

# Pressure Venting Tests of Phenolic Impregnated Carbon Ablator (PICA)

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## *Abstract*

*A series of tests was devised to investigate the pressure venting behavior of one of the candidate ablators for the Orion capsule heat shield. Three different specimens of phenolic impregnated carbon ablator (PICA) were instrumented with internal pressure taps and subjected to rapid pressure changes from near vacuum to one atmosphere and simulated Orion ascent pressure histories. The specimens vented rapidly to ambient pressure and sustained no detectable damage during testing. Peak pressure differences through the thickness of a 3-inch-thick specimen were less than 1 psi during a simulated ascent pressure history.*

## Introduction

Phenolic impregnated carbon ablator (PICA) (Ref. 1) was one of the two heat shield materials carried to the final down selection for the Orion thermal protection system (TPS) Advanced Development Project (ADP) (Ref. 2). During the development process, a concern was raised about the possibility of air at one atmosphere being trapped, either within PICA or in the strain isolation pad (SIP) beneath the PICA, and causing failure of the ablator during ascent.

This paper describes tests that were developed to address the concern that air at one atmosphere might become trapped beneath the surface of PICA and cause failure. Details are presented for the test apparatus, test procedure, specimens, and instrumentation. Plots of internal and ambient pressure histories are presented for rapid pressurization, rapid depressurization, and a simulated Orion ascent pressure profile.

## Test Description

### **Objective and Approach**

The tests were devised to address two key questions: 1) How much will internal PICA pressures lag external pressure changes? 2) Are these internal pressure gradients likely to cause PICA failure or disbonding from the underlying structure?

Cylindrical PICA specimens with sealed edges and internal pressure taps were bonded to aluminum substrates and subjected to rapid external pressure changes to address these questions. The pressure changes were intended to be much more rapid than any conditions expected during flight. The rationale was that if the specimens were unaffected by these rapid pressure changes, then venting is not likely to be a significant design issue for PICA. A simulated Orion ascent pressure profile was also included in the testing to determine the resulting maximum internal pressure gradients.

### **Specimens and Instrumentation**

Cylindrical PICA specimens, 3 inches in diameter and 3 inches thick were fabricated in several different configurations for testing. Initially, three specimens were fabricated in the three different configurations illustrated in Figure 1. One specimen was directly bonded to a 0.25-inch-thick aluminum plate. The other two specimens had a 0.090-inch-thick SIP bonded between the specimen and the aluminum plate. All bonds used room temperature

vulcanization silicone (RTV). The sides of all three specimens were also sealed with a coat of RTV. The specimen on the right side of Figure 1 had the edges of the SIP sealed with a coat of RTV, the center specimen did not. A photograph of the three initial specimens as received is shown in Figure 2.

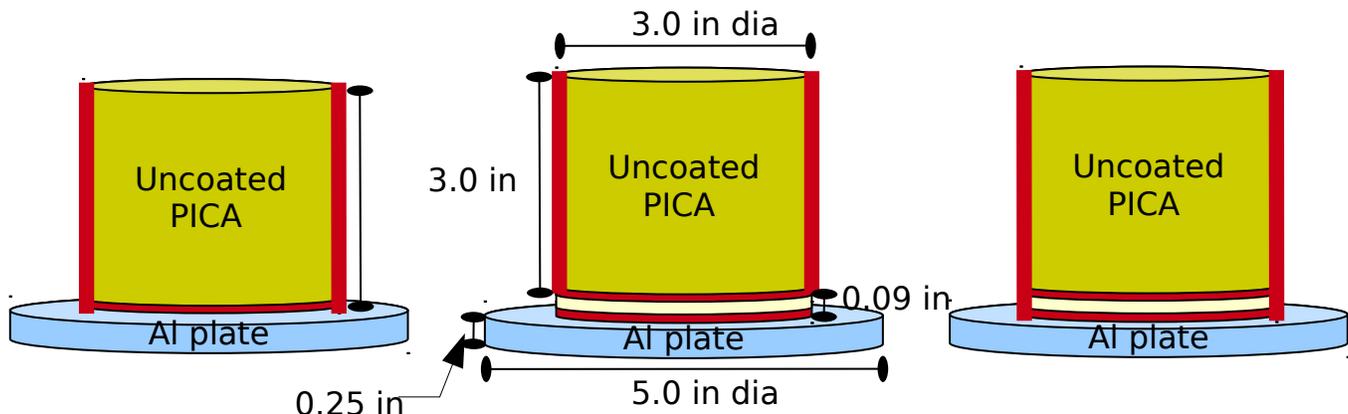


Figure 1: Configuration of the three initial specimens

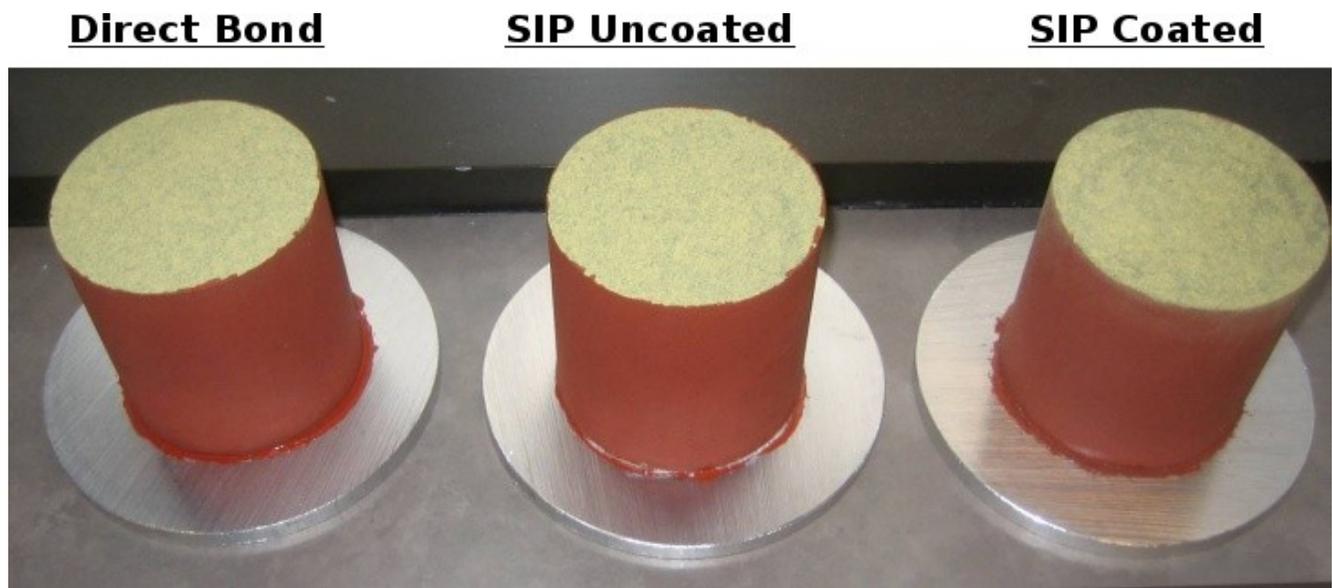


Figure 2: Initial three specimens as received

Each specimen was instrumented with pressure taps located as shown in Figure 3. Pressure taps were 1 and 2 inches from the outer surface of the specimen and just above the inner surface bond line along the centerline of the cylindrical specimens. An additional pressure tap was located in the SIP for specimens bonded onto SIP. Pressures were measured using an Omega\* PX-184 pressure transducer for each pressure tap. These transducers measure relative to ambient pressure so they were calibrated before each test. The transducers are rated for 1 millisecond response time. Pressures were sampled at 100 Hz for the rapid tests and at 1 Hz for the simulated Orion ascent history tests.

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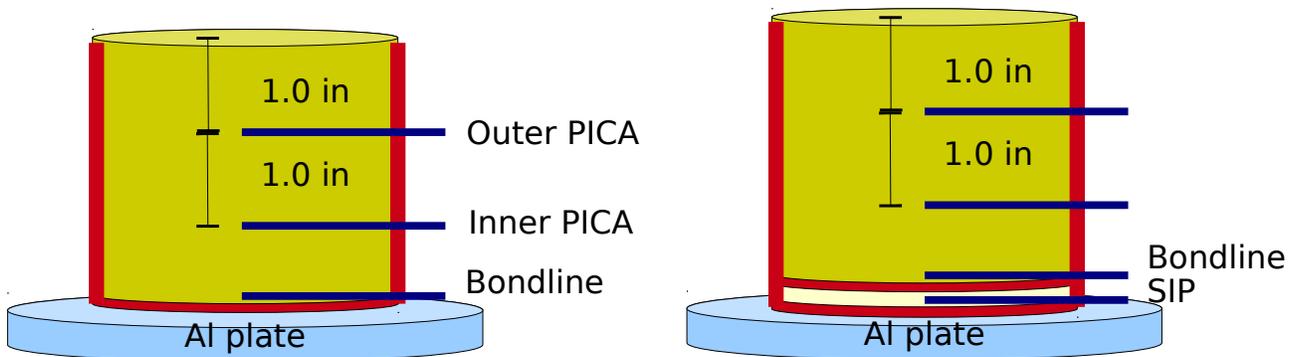
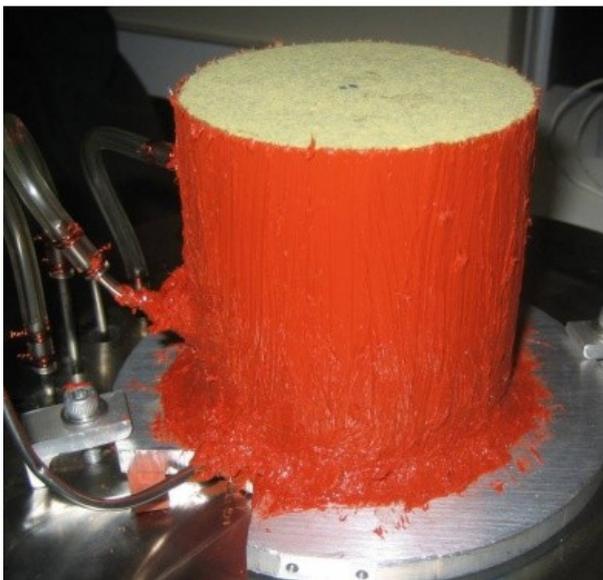


Figure 3: Pressure tap locations in specimens

Preliminary tests indicated that the RTV on the sides of the specimens and SIP was inadequate to seal the specimens. Four thick additional coats of RTV were required to fully seal the specimen sides. Preliminary tests results indicated that there was no need to test the specimen with unsealed SIP. The instrumented specimens with fully sealed sides are shown in Figure 4.

**Direct Bond**



**SIP Coated**



Figure 4: Sealed, instrumented specimens

The uncoated SIP specimen, was reconfigured and subsequently tested with sides fully sealed like the specimens in Figure 4. This specimen had the outer and inner surfaces of the PICA densified with additional phenolic matrix material. This treatment was being considered for the Orion heat shield and was anticipated to further impede venting of PICA.

## Apparatus

A sketch of the test apparatus is shown in Figure 5. A small, cylindrical pressure chamber was built to contain the test specimen. The small chamber consisted of a flanged, cylindrical tube (8-inch outer diameter) with grooves in the flanges for O-ring seals and flat, circular plates (11-inch diameter) that bolted to the flanges to complete the enclosure. The specimen was mounted to the base plate and tubes were connected between the pressure taps in the specimen and pressure feed-throughs in the base plate as shown in Figures 4 and 5. The small chamber was connected to a much larger (5-foot diameter) vacuum chamber with a pressure line containing a pressure relief valve. By using the large vacuum chamber and the valve, the small chamber and specimen could be subjected to rapid de-pressurization and pressurization. With the valve open, the controls of the large vacuum could be used to simulate an Orion ascent pressure history. The test apparatus is shown in Figure 6.

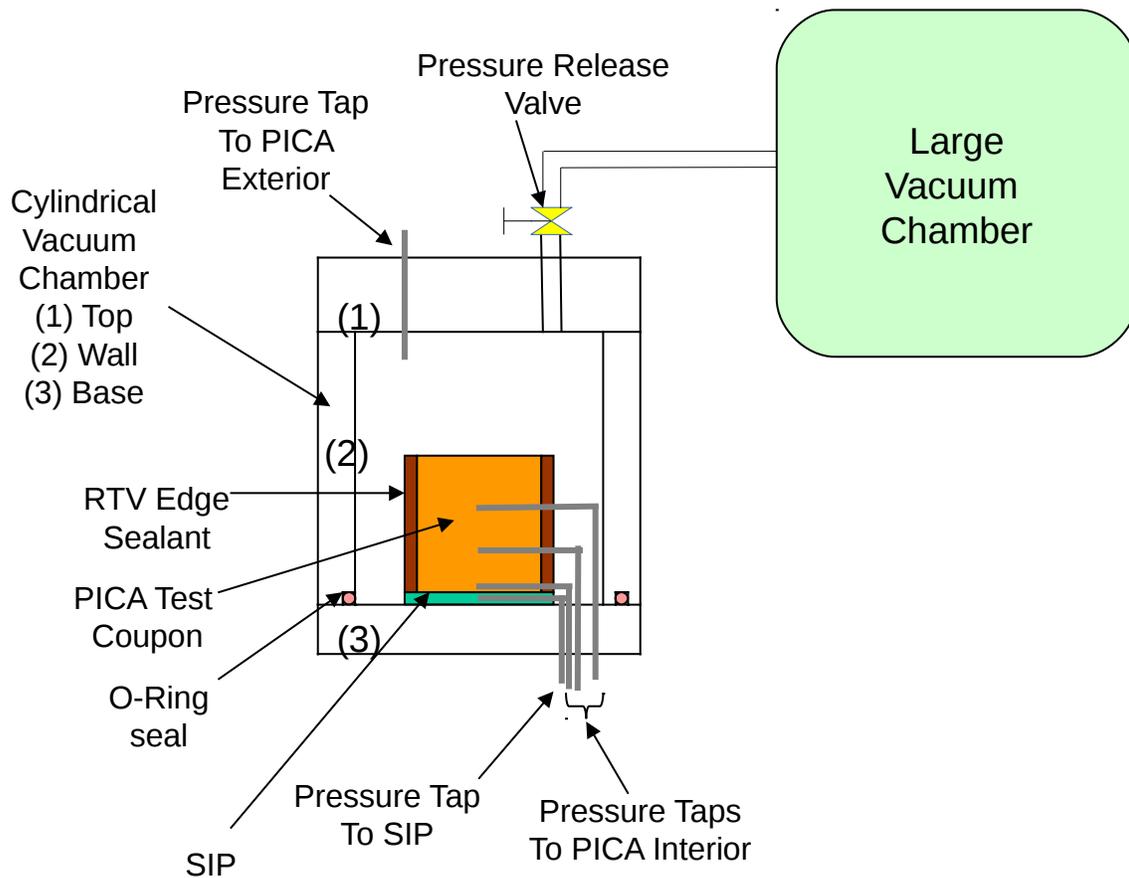


Figure 5: Schematic of test apparatus

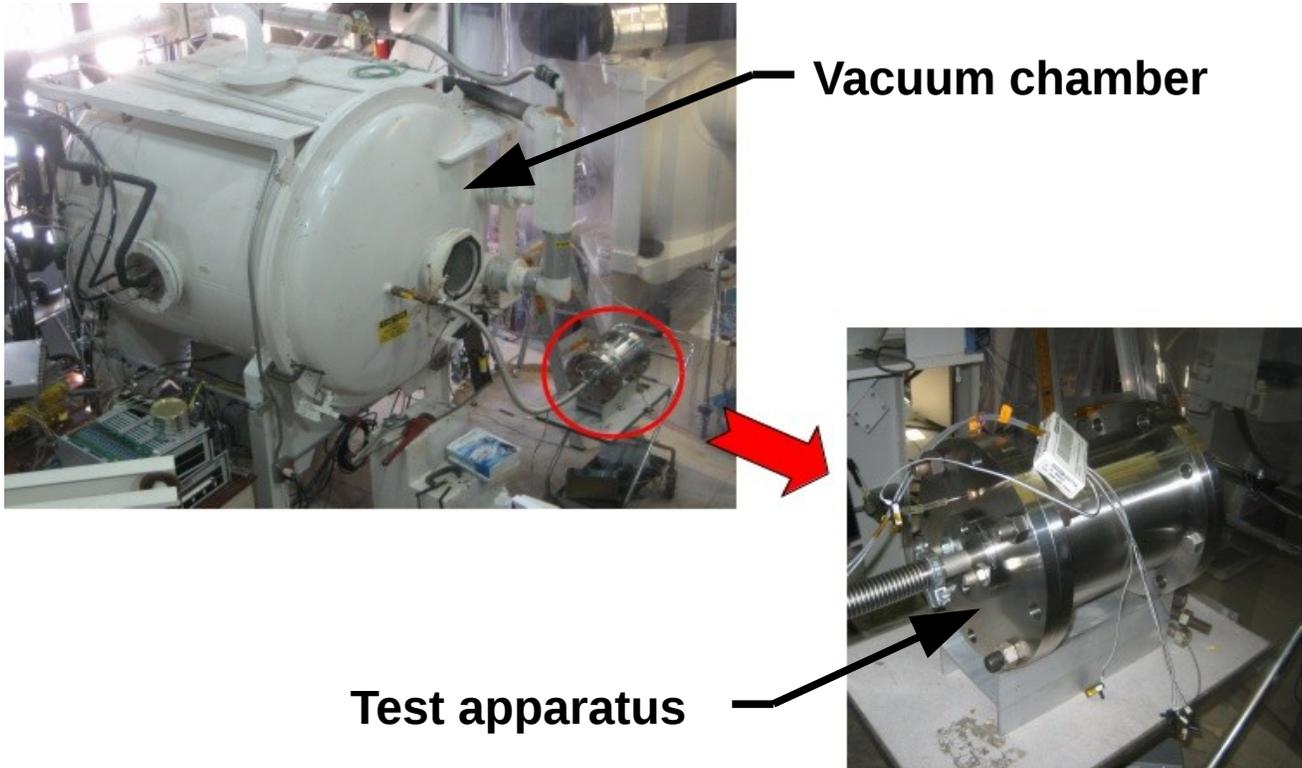


Figure 6: Test apparatus connected to a 5-ft diameter vacuum chamber

### Testing Scenario

All of the specimens were subjected to at least three rapid de-pressurizations and pressurizations. The densified PICA specimen was subjected to two simulated Orion ascent pressure histories, three rapid de-pressurizations and pressurizations and then subjected to additional simulated Orion ascent pressure histories. Some of the pressure readings were inadvertently not recorded for the first two ascent pressure histories.

The following procedure was used for each rapid de-pressurization and pressurization test:

Initially:

- Mount specimen on base plate
- Connect pressure taps to pressure transducers
- Calibrate pressure transducers

For each test cycle:

- Close valve to large vacuum chamber and pump large chamber to less than 0.0014 psi
- Open valve quickly and record pressure responses (de-pressurization)
- Close valve and vent large vacuum chamber to atmospheric pressure
- Open valve quickly and record pressure responses (pressurization)

These tests were repeated at least 3 times in succession.

The simulations of the Orion ascent pressure history used the same initial steps previously described. However, for simulated ascent test the following procedure was followed:

- Make sure small and large chambers are at 1 atm and the valve between them is open
- Control pump of large vacuum chamber to simulate ascent pressure history. (The pump is cycled on and off, so the pressure history is not perfectly smooth.)

## Results

Results of each of the three different types of tests are discussed separately. All three specimens were subjected to rapid depressurization and pressurization tests, but only the densified specimen was subjected to a simulated Orion ascent pressure history.

### Depressurization Tests

The depressurization tests involved rapidly dropping the chamber pressure from 1 atm to a very low pressure and measuring the resulting internal pressure histories of the specimens. The tests were repeated at least three times and the variations in the results were found to be negligible. The results for the first and third depressurization tests shown on Figure 7 for the undensified specimen mounted on SIP show that differences from test to test are negligible. Differences in internal pressure histories are barely perceptible on the figure. Differences between pressures at different locations will be discussed using the results shown on Figure 8.

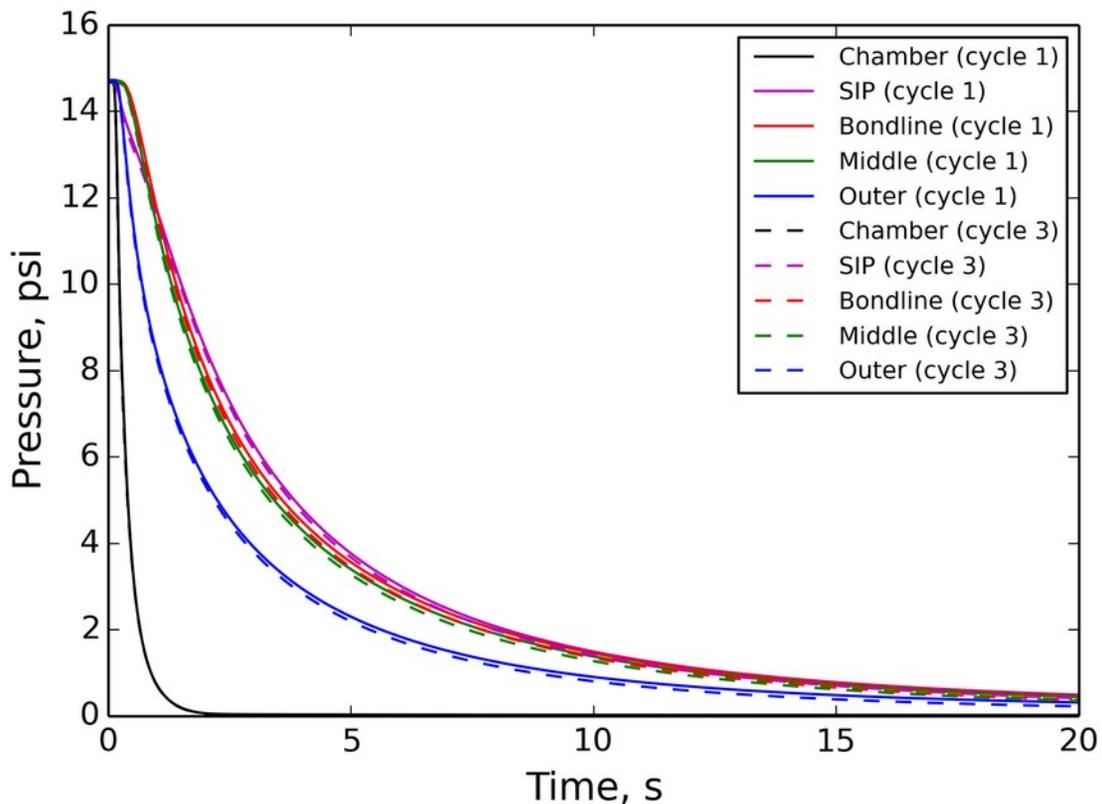


Figure 7: First and third de-pressurization tests for specimen mounted on SIP

A comparison of the responses of all three specimens is shown on Figure 8. The three specimens are identified as DB (directly bonded), SIP (mounted on SIP), and Den (PICA surfaces densified and mounted on SIP). The colors correspond to the locations of the pressure readings and the line patterns correspond to the specimen configurations.

As expected, the locations nearer the outer surface vented more quickly than those closer to the structure for all specimens. The internal PICA pressure responses do not appear to have large variations between specimens. The small differences could result from variations in the PICA material or slight differences in the pressure tap location from the outer surface. There is a larger difference in the pressure response in the SIP between the undensified and densified specimens. This difference could be caused by the densification of the PICA inner surface or by differences in the RTV bond between the PICA and the SIP.

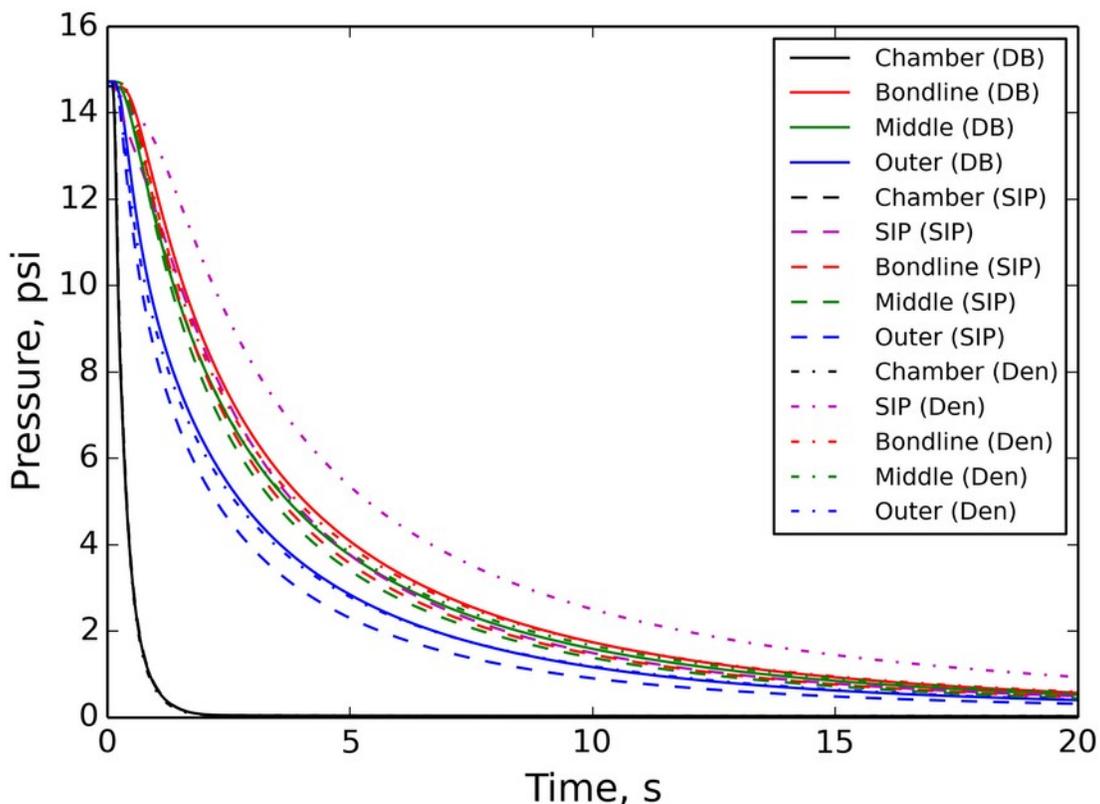


Figure 8: De-pressurization responses for all three specimens

Within the first second, nearly the entire 1 atm is acting to pull the specimen from the plate on which it is mounted, yet the specimen was undamaged. Multiple rapid pressure cycles produced no evidence of damage to any of the specimens.

### Pressurization Tests

The pressurization tests involved rapidly raising the chamber pressure from a very low pressure to 1 atm and measuring the resulting internal pressure histories of the specimens. The tests were repeated at least three times and the variations in the results were found to be negligible, as for the de-pressurization tests.

A comparison of the responses of all three specimens (directly bonded, SIP mounted, and densified) is shown on Figure 9. Again, as expected, the locations nearer the outer surface vented more quickly than those closer to the structure for all specimens. As for the de-pressurization tests, similar small variations in internal PICA pressures from specimen to specimen were observed, with a larger difference in the SIP pressures. However, the pressures are all at nearly 1 atm after 7 seconds, which is much faster than the de-pressurization response shown on Figure 8.

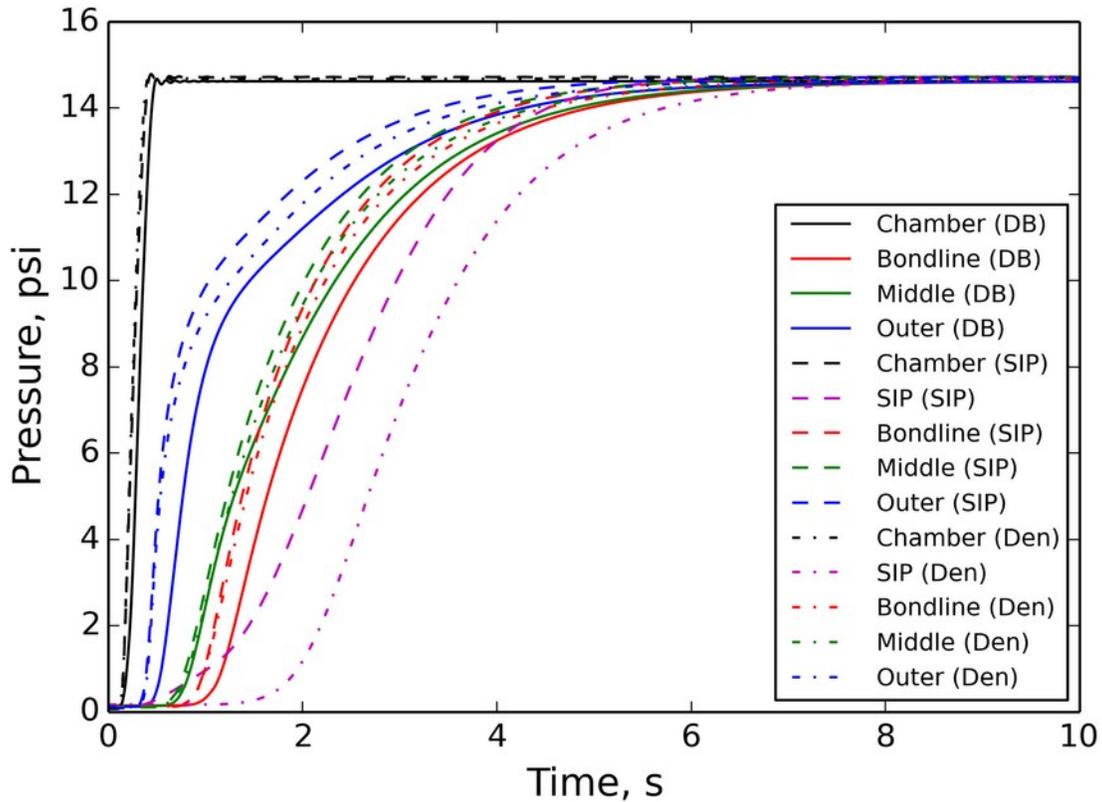


Figure 9: Pressurization responses for all three specimens

### Simulated Orion Ascent Tests

The Orion ascent pressure profile was simulated with discrete opening and closing of the valve so that the chamber pressure was not a totally smooth function with time. The response of the densified specimen to a simulated Orion ascent pressure profile is shown in Figure 10. Although the black line representing the chamber pressure closely follows the desired set point, it is not smooth. Therefore, the internal PICA and SIP pressure histories are also not perfectly smooth. The internal PICA and SIP pressures shown on Figure 10 are not greatly different from the chamber pressure. The pressure differences between the SIP and chamber and between the bondline and chamber are shown in Figure 11. Although there are oscillations due to the imperfect pressure control in the chamber, the maximum pressure difference between the SIP and the chamber due to the ascent pressure profile was about 1 psi. The corresponding maximum pressure difference between the bondline and chamber was about 0.7 psi. Therefore, the maximum pressure difference across the RTV bond between the SIP and PICA was about 0.3 psi, indicating that the bond is relatively porous. These pressure differences are all much lower than those from the rapid de-pressurization and pressurization tests and very unlikely to cause damage to the specimens.

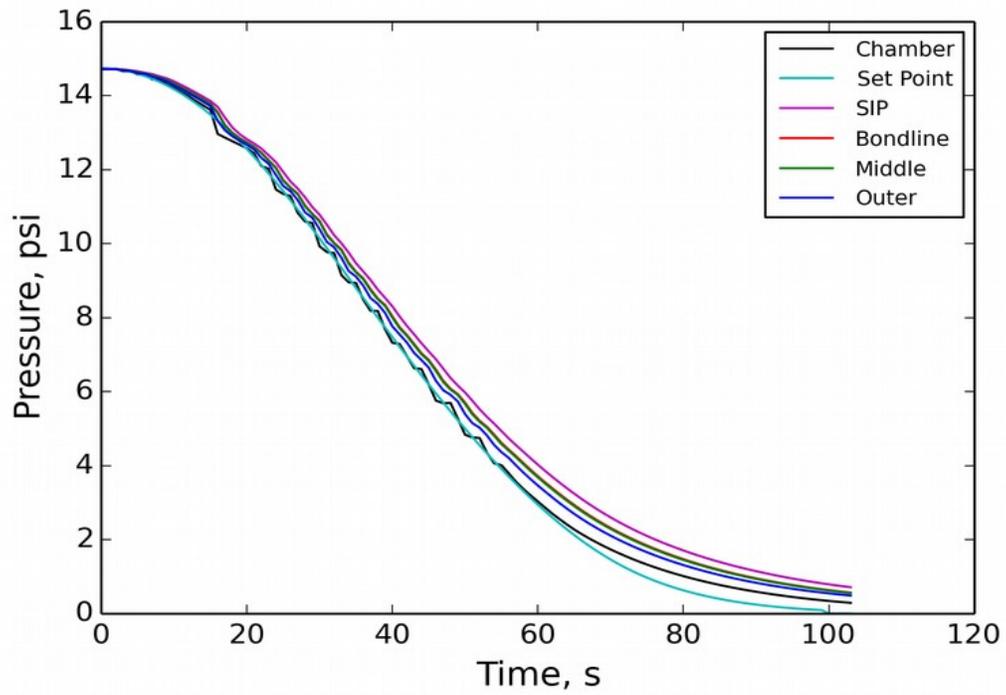


Figure 10: Response of densified specimen to Orion ascent pressure profile

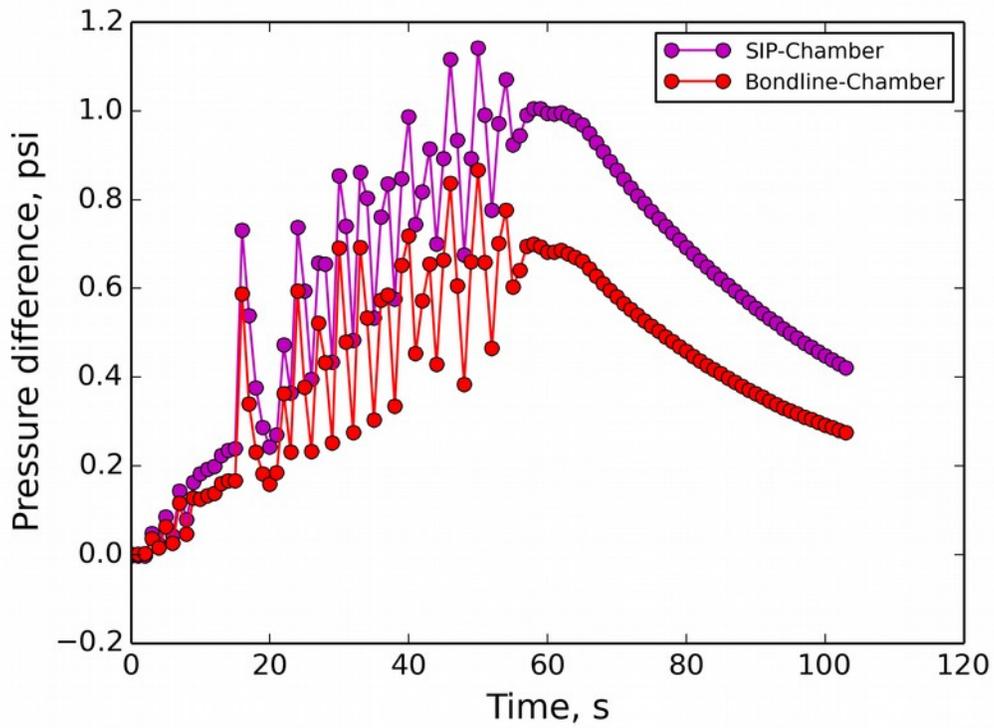


Figure 11: Pressure differences in SIP and at bondline

## Summary

Three cylindrical PICA specimens were subjected to rapid de-pressurization and pressurization tests, between 1 atm and a low pressure, while measuring internal pressure responses. One of the specimens was also subjected to repeated simulated Orion ascent pressure profiles.

Sealing the sides of the specimen proved to be much more difficult than anticipated. Sealing required at least four thick coats of RTV. The RTV bond between the strain isolation pad and the PICA specimen is porous.

Each of the three specimens was subjected to at least three rapid de-pressurization and pressurization cycles with no evidence of failure and negligible variation in response. The densified PICA specimen was also subjected to five simulated Orion ascent pressure histories with no evidence of damage. The peak difference between the interior and exterior of the specimen during the simulated ascent was about 1 psi.

The rapid de-pressurization and pressurization tests were much more severe than any anticipated flight conditions, yet the specimens were undamaged. The simulated ascent profile resulted in internal pressures more than an order of magnitude lower than those for the more severe tests. Considering these test results and the fact that it was very difficult to seal the edges of the specimen, it appears unlikely that inadequate venting of PICA will be a significant design consideration.

## References

1. Tran, H., Johnson, C., Rasky, D., Hui, F., Chen, Y.-K., and Hsu, M., "Phenolic Impregnated Carbon Ablators (PICA) for Discovery Class Missions," AIAA Paper 96-1911, June 1996.
2. Reuther, James, "Overview of the Orion Thermal Protection System Advanced Development Project," Presented at the 7th International Planetary Probe Workshop, Barcelona, Spain, June 16th, 2010.

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