MONOLITHIC HIGH STRENGTH ALUMINUM BOTTOM CARRIAGE STRUCTURE FOR 155mm HOWITZER, XM198

May 1974

Final Report

PREPARED BY
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Insert new Appendix D (attached) after Page 107
(Pages 107-1 – 107-7)
**Title:** Nonlithic High Strength Aluminum Bottom Carriage Structure for 155mm Howitzer, XM198

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- Bottom Carriage Design
- Aluminum Casting
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**Abstract:**
This final report summarizes the contractor's effort to conduct engineering studies and to produce a high strength aluminum bottom carriage for the XM198 155mm Howitzer. This effort is a follow-up to contract no. DAFF01-72-C-0150. Engineering calculations, technical data, and photographs of the finished casting, the mold, and the pouring operation are presented. Technical progress reports are also incorporated to give a chronological synopsis of the work accomplished.
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CONTRACT DAAFO3-73-C-0065

MONOLITHIC HIGH STRENGTH ALUMINUM BOTTOM CARRIAGE STRUCTURE FOR 155MM HOWITZER XM198

This report is submitted in accordance with item A003AA of DD Form 1423 which constitutes Exhibit A to Contract DAAFO3-73-C-0065.

INTRODUCTION

Contract DAAFO3-73-C-0065 was issued to FMC Corporation/Northern Ordnance Division on 12 March 1973. The contract requested four Aluminum Bottom Carriages for use on the 155mm Howitzer XM198. The amount of the contract was $53,640.46 including a fixed cost of $4,429.03. An address error in the original contract was corrected by Amendment 1 dated 30 March 1973. Amendment 2, dated 1 June 1973, extended the delivery schedule. Shipping information was changed by Amendment 3 dated 6 August 1973. Amendment 4, dated 29 October 1973, permitted defects up to 3/4 inch long to be acceptable in all areas except the hinge areas and the rear structure. Preliminary data in E.C. 950 Redesigned 155mm Howitzer Bottom Carriage Aluminum Casting Stress Analysis, was submitted to Rock Island Arsenal on 27 August 1973.

Weld repair attempts on four initial castings, while showing some improvement, were never 100% successful with new cracks developing as each repair was completed and heat-treated. These problems were brought to the attention of Mr. Avery Kearny, Chief Metallurgist
of the Olin Aluminum Division, who was one of the leaders in the development of the KO-l aluminum alloy. It was his judgement that our basic problem was micro-shrinkage. The micro-shrinkage provided conditions causing propagation of new cracks as a result of stresses induced during weld repair of defects. It was suggested that the micro-shrinkage could be overcome by the judicious placement and increase in number of risers in making the mold. The risers help bring about controlled solidification of the casting.

Considering micro-shrinkage as the basic problem, it was established that all poured castings were unreparable. With a minimum amount of remaining funds, evaluation of a new course of action was necessary. Effort was directed to making pattern changes and to developing improved riser placement in order to overcome the micro-shrinkage.

On 6 November 1973, sufficient additional funds were added to the contract by telegram to permit completion and shipment of one casting. The initial casting, under the new effort, required a fair amount of repair, but comprehensive inspection indicated that most of the micro-shrinkage problem was solved.

Amendment 6, dated 18 December 1973, reduced the quantity of Aluminum Bottom Carriages from four to two, increased the estimated cost by $6,305.00, extended the delivery schedule,
and deleted the draft copy of the final technical report. Remanufacture of the first casting was completed and shipped on 18 December 1973. Manufacture of the second casting was completed and shipped in April 1974.

CASTING KO-1 ALUMINUM

KO-1 Aluminum is an aluminum alloy containing silver, manganese, magnesium, titanium, and copper. The aluminum alloy is as strong as steel, but is more desirable than steel due to its lightweight quality. The alloy melts from 1225°F to 1250°F. The alloy melt is superheated to 1400°F before it is poured into the mold. Two crucibles and two pouring ladles (figure B-5) fill the mold with the KO-1 Aluminum at 1325°F.

The mold has two sections — the drag half (figure B-1) and the cope half (figure B-3) — which together form the pattern for the casting. Sand is the molding medium. Air set is the process for solidifying the melt. The facing sand, the part of the mold that forms the pattern next to the melt, is a fine texture #97 sand treated with Chem Res 280 and phosphoric acid. The backup sand, outside of the facing sand, is a coarse texture #2 sand. Isocure bonded #97 sand forms the core material (figure B-2). The center of the core (figure B-2) is Isocure bonded-Zircon sand. To prevent excessive shrinking in some areas of the casting, metal strips, called chills, are placed in the mold where the
shrinkage occurs. The chills are composed of iron or steel strips and vary in thickness from 1/2 inch to 3 inches. The location of the chills used on the castings can be seen in figure B-10. The placement of the chills in the drag half of the mold can be identified in figure B-1 by the dark color of the metal strips compared to the light color of the sand background. Figure B-3 shows 13 risers that provide reservoirs of melt to the mold while the molten aluminum cools and contracts.

The melt solidifies and cools to room temperature in 5 days of natural aging before the casting is removed from the mold. To reduce stress and ensure uniformity of the metals in the alloy, the casting is heat-treated. Seven thermocouples monitor the casting during the heat-treatment. The temperature of the casting is raised to 240°F for 2 hours and then elevated to 986°F - 993°F for 20 hours. Next the casting is immersed in a 30% solution of Ucon Quenchant A in water. The casting does not fully immerse in the quenchant due to the large size of the casting and the limited size of the quenchant container. The part of the casting that is not immersed (figure B-11, sheet 1) is quenched with water applied by two fire hoses for 5 minutes.

The heat-treated casting is tested for defects using the dye penetrant inspection method in accordance with MIL-I-6866, type 1, method A. Defects found in the first delivered casting are shown in figure B-11; defects found in the second delivered casting are shown in figure B-12.
Defects were removed with a Carballoy cutter. After the casting was heated to the proper temperature, weld areas and surrounding areas were thoroughly cleaned with a stainless steel wire brush or wheel. The cleansed areas were then protected from contamination.

The welding position was usually horizontal. A few small surface welds (cosmetic welds) in noncritical areas were welded in the vertical position.

The time between joint preparation and weld repair was normally less than 15 seconds. When the type of welding process changed, the second weld machine was prepared beforehand to minimize the time delay. In this case, about 1/2 minute time delay occurred.

Pass times were not measured because welds were made as a continuous pass. Each weld area was given a generous fillet. No official record of weld repairs was made. If a weld repair was found defective, it was removed and rewelded.

A couple problems were encountered during weld repair. Wire stoppages in the Mig gun occurred due to the wire being seized in the gun. The Mig machine failed once due to an internal malfunction. No gas flow changes were observed.

Three welding processes are in general use; GMAW (Mig), GTAW (Tig), and PAW (Plasma). All three welding processes were hand operated.
## WELDING PROCESS PARAMETERS

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Mig</th>
<th>Tig</th>
<th>Plasma</th>
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<tr>
<td>Amperage</td>
<td>160-220</td>
<td>180-250</td>
<td>50-100</td>
</tr>
<tr>
<td>Voltage</td>
<td>22-26</td>
<td>12-14</td>
<td>Not available</td>
</tr>
<tr>
<td>Wire feed</td>
<td>190 in./min</td>
<td>Not applicable</td>
<td>Not applicable</td>
</tr>
<tr>
<td></td>
<td>at 170 amp</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>+10 amps/+11 in./min</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Filler metal</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type</td>
<td>KO-1 Aluminum</td>
<td>KO-1 Aluminum</td>
<td>KO-1 Aluminum</td>
</tr>
<tr>
<td>Size</td>
<td>1/16-in. spooled wire</td>
<td>1/8- by 36-in. rod</td>
<td>1/8- by 36-in. rod</td>
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<tr>
<td>Cleanliness</td>
<td>No other wire used after machine was cleaned</td>
<td>Rod removed from container when used</td>
<td>Rod removed from container when used</td>
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<td>Shielding gas</td>
<td></td>
<td></td>
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<tr>
<td>Type</td>
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<td>Argon</td>
<td>Helium</td>
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<tr>
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<td>20-30 CFH</td>
<td>10-20 CFH</td>
<td>20-30 SCFH</td>
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<tr>
<td>Electrode type</td>
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<td>Tungston with 2% Thorium</td>
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<td>Unit used</td>
<td></td>
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</tr>
<tr>
<td>Make</td>
<td>AIRCO-Pulse Arc Power</td>
<td>Miller Heliarc</td>
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<tr>
<td>Mod</td>
<td>3-DCPA-224A</td>
<td>Model 340 AB-P</td>
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<td>Welding</td>
<td>Gun AIRCO AH-20P</td>
<td>Linde Heliarc torch HW18-300A</td>
<td>PWH/M-5A Plasma welding torch</td>
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<td>Plasma</td>
<td></td>
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<tr>
<td>Gas</td>
<td>Not applicable</td>
<td>Not applicable</td>
<td>Argon</td>
</tr>
<tr>
<td>Flow rate</td>
<td>Not applicable</td>
<td>Not applicable</td>
<td>2.0 SCFH</td>
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The defects in the first delivered casting (figure B-11) were corrected by mig, tig, and plasma welds. Mig welds use wire and argon gas; plasma welds use rods and ionized gas. Large surface welds are preheated for 3 hours at 800° F and postheated for 1 to 2 hours at 800° F. Small surface welds are preheated for 3 hours at 600° F and postheated for 1 to 2 hours at 600° F. Deep welds, difficult to reach, are preheated and postheated to 300° F. Defects in the second delivered casting (figure B-12) were corrected by mig welds only.

After all the detected defects are corrected by welds, the casting is heat-treated and inspected for defects once more. When the point of zero defects is reached, the casting is prepared for delivery. After the final heat-treatment, no repair welding is performed.

The actual weight of the casting is 1030 pounds. Machining the casting will reduce the weight to 890 pounds. The calculations for finished weight is found in Appendix A.

Appendix A consists of a stress analysis of the 155mm Howitzer XM198 redesigned bottom carriage aluminum casting E.C.950 and machined weight calculations based on a casting weight of 1030 pounds. Appendix B contains photographs and drawings. The photographs (figure B-1 through B-8) show the mold, pouring operation, and views of the finished casting. The detail drawing of the bottom carriage casting (figure B-9) is also used to show the location
of chilled areas (figure B-10) and defects in the two castings (figures B-11 and B-12). Appendix C contains copies of the Technical Progress Reports that were submitted in accordance with item A00201 of DD Form 1423 (Exhibit A to Contract DAAFO3-73-C-0065).

MAJOR PROBLEMS ENCOUNTERED

The seven Technical Progress Reports in Appendix C give a chronological synopsis of the work accomplished. In August 1973, two castings were poured. The first casting had too many defects to be given consideration for use as the first shipment. The second casting was poured with better results, but the sand set up too hard and was quite difficult to remove. The mold-making technique was improved by reducing the amount of binder in the sand to assure easier shake-out.

In September 1973, two more castings were poured. Both castings had cracks in the basic casting. A number of weld repairs by a variety of procedures, depending on size and location of the defect, were attempted with a certain degree of success; but we could not achieve a casting with zero defects. New cracks developed as repairs were corrected and heat-treated.

Internal cracks in the basic casting were reduced by increasing the number of risers in making the mold. The risers kept the top of the melt in a liquid form longer. This allowed the
solidification of the KO-1 Aluminum to proceed from the bottom to the top, instead of from the outside to the center. The first shipped casting had 13 risers in its mold and the second shipped casting had 43 risers in its mold.

To further reduce micro-shrinkage, the rough casting was heat-treated before weld repairs were attempted. The number of new cracks developed during weld repair was reduced.

Shrinkage of fillets and some heavy sections on the casting still posed a problem. The fillet shrinkage was solved by increasing the radii of the corners. This additional material will have to be machined, but this action did solve the problem of shrinkage and cracking at the fillets. Additional chills were used to reduce shrinking in the heavy sections.

CONCLUSION

Although each casting poured has had defects, improvement has been made in casting KO-1 Aluminum for the bottom carriages. KO-1 Aluminum is a critical material to cast in the bottom carriage configuration but we have produced some satisfactory castings under the prior development contract. The nature of KO-1 Aluminum is such that some repair may always be required but that successful castings should be achieved by paying close attention to the process developed for preparing the mold and for pouring the casting. The mold-making technique was improved
three ways: (1) by reducing the amount of binder in the core, (2) by placing a circular groove in the bottom of the core over the metal chills, and (3) by the additional use and placement of risers in the cope half of the mold.

Reducing the amount of binder prevents excessive hardness of the core sand to increase collapsibility and to ensure easier shake-out. Increasing the collapsibility of the core reduces the chances of cracking around the core as the casting contracts during solidification.

Placing a circular groove in the bottom of the core over the metal chills permits the chills to move as the casting contracts. Large cracks developed in the basic casting around the chills when the chills had no room for movement as the solidifying casting cooled.

The additional use and placement of risers in the mold permits a slower and more controllable solidification. The controlled solidification reduces internal stress and results in castings with fewer and smaller defects. In addition, the reduction of internal stresses is aided by the use of a preliminary heat-treatment prior to weld repair.

The number of new cracks appearing during weld repair has been substantially reduced. Future castings of the KO-1 Aluminum in the bottom carriage configuration should require one weld repair stage before the final heat-treatment.
Appendix A

ENGINEERING CALCULATIONS

and

TECHNICAL DATA
155MM HOWITZER
REDESIGNED BOTTOM CARRIAGE ALUMINUM CASTING
STRESS ANALYSIS

E. C. 950
CODE IDENT. NO. 44114

Prepared by: F. H. Morse, Jr.
R. H. Wiethoff
Examined by: D. L. Beihoffer
Date: 13 August 1973
FOREWORD

The structure analyzed in this report is a redesigned aluminum sand casting. It is similar to the first casting design that underwent successful simulated loading and actual firing tests. A stress analysis was performed on the first design in E.C. 922.

In the present design, modifications were made to reduce the stress caused by firing. As a result, the purpose of this calculation is to verify that the redesigned 155MM Howitzer Bottom Carriage can take the loads induced from firing. It is cast out of the same material as the first design, KO-1 aluminum alloy, supplied by Aluminum Division, Olin Corporation.

The stress analysis is based on gravity loads plus a maximum recoil brake load of 70,000 lb which was increased to 80,000 lb to account for dynamic effects. Other areas, loaded under various conditions, were examined for possible overstress and found to be safe. These minor stress calculations are not included in this report.
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III: Bottom Carriage With Trails: Geometry and Force Analysis

A. Gravity Loads at the Recoil Position

Using the diagrams shown on sheet 8, the force contribution due to gravity can be calculated for any angle Θ and β. The equations are then shown for β = 0°, 11.25°, and 22.5° with Θ allowed to vary from 0° to 75°.

\[ \sum M_{F_1} = 0 = -(F_2 + F_3) \quad 218.7 + 4800 \times 95.75 + 1226 \times 34.75 \]
\[ + 8150 (34.75 + 28.25 \cos \beta - 60 \cos \Theta \cos \beta) \]

(1) \[ F_2 + F_3 = 2591.306 + 1052.765 \cos \beta - 2235.96 \cos \Theta \cos \beta \]

\[ \sum M_{F_1} = -F_2 (196.5 \sin 35° + 35.38) + F_3 (196.5 \sin 35° + 35.38) \]
\[ + 8150 (28.25 \sin \beta - 60 \cos \Theta \sin \beta) \]

(2) \[ F_2 - F_3 = 1554.734 \sin \beta - 3302.091 \cos \Theta \sin \beta \]

\[ \sum F_V = 0 = F_1 + F_2 + F_3 - 14,176 \]

(3) \[ F_1 + F_2 + F_3 = 14,176 \text{ lb} \]
GRAVITY LOADS AT RECOIL

\[ V = 35 \text{°} \]

\[ e_\text{Elevation Angle} \]

\[ A = V4800 \text{ lb} \]

\[ 218.7 \text{ lb} \]

\[ 8150 \text{ lb} \]

\[ 28.25 \]

\[ 34.75 \]

\[ F_1 \]

\[ F_2, F_3 \]

\[ 95.75 \]

\[ 218.7 \]

\[ 19 \]
Solving for \( F_1 \), \( F_2 \) and \( F_3 \) (g indicates gravity)

\[
\begin{align*}
F_{1g} &= 10,585 - \cos \beta (1,052 - 2,236 \cos \Theta) \\
F_{2g} &= 1,796 + \sin \beta (777 - 1651 \cos \Theta) + \cos \beta (526 - 1118 \cos \Theta) \\
F_{3g} &= 1,795 + \sin \beta (-778 + 1651 \cos \Theta) + \cos \beta (527 - 1118 \cos \Theta)
\end{align*}
\]

Because these equations will be combined with the recoil contribution, they are rewritten in terms of \( F \) (recoil force = 80,000 lb).

\[
\begin{align*}
F_{1g} &= F \left[ .1323 - \cos \beta (.0132 - .0280 \cos \Theta) \right] \\
F_{2g} &= F \left[ .0225 + \sin \beta (.0097 - .0206 \cos \Theta) + \cos \beta (.0066 - .0140 \cos \Theta) \right] \\
F_{3g} &= F \left[ .0224 + \sin \beta (-.0097 + .0206 \cos \Theta) + \cos \beta (.0066 - .0140 \cos \Theta) \right]
\end{align*}
\]

The equations are then solved for various angles of \( \beta \).
For $\beta = 0^\circ$

$$F_{1g} = F(.1191 - .0280 \cos \Theta)$$

$$F_{2g} = F_{3g} = F(.0290 - .0140 \cos \Theta)$$

For $\beta = 11.25^\circ$

$$F_{1g} = F(.1194 + .0275 \cos \Theta)$$

$$F_{2g} = F(.0310 - .0177 \cos \Theta)$$

$$F_{3g} = F(.0290 - .0097 \cos \Theta)$$

For $\beta = 22.5^\circ$

$$F_{1g} = F(.1201 + .0259 \cos \Theta)$$

$$F_{2g} = F(.0323 - .0208 \cos \Theta)$$

$$F_{3g} = F(.0248 - .0050 \cos \Theta)$$
B. Recoil Loads

In a similar manner, the reaction forces due to recoil are calculated. The force diagram on sheet 12 is used and is reprinted from U.S. Army Government Document DAAF03-73-Q-0068.

\[ \sum F_v = 0 = F_1 + F_2 + F_3 - F \sin \Theta \]

(1) \[ F_1 + F_2 + F_3 = F \sin \Theta \]

\[ \sum F_H = 0 = F \cos \Theta - H_2 - H_3 \]

(2) \[ H_2 + H_3 = F \cos \Theta \]

\[ \sum M_F = 0 = \left[ 196.5 \sin (35 - \beta ) + 35.38 \cos \beta - 23 \sin \beta \right] H_2 \]

\[ - \left[ 196.5 \sin (35 + \beta ) + 35.38 \cos \beta + 23 \sin \beta \right] H_3 \]

(3) \[ \left[ 196.5 \sin (35 - \beta ) + 35.38 \cos \beta - 23 \sin \beta \right] H_2 \]

\[ = \left[ 196.5 \sin (35 + \beta ) + 35.38 \cos \beta + 23 \sin \beta \right] H_3 \]
\[ \sum M_{F_1} = 0 = \left[ 196.5 \sin (35^\circ - \beta) + 35.38 \cos \beta - 23 \sin \beta - 34.75 \sin \beta \right] F_2 \]

\[ + 34.75 F \sin \beta \sin \Theta - \left[ 196.5 \sin (35^\circ + \beta) + 35.38 \cos \beta + 23 \sin \beta + 34.75 \sin \beta \right] F_3 \]

(4) \[ \left[ 196.5 \sin (35^\circ - \beta) + 35.38 \cos \beta - 23 \sin \beta - 34.75 \sin \beta \right] F_2 \]

\[ - 196.5 \sin (35^\circ + \beta) + 35.38 \cos \beta + 23 \sin \beta + 34.75 \sin \beta F_3 = -34.75 F \sin \beta \sin \Theta \]

\[ \sum M_{F_1} = 0 = \left[ 34.75 \cos \beta + 23 \cos \beta + 35.38 \sin \beta + 196.5 \cos (35^\circ - \beta) \right] F_2 \]

\[ + \left[ 34.75 \cos \beta + 23 \cos \beta - 35.38 \sin \beta + 196.5 \cos (35^\circ + \beta) \right] F_3 \]

\[ - 56 F \cos \Theta - (34.75 \cos \beta + 28.25) F \sin \Theta \]

(5) \[ \left[ 57.75 \cos \beta + 35.38 \sin \beta + 196.5 \cos (35^\circ - \beta) \right] F_2 \]

\[ + \left[ 57.75 \cos \beta - 35.38 \sin \beta + 196.5 \cos (35^\circ + \beta) \right] F_3 \]

\[ = 56 F \cos \Theta + (34.75 \cos \beta + 28.25) F \sin \Theta \]
As before, simplifying equations and writing in terms of recoil force F for various angles of \( \beta \). (r indicates recoil)

For \( \beta = 0^\circ \)

\[
F_{1r} = F \left( .7120 \sin \Theta - .2560 \cos \Theta \right)
\]

\[
F_{2r} = F_{3r} = F \left( .1440 \sin \Theta + .1280 \cos \Theta \right)
\]

\[
H_2 = H_3 = .5 F \cos \Theta
\]

For \( \beta = 11.25^\circ \)

\[
F_{1r} = F \left( .7144 \sin \Theta - .2511 \cos \Theta \right)
\]

\[
F_{2r} = F \left( .1614 \sin \Theta + .1624 \cos \Theta \right)
\]

\[
F_{3r} = F \left( .1242 \sin \Theta + .0887 \cos \Theta \right)
\]

\[
H_2 = .6236 F \cos \Theta
\]

\[
H_3 = .3764 F \cos \Theta
\]
For $\beta = 22.5^\circ$

$$F_{1r} = F (.7218 \sin \Theta - .2366 \cos \Theta)$$

$$F_{2r} = F (.1756 \sin \Theta + .1907 \cos \Theta)$$

$$F_{3r} = F (.1026 \sin \Theta + .0459 \cos \Theta)$$

$$H_2 = .7573 \, F \cos \Theta$$

$$H_3 = .2427 \, F \cos \Theta$$

C. Combined Loads: Gravity Plus Recoil

All load combinations and solutions have been listed up to this point. However, only certain loads are necessary to calculate the stress in the bottom carriage. These are listed below. $F_{2t} = F_{2r} + F_{2g}$

For $\beta = 0^\circ$

$$F_{2t} = F (.0290 + .1140 \sin \Theta + .1140 \cos \Theta)$$

$$H_2 = .5 \, F \cos \Theta$$
For $\beta = 11.25^\circ$

$$F_{2t} = F (.0310 + .1614 \sin \Theta + .1447 \cos \Theta)$$

$$H_2 = .6236 F \cos \Theta$$

For $\beta = 22.5^\circ$

$$F_{2t} = F (.0323 + .1756 \sin \Theta + .1699 \cos \Theta)$$

$$H_2 = .7573 F \cos \Theta$$
IV. Calculation of Bending Moment

The bending moment is determined by calculating the reduction of load along the load axis of the base. Maximum stresses are assumed to occur when $\beta = 22.5^\circ$ and $\Theta = 57^\circ$. Upper carriage loads are distributed at 24 equally spaced points on the bearing circle. The reaction load on axis 2, $R_2$, from any load $P$ on bearing is

$$R_2 = \frac{PL_3}{L_2 + L_3}$$

Using the sketch on sheet 18, additional relationships are determined.

$$L_2 = \sec 16.49^\circ \left[ 34.75 \sin 31.49^\circ - 20 (\sin 22.5^\circ + \alpha - 31.49^\circ) \right]$$

$$L_2 = 18.9303 - 20.8579 \sin (\alpha - 8.99^\circ)$$

$$L_3 = \sec 16.49^\circ \left[ 20 \sin (\alpha + 53.99^\circ) + 34.75 \sin 31.49^\circ \right]$$

$$L_3 = 18.9303 + 20.8579 \sin (\alpha + 53.99^\circ)$$

$$\frac{L_3}{L_2 + L_3} = \frac{0.9076 + \sin (\alpha + 53.99^\circ)}{1.8152 + \sin (\alpha + 53.99^\circ) - \sin (\alpha - 8.99^\circ)}$$

$$X_2 = 32.73 - 20 \cos (\alpha - 8.99) + 5.92 (\sin (\alpha - 8.99))$$
UPPER CARRIAGE LOADS

\[ P_n = K r \cos \alpha_n \]

Moment \[ P = K r^2 \cos^2 \alpha_n \]

\[ M = \sum m P_1^{24} r^2 \cos^2 \alpha_n = K r^2 \sum \cos^2 \alpha_n = 12 K r^2 \]

\[ K = \frac{M}{12 r^2} \]

\[ P_n = \frac{M \cos \alpha_n}{12 r} = \frac{M}{240} \cos \alpha_n \]
\[ M = 80,000(28.25 \sin 57^\circ + 32.7 \cos 57^\circ) - 8,150(60 \cos 57^\circ - 28.25) \]

\[ M = 3,284,080 \text{ lb in.} \]

\[ V = 80,000 \sin 57^\circ + 8,150 + 1,226 = 76,470 \text{ lb} \]

\[ H = 80,000 \cos 57^\circ = 43,571 \text{ lb} \]

\[ P_r = P_v + P_m = 3,186 + 13,684 \cos \alpha_n \]

\[ P_v = \frac{76,470}{24} = 3,186 \text{ lb} \]

\[ P_m = \frac{3,284,080}{240} \times \cos \alpha_n = 13,684 \cos \alpha_n \]
<table>
<thead>
<tr>
<th>n</th>
<th>$\alpha$</th>
<th>$P_m$</th>
<th>$P_n$</th>
</tr>
</thead>
<tbody>
<tr>
<td>24</td>
<td>7.5</td>
<td>13,567</td>
<td>16,753</td>
</tr>
<tr>
<td>23</td>
<td>22.5</td>
<td>12,642</td>
<td>15,828</td>
</tr>
<tr>
<td>22</td>
<td>37.5</td>
<td>10,856</td>
<td>14,042</td>
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<td>21</td>
<td>52.5</td>
<td>8,330</td>
<td>11,516</td>
</tr>
<tr>
<td>20</td>
<td>67.5</td>
<td>5,237</td>
<td>8,423</td>
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<tr>
<td>19</td>
<td>82.5</td>
<td>1,786</td>
<td>4,972</td>
</tr>
<tr>
<td>18</td>
<td>97.5</td>
<td>-1,786</td>
<td>1,400</td>
</tr>
<tr>
<td>17</td>
<td>112.5</td>
<td>-5,237</td>
<td>-2,051</td>
</tr>
<tr>
<td>16</td>
<td>127.5</td>
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</tr>
<tr>
<td>14</td>
<td>157.5</td>
<td>-12,642</td>
<td>-9,456</td>
</tr>
<tr>
<td>13</td>
<td>172.5</td>
<td>-13,567</td>
<td>-10,381</td>
</tr>
<tr>
<td>n</td>
<td>α</td>
<td>(α - 8.99)</td>
<td>X₂</td>
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<td>-----</td>
<td>------------</td>
<td>-----</td>
</tr>
<tr>
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<td>7.5</td>
<td>-1.49</td>
<td>12.58</td>
</tr>
<tr>
<td>2</td>
<td>22.5</td>
<td>13.51</td>
<td>14.67</td>
</tr>
<tr>
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<td>37.5</td>
<td>28.51</td>
<td>17.98</td>
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<tr>
<td>4</td>
<td>52.5</td>
<td>43.51</td>
<td>22.30</td>
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<td>5</td>
<td>67.5</td>
<td>58.51</td>
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<td>7</td>
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<td>103.51</td>
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<tr>
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<td>127.5</td>
<td>118.51</td>
<td>47.48</td>
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<tr>
<td>10</td>
<td>142.5</td>
<td>133.51</td>
<td>50.79</td>
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<tr>
<td>11</td>
<td>157.5</td>
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</tr>
<tr>
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<td>52.88</td>
</tr>
<tr>
<td>14</td>
<td>202.5</td>
<td>193.51</td>
<td>50.79</td>
</tr>
<tr>
<td>15</td>
<td>217.5</td>
<td>208.51</td>
<td>47.48</td>
</tr>
<tr>
<td>16</td>
<td>232.5</td>
<td>223.51</td>
<td>43.16</td>
</tr>
<tr>
<td>17</td>
<td>247.5</td>
<td>238.51</td>
<td>38.18</td>
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<td>---</td>
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<td>---</td>
</tr>
<tr>
<td>18</td>
<td>262.5</td>
<td>253.51</td>
<td>32.73</td>
</tr>
<tr>
<td>19</td>
<td>277.5</td>
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<td>27.33</td>
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<td>292.5</td>
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<td>307.5</td>
<td>298.51</td>
<td>17.98</td>
</tr>
<tr>
<td>22</td>
<td>322.5</td>
<td>313.51</td>
<td>14.67</td>
</tr>
<tr>
<td>23</td>
<td>337.5</td>
<td>328.51</td>
<td>12.58</td>
</tr>
<tr>
<td>24</td>
<td>352.5</td>
<td>343.51</td>
<td>11.87</td>
</tr>
</tbody>
</table>

Now

\[ F_2 = F (0.0323 + 0.1756 \sin \Theta + 0.1699 \cos \Theta) \]

\[ F_2 = 21,768 \text{ lb for } F = 80,000 \text{ lb and } \Theta = 57^\circ \]

\[ H_2 = 0.7573 F \cos \Theta \]

\[ H_2 = 33,000 \text{ lb} \]
Since $F_2$ is not based on a length of 264.2, the loads $f_{2n}'$ (next sheet) should be artificially increased by the ratio 1.2126 so that the moments on the X-axis will reduce to zero.

$$F_2 = 21,768 \text{ lb}$$

$$\text{less } 2,913 = 33,000 \times \frac{23.32}{264.23}$$

$$18,855 \text{ lb}$$

$$\frac{18,855}{15,549} f_{2n}' = 1.2126 f_{2n}' = F_{2n}$$

The moment along the X-axis is:

$$M_x = 21,768 (196.5 + x) - 33,000 \times 23.32 - \sum F_n (x - x_n)$$

A graph of the values calculated from the above equation is shown on sheet 26.
V. Stress Analysis of Bottom Carriage

A. Cross-Section Properties

The sketches shown on sheets 28 through 35 are 1/4 scale cross-sections of the bottom carriage $X = 0$ in. through $X = 23.5$ in. toward the ground pan. The cross-sectional inertia $I$ has been calculated along with the total section area $A$. The distance from the neutral axis to the most extreme fiber in tension or compression is also listed ($y_t$ and $y_c$). Both the vertical and side (lateral) section properties are listed when needed.
Vertical Section Properties

\[ y_t = 9.925 \text{ in.} \]
\[ y_c = 10.575 \text{ in.} \]
\[ I = 2312 \text{ in.}^4 \]
\[ A = 29.43 \text{ in.}^2 \]
$X = 4.5 \text{ in. from Pin}$

**Section Properties**

**Vertical**

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$y_t$</td>
<td>10 in.</td>
</tr>
<tr>
<td>$y_c$</td>
<td>10 in.</td>
</tr>
<tr>
<td>$I$</td>
<td>2591 in.$^4$</td>
</tr>
<tr>
<td>$A$</td>
<td>35.936 in.$^2$</td>
</tr>
</tbody>
</table>

**Side**

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$y_t$</td>
<td>6.293 in.</td>
</tr>
<tr>
<td>$y_c$</td>
<td>6.397 in.</td>
</tr>
<tr>
<td>$I$</td>
<td>530 in.$^4$</td>
</tr>
<tr>
<td>$A$</td>
<td>35.936 in.$^2$</td>
</tr>
</tbody>
</table>
X = 6.5 in. from Pin

Section Properties

Vertical

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$y_t$</td>
<td>9.843 in.</td>
</tr>
<tr>
<td>$y_c$</td>
<td>10.157 in.</td>
</tr>
<tr>
<td>$I$</td>
<td>3259 in.$^4$</td>
</tr>
<tr>
<td>$A$</td>
<td>69.731 in.$^2$</td>
</tr>
</tbody>
</table>

Side

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$y_t$</td>
<td>6.3833 in.</td>
</tr>
<tr>
<td>$y_c$</td>
<td>6.786 in.</td>
</tr>
<tr>
<td>$I$</td>
<td>1534 in.$^4$</td>
</tr>
<tr>
<td>$A$</td>
<td>69.731 in.$^2$</td>
</tr>
</tbody>
</table>
X = 12.5 in. from Pin

Section Properties

<table>
<thead>
<tr>
<th>Vertical</th>
<th>Side</th>
</tr>
</thead>
<tbody>
<tr>
<td>(y_t) = 7.702 in.</td>
<td>(y_t) = 8.038 in.</td>
</tr>
<tr>
<td>(y_c) = 7.731 in.</td>
<td>(y_c) = 7.962 in.</td>
</tr>
<tr>
<td>(I) = 2012 in.(^4)</td>
<td>(I) = 1725 in.(^4)</td>
</tr>
<tr>
<td>(A) = 59.771 in.(^2)</td>
<td>(A) = 59.771 in.(^2)</td>
</tr>
</tbody>
</table>
$X = 13.5$ in. from Pin

Vertical Section Properties

$y_t = 8.165$ in.

$y_c = 6.845$ in.

$I = 2277$ in.$^4$
$X = 15$ in. from Pin

Vertical Section Properties

$y_t = 8.166$ in.

$y_c = 6.844$ in.

$I = 2332$ in.$^4$
X = 18 in. from Pin

Vertical Section Properties

\[ y_t = 8.210 \text{ in.} \]
\[ y_c = 6.800 \text{ in.} \]
\[ I = 2238 \text{ in.}^4 \]
$X = 23.5 \text{ in. from Pin}$

Vertical Section Properties

\[ y_t = 7.754 \text{ in.} \]
\[ y_c = 7.259 \text{ in.} \]
\[ I = 1574 \text{ in.}^4 \]
B. Equations Used to Calculate Force and Moments

A sketch of the bottom carriage left hinge is shown on sheet 37. It illustrates how the forces and moments are acting on the bottom carriage hinge. A similar type of loading occurs at the right hinge pin.

1. Left Side of Bottom Carriage (Hinge)

Compression Force

\[ F_{cl} = H_2 \cos (35^\circ - \beta) \]

\[ F_{cl} (\beta = 0^\circ) = -0.4096 \, F \cos \theta \]

\[ F_{cl} (\beta = 11.25^\circ) = -0.5708 \, F \cos \theta \]

\[ F_{cl} (\beta = 22^\circ) = -0.7393 \, F \cos \theta \]

Side Bending Moment

\[ M_{2l} = \left[ H_2 \sin (35^\circ - \beta) (196.5 + X) \right] 0.2 \]

\[ M_{2l} (\beta = 0^\circ) = 0.0574 (196.5 + X) \, F \cos \theta \]
BOTTOM CARRIAGE LEFT HINGE

(FORCES AND MOMENTS)
Vertical Bending Moment

\[ M_{1,1} (\beta = 11.25^\circ) = 0.0502 (196.5 + X) F \cos \Theta \]

\[ M_{1,1} (\beta = 22.5^\circ) = 0.0328 (196.5 + X) F \cos \Theta \]

\[ M_{1,1} = F_2 (196.5 + X) - (16 + \bar{y}) H_2 \cos (35^\circ - \beta) \]

\[ M_{1,1} (\beta = 0^\circ) = (196.5 + X) F \left[ 0.029 + 0.144 \sin \Theta + 0.114 \cos \Theta \right] - (16 + \bar{y}) \cdot 0.4096 F \cos \Theta \]

\[ M_{1,1} (\beta = 11.25^\circ) = (196.5 + X) F \left[ 0.031 + 0.1614 \sin \Theta + 0.1447 \cos \Theta \right] - (16 + \bar{y}) \cdot 0.5708 F \cos \Theta \]

\[ M_{1,1} (\beta = 22.5^\circ) = (196.5 + X) F \left[ 0.0323 + 0.1756 \sin \Theta + 0.1699 \cos \Theta \right] - (16 + \bar{y}) \cdot 0.7393 F \cos \Theta \]
2. Right Side of Bottom Carriage (Hinge)

Compression Force

\[ F_{cr} = H_3 \cos (35^\circ + \beta) \]

Side Bending Moment

\[ M_{2r} = H_3 \left[ \sin (35^\circ + \beta) (196.5 + X) \right] \cdot 2 \]

Vertical Bending Moment

\[ M_{1r} = F_3 (196.5 + X) - (16 + \bar{y}) H_3 \cos (35^\circ + \beta) \]

C. Stress Calculation Method (High Stress Areas)

Detailed calculations are presented for \( X = 0 \text{ in.}, 12.5 \text{ in.}, \) and \( 23.5 \text{ in.} \) with \( \beta = 22.5^\circ. \) These three calculations are representative of the methods used to calculate all the conditions. For sections up to and including \( X = 4.5 \text{ in.} \), the example at \( X = 0 \text{ in.} \) applies. For sections beyond \( X = 4.5 \text{ in.} \), the example at \( X = 12.5 \text{ in.} \) applies. Tensile and compressive stresses add such that the upper left hand corner of the section is the location
STRESS DISTRIBUTION (X = 5.5 in. through X = 12.5 in.)

Maximum Compressive Stress

Maximum Tensile Stress
of high compressive stress, and the lower right hand corner of the section is the location of high tensile stress. This is shown by the sketch on sheet 40. For sections beyond \( X = 12.5 \) in., the vertical bending moment developed in Part IV is used to calculate the bending stress. The three distinct methods are necessary because there are internal lateral webs at approximately \( X = 4.5 \) in. and \( X = 12.5 \) in. (see drawing on sheet 6). Also, beyond \( X = 12.5 \) in., the side bending moment and compressive force are not significant because the cross-section has widened out.

1. \( X = 0 \) in. from Pin, \( \beta = 22.5^\circ, \ F = 80,000 \) lb

For the area about the pin, see sheet 37, one compressive force and two moments add to produce the total stress. On sheet 28 the section is shown. The top part is in compression and the bottom part is in tension.

\[
\frac{F_c F}{2} = -\frac{.7393}{2} \ F \cos \Theta = -.3697 \ F \cos \Theta
\]
\[ M_{2f/2} \times 10.5 = \frac{0.0328}{2 \times 10.5} (196.5 + X) F \cos \Theta \]

\[ M_{2f/2} \times 10.5 = 0.3069 F \cos \Theta \]

\[ M_{1f/17.56} = \frac{1}{17.56} \left[ F_2 (196.5 + X) - (16 + \bar{y}) H_2 \cos (35° - \beta) \right] \]

\[ M_{1f/17.56} = -F \left[ 0.3614 + 1.965 \sin \Theta + 0.8098 \cos \Theta \right] \]

\[ \sum F_p \text{ (top)} = -F \left[ 0.3614 + 1.965 \sin \Theta + 0.8726 \cos \Theta \right] \]

\[ \frac{\partial \sum F_p}{\partial \Theta} = 0 = 1.965 \cos \Theta - 0.8726 \sin \Theta \]

\[ \frac{\sin \Theta}{\cos \Theta} = \frac{1.965}{0.8726} = 2.252 \]

\[ \Theta = \arctan 2.252 = 66.1° \]
Then

\[ \sum F_p \text{ (top)} = -200,915 \text{ lb (compression on Top Hole)} \]

\[ \sigma_c = \frac{F}{A} = \frac{-200,915}{4.375 \times 2.43} \]

\[ \sigma_c = -18,900 \text{ psi (Compressive Stress on Top Hole)} \]

---

**BOTTOM PART**

\[ F_{c/2} = -\frac{.7393}{2} \ F \cos \Theta = -.3697 \ F \cos \Theta \]

\[ M_{2/2} \times 10.5 = \frac{.0328}{2 \times 10.5} (196.5 + X) \ F \cos \Theta \]

\[ M_{2/2} \times 10.5 = .3069 \ F \cos \Theta \]
\[
M_{1\ell/17.56} = \frac{1}{17.56} \left[ F_2 (196.5 + x) - (16 + y) H_2 \cos (35^\circ - \beta) \right]
\]

\[
M_{1\ell/17.56} = F \left[ .3614 + 1.965 \sin \Theta + .8098 \cos \Theta \right]
\]

\[
\sum F_p \text{ (bottom)} = F \left[ .3614 + 1.965 \sin \Theta + .747 \cos \Theta \right]
\]

\[
\frac{\partial \sum F_p}{\partial \Theta} = 0 = 1.965 \cos \Theta - .747 \sin \Theta
\]

\[
\frac{\sin \Theta}{\cos \Theta} = \frac{1.965}{.747} = 2.631
\]

\[
\Theta = \arctan 2.631 = 69.2^\circ
\]

then

\[
\sum F_p \text{ (bottom)} = 197,090 \text{ lb (tension on area of the eye)}
\]

\[
\sigma_t = \frac{F}{A} = \frac{197,090}{(10.06 - 3.875) 2.44}
\]

\[
\sigma_t = 13,060 \text{ psi (tensile stress on area of the eye)}
\]
2. \( X = 12.5 \text{ in. from Pin, } \beta = 22.5^\circ, \ F = 80,000 \text{ lb} \)

The stress is calculated as explained on sheets 39 through 41 and as illustrated on sheet 40, upper left highest compression and lower right highest tension.

\[
F_{c, \ell} = -0.7393 \ F \cos \Theta
\]

\[
M_{2, \ell} = 0.0328 (196.5 + X) \ F \cos \Theta = 6.8552 \ F \cos \Theta
\]

\[
M_{1, \ell} = F_2 (196.5 + X) - (16 + \bar{y}) H_2 \cos (35^\circ - \beta)
\]

\[
M_{1, \ell} = F (6.7507 + 36.7004 \sin \Theta + 17.9964 \cos \Theta)
\]
\[
\sigma_{c1} = \frac{F_c l}{A} = -\frac{.7393 F \cos \Theta}{59.7706} = -.0124 F \cos \Theta
\]

\[
\sigma_{2l} = \pm \frac{M_{2l} y}{I}
\]

where \( y_t = 8.038 \) in.

\( y_c = 7.962 \) in.
\( I = 1725 \) in.\(^4\)

\[
\sigma_{2l} = +.0319 F \cos \Theta
\]

\[
\sigma_{2l} = -.0316 F \cos \Theta
\]

\[
\sigma_{1l} = \pm \frac{M_{1l} y}{I}
\]

where \( y_t = 7.702 \) in.

\( y_c = 7.731 \) in.
\( I = 2012 \) in.\(^4\)

\[
\sigma_{1l} = + F (.0258 + .1405 \sin \Theta + .0689 \cos \Theta)
\]

\[
\sigma_{1l} = - F (.0245 + .1333 \sin \Theta + .0653 \cos \Theta)
\]
\[
\sum \sigma = \sigma_{c_\ell} + \sigma_{2_\ell} + \sigma_{1_\ell} = -F \left[ .0245 + .1333 \sin \Theta + .1093 \cos \Theta \right]
\]

\[
\frac{\partial \sum \sigma}{\partial \Theta} = 0 = .1333 \cos \Theta - .1093 \sin \Theta
\]

\[
\sin \Theta = .1333 \quad \quad \cos \Theta = .1093 = 1.22
\]

\[
\Theta = \arctan 1.22 = 50.6^\circ
\]

\[
\sum \sigma_c = -15,750 \text{ psi (compression)}
\]

\[
\sum \sigma = \sigma_{c_\ell} + \sigma_{2_\ell} + \sigma_{1_\ell} = F \left[ .0258 + .1405 \sin \Theta + .0884 \cos \Theta \right]
\]

\[
\frac{\partial \sum \sigma}{\partial \Theta} = 0 = .1405 \cos \Theta - .0884 \sin \Theta
\]

\[
\sin \Theta = .1405 \quad \quad \cos \Theta = .0884 = 1.589
\]

\[
\Theta = \arctan 1.589 = 57.8^\circ
\]

\[
\sum \sigma_t = 15,340 \text{ psi (tension)}
\]
3.  \( X = 23.5 \text{ in.}, \beta = 22.5^\circ, F = 80,000 \text{ lb} \)

Using the value for the vertical bending moment as shown on sheet 26, the bending stress is easily calculated.

\[
\sigma = \frac{My}{I}
\]

where  
\( M = 3,310,000 \text{ lb in.} \)
\( y_t = 7.754 \text{ in.} \)
\( y_c = 7.259 \text{ in.} \)

\( \sigma_t = 16,310 \text{ psi (bottom surface)} \)

\( \sigma_c = -15,260 \text{ psi (top surface)} \)

As stated earlier the sections at 13.5, 15, and 18 are calculated in the same manner.
### VI. Tabulation of Calculated Stresses

#### $\beta = 0^\circ$

<table>
<thead>
<tr>
<th>$X$ (in.)</th>
<th>$\sigma_c$ (psi) Top</th>
<th>$\sigma_t$ (psi) Bottom</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>-14,830</td>
<td>11,780</td>
</tr>
<tr>
<td>4.5</td>
<td>-8,900</td>
<td>10,030</td>
</tr>
<tr>
<td>6.5</td>
<td>-12,080</td>
<td>11,190</td>
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<tr>
<td>12.5</td>
<td>-14,370</td>
<td>14,220</td>
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</tbody>
</table>

#### $\beta = 11.25^\circ$

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<th>$\sigma_c$ (psi) Top</th>
<th>$\sigma_t$ (psi) Bottom</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>-16,910</td>
<td>12,680</td>
</tr>
<tr>
<td>4.5</td>
<td>-10,420</td>
<td>10,420</td>
</tr>
<tr>
<td>6.5</td>
<td>-12,940</td>
<td>11,790</td>
</tr>
<tr>
<td>12.5</td>
<td>-15,530</td>
<td>15,210</td>
</tr>
<tr>
<td>X (in.)</td>
<td>( \sigma_c ) (psi) Top</td>
<td>( \sigma_t ) (psi) Bottom</td>
</tr>
<tr>
<td>--------</td>
<td>----------------</td>
<td>-------------------</td>
</tr>
<tr>
<td>0</td>
<td>-18,900</td>
<td>13,060</td>
</tr>
<tr>
<td>4.5</td>
<td>-11,350</td>
<td>11,130</td>
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<tr>
<td>6.5</td>
<td>-12,980</td>
<td>11,680</td>
</tr>
<tr>
<td>* 12.5</td>
<td>-15,750</td>
<td>15,340</td>
</tr>
<tr>
<td>13.5</td>
<td>-11,270</td>
<td>13,450</td>
</tr>
<tr>
<td>15</td>
<td>-10,920</td>
<td>13,030</td>
</tr>
<tr>
<td>18</td>
<td>-10,970</td>
<td>13,240</td>
</tr>
<tr>
<td>* 23.5</td>
<td>-15,260</td>
<td>16,310</td>
</tr>
</tbody>
</table>

* Indicates that sample calculations are shown in full detail in Part V, Section C, sheet 39.
<table>
<thead>
<tr>
<th>Step</th>
<th>Calculation</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>( \frac{1}{4} \left( 7^2 - 6.5^2 \right) (3.5 + 4.5) )</td>
<td>42.4 m³</td>
</tr>
<tr>
<td></td>
<td>( \frac{1}{4} \left( 7^2 - 6.5^2 \right) \cdot 3.5 )</td>
<td>4.1</td>
</tr>
<tr>
<td></td>
<td>( \frac{1}{4} \left( 6.5^2 - 6.5^2 \right) \cdot 3.8 )</td>
<td>9.3</td>
</tr>
<tr>
<td></td>
<td>( 55.5 \text{ m}^3 \cdot 2 \times 102 )</td>
<td>11.3 ft</td>
</tr>
<tr>
<td>2</td>
<td>( 0.312 \times 2 \times 2.12 )</td>
<td>1.32</td>
</tr>
<tr>
<td></td>
<td>( 2 \times 102 )</td>
<td>1.3</td>
</tr>
<tr>
<td>3</td>
<td>( 0.312 \times 1 \times 1.12 )</td>
<td>0.35</td>
</tr>
<tr>
<td></td>
<td>( 2 \times 102 )</td>
<td>1.1</td>
</tr>
<tr>
<td>4</td>
<td>( 0.5 \times 2.5 \times 0.25 )</td>
<td>1.23</td>
</tr>
<tr>
<td></td>
<td>( 0.5 \times 2.5 \times 0.25 )</td>
<td>0.8</td>
</tr>
<tr>
<td></td>
<td>( 0.5 \times 1.46 \times 0.38 )</td>
<td>0.43</td>
</tr>
<tr>
<td></td>
<td>( 0.5 \times 1.46 \times 0.38 )</td>
<td>1.61</td>
</tr>
<tr>
<td></td>
<td>( 0.5 \times 0.47 \times 1.47 )</td>
<td>0.46</td>
</tr>
<tr>
<td></td>
<td>( 0.5 \times 0.47 \times 1.47 )</td>
<td>28.38</td>
</tr>
<tr>
<td></td>
<td>( 0.5 \times 0.47 \times 1.47 )</td>
<td>48.60</td>
</tr>
<tr>
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<td>( 2 \times 102 )</td>
<td>9.9</td>
</tr>
<tr>
<td>5</td>
<td>( 0.25 \times 1.94 \times 12 )</td>
<td>5.82</td>
</tr>
<tr>
<td></td>
<td>( 2 \times 102 )</td>
<td>1.2</td>
</tr>
<tr>
<td>6</td>
<td>( \frac{1}{4} \left( 4.6 \times 0.5 \right) )</td>
<td>0.78</td>
</tr>
<tr>
<td></td>
<td>( \frac{1}{4} \left( 4.6 \times 0.5 \right) )</td>
<td>0.35</td>
</tr>
<tr>
<td></td>
<td>( 2 \times 102 )</td>
<td>23.0</td>
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</tbody>
</table>
7 Ground plate pin hole

<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>7/4 \times 4.25^2 \times 0.25 =</td>
<td>3.55</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9/4 \times 2.75^2 \times 3.25 =</td>
<td>19.31</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7.25 \times 8.25 = 59.61</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>4 \times 1.25 \times 3</td>
<td>10.55</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7.25 \times 8.25 = 59.61</td>
<td></td>
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<tr>
<td>7.25 \times 0.102 = 75.37</td>
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</table>

8 Cylinder semi boss (projected)

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<tbody>
<tr>
<td>7/4 \times 2.75^2 \times 0.25 =</td>
<td>19.31</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 \times 0.88 \times 3</td>
<td>10.55</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7.25 \times 8.25 = 59.61</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7.25 \times 0.102 = 75.37</td>
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9 Side pads

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</thead>
<tbody>
<tr>
<td>7.25 \times 8.25 = 59.61</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>4 \times 0.88 \times 5</td>
<td>19.12</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7.25 \times 0.102 = 75.37</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>7.25 \times 0.102 = 75.37</td>
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<td></td>
</tr>
</tbody>
</table>

10 Top pad

<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>(6 \times 6 \times 2.5) = 9.0 \times 2 \times 0.102 = 1.9</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(10.75 \times 12.78 - 8.28 \times 0.68) \times 2.5</td>
<td>13.78 \times 0.102 = 1.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(10.78 \times 8.79 - 8.28 \times 0.68) \times 1.0</td>
<td>12.9 \times 0.102 = 1.3</td>
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<td></td>
</tr>
<tr>
<td>2 \times 2.5 \times 0.38</td>
<td>1.97 \times 2 \times 0.102 = 4</td>
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</table>

11 Hole in brct

<p>| | | | |</p>
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<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>7/4 (95^2 - 3.0^2) \times 0.8</td>
<td>13.78 \times 0.102 = 1.1</td>
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</tr>
<tr>
<td>7/4 (15^2 - 7.0^2) \times 0.8</td>
<td>21.6 \times 4 \times 0.102 = 9</td>
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</tr>
<tr>
<td>(10 \times 0.75 - 9.52 \times 0.75) \times 0.8</td>
<td>3.28 \times 0.102 = 0.3</td>
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<td></td>
</tr>
</tbody>
</table>

12 Center boss

<p>| | | | |</p>
<table>
<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>7/4 (9.5^2 - 5.58^2) \times 0.5</td>
<td>21.64</td>
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<td></td>
</tr>
<tr>
<td>3 \times 0.75 \times 5 \times 0.75 \times 11</td>
<td>1.53</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7/4 (9.25^2 - 5.68^2) \times 0.25</td>
<td>3.90</td>
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<tr>
<td>7/4 (4.63^2 - 5.68) \times (3.12 + 2.62)</td>
<td>42.22 \times 0.102 = 16.7</td>
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<tr>
<td>7/4 (4.75^2 - 5.58^2) \times 0.1094</td>
<td>9.94 \times 0.102 = 0.99</td>
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<p>| | | | |
|               |               |               |               |</p>
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<tr>
<td>13</td>
<td>Silver pin holes</td>
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</tr>
<tr>
<td>7/4</td>
<td>2.53² x 1.88</td>
<td>94</td>
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<tr>
<td>7/4</td>
<td>1.875² x 1.44</td>
<td>1.37</td>
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<tr>
<td>7/4</td>
<td>7.6² x 2.63</td>
<td>1.16</td>
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<tr>
<td>14</td>
<td>Trail brake lugs</td>
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</tr>
<tr>
<td>4 x 2.25 x 2.5</td>
<td>2.28</td>
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</tr>
<tr>
<td>4 x 2.9 x 2.5 x 2</td>
<td>4.38</td>
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</tr>
<tr>
<td>1/2 x 2.25 x 2</td>
<td>3.11</td>
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<tr>
<td>2.5 x 3.8 x 2.23</td>
<td>2.12</td>
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<tr>
<td>7/4 x 2.23</td>
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<tr>
<td>16</td>
<td>Trail pin holes</td>
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<td>7/4 x (3.63² - 3.13²) x 2.25</td>
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<tr>
<td>7/4 x (3.63² - 3.13²) x 2.25</td>
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<td>8 x 2.5 x 2.25</td>
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<td>17</td>
<td>Total Surface</td>
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<td>6.5 x 2.5 x 2.25</td>
<td>74.7</td>
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<td>1 x 5.2 x 2.25</td>
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<tr>
<td>1/2 x (4.25² - 3.75²) x 3.22</td>
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<tr>
<td>18</td>
<td>Running start &amp; real score</td>
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<td>----</td>
<td>---------------------------</td>
<td>----</td>
<td>----</td>
<td>----</td>
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<tr>
<td></td>
<td>(34.88 - 34.38) / 1.25</td>
<td>34</td>
<td>0</td>
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<tr>
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<td>(35.75 - 34.88) / 2.5</td>
<td>12</td>
<td>1</td>
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<tr>
<td></td>
<td>(45.75 - 35.75) / 6.05</td>
<td>35</td>
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<tr>
<td></td>
<td>π x 35.75 x 1.65 x 47</td>
<td>12</td>
<td>7</td>
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<tr>
<td></td>
<td>π x (45.75 - 41.12) / 3.7</td>
<td>39</td>
<td>7</td>
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</tr>
<tr>
<td></td>
<td>x 1.02</td>
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</tr>
<tr>
<td>19</td>
<td>Hz</td>
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<td>π x 105² x 1.65 x 6.4</td>
<td>43</td>
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<td></td>
<td>π x 10² x 1.65 x 16</td>
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<td>π x 5² x 1.65 x 8</td>
<td>16</td>
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<td></td>
<td>π x 10² x 1.62 x 24</td>
<td>12</td>
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<td>π x 5² x 1.38 x 30</td>
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<td>π x 1.38 x 3</td>
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<td>π x 1.02</td>
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<td>Smitheburg</td>
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</tbody>
</table>
Appendix B

PHOTOGRAPHS

and

DRAWINGS
Figure 1-1. Bottom Carriage Structure, Casting for 155mm Howitzer XL198
Figure B-3. Cope Half of Mold
Figure B-4. Complete Mold, Ready for Pouring
Figure B-5. Pouring KO-1 Aluminum for Bottom Carriage Structure
Figure 8.6. Bottom Carriage Structure, Finished Casting, Top View
Figure B-7. Bottom Carriage Structure, Finished Casting, Bottom View
Figure B-8. Bottom Carriage Structure, Finished Casting, Side View

75
1. INTERPRET DRAWING IN ACCORDANCE WITH MIL-D-306 FOR CATEGORY A AND FORM Z.
2. FOR MACHINING DRAWING, SEE RIA 14011.A4.
3. ALL MACHINED SURFACES ARE MARKED.
4. 1/4 MIN STOCK ALLOWED ON ALL MACHINED SURFACES.
5. CAST EDGES .25 R.
6. EXCEPT AS NOTED.
7. DRAFT ANGLE ALLOWED 1\(^\circ\).
8. RIA JUMBO CAST INTEGRAL IN 3/D CHARACTERS IN POSITION SHOWN.
9. PENTRENT METHOD OF INSPECTION ENTIRE CASTING IN ACCORDANCE WITH MIL-1-4646, TYPE 3.

**Ident Mark:** See Note 8

**Penetant Method of Inspection**

**Entire Casting**

**In Accordance With**

**MIL-4655**

**Type 3**

**Method A.**

No linear defects over \(1/4\) in. are acceptable in area designated. No linear defects over \(3/4\) in. are acceptable in balance of casting.

**Note 9:**

**Ria Jumbo**

**Cast Integral in 3/D Characters**

**In Position Shown.**

**See Note 9**
Figure B-9. Bottom Carriage Casting Detail (Sheet 1 of 5)
Figure B-9. Bottom Carriage Casting Detail (Sheet 3 of 5)
Figure B-9. Bottom Carriage Casting Detail (Sheet 4 of 5)
SECTION P-P
SEE SHEET 1

SECTION M-M
SEE SHEET 3

SECTION R-R
SEE SHEET 1
Figure B-9. Bottom Carriage Casting Detail (Sheet 5 of 5)
1. Interpret drawing in accordance with MIL-D-1000 for Category A and Form Z.
2. For machining drawing, see RIA 14018.
3. All machined surfaces are marked.
4. 1/4 in. stock allowed on all machined surfaces.
5. Cast edges .20 R.
6. Except as noted:
   - Cast fillets .38 R.
8. RIA 14018 cast integral in 1/8 characters in position shown.
9. Penetrent method of inspection cast integral in accordance with MIL-I-4646, Type I.
   - Method A, no linear defects over .04 in. are acceptable in area designated.
   - No linear defects over .04 in. are acceptable in balance of casting.
10. Integrally cast-on coupons shall be tested in accordance with MIL-I-2110. Coupons must be as massive as the section from the test area and undistributed test bars will be from the center of the coupon. Removal of coupons from the carriage structure shall not degrade the structural integrity of the casting.

See Note 9.

Figure B-10.
Figure B-10. Chilled Areas of Bottom Carriage Casting (Sheet 1 of 3)
Figure B-10. Chilled Areas of Bottom Carriage Casting (Sheet 2 of 3)
Figure B-10. Chilled Areas of Bottom Carriage Casting (Sheet 3 of 3)
1. INTERPRET DRAWING IN ACCORDANCE WITH MIL-D-300 FOR CATEGORY A AND FORM Z.
2. FOR MACHINING DRAWING, SEE MIL-I-44014.
3. ALL MACHINED SURFACES ARE MARKED.
4. 1/4" MIN. STOCK ALLOWED ON ALL MACHINED SURFACES.
5. CAST EDGES .250 R.
6. EXCEPT AS NOTED.
7. CAST PORTS, .10 R.
8. DRAFT ANGLE ALLOWED 1/2.
9. MIL-I-44014 CAST INTEGRAL IN 3/8 CHARACTERS IN POSITION SHOWN.
10. PENETRANT METHOD OF INSPECTION.
11. ENTIRE CASTING IN ACCORDANCE WITH MIL-I-44014, TYPE 2.
12. METHOD A, NO LINEAR DEFECTS OVER 3/4 IN ARE ACCEPTABLE IN AREA DESIGNATED. NO LINEAR DEFECTS OVER 3/4 IN ARE ACCEPTABLE IN BALANCE OF CASTING.

Figure 1
Casting not immersed above this line. Water was applied by 2 fire hoses for 5 minutes.

Figure B-11. Location, Size, and Depth of Defects (Sheet 1 of 2)
Figure B-11. Location, Size, and Depth of Defects (Sheet 2 of 2)
1. INTERPRET DRAWING IN ACCORDANCE WITH MIL-D-1303D FOR CATEGORY A AND FORM E.
2. FOR MACHINING DRAWING, SEE RIA 1401.
3. ALL MACHINED SURFACES ARE MARKED.
4. 1/4 MIN STOCK ALLOWED ON ALL MACHINED SURFACES.
5. CAST EDGES .200 R.
6. EXCEPT AS NOTED:
   CAST FILLETS .38 R.
7. DRAFT ANGLE ALLOWED 1°.
8. RIA 1401 CAST INTEGRAL 1/16 IN CHARACTERS IN POSITION SHOWN.
9. PENETRANT METHOD OF INSPECTION ENTIRE CASTING IN ACCORDANCE WITH MIL-I-46244 TYPE I.

Figure B:
Figure B-12. Location, Size, and Depth of Defects (Sheet 1 of 3)
Figure B-12. Location, Size, and Depth of Defects (Sheet 2 of 3)
Figure B-12. Location, Size, and Depth of Defects (Sheet 3 of 3)
Appendix C

TECHNICAL PROGRESS REPORTS
4 June 1973

Commander
U. S. Army Weapons Command
Rock Island, Illinois 61201

Attention: SWERR-A-TA

Subject:
Contract DAAF03-73-C-0065
Technical Progress Report No. 1

Enclosure:
(1) Schedule - Delivery Status Report - Three (3) Copies
(2) Two (2) Polaroid Photos of Present Pattern Status

1. In accordance with the requirements of the subject Contract, this Technical Progress Report for the period 12 March thru 31 May 1973 is forwarded for information and record. Enclosure (1) presents the schedule-delivery status of the program.

2. Milestones/Work Schedules for the Reporting Period

2.1 Preliminary design calculations.
2.2 Detail drawings.
2.3 Weight calculations.
2.4 Start final stress analysis.
2.5 Furnish old pattern equipment to pattern maker and start redesign and fabrication of new pattern equipment.
Milestones/Work Accomplished During the Reporting Period

1. Preliminary design calculations were completed.

2. Preliminary detail drawings were completed and were submitted to Mr. C. Shaffer, SWERR-A, on 8 May 1973. (See Enclosure (1))

3. Weight calculations were completed.

4. Work on final stress analysis was started and is estimated to be 25% completed as of the end of this Reporting Period.

5. The old pattern equipment was received at our plant on 25 April 1973. It was checked and turned over to the pattern maker on 7 May 1973. Two (2) Polaroid camera photos reflecting current physical status are also enclosed. Partial utilization of the original pattern equipment is reflected by the reddish brown area in Photo #1. It is estimated that the pattern and core box effort is 20% complete.

6. No problems were encountered during the Reporting Period.

Milestones/Work to be Accomplished During the Next Reporting Period

1. Final stress analysis will be continued and may be completed.

2. An additional 60% to 70% of the pattern effort should be completed during the coming Reporting Period.

Percent of Total Task Completed

1. It is estimated that the engineering effort is 70% complete and the pattern effort 20% complete with the manufacturing waiting on completion of the new pattern equipment expected in July 1973.

FMC CORPORATION
Northern Ordnance Division

Albert E. Wickman
Senior Contract Administrator

AEW:ng

cc AMC/PM-CAWS (2)
5 July 1973

Commander
U. S. Army Weapons Command
Rock Island, Illinois 61201

Attention: SWERR-A-TA

Subject:
Contract DAAF03-73-C-0065
Technical Progress Report No. 2

Enclosure:
(1) Schedule - Delivery Status Report - Three (3) Copies

1. In accordance with the requirements of the subject Contract, this Technical Progress Report for the period 1 June thru 30 June 1973 is forwarded for information and record. Enclosure (1) presents the schedule-delivery status of the program.

2. Milestones/Work Schedules for the Reporting Period

2.1 Continue final stress analysis.

2.2 An additional 60% to 70% of the pattern effort should be completed.

3. Milestones/Work Accomplished During the Reporting Period

3.1 Stress analysis effort was continued and is 50% complete.

3.2 Corrected preliminary detail drawings covering the casting detail of the bottom carriage were submitted 6 June 1973.
3. Both halves of the pattern are basically complete except for some touch-up work and rounding of edges. One-half of the main core which will be plastic was poured on 29 June with the other half to be poured during the first week of July.

4. No problems were encountered during the Reporting Period.

5. Milestones/Work to be Accomplished During the Next Reporting Period

5.1 Final stress analysis will be completed. A target date of 16 July has been established for completion.

5.2 The pattern and core box equipment will be completed and should be available to the Foundry by 17 July.

5.3 Foundry effort will commence in preparation for pouring of the castings.

6. Percent of Total Task Completed

6.1 It is estimated that the engineering effort is 83% complete and the effort on the pattern and core box equipment is 85% complete.

FMC CORPORATION
Northern Ordnance Division

Albert E. Wickman
Senior Contract Administrator

cc: Commander
    U. S. Army Weapons Command
    Rock Island, Illinois 61201
    Attention: AMC15M-CAWS
7 September 1973

Commander
U. S. Army Weapons Command
Rock Island, Illinois 61201

Attention: SWERR-A-TA

Subject:
Contract DAAF03-73-C-0065
Technical Progress Report No. 3

Enclosure:
(1) Schedule-Delivery Status Report
Three (3) Copies

1. In accordance with the requirements of the subject Contract, this Technical Progress Report for the period 1 August thru 31 August 1973 is forwarded for your information and record. Enclosure (1) presents the schedule-delivery status of the program.

2. Milestones/Work Schedules For The Reporting Period

   2.1 Completion of final stress analysis.

   2.2 Shipment of first casting.

   2.3 Start of foundry effort and pouring of second casting.

3. Milestones/Work Accomplished During The Reporting Period

   3.1 The final stress analysis was completed. A copy was mailed to Mr. C. Shaffer, SWERRA, on 27 August 1973.

   3.2 The first and second castings were poured during August.
4. Problems Encountered During The Reporting Period

4.1 Due basically to problems with the mold, the first casting had too many defects to be given consideration for use as the first shipment.

4.2 A second casting was poured with better results though there still are problems. The sand set up too hard and was quite difficult to remove. The casting did require a number of weld repairs.

4.3 Mold making technique is being improved as a result of experience on the first two including a reduction of the binder in the sand to assure easier shake out of future castings.

4.4 It is planned that all remaining castings will be poured during September, if possible, to enhance the chance of completing shipment on schedule.

4.5 Balancing worst and best possible conditions, Foundry management predicts shipment as follows:

First Casting 13 September 1973
Second Casting 28 September 1973
Third Casting 17 October 1973
Fourth Casting 9 November 1973

5. Milestones/Work To Be Accomplished During the Next Reporting Period

5.1 Pouring of all remaining castings due by the end of September.

5.2 Shipment of the first casting by 13 September and the second casting by 28 September.
U. S. Army Weapons Command  
7 September 1973  
Page three

6. Percent Of Total Task Completed

6.1 It is estimated that the Engineering effort is 96% complete and that the Foundry effort is 26% complete.

FMC CORPORATION  
Northern Ordnance Division

A. E. Wickman  
Senior Contract Administrator

AEW: mj

cc: Commander  
U. S. Army Weapons Command  
Rock Island, Illinois  61201  
Attention: AMCPM-CAWS
11 October 1973

Commander
U. S. Army Weapons Command
Rock Island, Illinois 61201

Attention: SWERR-A-TA

Subject:
Contract DAAFO3-73-C-0065
Technical Progress Report No. 4

Enclosure:
(1) Schedule-Delivery Status Report
Three (3) Copies

1. In accordance with the requirements of the subject Contract, this Technical Progress Report for the period 1 September through 30 September, 1973, is forwarded for your information and record. Enclosure (1) presents the schedule-delivery status of the program.

2. Milestones/Work Schedules For The Reporting Period

2.1 Pouring of all remaining castings due.

2.2 Shipment of first and second castings.

3. Milestones/Work Accomplished During The Reporting Period

3.1 The third and fourth castings were poured during September.

4. Problems Encountered During The Reporting Period

4.1 Due to cracks in the basic casting and problems in achieving successful weld repair, the two castings scheduled for shipment in September were not shipped.

4.2 A number of weld repairs by a variety of procedures, depending on size and location of the defect, were tried with a certain degree of success but throughout the month we could not achieve a casting with zero defects.
4.3 A technique of heat treating the casting to relieve all stresses prior to weld repair will be tried in our next effort to achieve total satisfactory weld repair.

4.4 Anticipating reasonable success with this latest effort and evaluating current work load and work to be completed on each of the four castings, Foundry management predicts shipment as follows:

| First Casting | 19 October 1973 |
| Second Casting | 2 November 1973 |
| Third Casting | 16 November 1973 |
| Fourth Casting | 30 November 1973 |

5. Milestones/Work To Be Accomplished During The Next Reporting Period

5.1 A fifth casting will be poured early in October to replace the initial casting which will be scrapped.

5.2 Shipment of the first casting is scheduled for 19 October.

5.3 Preliminary planning and data collection for compilation of the final technical report will be started.

6. Percent Of Total Task Completed

6.1 It is estimated that the Engineering effort is 97% complete and that the Foundry effort is 50% complete.
11 December 1973

Commander
U. S. Army Weapons Command
Rock Island, Illinois 61201

Attention: SWERR-A-TA

Subject:
Contract DAAF03-73-C-0065
Technical Progress Report No. 5

1. Problems encountered subsequent to Report No. 4 and the expenditure of most of the initial funding brought the program to a potential standstill with an indefinite future so the report for the end of October was delayed. Now that a new course of action has been defined with every indication that it will be funded, this correspondence is submitted as Technical Progress Report No. 5 for the period 1 October thru 30 November 1973.

2. Milestones/Work Schedules for the Reporting Period

2.1 Shipment of the first casting by 19 October.

2.2 Pouring of fifth casting to replace initial casting which will be scrapped.

2.3 Shipment of second, third and fourth castings in November.

2.4 Preliminary planning and data collection for compilation of the final technical report.

3. Milestones/Work Accomplished During the Reporting Period

3.1 The fifth casting was poured during October.
4. Problems Encountered During the Reporting Period

4.1 Weld repair attempts on the second, third and fourth castings, while showing gain or improvement, were never 100% successful with new cracks developing as each repair was completed and heat treated. Since the fifth casting was better in appearance and showed a minimum number of defects, it was planned that repair efforts would be concentrated on this casting when it became available.

4.2 Meanwhile, these problems were brought to the attention of Mr. Avery Kearny, Chief Metallurgist of the Olin Aluminum Division, who was one of the leaders in the development of the KO-1 aluminum material. Upon invitation, he came to our foundry on October 18 and 19 and looked over the castings on hand. It was his judgement that our basic problem was micro-shrinkage which provided conditions causing propagation of new cracks as a result of stresses induced during weld repair of any visible defects. It was Mr. Kearny's and our technical foundry personnel's opinion that the micro-shrinkage could be successfully overcome by judicious placement of, and an increase in, the number of risers in making the mold which would bring about controlled solidification after pouring of the casting.

4.3 Considering the aforementioned judgement which established all poured castings as unrepairable, and the minimum amount of remaining funds, evaluation of a new course of action was necessary. A proposal was developed and submitted on 26 October 1973 setting forth costs and outlining a new schedule for the completion and shipment of four new castings and the preparation and submission of a final report. Meanwhile, covered by the funds remaining, effort was initiated in making pattern changes and developing improved riser placement within the flask in order to overcome the micro-shrinkage condition.
Messrs. Peter Hogberg and Charles Schaffer, of the Armament Command Project Office, visited our plant on 5 and 6 November to discuss the situation and to see the new casting which was poured on 31 October. It was agreed that we would proceed carefully and that no effort towards a second casting would be taken until we had completely studied the first casting and established all potential corrective adjustments or improvements that could be incorporated into the follow-on units.

Also, on 6 November, sufficient additional funds were added to the contract by telegram to permit completion and shipment of one casting. Discussion with the Contracting Officer as well as with Messrs. Hogberg and Schaffer indicated the likelihood that the quantity of castings required would be reduced from 4 to 2 since that quantity would satisfy the basic requirements and would minimize the additional expenditure required. A final Technical Report without a preliminary draft copy would also be required.

The initial casting under the new effort required a fair amount of repair but comprehensive inspection indicated that the micro-shrinkage problem had been overcome. It is anticipated that this casting will be shipped around the 17th or 18th of December.

Milestones/Work to be Accomplished During the Next Reporting Period

5.1 Ship first casting by 18 December.

6. Percent of Total Task Completed

6.1 It is estimated that the Engineering effort is 97% complete and that the foundry effort is 45% complete based on the reduced quantity of castings.

FMC CORPORATION
Northern Ordnance Division

A. E. Wickman
Senior Contract Administrator

cc: Commander
U. S. Army Weapons Command
Rock Island, Illinois 61201
Attention: AMCPM-CAWS

Ed Beck
DCAS
FMC/NOD

R. Wirshoff
FMC Corporation
Northern Ordnance Division
Columbia Heights Post Office
48th and Marshall Street Northeast
Minneapolis Minnesota 55421
(612) 560 9201

2 January 1974

Commander
U. S. Army Weapons Command
Rock Island, Illinois 61201

Attention: SWERR-A-TA

Subject:
Contract DAAF03-73-C-0065
Technical Progress Report No. 6

1. In accordance with the requirements of the subject contract, this Technical Progress Report for the period 1 December thru 31 December, 1973, is forwarded for your information and record.

2. Milestones/Work Schedules for the Reporting Period

2.1 Ship first casting by 18 December.

2.2 Start preparation for pouring of second casting.

3. Milestones/Work Accomplished During the Reporting Period

3.1 The first casting was shipped on 18 December 1973.

3.2 In preparation for the second casting, alterations have been made to the pattern equipment to provide additional risers and collapsible chills are being developed.

4. Problems Encountered During the Reporting Period

4.1 A considerable amount of weld repair was required to bring the initial casting into an acceptable state. The repairs were required on cracks that developed during the casting cooling period which we believe can be prevented by incorporation of more risers and collapsible chills into the mold for the second casting. As reported in 3.2 above, work is already in progress in applying the corrective measures.
U. S. Army Weapons Command 2 January 1974

5. Milestones/Work to be Accomplished During the Next Reporting Period

5.1 The mold should be ready for pouring of the second casting on 9 January.

5.2 The second casting should be shipped 22 January.

5.3 Initial effort, such as gathering of data, should begin during last week of January in preparation of the Final Technical Report.

6. Percent of Total Task Completed

6.1 It is estimated that the Engineering effort is 98% complete and that the foundry effort is 58% complete based on the reduced quantity of castings.

6.2 One hundred percent of the Final Technical Report effort remains to be accomplished.

6.3 Based on total expenditure of manpower and material, the program could be considered 80% complete.

FMC CORPORATION
Northern Ordnance Division

A. E. Wickman
Senior Contract Administrator

cc: Commander
U. S. Army Weapons Command
Rock Island, Illinois 61201
Attention: AMCPM-CAWS

Ed Beck
DCAS
FMC/NOD
FMC Corporation
Northern Ordnance Division
Columbia Heights Post Office
48th and Marshall Street Northeast
Minneapolis Minnesota 55421
(612) 560 9201

7 February 1974

Commander
U. S. Army Weapons Command
Rock Island, Illinois 61201

Attention: SWERR-A-TA

Subject:
Contract DAAF03-73-C-0065
Technical Progress Report No. 7

1. In accordance with the requirements of the subject contract, this Technical Progress Report for the period 1 January thru 31 January, 1974, is forwarded for your information and record.

2. Milestones/Work Schedules for the Reporting Period

2.1 Pour second casting on 9 January.

2.2 Ship second casting on 22 January.

2.3 Start initial effort in preparation of Final Technical during last week of January.

3. Milestones/Work Accomplished During the Reporting Period

3.1 Collapsible chills were developed and the mold completed so that the second casting was poured on 16 January. It was shaken out, gates and risers removed and underwent initial inspection on 27 January.

4. Problems Encountered During the Reporting Period

4.1 While the casting at initial inspection basically appeared better than the first casting shipped and did not have the large cracks which were apparently overcome by the collapsible chills, the casting never-the-less had a large number of smaller cracks scattered over all areas. As a result, all milestones scheduled for January were missed.
5. **Milestones/Work to be Accomplished During the Next Reporting Period**

5.1 Since the casting must be preheated prior to weld repair and the welder can only make a limited number of weld repairs per each heat, a considerable number of days will be required to correct all defects and to produce a sound casting. A dye penetrant check is made on each group of repairs to determine success of the repair before going on to the next group. This effort was started 31 January 1974.

5.2 When the final group of weld repairs successfully pass the spot dye check, the casting will be cleaned and turned over to the Inspection Department for a total PT examination. Successfully passing of this examination will be followed by final casting heat treatment, cleaning and another total PT examination. With no major weld repair problem encountered, this milestone should be achieved by 22 February.

5.3 After final PT examination, the casting will undergo dimensional check and other necessary final inspection. Final papers will be prepared and the casting packaged, crated and shipped. This should be accomplished by 1 March 1974.

5.4 The initial effort, such as the gathering of the available data, should begin during the last week in February in preparation of the Final Technical Report.

6. **Percent of Total Task Completed**

6.1 It is estimated that the Engineering effort is 99% complete and that the foundry effort is 78% complete based on the reduced quantity of castings.
6.2 One hundred percent of the Final Technical Report effort remains to be accomplished.

6.3 Based on total expenditure of manpower and material, the program could be considered 91% complete.

FMC CORPORATION
Northern Ordnance Division

C. E. Wickman
A. E. Wickman
Senior Contract Administrator

cc: Commander
    U. S. Army Weapons Command
    Rock Island, Illinois 61201
    Attention: AMCPM-CAWS

Ed Beck
DCAS
FMC/NOD

bcc:
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Appendix D

CHEMICAL

and

MECHANICAL TEST REPORTS
**FMC CORPORATION**
NORTHERN ORDNANCE DIVISION
METALLURGICAL LABORATORY

**CHEMICAL ANALYSIS**

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**REMARKS.**

LAB. TECH. | D.W. | METALLURGIST | P.M.W. | FILE NO. | 6913 |
|-----------|------|--------------|--------|----------|------|
### Mechanical Test Report

**Material:** Aluminum  
**Specification:** KO-1  
**Test Requested By:** Foundry  
**Date:** 12-11-73

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**Remarks:**

---

**Labor Tech:** D.L.  
**Metallurgist:** R. Mark  
**File No.:** 5989
### Chemical Analysis

**Material:** Al. C452115  
**Specification:** A-201  
**Supplier:** No Foxy  
**Analysis Requested By:** S.M.  
**M.R. No.:**

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**Element:** Si, Mn, Ni, Fe, Al  
**Ident:** 14-A-9-4  
**Analysis:** 0.3% Si, 0.28% Mn, 0.18% Ni, 0.35% Fe, 0.33% Al

**Remarks:**

**Lab. Tech.:** D2  
**Metallurgist:** P.M.  
**File No.:** 2203
**METALLURGICAL LABORATORY MECHANICAL TEST REPORT**

**Material:** Aluminum  
**Specification:** A201  
**Supplier:** NOD FMC  
**Test Requested By:**  

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**Remarks**

**Laboratory Technician:** D.L.  
**Metallurgist:** R.M. W.  
**File No.:** 6475