ATK
ALLIANT TECHSYSTEMS
THIOKOL PROPULSION

CRITICAL ITEMS LIST (CIL)

No. 10-02-01-05R/02

SYSTEM:	Space Shuttle RSRM 10	CRITICALITY CATEGORY:	1
SUBSYSTEM:	Nozzle Subsystem 10-02	PART NAME:	Aft Exit Cone (1)
ASSEMBLY:	Nozzle and Aft Exit Cone 10-02-01	PART NO.:	(See Section 6.0)
FMEA ITEM NO.:	10-02-01-05R Rev M	PHASE(S):	Boost (BT)
CIL REV NO.:	M (DCN-533)	QUANTITY:	(See Section 6.0)
DATE:	10 Apr 2002	EFFECTIVITY:	(See Table 101-6)
SUPERSEDES PAGE:	315-1ff.	HAZARD REF.:	BN-04, BN-05
DATED:	31 Jul 2000		
CIL ANALYST:	B. A. Frandsen		
APPROVED BY:		DATE:	

RELIABILITY ENGINEERING: K. G. Sanofsky 10 Apr 2002

ENGINEERING: B. H. Prescott 10 Apr 2002

1.0 FAILURE CONDITION: Failure during operation (D)

2.0 FAILURE MODE: 2.0 Structural failure of the metal housing

3.0 FAILURE EFFECTS: Breakup causing loss of nozzle, RSRM, SRB, crew, and vehicle

4.0 FAILURE CAUSES (FC):

FC NO.	DESCRIPTION	FAILURE CAUSE KEY
2.1	Nonconforming dimensions	
2.1.1	Initial manufacturing dimensions	A
2.1.2	Metal dimensions reduced by corrosion and/or refurbishment	B
2.2	Nonconforming material	
2.2.1	Improper heat treatment	C
2.2.2	Nonconforming voids, inclusions, or other material defects	D
2.3	Fatigue	E
2.4	Stress-corrosion cracking	F
2.5	Transportation, handling, and assembly damage	G

5.0 REDUNDANCY SCREENS:

SCREEN A: N/A
SCREEN B: N/A
SCREEN C: N/A

6.0 ITEM DESCRIPTION:

1. Aft Exit Cone Shell is a part of the Exit Cone Assembly-Nozzle, Aft that consists of metal components (Figures 1 and 2). Materials are listed in Table 1.

TABLE 1. MATERIALS

Drawing No.	Name	Material	Specification	Quantity
1U79157	Exit Cone Assembly-Nozzle, Aft			1/motor
1U52842	Shell, Exit Cone, Aft	7075-T73 or 7075-T7351		1/motor
	Forgings, Mandrel and Rolled Ring, Aluminum	Aluminum Forging Alloy (7075), Space Shuttle Solid Rocket Motor	STW3-3155	A/R
	Corrosion-Preventive Compound and O-Ring Lubricant	Heavy-Duty Calcium Grease	STW5-2942	A/R
	Primer Coating, Corrosion-Resistant, Epoxy Resin	Corrosion-Resistant Epoxy Primer	STW5-2914	A/R
	Enamel Protective Coating, Epoxy Resin	Enamel-Protective Epoxy Resin	STW5-2922	A/R
	Chemical Coating	Alodine 1200 Chemical Coating	MIL-C-5541, Class 1A	A/R

6.1 CHARACTERISTICS:

1. The aft exit cone shell is an aluminum forging. It is attached to the forward exit cone.

2. Waiver RWW0533 provides flight rationale regarding the detection capability of penetrant inspection of nozzle aluminum parts. Affected nozzle aluminum parts include the Aft Exit Cone, Compliance Ring, Cowl Housing, and Actuator Bracket. Various levels of penetrant inspection performed on nozzle aluminum hardware may not reliably detect critical flaw sizes. A minimum flaw of 0.100 inches was assumed for capability of the penetrant inspection and was used in the fracture mechanics analysis per TWR-16875. Recent testing of effects of the glass beaded and grit blasted bonding surfaces suggest that these manufacturing processes impact crack detection capability. The waiver allows for the use of the identified nozzle parts.

   Nozzle Aluminum Hardware along with applicable flaw data are provided in the table below.

COMPONENT	FRACTURE CRITICAL	MINIMUM CRITICAL INITIAL FLAW SIZE	INITIAL CRITICAL FLAW SIZE (3-SIGMA FLIGHT LOADS)	CRITICAL FLAW SCREENING TECHNIQUE	IS WAIVER REQUIRED
Compliance Ring	Yes	0.54 corner crack (bolt holes)	>1.2 inches	Penetrant (1)	Yes
Aft Exit Cone	Yes	0.67 thru (joint 1)	>2.0 inch	Penetrant	Yes
Actuator Bracket	Yes	0.52 corner crack (bushing hole)	>1.2 inch	Penetrant	Yes
Nose Inlet Housing	Yes	0.36 thru (joint 2 bolt holes)	N/A	Proof Test	No
Cowl Housing	Yes	0.42 through (holes)	N/A	Penetrant (only new parts)	Yes
Snubber	No	N/A	N/A	N/A	N/A

(1) Bolt holes are fail safe

Flight rationale is based on the following:

New Hardware-Manufacturing Induced Flaws

New nozzle aluminum parts are forged and ultrasonic inspected (longitudinal) to verify forging is free of sub-surface flaws. This inspection is capable of detecting internal flaws of 0.130 inches diameter or larger. Etching, per aerospace industry standards (up to 0.0004 inches), is performed and immediately followed by penetrant inspection. Penetrant inspection performed on new hardware detected cracks as small as 0.080 inches long.

A crack missed during initial and subsequent inspections could exceed or grow to critical size during flight and/or splashdown to be of concern. The flaw would need to be "smart". To create a smart crack, a flaw would need to be generated during the new hardware fabrication and the flaw must be located in a specific critical location (circumferential and axial). In addition, smart cracks must have a specific critical orientation (longitudinal in right plane and radial in thickness). Critical flaw sizes are relatively large (>0.5 inch). Critical flaw size is based on MEOP loads and for 3 sigma statistical flight loads critical flaw size is over twice as large. A smart crack flaw would have to be missed by all inspections (penetrant, visual, and ultrasonics). The probability of this occurring simultaneously is extremely low.

Refurbishment Hardware - Water Impact Induced Cracks

Nozzle aluminum parts are acceptable for reuse provided they meet the requirements of STW7-2863. Dimensional checks, i.e., diameter, lengths, parallelism, etc. screens hardware that saw minor damage from water impact loads. More severe loads result in structural failure (cracks) of the parts. These cracks are easily detected during visual inspection. Aluminum parts receive penetrant inspections in addition to visual and dimensional inspection. Impact damage from debris is detected visually.

Maximum load on nozzle hardware occurs during splashdown. Splashdown loads may cause local yielding that permanently deforms the hardware. Deformed hardware will not meet refurbishment dimensional requirements (roundness, etc.). In addition, higher splashdown loads that exceed material ultimate strength will result in localized structural failure (cracks). Post flight inspections history confirms these cracks are open and readily detectable.

The compliance ring is fail safe in bolt hole areas. Critical cracks in compliance ring bolt holes can propagate to the next hole or through the ligament and not cause failure. Critical flaw size in membrane areas is a 1.28 inch surface crack with actuator stall loads and a 1.22 inch through crack with 3-sigma flight loads (load data from 6 flights, 46.4 kip). Cracks will occur in bolt holes before they occur in the membrane. Compliance rings will be rejected for dimensional non-conformance before stresses are high enough to cause overload cracks due to water impact loads.

The aft exit cone critical flaw size is 0.67 inches long based on CEI design loads (i.e., stall load, MEOP, etc.). Critical flaw size based on 3 - sigma expected loads (load data from 6 flights, 46.4 kip), is 2.0 inches long. Aft exit cones will be out of round and scrapped due to dimensional non-conformance before loads are of the magnitude to initiate cracks.

The actuator bracket critical flaw size is 0.52 corner crack using CEI design loads and minimum part thickness. Critical flaw size, based on 3-sigma actuator loads is 1.2 through crack (load data from 6 flight, 46.4 kip). Water impact damage and other overload conditions create large flaws. Dimensions of the actuator bracket flanges would exceed refurbishment specifications before stresses are high enough to generate cracks.

The cowl housing does not receive non-destructive examination. Damage to the forward end ring and nose inlet housing would occur and be detected prior to or in conjunction with possible damage to the cowl housing. No visible damage to the cowl housing has ever been observed (other than corrosion). Due to low stress levels, critical initial flaw sizes for the cowl are large. Flight loads are well characterized and much less severe when compared to water impact loads. Cracks generated by water impact loading would be wide and visible.

The nose inlet is not included in this wavier. The nose inlet housing meets safe-life requirements through valid proof test.

Demonstrated reliability (with 50% confidence level) of RSRM aluminum hardware, using flight and test motors, is as follows:

Compliance Ring	0.9960
Aft Exit Cone	0.9960
Actuator Bracket	0.9980
Cowl Housing	0.9960

Effectivity for RWW0533 is RSRM 360X046, 360X047, 360X049 and 360X053 through 360X084.

7.0 FAILURE HISTORY/RELATED EXPERIENCE:

1. Current data on test failures, flight failures, unexplained failures, and other failures during RSRM ground processing activity can be found in the PRACA Database.

8.0 OPERATIONAL USE: N/A

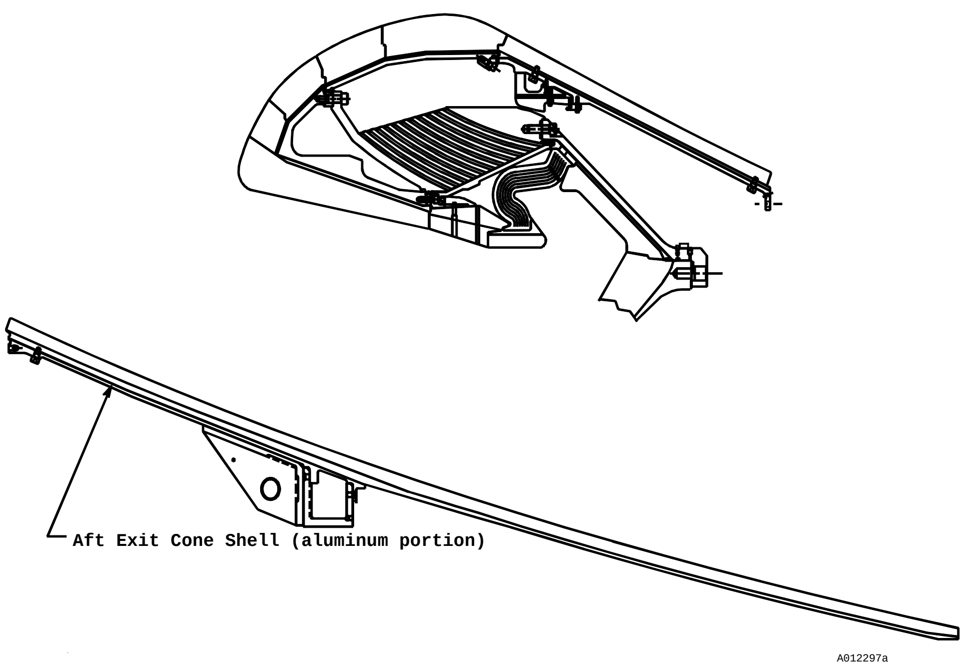

Figure 1. Aft Exit Cone Shell (Aluminum Portion) Location

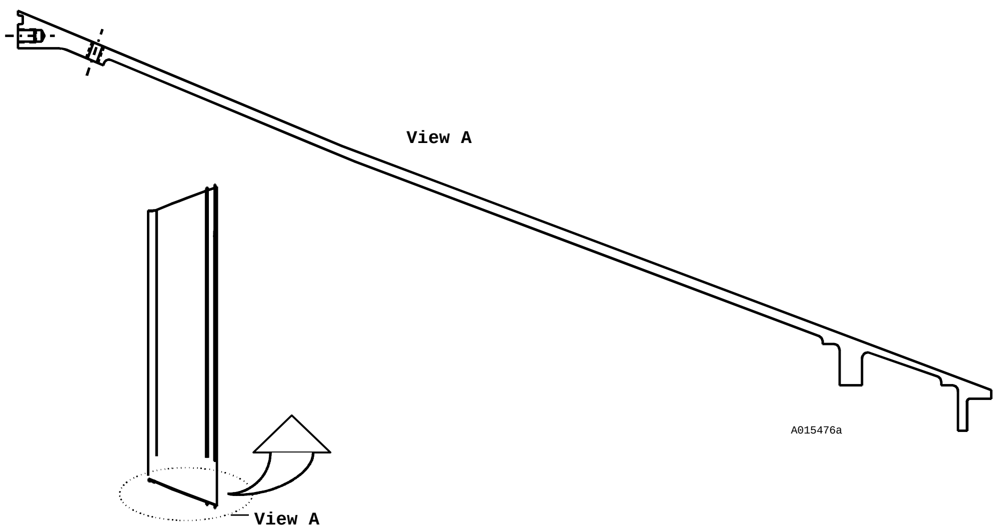

Figure 2. Aft Exit Cone Shell (Aluminum Portion)

9.0 RATIONALE FOR RETENTION:

9.1 DESIGN:

DCN	FAILURE CAUSES	
A,B	1.	Aft exit cone shell dimensions are per engineering drawings.
A,B	2.	Refurbished aft exit cone shell dimensions are per engineering.
A,B	3.	Paint primer and white paint coating are applied to aft exit cone shell surfaces.
A,B	4.	Alodine coating is applied to aft exit cone surfaces.
A,B,C,D,E,F	5.	The aft exit cone shell shows a positive margin of safety based upon safety factors of 1.4 ultimate and 1.1 on yield per TWR-16975.
C,D,E,F	6.	Aluminum alloy material 7075-T73 or 7075-T7351 composition and heat treatment are per engineering. This material is resistant to stress-corrosion cracking per MSFC-SPEC-522.
C,D,E,F	7.	Analysis for useful life of the aft exit cone shell is per TWR-16875.
C,D,E,F	8.	Refurbishment of the aluminum aft exit cone shell is per engineering drawings and specifications.
C,D,E,F	9.	The basic forging was analyzed per JSC Specification SE-R-0006 and reported in TWR-10725. This report shows the forging to be free of re-entrant or sharply folded lines, and that the principal grain flow is oriented parallel with principal stresses.
C,D,E,F	10.	Design verification analysis shows that the materials and geometry of the aft exit cone shell are acceptable for flight per TWR-18764-11.
C,D,E,F	11.	As part of the post-flight inspection plan, char and erosion of the nozzle insulation is inspected and analyzed. If char and erosion of the insulation is determined to be such that the supporting aluminum housing was exposed to high temperature, the suspect housing is analyzed. For Qualification and Production Verification motors, these char and eroding data are recorded per TWR-16473. For flight motors these data are recorded per TWR-50051.
G	12.	Transportation and handling of nozzle assembly items by Thiokol is per Thiokol IHM 29.
G	13.	The RSRM and its component parts, when protected per TWR-10299 and TWR-11325 are capable of being handled and transported by rail or other suitable means to and from fabrication, test operational launch, recovery or retrieval, and refurbishment sites.
G	14.	Positive cradling or support devices and tie downs that conform to shape, size, weight, and contour of components to be transported are provided to support RSRM segments and other components. Shock mounting and other protective devices are used on trucks and dollies to move sensitive loads per TWR-13880.
G	15.	Support equipment used to test, handle, transport, and assemble or disassemble the RSRM is certified and verified per TWR-15723.
G	16.	The nozzle assembly is shipped in the aft segment. Railcar transportation shock

and vibration levels are monitored per engineering and applicable loads are derived by analysis. Monitoring records are evaluated by Thiokol to verify shock and vibration levels per MSFC Specification SE-019-049-2H were not exceeded. TWR-16975 documents compliance of the nozzle with environments per MSFC specifications.

G 17. Analysis is conducted by Thiokol engineering to assess vibration and shock load response of the RSRM nozzle during transportation and handling to assembly and launch sites per TWR-16975.

E,F,G 18. Analysis of carbon-cloth phenolic ply angle changes for the nozzle was performed. Results show that redesigned nozzle phenolic components have a reduced in-plane fiber strain and wedge-out potential per TWR-16975. New loads that were driven by the Performance Enhancement (PE) Program were addressed in TWR-73984. No significant effects on the performance of the RSRM nozzle were identified due to PE.

533 E,F,G 19. Thermal analysis per TWR-17219 shows the nozzle phenolic meets the new performance factor equation based on the remaining virgin material after boost phase is complete. This performance factor will be equal to or greater than a safety factor of 1.4 for the aft exit cone assembly per TWR-74238 and TWR-75135. (Carbon phenolic-to-glass interface, bondline temperature and metal housing temperatures were all taken into consideration). The new performance factor will insure that the CEI requirements will be met which requires that the bond between carbon and glass will not exceed 600 degree F, bondline of glass-to-metal remains at ambient temperature during boost phase, and the metal will not be heat affected at splashdown.

E,F 20. The aft exit cone housing is a fracture control item per TWR-16875. TWR-16875 documents that the aft exit cone housing passes the safe life requirements. Structural verification analysis per TWR-16975 shows the maximum stress obtained during operation will have a positive margin of safety using the factor of safety of 1.4 ultimate and 1.1 on yield.

9.2 TEST AND INSPECTION:

DCN	FAILURE CAUSES and TESTS (T)				CIL CODE
		1.	For New Aft Exit Cone, Shell verify:		
	A,B		a.	.70 cross-sectional dimension (forward end)	ADK000,ADK001
	A,B		b.	Thickness of aft compliance ring flange	ADK007,ADK008
	A,B		c.	Countersink .957 diameter X 81 degrees (20 holes marked A)	ADK012A,ADK013A
	A,B		d.	Countersink .957 diameter X 81 degrees (72 holes)	ADK012D,ADK013D
	A,B		e.	Countersink .957 diameter X 81 degrees (12 holes, 2 places)	ADK012H,ADK013H
	A,B		f.	Depth of alignment hole (forward end)	ADK037,ADK038
	A,B		g.	Depth of alignment hole (aft end)	ADK037A,ADK038A
	A,B		h.	Diameter of alignment hole (forward end)	ADK039,ADK040
	A,B		i.	Diameter of alignment hole (aft end)	ADK039A,ADK040A
	A,B		j.	Diameter 116.530	ADK042,ADK043
	A,B		k.	.530-.539 diameter mounting holes (20 holes marked A)	ADK044,ADK045
	A,B		l.	.530-.539 diameter mounting holes (72 places)	ADK044A,ADK045A
	A,B		m.	.530-.539 diameter mounting holes (12 holes, 2 places)	ADK044B,ADK045B
	A,B		n.	Diameter of datum G	ADK048,ADK049
	A,B		o.	Diameter of datum B	ADK053,ADK054
	A,B		p.	Diameter of datum H	ADK056,ADK057
	A,B		q.	Thickness of forward compliance ring flange	ADK089,ADK090
	A,B		r.	Overall length	ADK121,ADK122
	A,B		s.	Length between datum A and C	ADK133,ADK134
	A,B		t.	Length between datum C and F	ADK136,ADK137
	A,B		u.	Point C to D profile	ADK141,ADK142
	A,B		v.	Run out diameter B to datum C and H	ADK157,ADK158
	A,B		w.	Run out of datum A to datum C and B	ADK171,ADK172
	A,B		x.	Run out of datum F to datum C and B	ADK176,ADK177
	A,B		y.	Forward end secondary O-ring groove surface finish value	ADK184,ADK186
	A,B		z.	Flatness of datum C	ADK191,ADK192
	A,B		aa.	Threads per MS33537 (192 holes)	ADK207,ADK208
	A,B		ab.	Threads per MS33537 (72 holes)	ADK207A,ADK208A
	A,B		ac.	Threads per MS33537 (96 holes)	ADK207B,ADK208B
	A,B		ad.	Threads per MS33537 (16 holes marked B)	ADK207C,ADK208C
	A,B		ae.	Threads per MS33537 (4 holes, 2 places)	ADK207D,ADK208D
	A,B		af.	Threads per MS33537 (60 holes)	ADK207E,ADK208E
	A,B		ag.	True position to datums C, H and D is within .010 diameter (4 holes, 2 places)	ADK210,ADK211
	A,B		ah.	True position to datums C, H and D is within .010 diameter (4 holes, 4 places)	ADK210A,ADK211A
	A,B		ai.	True position to datums A and B is within .010 diameter (96 holes)	ADK210B,ADK211B
	A,B		aj.	True position to datums C, H and D is within .010 diameter (72 holes)	ADK210C,ADK211C
	A,B		ak.	True position to datums E, G and D is within .030 diameter	ADK210D,ADK211D
	A,B		al.	True position is within .060 diameter (60 holes)	ADK210E,ADK211E
	A,B		am.	True position to datums E, H and D is within .010 (72 holes)	ADK212A,ADK213A
	A,B		an.	True position to datums J, C and D is within .010 diameter	ADK212B,ADK213B
	A,B		ao.	True position to datums F, H and D is within .010 diameter (10 holes, 2 places)	ADK213,ADK212
	A,B		ap.	Point E to A profile	BHU109,BHU107
	A,B		aq.	Point A to B profile	BHU110,BHU108
	C,D,E,F (T)		ar.	Chemical composition of aluminum forging material	ADK023

C,D,E,F		as.	Dye penetrant (after machining)	ADK063
C,D,E,F	(T)	at.	Heat treat condition of aluminum forging material	ADK101
C,D,E,F	(T)	au.	Test results for stress-corrosion resistance of aluminum forging material	ADK182
C,D,E,F	(T)	av.	Tensile strength	ADK202
C,D,E,F	(T)	aw.	Yield strength	ADK202A
C,D,E,F	(T)	ax.	Elongation	ADK202B
C,D,E,F	(T)	ay.	Ultrasonic test prior to machining	ADK214

2. For Refurbished Aft Exit Cone, Shell verify:

A,B	a.	116.530 dimension B diameter	ADK002
A,B	b.	0.290 wall thickness	ADK006
A,B	c.	Threaded holes	ADK017
A,B	d.	Non-threaded hole diameter	ADK020
A,B	e.	Surface defects	ADK031
A,B	f.	0.70 wall thickness	ADK035
A,B	g.	0.385 wall thickness	ADK036
A,B	h.	119.820 dimension diameter	ADK055
A,B	i.	43.315 dimension overall height	ADK120
A,B	j.	36.565 dimension flange-to-flange height	ADK126
A,B	k.	5.275 dimension flange-to-flange height	ADK129
A,B	l.	A-to-B dimension straightness	ADK139
A,B	m.	B-to-C dimension straightness	ADK140
A,B	n.	93.00 dimension roundness	ADK151
A,B	o.	119.820 dimension roundness	ADK154
A,B	p.	Surface finish on repaired sealing surfaces	ADK178
A,B	q.	0.405 wall thickness	ADK179
A,B	r.	Tapped threads are cleaned	ADK198
C,D,E,F	s.	Painted surfaces for indications of heat degradation	ADK117
C,D,E,F	t.	Dye penetrant	ADK215

3. For New Exit Cone Assembly--Nozzle, Aft verify:

G	a.	Handling of aft exit cone	AGK011

4. KSC verifies:

G	a.	Nozzle aft exit cone for damage or contamination to metal components, cork insulation, and painted surfaces prior to assembly per OMRSD File V, Vol I, B47NZ0.020	OMD046
G	b.	Aft exit cone mating surfaces for damage or contamination prior to application of primer and again just prior to assembly (including black light inspection for contamination) per OMRSD File V, Vol I, B47NZ0.032	OMD048