AI 31.3_NASA Input on Fluid lines to Vulnerability Report, authors of this summary: E.L. Christiansen, F. Lyons, and J.E. Miller, NASA JSC HVIT group, June 2018

1 Fluid Lines

Damage Mode

Fluids are essential to the operation of the International Space Station (ISS) in their role of transporting heat, and as such, understanding the vulnerability due to micrometeoroid and orbital debris (MMOD) impact has been a focus for ISS mission support. Of most concern is the complete loss of a critical fluid; however, even if the leak can be isolated, the system is then operating with reduced functionality and is at more risk of failure or requiring crew operation constraints. While there are many types of fluid lines, the fluid lines configurations that have been evaluated to the greatest extent by personnel in the NASA Johnson Space Center (JSC) Hypervelocity Impact Technology (HVIT) group are metallic tubes and embedded metallic tubes in radiator panels.

Hypervelocity impact experiments have supported the HVIT risk assessments for these fluid lines. These experiments have been performed with aluminum and steel spherical projectiles accelerated to 7-8 km/s by the two-stage light-gas gun launchers at the Remote Hypervelocity Test Laboratory at NASA White Sands Test Facility (WSTF).

Impact Experiments

Thirty (30) direct-impact experiments were performed on surrogates of the stainless steel tubes running through the Segment Zero (S0), Starboard One (S1), and Port One (P1) trusses. The operational tubes transport ammonia, which is used as a coolant for nearby electronics, and like those operational tubes, the tubing used for the experiments were made of 0.71 mm (0.028”) thick, stainless steel at various diameters. In addition to the tubing, the on-orbit configurations include varying layers of blankets for passive-thermal reasons; therefore, these experiments included both the tubing and the blankets, which are made up of beta cloth and multilayer insulation (MLI), as illustrated in Figure 1.2-1, to best represent the on-orbit configuration. As the blankets in the operational environment fit loosely, an artificial separation of about 9.5 mm (3/8”) was included in the experimental article.

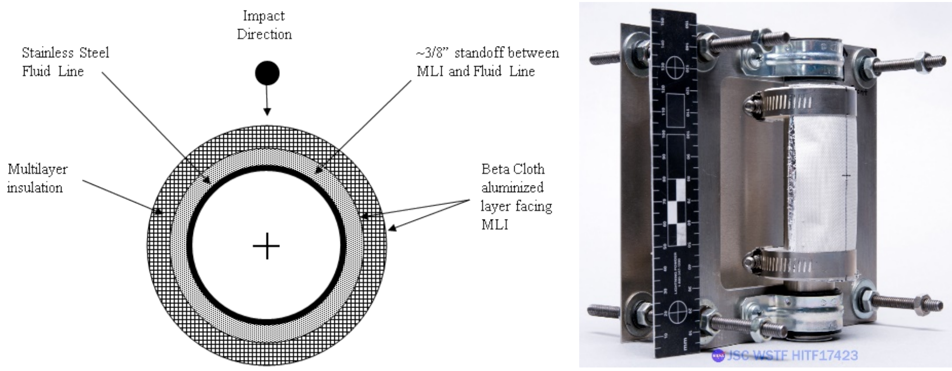

Figure 1.2-1 A diagram of ISS truss stainless steel tubing with insulation (left) and an image of a representative experimental article (right)

While in the proximity of the electronic heat sources the fluid lines are typical of those in Figure 1.2-1; however, in the radiators, where the heat is rejected, the fluid lines are frequently embedded inside panels to increase radiant exchange. A total of seventy-eight (78) tests have been performed in this configuration under both unpressurized and pressurized conditions. On the ISS these panels are aluminum honeycomb panels with Inconel tubing running through the center of an extruded conductive fins like those shown in Figure 1.2-2. The Inconel tubing has an outer diameter of 4 mm and an inner diameter of 3 mm. The panel itself has a 0.3 mm (0.01") thick Al 7075-T3 face sheets (with Z-93 outer coating) on front and back of a 1.7 cm (0.67") thick Al 6061-T651 honeycomb core containing embedded tubes. The extruded element has a thickness of 1 mm (0.04") on the top and bottom and varies in thickness towards the middle with a minimum thickness of 0.5 mm (0.02").

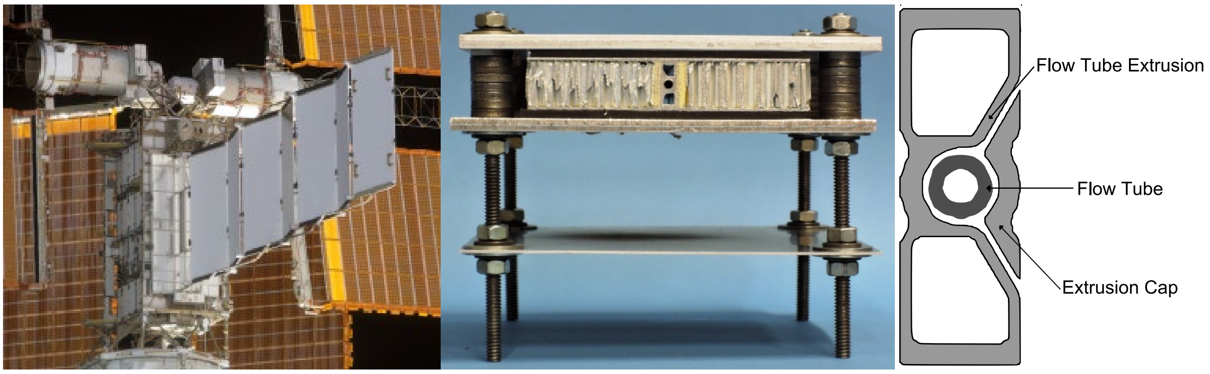

Figure 1.2-2 Image of an ISS photovoltaic radiator (PVR) panel (left) an image of a representative PVR experimental article (center) and a diagram of the flow tube insert (right)

Experimental Conditions and Results

S0 Steel Tube Tests. Table 1.3 -1 summarizes results from several of the impact experiments on ISS steel fluid lines [Ref.1-4]. These experiments have been performed with spherical projectiles of aluminum 2017-T4 and stainless steel 440C at various impact speeds and obliquities relative to the target normal. Multiple tube diameters have been considered including 0.635 cm, 1.27 cm and 2.54 cm (¼", ½" and 1"). In addition to the tube sizes, configurations with no MLI and cases where a MLI blanket with the mass of 0.0289 g/cm^2 have been considered. With respect to the MLI, consideration has also been given to mounting the MLI directly against the fluid line and stood-off slightly by 9.525 mm (⅜"). All of these parameters affected the final result of the experiment, which is determined to be a fail if any leaks occur post-impact and a pass otherwise.

Table 1.3-1 Results of S0 Steel Tube Experiments

Tracking #	Tube Diameter (cm)	MLI Mass (g/cm^2)	Projectile Material	Impact Speed (km/s)	Impact Obliquity (°)	Projectile Diameter (mm)	Standoff (mm)	Result
A3125	2.54	0	Al 2017-T4	7.09	0	0.43	0	Fail
HD9820034	2.54	0	Al 2017-T4	6.8	0	0.4	0	Pass
HD919820006	1.27	0	Al 2017-T4	7.1	0	0.35	0	Pass
HD919820007	0.635	0	Al 2017-T4	7.2	0	0.3	0	Pass
HITF02253	2.54	0.0289	Al 2017-T4	3.06	0	1.25	9.525	Fail
HITF02251	2.54	0.0289	Al 2017-T4	3.5	0	1.42	9.525	Fail
HITF02250	2.54	0.0289	Al 2017-T4	5.28	0	1.25	9.525	Fail
HITF02213	2.54	0.0289	Al 2017-T4	6.8	0	1.143	9.525	Fail
A3127	2.54	0.0289	Al 2017-T4	7.11	0	0.71	0	Fail
HITF02219	2.54	0.0289	Al 2017-T4	4.7	0	1	9.525	Pass
HITF02252	2.54	0.0289	Al 2017-T4	4.94	0	1.143	9.525	Pass
HITF02211	2.54	0.0289	Al 2017-T4	6.65	0	0.7	9.525	Pass

HITF02212	2.54	0.0289	Al 2017-T4	6.78	0	0.9	9.525	Pass
HITF02214	2.54	0.0289	Al 2017-T4	6.86	0	1	9.525	Pass
HITF02210	2.54	0.0289	Al 2017-T4	6.95	0	0.5	9.525	Pass
HITF02218	2.54	0.0289	Al 2017-T4	6.84	30	1.25	9.525	Pass
HITF02216	2.54	0.0289	Al 2017-T4	6.84	45	1.25	9.525	Pass
HITF02215	2.54	0.0289	Al 2017-T4	6.87	45	1.143	9.525	Pass
HITF02217	2.54	0.0289	Al 2017-T4	6.75	60	1.42	9.525	Pass
HITF17422	2.54	0.0289	440C SS	6.87	0	0.7	9.525	Fail
HITF17411	1.27	0.0289	440C SS	6.97	0	0.7	9.525	Fail
HITF17416	0.635	0.0289	440C SS	6.97	0	0.7	9.525	Fail
HITF17426	2.54	0.0289	440C SS	6.93	45	0.7	9.525	Fail
HITF17414	1.27	0.0289	440C SS	6.97	45	0.8	9.525	Fail
HITF17425	2.54	0.0289	440C SS	6.99	45	0.8	9.525	Fail
HTIF17419	0.635	0.0289	440C SS	7.04	45	0.8	9.525	Fail
HITF17423	2.54	0.0289	440C SS	7	0	0.6	9.525	Pass
HITF17410	1.27	0.0289	440C SS	7.01	0	0.6	9.525	Pass
HITF17420	0.635	0.0289	440C SS	6.96	45	0.7	9.525	Pass
HITF17413	1.27	0.0289	440C SS	6.98	45	0.7	9.525	Pass

Figure 1.3-3 graphically demonstrates the importance of MLI. In the figure, the spherical, aluminum projectile diameter from experiments in Table 1.3-1 are shown as a function of the impact speed for the 0° to normal impacts when MLI is present and when it is not. Three conditions are shown: MLI present and stood-off slightly from the steel tube (blue), MLI not present (gray) and MLI present but touching the tubing (dark blue). In the figure, impact conditions that resulted in a failure are filled, and impact conditions that did not result in any leak are left empty.

As can be seen in the figure, when MLI is present and slightly separated from the steel tubing, the performance increases considerably from the case of bare steel tubing. For these 0.71 mm (0.028”) thick steel tubes, a 0.4 mm Al2017-T4 projectile at ~7 km/s is at the threshold of perforation; however, by accounting for the MLI and separating it slightly, the performance at ~7 km/s goes up considerably to a threshold of perforation at approximately 1.1 mm. This almost tripling of critical particle size greatly increases the reliability of these components operating in the near-Earth orbital debris environment. It can also be seen, that just placing the MLI flush to the flow line doesn’t yield nearly as large performance increase, and that ensuring a slight separation is important.

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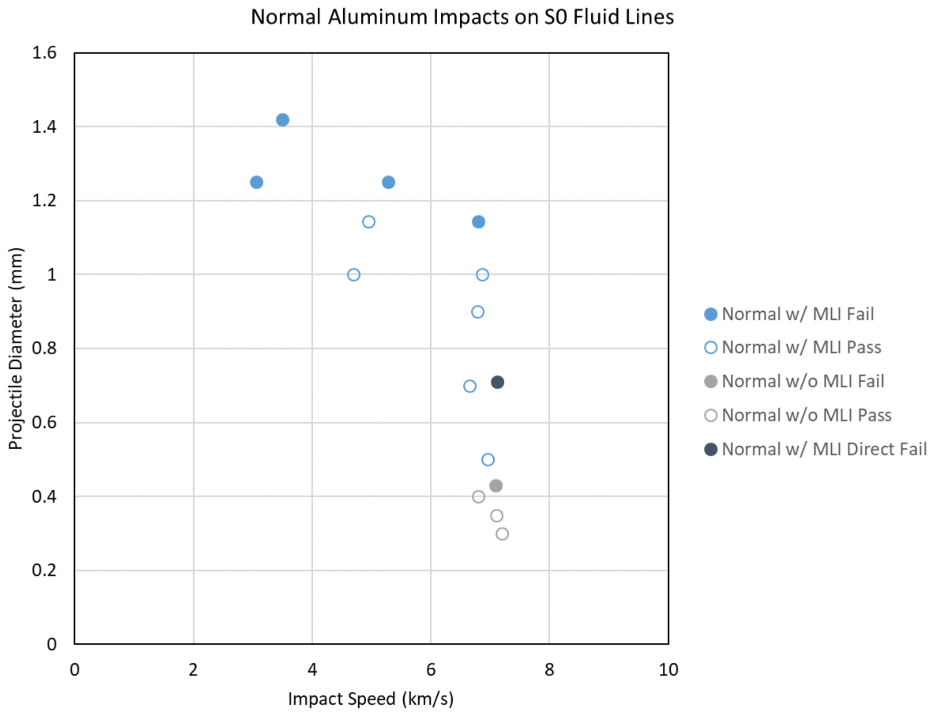

Figure 1.3-3 Experimental projectile diameter versus normal impact speed for various target configurations. The filled points are experiments that resulted in a leak, and the empty points are experiments that did not result in a leak.

Radiator Panel Fluid Lines. Results of NASA tests on fluid lines running through ISS radiator panels are given in Figure 1.3-4 for aluminum and Figure 1.3-5 steel projectiles [Ref.5-6]. In the figures, the spherical projectile diameter from the experiments are shown as a function of the impact speed for 0° (blue), 45° (gray) and 60° (dark blue) to normal impacts into the radiator panel. Both unpressurized (circles) and pressurized to 17.2 Bar (diamonds) have been considered for aluminum projectiles. In the figure, impact conditions that resulted in a failure are filled, and impact conditions that did not result in any leak are left empty.

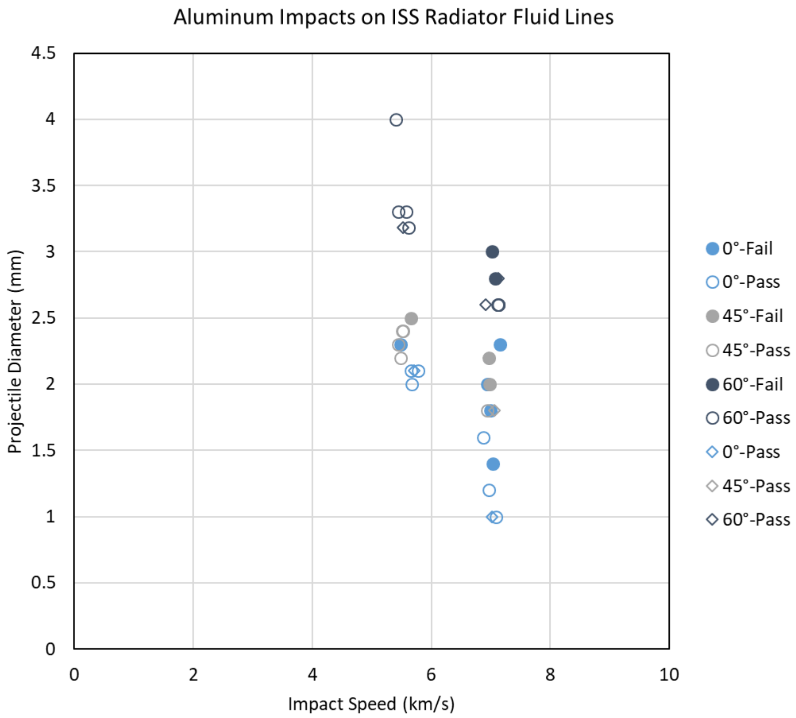

Figure 1.3-4 Impacts into ISS radiator fluid lines with spherical aluminum projectiles

As can be seen in the figures, the routing of the fluid lines through the center of the panel has resulted in a robust design against impacts from orbital debris while achieving thermal and structural requirements of the radiator. It is also noted that a significant variation occurs on impact performance. Due to the design of a small tube at a distance from the face of panel and the directional focusing of the honeycomb, it is difficult for an impact to affect the fluid line when the impact is not directly over the fluid line. It is also noted that impacts occurring at pressure did not behave significantly different from impacts without pressurized fluid lines.

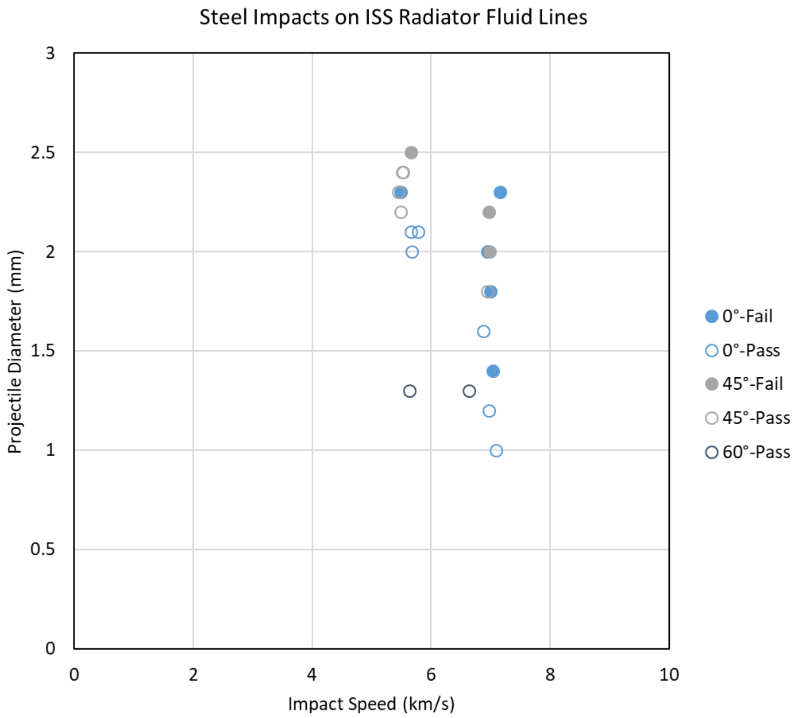

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Figure 1.3-5 Impacts into ISS radiator fluid lines with spherical steel projectiles

Recommendation for MMOD risk reduction

For fluid lines it is beneficial to raise any thermally required insulation from tubing whether through the use of foams or from periodic spacers. Even relatively modest blankets can increase impact robustness greatly over that realized from a bare fluid line or a fluid line that has the thermal insulation flush to the fluid line surface. For cases where fluid lines are part of a radiator, routing the lines away from the face of the panel greatly increases radiator reliability. Honeycomb in the vicinity of the fluid lines can redirect the debris away from the fluid line minimizing the critical surface area; consequently, lowering the probability of a critical impact. Finally, results of impacts onto pressurized fluid lines are similar to those on unpressurized fluid lines.

References

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