# Orbiter Auxiliary Power Unit Hydrazine Fuel Line Vacuum Test

***Michelle H. Barragan,*** *White Sands Test Facility*

***Darren M. Cone,*** *White Sands Test Facility*

We have uncovered, through investigations into orbiter in-flight anomalies during STS-121 and STS-123, the critical need to thoroughly understand the physical behavior of a hydrazine ($N_2H_4$) leak in a space vacuum, as well as the resulting impacts to vehicle system integrity and exposure risk to crew members.

Although post-flight inspections revealed neither the STS-121 nor the STS-123 anomaly resulted from an $N_2H_4$ leak, in-flight data revealed a pressure decay corresponding to an equivalent $N_2H_4$ leak of approximately 2.0 $lb_m$/day. Except for a case in which the orbiter auxiliary propulsion unit (APU) fuel tank was nearly depleted, in-flight pressure and temperature data are not sufficient to distinguish between a gaseous nitrogen ($GN_2$) tank leak and an $N_2H_4$ tank leak. Therefore, the most conservative approach during flight is to assume an $N_2H_4$ leak occurred, resulting in potentially significant risk and mission impact implications.

The objective of the orbiter APU hydrazine fuel line vacuum test is to characterize the physical behavior of an $N_2H_4$ leak in a simulated space vacuum using a representative segment of orbiter APU fuel feed-line containing a laser-machined, 20-µm orifice sized specifically to allow for a media leakage rate that approximates the pressure decay noted during in-flight anomalies. The test line is roughly 2 ft in length and is made of 304L corrosion-resistant steel with a 0.50-in. outside diameter and a 0.025-in. wall thickness. This test also investigates the effects provided by the associated APU line heater and thermal insulation on the behavior of the fuel leak, and any deviation in the performance of the heater controller feedback circuit. We performed initial testing with water, as water is the most suitable physical analog for propellant-grade $N_2H_4$ and allows preliminary experimentation in the absence of toxic media.

Pressurization of the test media is provided by $GN_2$ at pressures up to 250 psia, representative of typical orbiter APU fuel tank on-orbit pressure. We used a modified vacuum test chamber capable of maintaining $10^{-1}$ Torr minimum through use of mechanical pumps and an in-line cryogenic trap to provide the vacuum surrounding the test article. Our team then positioned eight thermocouples axially along the tubing at specific interval distances from the leak orifice, and monitored and recorded vacuum chamber and test media pressure together with the thermocouple data at a 1-Hz sampling rate. The vacuum test chamber includes accommodations for the installation and control of an electrical feed-line heater, with and without thermal insulation, in configurations representing the actual orbiter APU feed-line system as installed. Nominal test media temperature is 65°F.

Results from preliminary tests, with water as the test media, reveal the development of ice structures at the orifice leak site, in either complex crystalline or continuous "ribbon" forms (figure 1).

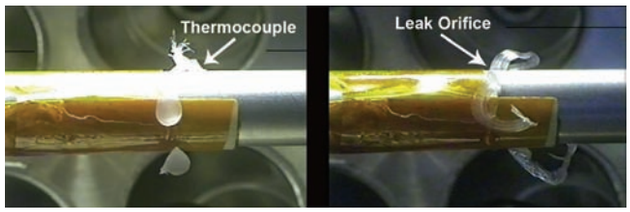


***Fig. 1.*** *Typical ice structure formations.*

Figure 2 shows leak-site behavior typical to this series of tests in the formation of an ice "plug" structure blocking the media leak path and maintaining stability over varying amounts of time. Specific to this test, however, as the test media pressure was increased to 250 psi, a fine, nearly vertical stream of water was ejected from the orifice and through the "plug" structure. After several minutes, the ice formation shown in figure 2 was observed from the

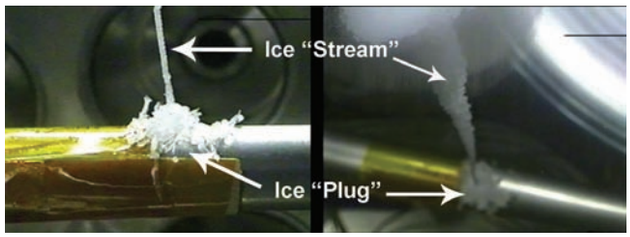


***Fig. 2.*** *Ice plug and stream structures in front (left) and top (right) views.*

top port of the vacuum chamber. Fluid began freezing at the chamber wall and proceeded back to the orifice site, creating an ice stream that momentarily stopped the leakage. This behavior and physical structure

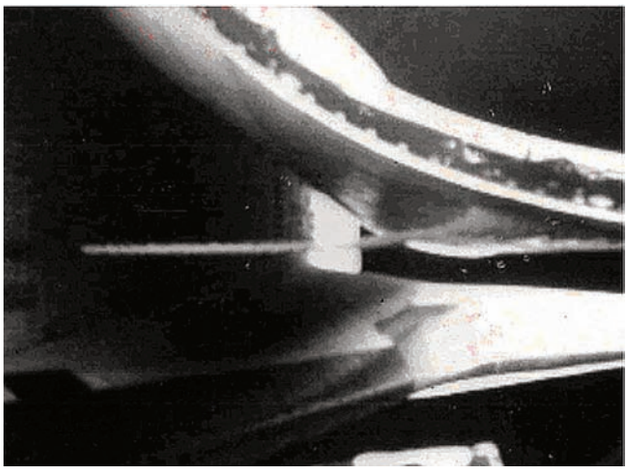

***Fig. 3.*** *Space shuttle orbiter during on-orbit water dumps.*

matches very well with that observed in the space shuttle orbiter during on-orbit water dumps (figure 3).

We performed additional tests, approximating typical on-orbit usage of the APU fuel line heaters, using an actual APU line heater with representative wrap factor and a heater duty cycle of 17%. Test results with the line heater installed and energized (figure 4) show an ice structure formation that characteristically differs from those observed during previous tests without the line heater. For this test, we pressurized the test article to 250 psia, and placed the heater control thermocouple immediately adjacent to the leak orifice with the heater set point maintained at 65°F. Once this particular ice structure formed, it persisted with only slight alteration for the remainder of the test (~2 hours). This contrasts with the previous test's supplemental heating in which the ice structures detached after varying amounts of time, allowing subsequent formation of new, partially stable ice structures with different configurations.

***Fig. 4.*** *Stabilized ice structure with electrical line heater installed.*

## Conclusion

Preliminary testing with water allowed us to characterize several unique physical behaviors at the leak site simulating on-orbit space shuttle orbiter APU fuel leakage. As a function of test article pressure and application of supplemental heating, ice structure formations exhibit varying structural configurations and levels of stability. These results match very well with the ice formations observed in the orbiter during on-orbit water dumps. For tests including the flight configuration line heater, the heater controller response reflects the local thermal variation of the feed line near the leak orifice during vacuum solidification of leaking test media, physical detachment, and subsequent solidification of another structure. Based on the test expertise we have developed thus far, and with insights into the nature of the physical behavior of water leaking into the simulated space vacuum, the test team will move forward to perform identical test sequences with $N_2H_4$ as the test media to best represent the orbiter flight configurations. The new data will help characterize APU system performance and impacts to crew safety should an $N_2H_4$ fuel leak occur while the orbiter is in orbit.



Click here for next report