TWR-50138

SPACE SHUTTLE

Solid Rocket Motors
Thiokol Corporation

Thiokol/Wasatch Installation Evaluation of the Redesigned Field Joint Protection System (Concepts 1 and 3) Final Test Report

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Thiokol/Wasatch Installation Evaluation of the Redesigned Field Joint Protection System (Concepts 1 and 3) Final Test Report

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ABSTRACT

Redesigned field joint protection system installations were performed between 7 and 15 Nov 1989 at the Thiokol Corporation Static Test Bay T-18. The purpose of the installations was to develop procedures for two field joint protection system redesign concepts (Concepts 1 and 3), and to evaluate the processing capability of each concept. The Concept 1 (Double Cork Band Design) configuration consists of two cork bands with K5NA ablation compound applied between them and to the bottom edge of the aft cork band. The Concept 3 (K5NA Design) configuration consists of a single layer of K5NA over the joint/heater/sensor/pin retainer band area.

A single nylon rolling pin application method for the K5NA application of the Concept 3 configuration gave the best results when compared to the screed and double rolling pin methods also evaluated. However, the overhead application of this configuration, used to simulate installation on a technical evaluation motor, was particularly strenuous for the four people performing the work.

The two cork bands for the Concept 1 configuration were installed and cured with pressure applied by four steel strapping bands. The steel strapping bands worked well; adhesive squeezout occurred across the entire cork-to-case bondline. A post-cure removal/inspection revealed a continuous void along the forward portion of the pin retainer band-to-sheet cork bondline. To eliminate this void, the sheet cork tolerance over the pin retainer band should be reduced, and a filler (Cab-O-Sil®, a micro-fine silicon dioxide) should be added to the adhesive to increase viscosity.

K5NA adhered best if a small amount was rubbed onto the bonding surface (wetting the surface) just prior to application of large amounts of K5NA. Also, keeping the K5NA as warm as possible prior to and during application improved adhesion and contour shaping ability.

Under ideal conditions, a complete Concept 1 installation would require approximately 67 hours; a complete Concept 3 installation would require approximately 55 hours. Both configurations are capable of reducing the current FJPS installation time of 144 hours by the design goal of 50 percent.

Because the Concept 3 installation was so labor intensive, its development should be discontinued. Concept 1 and an additional configuration (Concept 1C) should be further developed. Concept 1C uses two cork bands, but eliminates the Concept 1 tolerance/void problem at the pin retainer band-to-sheet cork interface by covering this area with K5NA.

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ACRONYMS

FJPS	field joint protection system
LSOC	Lockheed Space Operations Company
KSC	Kennedy Space Center
MSFC	Marshall Space Flight Center
TEM	technical evaluation motor
RSRM ...	redesigned solid rocket motor
SRM	solid rocket motor
VAB	vehicle assembly building
lbf	pounds-force

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INTRODUCTION

This report documents the procedures, performance, and results obtained from the Thiokol Corporation/Wasatch Redesigned Field Joint Protection System (FJPS) Installation Evaluation. The evaluation was performed between 7 and 15 Nov 1989, at Thiokol Corporation Static Test Bay T-18. Testing was performed in accordance with ETP-0600, Thiokol/Wasatch FJPS Short Stack Demonstration Test Plan. The purpose of the evaluation was to demonstrate and develop the procedures required to install two different concepts (referred to as Concepts 1 and 3) of the redesigned FJPS. The processing capability of each configuration was then evaluated and compared. The evaluation was accomplished jointly by Thiokol Corporation, Lockheed Space Operations Company (LSOC), Kennedy Space Center (KSC), and Marshall Space Flight Center (MSFC) personnel.

The FJPS is installed on redesigned solid rocket motors (RSRM) to protect the field joints from rain intrusion and to maintain the joint temperature sensor measurement between 85° and 122°F while the boosters are on the launch pad. The FJPS is being redesigned to reduce installation timelines at KSC and to simplify or eliminate installation processing problems related to the present design of an EPDM moisture seal/extruded cork combination (Figure 1).

Several installation techniques were evaluated, and a preferred method of application was developed for each concept. The installations were performed with the test article in the vertical (flight) position. Comparative timelines between the two concepts were also developed. An additional evaluation of the Concept 3 configuration was performed with the test article in the horizontal position, to simulate an overhead installation on a technical evaluation motor (TEM).

1.1 TEST ARTICLE DESCRIPTION

Concept 1 (Double Cork Band Design) of the redesigned FJPS proposals utilizes two cork bands with STW5-3183 ablation compound (K5NA) applied between them and to the bottom edge of the aft cork band (Figure 2). The cork bands are positioned over the pin retainer band area and over the joint temperature sensor area. STW4-3218 adhesive (EA 934 NA) is used to bond the cork bands. The aft sheet cork sections were machined for a maximum tolerance over the pin retainer band, and this tolerance resulted in cork-to-band interface gaps that were approximately 0.25-in. thick. The forward sheet cork sections were machined to fit directly over the joint temperature sensor. The Concept 3 (K5NA Design) configuration consists of a single layer of K5NA ablation compound over the joint/heater/sensor/pin retainer band area (Figure 3).

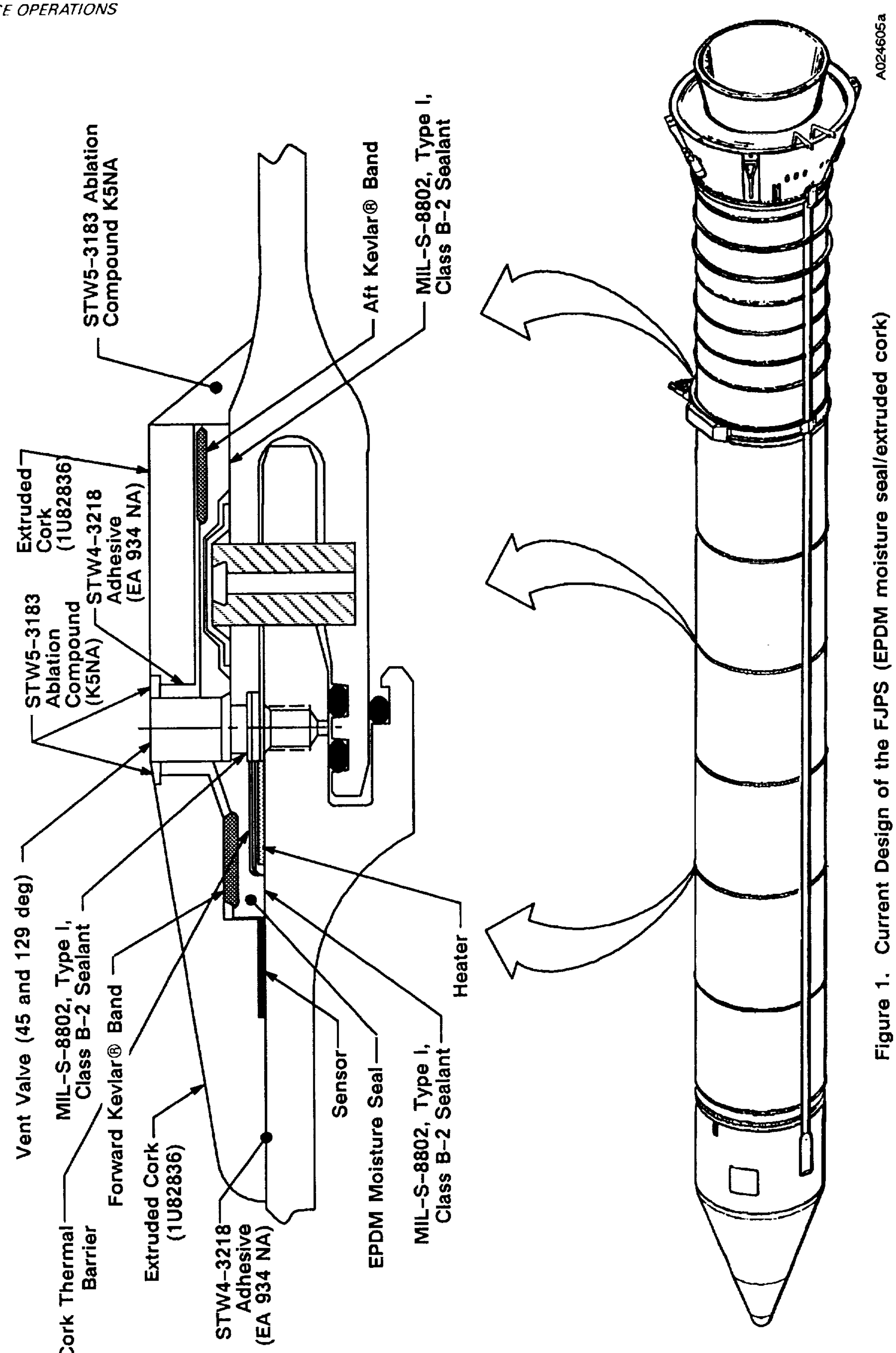
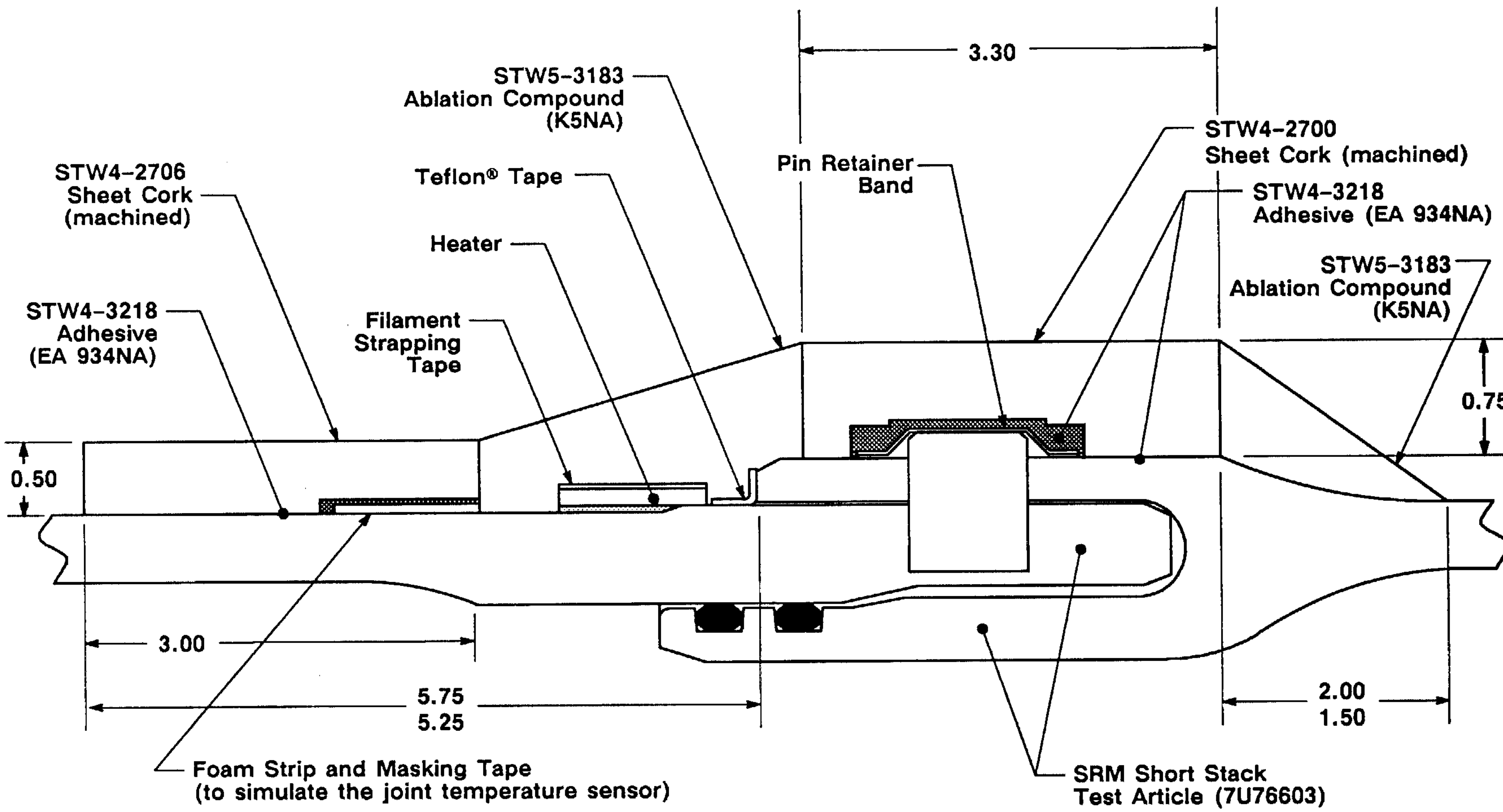


Figure 1. Current Design of the FJPS (EPDM moisture seal/extruded cork)



Note: This configuration does not represent exact RSRM specifications. Dimensions in Inches

Figure 2. Concept 1 of the Redesigned FJPS—Installation Evaluation

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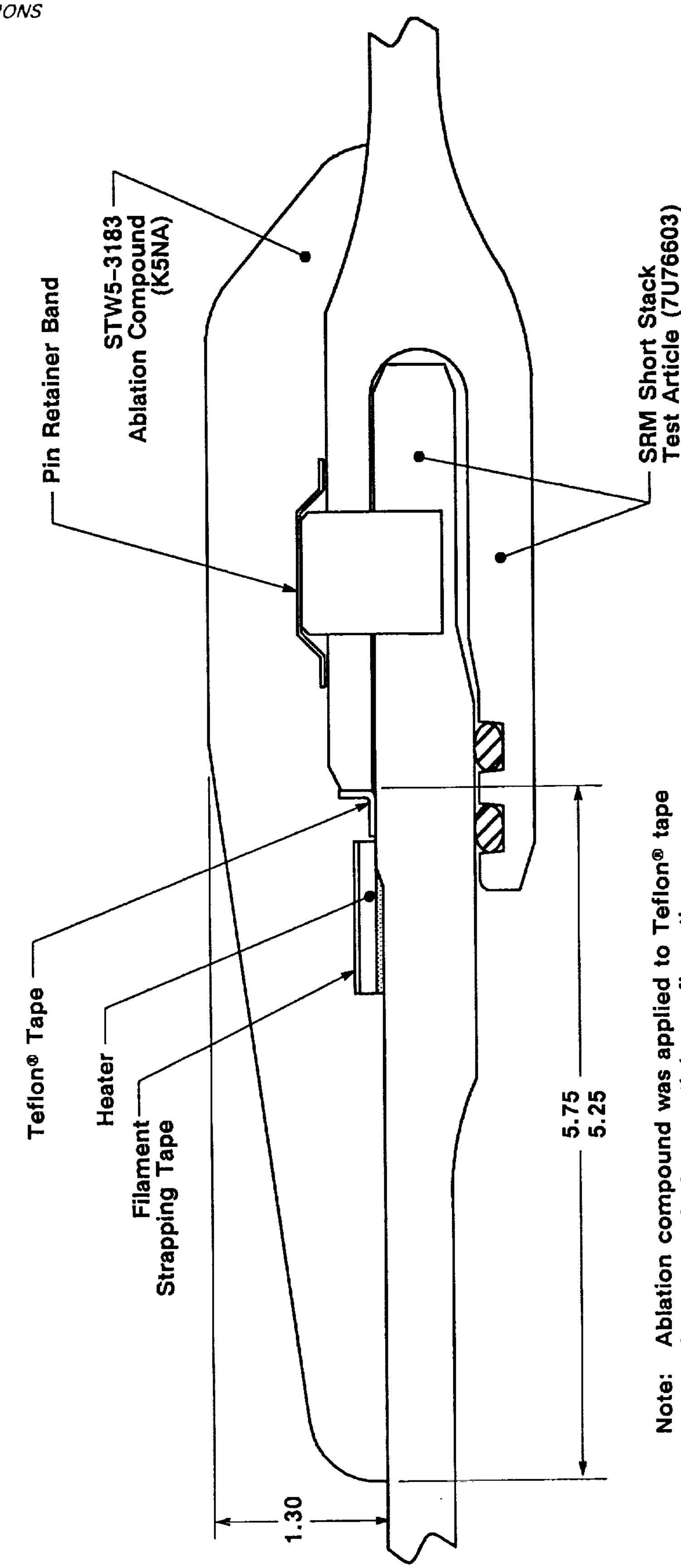

Note: Ablation compound was applied to Teflon® tape for the vertical test article configuration

Note: This configuration does not represent exact RSRM specifications. Dimensions in Inches

Figure 3. Concept 3 of the Redesigned FJPS—Installation Evaluation

Both proposals eliminate the vent valves, the vacuum bagging process, and the need for a separate moisture seal. Both concepts use a single Kevlar® strap to hold the heater in place, as compared to the moisture seal/Kevlar strap method of the current configuration. For this evaluation the heater was held in place with filament strapping tape. Specific dimensions of each concept were determined through structural and thermal analysis (TWR-50044).

The proposed FJPS configurations were installed onto a mated solid rocket motor (SRM) short stack (7U76603) in the vertical (flight) and horizontal position. (The outside surface contour of an SRM field joint is the same as an RSRM contour.) The assembly included the joint pins and pin retainer band. For the Concept 1 installation, a foam strip was installed to simulate the joint temperature sensor. To prevent joint contamination, a layer of Teflon® tape was installed over the gap at the clevis-to-tang interface for each installation.

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OBJECTIVES

The objectives of test plan ETP-0600 were to:

a. Demonstrate the process to install redesigned FJPS concepts
b. Develop comparative timelines between Concept 1 and Concept 3
c. Determine if cracking, shrinking, or slumping occurs in the ablation compound after application
d. Evaluate the bondline void effects of steel strapping bands used to secure the cork during cure

3
EXECUTIVE SUMMARY

3.1 SUMMARY

This section contains an executive summary of the key results from test data evaluation and post-test inspection. Additional information and details can be found in Section 6, Results and Discussion.

Both redesigned FJPS configurations were installed onto the vertical short stack test article per Drawing TUL-16825. Bondline surfaces were abraded, blacklight inspected, and solvent cleaned as necessary prior to each installation.

The Concept 3 (K5NA Design) configuration was installed first, over Teflon tape, over 180 deg of the joint. A single nylon rolling pin application method worked best. A problem with this method was the difficulty in maintaining the rolling pin in a vertical position. The rolling operation was also very operator sensitive, so results varied between operators. Several batches of K5NA were worked beyond their 30-minute pot life. No evidence of K5NA slumping occurred during application or the 20 hours of cure. The layer of K5NA was removed in one single section after the cure; no significant voids were present.

A Concept 1 (Double Cork Band Design) configuration was then installed around the entire joint. A 90-deg section of this configuration was applied over Teflon tape, the rest was applied directly to the case. The two cork bands were installed and cured with pressure applied by four steel strapping bands. The steel strapping bands worked well; adhesive squeezout occurred across the entire cork-to-case bondline. Installation of the K5NA began 15 hours after the completion of the cork installation. The section that was applied over Teflon tape was removed 22 hours after the completion of the K5NA application. Visual inspection showed adequate K5NA and EA 934 NA adhesion everywhere except for a continuous void, approximately 0.125-in. thick, along the pin retainer band-to-sheet cork adhesive bondline. Pull testing showed that bondline pressure on the cork was adequate, resulting in a consistent cork-to-case bondline.

Lastly, a Concept 3 configuration was installed onto the horizontally oriented short stack to simulate installation on a TEM. The K5NA was installed directly to the case surface, on the 90-deg area where the Concept 1 configuration was removed. Application was performed with the single nylon rolling pin. Because a portion of this K5NA application was performed overhead, it was particularly strenuous for the four people performing the work. A portion of the K5NA, approximately 3-in. square, became unbonded and slumped during cure.

It was found that K5NA adhered best if a small layer or film was vigorously rubbed onto the bonding surface (wetting the surface) just prior to application of large amounts of K5NA. Rubbing small amounts onto the bonding surface gave a tacky surface for the K5NA to adhere to. It was also found that keeping the K5NA as warm as possible prior to and during application improved adhesion and contour shaping ability.

3.2 CONCLUSIONS

The following list is the conclusions as they relate specifically to the objectives. Additional information about the conclusions can be found in Section 6, Results and Discussion.

	Objective	Conclusion
a.	Demonstrate the process to install redesigned FJPS concepts.	Both redesigned FJPS configurations were installed, and a preferred method of application was developed for each configuration. The Concept 1 (Double Cork Band Design) installation was less labor intensive for each operator, as compared to the Concept 3 (K5NA Design) installation. However, a Concept 3 installation requires less people and can be completed quicker than a Concept 1 installation. The Concept 3 installation allows the option of taking the crew off the operation at anytime, and returning to assembly at any future time. During the cork band installation for concept 1, once the adhesive is applied to the pin retainer band crews must remain working until the entire aft cork band is installed (approximately 35 minutes).

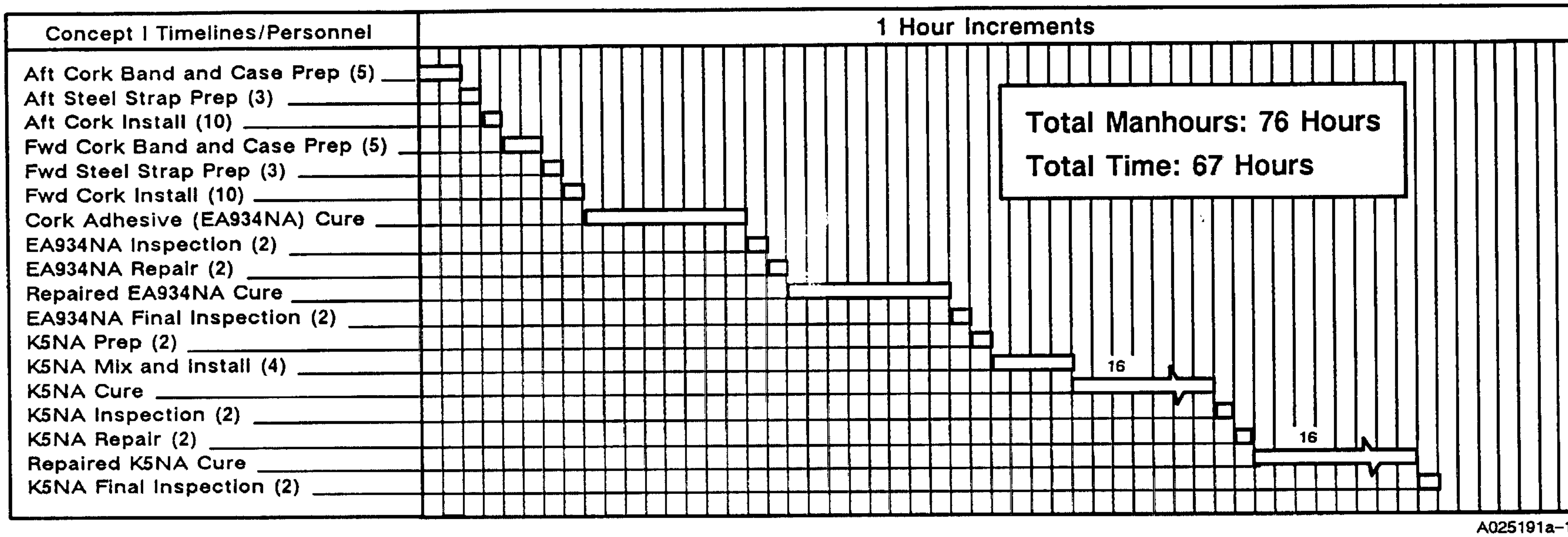
<u>Objective</u>

b. Develop comparative timelines between Concept 1 and Concept 3.

<u>Conclusions</u>

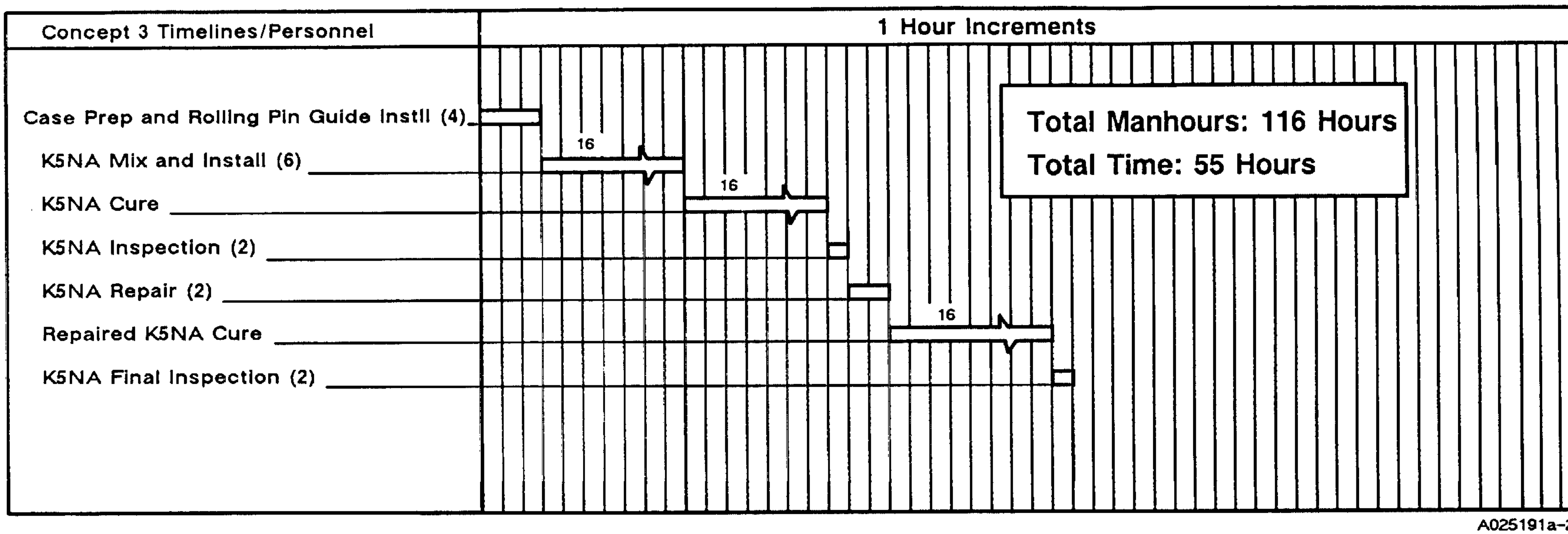
Under ideal conditions, a complete Concept 1 installation would require approximately 67 hours; a complete Concept 3 installation would require approximately 55 hours. Both configurations are capable of reducing the current FJPS installation time of 144 hours per joint by the design goal of 50 percent. Timelines are shown in Tables 1 and 2.

Application of the sheet cork for the Concept 1 configuration required ten people, the largest single crew required to install any portion of the two concepts. The largest crew necessary for the Concept 3 installation was six people. The total manhours required for a Concept 1 installation is approximately 76; total manhours required for a Concept 3 installation is 116.



Note: K5NA installation times are based on application of one batch after another, with one quality control person. Each batch of K5NA has a 30-minute pot life. Eight batches of K5NA are required for Concept 1

Table 1. Redesigned FJPS Timelines (Concept 1-Double Cork Band Design)



Note: K5NA installation times are based on application of one batch after another, with one quality control person. Each batch of K5NA has a 30-minute pot life. Thirty-two batches of K5NA are required for Concept 3

Table 2. Redesigned FJPS Timelines (Concept 3–K5NA Design)

c. Determine if cracking, shrinking, or slumping occurs in the ablation compound after application.

No visible cracking, shrinking, or slumping occurred in the K5NA ablation compound after installation of the Concept 1 configuration. The sheet cork and K5NA interface did require special attention during application. This bondline, particularly when cork was on top, would tend to separate if extra pressure was not applied during application. Pulling apart sections of the cork-to-K5NA bondline, after cure and removal, resulted in approximately 80 percent cohesive failure in the cork and 20 percent adhesive failure at the bondline.

No visible cracking, shrinking, or slumping occurred in the K5NA ablation compound after installation of the Concept 3 configuration to the vertically oriented short stack. During the horizontally oriented short stack Concept 3 installation, a small portion of the K5NA became unbonded during cure. This resulted in a separation, approximately 3-in. square, between the K5NA and the case. No additional slumping, no cracking or shrinking occurred during horizontal Concept 3 application.

d. Evaluate the bondline void effects of steel strapping bands used to secure the cork during cure.

During application, EA 934 NA adhesive seeped out at the cork end joints. A post-cure removal/inspection showed adequate adhesion everywhere except for a continuous void, approximately 0.125-in. thick, along the forward portion of the pin retainer band-to-sheet cork bondline. The void at the retainer band-to-cork interface was due to the cork being machined to maximum pin retainer band installation tolerances. This void increases the debris potential over the Concept 3 installation, which was installed free of voids.

The steel strapping bands worked well during the installation and cure of the sheet cork bands.

3.3 RECOMMENDATIONS

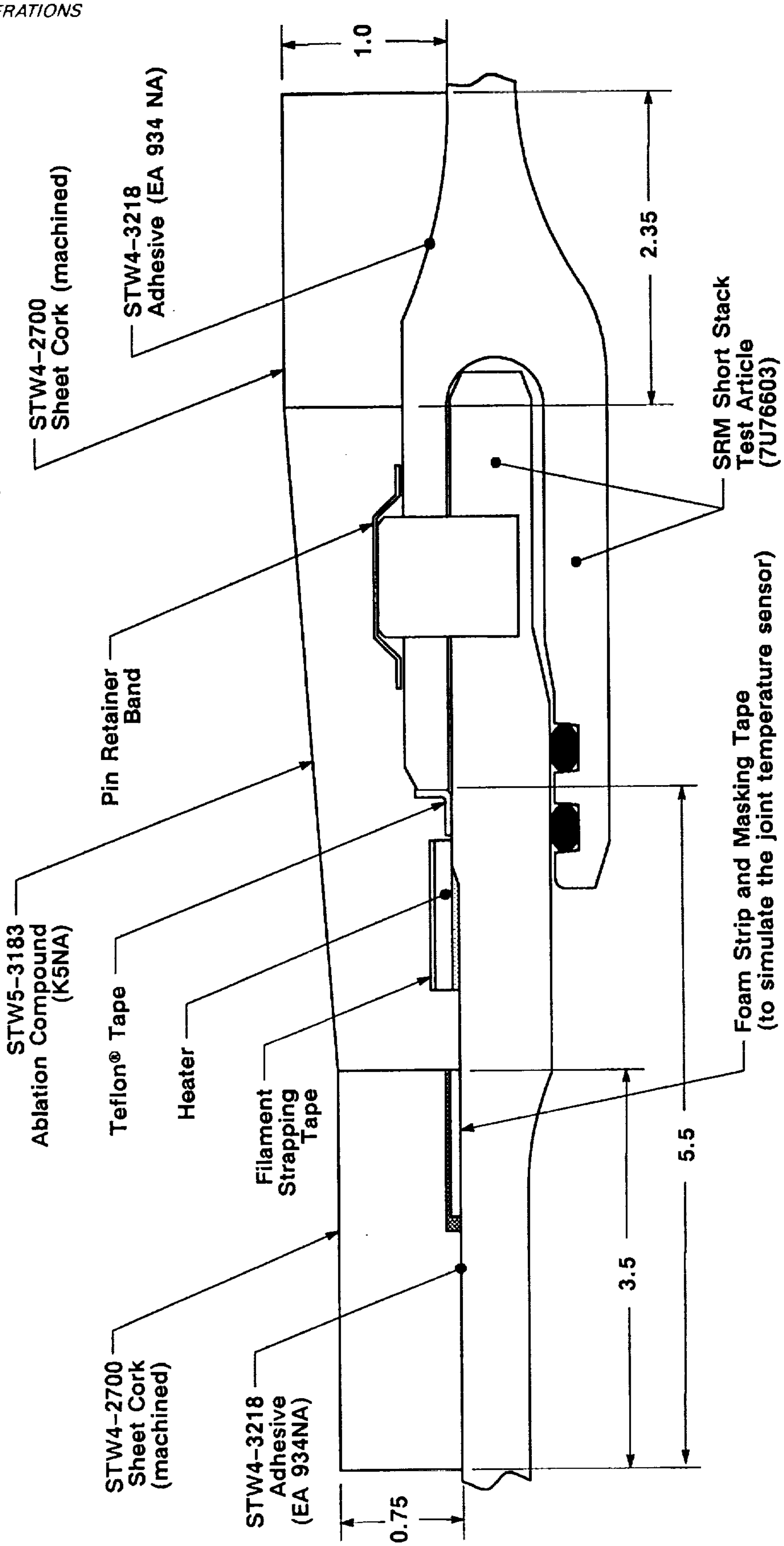
Based on the results of this test, the following recommendations can be made:

Because the Concept 3 configuration (K5NA Design) installation was so labor intensive per person, further development of this configuration should be discontinued and Concept 1 (Double Cork Band Design) and other configurations should be further developed.

The gap between the pin retainer band and the aft sheet cork band for the Concept 1 configuration should be reduced to nominal dimensions. With closer pin retainer band-to-cork tolerances, the option to carve the cork to fit occasional pin retainer band protuberances should be instated.

For the Concept 1 configuration, a filler (Cab-O-Sil; a micro-fine silicon dioxide) should be added to the EA 934 NA adhesive to increase its viscosity, thereby reducing flow from voids between the machined sheet cork and pin retainer band.

A hybrid between the Concepts 1 and 3 should be developed. This configuration could consist of two cork bands, and could eliminate the Concept 1 tolerance/void problem at the pin retainer band-to-sheet cork interface by covering this area with K5NA (Figure 4). This configuration has been labeled Concept 1C, Double Cork Band/K5NA Design.



Notes: This configuration does not represent exact RSRM specifications. Dimensions in inches

Figure 4. Concept 1C of the Redesigned FJPS—Installation Evaluation

The chosen configuration(s) should be demonstrated at KSC using LSOC planning, and installed by Shuttle Processing Contractor personnel. This demonstration should also include Quality Assurance approval, just as if the installation were for a flight motor. Timelines and accessibility to perform the work at the Vehicle Assembly Building (VAB) should be demonstrated.

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INSTRUMENTATION

A multimeter (Fluke 8024B) and a surface pyrometer were used to measure ambient and case surface temperature during the vertical Concept 3 configuration installation. A hydrothermograph (Rustrak S-A23417), was used to measure ambient and case surface temperature during the Concept 1 and horizontal Concept 3 configuration installations.

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PHOTOGRAPHY

Still color photographs of the two redesigned FJPS configurations were taken throughout each assembly and disassembly process. Copies of the photographs (Series No. 113965, 114073, 114262, 114269, 114275, 114293, 114300, and 114578) are available from the Thiokol Corporation Photographic Services Department.

6

RESULTS AND DISCUSSION

6.1 SHORT STACK TEST ARTICLE ASSEMBLY

The test article consisted of a mated SRM short stack (7U76603) in the vertical (flight) and horizontal position. (The outside surface contour of an SRM field joint is the same as an RSRM contour.) The assembly included the joint pins and pin retainer band. A joint heater was installed and held in place with 1-in.-wide filament strapping tape. A joint temperature sensor was not installed because one was not available (a foam strip was installed during the Concept 1 installation to simulate the sensor). For each installation, a layer of Teflon tape was installed over the gap at the clevis-to-tang interface to prevent joint contamination.

6.2 CONCEPT 3 VERTICAL INSTALLATION EVALUATION

This test demonstrated the redesigned FJPS configuration which consists of a contoured layer of K5NA ablation compound (Figure 3). The assembly was installed following the configuration of drawing TUL-16825. Several application methods were evaluated.

Installation Preparation. Prior to installation, the case surface, pin retainer band, and heater (the entire FJPS surface) was covered with Teflon tape. The tape was installed to aid the removal/inspection of the K5NA bondline and to prevent contamination of the joint surface. The case surface was solvent cleaned prior to installation of the tape, and the tape surface was also solvent cleaned prior to the K5NA application. The Concept 3 configuration was not affected by the lack of sensor installation. A layer of 0.250-in.-thick sheet cork was banded to the case to guide the bottom of the rolling pin during application.

Installation. Initially, a template of the proper profile was pushed across the roughly applied K5NA surface (Figure 5). This method did not work well; the template scraped off too much K5NA and left a very rough surface.

A double rolling pin method of application was then evaluated. Two nylon rolling pins were fastened together and the bottom edges of the rolling pins were run on the sheet cork guide. It was difficult to apply enough pressure to contour the K5NA with the double rolling pin, so the pins were disassembled and application with a single rolling pin was then evaluated.

The single nylon rolling pin application method worked best (Figure 6). This method made it easier to apply enough pressure to the surface and achieve the proper contour, as compared to the double rolling pin method. A problem of this method was the difficulty in maintaining the rolling pin in a vertical position. With patient application however, a consistent profile was achieved.

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Figure 5. Concept 3 of the Redesigned FJPS—Template Shaping of the Surface Contour

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Figure 6. Concept 3 of the Redesigned FJPS—Single Nylon Rolling Pin Shaping of the Surface Contour (applied over plastic film)

An anti-static plastic film was held tightly over the K5NA surface during the rolling, and the rolling pin surface (not the K5NA surface) was kept wet with a water spray. The nylon rolling pin was cleaned during use if K5NA became stuck to its surface. If the plastic film was removed during the application for surface inspection, the old film would be discarded and replaced prior to further rolling.

A method of spraying water directly to the surface of the K5NA while finishing with the rolling pin was evaluated. This method did not work well because the K5NA stuck to the roller.

K5NA adhered best if a small layer or film was vigorously rubbed onto the bonding surface just prior to application of large amounts of K5NA. Rubbing small amounts onto the bonding surface gave a tacky surface for the K5NA to adhere to. The K5NA was too viscous to be rolled or pushed forward, so it was best not to apply excessive amounts of K5NA prior to shaping the surface.

The surface was finished with a small, flexible, Teflon-covered rolling pin and hand pressing of the contour edges. Rolling the small rolling pin directly over the K5NA surface and over the plastic film were both evaluated; both gave satisfactory results when the roller surface was kept clean.

In several areas the final layer of plastic film was left on the K5NA surface until the K5NA could partially cure for at least 8 hours. Leaving the film on caused the resin to rise to the surface (which may aid in moisture protection) and resulted in a very smooth, glossy K5NA surface. Where plastic film was removed prior to the K5NA cure, a more abrasive surface resulted.

Lack of rolling pin control was the main problem with the roller-type installations. The rolling operations were very operator sensitive. The amount of pressure applied to the K5NA could not be measured, and varied from person to person. Also, the process was messy; large amounts of K5NA dropped to the floor.

Installation Temperature/Pot Life/Material. The evaluation was performed with the case surface and room temperatures between 55° and 65°F. Thiokol-specified K5NA application temperature limits are between 50° and 110°F (STW7-3260). This temperature range will be changed, with pot life varying with temperature: at 50°F, the pot life will be 101 minutes; at 105°F, the pot life will be 28 minutes. The K5NA application temperature range at KSC is not defined.

The currently specified pot life of K5NA, at 75°F, is 30 minutes from the time mixing begins, per Thiokol (STW7-3631) and KSC specifications. As stated earlier, the pot life will be changed. The K5NA was mixed in 1-gal kit batches with a Hobart mixing machine. Approximately 16 batches of K5NA were used over the 180-deg area. Several batches of K5NA were worked beyond their pot life. Because the installation was for evaluation only, it was decided that applying the K5NA beyond its current specified pot life was acceptable.

Timelines/Personnel. The installation process, in which 180-deg of the joint was covered, lasted 3.5 hours. The operation required six people: two mixed K5NA, one or two applied the K5NA to the case surface, two held the plastic film taut over the K5NA while one handled the roller, and one sprayed the rolling pin (not the K5NA surface) with water. A complete Concept 3 installation at KSC would require approximately 55 hours (Table 2).

Post-Cure Inspection. No visible evidence of K5NA slumping or cracking occurred during the application or the 20 hours of cure. After cure, the K5NA was removed in one pliable section, and no significant voids were present (Figure 7). Some portions of the K5NA did not bond smoothly to the Teflon tape, although no K5NA remained on the tape. Inconsistencies in bond appearance were probably due to the involvement of several people in a new process, with everyone applying different pressure to the K5NA. Also, as new batches were made available, they were set by open doors. This cooled the batches considerably, as the outside temperature was between 40° and 50°F. Cooling of the batches prior to application affected installation the most (it was later determined that warm K5NA adheres better and is easier to contour than cold K5NA).

6.3 CONCEPT 1 VERTICAL INSTALLATION EVALUATION

The Concept 1 (Double Cork Band) installation evaluation demonstrated the redesigned FJPS configuration which consists of two cork bands with K5NA applied between them and to the bottom edge of the aft cork band (Figure 2). The assembly was installed following the configuration of drawing TUL-16825. The aft sheet cork sections were machined for a worst-case tolerance over the pin retainer band, and this tolerance resulted in cork-to-band interface gaps that were approximately 0.25-in. thick (Figure 8). The forward sheet cork sections were machined to fit directly over the joint temperature sensor.

Installation Preparation. The Concept 1 configuration was installed around the entire joint. A 90-deg section of the bondline area was covered with Teflon tape, the rest was prepared for a direct bondline to the case. The Teflon tape was installed to aid the removal/inspection of the bondline and to prevent contamination of the joint. The case surface was solvent cleaned prior to installation of the Teflon tape. An adhesive-coated foam strip and masking tape were installed to simulate the joint temperature sensor. Areas of the bondline surface that were not covered with Teflon tape were abraded. The bondline surface was blacklight inspected for contamination and solvent cleaned prior to the cork installation. After the joint was cleaned, the four steel strapping bands used to apply pressure to the cork strips were taped to the case.

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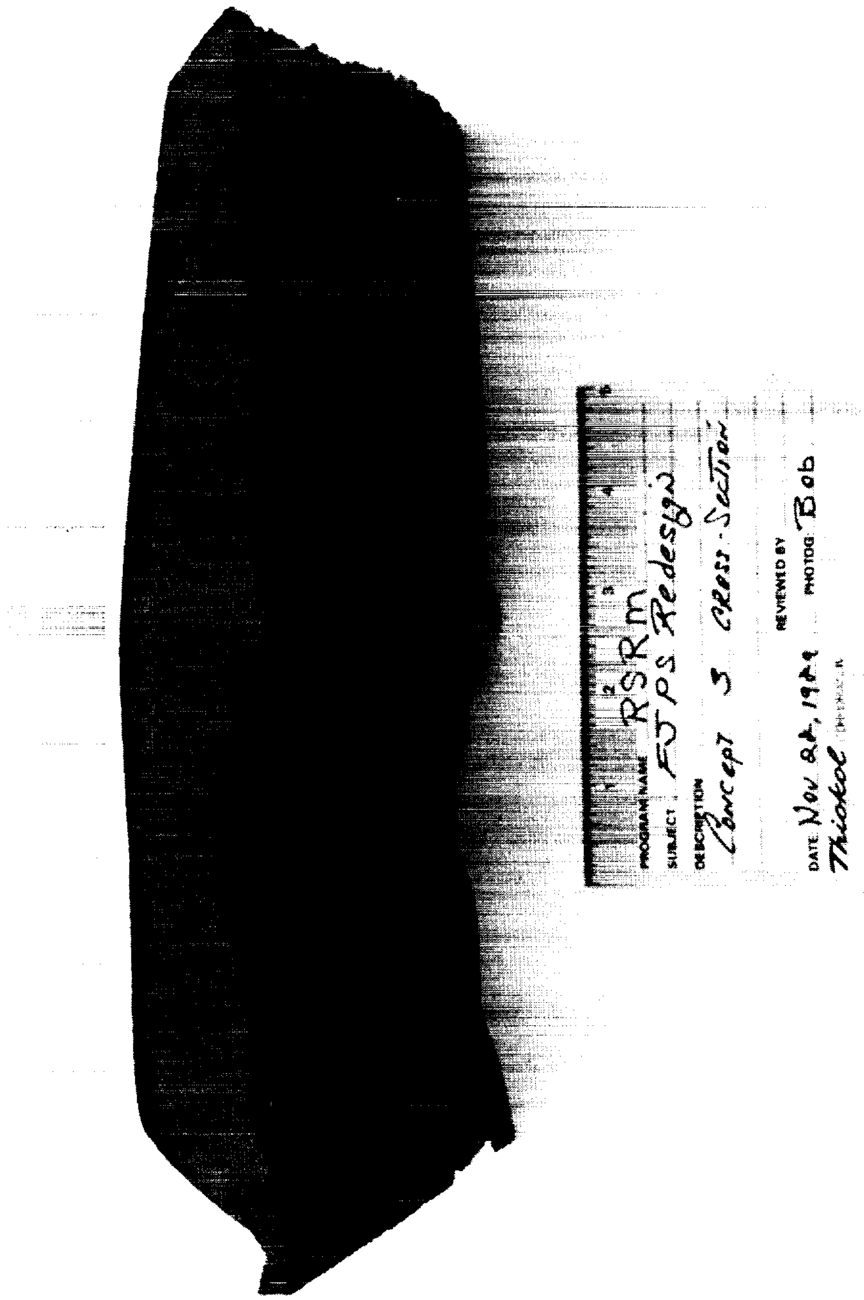

Figure 7. Concept 3 of the Redesigned FJPS—Typical Cross Section

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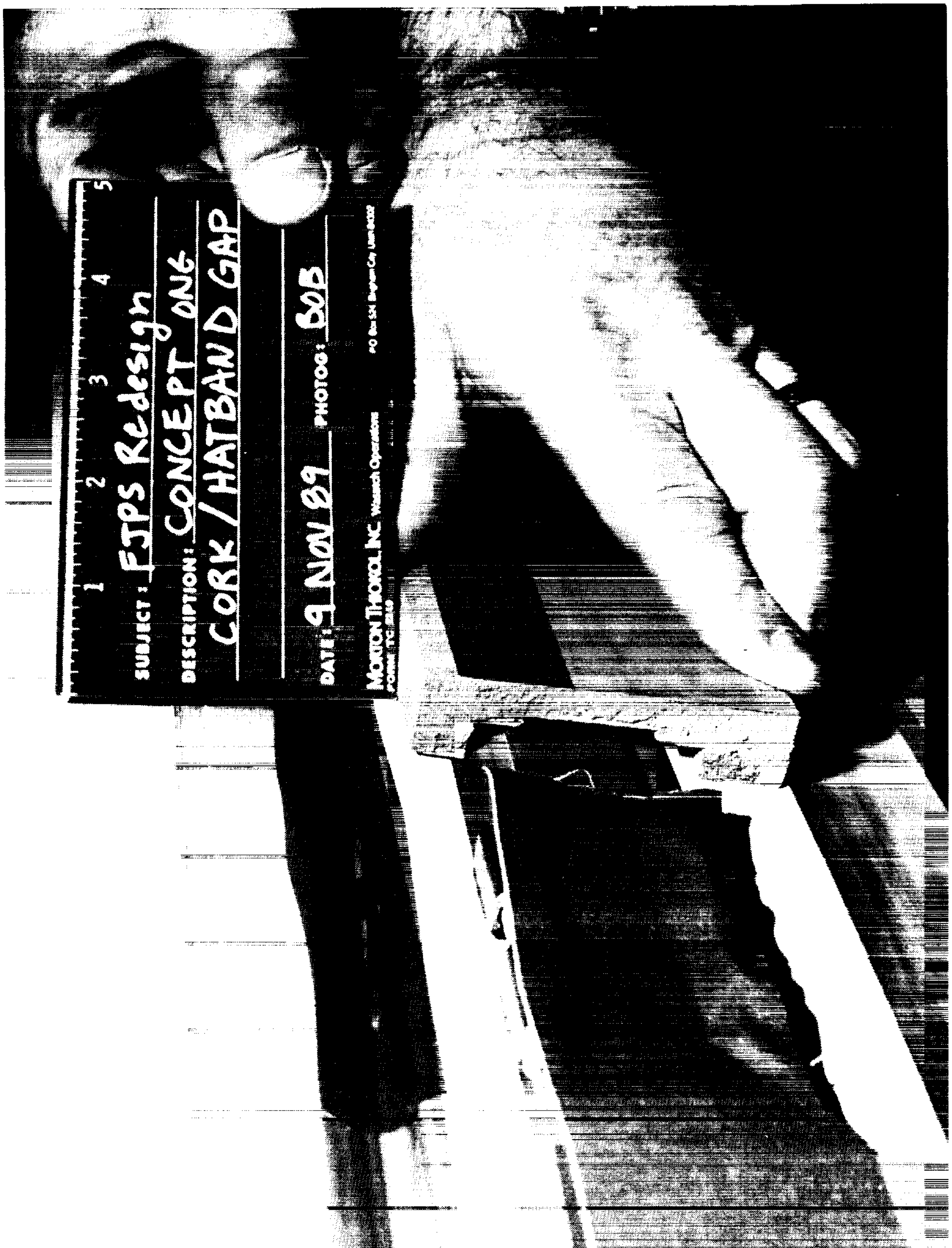

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Figure 8. Concept 1 of the Redesigned FJPS—Pin Retainer Band/Cork Interface Gap

6.3.1 Concept 1 Aft Cork Band

Installation Preparation. Teflon tape was applied to the outer surface of each cork section, 0.125-in. in from the edges to be bonded. The tape was applied to reduce the friction between the cork and the steel strapping bands, and to prevent contamination of the cork surface. The bonding surface of each cork section was lightly abraded and solvent cleaned. The aft cork sections were then dry fitted, taped in place, and numbered. The individual cork sections were flexible enough to bend to the curvature of the case.

Installation. The cork was removed from the case and placed on a clean table. EA 934 NA adhesive was then applied to the cork bonding surface, with a thick layer applied in the machined grooves. A layer of adhesive was also applied to the case-to-pin retainer band bonding surface. The cork sections were then installed and held in place with two of the steel bands. The band tensioning tool pressure for each steel band was started at 10 psi, and then increased to 30 psi in 5 psi increments. The 30 psi in the tool corresponded to approximately 700 lb tension in each steel band. By analysis, approximately 10 lbf (from each steel band) was applied to the cork 180-deg away from the band tensioning tool, and approximately 12 lbf was applied to the cork at the band tensioning tool (refer to the Appendix for the step-by-step analysis). The steel strapping bands worked well during the installation and cure of sheet cork; adhesive squeezout occurred across the entire cork-to-case bondline (Figure 9).

Installation Temperature/Potlife. Room and case surface temperatures were 72° and 70°F, respectively, at the beginning of the adhesive mixing operation, and 61° and 65°F at the completion of the strapping process. During application the doors to the test bay were left open to improve ventilation; it was approximately 50°F outside of the test bay. The Thiokol-specified minimum application temperature of EA 934 NA adhesive is 70°F (STW7-3631). This minimum temperature will change, with pot life varying with temperature: at 60°F, the pot life will be 98 minutes; at 90°F, the pot life will be 46 minutes. KSC does not have an application temperature range for EA 934 NA. Because the installation was for evaluation only, it was decided that applying the adhesive below the current specified minimum temperature was acceptable.

Timelines/Personnel. The aft cork application/steel banding process took ten people nine minutes to complete. The installation lasted 38 minutes from the beginning of adhesive mix until the strapping process was complete. The pot life of EA 934 NA adhesive is 40 minutes, per Thiokol (STW4-3218) and KSC specifications (as stated earlier, this pot life will be replaced by a range which varies with temperature). Five 1-qt kits of adhesive were used to bond the cork. After application, adhesive tended to seep out at the cork end joints from the cork-to-pin retainer band interface void.

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Figure 9. Concept 1 of the Redesigned FJPS—Adhesive Squeezout During Aft Cork Installation

6.3.2 Concept 1 Forward Cork Band

Installation/Timelines/Personnel. The same procedures to install the aft band of cork were used during forward cork band installation. Since the steel bands had to go over the systems tunnel floor plates, cork blocks were placed between the sheet cork and raised steel bands; this ensured pressure on the sheet cork bonded near the systems tunnel. Total installation time from the start of the first mix of EA 934 NA was 33 minutes. Four 1-qt kits of adhesive were used to bond the forward cork band. Again, 10 people installed the cork band.

Installation Temperature. Room and case surface temperatures were 68° and 61°F, respectively, at the beginning of the adhesive mixing operation, and 71° and 65°F at the completion of the strapping process. Doors were left open to improve ventilation; it was approximately 50°F outside.

6.3.3 Concept 1 K5NA Application

Installation. Installation of the K5NA began 15 hours after the completion of the cork installation. The steel bands were removed just before the K5NA was applied.

Masking tape was applied at the edges of the K5NA bondline, and removed after the K5NA was installed. The preferred application method consisted of one person firmly applying the rough mixture to the desired area, another person sculpting the surface with a plastic spatula, and a third person finishing the surface with a small Teflon-coated rolling pin. The rolling pin was applied directly to the K5NA surface and was frequently cleaned with solvent (Figure 10).

The sheet cork and K5NA interface did require special attention during application. This bondline, particularly when cork was forward of the K5NA, would tend to separate if extra pressure was not applied to the K5NA during application.

Installation Temperature/Timelines/Personnel/Material. Room and case surface temperatures varied between 50° and 60°F during application. The installation was performed in just over three hours with an average of three people. Each batch of K5NA was applied within the currently specified 30-minute pot life (at least two people were required to apply a batch within the pot life). Approximately eight batches of K5NA were used over the 360-deg area. A complete Concept 1 installation at KSC would require approximately 67 hours (Table 1).

6.3.4 Concept 1 Post-Cure Inspection

Inspection. No visible cracking, shrinking, or slumping occurred in the K5NA ablation compound after installation (Figure 11). The section that was applied over Teflon tape was removed 22 hours after the completion of the K5NA application. Visual inspection showed a continuous void approximately 0.125-in. thick along the pin retainer band-to-sheet cork adhesive bondline (Figure 12).

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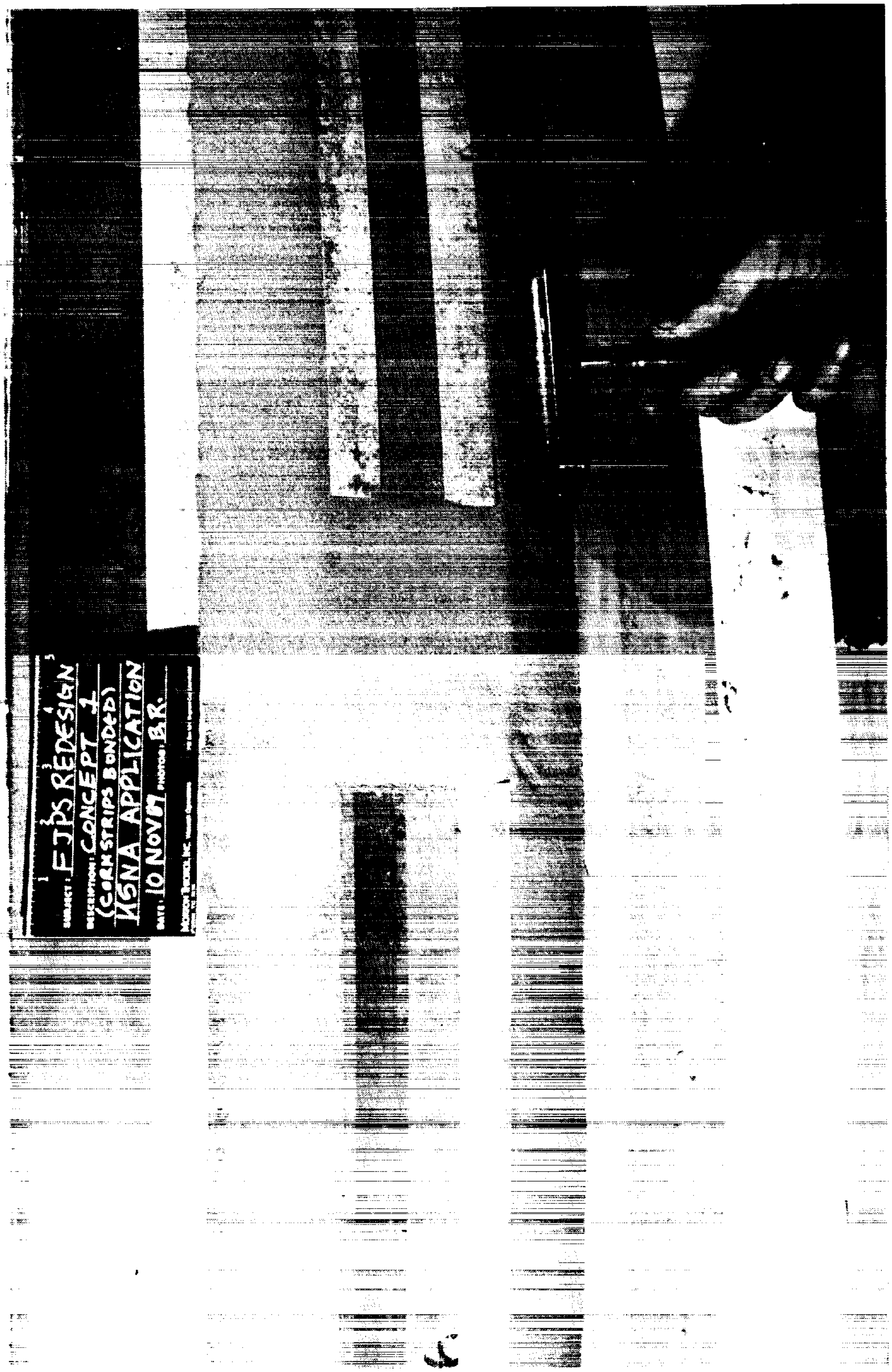

Figure 10. Concept 1 of the Redesigned FJPS—K5NA Surface Finishing With Small Teflon-Coated Roller

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Figure 11. Concept 1 of the Redesigned FJPS—Installation Complete

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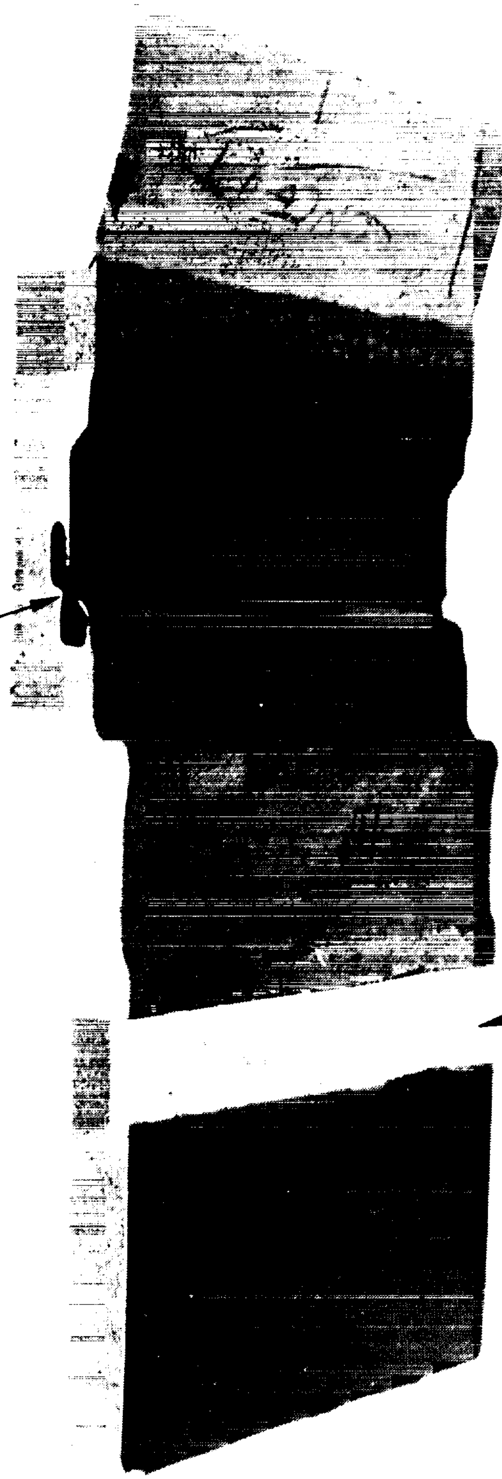

Figure 12. Concept 1 of the Redesigned FJPS—Typical Cross Section

K5NA was not present in some areas of the case/cork corners. This indicated that special attention (small amounts of K5NA pressed firmly into the corners) is required in these areas, instead of applying handfuls of K5NA at a time. Adhesion was adequate across the remainder of the bondline.

Tap/Pull Testing. Three days after the completion of K5NA application, tap testing to locate bondline voids and pull testing to determine bondline integrity were performed on the remaining 270-deg of the installation. Tap testing confirmed that extensive pin retainer band-to-sheet cork adhesive bondline voids existed above and forward of the pin retainer band. These voids were verified by removing cork in a few places to expose the voids. No bondline voids were found in the forward band of cork.

Pull tests were performed in areas where voids were not detected (Tables 3 and 4). All pull test results were above the KSC minimum requirement of 50 psi. The pull test failure modes were either 100 percent cohesive in the cork or a combination of cohesive failure and adhesive failure between the cork and tensile button. The pull testing showed that bondline pressure on the cork was adequate to result in a consistent 360-deg bondline where the cork contacted the case surface.

Cross sections of the Concept 1 configuration were broken apart as close to the sheet cork-to-K5NA bondline as possible. Failure modes were approximately 80 percent cohesive in the cork, 20 percent adhesive at the bondline.

6.4 CONCEPT 3 HORIZONTAL INSTALLATION EVALUATION

Installation Preparation. A Concept 3 configuration was installed overhead onto the horizontally oriented short stack to simulate installation on a TEM. The short stack was positioned with the 0-deg location at the bottom. Two bands of 0.25-in.-thick cork were banded to the case to guide the rolling pin. The bondline surface was abraded, blacklight inspected for contamination, and solvent cleaned prior to K5NA application. The 90-deg of case surface required approximately 1.5 hours of preparation time prior to K5NA application.

Installation. K5NA was applied from the systems tunnel, 90-deg, towards 0-deg (the same 90-deg area where the Concept 1 configuration was installed over Teflon tape) (Figure 13). The K5NA was installed directly to the case surface. Application was performed with the single nylon rolling pin, which was wetted while rolled over the K5NA/plastic poly surface (the K5NA surface was not wet). Two roller guides improved application as compared to the single guide used for the vertical installation. Rolling the K5NA in a downward motion tended to pull the material behind the roller away from the case; future installations should be performed with application beginning at the bottom, working upward.

Table 3. Concept 1--Pull Test Data for Forward Cork Band

Specimen No.	Ultimate Load (lb)	Ultimate Stress (psi)	Cohesive Failure Mode (%)
1	270	231	100
2	130	111	50
3	260	222	100
4	300	256	95
5	275	235	100
6	280	239	100

Note: Only percentage of cohesive is listed. The remaining failure is adhesive between the cork/K5NA and tensile button. The high amount of adhesive failure is due to an irregular surface and using a low-viscosity cyanoacrylate adhesive.

Table 4. Concept 1--Pull Test Data for Aft Cork Band

Specimen ID	Ultimate Load (lb)	Ultimate Stress (psi)	Failure Mode (%)		
			Adhesive Failure		
			Tensile Button	Pin Retainer Band	Cohesive Cork Failure
A	475	406	60	--	40
B	400	342	50	--	50
C	300	256	--	45	55
D	500+	427+	5	--	95
E	500+	427+	40	--	60
F	500+	427+	30	--	70
G	500+	427+	--	95	5
H	500+	427+	--	100	--
I	500+	427+	--	90	10
J	500+	427+	--	95	5

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Figure 13. Concept 3 of the Redesigned FJPS—Horizontal Installation, Single Nylon Rolling Pin Over Plastic Film

The plastic film was left on the K5NA surface during cure. Utility tape was strapped across the plastic film surface to provide additional support for the K5NA. Because the application was performed overhead, this application of the K5NA was particularly strenuous for the four people performing the work.

Installation Temperature. The room and case surface temperatures varied between 50° and 55°F. The unmixed K5NA was warmed by the facility heater prior to mixing/applying. It was found that, when in a cold environment, warming the K5NA prior to mixing improved its adhesive properties and contour shaping ability.

Timelines/Pot Life/Personnel/Material. The application took just over 2 hours to complete. Eight batches of K5NA were applied over the 90-deg area. As application became more difficult toward the bottom of the case, several batches were worked beyond their 30-minute pot life. Four people were required to perform the installation.

Post-Cure Inspection. A small portion of the K5NA became unbonded during cure, resulting in a separation, approximately 3-in. square, between the K5NA and the case. No additional slumping, no cracking or shrinking was visible.

Two days after the completion of K5NA application, tap testing to locate bondline voids and pull testing to determine bondline integrity were performed. Other than the 3-in. square edge separation, no voids were located during the tap testing.

Pull tests were performed in various locations (Table 5). The failure modes were a combination of K5NA cohesive failure and adhesive failure between the K5NA and the tensile buttons.

Table 5. Concept 3 Vertical Installation--Pull Test Data

Specimen No.	Ultimate Load (lb)	Ultimate Stress (psi)	Cohesive Failure Mode (%)
13	205	175	5
14	190	162	5
15	220	188	5
16	290	248	7
17	425	363	40

Note: Only percentage of cohesive failure is listed. The remaining failure is adhesive between the cork/K5NA and tensile button. The high amount of adhesive failure is due to an irregular surface and using a low-viscosity cyanoacrylate adhesive

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APPLICABLE DOCUMENTS

Document No.	Title
ETP-0600	Thiokol/Wasatch FJPS Short Stack Demonstration Test Plan
STW4-2700	Cork, Sheet
STW5-3183	Ablation Compound, Cork-Filled (K5NA)
STW4-3218	Epoxy Resin Adhesive, Non-Asbestos, Structural Bonding (EA 934 NA)
STW7-3260	Ablation Compound, Cork-Filled, Application and Cure of
STW7-3631	Cork Insulation Installation, Process Finalization
TWR-50044	Redesigned Solid Rocket Motor Field Joint Protection System Technical Interchange Meeting

Military Std	Title
MIL-S-8802	Type I Class B-2 Sealant (PR 1422 Polysulfide)

Drawing No.	Title
7U76603	Short Stack Assembly, FJPS
1U82836	Insulation, Extruded Cork
TUL-16825	FJPS Vertical Demonstration

APPENDIX A

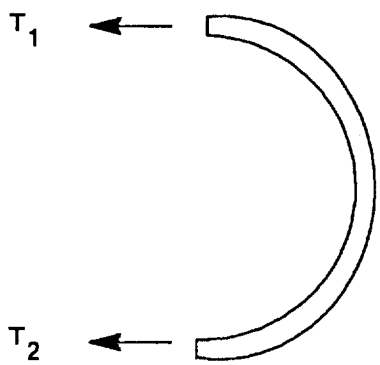
Radial Force Applied to Cork During Bonding With Steel Strapping Bands

Appendix A

Radial force applied to cork during bonding with steel strapping bands

Assuming radial force will be at a minimum 180-deg from the tensioning tool and tensioning tool force = 700 lb

Consider a 180-deg section of one steel strapping band



T_1 location near tensioning tool

T_2 180 deg from tensioning tool

$T_1 > T_2$

$$\frac{T_1}{T_2} = e^{f\theta}$$

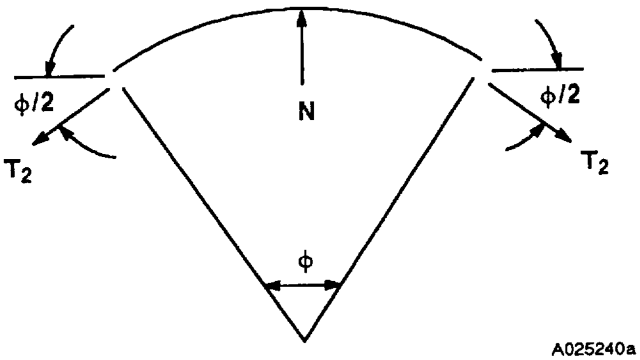
From: *Fundamentals of Machine Component Design* (pg 581) by Robert C. Juvinal, John Wiley and Sons, 1983

Where f = coefficient of friction for Teflon/steel
f = 0.04, *Mark's Standard Handbook for Mechanical Engineers*, Baumiester, Avallone, Baumiester, 1979

θ = angle of contact
= 180 deg = π radians

$$T_2 = \frac{T_1}{e^{f2}} = \frac{700 \text{ lb}}{e^{(0.04)\pi}}$$ = 617 lb, tension in band 180 deg from tensioning tool

Radial force: consider a free body diagram of a 1-deg section at 180-deg



Assume band tension does not vary significantly over a 1-deg section

ϕ = 1 deg = 0.1745 rad

$\Sigma Fy = O = N - 2T_2 (\sin \frac{\phi}{2})$

$N = 2T_2 (\sin \frac{\phi}{2}) = 2(617) (\sin \frac{0.01745 \text{ rad}}{2})$

N = 10.81 lb, radial force applied by band, 180-deg from tensioning tool

At tensioning tool:

$N = 2(700 \text{ lb}) (\sin \frac{0.01745 \text{ rad}}{2})$

N = 12.22 lb, radial force applied by band, at tensioning tool

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