

Development and Testing of Pulse Guns for Combustion Instability Testing

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To test liquid rocket engines (LREs) for combustion instabilities, devices such as bombs are often used to create pressure wave disturbances. Bombs, while effective, are inherently dangerous, expensive, and difficult to procure. Over the years, pulse guns have been used as a safer and more cost-effective way to generate controlled pressure disturbances in engine chambers. In anticipation of the need for stability testing of prototype LREs at NASA Marshall Space Flight Center (MSFC), a set of pulse guns have been designed, fabricated, tested, and characterized. The pulse gun program is funded by the RS-25 Engine Program managed through the MSFC Liquid Engines Office (LEO).

A pulse gun is a simple device – like a traditional gun, it has a breech and barrel section. However, unlike a traditional gun, there is no bullet, as the purpose of the pulse gun is strictly to fire a high pressure pulse. Instead of a firing pin and primer that would normally be used in a traditional gun, an initiator is used to activate the gun powder. The initiator is a highly reliable pyrotechnic initiator. For this study, clone versions of the NASA Standard Initiator (NSI) were used. The initiator is used to ignite a pre-measured amount of gun powder loaded into the breech. When the pressure of the burnt gun powder exceeds the set point of a downstream burst disk, the disk ruptures, allowing the high pressure pulse to travel downstream through the barrel section. A ballistic pressure transducer located in the breech section is used to measure the short duration, high pressure pulse. Some configurations of the pulse gun have barrel sections that include one or more additional ballistic pressure transducers. These additional pressure measurements help track the degradation and damping of the pulse as it travels out of the barrel section. The measurements may also be used to determine the velocity of pulse.

The objective of this paper is to present the different variants of this newly-developed pulse gun and characterize performance over a range of parameters. The parameters include breech diameter, barrel length, amount of gun powder used, the way the gun powder is packed, and the pressure setting of the burst disk. A cross-section schematic of a pulse gun with a 0.25 inch inner diameter (ID) breech and two-port instrumentation barrel is provided in Figure 1. There are a total of six pulse guns: three with the 0.25 inch breech and three different length barrels, and three with the 0.40 inch breech and three different length barrels. For both breech sizes, the associated barrels are referred to as standard, one-port, and two-port barrels. The standard barrel has no instrumentation and is likely the barrel that will be used for engine stability testing. The one- and two-port barrels were designed specifically for pulse gun component testing to allow measurements of the magnitude and timing of the high pressure pulse as it makes its way through the pulse gun. The burst disks tested were commercially-available burst disks designed to rupture at 8,000, 16,000, and 24,000 psid.

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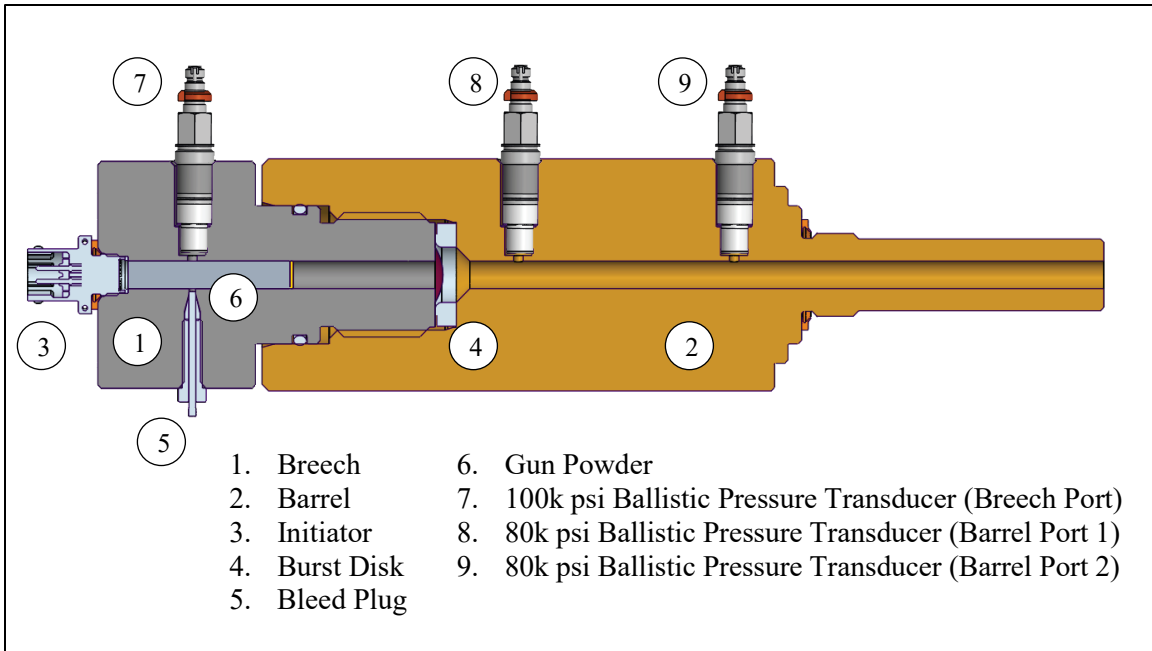


Fig. 1 Pulse gun configuration with 0.25 inch ID breech section.

Testing was accomplished by firing the pulse gun into a test chamber pressurized with nitrogen at about 2300 psig. A photo of the test chamber is shown in Figure 2. A total of four Model 113B23 High frequency ICP® pressure sensors (10k psi) were mounted in the test chamber, in the same plane as the pulse gun. Two of the sensors had “trimmed” adapters, and two did not. Given the symmetrical configuration of the sensors within the test chamber, different amplitudes of pressure measurements are attributed to the use of trimmed versus untrimmed adapters. The untrimmed adapters, with their narrower passages, tended to amplify the pressure amplitudes by as much as 50%.



Figure 2. Photograph of high pressure test chamber with pulse gun and instrumentation installed.

In total, 44 pulse gun tests have been conducted. Data are still being analyzed, but some trends are apparent. For example, measurements taken within the pulse gun are shown in Figures 3 and 4 for Hot-fires (HFs) # 11 and 39, respectively. Both tests were identical in that the 0.40 inch ID breech, two-port barrel, 8,000 psid burst disk, and same amount of gunpowder (6.639 grains for HF# 11, and 6.576 grains for HF# 39) were used, and the back pressure in the nitrogen test chamber was ~2300 psig. Despite keeping all these variables constant, the results from these two tests look quite different. For both tests, the first pressure peak shown in the P2111 trace within the breech is the firing of the initiator. The second peak and any subsequent peaks are from the combustion of the gunpowder. It should be noted that because the sensors are dynamic, the ~2300 psig baseline static pressure is not shown in the figures. For HF# 11, the burst disk clearly ruptured in a little over 0.1 ms from the time the initiator was fired. This is evident from the abrupt rise in pressure for P2112 followed by another abrupt rise in pressure for P2113. The sensors track the movement of the high pressure pulse through the pulse gun. For HF# 39, however, there was nearly 1 ms delay between the initiator firing and the burst disk rupturing. The only difference between these two tests was the way in which the gunpowder was packed within the breech. For HF# 11, the gunpowder was poured directly into the breech, atop the initiator, and held in place with a vegetable fiber wad appropriately sized for the barrel diameter. Once in place, the wad firmly held the gunpowder in place. For HF# 39, the gunpowder was rolled within cigarette paper with the ends of the paper twisted. The rolled gunpowder was gently pushed down into the breech, toward the initiator, and no wad was used. This method of loading the gunpowder consistently produced longer delays in the rupture of the burst disk, presumably because there was a steady, fuller burning of the gunpowder. The burst disk was rated for 8,000 psid, which means that the burst disk should not have opened until the pressure in the breech reached ~10,300 since there was ~2300 psig back pressure in the test chamber. In the case of HF# 11, the breech pressure only reached roughly 4200 psi before there was leakage either through or past the burst disk, but for HF#39, the breech pressure reached 10,600 psi prior to the burst disk opening. The temperature of the burst disk is certainly a factor in determining when the burst disk will rupture. A sharp rise in the burst disk temperature could weaken it and cause it to stray from the designed set point burst pressure. The burst disks are manufactured of Inconel to try to reduce their sensitivity to temperature, but how the burst disks perform above 900°F is not documented. All burst disks were engineered and tested by the manufacturer for ambient temperature conditions. One theory for why rolling the gunpowder in cigarette paper may produce better results is related to a more controlled temperature environment. The cigarette paper may act as a sheath that protects the burst disk from excessive temperatures during the rapid buildup of pressure in the breech.

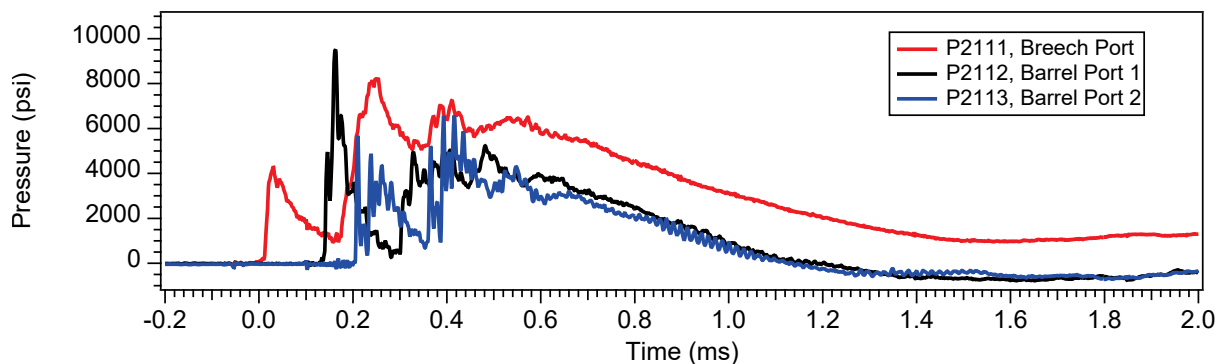


Figure 3. Pulse gun data from HF# 11.

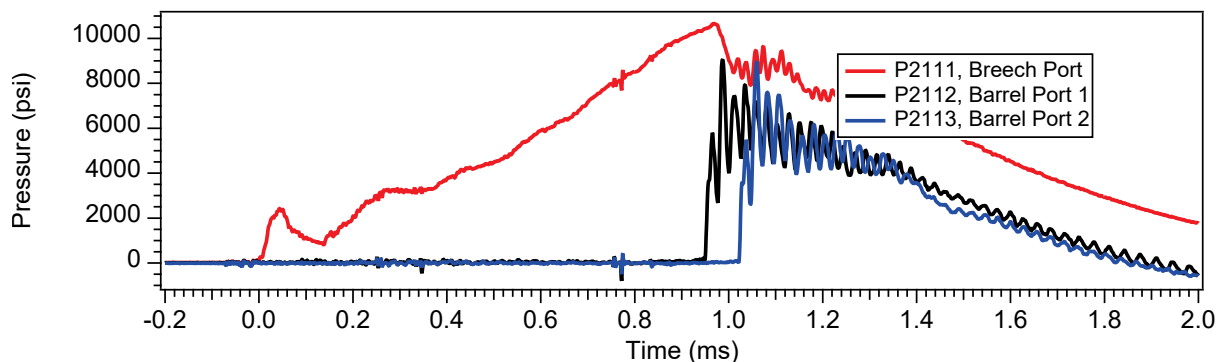


Figure 4. Pulse gun data from HF# 39.

The ultimate benefit of not breeching the burst disk prematurely is shown in Figures 5 and 6, which graphs the resultant pressure pulse produced in the test chamber. For HF #11, the peak pressure on the P2123 trimmed adapter is about 270 psi, while for HF# 39 it is 343 psi, which is about 1.27 times greater in magnitude. In either case, the pressure pulse is $\sim 20 \mu\text{s}$ in width once it reaches the test chamber. Another pressure rise about $100 \mu\text{s}$ later can be seen on the sensors located across from the pulse gun port, P2124 and P2121. These pressures are lower due to attenuation of the pressure wave as it moves across the test chamber. After the wave encounters the wall, it reflects back and forth within the chamber until it completely dissipates.

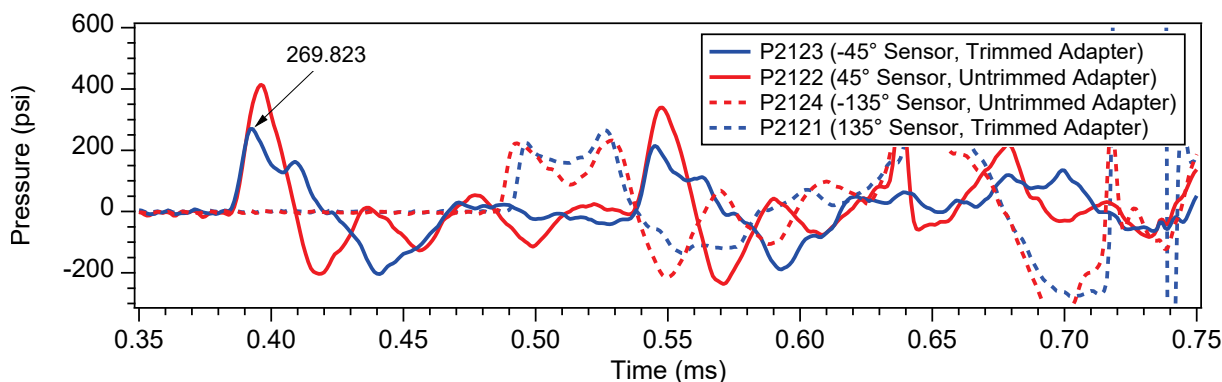


Figure 5. Test chamber data from HF# 11.

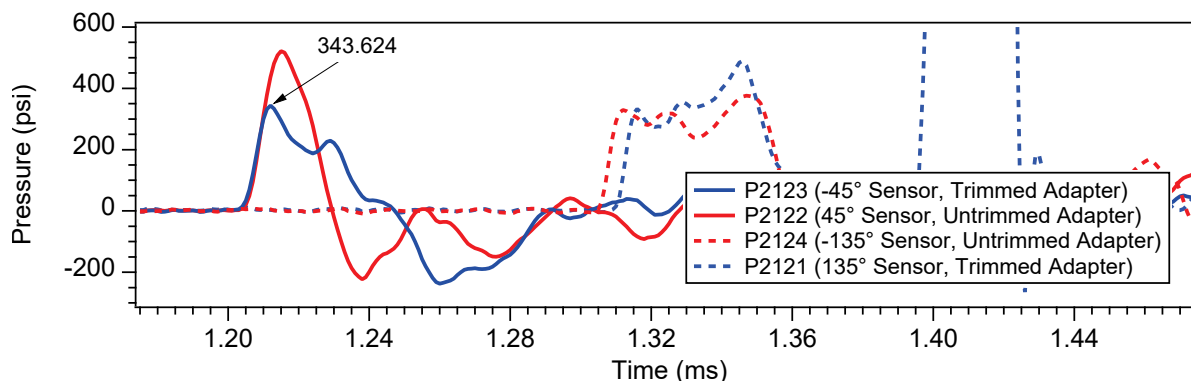


Figure 6. Test chamber data from HF# 39.

The most extreme test condition was conducted using the 24,000 psid burst disk with 20.679 grains of gunpowder loaded in the 0.40 inch ID breech. This condition, shown in Figures 7 and 8, produced about 1000 psi on P2123 in the test chamber. Random high pressure peaks within the test chamber are hypothesized to be small, local “mini-explosions” of gunpowder ejected out of the pulse gun. Throughout testing, the pulse gun has remained in good condition, as evidenced from videoscope images taken before and after each test firing. The interior of the breeches, as expected, have some surface roughening and pitting. The barrel sections show very little wear.

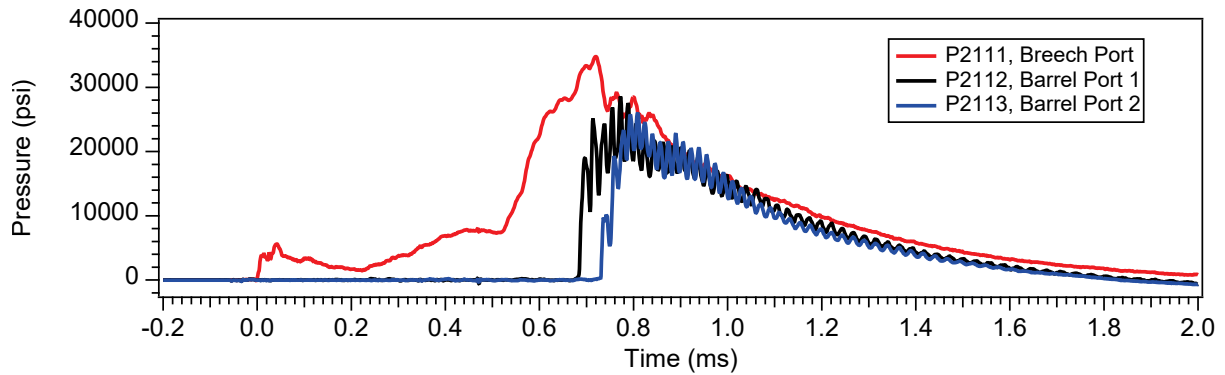


Figure 7. Pulse gun data from HF# 41.

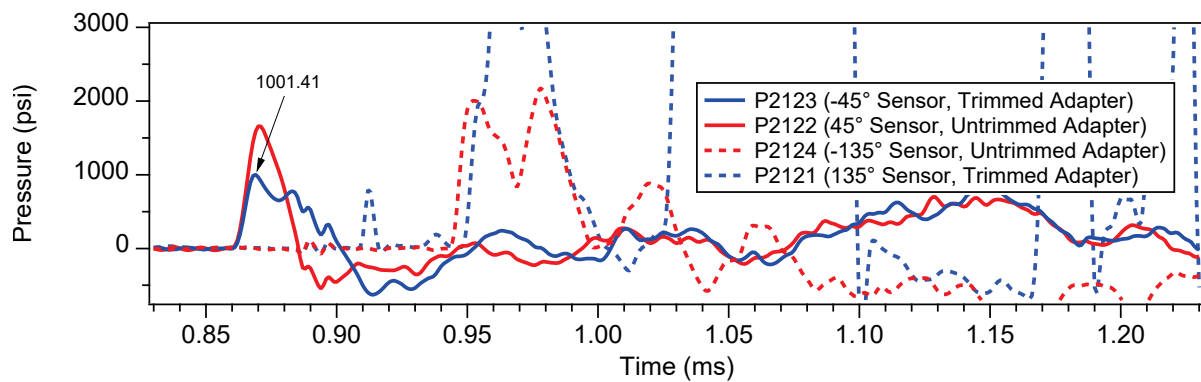


Figure 8. Test chamber data from HF# 41.