Design of P-3 Nadir Port

Early Career Forum: Structures, Loads, and Mechanical Systems

September 2019

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Civil Servant, Code 548 Wallops Flight Facility (WFF)

Introduction

- Started at NASA WFF through the Pathways Program 2012-2014
- Converted to full-time Dec. 2014
- Design of science installations for flight on the WFF aircraft P-3B, C-130H, & Sherpa
- Support WFF Sounding Rockets, Internal Research and Development (IRAD), and SmallSat

Water Content Multi-element System (WCM) & Axial Cyclone Cloud-Water Collector (AC3) Pylon for Cloud, Aerosol and Monsoon Processes Philippines Experiment (CAMP^{2}Ex)

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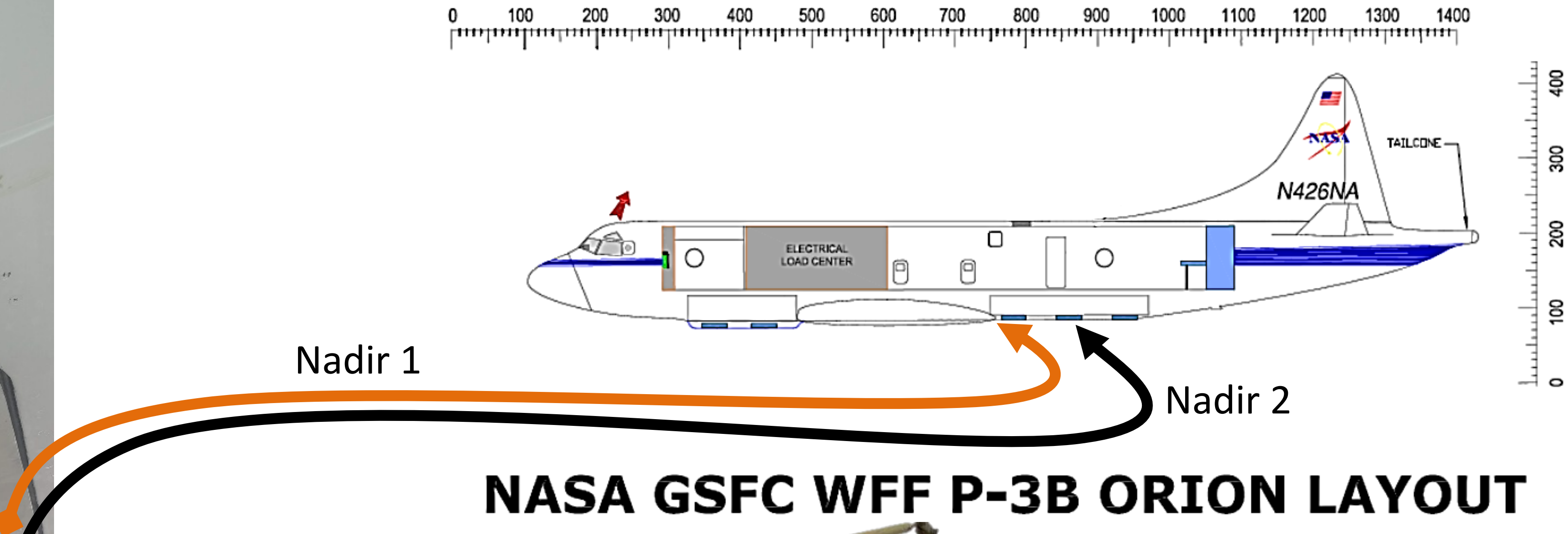
P-3B Introduction



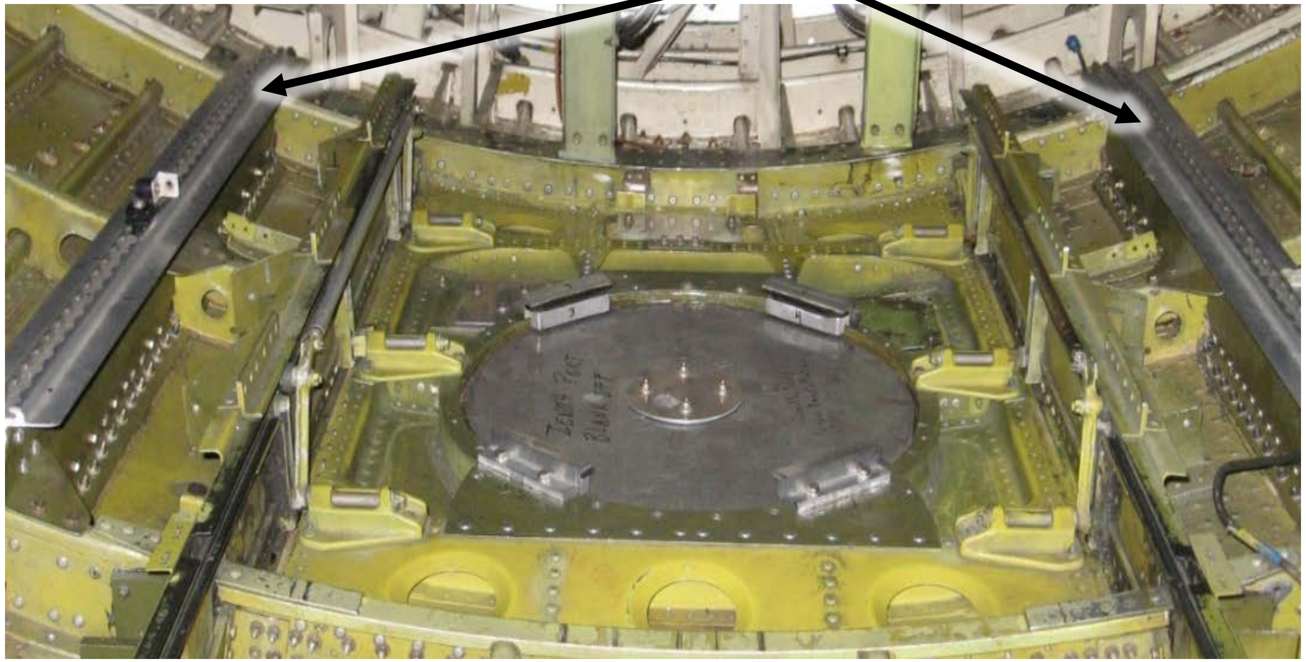
NASA GSFC WFF P-3B ORION LAYOUT

Standard Sonobuoy Door Install

Project Goals and Objectives

- WFF Aircraft Project Office (Code 830) requirements:
  - Use existing aircraft interface
  - Interchangeable instrument/port/window structures for mission-specific instruments
  - **Must fit both Nadir 1 and Nadir 2 ports**
    - Nadir 2 does not have the seat tracks
  - **Must maintain removability of port**

Nadir 1 Seat Tracks



Internal view of door install in Nadir 1

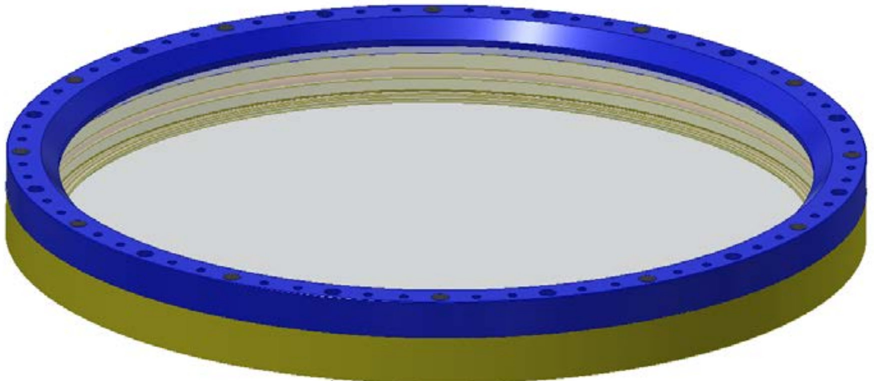
Project Goals and Objectives

- Science requirements, Operation Ice Bridge (OIB):
  - Support the following window specs

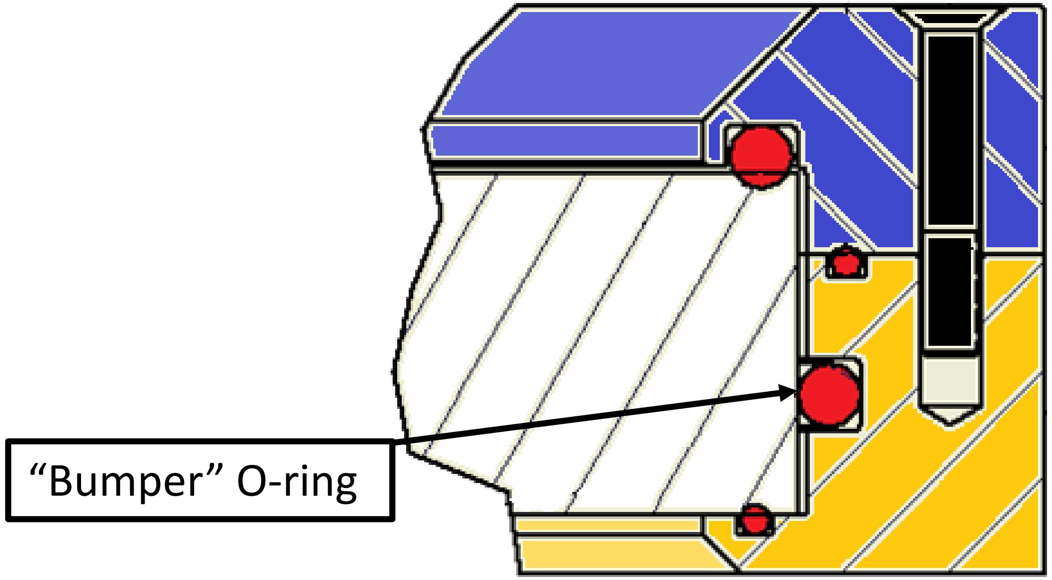
Glass Diameter	Viewport Diameter	Thickness	Material
16.875″	16.0″	1.125″	BK-7
5.90″	*5.0″	0.256″	BK-7
5.90″	*5.0″	0.256″	BK-7

*Later determined to be 4.6″

  - Modify previously flown window casing system
    - “Bumper” O-ring hard to install
      - Previous flight this O-ring was not installed
      - Cause the edge of glass to crack

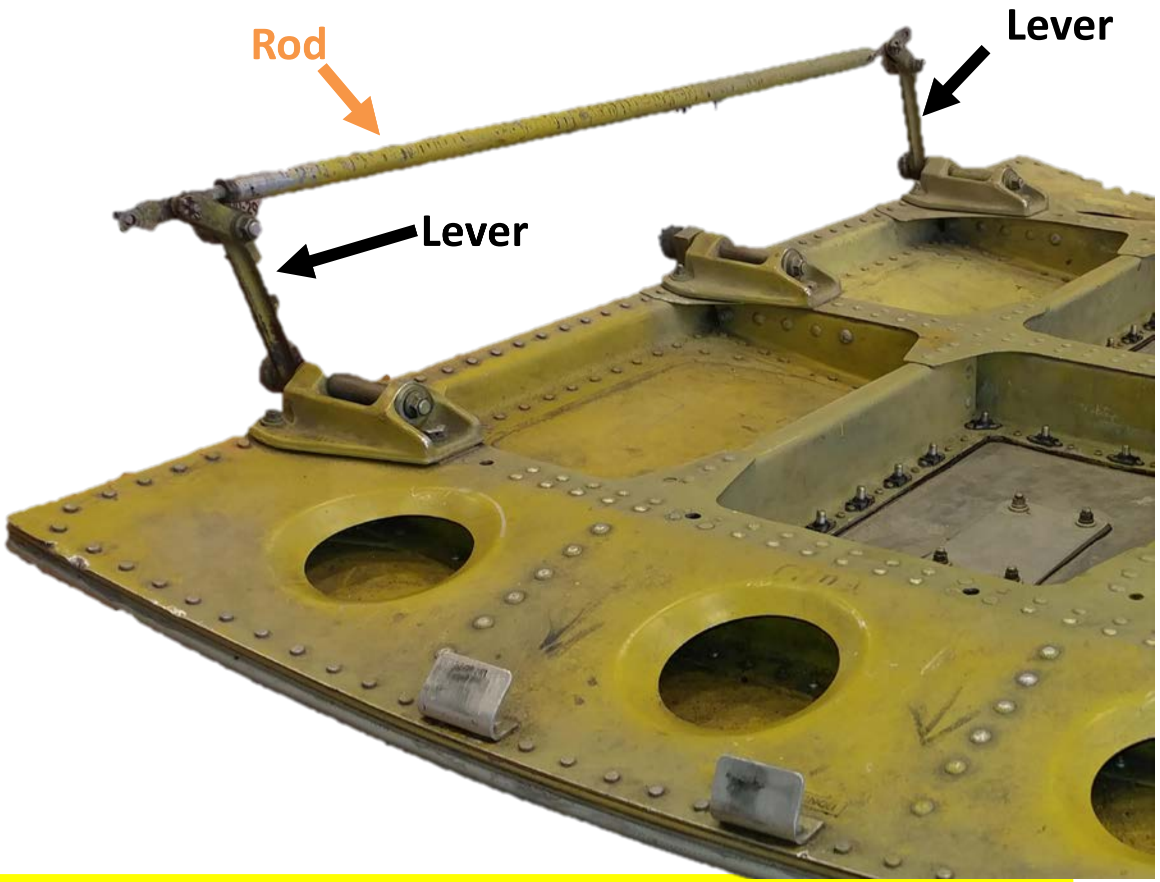


Window Casing System

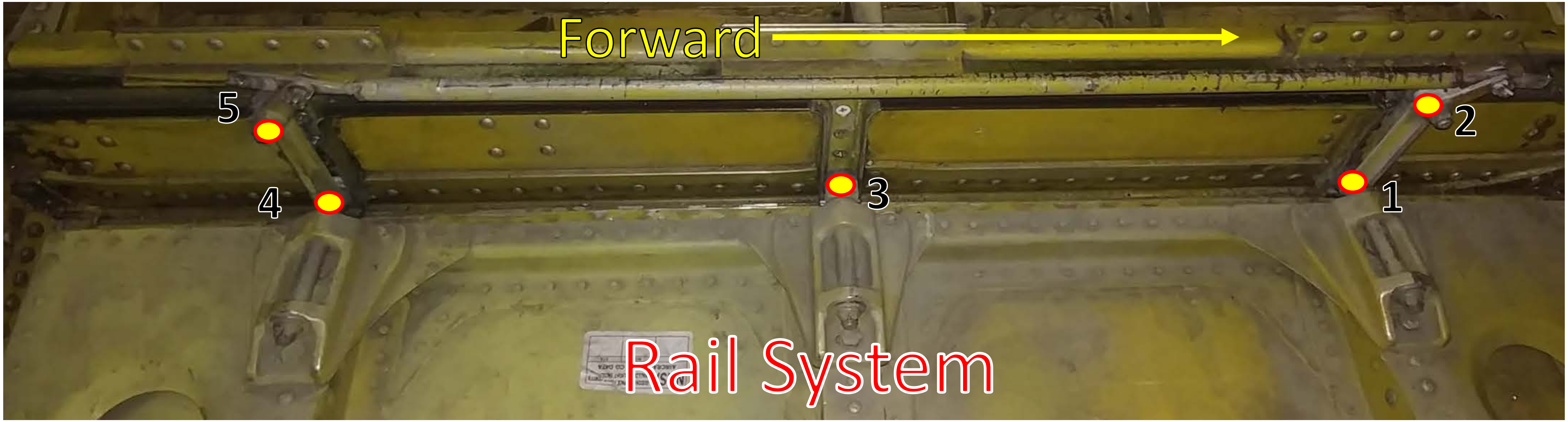


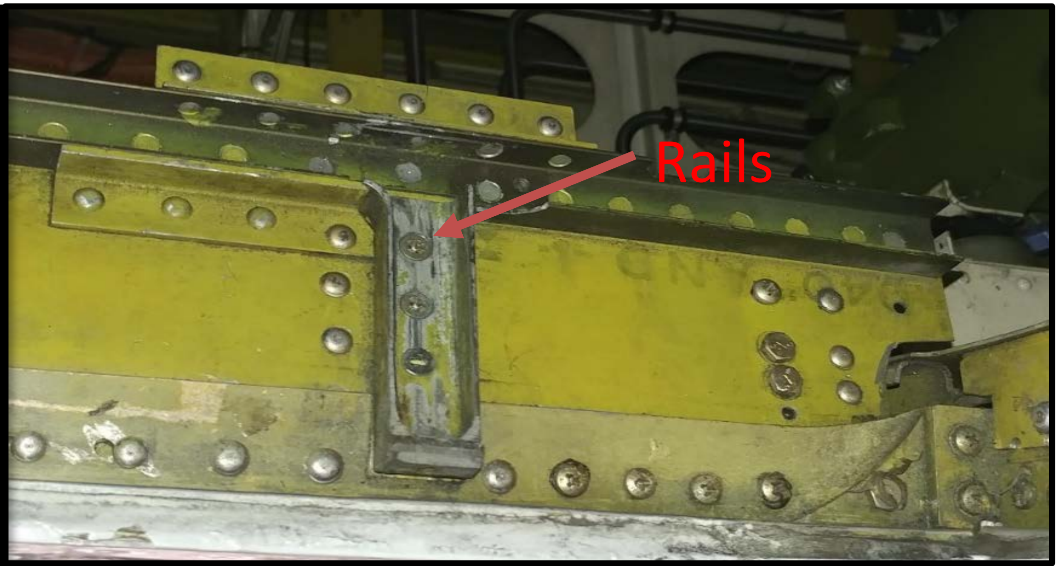
Cross section of Window Casing System

Introduction-Door



Introduction-Aircraft Interface



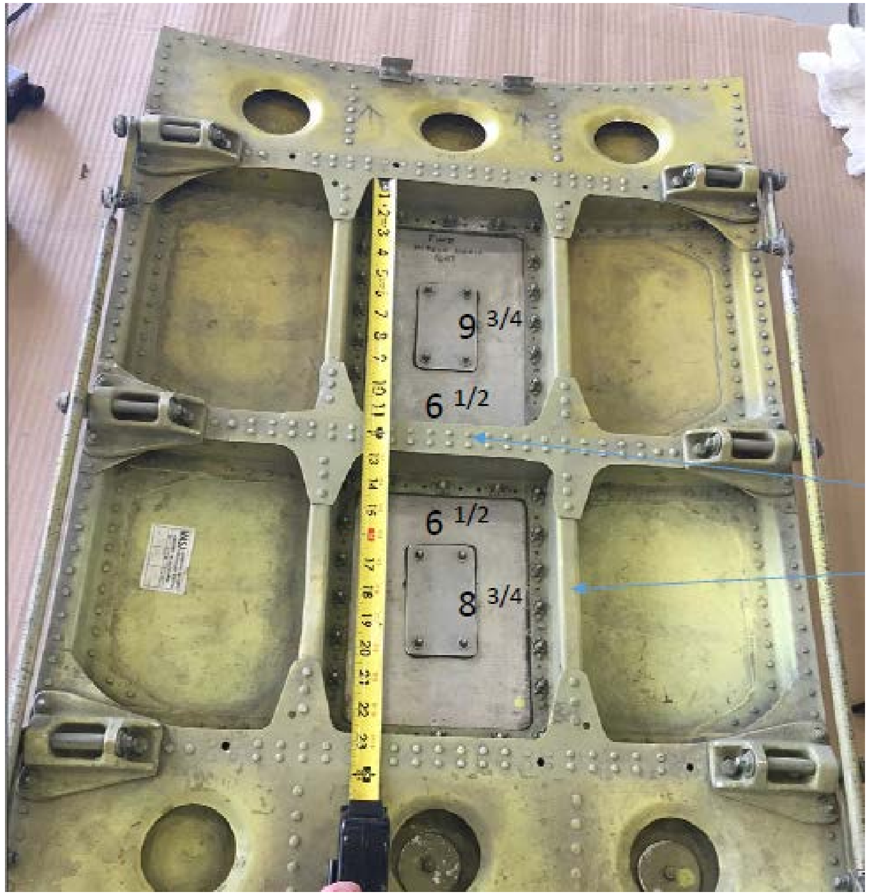


Introduction-Historical Installs

Previous science installs use one of the modified original equipment doors shown.

- Limited the science potential
    - Size and number of the viewports

Modified Door: 16" Circular viewport



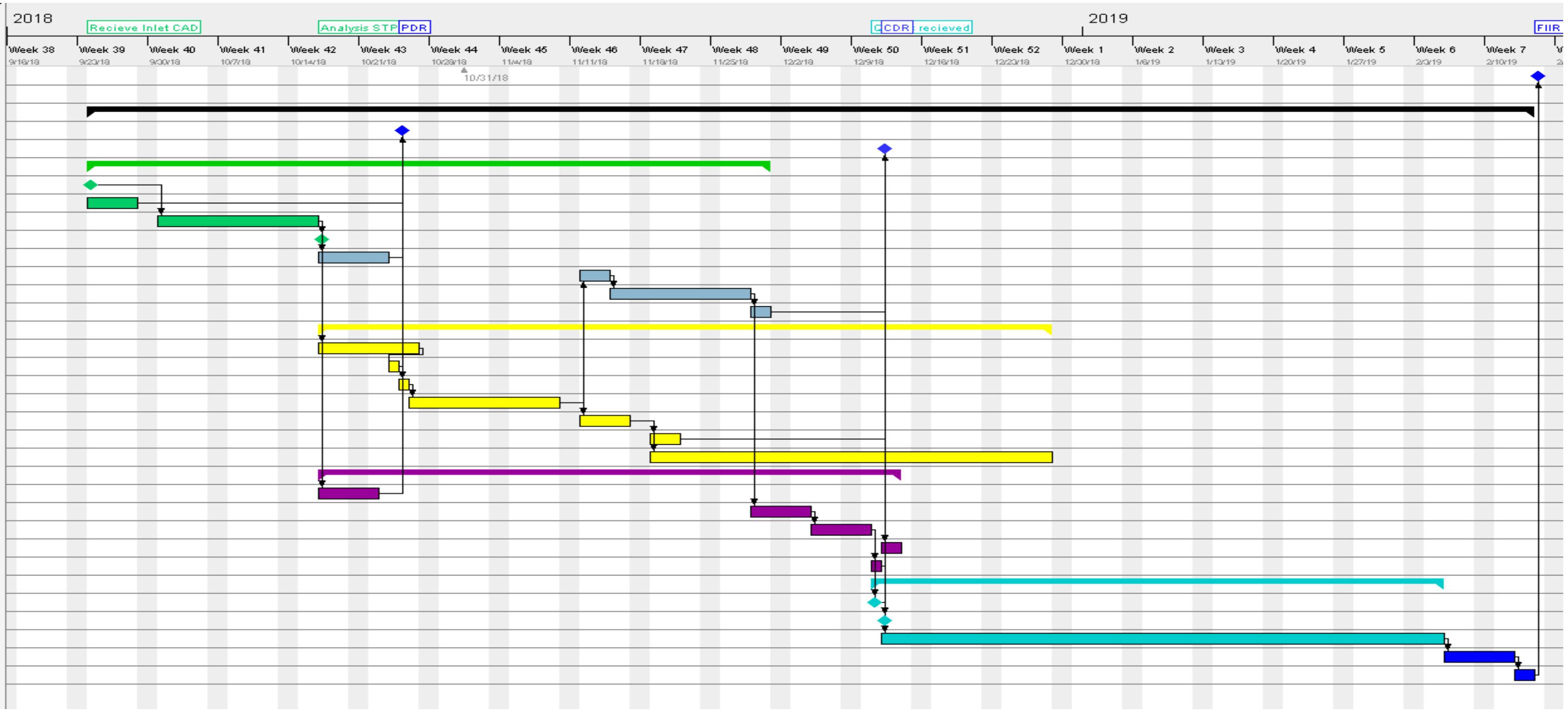
Modified Door: Rectangular viewports

Design-Project Schedule

- Total time for design, analysis, drafting: ~4 Months
- Task assigned: ~ August 2018
- Parts to manufacturing: Dec. 10, 2018
- First mission: Jan. 2019

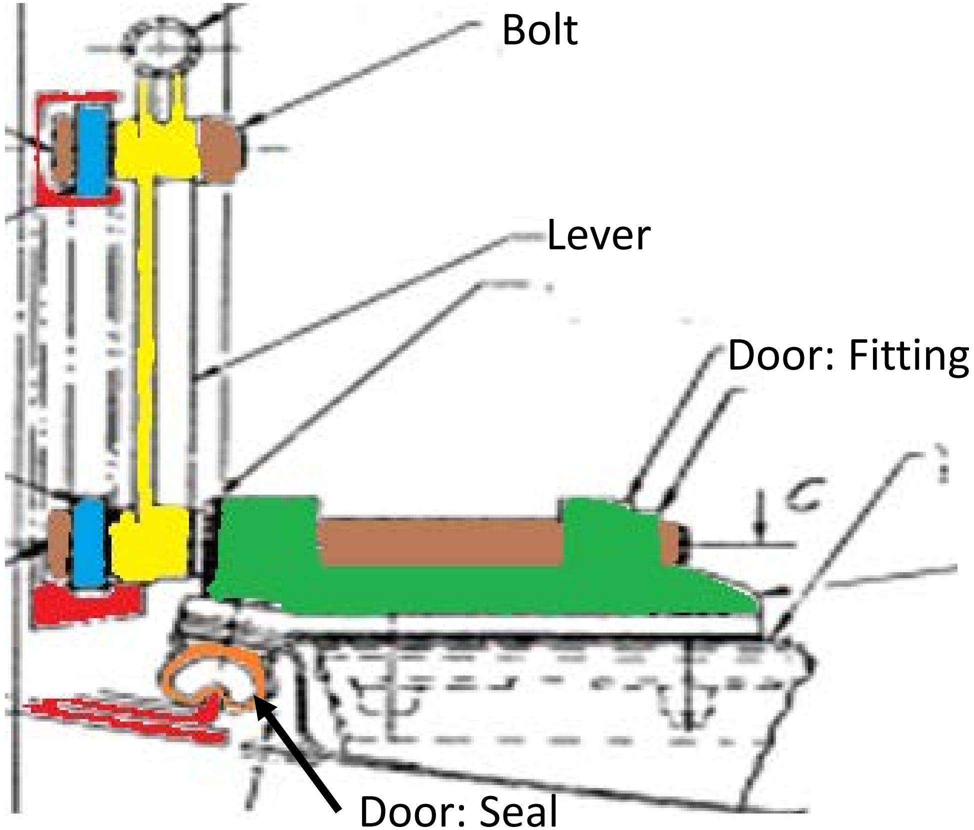
GANTT project

ID	Name	Duration	Begin date	End date	Predecessors
172	FIIR	0	2/15/19	2/15/19	101
175	Test Flight	1	2/20/19	2/20/19	
0	OIB Nadir Port	104	9/24/18	2/14/19	
35	PDR	0	10/25/18	10/25/18	3,14,21,48
36	CDR	0	12/12/18	12/12/18	17,43,59
1	CAD	50	9/24/18	11/30/18	
2	Recieve Inlet CAD	0	9/24/18	9/24/18	
3	Final Rqmts	5	9/24/18	9/28/18	
4	Initial Design	12	10/1/18	10/16/18	2,3
11	Analysis STP	0	10/17/18	10/17/18	4
14	PDR Prep	5	10/17/18	10/23/18	4
15	Changes from Stress	3	11/12/18	11/14/18	27
16	Final Design	10	11/15/18	11/28/18	15
17	CDR Prep	2	11/29/18	11/30/18	16
18	ANALYSIS	53	10/17/18	12/28/18	
19	Initial Mesh	8	10/17/18	10/26/18	11
21	Load Cases	1	10/24/18	10/24/18	19-FS=P-3D
25	Initial Stress	1	10/25/18	10/25/18	21
27	Changes to CAD	11	10/26/18	11/9/18	25
41	Final Results	5	11/12/18	11/16/18	27
43	CDR Prep	3	11/19/18	11/21/18	41
62	Stress Report	30	11/19/18	12/28/18	41
47	DWGs	42	10/17/18	12/13/18	
48	Dwg tracker/tree	4	10/17/18	10/22/18	4
49	50% Release	4	11/29/18	12/4/18	16
50	80% Release	4	12/5/18	12/10/18	49
51	100% Release	2	12/12/18	12/13/18	36
59	CDR Prep	1	12/11/18	12/11/18	50
86	MFG	41	12/11/18	2/5/19	
87	Quotes recieved	0	12/11/18	12/11/18	50
88	Job Submit	0	12/12/18	12/12/18	36,87
89	Mfg time	40	12/12/18	2/5/19	88
100	Assy	5	2/6/19	2/12/19	89
101	Install	2	2/13/19	2/14/19	100



Design-Historical Records

- Initial approach: Find records of the existing aircraft components and interface.
- LOCKHEED AIRCRAFT CORP (1959-1960):
  - **ASSY OF SONOBUOY DOOR**
  - **INSTALL OF SONOBUOY DOOR**
  - Lever Drawing (make-from drawing)



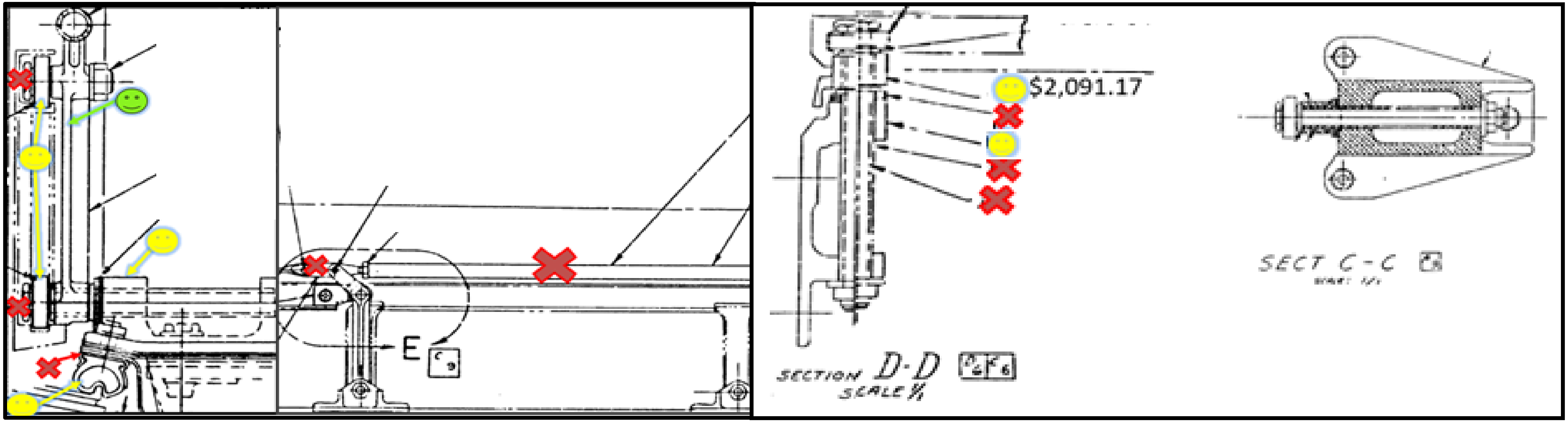
Cross Section view of Door/Aircraft Interface

Design-Historical Records

In stock (ready to order)

In DLA (lead time unknown)

Not in DLA/discontinued



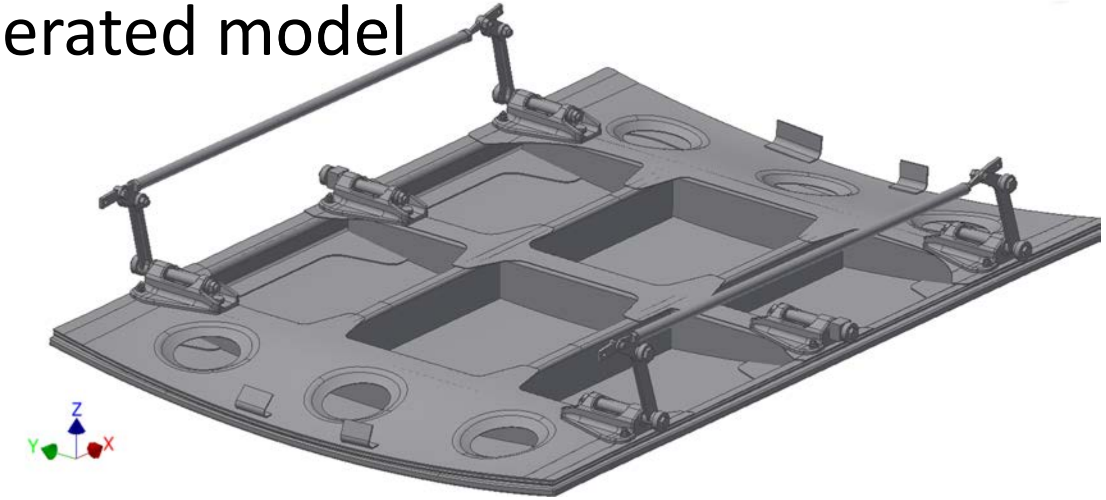
DLA: Defense Logistics Agency, government source to procure hardware

Design – Laser Scan: 3D Model

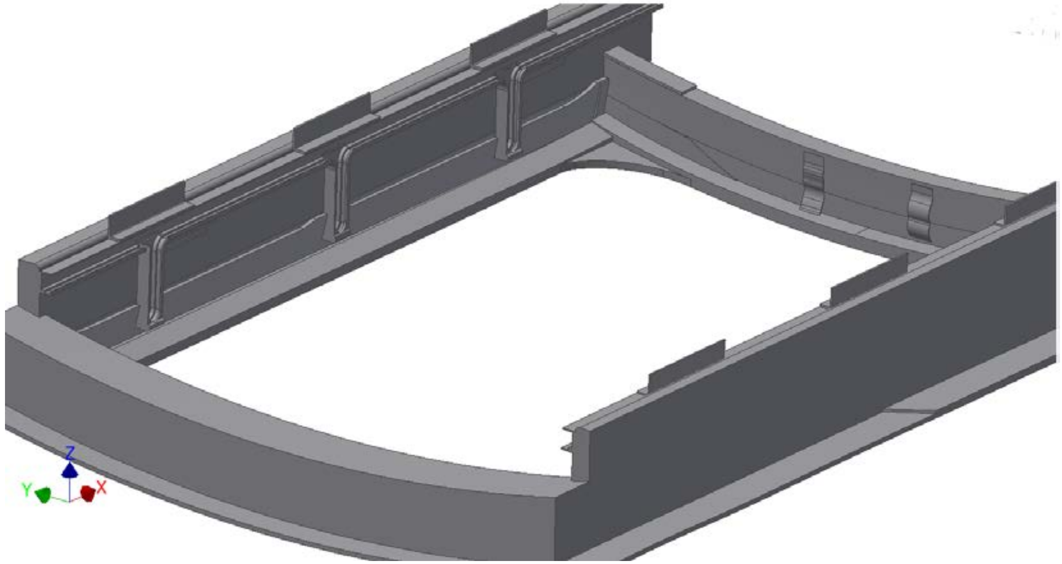
LASERDESIGN A CyberOptics Corporation Brand scanned the Nadir 1 and modified rectangular sonobuoy door.

- Generated a CAD from point cloud scan.
- Pictorial comparison of point cloud to generated model
- Received CAD Sept. 24, 2018

10 weeks remaining for reverse engineering

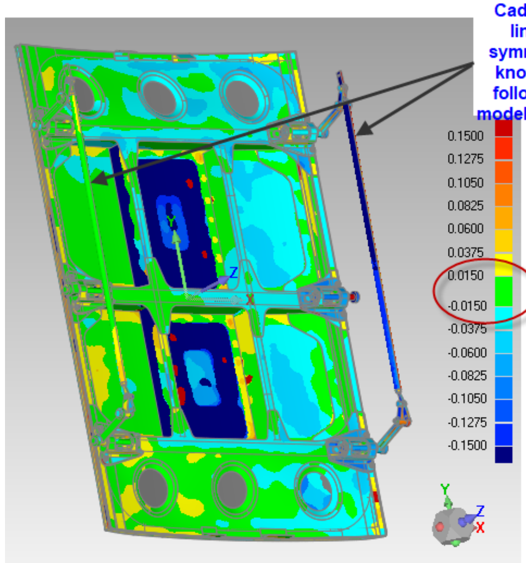


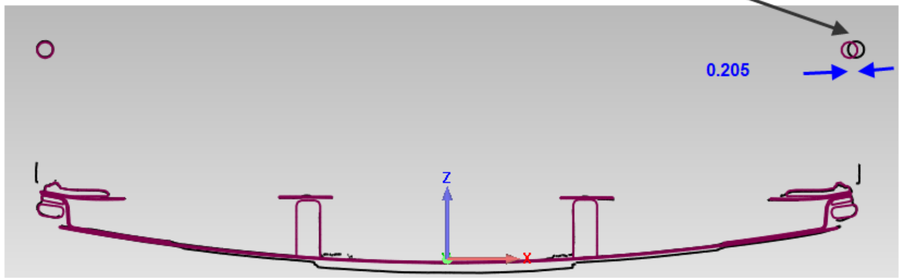
CAD Model of Door



CAD Model of Aircraft

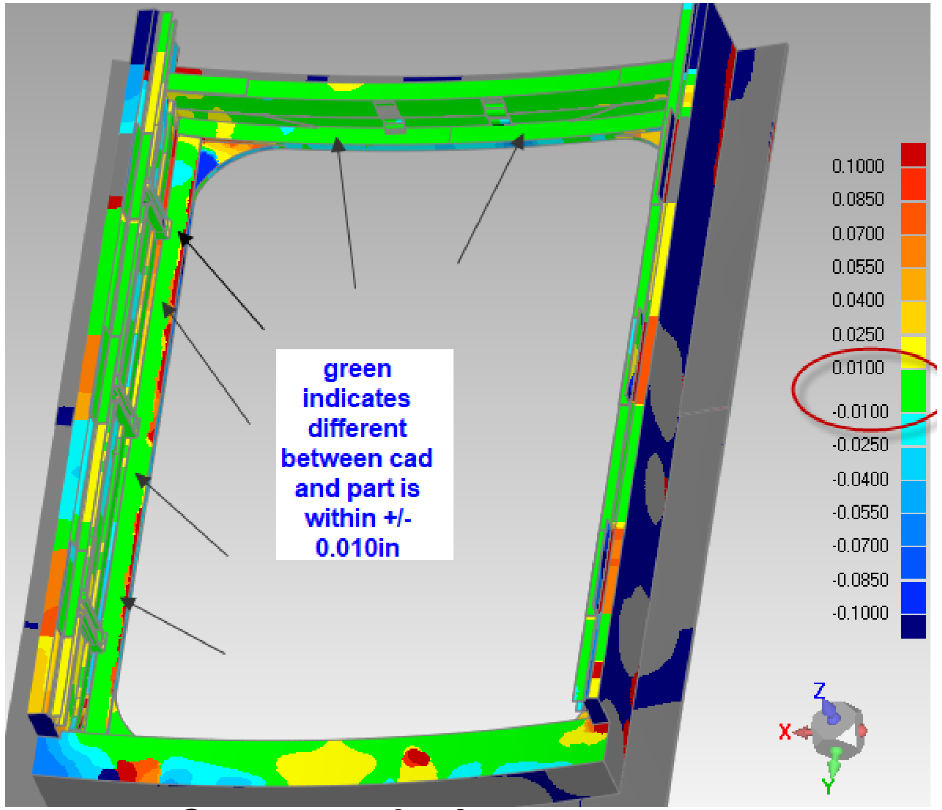
Design – Laser Scan: 3D Model





Point Cloud and Door Model Comparison

- Comparison shows the door model within .015” and aircraft model within .010”

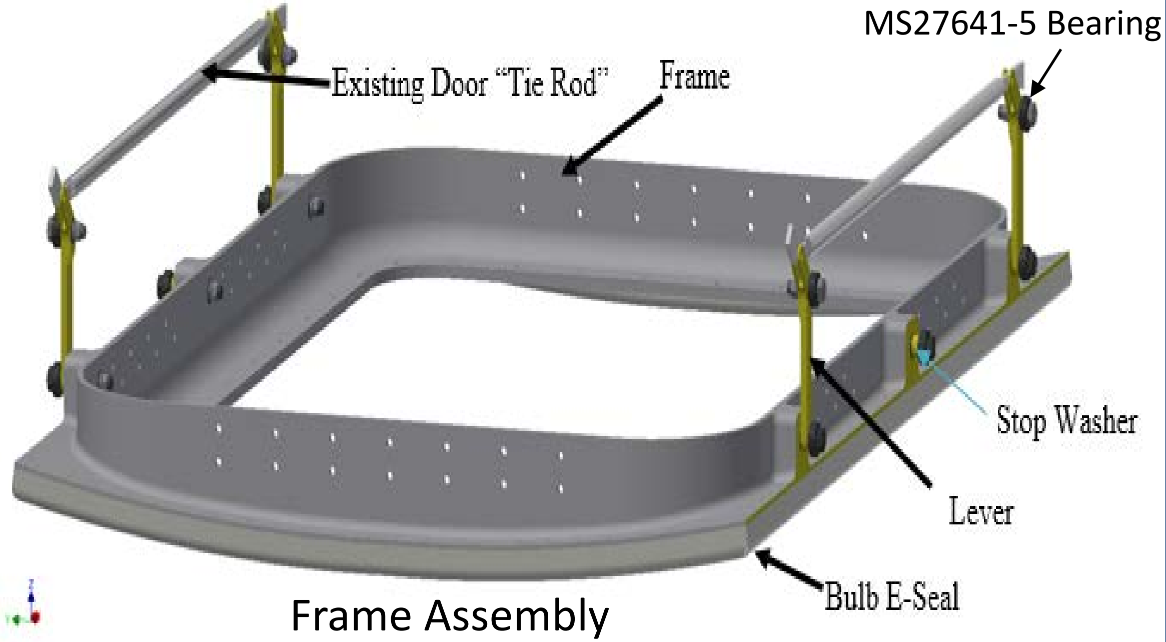


Point Cloud and Aircraft Model Comparison

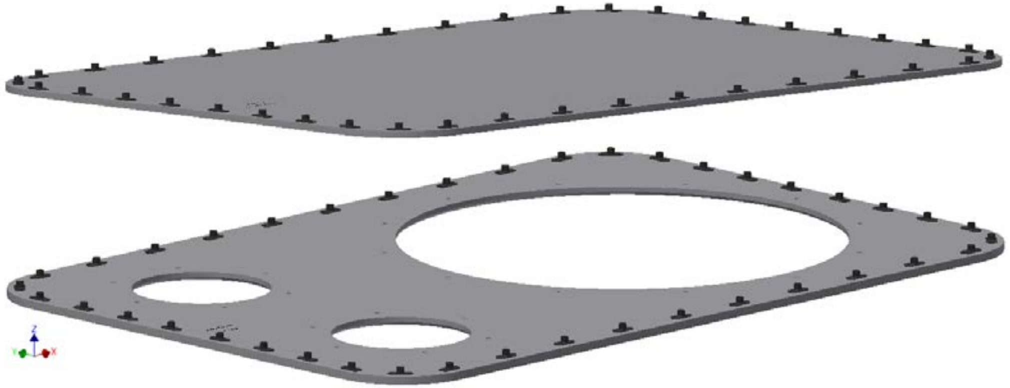
Final Design: Frame

- Milled 3.00″ thick, Al 2024-T351 Plate (37″ x 26″)
- Science Opening: 20.24″ x 31.05″
- Design allows for flat plate install

Frame
Weight: 14.0 lb (original 21 lb)



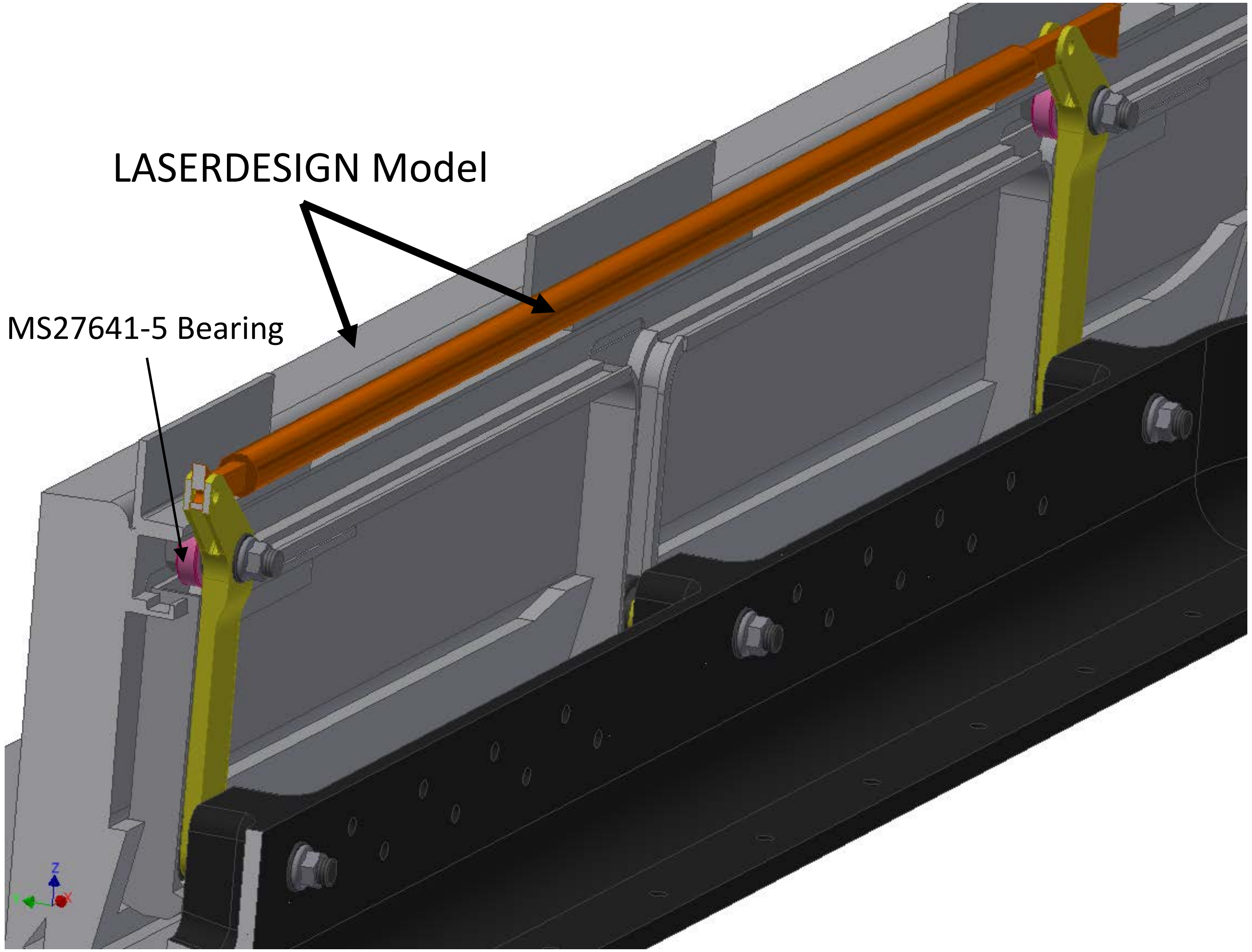
Frame Assembly



Cover Plate

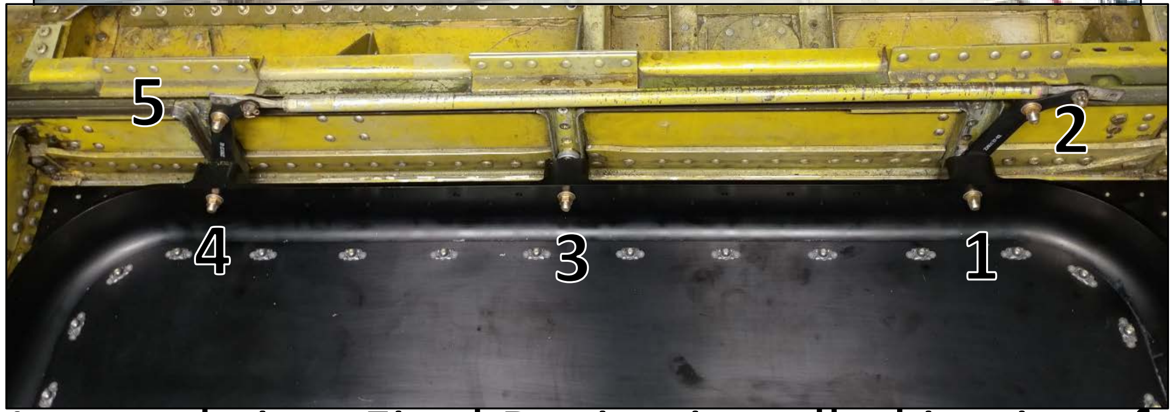
Science Plate

Final Design: Frame



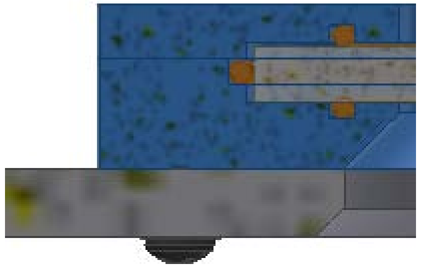
CAD of Final Design with the LASERDESIGN Model

External view Final Design installed in aircraft



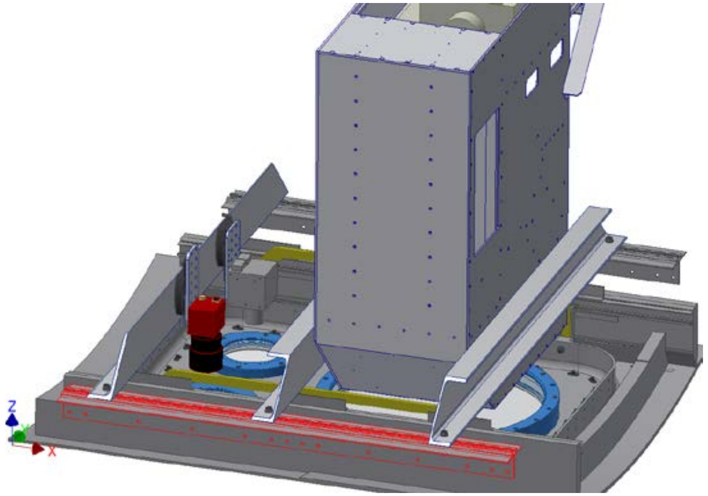
Internal view Final Design installed in aircraft

Design: Science

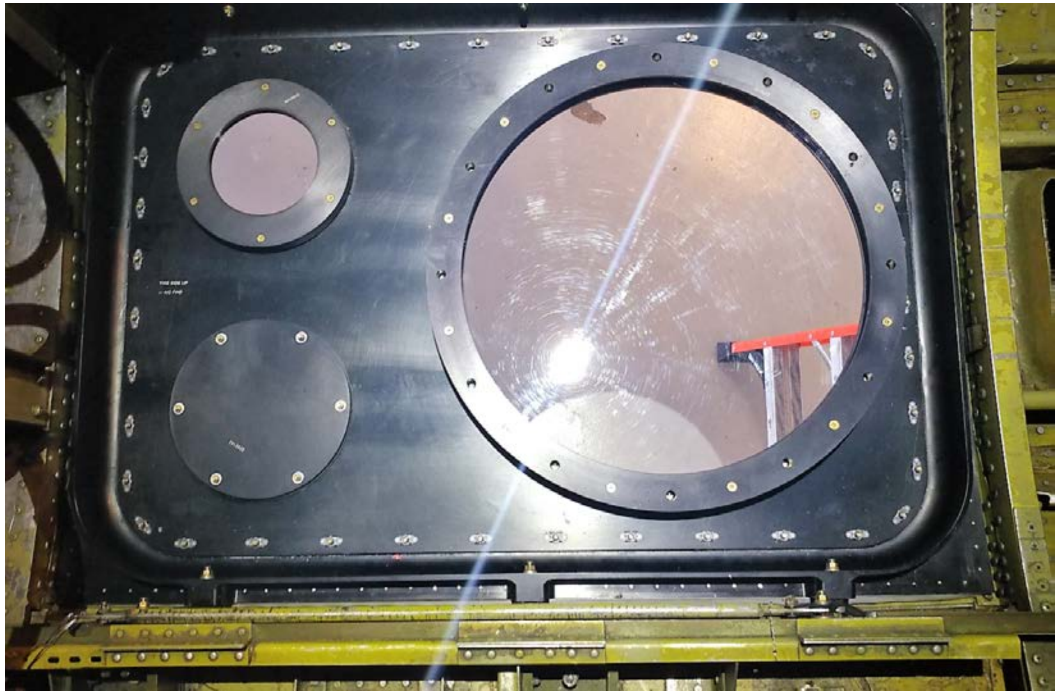


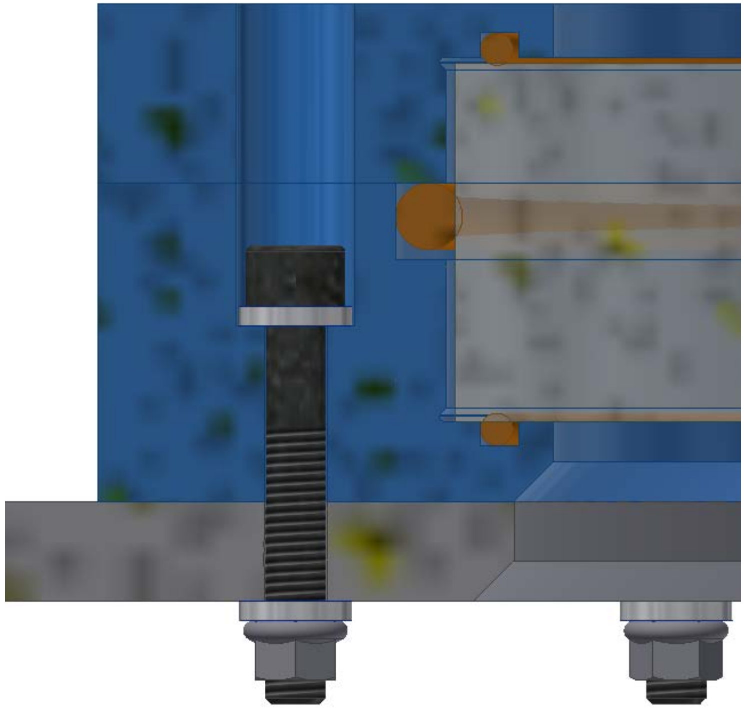
4.6″ (5 ″) Window

- 1x 16″ Windows
- 2x 5″ Windows



← Forward





16″ Window

Load Cases

- Based on P-3B Requirements Document
  - 548-RQMT-001A
- Ultimate Pressure Loads (FS=2):
  - 11.98 psi
- Ultimate Inertial Loads (FS=2):
  - 3.0G Fwd
  - 10.2G Down
  - 6.4G Up
  - 3.2G Side
  - 1.5G Aft

Table 1. Minimum aircraft pressure vessel design criteria.*

Design Parameter	Pressure Limit (psi)
Maximum Cabin Differential Pressure	5.66
Maximum Emergency Relief Pressure (*P*)	5.99
Design Limit Pressure (1.33*P*)	7.97
Design Ultimate Pressure (2*P*)**	11.98

Table 4. Minimum emergency landing load criteria for the below cabin floor area.*

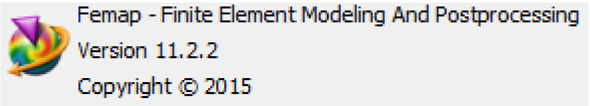
Load Direction	Ultimate Load Factor (g)
Forward	3.0
Down	4.5**
Up	2.0**
Lateral	1.5**
Aft	1.5

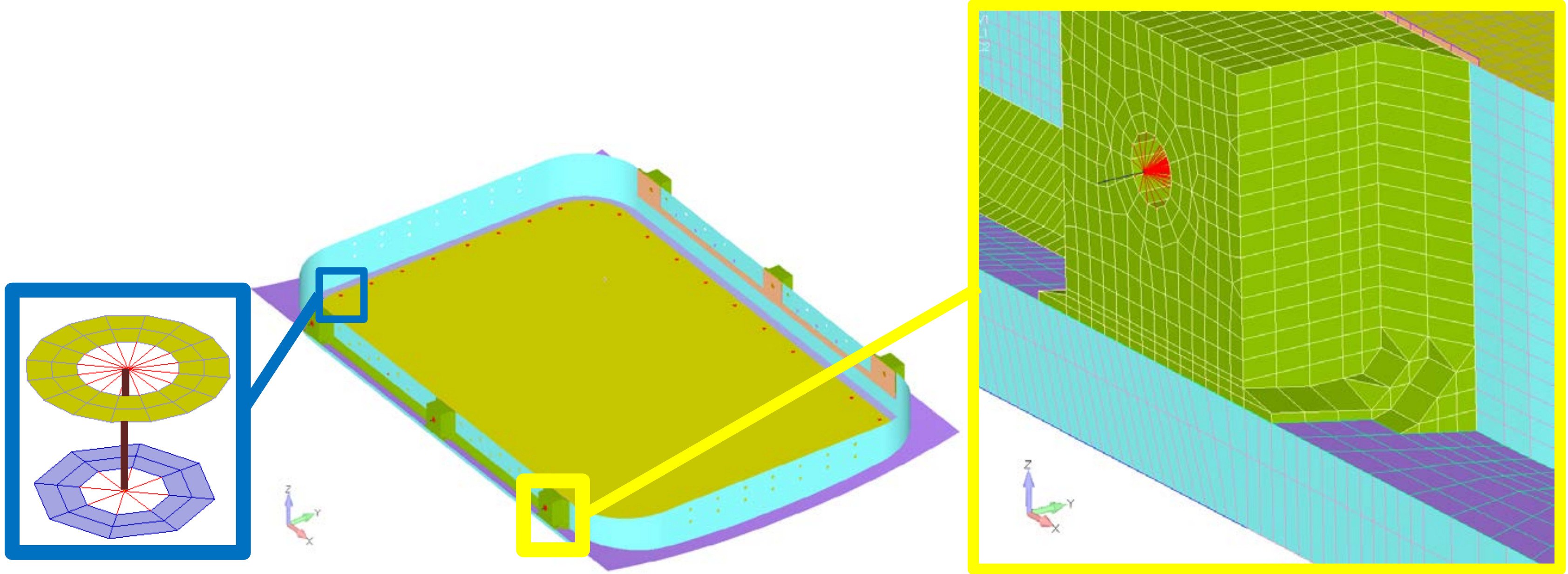
Table 8. Ultimate flight load factors FS280 to FS1130.[2]

Load Direction	Ultimate Load Factor (g)
Down	10.2
Up	6.4
Side	3.2

Frame Analysis Details

- Finite element model created in FEMAP version 11.2.2 and run through NX Nastran solver version 10.2
- Simplified the model to Plate (shell) elements & Solid at 6x Bolts that interact with the aircraft.
- Fasteners: bar elements with spidered rigid elements (RBE2) at the ends. RBE2’s connect to the components on the nodes of the hole boundary.
- Non-structural mass is added to the flat plate property to simulate an additional equally distributed mass



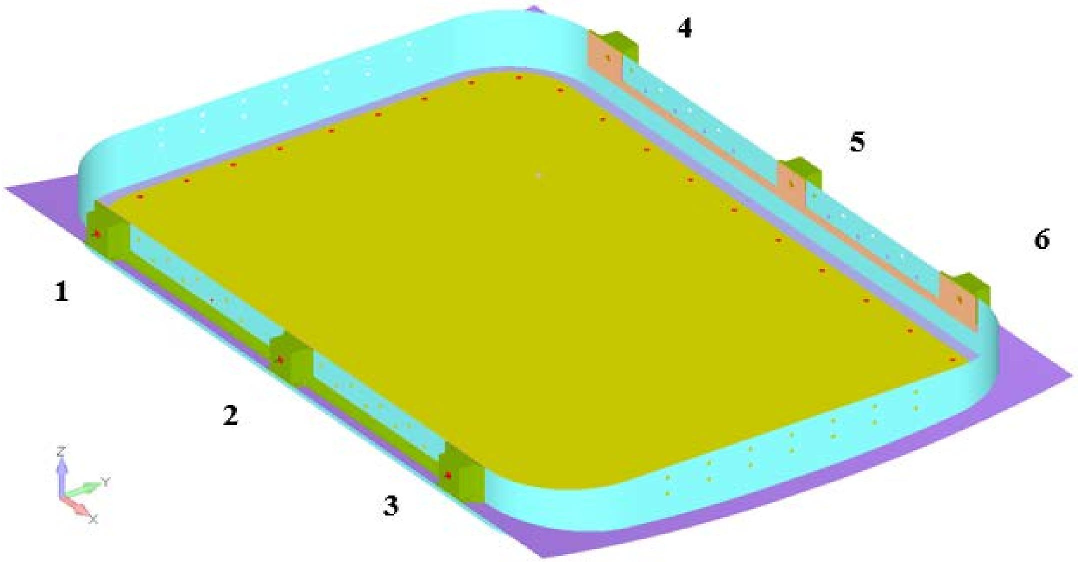


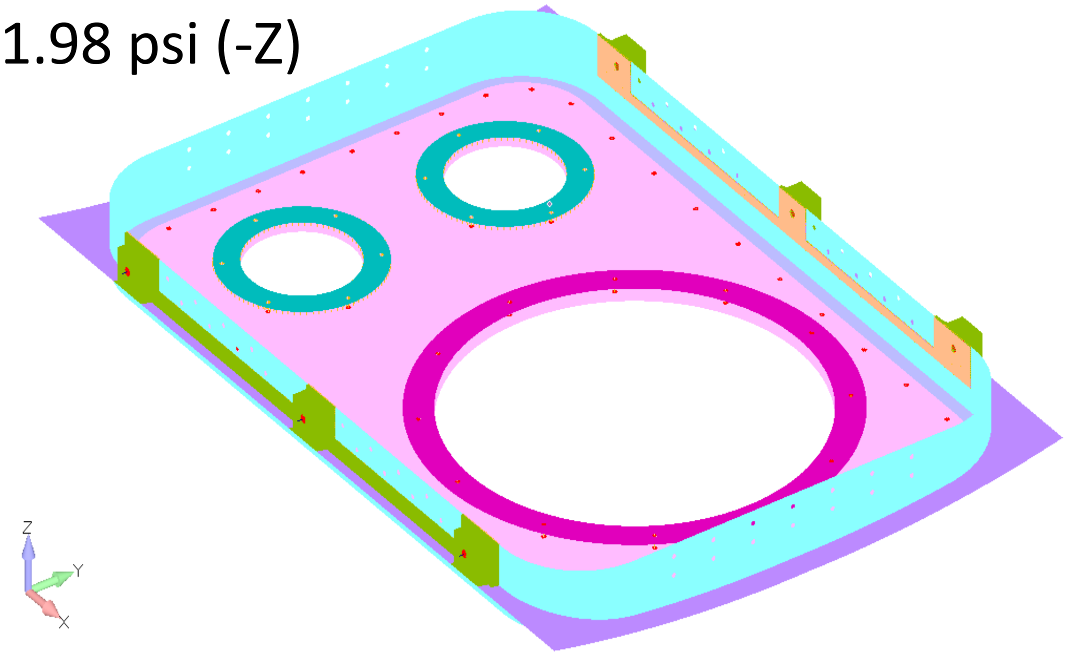
Frame Analysis Details

- Constraints:

Load Case	Bolt Constraint	Seal Constraint
10.2 G Down	1,2,3,4,5,6: Tx	Surface allows sliding (symmetry)
6.4 G Up	1,3,4,6: Tx, Ty, Tz; 2,5: Tx	NONE
3.0 G Forward	1,2,3,4,5,6: Tx	Surface allows sliding (symmetry)
3.2 G Side	4,5,6: Tx, Ty	Surface allows sliding (symmetry)
1.5 G Aft	1,2,3,4,5,6: Tx	Surface allows sliding (symmetry)

- Loads:
  - Combined load case: Inertial Loads and 11.98 psi (-Z)

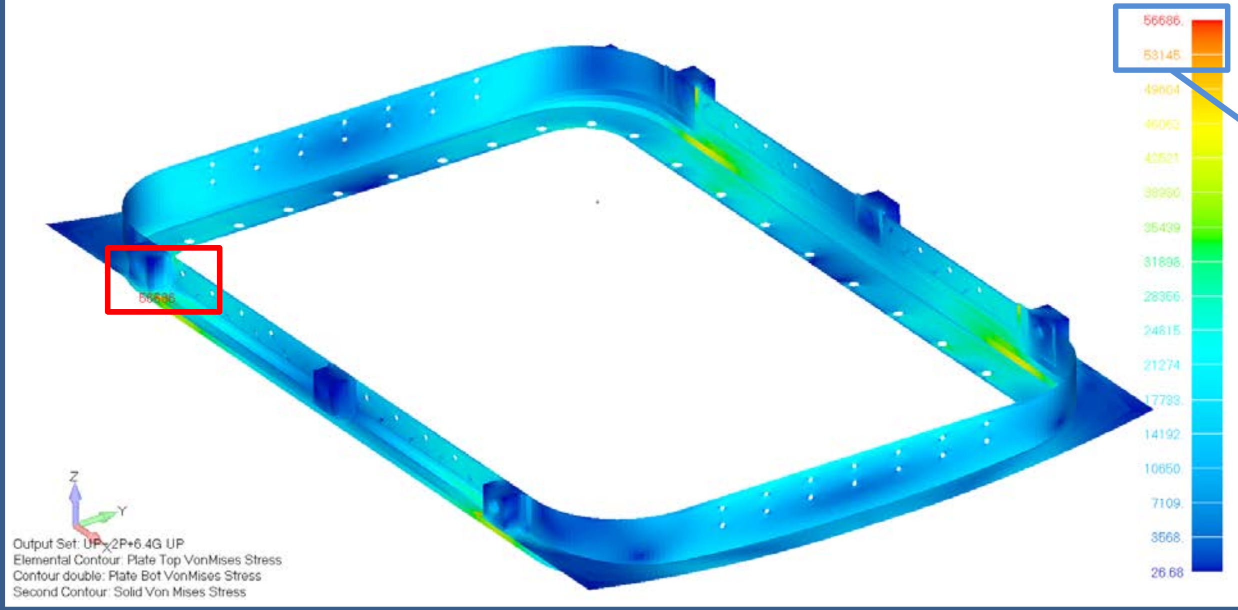




Analysis- Flat Plate Model

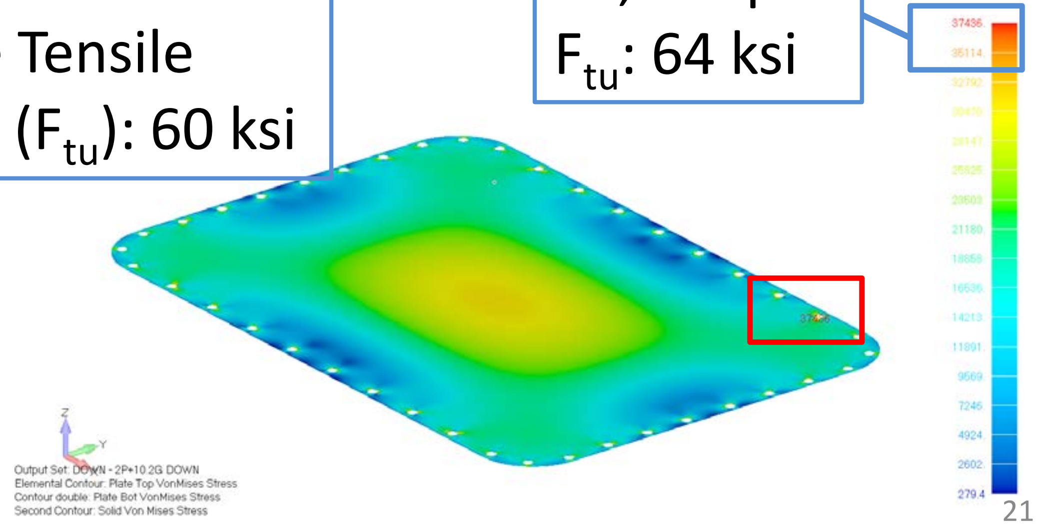
Summary of Results for Flat Plate Analysis Model

	Frame Von Mises Stress (psi)			Plate Von Mises Stress(psi)		
	17.5 lb Plate	59.2 lb Plate	115 lb Plate	17.5 lb Plate	59.2 lb Plate	115 lb Plate
10.2G Down + 2P	53,856	56,496	59,986	37,436	39,275	41,706
6.4G Up + 2P	56,686	54,871	52,471	35,903	34,759	33,247
Min MS	0.058	0.062	0.000	0.709	0.629	0.534
	Frame Shear Stress (psi)			Plate Shear Stress(psi)		
10.2G Down + 2P	21,823	22,893	24,307	20,238	21,232	22,546
6.4G Up + 2P	27,600	26,717	25,549	19,065	18,457	17,654
Min MS	0.268	0.310	0.369	0.877	2.014	1.838



56,686 psi
Ultimate Tensile Strength (F_{tu}): 60 ksi

37,436 psi
F_{tu}: 64 ksi

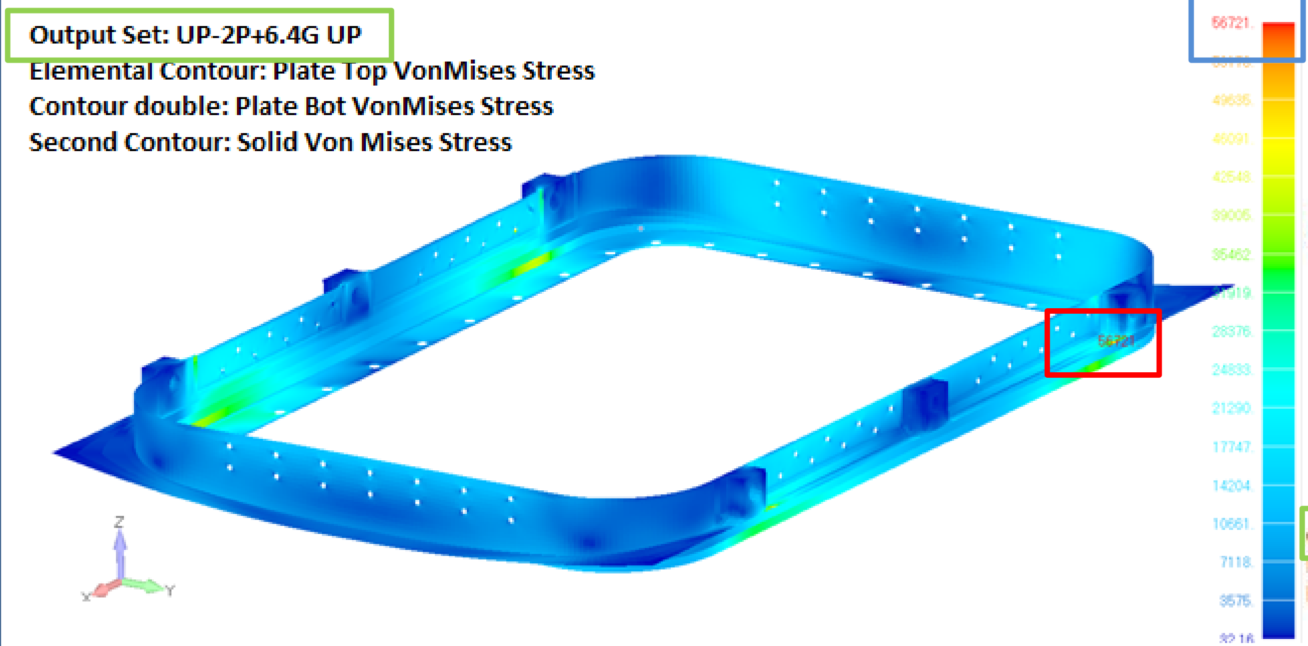


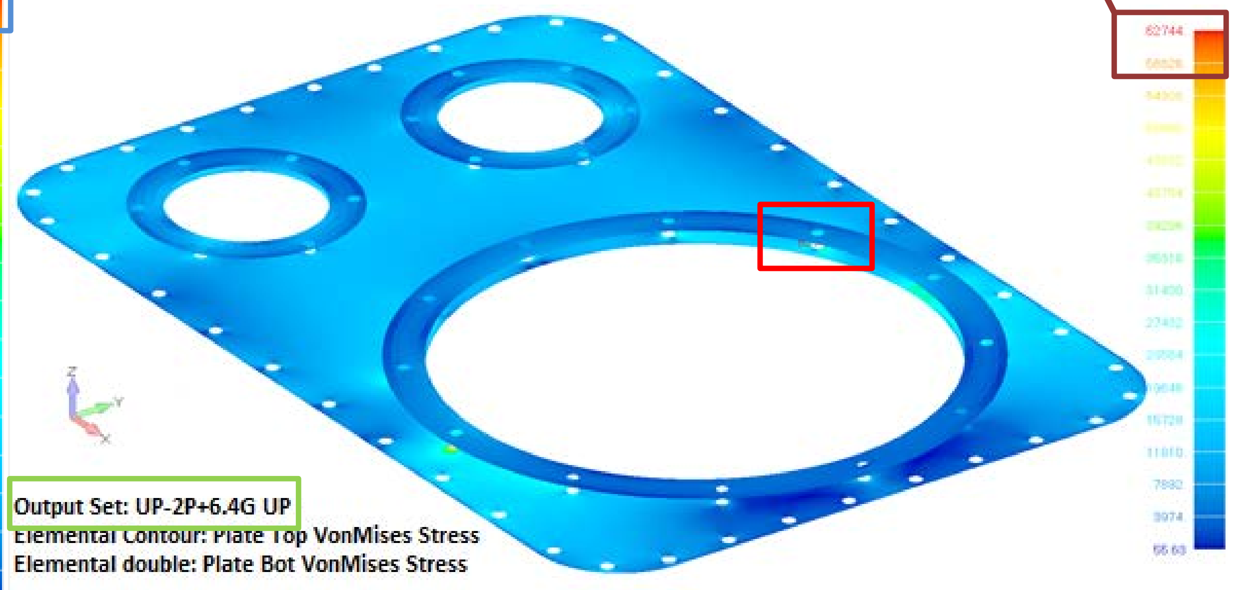
Stress Results-Science Model

Summary of Results for 59.2 lb Flat Plate Analysis Model		
	Frame Von Mises Stress	Plate Von Mises Stress
10.2G Down + 2P	56,496	39,275
6.4G Up + 2P	54,871	34,759
Min MS	.062	.629

56,721 psi
F_{tu}: 60 ksi
MS=0.057

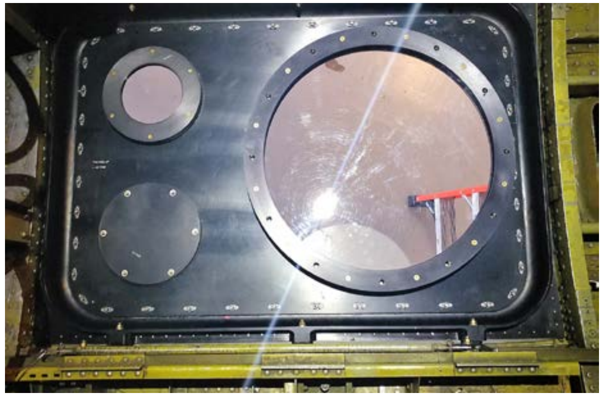
62,744 psi
F_{tu} : 64 ksi
MS=0.020



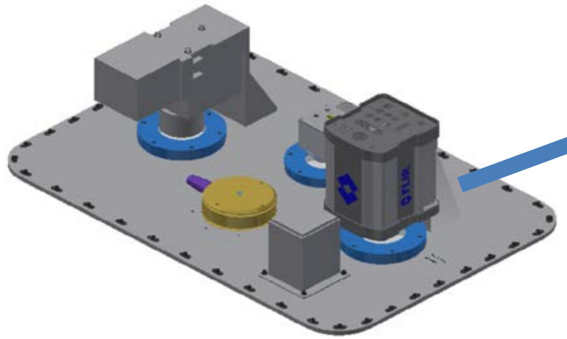


Conclusion

- Designed a fixture that increased the capability of the WFF P-3B Aircraft
- Science can be outfitted on a **flat** plate with a 20.24" x 31.05" opening
- The scanning technology open the potential to further improve aircraft science capabilities



OIB Plate Install



CAMP^{2}Ex Plate Install

Lessons Learned & Challenges

- Challenges:
  - Constrained schedule
    - Plan for shutdown
  - Lack of historical references & reverse engineer from these references
    - Request 3D scans in August, and use of scan was critical to design
  - Communicating the use of 3D scan technology with senior members
- Lessons learned
  - Don’t depend on only one source (Historical References)
  - Don’t let schedule impact engineering

Thank you

Questions?

Acronym List

AC3	Axial Cyclone Cloud-Water Collector
CAD	Computer Aided Design
CAMP^{2}Ex	Cloud, Aerosol and Monsoon Processes Philippines Experiment
FEMAP	Finite Element Modeling and Postprocessing
F_{tu}	Ultimate Tensile Strength
GSFC	Goddard Space Flight Center
IRAD	Internal Research and Development
OIB	Operation Ice Bridge
WCM	Water Content Multi-element System
WFF	Wallops Flight Facility

BACK UP SLIDES

Model Verification

The inertial loads are applied as body loads. The pressure load is applied as elemental pressure to the plate, whose surface area is 712 in^2. As a modeling check, resultant loads are extracted from the .F06 file and show that they are equal but opposite to the applied loads.

	1 G Weight (lbs)
Frame	14.0
Plate	17.5
Total 1G Weight	31.5

	10.2G Dwn (lbs)			6.4G Up (lbs)			3.0G Fwd (lbs)			3.2G Side (lbs)			1.5G Aft (lbs)		
	x	y	z	x	y	z	x	y	z	x	y	z	x	y	z
Pressure	0	0	-8546	0	0	-8546	0	0	-8546	0	0	-8546	0	0	-8546
Inertial	0	0	-322	0	0	202	-95	0	0	0	101	0	47	0	0
Total	**0**	**0**	**-8869**	**0**	**0**	**-8344**	**-95**	**0**	**-8546**	**0**	**101**	**-8546**	**47**	**0**	**-8546**

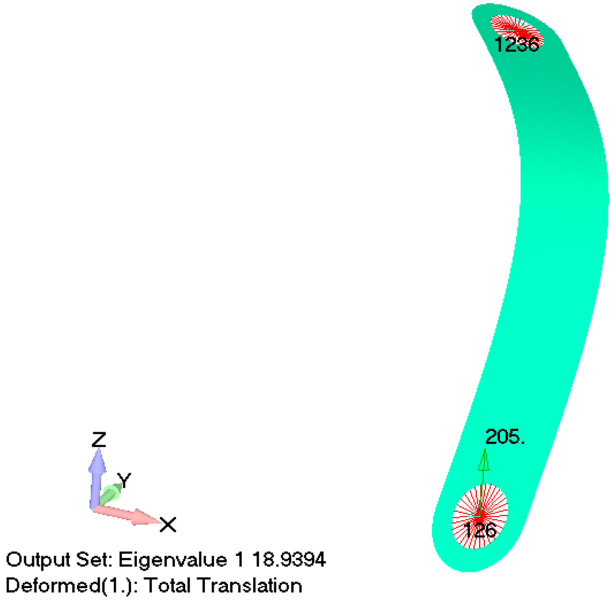
	SPCFORCE RESULANT		
LOAD CASE	FX	FY	FZ
10.2 G Down	**0**	**0**	**8,869**
6.4G Up	0	0	8,344
3.0G Fwd	**95**	**0**	**8,546**
3.2G Side	0	-101	8,546
1.5G AFT	**-47**	**0**	**8,546**

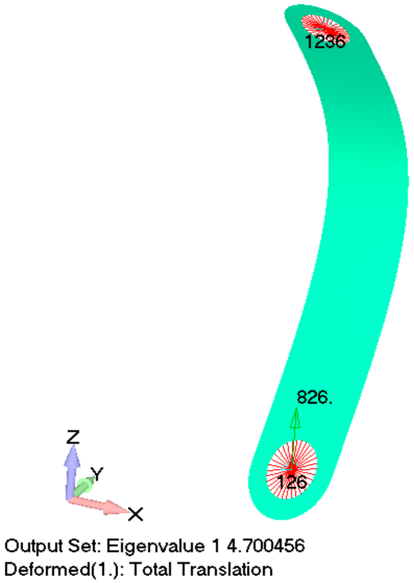
Analysis Results

- Additional analysis included:
  - Buckling analysis of the Lever

The buckling load is calculated for the 6.4G UP load without the 2P pressure.

$$F_{17.5(buckling)} = 6.4 * (17.5 + 14) = 205\ lbs$$
$$F_{115(buckling)} = 6.4 * (115 + 14) = 826\ lbs$$





  - Lever strength analysis

$$P_{u(tension)} = F_{tu} * (2R - D) * t$$
$$= 63 * 10^3(.687 - .328) * .2 = 4{,}523\ lbs$$

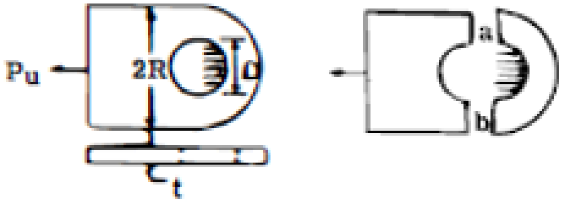


Fig. D1. 8

Bolt and Lug Strength Analysis, Bruhn's Fig. D1.8

Analysis Results-Continued

- Bolt analysis using load extracted from the bar elements in the finite element model

7.2.5 #10-32 Bolt Analysis

The #10-32 bolts are used to attach the plate to the frame. Bar forces are extracted from the FEM model and used to conduct the analysis. Table 10 shows the critical loads for the bolts for the 10.2G Down and 6.4G Up load cases for the 17.5 and 115 lb plates. The worst case adjusted loads (Load*FF) occur for the 17.5 lb plate and are 686 lb. in shear and 509 lb. in tension. These values are used in the MS_{shear}, $MS_{tension}$, and interaction equation.

$$MS_{shear} = \frac{2{,}690}{686} - 1 = 2.92$$

$$MS_{tension} = \frac{2{,}890}{509} - 1 = 4.68$$

$$\left(\frac{(\mathrm{MS}+1)*686}{2{,}690}\right)^2 + \left(\frac{(\mathrm{MS}+1)*509}{2{,}890}\right)^2 = 1 \xrightarrow{\text{yields}} \mathrm{MS} = 2.23$$

The max shear load (686 lb.) is used to conduct a shear tear-out and bearing stress calculation where D = 0.19, and t = 0.25 (thickness of plate). The frame thickness is 0.30" but has lower shear and bearing strength, 35 ksi and 91 ksi respectively. The MS shear and bearing are 7.72 and 6.56 respectively.

$$\sigma_{shear} = \frac{686\ lb}{0.1425\ in^2} = 4{,}812\ psi$$

$$MS_{shear} = \frac{\sigma_{allowable}}{Max\ \sigma} - 1 = \frac{38\ ksi}{4{,}812\ psi} - 1 = 6.90$$

$$\sigma_{bearing} = \frac{686\ lb}{0.0475\ in^2} = 14{,}436\ psi$$

$$MS_{bearing} = \frac{\sigma_{allowable}}{Max\ \sigma} - 1 = \frac{97\ ksi}{14{,}436\ psi} - 1 = 5.72$$

7.2.6 5/16-24 Bolt Analysis

$$F_{prying} = \frac{\sqrt{{M_{plane1}}^2 + {M_{plane2}}^2}}{0.66 * e} = \frac{\sqrt{(-523)^2 + 451^2}}{0.66 * 0.406} = 2{,}544$$

$$F_{tension} = 3{,}350 + 1.15 * (2{,}544) = 6{,}276$$

$$MS_{shear} = \frac{7{,}290}{3{,}168} - 1 = 1.30$$

$$MS_{tension} = \frac{8{,}590}{6{,}276} - 1 = 0.37$$

$$\left(\frac{(\mathrm{MS}+1)*3{,}168}{7{,}290}\right)^2 + \left(\frac{(\mathrm{MS}+1)*6{,}276}{8{,}590}\right)^2 = 1 \xrightarrow{\text{yields}} \mathrm{MS} = 0.18$$

The max shear load (3,168 lb.) is used to conduct a shear tear-out and bearing stress calculation where D = 0.3125, and t = 0.2 (thickness of lever). The frame thickness is 1.03" but has lower shear and bearing strength, 35 ksi and 91 ksi respectively. The MS shear and bearing are 9.67 and 8.24 respectively.

$$\sigma_{shear} = \frac{3{,}168\ lb}{0.1875\ in^2} = 16{,}894\ psi$$

$$MS_{shear} = \frac{\sigma_{allowable}}{Max\ \sigma} - 1 = \frac{37\ ksi}{16{,}894\ psi} - 1 = 1.190$$

$$\sigma_{bearing} = \frac{3{,}168\ lb}{0.0625\ in^2} = 50{,}682\ psi$$

$$MS_{bearing} = \frac{\sigma_{allowable}}{Max\ \sigma} - 1 = \frac{95\ ksi}{50{,}682\ psi} - 1 = 0.874$$

Analysis Results-Continued

- Glass window Analysis

8.2 Results Summary

This section contains the calculation results from the window Analysis. Each window of the installation is looked at separately for peak stress values.

Table 14: Stress Summary

Component	Combined Stress (psi)	MS	Flaw Allowance Stress (psi)	MS	Min MS
16" Window	1,749	2.20	5,247	0.07	0.07
5" Window	1,838	2.05	5,513	0.01	0.01

8.2.1 16" Window Analysis

$$\Delta T = \left| -2.65 - \frac{\frac{0.64(-2.65)}{(1.125/12)} + 10*70}{\frac{0.64}{(1.125/12)} + 10} \right| = 43.18$$

$$S_{max} = \frac{3(5.99)(3+0.207)8.112^2}{8(1.125^2)} = 375\ psi * 2\ = 749\ psi$$

$$\sigma_{th} = \frac{(3.9*10^{-6})(1.18*10^{7})43.18}{4} = 497\ psi * 1.2 = 596\ psi$$

$$\sigma_{st} = 749\ + 596 = 1{,}345\ psi * 1.3 = 1{,}749\ psi$$

$$MS = \frac{5{,}600\ psi}{1{,}749\ psi} - 1 = 2.20$$

$$\sigma_{flaw} = 3 * 1{,}749 = 5{,}247\ psi$$

$$MS = \frac{5{,}600\ psi}{5{,}247\ psi} - 1 = 0.07$$

8.2.2 5" Window Analysis

$$\Delta T = \left| -2.65 - \frac{\frac{0.64(-2.65)}{(0.256/12)} + 10*70}{\frac{0.64}{(0.256/12)} + 10} \right| = 18.16$$

$$S_{max} = \frac{3(5.99)(3+0.207)2.3^2}{8(0.256^2)} = 581\ psi * 2\ = 1{,}163\ psi$$

$$\sigma_{th} = \frac{(3.9*10^{-6})(1.18*10^{7})18.16}{4} = 209\ psi * 1.2 = 251\ psi$$

$$\sigma_{st} = 1{,}163\ + 251 = 1{,}414\ psi * 1.3 = 1{,}838\ psi$$

$$MS = \frac{5{,}600\ psi}{1{,}838\ psi} - 1 = 2.05$$

$$\sigma_{flaw} = 3 * 1{,}838\ = 5{,}513\ psi$$

$$MS = \frac{5{,}600\ psi}{5{,}513\ psi} - 1 = 0.0157$$

MMPDS- Data Sheet

Table 3.2.4.0(b$_2$). Design Mechanical and Physical Properties of 2024 Aluminum Alloy Sheet and Plate

Specification	AMS 4037[a]											
Form	Plate											
Temper	T351											
Thickness, in.	0.250-0.499		0.500-1.000		1.001-1.500		1.501-2.000		2.001-3.000		3.001-4.000	
Basis	A	B	A	B	A	B	A	B	A	B	A	B
Mechanical Properties:												
F_{tu}, ksi:												
L	64	66	63	65	62	64	62	64	60	62	57	59
LT	64	66	63	65	62	64	62	64	60[d]	62[d]	57[d]	59[d]
ST	...	...	...	...	...	...	...	...	52[b]	54[b]	49[b]	51[b]
F_{ty}, ksi:												
L	48	50	48	50	47	50	47	49	46	48	43	46
LT	42	44	42	44	42	44	42	44	42	44	41	43
ST	...	...	...	...	...	...	...	...	38[b]	40[b]	38[b]	39[b]
F_{cy}, ksi:												
L	39	41	39	41	39	40	38	40	37	39	35	37
LT	45	47	45	47	44	46	44	46	43	45	41	43
ST	...	...	...	...	...	...	...	...	46	48	44	47
F_{su}, ksi (L & LT)	38	39	37	38	37	38	37	38	35	37	34	35
F_{bru}[c], ksi:												
L & LT (e/D = 1.5)	97	100	95	98	94	97	94	97	91	94	86	89
L & LT (e/D = 2.0)	119	122	117	120	115	119	115	119	111	115	106	109
F_{bry}[c], ksi:												
L & LT (e/D = 1.5)	72	76	72	76	72	76	72	76	72	76	70	74
L & LT (e/D = 2.0)	86	90	86	90	86	90	86	90	86	90	84	88
e, percent (S-Basis):												
LT	12	...	8	...	7	...	6	...	4	...	4	...
E, 10^3 ksi	10.7											
E_c, 10^3 ksi	10.9											
G, 10^3 ksi	4.0											
μ	0.33											
Physical Properties:												
ω, lb/in^3	0.100											
C, K	See Figure 3.2.4.0(a)											
α	See Figure 3.2.4.0(b)											

Last Revised: Apr 2015, MMPDS-10, Item 14-35. Design allowables were last confirmed in Item 07-41, MMPDS-04CN1.

a Mechanical properties were established under QQ-A-250/4.

b Caution: This specific alloy, temper, and product form exhibits poor stress corrosion cracking resistance in this grain direction. It corresponds to an SCC resistance rating of D, as indicated in Table 3.1.2.3.1(a).

c Bearing values are "dry pin" values per Section 1.4.7.1. See Table 3.1.2.1.1.

d The following rounded T_{99} and T_{90} values represent production capacity at the time the table was last confirmed; F_{tu} LT for 2-3 inches T_{99} = 63 ksi, T_{90} = 64 ksi; for 3-4 inches T_{99} = 60 ksi, T_{90} = 62 ksi.

MMPDS-13
1 July 2018

3-116

Material Certifications- Frame

AMAG ROLLING

Abstnahmeprüfzeugnis 3.1 (EN 10204)
Inspection certificate - mill certificate

Nr.: 89099446 01 / 1
Rev.: 0

Zertifiziert nach / certified to ISO 9001, ISO/TS 16949, EN/AS 9100, ISO 14001, NADCAP

Seite / page: 1 von / of 2
Datum / date: 2018 07 09

Auftraggeber / customer:
Alro Steel Corporation
3100 E. High Street
JACKSON MI 49204-0927
USA

Warenempfänger / consignee:
Alro Steel Corporation
5859 Alro Park Drive
POTTERVILLE MI 48876
USA

Bestell Nr. / order no.: 13379301
Datum / date: 2018 04 10
Auftragsbest. Nr. / order confirm no.: 147180
Datum / date: 2018 04 11
Lieferschein Nr. / delivery note: 89099446
Datum / date: 2018 07 31

Produkt / product
Form / form: Plate, stretched
Werkstoff / material: 2024
Zustand / temper: T351
Dim. / dim.: [inch]: 3,000x48,50x144,50
Kundenartikel Nr. / cust. article no.: 27922500

Bedingungen / terms
Technische Lieferbedingungen / techn. spec.:
AMS-QQ-A-250/4 Rev.B, 2015-02
ASTM B 209 - 14
AMS 4037Q, 12.2014
Sondervorschrift / special terms:
not US tested

AB-Pos. ord.-item	BNr/Los Lot/No.	Teillos Part	Guss Nr. cast no.	Werkstoff material	Kollo packno.	Gewicht netto weight net	Stk. pcs.
04	76288/01	00	01/0092766/8	2024	1471800011	4307,760 lbs	2
04	76288/01	00	01/0092766/8	2024	1471800012	4312,169 lbs	2

Chemische Zusammensetzung ([%] Gewichtsanteile) / Chemical composition ([%] weight proportion (OES))

Guss Nr. / cast no	material		Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Others Each	Others Total
01/0092766/8	2024	spec. min.	-	-	3,8	0,30	1,2	-	-	-	-	-
		spec. max.	0,50	0,50	4,9	0,9	1,8	0,10	0,25	0,15	0,05	0,15
		actual	0,05	0,09	4,3	0,57	1,5	0,03	0,07	0,04	0,02	0,03

Zugprüfung LT / tensile test LT

BNr/Los Lot/No.	Zustand temper	Richtung direction	Tests		UTS [ksi]	YS [ksi]	A2" [%]
				spec.min.	60,0	42,0	4
				spec.max.	-	-	-
76288/01	T351	LT	3	from	67,7	47,0	16
76288/01	T351	LT		to	68,0	47,6	17

Sonstige Prüfungen / other tests
Maßkontrolle: OK. / Dimensional Check: OK.
Oberfläche: OK. / Surface inspection: OK

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ALRO STEEL PV

Alro Metals/Plastics
RT09406262

AMAG rolling GmbH, Postfach 32, A-5282 Ranshofen, Österreich - www.amag.at
AMAG rolling GmbH, P.O. Box 32, A-5282 Ranshofen, Austria - www.amag.at

Produkt / product
Form / form: Plate, stretched
Werkstoff / material: 2024
Zustand / temper: T351
Dim. / dim.: [inch]: 3,000x48,50x144,50
Kundenartikel Nr. / cust. article no.: 27922500
Bedingungen / terms
Technische Lieferbedingungen / techn. spec.:
AMS-QQ-A-250/4 Rev.B, 2015-02
ASTM B 209 - 14
AMS 4037Q, 12.2014
Sondervorschrift / special terms:
not US tested

BNr/Los Lot/No.	Zustand temper	Richtung direction	Tests		UTS [ksi]	YS [ksi]	A2" [%]
				spec.min.	60,0	42,0	4
				spec.max.	-	-	-
76288/01	T351	LT	3	from	67,7	47,0	16
76288/01	T351	LT		to	68,0	47,6	17

Material Certifications- Plate

SHIP TO:
AFFILIATED - DIV OF BRALCO 450 N BILLY MITCHELL ROAD SALT LAKE CITY, UT 84116

SOLD TO:
AFFILIATED - DIV OF BRALCO 450 N BILLY MITCHELL ROAD SALT LAKE CITY, UT 84116

KAISER ALUMINUM

Trentwood Works - Spokane, WA 99215
Phone: (800) 367-2586

CERTIFIED TEST REPORT

Serial Number
4473869

CUSTOMER PO NUMBER:	WORK PACKAGE:	CUSTOMER PART NUMBER:	SHIP RUN/LOAD:	GOV'T CONTRACT NUMBER:
16-10514-1			104009/9	

KAISER ORDER NO:	SHIP DATE:	ALLOY:	CLAD:	TEMPER:	PRODUCT DESCRIPTION:
1239605-1	13-AUG-2017	2024	BARE	T351	Sawed Plate

WEIGHT SHIPPED:	QUANTITY:	TRUCK B/L #:	GAUGE:	DIAMETER/WIDTH:	LENGTH:
4820 LB	22 PCS EST.	2068433	0.2500 IN (6.3500 MM)	58.000 IN (1473.2 MM)	144.500 IN (3670.3 MM)

MHU 2142043: LOT 231987B9: 22 pieces;

Certified Specifications

AMS 4037/RevQ AMS-QQ-A-250/4/RevB ASTM B 209/Rev14

Test Results

Test Code: 1504
Lot: 231987B9 Cast 493 Drop 59 Ingot 2 Melted in USA

(ASTM E8/B557)
(EN 2002-1)

Tensile:	Temper	Dir / # Tests	Ultimate KSI (MPA)	Yield KSI (MPA)	Elongation %
	T351	LT / 2 (Min:Max)	70.4 : 70.6 (485 : 487)	48.6 : 48.6 (335 : 335)	18.6 : 19.9

(ASTM E1251)

Chemistry:	SI	FE	CU	MN	MG	CR	ZN	TI	V	ZR		OTHER
Actual(wt%)	0.06	0.17	4.7	0.59	1.4	0.01	0.09	0.02	0.01	0.01	TOT	0.06

ALLOY LIMITS

2024	SI	FE	CU	MN	MG	CR	ZN	TI	V	ZR	OTHER	MAX
MIN(wt%)	0.00	0.00	3.8	0.30	1.2	0.00	0.00	0.00	0.00	0.00	EACH	0.05
MAX(wt%)	0.50	0.50	4.9	0.9	1.8	0.10	0.25	0.15	0.05	0.05	TOT	0.15

Aluminum Remainder