High-Speed Measurements Provide Key Information on Events Inside a Pyrovalve

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In 2008, the NASA Engineering & Safety Center (NESC) conducted an assessment of four spacecraft propulsion system pyrovalve anomalies that occurred during ground testing. In all four cases, a common aluminum (Al) primer chamber assembly (PCA) was used with dual NASA Standard Initiators (NSIs) and the nearly simultaneous (separated by less than 80 microseconds [µs]) firing of both initiators failed to ignite the booster charge.

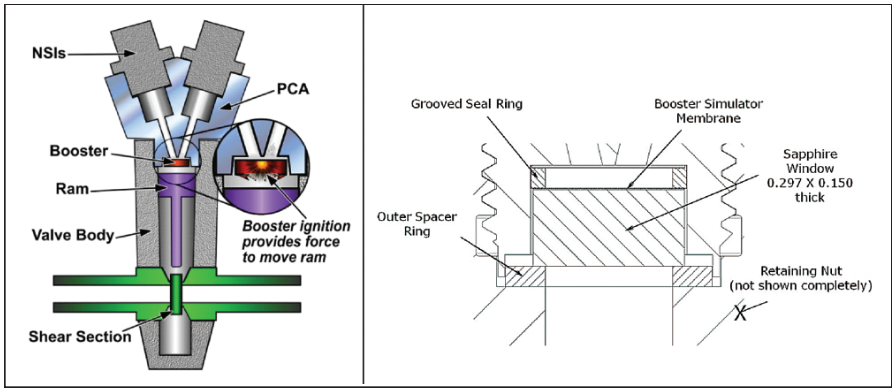

Fig. 1. *Typical stainless steel V-PCA pyrovalve and sapphire window assembly.*

As a result of the assessment's work, and because the Mars Science Laboratory (MSL) spacecraft planned to use pyrovalves with similar features, the MSL project team made changes to the PCA. The material for the PCA body was changed from aluminum to stainless steel to avoid melting and distortion of the NSI flow passages. The flow passages, which were interconnected in a Y-shaped configuration (Y-PCA), were separated into a V-shaped configuration (V-PCA). The V-shape was used to more efficiently transfer energy from the NSIs to the booster (figure 1). Development and qualification testing of the new design clearly demonstrated improved performance in terms of shorter booster ignition delays and greater margin for booster ignition.

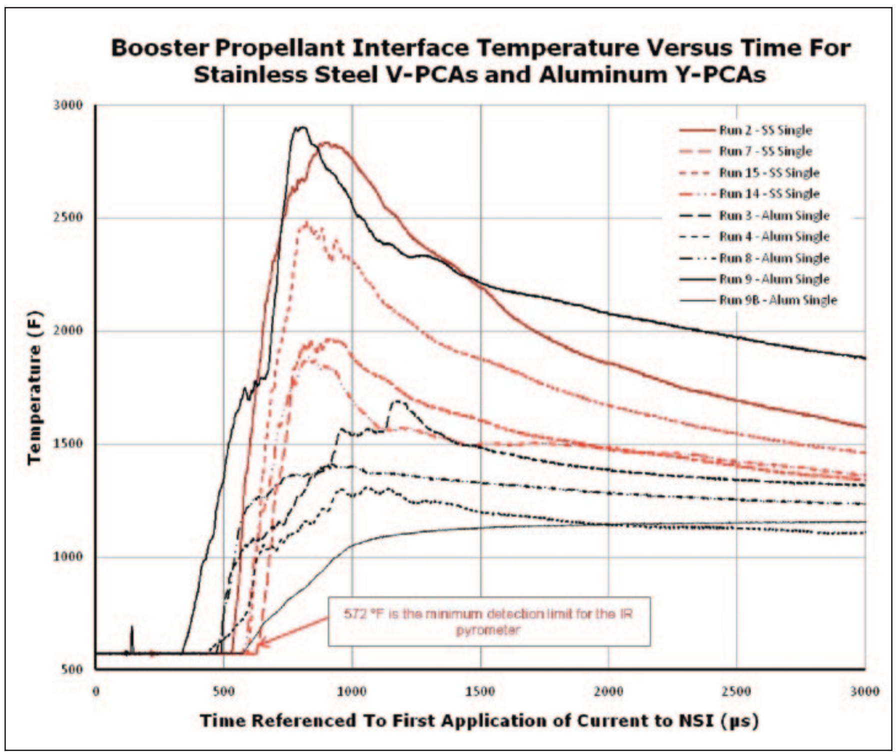

Fig. 2. *Stainless steel V-PCAs (red lines) produce much higher temps than aluminum Y-PCAs (black line).*

However, the final NESC assessment report recommended that the stainless steel V-PCA be experimentally characterized and quantitatively compared to the aluminum Y-PCA design. In addition to benefitting MSL, these data would help future NASA projects to properly evaluate the selection and use of the stainless steel V-PCA vs. the aluminum Y-PCA.

In the first phase of this new assessment, the team performed single and dual simultaneous firings of the NSIs in both PCA types to measure the peak temperature delivered to the booster propellant. This required the measurement of temperatures as high as 1649°C (3000°F) and pressures as high as 25,000 pounds per square inch gauge (psig) within time periods measured in microseconds. To accomplish this, a 0.003-in.-thick disk of booster cover stainless steel was installed where the top of the booster would normally be. A grooved seal ring, sapphire window, and retaining nut were manufactured and installed to provide a sealing arrangement that passed hydrotesting to 30,000 psig without leakage (figure 1).

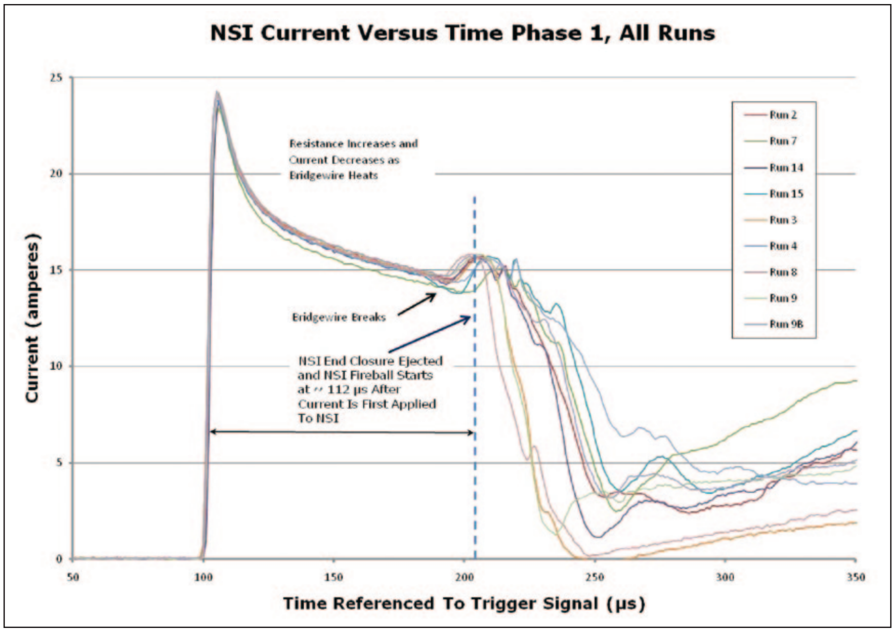

Fig. 3. *NASA Standard Initiator (NSI) current provides insights on timing of events within the primer chamber assembly.*

With such a small test article, it was important to measure temperature without adding any additional mass that would cause an unwanted heat sink. Temperature was measured with an infrared pyrometer with response time of 6 µs and a range of 300°C to 2000°C (572°F to 3632°F). The effects on the booster simulator membrane were recorded with a high-speed video camera aimed through the sapphire window at the underside of the membrane and operating at 20,000 frames per second. Special firing circuitry provided variable timing such that one or both NSIs could be fired with a precision of ±2 µs. To minimize small variations in firing times, the firing circuitry provided current of 22 to 24 amps vs. the normal NSI firing current of about 3 to 5 amps (figure 3). Data were acquired at 1 to 2 megahertz (MHz) for 20 to 40 milliseconds (ms), depending on test requirements. The data acquisition system is capable of 60 MHz. The team paid special attention to eliminate ground loops or other interferences that could compromise the data.

Testing showed the stainless steel V-PCA units delivered an average booster/propellant interface temperature much greater than that delivered by the aluminum Y-PCA units. Although the aluminum Y-PCAs ignited the booster propellant reliably, the stainless steel V-PCAs provided extra margin and produced maximum temperature in half the time. The stainless steel V-PCA units also produced pressures in the NSI cavity that were several thousand psi greater than the aluminum Y-PCA units produced (figure 2).

Dual, simultaneous (within 20 µs) firing of the redundant NSIs was shown to significantly reduce the performance of either PCA design to the point where it is doubtful the booster charge would be reliably ignited. This is consistent with findings from previous NESC assessments. The booster interface temperature needed to ignite the titanium hydride/potassium perchlorate booster charge is approximately 538°C (~1000°F). In the dual, simultaneous test firings, the maximum temperature observed was several hundred degrees below this threshold.

The second phase of the assessment evaluated the effects of various NSI ignition delays (skews) and NSI flow passages of greater cross-sectional areas with only the stainless

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continued

steel V-PCAs. The stainless steel V-PCAs were modified to have NSI flow passages with cross-sectional areas two and four times larger than the original design. The second phase tests showed that even with flow paths having four times the original cross-sectional area, dual, simultaneous (within 20 µs) firings of the redundant NSIs significantly reduced performance to the point the booster charge would not be reliably ignited.

The high-speed data acquisition during these tests allowed characterization of events early in the firing of an NSI (figure 4).

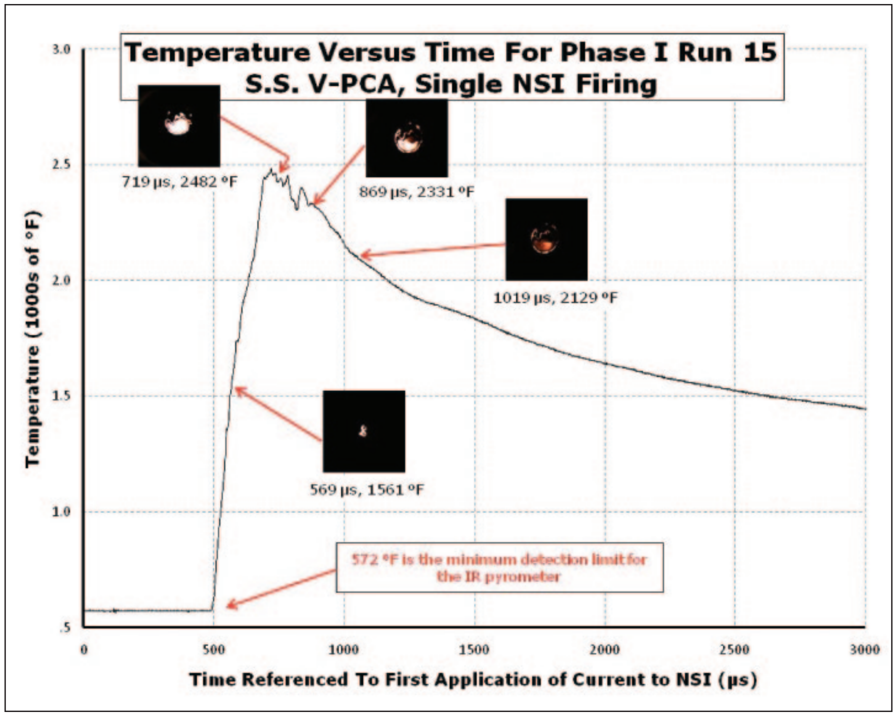

Fig. 4. High-speed video evidence of diaphragm burn-through and correlation with pyrometer temp measurements.

The assessment successfully characterized the greater margin for booster ignition provided by the stainless steel V-PCA design over the heritage aluminum Y-PCA design. Designers of spacecraft and pyrovalves now have additional information to make informed decisions regarding the trade-off between the greater weight and improved performance of the stainless steel V-PCA.