CARLO GAVAZZI SPACE SpA

ACOP

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LIST OF ACRONYMS

AD	APPLICABLE DOCUMENTS
CCS	CRITICAL CRACK SIZE
DL	DESIGN LOAD
EVA	EXTRA VEHICULAR ACTIVITY
EVR	EXTRA VEHICULAR ROBOTIC
FEM	FINITE ELEMENT MODEL
ICS	INITIAL CRACK SIZE
KA	ACCEPTANCE FACTOR
KM	MODEL FACTOR
KP	PROJECT FACTOR
KQ	QUALIFICATION FACTOR
LA	LOT ACCEPTANCE
MoS	MARGIN OF SAFETY
NA	NOT APPLICABLE
NDE	NON DESTRUCTIVE EVALUATION
NDI	NON DESTRUCTIVE INSPECTION
NSTS	NATIONAL SPACE TRANSPORTATION SYSTEM
PFCI	POTENTIALLY FRACTURE CRITICAL ITEM
PFCIL	POTENTIALLY FRACTURE CRITICAL ITEM LIST
PSD	POWER SPECTRAL DENSITY
RD	REFERENCE DOCUMENTS
SAR	STRUCTURAL ANALYSIS REPORT
SF	SAFETY FACTOR

1. INTRODUCTION

1.1 SCOPE OF THE DOCUMENT

This document describes the fracture and fatigue analyses and methodologies utilized to define and document the design of the ACOP structure assembly.

This analyses results will demonstrate that all the applicable structural requirements are met. The following dot-list shows the output of this report:

- Potential Fracture Critical Item List (PFCIL);
- Safe life analysis;
- Fail safe analysis;
- Containment analysis.
- Fracture Critical Item List (FCIL);
- Fracture Limited Life Item List (FLLIL);

2. RELEVANT DOCUMENTS

2.1 APPLICABLE DOCUMENTS

AD	Doc. Number	Issue / Date	Rev.	Title / Applicability
1	SSP 52000-IDD-ERP	D / 6/08/03		EXpedite the PRocessing of Experiments to Space Station (EXPRESS) Rack Payloads Interface Definition Document
2	NSTS/ISS 13830	C / 01/12/1996		Implementation Procedures for Payloads System Safety Requirements – For Payloads Using the STS & ISS.
3	JSC 26493	17/02/1995		Guidelines for the preparation of payload flight safety data packages and hazard reports.
4	SSP 50004	April 1994		Ground Support Equipment Design requirements
5	SSP-52000-PDS	March 1999	B	Payload Data Set Blank Book
6	SSP 57066	October 28, 2003		Standard Payload Integration Agreement for EXPRESS/WORF Rack Payloads
7	GD-PL-CGS-001	3 / 17/03/99		PRODUCT ASSURANCE & RAMS PLAN
8	SSP 52000 PAH ERP	Nov. 1997		Payload Accommodation Handbook for EXPRESS Rack
9	SSP 50184	D / Feb. 1996		Physical Media, Physical Signaling & link-level Protocol Specification for ensuring Interoperability of High Rate Data Link Stations on the International Space Program
10	SSP 52050	D / 08/06/01		S/W Interface Control Document for ISPR ***ONLY FOR HRDL, SECTION 3.4 ***
11	ECSS-E-40	A / April 1999	13	Software Engineering Standard
12	AMS02-CAT-ICD-R04	29/08/2003	04	AMS02 Command and Telemetry Interface Control document. Section AMS-ACOP Interfaces
13	SSP 52000-PVP-ERP	Sept. 18, 2002	D	Generic Payload Verification Plan EXpedite the PRocessing of Experiments to Space Station (EXPRESS) Rack Payloads
14	NSTS 1700.7B	Rev. B Change Packet 8 / 22.08.00		Safety Policy and Requirements for Payloads using the STS
15	NSTS 1700.7B Addendum	Rev. B Change Packet 1 01.09.00		Safety Policy and Requirements for Payloads using the International Space Station
16	SSP 52005	Dec. 10, 1998		Payload Flight equipment requirements and guidelines for safety critical structures
17	NSTS 18798B	Change Packet 7 10.00		Interpretation of NSTS Payload Safety Requirements
18	MSFC-HDBK-527	15/11/86	E	Materials selection list for space hardware systems Materials selection list data
19	GD-PL-CGS-002	1/ 12-02-99		CADM Plan
20	GD-PL-CGS-004	2/07-04-03		SW Product Assurance Plan
21	GD-PL-CGS-005	2/09-05-03		SW CADM Plan

2.2 REFERENCE DOCUMENTS

RD	Doc. Number	Issue / Date	Rev.	Title
1	GPQ-MAN-02	1		Commercial, Aviation and Military (CAM) Equipment Evaluation Guidelines for ISS Payloads Use
2	BSSC (96)2	1 / May 96		Guide to applying the ESA software engineering standards to small software projects
3	GPQ-MAN-01	2 / Dec. 98		Documentation Standard for ESA Microgravity Projects
4	MS-ESA-RQ-108	1 / 28-Sep-2000		Documentation Requirements For Small And Medium Sized MSM Projects
5	PSS-05			Software Engineering Standards
6	GPQ-010	1 / May 95	A	Product Assurance Requirements for ESA Microgravity Payload. Including CN 01.
7	GPQ-010-PSA-101	1		Safety and Material Requirements for ESA Microgravity Payloads
8	GPQ-010-PSA-102	1		Reliability and Maintainability for ESA Microgravity Facilities (ISSA). Including CN 01
9	SSP 52000-IDD-ERP	E / 09/09/03		EXpedite the PRocessing of Experiments to Space Station (EXPRESS) Rack Payloads Interface Definition Document
10	ACD-Requirements-Rev-BL	September 2005	Base Line	ACOP Common Design Requirements Document
11	MIL-HDBK-5	J/2003	H	Metallic Materials and Element for Aerospace Vehicle Structures
12	NSTS 08307	July, 1998	A	Criteria for Preloaded Bolts
13		June, 1973		E. F. BRUHN – Analysis & Design Of Flight Vehicle Structure
13	SSP 30558	30/06/1994	B	Fracture control requirements for space station
14	NASA-STD-5003	07/10/1996		Fracture control requirements for payloads using the space shuttle
15	ACP-PL-CGS-005	1 / JAN 2005		Fracture Control Plan
16	ACP-RP-CGS-005	2 / OCT 2005		Structural Analysis And Design Report

3. SOFTWARE USED

For fatigue and crack growth analysis ESACRACK V. 4.0 (February 2000) is used.

4. ACOP STRUCTURE HARDWARE DESCRIPTION

In the following figure the ACOP design is presented:

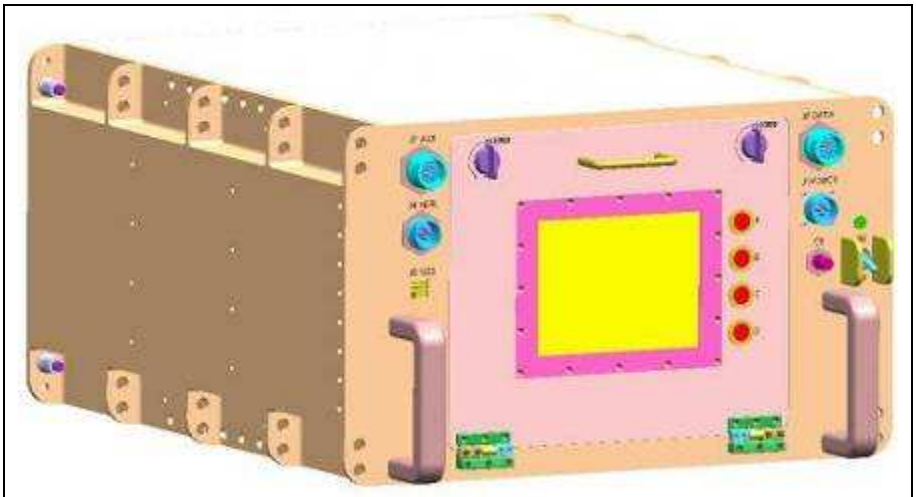


Figure 4-1: View of the ACOP (front view)

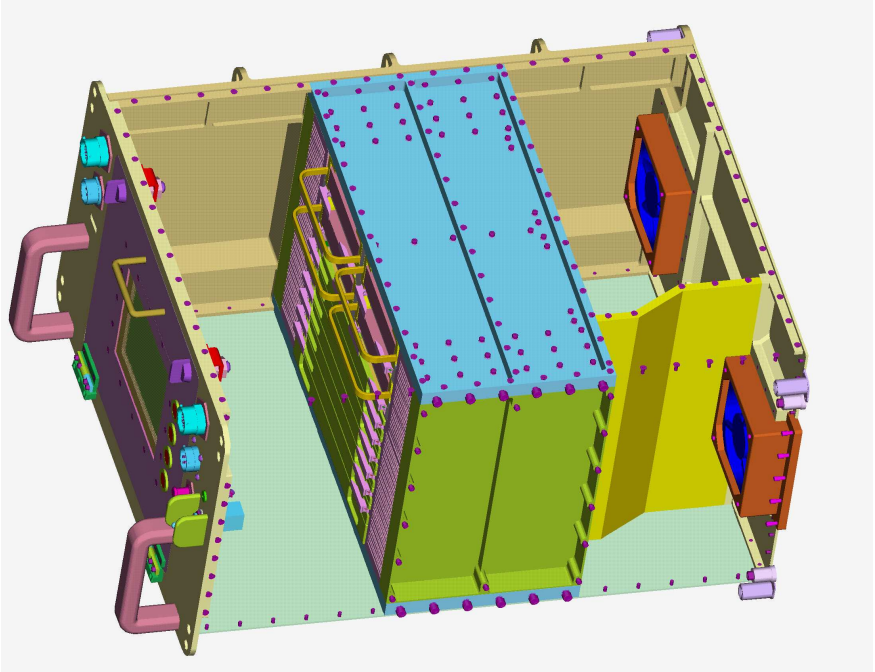


Figure 4-2: View of the internal items of ACOP

5. FRACTURE CONTROL APPLICABILITY

ACOP payload shall be used on a Manned single mission, therefore full fracture control screening is applicable to the payload according to AD 16requirements, summarized in the following flowchart:

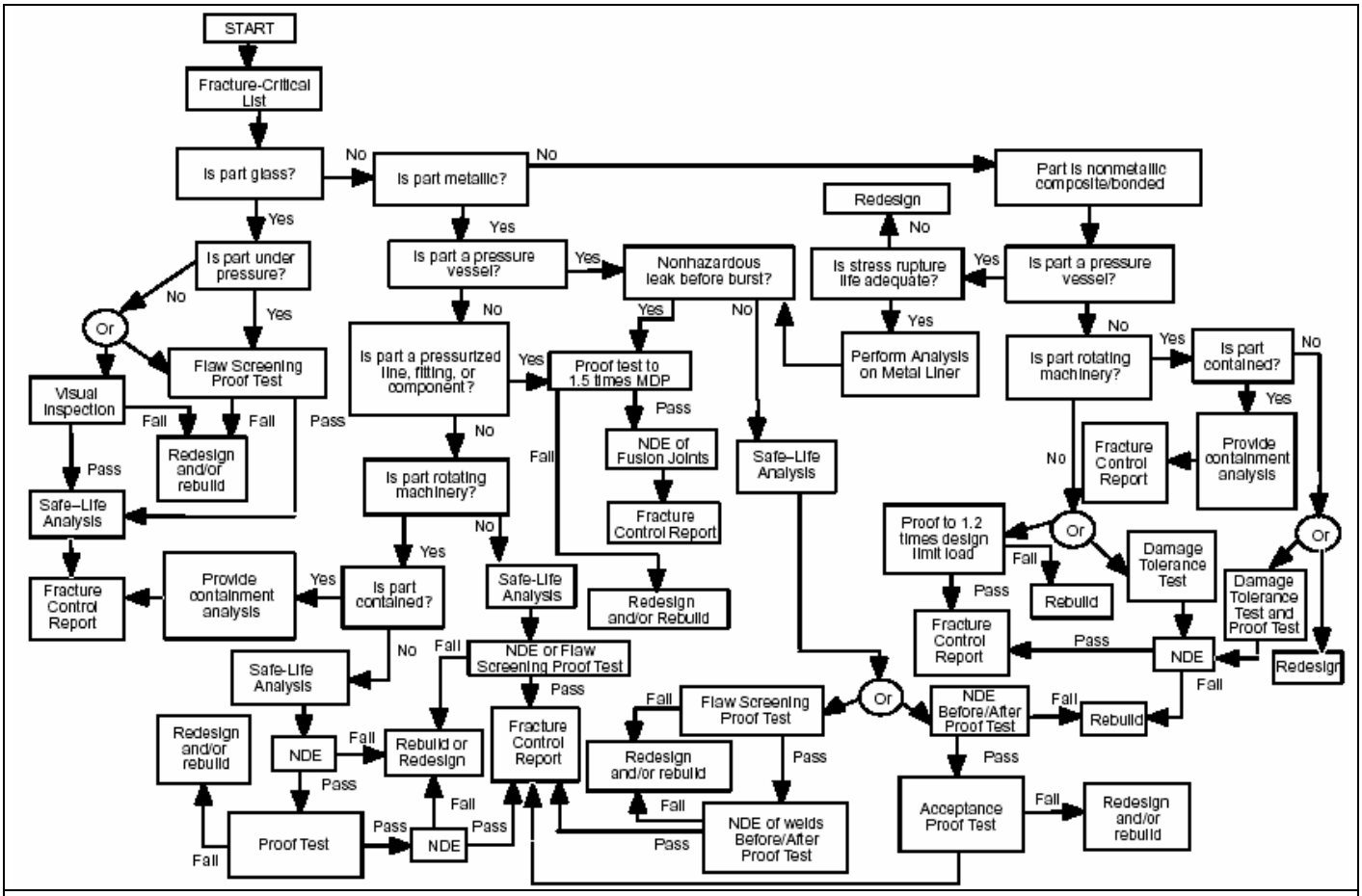


Figure 5-1 Fracture control applicability

Items defined as potentially fracture critical are listed in the potentially fracture critical items list (PFCIL).

6. EVALUATION OF POTENTIALLY FRACTURE CRITICAL ITEMS

6.1 PFCIS TYPE

PFCIs are typically:

1. pressurized systems;
2. composites;
3. welding and castings;
4. rotating machinery;
5. other items of which the structure is comprised.

The following diagram is used to define the type of PFCI.

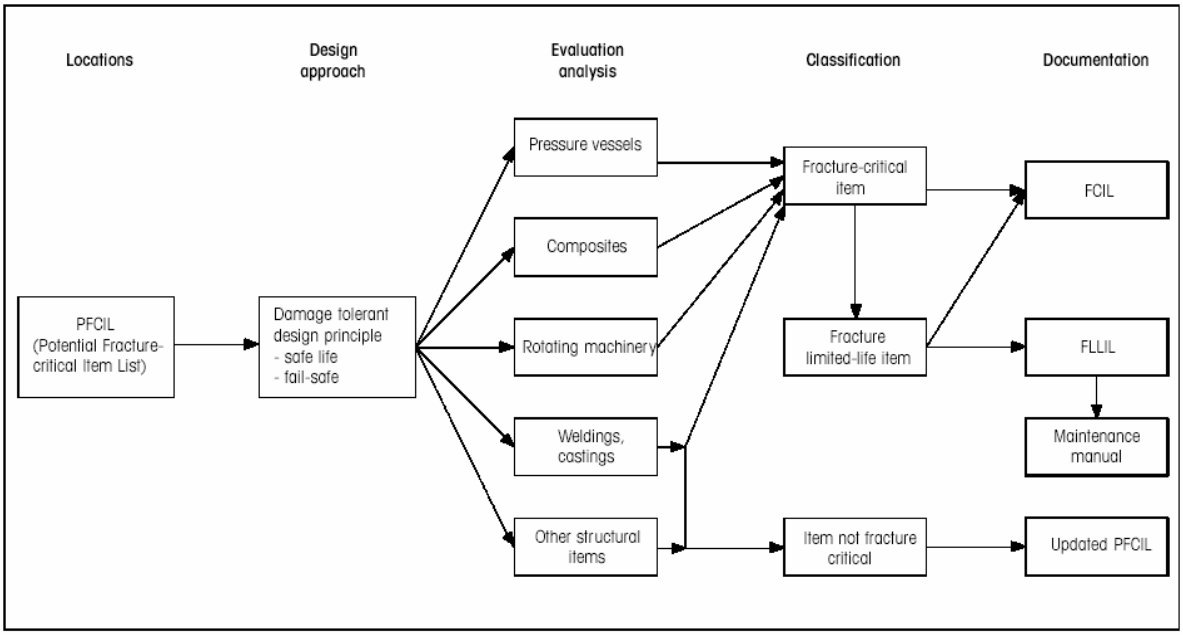


Figure 6-1: PFCIs type and classification

The ACOP structure is mainly composed by the components listed hereafter. For each component the damage tolerant design philosophy and classification is defined and shall be one of the following:

- fail-safe or safe-life (shall comply also with low mass release)
- contained
- low risk

ITEM TYPE		CLASSIFICATION		
		FAIL-SAFE or SAFE-LIFE	CONTAINED	LOW RISK
Pressurized systems.	Non present			
Composites.	**Present**			X
Weldings and castings.	Non present			
Rotating machinery.	**Present**		X	
Metallic parts	**Present**	X		X
Fasteners	**Present**	X		X
PCB and electronic components	**Present**		X	
Glass	Non present			

Table 6-1: Damage tolerance design philosophy

6.2 SELECTION OF PFCI CRITICAL LOCATIONS

The most critical locations on a PFCI shall be identified, to enable fracture analysis to be performed. The following parameters shall be considered as criteria for the selection of PFCIs:

a. the maximum level of local stress;
b. the range of cycling stress;
c. locations to be analyzed showing high stress intensities (correction function);
d. areas where material fracture properties can be low;
e. stresses which, combined with the environment, result in reduced fracture resistance.

If, as a result of the assessment, there is no obvious ranking in criticality, a sufficient number of locations shall be analysed to permit the criticality of the item to be defined .

6.3 DAMAGE TOLERANT DESIGN

There are two ways of implementing damage tolerance:

a. Safe life
A PFCI is a safe life item if it can be shown that the greatest defect in the part will not grow to such an extent that the minimum specified performance (for example the limit-load capability or no-leak) is no longer assured within a safe life interval. The maximum sustained stress-intensity factor *Kmax*, shall not exceed the threshold stress-intensity factor for stress-corrosion cracking *KISCC*.

b. Fail-safe
A PFCI is a fail-safe item if it can be shown by analysis or test that, as a result of structural redundancy, the structure remaining after failure of any element of the PFCI can sustain the new higher loads with a safety factor 1.0 without losing limit-specified performance. In addition, the failure of the item shall not result in the release of any part or fragment which results in an event having catastrophic or critical consequences or which has a mass in excess of that stated as allowable.

6.3.1 SAFE LIFE COMPLIANCE PROCEDURE

The evaluation procedure to be followed for a PFCI considered as a safe life item is specified in the next figure. The term: “two flights” is required in order to take into account one aborted flight, i.e. the service life shall as a minimum include two ascent and one descent flight events.

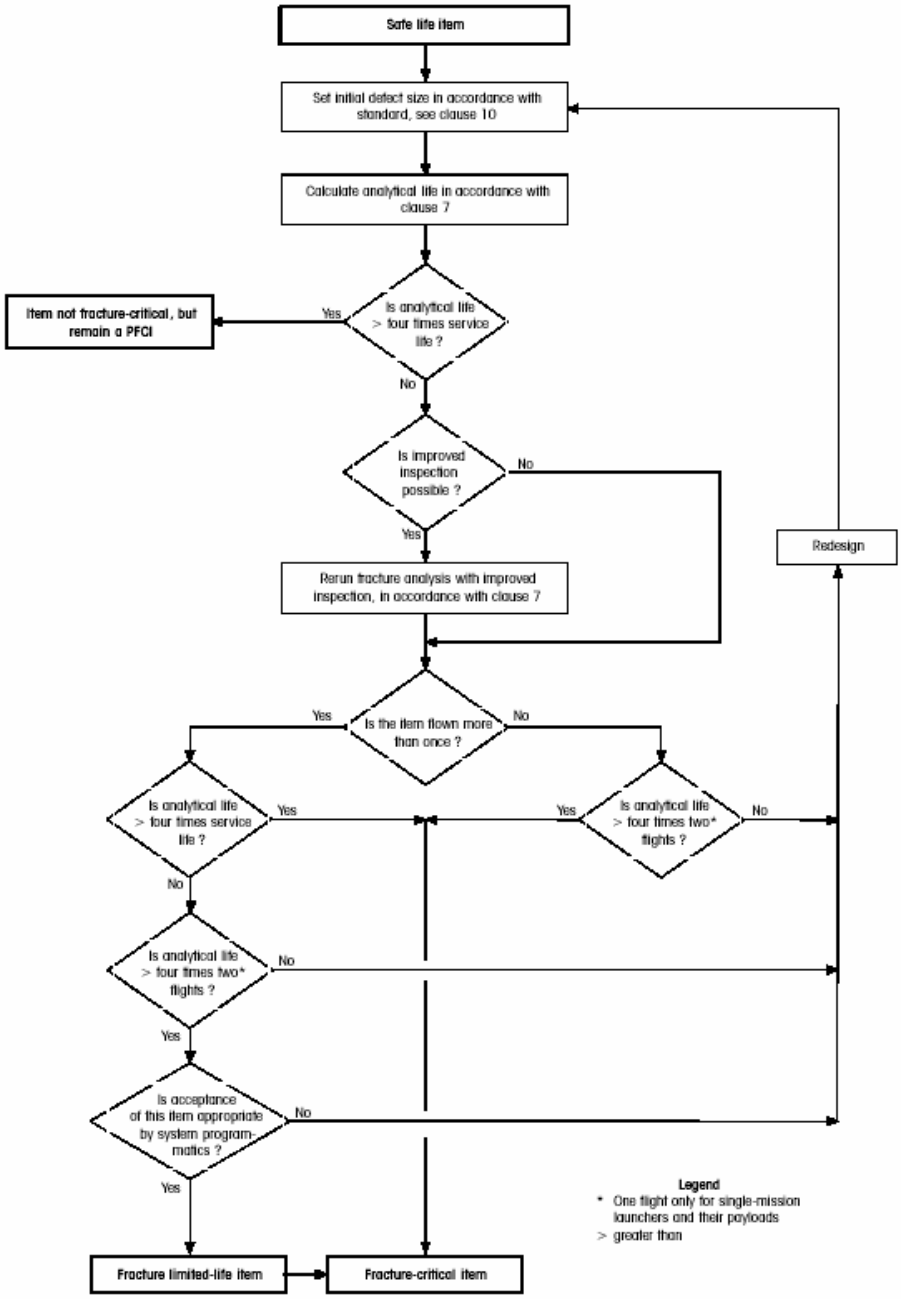


Figure 6-2 Safe life item evaluation procedure

6.3.2 FAIL SAFE COMPLIANCE PROCEDURE

The evaluation procedure to be followed for a PFCI considered as fail-safe item is specified in the next figure.

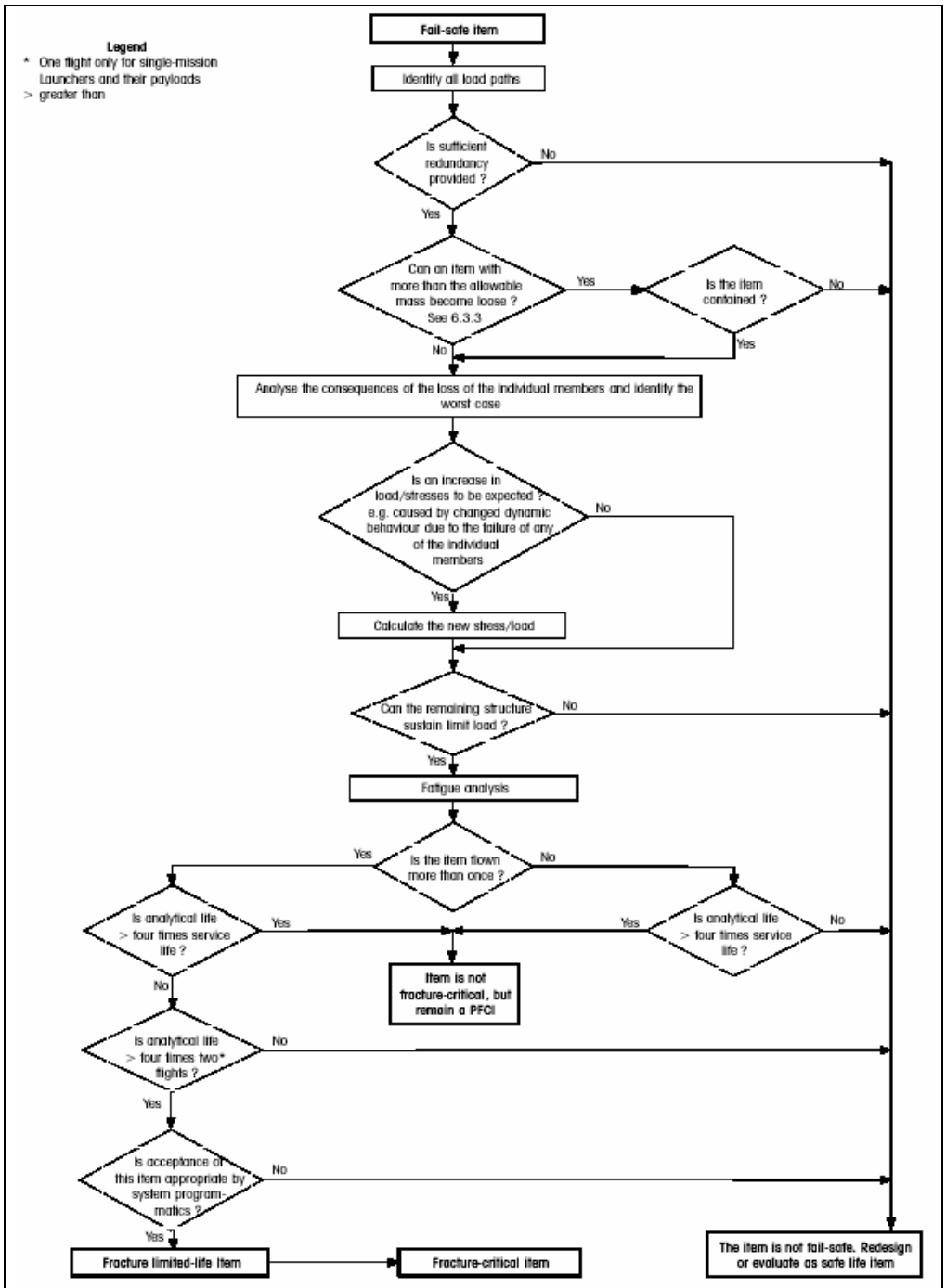


Figure 6-3 Evaluation procedure for fail-safe items

6.4 ROTATING MACHINERY

All rotating machinery are safety critical, if the kinetic energy ($1/2*I*\omega^2$) is greater than 14.240 ft-lb (19.3 J) the item is fracture critical. If the item show low kinetic energy it must be considered as the other structural components and must be contained.

6.5 COMPOSITE OR NON METALLIC STRUCTURAL COMPONENTS

The composite and non metallic structural components are analyzed as specified in 3.3.2 of the AD 16.

6.6 CONTAINED ITEM

Any item that due to failure is not compliant with the requirements of chapter 6 shall be analyzed to demonstrate the contained design.

6.6.1 CONTAINED COMPLIANCE PROCEDURE

It shall be demonstrated by analysis or test that the release of any loose item which can lead to a hazard having serious or catastrophic consequences will be effectively prevented. For payloads of the NASA STS or ISS, it shall be shown by analysis or test that any loose item exceeding the allowable mass defined in chapter 6 will be prevented from being released into the cargo bay or crew compartments.
A reference approach can be found in AD 16 (punch equation Chapter 6.2.1).

6.7 LOW-RISK FRACTURE PART.

A low-risk fracture part shall comply with the requirements of 4.2.2.4.1 and 4.2.2.4.2 of RD 14 except for fasteners and shear pins, which need comply only with 4.2.2.4.3. of RD 14.

6.8 LOW RELEASED MASS PART

For a payload component to be classified as a low released mass part, it shall meet requirements a, b, and c listed below:

a. The part satisfies one of the following two conditions:

(1) Total mass of the part or any other released part is less than 0.25 pounds (113 grams).

(2) Total mass in pounds (kilograms) supported by the part is not more than 14/h, where his the part's travel distance in feet (or 1.94/h, where h is in meters) to the aft bulkhead of the Space Shuttle cargo bay. When the installation location of a potential released mass is not known, a documented maximum travel distance estimate may be used. Total mass of the released part shall not exceed 2 pounds (0.9 kilograms).

b. It can be shown that the release of this component will not cause a catastrophic hazard to the Space Shuttle because of subsequent damage to the payload from which it came.

c. For parts which have low fracture toughness and are preloaded in tension, a fragment may be released at high velocity immediately following failure; therefore, the total released mass may not exceed 0.03 pounds (14 grams). A part shall be considered to have low fracture toughness when its material property ratio KIc/Fty < 0.33 in.1/2 (1.66 mm1/2), where KIc is the plane strain fracture toughness and Fty is the allowable yield tensile strength. If the part is a steel bolt and the KIc value is unknown, low fracture toughness shall be assumed when the specified minimum Ftu > 180 ksi (1240 mPa), where Ftu is the allowable ultimate tensile strength.

6.9 CLASSIFICATION

The results of the safe life or fail-safe analysis, the type of non-destructive inspection used and the type of material used shall determine whether or not PFCIs are identified as fracture-critical items. A fracture-critical item (FCI) is defined as any of the following:

a. any item which requires NDI better than standard NDI, as defined in chapter c. any item which requires periodic re-inspection in order to achieve the required life. Such items are called fracture limited-life items (FLLI) as a subset of FCI;

d. any composite or non-metallic PFCI, unless contained.

7. POTENTIALLY FRACTURE CRITICAL ITEMS IDENTIFICATION

The following PFCIL contains all the parts and connections in the primary load path to be considered potentially fracture critical and need to be analyzed.

Columns are defined as:

- **PFCI N.** : Potentially fracture critical item identification number
- **Item Name** : Name of the item
- **Type** :
    1. Part: Monolithic part
    2. Conn : Connection between parts (threaded bolt)
    3. Mech : Mechanism assembly
- **Dwg. N.** : number of drawing
- **Material** : Material used for item manufacturing
- **Type of Construction** : manufacturing method
- **Typical Thickness** : Typical Thickness of item used for analysis
- **Load Type** : Load applied to the item
- **Fracture Classification** :
    1. FAIL SAFE: a PFCI can be considered fail safe if it is redundant and in case of failure the remaining structure is able to sustain the loads. Fatigue analysis is performed to ensure that the remaining items have sufficient strength to sustain the new limit loads completing the mission, for the HMA this approach is used for all the structural bolts, considering the fatigue life of the connected parts already covered by crack growth analysis.
    2. SAFE LIFE: a PFCI can be considered safe life if the greatest undetected flaw is not critical during specified life. Fracture mechanics analysis is performed to ensure that the analytical life is more than 4 times the service life.
    3. CONTAINED: a PFCI can be considered contained if detachment caused from failure does not cause penetration of the containment walls\structure.
    4. LOW RISK: a PFCI can be considered low risk if the requirements in chapter 0are met.
    5. LOW MASS: a PFCI can be considered low mass if the requirements in chapter 6.8 are met.
- **NDI** : US (ultrasonic on raw material) , DP (dye penetrant on machined parts) LA (lot acceptance)

In the following figures the items of the ACOP structure are presented:

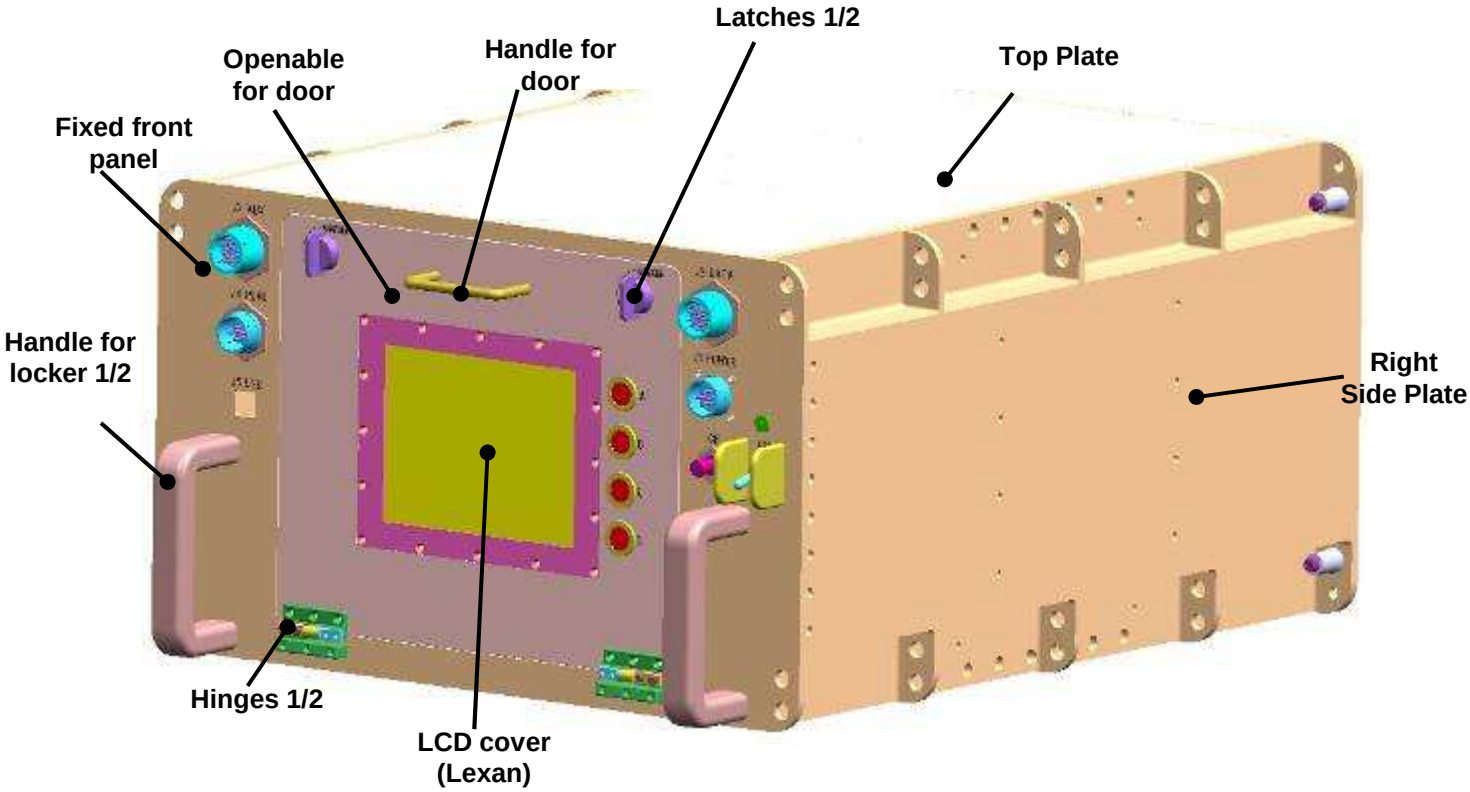


Figure 7-1 ACOP items presentation

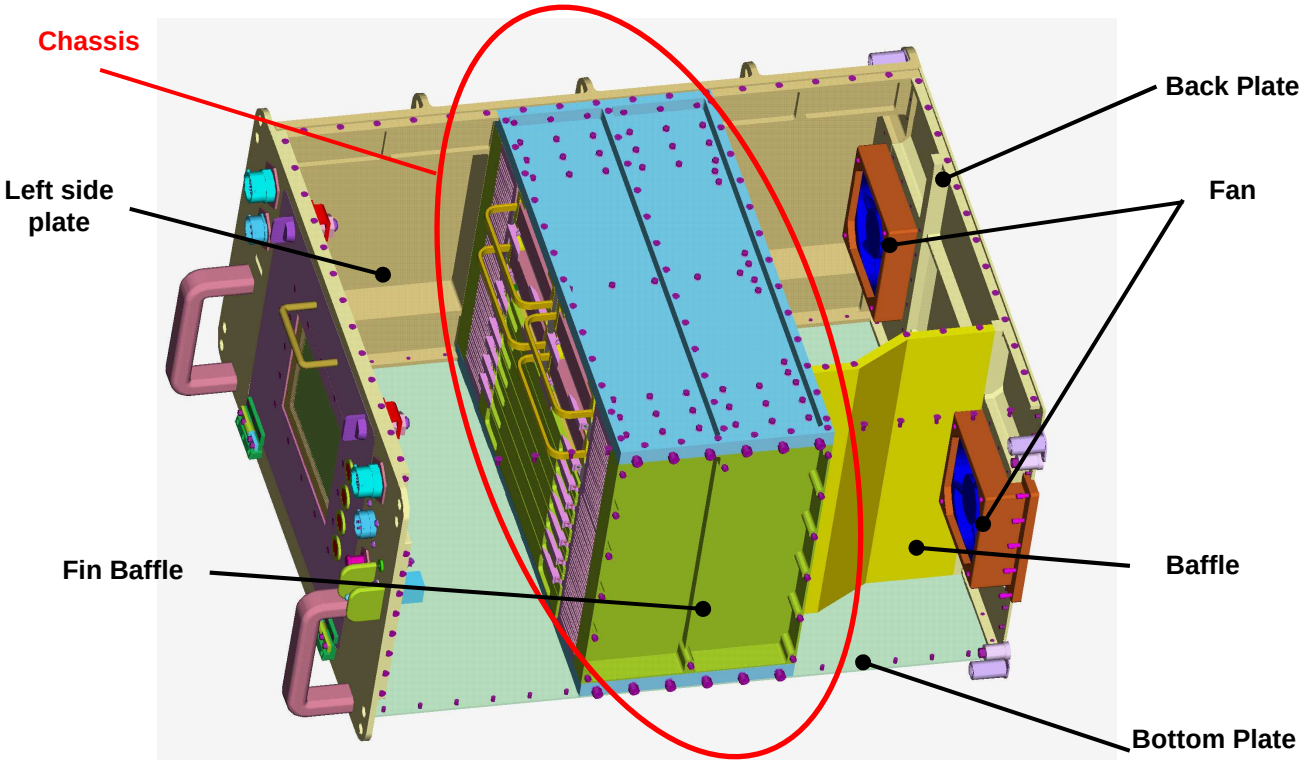


Figure 7-2 ACOP items presentation

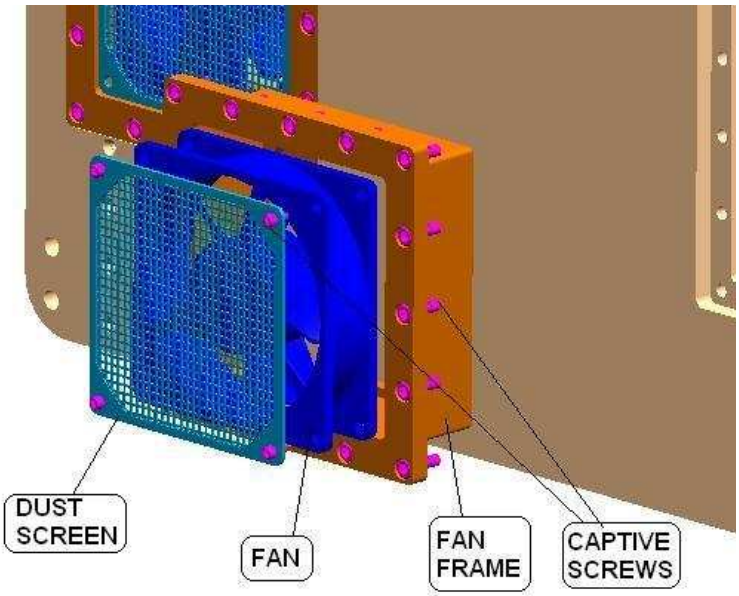


Figure 7-3 ACOP items presentation

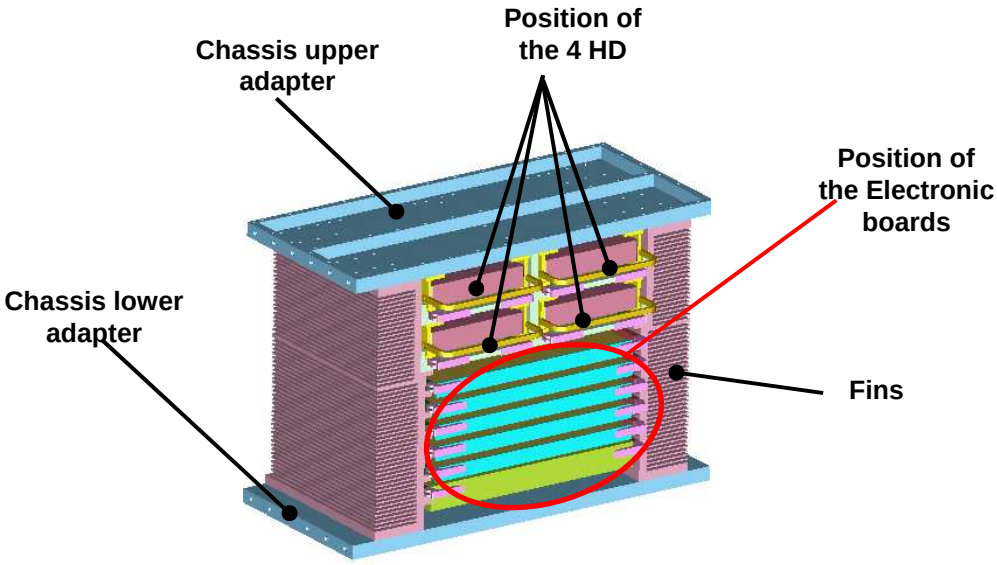


Figure 7-4 ACOP Chassis presentation

The joint ID's for the joint analysis are defined in the following figures.

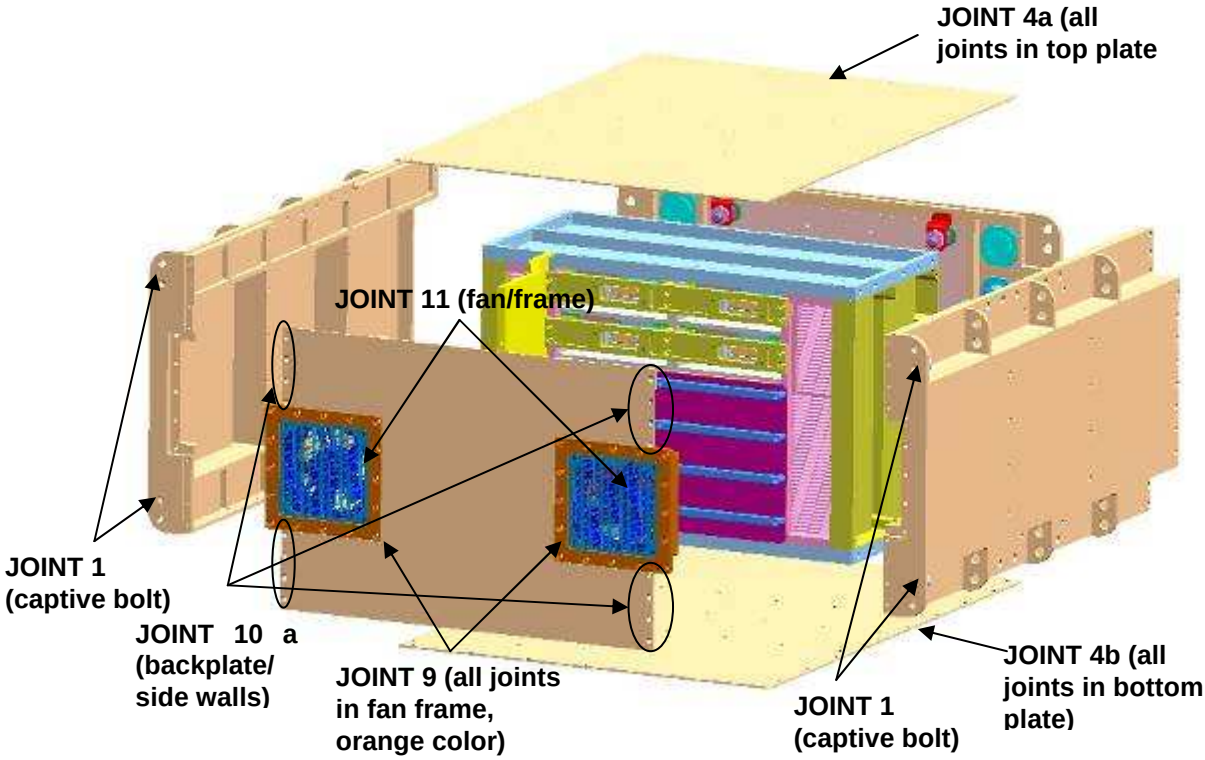
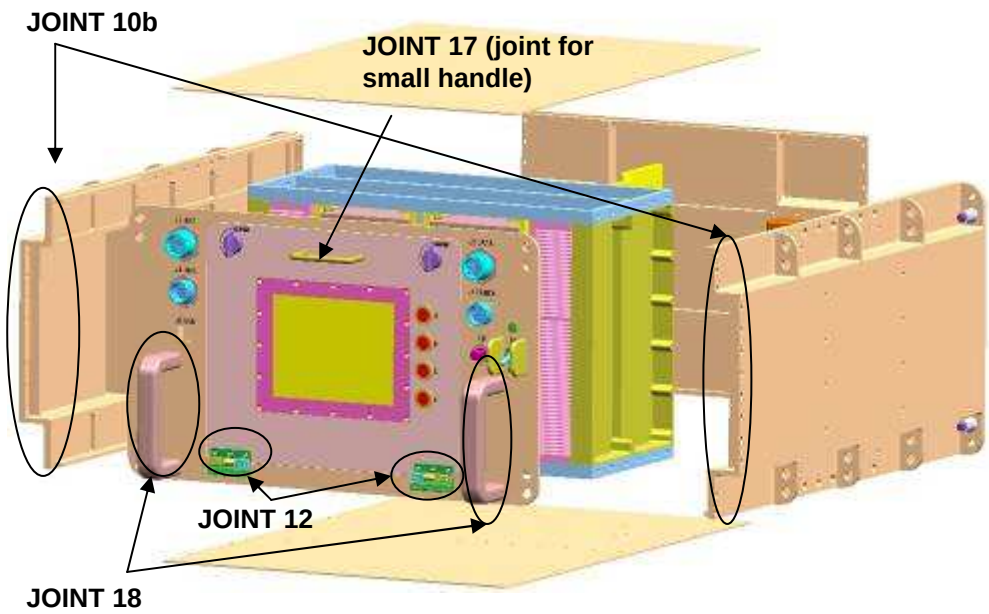


Figure 7-5: Joint ID in Nominal and Fail-Safe configuration



+

Figure 7-6: Joint ID in Nominal and Fail-Safe configuration

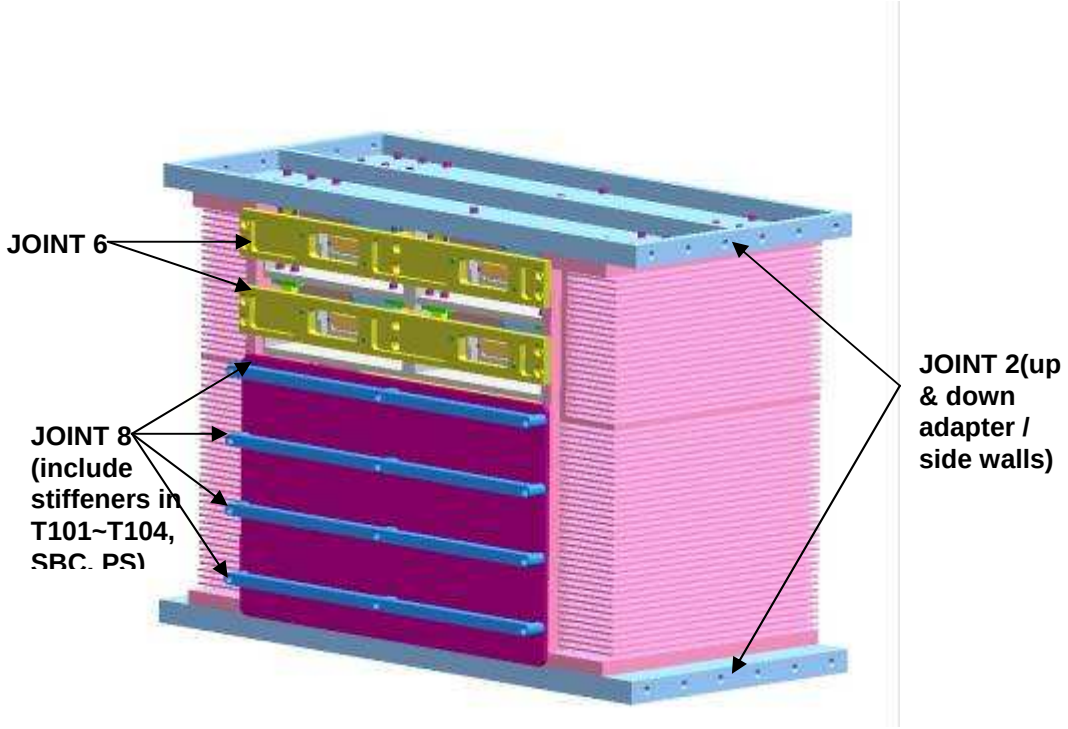


Figure 7-7: Joint ID in Nominal and Fail-Safe configuration

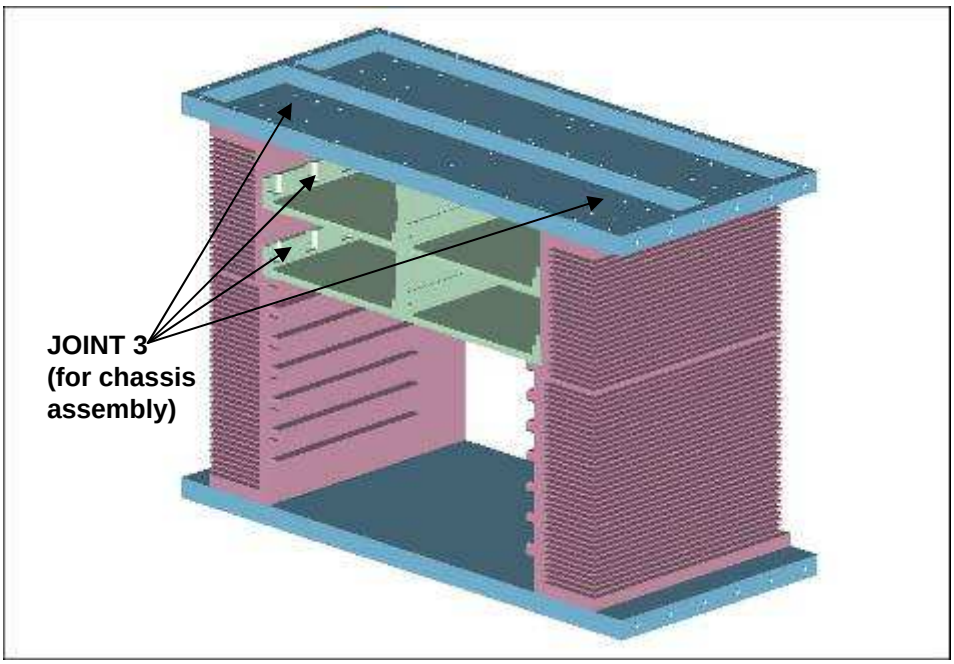


Figure 7-8: Joint ID in Nominal and Fail-Safe configuration

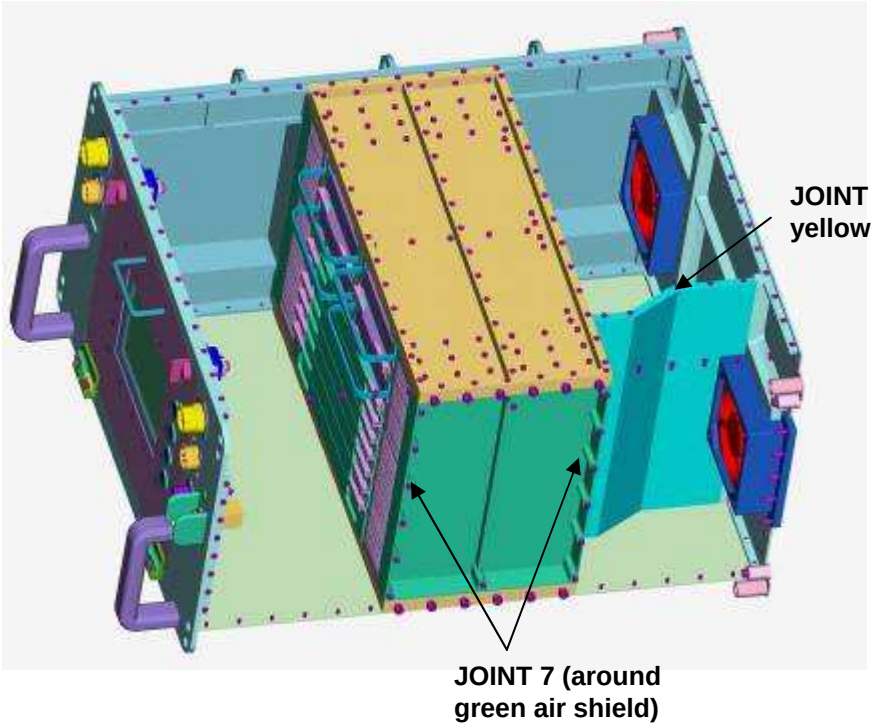


Figure 7-9: Joint ID in Nominal and Fail-Safe configuration

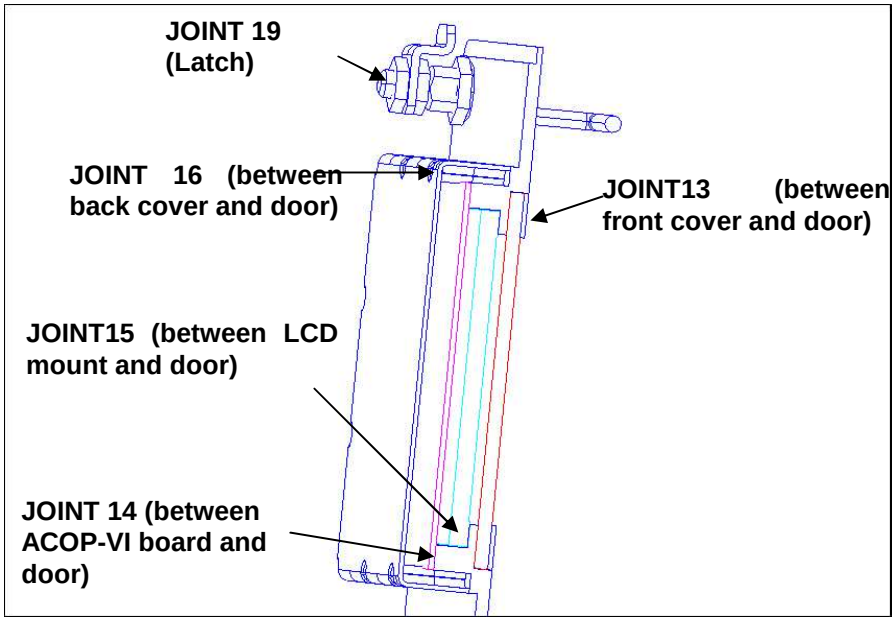


Figure 7-10: Joint ID in Nominal and Fail-Safe configuration

8. POTENTIALLY FRACTURE CRITICAL ITEM LIST (PFCIL)

In the following table the list of all the items is presented.

POTENTIALLY FRACTURE CRITICAL ITEM LIST

PFCI	ITEM	TYPE	DRAW.NO./ PART NO.	MATERIAL	TYPE OF CONSTRUCTION	LOAD TYPE	FRACTURE CLASSIFICATION	NDI	NOTE
1	Top plate	PART	AM9408-04	7075T7351	MACHINED	Inertial	LOW RISK	US	1
2	Bottom plate	PART	AM9408-05	7075T7351	MACHINED	Inertial	LOW RISK	US	1
3	Left side plate	PART	AM9408-06	7075T7351	MACHINED	Inertial	**SAFE LIFE**	US/DP	
4	Right side plate	PART	AM9408-07	7075T7351	MACHINED	Inertial	**SAFE LIFE**	US/DP	
5	Fixed front panel	PART	AM9408-02	7075T7351	MACHINED	Inertial	LOW RISK	US	1
6	Back plate	PART	AM9408-03	7075T7351	MACHINED	Inertial	**SAFE LIFE**	US/DP	
7	Door	PART	AM9408-0801	7075T7351	MACHINED	Inertial	LOW RISK	US	1
8	Handle for door	PART	AM9408-0806	7075T7351	MACHINED	Inertial	LOW RISK	US	1
9	Handle for Locker	PART	AM9408-09	7075T7351	MACHINED	Inertial	LOW RISK	US	1
10	Fin Baffle	PART	AM9408-10	6061T6	MACHINED	Inertial	LOW MASS	US	1
11	Baffle	PART	AM9408-11	6061T6	MACHINED	Inertial	LOW RISK	US	1
11/15	Hinge pad 1-4	PART	AM9408-04/ AM9408-05/ AM9408-15/ AM9408-16	AM-355 stainless steel	MACHINED	Inertial	LOW RISK	US	1
16	Hinges	PART	CFHG16	AISI 316	MACHINED	Inertial	LOW RISK	US	1
17	LCD front cover	PART	AM9408-0803	6061T6	MACHINED	Inertial	LOW RISK	US	1
18	LCD back cover	PART	AM9408-0802	6061T6	MACHINED	Inertial	LOW RISK	US	1
19	LEXAN	PART	NA	935 A	NA	Inertial	LOW RISK	NA	1
20	Fan Frame	PART	AM9404-13	6061T6	MACHINED	Inertial	LOW RISK	US	1
21	Dust Screen	PART	TBD		NA	Inertial	LOW RISK	NA	1

PFCI	ITEM	TYPE	DRAW.NO./ PART NO.	MATERIAL	TYPE OF CONSTRUCTION	LOAD TYPE	FRACTURE CLASSIFICATION	NDI	NOTE
22	JOINT 1 ACOP/EXPRESS Rack interface	CONNECTION	CS5108-4-5	A286 160KSi	FASTENER	Inertial / Preload	FAIL SAFE	LA	
23	JOINT 4a Top plate/Side wall, backplate, front panel, chassis	CONNECTION	SPS 96395-94-C	A286 160KSi	FASTENER	Inertial / Preload	FAIL SAFE	LA	Covered by PFCI 28
24	JOINT 4b Bottom plate/Side wall, backplate, front panel, chassis	CONNECTION	SPS 96395-94-C	A286 160KSi	FASTENER	Inertial / Preload	FAIL SAFE	LA	Covered by PFCI 28
25	JOINT 9 Fan frame/backplate, side walls	CONNECTION	CA2261-06	A286 160KSi	FASTENER	Inertial / Preload	FAIL SAFE	LA	Covered by PFCI 28
26	JOINT 10a Side walls/ backplate	CONNECTION	SPS 96395-94-C	A286 160KSi	FASTENER	Inertial / Preload	FAIL SAFE	LA	Covered by PFCI 28
27	JOINT 10b Side walls/ front panel	CONNECTION	SPS 96395-94-C	A286 160KSi	FASTENER	Inertial / Preload	FAIL SAFE	LA	Covered by PFCI 28
28	JOINT 13 LCD front cover plate/door adapter	CONNECTION	SPS 96395-94-C	A286 160KSi	FASTENER	Inertial / Preload	FAIL SAFE	LA	
29	JOINT 16 LCD back-cover/door adapter	CONNECTION	NAS 1352N04	A286 160KSi	FASTENER	Inertial / Preload	FAIL SAFE	LA	Covered by PFCI 28
30	JOINT 18 Large handle/front panel	CONNECTION	NAS 1351N3	A286 160KSi	FASTENER	Inertial / Preload	FAIL SAFE	LA	Covered by PFCI 38
31	JOINT 19 Latch shaft	CONNECTION	Southco® E3-57-42	NA	LATCH	Inertial	FAIL SAFE	NA	

PFCI	ITEM	TYPE	DRAW.NO./PART NO.	MATERIAL	TYPE OF CONSTRUCTION	LOAD TYPE	FRACTURE CLASSIFICATION	NDI	NOTE
32	Top plate of Chassis	PART	AM9408-0101	6061T6	MACHINED	Inertial	LOW RISK	US	1
33	Right fin	PART	AM9408-0102	6061-T6	MACHINED	Inertial	LOW RISK	US	1
34	Left fin	PART	AM9408-0103	6061-T6	MACHINED	Inertial	LOW RISK	US	1
35	HD up house	PART	AM9408-0104	6061-T6	MACHINED	Inertial	LOW RISK	US	1
36	HD down house	PART	AM9408-0105	6061-T6	MACHINED	Inertial	LOW RISK	US	1
37	Bottom plate of Chassis	PART	AM9408-0106	6061-T6	MACHINED	Inertial	LOW RISK	US	1
38	JOINT 2 Chassis /Side walls	CONNECTION	NAS 1351N3	A286 160KSi	FASTENER	Inertial / Preload	FAIL SAFE	LA	Covered by PFCI 28
39	Fan	PART	SAN ACE 92W	NA	NA	Inertial / On orbit load	ROTATING MACHINERY / CONTAINED	NA	
40	Electronic Boards	PART	NA	NA	NA	Inertial	CONTAINED	NA	
41	LCD	PART	NA	NA	NA	Inertial	CONTAINED	NA	
42	Hard Disc	PART	Deskstar T7K250	NA	NA	On orbit load	ROTATING MACHINERY / CONTAINED	NA	
NOTE 1: Low stress according to RD 16.									

Table 8-1: Potentially Fracture Critical Item List for ACOP Structure

Following table shows a description of locations for each safe life classified PFCI:

SAFE LIFE ITEMS			
PFCI N	**ITEM NAME**	**LOCATION**	**DESCRIPTION**
3	Left side plate	A	Interface Hole
		B	Hole for the connection to the back plane
		C	End Pad
4	Right side plate	A	Interface Hole
		B	Hole for the connection to the back plane
		C	End Pad
6	Back plate	A	Hole for the connection to the lateral plate
		B	End Pad

Table 8-2: SAFE LIFE List for ACOP Structure

9. FRACTURE ANALYSIS INPUT DATA

9.1 CRACK GROWTH MATERIAL DATA

9.1.1 AL 7075 T7351 ALUMINUM ALLOY

ESACRACK MATERIAL CONSTANT – SI (ESA) Units (MPa, MPa $\sqrt{mm}$)																	
Material; Condition; Environment*	Code	YS	UTS	K_{Ie}	K_{Ic}	A_K	B_K	C	n	p	q	DK_o	C^+_{th}	C^-_{th}	R_{cl}	α	S.R.
7075-T7351 Plt & Sht ; S-T ; LA	M7HH15A B1	400	448	869	660	1.0	1.0	0.145^E-9	2.300	0.5	1.0	104	2.0	0.1	0.7	1.9	0.3

Table 9-1: Material Properties for ESACRACK: AL 7075 T7351

9.2 CRACK GEOMETRIES

The following crack models from RD14 are used:

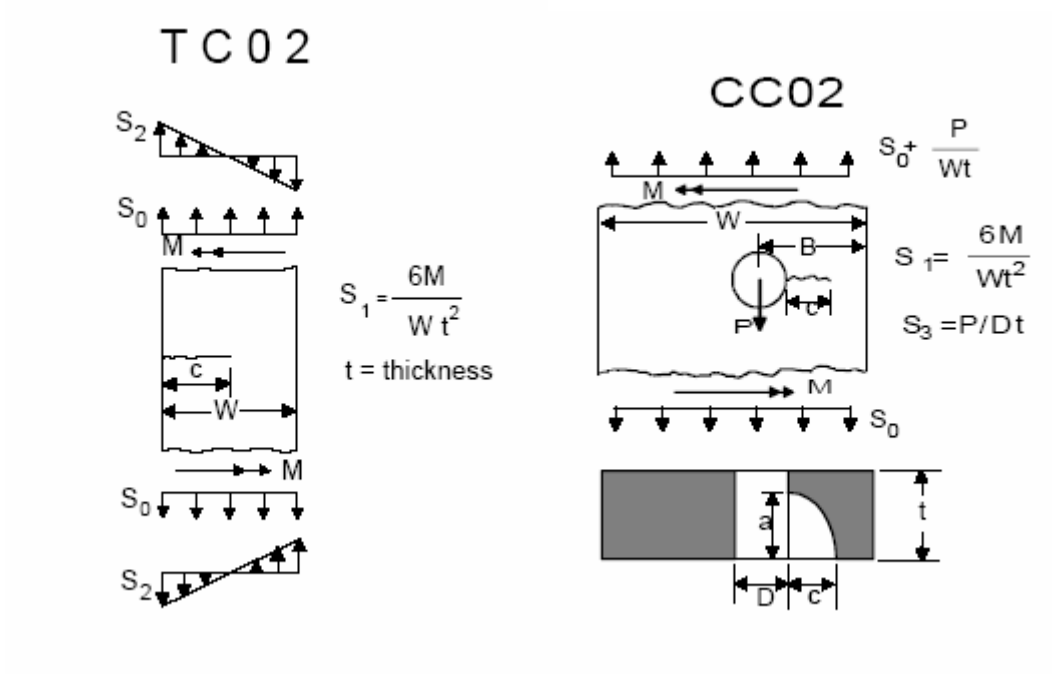


Figure 9-1 Initial crack geometries for parts

U.S. Customary Units (in.)

Crack Location	Part Thickness, t	Crack Type	Crack Dimension a	Crack Dimension c
		Eddy Current NDE		
Open Surface	t ≤ 0.050 t > 0.060	Through PTC[1]	t {0.020, 0.050}	0.050 {0.100, 0.050}
Edge or Hole	t ≤ 0.075 t > 0.075	Through Corner	t 0.075	0.100 0.075
		Penetrant NDE		
Open Surface	t ≤ 0.050 .050 < t < .075 t > 0.075	Through Through PTC	t t {0.025, 0.075}	0.100 0.15-t {0.125, 0.075}
Edge or Hole	t ≤ 0.100 t > 0.100	Through Corner	t 0.100	0.100 0.100
		Magnetic Particle NDE		
Open Surface	t ≤ 0.075 t > 0.075	Through PTC	t {0.038, 0.075}	0.125 {0.188, 0.125}
Edge or Hole	t ≤ 0.075 t >0.075	Through Corner	t 0.075	0.250 0.250
		Radiographic NDE[2]		
Open Surface	.025 ≤ t ≤ 0.107 t > 0.107	PTC	0.7t 0.7t	0.075 0.7t
		Ultrasonic NDE[2]		
Open Surface	t ≥ 0.100	PTC	{0.030, 0.065}	{0.150, 0.065}

Table 9-2 Initial crack size summary, standard NDI

SI Units (mm)

Crack Location	Part Thickness, t	Crack Type	Crack Dimension a	Crack Dimension c
		Eddy Current NDE		
Open Surface	t ≤ 1.27	Through	t	1.27
	t > 1.27	PTC[1]	0.51 – 1.27	2.54 – 1.27
Edge or Hole	t ≤ 1.91	Through	t	2.54
	t > 1.91	Corner	1.91	1.91
		Penetrant NDE		
Open Surface	t ≤ 1.27	Through	t	2.54
	1.27 < t < 1.91	Through	t	3.81 - t
	t > 1.91	PTC	0.64 – 1.91	3.18 – 1.91
Edge or Hole	t ≤ 2.54	Through	t	2.54
	t > 2.54	Corner	2.54	2.54
		Magnetic Particle NDE		
Open Surface	t ≤ 1.91	Through	t	3.18
	t > 1.91	PTC	0.97 – 1.91	4.78 – 3.18
Edge or Hole	t ≤ 1.91	Through	t	6.35
	t > 1.91	Corner	1.91	6.35
		Radiographic NDE[2]		
Open Surface	0.64 ≤ t ≤ 2.72	PTC	0.7t	1.91
	t > 2.72		0.7t	0.7t
		Ultrasonic NDE[3]		
Open Surface	t ≥ 2.54	PTC	0.76 – 1.65	3.81 – 1.65

Table 9-3 Initial crack size summary, standard NDI

10.FATIGUE ANALYSIS INPUT DATA

10.1 FATIGUE MATERIAL DATA

10.1.1 A-286 M5, W. NO. 1.4944.4 SCREW R=(0.04;0.65)

```
material :     A-286 M5, W. No. 1.4944.4 screw R=(0.04;0.65)

     R valid interval :  (  0.04;  0.65)

     Material data - fatigue curvefit constants:
     ----------------------------------------
     |   p   |   A   |   B   |   C   |   l   |
     ----------------------------------------
     |  0.780| 18.316|  4.964|  0.000|119.719|
     ----------------------------------------
```

Table 10-1: Material Properties for ESAFATIG: A-286 M5, W. No. 1.4944.4 screw

10.1.2 AL7075-T7351, L, KT=1.5, BAR SHEET, R=(-1;0.5)

ESAFATIGUE material data base does not include Al 7075-T7351 , Al 7075-T6 is used for, having similar fatigue curve constants.

```
material :     7075-T6, l , Kt=2.0  bare sheet        R=(-1;0.5)

     R valid interval :  ( -1.00;  0.50)

     Material data - fatigue curvefit constants:
     ----------------------------------------
     |   p   |   A   |   B   |   C   |   l   |
     ----------------------------------------
     |  0.540|  9.563|  2.460|128.242|128.242|
     ----------------------------------------
```

Table 10-2: Material Properties for ESAFATIG: AL7075-T6, Kt=2 bare sheet aluminium alloy (in place of T7351)

10.2 PFCI K_T DATA

For all fatigue reside analyses, the used materials already include effect of K_T.

11.STRESS SPECTRUM DEFINITION

11.1 DEFINITION OF LIFE EVENTS

ACOP shall be subject to the following events during its life:

DESCRIPTION	ACOP	
	occurrence	note
GENERIC GROUND HANDLING AND ASSEMBLY ACTIVITY	TBD	(a)
GROUND TRANSPORTATION FROM PD TO TEST FACILITY	1000 Km	(a)
AIR TRANSPORTATION FROM PD TO TEST FACILITY	0 Km	(a)
MODAL SURVEY TEST	1	(b)
PROTOQUALIFICATION RANDOM VIBRATION TEST	**1**	
THERMAL VACUUM TEST	1	(b)
GROUND TRANSPORTATION FROM TEST FACILITY TO PD	1000 Km	(a)
AIR TRANSPORTATION FROM TEST FACILITY TO PD	0 Km	(a)
GROUND TRANSPORTATION TO LAUNCH SITE	200 Km	(a)
AIR TRANSPORTATION TO LAUNCH SITE	1000 Km	(a)
INSTALLATION TO LAUNCH VEHICLE PAYLOAD BAY	1	(a)
LAUNCH	**1**	
ABORT LANDING	**1**	
LAUNCH	**1**	
DOCKING AND TRANSPORTATION TO EXPOSURE LOCATION	1	(a)
ON ORBIT LOADS	**5 Years**	
LANDING	**1**	
GROUND TRANSPORTATION TO POST FLIGHT STORAGE SITE	200 Km	(a)
AIR TRANSPORTATION TO POST FLIGHT STORAGE SITE	1000 Km	(a)

(a): not applicable due to low stress levels and low number of cycles
(b): not applicable due to low stress

Table 11-1: Events during ACOP assembly life

Only the highlighted events are assumed to induce significant cyclic loads and stress levels.
A reduced set of events is used both for crack growth and fatigue analysis:

EVENT	DESCRIPTION	ACOP	
		occurrence	note
1	**PROTOQUALIFICATION RANDOM VIBRATION TEST**	**1**	
2	**LAUNCH**	**1**	
3	**ABORT LANDING**	**1**	
4	**LAUNCH**	**1**	
5	**LANDING**	**1**	

Table 11-2: Events during ACOP assembly life used for analysis

11.2 STRESS SPECTRUM CALCULATION

For each event the stress spectrum is calculated according to the rules defined in the next chapters.

11.2.1 EVENT 1: PROTOQUALIFICATION RANDOM VIBRATION TEST

11.2.1.1 UNIT STRESS

NA

11.2.1.2 LIMIT LOAD

NA

11.2.1.3 LIMIT STRESS

From The FEM analysis of RD 16 the limit stress is calculated for each PFCI in the critical location(s) and shall be used as maximum value acting on the spectrum.
As a conservative assumption spectrum Limit stress is calculated using the ACOP Design limit stress form RD 16.

11.2.1.4 STRESS SPECTRUM CALCULATION

For each axis of vibration the total number of cycles is defined as:

$$N_{TOT,i} = F_{n,i} \cdot T_i \cdot R$$

where

- $N_{TOT,i}$ = total number of cycles
- $F_{n,i}$ = first natural frequency in the i axis
- T_i = test time for the i axis (60 sec protoqualification time per axis)
- R = test repetition factor (2 for protoqualification)

According to the Raileigh Law the limit stress is distributed among different stress levels on the total number of cycles following the cycles and stress factors defined hereafter:

Step	P(si)	Cycles factor	Stress factor
1	0,125	0,0313	0,083
2	0,344	0,086	0,167
3	0,506	0,1265	0,25
4	0,594	0,1485	0,333
5	0,594	0,1485	0,417
6	0,531	0,1328	0,5
7	0,431	0,1078	0,583
8	0,319	0,0798	0,667
9	0,219	0,0548	0,75
10	0,143	0,0358	0,833
11	0,113	0,0283	0,917
12	0,05	0,0125	1
Sum	3,969	0,9926	

Table 11-3: Stress and cycles scaling factors according to Raileigh distribution

11.2.1.5 EXAMPLE STRESS SPECTRUM FOR ESACRACK

Example for PFCI 6 location B.
Limit stress by FEM analysis 70 MPa (Tension).

RANDOM VIBRATION TEST (X-AXIS)

		σ_t		σ_{b1}		σ_{b2}		σ_p		$\sigma_{bi\text{-}axial}$	
f1	time*	min	max	min	max	min	max	min	max	min	max
173.00	60	-70.000	70.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

total cycles= 10303

Cycles factor	Stress factor	Test repetition factor
0.0313	0.083	1
0.0860	0.167	
0.1265	0.250	
0.1485	0.333	
0.1485	0.417	
0.1328	0.500	
0.1078	0.583	
0.0798	0.667	
0.0548	0.750	
0.0358	0.833	
0.0283	0.917	
0.0125	1.000	

	σ_t		σ_{b1}		σ_{b2}		σ_{pin}		$\sigma_{bi\text{-}axial}$	
Cycles	min	max	min	max	min	max	min	max	min	max
325	-5.81	5.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
893	-11.69	11.69	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1313	-17.50	17.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1541	-23.31	23.31	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1541	-29.19	29.19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1378	-35.00	35.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1119	-40.81	40.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
828	-46.69	46.69	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
569	-52.50	52.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
372	-58.31	58.31	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
294	-64.19	64.19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
130	-70.00	70.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

total cycles
10303

RANDOM VIBRATION TEST (Y-AXIS)

		σ_t		σ_{b1}		σ_{b2}		σ_p		$\sigma_{bi\text{-}axial}$	
f1	time*	min	max	min	max	min	max	min	max	min	max
431.00	60	-70.000	70.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

total cycles= 25669

Cycles factor	Stress factor	Test repetition factor
0.0313	0.083	1
0.0860	0.167	
0.1265	0.250	
0.1485	0.333	
0.1485	0.417	
0.1328	0.500	
0.1078	0.583	
0.0798	0.667	
0.0548	0.750	
0.0358	0.833	
0.0283	0.917	
0.0125	1.000	

	σ_t		σ_{b1}		σ_{b2}		σ_{pin}		$\sigma_{bi\text{-}axial}$	
Cycles	min	max	min	max	min	max	min	max	min	max
809	-5.81	5.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2224	-11.69	11.69	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3271	-17.50	17.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3840	-23.31	23.31	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3840	-29.19	29.19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3434	-35.00	35.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2788	-40.81	40.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2064	-46.69	46.69	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1417	-52.50	52.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
926	-58.31	58.31	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
732	-64.19	64.19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
323	-70.00	70.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

total cycles
25669

RANDOM VIBRATION TEST (Z-AXIS)

		σ_t		σ_{b1}		σ_{b2}		σ_p		$\sigma_{bi\text{-}axial}$	
f1	time*	min	max	min	max	min	max	min	max	min	max
128.00	60	-70.000	70.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

total cycles= 7623

Cycles factor	Stress factor	Test repetition factor
0.0313	0.083	1
0.0860	0.167	
0.1265	0.250	
0.1485	0.333	
0.1485	0.417	
0.1328	0.500	
0.1078	0.583	
0.0798	0.667	
0.0548	0.750	
0.0358	0.833	
0.0283	0.917	
0.0125	1.000	

	σ_t		σ_{b1}		σ_{b2}		σ_{pin}		$\sigma_{bi\text{-}axial}$	
Cycles	min	max	min	max	min	max	min	max	min	max
240	-5.81	5.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
660	-11.69	11.69	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
972	-17.50	17.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1140	-23.31	23.31	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1140	-29.19	29.19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1020	-35.00	35.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
828	-40.81	40.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
613	-46.69	46.69	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
421	-52.50	52.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
275	-58.31	58.31	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
217	-64.19	64.19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
96	-70.00	70.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

total cycles
7623

11.2.2 EVENT 2: LAUNCH

11.2.2.1 UNIT STRESS

NA

11.2.2.2 LIMIT LOAD

NA

11.2.2.3 LIMIT STRESS

From The FEM analysis of RD 16 the limit stress is calculated for each PFCI in the critical location(s) and shall be used as maximum value acting on the spectrum.
As a conservative assumption spectrum Limit stress is calculated using the ACOP Design limit stress form RD 16.

11.2.2.4 STRESS SPECTRUM CALCULATION

Load spectrum cycles used are defined in JSC-22267 NASA\FLAGRO database for structures with first natural frequency between 100 and 200 Hz:

Load Step ID	Cycles/flight			Cyclic Stress (% limit value)	
	Launch			Minimum	Maximum
1	4			-100	100
2	12			-90	90
3	20			-80	80
4	48			-70	70
5	184			-60	60
6	312			-50	50
7	660			-40	40
8	1972			-30	30
9	8916			-20	20
10	8528			-10	10
11	11680			-7	7
12	89088			-5	5
13	331816			-3	3
Total					

Table 11-4: Stress spectrum cycles and stress scaling factors for launch

11.2.2.5 EXAMPLE STRESS SPECTRUM FOR ESACRACK

Example for PFCI 6 location B.
Limit stress by FEM analysis 70 MPa (Tension).

LAUNCH

		σ_t		σ_{b1}		σ_{b2}		σ_p		$\sigma_{bi\text{-}axial}$	
f1	time*	min	max	min	max	min	max	min	max	min	max
128.00		-70.000	70.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Cycles factor	Stress factor(%)
na	100
na	90
na	80
na	70
na	60
na	50
na	40
na	30
na	20
na	10
na	7
na	5
na	3

		σ_t		σ_{b1}		σ_{b2}		σ_{pin}		$\sigma_{bi\text{-}axial}$	
Cycles 50Hz	Cycles 200Hz	min	max	min	max	min	max	min	max	min	max
1	4	-70.00	70.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	12	-63.00	63.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	20	-56.00	56.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12	48	-49.00	49.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
46	184	-42.00	42.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
78	312	-35.00	35.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
165	660	-28.00	28.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
493	1972	-21.00	21.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2229	8916	-14.00	14.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2132	8528	-7.00	7.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2920	11680	-4.90	4.90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
22272	89088	-3.50	3.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
82954	331816	-2.10	2.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	total cycles										
	453240										

11.2.3 EVENT 3: ABORT LANDING

11.2.3.1 UNIT STRESS

NA

11.2.3.2 LIMIT LOAD

NA

11.2.3.3 LIMIT STRESS

From The FEM analysis of RD 16 the limit stress is calculated for each PFCI in the critical location(s) and shall be used as maximum value acting on the spectrum.
As a conservative assumption spectrum Limit stress is calculated using the ACOP Design limit stress form of RD 16.

11.2.3.4 NUMBER OF CYCLES CALCULATION

Load spectrum cycles used are defined in JSC-22267 NASA\FLAGRO database for structures with first natural frequency between 100 and 200 Hz:

Load Step ID	Cycles/flight			Cyclic Stress (% limit value)	
	Landing			Minimum	Maximum
1	4			-100	100
2	4			-90	90
3	12			-80	80
4	12			-70	70
5	12			-60	60
6	12			-50	50
7	52			-40	40
8	592			-30	30
9	3564			-20	20
10	5092			-10	10
11	8396			-7	7
12	26324			-5	5
13	34804			-3	3
total					

Table 11-5: Stress spectrum cycles and stress scaling factors for launch

11.2.3.5 EXAMPLE STRESS SPECTRUM FOR ESACRACK

Example for PFCI 6 location B.
Limit stress by FEM analysis 70 MPa (Tension).

ABORT LANDING

		σ_t		σ_{b1}		σ_{b2}		σ_p		$\sigma_{bi\text{-}axial}$	
f1	time*	min	max	min	max	min	max	min	max	min	max
128.00		-70.000	70.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Cycles factor	Stress factor(%)
na	100
na	90
na	80
na	70
na	60
na	50
na	40
na	30
na	20
na	10
na	7
na	5
na	3

		σ_t		σ_{b1}		σ_{b2}		σ_{pin}		$\sigma_{bi\text{-}axial}$	
Cycles 50 Hz	Cycles 200Hz	min	max	min	max	min	max	min	max	min	max
1	4	-70.00	70.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1	4	-63.00	63.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	12	-56.00	56.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	12	-49.00	49.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	12	-42.00	42.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	12	-35.00	35.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13	52	-28.00	28.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
148	592	-21.00	21.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
891	3564	-14.00	14.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1273	5092	-7.00	7.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2099	8396	-4.90	4.90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6581	26324	-3.50	3.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8701	34804	-2.10	2.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	total cycles	78880									

11.2.4 EVENT 4: LAUNCH

Same as event 2.

11.2.5 EVENT 5: LANDING

Same as event 3.

12.SAFE LIFE ANALYSIS

Refer to Table 8-1 for items' fracture classification.

12.1 PFCI 3

In the following figure the PFCI 3 is presented:

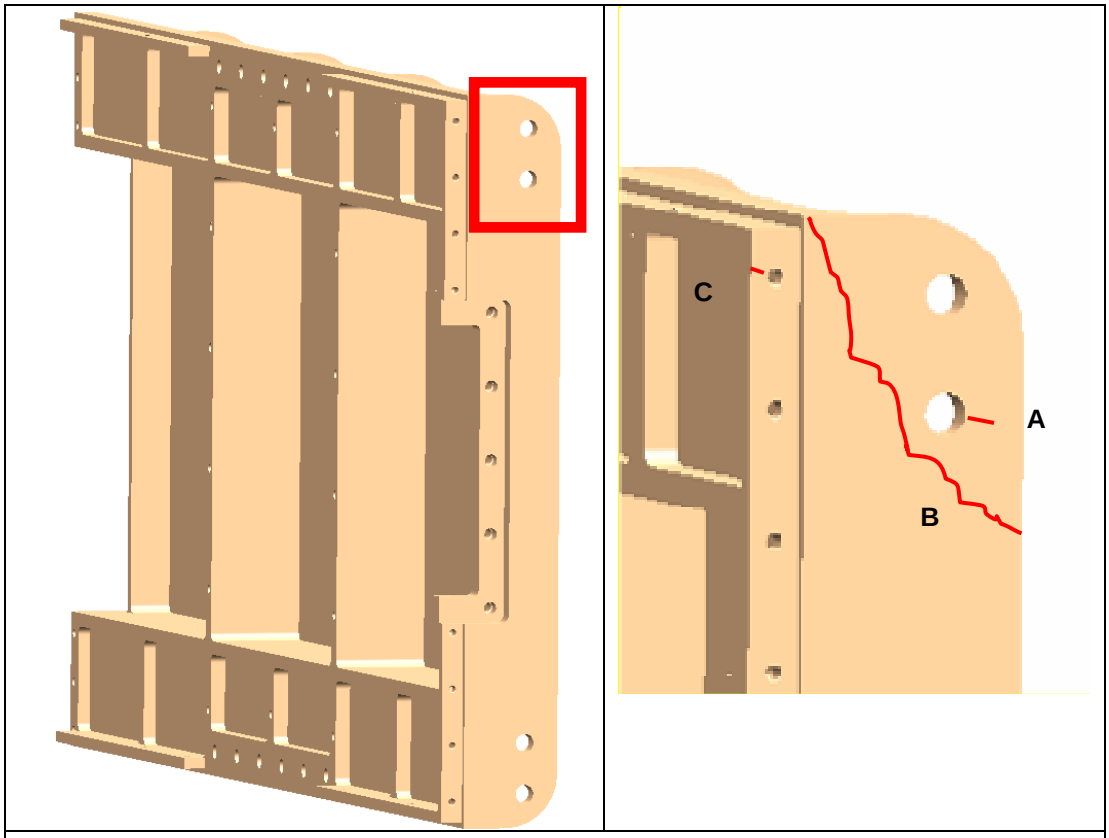


Figure 12-1 ACOP PFCI 3presentation

In this PFCI the stress is concentrated near the interface bolts (highlighted in the figure). For this PFCI three cracks are considered:

PFCI	ITEM NAME	LOCATION	TYPE	DESCRIPTION	NOTE
3	Left side plate	A	CC02	Hole for Interface bolts	This location is covered by the fail safe analysis of the interface bolts.
		B	CC01	Near the connection to the beams	
		C	CC02	Hole for Interface bolts	This location is covered by the fail safe analysis of the interface bolts.

Table 12-1: Description of potentially fracture critical location for ACOP

The used stress level is based on the average stress from RD16. Maximum stress of 176 Mpa near to the RBE2 element is considered not representative for fracture analysis:

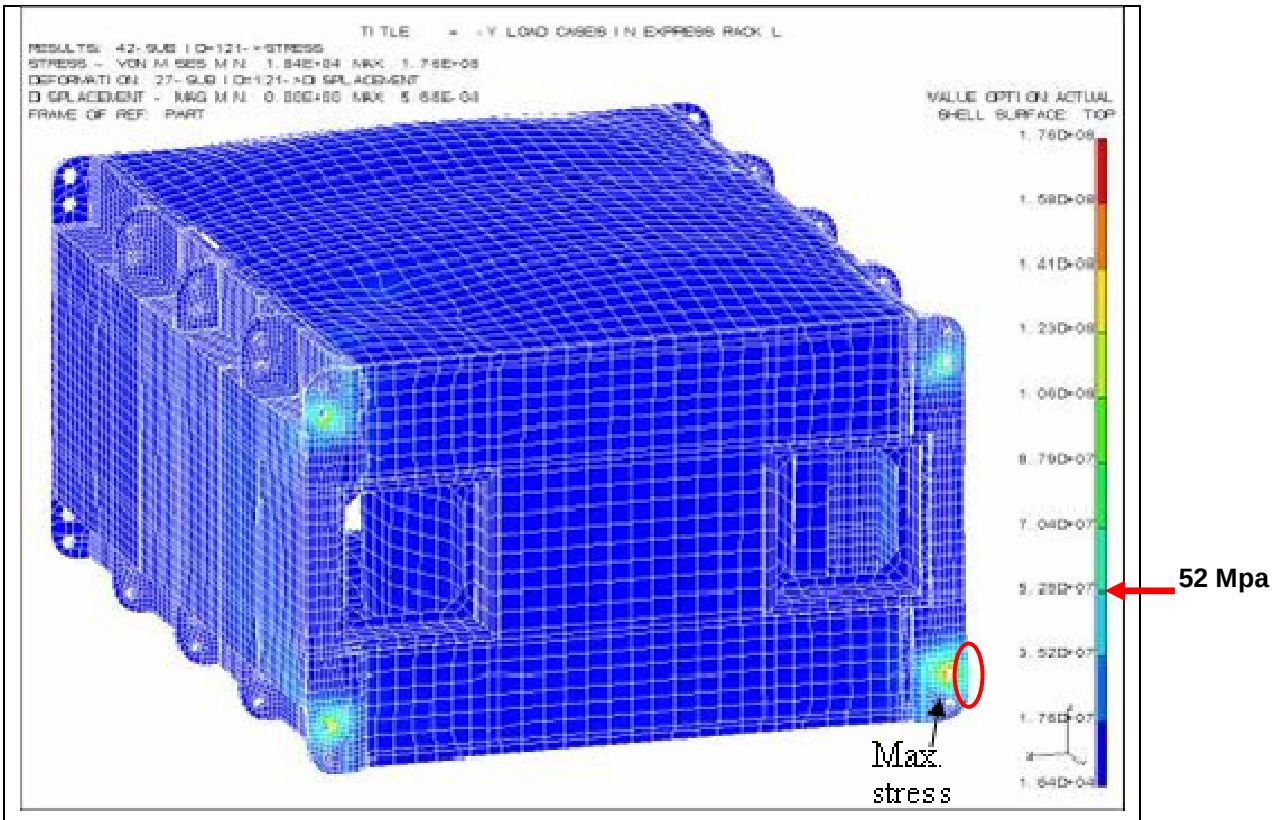


Figure 12-2 ACOP PFCI 3 B stress in nominal configuration for crack growth analysis

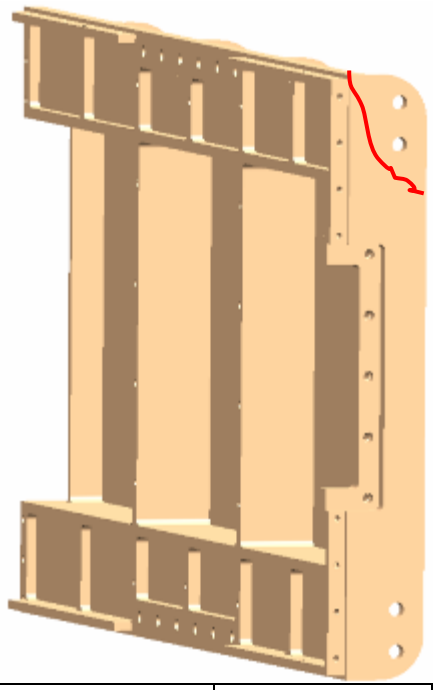
Project : ACOP Structure : Left side plate

Part Name : PLATE

PFCI No : 3

Classification : Safe Life

Sketch for crack location



Location Code :
B

Drawing No :
AM9408-06

NASGRO crack model:
CC02

Geometry [mm] :

W : 30	T : 6
B :	D :
L :	D_0 :

Material:
AL 7075-T7351
Plt & Sht; S-T; LA

Unit Stress [MPa]	Tension	Bending-1	Bending-2	Point	Biaxial
X	NA	0	0	NA	0
Y	NA	0	0	NA	0
Z	NA	0	0	NA	0
Φ	0	0	0	0	0
Θ	0	0	0	0	0
Ψ	0	0	0	0	0
Pressure	0	0	0	0	0
Constant	0	0	0	0	0

Max Stress (in the spectrum) [MPa]	Material yield stress [MPa]	Critical stress intensity [MPa $\sqrt{mm}$]
σ_{max} = 52 (Tension)	σ_y = 400	K_C = 675
Initial Crack Size [mm]	**Final Crack Size [mm]**	**Critical Crack Size [mm]**
a = 2.54 c = 2.54	a = 2.546 c = 2.547	c = 10.3
NDI : Dye Penetrant	Analytical life : 323 Schedule	Analytical life > 4 times the service life ? Yes : X No :

NOTES:
Transition to 1-d solution, TC02 at 319 schedule
1 schedule corresponds to 1 Service Life.
Final Crack Size reached at 4 complete schedule.

12.2 PFCI 4

In the following figure the PFCI 4 is presented:

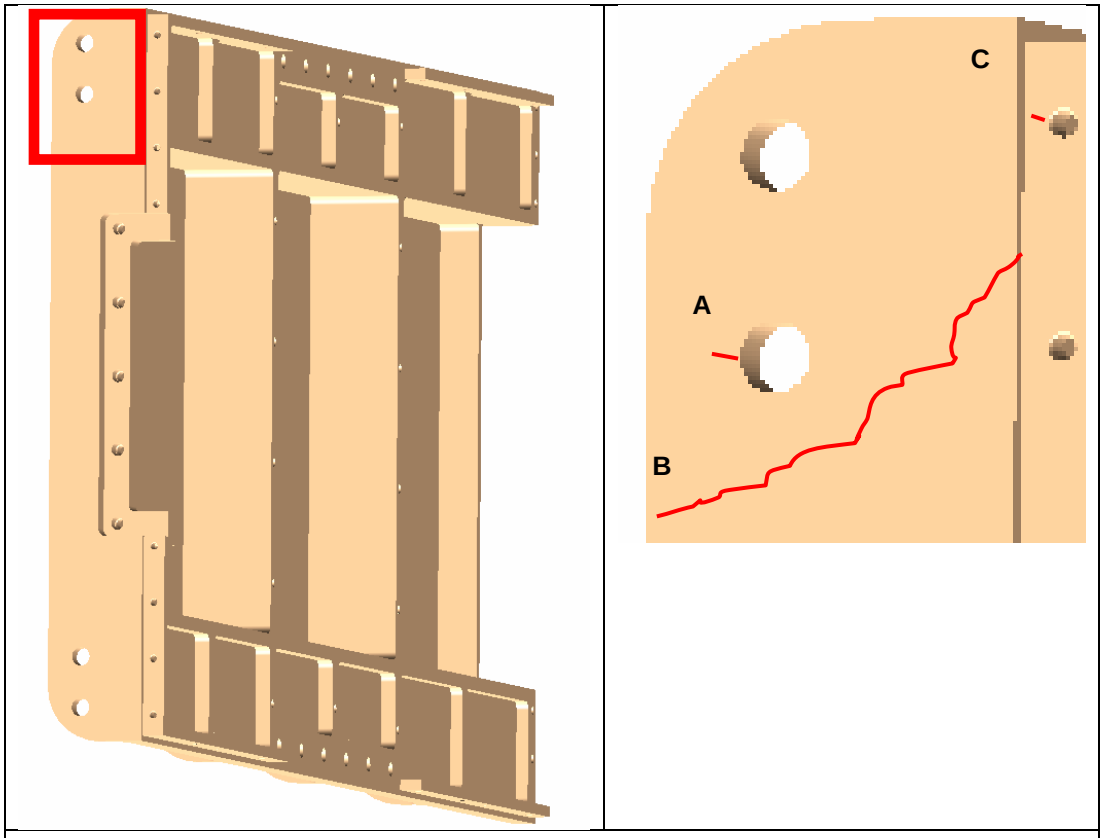


Figure 12-3 ACOP PFCI 4presentation

In this PFCI the stress is concentrated near the interface bolts (highlighted in the figure). For this PFCI three cracks are considered:

PFCI	ITEM NAME	LOCATION	TYPE	DESCRIPTION	NOTE
4	Right side plate	A	CC02	Hole for Interface bolts	This location is covered by the fail safe analysis of the interface bolts.
		B	CC01	Near the connection to the beams	Covered by PFCI 3 Location B
		C	CC02	Hole for Interface bolts	This location is covered by the fail safe analysis of the interface bolts.

Table 12-2: Description of potentially fracture critical location for ACOP

12.3 PFCI 6

In the following figure the PFCI 6is presented:

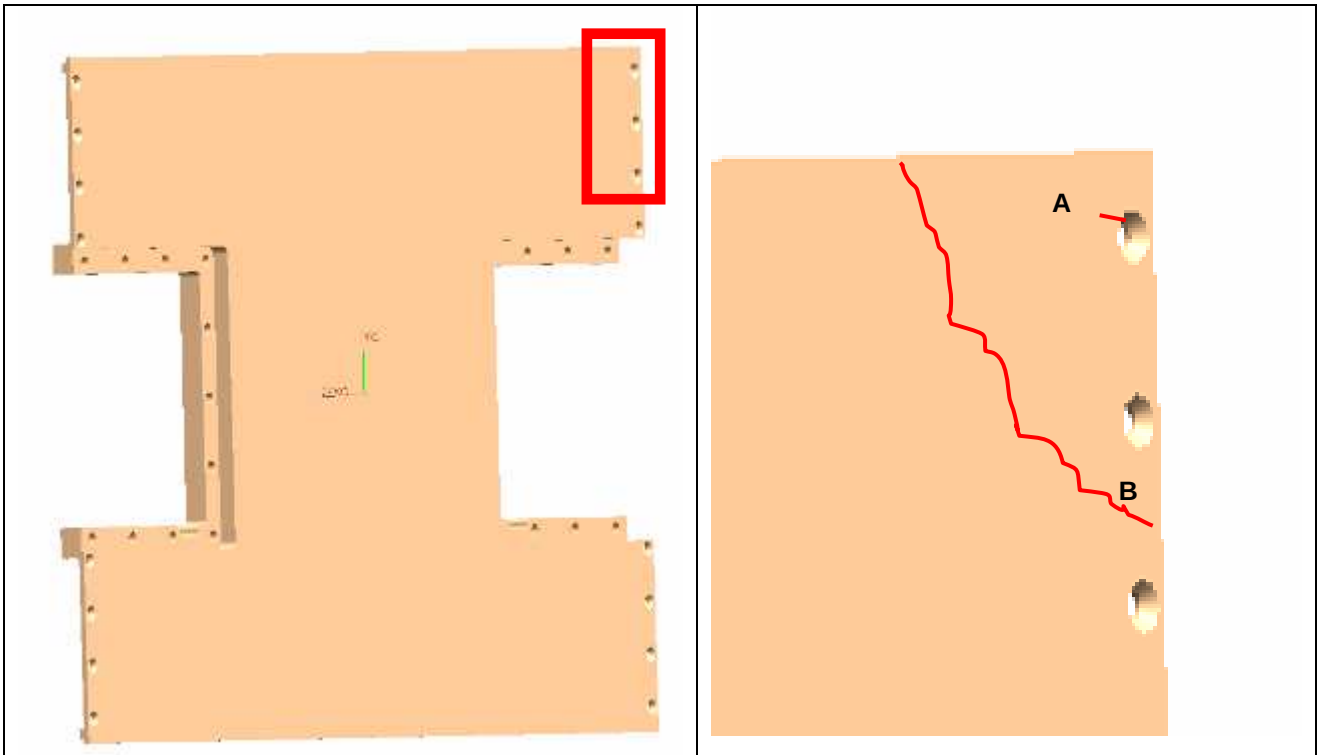


Figure 12-4 ACOP PFCI 6presentation

In this PFCI the stress is concentrated near the interface bolts (highlighted in the figure). For this PFCI three cracks are considered:

PFCI	ITEM NAME	LOCATION	TYPE	DESCRIPTION	NOTE
6	Back plate	A	CC02	Hole for the connection to the lateral plate	This location is covered by the fail safe analysis of the interface bolts.
		B	TC02	End Pad	

Table 12-3: Description of potentially fracture critical location for ACOP

The used stress level is based on the average stress from RD16. Maximum stress of 136 Mpa near to the RBE2 element is considered not representative for fracture analysis:

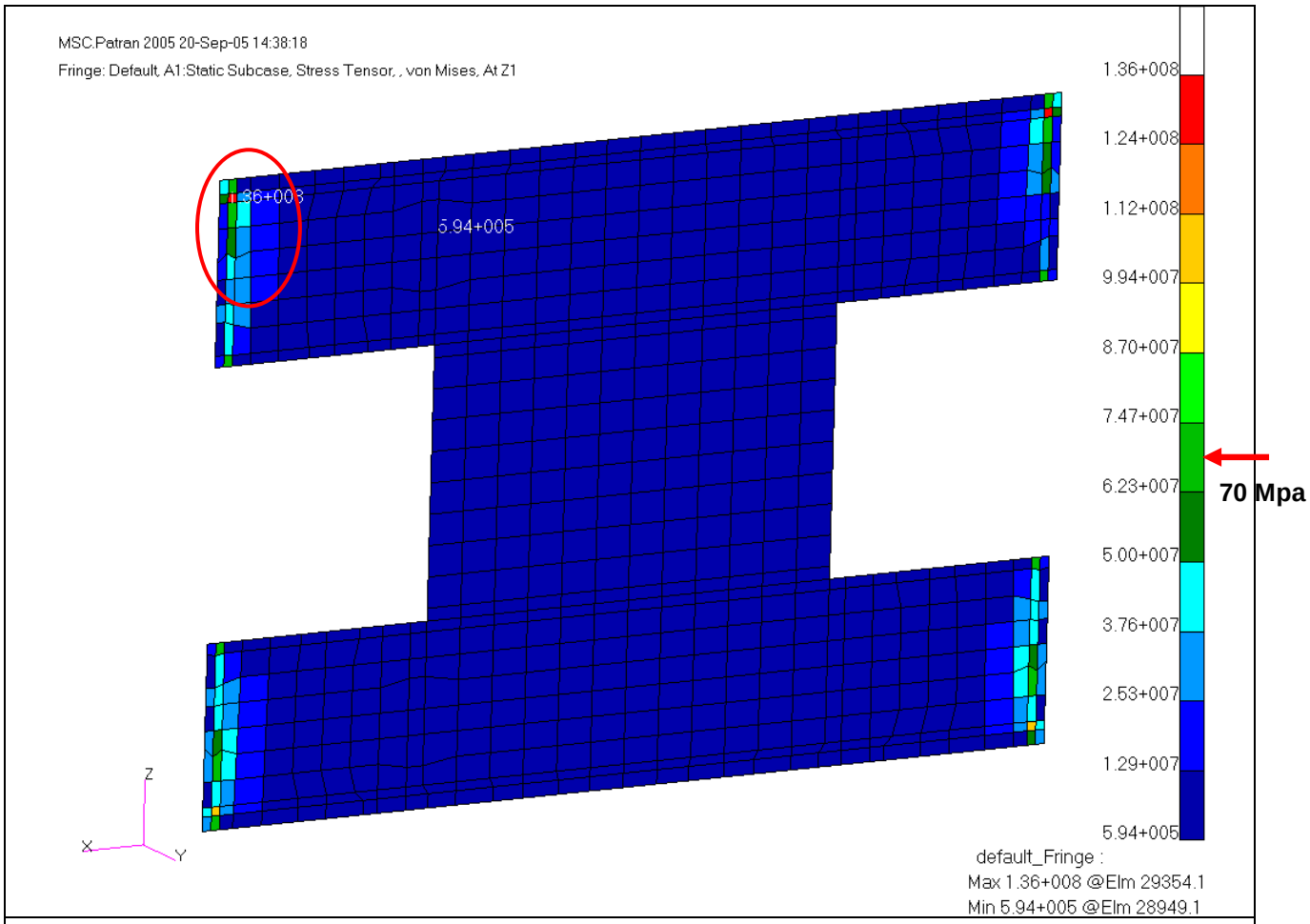


Figure 12-5 ACOP PFCI 6 location B stress in nominal configuration for crack growth analysis

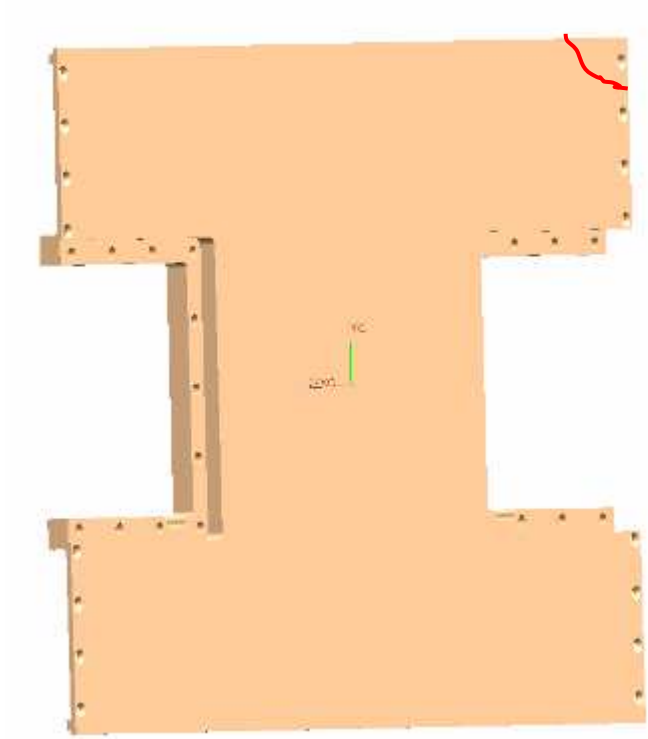
Project : ACOP Structure : Back plate

Part Name : PLATE

PFCI No : 6

Classification : Safe Life

Sketch for crack location



Location Code :
B

Drawing No :
AM9408-03

NASGRO crack model:
TC02

Geometry [mm] :	
W : 70	T : 2
B :	D :
L :	D_0 :

Material:
AL 7075-T7351
Plt & Sht; S-T; LA

Unit Stress [MPa]	Tension	Bending-1	Bending-2	Point	Biaxial
X	NA	0	0	NA	0
Y	NA	0	0	NA	0
Z	NA	0	0	NA	0
Φ	0	0	0	0	0
Θ	0	0	0	0	0
Ψ	0	0	0	0	0
Pressure	0	0	0	0	0
Constant	0	0	0	0	0

Max Stress (in the spectrum) [MPa]	Material yield stress [MPa]	Critical stress intensity [MPa $\sqrt{mm}$]
σ_{max} = 70 (Tension)	σ_y = 400	K_C = 886
Initial Crack Size [mm]	**Final Crack Size [mm]**	**Critical Crack Size [mm]**
c = 2.54	c = 3.12	c = 19.9
NDI : Dye Penetrant	Analytical life : 21 Schedule	Analytical life > 4 times the service life ? Yes : X No :

NOTES:
1 schedule corresponds to 1 Service Life.
Final Crack Size reached at 4 complete schedule.

13.FAIL SAFE (RESIDUAL FATIGUE) ANALYSIS

Only fasteners are classified as Fail safe items (Refer to Table 8-1 for items' fracture classification).
MoS for Fail Safe analysis are defined in RD 16.

For the PFCI that are classified as Safe Life only the worst condition is analyzed.

For the PFCI that are classified as Fail Safe the residual fatigue analysis is performed using the maximum forces that come from the fail safe analysis.

13.1 PFCI 4

Fail safe stress is based on fail safe analysis stress results of RD 16. The maximum stress in all the structure is 290 MPa near to the RBE2 element for the PFCI 4.

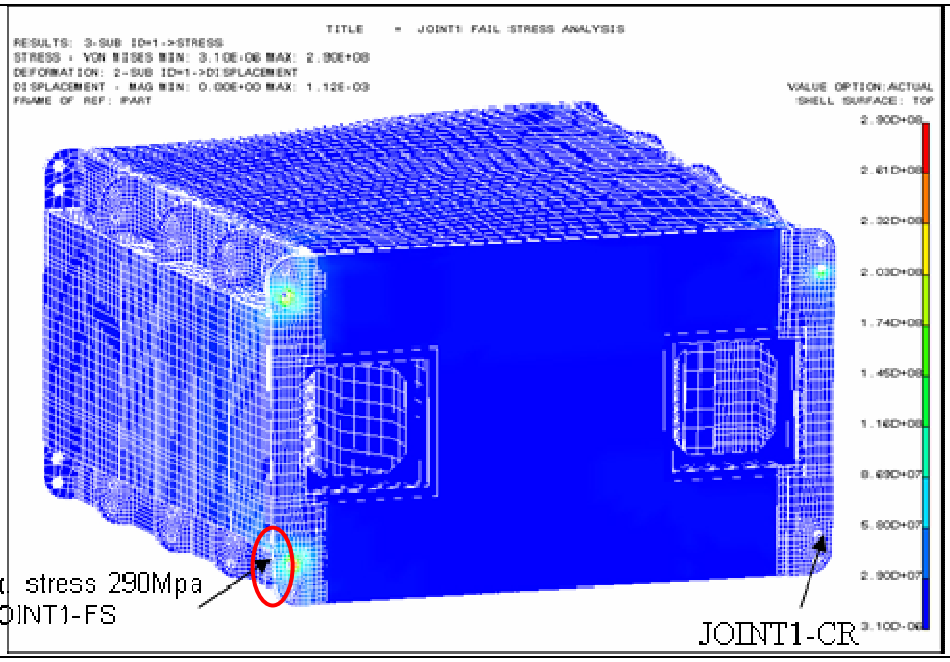


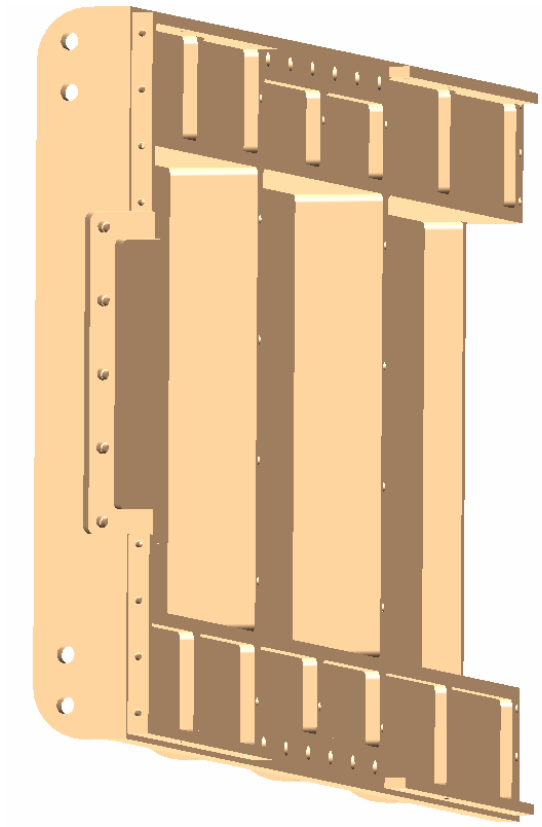
Figure 13-1 ACOP PFCI 4 stress for residual fatigue analysis

Project : ACOP Structure : Right side plate

Part Name : PLATE

PFCI No : 4

Residual fatigue



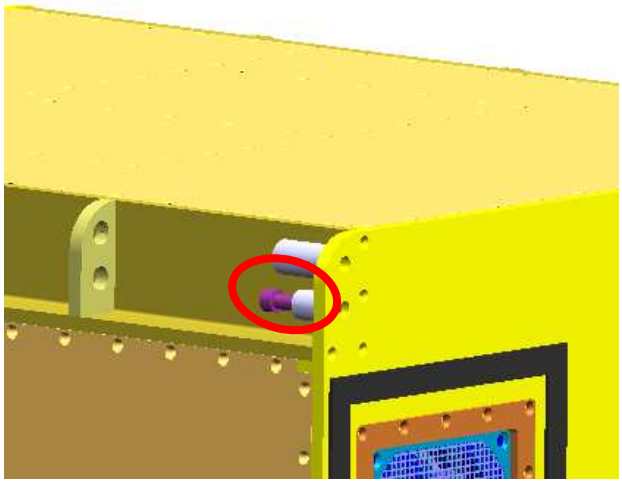
Drawing No :
AM9408-07

Material:
7075-T6, Kt=1. bare sheet
R=(-1;0.5)

Unit Stress [MPa]	Tension	Bending-1	Bending-2	Point	Biaxial
X	NA	0	0	NA	0
Y	NA	0	0	NA	0
Z	NA	0	0	NA	0
Φ	0	0	0	0	0
Θ	0	0	0	0	0
Ψ	0	0	0	0	0
Pressure	0	0	0	0	0
Constant	0	0	0	0	0

Max Stress (in the spectr.) [MPa]	Max Eq. Stress (in the spectr.) [MPa]	Min R (in the spectr.)
σ_{max} = 290	σ_y = 407	R_{min}=-1
	Life (scatter factor of 4 considered) Total Damage = 0.32 Life = 3.09	Analytical life > 4 times the service life ? Yes : X No :

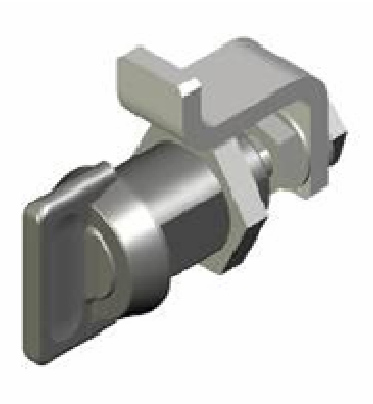
13.2 PFCI 22

Project : ACOP Structure : NA Part Name : CONNECTION				PFCI No : 22 Residual fatigue	
				Location Code : NA Drawing No : NA Material: A-286 M5, W. No. 1.4944.4 screw R=(0.04;0.65)	
Unit Stress [MPa]	Tension	Bending-1	Bending-2	Point	Biaxial
X	NA	0	0	0	0
Y	NA	0	0	0	0
Z	NA	0	0	0	0
Φ	0	0	0	0	0
Θ	0	0	0	0	0
Ψ	0	0	0	0	0
Pressure	0	0	0	0	0
Constant	0	0	0	0	0
Max Stress (in the spectr.) [MPa] σ_{max} = 717		Min Eq. Stress (in the spectr.) [MPa] σ_{min} = 238		Min R (in the spectr.) R_{min} = 0.33	
NDI : Lot Acceptance		Life (scatter factor of 4 considered) Total damage = 0.315 Life = 3.176		Analytical life > 4 times the service life ? Yes : X No :	
NOTE: stress derived from a load of 7595 N from RD16 and a preload torque of 11 Nm, resulting in a applied stress of 239 Mpa and a preload stress of 478 Mpa.					

13.3 PFCI 28

Project : ACOP Structure : NA Part Name : CONNECTION				PFCI No : 28 Residual fatigue	
				Location Code : NA Drawing No : NA Material: A-286 M5, W. No. 1.4944.4 screw R=(0.04;0.65)	
Unit Stress [MPa]	Tension	Bending-1	Bending-2	Point	Biaxial
X	NA	0	0	0	0
Y	NA	0	0	0	0
Z	NA	0	0	0	0
Φ	0	0	0	0	0
Θ	0	0	0	0	0
Ψ	0	0	0	0	0
Pressure	0	0	0	0	0
Constant	0	0	0	0	0
Max Stress (in the spectr.) [MPa] σ_{max} = 491		Min Eq. Stress (in the spectr.) [MPa] σ_{min} = NA		Min R (in the spectr.) R_{min} = 0.92	
NDI : Lot Acceptance		Life (scatter factor of 4 considered) Total damage = 0.00 Life = ∞		Analytical life > 4 times the service life ? Yes : X No :	
NOTE: stress derived from a load of 111 N from RD16 and a preload torque of 3 Nm, resulting in a applied stress of 17.6 MPa and a preload stress of 473 Mpa.					

13.4 PFCI 31

Project : ACOP Structure : NA	PFCI No : 31
Part Name : LATCH	Residual fatigue
	Location Code : NA
	Drawing No : NA
	Material: 300M steel

Unit Stress [MPa]	Tension	Bending-1	Bending-2	Point	Biaxial
X	NA	0	0	0	0
Y	NA	0	0	0	0
Z	NA	0	0	0	0
Φ	0	0	0	0	0
Θ	0	0	0	0	0
Ψ	0	0	0	0	0
Pressure	0	0	0	0	0
Constant	0	0	0	0	0

Max Stress (in the spectr.) [MPa] σ_{max} = 55	Min Eq. Stress (in the spectr.) [MPa] σ_{min} = NA	Min R (in the spectr.) R_{min} = -1
NDI : Lot Acceptance	Life (scatter factor of 4 considered) Total damage = 0.0 Life = ∞	Analytical life > 4 times the service life ? Yes : X No :

14.ROTATING MACHINERY

In the following chapters the two rotating machineries are analyzed: the items with a value of kinetic energy lower than 19.3J can be considered as non fracture items and the other structural components and must be contained.

14.1 PFCI 39 (FAN)

The kinetic energy of the fan is:

$$K = \frac{1}{2} * \omega^2 * I$$

Where ω is the angular velocity and I is the moment of the inertia of the fan:

Where w is the angular velocity and I is the moment of the inertia of the fan:
ω=2850RPM

$$I = \frac{1}{2} * R^2 * m = \frac{1}{2} * (0.05m)^2 * (0.02Kg) = 2.5e-5Kgm^2$$

$$K = 0.2J$$

This value of kinetic energy permit to consider the hard disc as a structural component and it shall be verified by the containment analysis.

14.2 PFCI 42 (HARD DISC)

The kinetic energy of the Hard Disc is:

$$K = \frac{1}{2} * \omega^2 * I$$

Where ω is the angular velocity and I is the moment of the inertia of the Hard Disc:
ω=7200RPM

$$I = \frac{1}{2} * R^2 * m = \frac{1}{2} * (0.05m)^2 * (0.32Kg) = 4e-4Kgm^2$$

$$K = 9.1J$$

This value of kinetic energy permit to consider the hard disc as a structural component and it shall be verified by the containment analysis.

15.CONTAINMENT ANALYSIS

In accordance with AD 16, Section 6.2.1.1, the punch equation approach is followed:

$$T_R = \sqrt{\frac{1}{2} \cdot V^2 \cdot \frac{W}{g} \cdot \frac{1}{\pi \cdot d \cdot F_{ty}}}$$

where:

- T_R = The minimum required wall thickness (inches) of the container to prevent escape of the component/part
- W = Weight (pound-force) of the detached piece or part to be contained
- g = Gravitational acceleration (in/sec^2)
- V = Velocity (inches per second) that may be attained by that piece or part
- d = Minimum profile diameter (inches) of piece or part that will produce a shear load on the container wall before escape by any particular piece or part resulting from a structural failure
- F_{ty} = The yield strength (pounds per square inch) of the container wall material.

In accordance with AD 16, Section 6.2.1.1.2, factor $(\pi \cdot d)$ is considered as the perimeter of the smallest face of a rectangular object.

In accordance with AD 16, Section 6.2.1.1.3, the velocity V is calculated with the following formula:

$$V = \frac{A_{LF}}{2 \cdot \pi \cdot f_n} + \sqrt{2 \cdot a \cdot S_d}$$

where:

- A_{LF} = Low frequency acceleration
- f_n = Minimum natural frequency (Hz)
- a = Steady state acceleration $(\approx 1.5 \cdot g)$ of the NSTS Orbiter
- S_d = Maximum travel distance of the projectile within the container

Following chapters show that following this approach no contained item can be considered critical.

15.1 PFCI 39 (FAN)

The fan is contained by the air filter see Figure 7-3; the air filter is composed by several wire of aluminum of 0.6mm thickness.

With respect to symbols and acronyms exposed in 15 CONTAINMENT ANALYSIS for containment analysis, the following assumption are done:

A_{LF} = 14
See RD 16

- f_n = 100 Hz
  (conservative assumption)
- a = 13 g
- S_d = 0.03 m
- V = 3m/s
  (see previous formula)
- W = 0.19 N
- g =9.81 m/s^2
  (gravitational constant)
- (π d) = 0.03m
- F_{ty} = 119 MPa

The minimum required wall thickness from the punch formula is:

$$T_{R;min} = 0.15 \text{ mm}$$

The air filter has a . thickness of 6mm.

Then, the item is **NOT** critical.

15.2 PFCI 40 (ELECTRONIC BOARDS)

With respect to symbols and acronyms exposed in 15 CONTAINMENT ANALYSIS for containment analysis, the following assumption are done:

A_{LF} = 23
See RD 16

- f_n = 100 Hz
  (conservative assumption)
- a = 6 g
- S_d = 0.5 m
- V = 8m/s
  (see previous formula)
- W = 9.81 N
- g =9.81 m/s^2
  (gravitational constant)
- (π d) = 0.03m
- F_{ty} = 393 MPa

The minimum required wall thickness from the punch formula is:

$$T_{R;min} = 1.61 \text{ mm}$$

ACOP walls minimum effective thickness is 2 mm.

Then, the item is **NOT** critical.

15.3 PFCI 41 (LCD LEXAN)

With respect to symbols and acronyms exposed in 15 CONTAINMENT ANALYSIS for containment analysis, the following assumption are done:
For the LCD the containment analysis is performed with respect to the 5mm of LEXAN in front of the LCD.

A_{LF} = 24
See RD 16

- f_n = 100 Hz
  (conservative assumption)
- a = 20 g
- S_d = 0.03 m
- V = 3.8m/s
  (see previous formula)
- W = 4.5 N
- g =9.81 m/s^2
  (gravitational constant)
- (π d) = 0.03 m
- F_{ty} = 34 MPa

The minimum required wall thickness from the punch formula is:

$$T_{R;min} = 2.1 \text{ mm}$$

ACOP LEXAN COVER minimum effective thickness is 5 mm.

When the Front panel door is open, the containment is performed by a metallic case enclosing the LCD.

Then, the item is **NOT** critical.

15.4 PFCI 41 (LCD BACK COVER)

With respect to symbols and acronyms exposed in 15 CONTAINMENT ANALYSIS for containment analysis, the following assumption are done:
For the LCD COVER the containment analysis is performed with respect to the 5mm of LEXAN that cover the LCD.

A_{LF} = 24
See RD 16

- f_n = 100 Hz
  (conservative assumption)
- a = 20 g
- S_d = 0.03 m
- V = 3.8m/s
  (see previous formula)
- W = 4.5 N
- g =9.81 m/s^2
  (gravitational constant)
- (π d) = 0.03 m
- F_{ty} = 137 MPa

The minimum required wall thickness from the punch formula is:

$$T_{R;min} = 1.1mm$$

ACOP LEXAN COVER minimum effective thickness is 1.6 mm.

Then, the item is **NOT** critical.

15.5 PFCI 42 (HARD DISC)

The Hard disc shall be mounted into the ACOP only when the unit is mounted on the ISS.

16.LOW RISK ITEM LIST

In the low risk item list only the item defined as LOW RISK in Table 8-1 are recovered:

LOW RISK									
PFCI	ITEM	TYPE	DRAW.NO./ PART NO.	MATERIAL	TYPE OF CONSTRUCTION	LOAD TYPE	FRACTURE CLASSIFICATION	NDI	NOTE
1	Top plate	PART	AM9408-04	7075T7351	MACHINED	Inertial	LOW RISK	US	
2	Bottom plate	PART	AM9408-05	7075T7351	MACHINED	Inertial	LOW RISK	US	
5	Fixed front panel	PART	AM9408-02	7075T7351	MACHINED	Inertial	LOW RISK	US	
7	Door	PART	AM9408-0801	7075T7351	MACHINED	Inertial	LOW RISK	US	
8	Handle for door	PART	AM9408-0806	7075T7351	MACHINED	Inertial	LOW RISK	US	
9	Handle for Locker	PART	AM9408-09	7075T7351	MACHINED	Inertial	LOW RISK	US	
10	Fin Baffle	PART	AM9408-10	6061T6	MACHINED	Inertial	LOW MASS	US	
11	Baffle	PART	AM9408-11	6061T6	MACHINED	Inertial	LOW RISK	US	
11/15	Hinge pad 1-4	PART	AM9408-04/ AM9408-05/ AM9408-15/ AM9408-16	AM-355 stainless steel	MACHINED	Inertial	LOW RISK	US	
16	Hinges	PART	CFHG16	AISI 316	MACHINED	Inertial	LOW RISK	US	
17	LCD front cover	PART	AM9408-0803	6061T6	MACHINED	Inertial	LOW RISK	US	
18	LCD back cover	PART	AM9408-0802	6061T6	MACHINED	Inertial	LOW RISK	US	
19	LEXAN	PART	NA	935 A	NA	Inertial	LOW RISK	NA	
20	Fan Frame	PART	AM9404-13	6061T6	MACHINED	Inertial	LOW RISK	US	
21	Dust Screen	PART	TBD		NA	Inertial	LOW RISK	NA	

PFCI	ITEM	TYPE	DRAW.NO./ PART NO.	MATERIAL	TYPE OF CONSTRUCTION	LOAD TYPE	FRACTURE CLASSIFICATION	NDI	NOTE
32	Top plate of Chassis	PART	AM9408-0101	6061T6	MACHINED	Inertial	LOW RISK	US	
33	Right fin	PART	AM9408-0102	6061-T6	MACHINED	Inertial	LOW RISK	US	
34	Left fin	PART	AM9408-0103	6061-T6	MACHINED	Inertial	LOW RISK	US	
35	HD up house	PART	AM9408-0104	6061-T6	MACHINED	Inertial	LOW RISK	US	
36	HD down house	PART	AM9408-0105	6061-T6	MACHINED	Inertial	LOW RISK	US	
37	Bottom plate of Chassis	PART	AM9408-0106	6061-T6	MACHINED	Inertial	LOW RISK	US	

Table 16-1: Low Risk Item List

17.FRACTURE CRITICAL ITEM LIST

In the fracture critical item list only the safe life items are reported with the fracture and fatigue analysis results. The fail safe items are not defined as fracture critical according to paragraph 5.3.1.4.3 of AD 16.

FRACTURE CRITICAL ITEM LIST								
PFCI	**ITEM**	**MATERIAL**	**DRAW.NO./PART NO**	**NDI**	**FRACTURE CLASSIFICATION**	**ANALYITICAL LIFE (FRACTURE)**	**ANALYITICAL LIFE (FATIGUE)**	**NOTE**
3	Left side plate	7075T7351	AM9408-06	US/DP	**SAFE LIFE**	>4	>4	
4	Right side plate	7075T7351	AM9408-07	US/DP	**SAFE LIFE**	>4	>4	
6	Back plate	7075T7351	AM9408-03	US/DP	**SAFE LIFE**	>4	>4	

Table 17-1: 1.Fracture Critical Item List

18.FRACTURE LIMITED LIFE ITEM LIST

In the limited life item list all the item that shown analytical life lower than 4 are reported

FRACTURE LIMITED LIFE ITEM LIST								
PFCI	ITEM	MATERIAL	DRAW.NO./PART NO	NDI	FRACTURE CLASSIFICATION	ANALYITICAL LIFE (FRACTURE)	ANALYITICAL LIFE (FATIGUE)	NOTE
No FLLI defined by the analyses								

Table 18-1: Fracture Limited Life Item List

19.FAIL SAFE ITEM LIST

In the fail safe item list all the item that are verified as fail safe and with an analytical life for the fatigue higher than 4 are reported

FAIL SAFE ITEM LIST									
PFCI	ITEM	TYPE	DRAW.NO./ PART NO.	MATERIAL	TYPE OF CONSTRUCTION	ANALYITICAL LIFE (FATIGUE)	FRACTURE CLASSIFICATION	NDI	NOTE
22	JOINT 1 ACOP/EXPRESS Rack interface	CONNECTION	CS5108-4-5	A286 160KSi	FASTENER	>4	FAIL SAFE	LA	
23	JOINT 4a Top plate/Side wall, backplate, front panel, chassis	CONNECTION	SPS 96395-94-C	A286 160KSi	FASTENER	>4	FAIL SAFE	LA	
24	JOINT 4b Bottom plate/Side wall, backplate, front panel, chassis	CONNECTION	SPS 96395-94-C	A286 160KSi	FASTENER	>4	FAIL SAFE	LA	
25	JOINT 9 Fan frame/backplate, side walls	CONNECTION	CA2261-06	A286 160KSi	FASTENER	>4	FAIL SAFE	LA	
26	JOINT 10a Side walls/ backplate	CONNECTION	SPS 96395-94-C	A286 160KSi	FASTENER	>4	FAIL SAFE	LA	
27	JOINT 10b Side walls/ front panel	CONNECTION	SPS 96395-94-C	A286 160KSi	FASTENER	>4	FAIL SAFE	LA	
28	JOINT 13 LCD front cover plate/door adapter	CONNECTION	SPS 96395-94-C	A286 160KSi	FASTENER	>4	FAIL SAFE	LA	
29	JOINT 16 LCD back-cover/door adapter	CONNECTION	NAS 1352N04	A286 160KSi	FASTENER	>4	FAIL SAFE	LA	
30	JOINT 18 Large handle/front panel	CONNECTION	NAS 1351N3	A286 160KSi	FASTENER	>4	FAIL SAFE	LA	
31	JOINT 19 Latch shaft	CONNECTION	Southco® E3-57-42	NA	LATCH	>4	FAIL SAFE	LA	
38	JOINT 2 Chassis /Side walls	CONNECTION	NAS 1351N3	A286 160KSi	FASTENER	>4	FAIL SAFE	LA	

Table 19-1: Fail Safe Item List

20.CONCLUSION AND COMMENTS

ACOP PFCI have been selected according to AD 16

The following analyses have been performed for the selected PFCI:

- Safe life analysis (chapter 12);
- Fail safe analysis (chapter13);
- Containment analysis (chapter 15).

NO Fracture Limited Life Items have been identified.