Pitting of Space Shuttle's Inconel Honeycomb Conical Seal Panel

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During return to flight servicing of the rudder speed brake (RSB) for each Space Shuttle Orbiter, inspectors discovered numerous small pits on the surface of the #4 right hand side honeycomb panel that covers the rudder speed brake actuators. Shortly after detection of the problem, concurrent investigations were initiated to determine the extent of damage, the root cause, and to develop a repair plan, since fabrication of a replacement panel is impractical for cost, schedule, and sourcing considerations.

There are ten conical seal panels that cover the actuators and other structure associated with the Space Shuttle's rudder speed brake, five panels on the right side of the tail section and three on the left. The panels are a brazed Inconel 718 honeycomb structure 0.520 inch thick, and curved to about a 24 inch radius. When installed on the tail section, the panels seal the gap between the fixed portion of the rudder, and the "flaps" of the speed brake as it deploys. They also provide a seal or barrier between the rotary actuators and the external environment, including providing a thermal seal that withstands reentry temperatures while permitting the speed brake to articulate. Thus, two flight failure modes must be considered: (1) the seal is breached and objects or hot gas is permitted to enter the RSB cavity and case damage to or failure of the RSB assembly, (2) the seal fails structurally and mechanically interferes with the proper operation of the RSB resulting in damage to or failure of the RSB assembly. Secondary failure modes of undetected corrosion, ice expansion, and loss of high temperature coating were identified as service life issues.

Over 100 pits, most of which were located in a 2-inch band running from top to bottom, were recorded as being beyond an arbitrary threshold of 0.003 inch deep. While most of these pits were barely large enough to see with the unaided eye, some fully penetrated the 0.010 inch thick Inconel 718 face sheet with hole diameters from 0.010 inch up to 0.035 inch. These holes, and to some extent the pits, present structural, contamination, and hot gas intrusion issues to the vehicle. Additionally, a sort of "micro-pitting" was observed when the surface was examined using 10x and 20x magnification. This is the only conical seal panel in the fleet exhibited any sort of surface anomaly.

A fault tree was developed to identify the cause of the pitting. Evaluation of the pits, service environment, manufacturing and service records indicate corrosion or chemical attack (Ref. Danford, M. D., and R. H. Higgins. "Galvanic Coupling Between D6AC Steel, 6061-T6

Aluminum, Inconel® 718, and Graphite-Epoxy Composite Material: Corrosion Occurrence and Prevention." NASA TM-2236, 1983), and electrical discharge as the most likely causes, though credible mechanisms for either were difficult to conceive. Improper hardware processing, debris strikes, material defects, and anomalous alloy content were ruled out. Defects or degradation of the high temperature protective paint, niobium segregation or coarsened precipitates (Ref. "Influence of Corrosion Pitting on Alloy 718 Fatigue Capability." *Superalloys 718, 625, 706, and Various Derivatives*. E. A. Loria, ed. TMS (2001): 583-592. and Simon, H., and M. Thoma. "Attack on Superalloys by Chemical and Electrolytic Processes," *Product Finishing,* October (1981): 34-39. and Kolts, J. "Alloy 718 for the Oil and Gas Industry." *Superalloy 718 – Metallurgy and Applications*. Proc. of the Int'l. Symp. on the Metallurgy and Applications of Superalloy 718, E. A. Loria, ed. The Minerals, Metals & Materials Society, Pittsburgh, PA, (1989): 329-344.), anomalous manufacturing event, and inadequate grounding were identified as possible contributors.

It was determined that the holes, and at least some of the pits would have to be repaired based on structural, thermal and contamination requirements. Plasma spray coating is currently the only additive repair process qualified for use on these panels, though the depth and extent of the pitting, and particularly the holes, exceed the repair specification for this hardware. While it is technically feasible to extend and demonstrate plasma spray for the conditions seen on this panel, other means of repair were considered in a structured, methodical program. Considerations of hardware performance, material and process compatibility, service environment, risk to hardware, and efficacy were traded among several identified processes. Hardware performance defined repair requirements, which in turn defined repair process(es) selected, and what if any post processing was required. These issues were traded among the repair processes while resolving the following questions:

- Repair or use as-is? (stress & contamination criteria)
- Repair some or all defects? (stress, process, risk criteria)
- Individual or global repair? (process & risk criteria)
- Restore to print or alter surface? (function, process & risk criteria)

While there are various means for depositing materials or otherwise repairing pits, several critical requirements applied to all of the candidate repair process:

- Proper surface preparation
- Thermal control/monitoring during processing of thin section
- Low stress/distortion associated with process
- Proper surface contour and finish (post processing)

Holes that penetrate the face sheet present a more complex situation than pits because they do not have anything for the deposition processes (thermal spray, electroplating, electrospark, cold spray, etc) to adhere. This is further complicated by honeycomb structure that prevents access to opposite side and application of a backing over the hole that could serve as deposit surface. Tests of thermal spray on test panels with 0.020 inch diameter holes confirmed that such processes will not fill the holes. Consequently, welding or brazing techniques were included in the repair process trades to fill the holes, since it was unlikely that any of the deposition processes alone would not be effective. This initiated consideration of repair processes based on welding or brazing, either as a stand-alone repair, or in preparation for a subsequent deposition process.

This paper describes the approach, findings, conclusions and recommendations associated with the investigation of the conical seal pitting. It documents the cause and contributing factors of the pitting, the means used to isolate each contributor, and the supporting evidence for the primary cause of the pitting. Finally, the selection, development and verification of the repair procedure used to restore the conical seal panel is described with supporting process and metallurgical rationale for selection.