Orion Composite Overwrapped Pressure Vessel Safety Testing

Nathanael J. Greene, *White Sands Test Facility*
Regor L. Saulsberry, *White Sands Test Facility*
Ralph Lucero, *White Sands Test Facility*
Tommy B. Yoder, *White Sands Test Facility*

A joint test and analysis effort is under way at Johnson Space Center and NASA White Sands Test Facility (WSTF) to develop data and analysis to better understand the durability and reliability of composite overwrapped pressure vessels (COPVs). COPVs are used in virtually all launch vehicles and the International Space Station, and are planned for use on Constellation Program vehicles because of mass savings over all-metal pressure vessels. The mass savings come, however, with the added complexity of the anisotropic behavior of the carbon fiber-epoxy structure, sensitivity to mechanical damage, and the bond interface between overwrap and liner. In a study at WSTF, we are developing novel approaches to measure vessel health to understand pressure vessel durability with time, pressure, and temperature for the Orion Crew Exploration Vehicle.

Exploration of the moon, Mars, and other planets requires mass restrictions that drive these pressure vessels toward new technological limits. New applications for visual inspection and nondestructive evaluation (NDE) for verification of manufactured integrity include laser profilometry, laser shearography, heat soak or flash thermography, radiography, and videoscope. These applications have been applied to the vessels we are testing for Orion. We are also developing wired and wireless health-monitoring approaches for application during vessel lifetime, including strain measurement, acoustic emission, impact detection, audio signature, and video event mapping. The data collected are providing information for mass and factor-of-safety traits required for the optimization of Orion vehicle designs. Figure 1 shows an Orion test COPV instrumented in a recent test for measurement of strain, acoustic emission, internal volume, audio, and video health signatures to the point of burst failure.

Fig. 1. *Orion test COPV instrumented for multiple measurements during test to failure.*

We successfully used flash thermography and laser shearography to map manufacturing design features, including ply termination and wrap pattern bridges (figure 2). Laser profilometry has provided a full map of the interior of the vessel with precise measurement of liner ripple period and amplitude. Videoscope, laser imaging, and radiographic inspection have also been successful in identifying weld anomalies that may cause in-service premature leakage or rupture. As a result of this testing, three new American Society for Testing and Materials standards are being written for COPV inspection with multiple NDE methods. These are being broken down into composite, liner, and liner-to-composite interface standards.

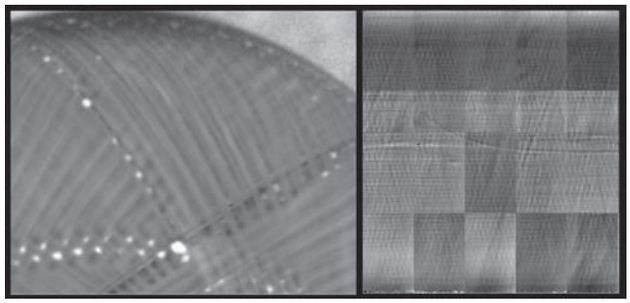

Fig. 2. *Heat soak thermography of ply layup (left); laser shearography of external surface (right).*

We correlated data collected during testing to provide a comprehensive assessment of vessel health over time. The analyzed data provide information useful for ranking health assessment techniques that can be applied for Constellation vehicle health monitoring. We also collected health data from an Orion test vessel during a burst test for instrument

sensitivity analysis (as shown in figure 1). Video and audio events during a typical test are shown in figure 3.

The new NDE and health monitoring techniques in development will open the door for safer space exploration tomorrow.

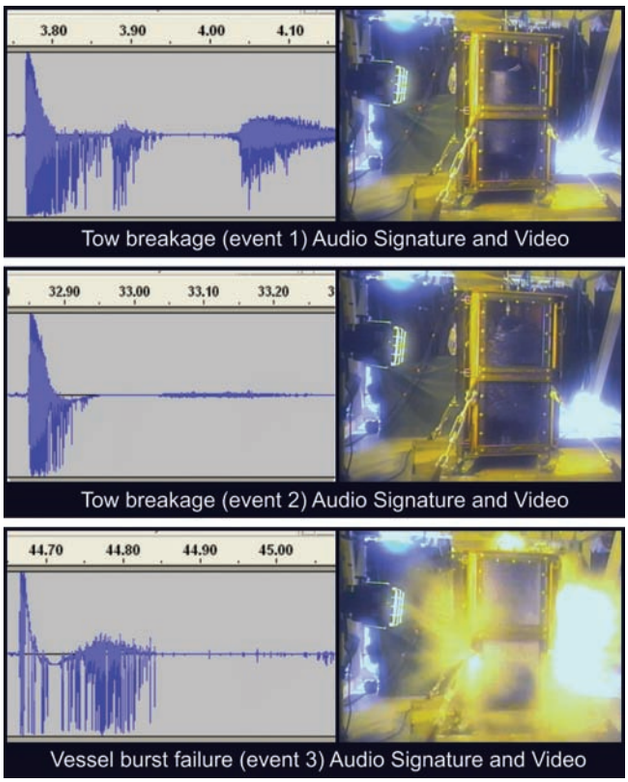

Fig. 3. *Example of data for vessel health during lifetime.*

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