Innovative Thermal Measurement Techniques for Y-shaped Primer Chamber Assembly Pyrotechnic Valves

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Several unique measurement techniques were developed at the NASA White Sands Test Facility in support of NASA's Conax® Pyrotechnic Valve Failures Investigation. This report discusses two techniques developed to measure the thermal environment at the pyrovalve booster interface: comparison of thermocouple (TC) and optical pyrometer thermal measurements, and use of an optical pyrometer method with a sapphire viewport.

The pyrovalve under investigation uses a Y-shaped primer chamber assembly (Y-PCA) design (figure 1). Two NASA standard initiators (NSIs), one on each branch of the Y, provide redundancy. Either one of the two NSIs is sufficient to ignite the booster, which then provides the force to drive the ram. The booster, essentially a small container made of 76-µm (0.003-in.)-thick stainless steel, contains a pyrotechnic charge that produces a relatively large amount of gas when ignited.

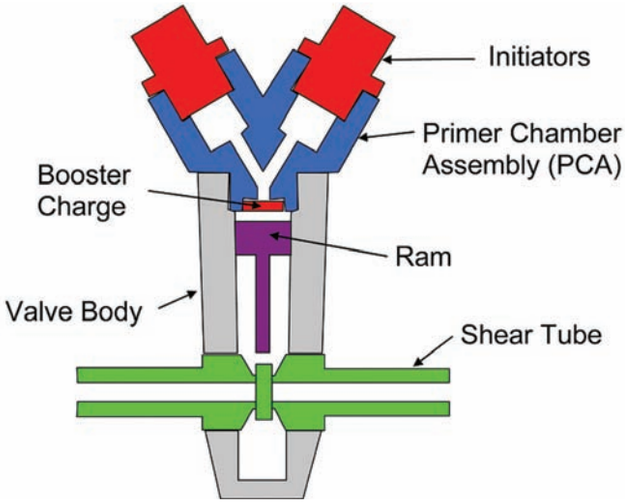

Fig. 1. *Conax® Y-PCA pyrovalve.*

We evaluated the two measurement techniques for characterizing the thermal environment in the booster area for both single and dual simultaneous NSI firing situations.

Comparison of thermocouples and infrared pyrometers

We selected fine-wire TCs and high-speed optical infrared (IR) pyrometers to measure temperatures on the underside of the booster's top cover. Both techniques were used previously, but this test compared temperature readings from the two methods at very high rates of temperature increase.

Technicians made inert boosters with thermal and mechanical properties to match the actual live boosters. The test articles consisted of a booster case with two fine-wire TCs welded onto the underside of the stainless-steel cover. To improve the structural stability of the booster top during the firings, an insulation disk filled the gap under the top of the booster case. An inert filler took the place of the pyrotechnic material inside the booster case. The TC leads were routed through this inert material and connected to the instrumentation system.

We installed the instrumented, inert boosters in a holding fixture such that a laser could be focused on the top cover. The laser provided the rapid heating necessary for the test. Two high-speed optical pyrometers were positioned to monitor the temperature from the front of the instrumented inert boosters.

Personnel encountered several difficulties with this test. One was ensuring that the TCs and the pyrometers were aligned with each other and with the laser-heated hot spot. The exact positions of the TCs could not be seen because of the filler in the booster case, so their positions had to be estimated when aligning the laser. Aiming the two optical pyrometers toward the exact spot illuminated by the laser was also difficult, and perfect alignment with the laser was hard to determine. Furthermore, any change in emissivity of the cover would affect the temperature indicated by the optical pyrometer, and any deflection of the cover could change the alignment slightly. The two pyrometers had different detection ranges, and neither would provide data below its lower limit. Despite the difficulties, we achieved fairly close agreement between the two methods. As shown in figure 2, an initial ramp-up rate of approximately 1,420°C (2,588°F) per second was reached. The maximum temperatures were approximately 370°C (698°F) for TC 1, 390°C (734°F) for both pyrometers, and 425°C (797°F) for TC 2.

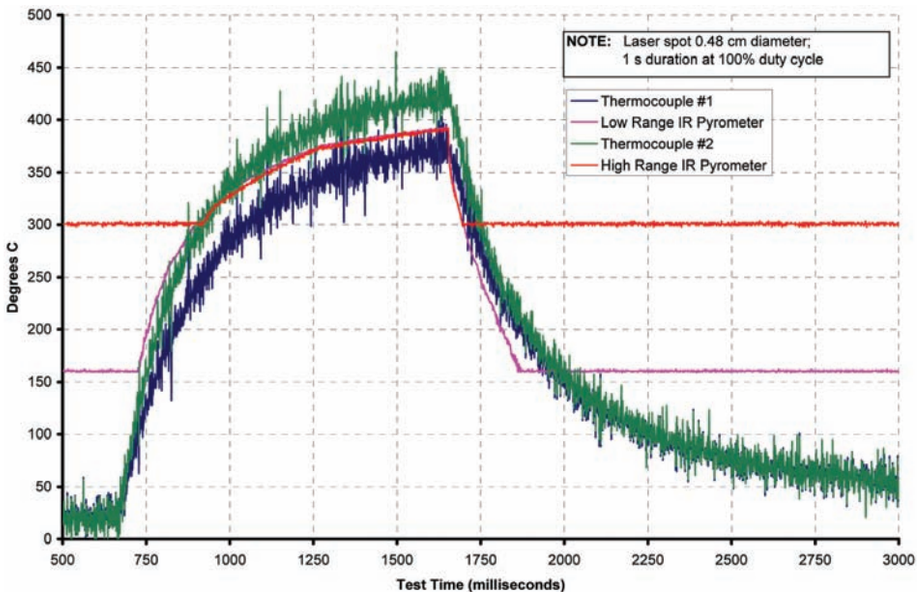

Fig. 2. *Response of TCs and IR pyrometers to rapid heating of an instrumented inert booster.*

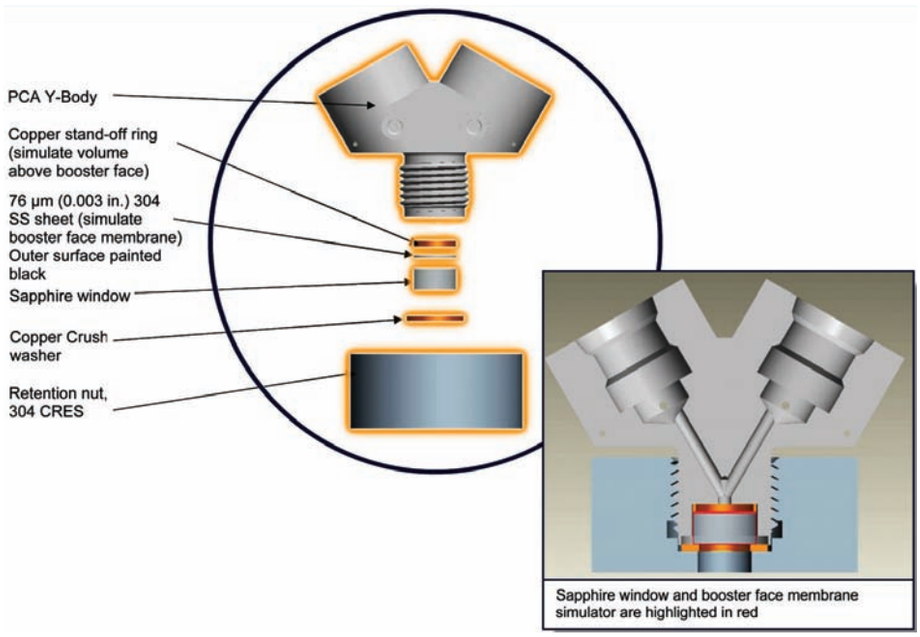

Fig. 3. *Exploded view of sapphire window assembly.*

Optical pyrometer method with sapphire viewport

This method used an optical pyrometer to measure the temperature in the booster cover. To apply the optical pyrometer method, we needed a new design for the Y-PCA test fixture (figure 3). This new design used a stainless-steel membrane to simulate the typical booster cover used in the Y-PCA pyrovalve application, similar to the one described in the previous technique. This cover was held in position and sealed with a copper standoff ring. A viewport, made from industrial sapphire, was installed underneath the sheet metal insert to provide viewing and necessary structural support and to allow the IR pyrometers to measure the temperature of the underside (propellant interface) of the simulated membrane. Sapphire is highly transparent to IR in the desired wavelength.

Through the sapphire viewport, a high-speed Phantom® video camera and a high-speed optical pyrometer recorded video and temperature on the back side of the simulated booster cover. The back side was painted black to provide a surface of known emissivity. Pressure transducers were installed in both Y-PCA NSI cavities.

We performed five dual- and three single-fire tests. It was important to maintain a seal around the stainless-steel membrane (booster cover simulator) and the sapphire window. The second dual-fire test was invalidated due to a leak (apparent from the video), which indicated much more flow and lower pressure in the NSI cavity on one side of the Y-PCA. However, this test did indicate that higher interface temperatures result from additional flow, agreeing with the overall test results. Booster interface temperatures for the dual fire series, excluding the second test due to the leakage, ranged from less than 150°C (300°F) to 383°C (721°F). Dual-fire test 5 resulted in a booster interface temperature of 603°C (1,117°F), but this appeared to be caused by burn-through that occurred very late in the event. Booster interface temperatures for the single-fire series ranged from 274°C (525°F) to 677°C (1,250°F). Posttest examination of the test articles revealed significantly more melted metal for the single NSI firings than for the dual simultaneous firings.

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