Design of P-3 Nadir Port

Early Career Forum: Structures, Loads, and Mechanical Systems
September 2019
Author: Monica Chance, Aerospace Engineer
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 (CAMP2Ex)
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</table>
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
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

“Bumper” O-ring
Introduction-Door

Seal

Lever System

1 2 3

4 5

Rod

Lever

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

- Limited the science potential
- Size and number of the 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
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)
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
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
Point Cloud and Door Model Comparison

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

- 1x 16” Windows
- 2x 5” Windows

4.6” (5 ”) Window

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>
<thead>
<tr>
<th>Design Parameter</th>
<th>Pressure Limit (psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum Cabin Differential Pressure</td>
<td>5.66</td>
</tr>
<tr>
<td>Maximum Emergency Relief Pressure (P)</td>
<td>5.99</td>
</tr>
<tr>
<td>Design Limit Pressure (1.33P)</td>
<td>7.97</td>
</tr>
<tr>
<td>Design Ultimate Pressure (2P)**</td>
<td>11.98</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Load Direction</th>
<th>Ultimate Load Factor (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forward</td>
<td>3.0</td>
</tr>
<tr>
<td>Down</td>
<td>4.5**</td>
</tr>
<tr>
<td>Up</td>
<td>2.0**</td>
</tr>
<tr>
<td>Lateral</td>
<td>1.5**</td>
</tr>
<tr>
<td>Aft</td>
<td>1.5</td>
</tr>
</tbody>
</table>

1. Minimum aircraft pressure vessel design criteria.
2. Minimum emergency landing load criteria for the below cabin floor area.
3. Ultimate flight load factors FS280 to FS1130.
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:

<table>
<thead>
<tr>
<th>Load Case</th>
<th>Bolt Constraint</th>
<th>Seal Constraint</th>
</tr>
</thead>
<tbody>
<tr>
<td>10.2 G Down</td>
<td>1,2,3,4,5,6: Tx</td>
<td>Surface allows sliding (symmetry)</td>
</tr>
<tr>
<td>6.4 G Up</td>
<td>1,3,4,6: Tx, Ty, Tz; 2,5: Tx</td>
<td>NONE</td>
</tr>
<tr>
<td>3.0 G Forward</td>
<td>1,2,3,4,5,6: Tx</td>
<td>Surface allows sliding (symmetry)</td>
</tr>
<tr>
<td>3.2 G Side</td>
<td>4,5,6: Tx, Ty</td>
<td>Surface allows sliding (symmetry)</td>
</tr>
<tr>
<td>1.5 G Aft</td>
<td>1,2,3,4,5,6: Tx</td>
<td>Surface allows sliding (symmetry)</td>
</tr>
</tbody>
</table>

• Loads:

– Combined load case: Inertial Loads and 11.98 psi (-Z)
## Summary of Results for Flat Plate Analysis Model

<table>
<thead>
<tr>
<th>Condition</th>
<th>Frame Von Mises Stress (psi)</th>
<th>Plate Von Mises Stress (psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10.2G Down + 2P</td>
<td>53,856</td>
<td>37,436</td>
</tr>
<tr>
<td></td>
<td>56,496</td>
<td>39,275</td>
</tr>
<tr>
<td></td>
<td>59,986</td>
<td>41,706</td>
</tr>
<tr>
<td>6.4G Up + 2P</td>
<td>56,686</td>
<td>35,903</td>
</tr>
<tr>
<td></td>
<td>54,871</td>
<td>34,759</td>
</tr>
<tr>
<td></td>
<td>52,471</td>
<td>33,247</td>
</tr>
<tr>
<td>Min MS</td>
<td>0.058</td>
<td>0.709</td>
</tr>
<tr>
<td></td>
<td>0.062</td>
<td>0.629</td>
</tr>
<tr>
<td></td>
<td>0.000</td>
<td>0.534</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Condition</th>
<th>Frame Shear Stress (psi)</th>
<th>Plate Shear Stress (psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10.2G Down + 2P</td>
<td>21,823</td>
<td>20,238</td>
</tr>
<tr>
<td></td>
<td>22,893</td>
<td>21,232</td>
</tr>
<tr>
<td></td>
<td>24,307</td>
<td>22,546</td>
</tr>
<tr>
<td>6.4G Up + 2P</td>
<td>27,600</td>
<td>19,065</td>
</tr>
<tr>
<td></td>
<td>26,717</td>
<td>18,457</td>
</tr>
<tr>
<td></td>
<td>25,549</td>
<td>17,654</td>
</tr>
<tr>
<td>Min MS</td>
<td>0.268</td>
<td>0.877</td>
</tr>
<tr>
<td></td>
<td>0.310</td>
<td>2.014</td>
</tr>
<tr>
<td></td>
<td>0.369</td>
<td>1.838</td>
</tr>
</tbody>
</table>

Ultimate Tensile Strength ($F_{tu}$): 60 ksi

56,686 psi Ultimate Tensile Strength ($F_{tu}$): 64 ksi
## Stress Results - Science Model

<table>
<thead>
<tr>
<th>Case</th>
<th>Frame Von Mises Stress</th>
<th>Plate Von Mises Stress</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>10.2G Down + 2P</strong></td>
<td>56,496</td>
<td>39,275</td>
</tr>
<tr>
<td><strong>6.4G Up + 2P</strong></td>
<td>54,871</td>
<td>34,759</td>
</tr>
<tr>
<td><strong>Min MS</strong></td>
<td>0.062</td>
<td>0.629</td>
</tr>
</tbody>
</table>

**Additional Observations**

- **56,721 psi**  
  - $F_{tu}: 60$ ksi  
  - Min MS = 0.057

- **62,744 psi**  
  - $F_{tu}: 64$ ksi  
  - Min MS = 0.020

---

**Diagram Notes**

- Output Set: UP-2P+6.4G UP
- Elemental Contour: Plate Top VonMises Stress
- Contour double: Plate Bot VonMises Stress
- Second Contour: Solid Von Mises Stress
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
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?
<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AC3</td>
<td>Axial Cyclone Cloud-Water Collector</td>
</tr>
<tr>
<td>CAD</td>
<td>Computer Aided Design</td>
</tr>
<tr>
<td>CAMP²Ex</td>
<td>Cloud, Aerosol and Monsoon Processes Philippines Experiment</td>
</tr>
<tr>
<td>FEMAP</td>
<td>Finite Element Modeling and Postprocessing</td>
</tr>
<tr>
<td>$F_{tu}$</td>
<td>Ultimate Tensile Strength</td>
</tr>
<tr>
<td>GSFC</td>
<td>Goddard Space Flight Center</td>
</tr>
<tr>
<td>IRAD</td>
<td>Internal Research and Development</td>
</tr>
<tr>
<td>OIB</td>
<td>Operation Ice Bridge</td>
</tr>
<tr>
<td>WCM</td>
<td>Water Content Multi-element System</td>
</tr>
<tr>
<td>WFF</td>
<td>Wallops Flight Facility</td>
</tr>
</tbody>
</table>
BACK UP SLIDES
The inertial loads are applied as body loads. The pressure load is applied as elemental pressure to the plate, whose surface area is 712 in². As a modeling check, resultant loads are extracted from the .F06 file and show that they are equal but opposite to the applied loads.
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.

\[
F_{17.5(\text{buckling})} = 6.4 \times (17.5 + 14) = 205 \text{ lbs}
\]

\[
F_{115(\text{buckling})} = 6.4 \times (115 + 14) = 826 \text{ lbs}
\]

– Lever strength analysis

\[
P_u(\text{tension}) = F_{tu} \times (2R - D) \times t
\]

\[
= 63 \times 10^3 \times (0.687 - 0.328) \times 0.2 = 4,523 \text{ lbs}
\]

Bolt and Lug Strength Analysis, Bruhn’s Fig. D1.8
Analysis Results-Continued

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\textsubscript{shear}, MS\textsubscript{tension}, and interaction equation.

\[
MS_{\text{shear}} = \frac{2.690}{686} - 1 = 2.92
\]

\[
MS_{tension} = \frac{2.890}{509} - 1 = 4.68
\]

\[
\left(\frac{(MS + 1) \times 686}{2.690}\right)^2 + \left(\frac{(MS + 1) \times 509}{2.890}\right)^2 = 1 \quad \text{yields} \quad MS = 2.23
\]

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.

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

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

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

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

7.2.6 5/16-24 Bolt Analysis

\[
F_{\text{prying}} = \frac{\sqrt{M_{\text{plane}}^2 + M_{\text{plane}}^2}}{0.66 + e} = \frac{\sqrt{(-523)^2 + 451^2}}{0.66 + 0.406} = 2.544
\]

\[
F_{\text{tension}} = 3,350 + 1.15 \times (2,544) = 6,276
\]

\[
MS_{\text{shear}} = \frac{7,290}{3,168} - 1 = 1.30
\]

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

\[
\left(\frac{(MS + 1) \times 3,168}{7,290}\right)^2 + \left(\frac{(MS + 1) \times 6,276}{8,590}\right)^2 = 1 \quad \text{yields} \quad MS = 0.18
\]

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.

\[
\sigma_{\text{shear}} = \frac{3,168 \text{ lb}}{0.1075 \text{ in}^2} = 16,894 \text{ psi}
\]

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

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

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

<table>
<thead>
<tr>
<th>Component</th>
<th>Combined Stress (psi)</th>
<th>MS</th>
<th>Flaw Allowance Stress (psi)</th>
<th>MS</th>
<th>Min MS</th>
</tr>
</thead>
<tbody>
<tr>
<td>16” Window</td>
<td>1,749</td>
<td>2.20</td>
<td>5,247</td>
<td>0.07</td>
<td>0.07</td>
</tr>
<tr>
<td>5” Window</td>
<td>1,838</td>
<td>2.05</td>
<td>5,513</td>
<td>0.01</td>
<td>0.01</td>
</tr>
</tbody>
</table>

8.2.1 16” Window Analysis

\[
\Delta T = -2.65 - \frac{\frac{9.99 \times 10^6}{23.2}}{\frac{10}{10^7}} + 10 = 43.18
\]

\[
S_{\text{max}} = \frac{3(5.99)(3 + 0.207)8.112^2}{8(1.125^2)} = 375 \text{ psi} \ast 2 = 749 \text{ psi}
\]

\[
\sigma_{\text{th}} = \frac{(3.9 \times 10^{-6})(1.18 \times 10^7)43.18}{4} = 497 \text{ psi} \ast 1.2 = 596 \text{ psi}
\]

\[
\sigma_{\text{fl}} = 749 + 596 = 1,345 \text{ psi} \ast 1.3 = 1,749 \text{ psi}
\]

\[
MS = \frac{5,600 \text{ psi}}{1,749 \text{ psi}} = 2.20
\]

\[
\sigma_{\text{flaw}} = 3 \times 1,749 = 5,247 \text{ psi}
\]

\[
MS = \frac{5,600 \text{ psi}}{5,247 \text{ psi}} = 0.07
\]

8.2.2 5” Window Analysis

\[
\Delta T = -2.65 - \frac{\frac{9.99 \times 10^6}{23.2}}{\frac{10}{10^7}} + 10 = 18.16
\]

\[
S_{\text{max}} = \frac{3(5.99)(3 + 0.207)2.3^2}{8(0.256^2)} = 581 \text{ psi} \ast 2 = 1,163 \text{ psi}
\]

\[
\sigma_{\text{th}} = \frac{(3.9 \times 10^{-6})(1.18 \times 10^7)18.16}{4} = 209 \text{ psi} \ast 1.2 = 251 \text{ psi}
\]

\[
\sigma_{\text{fl}} = 1,163 + 251 = 1,414 \text{ psi} \ast 1.3 = 1,838 \text{ psi}
\]

\[
MS = \frac{5,600 \text{ psi}}{1,838 \text{ psi}} = 2.05
\]

\[
\sigma_{\text{flaw}} = 3 \times 1,838 = 5,513 \text{ psi}
\]

\[
MS = \frac{5,600 \text{ psi}}{5,513 \text{ psi}} = 0.0157
\]
### Table 3.2.4.0(b). Design Mechanical and Physical Properties of 2024 Aluminum Alloy Sheet and Plate

<table>
<thead>
<tr>
<th>Specification</th>
<th>Form</th>
<th>Temper</th>
<th>Thickness, in.</th>
<th>Basis</th>
<th>Mechanical Properties:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.250-0.499</td>
<td>A</td>
<td>P&lt;sub&gt;u&lt;/sub&gt;, ksi</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.500-1.000</td>
<td>B</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1.001-1.500</td>
<td>A</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1.501-2.000</td>
<td>B</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2.001-3.000</td>
<td>A</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3.001-4.000</td>
<td>B</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **P<sub>u</sub>**, ksi:
  - L: 64, 66, 63, 65, 62, 64, 62, 60, 62, 55
  - LT: 64, 66, 63, 65, 62, 64, 62, 60, 62, 55
  - ST: 64, 66, 63, 65, 62, 64, 62, 60, 62, 55

- **P<sub>r</sub>**, ksi:
  - L: 48, 50, 48, 50, 47, 50, 47, 46, 45, 46
  - LT: 48, 50, 48, 50, 47, 50, 47, 46, 45, 46
  - ST: 48, 50, 48, 50, 47, 50, 47, 46, 45, 46

- **P<sub>c</sub>**, ksi (L & LT):
  - 97, 100, 95, 98, 94, 97, 94, 97, 94, 88

- **P<sub>UT</sub>**, ksi (L & LT (t<sub>D</sub> = 1.5)):
  - 72, 76, 72, 76, 72, 76, 72, 76, 72, 74
  - 86, 90, 86, 90, 86, 90, 86, 90, 86, 88

- **P<sub>UT</sub>**, ksi (L & LT (t<sub>D</sub> = 2.0)):
  - 72, 76, 72, 76, 72, 76, 72, 76, 72, 74
  - 86, 90, 86, 90, 86, 90, 86, 90, 86, 88

- **L & LT** (t<sub>D</sub> = 1.5):
  - 97, 100, 95, 98, 94, 97, 94, 97, 94, 88

- **L & LT** (t<sub>D</sub> = 2.0):
  - 72, 76, 72, 76, 72, 76, 72, 76, 72, 74
  - 86, 90, 86, 90, 86, 90, 86, 90, 86, 88

**Physical Properties**:
- E<sub>u</sub>, ksi: 10.7
- E<sub>u</sub>, ksi: 10.9
- G<sub>10</sub>, ksi: 4.0
- σ<sub>0</sub>, ksi: 0.33

---

**Notes**:
- Revised: Apr 2015, MMADS-10, Item 14-35. Design allowances were last confirmed in Item 07-41, MMADS-04CN1.
- Mechanical properties were established under QQ-A-250-4.
- Components: This specific alloy, temper, and product form exhibits poor transverse corrosion cracking resistance in this grain orientation. It corresponds to an SCC resistance rating of D, as indicated in Table 3.1.2.1(a).
- Bearing values are "dry pin" values per Section 14.7.1. See Table 3.1.2.11.
- The following rounded T<sub>UT</sub> and T<sub>UT</sub> values represent production capability at the time the table was last confirmed: P<sub>UT</sub> LT for 2-3 inches T<sub>UT</sub> = 68 ksi, T<sub>UT</sub> = 54 ksi, for 3-4 inches T<sub>UT</sub> = 60 ksi, T<sub>UT</sub> = 62 ksi.
### Material Certifications - Frame

#### AMAG

**Form / form:** Plate, stretched  
**Werkstoff / material:** 2024  
**Zustand / temper:** T351  
**Dim. / dim. (inch):** 3.000 x 48.50 x 144.50  
**Kundenartikel Nr. / cust. article no.:** 27922000

<table>
<thead>
<tr>
<th>Lab No.</th>
<th>Lot No.</th>
<th>Width (in)</th>
<th>Thickness (in)</th>
<th>Length (in)</th>
<th>UTS (ksi)</th>
<th>YS (ksi)</th>
<th>A%</th>
</tr>
</thead>
<tbody>
<tr>
<td>76288/01</td>
<td>T351</td>
<td>7.50</td>
<td>3</td>
<td>66.0</td>
<td>42.0</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>76288/01</td>
<td>T351</td>
<td>7.50</td>
<td>3</td>
<td>from 67.7 to 47.0</td>
<td>16</td>
<td></td>
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</tr>
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</table>

**Received**  
Aug 17, 2024  
ALRO-STEEL-PV

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**Product / product:**  
**Bedingungen / terms:**  
**Technische Lieferbedingungen / techn. spec.:**  
ASTM 8 209 - 14  
AMS 4037Q, 12 2014  
Sondervorschrif/ special terms:  
not US tested.
Material Certifications - Plate

**CERTIFIED TEST REPORT**

**Serial Number:** 4473869

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**Certified Specifications**

**Test Code:** 1594  
**Lot:** 23198789  
**Cast:** 403  
**Drop S9:**  
**Ingot 2:**

**Test Results**

<table>
<thead>
<tr>
<th>ASTM E8/E8M-17</th>
<th>Tension Test (ksi)</th>
<th>Ultimate KSI (MPa)</th>
<th>Yield KSI (MPa)</th>
<th>Elongation %</th>
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</thead>
<tbody>
<tr>
<td>T351</td>
<td>70.4 - 70.6</td>
<td>48.6 - 48.6</td>
<td>19.6 - 19.9</td>
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<tr>
<td>(485 - 487)</td>
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**Chemistry:**

<table>
<thead>
<tr>
<th>Element</th>
<th>Actual(wt%)</th>
<th>Limit (Min)</th>
<th>Limit (Max)</th>
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<tbody>
<tr>
<td>Si</td>
<td>0.08</td>
<td>0.17 - 0.25</td>
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</tr>
<tr>
<td>Fe</td>
<td>4.7</td>
<td>4.5 - 5.5</td>
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</tr>
<tr>
<td>Cu</td>
<td>0.50</td>
<td>0.40 - 0.60</td>
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</tr>
<tr>
<td>Mn</td>
<td>1.4</td>
<td>1.2 - 1.8</td>
<td></td>
</tr>
<tr>
<td>Mg</td>
<td>0.01</td>
<td>0.00 - 0.05</td>
<td></td>
</tr>
<tr>
<td>Cr</td>
<td>0.30</td>
<td>0.25 - 0.40</td>
<td></td>
</tr>
<tr>
<td>Zn</td>
<td>0.02</td>
<td>0.01 - 0.06</td>
<td></td>
</tr>
<tr>
<td>Ti</td>
<td>0.01</td>
<td>0.01 - 0.06</td>
<td></td>
</tr>
<tr>
<td>V</td>
<td>0.01</td>
<td>0.01 - 0.06</td>
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</tr>
<tr>
<td>ZR</td>
<td>0.00</td>
<td>0.00 - 0.05</td>
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</tr>
<tr>
<td>OTHER</td>
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<td>0.00 - 0.10</td>
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**ALLOY LIMITS**

<table>
<thead>
<tr>
<th>Element</th>
<th>MIN(wt%)</th>
<th>MAX(wt%)</th>
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</thead>
<tbody>
<tr>
<td>Si</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Fe</td>
<td>8.0</td>
<td>8.0</td>
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<tr>
<td>Cu</td>
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<td>4.9</td>
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<tr>
<td>Mn</td>
<td>0.9</td>
<td>0.9</td>
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<tr>
<td>Mg</td>
<td>0.8</td>
<td>0.8</td>
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<tr>
<td>Cr</td>
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<td>0.28</td>
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<tr>
<td>Zn</td>
<td>0.15</td>
<td>0.15</td>
</tr>
<tr>
<td>Ti</td>
<td>0.06</td>
<td>0.06</td>
</tr>
<tr>
<td>V</td>
<td>0.06</td>
<td>0.06</td>
</tr>
<tr>
<td>ZR</td>
<td>0.05</td>
<td>0.05</td>
</tr>
<tr>
<td>OTHER</td>
<td>0.12</td>
<td>0.12</td>
</tr>
</tbody>
</table>

**Aluminum Remainder**

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**Kaiser Aluminum**

Trentwood Works - Spokane, WA 99215

Phone: (800) 367-2586