



AIAA 2003-5102

RSRM Nozzle-to-Case Joint J-leg Development

**Kevin U. Albrechtsen, Norman F. Eddy, Mark E. Ewing
and John R. McGuire**
ATK Thiokol Propulsion
Brigham City, UT

AIAA Joint Propulsion Conference

July 21 - 23, 2003
Huntsville, Alabama

RSRM NOZZLE-TO-CASE JOINT J-LEG DEVELOPMENT
Kevin U. Albrechtsen, Norman F. Eddy, Mark E. Ewing and John R. McGuire
ATK Thiokol Propulsion
Brigham City, UT

ABSTRACT

Since the beginning of the Space Shuttle Reusable Solid Rocket Motor (RSRM) program, nozzle-to-case joint polysulfide adhesive gas paths have occurred on several flight motors. These gas paths have allowed hot motor gases to reach the wiper O-ring. Even though these motors continue to fly safely with this condition, a desire was to reduce such occurrences.

The RSRM currently uses a J-leg joint configuration on case field joints and igniter inner and outer joints. The J-leg joint configuration has been successfully demonstrated on numerous RSRM flight and static test motors, eliminating hot gas intrusion to the critical O-ring seals on these joints.

Using the proven technology demonstrated on the case field joints and igniter joints, a nozzle-to-case joint J-leg design was developed for implementation on RSRM flight motors. This configuration provides an interference fit with nozzle fixed housing phenolics at assembly, with a series of pressurization gaps incorporated outboard of the joint mating surface to aid in joint pressurization and to eliminate any circumferential flow in this region. The joint insulation is bonded to the nozzle phenolics using the same pressure sensitive adhesive used in the case field joints and igniter joints. An enhancement to the nozzle-to-case joint J-leg configuration is the implementation of a carbon rope thermal barrier. The thermal barrier is located downstream of the joint bondline and is positioned within the joint in a manner where any hot gas intrusion into the joint passes through the thermal barrier, reducing gas temperatures to a level that would not affect O-rings downstream of the thermal barrier.

This paper discusses the processes used in reaching a final nozzle-to-case joint J-leg design, provides structural and thermal results in support of the design, and identifies fabrication techniques and demonstrations used in arriving at the final configuration.

INTRODUCTION

The current RSRM nozzle-to-case joint, illustrated in Fig. 1, employs a polysulfide adhesive bondline to preclude gas penetration to the O-ring sealing system. Gas penetration through the polysulfide adhesive has been an issue throughout the RSRM program.

Based on the RSRM flight history, 17 gas path occurrences have been identified in 15 out of 158 joints

(2 joints had dual gas paths). Erosion to the wiper O-ring has resulted from most of these gas paths. Although no flight safety issues have been identified with these gas paths, elimination of this condition was desirable.

RSRM Baseline

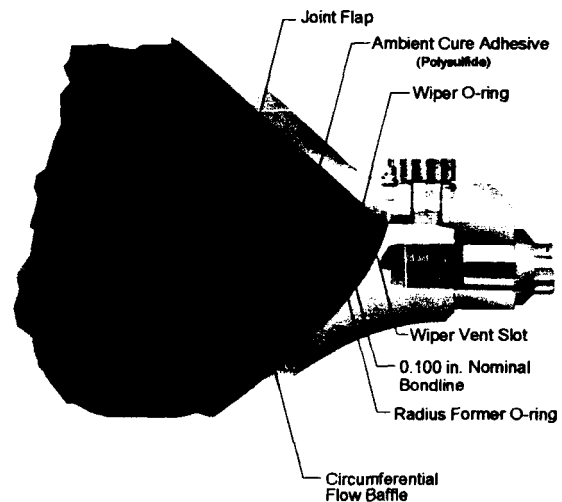


Figure 1. RSRM Nozzle-to-Case Joint Assembled Polysulfide Configuration

Changes to the polysulfide joint were implemented on RSRM-80, with the incorporation of a precured polysulfide "bump" at the step region, reduced wiper vent slots, and the use of slower assembly rates. These changes provided a more reliable joint, which has experienced no gas penetration. This modified configuration has flown successfully on 18 joints. There are, however, issues with material obsolescence (the polysulfide adhesive) and manufacturability; many assembly controls are required to ensure a good joint. As a result, efforts have continued for an improved design.

In March 1994, a team was organized in an effort to brainstorm solutions to the nozzle-to-case joint gas path concerns. Several design changes and modifications were evaluated. Some concepts were generated that resembled the J-joint design used on the RSRM case field joints and igniter inner and outer joints.

The J-leg configuration is a proven design feature based on successful application in the case field joint since RSRM-1 and igniter joints since RSRM-35. Success in these applications, motivated the incorporation of a J-leg configuration into the nozzle-to-case joint. This paper presents design considerations, details of the final redesigned joint and manufacturing processes, as well as a summary of analyses and testing used for verification of the new design. First, a brief description of historical application of the J-leg configuration is provided below.

J-Leg Configuration History

Following the Space Shuttle Challenger incident, the case field joint was redesigned. A J-leg case field joint configuration was incorporated as shown in Fig. 2. This J-leg configuration has flown on 528 RSRM case field joints with no anomalous conditions extending beyond the J-leg, successfully protecting critical O-ring seals.

Based on the success of the case field joint J-leg configuration, changes were made to the igniter inner and outer joints in 1992 (Fig. 3). These igniter joint configurations have flown in over 100 joints with no anomalous conditions.

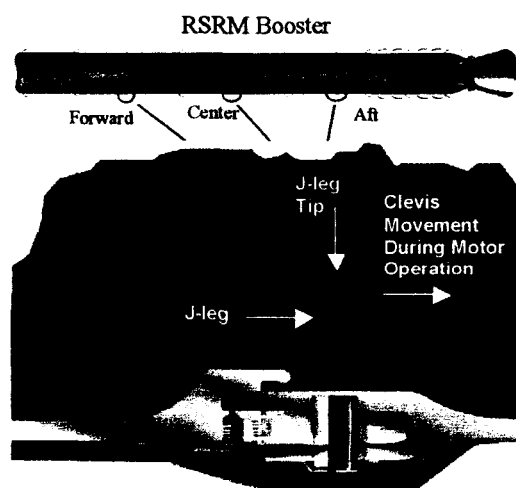


Figure 2. Assembled RSRM Case Field Joint J-leg Configuration

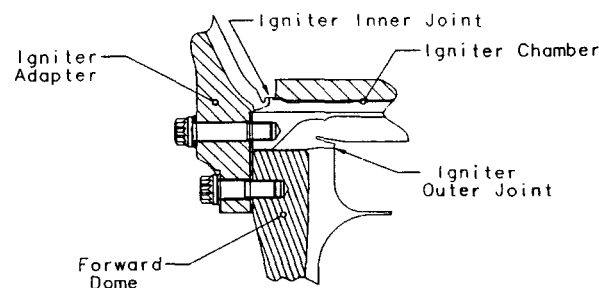


Figure 3. Assembled Igniter Inner and Outer Joint J-leg Configurations

Groundrules, Design Goals and Design Constraints

Design considerations for the nozzle-to-case joint using a J-leg configuration are similar to those for the RSRM case field joints and igniter inner and outer joints. Groundrules, design goals and design constraints were established early in the program to provide direction in the design activities. Some of the critical requirements included:

1. No changes allowed to aft dome or fixed housing metal hardware
2. No changes to primary or secondary O-ring grooves and seal surfaces
3. Current aft dome insulation and fixed housing materials will be maintained, however, as an enhancement, a new material may be used as a thermal barrier in the joint
4. Minimal changes to the aft dome insulation profiles to assure flow characteristics are not changed
5. Reduce/eliminate potential for gas penetration into the joint
6. No sustained hot gas/circumferential flow at the seal
7. Maintain a pressurization gap and J-leg contact to accommodate 40° to 90°F temperature requirements and joint rotation
8. Maintain a circumferential flow baffle as part of the pressurization gap.
9. Assuming a leak, the joint performance shall be equal to, or better than, the current polysulfide joint configuration
10. The deflected J-leg shall assure contact is maintained during storage, and throughout motor operation
11. The design of the joint shall be such that the thermal analysis predicts no primary O-ring damage assuming a leak
12. A 0.050 inch minimum pressurization gap shall be maintained

13. Damage to the joint shall be minimized during potential disassembly of a preflight joint
14. The design shall provide minimal impact to the assembly process with a goal to provide for a less labor intensive or a more robust process
15. The assembly shall not require external loads to the segment or nozzle
16. The nozzle must fit into the aft segment without damage to either component
17. The propellant shall continue to be cast from the aft end of the motor
18. There shall be no modifications to the propellant grain

A new design for the nozzle-to-case joint, which meets the design goals described above, has been completed. The design, which incorporates the J-leg configuration along with a carbon fiber rope thermal barrier, is described below.

Nozzle-to-Case Joint J-leg Configuration

The final nozzle-to-case J-leg design is shown in Fig. 4. The objective of the design is to reduce the possibility of concentrated gas paths and subsequent heat effects to the leak check barrier O-ring, while improving manufacturability.

The J-leg design is an unvented, pressure actuated interference fit between the aft dome J-leg [asbestos and silicon dioxide (silica) filled acrylonitrile butadiene rubber (NBR)] and nozzle fixed housing (joint phenolics). The joint is assembled using the same pressure sensitive adhesive utilized in the current case field joint, and igniter inner and outer joints. An enhancement to this design was the incorporation of a thermal barrier, secondarily bonded at the step region of the aft dome.

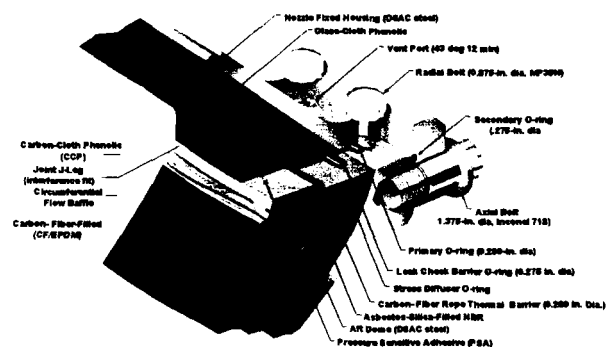


Figure 4. RSRM Nozzle-to-Case Joint Assembled J-leg Configuration

The J-leg is fabricated in a deflected position. The deflected J-leg engagement is predicted to vary with changes in temperature. It is also predicted to deflect and provide more joint engagement as a result of motor pressurization.

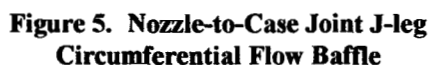
The J-leg design consists of a pressure assisted interference fit between the deflected J-leg and the nozzle fixed housing phenolics. The J-leg is placed in circumferential tension in the assembled state. This places the joint in a hoop configuration in positive retention representing a 'rubber band effect'. The J-leg is pressure actuated during motor operation, which provides increased load between the mating parts. Details on various design features and manufacturing processes are given below.

Circumferential Flow Baffles / Baffle Formers

The J-leg design maintains a circumferential flow baffle, as shown in Fig. 5. This feature is consistent with the current RSRM nozzle-to-case joint. The baffle provides a 1.00 to 1.25 inch vulcanized region approximately every 12 inches around the circumference, typical of the configuration used in the previous polysulfide joint. The spacing between the bonded regions of the baffle is specifically designed to allow deflection without over stressing the baffle or its bondlines. This allows the J-leg to remain in contact with the fixed housing phenolics during changes in temperature and motor operation.

Pressurization gaps are provided in the J-leg configuration using new mold tooling referred to as baffle formers. Development of the inner and outer baffle formers was critical to this design. To provide repeatable pressurization gaps and minimize defects on the surfaces of the baffle formers, steel was used in the fabrication of the formers.

The baffle is formed using the inner and outer baffle formers during insulation layup and cure. In the previous polysulfide design, the baffles were typically in contact with the insulation after insulation cure. The baffle formers provide pressurization gaps of approximately 0.6 inch, which are reduced to less than 0.1 inch at assembly. The baffle acts to redirect the flow in the pressurization gap and precludes significant circumferential flow velocities.



The NBR insulation and nozzle phenolic materials used in the fabrication of the nozzle-to-case joint J-leg configuration are the same as those used in the current RSRM polysulfide joint configuration. The fabrication process is similar to the current configuration with the exception of the use of the baffle formers, which create the pressurization gaps. The installation process for these formers was developed and is used by team members in the fabrication of the J-leg configuration. The fabricated nozzle-to-case joint J-leg configuration is inspected to established engineering requirements.

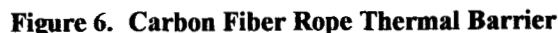
The nozzle is installed into the J-leg joint in the vertical position with pressure sensitive adhesive applied to both the molded joint insulation and fixed housing phenolics. The installation process is similar to the installation of case field joints and the igniter inner and outer joints with pressure sensitive adhesive applied to both sides of the mating joint surfaces prior to installation.

If prefire disassembly of the J-leg configuration is required it is a much simpler process since the need for

No evidence of damage to the aft dome insulation or fixed housing phenolics have been identified on any of the disassembled joints, which include several full-scale tests. Testing is discussed in subsequent sections.

The incorporation of the carbon fiber rope thermal barrier, which is bonded at the step region of the insulated aft dome, introduces a new material into the process not previously used on the RSRM program.

The thermal barrier has been shown to be capable of sustaining extreme temperatures (2500-5500°F) for extended durations without loss of integrity.^{1,3} The barrier is fabricated using 10 sheaths of woven carbon fibers wrapped over a carbon fiber core, as illustrated in Fig. 6.



At assembly the fixed housing provides a compression fit with the thermal barrier, which locks the thermal barrier in place. The ends of the thermal barrier are connected using an overlapping splice joint (Fig. 7) that is bonded with a cyanoacrylate, quick setting adhesive.

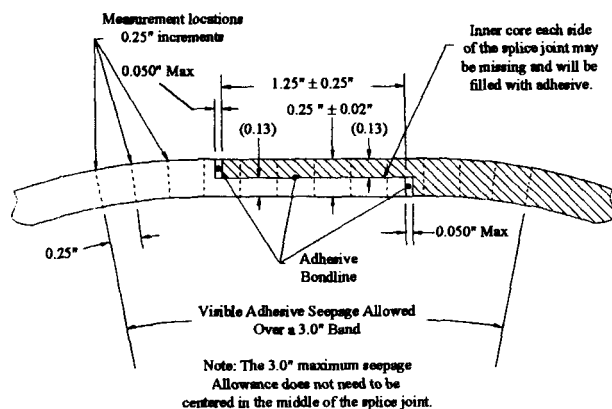


Figure 7. Thermal Barrier Splice Joint

Team members have been trained in the process of fabricating this splice joint and along with the incorporation of special tooling, consistent splice joints are provided.

Extensive testing has been done to obtain mechanical properties (tensile pull tests, transverse compression tests, transverse resiliency tests and splice joint strength tests) as well as thermal and hydraulic properties (thermal conductivity, specific heat and permeability). These properties have been used in analyses, which along with evaluation in subscale and full-scale hot motor tests, have identified no adverse issues.

Thermal Analysis

In the event of gas penetration into the joint, the J-leg design with the thermal barrier provides much better thermal protection than the previous polysulfide designs due to flow diffusion and temperature reduction provided by the thermal barrier. This enhancement is redundant however, since the J-leg can be manufactured, and inspected to insure that there will not be a significant gas path through the joint. The features of the thermal barrier are only of use in the unlikely event of any hot motor penetration through the J-leg.

Thermal analysis of the redesigned joint has shown that any gas flow around the leak check barrier O-ring would be at a very low rate. Pressurization of the primary O-ring groove would therefore be very slow, allowing gases to cool to very low temperatures; predictions with flaw scenarios have shown gas temperatures at the O-ring below 137°F, well below the ablation temperature (805°F) of the Viton O-ring. Based on the thermal analysis, no heat effect is expected on any O-ring, including the leak check

barrier O-ring and no metal parts are expected to see hot motor chamber gas.

A thermostructural analysis of the nozzle phenolics in the joint have indicated no significant changes in margins of safety on the nozzle fixed housing phenolics.

Structural Analysis

A complete set of structural analyses was performed for the J-leg configuration. The analyses included the post-cure cool-down event, the nozzle assembly event, storage and transportation events, as well as the launch event. Positive margins of safety were predicted for each event.

Nominal, maximum and minimum material definitions for the J-leg configuration were established from the measured as-built geometry of six full-scale J-leg joint configurations. The maximum and minimum material conditions were defined as the nominal plus/minus 3-sigma.

Joint Assembly

Contact surfaces to simulate the contact interaction between the J-leg, the thermal barrier, and the fixed housing were incorporated in the analysis.

Structural analysis included short-term and long-term assembly conditions. The short-term assembly analysis simulated the state of stress as the assembly event occurs. The long-term assembly event simulated the state of stress, strain, and displacement at some time long after assembly has occurred.

Differences in the displaced shape between long-term assembly and short-term assembly were observed to be insignificant.

The displaced shape for the nominal material condition is shown in Figure 8. Close-ups of the displaced shape of the thermal barrier and the step region are shown in Figure 9. Displacement results predicted contact between the fixed housing and the J-leg insulation in the step region outboard of the thermal barrier for nominal, maximum, and minimum material conditions.

Storage

The storage event simulated the long-term horizontal and vertical storage of the assembled J-leg at the extreme cold temperature (40°F). Storage at the opposite temperature range (90°F) is not as severe, and was not considered in the evaluation.

Because gravity loads are insignificant in the J-leg region, no distinctions were made between vertical and horizontal storage.

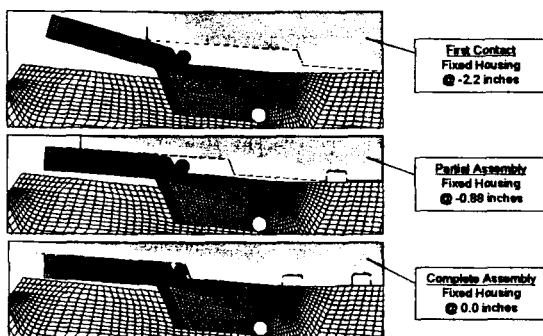


Figure 8. Nominal Joint Assembled

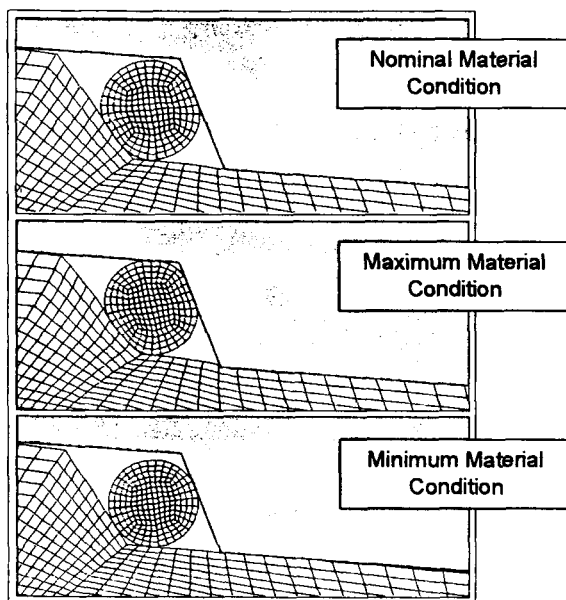


Figure 9. Close-up of Thermal Barrier in Assembled Joint

Launch at 75°F

The launch at 75°F event simulates the high rate pressurization of the motor at 75°F. Material properties for this time and temperature were used. Pressure loads of 920 psi were applied to all surfaces exposed to the internal pressure of the motor. Case and fixed housing displacements that simulate case expansion as well as joint rotation for this pressure were imposed. Residual stresses from the post-cure cool-down event and the assembly event were used as initial conditions for this event.

Stress and strain margins of safety were all positive for the launch at 75°F event. The lowest margin of

safety was 1.0 for axial strain in the J-leg material region for the maximum material condition.

Test Summary

The qualification of the nozzle-to-case joint J-leg configuration required a significant number of full-scale tests and test articles. The following provides a summary of the tests conducted and a brief discussion of the results of the specific test.

Process Simulation Article

A full-scale aft dome process simulation article was fabricated which demonstrated the insulation layup of the J-leg configuration, the use of a new mold ring and evaluation of baffle formers.

This article showed that the configuration could be fabricated using the new tooling, and provided acceptable post-cure dimensions including the pressurization gaps formed by the baffle formers.

Full-scale Resiliency Tests

A full-scale resiliency/compression set test was conducted for the nozzle-to-case joint J-leg configuration. The assembled joint was placed in a controlled storage environment, and was disassembled periodically to evaluate resiliency/compression set of the J-leg. The humidity and temperature were varied during a controlled storage time. The joint resiliency was measured after each disassembly to determine the percent return (compression set) of the J-leg.

The resiliency at the J-leg tip after 20 months of assembly time was 32%. The average joint interference after 20 months was 0.106-inch. Structural analysis showed that the minimum joint interference required to maintain joint contact is 0.025 inch (5%).

Nozzle-to-Case Joint Assembly Demonstration (NJAD)

A total of nine NJAD tests were conducted. The first series of tests evaluated the assembly process of the full-scale J-leg configuration with a nozzle fixed housing designed to provide joint engagement during joint assembly.

These tests showed the J-leg assembly process was a much simpler assembly process than the polysulfide joint configuration. The assembled joint showed good joint contact over the full circumference. There was no damage to the joint insulation or other assembly process issues that could affect the performance of the assembled joint.

One issue identified during these tests was that the pressurization gaps were larger than desired. A change

to the phenolic contours was made on later fixed housings, which reduced these gaps.

The second series of NJAD tests evaluated the assembly of the J-leg with a modification of the fixed housing to accept the thermal barrier at the step region.

The fixed housing modification in addition to the incorporation of the thermal barrier showed acceptable results with no anomalous results noted.

The joint showed excellent performance and nominal bondline contact of over 1 inch axially in all cases. There was no damage to the joint insulation or other assembly process issues that could affect the performance of the assembled joint.

Measurements of the joint profile and baffle gap were taken for each NJAD test. These measurements showed some deformation and some short term set in the J-leg. Most dimensions returned to normal after being allowed to relax for one week.

Carbon Rope Thermal Barrier SPC Tests

Several subscale seventy-pound charge (SPC) hot fire motor tests were conducted to evaluate the ability of the carbon rope thermal barrier to spread and cool hot gases, and to quantify temperature drop and provide O-ring protection in a joint configuration similar to the actual joint J-leg configuration.

The SPC tests showed the thermal barrier diffused and cooled hot gasses. The thermal barrier allowed gas to pass through at a velocity slow enough that heat absorption took place and conduction to surrounding materials was also realized. Temperature drops through the barrier were as high as 2500°F.

Modified NASA (MNASA) Motor Evaluations

The MNASA motor simulates a 1/5 scale RSRM nozzle inner contour and aft segment, providing a ballistic environment similar to RSRM although over a shorter duration (~20 seconds).

The MNASA-9 motor was fabricated to evaluate the nozzle-to-case joint J-leg configuration in a subscale motor. The MNASA-9 joint configuration was fabricated to match the axial dimensions of the full-scale J-leg joint configuration with the thickness of the J-leg reduced to 0.250 inch to more closely represent the full-scale motor assembly loads, joint movement, and material decomposition rates (MDRs). There was no circumferential flow baffle or thermal barrier in this design.

As part of this test, there were four different materials evaluated outboard of the J-leg including baseline carbon fiber filled ethylene propylene diene monomer (CFEPDM), 11% kevlar filled EPDM (KFEPDM) and two quadrants of 7% KFEPDM.

MNASA-9 provided a worse case evaluation of the joint when the 7% KFEPDM materials eroded more than the baseline CFEPDM typically installed in this region. The high MDRs demonstrated with the 7% KFEPDM materials resulted in a cavity for flow, impinging on the outboard side of the J-leg. This condition resulted in loss of all but 0.1 inch of the J-leg.

This was a significant test because even with the loss of most of the J-leg, the joint performed as designed allowing no hot gas beyond the remaining J-leg bondline. In the quadrant containing CFEPDM the J-leg showed much less erosion with an average of 1.25 inch of J-leg remaining.

Structural characteristics of the J-leg design provided good joint contact and sealing pressure at the bondline. This was expected since lower erosion of the CFEPDM material provided greater protection of the J-leg.

The MNASA-10 motor evaluated additional design features of the J-leg configuration. This motor was fabricated with several changes. Changes to the fixed housing were made to reduce the assembled pressurization gap from a 0.380-inch gap demonstrated on MNASA-9 to a 0.150-inch gap. CFEPDM materials were used outboard of the J-leg, and the thermal barrier was incorporated at the step.

This test also evaluated a flaw (0.125-inch wide by 0.050-inch depth) through the J-leg, which exposed the thermal barrier to hot motor gases.

The postfire evaluation of this joint showed the joint performed as designed allowing no gas penetration within the joint bondline, except at the flaw location. The thermal barrier showed no evidence of heat effects or degradation.

Instrumentation installed in the joint region showed that the thermal barrier allowed flow through the barrier reducing hot gas temperatures and providing protection of the insulation and O-rings downstream of the thermal barrier.

Nozzle Joint Environmental Simulation (NJES)

NJES-4A was the first full-scale hot fire pressurization test of the nominal J-leg joint configuration.

The NJES motor is a closed vessel test that operates at a pressure approximating the nozzle-to-case joint Maximum Expected Operating Pressure (MEOP) and aft end maximum rise-rate. The RSRM ignition transient was simulated, and test pressure was maintained for 125 seconds.

Postfire inspection showed the joint bondline contact was evident over the full circumference, allowing no hot gas leakage or pressurization aft of the J-leg.

The thermal barrier had become displaced from the step region at several circumferential locations, coming to rest forward of the step upon the J-leg. It appeared that the thermal barrier had become displaced during joint assembly since the impression of the thermal barrier was evident on the J-leg surface in these areas.

The displaced thermal barrier appeared to allow gas intrusion at ignition to a maximum depth of 0.5 inch from the remaining J-leg tip. "Wispy soot" regions were identified in these regions but no erosion occurred, light discoloration was evident under the soot on the insulation surface.

After further investigation it was determined that the spacing between the cyanoacrylate adhesive spot bonds used to secure the thermal barrier in place in the step region were approximately 20.0 inches apart, which was double the expected 10.0 inch spacing. This condition allowed the thermal barrier to sag down during joint assembly making contact with the pressure sensitive coated fixed housing phenolics early in assembly process. It was also determined that the thermal barrier splice joint was shorter (~0.25 inch overlap) than the desired 1.0 inch overlap joint.

With the issues associated with the thermal barrier on this test, changes were made to bond the thermal barrier over the full circumference using pressure sensitive adhesive. An additional change was the development of tooling, to control cutting the thermal barrier overlap splice joint and to aid in the splice joint bonding process. This configuration was successfully demonstrated on the NJES-4B, FSM-9 and FSM-10 tests.

The NJES-4B motor test used the same test hardware fired in the NJES-4A test. Due to the J-leg erosion that occurred on NJES-4A, less joint engagement was provided during joint assembly.

This test evaluated a flaw (0.125-inch wide by 0.050-inch depth) through the J-leg to the thermal barrier, thus evaluating the gas spreading and cooling capability of the thermal barrier.

The flawed J-leg performed as designed with no erosion or heat effects of the leak check barrier O-ring observed. Thermocouples located upstream and downstream of the thermal barrier showed the upstream peak temperature of ~4400°F was reduced to ~300°F downstream of the thermal barrier.

The thermal barrier remained in place during the duration of the test. The thermal barrier splice joint was well bonded and intact

5-Year Aging

As part of an aging program for the nozzle-to-case joint J-leg configuration, a five-year resiliency test is

being conducted; this evaluation includes the assembly of a full-scale nozzle-to-case joint J-leg configuration over a five-year period.

The full-scale article will be assembled for three years in Utah, after which the article will be shipped to Florida where humidity effects will be introduced.

Additional aging tests are also being conducted using witness panels that include tensile and peel tests. Tests will evaluate different times, temperatures, and humidity's to provide an understanding of aging effects on the pressure sensitive adhesive bondline.

Flight Simulation Motors (FSMs)

The FSM-9 motor provided the first full-scale static test of the nozzle-to-case joint J-leg configuration in a full-scale static test motor.

Postfire evaluation showed no evidence of hot gas intrusion into the joint bondline. Joint bondline contact was evident over the entire joint mating surface. There was no evidence of heat effects or discoloration of the insulation surface aft of the thermal barrier.

The baffle was eroded back to the step region; sooted Teflon tape remained aft of the step. The remaining J-leg was shorter than the normal polysulfide joint, but sufficient J-leg remained to ensure thermal safety factor requirements were met. The average remaining J-leg (measured from the step to the remaining J-leg tip) was 1.20, with a minimum remaining J-leg of 1.05 inch. The prefire length of the J-leg was approximately 2.25 inch.

At disassembly of the joint, charred NBR was deposited over the pressure sensitive adhesive coated joint surfaces when the fixed housing slid across the deflected J-leg tip. The noted condition was intermittent over the full circumference. The pressure sensitive adhesive in these regions was sticky and pliable, indicating no significant heat had entered the joint bondline. No discoloration or staining of the NBR remained after joint cleaning at these locations.

There were six areas identified in the joint where dark brown staining was noted on the insulation surface, extending to the step region. The stained conditions were all located in the upper half of the joint. Other areas existed throughout the circumference where staining did not extend to the step region. There was no evidence of soot in the joint at these locations other than from joint disassembly. The pressure sensitive adhesive in these regions was sticky and pliable. The stain remained after joint cleaning. Similar stains had been previously identified in the case field joints of two flight motors (RSRM-63 & 77), and it was determined that the staining was the result of a dark semi-liquid by-product of NBR decomposition

being deposited onto pressure sensitive adhesive coated NBR.

Two areas in the joint showed heat affected NBR near the remaining J-leg tip. The heat affected areas extended approximately 6 inches circumferential, to approximately 0.5 inch of the pyrolyzed NBR line at the J-leg tip. The pyrolysis line was uniform across these regions indicating that there was no gas flow into the joint during motor operation. Several small slag deposits were imbedded in the insulation surface in these regions. There was no uniform sticky pliable PSA in these regions. Visual observation indicated that there was no erosion, no flow paths or evidence of soot in the joint. One of these areas was cleaned with solvent. The insulation surface showed no visible material loss, only darkened, heat affected NBR and small pockmarks created by the slag deposits.

The FSM-10 nozzle-to-case J-leg joint configuration evaluated a flaw (0.125-inch wide by 0.050-inch depth) through the J-leg to the thermal barrier at the 135-degree location. In addition to exposing the thermal barrier to hot motor gases, a splice joint in the thermal barrier was also positioned in-line with the flaw.

Charred NBR was deposited onto the pressure sensitive adhesive coated joint surface during joint disassembly similar to FSM-9. The insulation surface showed no discoloration after cleaning with a solvent.

Discoloration of the J-leg surface was evident at several locations, extending to the step region; this condition was typical of that identified on FSM-9.

There was no indication of hot gas intrusion into the joint except at the flaw. Hot motor gases entered the flaw at 135 degrees and after impinging on the thermal barrier splice joint, gases appeared to turn circumferential in the channel forward of the thermal barrier, the cyanoacrylate adhesive appeared to restrict flow through the thermal barrier for some period of time. Once the flow was beyond the splice region the gases flowed through the thermal barrier. Most flow appeared to occur toward the 136-degree location with darkest discoloration identified in this region. Circumferential gas flow was evident forward of the thermal barrier with heavy sooting noted between 120 and 156 degrees and decomposed PSA between from 87 to 158 degrees.

Light brown discoloration of the NBR was observed downstream of the thermal barrier from 76 to 156 degrees, extending to the leak check barrier O-ring in some locations. There was no evidence of heat affected material in this region. No heat effects or erosion were identified on the leak check barrier O-ring.

Thermocouples and pressure transducers were installed directly downstream of the thermal barrier at the flaw and 90 degrees away from the flaw. Data obtained from the thermocouples located in-line with the flaw showed a maximum temperature of 396°F. Temperatures measured at those locations 90 degrees away from the flaw indicated ambient temperatures. Data showed that after initial pressurization, pressure measured downstream of the thermal barrier duplicated the motor headend pressure. Thus the capability of the thermal barrier to reduce hot gas temperatures without restricting flow was verified.

Implementation on Flight Hardware

A series of tests were successfully completed to evaluate the various components of the nozzle-to-case joint J-leg configuration. Extensive thermal and structural analyses were also completed. The design efforts culminated with the successful demonstration on the FSM-9 and FSM-10 static test motors by providing final certification of the nozzle-to-case joint J-leg configuration.

The nozzle-to-case joint J-leg configuration has been approved for implementation on flight hardware. The first nozzle-to-case joint J-leg configuration is scheduled for implementation on the RSRM program beginning with RSRM-99.

ACKNOWLEDGEMENTS

There have been many involved with the development and implementation of the nozzle-to-case joint J-leg configuration. The writers thank all of the individuals who have contributed. Some key individuals in this effort include: Lee Hamilton, Ed Mathias, Todd Noble, Robert Riley, and Dayna Serna.

REFERENCES

¹Ewing, M. E., McGuire, J. R., McWhorter, B. B., and Frost, D. L., "Performance Enhancement of the Space Shuttle RSRM Nozzle-to-Case Joint using a Carbon Rope Barrier," AIAA-99-2899, June, 1999.

²Foot, J. O., "Titan IV Solid Rocket Motor Upgrade Program at Alliant Techsystems, Inc.," AIAA-97-2991, July, 1997.

³Steinetz, B. M., and Dunlap, P. H., "Feasibility Assessment of Thermal Barrier Seals for Extreme Transient Temperatures," AIAA-98-3288, July, 1998.