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SPACE SHUTTLE

Solid Rocket Motors
Thiokol Corporation

PHASE II - TESTING FOR FULL-SCALE PROCESS EVALUATION OF INSULATION EDGE SEPARATIONS AND VOIDS IN THE (TANG) FLAP AREA

FINAL REPORT

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Process Engineering Technical Report Categories

Aft Segment	Contamination
Center Segment	Forward Segment
Bond and Void Problems	Grit Blasting
Delaminations	Rubber, NBR
Insulation	Void
Adhesives	Vulcanization
Surface Preparation	Vacuum Bagging

1.0 INTRODUCTION AND SUMMARY

The second process test article (Phase II) processing and evaluation results are documented in this report. This full-scale investigation identified possible causes and process improvements that could eliminate edge insulation-to-case separations on both the clevis and tang ends. The Phase II test article was to further understand edge separation causes, determine if they are process or operator sensitive, and define refinements that will optimize bonding conditions and eliminate edge separations. Some variables (that would not affect the edge unbond study) were introduced in the tang end testing to attempt to eliminate voids in the flap area.

Phase II testing was controlled by Test Plan WTP-0179, Rev. A, Phase II - Testing For Full-Scale Process Evaluation Of Insulation Edge Separations. This test article was processed as close as possible to standard production practices. Processing progressed from case preparation at the Clearfield H-7 facility through insulation layup and cure at the M-111 facility. All operations were performed by Production personnel. The Phase II process sequence is defined in References 1, 2, and 3. Tables I and II (tang and clevis end test matrices) are provided for a quick reference variable overview.

The variables evaluated in the tang end were:

1. Grit blast dimensional variations of the capture feature
2. Chemlok 233 application thickness variations
3. Separator film with and without holes
4. Layup, ideal and normal
5. Vacuum bag and breather installation to provide tight (bridging), loose, and normal installation.

The variables evaluated in the clevis end were:

1. Normal grit blasting at H-7, and a second (cosmetic) grit blast at M-52 in some sections.
2. The use of three different tapes and no tape to provide the Chemlok edge.
3. Chemlok 233 application thickness variations, Chemlok 233 touchup, and finger contaminated sections of the Chemlok 233 surface.

4. Shear ply layup before mold installation after various Chemlok 233 variations as listed in three above.

5. Layup to standard production procedures, with a silica-filled NBR shear ply and trimming the tip from the forward end of the 3014 extrusion.

Since there were no large or obvious areas of defects (edge separations or voids) to evaluate in this test article, many of the effects from the variables are not apparent.

It is concluded that contamination from bare finger contact on Chemlok 233 adhesive contributes to edge separation. In addition, edge separation detection is a judgmental function and separation detection is very subjective. Grit blasting of the capture feature face and tip is necessary to provide an adequate bond surface to eliminate edge separations.

2.0 CONCLUSIONS

2.1 Clevis End Edge Unbonds

a. Contamination from excessive bare finger contact on the Chemlok 233 adhesive contributes to edge separations.

b. Edge separation detection is a judgmental function and unbond detection is very subjective.

2.2 Tang End Edge Unbonds

a. Not performing the grit blast of the capture feature face and tip contributes to edge unbonds.

2.3 Tang End (Flap Area) Unbonds

a. The unbond variable effect in the flap area was inconclusive.

3.0 RECOMMENDATIONS

It is recommended that:

1. Bare finger contact be prohibited and the use of gloves be required whenever performing operations that might allow bare hand contact with Chemlok 233 adhesive where rubber is to be vulcanized.

2. Edge separation inspection methods and training be well coordinated to assure consistency.

3. Grit blast of the capture feature end and chamfer areas be accomplished and verified on all flight hardware.

4. Additional testing be conducted on full-scale articles to better define causes and methods to eliminate voids in the flap area (including the use of MEK as a raw calendered rubber activator).

4.0 DISCUSSION

4.1 General

The grit blast variables on the clevis end compared the H-7 Flight 3 (and subsequent) extended grit blast and the optional M-52 Flight 3 grit blasts to determine if the M-52 grit blast had any effect on edge unbonds. Silane primer was introduced in one section to evaluate if it had any effect on edge unbonds. The grit blasting dimension variables of the tang end capture feature were (Figure 1): 1) no blasting from the flat parallel to the case section aft (Dimension C), 2) to the capture feature face (Dimension A), and 3) the chamfer beyond the capture feature face (Dimension B) (Figure 1).

Three different masking tapes (3M #219, 3M #218, and Permacel 703) and no masking tape (in two sections) were used to provide the Chemlok termination line on the clevis end to determine:

1. If there was an edge effect because of tapes.

2. If there were differences from tape to tape.

3. If there was a better edge bond when no tape was used.

Chemlok 233 adhesive was applied in various thicknesses (heavy, medium, and light) on each end in specified areas to determine the effect of adhesive thickness on edge separations. Cobwebbing of adhesive was to be accomplished on six sections of the tang end, but new spray equipment had recently been acquired and cobwebbing could not be achieved at the time of this test. Chemlok touchup using the air brush (as used for process finalization on production segments) was achieved in several specified sections of the clevis end.

Two sections that were protected from Chemlok 233 adhesive application during the adhesive application operation and one section that had previously had adhesive applied, then contaminated by finger contact, had Chemlok 233 spray applied, normal (30 minute minimum) dry time and shear ply applied immediately. This was accomplished to determine if a fresh surface (no chance of Chemlok adhesive contamination) provided a better edge bond effect. The previously mentioned and one other section of Chemlok 233 adhesive had three operators rub their fingers extensively over the first one inch (from the clevis forward Chemlok line) of the Chemlok 233 adhesive. This was to determine if accidental bare finger contact on the adhesive contributes to edge separations.

During the subsequent preparation of this article, no edge separation variables were introduced on the tang end in the Phase II test. The clevis end, as discussed above, had several sections that had the shear ply laid on the case wall just prior to installation of the mold ring. This variable was included to assure proper location of the shear ply by locating it on the case before the mold ring application and thus, no sliding (scuffing) along the Chemlok surface would occur during the cure.

Three specified sections had the forward ¼-in. of the 3014 extrusion trimmed off before the shear and tie plies were installed prior to extrusion installation. These sections were to determine if edge separations were affected where excess rubber flow had been required.

Six sections received the current normal layup with asbestos NBR shear and tie plies being placed on the 3014 extrusion (as were the trimmed extrusion sections). These sections were to serve as a control sample for flow and edge layup evaluations. One section had a silica NBR shear ply over the extrusion. This section was to determine if the non-asbestos NBR (shear ply) provided any flow or edge bond advantages over the asbestos NBR sections.

To take full advantage of the test article, several variables were introduced to evaluate their influences on voids on the tang flap area. Punched hole, pin prick, and normal FEP films were used to form the flap. The films containing the holes were to evaluate if some entrapped air vertical movement would reduce voids beneath the flap. The ideal layup (extra rolling) was conducted in two sections to determine if there would be a reduced number of voids in these sections.

The pattern and breather cloths were installed in three controlled methods to determine if extreme bridging over the flap area (especially on each side of the flap terminus) increased or eliminated voids, as follows:

1. Four sections had the cloth stretched extremely tight, causing bridging,

2. Four sections had two-piece pattern and breather to allow slippage during debulk and loose (tucks to allow movement during debulk) nylon bagging film to ensure that the vacuum bag system absolutely did not bridge,

3. Pattern cloth, breather cloth, and nylon vacuum bag were installed per production procedures to serve as a control for vacuum bag system installation methods.

4.2 Processing

4.2.1 Grit Blasting

The test segment had previously been grit blasted to remove the Chemlok 205 and 233 from a prior use. The controlled grit blasting addressed in this report is the cosmetic or cleanup grit blast that normally occurs after hydrotest at H-7.

a. Tang End - The tang end of the test segment was masked to ensure the zirconium blasting was controlled as outlined in the Tang End Test Matrix (Table I) and in the Capture Feature Masking Schematic (Figure 1). Section 6 that was to receive "none" was masked to ensure that no grit blasting occurred 7 to 7.5 inches from the capture feature tip forward.

b. Clevis End - The clevis end of the test segment was masked to control zirconium grit blasting from 0.95 to 1.05 inch from the tip of the ID clevis leg forward 19.0 to 20.0 inches.

4.2.2 Special Surface Preparation

Silane primer was brush applied to the first 19 to 20 inches of clevis end of section 15.

4.2.3 Masking Tape Type (Clevis End)

The Chemlok 205 and 233 aft edge is controlled by masking tape being applied to the desired dimensional line. 3M-#219 is normally used in production segments. This testing also used 3M-#218 (Permacel masking tapes) and two sections with no masking of this edge. The locations of the usage of the different tapes was per section specified in the Clevis End Test Matrix (Table II) and degree locations as indicated in Figure 2. The one-inch masking to prevent application of Chemlok 233 adhesive during the original adhesive application was accomplished by overlapping 3M-#219 masking tape over the edge of a strip of FEP film. Tape was then placed along the one-inch line of Chemlok 205 primer. This was accomplished to prevent tape residue from contaminating the critical ½-in. of the edge bond.

4.2.4 Chemlok Application

The Chemlok 205 application to both the tang and clevis end was per standard shop practice and was applied at a fairly high viscosity (approximately 0.4 mil thick) with no variables introduced. Since this testing was to evaluate edge unbonds, the tang end had the Chemlok system applied for the first six to seven inches and the clevis end had the Chemlok system applied to the first 19 to 20 inches. Variables in the Chemlok 233 adhesive were in the sections as outlined in the test matrices (Tables I and II) and located per Figure 2. Each coat of Chemlok 233 adhesive is considered to be 0.10 mil thick. The heavy, medium, and light coats are defined as follows:

Heavy - Approximately 1.0 mil thick

Medium - Approximately 0.2 mil thick

Light - Approximately 0.1 mil thick

a. Tang End - Cobwebbing was planned to be accomplished in this testing by holding the spray nozzle further from the segment surface than normal. We were not successful in producing cobwebbing during this testing; therefore, this variable was not evaluated in these tests.

b. Clevis End - Chemlok 233 touchup was accomplished where specified by spraying it over the top of previously applied coats of Chemlok 205 and Chemlok 233. On the sections where adhesive (Chemlok 233) was applied and allowed its normal dry time, the tie ply was laid up immediately in the assembly stand just prior to the mold ring installation.

The required "finger contamination" of the one-inch adhesive sections was also accomplished just prior to the mold ring installation.

NOTE

Finger contamination was accomplished by three operators rubbing their fingers extensively over the first inch (from the clevis forward Chemlok line) of the Chemlok 233 adhesive.

4.2.5 **Rubber Layup**

NOTE

MEK was used to activate all NBR patterns in the tang flap area of this test article. MEK was used to enhance pattern-to-pattern tack and to evaluate if this better green tack would reduce or eliminate voids in this area.

a. Tang End - Normal layup was considered to be per the normal manufacturing technique (pattern placement, activation, rolling, etc.). Normal pattern layup was accomplished in sections 1 through 4, and 7 through 16. Ideal layup was considered to be taking extra precautions in placement of patterns and taking extra effort to roll down and remove air to perfection. Ideal pattern layup was accomplished in sections 5 and 6.

(1) Flap separator was laid into the layup at the normal placement and time as a normal production segment.

(a) Normal etched FEP film in sections 1, 4 through 7, 10, 15, and 16.

(b) Punched hole (0.045-in. on ½-in. centers) film in sections 2, 8, 11, 13, and 14.

(c) Pin prick (on ¼-in. centers) film in sections 3, 9, and 12.

b. Clevis End - The variations in the clevis layup were to the 3014 extrusion or the shear/tie plies.

(1) The asbestos NBR shear ply was laid on the case clevis end before the installation of the clevis mold ring in sections 1, 2, and 11 through 14.

(2) The forward ¼-in. tip of the 3014 extrusion was trimmed off the shear and tie plies installed in sections 3 through 5.

(3) A silica NBR shear ply was used in section 10. It was installed onto the 3014 extrusion before layup as to the normal manufacturing method that uses an asbestos shear ply.

NOTE

The silica NBR rubber used in this testing was from another program. The manufacturer of the prior evaluated Space Shuttle silica NBR rubber and the tested silica NBR rubber was very similar and would serve as equals for this testing.

(4) Installation of asbestos-filled NBR shear plies onto the 3014 extrusion before layup (current manufacturing method) was conducted in sections 6 through 9, 15, and 16.

4.2.6. **Vacuum Bag System Installation**

a. Tang End

(1) Bridging Of The Pattern Cloth, Breather Cloth, And Nylon Film - This was accomplished by installing each to ensure they stretched tightly especially over the flap terminus buildup.

(2) Loose, Two-Piece Pattern, Breather Cloths, And Loose Nylon Film - The two-piece pattern and breather cloths were installed to meet and overlap over the flap terminus area. The nylon film was installed with tucks at the edge of the flap terminus edges to allow for excessive debulk.

(3) Normal - This was per standard production practices of cloth and nylon bag installation.

b. Clevis End

Per normal standard production practices.

4.3 Evaluation

4.3.1 Clevis End

a. Flashing Flow Observation After Mold Ring Removal

(1) Sections 1, 2, and 11 thru 14 had the asbestos NBR shear ply installed on the clevis leg just prior to the clevis mold ring installation and had more than normal flashing.

(2) Sections 3, 4, and 5 had the forward ¼-in. tip of the 3014 extrusion trimmed off before the tie plies were installed. The flashing in this area was near nonexistent. However, the clevis tip was fully formed.

(3) Sections 6 thru 9, 15, and 16 were laid up to the current normal layup process. The flashing was good (normal) flow.

(4) Section 10 had a silica NBR tie ply installed as per normal layup. The flashing was more than normal in this area.

An adequate flash seems to have a relationship to rubber bond at the adjacent molded surface. Where there is a definite bead of flashing, an adequate bond is apparent. Where flashing is minimal, edge unbonds are frequent.

b. Clevis Unbond Probe Results

(1) Probe results for before and after exercising are provided as Table III. Discounting the unbonds that were caused by the use of Teflon tape, the only variable that demonstrated contributing to clevis unbonds was finger contamination in section 9.

4.3.2 **Tang End**

a. The flashing flow was well into the capture feature O-ring groove the full circumference of the tang end.

b. Tang Unbond Probe Results

(1) Probe results for before and after exercising are provided as Table IV. There were no unbonds before exercise, one after exercising checking with a hand probe, and four after exercise using shimstock. These unbonds were felt to be random, not resulting from any variables introduced in this study.

c. X-Ray Results - Void Detection

(1) X-ray was conducted on the forward 28 inches of the tang area. The detected low density areas and unbonds are provided as Attachment I. NDE Quality Engineering reviewed all film from this test segment and provided the table as Attachment I. This table only reports five defects with the ones at 56, 192, and 201 degrees felt to be comparable with the three detected by dissection. Low density bonds were detected intermittently throughout which are most likely density differences per NDE.

d. Dissection Results - Void Detection

(1) Sections 2, 3, 6, and 9 (22.5-67.5, 112.5-135, and 180-202.5 degrees) were dissected into approximate ½-in. strips extending longitudinal to the case. The defect mapping of these sections are provided in Table V. These were considered to be minor in effect of the final product.

The variables in the flap separators were inconclusive because there were more defects in the areas of the pin prick film than on the no punched or punched hole film. Since the pin prick is the middle of the separator variables, this indicates a need to reevaluate the film in Phase III testing. The variables of vacuum bag system installation did not produce any obvious defects or advantages in voids in this study. Therefore, no viable conclusions were made in eliminating voids in the flap area.

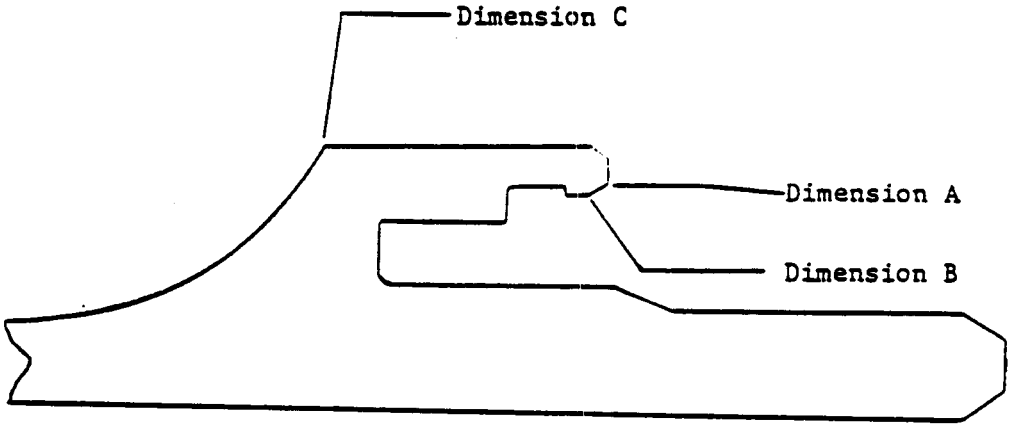

Figure 1. Capture Feature Masking Schematic

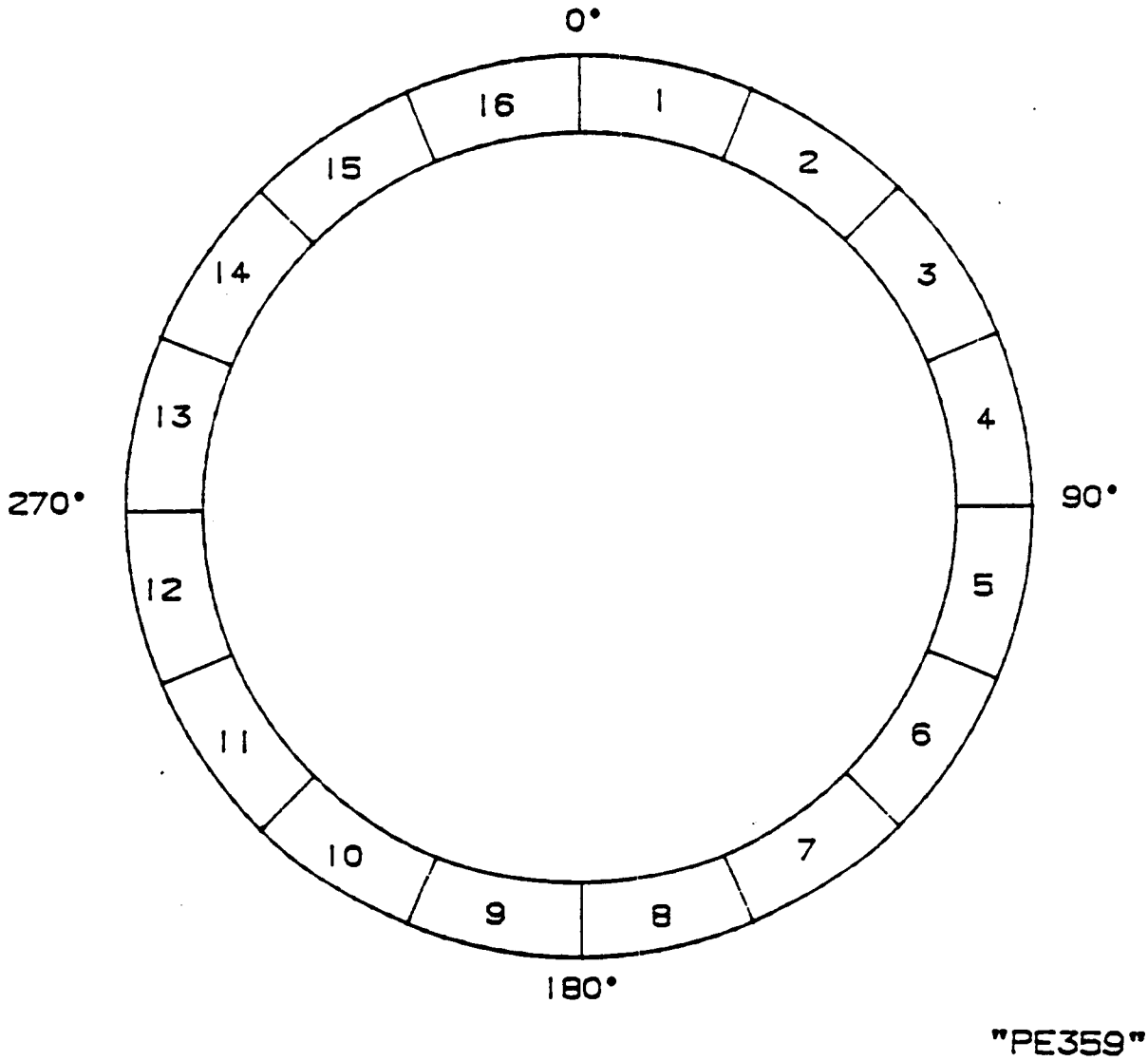

Figure 2. Full-Scale Article Section Layout Aft and Forward View

TABLE I. Tang End RSRM Edge Separation Full-Scale Article Test Matrix

TANG END

SECTION NO.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
GRITBLAST																
Extended																
A Dimension		X	X								X	X				
B Dimension				X												
C Post Normal	X				X		X	X	X	X			X	X	X	X
None						X										
CHEMLOK (233)																
Heavy					X			X			X					
Light						X	X		X			X				
Medium	X	X	X	X						X			X	X	X	X
Spider Webb						X		X	X	X	X	X				
FLAP (FEP) SEPARATOR																
Normal	X			X	X	X	X			X					X	X
Punched Hole (.045 inch on 1/2 inch centers)		X						X			X		X	X		
Pin Prick (on 1/4 inch centers)			X						X			X				
LAYUP																
Ideal (extra rolling)					X	X										
Normal (MFG. technique)	X	X	X	X			X	X	X	X	X	X	X	X	X	X
VACUMN BAG & BREATHER																
Bridge (of breather system and nylon film at step off of flap terminus)						X	X	X	X							
Loose (2 piece pattern & breather, also loose nylon film bag)											X	X	X	X		
Normal (bagging above step terminus)	X	X	X	X	X					X					X	X

NOTE EACH SECTION IS 22.5 DEGREES, NO.1 STARTING AT 0 DEGREES AND NO.16 ENDING AT 360 DEGREES.

"PE277"

TABLE II. Clevis End RSRM Edge Separation Full-Scale Test Article Test Matrix

CLEVIS END

SECTION NO.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
SURFACE PREP																
o GRIT BLAST AT H-7 TO FLIGHT 3 DIMENSIONS	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
o M-52 FLIGHT 3 COSMETIC GRIT BLAST	X	X			X	X	X		X	X						
o SILANE PRIMER															X	
TAPE(MASKING)																
3M-#219	X	X	X	X	X		X		X		X					
3M-#218														X		
PERMACEL						X		X		X		X			X	
NONE													X			X
CHEMLOK (233)																
MASK 1" FROM START OF 205, INWARD	X	X														
o VARIED THICKNESSES																
HEAVY				X	X											
MEDIUM	X	X					X	X	X	X	X		X	X	X	X
LIGHT			X			X						X				
CONTAMINATE 1" INWARD ONTO 233 WITH FINGERS									X		X					
CHEMLOK TOUCHUP				X 1/2							X		X 1/2			X 1/2
LAYUP																
APPLY 233, NORMAL DRY, THEN LAYUP TIE PLY IMMEDIATELY	X	X									X					
TRIM OFF EXTRUSION TIP			X	X	X											
Current Method ASBESTOS/NBR TIE PLY LAYUP PROCESS						X	X	X	X						X	X
SILICA NBR TIE PLY LAYUP PROCESS										X						
LAYUP (ASBESTOS/NBR) SHEAR PLY BEFORE INSTALLATION OF MOLD RING	X	X									X	X	X	X		

NOTE: EACH SECTION IS 22.5 DEGREES, NO.1 STARTING AT 0 DEGREES AND NO.16 ENDING AT 360 DEGREES

"PE276"

TABLE III. Clevis End, Edge Separation, Probe Results

Probe Results - Before Exercising (Using Missile Tool)

Defect Degree Location	Circumferential Length (in.)	Longitudinal Depth (in.)
65	0.25	0.040
185	0.25	0.075
299	0.25	0.050
307	0.25	0.025

Probe Results - After Exercise (Using Shim Stock)

Defect Degree Location	Circumferential Length (in.)	Longitudinal Depth (in.)
70	0.100	0.050
* 112.5	0.300	0.065
* 114	0.630	1.750
* 180	0.700	1.000
* 182	0.800	0.200
183	0.350	0.075
183.5	0.800	0.200
184	0.350	0.075
189	0.900	0.050
* 332-334	2.0	1.68 Avg

*Teflon tape was felt to have caused this defect.

NOTE

Teflon tape was placed between the Chemlok adhesive and the rubber layup as follows:

.5-in. wide x 3-in. at approximately 180 degrees
1.0-in. wide x 3-in. at approximately 112 degrees
2.0-in. wide x 3-in. at approximately 337 degrees

This tape was placed for ultrasonic inspection equipment testing.

TABLE IV. Tang End, Edge Separation, Probe Results

Probe Results - Before Exercise (Using Shimstock)

Defect Degree Location	Circumferential Length (in.)	Longitudinal Depth (in.)

No unbonds detected.

Probe results - After Exercising (Using A Hand Probe)

Defect Degree Location	Circumferential Length (in.)	Longitudinal Depth (in.)
170	.250	.050

Probe Results - After Exercising (Using Shimstock)

Defect Degree Location	Circumferential Length (in.)	Longitudinal Depth (in.)
147	.300	.030
149.5	.150	.030
166	.100	.050
170	.300	.050

TABLE V. Dissection Defect Mapping

Approximate Location Degrees	Distance From ID Case Wall (in.)	Distance Fwd Or Aft From Flap Terminus (in.)	Longitudinal Lenth Of Void (in.)	Depth Of Void (in.)	Circumferential Length (in.)
56.5	.320	5.0 Aft	0.78	0.020	0.84
60	.180 - .200	7.2 Fwd	0.34	0.025	0.45
62	.180 - .200	7.2 Fwd	0.32	0.010	0.28
197.5	.190	3.3 Aft	3.2	0.045	0.76
200	.7	5.4 Aft	0.32	0.005	0.4

NDT, X-RAY REPORT

ATTACHMENT I

Thiokol CORPORATION
SPACE OPERATIONS

SERIAL NO.	PART NAME	PART NO.	DATE	GROUP LEADER/FOREMAN REVIEW	PAGE
0000028	Process Cylinder	1U51633-14	12-10-89	Dat Lar / DCB	1 of 1

FILM I.D.			DISCONTINUITY				DISCONTINUITY SIZE					
FILM POSITION (SECTION)	INSP. AREA T-TANGENT B-BODY R-RADIAL	DEG	SPECIFICATION NO. / JOB NO. / PROJECT NO. / INDICATION IDENTIFICATION AND DESCRIPTION	LDI-OD	Dist- Term	FIRST READER'S INITIAL	REVIEW READER'S INITIAL	LENGTH (LONG)	WIDTH (CIR)	DEPTH (RAD)	CLASSIFICATION
V-2	T	all	Low density bands intermittent throughout, mainly on the 304" film These bands are not well defined and are mostlikely density differences in the plys of rubber.								
		18	Void/Unbond	.52	1.5 Aft	DT	DCB	3.7		.10	
		56	Void/Unbond	.75	4.9 Aft			.85		.04	
		91	Void/Unbond	.54	0			6.4		.17	
		192	Void/Unbond	.97	3.2 Aft			3.18		.04	
		201	Void/Unbond	.61	5.2 Aft	DT	DCB	.59		.003	

LEGEND

LDI-OD: Distance to case outside diameter.

DIST-TERM: Distance to flap terminus.

LENGTH: Longitudinal length of void or unbond.

DEPTH: Depth of void or unbond.

NOTE: Circumferential extent was not furnished in this report because of x-ray's inability to furnish accurate circumferential measurements.

FORM TC 1558 (REV 12-83)

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2) Manufacturing Plan, CPI 4BBSV, Part Number 1U51633-14, SN 0000028, Morton Thiokol, Inc., December 1988

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