.0016 seconds.)

When this peak occurs, there is another opportunity for the rocket to be blown off the piston launcher. If the rocket motor is not sufficiently friction fitted into the piston tube, this will occur. If it does, then there will be little performance gain, because the velocity at this point is about 3-4 meters per second (7-8 mph).

If the rocket is still connected, it will continue to accelerate under the influence of the piston launcher. Because the pressure at this point will remain below that of the peak, it is highly unlikely that the rocket will now be blown off during the remainder of the flight.

The rocket and piston tube continue until the ring in the bottom of the piston tube reaches the bottom of the piston head.

It might appear that, at this point, the rocket must wait for the pressure inside of the piston to reach high levels to finally be blown off. If this is the case, then again the rocket is starting from rest. But the interesting fact is that it doesn't have to be "blown off." It is pulled off.

Someone who has watched the children's science show "Bill Nye the Science Guy" has probably seen the eccentric opening sequence. While mostly interesting camera tricks, one good and very important point is made by an unidentified voice in the background is "Inertia is a property of matter." This is precisely the concept that affects the final phase of piston launcher operation, called "Disconnect".

The piston tube is at this point brought to a stop. By necessity, it can travel no further -- the piston head is in the way.

However, the friction fit between the rocket motor and the piston tube only restrains the rocket. The rocket is still moving because it has inertia from the previous acceleration. It is probably traveling at about 25-30 meters per second (55 mph). Thus, it will continue moving, and will slide out of the grip of the piston tube and proceed on to normal flight.

This is not to say that overcoming the friction fit between the piston tube and the rocket motor does not decrease the velocity of the rocket -- it certainly does. An equation that approximates this deceleration is:

$$\Delta V_{rocket} = -\sqrt{\frac{2 \times F_{fric} \times L_{fit}}{m_{rocket}}}$$

Where the terms are the velocity of the rocket, the force of the friction fit, the distance that the motor is fitted into the

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piston tube, and the mass of the rocket.

Chuck Weiss and Jeff Vincent invented the floating head piston launcher (FHPL) in 1985. They sought to eliminate the performance-reducing tug at the end of ZVPL operation. This was achieved by making the piston head "floating", or allowing it to slide freely off of the support rod.

The FHPL works in exactly the same fashion as the ZVPL, except that when the ring in the bottom piston tube reaches the piston head, the ring grabs the head and carries it along with the piston tube and rocket. The head blocks the bottom of the tube, fixing its volume.

Because the volume is now fixed, the pressure will begin to rise (as in the static phase.) This will continue until the piston tube (with piston head) is blown off of the bottom of the rocket.

Although this method eliminated the velocity reduction from the friction fit, it still had a slight performance decease due to the added mass of the piston head. An equation that can be used approximate this decrease is shown here:

$$\Delta V_{rocket} = \left(\frac{V_{rocket} \times m_{rocket+tube}}{m_{rocket+tube+head}} \right) - V_{rocket}$$

Where the terms are the same as in previous equations.

Hopefully, I have explained the topic of piston launcher operation to everyone's satisfaction. If there are major questions, comments or controversy, please contact me!

About the Author

SCOTT JOHNSGARD JR. is a model rocketeer and NAR section NASA-Houston member living near Houston, Texas. He enjoys scale modeling, competition (he is currently in the B division), sport flying and research & development. He is the author of the upcoming *"Handbook of Piston Launchers"*,

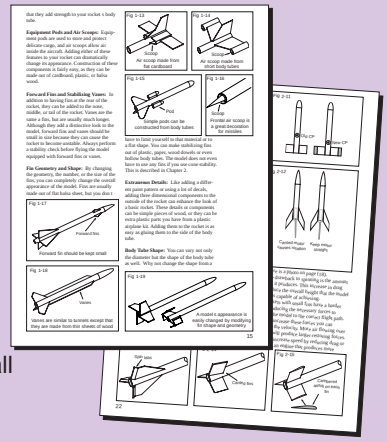
References

Stine, G. Harry. *Handbook of Model Rocketry.* 6th Ed. (New York, Chichester, Brisbane, Toronto, Singapore: John Wiley & Sons. 1994)

Weiss, Chuck, and Vincent, Jeff. The Floating Head Piston Launcher. National Association of Rocketry Annual Meet "Research & Development" Report. (1986)

So you think you know about designing rockets? Here's a test:

- What thickness of wood should you use for fins a rocket powered by a D motor?
- What are the nine types of fin construction?
- What are the other five different recovery methods besides: parachute, streamer, glider, and helicopter recovery?
- What size wing do you need for a rocket glider?
- How does high power construction differ from small rockets?



How did you do? If you couldn't answer them, you'll be happy to know the answers are in the book *Model Rocket Design & Construction.* It was written for modelers that want to build their own designs.

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