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THERMOGRAPHIC LEAK DETECTION OF THE SPACE SHUTTLE MAIN ENGINE NOZZLE

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ABSTRACT

The Space Shuttle Main Engines Nozzles consist of over one thousand tapered Inconel coolant tubes brazed to a stainless steel structural jacket. Liquid Hydrogen flows through the tubing, from the aft to forward end of the nozzle, under high pressure to maintain a thermal balance between the rocket exhaust and the nozzle wall. Three potential problems occur within the SSME nozzle coolant tubes as a result of manufacturing anomalies and the highly volatile service environment including poor or incomplete bonding of the tubes to the structural jacket, cold wall leaks and hot wall leaks. Of these conditions the identification of cold wall leaks has been the most problematic. The methods and results presented in this summary addresses the thermographic identification of cold wall "interstitial" leaks between the structural jacket and coolant tubes of the Space Shuttle Main Engines Nozzles.

INTRODUCTION

The current inspection technique for locating interstitial leaking is the application of a liquid leak check solution in the openings where the interstitials "space between the tubing and the structural jacket" vent out the aft end of the nozzle "below the ninth hatband", while the tubes are pressurized to 25 psig with Helium. When a leak is found, it is classified as described in the following Table, and if the leak is severe enough the suspect tube is cut open so that a boroscope can be inserted to find the leak point. Since the boroscope can only cover a finite tube length and since it is impossible to identify which tube (to the right or left of the identified interstitial) is leaking, many extra and undesired repairs must be made to fix just one leak. In certain instances when the interstitials are interlinked by poor braze bonding, many interstituals will show indications of leaking from a single source. What is desired is a technique that can identify the leak source so that a single repair can be performed.

Class	Flow rate (scim)	Description
1	> 2	Foaming
2	2 to 50	Bubbling

Class	Flow rate (scim)	Description
3	50 to 100	Strong bubbling that burst and re-form
4	> 100	Blowing (Bubbles can't persist)

scim = Standard cubic inch per minute

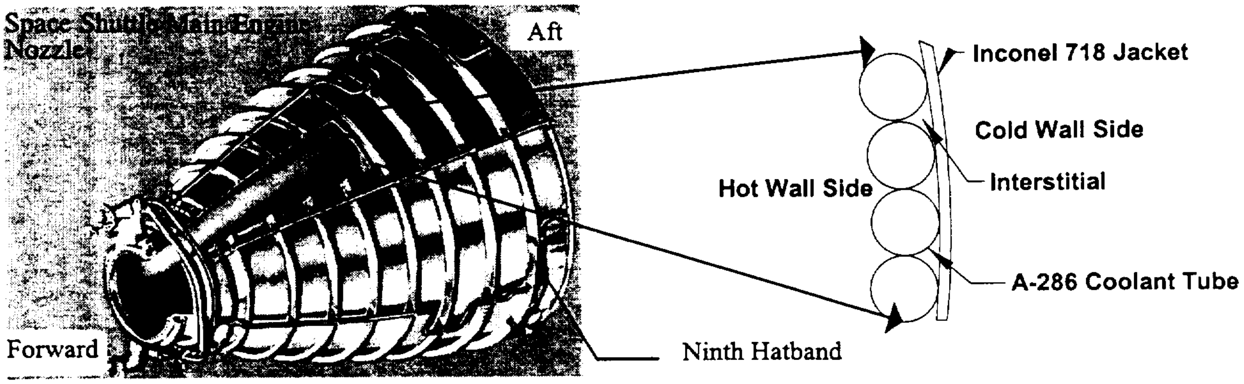


Figure 1. SSME nozzle cross section.

The small size of these leaks inhibit the ability to locate them using x-ray, ultrasound or computed tomography techniques. Due to the geometry and location of the defects, eddy current and visual inspections are not possible. It was proposed to try thermographic methods to locate the interstitial leak by measuring the local cooling created by the escaping gas at the location of the defect from the hot wall side of the nozzle.

As an initial attempt to create a interstitial leak in the nozzle a 1/16 inch diameter hole was drilled though the structural jacket into the interstitial region of the tubing. Using the same bit, a hole was started in the wall of a coolant tube. Once the wall was thinned sufficiently, a sharp pin was used to puncture the coolant tube. The resulting hole in the tube was then partially closed back off by forcing solder into the hole with a pointed chisel. The resulting defect was leak tested with a soap solution under 25 psig Helium pressure. The leak produced a foaming indication similar to the class one or two defect. Finally the hole in the structural jacket was plugged with a piece of vacuum bag sealant tape. To verify that the thermographic inspection was "seeing" the leak and not the sealant tape, another piece of tape was place 2 inches away from the sealed hole.

The defect was inspected using an Amber Radiance 1 camera (25 mm lens), running under the TWI software from the hot wall side. The resulting thermogram is provided in Figure 2 at a time of 6.1 seconds after initial pressurization. In the unaltered image the defect was just barely visible but by subtracting the initial frame (no pressure) from all subsequent frames (with pressure) the defect resolution was increased drastically. Note also, that the slight increase in temperature associated with increasing pressure can be detected using image subtraction. Given time though, even this effect becomes less noticeable with the tubes returning to near ambient thermal conditions.

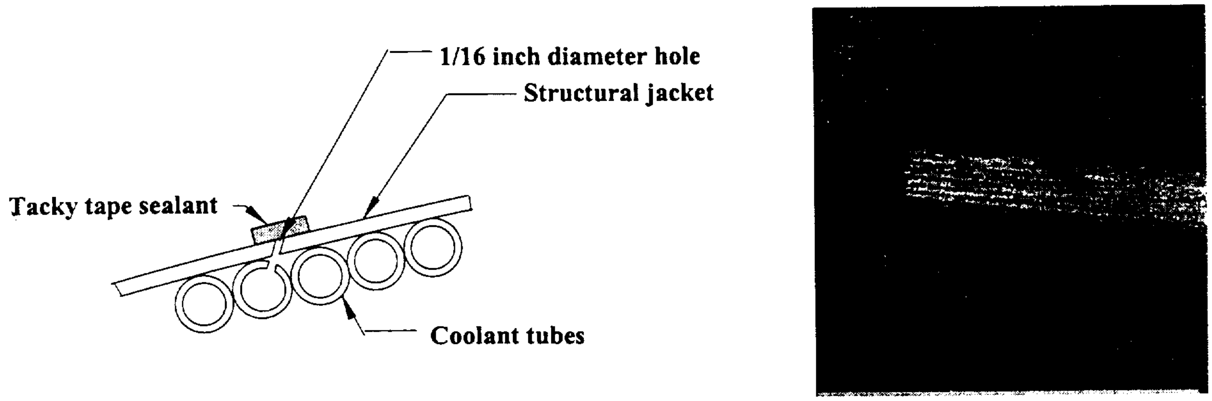


Figure 2. Pinhole leak.

Quite often it is required that an inspection be performed over a region that had been previously repaired. A repair typically consists of milling open a tube over a length of a few inches, repairing the damaged zone, and then applying a weld cover patch to reseal the tube. Due to the small size of the tubes and amount of heat require to perform the repair, it is possible to create addition damage from the repair itself. Artificial defects were fabricated to simulate this condition by cutting open the tubing on the hot wall side of the nozzle, then puncturing the tube into the interstitial region and finally resealing the tube through a welding operation. During the reweld operation the hot wall surface of the tubes had to be cleaned with a wire brush. This left the surface shiny, which greatly limited the thermographic inspection capability. To dull the surface it was painted with three coats of a water washable flat black paint. The paint was applied by first heating the metal surface with a hot air gun, applying a light coat of paint, and then reheating the surface to speed evaporation of the water carrier. This process provides a consistent finish and permits a thinner coat of paint be applied and still have adequate dulling of the surface.

Leak regions were manufactured in both forward and aft end sections of the SSME Nozzle. The leak type and interstitial location were verified by individually pressurizing the tubes and checking with liquid leak solution. The panels were then thermographically inspected at various flow rates, peak pressure levels and with a range of gasses to bound the detection capability.

The pressurization rate was found to have a strong influence on the ability to detect the leak with higher pressurization rates yielding the best thermal response. When the pressurization rate is to slow the thermal signature is lost due to the highly diffusive nature of the tubing material. Maximum pressure too was found to have a large effect on thermal detectability of the leak. For example, as shown in Figure 4 the thermal response, as determined by computing the maximum difference between the IR camera values in the defect region and acreage region, increases nearly linearly with increasing pressure.

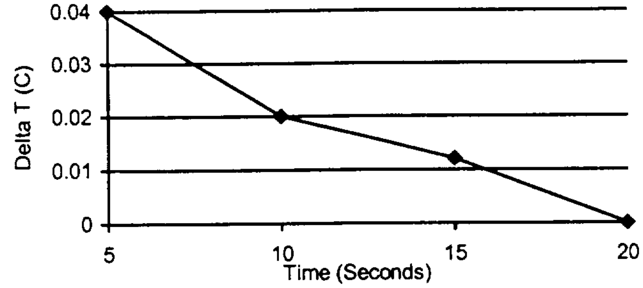


Figure 3. Thermal response as a function of pressurization rate.

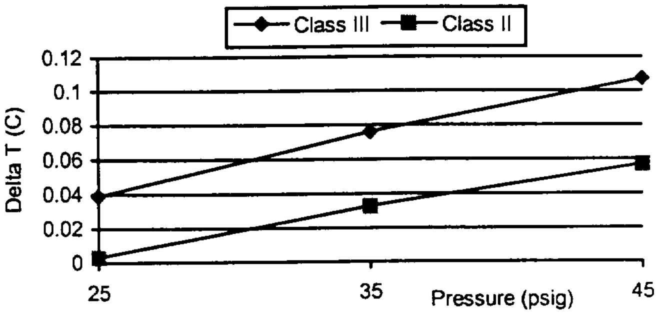
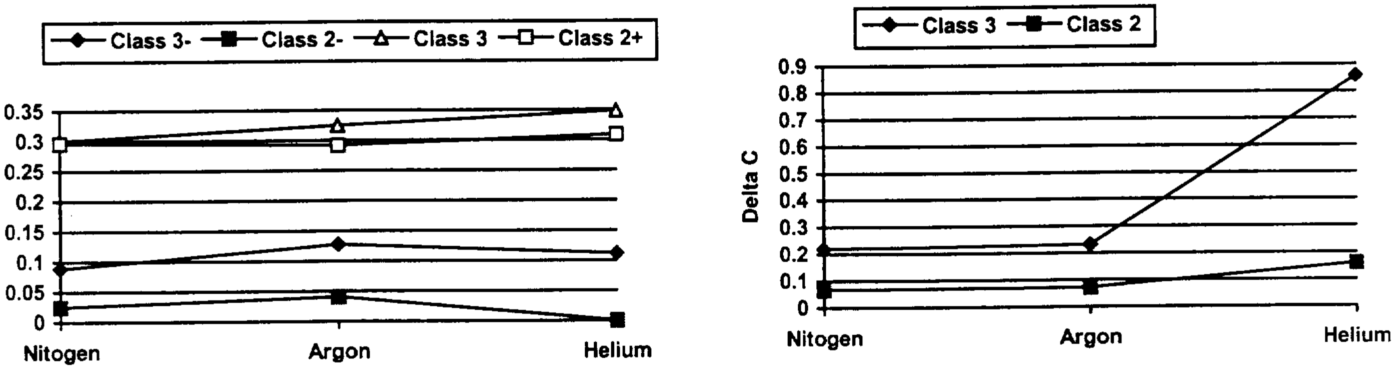


Figure 4. Thermal response at three pressures.

When the leaks were inspected using different pressurizing gas types it was found that the thermal resonance not only varied with gas type but also with the location of the leak along the nozzle length. For example, when helium was used to pressurize the aft nozzle segment no indication was present yet on the forward end of the nozzle it gave the best response.



Aft end of Nozzle

Forward end of Nozzle

Figure 5. Thermal response as a function of gas type.

CONCLUSIONS

The limitations and requirements for thermographic identification of interstitial leaking of the Space Shuttle Main Engine Nozzle has been addressed. With a standard thermographic test procedure established for the nozzle it should be possible to locate and quantify the nature of cold wall leaking in the SSME nozzle. From these results it has been determined that the following conditions must be met to ensure adequate confidence that all cold wall "interstitial" leaks are detected. First, the flow rate of gas into the nozzle must be sufficiently high to permit the transient thermal signature of the leak to be detected before it is lost to thermal conduction. Dwell times in excess of 10 seconds, to reach full test pressure, greatly inhibit defect resolution. Next, the greater the maximum pressure reached during the pressurization the better the ability to detect a leak. Although the liquid leak check is performed at 25 psig it was found that for the best thermal response pressures of at least 40 psig were required. Finally, depending upon the region of interest the type of gas used to pressurize the nozzle can influence the detection threshold. At the forward end of the nozzle Helium was found to be the best choice, while at the aft end of the nozzle, either Argon or Nitrogen was found to work best.

ACKNOWLEDGMENTS

The authors are grateful to Melvin Bryant and Paul Caraccioli of the NASA Marshall Space Flight Center and Ron Daniel of Boeing North American/Rocketdyne for their technical support in this investigation.