Strength and Fracture Assessment of the Human Research Facility (HRF) Surface, Water and Air Biocharacterization (SWAB) Air Sampling Device (ASD)

[P/N: SEG46119448-301]

Structural Analysis Section
Mechanical Systems Analysis Department
Science, Engineering, Analysis and Test (SEAT) Operation

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Strength and Fracture Assessment of the Human Research Facility (HRF) Surface, Water and Air Biocharacterization (SWAB) Air Sampling Device (ASD)

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Revision History

Revision	Date	Rev By	Pages Affected	Remarks

0.1 Abstract

The results of a strength and fracture control assessment of the HRF Surface, Water, and Air Biocharacterization (SWAB) Air Sampling Device (ASD) (P/N: SEG46119448-301) are presented in this report. The Air Sampling Device is a commercial off the shelf (COTS) item from Sartorius Technology of Germany (vendor number is AirPort MD-8). The SWAB ASD is intended for use on board the International Space Station (ISS) and the Shuttle Orbiter for collecting air samples in connection with the SWAB experiment. The ASD will be soft stowed during launch/landing in the Shuttle Mid-deck Locker and can be hand-held or attached to the walls of the Shuttle Orbiter or Space Station for operation by a Velcro fastener patch. The ASD was analyzed using a factor of safety of 2.0 for ultimate failure. All loading conditions that affect the ASD are analyzed for this report. Due to the brittle nature of the ASD housing material (ETOL Polyurethane Foam), only ultimate failure analysis, based on a factor of safety of 2.0, was performed for the ASD housing. Positive margins were obtained for all loading conditions (125 lbf. external kick loads, 0.2 g orbit maneuvering, and venting) with the exception of the 50 lbf. push load on the handle (MS = -0.351 resulted for the push load). This negative margin is to be resolved by a waiver request by the ASD project team.

0.2 Table of Contents

0.3 Minimum Margins of Safety

Table 0-1: Minimum Margins of Safety

Part /Drawing Number	**Part Name/ Description**	**MATERIAL & Heat Treatment**	**Critical Load Condition**	**Failure Mode**	**Margin of Safety**	**Reference Page**
AirPort MD-8, Sartorius Technology	Air Sampler Device Enclosure	ETOL Polyurethane Foam	125 lbf kick load	Bending, ultimate	0.21	2-5
AirPort MD-8, Sartorius Technology	Air Sampler Device Handle	ETOL Polyurethane Foam	50 lbf push load on handle	Bending, ultimate	**-0.351**	2-8
Type I, Class II	Velcro Tape, Enclosure Side	Velcro-Nylon and Aramid	0.2 g load	Tensile, ultimate	1.727	2-10

Note: Factor of safety used (F.S.) is 2.0.

0.4 List of Figures

0.5 List of Tables

0.6 Acronyms

ASD	Air Sampling Device
COTS	Commercial Off The Shelf
F	Fahrenheit
HDBK	Handbook
HRF	Human Research Facility
ISS	International Space Station
IVA	Intra-vehicular Activity
J	Joules
JSC	Johnson Space Center
kg.	kilogram
lbf.	pound force
LS	Life Science
mAh	milli-amp hours
MIL	Military
MS	Margin of Safety
NASA	National Aeronautics and Space Administration
psi	Pounds per square inch
SWAB	Surface, Water, and Air Biocharacterization
SEAT	Science, Engineering, Analysis and Test
SRD	Systems Requirements Document
SSP	Space Station Program

0.7 References

1. Fracture Control Plan for Human Research Facility Payload and Racks, LS-71010A, prepared by LMSO for NASA, Johnson Space Center, November 2001.

2. Fracture Control Requirements for Space Station, SSP 30558C, Rev. B, NASA, June 1994.

3. Pressurized Payloads Interface Requirements Document, International Space Station Program, SSP 57000, Rev. E, NASA, November 1, 2000.

4. Structural Design and Verification Requirements, International Space Station Alpha, SSP 30559, Rev. B, NASA, June 30, 1994.

5. Systems Requirements Document (SRD) for the Human Research Facility (HRF) Surface, Water, and Air Biocharacterization (SWAB) Experiment System, LS-20444-1, NASA, Johnson Space Center, January 2002.

6. Young, Warren C. "Roark's Formulas for Stress and Strain", 6th Ed., McGraw-Hill Inc., 1989.

7. A-A-55126A (MIL-F-21840G) Fastener Tapes, Hook and Loop, Synthetic Specification, June 23, 1999.

8. Fracture Control Requirements for Payloads Using the Space Shuttle, NASA-STD-5003, NASA, October 7, 1996.

9. Fracture Control Plan for JSC Flight Hardware, JSC 25863, Rev. A, NASA, Johnson Space Center,

1.0 Introduction

The HRF Surface, Water, and Air Biocharacterization (SWAB) Air Sampling Device (ASD) is a COTS item that is intended for use on board the International Space Station and Orbiter for collecting and sampling the air content for the presence of microorganisms. Sartorius Biotechnology of Germany manufactures the ASD and the unit is designated with a vendor part number and name of AirPort MD-8. Figure 1 shows an external view of the ASD. The ASD can either be mounted to an interior surface or hand held during use. The unit is soft stowed for launch and landing.

Figure 1. **SWAB Air Sampling Device (ASD)**

1.1 Hardware Description

The air-sampling device consists of a nozzle and behind the nozzle is a sealed impeller wheel powered by an electric motor. Once the hardware is taken out from the SWAB storage kit, a gelatin membrane filter will be attached to the membrane filter adapter and the crewmember will turn on the device and a select a sample rate and volume to be taken by the ASD. Air is drawn through the membrane filter attached to the filter adapter via the internal impeller wheel. After sampling is complete, the air sampler filter adaptor is simply removed from the ASD. The membrane filter is then removed from the adaptor and placed in a sealed bag. A single pack of five Li-BCX batteries powers the ASD. The air sampling device is encased in ETOL Polyurethane Foam and the enclosure includes a handle for the crewmember to hold the device during sampling. The air sampling device measures 5.31 inches in width, 6.5 inches in height and 11.81 inches in over all length. The overall weight of the air sampler is 5.5 lb (2.5 kg).

1.2 Load Conditions

The following applicable load conditions are analyzed for the ASD.

1.2.1 Launch/Landing Loads

The SWAB ASD will be soft stowed during launch and landing in one of the following locations: Mid-deck locker, MPLM, or Cargo Transfer Bags (CTB) per LS-20444-1, ASD Systems Requirements Document, section 3.2.2.1 [Ref. 5]. Based on the soft-stowage configuration of the hardware, no analysis is required for launch and landing of the hardware.

1.2.2 125 lbf. Crew-induced Kick Load

125 lbf. kick load in any direction and on any enclosure surface per requirement 3.2.7.5.3 of the SWAB Air Sampling Device SRD (LS-20444-1) [Ref. 5]. This requirement is consistent with the requirement listed in Table 3.1.1.3-1 (Crew-Induced Loads) of SSP 57000, Rev E [Ref. 3].

1.2.3 50 lbf. Crew-Induced Handling Load

The handle of the ASD must withstand a crew-induced handling load of 50 lbf. per Table 3.1.1.3-1 (Crew-Induced Loads) of SSP 57000, Rev E [Ref. 3].

1.2.4 0.2 g On-Orbit Maneuvering Load

The Air Sampling Device must remain attached to the wall of the cabin given a 0.2 maneuvering load on orbit of the (International Space Station) ISS or Orbiter per 3.1.1.3 b, of SSP 57000, Rev E [Ref. 3]. This maneuvering load occurs when the ISS or Orbiter is re-positioning or making course corrections.

1.3 Factors of Safety

Factors of safety used in the calculation of margins of safety are 2.0 for ultimate for all loading conditions considered herein. Yield strength is not available for the material of this COTS item. The margin of safety (MS) for yield was not calculated. This is considered acceptable since the ASD housing material (ETOL hardened Polyurethane Foam) is a brittle material that would exhibit an ultimate brittle failure mode. Ultimate failure would be the controlling failure mode as opposed to yield failure for the ASD housing.

1.4 Materials and Temperature

The nominal operating temperature environment of the ASD is 65^o to 80^o F per LS-20444-1 [Ref. 5]. This temperature range is considered ambient temperature for the ASD housing material (ETOL hardened Polyurethane Foam). Therefore, no material strength degradation factor is used for the analysis. The material strengths of this material were obtained from the vendor. This material had a maximum flexural strength of 20 N/mm^2, which converts to an ultimate bending strength of 2,900.755 psi.

The Velcro tape used for on-orbit retention of the ASD is A-A-55126A Type 1, Class 2 Velcro Fastener tape (formerly MIL-F-21840G). The strength of the Velcro Fastener Tape is from the A-A-55126A specification.

The air sampler's Velcro tape dimensions are 2 inches wide by 2 inches long. For a 2-inch wide Velcro tape, the allowable load is 10.0 lb/in. (2 in. strip) for shear and 0.5 lb/in. (1 in. strip) for peel. Since the ASD will be mounted to the wall of the cabin in a way to allow a pull load and not a peel load, the peel load is not applicable. A factor of 3 was applied to the allowable peel load to approximate the allowable pull load. This was estimated by conservatively applying a ratio of the number of fibers/hooks sharing the load in tension to the number of fibers/hooks that are sharing the load in peeling per unit length. See page 2-10 for details of the assessment against pull and shear strengths of the Velcro.

2.0 Detailed Stress Assessment

The detailed stress assessment was conducted using the loads described in section 1.2 and using factors of safety stated in section 1.3. The Velcro fastener tape exhibited positive margins of safety for their respective load cases. The ASD enclosure exhibited positive margins for 125 lbf crew kick load but exhibited negative margins when the 50 lbf. operational push load is applied to the handle. The following subsections present the detailed analysis of the ASD.

2.1 125 lbf. Kick Load to ASD Enclosure

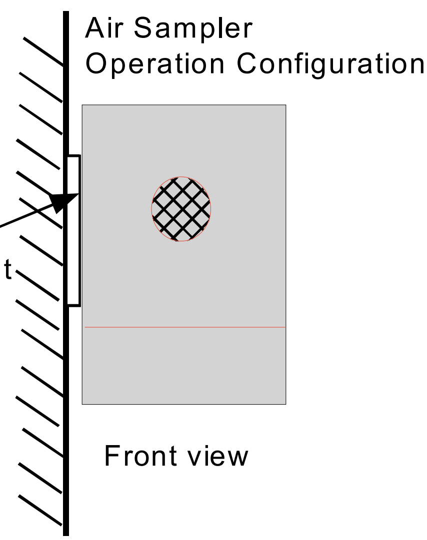
The kick load case mentioned in section 1.2.1 was applied to the side of the ASD enclosure and the enclosure was analyzed for maximum plate bending stress. Using a measured value of 0.25” thickness for the side plate, maximum plate bending stress was calculated using Case 1c of Table 26 from *Roark’s Formulas for Stress and Strain* [Ref. 6]. The 125 lb. kick load was applied over a uniformly distributed area of 4” by 4” in the center of the side plate. Only an ultimate margin of safety was calculated. The minimum margin of safety for the ASD enclosure under compressive bending stress is +0.209 using the factor of safety specified in section 1.3. The following MathCAD sheets detail the 125 lbf. kick load analysis for the ASD.

125 lbf. Kick Load Analysis

Since the MD8 Air Sampler is attached by velcro along the wall of the ISS or shuttle mid-deck, a kick load on any surface that is not opposite of the Velcro surface of the Air Sampler would likely cause the air sampler to become detached from the velcro patch. For analysis purpose, the ASD is assumed not to freely move and the 125 lbf. crew induced load is applied to the most vulnerable surface of the ASD.

Factors of Safety: $SF_{ut} := 2.0$ Ultimate Safety Factor

ASD Enclosure
Part number: SEG4611944-301
Material: ETOL hardened Polyurethane Foam



ASD attached to ISS/Mid-deck wall.

Material Properties - Hardened Polyurethane Foam

From ETOLPUR Integral rigid skin foam data sheet:
(See Appendix A)

density = 0.4 kg/dm³

flexural strength = 20 N/mm²

Convert these values from N/mm² to PSI

$Flex\_st := 20 \frac{N}{mm^2}$ $Flex\_st = 2 \cdot 10^7 \cdot Pa$

$Flex\_mod := 610 \frac{N}{mm^2}$ $Flex\_mod = 6.1 \cdot 10^8 \cdot Pa$

$Ftu\_st := 13 \frac{N}{mm^2}$ $Ftu\_st = 1.3 \cdot 10^7 \cdot Pa$

$F_{bu} := Flex\_st$ $E := Flex\_mod$ $F_{tu} := Ftu\_st$

$F_{bu} = 2900.755 \cdot psi$ Ultimate Breaking Strength for bending

$E = 8.847 \cdot 10^4 \cdot psi$ Flex Modulus

$F_{tu} = 1885.491 \cdot psi$ Ultimate Tensile Strength

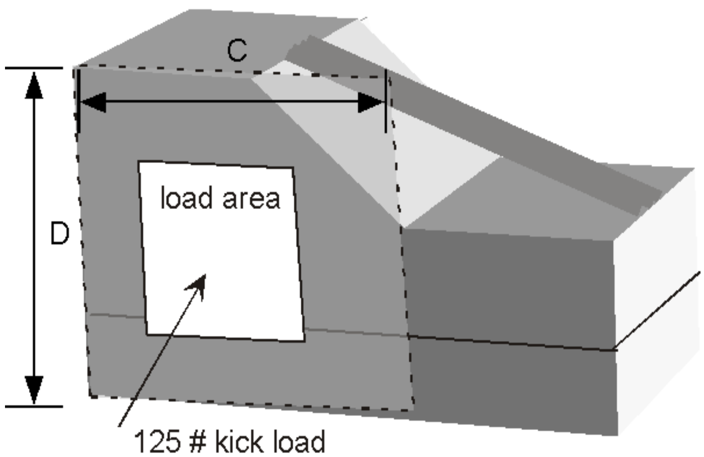
Plate dimensions:

ASD side plate length: $c \equiv 6.63 \cdot in$

ASD side plate width: $d \equiv 6.5 \cdot in$

ASD side plate minimum thickness: $th \equiv 0.25 \cdot in$

Note: The Effective surface of the Air Sampling Device's enclosure is taken as 6.5" in height and 6.63" in width.



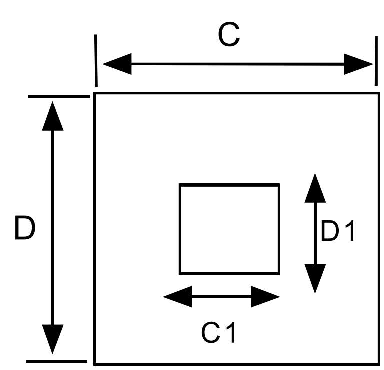
AirPort MD8 Air Sampling Device
Kick Load Case 1 Effective Area

Load over central area: $W := 125 \cdot lbf$

Height of central area: $c_1 \equiv 4.0 \cdot in$

Width of central area: $d_1 \equiv 4.0\ in$

$\frac{c}{d} = 1.02$ $\frac{c_1}{d} = 0.615$ $\frac{d_1}{d} = 0.615$



Definition of kick load area

Reference- Roark's Formulas for Stress and Strain 6th Ed. Table 26 Case 1-c for the tabulation of β

$\beta \equiv 0.6$

Assume conservatively that all edges simply supported for the plate.

Calculating Maximum compressive bending stress on the face plate

The maximum stress for materials with ν approximately equal
to 0.3 is given by

$$\sigma_c := \frac{\beta \cdot W}{th^2}$$

$$\sigma_{max} := \sigma_c$$

$$\sigma_{max} = 1200 \circ \frac{lbf}{in^2}$$

Calculating Margins of Safety on the face plate

Ultimate Bending Margin of Safety

$$MSu := \frac{F_{bu}}{\sigma_{max} \cdot SF_{ut}} - 1$$

$MSu = 0.209$ Margins of Safety <==========

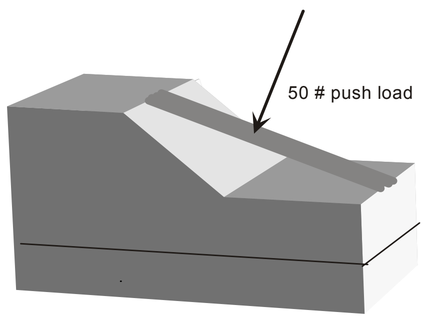
Conclusion:

The ASD enclosure can withstand a kick load of 125 lbf. on the side.
(the largest and weakest surface of the ASD).

2.2 50 lbf. Push Load On the ASD Handle

The Air Sampler Device Handle is an integrated part of the ASD enclosure and is molded from the same material. The handle was analyzed as a fixed elliptically hollow beam with a central load of 50 lbf. applied at the center to generate maximum bending moments. Cross-sectional moment of inertia of the handle was modeled using case 25 from *Roark's Formulas for Stress and Strain*, 6th Ed. [Ref. 6] for hollow ellipse with constant thickness. The thickness was estimated to be 0.125 inches. The maximum moment was calculated using Table 3 of Roark's, case 1d. A negative margin of safety of **–0.351** was obtained using the factor of safety of 2.0 specified in section 1.3. The analysis was done with the application of the 50 lbf. Handling load when the air-sampling device is constrained. It will be more realistic to assume that the Velcro will become detached and the ASD will move before the full application of the 50-lbf kick load on the handle. After the ASD has become displaced, the load seen by the handle will be decreased.

A crew induced load of 50 lbf is applied to the top of the handle of the air sampler. The handle is modeled as a beam fixed at both ends and is loaded in the center with 50 lbf. The handle is made of the same material as the chassis and the thickness is estimated to be 0.125". The handle will be analyzed for bending stress.



AirPort MD8
Air Sampling Device
with handling load

Calculating the cross-sectional properties of the handle using case 25, Table 1 of <u>Roark's Formulas for Stress and Strain</u> 6th ed. page 70.

Handle Height: $H_h := 0.585\ in$ Handle Thickness: $T_h := 0.125\ in$

Handle Width: $W_h := 1.1\ in$

$y1 := \frac{0.585\ in}{2}$ $y1 = 0.292\ in$

$y2 := \frac{1.1\ in}{2}$ $y2 = 0.55\ in$

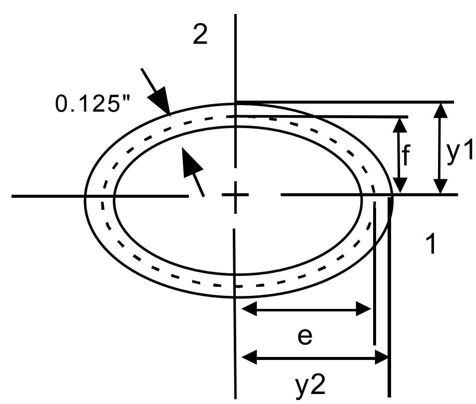
$f := y1 - \frac{T_h}{2}$ $f = 0.23\ in$

$e := y2 - \frac{T_h}{2}$ $e = 0.487\ in$

$K_1 := 0.2464 + 0.002222 \cdot \left(\frac{e}{f} + \frac{f}{e}\right)$ $K_1 = 0.252$

$K_2 := 0.1349 + 0.1279 \cdot \left(\frac{f}{e}\right) - 0.01284 \cdot \left(\frac{f}{e}\right)^2$ $K_2 = 0.192$

$K_3 := 0.1349 + 0.1279 \cdot \left(\frac{e}{f}\right) - 0.01284 \cdot \left(\frac{e}{f}\right)^2$ $K_3 = 0.348$



Handle Cross-section

Moments of Inertia:

$$I_1 := \frac{\pi}{4} \cdot T_h \cdot f^2 \cdot (f + 3 \cdot e) \cdot \left[1 + K_2 \cdot \left(\frac{f - e}{f + e}\right)^2\right] + \frac{\pi}{16} \cdot (T_h)^3 \cdot (3 \cdot f + e) \cdot \left[1 + K_3 \cdot \left(\frac{f - e}{f + e}\right)^2\right]$$

$$I_2 := \frac{\pi}{4} \cdot T_h \cdot e^2 \cdot (e + 3 \cdot f) \cdot \left[1 + K_3 \cdot \left(\frac{e - f}{e + f}\right)^2\right] + \frac{\pi}{16} \cdot (T_h)^3 \cdot (3 \cdot e + f) \cdot \left[1 + K_2 \cdot \left(\frac{e - f}{e + f}\right)^2\right]$$

Cross-sectional moment of inertia $I_1 = 0.00948\ in^4$ $I_2 = 0.02937\ in^4$

Cross-sectional area of handle $A\_c := \pi \cdot T_h \cdot (e+f) \cdot \left[1 + K_1 \cdot \left(\frac{f-e}{f+e}\right)^2\right]$ $A\_c = 0.291 \cdot in^2$

Assume fixed straight beam on both ends with reaction forces at each end and the maximum bending moment is highest in the center of the handle. To be conservative, we assume the handle is straight and not a curved beam. Note that the larger moment of inertia is used in the calculation.

Reference: Roark's Formulas for Stress and Strain 6th ed. pg. 101, Table 3, case 1d- Left end fixed, Right end fixed

$l := 9.79\ in$ length of the handle (Distance from end to end assuming a straight beam.)

$A := \frac{l}{2}$ half the distance from one end of the handle to the other.

$C1 := y1$ distance to outer fiber along axis 2 $C2 := y2$ distance to outer fiber along axis 1

$F_{handle} := 50\ lbf$ Crew induced load on the handle

Maximum Bending moment due to the applied load (Roark's case 1d Table 3 for fixed ends and kick load at L/3)

$M := 0.148 \cdot F_{handle} \cdot l$ $M = 72.446 \cdot in \cdot lbf$

Calculation of Bending Stress about axis 1

$\sigma_{b1} := \frac{M \cdot C1}{I_1}$ $\sigma_{b1} = 2235.39 \cdot psi$

Calculation of Bending Stress about axis 2

$\sigma_{b2} := \frac{M \cdot C2}{I_2}$ $\sigma_{b2} = 1356.625 \cdot psi$

Ultimate Margin of Safety for Bending about axis 1 (Load applied from top)

$MS_{bu1} := \frac{F_{bu}}{\sigma_{b1} \cdot SF_{ut}} - 1$ $MS_{bu1} = -0.351$ <==========

Ultimate Margin of Safety for Bending about axis 2 (Load applied from side)

$MS_{bu2} := \frac{F_{bu}}{\sigma_{b2} \cdot SF_{ut}} - 1$ $MS_{bu2} = 0.069$ <==========

Conclusion:

Based on the analysis result, the handle of the air sampler is not sufficient to withstand a crew-induced load of 50 lbf delivered to the handle from the top.

2.3 0.2 g On-Orbit Maneuvering Load

The Velcro tape attached to one side of the ASD enclosure must prevent the ASD from becoming detached in a 0.2 g maneuvering load as described in section 1.2.4. The maximum inertial load of the ASD in any direction due to the 0.2 g maneuvering load is 1.1 lb (based on a maximum 5.5 lb weight of the ASD). The Velcro tape used is Type 1, Class 2 from the A-A-55126A (MIL-F-21840G) specification. The inertial load was compared to maximum allowable shear and tensile loads published in A-A-55126A (MIL-F-21840G). Positive margins were obtained for the Velcro Tape using the ultimate factor of safety of 2.0 from section 1.3. The following delineates the Velcro strength analysis against the 0.2 maneuvering load.

Verify that the SWAB velcro patch can retain the air sampler during a 0.2 g on-orbit maneuvering load. The Velcro tape used is Type I, Class 2. Area of the Velcro patch is 2" by 2".

Factor of Safety: $SF_{vel} := 2.0$

The minimum shear strength of the Velcro strap is 10.0 lb./inch and and peel strength: 0.5 lb./inch.
Reference: Military Specification for Fastener Plates, Hook & Pile, Synthetic A-A-55126A (MIL-F-21840G) Oct. 20, 1999. page 4:

Shear and Tensile Strength from Specification for 2" by 1" strap:

$$S_{vel\_allow} := 10\,\frac{lbf}{in} \qquad T_{vel\_allow} := \left(0.5\,\frac{lbf}{in}\right)\cdot 3\cdot 2$$

Note: Pull or tensile strength is estimated to be 3 times the documented peel strength.

weight of the MD8 Air Sampler: $Weight := 5.5\ lbf$ (converted from 2.5 kg)

Maneuvering loads in any direction: $Nxyz := 0.2$ g

Velcro Strap Loads in any direction: $Fxyz := Nxyz\cdot Weight$ $Fxyz = 1.1\,lbf$

$P\_S_{vel} := S_{vel\_allow}\cdot 2\ in$ $P\_S_{vel} = 20\,lbf$ Allowable shear force

$P\_P_{vel} := T_{vel\_allow}\cdot 2\ in$ $P\_P_{vel} = 6\,lbf$ Allowable tensile force

Shear margin of safety:

$$MS_{vel\_sh} := \frac{P\_S_{vel}}{SF_{vel}\cdot Fxyz} - 1 \qquad MS_{vel\_sh} = 8.091$$ <==============

Pull margin of safety:

$$MS_{vel\_pull} := \frac{P\_P_{vel}}{SF_{vel}\cdot Fxyz} - 1 \qquad MS_{vel\_pull} = 1.727$$ <==============

3.0 Venting Analysis

The venting analysis determines the maximum stresses caused by depressurization and repressurization of enclosed volumes due to gases entering and exiting the volume through leakage areas. A FORTRAN source code is used to calculate the difference in internal and external pressures using the orifice mass flow equation and the Ideal Gas Law. The maximum pressures and pressure rates of the ASD are shown in Table 3-1. Results of the venting analysis are presented in Tables 3-2 to 3.4.

Table 3-1: Depressurization/Repressurization Rates and Ranges

<table>
<tr><td rowspan="2">ISS</td><td>Depressurization</td><td>From 15.2 psi to 0.0 psi @ 7.64 psi/min</td><td rowspan="2">Table 3.2.5.1.5-1 of SRD and para. 3.1.1.4 of SSP 57000, Rev. E</td></tr>
<tr><td>Repressurization</td><td>From 0.0 psi to 15.2 psi @ 2.0 psi/min</td></tr>
<tr><td rowspan="2">Shuttle Mid-deck</td><td>Depressurization/Repressurization</td><td>9.0 psi/min (Contingency)</td><td rowspan="2">Table 3.2.5.1.5-3 or SRD and Section 6.1, NSTS-21000-IDD-MDK, Rev. B</td></tr>
<tr><td>Depressurization (Emergency Bail-out)</td><td>From 15.2 psi to 3.95 psi @ 24.0 psi/min</td></tr>
<tr><td rowspan="2">MPLM</td><td>Depressurization</td><td>From 15.2 psi to 0.0 psi @ 7.75 psi/min</td><td rowspan="2">Table 3.2.5.1.5-2 of SRD and para. 3.1.1.2 and 3.9.1.1 of SSP 57000, Rev. E</td></tr>
<tr><td>Repressurization</td><td>From 0.0 psi to 15.2 psi @ 6.96 psi/min</td></tr>
</table>

The following pages detail the venting analysis for the ASD.

DEPRESSURIZATION / REPRESSURIZATION ANALYSES

The purpose of this analysis is to show that the ASD can withstand the maximum rates of depressurization/repressurization without any structural failure. The depress/repress rates for the Shuttle, MPLM and ISS are listed below:

<u>Depress/Repress Rates and Pressure Ranges in flight</u>

ISS depress/repress rates (Table 3.2.5.1.5-1 of SRD and SSP57000, Rev. E, para. 3.1.1.4):

Depress rate: from 15.2 psi to 0.0 psi at 7.64 psi/min

Repress rate: from 0.0 psi to 15.2 psi at 2.0 psi/min

Mid-deck depress/repress rates (Table 3.2.5.1.5-3 of SRD and NSTS-21000-IDD-MDK, Rev. B, Section 6.1):

Contingency: 9.0 psi/min depress/repress rate
Emergency bailout: from 15.2 psi to 3.95 psi/min at 24.0 psi/min

MPLM depress/repress rates (Table 3.2.5.1.5-2 of SRD and paragraph 3.1.1.2 and paragraph 3.9.1.1 of SSP5700, Rev. E):

Depress rate: from 15.2 psi to 0.0 psi at 7.75 psi/min depress rate

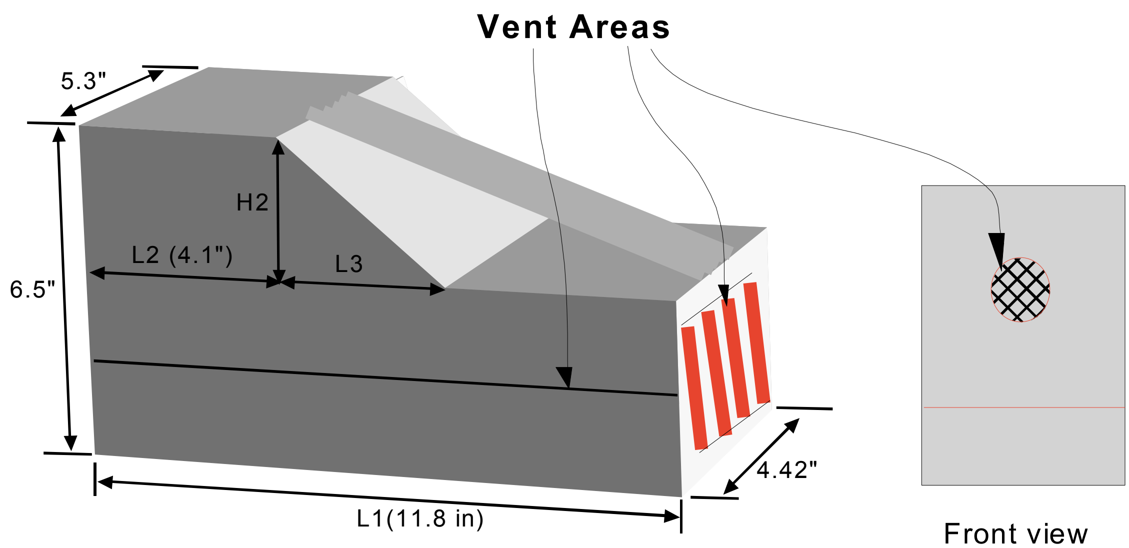
Repress rate: from 0.0 psi to 15.2 psi at 6.96 psi/min repress rate

The Mid-deck repress/depress rates of 9.0 psi/min and 24.0 psi/min envelope the ISS and MPLM rates. The 3 worst-case scenarios that will be analyzed are listed below. These three cases that were simulated envelope the venting rates listed in the Systems Requirements Document pg. 3-23.

1. Depressurization from 15.2 psi to 0.0 psi at 9.0 psi/min — CASE 1
2. Depressurization from 15.2 psi to 3.95 psi at 24.0 psi/min — CASE 2
3. Repressurization from 0.0 psi to 15.2 psi/min at 9.0 psi/min — CASE 3

Note: Fire Suppression Bottle Discharge analysis is not a requirement indicated for the ASD. There is not a provision for a fire suppression bottle discharge port for the ASD.

Prepared By	R. Lee 1/10/03	LOCKHEED MARTIN Science, Engineering, Analysis, & Test Mechanical Systems Department	Page No. 3-3	Report No. LMSEAT-34164
Checked By			Drawing No	SEG46119448-301
Title	Venting Analysis of the AirPort MD8 Air Sampler			SWAB



Side View

Front view

The maximum internal volume of the SWAB Air Sampling Device is based on the following measurements of the hardware (taken in JSC Bldg 37 12/20/02, 09:45 hrs)

$L1 := 11.8\ \text{in}$	length of the bottom portion of the chassis
$L2 := 4.1\ \text{in}$	length of the top portion of the chassis
$L3 := 2.53\ \text{in}$	length of the sloped portion of the chassis
$W := \frac{(5.3\ \text{in} + 4.42\ \text{in})}{2}$	average width of the chassis
$H1 := (6.5\ \text{in} - 2.77\ \text{in})$	height of the bottom portion of the chassis
$H2 := 2.77\ \text{in}$	height of the top portion of the chassis

Calculation of free volume:

$$V := (L1 \cdot W \cdot H1) + (L2 \cdot W \cdot H2) + W \cdot (0.5 \cdot (H2 \cdot L3)) \qquad V = 286.133 \cdot \text{in}^3$$

For this analysis, we assume the maximum volume shown above is reduced to 85% for the space occupied by the internal components (battery, circuits, fan, fan motor, etc).

$$V_{vent} := V \cdot 85\ \% \qquad V_{vent} = 243.213 \cdot \text{in}^3$$

Free volume of air

Calculation of venting area:

The chassis venting area includes cooling vents for the battery at the rear, the air intake, and the 0.001" gap between the top and bottom chassis housings.

Gap perimeter: $P_r := L1 \cdot 2$ $\quad P_r = 23.6 \cdot in$

Gap leak area: $A_{gap} := P_r \cdot 0.001 \text{ in}$ $\quad A_{gap} = 0.024 \cdot in^2$

Note: the gap area assumes a 0.001" gap between the top and bottom housing covers.

Battery vent area: $A_{bat} := (0.86 \text{ in} \cdot 0.17 \text{ in}) \cdot 4$ $\quad A_{bat} = 0.585 \cdot in^2$

Note: the battery vent area consists of 4 symmetrical slots.

Fan intake area: $A_{fan} := 0.6 \cdot \left(\frac{\pi}{4}\right) \cdot (0.87 \text{ in})^2$ $\quad A_{fan} = 0.357 \cdot in^2$

Note: the fan intake area is reduced 40% by a grill.

Venting area: $A_v := A_{gap} + A_{bat} + A_{fan}$

$A_v = 0.965 \cdot in^2$

Analysis is performed using the following orifice equation:

$$dm := dt \cdot A \cdot C_d \cdot \sqrt{2 \cdot \rho \Delta P}$$

Where,

dm = delta mass
dt = delta time
A = leak area
Cd = discharge constant
ρ = air density
P = Pressure

And

$$P := \frac{M \cdot R \cdot T}{V}$$

Where,

M = mass of air inside
R = gas constant
T = temperature (Kelvins)
V = internal volume

For the depressurization case, internal and external pressures are initially assumed to be at the maximum operating pressure and the mass flow is one-way (leaving the container). For the repressurization case, the internal and external pressures are initially assumed to be zero, mass flow is also one-way (entering the container), and there is no initial air mass in the container. By incrementing time and tracking mass flow out of or into the chassis, it is possible to calculate the pressure differential between the inside and outside air volumes by way of the orifice equation and the ideal gas law. The task of performing the iterations was automated with in-house software resulting in a table of container's internal and external pressures, delta pressure, mass inside, and mass discharge versus time. The maximum delta pressure is shown at the bottom of each table. Tables 3.2 through 3.4 are the outputs for the container's worst-case depressurization/repressurization analysis.

ANALYSIS RESULTS

The maximum pressure differentials for each CASE is listed below. A reduced printout for each case is attached.

CASE 1:	max differential = 0.0022073 psi	Conservative pressure range from 16.0 psi to 0.0 psi was used for the analysis.
CASE 2:	max differential = 0.0001144 psi	
CASE 3:	max differential = 0.0011143psi	Conservative pressure range from 0.0 psi to 16.0 psi was used for the analysis.

MARGINS OF SAFETY:

For the depressurization/repressurization rates analyzed, the maximum delta pressure seen (Case 1, 2.20729×10^{-3} psi) is considered negligeable. Using engineering judgement, the MS due to venting for the ASD is decidedly high (MS> 10.0) after comparison to the 2900 psi flexural strength of ETOL hardened polyurethane foam .

MS > +10.0 <===========

Table 3-2: Depressurization Output

HRF SWAB Air Sampler - DEPRESSURIZATION ANALYSIS
TOTAL VOLUME = 243.213 IN**3
TOTAL LEAK AREA = 1.177 IN**2
DEPRESSURIZATON RATE = 9.0 PSI/MIN
PRESSURE AT START OF SIMULATION = 16.0 PSI
PRESSURE AT END OF SIMULATION = 0.0 PSI
TIME STEP = 1.00000E-04 SEC

TIME (SECS)	PINSIDE	POUTSIDE	PDELTA	MINSIDE	MEXITING
0.0000	16.0000	16.0000	0.00E+00	0.0116	0.00E+00
0.1000	15.9850	15.9850	0.00E+00	0.0116	0.00E+00
0.2000	15.9700	15.9700	0.00E+00	0.0116	0.00E+00
0.3000	15.9550	15.9550	0.00E+00	0.0115	0.00E+00
0.4000	15.9400	15.9400	0.00E+00	0.0115	0.00E+00
0.5000	15.9250	15.9250	0.00E+00	0.0115	0.00E+00
0.6000	15.9100	15.9100	0.00E+00	0.0115	0.00E+00
0.7000	15.8950	15.8950	0.00E+00	0.0115	0.00E+00
0.8000	15.8800	15.8800	0.00E+00	0.0115	0.00E+00
0.9000	15.8650	15.8650	0.00E+00	0.0115	0.00E+00
1.0001	15.8500	15.8500	0.00E+00	0.0115	0.00E+00
1.1001	15.8350	15.8350	0.15E-04	0.0115	0.51E-07
1.2001	15.8200	15.8200	0.00E+00	0.0114	0.00E+00
1.3001	15.8050	15.8050	0.00E+00	0.0114	0.00E+00
1.4001	15.7900	15.7900	0.00E+00	0.0114	0.00E+00
1.5001	15.7750	15.7750	0.00E+00	0.0114	0.00E+00
1.6002	15.7600	15.7600	0.38E-05	0.0114	0.52E-07
1.7002	15.7450	15.7450	0.00E+00	0.0114	0.00E+00
1.8002	15.7300	15.7300	0.00E+00	0.0114	0.00E+00
1.9002	15.7150	15.7150	0.12E-04	0.0114	0.51E-07
2.0002	15.7000	15.7000	0.00E+00	0.0114	0.00E+00
105.0799	0.2381	0.2380	0.28E-04	0.0002	0.11E-07
105.1791	0.2232	0.2232	0.31E-04	0.0002	0.11E-07
105.2782	0.2083	0.2083	0.34E-04	0.0002	0.11E-07
105.3774	0.1934	0.1934	0.38E-04	0.0001	0.11E-07
105.4766	0.1786	0.1785	0.42E-04	0.0001	0.11E-07
105.5758	0.1637	0.1636	0.47E-04	0.0001	0.11E-07
105.6750	0.1488	0.1488	0.53E-04	0.0001	0.11E-07
105.7741	0.1340	0.1339	0.61E-04	0.0001	0.11E-07
105.8733	0.1191	0.1190	0.70E-04	0.0001	0.11E-07
105.9725	0.1042	0.1041	0.82E-04	0.0001	0.11E-07
106.0717	0.0894	0.0893	0.98E-04	0.0001	0.11E-07
106.1709	0.0745	0.0744	0.12E-03	0.0001	0.11E-07
106.2701	0.0597	0.0595	0.15E-03	0.0000	0.11E-07
106.3692	0.0448	0.0446	0.21E-03	0.0000	0.11E-07
106.4684	0.0301	0.0298	0.31E-03	0.0000	0.11E-07
106.5676	0.0155	0.0149	0.60E-03	0.0000	0.10E-07
106.6668	0.0022	0.0000	0.22E-02	0.0000	0.75E-08

MAXIMUM DELTA PRESSURE = 2.20729E-03
TIME = 106.6668

Table 3-3: Emergency Bailout Depressurization Output

```
HRF SWAB Air Sampler - DEPRESSURIZATION ANALYSIS
TOTAL LEAK AREA = 1.177 IN**2
FREE VOLUME = 243.213 IN**3
DEPRESSURIZATION RATE = 24.0 PSI/MIN
PRESSURE AT START OF SIMULATION = 15.2 PSI
PRESSURE AT END OF SIMULATION = 3.95 PSI
TIME STEP = 1.00000E-04 SEC
```

TIME (SECS)	PINSIDE	POUTSIDE	PDELTA	MINSIDE	MEXITING
0.0000	15.2000	15.2000	0.00E+00	0.0110	0.00E+00
0.1000	15.1601	15.1600	0.32E-04	0.0110	0.83E-07
0.2000	15.1200	15.1200	0.00E+00	0.0109	0.00E+00
0.3000	15.0801	15.0800	0.11E-04	0.0109	0.83E-07
0.4000	15.0400	15.0400	0.00E+00	0.0109	0.00E+00
0.5000	15.0001	15.0001	0.19E-05	0.0109	0.83E-07
0.6000	14.9600	14.9600	0.00E+00	0.0108	0.00E+00
0.7000	14.9200	14.9200	0.00E+00	0.0108	0.00E+00
0.8000	14.8800	14.8800	0.15E-04	0.0108	0.83E-07
0.9000	14.8400	14.8400	0.29E-05	0.0107	0.83E-07
1.0001	14.8000	14.8000	0.22E-04	0.0107	0.82E-07
1.1001	14.7600	14.7600	0.00E+00	0.0107	0.00E+00
1.2001	14.7200	14.7200	0.24E-04	0.0107	0.82E-07
1.3001	14.6800	14.6800	0.00E+00	0.0106	0.00E+00
1.4001	14.6400	14.6400	0.30E-04	0.0106	0.82E-07
1.5001	14.6000	14.6000	0.00E+00	0.0106	0.00E+00
1.6002	14.5600	14.5600	0.33E-04	0.0105	0.82E-07
1.7002	14.5200	14.5200	0.00E+00	0.0105	0.00E+00
1.8002	14.4800	14.4800	0.38E-04	0.0105	0.82E-07
1.9002	14.4400	14.4400	0.00E+00	0.0105	0.00E+00
2.0002	14.4000	14.4000	0.26E-04	0.0104	0.81E-07
20.1800	7.1282	7.1281	0.10E-03	0.0052	0.57E-07
20.2792	7.0885	7.0884	0.82E-04	0.0051	0.56E-07
20.3783	7.0487	7.0487	0.00E+00	0.0051	0.00E+00
20.4775	7.0091	7.0090	0.93E-04	0.0051	0.56E-07
20.5767	6.9695	6.9694	0.11E-03	0.0050	0.56E-07
20.6759	6.9298	6.9297	0.81E-04	0.0050	0.56E-07
20.7751	6.8900	6.8900	0.00E+00	0.0050	0.00E+00
20.8742	6.8504	6.8503	0.42E-04	0.0050	0.55E-07
20.9734	6.8107	6.8107	0.00E+00	0.0049	0.00E+00
27.4203	4.2320	4.2319	0.41E-04	0.0031	0.44E-07
27.5194	4.1923	4.1923	0.00E+00	0.0030	0.00E+00
27.6186	4.1526	4.1526	0.27E-04	0.0030	0.43E-07
27.7178	4.1129	4.1129	0.00E+00	0.0030	0.00E+00
27.8170	4.0733	4.0732	0.42E-04	0.0029	0.43E-07
27.9162	4.0336	4.0336	0.61E-04	0.0029	0.43E-07
28.0154	3.9939	3.9939	0.00E+00	0.0029	0.00E+00
28.1145	3.9543	3.9542	0.64E-04	0.0029	0.42E-07

```
MAXIMUM DELTA PRESSURE = 1.14441E-04
TIME = 20.5767 SEC
```

Table 3-4: Repressurization Output

```
HRF SWAB Air Sampler - REPRESSURIZATION ANALYSIS
TOTAL VOLUME = 243.213 IN**3
TOTAL LEAK AREA = 1.177 IN**2
REPRESSURIZATON RATE = 9.0 PSI/MIN
PRESSURE AT START OF SIMULATION = 0.0 PSI
PRESSURE AT END OF SIMULATION = 16.0 PSI
TIME STEP = 1.00000E-04 SEC
```

TIME (SECS)	PINSIDE	POUTSIDE	PDELTA	MINSIDE	MEXITING
0.0000	0.0000	0.0000	0.00E+00	0.0000	0.00E+00
0.1000	0.0139	0.0150	0.11E-02	0.0000	0.13E-07
0.2000	0.0296	0.0300	0.34E-03	0.0000	0.11E-07
0.3000	0.0448	0.0450	0.21E-03	0.0000	0.11E-07
0.4000	0.0598	0.0600	0.16E-03	0.0000	0.11E-07
0.5000	0.0749	0.0750	0.12E-03	0.0001	0.11E-07
0.6000	0.0899	0.0900	0.99E-04	0.0001	0.11E-07
0.7000	0.1049	0.1050	0.82E-04	0.0001	0.11E-07
0.8000	0.1199	0.1200	0.70E-04	0.0001	0.11E-07
0.9000	0.1349	0.1350	0.61E-04	0.0001	0.11E-07
1.0001	0.1499	0.1500	0.53E-04	0.0001	0.11E-07
1.1001	0.1649	0.1650	0.47E-04	0.0001	0.11E-07
1.2001	0.1800	0.1800	0.42E-04	0.0001	0.11E-07
1.3001	0.1950	0.1950	0.37E-04	0.0001	0.11E-07
1.4001	0.2100	0.2100	0.34E-04	0.0002	0.11E-07
104.3856	15.6578	15.6578	0.95E-05	0.0112	0.52E-07
104.4848	15.6727	15.6727	0.00E+00	0.0112	0.00E+00
104.5840	15.6876	15.6876	0.29E-05	0.0112	0.52E-07
104.6831	15.7025	15.7025	0.00E+00	0.0113	0.00E+00
104.7823	15.7173	15.7173	0.48E-05	0.0113	0.52E-07
104.8815	15.7322	15.7322	0.00E+00	0.0113	0.00E+00
104.9807	15.7471	15.7471	0.00E+00	0.0113	0.00E+00
105.0799	15.7620	15.7620	0.00E+00	0.0113	0.00E+00
105.1791	15.7768	15.7768	0.00E+00	0.0113	0.00E+00
105.2782	15.7917	15.7917	0.00E+00	0.0113	0.00E+00
105.3774	15.8066	15.8066	0.00E+00	0.0113	0.00E+00
105.4766	15.8215	15.8215	0.00E+00	0.0113	0.00E+00
105.5758	15.8364	15.8364	0.00E+00	0.0114	0.00E+00
105.6750	15.8512	15.8512	0.95E-05	0.0114	0.52E-07
105.7741	15.8661	15.8661	0.00E+00	0.0114	0.00E+00
105.8733	15.8810	15.8810	0.76E-05	0.0114	0.52E-07
105.9725	15.8959	15.8959	0.00E+00	0.0114	0.00E+00
106.0717	15.9107	15.9107	0.00E+00	0.0114	0.00E+00
106.1709	15.9256	15.9256	0.00E+00	0.0114	0.00E+00
106.2701	15.9405	15.9405	0.00E+00	0.0114	0.00E+00
106.3692	15.9554	15.9554	0.10E-04	0.0114	0.53E-07
106.4684	15.9702	15.9702	0.00E+00	0.0114	0.00E+00
106.5676	15.9851	15.9851	0.00E+00	0.0115	0.00E+00

```
MAXIMUM DELTA PRESSURE = 1.11425E-03
TIME = 0.100001
```

4.0 Fracture Control Assessment

4.1 Fracture Classification

Fracture control is implemented based on LS-71010A [Ref. 1], which is in conformance to NASA-STD-5003, SSP 30558 requirements, and JSC 25863A. The ASD is intended not to be used as a load path or mechanical stop, nor does it contains pressure systems, glass, high energy rotating machineries, structural composite nor operates as a containment device. The ASD is soft stowed for lift-off and landing and is hand-held or wall-attached by Velcro for on-orbit operation. For on-orbit use, the ASD can safely react to loads from on-orbit maneuvers of the ISS during re-boost and docking given that the mass of the ASD is at a maximum of 5.5 lbm. In addition, the program and project has determined that structural failure of the hardware will not result in a catastrophic hazard or failure. The ASD is classified as non-fracture critical per guidelines established in the previously mentioned documents.

4.2 Kinetic Energy and Containment Assessment of ASD Fan

The ASD contains a small air-driving fan that operates at a maximum speed of 20,000 rpm. The section determines that the fan has low rotational kinetic energy and that it is contained in case of a blade failure.

The impeller wheel measures 4.27 inches in diameter, weighs approximately 0.5 lb. and spins at a maximum rotational velocity of 20,000 rpm. Since the rotational kinetic energy calculated is less than 19,307J (14,260 ft. lb) per paragraph 3.1.6 of LS-71010 (HRF Fracture Control Plan), the impeller wheel is considered non-fracture critical.

4.3 Battery Assessment

The ASD contains a battery pack for power for on-orbit operation. The pack consists of five Li-BCX C cells. Fracture control assessment for the battery pack is not provided in the report but is being addressed by an in-work battery certification by the ASD project team.

FAN CONTAINMENT ANALYSES

Calculate Rotational Kinetic Energy of the HRF SWAB Fan.

$T_{fan} := 0.125\ in$ Fan estimated thickness

$D_{fan} := 4.27\ in$ Fan diameter

$n := 20000$ rpm Fan maximum speed

Calculate rotational velocity of the fan

$\omega := \frac{2\ \pi \cdot n}{60\ sec}$ $\omega = 2094.395 \frac{rad}{sec}$

Calculate mass of fan

$\rho_{steel} := 0.286 \frac{lb}{in^3}$ Density of Steel

$V_{fan} := \frac{\pi}{4} \cdot D_{fan}{}^2 \cdot T_{fan}$ volume of fan $V_{fan} = 1.79\ in^3$

$m_{fan} := \rho_{steel} \cdot V_{fan}$ $m_{fan} = 0.512\ lb$

Calculate mass moment of inertia of fan:

$I\_x := \frac{m_{fan} \cdot D_{fan}{}^2}{8} \cdot \left(32.2 \frac{ft}{sec^2}\right)^{-1}$ $I\_x = 2.566 \cdot 10^{-5} \cdot m^{-1} \cdot s^4\ ft \cdot lb\ g$

$KE_{fan} := \frac{1}{2} \cdot I\_x \cdot \omega^2$ $KE_{fan} = 551.895\ ft \cdot lb$

The Kinetic Energy of the fan is less than 14,240 ft-lbs threshold specified in Fracture Control Document for the International Space Station (SSP 30558) section 4.5.1, and the Fracture Control Document for Payloads Using the Space Shuttle (NASA-STD-5003) section 4.2.3.3. Therefore, the fan is considered non-fracture critical per low kinetic energy criterion.

The fan blades are enclosed in a standard COTS thick plastic housing. In addition, the fan housing is enclosed within the polyurethane case of the ASD. In the event a fan blade fails, the fan blade will be sufficiently contained by this double containment system.

Appendix A: ETOL Polyurethane Foam Properties

Appendix B: AirPort MD-8 Air Sampler Vendor Specifications

Appendix C: A-A-55126A (MIL-F-21840G) Fastener Tapes, Hook and Loop, Synthetic Specification

Table of File Names of Archived Files

Project Name – HRF ASD
Report Title -- Strength and Fracture Assessment of the Human Research Facility (HRF) Surface, Water and Air Biocharacterization (SWAB) Air Sampling Device P/N: SEG46119448-301, LMSEAT-34164.

Man Hour Estimate –
Man Hours Used –
Date Report Issued --
Project Manager – Micah Johnson
NASA Division -
Technical Lead – Doan Van

All files are archived on 23M1 web page.

File Type	File Name	Description
Microsoft Word	Memo MSAD-03-0032 CLLT.doc	Transmittal memo
	St Report LMSEAT 34164.doc	Stress report
MathCad	SWAB.mcd	Venting analysis of SWAB ASD (SEG461191448-301)
	SWAB1.mcd	Detailed stress analysis of SWAB ASD (SEG461191448-301)
	SWAB2.mcd	Kinetic Energy calculation of SWAB ASD impeller wheel
Other Files	LMSEAT 34164.pdf	Adobe Acrobat PDF copy of SWAB ASD Stress Report