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ISS Radiator Face Sheet Anomaly Investigation and Return to Function

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Maintaining sufficient heat rejection on the International Space Station (ISS) is critical to the function of the Low-Earth Orbit station. The External Active Thermal Control System (EATCS) rejects the excess heat generated by the US On-Orbit Segment (USOS) modules. The system uses single-phase liquid ammonia to collect the heat and reject it to six radiators (three on the Starboard side, three on the Port side). Each radiator is made up of eight panels. In September 2008, imagery of the Starboard radiators was conducted and showed one of the panels' face sheets had peeled up from the internal honeycomb core structure. Out of an abundance of caution, the radiator was isolated from the rest of the EATCS and the ammonia was vented to space. Since the radiator was vented, periodic imagery of all radiator panels was taken to monitor any changes in the face sheet and inspect for other radiator anomalies. In January 2025, after years of trending and inspections, the radiator was reintegrated into the system to increase heat rejection capabilities. This paper will document the multi-year investigation that took place to determine root cause and mitigations implemented to reduce risk to the system. A summary of the data since the investigation will show rationale for reintegrating the radiator even with the damaged panel. The goal of the paper is to document the investigation for historical purposes and provide future programs with findings discovered during the investigation.

Acronyms and Nomenclature

ATA	=	Ammonia Tank Assembly
ATCS	=	Active Thermal Control System
CTE	=	Coefficient of Thermal Expansion
EATCS	=	External Active Thermal Control System
EVA	=	Extravehicular Activities
FEA	=	Finite Element Analysis
He	=	Helium
IR	=	Infrared
ISS	=	International Space Station
JSC	=	Johnson Space Center
kPa	=	Kilopascal
KSC	=	Kennedy Space Center
lbm	=	Pound-mass
MMOD	=	Micro-Meteoroid Orbital Debris
NESC	=	NASA Engineering and Safety Center
NDE	=	Non-destructive Evaluation
OEM	=	Original Equipment Manufacturer
PM	=	Pump Module
psi	=	Pound per Square Inch
PTCS	=	Passive Thermal Control System
PVTCS	=	Photovoltaic Thermal Control System
QD	=	Quick Disconnect
RBVM	=	Radiator Beam Valve Module

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RPM = Revolutions per Minute
TRRJ = Thermal Radiator Rotary Joint
USOS = US On-Orbit Segment

I. Introduction

The International Space Station (ISS) US On-Orbit Segment (USOS) maintains thermal control by rejecting heat through the External Active Thermal Control System (EATCS) and Photovoltaic Thermal Control System (PVTCS). Both systems use mechanically pumped single-phase liquid ammonia loops to reject heat to space with radiator panels. The EATCS comprises of two independent loops. Loop A is located on the starboard side of ISS whereas Loop B is on the Port side. Each loop has three radiators, and each radiator is made up of eight radiator panels. Each radiator has two flow paths that flow through each of the eight radiator panels. Loop A was activated in December 2006 and two years later in September 2008 imagery of the radiator showed one of the face sheets had pulled away from the panel, revealing the internal honeycomb structure and flow tubes. This radiator had one flow path filled with ammonia and one filled with nitrogen gas pad (flow path never used). While no leak was detected, the ISS Program decided to isolate and vent the ammonia in the radiator to prevent a leak from impacting the rest of the system. ISS was being assembled at this time and a large EATCS leak could have risked the assembly sequence. The radiator remained isolated from the rest of the system until January 2025, when the flow path was reintegrated into the rest of Loop A.

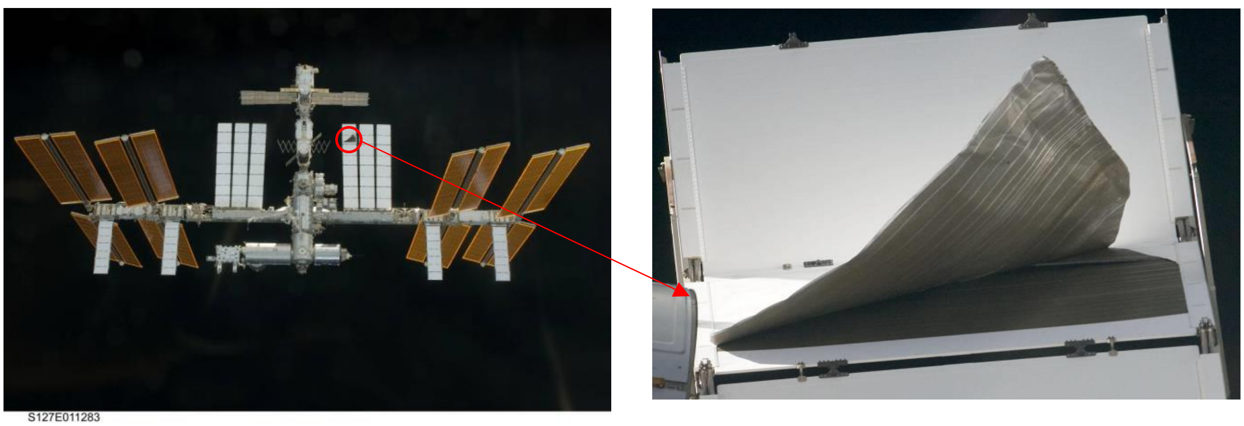

Figure 1. Image of ISS with detailed image of peeled face sheet.

Following the discovery of the face sheet separation, infrared (IR) and high-resolution images of the radiators were taken to assess damage and trend further peeling of the face sheet. A fault tree was developed, and using analysis and ground testing, most probable cause was determined to be a small undetectable flaw in the raw tube stock of the flow path. The flaw in the flow tube caused a leak inside of the radiator panel which caused pressure to build and rupture the panel. This leak was not detected at the system level. A flaw of this size could have only been discovered with x-ray inspection or helium leak tests of the raw tube stock which were not required as part of verification.

Periodic imagery for the past 15 years shows no significant increase in the damaged panel nor signs of any other face sheet delaminating. This likely indicates no flaws in the other flow tubes or MMOD strikes have allowed for venting of any pressure build up. Data trending of the small amount of ammonia gas left in the flow path after venting shows the flow path maintained integrity. While MMOD strikes are present on all radiators, to-date, no MMOD strike has caused a leak on either the EATCS or PVTCS.

As ISS utilization increased, so has the need to reject heat. With this increase, the ISS is no longer single fault tolerant to loss of an EATCS Loop, as one loop can no longer support the total ISS heat rejection needs. In June 2024, ISS Program approved filling a flow path in each loop to increase heat rejection so that each loop can fully support ISS heat rejection, restoring redundancy in the system. The flow path that was vented after the peeled face sheet was discovered was selected for filling as it is the only evacuated flow path on Loop A (the rest have the nitrogen pad from launch), and data shows it is not damaged and can hold pressure. With the fill completed in January 2025, the radiator is now providing heat rejection to the ISS. Understanding the failure mechanism, performing periodic imaging, and trending pressures inside of the damaged flow paths were critical in returning the radiator to function and putting the EATCS in a better posture for future failures.

II. ISS EATCS Overview

Overall, the EATCS has performed well over its 18 years of service and continues to provide effective heat rejection for ISS. Each loop uses a Pump Module (PM) to circulate the ammonia and an Ammonia Tank Assembly (ATA) to provide thermal compliance and to make up any ammonia lost in the system. The ATA has a quantity sensor which allows for trending to determine if a leak in the system exists and when an ATA requires replacement. The Thermal Radiator Rotary Joint (TRRJ) rotates the three radiators on each loop. They can either be parked at a specific angle or placed in Autotrack, which automatically adjusts the angle of the radiators to maximize heat rejection. Typically, this places the radiators edge to Sun during day pass and face to Earth during night pass. TRRJs are nominally parked at specific angles that provide adequate heat rejection, minimize contamination of the radiator (which would irreversibly degrade the performance of the radiator), and protect against unacceptable hot and cold environments. Autotracking provides the maximum heat rejection capability for the system but can cause wear to the rotating mechanism so ISS Program decided parked would be the normal configuration. Autotracking is used primarily during contingency cases when one loop goes down or loss of attitude control.

The EATCS radiators each have two isolated flow paths for a total of six flow paths on each loop. Each flow path can be isolated, integrated into the system, or vented overboard with the Radiator Beam Valve Module (RBVM). The RBVMs also monitor both temperature and pressure in each flow path. Currently, Loop A has four of six flow paths filled and Loop B has five of six flow paths filled. All other flow paths are filled with nitrogen, which allows their integrity to be monitored by the pressure sensors in the RBVMs. The ammonia flows from the RBVM to the manifolds that run along the side of the radiator and branch to the parallel flow tubes in all eight radiators as shown in Figure 2. The flow tubes are welded to the manifolds. Each radiator panel contains 22, 1/8" outer diameter flow tubes, 11 for each flow path. The panel is constructed of a honeycomb core between flow tubes sandwiched between face sheets (reference Figure 4). The flow tubes sit within extrusions which provide additional armoring to MMOD strikes. All materials of the panel are aluminum except the flow tubes which are Inconel for its strength and corrosion resistant properties. Epoxy and expanding foam adhesive are used to bond all the materials together. The panels are painted with Z93. The following section will be discussing the findings from the investigation and how root cause was determined.

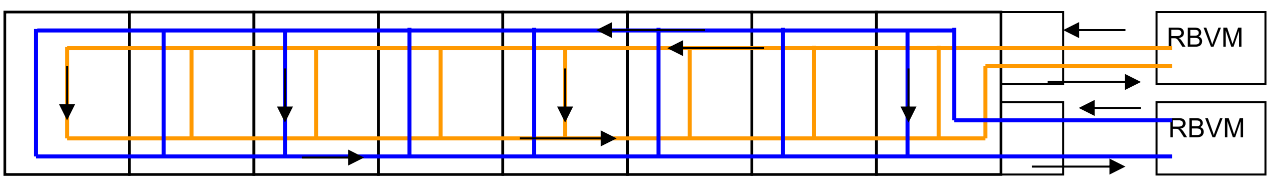

Figure 2. Simplified Schematic of EATCS Radiator.

III. Face Sheet Peel Investigation and Findings

The original purpose for taking the radiator imagery that identified the peeled face sheet was to check the S1 Radiator for damage after a thruster cover jettisoned during Russian Extravehicular Activity (EVA) 20 impacted the radiator. Imagery showed the cover did not cause any damage, but it was then that the peeled face sheet was discovered. The face sheet peel had little impact if any to the overall heat rejection of the system at the time as the panel was only one of 24 and the system had plenty of heat rejection margin. Telemetry showed no indication of a degradation of performance. Following the discovery, a formal investigation took place and began with building a fault tree. This investigation was worked by an interdisciplinary team consisting of experts from ATCS, Structures and Mechanisms, Materials and Processes, MMOD, Passive Thermal Control Systems (PTCS), Environments, and Safety with representatives from NASA, Boeing (ISS Prime Contractors) and Lockheed Martin (Radiator OEM). A simplified version of the fault tree can be seen in Figure 3.

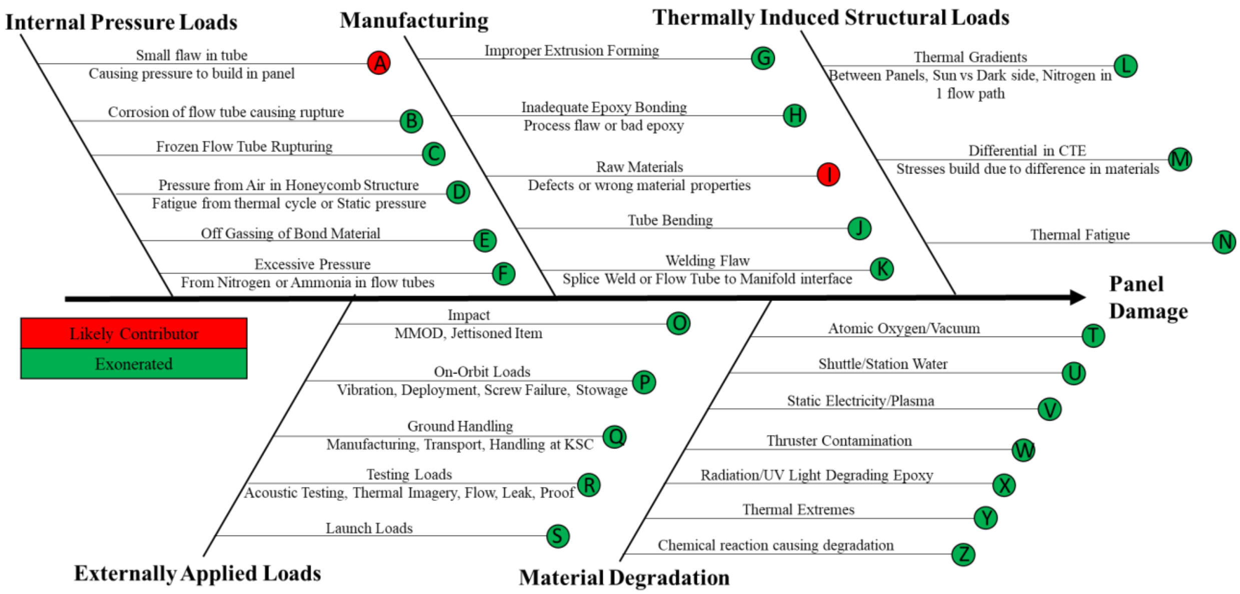

Figure 3. Simplified Fault Tree.

A. Fault Tree

The failure team used a combination of analysis and data from Qualification and Acceptance testing to close many of the branches of the fault tree. The thermal load induced by gradients, differences in CTE (Coefficient of Thermal Expansion), and thermal cycling of the hardware all had margin to failure. The thermal extremes were also well below the temperature that would impact the material properties.

Atomic Oxygen and UV can only attack line-of-sight, meaning the Z93 paint and aluminum face sheet protect the epoxy from degradation. All materials are stable in vacuum and are resistant to radiation. Water or Hydrazine from thrusters would not have influenced the Z93 paint aside from decoration and could not have entered the radiator panel in high enough quantities to impact the internal structure.

A review of the design and build documents showed no issues with the extrusions. Process review of all epoxies used in radiator showed all were applied correctly with no non-conformances recorded. Post-bond Non-destructive Evaluation (NDE) and coupon evaluations showed no bonding defects. Tube samples were bent during the investigation and showed they did not cause leaks in the tube. There are no welds within the radiator face sheet thus no weld failure could have caused the panel face sheet to separate, as any weld failure would cause venting to space.

Test data, on-orbit data and imagery show on-orbit, ground handling, and launch loads were not high enough to cause damage to the radiator design. Most testing loads were within design limits except for acoustic testing, which included environments above the specification limit. No evaluation after acceptance testing occurred to verify the integrity of the radiator. However, the qualification radiator experienced more severe environments and showed no delamination. Jettisoned items were shown by analysis to be unable to reproduce the failure. MMOD strikes were also ruled out as a cause of the face sheet failure but could have triggered the peel back assuming another failure occurred. This will be discussed further in the Failure Scenario section below.

Corrosion of the flow tube due to foreign contaminants was ruled out by reviewing the cleaning processes and documentation that took place during build. The Inconel is resistant to corrosion, therefore corrosion caused by the ammonia, nitrogen, or epoxy is not credible. The flow tubes are designed to freeze, and analysis shows pressure from freezing is much lower than the tube strength. Epoxy off-gassing and air trapped in panel during build is unable to create enough pressure to cause the failure. With pressure insight into the flow path from the RBVM, telemetry shows the flow tubes never experienced high enough pressures to cause failure. The following sections will discuss the testing and analysis performed to show the failure was likely caused by a flaw in the tube, which allowed pressure to build within the panel that lead to the failure.

B. Testing

A suite of testing was proposed but due to funding constraints, only a subset was funded by the NASA Engineering and Safety Center (NESC). Four tests were conducted to inform the failure investigation. The first was an evaluation of the qualification radiator. The second tested residual stock of 12-foot flow tubes with the third test using flow tubes taken from the qualification radiator. The final test pressurized a representative sample of the panel including flow tubes, epoxy, honeycomb structure, and face sheets (see Figure 4).

The qualification radiators underwent a suite of testing to validate the design of the radiators. This puts the radiators in the “worst-case” design condition when compared to the flight radiators as qualification testing was more severe than the environment the flight radiators have experienced. The goal of the NDE was to determine if the design showed any damage or degradation. This assessment was performed using visual inspection, “tap” test, and x-ray. No damage was found visually and tap testing, which used a tighter criterion than during qualification testing, showed no delamination of the face sheet. X-ray of the panels were taken and compared to the 1996 “As-Cured” results and showed no damage or degradation. Flash thermography of the panels also confirmed no delamination between the face sheet and flow paths.

Next, residual flow tube stock was Helium (He) leak tested with the detection limit set to three orders of magnitude less than a leak that could have caused the face sheet peel. The test showed the flow tubes did not leak. This does not guarantee the flight tubes are leak tight, as most of the flight tubes came from a different lot than the residual tubes. A detailed inspection of the flow tubes showed a small flaw that, while not large enough to cause a leak, was present and due to the manufacturing process of the flow tube. A more severe flaw could have caused a leak and would have gone unidentified during inspection. Testing of bent flow tubes did show no damage caused from bending.

As-qualified flow tubes were tested by removing flow tubes from the qualification panels and performing the same He leak tests as performed on the residual flow tube stock. These flow tubes also passed the leak test. Caveats similar to the previous test apply as only a small subset of flow tubes were extracted from the qualification radiator panel. Radiator face sheet to core/extrusion bonding showed no evidence of strength degradation.

For the final test, a qualification radiator panel was sectioned and the volume between the face sheet and outside the flow tubes were pressurized. The goal of the test was to determine the failure mode and failure pressure of the panel if pressure were to build within the panel. This assumes a small leak in the flow tubes that passes through the extrusion into the honeycomb structure. This is possible as the aluminum extrusion consists of two parts that are epoxied together to hold the flow tube. The test showed that the bond between the honeycomb layers were the first to fail at around 20–40 Pounds per Square Inch (psi) (138–207 kPa). The core peeled inward away from the face sheet to start. Once the honeycomb failed, the face sheet began to delaminate as the bond between the face sheet and honeycomb structure failed at around 150 psi (1034 kPa). Figure 5 shows the damage to the honeycomb structure and where the damage occurred relative to the test sample.

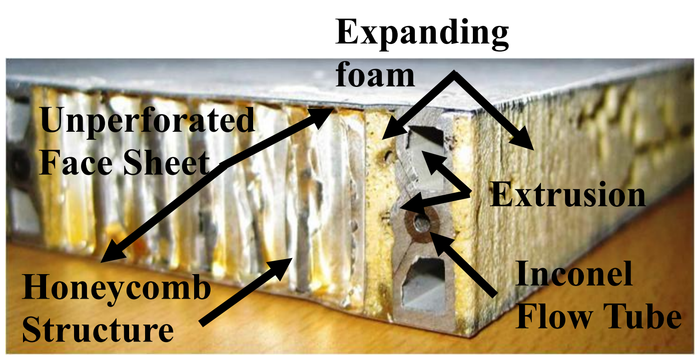

Figure 4. Cross Section of Radiator Panel.

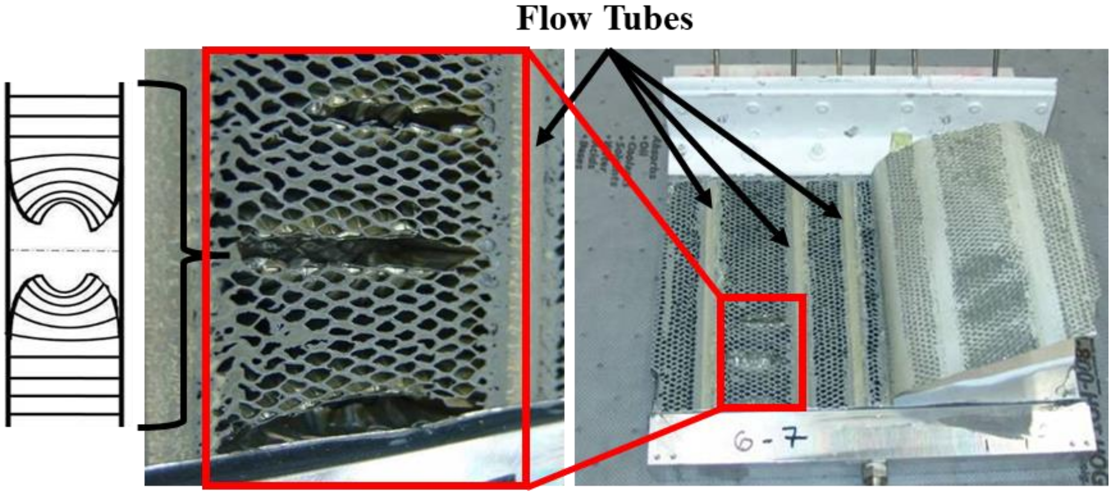

Figure 5. Honeycomb structure damage after pressurization. Face sheet peeled back to show damage, not caused by pressure.

Once the honeycomb bond failed the face sheet began to delaminate, as showed by Figure 6. The tap test was used to identify where the delamination took place. The tap test showed the gas pocket jumped the flow tube extrusions and grew the delamination without further damaging the honeycomb structure. A failure of this nature could have caused pressure to build in the panel until the face sheet rips away from the rest of the panel structure. This test also showed that the panel design could hold internal pressure and that a leak would not simply vent to space. The combination of these tests provides a plausible scenario for how the damage to radiator could have occurred.

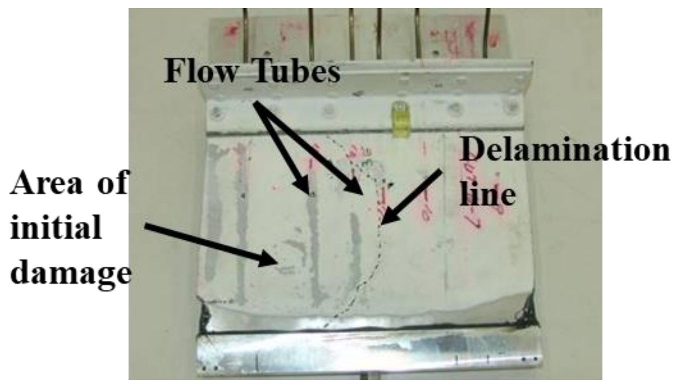

Figure 6. Pressurized panel test article.

C. Failure Scenario

The investigation team next determined where the pressure came from. The panel was shown to hold pressure, meaning the pressure must have come from the flow tubes. A review of the historical pressure in the nitrogen flow path, read from the RBVM, showed a small leak. This leakage amounted to about 0.05 Pound-mass (lbm) (0.023 kg) of nitrogen from the entire radiator. There is no way to confirm how much of this nitrogen leaked from the flow tubes in the failed panel, but analysis shows only 40% (0.02 lbm, 0.009 kg) of the nitrogen is required to cause this failure. It is also possible for the ammonia path to leak but due to the flow path being integrated into the system, there is no way to tell if it was leaking as the leak rate would have been too small to identify in the ATA quantity sensor. Telemetry confirms that the flow path was not leaking before it was integrated into the system.

There are two possible scenarios for the leak to migrate to the panel core. The first relies on a pre-existing flaw that was too small to detect during the pressurized leak test prior to build up. The leak travels through the epoxy through degradation or freeze/thaw cycling creating micro-cracks. This path is shown in Figure 7 with the green and purple lines. The other scenario relies on a flaw in the flow tube that is not through the entire flow tube. This is similar to the flaw found on reinspected flow tube stock. This flaw could worsen due to

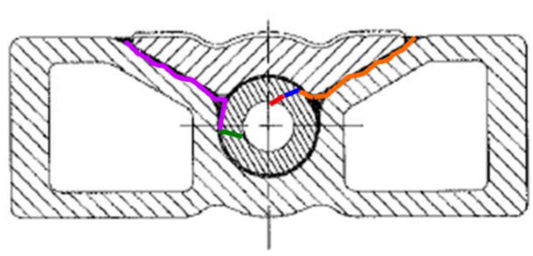

Figure 7. Flow tube and extrusion cross section with possible leak paths.

the freeze-thaw cycles and leak through the epoxy the same way as the previous scenario as shown by the red, blue, and orange lines in Figure 7.

Once the leak progressed out of the aluminum extrusion and into the rest of the panel the honeycomb bond can fail at pressures between 20 and 40 psi (138–207 kPa), which are achievable since maximum pressure from the leak was calculated to be 98 psi (676 kPa) and 96 psi (662 kPa) from a nitrogen and ammonia leak, respectively. Analysis also showed delamination requires higher pressures to initiate failure but lower pressures as the area of delamination increases. This means failure was initiated by a honeycomb bond failure, which created a large enough area of delamination for the pressure to act against to further delaminate the panel. This is supported by the testing performed on the panel section. This scenario is also supported by the on-orbit imagery in Figures 8 and 9. Figure 8 shows delamination across the top of the panel, not just where the face sheet peeled back. The zoomed in image overlays the ammonia (blue) and nitrogen (green) flow path lines over the area with the most face sheet distortion. Figure 9 shows the back of the panel, which also shows distortion localized to the area between the last nitrogen and ammonia flow path. This damage is consistent with the failure scenario and the ground testing.

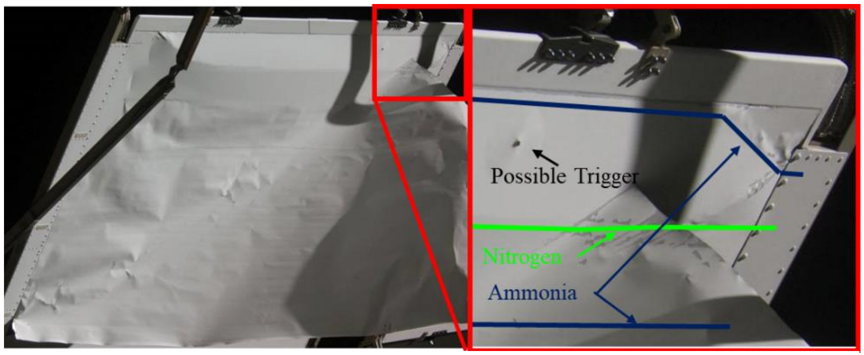

Figure 8. Top of radiator panel with detailed image of delamination and possible MMOD trigger site.

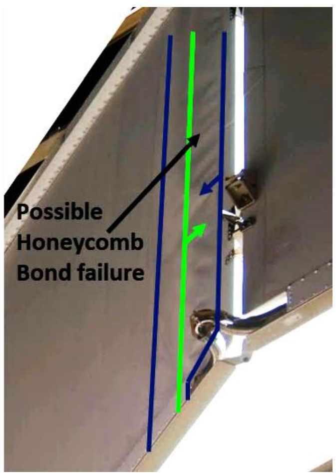

Figure 9. Back of radiator panel.

With the face sheet delaminated from the honeycomb structure, a trigger event must have occurred to cause the face sheet to rip and expose the interior of the panel. There are two possible triggers that could have caused this. The first is an MMOD strike that created a shock wave in the gas pocket on the already strained face sheet. A possible trigging MMOD strike is identified in Figure 8. The second possible trigger event could be from the self-propagation of delamination. As previously stated, as the area of delamination increases, the pressure required to continue delamination decreases. In practice, this occurs in a cyclic nature where pressure in the panel increases from the leak, which causes the face sheet to delaminate. This increases the volume of the gas pocket and causes pressure to drop. As more fluid leaks into the volume, the pressure rises again, continuing the cycle. This would continue until no additional leakage is required to maintain pressure above what is required to delaminate the faces sheet causing a rapid progression to failure.

To further validate this scenario, NESC funded an LS-DYNA (Ansys Software Package for dynamic FEA) analysis. The results show sudden, rapid face sheet blow-out is possible with this design. The crinkled face sheet is replicated in the analysis. The analysis also showed the face sheet tore from the fasteners that hold the face sheet to the manifold as well as the panel peeling back and striking the panel

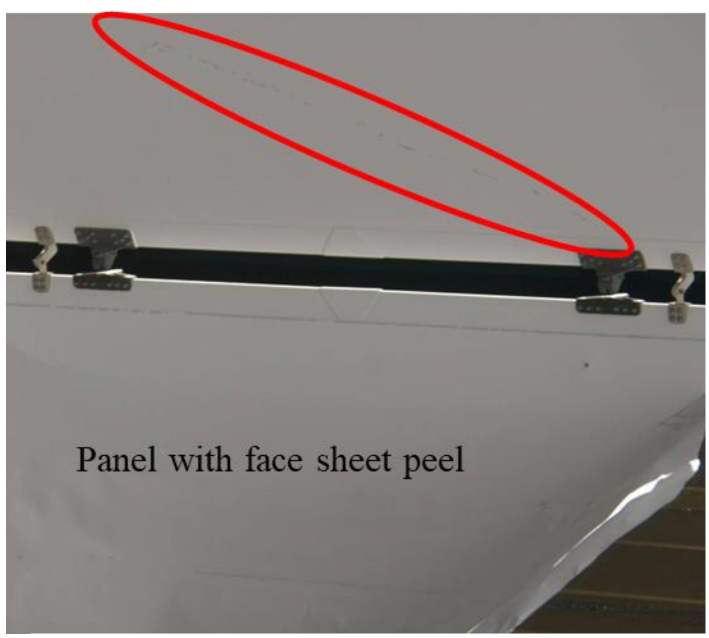

Figure 10. Image of mark caused by peeled panel.

above. On-orbit imagery confirms the analysis successfully reproduced the failure. Figure 10 shows possible evidence of a scuff mark on the panel above the peeled face sheet indicating the panel stuck the face sheet. Figure 11 compares the analysis to on-orbit imagery and shows a detailed view of the fastener holes in the face sheet.

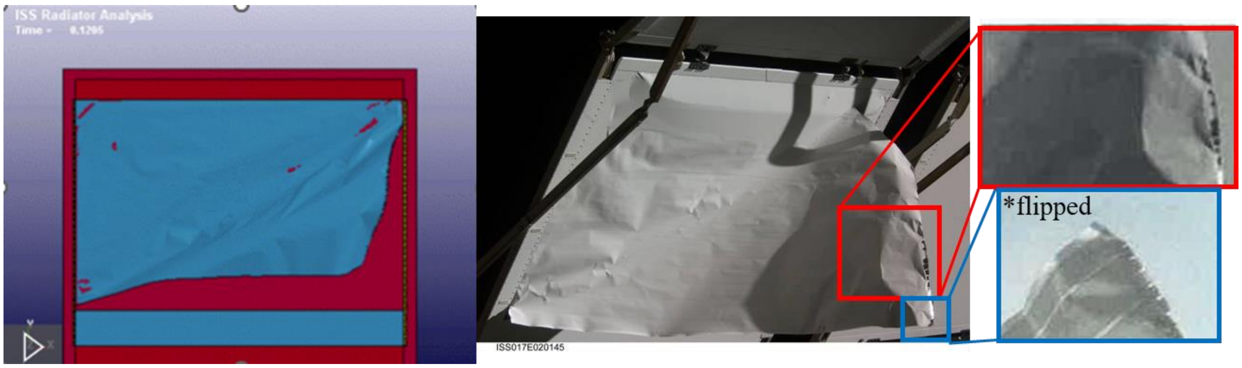

Figure 11. NESC LS-DYNA analysis compared to on-orbit imagery.

D. Investigation Closure

With the failure well understood and the probable cause identified, the team assessed forward plan including failure recurrence control and next worst failure. The decision to keep the radiator deployed was based on analysis that showed the panel can tolerate orbital loads with this damage. This damage could also prevent retraction or produce debris that could cause damage to adjacent radiators. From an ATCS perspective, worst case recurrence of this failure would be a blowout that caused a leak of a flow tube. This could cause loop shutdowns and possibly require extensive repair operations. To manage this risk, software was updated to reduce ammonia loss if a large leak occurred. Additional, periodic imagery of the radiators are taken to identify any delamination in the panels. To date, no further delamination was discovered. Detailed imagery of the peeled face sheet is taken periodically and shows no significant changes for the past 14 years.

IV. Use-As-Is Rationale and Return to Function

The investigation concluded that the ammonia flow path in the radiator was available for use but due to the available heat rejection margin on ISS at the time, refilling the radiator was deferred. As the ISS Program progressed, payload utilization increased. Finding new ways to perform additional science on the orbiting laboratory meant all system teams had to optimize their systems to accommodate the increased power, data, stowage, etc. required by the additional payloads. This also led to an increase in heat rejection needs, forcing flight controllers to manage the system more actively. It also decreased the ability for system to maintain fault tolerance. This lack of margin was addressed by filling a flow path in both EATCS loops. The ammonia flow path in the radiator with the face sheet separation was chosen as it is the only evacuated flow path on Loop A and would not require the venting of a nitrogen pad. This fill finally restored the radiator to its 2009 configuration, providing much needed heat rejection to the system.

A. Use-As-Is Rationale

The radiator panel was analyzed for structural integrity and shown to not be at risk of breaking away with the face sheet peeled back. This would be a major debris hazard to ISS and cause a large leak in the EATCS system. The analysis also showed the radiator could not deflect enough to contact adjacent radiators. Periodic inspections have also shown there is no change to the damaged face sheet, so it is not at risk of breaking away and becoming debris itself.

The nitrogen flow path continues to maintain the slow leak since launch, as noted by the RBVM pressure slowly decreasing. Calculating a leak rate from the pressure drop shows the leak is still well below specification. This flow path could be used but it would require accepting the slow leak to translate to loss of ammonia. The loss of ammonia could cause an ATA to be replaced sooner if the leak was allowed to leak for a long time or grow. The vented ammonia path has remained isolated from the EATCS since 2010. In that time, RBVM pressures have trended up from vacuum. This means there is a small leak in the RBVM valves that isolate the flow path from the system and ammonia is leaking into the flow path. This also means the flow path does not have a large leak, meaning it can be integrated into the

EATCS without a major risk of leaking to space. It is possible this flow path has the flow tube flaw but due to its size, it should not impact the overall systems leak rate.

The final concern was loss of heat rejection capability of the radiator. With a panel peeled back, there is likely an impact to the optics of the panel as the internal structure of the radiator is not white like the Z93 paint. During the few months the flow path was flowing, there was no appreciable impact to the performance of the EATCS system. The fact that the panel is one of 24 panels means no single panel has a major influence on the heat rejection capability to the loop. The panels further from the truss also play a smaller effect on the heat rejection capability compared to the panels closer to the truss. With the damaged panel being the seventh panel truss its impact to the radiator's performance is further reduced.

B. Heat Rejection Shortfall

ISS payload utilization has increased and with it, the need to reject more heat. Additionally, since 2009, each loop has vented a flow path. One due to the face sheet peel and one due to a leaking Quick Disconnect (QD) [1]. This left the system with little-to-no heat rejection margin. Nominally, this forces ISS flight controllers to actively manage the heat loads on the EATCS by either transferring heat load between the two loops or adjusting the TRRJ to temporarily place the radiator in a better heat rejection environment. This causes unnecessary workload and creates the possibility for mistakes to be made. In contingency scenarios that force the shutdown of one of the loops, the functional loop would not be able to maintain heat rejection even with placing the TRRJ in Autotrack, forcing up to 80% of payloads to be shut down. This would cause a major loss of science until the failed loop could be brought back up. Depending on the failure, this down time could be on the order of months. If in that time Autotracking is not an option due to EVAs, dockings, robotic tasks, or thruster firings, and the TRRJ must be parked, all payloads would need to be shut down and some system loads that operate the station would be impacted. This could lead to reduced capabilities or a further reduction of fault tolerance during those critical operations.

All these impacts would be eliminated by filling a flow path in each loop. The EATCS would no longer need to be actively managed, as the flow path would allow for much needed flexibility for the flight control team. This would also greatly improve the heat rejection capability in Autotrack such that the loss of an entire loop would not impact ISS from a heat rejection perspective and would allow the team to focus on restoring the lost loop instead of managing heat rejection.

C. Flow Path Fill

Given the benefits of filling a flow path, ISS Program decided to proceed with filling a flow path. To do this, the RBVM valves need to be opened to allow ammonia into the flow path. This causes a reduction in the ATA quantity, but there are sufficient stores in both ATAs to fill the flow paths. This also causes the system to drop to 2-phase as the volume increase reduces the system pressure. The EATCS avoids going 2-phase as it can lead to a catastrophic hazard of freezing the heat exchangers, causing rupture and allowing ammonia to enter the cabin. To prevent this, the EATCS is repressurized prior to filling the flow path so that once the flow path is filled, the system is still single phase. Prior to opening the flow path, the PM is shutdown to prevent cavitation while filling the flow path. This was a source of concern, as this imposes some additional risk on the PM. If the PM failed to turn back on the PM would need to be replaced, which would require three EVAs. This would have major impacts across the ISS Program. The PMs showed no signs of degradation but have been operating for 13 and 20 years on Loop A and Loop B, respectively. With an operation life of 13 years from the OEM, there was concern a shutdown could cause premature failure of the PM. To mitigate this concern, the PM was not shut down. Instead, the pump speed was set to 0 RPM. This kept the controller energized, eliminating the risk to the controller. These mitigations improved upon the flow path fill procedure used to initially fill the flow paths.

The flow paths were successfully filled without anomalies. This returned the damaged radiator to use, and it is currently rejecting heat. All telemetry shows nominal performance. Imagery of the radiator shows no change in the structure of the radiator.

V. Conclusion

Based on the findings from the investigation, this failure could have been prevented by implementing one of two changes.

1. Performing helium leak checks on the entire raw tube stock would have identified any leaks in the flow tubes and allowed for repair or replacement. Leak rates of this magnitude would have been well below the

specification of the system, so the requirement was not levied. For ISS, this would have required leak checking almost 5 miles of flow tube stock.

2. Using perforated honeycomb panels so that any small leaks are vented to space and do not cause pressure to build in the panels. This would cause a small amount of gas or liquid to vent from the system but would be at low enough rates as to not impact the larger system.

Due to the large capability and robustness of the EATCS design, Loop A could operate at about half its full capability and still accommodate ISS heat loads for over 16 years. This gave the team runway to fully investigate face sheet damage without impacting operations or science. Designing the system with a large heat rejection capacity paid dividends, as failures and unexpected anomalies can be absorbed while keeping the mission successful. Using telemetry and on-orbit imagery, we were further able to confirm the integrity of the radiator panel and the flow path. The additional flow path increases the Loop A heat rejection capability by about 40% , which greatly expands the operational flexibility of the system and mitigates the impacts of future failures.

Acknowledgments

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