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DESIGN PROGRESS REPORT
PRIVY ROOF MOUNTED SHIELD
AND
SHIELD SUPPORT

ACF-SA-727

MASTER

June 15, 1965

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1.0 INTRODUCTION

This report presents the current designs, analyses, material investigations and testing efforts for the NRX Privy Roof Mounted Shield and Support as requested at the PRMS Meeting held at SNPO-C on April 29, 1965. It should be emphasized that all calculations contained in this report are still considered to be of a preliminary nature and are subject to review and revision. It is recognized that there may be some points of inconsistency in the design inputs used in the calculations. These inconsistencies will be removed as firm design information becomes available.

To provide guidance, and to establish control over the project, a formal ACF Project Plan* for the Privy Roof Mounted Shield and Support was written during the early weeks of the project. This planning was conducted concurrently with the initial design and analysis efforts. One of the guiding philosophies followed in planning specific analysis activities was to give the greatest priority to those analyses concerned with the primary loads on the shield, i.e., the temperature distributions due to the internal heat generation within the shield structure; and the stresses due to internal coolant water pressure and thermal effects. For this reason, the analyses presented in this report are concerned almost exclusively with these effects. In general, the stresses due to those loads considered to be of secondary importance have not yet been calculated in detail and are not presented. This is not to say that these effects have

* "ACF Project Plan for the Privy Roof Mounted Shield and Support",
ACF-SA-726, May 28, 1965.

been totally ignored up to this point, since many preliminary informal calculations were necessary to size parts of the shield structure during the design layout activities. The calculations of the effects of the secondary loads will be presented at the final Design Review Meeting. A complete listing of the analyses to be conducted is given in the ACF Project Plan.

One of the early activities of the project was to consider other shield design concepts. The concepts considered ranged from a shield with virtually a solid cross section to one which consisted of an array of extruded rectangular tubes, similar in appearance to an old fashioned musical organ. Each of the concepts was judged with regard to design, analysis, fabrication and scheduling problems. Although some of the concepts indicated certain specific advantages, it was concluded that the best overall shield design concept was one similar to that of the NRX A-3 shield. Although the concepts of the present shield and the NRX A-3 shield are similar, there are substantial and important design differences which have been incorporated in the new shield.

2.0 DESIGN

2.1 Privy Roof Mounted Shield (PRMS)

The design of the Privy Roof Mounted Shield is shown in detail on the ACF design layout entitled "Preliminary Shield Concept" dated June 15, 1965. A less detailed sketch of the shield is given in Figure 2.1, together with certain overall dimensions.

As noted in Figure 2.1, the arrangement of the nuclear shielding elements has been maintained essentially the same as in the NRX-A3 shield, except that the back boral plate (the boral plate farthest away from the reactor) is no longer in contact with the back aluminum plate. This permits the incorporation of a coolant passage between the aluminum and boral, thus providing more positive temperature control. The figure also shows the water flow pattern through the shield.

The water inlet manifold has been moved from the inside diameter of the shield to the outside diameter. This change provides more clearance between the shield and reactor, and eliminates a definite interference with the diluent piping on the EST Test Assembly. Eight inlet pipes carry cooling water into the inlet plenum of the shield.

The water outlet plenum is now an integral portion of the shield structure. It is anticipated that this arrangement will alleviate potential problems with stagnant water and incomplete filling of the shield. Six discharge pipes carry the cooling water from the outlet plenum to an outlet manifold pipe.

To eliminate potential thermal stress problems due to thermal growth of the interior boron and aluminum plates, the interior plates are not rigidly fastened to the outer structure of the shield. The plates are allowed to "float" within the shield and are kept in position by spacers and slotted guides around the plate perimeters. Adequate clearance is provided around each of the staybolts so that bolts do not inhibit free axial expansion of the plates.

During the design of the shield, extreme care was exercised in eliminating potential stress concentrations which could cause excessive localized stresses. Concurrently, the structural welds were located, where possible, in positions subjected to low stress levels. In addition, particular attention was given to the problem of locating welds in positions where they can be radiographically inspected in conformance with the ASME Boiler and Pressure Vessel Code. Section III of the ASME Code is extremely restrictive with regard to the types of weld geometries or configurations allowed. Due to the non-axisymmetric shape of the shield and the limited amount of space available to work in, unusual and difficult fabrication and welding problems are anticipated during construction of the shield.

2.2 Privy Roof Mounted Shield Support (PRMSS)

The design of the Privy Roof Mounted Shield Support is shown in detail on the ACF design layout entitled "Preliminary Support Concept", dated June 15, 1965. A less detailed sketch of the shield support is given in Figure 2.2, together with certain overall dimensions.

As noted in Figure 2.2, the support consists of three separate assemblies. The two side assemblies provide the support for the shield, while the center assembly serves only as a shielding element and provides no support to the shield.

Figure 2.2 also indicates the water flow pattern and the interior arrangement of the boral and steel plates required for shielding purposes.

Since the internal heat generation in the shield support structure is considerably lower than in the shield proper, the support is fabricated of much heavier material. This was purposely done since the complex geometry of the support introduces considerable uncertainty in the stress analysis of the structure. Following the same philosophy as used in the shield, the interior plates are fastened in the support in a manner which minimizes thermal growth problems.

As with the shield, care was taken in locating structural welds in advantageous positions within the support. Nevertheless, in order to conform to the ASME Boiler and Pressure Vessel Code it was necessary to totally eliminate some structural welds, and to substitute bolted joints. This was primarily due to the complex shape of the support, which made it virtually impossible to assure that sound, high quality welds could be produced.

Figure 2.1

SKETCH OF THE
PRIVY ROOF MOUNTED SHIELD

Figure 2.2

SKETCH OF THE PRIVY ROOF MOUNTED
SHIELD SUPPORT

3.0 Fluid Flow and Heat Transfer

3.1 Privy Roof Mounted Shield

After review and consideration of the design criteria and analysis requirements specified in GSE-1371, Revision A, May 17, 1965, it became apparent that a complete heat transfer analysis of the PRMS was in order. In order to accomplish the tasks outlined, it was decided that a digital computer analysis must be used. After an examination of the computer programs available, it was determined that the THTB Code* was the only one adequate for the purpose.

The initial fluid flow studies of the shield indicated that many of the results required by the design criteria outlined in GSE-1371 could not be obtained by theoretical calculations alone. For this reason, it was decided to construct a half-scale flow model of the proposed shield design. The purpose of the model is to answer the requirements of paragraph 4.2 of GSE-1371; and to furnish other design information detailed in the flow model test specification presented elsewhere in this report.

The reports and analyses listed below may be found on the following pages:

- 3.1.1 "Water Velocity and Pressure Drop Calculations for The PRMS and PRMS Flow Model."
- 3.1.2 "THT Models of the Front and the Back Plates of the PRMS."
- 3.1.3 "THT-B Model of a PRMS Side Plate."

* G. L. Stephens and D. J. Campbell
"Program THTB for Analysis of General Transient Heat Transfer Systems",
R60FPD647, General Electric Co., April 21, 1961.

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3.1.4 "Temperature Distribution in the Front Plates
of the PRMS."

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WATER VELOCITY AND PRESSURE DROP
CALCULATIONS FOR THE PRMS
AND THE PRMS FLOW MODEL

TITLE 3.1.1
JOB NO. 50-4804-01
DATE 6-14-65
BY M.A. & R.W.
PAGE NO. 1

INTRODUCTION:

A $\frac{1}{2}$ SCALE FLOW MODEL OF THE PRMS HAS BEEN MADE. TWO OF THE MAIN OBJECTIVES OF THIS MODEL ARE:

- (1) TO DETERMINE THE TYPE OF FLOW DISTRIBUTION TO EXPECT IN THE FULL SIZE SHIELD.
- (2) TO DETERMINE THE PRESSURE DROPS THAT WILL RESULT IN THE FULL SIZE SHIELD.

IN ORDER TO USE THE TEST DATA FROM THE PRMS FLOW MODEL TO DETERMINE THE ABOVE, DYNAMIC SIMILARITY MUST EXIST BETWEEN THE MODEL AND THE FULL SIZE SHIELD. THIS MEANS THE REYNOLDS NUMBERS MUST BE EQUAL FOR BOTH CASES.

VELOCITIES AND PRESSURE DROPS FOR BOTH THE PRMS AND THE PRMS FLOW MODEL ARE CALCULATED AND TABULATED BELOW. THE PURPOSE FOR THIS IS TWO FOLD (1) TO CHECK THE RELIABILITY OF CALCULATIONS AND (2) TO INDICATE WHAT PRESSURES AND VELOCITIES CAN BE EXPECTED DURING THE FLOW TEST OF THE $\frac{1}{2}$ SCALE MODEL.

DISCUSSION:

WHILE DESIGN REQUIREMENTS CALL FOR 80% OF THE TOTAL FLOW RATE TO PASS THROUGH THE BALLS, THE PRESENT DESIGN (6-9-65) WILL ALLOW ONLY 38% (CALCULATED). THIS

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MEANS THAT A FLOW IMPEDANCE MUST BE DESIGNED FOR THE BACK CHANNEL. DUE TO THE UNCERTAIN VALUES FOR THE CONSTANTS IN THE EMPIRICAL EQUATIONS FOR SIZING ORIFICES, CALCULATIONS ARE NOT MADE. RATHER, ORIFICE SIZE WILL BE VARIED ON THE PRMS FLOW MODEL UNTIL 80/20 FLOW DISTRIBUTION IS OBTAINED. SIMILITUDE ANALYSIS SHOWS THAT IF THE RATIO OF

$$\frac{\text{TOTAL IMPEDANCE FLOW AREA}}{\text{CHANNEL FLOW AREA}}$$

IN THE BACK CHANNEL IS HELD CONSTANT BETWEEN THE FLOW MODEL AND THE PRMS, THE SAME FLOW DISTRIBUTION WILL EXIST BETWEEN MODEL AND SHIELD. IT SHOULD BE NOTED THAT THE 80/20 FLOW DISTRIBUTION WILL ONLY EXIST FOR THE FLOW RATES DESIGNED FOR, i.e. $\dot{w}$ FOR THE FLOW MODEL AND $2\dot{w}$ FOR THE PRMS. ALL OTHER FLOW RATES WILL RESULT IN DIFFERENT FLOW DISTRIBUTION. TEST DATA FROM THE MODEL SHOULD GIVE A PLOT OF % FLOW DISTRIBUTION VS FLOW RATE FOR THE ORIFICE USED. WITH THIS IT WOULD BE POSSIBLE TO PICK A LOWER AND UPPER LIMIT ON ALLOWABLE FLOW RATES.

RESULTS:

AS STATED ABOVE DYNAMIC SIMILITUDE CAN EXIST ONLY IF THE REYNOLDS NUMBERS IN THE PRMS AND THE 1/2 SCALE PRMS FLOW MODEL ARE EQUAL. TO OBTAIN THIS,

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CALCULATIONS SHOW THAT THE FLOW RATE IN THE FLOW MODEL MUST BE $\frac{1}{2}$ THE FLOW RATE IN THE PRMS. FOR THIS RELATIONSHIP OF FLOW RATES CALCULATIONS ALSO SHOW THAT THE CHANNEL VELOCITIES IN THE PRMS WILL BE $\frac{1}{2}$ THE CHANNEL VELOCITIES IN THE FLOW MODEL (THIS IS TRUE THROUGH THE BALLS ALSO). IN ADDITION, IT IS POSSIBLE TO SHOW THAT THE FRICTIONAL PRESSURE LOSS THROUGH THE BALLS WILL BE FOUR TIMES GREATER FOR THE FLOW MODEL THAN IT WILL BE FOR THE PRMS. THIS IS AN INTERESTING RESULT WHEN NOTING THE EMPIRICAL EQUATION USED TO CALCULATE THE ΔP THROUGH THE BALLS (SEE CALCULATIONS).

FIGURES #2 AND #3 ARE GRAPHS OF THE RELATIONSHIP BETWEEN THE VELOCITY OF H_2O THROUGH THE BALLS AND THE VELOCITY OF H_2O UP THE BACK CHANNEL.

FIGURE #4 GIVES THE PLOT OF FLOW RATE VS VELOCITY THROUGH THE BALLS FOR BOTH THE PRMS AND THE PRMS FLOW MODEL.

FIGURE #5 SHOWS THE RELATIONSHIP BETWEEN TOTAL FLOW AND FLOW THROUGH THE BALLS FOR CONSTANT LINES OF FLOW DISTRIBUTION.

WITH THE USE OF FIGURES #4 AND #5 AND THE TEST DATA, THE VELOCITY AND FLOW RATE THROUGH THE BALLS FOR ANY FLOW RATE CAN BE DETERMINED.

THE RESULTS TABULATED BELOW WERE CALCULATED ASSUMING THAT THE 80/20 FLOW DISTRIBUTION WILL BE OBTAINED.

TITLE 3.1.1
JOB NO. _____
DATE _____
BY _____
PAGE NO. 4

	PRMS	FLOW MODEL
TOTAL FLOW RATE - 16/SEC	<u>54.1</u>	<u>27.05</u>
INLET VELOCITY (MANIFOLD) FT/SEC	7.35	14.70
VELOCITY (LEAVING INLET PLENUM) FT/SEC	3.275	6.55
VELOCITY (UP FIRST CHANNEL) FT/SEC	2.85	5.70
VELOCITY (DOWN 2 ND CHANNEL) FT/SEC	2.85	5.70
VELOCITY (THROUGH BALLS) FT/SEC	0.475	0.95
VELOCITY (UP BACK CHANNEL) FT/SEC	0.80	1.65
EXIT VELOCITY FT/SEC	2.60	5.20
ΔP (THROUGH INLET MANIFOLD) PSID	0.725	1.45
ΔP (1 TO 2 SEE FIG. #1) PSID	0.134	0.267
ΔP (2 TO 3 SEE FIG #1) PSID	0.215	0.859
ΔP (3 TO 4 SEE FIG #1) PSID	5.576*	7.849*
ΔP (4 TO 5 SEE FIG #1) PSID	0.0225	0.09
TOTAL ΔP PSID	<u>6.67</u>	<u>10.52</u>

*THESE ΔP 'S INCLUDE POTENTIAL ENERGY LOSSES. 2.065 PSID FOR THE FLOW MODEL AND 4.13 PSID FOR THE PRMS.

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CALCULATIONS:

FOR SIMILITUDE THE REYNOLDS NUMBERS IN THE SHIELD AND THE MODEL MUST BE EQUAL.

$$\left(\frac{\rho V D}{\mu}\right)_{\text{SHIELD}} = \left(\frac{\rho V D}{\mu}\right)_{\text{MODEL}}$$

SINCE $\rho_S = \rho_M$, $\mu_S = \mu_M$, AND $D_S = 2 D_M$

$$\underline{V_S = \frac{1}{2} V_M \text{ (IN ANY CHANNEL)}}$$

FROM THIS AND $\dot{W} = \rho V A$

$$\underline{\dot{W}_S = 2 \dot{W}_M}$$

$$\therefore \dot{W}_M = \frac{1}{2} \dot{W}_S = \frac{1}{2} 54.1 \frac{\text{lb}}{\text{sec}}$$

$$\dot{W}_M = \underline{27.05 \text{ lb/sec}} = \underline{195 \text{ G.P.M.}}$$

VELOCITY CALCULATIONS:

CHANNEL VELOCITIES ARE CALCULATED USING AND THE EQUATION

$$V = \dot{W} / \rho A$$

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WHERE

$\dot{W}$ = TOTAL FLOW RATE OF H_2O

ρ = DENSITY OF H_2O @ $80^\circ F = 62.2 \text{ lb/ft}^3$

A = CROSS SECTIONAL AREA OF CHANNEL - CROSS SECTIONAL AREA OF RIBS IN CHANNEL

THERE IS ONLY 20% OF THE TOTAL FLOW GOING UP THE BACK CHANNEL (DESIGN CONDITIONS). THEREFORE THE FLOW RATE IN THE ABOVE EQUATION IS $0.2\dot{W}$.

TO CALCULATE THE VELOCITY THROUGH THE BALLS THE ABOVE EQUATION IS USED WITH THE FOLLOWING ASSUMPTIONS.

- (1) 80% OF TOTAL FLOW RATE
- (2) 0.3 VOID AREA FOR BALL PACKING

PRESSURE DROP CALCULATIONS:

PRESSURE DROPS ALONG THE CHANNELS ARE CALCULATED USING THE MODIFIED BERNOULLI'S EQUATION.

$$\Delta P = \left[\rho \left(\frac{V_2^2 - V_1^2}{2} \right) + \rho g (y_2 - y_1) + \left(\frac{1}{2} \right) \rho \right] \left(\frac{1}{\rho_c} \right)$$

WHERE

ρ = DENSITY OF H_2O @ $80^\circ F = 62.2 \text{ lb/ft}^3$

$g = 32.2 \text{ ft/sec}^2$

$\rho_c = 32.2 \frac{\text{lbm ft}}{\text{lb}_f \text{ sec}^2}$

$(V_2^2 - V_1^2)$ = VELOCITY CHANGE - ACCOUNTING FOR THE KINETIC ENERGY LOSS = 0

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$(y_2 - y_1) = \text{HEIGHT (FT)} - \text{ACCOUNTING FOR POTENTIAL ENERGY LOSS}$

$(h_e)_T = \text{TOTAL HEAD LOSS}$

$$= \rho K \frac{V^2}{2g_c} + \rho f \frac{4L}{D} \frac{V^2}{2g_c}$$

THE FIRST TERM IS THE MINOR HEAD LOSS DUE TO THE GEOMETRY OF THE SYSTEM.

$K = \text{LOSS COEFFICIENT (VALUES FOUND IN "CHEMICAL ENGINEER'S HANDBOOK")}$

$V = \text{MAXIMUM CHANNEL VELOCITY (FT/SEC)}$

THE SECOND TERM IS THE HEAD LOSS DUE TO FRICTION ALONG THE CHANNEL. THE EQUATION IS THE "FANNING EQUATION" AND USES THE "FANNING" FRICTION FACTOR.

SINCE PARALLEL FLOW EXISTS THROUGH THE BALLS AND THE BACK CHANNEL, A BALANCE ON PRESSURE DROPS IN THE TWO PASSAGES IS MADE.

FOR THE BALLS

$$\Delta P_B = V_B^{1.85} \left(\frac{2.36 L^{1.5} \rho^{0.85} A f}{D_B^{1.15}} \right)$$

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FOR THE BACK CHANNEL

$$\Delta P_{BC} = \rho \frac{V^2}{2g_c} \left(\frac{4L}{D_c} f + K \right)_{BC}$$

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FOR PARALLEL FLOW

$$V_B^{1.85} \left(\frac{2.36 \mu^{.15} L P^{.85} A_f}{D_B^{1.15}} \right) = \rho \frac{V_{BC}^2}{2g_c} \left(\frac{4L}{D_c} f + K \right)_{BC}$$

WHERE

V_B = VELOCITY THROUGH EMPTY BALL CHANNEL

V_{BC} = VELOCITY UP BACK CHANNEL

μ = VISCOSITY OF H_2O @ $80^\circ F = 0.48 \times 10^{-4}$ lbm/ft sec

L = LENGTH OF CHANNEL

D_B = DIAMETER OF BALLS

A_f = WALL EFFECT FACTOR (DIMENSIONLESS); PAGE 394
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ALL OTHER TERMS ARE AS DEFINED ABOVE

THIS BALANCE SHOWS THAT ONLY 38% OF THE H_2O WILL PASS THROUGH THE BALLS.

ASSUMING THAT AN IMPEDANCE WILL BE DESIGNED TO LIMIT 20% UP BACK PLATE, THE ΔP THROUGH THE BALLS CAN BE CALCULATED.

$$\Delta P = V_B^{1.85} \left(\frac{2.36 \mu^{.15} L P^{.85} A_f}{D_B^{1.15}} \right)$$

WHERE V_B IS CALCULATED ABOVE

THIS WILL ALSO BE THE ΔP THROUGH THE BACK CHANNEL.

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IT CAN BE SHOWN THAT THE PRESSURE DROP THROUGH THE BALLS IN THE MODEL IS 4 TIMES THE PRESSURE DROP THROUGH THE BALLS IN THE FULL SIZE SHIELD.

$$\Delta P_M = V_{B_M}^{1.85} \left(\frac{2.36 \mu^{1.5} L P^{0.85} A_f}{D_B^{1.15}} \right)_M$$

$$\Delta P_S = V_{B_S}^{1.85} \left(\frac{2.36 \mu^{1.5} L P^{0.85} A_f}{D_B^{1.15}} \right)_S$$

$$\rho_M = \rho_S$$

$$\mu_M = \mu_S$$

$$2L_M = L_S$$

$$2D_{B_M} = D_{B_S}$$

$$A_{f_M} = A_{f_S}$$

$$V_{B_M} = 2V_{B_S}$$

$$\frac{\Delta P_M}{\Delta P_S} = \left\{ \frac{(2V_{B_S})^{1.85} \left[\frac{2.36 \mu^{1.5} L P^{0.85} A_f}{D_{B_S}^{1.15}} \right]}{(V_{B_S})^{1.85} \left[\frac{2.36 \mu^{1.5} L P^{0.85} A_f}{(2D_{B_S})^{1.15}} \right]} \right\}$$

$$= \frac{2^{1.85} \times 2^{1.15}}{2} = 3.6 \times 2.24 / 2$$

$$= \underline{\underline{4/1}}$$

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Velocity & Pressure Drop Calculations
for Model of MAX H. Jet Shield

TITLE

31.1

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DATE 6-9-65

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FIGURE #2

VELOCITY THROUGH BALLS VS VELOCITY UP BACK
PLATE FOR PRMS WITH $\omega = 54.1^\circ/\text{SEC}$

$$V_B = 0.59 - .145 V_{BC}$$

FIGURE #3

6-15-65
R.M.M.

FIGURE #4

FLOW RATE THROUGH BALLS VS TOTAL FLOW RATE
LINES OF CONSTANT % OF FLOW THROUGH BALLS
FOR PRMS & FLOW MODEL

FIG. #5

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THT MODELS OF THE FRONT
PLATES AND THE BACK PLATES
OF THE PRMS

TITLE

3.1.2

JOB NO.

50-4804-01 (P-127)

DATE

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BY

G.A. WINKLER

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1

INTRODUCTION

FOLLOWING IS A SHORT EXPLANATION OF THE MODELS FOR THT-B OF THE FRONT PLATES AND THE BACK PLATES OF THE NRX-A4/EST VERTICAL SHIELD. FIGS. 3.1.2a & b SHOW THE BASIC OUTLINE OF THE MODELS VERSUS THE ACTUAL PIECE. A DISCUSSION OF ASSUMPTIONS AND INPUT IS GIVEN.

DISCUSSION

FIGS. 3.1.2a & b. DESCRIBE THE ACTUAL SHIELD CONFIGURATION VERSUS THAT USED FOR THT-B.

BALLS: THE BALLS WERE MOCKED UP BY A SERIES OF PLATES WHICH WERE DESIGNED TO DELIVER THE PROPER AMOUNT OF HEAT TO THE WATER. THE HEAT TRANSFER COEFFICIENT USED WAS CALCULATED USING AN EXPRESSION FOR PACKED BEDS. *

CORNERS: ROUND CORNERS WERE MOCKED UP BY SQUARE CORNERS. IN THE INSTANCE OF THE BOTTOM, REACTOR SIDE CHANNEL (SEE "A", FIG. 3.1.2a), THE HEAT TRANSFER COEFFICIENT WAS ADJUSTED TO TAKE INTO ACCOUNT THE FLOW AREA CHANGE.

* BIRD, STEWART, & LIGHTFOOT, "TRANSPORT PHENOMENA", p. 411.

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OTHERS: THE FIN (SEE "B", FIG 3.1.2a) WAS PUT IN TO AID IN EASING THE THT-B INPUT REQUIREMENTS. SINCE IT IS IN A LOW HEATING AREA AND DOES NOT AFFECT BUT A SMALL LOCAL AREA, THE ASSUMPTION IS A GOOD ONE. THE PART OF THE FIN INPUT WAS NEEDED IN ORDER TO OBTAIN AN ADIABATIC IN THAT AREA OF THE MODEL. ADIABATICS ARE INDICATED ON THE FIGURES. THE ADIABATICS IN THE PLATES WERE TAKEN AT THE MIDPOINT. THIS WILL NOT BE EXACTLY CORRECT DUE TO ATTENUATED GAMMA HEATING BUT IS WITHIN THE ACCURACY THAT THE HEAT TRANSFER COEFFICIENT FOR THE BALLS CAN BE CALCULATED. THESE ADIABATICS WERE CHOSEN IN ORDER TO SPLIT THE SHIELD INTO TWO PARTS. THIS WAS NECESSARY TO FIT THE PROBLEM TO THE DIMENSIONS OF THT-B.

INPUT:

INTERNAL HEAT GENERATION - HEATING RATES FOR THE VERTICAL SHIELD AS OF THIS DATE ARE NOT FINAL. THE HEATING RATES BEING USED HAVE BEEN GENERATED FROM RATES TRANSMITTED IN GSE-1371, DATED MAY 4, 1965. PLUS DATA FROM A TELECON ON MAY 28, 1965 (R.T. JOHNSON AND H.C. WOODSUM). THESE HEATING RATES ARE PRESENTED IN FIGURES 3.1.2 d & e. IT WAS NECESSARY TO ADJUST THE HEATING RATES FROM GSE-1371 FOR THE FOLLOWING REASONS:

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- 1) THE WATER CHANNELS GIVEN IN GSE-1371 ARE THE WRONG SIZE.
- 2) THE $\frac{1}{2}$ INCH ALUMINUM PLATE SHOWN IN GSE-1371 IS NOW $\frac{1}{4}$ INCH.
- 3) THE OUTER $\frac{1}{4}$ INCH BOREAL NOW FORMS A $\frac{1}{4}$ INCH WATER CHANNEL WITH THE OUTER $\frac{3}{4}$ INCH ALUMINUM.

FLOW RATES:

TOTAL FLOW RATE = 390 GPM (54.1 #/SEC)
FOR THE FRONT PLATES MODEL, A FLOW RATE OF 130 GPM (18 #/SEC) WAS INPUT AS THE FLOW RATE PAST THE O.D. OF THE $\frac{1}{4}$ INCH ALUMINUM PLATE AND THE I.D. OF THE MOCKED UP BALLS. THIS IS A POOR ESTIMATE. BETTER NUMBERS WILL BE FORTHCOMING FROM A FLOW TEST. THE TOTAL FLOW RATE WAS OBTAINED FROM GSE-1371.

MATERIALS:

PROPERTIES OF THE MATERIALS USED ARE GIVEN IN SECTION 5.10 OF THIS REPORT
THESE PROPERTIES ARE PRESENTED VERSUS TEMPERATURE.

TRANSIENTS:

THE TRANSIENT POWER RAMP IS SHOWN IN FIG 3.1.2c
THIS CURVE WAS GIVEN IN GSE-1371. WATER FLOW RATE IS A CONSTANT.

FIGURE 3.1.2a

NRX-A4/EST VERTICAL SHIELD
 BOTTOM SECTION

FIGURE 3.1.2b
NRX-A4/ES7 VERTICAL SHIELD
TOP SECTION

FIGURE 3.1.2C
TRANSIENT POWER RAMP (FROM GSE-1371)

6-2-65 GAW

KE SEMI-LOGARITHMIC 350-51
KUMMEL & EBERLE CO. NEWARK, N.J.
CYCLES TO DISINTEGRATION

KE SEMI-LOGARITHMIC 350-51
KUMMEL & EBERLE CO. NEWARK, N.J.
CYCLES TO DISINTEGRATION

HEATING RATE, WATTS/CM

2 ALUMINUM
100 WATER
20 BORAL
100 WATER
20 ALUMINUM

WATER-STEEL

100
20

100 BORAL
20 WATER
300 ALUMINUM

100 WATERS

20 JUN 1958

10000 31100

THT-B MODEL
OF A
PRMS SIDE PLATE

TITLE 3.1.3
JOB NO. 50-4804-01
DATE 6-14-65
BY R.M. WALKER
PAGE NO. 1/3 4

INTRODUCTION:

IN ORDER TO DETERMINE THE THERMAL STRESSES THAT WILL EXIST IN THE SIDE PLATES OF THE PRMS DURING THE NRX A-4 TEST, THE MAXIMUM ΔT 'S ACROSS THE PLATES MUST FIRST BE DETERMINED. TO FIND THESE ΔT 'S A THREE-DIMENSIONAL THT-B MODEL OF ONE OF THE SIDE PLATES IS BEING SET UP. THIS MODEL IS DISCUSSED BELOW.

DISCUSSION OF MODEL:

FIGURE 3.1.3 IS A "NON-SCALE" SKETCH OF THE PRMS END PLATE MODEL. THIS SKETCH SHOWS ONLY THE GENERAL SHAPE OF THE MODEL, AND THE LOCATION OF THE SIDE PLATE IN QUESTION.

THE CONSIDERATIONS AND ASSUMPTIONS BEING USED ON THIS MODEL ARE:

- (1) INPUT CONDITIONS ARE HELD AS CLOSE AS POSSIBLE TO THE ACTUAL CONDITIONS PREDICTED FOR THE NRX A-4 TEST.
- (2) HEATING RATES ARE THOSE GENERATED BY 'WANL. I.E. THE POWER RAMP IS THE SAME AS USED FOR THE FRONT AND BACK PLATE MODELS OF THE SHIELD.
- (3) MATERIAL PROPERTIES ARE THE SAME AS THOSE SPECIFIED IN SECTION 5.0 OF THIS REPORT

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- (4) HEAT TRANSFER COEFFICIENTS ARE CALCULATED USING THE DITTUS & BOELTER EQUATION. THIS ASSUMES THAT HEAT FLOWS FROM THE WALL TO THE FLUID (M.O.). IF THERE ARE AREAS WHERE THIS IS NOT TRUE NEW HEAT TRANSFER COEFFICIENTS WILL BE CALCULATED. } WAF 2/6
- (5) THREE-DIMENSIONAL HEAT TRANSFER IS ASSUMED
- (6) ALL OUTSIDE WALLS ARE ASSUMED ADIABATIC.
- (7) DIMENSIONS ARE TAKEN FROM THE PRMS DRAWING OF 6-9-65. THESE DIMENSIONS WILL BE REVISED IF NECESSARY.
- (8) SINCE THT-8 CANNOT HANDLE PARALLEL FLOW OF FLUIDS, A METHOD IS BEING DEVISED TO GET AROUND THIS PROBLEM.
- (9) AS SEEN IN FIG. 3.1.3 THE MODEL USED INCLUDES ALL OF THE SIDE PLATE OF THE SHIELD. THIS MEANS THAT THE NUMBER AND FINENESS OF THE NODES USED IS LIMITED. THIS MAY OR MAY NOT RESULT IN POOR ΔT_s . IF IT IS BELIEVED THAT THE ΔT_s ARE POOR THE PROBLEM WILL BE RERUN WITH THE AREAS INDICATING MAXIMUM ΔT_s REDIVIDED INTO SMALLER NODES.

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FIGURE 3.1.3

SHADED PORTION INDICATES AL PORTION OF SIDE PLATE
NON-SHADED PORTION INDICATES H₂O PORTION OF SIDE
PLATE MODEL.

3.1.4 Temperature Distribution in the Front Plates of the PRMS

(The input for this THTB heat transfer analysis is in the process of being debugged on the computer. It is anticipated that all input errors will be eliminated before June 22, 1965 at which time the results will be available.)

3.2 Privy Roof Mounted Shield Support

3.2.1 General

The present shield support design is the fifth in a series which has evolved since the 26th of May. No heat transfer calculations have been completed on this specific design for the reasons listed below:

- a) Many of the calculations already completed on previous configurations are applicable to this design.
- b) Previous results have disclosed no severe problem areas. Inspection of the design, coupled with these results, makes it possible to state with high confidence that no problems exist with this one. Thus, no quick calculations in critical areas have been required.
- c) The position of the support stand, under the shield, reduces the published heating rates to estimates. A simple estimate of attenuation of gammas by the internal plates as was done for previous designs will not improve their applicability. Consequently, the calculations already performed have yielded results which are well within the accuracy of the heating rates available at this time. It is estimated that the temperature levels reported here are slightly severe.
- d) The schedule dictates that work progress on problems unaffected by the support design changes and lack of firm heat generation input.

No pressure loss calculations have been performed specifically for this design. Those performed for previous designs showed that the exit configuration would have to be carefully designed to prevent flow mal-distributions. A qualitative design input was made, and it is felt that the problem is solved; however, confirming calculations have not yet been completed.

3.2.2 Discussion

The components in this design are as follows starting on the reactor side:

- a) A 2" vertical aluminum structural member cooled on one side
- b) A 1/2" vertical aluminum baffle cooled on one side
- c) A 2.5" internal plenum
- d) A 1/2" horizontal aluminum baffle cooled on one side which forms the plenum top and raises the heat transfer coefficient on the 2" structural aluminum top plate
- e) A 1/2" aluminum baffle cooled on one side, forming the back side of the plenum
- f) A 1/4" vertical boral sheet cooled on both sides
- g) A 3" steel plate cooled on both sides
- h) A 1/4" boral plate cooled on both sides
- i) A 2" vertical aluminum structural member

Two inch aluminum plates form the top and bottom closures of the support.

Because of the axial heating distribution, the location of the peak temperatures was known to be at the top of the stand at the adiabatic lines in each of the components. Peak surface temperatures would be found there also. Minimum temperatures were known to exist at the outside radius and at the bottom of the support. One dimensional slab geometry applied in all components except the corners. Cylindrical geometry was used for the two-dimensional and spherical geometry for the three-dimensional corners. In these latter cases the length of the corner effect was assumed to be limited to a thickness of the component. The inner radius was chosen to yield the same heat transfer surface as the square corner. The outer surface was chosen to yield the same total volume as the square section being considered.

The temperatures presented on the summary sheets have been calculated for previous designs but, as discussed before, are regarded as applicable for the present design.

The results show that over a general area in structural components the maximum temperature is 202°F with a temperature gradient of less than 30°F . It was found that the local condition existing in the two dimensional corner was a relatively minor effect. In the three dimensional corner the local effect raised the maximum temperature by 100°F and at this point the local boiling temperature was approached. It is expected that a three dimensional THT problem now in preparation will show that these results are more severe than the actual case.

As the present design is firmed up, the calculations will be updated to reflect only the configuration of the final design.

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**3.2.3 Summary of Temperature Calculations
along a Plane through the Support**

Stand

TITLE

3.2.3

JOB NO.

DATE

BY

PAGE NO.

1**MAXIMUM TEMPERATURES**

<u>Point Number*</u>	<u>Location</u>	<u>Temperature, °F</u>
1)	Aluminum plate closest to reactor; $T_{\max}$ at outside surface	190
2)	Same plate; T_s at internal surface	164
3)	1/2" aluminum baffle closest to reactor; T_s	102
4)	Same plate; $T_{\max}$	103
5)	2" aluminum top plate; $T_{\max}$	190
6)	Same plate; T_s	164
7)	1/2" aluminum plenum cover; T_s	102
8)	Same plate; $T_{\max}$	103
9)	1/2" aluminum plenum back wall; $T_{\max}$	98
10)	Same plate; T_s	97
11)	First boral sheet; T_{s1}	152
12)	Same plate; $T_{\max}$	187

*The point numbers refer to those shown in Figure 3.2.3.

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<u>Point Number</u>	<u>Location</u>	<u>Temperature, °F</u>
13)	Same plate; T_{s2}	146
14)	3" steel plate; T_{s1}	120
15)	Same plate; T_{max}	152
16)	Same plate; T_{s2}	120
17)	Second boron sheet; T_{s1}	93
18)	Same sheet; T_{max}	93
19)	Same sheet; T_{s2}	93
20)	2" aluminum plate; T_s	90
21)	Same plate; T_{max}	90
MINIMUM TEMPERATURES		
22)	2" aluminum plate; T_{max}	155
23)	Same plate; T_s	138
24)	1/2" aluminum baffle; T_s	98
25)	Same plate; T_{max}	98
26)	1/2" aluminum plenum back; T_{max}	95

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Point Number	Location	Temperature, °F
27)	Same plate; T_s	95
28)	First boral sheet; T_{s1}	137
29)	Same sheet; T_{max}	160
30)	Same sheet; T_{s2}	127
31)	3" steel plate; T_{s1}	110
32)	Same plate; T_{max}	131
33)	3" steel plate; T_{s2}	110
34)	Second boral sheet; T_{s1}	92
35)	Same sheet; T_{max}	92
36)	Same sheet; T_{s2}	92
37)	2" aluminum plate; T_s	90
38)	Same plate; T_{max}	90
SPECIAL AREAS		
39)	2" bottom plate under the plenum; T_{max}	124
	Same plate; $T_{s(max)}$	124

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<u>Point Number</u>	<u>Location</u>	<u>Temperature, °F</u>
40)	2" top plate at end of top baffle; T_s	164
41)	Same plate; T_{max}	190
42)	Corner of 2" top and side plates; T_{max}	233
43)	Same type of corner; T_s	203
44)	Corner of 2" top, side and end plates; T_{max}	324
45)	Same type of corner; T_s	276

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Figure 3.2.3
CROSS SECTION OF PRMSS SHOWING
LOCATIONS OF CALCULATED TEMPERATURES

4.0 Stress

4.1 Pressure Stress Analysis of the Privy Roof Mounted Shield

A preliminary stress analysis was conducted on the shield to determine the stresses caused by internal pressure. Because the pressure drop through the shield has not been determined, a firm design pressure is not yet available. It is estimated that the design pressure will be approximately 60 psi.

However, a pressure of 100 psi was used in the calculations. When the design pressure is definitely established, a final pressure stress analysis will be conducted. In addition, the final analysis will include the effects of the entire load environment which includes thermal loading, vibration and acoustical loading, wind loading, acceleration loading, etc.

In all areas examined stress levels are within the limits established by the design criteria. Some of the analyses have been conducted using simplified, but conservative, approaches. Justification for using such techniques are generally presented with the analysis. Models will be improved as time permits. As in the thermal stress analysis, a 22-region PETS code model will be used to provide a backup for determining axial forces, moments and stresses.

It should be noted that one variation to Section VIII of the ASME Pressure Vessel Code has been made. This variation occurs with respect to the spacing of the tie bolts. Specifically, paragraph UG-47 (g) states, "The maximum pitch shall be 8-1/2 in, except that for welded-in staybolts the pitch may be greater provided it does not exceed 15 times the diameter of the staybolt." The actual pitch on the shield is 14.1 in. Using 14.1 in. as input into the referenced formula yields a minimum plate thickness of .625 which is below the actual plate thickness of .75 inches.

The individual analyses are shown below. When material temperatures and corresponding thermal stresses are determined, they will be combined with actual pressure induced stresses to assure combined stresses are below design allowables.

The reports and analyses listed below may be found on the following pages:

- 4.1.1 "Pressure Stress Analysis of the Front and Back Plates of the PRMS"
- 4.1.2 "Pressure Stress Analysis of the Side and Top Plates of the PRMS"
- 4.1.3 "Stress Analysis of the Interior Aluminum and Boral Plates of the PRMS"
- 4.1.4 "Stress Analysis of the Ribs Supporting the Steel Balls in the PRMS"
- 4.1.5 "Pressure Stress Analysis of Welded Areas of the PRMS"
- 4.1.6 "Weight and Center of Gravity Analysis of the PRMS"

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4.1.1 PRESSURE STRESS ANALYSIS
OF THE
SIDE AND TOP PLATES
OF THE PRMS

TITLE 4.1.1
JOB NO. ST-166, 50-4804-01
DATE _____
BY _____
PAGE NO. 1

INTRODUCTION:

The analysis of the front and back ^{plates} is approached by breaking the plates into a "unit" area defined by the rectangle enclosed by the tie-bolts. The pressure acting over this area is then reacted by the four tie-bolts. Flat plate analysis may be used because the thickness-to-radius ratio of the curved panels is small.

The analysis is done in three parts. In Part 1, the stresses in the panels between the tie bolts are determined. Part 2 is an analysis using Section 8 of the ASME Pressure Vessel Code to determine the minimum wall thickness under the tie-bolts. Part 3 is an analysis of the tie-bolts, aluminum plugs, and Slimserts.

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Stresses on Outer Plate
From Pressure & Bolt Reactions
(Part 1)

TITLE 4.1.1
JOB NO. ST-166 50420401
DATE _____
BY LAN
PAGE NO. 2

The following model is used, a continuous flat plate supported on columns.

The columns are the steel bolts which support the internal pressure load which is here assumed to be 100PSI. The deflection and moments are obtained by the method in Timoshenko, "Plates & Shells".

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2nd ed., p. 249. The deflection at the center of the plate section is

$$W = \alpha \frac{Pb^4}{D} \quad \text{where } D = \frac{Eh^3}{12(1-\nu^2)} = 3.864 \times 10^5$$

$$b = 13.654 \text{ in}$$

$$a = 11.75 \text{ in}$$

$$b/a = 1.162$$

From Table 57 for b/a of 1.16 we have

$$\alpha = .00458 \times .948 = .435 \quad (\text{corrected for } \nu=.3)$$

$$\therefore W = \frac{(.00435)(100)(13.654)^4}{3.864 \times 10^5} = \frac{15,119}{3.864 \times 10^5} = .0391 \text{ in}$$

Also from Table 57, the moments are

$$M_y = \beta P b^2 \quad M_x = \beta_1 P b^2$$

For b/a of 1.16

$$\beta = .0236 \times .948$$

$$= .0224$$

$$\beta_1 = .0358 \times .948$$

$$= .0339$$

$$\therefore M_y = (.0224)(100)(13.654)^2 = 417.6 \text{ in.lb./in}$$

$$M_x = (.0339)(100)(13.654)^2 = 632.0 \text{ in.lb./in}$$

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These moments are at the center of the plate. The corresponding stresses are

$$\sigma_y = \frac{6 \times 417.6}{.5625} = \underline{4450 \text{ PSI}}$$

$$\sigma_x = \frac{6 \times 632}{.5625} = \underline{6750 \text{ PSI}}$$

Similar coefficients are obtained from Table 61, p.258 for the location $y = \frac{1}{2}, x = 0$

$$\beta_2 = -.0179 \times .948 = -.0170$$

$$\beta_1 = .0494 \times .948 = .0468$$

$$\therefore M_y = (-.0170)(100)(13.654)^2 = \underline{-317 \text{ in lb/in}}$$

$$M_x = (.0468)(100)(13.654)^2 = \underline{873 \text{ in lb/in}}$$

and

$$\sigma_y = \frac{6 \times (-317)}{.5625} = \underline{-3380 \text{ PSI}}$$

$$\sigma_x = \frac{6 \times 873}{.5625} = \underline{9300 \text{ PSI}}$$

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The same coefficients can be used in reverse order for the location $x = b/2$
 $y = 0$.

$$M_y = (.0468)(100)(11.75)^2 = \underline{647 \text{ in lb/in}}$$

$$M_x = (-.0170)(100)(11.75)^2 = \underline{-234.5 \text{ in lb/in}}$$

and

$$\sigma_y = \frac{6 \times 647}{.5625} = \underline{6900 \text{ PSI}}$$

$$\sigma_x = \frac{6 \times (-234.5)}{.5625} = \underline{2500 \text{ PSI}}$$

By symmetry, the shear across the plate at all these points is zero.

To these stresses the membrane stresses must be added.

In the vertical direction the membrane stress is can be obtained simply as P/A .

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$$P = \left[135 * \frac{\pi}{180} * 51.5 + 3.5 \right] * 7.5 * 100 = \underline{93600 \text{ lb}}$$

$$A = \left[135 * \frac{\pi}{180} * 51.5 \right] [9 - 7.5] - 3.5 * 7.5 + 5 * 9 = \underline{199 \text{ in}^2}$$

$$\sigma_y (\text{membrane}) = \frac{93600}{199} = \underline{470 \text{ PSI}}$$

In the horizontal direction the membrane stress will be a sum of a similar P/A calculation plus the bourdon tube bending stress, treating the shield cross section as a simple beam.

$$P = 121.875 * 7.5 * 100 = \underline{91,300 \text{ lb}}$$

$$A = 122.675 * 1.5 + 9 + 7.5 * 7.5 = \underline{198.6 \text{ in}^2}$$

$$q = \frac{2(R_o - R_i) 100 \text{ PSI}}{2(R_o + R_i)/2} \quad 121.875 = 1773 \text{ lb/in}$$

$$M = \frac{q l^2}{2} = \frac{1773}{2} (51.5 \sin 33.75^\circ)^2 = 725000 \text{ in lb}$$

$$I = \frac{1}{12} [123.625 * 9^3 - 121.875 * 7.5^3] = 387066 \text{ in}^4$$

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$$\begin{aligned}\sigma_x(\text{membrane}) &= \frac{P}{A} + \frac{M_e}{I} = \frac{91300}{1986} + \frac{725000 \times 4.5}{38706.6} \\ &= 460. + 84. = \underline{\underline{544 \text{ PSI}}}\end{aligned}$$

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Stresses on Outer Plate
From Pressure and Bolt
Reactions

(Part 2)

TITLE 4.1.1
JOB NO. 50-4804-01
DATE JUNE 14, 1965
BY PUTMAN
PAGE NO. 1 8

PROBLEM: TO DETERMINE THE MINIMUM ALLOWABLE PLATE THICKNESS FOR THE STAYED OUTER PLATE OF THE PRMS, DUE TO INTERNAL PRESSURE, EXCLUSIVE OF CORROSION ALLOWANCE.

SOLUTION: THE SOLUTION IS TAKEN FROM SECTION VIII OF THE BOILER CODE; BRACED AND STAYED SURFACES, UG 47, PAGES 27-28.

A. MINIMUM THICKNESS FOR THE
OUTER ALUMINUM PLATE WHEN
RADIALLY SUPPORTED WITH TIE
BOLTS(t)

$$\begin{aligned} t &= p \sqrt{\frac{P}{SC}} \\ &= (14.1) \sqrt{\frac{100}{(20400)(2.5)}} \\ &= \frac{14.1}{\sqrt{(2.04)(2.5)(10^3)}} \\ &= \underline{\underline{0.6244 \text{ IN}}} \end{aligned}$$

THE TERMS USED IN THIS
EXPRESSION WERE SELECTED ON
THE FOLLOWING BASIS:
(NEXT PAGE)

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1. P = MAXIMUM PITCH MEASURED BETWEEN STRAIGHT LINES PASSING THROUGH THE CENTERS OF THE TIE BOLTS IN DIFFERENT ROWS. THE MAXIMUM DISTANCE OCCURS BETWEEN ANY TWO ROWS OF BOLTS VERTICALLY. THIS DISTANCE IS ALONG THE ARC LENGTH OF THE OUTSIDE DIAMETER.

$$\begin{aligned} H &= 2\Theta \\ R^* &= 56 \text{ IN} \\ C^* &= 14.0 \text{ IN} \end{aligned}$$

$$p = R H$$

$$\tan \Theta = \frac{c/2}{b} = \frac{c/2}{\sqrt{R^2 - (c/2)^2}} = \frac{7}{\sqrt{56^2 - 7^2}} = \frac{7}{55.56}$$

$$= 0.126$$

$$\Theta = 7.183^\circ$$

$$H = 14.366^\circ \text{ OR } 0.251 \text{ RADIANS}$$

* REFERENCE PRELIMINARY PRMS LAYOUT

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1. (CONTINUED)
THEREFORE:

$$\begin{aligned} P &= R \textcircled{H} \\ &= (56)(.25) \\ &= \underline{14.10 \text{ IN}} \end{aligned}$$

2. $S = 20,400 \text{ PSI.}$

FROM SECTION III OF THE BOILER CODE THE MAXIMUM ALLOWABLE TENSILE STRESS IS GIVEN AS $\frac{2}{3}$ OF YIELD OR $\frac{1}{3}$ OF THE ULTIMATE STRENGTH WHICHEVER IS LESS. THE PREDICTED TEMPERATURE FOR THE SHIELD WALL IS 150°F. AT 150°F THE MAXIMUM ALLOWABLE TENSILE STRESS IS $13,600 \text{ PSI}$ BASED ON SECTION II OF CODE. HOWEVER, THE STRESS IN THIS PROBLEM IS PRIMARY BENDING. SECTION III OF THE CODE ALLOWS THE MAXIMUM PRIMARY BENDING STRESS TO BE 1.5 OF THE MAXIMUM MEMBRANE STRESS, AS SHOWN IN FIG. N-414 PAGE 17 OF SECTION III.

THEREFORE, MAXIMUM ALLOWABLE STRESS IN PRIMARY BENDING IS $(1.5)(13600)$ OR 20400 PSI.

3. THE CONSTANT $C = 2.5.$

THIS VALUE WAS SELECTED FROM THE LIST GIVEN ON PAGES 27-28

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OF SECTION VIII OF THE CODE, THE VALUE OF $C=2.8$ WAS CONSIDERED AS SATISFYING MOST OF THE CONDITIONS WHICH ACTUALLY EXIST IN THE SHIELD. HOWEVER, TO BE CERTAIN OF A CONSERVATIVE SOLUTION THE VALUE OF $C=2.5$ WAS SELECTED FOR THIS ANALYSIS.

4. DESIGN PRESSURE (P)

THE DESIGN PRESSURE USED FOR THIS ANALYSIS IS 100 PSI

NOTE:

If a value for S of 13,600 psi which is the design allowable σ_m of 6061-T6 aluminum at 150°F is used, the min thickness is:

$$\begin{aligned}
 t &= p \sqrt{\frac{P}{SC}} \\
 &= 14.1 \sqrt{\frac{100}{(13,600)(2.5)}} \\
 &= \frac{141}{(36,500)^{1/2}} = \frac{141}{191} = .74
 \end{aligned}$$

This value of t is approximately the actual wall thickness although the design pressure used is 100 psi rather than the estimated design pressure of 60 psi.

Tie Bolts

And Vicinity (Part 3)

TITLE 4.1.1
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Tie Bolt Calculations

The worst condition on the tie bolts occurs near the center of the shield where almost all the pressure load on the outer plate is transmitted thru the bolts to the inner plate. The pressure area that an individual bolt must support on the outer plate is shown. On the inner plate the horizontal length is only 11.801"

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If we assume each of the inner and outer plates take half of the bourdon tube bending load, then an average pressure area should be used in this calculation.

The tensile load in the bolt is then

$$100 \times \frac{13.654 + 11.801}{2} \times 11.75 = 14,980.16.$$

where 100 PSI has temporarily been assumed.

The tensile stress is

$$\sigma = \frac{\text{Load}}{A_{\text{min}}} = \frac{14,980}{0.2506} = 59,776 \text{ PSI } \left(\frac{5}{8} \text{ bolt}\right)$$

Since Section III allows $\frac{1}{3} S_y$ in bolts, This is acceptable for 180,000 PSI bolts.

Bearing Stress (under bolt head):

A special head and an 'O' ring seal groove as shown will be used.

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The bearing area is then

$$A_b = \frac{\pi}{4} (1.195^2 - .750^2) = .680 \text{ in}^2$$

And the bearing stress is

$$\sigma_b = \frac{14,980}{.680} = \underline{22,030 \text{ PSI}}$$

Since the bearing stress allowable in Section III is $2.25 S_m$ or 31,500 PSI where the bearing area is not near the edge of a plate, this is good @ 100 PSI.

Direct Shear Stress

The shear area in the plate under the head of the bolt is

$$A_s = \pi * 1.195 * .750 = \underline{2.816 \text{ in}^2}$$

The direct shear stress is then

$$\tau_s = \frac{14,980}{2.816} = \underline{5320 \text{ PSI}}$$

which is well below the allowable of $.6 S_m = 8400 \text{ PSI}$.

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SHEAR ANALYSIS

The critical shear area of the joint assembly should be the internal threads of the aluminum plug. Since the outer plug threads have more shear area than the inner threads, this stress need not be calculated. However, as a precaution the shear stress of the external thread of the 5/8" bolt and the shear stress of the internal thread of the slimsert should be examined.

The analysis is taken from a paper by R.C. Boucher entitled "Strength of Threads", Product Engineering, 11/27/61.

The slimsert (SR 628 L) has a 5/8-18 UNF internal thread and a 3/4-16 UNF external thread.

Shear stress in the internal threads of the Al plug

The min shear area of an internal 3/4-16 UNF class 3B thread is $1.728 \text{ in}^2/\text{in}$.

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The total thread length of the slimsert is .94 inches, however the last two threads do not engage completely. The length of thread engagement is therefore:

$$.94 - \frac{2}{16} = .815 \text{ inches.}$$

$$\begin{aligned} \sigma_{\text{shear}} &= F/A \quad \text{where } F = \text{pressure reaction load.} \\ &= \frac{14,980}{1.7285(.815)} \\ &= 10,600 \text{ psi} \end{aligned}$$

The direct shear allowable for 6061-T6 Al is .65m or 8300 psi at 150°F. Therefore the shear allowable is exceeded at a design pressure of 100 psi. However, at the expected design pressure of 60 psi, the shear stress in the threads of the plug is only 6400 psi, which is well below the design allowable.

Shear stress in the external threads of the A-286 bolt.

Since the strength of the slimsert is the same strength as the A-286 5/8" bolt, the weaker thread is the external thread of the bolt. The shear area for a 5/18-UNF Class 3A external thread is 1.1349 in²/in

$$\sigma_{\text{shear}} = \frac{14,980}{1.1349(.815)} = 16,300 \text{ psi}$$

which is well below, the design allowable of 60 KSI.

4.1.2 Pressure Stress Analysis of the Side and Top Plates of the PRMS

(This analysis is complete, but is being reviewed and checked before being released. It will be released before June 22, 1965)

4.1.3 Stress Analysis of the Interior Aluminum and Boral Plates of the
PRMS

(This analysis is complete, but is being reviewed and checked
before being released. It will be released before June 22, 1965.)

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4.1.4 STRESS ANALYSIS OF RIBS
SUPPORTING THE STEEL BALLS
IN THE PRMS

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I BEARING STRESS ON THE VERTICAL RIBS
DUE TO THE WEIGHT OF THE STEEL
BALLS (σ_B)

A. DETERMINE THE WEIGHT OF THE STEEL
BALLS

1. VOLUME OF CHAMBER FOR STEEL
BALLS. (V)

TOP VIEW
FIGURE 1

a. CROSS SECTIONAL AREA (A)

$$\begin{aligned}
 A &= A_1 + A_2 \\
 &= \frac{\pi}{4} \cdot \frac{3}{8} (D_o^2 - D_i^2) + (3.5)(5.75) \\
 &= \frac{3\pi}{32} [(109.5)^2 - (98)^2] + 20.125 \\
 &= \frac{3\pi}{32} (11,990 - 9604) + 20.125 \\
 &= \frac{3\pi}{32} (2386) + 20.125 \\
 &= 702.75 + 20.125
 \end{aligned}$$

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$$A = \underline{722.875 \text{ IN}^2}$$

b. VOLUME OF CHAMBER (V)

$$\begin{aligned} V &= Ah \\ &= (722.875)(115) \\ &= \underline{83,130 \text{ IN}^3} \end{aligned}$$

h = HEIGHT OF
CHAMBER
= 115"

2. VOLUME OF STEEL BALLS (V_B)

ASSUME VOLUME OF BALLS 70%
OF VOLUME OF CHAMBER, I.E. 30% VOIDS
BETWEEN BALLS.

$$\begin{aligned} V_B &= (0.7)(83,130) \\ &= \underline{58,191.0 \text{ IN}^3} \end{aligned}$$

3. WEIGHT OF STEEL BALLS (W)

$$\begin{aligned} W &= \rho V_B \\ &= (0.286)(58,191) \\ &= \underline{16,643 \text{ LB}} \end{aligned}$$

ρ = DENSITY OF STEEL
= 0.286 LB/IN³

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B. VERTICAL LOAD PER VERTICAL RIB (V)

$$\begin{aligned} V &= \frac{16,643}{n} \\ &= \frac{16643}{76} \\ &= \underline{\underline{219 \text{ LB/RIB.}}} \end{aligned}$$

n = NUMBER OF RIBS

C. BEARING STRESS ON RIB DUE TO LOAD FROM BALLS (σ_B)

$$\begin{aligned} \sigma_B &= \frac{V}{A} \\ &= \frac{219}{(5.75)(.25)} \\ &= \underline{\underline{152.34 \text{ PSI}}} \end{aligned}$$

A = BEARING AREA
= (0.25)(5.75)

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II BUCKLING OF THE VERTICAL RIB DUE TO LOADS FROM THE STEEL BALLS

A. THE LOAD FROM THE STEEL BALLS WAS 219 LB OR $\frac{219}{5.75} = 38.1 \frac{\text{LB}}{\text{IN.}}$

B. CRITICAL BUCKLING LOAD FOR A FLAT PLATE SIMPLY SUPPORTED ON TWO OPPOSITE SIDES AND LOADED IN COMPRESSION ON THE OTHER TWO SIDES WHICH ARE UNSUPPORTED. * (N_{CR})

FIGURE 2

$$* N_{CR} = \frac{\pi^2 D}{b^2} \left(\frac{b}{a} + \frac{a}{b} \right)^2$$

$$= \frac{\pi^2 E h^3}{b^2 12(1-\nu^2)} \left(\frac{b}{a} + \frac{a}{b} \right)^2$$

$$b = 5.75''$$

$$a = 1.875''$$

$$h = .25''$$

$$D = \frac{E h^3}{12(1-\nu^2)}$$

* S. P. TIMOSHENKO & J. M. GERE, "THEORY OF ELASTIC STABILITY", MCGRAW HILL, NY, 1961, PP. 351-53.

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$$\begin{aligned}
 N_{cr} &= \frac{\pi^2 (10^7) (.25)^3}{(5.75)^2 (12) (1-.33^4)} \left(\frac{5.75}{1.875} + \frac{1.875}{5.75} \right)^2 \\
 &= \frac{(\pi^2) (10^7) (.015625)}{(33.0625) (12) (.891)} (3.067 + .326)^2 \\
 &= \frac{\pi^2 (10^4) (15.625) (11.512)}{(33.0625) (12) (.891)} \\
 &= \underline{50220. \text{ LB/IN.}} \quad \checkmark
 \end{aligned}$$

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III BEARING STRESS FROM THE OUTSIDE
VERTICAL BORAL SHIELD RESTING ON THE
VERTICAL RIB. (∇_B)

A VOLUME OF THE OUTSIDE BORAL
SHIELD (V)

$$\begin{aligned} V &= L \times h \times t \\ &= \left[\frac{3}{8} \pi D_m + 1.5 \right] (116) \left(\frac{1}{4} \right) \\ &= \left[\frac{3}{8} \pi (109.75) + 1.5 \right] (29) \\ &= (129.3 + 1.5) (29) \\ &= (130.8) (29) \\ &= \underline{3793.2 \text{ IN}^3} \end{aligned}$$

L = LENGTH OF SHIELD
 h = HEIGHT OF SHIELD
 t = THICKNESS OF SHIELD

$$L = \frac{3}{8} \pi D_m + 1.5$$

D_m = MEAN DIA. OF
 BORAL SHIELD.

B. WEIGHT OF THE OUTSIDE BORAL SHIELD
(W)

$$\begin{aligned} W &= \rho V \\ &= (0.0914) (3793.2) \\ &= \underline{346.7 \text{ LB.}} \end{aligned}$$

ρ = DENSITY OF
 BORAL (LB/IN³)

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DISTRIBUTED TO VERTICAL RIBS (W/RIB)

$$W/RIB = \frac{346.7}{N}$$

N = NUMBER OF RIBS
= 76 RIBS

$$= \frac{346.7}{76}$$

$$= \underline{4.562 \text{ LB/RIB}}$$

D. BEARING STRESS BETWEEN VERTICAL RIB
AND OUTSIDE BORAL SHIELD (σ_B)

$$\sigma_B = W/RIB / A$$

$$= \frac{4.562}{\left(\frac{1}{4}\right)\left(\frac{1}{4}\right)}$$

$$= (4.562)(16)$$

$$= \underline{73 \text{ PSI}}$$

A = BEARING AREA

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IV BEARING STRESS DUE TO THE ALUMINUM FLOW DIVIDER RESTING ON THE VERTICAL RIB (T_B)

A. VOLUME OF THE FLOW DIVIDER (V)

$$V = L \times h \times t$$

$$= \left[\frac{3}{8} \pi D_m + 2.25 \right] (115.75) (t)$$

$$= \left[\frac{3\pi}{8} (97.75) + 2.25 \right] (115.75) (.25)$$

$$= (115.159 + 2.25) (115.75) (.25)$$

$$= (117.41) (115.75) (.25)$$

$$= \underline{\underline{3398 \text{ IN}^3}}$$

$$L = \text{LENGTH OF DIVIDER}$$

$$= \frac{3}{8} \pi D_m + 2.25$$

$$h = \text{HEIGHT OF DIVIDER}$$

$$t = \text{THICKNESS OF DIVIDER}$$

B. WEIGHT OF ALUMINUM FLOW DIVIDER (W)

$$W = \rho V$$

$$= (0.098) (3398)$$

$$= \underline{\underline{333 \text{ LB}}}$$

$$\rho = \text{DENSITY OF AL}$$

$$\text{FLOW DIVIDER}$$

C. WEIGHT OF ALUMINUM FLOW DIVIDER DISTRIBUTED TO VERTICAL RIBS (W/RIB)

$$W_{\text{RIB}} = \frac{W}{n}$$

$$= \frac{333}{76}$$

$$= \underline{\underline{4.38 \text{ LB/RIB}}}$$

$$n = \text{NUMBER OF RIBS}$$

$$= 76$$

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D. BEARING STRESS BETWEEN VERTICAL RIB AND ALUMINUM FLOW DIVIDER (σ_B)

$$\begin{aligned}\sigma_B &= W_{RIB} / A \\ &= \frac{4.38}{\frac{1}{4} \times \frac{1}{4}} \\ &= (4.38)(16) \\ &= \underline{70.08 \text{ PSI}}\end{aligned}$$

IV UNIFORM LOAD ON THE FLOW SEPARATOR WHERE INSIDE BORAL SHIELD RESTS ON FLOW SEPARATOR (W)

A. VOLUME OF INSIDE BORAL SHIELD (V)

$$\begin{aligned}V &= L \times h \times t \\ &= \left[\frac{3}{8} \pi (96.5) + 1.5 \right] (16)^{29} \left(\frac{1}{4} \right) \\ &= (113.69 + 1.5)(29) \\ &= (115.19)(29) \\ &= \underline{3341 \text{ IN}^3}\end{aligned}$$

B. WEIGHT OF INSIDE BORAL SHIELD (W)

$$\begin{aligned}W &= \rho V \\ &= (0.0914)(3341) \\ &= \underline{305.4 \text{ LB.}}\end{aligned}$$

$\rho = 0.0914 \text{ LB/IN}^3$

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C. UNIFORM LOAD (W) (LB/IN) ON FLOW SEPARATOR

$$W = \frac{W}{L}$$

$$= \frac{305.4}{115.19}$$

$$= \underline{\underline{2.65 \text{ LB/IN}}}$$

L = LENGTH OF
INNER BORAL
SHIELD.

SUMMARY:

It is seen that all stresses in the ribs are small although only a 1G vertical loading rather than a 2G vertical load.

4.1.5 Pressure Stress Analysis of Welded Areas of the PRMS

(This analysis is complete, but is being reviewed and checked before being released. It will be released before June 22, 1965.)

4.1.6 Weight and Center of Gravity Analysis of the PRMS

(This analysis is almost complete and must be reviewed and checked before being released. It will be released before June 22, 1965.)

4.2 Thermal Stresses in the Privy Roof Mounted Shield

During a full power run, the shield will experience a high, non-linear thermal environment. Because of this condition and because the boundary conditions for a shield with this geometry are unknown, an exact solution for the thermal stresses cannot be obtained. As usual, the practical stress analysis is conducted on the basis of a strength of materials approach.

The method of analysis used to determine the stresses in the top and end sections of the shield where they join the front and back plates is to allow an unconstrained thermal growth of all the plates and then calculate the stresses produced by forcing the plates to be a continuous structure. The analytical model considers a section of unit width in the circumferential direction, thereby ignoring the curvature of the shield. However, the error caused by ignoring curvature is small because the depth to radius ratio is small.

The thermal stresses in the top and side sections are due to differential growth of the front plate with respect to the back plate and the growth of the top and side plates. By using Castigliano's theorem, the deflections and rotations can be obtained in terms of unknown forces and moments. These forces and moments are evaluated by using compatibility relationships and known thermal growths.

Two analyses are presented. One considers the steady state thermal condition, and the other considers the worst transient condition. Actual stress values are not given at this time because thermal input is not available. The same analyses will be used for both the top section and the side sections. The only difference is that the axial height used in the top section analysis will be replaced by one-half the arc length in the end section analysis.

As a backup, thermal stresses in the shield will be determined by a 22-region PETS code model. Since the PETS code is an axi-symmetric shells of revolution computer code, and the shield is only $3/8$ of a complete surface of revolution, only the axial stress results are believed to be realistic.

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4.2.1 Thermal Stresses in the
Top and Side Sections
of the PRMS

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Top Section: Transient Condition

Transient Case

Figure 1

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During the transient condition, the front plate heats up faster than the back plate & the top plate sees a thermal gradient in the radial direction from the front to the back plate. Assuming that this top plate thermal growth is shared equally by the front & back plates, the model below will be used to obtain an approximate solution. Consider a unit width beam.

Figure 2
Back R

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Front Plate

Using Castigliano's theorem, the deflections & rotation at point ① of the front plate can be found by taking the partial derivative of the strain energy with respect to the loading under consideration, & the deflection will be in the direction of the loading.

The strain energy due to the loads is

$$U = \frac{V_1^2 l}{2AE} + \int_0^l \frac{m^2}{2EI} dx$$

and $m = m_1 - H_1 x$

Horizontal Deflection

$$\begin{aligned} \delta_{H_1} &= \frac{\partial U}{\partial H_1} = \frac{1}{EI} \int_0^l m \frac{dm}{dH_1} dx = \frac{1}{EI} \int_0^l (m_1 - H_1 x)(-x dx) \\ &= \frac{1}{EI} \left\{ -m_1 \int_0^l x dx + H_1 \int_0^l x^2 dx \right\} \\ &= \frac{1}{EI} \left\{ -m_1 \frac{l^2}{2} + H_1 \frac{l^3}{3} \right\} \end{aligned}$$

$$\delta_{H_1} = -\frac{m_1 l^2}{2EI} + \frac{H_1 l^3}{3EI}$$

(1)

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BY H. H. LukePAGE NO. Part 1, 4 of 34Vertical Deflection

$$\delta_{V_1} = \frac{\partial U}{\partial V_1} = \frac{V_1 l}{AE} \quad (2)$$

Rotation

$$\theta_1' = \frac{\partial U}{\partial m_1} = \frac{1}{EI} \int_0^l m \frac{dm}{dm_1} dx = \frac{1}{EI} \int_0^l (m_1 - H_1 x) dx$$

$$\theta_1' = \frac{1}{EI} \left\{ m_1 l - H_1 \frac{l^2}{2} \right\} = \frac{m_1 l}{EI} - \frac{H_1 l^2}{2EI} \quad (3)$$

Back Plate

In a similar manner, the deflections & rotation at point (4) of the back plate can be found by considering the strain energy.

Therefore,

$$U = \frac{V_4^2 l}{2AE} + \int_0^l \frac{m^2}{2EI} dx$$

and

$$m = m_4 + H_4 x$$

Thus, $\frac{dm}{dH_4} = x$ & $\frac{dm}{dm_4} = 1$

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Horizontal Deflection

$$\begin{aligned}\delta_{H_4} &= \frac{\partial U}{\partial H_4} = \frac{1}{EI} \int_0^l m \frac{dm}{dH_4} dx = \frac{1}{EI} \int_0^l (m_4 + H_4 x) (x dx) \\ &= \frac{1}{EI} \left\{ m_4 \int_0^l x dx + H_4 \int_0^l x^2 dx \right\} \\ &= \frac{1}{EI} \left\{ m_4 \frac{l^2}{2} + H_4 \frac{l^3}{3} \right\}\end{aligned}$$

$$\delta_{H_4} = \frac{m_4 l^2}{2EI} + \frac{H_4 l^3}{3EI} \quad (4)$$

Vertical Deflection

$$\delta_{V_4} = \frac{\partial U}{\partial V_4} = \frac{V_4 l}{AE} \quad (5)$$

Rotation

$$\begin{aligned}\theta_4' &= \frac{\partial U}{\partial m_4} = \frac{1}{EI} \int_0^l m \frac{dm}{dm_4} dx = \frac{1}{EI} \int_0^l (m_4 + H_4 x) dx \\ &= \frac{1}{EI} \left\{ m_4 l + H_4 \frac{l^2}{2} \right\}\end{aligned}$$

$$\theta_4' = \frac{m_4 l}{EI} + \frac{H_4 l^2}{2EI} \quad (6)$$

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Top Section Plate

Figure 3

Consider the left corner of Fig. 3.

The strain energy of corner

(1-2) is

$$U = \int_0^s \frac{m^2 ds}{2EI}$$

(7)

The moment at mn , any point along the arc, is

$$M = V_2 r \cos \phi - H_2 r (1 - \sin \phi) + m_2 + V_1 r (1 - \cos \phi) - H_1 r \sin \phi - m_1 \quad (8)$$

$$ds = r d\phi$$

$$\therefore U = \int_0^{\pi/2} \frac{m^2}{2EI} r d\phi \quad (9)$$

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Using Castigliano's theorem, the deflections & rotations of each end of the left corner can be determined by taking the partial derivative of the strain energy with respect to the loading under consideration. This will give the deflection or rotation in the direction of the load or moment being considered. Therefore, beginning at point ①, the horizontal deflection of ① is ΔH_1 and is

$$\Delta H_1 = \frac{\partial U}{\partial H_1} = \frac{1}{EI} \int_0^{\pi/2} m \frac{dm}{dH_1} r d\phi \quad (10)$$

$$\frac{dm}{dH_1} = -r \sin \phi$$

$$\Delta H_1 = \frac{1}{EI} \int_0^{\pi/2} [V_2 r \cos \phi - H_2 r (1 - \sin \phi) + m_2 + V_1 r (1 - \cos \phi) - H_1 r \sin \phi - m_1] [-r^2 \sin \phi] d\phi \quad (11)$$

Integrate (11)

$$\Delta H_1 = \frac{1}{EI} \left\{ - \int_0^{\pi/2} V_2 r^3 \cos \phi \sin \phi d\phi + \int_0^{\pi/2} H_2 r^3 \sin \phi (1 - \sin \phi) d\phi - \int_0^{\pi/2} m_2 r^2 \sin \phi d\phi - \int_0^{\pi/2} V_1 r^3 \sin \phi (1 - \cos \phi) d\phi + \int_0^{\pi/2} H_1 r^3 \sin^2 \phi d\phi + \int_0^{\pi/2} m_1 r^2 \sin \phi d\phi \right\}$$

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$$\Delta H_1 = \frac{1}{EI} \left\{ -V_2 r^3 \int_0^{\pi/2} \cos \phi \sin \phi d\phi + H_2 r^3 \int_0^{\pi/2} \sin \phi (1 - \sin \phi) d\phi \right. \\ \left. - m_2 r^2 \int_0^{\pi/2} \sin \phi d\phi - V_1 r^3 \int_0^{\pi/2} \sin \phi (1 - \cos \phi) d\phi \right. \\ \left. + H_1 r^3 \int_0^{\pi/2} \sin^2 \phi d\phi + m_1 r^2 \int_0^{\pi/2} \sin \phi d\phi \right\}$$

$$\Delta H_1 = \frac{1}{EI} \left\{ -\frac{V_2 r^3}{2} + H_2 r^3 \left(1 - \frac{\pi}{4}\right) - m_2 r^2 - \frac{V_1 r^3}{2} + \frac{H_1 r^3 \pi}{4} + m_1 r^2 \right\}$$

$$\Delta H_1 = -\frac{V_2 r^3}{2EI} + \frac{H_2 r^3}{EI} \left(1 - \frac{\pi}{4}\right) - \frac{m_2 r^2}{EI} - \frac{V_1 r^3}{2EI} + \frac{\pi H_1 r^3}{4EI} + \frac{m_1 r^2}{EI} \quad (12)$$

Vertical Deflection at ①

$$\Delta V_1 = \frac{\partial u}{\partial V_1} = \frac{1}{EI} \int_0^{\pi/2} m \frac{dm}{dV_1} r d\phi$$

$$\frac{dm}{dV_1} = r(1 - \cos \phi)$$

$$\Delta V_1 = \frac{1}{EI} \int_0^{\pi/2} [V_2 r \cos \phi - H_2 r (1 - \sin \phi) + m_2 + V_1 r (1 - \cos \phi) \\ - H_1 r \sin \phi - m_1] [r^2 (1 - \cos \phi)] d\phi \quad (13)$$

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$$\Delta V_1 = \frac{1}{EI} \left\{ V_2 r^3 \int_0^{\pi/2} \cos \phi (1 - \cos \phi) d\phi - H_2 r^3 \int_0^{\pi/2} (1 - \sin \phi)(1 - \cos \phi) d\phi \right. \\ \left. + m_2 r^2 \int_0^{\pi/2} (1 - \cos \phi) d\phi + V_1 r^3 \int_0^{\pi/2} (1 - \cos \phi)^2 d\phi \right. \\ \left. - H_1 r^3 \int_0^{\pi/2} \sin \phi (1 - \cos \phi) d\phi - m_1 r^2 \int_0^{\pi/2} (1 - \cos \phi) d\phi \right\}$$

$$\Delta V_1 = \frac{1}{EI} \left\{ V_2 r^3 \left(1 - \frac{\pi}{4}\right) - H_2 r^3 \left(\frac{\pi - 3}{2}\right) + m_2 r^2 \left(\frac{\pi}{2} - 1\right) \right. \\ \left. + V_1 r^3 \left(\frac{3\pi}{4} - 2\right) - \frac{H_1 r^3}{2} - m_1 r^2 \left(\frac{\pi}{2} - 1\right) \right\}$$

$$\Delta V_1 = \frac{V_2 r^3}{EI} \left(1 - \frac{\pi}{4}\right) - \frac{H_2 r^3}{2EI} (\pi - 3) + \frac{m_2 r^2}{EI} \left(\frac{\pi}{2} - 1\right) + \frac{V_1 r^3}{EI} \left(\frac{3\pi}{4} - 2\right) \\ - \frac{H_1 r^3}{2EI} - \frac{m_1 r^2}{EI} \left(\frac{\pi}{2} - 1\right) \quad (14)$$

Rotation at ①

$$\theta_1 = \frac{\partial u}{\partial m_1} = \frac{1}{EI} \int_0^{\pi/2} m \frac{dm}{dm_1} r d\phi$$

$$\frac{dm}{dm_1} = -1$$

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$$\Theta_1 = \frac{1}{EI} \int_0^{\pi/2} [V_2 r \cos \phi - H_2 r (1 - \sin \phi) + m_2 + V_1 r (1 - \cos \phi) - H_1 r \sin \phi - m_1] [-r d\phi] \quad (15)$$

$$\Theta_1 = \frac{1}{EI} \left\{ -V_2 r^2 \int_0^{\pi/2} \cos \phi d\phi + H_2 r^2 \int_0^{\pi/2} (1 - \sin \phi) d\phi - m_2 \int_0^{\pi/2} r d\phi - V_1 r^2 \int_0^{\pi/2} (1 - \cos \phi) d\phi + H_1 r^2 \int_0^{\pi/2} \sin \phi d\phi + m_1 \int_0^{\pi/2} r d\phi \right\}$$

$$\Theta_1 = \frac{1}{EI} \left\{ -V_2 r^2 + H_2 r^2 \left(\frac{\pi}{2} - 1 \right) - m_2 r \frac{\pi}{2} - V_1 r^2 \left(\frac{\pi}{2} - 1 \right) + H_1 r^2 + m_1 r \frac{\pi}{2} \right\}$$

$$\Theta_1 = -\frac{V_2 r^2}{EI} + \frac{H_2 r^2}{EI} \left(\frac{\pi}{2} - 1 \right) - \frac{\pi m_2 r}{2EI} - \frac{V_1 r^2}{EI} \left(\frac{\pi}{2} - 1 \right) + \frac{H_1 r^2}{EI} + \frac{\pi m_1 r}{2EI} \quad (16)$$

Horizontal Deflection at (2)

$$\Delta H_2 = \frac{\partial u}{\partial H_2} = \frac{1}{EI} \int_0^{\pi/2} m \frac{dm}{dH_2} r d\phi$$

$$\frac{dm}{dH_2} = -r(1 - \sin \phi)$$

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$$\Delta H_2 = \frac{1}{EI} \int_0^{\pi/2} [V_2 r \cos \phi - H_2 r (1 - \sin \phi) + m_2 + V_1 r (1 - \cos \phi) - H_1 r \sin \phi - m_1] [-r^2 (1 - \sin \phi) d\phi] \quad (17)$$

$$= \frac{1}{EI} \left\{ -V_2 r^3 \int_0^{\pi/2} \cos \phi (1 - \sin \phi) d\phi + H_2 r^3 \int_0^{\pi/2} (1 - \sin \phi)^2 d\phi - m_2 r^2 \int_0^{\pi/2} (1 - \sin \phi) d\phi - V_1 r^3 \int_0^{\pi/2} (1 - \cos \phi)(1 - \sin \phi) d\phi + H_1 r^3 \int_0^{\pi/2} \sin \phi (1 - \sin \phi) d\phi + m_1 r^2 \int_0^{\pi/2} (1 - \sin \phi) d\phi \right\}$$

$$= \frac{1}{EI} \left\{ -\frac{V_2 r^3}{2} + H_2 r^3 \left(\frac{3\pi}{4} - 2 \right) - m_2 r^2 \left(\frac{\pi}{2} - 1 \right) - \frac{V_1 r^3}{2} (\pi - 3) + H_1 r^3 \left(1 - \frac{\pi}{4} \right) + m_1 r^2 \left(\frac{\pi}{2} - 1 \right) \right\}$$

$$\Delta H_2 = -\frac{V_2 r^3}{2EI} + \frac{H_2 r^3}{EI} \left(\frac{3\pi}{4} - 2 \right) - \frac{m_2 r^2}{EI} \left(\frac{\pi}{2} - 1 \right) - \frac{V_1 r^3}{2EI} (\pi - 3) + \frac{H_1 r^3}{EI} \left(1 - \frac{\pi}{4} \right) + \frac{m_1 r^2}{EI} \left(\frac{\pi}{2} - 1 \right) \quad (18)$$

Vertical Deflection at (2)

$$\Delta V_2 = \frac{\partial U}{\partial V_2} = \frac{1}{EI} \int_0^{\pi/2} m \frac{dm}{dV_2} r d\phi$$

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$$\frac{dm}{dv_2} = r \cos \phi$$

$$\Delta V_2 = \frac{1}{EI} \int_0^{\pi/2} [V_2 r \cos \phi - H_2 r (1 - \sin \phi) + m_2 + V_1 r (1 - \cos \phi) - H_1 r \sin \phi - m_1] [r^2 \cos \phi d\phi] \quad (19)$$

$$\Delta V_2 = \frac{1}{EI} \left\{ V_2 r^3 \int_0^{\pi/2} \cos^2 \phi d\phi - H_2 r^3 \int_0^{\pi/2} \cos \phi (1 - \sin \phi) d\phi + m_2 r^2 \int_0^{\pi/2} \cos \phi d\phi + V_1 r^3 \int_0^{\pi/2} \cos \phi (1 - \cos \phi) d\phi - H_1 r^3 \int_0^{\pi/2} \sin \phi \cos \phi d\phi - m_1 r^2 \int_0^{\pi/2} \cos \phi d\phi \right\}$$

$$= \frac{1}{EI} \left\{ V_2 r^3 \frac{\pi}{4} - \frac{H_2 r^3}{2} + m_2 r^2 + V_1 r^3 \left(1 - \frac{\pi}{4}\right) - \frac{H_1 r^3}{2} - m_1 r^2 \right\}$$

$$\Delta V_2 = \frac{\pi V_2 r^3}{4EI} - \frac{H_2 r^3}{2EI} + \frac{m_2 r^2}{EI} + \frac{V_1 r^3}{EI} \left(1 - \frac{\pi}{4}\right) - \frac{H_1 r^3}{2EI} - \frac{m_1 r^2}{EI} \quad (20)$$

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Rotation at ②

$$\theta_2 = \frac{\partial u}{\partial m_2} = \frac{1}{EI} \int_0^{\pi/2} m \frac{dm}{dm_2} r d\phi$$

$$\frac{dm}{dm_2} = 1$$

$$\theta_2 = \frac{1}{EI} \int_0^{\pi/2} [V_2 r \cos \phi - H_2 r (1 - \sin \phi) + m_2 + V_1 r (1 - \cos \phi) - H_1 r \sin \phi - m_1] [r d\phi] \quad (21)$$

$$\theta_2 = \frac{1}{EI} \left\{ V_2 r^2 \int_0^{\pi/2} \cos \phi d\phi - H_2 r^2 \int_0^{\pi/2} (1 - \sin \phi) d\phi + m_2 \int_0^{\pi/2} r d\phi + V_1 r^2 \int_0^{\pi/2} (1 - \cos \phi) d\phi - H_1 r^2 \int_0^{\pi/2} \sin \phi d\phi - m_1 \int_0^{\pi/2} r d\phi \right\}$$

$$\theta_2 = \frac{1}{EI} \left\{ V_2 r^2 - H_2 r^2 \left(\frac{\pi}{2} - 1 \right) + m_2 r \frac{\pi}{2} + V_1 r^2 \left(\frac{\pi}{2} - 1 \right) - H_1 r^2 - m_1 r \frac{\pi}{2} \right\}$$

$$\theta_2 = \frac{V_2 r^2}{EI} - \frac{H_2 r^2}{EI} \left(\frac{\pi}{2} - 1 \right) + \frac{\pi m_2 r}{2EI} + \frac{V_1 r^2}{EI} \left(\frac{\pi}{2} - 1 \right) - \frac{H_1 r^2}{EI} - \frac{\pi m_1 r}{2EI} \quad (22)$$

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Consider the flat portion of the top section.

Figure 4

The strain energy of the above section is

$$U = \frac{H_2^2 b}{2AE} + \frac{H_3^2 b}{2AE} + \int_0^b \frac{m^2 dx}{2EI} \quad (23)$$

where

$$m = V_2 x - m_2 + V_3 (b - x) - m_3 \quad (24)$$

Using Castigliano's theorems, the deflections & rotations of each end can be determined & they will be in the direction of the load or moment under consideration. Therefore, beginning at point 2, the horizontal deflection of 2 is $\Delta H_2'$.

$$\Delta H_2' = \frac{\partial U}{\partial H_2} = \frac{H_2 b}{AE} \quad (25)$$

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Vertical Deflection at (2)

$$\Delta V_2' = \frac{\partial U}{\partial V_2} = \int_0^b \frac{m \frac{dm}{dV_2}}{EI} dx$$

$$\frac{dm}{dV_2} = \kappa$$

$$\Delta V_2' = \frac{1}{EI} \int_0^b [V_2 x - m_2 + V_3 (b-x) - m_3] \kappa dx$$

$$= \frac{1}{EI} \left\{ V_2 \int_0^b x^2 dx - m_2 \int_0^b x dx + V_3 \int_0^b (b-x) x dx - m_3 \int_0^b x dx \right\}$$

$$= \frac{1}{EI} \left\{ V_2 \frac{b^3}{3} - m_2 \frac{b^2}{2} + V_3 \left[\frac{bx^2}{2} - \frac{x^3}{3} \right]_0^b - m_3 \frac{b^2}{2} \right\}$$

$$\Delta V_2' = \frac{V_2 b^3}{3EI} - \frac{m_2 b^2}{2EI} + \frac{V_3 b^3}{6EI} - \frac{m_3 b^2}{2EI} \quad (26)$$

Rotation at (2)

$$\theta_2' = \frac{\partial U}{\partial m_2} = \frac{1}{EI} \int_0^b m \frac{dm}{dm_2} dx$$

$$\frac{dm}{dm_2} = -1$$

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$$\begin{aligned}\theta_2' &= \frac{1}{EI} \int_0^b [V_2 x - m_2 + V_3 (b-x) - m_3] [-dx] \\ &= \frac{1}{EI} \left\{ -\int_0^b V_2 x dx + \int_0^b m_2 dx - V_3 \int_0^b (b-x) dx + m_3 \int_0^b dx \right\} \\ &= \frac{1}{EI} \left\{ -V_2 \frac{b^2}{2} + m_2 b - V_3 \frac{b^2}{2} + m_3 b \right\}\end{aligned}$$

$$\theta_2' = -\frac{V_2 b^2}{2EI} + \frac{m_2 b}{EI} - \frac{V_3 b^2}{2EI} + \frac{m_3 b}{EI} \quad (27)$$

Consider Point (3)

Horizontal Deflection at (3)

$$\Delta H_3' = \frac{\partial u}{\partial H_3} = \frac{H_3 b}{AE} \quad (28)$$

Vertical Deflection at (3)

$$\Delta V_3' = \frac{\partial u}{\partial V_3} = \frac{1}{EI} \int_0^b m \frac{dm}{dV_3} dx$$

$$\frac{dm}{dV_3} = (b-x)$$

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$$\begin{aligned}
 \Delta V_3' &= \frac{1}{EI} \int_0^b [V_2 x - m_2 + V_3(b-x) - m_3] [b-x] dx \\
 &= \frac{1}{EI} \left\{ V_2 \int_0^b (b-x)x dx - m_2 \int_0^b (b-x) dx + V_3 \int_0^b (b-x)^2 dx \right. \\
 &\quad \left. - m_3 \int_0^b (b-x) dx \right\} \\
 &= \frac{1}{EI} \left\{ V_2 \int_0^b (bx - x^2) dx - m_2 \int_0^b (bdx - x dx) + V_3 \int_0^b (b^2 - 2bx + x^2) dx \right. \\
 &\quad \left. - m_3 \int_0^b (bdx - x dx) \right\} \\
 &= \frac{1}{EI} \left\{ V_2 \left(b \frac{x^2}{2} - \frac{x^3}{3} \right) - m_2 \left(bx - \frac{x^2}{2} \right) + V_3 \left(b^2 x - 2b \frac{x^2}{2} + \frac{x^3}{3} \right) \right. \\
 &\quad \left. - m_3 \left(bx - \frac{x^2}{2} \right) \right\}_0^b \\
 &= \frac{1}{EI} \left\{ V_2 \frac{b^3}{6} - m_2 \frac{b^2}{2} + V_3 \frac{b^3}{3} - m_3 \frac{b^2}{2} \right\}
 \end{aligned}$$

$$\Delta V_3' = \frac{V_2 b^3}{6EI} - \frac{m_2 b^2}{2EI} + \frac{V_3 b^3}{3EI} - \frac{m_3 b^2}{2EI} \quad (29)$$

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Rotation at ③

$$\theta_3' = \frac{\partial u}{\partial m_3} = \frac{1}{EI} \int_0^b m \frac{dm}{dm_3} dx$$

$$\frac{dm}{dm_3} = -1$$

$$\therefore \theta_3' = \frac{1}{EI} \int_0^b [V_2 x - m_2 + V_3 (b-x) - m_3] [-dx]$$

$$= \frac{1}{EI} \left\{ -V_2 \int_0^b x dx + m_2 \int_0^b dx - V_3 \int_0^b (b-x) dx + m_3 \int_0^b dx \right\}$$

$$= \frac{1}{EI} \left\{ -V_2 \frac{x^2}{2} + m_2 x - V_3 \left(bx - \frac{x^2}{2} \right) + m_3 x \right\}_0^b$$

$$= \frac{1}{EI} \left\{ -V_2 \frac{b^2}{2} + m_2 b - V_3 \frac{b^2}{2} + m_3 b \right\}$$

$$\theta_3' = -\frac{V_2 b^2}{2EI} + \frac{m_2 b}{EI} - \frac{V_3 b^2}{2EI} + \frac{m_3 b}{EI} \quad (30)$$

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Consider the right corner of Fig. 3

The strain energy of corner (3-4) is

$$U = \int_0^{\pi/2} \frac{m^2 ds}{2EI}$$

The moment at $m-n$, any point along the arc, is

$$m = V_3 r \cos \phi + H_3 r (1 - \sin \phi) + m_3 + V_4 r (1 - \cos \phi) + H_4 r \sin \phi - m_4 \quad (31)$$

$$ds = r d\phi$$

$$\therefore U = \int_0^{\pi/2} \frac{m^2 r d\phi}{2EI}$$

Again, using Castigliano's theorem, the deflections & rotations of each end of the right corner (3-4) can be determined. This will give the deflection or rotation in the direction of the load or moment being considered. Therefore, beginning at point ③, the horizontal deflection of ③ is ΔH_3 .

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$$\Delta H_3 = \frac{\partial u}{\partial H_3} = \frac{1}{EI} \int_0^{\pi/2} m \frac{dm}{dH_3} r d\phi$$

$$\frac{dm}{dH_3} = r(1 - \sin\phi)$$

$$\Delta H_3 = \frac{1}{EI} \int_0^{\pi/2} [V_3 r \cos\phi + H_3 r(1 - \sin\phi) + m_3 + V_4 r(1 - \cos\phi) + H_4 r \sin\phi - m_4] [r^2(1 - \sin\phi) d\phi] \quad (32)$$

$$\Delta H_3 = \frac{1}{EI} \left\{ V_3 r^3 \int_0^{\pi/2} \cos\phi (1 - \sin\phi) d\phi + H_3 r^3 \int_0^{\pi/2} (1 - \sin\phi)^2 d\phi + m_3 r^2 \int_0^{\pi/2} (1 - \sin\phi) d\phi + V_4 r^3 \int_0^{\pi/2} (1 - \cos\phi)(1 - \sin\phi) d\phi + H_4 r^3 \int_0^{\pi/2} \sin\phi (1 - \sin\phi) d\phi - m_4 r^2 \int_0^{\pi/2} (1 - \sin\phi) d\phi \right\}$$

$$= \frac{1}{EI} \left\{ V_3 r^3 \frac{\pi}{2} + H_3 r^3 \left(\frac{3\pi}{4} - 2 \right) + m_3 r^2 \left(\frac{\pi}{2} - 1 \right) + V_4 r^3 \frac{(\pi - 3)}{2} + H_4 r^3 \left(1 - \frac{\pi}{4} \right) - m_4 r^2 \left(\frac{\pi}{2} - 1 \right) \right\}$$

$$\Delta H_3 = \frac{V_3 r^3}{2EI} + \frac{H_3 r^3}{EI} \left(\frac{3\pi}{4} - 2 \right) + \frac{m_3 r^2}{EI} \left(\frac{\pi}{2} - 1 \right) + \frac{V_4 r^3}{2EI} (\pi - 3) + \frac{H_4 r^3}{EI} \left(1 - \frac{\pi}{4} \right) - \frac{m_4 r^2}{EI} \left(\frac{\pi}{2} - 1 \right) \quad (33)$$

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Vertical Deflection at (3)

$$\Delta V_3 = \frac{\partial U}{\partial V_3} = \frac{1}{EI} \int_0^{\pi/2} m \frac{dm}{dV_3} r d\phi$$

$$\frac{dm}{dV_3} = r \cos \phi$$

$$\Delta V_3 = \frac{1}{EI} \int_0^{\pi/2} [V_3 r \cos \phi + H_3 r (1 - \sin \phi) + m_3 + V_4 r (1 - \cos \phi) + H_4 r \sin \phi - m_4] [r^2 \cos \phi d\phi] \quad (34)$$

$$\begin{aligned} \Delta V_3 &= \frac{1}{EI} \left\{ V_3 r^3 \int_0^{\pi/2} \cos^2 \phi d\phi + H_3 r^3 \int_0^{\pi/2} \cos \phi (1 - \sin \phi) d\phi \right. \\ &\quad + m_3 r^2 \int_0^{\pi/2} \cos \phi d\phi + V_4 r^3 \int_0^{\pi/2} \cos \phi (1 - \cos \phi) d\phi \\ &\quad \left. + H_4 r^3 \int_0^{\pi/2} \sin \phi \cos \phi d\phi - m_4 r^2 \int_0^{\pi/2} \cos \phi d\phi \right\} \\ &= \frac{1}{EI} \left\{ V_3 r^3 \frac{\pi}{4} + H_3 r^3 \frac{1}{2} + m_3 r^2 + V_4 r^3 \left(1 - \frac{\pi}{4}\right) + H_4 r^3 \frac{1}{2} - m_4 r^2 \right\} \end{aligned}$$

$$\Delta V_3 = \frac{\pi V_3 r^3}{4EI} + \frac{H_3 r^3}{2EI} + \frac{m_3 r^2}{EI} + \frac{V_4 r^3}{EI} \left(1 - \frac{\pi}{4}\right) + \frac{H_4 r^3}{2EI} - \frac{m_4 r^2}{EI} \quad (35)$$

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Rotation at ③

$$\theta_3 = \frac{\partial u}{\partial m_3} = \frac{1}{EI} \int_0^{\pi/2} m \frac{dm}{dm_3} r d\phi$$

$$\frac{dm}{dm_3} = 1$$

$$\theta_3 = \frac{1}{EI} \int_0^{\pi/2} [V_3 r \cos \phi + H_3 r (1 - \sin \phi) + m_3 + V_4 r (1 - \cos \phi) + H_4 r \sin \phi - m_4] [r d\phi] \quad (36)$$

$$\theta_3 = \frac{1}{EI} \left\{ V_3 r^2 \int_0^{\pi/2} \cos \phi d\phi + H_3 r^2 \int_0^{\pi/2} (1 - \sin \phi) d\phi + m_3 r \int_0^{\pi/2} d\phi + V_4 r^2 \int_0^{\pi/2} (1 - \cos \phi) d\phi + H_4 r^2 \int_0^{\pi/2} \sin \phi d\phi - m_4 r \int_0^{\pi/2} d\phi \right\}$$

$$= \frac{1}{EI} \left\{ V_3 r^2 + H_3 r^2 \left(\frac{\pi}{2} - 1 \right) + m_3 r \frac{\pi}{2} + V_4 r^2 \left(\frac{\pi}{2} - 1 \right) + H_4 r^2 - m_4 r \frac{\pi}{2} \right\}$$

$$\theta_3 = \frac{V_3 r^2}{EI} + \frac{H_3 r^2}{EI} \left(\frac{\pi}{2} - 1 \right) + \frac{\pi m_3 r}{2EI} + \frac{V_4 r^2}{EI} \left(\frac{\pi}{2} - 1 \right) + \frac{H_4 r^2}{EI} - \frac{\pi m_4 r}{2EI} \quad (37)$$

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Horizontal Deflection at (4)

$$\Delta H_4 = \frac{\partial U}{\partial H_4} = \frac{1}{EI} \int_0^{\pi/2} m \frac{dm}{dH_4} r d\phi$$

$$\frac{dm}{dH_4} = r \sin \phi$$

$$\Delta H_4 = \frac{1}{EI} \int_0^{\pi/2} [V_3 r \cos \phi + H_3 r (1 - \sin \phi) + m_3 + V_4 r (1 - \cos \phi) + H_4 r \sin \phi - m_4] [r^2 \sin \phi d\phi] \quad (38)$$

$$\Delta H_4 = \frac{1}{EI} \left\{ V_3 r^3 \int_0^{\pi/2} \cos \phi \sin \phi d\phi + H_3 r^3 \int_0^{\pi/2} \sin \phi (1 - \sin \phi) d\phi + m_3 r^2 \int_0^{\pi/2} \sin \phi d\phi + V_4 r^3 \int_0^{\pi/2} \sin \phi (1 - \cos \phi) d\phi + H_4 r^3 \int_0^{\pi/2} \sin^2 \phi d\phi - m_4 r^2 \int_0^{\pi/2} \sin \phi d\phi \right\}$$

$$= \frac{1}{EI} \left\{ V_3 \frac{r^3}{2} + H_3 r^3 \left(1 - \frac{\pi}{4}\right) + m_3 r^2 + V_4 \frac{r^3}{2} + H_4 r^3 \frac{\pi}{4} - m_4 r^2 \right\}$$

$$\Delta H_4 = \frac{V_3 r^3}{2EI} + \frac{H_3 r^3}{EI} \left(1 - \frac{\pi}{4}\right) + \frac{m_3 r^2}{EI} + \frac{V_4 r^3}{2EI} + \frac{\pi H_4 r^3}{4EI} - \frac{m_4 r^2}{EI} \quad (39)$$

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Vertical Deflection at (4)

$$\Delta V_4 = \frac{\partial u}{\partial V_4} = \frac{1}{EI} \int_0^{\pi/2} m \frac{dm}{dV_4} r d\phi$$

$$\frac{dm}{dV_4} = r(1 - \cos \phi)$$

$$\therefore \Delta V_4 = \frac{1}{EI} \int_0^{\pi/2} [V_3 r \cos \phi + H_3 r(1 - \sin \phi) + m_3 + V_4 r(1 - \cos \phi) + H_4 r \sin \phi - m_4] [r^2(1 - \cos \phi) d\phi] \quad (40)$$

$$\Delta V_4 = \frac{1}{EI} \left\{ V_3 r^3 \int_0^{\pi/2} \cos \phi (1 - \cos \phi) d\phi + H_3 r^3 \int_0^{\pi/2} (1 - \cos \phi)(1 - \sin \phi) d\phi + m_3 r^2 \int_0^{\pi/2} (1 - \cos \phi) d\phi + V_4 r^3 \int_0^{\pi/2} (1 - \cos \phi)^2 d\phi + H_4 r^3 \int_0^{\pi/2} \sin \phi (1 - \cos \phi) d\phi - m_4 r^2 \int_0^{\pi/2} (1 - \cos \phi) d\phi \right\}$$

$$= \frac{1}{EI} \left\{ V_3 r^3 \left(1 - \frac{\pi}{4}\right) + H_3 r^3 \left(\pi - 3\right) + m_3 r^2 \left(\frac{\pi}{2} - 1\right) + V_4 r^3 \left(\frac{3\pi}{4} - 2\right) + H_4 r^3 \left(\frac{\pi}{2}\right) - m_4 r^2 \left(\frac{\pi}{2} - 1\right) \right\}$$

$$\Delta V_4 = \frac{V_3 r^3}{EI} \left(1 - \frac{\pi}{4}\right) + \frac{H_3 r^3}{2EI} (\pi - 3) + \frac{m_3 r^2}{EI} \left(\frac{\pi}{2} - 1\right) + \frac{V_4 r^3}{EI} \left(\frac{3\pi}{4} - 2\right) + \frac{H_4 r^3}{2EI} - \frac{m_4 r^2}{EI} \left(\frac{\pi}{2} - 1\right) \quad (41)$$

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Rotation at (4)

$$\theta_4 = \frac{\partial u}{\partial m_4} = \frac{1}{EI} \int_0^{\pi/2} m \frac{dm}{dm_4} r d\phi$$

$$\frac{dm}{dm_4} = -1$$

$$\begin{aligned} \theta_4 = \frac{1}{EI} \int_0^{\pi/2} [V_3 r \cos \phi + H_3 r (1 - \sin \phi) + m_3 + V_4 r (1 - \cos \phi) \\ + H_4 r \sin \phi - m_4] [-r d\phi] \end{aligned} \quad (42)$$

$$\begin{aligned} \theta_4 = \frac{1}{EI} \left\{ -V_3 r^2 \int_0^{\pi/2} \cos \phi d\phi - H_3 r^2 \int_0^{\pi/2} (1 - \sin \phi) d\phi - m_3 r \int_0^{\pi/2} d\phi \right. \\ \left. - V_4 r^2 \int_0^{\pi/2} (1 - \cos \phi) d\phi - H_4 r^2 \int_0^{\pi/2} \sin \phi d\phi + m_4 r \int_0^{\pi/2} d\phi \right\} \\ = \frac{1}{EI} \left\{ -V_3 r^2 - H_3 r^2 \left(\frac{\pi}{2} - 1 \right) - m_3 r \frac{\pi}{2} - V_4 r^2 \left(\frac{\pi}{2} - 1 \right) \right. \\ \left. - H_4 r^2 + m_4 r \frac{\pi}{2} \right\} \end{aligned}$$

$$\begin{aligned} \theta_4 = -\frac{V_3 r^2}{EI} - \frac{H_3 r^2}{EI} \left(\frac{\pi}{2} - 1 \right) - \frac{\pi m_3 r}{2EI} - \frac{V_4 r^2}{EI} \left(\frac{\pi}{2} - 1 \right) \\ - \frac{H_4 r^2}{EI} + \frac{\pi m_4 r}{2EI} \end{aligned} \quad (43)$$

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Compatibility Equations

$$\Delta F_{VT} = \delta_{V_1} + \Delta V_1 + \Delta V_2 + \Delta V_2' \quad (44)$$

where ΔF_{VT} = Axial thermal growth of the front plate including the corner

$$\Delta F_{HT} = \delta_{H_1} + \Delta H_1 + \Delta H_2 + \Delta H_2' \quad (45)$$

where $\Delta F_{HT} = \frac{1}{2}$ Total radial growth of the top plate including the corners

$$\Delta B_{VT} = \delta_{V_4} + \Delta V_4 + \Delta V_3 + \Delta V_3' \quad (46)$$

where ΔB_{VT} = Axial thermal growth of the back plate including the corner

$$\Delta B_{HT} = \delta_{H_4} + \Delta H_4 + \Delta H_3 + \Delta H_3' \quad (47)$$

where $\Delta B_{HT} = \frac{1}{2}$ total radial growth of the top plate including the corners

$$\Delta V_2 = \Delta V_2' \quad (48)$$

$$\theta_1 = -\theta_1' \quad (52)$$

$$\Delta H_2 = \Delta H_2' \quad (49)$$

$$\theta_2 = -\theta_2' \quad (53)$$

$$\Delta V_3 = \Delta V_3' \quad (50)$$

$$\theta_3 = -\theta_3' \quad (54)$$

$$\Delta H_3 = \Delta H_3' \quad (51)$$

$$\theta_4 = -\theta_4' \quad (55)$$

Let us now substitute the appropriate deflection & rotation relationships into the compatibility equations.

$$\begin{aligned}\Delta F_{VT} = & \frac{l}{AE} V_1 + \frac{r^3}{EI} \left(\frac{3\pi}{4} - 2 \right) V_1 - \frac{r^3}{2EI} H_1 - \frac{r^2}{EI} \left(\frac{\pi}{2} - 1 \right) m_1 + \frac{r^3}{EI} \left(1 - \frac{\pi}{4} \right) V_2 \\ & - \frac{r^3}{2EI} (\pi - 3) H_2 + \frac{r^2}{EI} \left(\frac{\pi}{2} - 1 \right) m_2 + \frac{r^3}{EI} \left(1 - \frac{\pi}{4} \right) V_1 - \frac{r^3}{2EI} H_1 - \frac{r^2}{EI} m_1 \\ & + \frac{\pi r^3}{4EI} V_2 - \frac{r^3}{2EI} H_2 + \frac{r^2}{EI} m_2 + \frac{b^3}{3EI} V_2 - \frac{b^2}{2EI} m_2 + \frac{b^3}{6EI} V_3 - \frac{b^2}{2EI} m_3\end{aligned}$$

Collecting terms yield

$$\begin{aligned}\Delta F_{VT} = & \left[\frac{r^3}{EI} \left(\frac{\pi}{2} - 1 \right) + \frac{l}{AE} \right] V_1 - \frac{r^3}{EI} H_1 - \frac{\pi r^2}{2EI} m_1 + \left[\frac{r^3}{EI} + \frac{b^3}{3EI} \right] V_2 - \frac{r^3}{EI} \left(\frac{\pi}{2} - 1 \right) H_2 \\ & + \left[\frac{\pi r^2}{2EI} - \frac{b^2}{2EI} \right] m_2 + \frac{b^3}{6EI} V_3 - \frac{b^2}{2EI} m_3\end{aligned}\quad (56)$$

$$\begin{aligned}\Delta F_{HT} = & \frac{l^3}{3EI} H_1 - \frac{l^2}{2EI} m_1 - \frac{r^3}{2EI} V_1 + \frac{\pi r^3}{4EI} H_1 + \frac{r^2}{EI} m_1 - \frac{r^3}{2EI} V_2 \\ & \frac{r^3}{EI} \left(1 - \frac{\pi}{4} \right) H_2 - \frac{r^2}{EI} m_2 - \frac{r^3}{2EI} (\pi - 3) V_1 + \frac{r^3}{EI} \left(1 - \frac{\pi}{4} \right) H_1 + \frac{r^2}{EI} \left(\frac{\pi}{2} - 1 \right) m_1 \\ & - \frac{r^3}{2EI} V_2 + \frac{r^3}{EI} \left(\frac{3\pi}{4} - 2 \right) H_2 - \frac{r^2}{EI} \left(\frac{\pi}{2} - 1 \right) m_2 + \frac{b}{AE} H_2\end{aligned}$$

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Collecting terms yield

$$\Delta F_{HT} = -\frac{r^3}{EI} \left(\frac{\pi}{2} - 1 \right) V_1 + \left[\frac{l^3}{3EI} + \frac{r^3}{EI} \right] H_1 + \left[\frac{\pi r^2}{2EI} - \frac{l^2}{2EI} \right] m_1 - \frac{r^3}{EI} V_2$$

$$\left[\frac{b}{AE} + \frac{r^3}{EI} \left(\frac{\pi}{2} - 1 \right) \right] H_2 - \frac{\pi r^2}{2EI} m_2 \quad (57)$$

$$\theta_1 + \theta_1' = 0$$

$$-\frac{r^2}{EI} V_2 + \frac{r^2}{EI} \left(\frac{\pi}{2} - 1 \right) H_2 - \frac{\pi r}{2EI} m_2 - \frac{r^2}{EI} \left(\frac{\pi}{2} - 1 \right) V_1 + \frac{r^2}{EI} H_1$$

$$+ \frac{\pi r}{2EI} m_1 - \frac{l^2}{2EI} H_1 + \frac{l}{EI} m_1 = 0$$

Collecting terms yield

$$-\frac{r^2}{EI} \left(\frac{\pi}{2} - 1 \right) V_1 + \left[\frac{r^2}{EI} - \frac{l^2}{2EI} \right] H_1 + \left[\frac{\pi r}{2EI} + \frac{l}{EI} \right] m_1 - \frac{r^2}{EI} V_2$$

$$+ \frac{r^2}{EI} \left(\frac{\pi}{2} - 1 \right) H_2 - \frac{\pi r}{2EI} m_2 = 0 \quad (58)$$

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$$\theta_2 + \theta_2' = 0$$

$$\frac{r^2}{EI} \left(\frac{\pi}{2} - 1 \right) V_1 - \frac{r^2}{EI} H_1 - \frac{\pi r}{2EI} m_1 + \frac{r^2}{EI} V_2 - \frac{r^2}{EI} \left(\frac{\pi}{2} - 1 \right) H_2$$

$$\frac{\pi r}{2EI} m_2 - \frac{b^2}{2EI} V_2 + \frac{b}{EI} m_2 - \frac{b^2}{2EI} V_3 + \frac{b}{EI} m_3 = 0$$

Collecting terms yield

$$\frac{r^2}{EI} \left(\frac{\pi}{2} - 1 \right) V_1 - \frac{r^2}{EI} H_1 - \frac{\pi r}{2EI} m_1 + \left[\frac{r^2}{EI} - \frac{b^2}{2EI} \right] V_2 - \frac{r^2}{EI} \left(\frac{\pi}{2} - 1 \right) H_2$$

$$\left[\frac{\pi r}{2EI} + \frac{b}{EI} \right] m_2 - \frac{b^2}{2EI} V_3 + \frac{b}{EI} m_3 = 0 \quad (59)$$

$$\Delta V_2' - \Delta V_2 = 0$$

$$\frac{b^3}{3EI} V_2 - \frac{b^2}{2EI} m_2 + \frac{b^3}{6EI} V_3 - \frac{b^2}{2EI} m_3 - \frac{\pi r^3}{4EI} V_2 + \frac{r^3}{2EI} H_2$$

$$- \frac{r^2}{EI} m_2 - \frac{r^3}{EI} \left(1 - \frac{\pi}{4} \right) V_1 + \frac{r^3}{2EI} H_1 + \frac{r^2}{EI} m_1 = 0$$

Collecting terms yield

$$- \frac{r^3}{EI} \left(1 - \frac{\pi}{4} \right) V_1 + \frac{r^3}{2EI} H_1 + \frac{r^2}{EI} m_1 + \left[\frac{b^3}{3EI} - \frac{\pi r^3}{4EI} \right] V_2 + \frac{r^3}{2EI} H_2$$

$$- \left[\frac{b^2}{2EI} + \frac{r^2}{EI} \right] m_2 + \frac{b^3}{6EI} V_3 - \frac{b^2}{2EI} m_3 = 0 \quad (60)$$

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$$\Delta H_2 - \Delta H_2' = 0$$

$$-\frac{r^3}{2EI}(\pi-3)V_1 + \frac{r^3}{EI}\left(1-\frac{\pi}{4}\right)H_1 + \frac{r^2}{EI}\left(\frac{\pi}{2}-1\right)m_1 - \frac{r^3}{2EI}V_2$$

$$+ \frac{r^3}{EI}\left(\frac{3\pi}{4}-2\right)H_2 - \frac{r^2}{EI}\left(\frac{\pi}{2}-1\right)m_2 + \frac{b}{AE}H_2 = 0$$

Collecting terms yield

$$-\frac{r^3}{2EI}(\pi-3)V_1 + \frac{r^3}{EI}\left(1-\frac{\pi}{4}\right)H_1 + \frac{r^2}{EI}\left(\frac{\pi}{2}-1\right)m_1 - \frac{r^3}{2EI}V_2$$

$$+ \left[\frac{b}{AE} + \frac{r^3}{EI}\left(\frac{3\pi}{4}-2\right)\right]H_2 - \frac{r^2}{EI}\left(\frac{\pi}{2}-1\right)m_2 = 0 \quad (61)$$

$$\Delta B_{VT} = \delta V_4 + \Delta V_4 + \Delta V_3 + \Delta V_3'$$

$$\Delta B_{VT} = \frac{b}{AE}V_4 + \frac{r^3}{EI}\left(1-\frac{\pi}{4}\right)V_3 + \frac{r^3}{2EI}(\pi-3) + \frac{r^2}{EI}\left(\frac{\pi}{2}-1\right)m_3$$

$$+ \frac{r^3}{EI}\left(\frac{3\pi}{4}-2\right)V_4 + \frac{r^3}{2EI}H_4 - \frac{r^2}{EI}\left(\frac{\pi}{2}-1\right)m_4 + \frac{\pi r^3}{4EI}V_3$$

$$+ \frac{r^3}{2EI}H_3 + \frac{r^2}{EI}m_3 + \frac{r^3}{EI}\left(1-\frac{\pi}{4}\right)V_4 + \frac{r^3}{2EI}H_4 - \frac{r^2}{EI}m_4$$

$$+ \frac{b^3}{3EI}V_3 - \frac{b^2}{2EI}m_3 + \frac{b^3}{6EI}V_2 - \frac{b^2}{2EI}m_2$$

Collecting terms yield

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$$\Delta B_{VT} = \frac{b^3}{6EI} V_2 - \frac{b^2}{2EI} m_2 + \left[\frac{r^3}{EI} + \frac{b^3}{3EI} \right] V_3 + \frac{r^3}{EI} \left(\frac{\pi}{2} - 1 \right) H_3$$

$$+ \left[\frac{\pi r^2}{2EI} - \frac{b^2}{2EI} \right] m_3 + \left[\frac{l}{AE} + \frac{r^3}{EI} \left(\frac{\pi}{2} - 1 \right) \right] V_4 + \frac{r^3}{EI} H_4 - \frac{\pi r^2}{2EI} m_4$$

(62)

$$\Delta B_{HT} = \delta H_4 + \Delta H_4 + \Delta H_3 + \Delta H_3'$$

$$\Delta B_{HT} = \frac{l^3}{3EI} H_4 + \frac{l^2}{2EI} m_4 + \frac{r^3}{2EI} V_3 + \frac{r^3}{EI} \left(1 - \frac{\pi}{4} \right) H_3 + \frac{r^2}{EI} m_3$$

$$+ \frac{r^3}{2EI} V_4 + \frac{\pi r^3}{4EI} H_4 - \frac{r^2}{EI} m_4 + \frac{r^3}{2EI} V_3 + \frac{r^3}{EI} \left(\frac{3\pi}{4} - 2 \right) H_3$$

$$+ \frac{r^2}{EI} \left(\frac{\pi}{2} - 1 \right) m_3 + \frac{r^3}{2EI} (\pi - 3) V_4 + \frac{r^3}{EI} \left(1 - \frac{\pi}{4} \right) H_4$$

$$- \frac{r^2}{EI} \left(\frac{\pi}{2} - 1 \right) m_4 + \frac{b}{AE} H_3$$

Collecting terms yield

$$\Delta B_{HT} = \frac{r^3}{EI} V_3 + \left[\frac{b}{AE} + \frac{r^3}{EI} \left(\frac{\pi}{2} - 1 \right) \right] H_3 + \frac{\pi r^2}{2EI} m_3 + \frac{r^3}{EI} \left(\frac{\pi}{2} - 1 \right) V_4$$

$$+ \left(\frac{l^3}{3EI} + \frac{r^3}{EI} \right) H_4 + \left(\frac{l^2}{2EI} - \frac{\pi r^2}{2EI} \right) m_4$$

(63)

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$$\theta_3 + \theta_3' = 0$$

$$\frac{r^2}{EI} V_3 + \frac{r^2}{EI} \left(\frac{\pi}{2} - 1 \right) H_3 + \frac{\pi r}{2EI} m_3 + \frac{r^2}{EI} \left(\frac{\pi}{2} - 1 \right) V_4 + \frac{r^2}{EI} H_4 - \frac{\pi r}{2EI} m_4$$

$$- \frac{b^2}{2EI} V_2 + \frac{b}{EI} m_2 - \frac{b^2}{2EI} V_3 + \frac{b}{EI} m_3 = 0$$

Collecting terms yield

$$- \frac{b^2}{2EI} V_2 + \frac{b}{EI} m_2 + \left[\frac{r^2}{EI} - \frac{b^2}{2EI} \right] V_3 + \frac{r^2}{EI} \left(\frac{\pi}{2} - 1 \right) H_3 + \left[\frac{\pi r}{2EI} + \frac{b}{EI} \right] m_3$$

$$+ \frac{r^2}{EI} \left(\frac{\pi}{2} - 1 \right) V_4 + \frac{r^2}{EI} H_4 - \frac{\pi r}{2EI} m_4 = 0 \quad (64)$$

$$\theta_4 + \theta_4' = 0$$

$$- \frac{r^2}{EI} V_3 - \frac{r^2}{EI} \left(\frac{\pi}{2} - 1 \right) H_3 - \frac{\pi r}{2EI} m_3 - \frac{r^2}{EI} \left(\frac{\pi}{2} - 1 \right) V_4 - \frac{r^2}{EI} H_4$$

$$+ \frac{\pi r}{2EI} m_4 + \frac{l^2}{2EI} H_4 + \frac{l}{EI} m_4 = 0$$

Collecting terms yield

$$- \frac{r^2}{EI} V_3 - \frac{r^2}{EI} \left(\frac{\pi}{2} - 1 \right) H_3 - \frac{\pi r}{2EI} m_3 - \frac{r^2}{EI} \left(\frac{\pi}{2} - 1 \right) V_4$$

$$+ \left[\frac{l^2}{2EI} - \frac{r^2}{EI} \right] H_4 + \left[\frac{\pi r}{2EI} + \frac{l}{EI} \right] m_4 = 0 \quad (65)$$

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$$\Delta V_3 - \Delta V_3' = 0$$

$$\frac{\pi r^3}{4EI} V_2 + \frac{r^3}{2EI} H_3 + \frac{r^2}{EI} m_3 + \frac{r^3}{EI} \left(1 - \frac{\pi}{4}\right) V_4 + \frac{r^3}{2EI} H_4 - \frac{r^2}{EI} m_4$$

$$- \frac{b^3}{6EI} V_2 + \frac{b^2}{2EI} m_2 - \frac{b^3}{3EI} V_3 + \frac{b^2}{2EI} m_3 = 0$$

Collecting terms yield

$$-\frac{b^3}{6EI} V_2 + \frac{b^2}{2EI} m_2 + \left[\frac{\pi r^3}{4EI} - \frac{b^3}{3EI} \right] V_3 + \frac{r^3}{2EI} H_3 + \left[\frac{b^2}{2EI} + \frac{r^2}{EI} \right] m_3$$

$$+ \frac{r^3}{EI} \left(1 - \frac{\pi}{4}\right) V_4 + \frac{r^3}{2EI} H_4 - \frac{r^2}{EI} m_4 = 0 \quad (66)$$

$$\Delta H_3 - \Delta H_3' = 0$$

$$\frac{r^3}{2EI} V_3 + \frac{r^3}{EI} \left(\frac{3\pi}{4} - 2\right) H_3 + \frac{r^2}{EI} \left(\frac{\pi}{2} - 1\right) m_3 + \frac{r^3}{2EI} (\pi - 3) V_4$$

$$+ \frac{r^3}{EI} \left(1 - \frac{\pi}{4}\right) H_4 - \frac{r^2}{EI} \left(\frac{\pi}{2} - 1\right) m_4 - \frac{b}{AE} H_3 = 0$$

Collecting terms yield

$$\frac{r^3}{2EI} V_3 + \left[\frac{r^3}{EI} \left(\frac{3\pi}{4} - 2\right) - \frac{b}{AE} \right] H_3 + \frac{r^2}{EI} \left(\frac{\pi}{2} - 1\right) m_3 + \frac{r^3}{2EI} (\pi - 3) V_4$$

$$+ \frac{r^3}{EI} \left(1 - \frac{\pi}{4}\right) H_4 - \frac{r^2}{EI} \left(\frac{\pi}{2} - 1\right) m_4 = 0 \quad (67)$$

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Equations (56) thru (67) can be represented in the following matrix form which will be used to solve for the unknown loads & moments.

$\frac{r^3(\pi-1)}{EI(2)} + \frac{l^3}{AE}$	$\frac{r^3}{EI}$	$\frac{\pi r^2}{2EI}$	$\frac{r^3}{EI} + \frac{b^3}{3EI}$	$\frac{r^3(\pi)}{EI(2)}$	$\frac{\pi r^2}{2EI}$	$\frac{b^3}{6EI}$	$\frac{b^3}{2EI}$	0	0	0	V_1	ΔF_{VT}
$\frac{r^3(\pi-1)}{EI(2)}$	$\frac{l^3}{3EI} + \frac{r^3}{EI}$	$\frac{\pi r^2}{2EI}$	$\frac{r^3}{EI}$	$\frac{b^3}{AE} + \frac{r^3(\pi)}{EI(2)}$	$\frac{\pi r^2}{2EI}$	0	0	0	0	0	H_1	ΔF_{HT}
$\frac{r^3(\pi-1)}{EI(2)}$	$\frac{r^3}{EI}$	$\frac{\pi r^2}{2EI}$	$\frac{r^3}{EI}$	$\frac{r^3(\pi)}{EI(2)}$	$\frac{\pi r^2}{2EI}$	0	0	0	0	0	M_1	0
$\frac{r^3(\pi-1)}{EI(2)}$	$\frac{r^3}{EI}$	$\frac{\pi r^2}{2EI}$	$\frac{r^3}{EI} + \frac{b^3}{3EI}$	$\frac{r^3(\pi)}{EI(2)}$	$\frac{\pi r^2}{2EI}$	$\frac{b^3}{2EI}$	$\frac{b^3}{EI}$	0	0	0	V_2	0
$\frac{r^3(\pi-1)}{EI(2)}$	$\frac{r^3}{2EI}$	$\frac{r^2}{EI}$	$\frac{b^3}{3EI} + \frac{\pi r^3}{4EI}$	$\frac{r^3}{2EI}$	$\frac{b^3}{2EI} + \frac{r^2}{EI}$	$\frac{b^3}{6EI}$	$\frac{b^3}{2EI}$	0	0	0	H_2	0
$\frac{r^3(\pi-3)}{2EI}$	$\frac{r^3(\pi-1)}{EI}$	$\frac{r^2(\pi-1)}{EI}$	$\frac{r^3}{2EI}$	$\frac{b^3}{AE} + \frac{r^3(\pi-2)}{EI}$	$\frac{r^2(\pi-1)}{EI}$	0	0	0	0	0	M_2	0
0	0	0	$\frac{b^3}{6EI}$	0	$\frac{b^3}{2EI}$	$\frac{r^3}{EI} + \frac{b^3}{3EI}$	$\frac{\pi r^2}{2EI}$	$\frac{l^3}{AE} + \frac{r^3(\pi)}{EI(2)}$	$\frac{r^3}{EI}$	$\frac{\pi r^2}{2EI}$	V_3	ΔB_{VT}
0	0	0	0	0	0	$\frac{r^3}{EI}$	$\frac{b^3}{AE} + \frac{r^3(\pi-1)}{EI}$	$\frac{\pi r^2}{2EI}$	$\frac{r^3(\pi)}{EI(2)}$	$\frac{l^3}{3EI} + \frac{r^3}{EI}$	$\frac{l^3}{2EI}$	ΔB_{HT}
0	0	0	$\frac{b^3}{2EI}$	0	$\frac{b^3}{EI}$	$\frac{r^3}{EI} + \frac{b^3}{3EI}$	$\frac{\pi r^2}{2EI}$	$\frac{r^2}{EI}$	$\frac{\pi r^2}{2EI}$	$\frac{r^2}{EI}$	M_3	0
0	0	0	0	0	0	$\frac{r^2}{EI}$	$\frac{\pi r^2}{2EI}$	$\frac{r^3(\pi-1)}{EI(2)}$	$\frac{l^3}{2EI}$	$\frac{\pi r^2}{2EI}$	V_4	0
0	0	0	$\frac{b^3}{6EI}$	0	$\frac{b^3}{2EI}$	$\frac{\pi r^3}{4EI} + \frac{b^3}{3EI}$	$\frac{b^3}{2EI} + \frac{r^2}{EI}$	$\frac{r^3(\pi)}{EI(2)}$	$\frac{r^3}{2EI}$	$\frac{r^2}{EI}$	H_4	0
0	0	0	0	0	0	$\frac{r^3}{2EI}$	$\frac{r^3}{EI}$	$\frac{b^3}{AE} + \frac{r^3(\pi-1)}{EI}$	$\frac{r^3(\pi-3)}{2EI}$	$\frac{r^3(\pi-1)}{EI}$	$\frac{r^2(\pi-1)}{EI(2)}$	M_4

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Top Section: Steady State Condition

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During the steady state condition, the back plate is hotter than the front plate & the top plate sees a thermal growth in the radial direction. Assuming that this top plate thermal growth is shared equally by the front & back plates & considering a unit width beam, the model below will be used to obtain an approximate solution.

Figure 2

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Front Plate

Using Castigliano's theorem, the deflections & rotation at point ① of the front plate can be determined by taking the partial derivative of the strain energy with respect to the loading under consideration. The deflection or rotation will be in the direction of the force or moment. The strain energy due to the loads is

$$U = \frac{V_1^2 l}{2AE} + \int_0^l \frac{m^2}{2EI} dx \quad (1)$$

and $m = -H_1 x - m_1 \quad (2)$

Vertical Deflection

$$\delta_{V_1} = \frac{\partial U}{\partial V_1} = \frac{V_1 l}{AE} \quad (3)$$

Horizontal Deflection

$$\begin{aligned} \delta_{H_1} &= \frac{\partial U}{\partial H_1} = \frac{1}{EI} \int_0^l m \frac{dm}{dH_1} dx = \frac{1}{EI} \int_0^l (-H_1 x - m_1)(-x) dx \\ &= \frac{1}{EI} \left\{ H_1 \int_0^l x^2 dx + m_1 \int_0^l x dx \right\} \end{aligned}$$

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$$\delta_{H_1} = \frac{1}{EI} \left\{ H_1 \frac{l^3}{3} + m_1 \frac{l^2}{2} \right\}$$

$$\delta_{H_1} = \frac{l^3 H_1}{3EI} + \frac{l^2 m_1}{2EI} \quad (4)$$

Rotation

$$\theta'_1 = \frac{\partial U}{\partial m_1} = \frac{1}{EI} \int_0^l m \frac{dm}{dm_1} dx = \frac{1}{EI} \int_0^l (-H_1 x - m_1) (-dx)$$

$$\theta'_1 = \frac{1}{EI} \left\{ H_1 \frac{l^2}{2} + m_1 l \right\} = \frac{l^2 H_1}{2EI} + \frac{l}{EI} m_1 \quad (5)$$

Back Plate

In a similar manner, the deflections & rotation at point (4) of the back plate can be found by considering the strain energy. Therefore,

$$U = \frac{V_4^2 l}{2AE} + \int_0^l \frac{m^2}{2EI} dx$$

and $m = H_4 x - M_4$

Vertical Deflection

$$\delta_{V_4} = \frac{\partial U}{\partial V_4} = \frac{l V_4}{AE} \quad (6)$$

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Horizontal Deflection

$$\begin{aligned}\delta_{H_4} &= \frac{\partial U}{\partial H_4} = \frac{1}{EI} \int_0^l m \frac{dm}{dH_4} dx = \frac{1}{EI} \int_0^l (H_4 x - m_4)(x dx) \\ &= \frac{1}{EI} \left\{ \int_0^l H_4 x^2 dx - \int_0^l m_4 x dx \right\} \\ &= \frac{1}{EI} \left\{ H_4 \frac{l^3}{3} - m_4 \frac{l^2}{2} \right\}\end{aligned}$$

$$\delta_{H_4} = \frac{l^3}{3EI} H_4 - \frac{l^2}{2EI} m_4 \quad (7)$$

Rotation

$$\begin{aligned}\theta_4' &= \frac{\partial U}{\partial m_4} = \frac{1}{EI} \int_0^l m \frac{dm}{dm_4} dx = \frac{1}{EI} \int_0^l (H_4 x - m_4)(-dx) \\ &= \frac{1}{EI} \left\{ \int_0^l -H_4 x dx + \int_0^l m_4 dx \right\} \\ &= \frac{1}{EI} \left\{ -H_4 \frac{l^2}{2} + m_4 l \right\}\end{aligned}$$

$$\theta_4' = -\frac{l^2}{2EI} H_4 + \frac{l m_4}{EI} \quad (8)$$

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Top Section Plate

Figure 3

Consider the left corner of Figure 3.

The strain energy of corner (1-2) is

$$U = \int_0^s \frac{m^2}{2EI} ds \quad (9)$$

The moment at m-n, any point along the arc, is

$$m = -V_1 r (1 - \cos \phi) - H_1 r \sin \phi + m_1 - H_2 r (1 - \sin \phi) - V_2 r \cos \phi - m_2 \quad (10)$$

$$ds = r d\phi$$

$$U = \int_0^{\pi/2} \frac{m^2}{2EI} r d\phi$$

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Again, Castigliano's theorem will be used to obtain the deflections & rotations of each end of the left corner. Therefore, beginning at point ①,

Vertical Deflection at ①

$$\Delta V_1 = \frac{\partial U}{\partial V_1} = \frac{1}{EI} \int_0^{\pi/2} m \frac{dm}{dV_1} r d\phi$$

$$\frac{dm}{dV_1} = -r(1 - \cos \phi)$$

$$\therefore \Delta V_1 = \frac{1}{EI} \int_0^{\pi/2} [-V_1 r(1 - \cos \phi) - H_1 r \sin \phi + m_1 - H_2 r(1 - \sin \phi) - V_2 r \cos \phi - m_2] [-r^2(1 - \cos \phi) d\phi] \quad (11)$$

$$\Delta V_1 = \frac{1}{EI} \left\{ V_1 r^3 \int_0^{\pi/2} (1 - \cos \phi)^2 d\phi + H_1 r^3 \int_0^{\pi/2} \sin \phi (1 - \cos \phi) d\phi - m_1 r^2 \int_0^{\pi/2} (1 - \cos \phi) d\phi + H_2 r^3 \int_0^{\pi/2} (1 - \sin \phi)(1 - \cos \phi) d\phi + V_2 r^3 \int_0^{\pi/2} \cos \phi (1 - \cos \phi) d\phi + m_2 r^2 \int_0^{\pi/2} (1 - \cos \phi) d\phi \right\}$$

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$$\Delta V_1 = \frac{1}{EI} \left\{ V_1 r^3 \left(\frac{3\pi}{4} - 2 \right) + H_1 \frac{r^3}{2} - m_1 r^2 \left(\frac{\pi}{2} - 1 \right) + H_2 \frac{r^3}{2} (\pi - 3) \right. \\ \left. + V_2 r^3 \left(1 - \frac{\pi}{4} \right) + m_2 r^2 \left(\frac{\pi}{2} - 1 \right) \right\}$$

$$\Delta V_1 = \frac{r^3}{EI} \left(\frac{3\pi}{4} - 2 \right) V_1 + \frac{r^3}{2EI} H_1 - \frac{r^2}{EI} \left(\frac{\pi}{2} - 1 \right) m_1 + \frac{r^3}{2EI} (\pi - 3) H_2 \\ + \frac{r^3}{EI} \left(1 - \frac{\pi}{4} \right) V_2 + \frac{r^2}{EI} \left(\frac{\pi}{2} - 1 \right) m_2 \quad (12)$$

Horizontal Deflections at ①

$$\Delta H_1 = \frac{\partial U}{\partial H_1} = \frac{1}{EI} \int_0^{\pi/2} m \frac{dm}{dH_1} r d\phi$$

$$\frac{dm}{dH_1} = -r \sin \phi$$

$$\therefore \Delta H_1 = \frac{1}{EI} \int_0^{\pi/2} \left[-V_1 r (1 - \cos \phi) - H_1 r \sin \phi + m_1 - H_2 r (1 - \sin \phi) \right. \\ \left. - V_2 r \cos \phi - m_2 \right] \left[-r^2 \sin \phi d\phi \right] \quad (13)$$

$$\Delta H_1 = \frac{1}{EI} \left\{ V_1 r^3 \int_0^{\pi/2} \sin \phi (1 - \cos \phi) d\phi + H_1 r^3 \int_0^{\pi/2} \sin^2 \phi d\phi \right. \\ \left. - m_1 r^2 \int_0^{\pi/2} \sin \phi d\phi + H_2 r^3 \int_0^{\pi/2} \sin \phi (1 - \sin \phi) d\phi \right. \\ \left. + V_2 r^3 \int_0^{\pi/2} \cos \phi \sin \phi d\phi + m_2 r^2 \int_0^{\pi/2} \sin \phi d\phi \right\}$$

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$$\Delta H_1 = \frac{1}{EI} \left\{ V_1 \frac{r^3}{2} + H_1 r \frac{\pi}{4} - m_1 r^2 + H_2 r^3 \left(1 - \frac{\pi}{4}\right) + V_2 \frac{r^3}{2} + m_2 r^2 \right\}$$

$$\Delta H_1 = \frac{r^3}{2EI} V_1 + \frac{\pi r^3}{4EI} H_1 - \frac{r^2}{EI} m_1 + \frac{r^3}{EI} \left(1 - \frac{\pi}{4}\right) H_2 + \frac{r^3}{2EI} V_2 + \frac{r^2}{EI} m_2 \quad (14)$$

Rotation at ①

$$\theta_1 = \frac{\partial u}{\partial m_1} = \frac{1}{EI} \int_0^{\pi/2} m \frac{dm}{dm_1} r d\phi \quad ; \frac{dm}{dm_1} = 1$$

$$\therefore \theta_1 = \frac{1}{EI} \int_0^{\pi/2} [-V_1 r (1 - \cos \phi) - H_1 r \sin \phi + m_1 - H_2 r (1 - \sin \phi) - V_2 r \cos \phi - m_2] [r d\phi] \quad (15)$$

$$= \frac{1}{EI} \left\{ -V_1 r^2 \int_0^{\pi/2} (1 - \cos \phi) d\phi - H_1 r^2 \int_0^{\pi/2} \sin \phi d\phi + m_1 r \int_0^{\pi/2} d\phi - H_2 r^2 \int_0^{\pi/2} (1 - \sin \phi) d\phi - V_2 r^2 \int_0^{\pi/2} \cos \phi d\phi - m_2 r \int_0^{\pi/2} d\phi \right\}$$

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$$\theta_1 = \frac{1}{EI} \left\{ -V_1 r^2 \left(\frac{\pi}{2} - 1 \right) - H_1 r^2 + m_1 r \frac{\pi}{2} - H_2 r^2 \left(\frac{\pi}{2} - 1 \right) - V_2 r^2 - m_2 r \frac{\pi}{2} \right\}$$

$$\theta_1 = -\frac{r^2}{EI} \left(\frac{\pi}{2} - 1 \right) V_1 - \frac{r^2}{EI} H_1 + \frac{\pi r}{2EI} m_1 - \frac{r^2}{EI} \left(\frac{\pi}{2} - 1 \right) H_2 - \frac{r^2}{EI} V_2 - \frac{\pi r}{2EI} m_2 \quad (16)$$

Vertical Deflection at (2)

$$\Delta V_2 = \frac{\partial u}{\partial V_2} = \frac{1}{EI} \int_0^{\pi/2} m \frac{dm}{dV_2} r d\phi \quad ; \quad \frac{dm}{dV_2} = -r \cos \phi$$

$$\Delta V_2 = \frac{1}{EI} \int_0^{\pi/2} [-V_1 r (1 - \cos \phi) - H_1 r \sin \phi + m_1 - H_2 r (1 - \sin \phi) - V_2 r \cos \phi - m_2] [-r^2 \cos \phi d\phi] \quad (17)$$

$$\Delta V_2 = \frac{1}{EI} \left\{ V_1 r^3 \int_0^{\pi/2} \cos \phi (1 - \cos \phi) d\phi + H_1 r^3 \int_0^{\pi/2} \sin \phi \cos \phi d\phi - m_1 r^2 \int_0^{\pi/2} \cos \phi d\phi + H_2 r^3 \int_0^{\pi/2} \cos \phi (1 - \sin \phi) d\phi + V_2 r^3 \int_0^{\pi/2} \cos^2 \phi d\phi + m_2 r^2 \int_0^{\pi/2} \cos \phi d\phi \right\}$$

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$$\Delta V_2 = \frac{1}{EI} \left\{ V_1 r^3 \left(1 - \frac{\pi}{4}\right) + H_1 \frac{r^3}{2} - m_1 r^2 + H_2 \frac{r^3}{2} + V_2 r^3 \frac{\pi}{4} + m_2 r^2 \right\}$$

$$\Delta V_2 = \frac{r^3}{EI} \left(1 - \frac{\pi}{4}\right) V_1 + \frac{r^3}{2EI} H_1 - \frac{r^2}{EI} m_1 + \frac{r^3}{2EI} H_2 + \frac{\pi r^3}{4EI} V_2 + \frac{r^2}{EI} m_2 \quad (18)$$

Horizontal Deflection at (e)

$$\Delta H_2 = \frac{\partial U}{\partial H_2} = \frac{1}{EI} \int_0^{\pi/2} m \frac{dm}{dH_2} r d\phi \quad ; \quad \frac{dm}{dH_2} = -r(1 - \sin\phi)$$

$$\Delta H_2 = \frac{1}{EI} \int_0^{\pi/2} \left[-V_1 r(1 - \cos\phi) - H_1 r \sin\phi + m_1 - H_2 r(1 - \sin\phi) - V_2 r \cos\phi - m_2 \right] \left[-r^2(1 - \sin\phi) d\phi \right] \quad (19)$$

$$\begin{aligned} \Delta H_2 &= \frac{1}{EI} \left\{ V_1 r^3 \int_0^{\pi/2} (1 - \cos\phi)(1 - \sin\phi) d\phi + H_1 r^3 \int_0^{\pi/2} \sin\phi(1 - \sin\phi) d\phi \right. \\ &\quad \left. - m_1 r^2 \int_0^{\pi/2} (1 - \sin\phi) d\phi + H_2 r^3 \int_0^{\pi/2} (1 - \sin\phi)^2 d\phi \right. \\ &\quad \left. + V_2 r^3 \int_0^{\pi/2} \cos\phi(1 - \sin\phi) d\phi + m_2 r^2 \int_0^{\pi/2} (1 - \sin\phi) d\phi \right\} \\ &= \frac{1}{EI} \left\{ V_1 \frac{r^3}{2} (\pi - 3) + H_1 r^3 \left(1 - \frac{\pi}{4}\right) - m_1 r^2 \left(\frac{\pi}{2} - 1\right) + H_2 r^3 \left(\frac{3\pi}{4} - 2\right) \right. \\ &\quad \left. + V_2 \frac{r^3}{2} + m_2 r^2 \left(\frac{\pi}{2} - 1\right) \right\} \end{aligned}$$

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$$\Delta H_2 = \frac{r^3}{2EI} (\pi - 3) V_1 + \frac{r^3}{EI} \left(1 - \frac{\pi}{4}\right) H_1 - \frac{r^2}{EI} \left(\frac{\pi}{2} - 1\right) m_1$$

$$+ \frac{r^3}{EI} \left(\frac{3\pi}{4} - 2\right) H_2 + \frac{r^3}{2EI} V_2 + \frac{r^2}{EI} \left(\frac{\pi}{2} - 1\right) m_2 \quad (20)$$

Rotation at (2)

$$\theta_2 = \frac{\partial u}{\partial m_2} = \frac{1}{EI} \int_0^{\pi/2} m \frac{dm}{dm_2} r d\phi \quad ; \quad \frac{dm}{dm_2} = -1$$

$$\theta_2 = \frac{1}{EI} \int_0^{\pi/2} [-V_1 r (1 - \cos\phi) - H_1 r \sin\phi + m_1 - V_2 r \cos\phi$$

$$- H_2 r (1 - \sin\phi) - m_2] [-r d\phi] \quad (21)$$

$$= \frac{1}{EI} \left\{ V_1 r^2 \int_0^{\pi/2} (1 - \cos\phi) d\phi + H_1 r^2 \int_0^{\pi/2} \sin\phi d\phi + m_1 r \int_0^{\pi/2} d\phi \right.$$

$$\left. + V_2 r^2 \int_0^{\pi/2} \cos\phi d\phi + H_2 r^2 \int_0^{\pi/2} (1 - \sin\phi) d\phi + m_2 r \int_0^{\pi/2} d\phi \right\}$$

$$= \frac{1}{EI} \left\{ V_1 r^2 \left(\frac{\pi}{2} - 1\right) + H_1 r^2 - m_1 r \frac{\pi}{2} + V_2 r^2 + H_2 r^2 \left(\frac{\pi}{2} - 1\right) + m_2 r \frac{\pi}{2} \right\}$$

$$\theta_2 = \frac{r^2}{EI} \left(\frac{\pi}{2} - 1\right) V_1 + \frac{r^2}{EI} H_1 - \frac{\pi r}{2EI} m_1 + \frac{r^2}{EI} V_2$$

$$+ \frac{r^2}{EI} \left(\frac{\pi}{2} - 1\right) H_2 + \frac{\pi r}{2EI} m_2 \quad (22)$$

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Consider the flat portion of the top section.

Figure 4

The strain energy of the above section is

$$U = \frac{H_2^2 b}{2AE} + \frac{H_3^2 b}{2AE} + \int_0^b \frac{m^2}{2EI} dx \quad (23)$$

where

$$m = -V_2 x + m_2 - V_3 (b-x) + m_3 \quad (24)$$

Again, using Castigliano's theorem, the deflections & rotation of each end of Fig. 4 can be found.

Beginning at point ②,

Vertical Deflection at ②

$$\Delta V_2' = \frac{\partial U}{\partial V_2} = \frac{1}{EI} \int_0^b m \frac{dm}{dV_2} dx ; \quad \frac{dm}{dV_2} = -x$$

$$\therefore \Delta V_2' = \frac{1}{EI} \int_0^b [-V_2 x + m_2 - V_3 (b-x) + m_3] [-x dx] \quad (25)$$

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$$\Delta V_2' = \frac{1}{EI} \left\{ +V_2 \int_0^b x^2 dx - m_2 \int_0^b x dx + V_3 \int_0^b (b-x) x dx - m_3 \int_0^b x dx \right\}$$

$$= \frac{1}{EI} \left\{ V_2 \frac{b^3}{3} - m_2 \frac{b^2}{2} + V_3 \frac{b^3}{6} - m_3 \frac{b^2}{2} \right\}$$

$$\Delta V_2' = \frac{b^3}{3EI} V_2 - \frac{b^2}{2EI} m_2 + \frac{b^3}{6EI} V_3 - \frac{b^2}{2EI} m_3 \quad (25)$$

Horizontal Deflection at ②

$$\Delta H_2' = \frac{\partial U}{\partial H_2} = \frac{b}{AE} H_2 \quad (26)$$

Rotation at ②

$$\theta_2' = \frac{\partial U}{\partial m_2} = \frac{1}{EI} \int_0^b m \frac{dm}{dm_2} dx ; \quad \frac{dm}{dm_2} = 1$$

$$\therefore \theta_2' = \frac{1}{EI} \int_0^b [-V_2 x + m_2 - V_3 (b-x) + m_3] dx$$

$$= \frac{1}{EI} \left\{ -V_2 \frac{b^2}{2} + m_2 b - V_3 \frac{b^2}{2} + m_3 b \right\}$$

$$\theta_2' = -\frac{b^2}{2EI} V_2 + \frac{b}{EI} m_2 - \frac{b^2}{2EI} V_3 + \frac{b}{EI} m_3 \quad (27)$$

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Now consider point (3) of Fig. 4.

Vertical Deflection at (3)

$$\Delta V_3' = \frac{\partial U}{\partial V_3} = \frac{1}{EI} \int_0^b m \frac{dm}{dV_3} dx ; \frac{dm}{dV_3} = -(b-x)$$

$$\therefore \Delta V_3' = \frac{1}{EI} \int_0^b [-V_2 x + m_2 - V_3 (b-x) + m_3] [-(b-x) dx] \quad (28)$$

$$= \frac{1}{EI} \left\{ V_2 \int_0^b (b-x) x dx - m_2 \int_0^b (b-x) dx + V_3 \int_0^b (b-x)^2 dx - m_3 \int_0^b (b-x) dx \right\}$$

$$= \frac{1}{EI} \left\{ V_2 \left(\frac{b^3}{2} - \frac{b^3}{3} \right) - m_2 \left(b^2 - \frac{b^2}{2} \right) + V_3 \left(b^3 - b^3 + \frac{b^3}{3} \right) - m_3 \frac{b^2}{2} \right\}$$

$$= \frac{1}{EI} \left\{ V_2 \frac{b^3}{6} - m_2 \frac{b^2}{2} + V_3 \frac{b^3}{3} - m_3 \frac{b^2}{2} \right\}$$

$$\Delta V_3' = \frac{b^3}{6EI} V_2 - \frac{b^2}{2EI} m_2 + \frac{b^3}{3EI} V_3 - \frac{b^2}{2EI} m_3 \quad (29)$$

Horizontal Deflection at (3)

$$\Delta H_3' = \frac{\partial U}{\partial H_3} = \frac{b}{AE} H_3 \quad (30)$$

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Rotation at (3)

$$\theta_3' = \frac{\partial U}{\partial m_3} = \frac{1}{EI} \int_0^b m \frac{dm}{dm_3} dx ; \frac{dm}{dm_3} = 1$$

$$\therefore \theta_3' = \frac{1}{EI} \int_0^b [-V_2 x + m_2 - V_3(b-x) + m_3] dx$$

$$= \frac{1}{EI} \left\{ -V_2 \int_0^b x dx + m_2 \int_0^b dx - V_3 \int_0^b (b-x) dx + m_3 \int_0^b dx \right\}$$

$$= \frac{1}{EI} \left\{ -V_2 \frac{b^2}{2} + m_2 b - V_3 \frac{b^2}{2} + m_3 b \right\}$$

$$\theta_3' = -\frac{b^2}{2EI} V_2 + \frac{b}{EI} m_2 - \frac{b^2}{2EI} V_3 + \frac{b}{EI} m_3 \quad (31)$$

Consider the right corner of Fig. 3

The strain energy of corner (3-4) is

$$U = \int_0^{\pi/2} \frac{m^2}{2EI} r d\phi$$

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The moment at m-n, any point along the arc, is

$$m = -V_3 r \cos \phi + H_3 r (1 - \sin \phi) - m_3 - V_4 r (1 - \cos \phi) + H_4 r \sin \phi + m_4 \quad (32)$$

Beginning at point (3), the deflections & rotations of corner (3-4) are

Vertical Deflection at (3)

$$\Delta V_3 = \frac{\partial U}{\partial V_3} = \frac{1}{EI} \int_0^{\pi/2} m \frac{dm}{dV_3} r d\phi ; \quad \frac{dm}{dV_3} = -r \cos \phi$$

$$\therefore \Delta V_3 = \frac{1}{EI} \int_0^{\pi/2} [-V_3 r \cos \phi + H_3 r (1 - \sin \phi) - m_3 - V_4 r (1 - \cos \phi) + H_4 r \sin \phi + m_4] [-r^2 \cos \phi d\phi] \quad (33)$$

$$\Delta V_3 = \frac{1}{EI} \left\{ V_3 r^3 \int_0^{\pi/2} \cos^2 \phi d\phi - H_3 r^3 \int_0^{\pi/2} \cos \phi (1 - \sin \phi) d\phi + m_3 r^2 \int_0^{\pi/2} \cos \phi d\phi + V_4 r^3 \int_0^{\pi/2} \cos \phi (1 - \cos \phi) d\phi - H_4 r^3 \int_0^{\pi/2} \cos \phi \sin \phi d\phi - m_4 r^2 \int_0^{\pi/2} \cos \phi d\phi \right\}$$

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$$\Delta V_3 = \frac{1}{EI} \left\{ V_3 r^3 \frac{\pi}{4} - H_3 \frac{r^3}{2} + m_3 r^2 + V_4 r^3 \left(1 - \frac{\pi}{4}\right) - H_4 \frac{r^3}{2} - m_4 r^2 \right\}$$

$$\Delta V_3 = \frac{\pi r^3}{4EI} V_3 - \frac{r^3}{2EI} H_3 + \frac{r^2}{EI} m_3 + \frac{r^3}{EI} \left(1 - \frac{\pi}{4}\right) V_4$$

$$- \frac{r^3}{2EI} H_4 - \frac{r^2}{EI} m_4 \quad (34)$$

Horizontal Deflection at (3)

$$\Delta H_3 = \frac{\partial U}{\partial H_3} = \frac{1}{EI} \int_0^{\pi/2} m \frac{dm}{dH_3} r d\phi ; \frac{dm}{dH_3} = r(1 - \sin\phi)$$

$$\Delta H_3 = \frac{1}{EI} \int_0^{\pi/2} [-V_3 r \cos\phi + H_3 r(1 - \sin\phi) - m_3 - V_4 r(1 - \cos\phi) + H_4 r \sin\phi + m_4] [r^2(1 - \sin\phi) d\phi] \quad (35)$$

$$\Delta H_3 = \frac{1}{EI} \left\{ -V_3 r^3 \int_0^{\pi/2} \cos\phi (1 - \sin\phi) d\phi + H_3 r^3 \int_0^{\pi/2} (1 - \sin\phi)^2 d\phi \right.$$

$$- m_3 r^2 \int_0^{\pi/2} (1 - \sin\phi) d\phi - V_4 r^3 \int_0^{\pi/2} (1 - \cos\phi)(1 - \sin\phi) d\phi$$

$$+ H_4 r^3 \int_0^{\pi/2} \sin\phi (1 - \sin\phi) d\phi + m_4 r^2 \int_0^{\pi/2} (1 - \sin\phi) d\phi \left. \right\}$$

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$$\Delta H_3 = \frac{1}{EI} \left\{ -V_3 \frac{r^3}{2} + H_3 r^3 \left(\frac{3\pi}{4} - 2 \right) - m_3 r^2 \left(\frac{\pi}{2} - 1 \right) - V_4 \frac{r^3}{2} (\pi - 3) \right. \\ \left. + H_4 r^3 \left(1 - \frac{\pi}{4} \right) + m_4 r^2 \left(\frac{\pi}{2} - 1 \right) \right\}$$

$$\Delta H_3 = -\frac{r^3}{2EI} V_3 + \frac{r^3}{EI} \left(\frac{3\pi}{4} - 2 \right) H_3 - \frac{r^2}{EI} \left(\frac{\pi}{2} - 1 \right) m_3 - \frac{r^3}{2EI} (\pi - 3) V_4 \\ + \frac{r^3}{EI} \left(1 - \frac{\pi}{4} \right) H_4 + \frac{r^2}{EI} \left(\frac{\pi}{2} - 1 \right) m_4 \quad (36)$$

Rotation at (3)

$$\theta_3 = \frac{\partial y}{\partial m_3} = \frac{1}{EI} \int_0^{\pi/2} m \frac{dm}{dm_3} r d\phi ; \quad \frac{dm}{dm_3} = -1$$

$$\theta_3 = \frac{1}{EI} \int_0^{\pi/2} \left[-V_3 r \cos \phi + H_3 r (1 - \sin \phi) - m_3 - V_4 r (1 - \cos \phi) \right. \\ \left. + H_4 r \sin \phi + m_4 \right] [-r d\phi] \quad (37)$$

$$\theta_3 = \frac{1}{EI} \left\{ V_3 r^2 \int_0^{\pi/2} \cos \phi d\phi - H_3 r^2 \int_0^{\pi/2} (1 - \sin \phi) d\phi + m_3 r \int_0^{\pi/2} d\phi \right. \\ \left. + V_4 r^2 \int_0^{\pi/2} (1 - \cos \phi) d\phi - H_4 r^2 \int_0^{\pi/2} \sin \phi d\phi - m_4 r \int_0^{\pi/2} d\phi \right\}$$

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$$\theta_3 = \frac{1}{EI} \left\{ V_3 r^2 - H_3 r^2 \left(\frac{\pi}{2} - 1 \right) + m_3 r \frac{\pi}{2} + V_4 r^2 \left(\frac{\pi}{2} - 1 \right) - H_4 r^2 - m_4 r \frac{\pi}{2} \right\}$$

$$\theta_3 = \frac{r^2}{EI} V_3 - \frac{r^2}{EI} \left(\frac{\pi}{2} - 1 \right) H_3 + \frac{\pi r}{2EI} m_3 + \frac{r^2}{EI} \left(\frac{\pi}{2} - 1 \right) V_4 - \frac{r^2}{EI} H_4 - \frac{\pi r}{2EI} m_4 \quad (38)$$

Now consider point (4).

Vertical Deflection at (4)

$$\Delta V_4 = \frac{\partial U}{\partial V_4} = \frac{1}{EI} \int_0^{\pi/2} m \frac{dm}{dV_4} r d\phi ; \frac{dm}{dV_4} = -r(1 - \cos \phi)$$

$$\therefore \Delta V_4 = \frac{1}{EI} \int_0^{\pi/2} \left[-V_3 r \cos \phi + H_3 r (1 - \sin \phi) - m_3 - V_4 r (1 - \cos \phi) + H_4 r \sin \phi + m_4 \right] \left[-r^2 (1 - \cos \phi) d\phi \right] \quad (39)$$

$$\Delta V_4 = \frac{1}{EI} \left\{ V_3 r^3 \int_0^{\pi/2} \cos \phi (1 - \cos \phi) d\phi - H_3 r^3 \int_0^{\pi/2} (1 - \cos \phi) (1 - \sin \phi) d\phi + m_3 r^2 \int_0^{\pi/2} (1 - \cos \phi) d\phi + V_4 r^3 \int_0^{\pi/2} (1 - \cos \phi)^2 d\phi - H_4 r^3 \int_0^{\pi/2} \sin \phi (1 - \cos \phi) d\phi - m_4 r^2 \int_0^{\pi/2} (1 - \cos \phi) d\phi \right\}$$

$$= \frac{1}{EI} \left\{ V_3 r^3 \left(1 - \frac{\pi}{4} \right) - H_3 r^3 \left(\frac{\pi}{2} - 3 \right) + m_3 r^2 \left(\frac{\pi}{2} - 1 \right) + V_4 r^3 \left(\frac{3\pi}{4} - 2 \right) - H_4 r^3 - m_4 r^2 \left(\frac{\pi}{2} - 1 \right) \right\}$$

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$$\Delta V_4 = \frac{r^3}{EI} \left(1 - \frac{\pi}{4}\right) V_3 - \frac{r^3}{2EI} (\pi - 3) H_3 + \frac{r^2}{EI} \left(\frac{\pi}{2} - 1\right) m_3 + \frac{r^3}{EI} \left(\frac{3\pi}{4} - 2\right) V_4 - \frac{r^3}{2EI} H_4 - \frac{r^2}{EI} \left(\frac{\pi}{2} - 1\right) m_4 \quad (40)$$

Horizontal Deflection at ④

$$\Delta H_4 = \frac{\partial U}{\partial H_4} = \frac{1}{EI} \int_0^{\pi/2} m \frac{dm}{dH_4} r d\phi ; \frac{dm}{dH_4} = r \sin \phi$$

$$\therefore \Delta H_4 = \frac{1}{EI} \int_0^{\pi/2} [-V_3 r \cos \phi + H_3 r (1 - \sin \phi) - m_3 - V_4 r (1 - \cos \phi) + H_4 r \sin \phi + m_4] [r^2 \sin \phi d\phi] \quad (41)$$

$$\Delta H_4 = \frac{1}{EI} \left\{ -V_3 r^3 \int_0^{\pi/2} \sin \phi \cos \phi d\phi + H_3 r^3 \int_0^{\pi/2} \sin \phi (1 - \sin \phi) d\phi - m_3 r^2 \int_0^{\pi/2} \sin \phi d\phi - V_4 r^3 \int_0^{\pi/2} \sin \phi (1 - \cos \phi) d\phi + H_4 r^3 \int_0^{\pi/2} \sin^2 \phi d\phi + m_4 r^2 \int_0^{\pi/2} \sin \phi d\phi \right\}$$

$$= \frac{1}{EI} \left\{ -V_3 \frac{r^3}{2} + H_3 r^3 \left(1 - \frac{\pi}{4}\right) - m_3 r^2 - V_4 \frac{r^3}{2} + H_4 r^3 \frac{\pi}{4} + m_4 r^2 \right\}$$

$$\Delta H_4 = -\frac{r^3}{2EI} V_3 + \frac{r^3}{EI} \left(1 - \frac{\pi}{4}\right) H_3 - \frac{r^2}{EI} m_3 - \frac{r^3}{2EI} V_4 + \frac{\pi r^3}{4EI} H_4 + \frac{r^2}{EI} m_4 \quad (42)$$

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Rotation at (4)

$$\theta_4 = \frac{\partial u}{\partial m_4} = \frac{1}{EI} \int_0^{\pi/2} m \frac{dm}{dm_4} r d\phi ; \quad \frac{dm}{dm_4} = 1$$

$$\therefore \theta_4 = \frac{1}{EI} \int_0^{\pi/2} [-V_3 r \cos\phi + H_3 r (1 - \sin\phi) - m_3 - V_4 r (1 - \cos\phi) + H_4 r \sin\phi + m_4] [r d\phi] \quad (43)$$

$$\begin{aligned} \theta_4 &= \frac{1}{EI} \left\{ -V_3 r^2 \int_0^{\pi/2} \cos\phi d\phi + H_3 r^2 \int_0^{\pi/2} (1 - \sin\phi) d\phi - m_3 r \int_0^{\pi/2} d\phi \right. \\ &\quad \left. - V_4 r^2 \int_0^{\pi/2} (1 - \cos\phi) d\phi + H_4 r^2 \int_0^{\pi/2} \sin\phi d\phi + m_4 r \int_0^{\pi/2} d\phi \right\} \\ &= \frac{1}{EI} \left\{ -V_3 r^2 + H_3 r^2 \left(\frac{\pi}{2} - 1 \right) - m_3 r \frac{\pi}{2} - V_4 r^2 \left(\frac{\pi}{2} - 1 \right) \right. \\ &\quad \left. + H_4 r^2 + m_4 r \frac{\pi}{2} \right\} \end{aligned}$$

$$\begin{aligned} \theta_4 &= -\frac{r^2}{EI} V_3 + \frac{r^2}{EI} \left(\frac{\pi}{2} - 1 \right) H_3 - \frac{\pi r}{2EI} m_3 - \frac{r^2}{EI} \left(\frac{\pi}{2} - 1 \right) V_4 \\ &\quad + \frac{r^2}{EI} H_4 + \frac{\pi r}{2EI} m_4 \quad (44) \end{aligned}$$

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Compatibility Equations

$$\Delta F_{VT} = \delta_{V_1} + \Delta V_1 + \Delta V_2 + \Delta V_2' \quad (45)$$

where ΔF_{VT} = axial thermal growth of the front plate including the corner (1-2)

$$\Delta F_{HT} = \delta_{H_1} + \Delta H_1 + \Delta H_2 + \Delta H_2' \quad (46)$$

where $\Delta F_{HT} = \frac{1}{2}$ total radial growth across the top plate including the corners

$$\Delta B_{VT} = \delta_{V_4} + \Delta V_4 + \Delta V_3 + \Delta V_3' \quad (47)$$

where ΔB_{VT} = axial thermal growth of the back plate including the corner (3-4)

$$\Delta B_{HT} = \delta_{H_4} + \Delta H_4 + \Delta H_3 + \Delta H_3' \quad (48)$$

where $\Delta B_{HT} = \frac{1}{2}$ total radial thermal growth of the top plate including the corners

$$\theta_1 = -\theta_1' \quad (49)$$

$$\Delta V_2 = \Delta V_2' \quad (53)$$

$$\theta_2 = -\theta_2' \quad (50)$$

$$\Delta H_2 = \Delta H_2' \quad (54)$$

$$\theta_3 = -\theta_3' \quad (51)$$

$$\Delta V_3 = \Delta V_3' \quad (55)$$

$$\theta_4 = -\theta_4' \quad (52)$$

$$\Delta H_3 = \Delta H_3' \quad (56)$$

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Let us now substitute the appropriate values into the compatibility equations (45) thru (56).

$$\Delta F_{VT} = \delta_1 + \Delta V_1 + \Delta V_2 + \Delta V_2'$$

$$\begin{aligned} \Delta F_{VT} = & \frac{l}{AE} V_1 + \frac{r^3}{EI} \left(\frac{3\pi}{4} - 2 \right) V_1 + \frac{r^3}{2EI} H_1 - \frac{r^2}{EI} \left(\frac{\pi}{2} - 1 \right) m_1 \\ & + \frac{r^3}{2EI} (\pi - 3) H_2 + \frac{r^3}{EI} \left(1 - \frac{\pi}{4} \right) V_2 + \frac{r^2}{EI} \left(\frac{\pi}{2} - 1 \right) m_2 + \frac{r^3}{EI} \left(1 - \frac{\pi}{4} \right) V_1 \\ & + \frac{r^3}{2EI} H_1 - \frac{r^2}{EI} m_1 + \frac{r^3}{2EI} H_2 + \frac{\pi r^3}{4EI} V_2 + \frac{r^2}{EI} m_2 \\ & + \frac{b^3}{3EI} V_2 - \frac{b^2}{2EI} m_2 + \frac{b^3}{6EI} V_3 - \frac{b^2}{2EI} m_3 \end{aligned}$$

Collecting terms yield

$$\begin{aligned} \Delta F_{VT} = & \left[\frac{l}{AE} + \frac{r^3}{EI} \left(\frac{\pi}{2} - 1 \right) \right] V_1 + \frac{r^3}{EI} H_1 - \frac{\pi r^2}{2EI} m_1 + \frac{r^3}{EI} \left(\frac{\pi}{2} - 1 \right) H_2 \\ & + \left[\frac{b^3}{3EI} + \frac{r^3}{EI} \right] V_2 + \left[\frac{\pi r^2}{2EI} - \frac{b^2}{2EI} \right] m_2 + \frac{b^3}{6EI} V_3 - \frac{b^2}{2EI} m_3 \end{aligned}$$

(57)

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$$\Delta F_{HT} = \delta_{H_1} + \Delta H_1 + \Delta H_2 + \Delta H_2'$$

$$\begin{aligned} \Delta F_{HT} = & \frac{l^3}{3EI} H_1 + \frac{l^2}{2EI} m_1 + \frac{r^3}{2EI} V_1 + \frac{\pi r^3}{4EI} H_1 - \frac{r^2}{EI} m_1 + \frac{r^3}{2EI} V_2 \\ & + \frac{r^3}{EI} \left(1 - \frac{\pi}{4}\right) H_2 + \frac{r^2}{EI} m_2 + \frac{r^3}{2EI} (\pi - 3) V_1 + \frac{r^3}{EI} \left(1 - \frac{\pi}{4}\right) H_1 \\ & - \frac{r^2}{EI} \left(\frac{\pi}{2} - 1\right) m_1 + \frac{r^3}{2EI} V_2 + \frac{r^3}{EI} \left(\frac{3\pi}{4} - 2\right) H_2 + \frac{r^2}{EI} \left(\frac{\pi}{2} - 1\right) m_2 \\ & + \frac{b}{AE} H_2 \end{aligned}$$

Collecting terms yield

$$\begin{aligned} \Delta F_{HT} = & \frac{r^3}{EI} \left(\frac{\pi}{2} - 1\right) V_1 + \left[\frac{l^3}{3EI} + \frac{r^3}{EI}\right] H_1 + \left[\frac{l^2}{2EI} - \frac{\pi r^2}{2EI}\right] m_1 \\ & + \frac{r^3}{EI} V_2 + \left[\frac{b}{AE} + \frac{r^3}{EI} \left(\frac{\pi}{2} - 1\right)\right] H_2 + \frac{\pi r^2}{2EI} m_2 \end{aligned} \quad (58)$$

$$\theta_1 + \theta_1' = 0$$

$$\begin{aligned} & -\frac{r^2}{EI} \left(\frac{\pi}{2} - 1\right) V_1 - \frac{r^2}{EI} H_1 + \frac{\pi r}{2EI} m_1 - \frac{r^2}{EI} V_2 - \frac{r^2}{EI} \left(\frac{\pi}{2} - 1\right) H_2 \\ & - \frac{\pi r}{2EI} m_2 + \frac{l^2}{2EI} H_1 + \frac{l}{EI} m_1 = 0 \end{aligned}$$

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Collecting terms yield

$$-\frac{r^2}{EI} \left(\frac{\pi}{2} - 1 \right) V_1 + \left[\frac{l^2}{2EI} - \frac{r^2}{EI} \right] H_1 + \left[\frac{l}{EI} + \frac{\pi r}{2EI} \right] m_1 - \frac{r^2}{EI} V_2 - \frac{r^2}{EI} \left(\frac{\pi}{2} - 1 \right) H_2 - \frac{\pi r}{2EI} m_2 = 0 \quad (59)$$

$$\theta_2 + \theta_2' = 0$$

$$\frac{r^2}{EI} \left(\frac{\pi}{2} - 1 \right) V_1 + \frac{r^2}{EI} H_1 - \frac{\pi r}{2EI} m_1 + \frac{r^2}{EI} V_2 + \frac{r^2}{EI} \left(\frac{\pi}{2} - 1 \right) H_2 + \frac{\pi r}{2EI} m_2 - \frac{b^2}{2EI} V_2 + \frac{b}{EI} m_2 - \frac{b^2}{2EI} V_3 + \frac{b}{EI} m_3 = 0$$

Collecting terms yield

$$\frac{r^2}{EI} \left(\frac{\pi}{2} - 1 \right) V_1 + \frac{r^2}{EI} H_1 - \frac{\pi r}{2EI} m_1 + \left[\frac{r^2}{EI} - \frac{b^2}{2EI} \right] V_2 + \frac{r^2}{EI} \left(\frac{\pi}{2} - 1 \right) H_2 + \left[\frac{b}{EI} + \frac{\pi r}{2EI} \right] m_2 - \frac{b^2}{2EI} V_3 + \frac{b}{EI} m_3 = 0 \quad (60)$$

$$\Delta V_2 - \Delta V_2' = 0$$

$$\frac{r^3}{EI} \left(1 - \frac{\pi}{4} \right) V_1 + \frac{r^3}{2EI} H_1 - \frac{r^2}{EI} m_1 + \frac{\pi r^3}{4EI} V_2 + \frac{r^3}{2EI} H_2 + \frac{r^2}{EI} m_2 - \frac{b^3}{3EI} V_2 + \frac{b^2}{2EI} m_2 - \frac{b^3}{6EI} V_3 + \frac{b^2}{2EI} m_3 = 0$$

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$$\frac{r^3}{EI} \left(1 - \frac{\pi}{4}\right) V_1 + \frac{r^3}{2EI} H_1 - \frac{r^2}{EI} m_1 + \left[\frac{\pi r^3}{4EI} - \frac{b^3}{3EI} \right] V_2 + \frac{r^3}{2EI} H_2 + \left[\frac{b^2}{2EI} + \frac{r^2}{EI} \right] m_2 - \frac{b^3}{6EI} V_3 + \frac{b^2}{2EI} m_3 = 0 \quad (61)$$

$$\Delta H_2 - \Delta H_2' = 0$$

$$\frac{r^3}{2EI} (\pi - 3) V_1 + \frac{r^3}{EI} \left(1 - \frac{\pi}{4}\right) H_1 - \frac{r^2}{EI} \left(\frac{\pi}{2} - 1\right) m_1 + \frac{r^3}{2EI} V_2 + \frac{r^3}{EI} \left(\frac{3\pi}{4} - 2\right) H_2 + \frac{r^2}{EI} \left(\frac{\pi}{2} - 1\right) m_2 - \frac{b}{AE} H_2 = 0$$

Collecting terms yield

$$\frac{r^3}{2EI} (\pi - 3) V_1 + \frac{r^3}{EI} \left(1 - \frac{\pi}{4}\right) H_1 - \frac{r^2}{EI} \left(\frac{\pi}{2} - 1\right) m_1 + \frac{r^3}{2EI} V_2 + \left[\frac{r^3}{EI} \left(\frac{3\pi}{4} - 2\right) - \frac{b}{AE} \right] H_2 + \frac{r^2}{EI} \left(\frac{\pi}{2} - 1\right) m_2 = 0 \quad (62)$$

$$\Delta B_{VT} = \delta_{V_4} + \Delta V_4 + \Delta V_3 + \Delta V_3'$$

$$\Delta B_{VT} = \frac{b}{AE} V_4 + \frac{r^3}{EI} \left(1 - \frac{\pi}{4}\right) V_3 - \frac{r^3}{2EI} (\pi - 3) H_3 + \frac{r^2}{EI} \left(\frac{\pi}{2} - 1\right) m_3 + \frac{r^3}{EI} \left(\frac{3\pi}{4} - 2\right) V_4 - \frac{r^3}{2EI} H_4 - \frac{r^2}{EI} \left(\frac{\pi}{2} - 1\right) m_4 + \frac{\pi r^3}{4EI} V_3 + \dots$$

equation is continued on next page.

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$$\dots - \frac{r^3}{2EI} H_3 + \frac{r^2}{EI} m_3 + \frac{r^3}{EI} \left(1 - \frac{\pi}{4}\right) V_4 - \frac{r^3}{2EI} H_4 - \frac{r^2}{EI} m_4$$

$$+ \frac{b^3}{6EI} V_2 - \frac{b^2}{2EI} m_2 + \frac{b^3}{3EI} V_3 - \frac{b^2}{2EI} m_3$$

Collecting terms yield

$$\Delta B_{VT} = \frac{b^3}{6EI} V_2 - \frac{b^2}{2EI} m_2 + \left[\frac{b^3}{3EI} + \frac{r^3}{EI} \right] V_3 - \frac{r^3}{EI} \left(\frac{\pi}{2} - 1 \right) H_3$$

$$+ \left[\frac{\pi r^2}{2EI} - \frac{b^2}{2EI} \right] m_3 + \left[\frac{l}{AE} + \frac{r^3}{EI} \left(\frac{\pi}{2} - 1 \right) \right] V_4 - \frac{r^3}{EI} H_4 - \frac{\pi r^2}{2EI} m_4 \quad (63)$$

$$\Delta B_{HT} = \delta_{H_4} + \Delta H_4 + \Delta H_3 + \Delta H_3'$$

$$\Delta B_{HT} = \frac{l^3}{3EI} H_4 - \frac{l^2}{2EI} m_4 - \frac{r^3}{2EI} V_3 + \frac{r^3}{EI} \left(1 - \frac{\pi}{4}\right) H_3 - \frac{r^2}{EI} m_3$$

$$- \frac{r^3}{2EI} V_4 + \frac{\pi r^3}{4EI} H_4 + \frac{r^2}{EI} m_4 - \frac{r^3}{2EI} V_3 + \frac{r^3}{EI} \left(\frac{3\pi}{4} - 2 \right) H_3$$

$$- \frac{r^2}{EI} \left(\frac{\pi}{2} - 1 \right) m_3 - \frac{r^3}{2EI} (\pi - 3) V_4 + \frac{r^3}{EI} \left(1 - \frac{\pi}{4}\right) H_4 + \frac{r^2}{EI} \left(\frac{\pi}{2} - 1 \right) m_4$$

$$+ \frac{b}{AE} H_3$$

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$$\Delta B_{HT} = \frac{r^3}{EI} V_3 + \left[\frac{b}{AE} + \frac{r^3}{EI} \left(\frac{\pi}{2} - 1 \right) \right] H_3 - \frac{\pi r^2}{2EI} m_3 - \frac{r^3}{EI} \left(\frac{\pi}{2} - 1 \right) V_4 + \left[\frac{l^3}{3EI} + \frac{r^3}{EI} \right] H_4 + \left[\frac{\pi r^2}{2EI} - \frac{l^2}{2EI} \right] m_4 \quad (64)$$

$$\theta_3 + \theta_3' = 0$$

$$\frac{r^2}{EI} V_3 - \frac{r^2}{EI} \left(\frac{\pi}{2} - 1 \right) H_3 + \frac{\pi r}{2EI} m_3 + \frac{r^2}{EI} \left(\frac{\pi}{2} - 1 \right) V_4 - \frac{r^2}{EI} H_4$$

$$- \frac{\pi r}{2EI} m_4 - \frac{b^2}{2EI} V_2 + \frac{b}{EI} m_2 - \frac{b^2}{2EI} V_3 + \frac{b}{EI} m_3 = 0$$

Collecting terms yield

$$- \frac{b^2}{2EI} V_2 + \frac{b}{EI} m_2 + \left[\frac{r^2}{EI} - \frac{b^2}{2EI} \right] V_3 - \frac{r^2}{EI} \left(\frac{\pi}{2} - 1 \right) H_3 + \left[\frac{\pi r}{2EI} + \frac{b}{EI} \right] m_3 + \frac{r^2}{EI} \left(\frac{\pi}{2} - 1 \right) V_4 - \frac{r^2}{EI} H_4 - \frac{\pi r}{2EI} m_4 = 0 \quad (65)$$

$$\theta_4 + \theta_4' = 0$$

$$- \frac{r^2}{EI} V_3 + \frac{r^2}{EI} \left(\frac{\pi}{2} - 1 \right) H_3 - \frac{\pi r}{2EI} m_3 - \frac{r^2}{EI} \left(\frac{\pi}{2} - 1 \right) V_4 + \frac{r^2}{EI} H_4$$

$$+ \frac{\pi r}{2EI} m_4 - \frac{l^2}{2EI} H_4 + \frac{l}{EI} m_4 = 0$$

Collecting terms yield

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$$-\frac{r^2}{EI} V_3 + \frac{r^2}{EI} \left(\frac{\pi}{2} - 1\right) H_3 - \frac{\pi r}{2EI} m_3 - \frac{r^2}{EI} \left(\frac{\pi}{2} - 1\right) V_4 + \left[\frac{r^2}{EI} - \frac{l^2}{2EI}\right] H_4 + \left[\frac{\pi r}{2EI} + \frac{l}{EI}\right] m_4 = 0 \quad (66)$$

$$\Delta V_3 - \Delta V_3' = 0$$

$$\frac{\pi r^3}{4EI} V_3 - \frac{r^3}{2EI} H_3 + \frac{r^2}{EI} m_3 + \frac{r^3}{EI} \left(1 - \frac{\pi}{4}\right) V_4 - \frac{r^3}{2EI} H_4$$

$$- \frac{r^2}{EI} m_4 - \frac{b^3}{6EI} V_2 + \frac{b^2}{2EI} m_2 - \frac{b^3}{3EI} V_3 + \frac{b^2}{2EI} m_3 = 0$$

Collecting terms yield

$$-\frac{b^3}{6EI} V_2 + \frac{b^2}{2EI} m_2 + \left[\frac{\pi r^3}{4EI} - \frac{b^3}{3EI}\right] V_3 - \frac{r^3}{2EI} H_3 + \left[\frac{r^2}{EI} + \frac{b^2}{2EI}\right] m_3 + \frac{r^3}{EI} \left(1 - \frac{\pi}{4}\right) V_4 - \frac{r^3}{2EI} H_4 - \frac{r^2}{EI} m_4 = 0 \quad (67)$$

$$\Delta H_3 - \Delta H_3' = 0$$

$$-\frac{r^3}{2EI} V_3 + \frac{r^3}{EI} \left(\frac{3\pi}{4} - 2\right) H_3 - \frac{r^2}{EI} \left(\frac{\pi}{2} - 1\right) m_3 - \frac{r^3}{2EI} (\pi - 3) V_4$$

$$+ \frac{r^3}{EI} \left(1 - \frac{\pi}{4}\right) H_4 + \frac{r^2}{EI} \left(\frac{\pi}{2} - 1\right) m_4 - \frac{b}{AE} H_3 = 0$$

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$$-\frac{r^3}{2EI} V_3 + \left[\frac{r^3}{EI} \left(\frac{3\pi}{4} - 2 \right) - \frac{b}{AE} \right] H_3 - \frac{r^2}{EI} \left(\frac{\pi}{2} - 1 \right) m_3 - \frac{r^3}{2EI} (\pi - 3) V_4 \\ + \frac{r^3}{EI} \left(1 - \frac{\pi}{4} \right) H_4 + \frac{r^2}{EI} \left(\frac{\pi}{2} - 1 \right) m_4 = 0 \quad (68)$$

Equations (57) thru (68) must be solved simultaneously to obtain the unknown loads & moments. These equations are represented in the following matrix form:

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K-5 10 X 10 TO 1/2 INCH 47 1323
10 X 10 INCHES
KUPPTEL & ESSER CO.

$\frac{l^2}{AE} \frac{r^2}{EI} \frac{\pi}{2}$	$\frac{r^2}{EI}$	$\frac{\pi r^2}{2EI}$	$\frac{b^2}{3EI} \frac{r^2}{EI}$	$\frac{r^2}{EI} \frac{\pi}{2}$	$\frac{\pi r^2}{2EI} \frac{b^2}{EI}$	$\frac{b^2}{6EI}$	$\frac{b^2}{2EI}$	0	0	0	V_1	ΔE_{V_1}
$\frac{r^2}{EI} \frac{\pi}{2}$	$\frac{l^2}{3EI} \frac{r^2}{EI}$	$\frac{l^2}{2EI} \frac{\pi r^2}{EI}$	$\frac{r^2}{EI}$	$\frac{b^2}{AE} \frac{r^2}{EI} \frac{\pi}{2}$	$\frac{\pi r^2}{2EI}$	0	0	0	0	0	H_1	ΔE_{H_1}
$\frac{r^2}{EI} \frac{\pi}{2}$	$\frac{l^2}{2EI} \frac{r^2}{EI}$	$\frac{l^2}{EI} \frac{\pi r^2}{2EI}$	$\frac{r^2}{EI}$	$\frac{r^2}{EI} \frac{\pi}{2}$	$\frac{\pi r^2}{2EI}$	0	0	0	0	0	M_1	0
$\frac{r^2}{EI} \frac{\pi}{2}$	$\frac{r^2}{EI}$	$\frac{\pi r^2}{2EI}$	$\frac{r^2}{EI} \frac{b^2}{EI}$	$\frac{r^2}{EI} \frac{\pi}{2}$	$\frac{b^2}{EI} \frac{\pi r^2}{2EI}$	$\frac{b^2}{2EI}$	$\frac{b^2}{EI}$	0	0	0	V_2	0
$\frac{r^2}{EI} \frac{\pi}{4}$	$\frac{r^2}{2EI}$	$\frac{r^2}{EI}$	$\frac{\pi r^2}{4EI} \frac{b^2}{EI}$	$\frac{r^2}{2EI}$	$\frac{b^2}{2EI} \frac{\pi r^2}{EI}$	$\frac{b^2}{6EI}$	$\frac{b^2}{2EI}$	0	0	0	H_2	0
$\frac{r^2}{2EI} \frac{\pi}{3}$	$\frac{r^2}{EI} \frac{\pi}{4}$	$\frac{r^2}{EI} \frac{\pi}{2}$	$\frac{r^2}{2EI}$	$\frac{r^2}{EI} \frac{\pi}{2}$	$\frac{b^2}{AE} \frac{r^2}{EI} \frac{\pi}{2}$	0	0	0	0	0	M_2	0
0	0	0	$\frac{b^2}{6EI}$	0	$\frac{b^2}{2EI} \frac{r^2}{EI}$	$\frac{b^2}{3EI} \frac{r^2}{EI}$	$\frac{\pi r^2}{2EI} \frac{b^2}{EI}$	$\frac{l^2}{AE} \frac{r^2}{EI} \frac{\pi}{2}$	$\frac{r^2}{EI}$	$\frac{\pi r^2}{2EI}$	V_3	ΔE_{V_3}
0	0	0	0	0	0	$\frac{r^2}{EI} \frac{b^2}{AE} \frac{\pi}{2}$	$\frac{\pi r^2}{2EI}$	$\frac{r^2}{EI} \frac{\pi}{2}$	$\frac{l^2}{3EI} \frac{r^2}{EI}$	$\frac{\pi r^2}{2EI} \frac{l^2}{EI}$	H_3	ΔE_{H_3}
0	0	0	$\frac{b^2}{2EI}$	0	$\frac{b^2}{EI}$	$\frac{r^2}{EI} \frac{b^2}{EI}$	$\frac{\pi r^2}{2EI} \frac{b^2}{EI}$	$\frac{r^2}{EI} \frac{\pi}{2}$	$\frac{r^2}{EI}$	$\frac{\pi r^2}{2EI}$	M_3	0
0	0	0	0	0	0	$\frac{r^2}{EI}$	$\frac{\pi r^2}{2EI}$	$\frac{r^2}{EI} \frac{\pi}{2}$	$\frac{r^2}{EI} \frac{l^2}{EI}$	$\frac{\pi r^2}{2EI} \frac{l^2}{EI}$	V_4	0
0	0	0	$\frac{b^2}{6EI}$	0	$\frac{b^2}{2EI}$	$\frac{\pi r^2}{4EI} \frac{b^2}{EI}$	$\frac{r^2}{EI} \frac{b^2}{EI}$	$\frac{r^2}{EI} \frac{\pi}{4}$	$\frac{r^2}{2EI}$	$\frac{r^2}{EI}$	H_4	0
0	0	0	0	0	0	$\frac{r^2}{2EI}$	$\frac{r^2}{EI} \frac{\pi}{2}$	$\frac{r^2}{2EI} \frac{\pi}{3}$	$\frac{r^2}{EI} \frac{\pi}{4}$	$\frac{r^2}{EI} \frac{\pi}{2}$	M_4	0

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4.3 Stress Analysis of the Privy Roof Mounted Shield Support (PRMSS)

A preliminary stress analysis of the shield support is presented below. The analysis verifies the ability of the support to withstand the design loads without exceeding material allowable stress values. The analysis is continuing and this preliminary analysis will be updated and modified to reflect later calculations.

The PRMSS consists of three sections that form an approximate 135° arc as shown in Figure 4.3.1. Each section is pressurized and water cooled and contains boral and steel shielding. Section "C" is located between two flow lines and rests on the horizontal shield. It supports none of the shield weight but is used primarily for shielding. Sections A and B rest on the privy roof and support the shield weight. The shield rests across the entire top surface of section A and only across a portion of section B as indicated by the shaded areas in Figure 1. The cantilevered portion of section B has a clearance between the shield base and thus supports none of its weight.

The analysis verifies the ability of the shield support to withstand the design loads. The wind loading was found to produce approximately one tenth the effect of the lateral acceleration loads. The analysis indicates that the hold down bolts are sufficient to resist the combined wind and acceleration loads during transportation to the test cell. Calculations indicate that the pressure loads on the support stand cross section are sufficiently resisted by the bolts and welds. Analysis is continuing on the welds at the four corners of the support stand sections.

The pressure produces stresses of 1300 psi and 7800 psi in the top and side plates respectively. The deflections are small and there is no danger of the side plates buckling. The compressive stresses in the side plates due to the shield weight (and 2g load) are less than 500 psi. The thermal stresses in the aluminum are approximately 2700 psi. Analysis is continuing on the stresses at the corners.

Both the boral and the steel shielding plates experience some temperature gradients, but since they are free to expand they are essentially stress free.

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DESIGN CRITERIA

The Shield Support stand was designed using the same Criteria as specified for the vertical shield in WANL GSE-1371, Design Fabrication and Test Specification for the Privy Roof Mounted Shield and Privy Roof Mounted Shield Support, dated May 17, 1965, Revision A. The two major design conditions are the loads imposed on the Shield Support during transporting the reactor to the test cell and the loads occurring during reactor operation. The loads used in the support stand design for these conditions are listed below:

Transportation Loads

Simultaneously applied 50 mph wind loading
with the following accelerations:

2g Vertical
1g Fore and aft
1g Lateral

Shield weight, empty of water = 22,000 lbs.

ANALYSIS APPROACH

The shield support was analyzed by considering Section "B" (Figure 1) as containing the most severe stress, deflection, and thermal problems. This is due to the fact that the pressure areas and plates are larger while the shield bearing area is the smallest of the three sections. Section "A" is similarly loaded but due to its smaller dimensions, its stresses are proportionally lower. Box Section "C" does not support any of the shield weight and thus contains lower stresses than "A" and "B".

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OPERATING LOADS

Internal design Pressure = 60 psi; Wind loading = 100 mph. (any direction);
Acceleration loads were assumed to be zero; Thermal loads as specified;
Weight of shield (filled with water) = 30,000 Lbs.

MATERIAL PROPERTIES

The following allowable stress values at the given temperatures were utilized in the design and analysis of the shield support.

ALUMINUM ALLOY & TEMPER	SM-ALLOWABLE STRESS AT						
	MINIMUM TENSILE PROPERTIES AT ROOM TEMP., ksi		100°F psi	150°F psi	200°F psi	250°F psi	300°F psi
	UTS	TYS					
6061-T4	30	16	10,000	9,600	9,300	8,900	8,540
6061-T6	42	35	14,000	13,600	13,200	12,150	10,500
6061-T6	24	--	8,000	7,860	7,600	7,200	6,650
Welded							
6061-T6			4,620	4,540	4,380	4,160	3,840
Welded, Shear							

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FIGURE 4.3.1

SHADED PORTIONS INDICATE AREAS SUPPORTING THE SHIELD

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Wind loading on the shield:

Static pressure corresponding to the kinetic energy of a wind of velocity V :

$$p = \frac{\gamma V^2}{2g}$$

With $\gamma_{\text{Air, } 60^\circ\text{F, } 14.7 \text{ psi}} = 0.0765 \left(\frac{\text{lb}}{\text{ft}^3} \right) = 44.2 \cdot 10^{-6} \left(\frac{\text{lb}}{\text{in}^3} \right)$

$$g = 386 \left(\frac{\text{in}}{\text{sec}^2} \right)$$

$$V = 100 \text{ (MPH)} = \frac{100 \times 63300}{3600} = 1760 \left(\frac{\text{in}}{\text{sec}} \right)$$

$$V^2 = 1760^2 = 3.095 \cdot 10^6 \left(\frac{\text{in}^2}{\text{sec}^2} \right)$$

$$p = \frac{44.2 \cdot 10^{-6} \cdot 3.095 \cdot 10^6}{2 \cdot 386} = 0.1772 \text{ (psi)}$$

For a 50 (MPH) wind $p = 0.0443 \text{ (psi)}$

Wind force on the shield ($V = 100 \text{ MPH}$):

$$F_{100} = pA = 0.1772 \cdot 105.3 \cdot 123.38 = 2310 \text{ (lb)}$$

Overturning Moment $M_{100} = F \left(\frac{h_{\text{shield}}}{2} + h_{\text{support}} \right) = 2310 (61.69 + 32) = 216,300 \text{ (in-lb)}$

For 50 (MPH) wind:

$$M_{50} = 54,100 \text{ (in-lb)}$$

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Centroid of the Shield Cross Section:

Static Moment with respect to, O-O:

$$M_{O-O} = 2 \int_{R_1}^{R_2} \int_0^\alpha dR R d\theta R \cos \theta = 2 \sin \theta \Big|_0^\alpha \left[\frac{R^3}{3} \right]_{R_1}^{R_2} = \frac{2}{3} \sin \alpha (R_2^3 - R_1^3)$$

$$\text{Area } A = 2 \int_{R_1}^{R_2} \int_0^\alpha dR R d\theta = 2 \alpha \left(\frac{R_2^2 - R_1^2}{2} \right) = \alpha (R_2^2 - R_1^2)$$

$$X = \frac{M_{O-O}}{A} = \frac{2 \sin \alpha (R_2^3 - R_1^3)}{3 \alpha (R_2^2 - R_1^2)}$$

Since the shield is not homogeneous the three parts (I, II and III) which have most effect on the C.G. are considered separately.

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$$\alpha \approx \frac{135^\circ}{2} + \frac{2.25}{\approx 51.5 \cdot 0.01745} = 67.5 + 2.50 = 70.0^\circ$$

$$\text{Plate I: } x_I = \frac{2}{3} \cdot \frac{0.9398}{1.222} \cdot \frac{(47.75^3 - 47.00^3)}{(47.75^2 - 47.00^2)} = 0.512 \frac{108,873 - 103,823}{2,280 - 2,209} = 36.45 \text{ (in)}$$

$$x_{II} = 0.512 \frac{(56.0^3 - 55.25^3)}{(56.0^2 - 55.25^2)} = 0.512 \frac{175,616 - 168,650}{3,136 - 3,052.5} = 42.75 \text{ (in)}$$

$$x_{III} = 0.512 \frac{(54.75^3 - 49.00^3)}{(54.75^2 - 49.00^2)} = 0.512 \frac{164,113 - 117,649}{2,997.5 - 2,401} = 39.9 \text{ (in)}$$

Average of I and II:

$$x_{I-II} = \frac{47.37 \cdot 36.45 + 55.62 \cdot 42.75}{47.37 + 55.62} = \frac{4110}{102.99} = 39.9 \text{ (in)}$$

Since $x_{I-II} = x_{III}$, the C.G. of the shield is located at $x = 39.9 \text{ (in)}$

This neglects the effect of the unsymmetry of the base of the shield.

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FIGURE 2
FOR DETERMINING BOLT LOADS

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Bolts - Support to Privy Roof (SEE FIGURE 2)

The max. overturning moment is due to the 1-g fore and aft acceleration

and is $M_{ov} = F \left(\frac{h_{shield}}{2} + h_{support} \right) = 22,000 \left(\frac{123.38}{2} + 32 \right) = 2.06 \times 10^6 \text{ (inlb)}$

In addition there is a wind moment of $M_{100} = 216,000 \text{ (inlb)}$ respectively $M_{50} = 54,000 \text{ (inlb)}$ and a counteracting moment M_{co} due to the vertical acceleration.

(a) Transportation Condition:

$M_{ov} = 2.06 \times 10^6 \text{ (inlb)}$ both, fore-aft and lateral

$M_{50} = 54,000 \text{ (inlb)}$

$M_{co} = 0$ (assume a 1g-1g condition).

Worst condition:

$M_{ov} + M_{50} = 2.11 \times 10^6 \text{ (inlb)}$ in fore-aft direction

$M_{ov} = 2.06 \times 10^6 \text{ (inlb)}$ in lateral direction.

Assuming a minimum distance between bolts of 23.5 (in) fore-aft and 100 (in) in lateral direction, the total bolt loads become:

$F_{b_{tot.}} = \frac{2.11 \times 10^6}{23.5} + \frac{2.06}{100} = 89,700 + 20,600 = 110,300 \text{ (lb)}$

Assume four $\frac{1}{2}$ " bolts. Load per bolt $F_b = 27,600 \text{ (lb)}$

Material should be selected so, that the allowable load equals $\geq 27,600 \text{ (lb)}$ at 500°F.

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(b) Operating Conditions

$$M_{0v} = 0 \quad (\text{no acceleration})$$

$$M_{100} = 216,000 \quad (\text{in lb})$$

$$M_{c0} \approx 30,000 \cdot 9.3 \approx 279,000 \quad (\text{in lb})$$

Since $M_{c0} > M_{100}$ the shield is stable and the bolts will not experience any additional load due to the 100 (MPH) wind.

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Stresses in the cross-section A-A (FIGURE 1)

The plates (and welds) of this rectangular cross section are under direct tension and bending.

$$F_a = pa \text{ (lb/in)}$$

$$F_b = pb \text{ (lb/in)}$$

$$\theta_a = -\frac{pa a^2}{6EI_a} + pa \frac{a^2}{2EI_a} - \frac{Ma}{EI_a} = \frac{1}{EI_a} \left[\frac{pa^3}{3} - Ma \right]$$

$$\theta_b = \frac{pb b^2}{6EI_b} - pb \frac{b^2}{2EI_b} + \frac{Mb}{EI_b} = \frac{1}{EI_b} \left[-\frac{pb^3}{3} + Mb \right]$$

But $\theta_a = \theta_b$:
$$\frac{1}{EI_a} \left[\frac{pa^3}{3} - Ma \right] = \frac{1}{EI_b} \left[-\frac{pb^3}{3} + Mb \right]$$

$$\frac{pa^3}{3EI_a} - \frac{Ma}{EI_a} = -\frac{pb^3}{3EI_b} + \frac{Mb}{EI_b}$$

$$M \left(\frac{b}{I_b} + \frac{a}{I_a} \right) = \frac{p}{3} \left(\frac{a^3}{I_a} + \frac{b^3}{I_b} \right)$$

$$M \frac{bI_a + aI_b}{I_a I_b} = \frac{p}{3} \frac{a^3 I_b + b^3 I_a}{I_a I_b}$$

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$$\therefore M = \frac{p}{3} \cdot \frac{a^3 I_b + b^3 I_a}{a I_b + b I_a} \quad \left(\frac{\text{in} \cdot \text{lb}}{\text{in}} \right)$$

$$\text{For } I_a = I_b; M = \frac{p}{3} \cdot \frac{a^3 + b^3}{a + b} \quad \left(\frac{\text{in} \cdot \text{lb}}{\text{in}} \right)$$

For cross section A-A:

$$a = 5.5, \quad b = 7.0, \quad p = 60 (\text{psi}).$$

$$\text{Then: } M = \frac{60}{3} \cdot \frac{5.5^3 + 7^3}{5.5 + 7} = 20 \cdot \frac{166.3 + 343}{12.5} = 815 \left(\frac{\text{in} \cdot \text{lb}}{\text{in}} \right)$$

$$I/c = \frac{h^2}{6} = \frac{2^2}{6} = \frac{2}{3}$$

$$\sigma_{A-A} = \frac{M}{I/c} = \frac{815}{\frac{2}{3}} = 1222 (\text{psi}) \quad (\text{at the corners})$$

For cross section B-B:

$$a = 5.5, \quad b = 15.0, \quad p = 60 (\text{psi})$$

$$\text{Then: } M = \frac{60}{3} \cdot \frac{5.5^3 + 15^3}{5.5 + 15} = 20 \cdot \frac{166 + 3375}{20.5} = 3460 \left(\frac{\text{in} \cdot \text{lb}}{\text{in}} \right)$$

$$\sigma_{B-B} = 5,180 (\text{psi})$$

Direct stress in the plates and welds due to p:

$$\sigma = \frac{F}{t} = \frac{F}{2} (\text{psi})$$

Cross section	A-A	B-B
Horizontal Plate	210 (psi)	450 (psi)
Vertical Plate	165 (psi)	165 (psi)

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The horizontal plates are bolted to the vertical plates.

The bolts are loaded directly by the pressure p and in addition by the edge moment M .

Direct load on the bolts (neglecting end plates):

$$F = pa = 60 \times 5.5 = 330 \text{ (lb/in)}$$

Load due to the edge moment (for zero vertical load on PRMS):

$$M = Fd$$

$$F = \frac{M}{d} = \frac{3460}{1} = 3460 \text{ (lb/in) at cross section B-B.}$$

Then total bolt load at cross section B-B:

$$F_{TOT} = 330 + 3460 = 3,790 \text{ (lb/in)}$$

Plate rotation at the bolts: (from p .)

$$\theta = \frac{1}{(1-\mu^2)EI} \left[-\frac{pb^3}{3} + Mb \right] = \frac{1}{0.91 \times 9.9 \times 10^6 \times \frac{2}{3}} \left[-\frac{60 \times 15^3}{3} + 3,460 \times 15 \right]$$

$$0.1663 \left[-67,500 + 51,900 \right] \times 10^{-6} = -2.61 \times 10^{-3}$$

$$\text{or: } \theta = 0.15^\circ$$

Since this angle is very small it is not necessary to consider bending of the bolts.

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SHIELD SUPPORT SECTION "B" HAS THE LARGEST TOP PL.
AS SHOWN BELOW:

THE ARC LENGTH AT THE SECTOR
CENTER IS.

$$S = R\theta = 53.5 \times .855 = 45.7 \text{ IN}$$

AS AN APPROXIMATE ASSUMPTION
A RECTANGULAR PLATE OF THE
SAME WIDTH AND LENGTH EQUAL
TO THE ARC LENGTH.

FOR A RECTANGULAR FLAT PLATE WITH ALL
EDGES SUPPORTED AND A UNIFORM LOAD
OVER THE ENTIRE SURFACE, THE MAX.
STRESS AND DEFLECTION IS GIVEN BY: *

$$\text{MAX. } S_b = - \frac{0.75 w b^2}{t^2 (1 + 1.61 \alpha^3)}$$

$$\text{MAX. } \delta = - \frac{0.1422 w b^4}{E t^3 (1 + 2.21 \alpha^3)}$$

* ROARK, FORMULA FOR STRESS & STRAIN, P. 203
CASE #36.

FOR CONSERVATISM ASSUME
THE PRESSURE ACTS OVER
THE BOLT CENTERS

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WHERE:

$w =$ UNIT LOAD = 60 PSI

$b =$ PLATE WIDTH = 11 IN.

$a =$ PLATE LENGTH = 43.7 IN.

$t =$ PLATE THICKNESS = 2 IN.

$E =$ MODULUS OF ELASTICITY = 10×10^6 PSI

$$\alpha = \frac{b}{a} = \frac{11}{43.7} = .252$$

$$\alpha^3 = .0159$$

MAX STRESS

$$S_b = \frac{0.75 \times 60 \times (11)^2}{(2)^2 (1 + 1.61 \times .0159)} = \frac{5450}{4 (1.0256)} = 1326 \text{ PSI}$$

THIS STRESS IS MUCH LOWER THAN THE ALLOWABLE

MAX DEFLECTION

$$\gamma = \frac{.1422 \times 60 \times (11)^4}{10 \times 10^6 \times (2)^3 (1 + 2.21 \times .0159)} = \frac{12500}{80 \times 10^6 (1.0351)}$$

$$\gamma = .000151 \text{ IN.} \quad \text{SMALL DEFLECTION}$$

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THE SHIELD WEIGHT WILL BE SUPPORTED BY THE 2" THICK SIDE PLATES OF THE SHIELD SUPPORT. THE SHIELD WEIGHT WILL BE SUPPORTED BY THE 2" THK. VERTICAL SIDE PLATES SHOWN BELOW: THE APPROXIMATE DIMENSIONS ARE ALSO SHOWN.

AREA "A"

THE TOTAL CROSS SECTIONAL SUPPORT AREA AT THE "A" SUPPORT IS CALCULATED AS:

$$A = \text{LENGTH} \times 2" \quad \text{WHERE } L = 79"$$

$$\underline{\text{AREA "A"} = 158 \text{ IN}^2}$$

AREA "B"

THE CROSS SECTIONAL SUPPORT AREA AT "B" IS:

$$A = 2L \quad \text{WHERE } L = 38.23"$$

$$\underline{\text{AREA "B"} = 76.5 \text{ IN}^2}$$

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THE COMPRESSIVE STRESSES IN THE 2" SIDE PLATES
DUE TO THE SHIELD WEIGHT ARE CALCULATED AS:

TRANSPORTATION STRESSES

$$\text{SHIELD WEIGHT (DRY)} = 22,000 \#$$

DURING TRANSPORTATION TO THE TEST CELL A 2g
VERTICAL ACCELERATION LOAD CAN EXIST.

$$\text{TOTAL DOWNWARD FORCE} = 44,000 \#$$

ASSUMING THAT THE SUPPORT REACTIONS ARE EQUAL
AND THEREFORE 22,000# EACH.

ALSO ASSUME THAT THIS LOAD IS EVENLY DISTRIBUTED
OVER THE SUPPORTING AREA. THE COMPRESSIVE
STRESSES IN THE SIDE PLATES THEN ARE:

AT "A"

$$S = \frac{P}{A} = \frac{22,000 \#}{158 \text{ IN}^2} = 139 \text{ PSI}$$

AT "B"

$$S = \frac{22,000}{76.5} = 288 \text{ PSI} \quad \text{VERY LOW STRESSES}$$

THE MAXIMUM COMPRESSIVE FORCE AT SUPPORT "B"
IS:

$$P = \frac{F}{L} = \frac{22,000 \#}{38.23} = 575 \#/\text{IN. OF LENGTH} \quad \left(\begin{array}{l} \text{VALUE} \\ \text{TO BE USED} \\ \text{LATER} \end{array} \right)$$

OPERATING STRESSES

THE H₂O FILLED SHIELD & SUPPORT SHALL NOT EXCEED

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30,000#. THE 29. ACCEL. LOAD DOES NOT ACT DURING REACTOR OPERATION SO THE 30,000# LOAD IS A MAX. VALUE. THE TOTAL REACTION AT EACH SUPPORT IS THEN 15000#. THE MAXIMUM COMPRESSIVE FORCE AT SUPPORT "B" IS:

$$P = \frac{F}{L} = \frac{15000}{38.23} = 392 \text{ \#/IN. OF LENGTH} \quad \left[\begin{array}{l} \text{TO BE USED} \\ \text{LATER} \end{array} \right]$$

SINCE THE LOADS ARE LOWER, THE OPERATING COMPRESSIVE STRESSES IN THE SIDE R. S. IS LESS THAN THE STRESSES DURING TRANSPORTATION.

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THE CRITICAL BUCKLING OF
 THE CURVED SIDE PL. IS
 GIVEN BY:

$$P' = \frac{Et^3 \left(\frac{\pi^2}{\alpha^2} - 1 \right)}{12 \alpha^3 (1 - \nu^2)} \quad \begin{matrix} \text{EDGES} \\ \text{FREE} \end{matrix}$$

$$P' = \frac{Et^3 (K^2 - 1)}{12 \alpha^3 (1 - \nu^2)} \quad \begin{matrix} \text{EDGES} \\ \text{CLAMPED} \\ \text{CASE 5.} \\ \text{(ROARK P.31B)} \end{matrix}$$

WHERE :

$$\alpha = \frac{47}{2} = 23.5^\circ = .412 \text{ RAD.}$$

$$E = 10 \times 10^6 \text{ PSI.}$$

$$\nu = .33 \text{ FOR 6061-T6 ALUM.}$$

$$K = \sim 6.50$$

THE ACTUAL CONDITION IS
 SOMEWHERE BETWEEN THESE
 TWO EXTREMES:

FREE EDGES

$$P' = \frac{10 \times 10^6 (2)^3 \left(\frac{\pi^2}{(.412)^2} - 1 \right)}{12 (47)^3 (1 - .33^2)} = \frac{80 \times 10^6 (57.3)}{1242 \times 10^6 (.1089)} = 33800$$

$$P' = \underline{33,800 \text{ PSI}}$$

CLAMPED EDGES

$$P' = \frac{80 \times 10^6 (6.5^2 - 1)}{.135 \times 10^6} = 24,300 \text{ PSI}$$

SINCE THE DESIGN PRESSURE IS 60 PSI, THE SIDE
 PLATES ARE IN NO DANGER OF BUCKLING IN THE
 LATERAL DIRECTION.

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THE 2" THICK SIDE PLATES IN THE AXIAL DIRECTION ARE LOADED AS SHOWN, WITH A PRESSURE LOAD (q) AND A COMPRESSIVE LOAD P DUE TO THE SHIELD WEIGHT.

THE DESIGN PRESSURE IS APPROX. 30 PSI.
THE DESIGN PRESSURE IS 60 PSI.

THE CRITICAL AXIAL COMPRESSIVE FORCE IS GIVEN BY:

$$P_{CR} = \frac{\pi^2 EI}{L^2} \quad I = \frac{bh^3}{12} = \frac{1 \times (2)^3}{12} = .666 \text{ IN}^4$$

$$P_{CR} = \frac{\pi^2 \times 10 \times 10^6 \times 1 \times (2)^3}{(32)^2 \times 12}$$

WHERE:

$h = 2 \text{ IN.}$
 $E = 10 \times 10^6 \text{ PSI}$
 $L = 32 \text{ IN.}$
 $b = \text{UNIT WIDTH} = 1 \text{ IN.}$

$$P_{CR} = 64,200 \text{ \#/1" WIDTH}$$

THE MAXIMUM COMPRESSIVE FORCE AT SUPPORT "B" IS:

$$P = 575 \text{ \#/IN. OF BEAM WIDTH}$$

THE SIDE PLATES ARE THEREFORE IN NO DANGER OF BUCKLING IN THE AXIAL DIRECTION.

THE DEFLECTION OF THE SIDE PLATES UNDER THE COMBINED AXIAL AND PRESSURE LOADS IS GIVEN BY:

$$\delta = \frac{5qL^4}{384 EI} \pi(u) *$$

* TIMOSHENKO, THEORY OF ELASTIC STABILITY, P. 6 & 9.

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WHERE:

$$u = \frac{\pi}{2} \sqrt{\frac{P}{P_{CR}}} = 1.57 \sqrt{\frac{392}{64200}} = .125$$

$P = 392 \#$ DURING OPERATION WHEN q ACTS.

$2u = .250$ FROM TABLE A-2 (TIMOSHENKO P. 529)

$$\eta(u) = 1.007$$

$$\delta = \frac{5 \times 60 \times (32)^4}{384 \times 10 \times 10^6 \times 1 \times (2)^{3/2}} (1.007) = \frac{314 \times 10^6 (1.007)}{2560 \times 10^6}$$

$$\delta = .123 \text{ IN.}$$

THIS DEFL. IS DECREASED BY THE AMOUNT OF $(1 - \eta^2)\delta$ SINCE THE SERIES OF BEAMS FORM A PLATE.

$$\delta_T = (1 - .33^2) \cdot .123 = \underline{.11 \text{ INCH}}$$

MAX. MOMENT

THE MAXIMUM MOMENT IS GIVEN BY:

$$M_{MAX} = w j^2 (\sec \frac{1}{2} U - 1) *$$

WHERE:

$$j = \sqrt{\frac{EI}{P}} = \sqrt{\frac{10^7 \times 1 \times (2)^{3/2}}{392}} = 130.2 \text{ IN}$$

$$U = \frac{l}{j} = .245$$

$$M_{MAX} = 60 \times (130.2)^2 (\sec \frac{.245}{2} - 1) = 1.09 \times 10^6 (1.0075^2 - 1) = 7640 \text{ IN-#}$$

*ROARK, FORMULAS FOR STRESS & STRAIN, P. 135, CASE 4.

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THE MAXIMUM BENDING STRESS IN THE SIDE R BEAM ANALYSIS IS:

$$S = \frac{Mc}{I} = \frac{7640 \times 1}{.666} = 11450 \text{ PSI}$$

FOR THE PLATE

$$S = (1 - \nu^2)(11450) = (1 - .33^2)(11450) = 10,200 \text{ PSI}$$

THE TOTAL PLATE STRESS IS THE BENDING + DIRECT

$$S = \frac{Mc}{I} \pm \frac{P}{A} = 10200 + 280 = \underline{10480 \text{ PSI}}$$

THIS IS LESS THAN THE ALLOWABLE STRESS OF 13200 PSI @ 200 °F.

THE ABOVE STRESSES WERE CALCULATED USING BEAM EQUATIONS AND GIVES A CONSERVATIVE STRESS VALUE. AN ALTERNATE METHOD IS TO ASSUME A RECTANGULAR FLAT PLATE, SUPPORTED ON ALL EDGES AND UNIFORMLY LOADED. THIS CALCULATION FOLLOWS:

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For a first approximation assume a rectangular plate, simply supported on all edges and uniformly loaded.

The max. stress occurs at the center of the plate and is:

$$\sigma_x = A_{1x} p \frac{b^2}{t^2} \quad \text{where } A_{1x} = f\left(\frac{b}{a}\right)$$

$$\sigma_y = A_{1y} p \frac{a^2}{t^2} \quad \text{where } A_{1y} = f\left(\frac{a}{b}\right)$$

For $2a = 52''$, $2b = 31''$; $\frac{b}{a} = 0.596$

and $A_{1x} = 2.15$, $A_{1y} = 1.15$

Then: $\sigma_x = 2.15 \cdot 60 \cdot \left(\frac{15.5}{2}\right)^2 = 7,750 \text{ (psi)}$

$\sigma_y = 1.15 \cdot 60 \cdot \left(\frac{15.5}{2}\right)^2 = 4,140 \text{ (psi)}$

Stress intensity $\sigma_i = \sigma_x - \sigma_y = 3,610 \text{ (psi)}$

or $\sigma_i = \sigma_x + p = 7,750 + 60 = 7,810 \text{ (psi)}$

The actual stresses will be lower than the stresses above because:

1. The plate has a initial curvature which reduces the stresses.
2. The actual plate has a more favorable shape than assumed above.
3. The boundary conditions can be expected to be between fixed and simply supp.

The allowable stress for 200°F is $13,200 \text{ (psi)}$.

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Differential Thermal Expansion between AL-Plate and S.S.-Plate:

The temperatures through the plates are shown in the Figure below. In circumferential direction the temperatures are approximately constant.

Assume an average temperature of the AL-Plate of $T_{AL} = 177^{\circ}\text{F}$
 " " " " " " S.S.-Plate of $T_{SS} = 135^{\circ}\text{F}$

Then: $\alpha_{AL} = 13.1 \times 10^{-6} \left(\frac{\text{in}}{\text{in}^{\circ}\text{F}} \right)$ $E_{AL} = 9.9 \times 10^6 \text{ (psi)}$ [AL 6061 T6]
 $\alpha_{S.S.} = 9.2 \times 10^{-6} \left(\frac{\text{in}}{\text{in}^{\circ}\text{F}} \right)$ $E_{S.S.} = 29.0 \times 10^6 \text{ (psi)}$ [S.S. Type 302]

$$\begin{aligned} \text{Differential thermal expansion } \Delta \ell &= \ell [\alpha_{AL}(T_{AL} - T_R) - \alpha_{S.S.}(T_{S.S.} - T_R)] \\ &= \ell [13.1 \times 10^{-6} (177^{107} - 70) - 9.2 \times 10^{-6} (135^{65} - 70)] \\ &= \ell [1402^{804} - 598] \cdot 10^{-6} = 0.804 \cdot 10^{-3} \ell \end{aligned}$$

Thermal expansion with respect to the mid of the steel plate:

$$\ell \approx 22.5''$$

$$\Delta \ell = 0.804 \times 10^{-3} \times 22.5 = 18.1 \cdot 10^{-3} \text{ (in)}$$

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DATE 6-11-65

BY E. A. H.

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THERMAL STRESSES

The max. temp. gradient through the aluminum plates is approximately 30°F. Assuming a linear transition through the thickness (steady heat flow) and suppressing any change in curvature the stress is:

$$\sigma_x = \sigma_y = \pm \frac{E\alpha(T_1 - T_2)}{2(1 - \nu)} = \frac{9.7 \times 10^6 \times 13.1 \times 10^{-6} \times 30}{2(1 - 0.3)} = \pm 2,780 \text{ (psi)} \quad *$$

The above max. stress occur only at the faces of the plate and are secondary bending stresses.

The steel plate "sees" some temperature gradient, but is essentially free to expand; therefore it is stress-free.

* "Thermal Stress and Deformation" by J.N. Goodier, Stanford, Calif., Journal of Applied Mechanics, September 1957.

5.0 Material Properties and Investigations.

5.1 Material Selection for Main Structure of the PRMS and the PRMSS.

The Criteria for reusability of the PRMS is most easily met by the selection of an aluminum alloy for the main structure of the shield. The selection of the particular alloy to be used was based on considerations such as strength, availability, fabrication characteristics and resistance to corrosion. The most important Criteria considered were the mechanical properties of welded and unwelded alloys. The design criteria for the PRMS and PRMSS requires the use of Table N-421 of Section III of the ASME Boiler and Pressure Vessel Code, or an equivalent. Since Section III is only applicable to ferrous alloys, it was decided to select Table UNF-23 of Section VIII of the ASME Code as a suitable alternate source of data. However, the allowable stress values given in Section VIII cannot be used without modification since GSE-1371 specifies that the design stress intensity values for materials other than those listed in Table N-421 shall be determined by the same rules as those given in Section III.

Appendix Q, Paragraph UA-601 of Section VIII of the ASME Code specifies that the maximum allowable stress values of Table UNF-23 are determined as the lowest of the following, when the tensile and yield strengths are obtained from standard short-time tests:

- a. One-fourth of the tensile strength as adjusted to minimum;
- b. Two-thirds of the yield strength as adjusted to minimum;
- c. The stress producing a secondary creep of 0.1 creep rupture units or 0.1 percent for 10,000 hours.

5.1 (Contd)

- d. The stress producing rupture in 100,000 hours.

The "Criteria of Section III of the ASME Boiler and Pressure Vessel Code for Nuclear Vessels" specifies that the allowable stresses, S_m , given in Table N-421 are determined as the lowest of the following:

- a. One-third of the minimum tensile strength.
- b. Two-thirds of the minimum yield strength.

With the criteria presented above in mind, the allowable stresses for standard aluminum alloys given in Table UNF-23 were adjusted and compared. Based on this comparison, the alloy selected for use in the PRMS and PRMSS was 6061 aluminum. Table 5.2.1.1 presents the adjusted values of allowable stresses for 6061 aluminum. Tables 5.2.1.2a and 5.2.1.3b present other physical properties of 6061 aluminum being used in the analyses of the PRMS and PRMSS.

5.2 Material Properties Used in the Design and Analysis of the PRMS and PRMSS.

5.2.1 6061 Aluminum

5.2.1.1 Allowable Stress Values.

The allowable stress values for 6061 Aluminum are given in Table 5.2.1.1.

5.2.1.2 Mechanical and Physical Properties

The mechanical and physical properties of 6061 aluminum other than allowable stresses are given in Table 5.2.1.2a and Table 5.2.1.2b.

5.2.2 Boral

5.2.2.1 Allowable Stress Values.

The tentative allowable stress values for the 50% B₄C Boral plates are given in Table 5.2.2.1. Preliminary data obtained from ALCOA, the supplier of the boral plate, indicate an average tensile strength of 12,000 psi. Since no actual minimum strength data are available, the minimum was arbitrarily set at 9,000 psi. The allowable room temperature stress, S_m , was then taken as one-third of the tensile strength as required by Section III of the ASME Code. The degradation of strength with temperature was assumed to be proportioned to that of 1100-0 aluminum, which is the matrix and cladding material in the boral plate.

5.2.2.2 Mechanical and Physical Properties.

Mechanical and physical properties for the 50% B₄C Boral are given in Table 5.2.2.2.

5.2.3 Steel for Staybolts.

5.2.3.1 Allowable Stress Values.

The allowable stress values for the steel staybolts are given in Table 5.2.3.1. These values were derived using the criteria of Section III of the ASME Code.

5.2.3.2 Mechanical and Physical Properties.

Mechanical and physical properties for the steel staybolts are given in Table 5.2.3.2.

5.2.4 Cooling water

5.2.4.1 The physical properties of the cooling water are given in Tables 5.2.4.1a and 5.2.4.1b.

5.2.5 Steel Balls/Water

5.2.5.1 The assumed physical properties of the steel balls/water combination used in the heat transfer calculations are given in Table 5.2.5.1.

TABLE 5.2.1.1Allowable Stresses of 6061 Aluminum[#]

Temper	Minimum Tensile Strength psi	Minimum Yield Strength psi	Allowable Stress, S _m , psi				
			100°F	150°F	200°F	250°F	300°F
6061-T4	30,000	16,000	10,000	9,600	9,330	8,900	8,540
6061-T6	42,000	35,000	14,000	13,600	13,200	12,150	10,500
6061-T6 Welded	24,000*	--	8,000	7,860	7,600	7,200	6,650

TABLE 5.2.1.2aMechanical and Physical Properties of 6061 Aluminum⁺

Modulus of Elasticity	10 x 10 ⁶ psi
Poissons Ratio	0.33
Coefficient of Thermal Expansion	13.1 in/in-°F (68°F to 212°F)
Density	170 lb/ft ³
Latent Heat	4680 Btu/lb

TABLE 5.2.1.2bThermal Conductivity and Heat Capacity of 6061 Aluminum⁺

Temperature °F	Thermal Conductivity Btu/hr-ft-°F	Heat Capacity Btu/lb-°F
50	87	0.201
100	92	0.207
150	95	0.212
200	98.5	0.217
250	101	0.222
300	103.5	0.226

[#] Derived from Section VIII, ASME Code, Table UNF-23.

* Strength of reduced - section tensile specimen required to qualify welding procedures.

⁺ Ref: MIL-HDBK-5, 1959, page 105, and Sibbit and Otway, LASL Memo dated October 26, 1959.

TABLE 5.2.2.1

Allowable Stresses, S_m , of Boral*

Estimated Minimum Tensile Strength, psi	Minimum Yield Strength, psi	Allowable Stress, psi				
		100°F	150°F	200°F	250°F	300°F
9,000	---	3,000	2,750	2,600	2,330	1,960

TABLE 5.2.2.2

Mechanical and Physical Properties of Boral

Modulus of Elasticity	(Unknown)
Poissons Ratio	0.3
Coefficient of Thermal Expansion**	7.4×10^{-6} in/in-°F (R.T. to 100°F)
	9.6×10^{-6} in/in-°F (R.T. to 200°F)
Density***	165 lb/ft ³
Heat Capacity***	0.17 Btu/lb-°F
Thermal Conductivity***	25 Btu/hr-ft-°F (at 50°F)
	19 Btu/hr-ft-°F (at 1000°F)

* Based on preliminary information from ALCOA.

** Private communication from WANL.

*** Ref: Brooks and Perkins, Inc., Detroit 16, Mich.

TABLE 5.2.3.1

Allowable Stresses for AMS-H11 Steel Staybolts*

Minimum Tensile Strength, psi	Minimum Yield Strength, psi	Allowable Stress, psi				
		100°F	150°F	200°F	250°F	300°F
220,000	180,000	60,000	59,500	58,500	58,000	57,500

TABLE 5.2.3.2

Mechanical and Physical Properties for AMS-H11 Steel Staybolts*

Modulus of Elasticity	28×10^6 psi
Poissons Ratio	0.281
Coefficient of Thermal Expansion	6.8×10^{-6} in/in-°F
Density	495 lb/ft ³
Heat Capacity	0.11 Btu/lb-°F
Thermal Conductivity	16.7 Btu/hr-ft-°F

* Ref: "Aerospace Structural Metals Handbook" ASD-TDR-63-741,v.1,
Code 1218, March 1963.

TABLE 5.2.4.1a

Density, Latent Heat and Heat Capacity for Water*

Density	62.0 lb/ft ³
Latent Heat	922 Btu/lb
Heat Capacity	1 Btu/lb

TABLE 5.2.4.1b

Thermal Conductivity of Water

<u>Temperature,</u> <u>°F</u>	<u>Thermal Conductivity</u> <u>Btu/hr-ft-°F</u>
50	0.333
70	0.346
90	0.358
100	0.362
120	0.371
140	0.378
160	0.384
180	0.388
200	0.392
220	0.394
240	0.396
283	0.396
300	0.396

* Ref: Badger and Blanchard, "Introduction to Chemical Engineering,"
Mc Graws Hill, 1955.

TABLE 5.2.5.1

Physical Properties of Steel Ball/Water Combination*

Density	362 lb/ft ³
Thermal Conductivity	7 Btu/hr-ft-°F
Heat Capacity	0.38 Btu/lb

* Based on random packing of 30 percent void steel.

5.3 Weld Joint Studies

Studies were undertaken to determine the characteristics of the proposed weld joint designs using 6061 base metal and X4643 filler wire. Preliminary data obtained indicates that welds of suitable strength (24,000 psi Minimum Ultimate as specified in the ASME Code, Section VIII, Table UNF-23) can be obtained by welding plates in the T-4 condition and aging at 380°F for 8 hours or welding in the T-6 condition and aging for 4 hours. Very similar strengths are obtained from both processes. Since almost all the required material is available in the T-6 condition, the latter process has been selected. It should be noted that both of these processes utilize mild heat treatments, which eliminate the possibility of heat treatment distortion in the shield assembly configuration.

The use of material welded in the T-6 condition with no heat treatment was rejected even though the ultimate strengths obtained were above 24,000 psi. It is felt that the small effort required to age hardens the material is worth while with the added advantage that some stress relief is obtained.

Detailed results of the weld joint studies will be presented in a later report.

6.0 TESTING

6.1 Flow Model Testing.

The test specification for the one-half scale flow test model is presented on the following pages.

Flow testing is presently in progress and preliminary results will be available by June 22, 1965.

NRX EST/A4 PRIVY ROOF MOUNTED SHIELD

ONE-HALF SCALE MODEL

FLOW TEST SPECIFICATION

ACF-SA-725

June 1, 1965

Prepared by: H. E. Hendricks
Engineering Systems Analysis
Albuquerque Division
ACF Industries, Incorporated

Approved by: L. P. Martin
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1. INTRODUCTION

This report specifies the flow test requirements for the one-half scale model of the NRX EST/A4 Privy Roof Mounted Shield. The test will be conducted at the Albuquerque Division of ACF Industries during the month of June, 1965.

2. OBJECT

The object of the test is to determine the flow parameters within the PRMS by a similitude study of the flow characteristics in the one-half scale model. This will be accomplished by pressure measurements and dye injection techniques. The purposes of the test are (1) to verify and support analytical studies, and (2) insure the absence of stagnation areas.

3. APPLICABLE DOCUMENTS

The following documents form a part of this specification. Documents not identified by a revision letter or date shall be the latest issue in effect.

3.1 ACF Drawing No. 513866

3.2 WANL-GSE-1371 Rev. A

3.3 ACF-SA-726

4. DESCRIPTION OF TEST UNIT

The test unit is fabricated from Plexiglas to allow visual and photographic observations. The interior dimensions were maintained to a one-half scale of the ACF proposed NRX EST/A4 Privy Roof Mounted Shield. A cutaway view of the model is shown in Figure 1. The only major configuration change is that the model is flat whereas the PRMS is curved. This difference will not significantly affect test results due to the large radius of curvature.

5. INSTRUMENTATION

The general instrumentation requirements are as follows:

5.1 Pressures - Bourdon Tube type pressure gages and/or manometers may be used. Pressure gages must have a certified accuracy of $\pm 2\%$ of reading.

5.2 Pressure Probes - All pressure probes such as pitot-static or total pressure must be calibrated prior to usage. They also must be fabricated to meet ASME standards.

5.3 Temperature - Laboratory type thermometers and/or precision thermocouples may be used. An accuracy of $\pm 5^\circ \text{F.}$ is required.

5.4 Flow - Any standard type of flow measuring device may be used. It must be calibrated prior to testing and have a repeatable accuracy of $\pm 2\%$.

- 5.5 Photographic - A sixteen millimeter movie camera will be required. It should be of the Fastax type. A minimum speed of 400 frames per second will be required.

6.

TEST REQUIREMENTS

- 6.1 General - Exercise caution to prevent damage to the model when working around or moving it. The model should be installed on the support stand and locked into position at all times. The support stand is mounted on casters but has locking mechanisms to prevent movement. The model was designed for a working pressure of 30 psig and a burst pressure of 50 psig. A pressure relief valve or blowout disc should be installed on the inlet manifold.

Total pressure, static pressure and dye injection probes shall be installed as shown in Figure 2. Additional probes may be installed at the discretion of the Test Engineer. The purposes of the dye injection probes are for observing the flow patterns and measuring water velocities. The latter will be accomplished by photographic techniques.

The model should be visually inspected for stagnation areas or unusual flow patterns during all flow tests. Testing may be interrupted at any time for instrumentation addition, adjustment or data evaluation. The test parameters specified are to be considered flexible. Changes in testing procedures and techniques are to be anticipated.

- 6.2 Proof Test - The model shall be subjected to a hydrostatic proof test prior to the installation of balls or instrumentation. It shall be pressurized to 30 psig for five minutes. Leakage areas, if any, shall be noted and corrected. The purpose of this test is to insure the structural integrity of the model.

- 6.3 Flow Test No. 1 - The test shall be run without the orifice strip, item 8 of Figure 1, installed. The following measurements shall be made at flow rates of 130 gpm and 195 gpm:

6.3.1 Water velocities in the front, secondary and rear chambers, i.e.,

D_1, D_2, D_3, D_4, D_5 and D_6 (photographically)

6.3.2 Absolute pressure, S_1

6.3.3 ΔP between S_1 and S_2

6.3.4 ΔP between S_2 and S_3

6.3.5 V_1, V_2

6.3.6 T_1

- 6.4 Flow Test No. 2 - Theoretical heat transfer calculations indicated that the ball chamber, item 5 of Figure 1, should receive 80% of the total flow. The rear chamber, item 6 of Figure 1, and the ball chamber are commonly fed by the ball plenum. The purpose of this test is to size the orifice strip, item 8 of Figure 1, to obtain a parallel flow condition where 20% of the water exits through the rear chamber. This condition is obtained when the average water velocity in the rear chamber is approximately 18 in/sec at 195 gpm total flow through the model.

The test will begin using an orifice strip with nineteen, evenly spaced, one-eighth inch holes. Additional holes will be drilled as necessary to obtain the desired flow condition. All testing will be conducted with a steady 195 gpm flow rate. The following measurements are required for each orifice strip configuration:

6.4.1 Water velocities in the rear chamber, i.e., D_4, D_5, D_6

6.4.2 S_1

6.4.3 ΔP between S_1 and S_2

6.4.4 ΔP between S_2 and S_3

6.4.5 T_1

- 6.5 Flow Test No. 3 - The test shall be conducted using the 20% orifice strip sized in Test No. 2. The measurements listed below shall be obtained at flow rates in gpm of 50, 75, 100, 130, 150, 175 and 195. Above 195 gpm the flow rate shall be increased in increments of 25 gpm until an inlet plenum pressure, S_1 , of 25 psig is reached.

6.5.1 Pressures

6.5.1.1 Absolute

6.5.1.1.1 S_1

6.5.1.2 Differentials

6.5.1.2.1 $S_1 - S_2$ 6.5.1.2.2 $S_3 - S_2$

6.5.2 Velocities

6.5.2.1 $V_{1, 2}$ 6.5.2.2 $V_{3, 4, 5}$ 6.5.2.3 $V_{6, 7}$ 6.5.2.4 $D_{1, 2}$ 6.5.2.5 D_3 6.5.2.6 $D_{4, 5, 6}$

6.5.3 Temperature

6.5.3.1 T_1

6.6 Flow Test No. 4- The purpose of this test is to evaluate the velocity of the water through the balls. The test will be run with flow rates of 130 gpm and 195 gpm. With an established flow rate, dye will be released from D_7 and the time for the dye to reach the top of the balls will be measured. The procedure will be repeated for D_8 , D_9 and D_{10} .

6.7 Flow Test No. 5 - The purpose of this test is to evaluate the model for stagnation areas or unusual flow patterns. Velocity and/or dye probes may be installed in suspected areas and at the discretion of the Test Engineer. Visual observations should be made at flow rates of 130 gpm and 195 gpm.

7.

REPORT REQUIREMENTS

7.1 A preliminary data report will be required within 3 working days after the completion of the test.

7.2 A final formal report will be prepared by July 9, 1965. It will include:

7.2.1 All data requested in this specification

7.2.2 Variations from the Test Specification

7.2.3 Description of unusual occurrences

7.2.4 Photographs of the test setup.

LEGEND

- 1 Inlet Plenum
- 2 Front Chamber
- 3 Secondary Chamber
- 4 Ball Plenum
- 5 Ball Chamber
- 6 Rear Chamber
- 7 Outlet Plenum
- 8 Orifice Strip

Figure 1
-7-

Instrumentation Layout
Figure 2

-8-

V designates pressure probe and the arrow indicates the probe direction
D designates dye injection probe
S designates static port or probe
T designates temperature sensor

6.2 Corrosion Tests.

The results of the NRDS water chemical analysis are presented on the following pages.

The test specification for galvanic corrosion testing will be available by June 22, 1965.

TO Rover Program - 431 FROM Analytical Chemistry - 413
LOCATION AND DEPARTMENT LOCATION AND DEPARTMENT
ATT. L. Martin DATE June 10, 19 65 BY GFM:me
SUBJ. WATER ANALYSIS A. C. 413-836
OUR REFERENCE YOUR REFERENCE

Account No. 50-4804-02

A sample of water, treated with a corrosion inhibiting agent, was analyzed with the results shown on the attached sheet. The yellow color of the water, in the as received condition, precluded determination of silica, since this is a colorimetric method.

G. F. Mortensen
Analyst: G. F. Mortensen
Chemist

Donald L. Davis
Approved: Donald L. Davis, Supervisor
Analytical Chemistry

Total Solids -----	449 ppm
R ₂ O ₃ -----	< 10 ppm
Calcium (Ca) -----	20 ppm
Magnesium (Mg) -----	17 ppm
Sulfate (SO ₄ ⁼) -----	28 ppm
Chloride (Cl ⁻) -----	18 ppm
Hardness (CaCO ₃) -----	120 ppm
Sodium Chromate -----	120 ppm

Alkalinity

Hydroxide (OH ⁻) -----	Nil
Carbonate (CO ₃ ⁼) -----	Nil
Bicarbonate (HCO ₃ ⁻) --	120 ppm
pH -----	7.4

7.0 Quality Control

- 7.1 A preliminary quality control manual for the privy roof mounted shield and support is presented on the following pages together with applicable specifications.

7.1

ALBUQUERQUE DIVISION

ACF INDUSTRIES

INCORPORATED

ALBUQUERQUE, NEW MEXICO

ROVER PROGRAM

PRELIMINARY QUALITY CONTROL PROGRAM PLAN

PRIVY ROOF

MOUNTED SHIELD AND SUPPORT

GSE-1371-A, MAY 17, 1965 NERVA-NRX-A4/EST

ACF-306-001

June 10, 1965

Prepared by: *V. J. Goetz*

V. J. Goetz,
Senior Q. C. Engineer

Approved by: *F. L. King*

F. L. King, General Supervisor
Quality Control Section 306

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1. INTRODUCTION

- 1.1 This report outlines the Quality Control and Inspection procedures to be used by the Albuquerque Division, ACF Industries, Incorporated, to provide assurance that the Privy Roof Mounted Shield and Support meets the fabrication and quality control specifications as outlined by the Westinghouse Astronuclear Laboratory in GSE-1371-A, May 17, 1965.

2. SUPPLIER AND MATERIAL CONTROL

- 2.1 Certified Test Reports demonstrating conformance to applicable procurement specifications shall be required of all material suppliers, per ACF Specification 6-000004. Verification of supplier certification shall be provided by the ACF Material Certification Laboratory to assure conformance to the applicable procurement specifications. In-plant control and marking shall be per Quality Policies and Procedures 620-002 and ACF Specification 6-000003.
- 2.2 All plate materials in excess of 3.0" thick shall meet the Class B requirements of the Aluminum Association Standards for Ultrasonic Quality for Aluminum Mill Products per paragraph N-321 of the ASME Boiler and Pressure Vessel Code.
- 2.3 Bolt manufacturers shall certify to the magnetic particle or liquid penetrant requirement of paragraph N-325 of the ASME Boiler and Pressure Vessel Code. Verification shall be provided by the ACF Material Certification Laboratory.
- 2.4 Supplier qualification for personnel and/or processes shall be performed per Quality Policies and Procedures 660-002 as required by the applicable specification.

3. INSPECTION

- 3.1 All procured manufactured components shall be 100% inspected to the requirements of the applicable purchase order by ACF Receiving Inspection or ACF Field Inspection, as appropriate.
- 3.2 All ACF manufactured components shall be 100% inspected. Inspection criteria shall be defined by the Inspection Traveler (Form AL-740), the process, the product drawing and applicable specifications.
- 3.3 Liquid penetrant and visual inspection shall be performed on the machined edges of the Top, Bottom, and End Plates, per paragraph N-513 of the ASME Boiler and Pressure Vessel Code.
- 3.4 The Hydrostatic test per paragraph N-714 of the ASME Boiler and Pressure Vessel Code shall be monitored for compliance to the design requirements.

- 3.5 All components shall be identified by part number and serial number and accompanied by an ACF Acceptance Tag, Form AL-815-A. Marking shall be defined on the product drawing per ACF Process Standard 6-9919100.
- 3.6 Certification Form, AL-900-KA, shall be completed for all major components and assemblies per ACF Inspection and Quality Control Procedure, IQC-195.
- 3.7 Certified test results and completed inspection reports shall be maintained on file and available to government agency audit, in addition to those reports called "End-Item" described in Section 8.

4. FABRICATION

- 4.1 All welders shall be qualified per ACF Specification 6-300005. This is equivalent to Section IX of the ASME Boiler and Pressure Vessel Code.
- 4.2 All welding procedures shall be qualified per paragraph N-522 of the ASME Boiler and Pressure Vessel Code.
- 4.3 All welds shall be individually coded on the product drawings and the manufacturing process sheets to assure joint identification with inspection and test records.
- 4.4 Individual welder identification shall be maintained on file for each weld per paragraph N-522.5 of the ASME Boiler and Pressure Vessel Code.
- 4.5 A separate test plate shall be prepared prior to, or concurrently with, the production weld for each welding procedure employed to make Category A and B joints as defined in paragraph N-461 and required by paragraph N-713 of the ASME Boiler and Pressure Vessel Code.
- 4.6 All destructive tests on the test plates shall conform to the requirements as specified in Section IX and required by paragraph N-713.3 of the ASME Boiler and Pressure Vessel Code.
- 4.7 All Category A and B joints as defined by paragraph N-461 of the ASME Boiler and Pressure Vessel Code shall be 100% radiographed, liquid penetrant, and visually inspected per ACF Specification 6-400215. The root pass shall also be liquid penetrant and visually inspected.
- 4.8 Liquid penetrant inspection shall be performed on all external welds after Hydrostatic Proof Test.

5. WORKMANSHIP

- 5.1 General workmanship shall be defined by ACF Process Standard 6-9900000.

- 5.2 All piece parts and subassemblies shall be cleaned to assure removal of ordinary foreign matter per ACF Specification 6-000012.
- 5.3 After partial assembly and drilling of the tie bolt holes and before welding of the Top plate, the unit will be disassembled, deburred, cleaned and flushed.
- 5.4 The steel balls shall be inspected prior to installation for the absence of foreign material.
- 5.5 The final assembly shall be flushed at least twice using high-pressure water. The screened outlet shall be monitored for particle discharge within the design requirements.

6. PACKAGING AND SHIPPING

- 6.1 All openings shall be sealed to prevent introduction of foreign materials during shipment and during installation at the site.
- 6.2 The packaging of the final assembly and separate subassemblies and piece parts shall provide adequate environmental and physical protection through shipment to the site.
- 6.3 The final package shall be verified by ACF Quality Control and Inspection for compliance with customer requirements.

7. GOVERNMENT AUDIT

- 7.1 ACF Industries, Inc., recognizes the South Albuquerque Area Office of the Atomic Energy Commission as the agency responsible for monitoring and surveillance of work performed by ACF on NERVA hardware.
- 7.2 ACF will comply with all requests of AEC-SAAO to witness, monitor, or perform specific inspection requirements, fabrication operations, and tests.

8. END-ITEM REPORT

- 8.1 An End-Item Report containing copies of all certification forms AL-900-KA and a record of all discrepancy deviations and their associated approvals shall be prepared and shipped with the Shield and Shield Support.

APPENDIX A
SPECIFICATIONS, FORMS, AND PROCEDURES

ACF Specification 6-000004

Quality Policies and Procedures 620-002

ACF Specification 6-000003

Ultrasonic Quality for Aluminum Mill Products

Quality Policies and Procedures 660-002

Inspection Traveler ACF Form AL-740

Acceptance Tag ACF Form AL-815

ACF Process Standard 6-9919100

Certification Form ACF Form AL-900-KA

Inspection and Quality Control Procedure IQC-195

ACF Specification 6-300005

ACF Specification 6-400215

ACF Process Standard 6-9900000

ACF Specification 6-000012

								DWG CLASSIFICATION LEVEL												
REVISIONS																				
ISS	DESCRIPTION									PREPARED BY				DATE	CHKR	ENGR				
A														3-18-61		JLD				
B																				
C																				
D																				
E																				
F																				
G														3-17-65						
SHEET	1	2	3	4	5	6	7	8	9	10										
ISSUE	G	G	G	G	G	G	G	G	G	G										
SHEET																				
ISSUE																				
SHEET INDEX																				
SUPERSEDES				FIRST APPLICATION				ORG	DATE	INITIALS	TITLE									
CLASSIFICATION CATEGORY UNCLASSIFIED				Signed: Date:				302	3-17-65	JLD	VENDOR QUALITY CONTROL AND SAMPLE REQUIREMENTS									
								305	3-18-65	[Signature]										
								451	3-17-65	[Signature]										
								412	3-17-65	[Signature]										
								542	3-18-65	HRR										
DOC REF SYM				DWG CLASSIFICATION LEVEL UNCLASSIFIED							A MFG AGENCY NUMBER 6-000004 DWG NUMBER									
								542	3-18-65	[Signature]	SHEET 1 OF 10									

- 4.3. Procurement Specification: Any Federal, Military, Society, Association, Agency, or ACF Industries specification or standard that defines product requirements.
- 4.4. Applicable Specifications: Those procurement specification(s), (See Paragraph 4.3.) that are specifically called out by number in the purchase order (See Paragraph 4.10.).
- 4.5. Referenced Specifications: Those specification(s) referenced within an Applicable Specification(s), (See Paragraph 4.4.). Referenced specification(s) are mandatory only to the extent specified and do not have to be certified to by number. Certification to the Applicable Specification(s) covers all specifications referenced therein.
- 4.6. Pre-Production Samples: A sample(s) of raw material(s) submitted to ACF Industries for product approval prior to acceptance of production shipments in fulfillment of the purchase order.
- 4.7. TMS (Tool Made Samples): Normally applicable to fabricated piece parts, assemblies, and subassemblies. (See ACF Specification 6-300072.)
- 4.8. Production Test Samples: A sample(s) of raw material(s) submitted for each production heat or lot for ACF Industries' approval and verification of supplier's certification.
- 4.9. Raw Materials: Any material, metallic or non-metallic, from which something may be made; e.g., sheet, plate, bar, bonding agents, fabrics, etc., forgings, castings, extrusions, and similar items for the purpose of this specification are considered raw materials.
- 4.10. Purchase Order: The term purchase order, insofar as this specification is concerned, shall apply to Form AL-346, latest revision, and all purchase descriptions contained therein; e.g., engineering drawings, specifications, Quality Control Purchase Instructions (AL-857), etc.
- 4.11. Process Approval: Certification or approval issued by ACF acknowledging qualifications of personnel, processes, or facilities to perform specified operations. (See Paragraph 6.5.)
- 4.12. ACF Certification Lot Number: Is the key for identification of raw material with inspection and test data substantiating its conformance to specified requirements and consists of:
- (1) An alphabetical prefix which serves as the year code ("H" means 1965).
 - (2) A sequential number which provides positive identification for each inspection lot.
5. VENDOR CERTIFICATION
- 5.1. The vendor shall furnish certification to the buyer as follows:

ISSUE

G

DWG CLASSIFICATION LEVEL

UNCLASSIFIED

TITLE

VENDOR QUALITY CONTROL
AND SAMPLE REQUIREMENTS

A

MFG AGENCY NUMBER

6-000004

DWG NUMBER

SHEET 3 of 10

SC 5402-AE (11-62)

- (8) Shall be signed by an authorized company representative.

5.2.2. Certificates of Compliance: Contain written statement(s) that all the requirements of the applicable procurement specification(s) have been complied with and that substantiating data to verify said compliance is on file and available for inspection. Actual test results are not required.

5.2.2.1. Certificates of Compliance must include, but are not limited to the following information:

- (1) Purchase Order Number.
- (2) Product Description; i.e., Drawing Number, Dimensions, etc.
- (3) Quantity Shipped.
- (4) When applicable, reference the unit serial numbers and the Raw Material Certification Identification for each inspection lot of piece parts, assemblies, and subassemblies.
- (5) Acknowledgment of all applicable material procurement specifications, by number, listing actual material purchased.

EXAMPLE:

- a. Drawing Requirements: Steel sheet, carbon, per ACF 6-400151.
- b. Statement: Material per ACF 6-400151, low carbon, cold rolled steel per QQ-S-636.

(6) Statement of compliance to all processing performed to a applicable specification, listing specification number.

EXAMPLE:

- a. Drawing Note: Cadmium plate per QQ-P-416, Type II, Class 2, or Zinc plate per QQ-Z-325, Type II, Class 2.
- b. Statement: Cadmium plated per QQ-P-416, Type II, Class 2.

(7) Statement that product has been manufactured, inspected, and meets all purchase order requirements.

(8) Shall be signed by an authorized company representative.

6. GENERAL REQUIREMENTS

6.1. The supplier shall maintain effective quality control throughout the entire

[illegible]

However, when any or all standards of Seller which are determined under Paragraph 6.3.2. to be pertinent to this order, have been calibrated by Buyer (or other AEC prime contractor or NBS) under another order of Buyer (or other AEC prime contractor), Buyer may, in lieu of the calibration for any or all of such standards required under this paragraph, authorize Seller in writing, to use such standards for as long as such prior calibration shall remain in effect. Such authorization to Seller shall be subject to all other provisions of this article including, but not limited to the provisions of Paragraph 6.3.3.

It is contemplated that calibration of Seller's standards by the NBS, at the option of the Buyer, will be utilized only where no AEC prime contractor can provide the necessary calibration service.

- 6.3.1. Notwithstanding anything herein to the contrary, where Seller does not elect to obtain calibration from the NBS, Seller shall, if Seller receives written directions from Buyer to do so, secure calibration required hereunder from such other AEC prime contractor as Buyer may designate. In that event, all references to "Buyer" in Paragraph 6.3.3. below shall be deemed to be references to both Buyer and such other AEC prime contractor except where otherwise indicated.
- 6.3.2. Buyer shall determine and advise Seller which standards are pertinent to the order and require calibration. This information will appear on the "Quality Control Purchase Instruction", Form AL-857. Such determination shall be based upon, but not necessarily limited to a list of standards which Seller shall submit to Buyer as pertinent to this order.
- 6.3.3. Calibration against laboratory standards of Buyer, or another AEC prime contractor, will be evidenced by a certificate or report of calibration (hereinafter called "certificate of calibration") issued by Buyer, or such other AEC prime contractor, and shall be subject to the following conditions:
- (1) Neither Buyer nor the Government assumes any responsibility with respect to the use of the certificate of calibration, the information contained therein or any physical device or instrument calibrated, by any person other than the Seller to whom originally issued. Any such use will be at the sole risk and responsibility of such other user.

Furthermore, neither Buyer nor the Government assumes any responsibility for the use of such certificate, the information contained therein, or any physical device or instrument calibrated, at any time beyond the resubmittal date required by the certificate of calibration or, except as permitted pursuant to Paragraph 6.3. above, on any order or contract other than the order or contract, including changes, under which the calibration is provided.

- (2) In no case will Buyer or the Government assume responsibility for loss, damage, or destruction of standards submitted by Seller or for consequential damages.

[illegible]

- 6.3.4. At all reasonable times during the order period Buyer and/or its designee shall have the right to inspect Seller's calibration program for compliance with the requirements of the order.
- 6.4. Source Inspection: When specified in the purchase order, ACF Industries will provide Field Inspection Representatives for tentative acceptance of the product at the supplier's facility. This inspection does not relieve the supplier of his responsibility to furnish an acceptable product, nor does it guarantee acceptance by ACF Industries. Such source inspection is to assist in quality liaison and give assurance of conformance of suppliers to purchase order requirements. Final acceptance shall normally be the responsibility of the ACF Industries, Receiving Inspection Department.
 - 6.4.1. When material is ready for inspection or, if practicable, two (2) days in advance thereof, notify the ACF Industries office that normally serves your area.
 - 6.4.2. Government Source Inspection (normally AEC inspection) is required for certain raw materials, piece parts, assemblies, and subassemblies. When applicable, such items must be presented by the ACF Industries, Field Inspection Representative to the Quality Assurance Inspection Agency (QAIA) for Government acceptance at the supplier's plant.
- 6.5. Special Approvals: When personnel, process, or facility approvals; e.g., welding, nondestructive testing, etc., are required in the applicable specification(s) said approvals shall be obtained from ACF prior to starting production. Work conducted by a supplier on product prior to ACF approval shall be at the supplier's risk.
 - 6.5.1. Suppliers are responsible for requesting ACF approval of their raw material, processing, or testing subcontractors when the services performed require approval as defined in the applicable specification(s).
 - 6.5.2. Request for special approvals shall be made through the ACF Industries, Purchasing Department.
- 6.6. Rejections: Materials, parts, assemblies, or subassemblies not conforming to the requirements of this specification shall be subject to rejection.

[illegible]

7. AW MATERIAL SAMPLE AND CERTIFICATION REQUIREMENTS

IN N ^o	RAW MATERIAL DESCRIPTION	TYPE OF CERTIFICATION	PRE- PRODUCTION SAMPLE	PRODUCTION TEST SAMPLE PER HEAT OR LOT ^(d)	IDENTIFICATION
7.1	Plate & Sheet	Certified Test Report	Not Applicable	2" x 10" for each heat or lot. ^(a) The major dimension in the direction specified for mechanical property testing in the applicable procurement specification.	As specified in the applicable procurement specification. In all cases shall be physically marked with a heat or lot number.
7.2	Bar & Rod	Certified Test Report	Not Applicable	10" in length for 1/2" or less diameter or thickness, or 6" in length for material over 1/2" diameter or thickness for each heat or lot. ^(a)	As specified in the applicable procurement specification. In all cases shall be physically marked with a heat or lot number.
7.3	Tubular Products	Certified Test Report	Not Applicable	12" in length for material 1/2" or less in wall thickness, or 8" in length for over 1/2" in wall thickness for each heat or lot. ^(a)	As specified in the applicable procurement specification. In all cases shall be physically marked with a heat or lot number.
7.4	Welding Electrodes & Wire	Certificate of Compliance	Not Applicable	Not applicable	As specified in the applicable procurement specification.
7.5	Extrusions ^(c) (Commercial & Special Shapes)	Certified Test Report	Yes - Special Shapes Only. See Foot-note ^(h)	12" in length for each heat or lot. ^(c) (Special Shapes) 12" in length for each heat or lot. ^(c)	As specified in the applicable procurement specification. For special shapes; i.e., when die design has been established for ACF Industries, each extrusion, unless otherwise specified, shall be identified by heat or lot number, part number, and vendor code.
7.6	Forgings	Certified Test Report	Yes See Foot-note ^(h)	(Ferrous) One forged test coupon 1" diameter x 12" in length for each heat. ^(c) (Non-Ferrous) One test segment for each lot. Samples shall be obtained by sectioning a production forging into as many equal cross-sectional sectors or segments as possible. Samples shall be large enough to obtain tensile specimens, parallel to forging flow, per Federal Test Method Standard Number 151 (Type R1 preferred). ^(c)	As specified in the engineering drawing. When method is not specified on drawing, ink stamping shall be employed. The minimum marking in all cases shall include vendor code (obtain from ACF Industries, Purchasing Department), heat or lot number, and part number.
7.7	Castings	Certified Test Report	Yes See Foot-note ^(h)	Two (2) separately cast tensile bars from each melt or heat treat batch. ^(c) Cast specimens shall conform approximately to type R1 per Federal Test Method Standard Number 151.	As specified in the engineering drawing. In all cases shall be marked with the vendor code, melt number, and when heat treated, the heat treat batch number. ^(c)
7.8	Non-Metallics	Certificate of Compliance	Not Applicable	Size and configuration as specified in the applicable procurement specification. ^(a)	As specified in the applicable procurement specification. Unless otherwise specified, include vendor name, type material. When shelf life and/or storage conditions are a limiting factor include date of manufacture, recommended shelf life, and storage condition.

- (a) Test samples required only when specifically called-out on Purchase Order.
- (b) Test samples required unless otherwise specified.
- (c) Refer to Paragraph 5.2. for definition and requirements of certified test report and certificate of compliance.
- (d) Heat Number or Lot Number
 - Heat - A heat number is normally applied to ferrous material, and, unless otherwise specified in the applicable procurement specification, a heat shall consist of material originating from a single mill melt.
 - Lot - A lot number is normally applied to non-ferrous material, and, unless otherwise specified on the applicable procurement specification, a lot shall consist of material having the same design or size, the same alloy and temper, and presented for inspection at one time.
- (e) The percentage reduction given the test sample shall not be greater than the minimum amount of reduction given the actual forging. When heat treatment is performed by the vendor, the test sample shall be heat treated with production forgings from the same heat.
- (f) Dimensionally rejected forgings may be used for test sample purposes provided quality of same is representative of production forgings. The test sample shall be heat treated with the lot it represents. Test samples for forgings supplied in the "as forged" or "O" condition shall be furnished in the heat treated condition.
- (g) Heat treat batch of castings shall consist of castings which are heat treated in the same furnace charge. If the castings are heat treated in a continuous furnace, those charged consecutively during continuous operation of the furnace shall be considered a furnace charge. In no case shall the maximum number of castings in a furnace charge exceed the limits specified in the applicable procurement specification.
- (h) Forgings, Castings, and Extrusions (All Types) Ferrous and Non-Ferrous
 - Pre-Production Samples: Unless otherwise specified on the Purchase Order, the forging, casting, or extrusion supplier shall, prior to initial shipment of production forgings, castings, or extrusions, furnish two (2) pre-production samples for ACF Industries approval.
 - Pre-production samples shall be representative of subsequent production, i.e., shall employ the same forging, casting, or extrusion techniques.
 - For any major change in forging, casting, or extrusion technique, additional pre-production samples are required.
 - Work conducted by a supplier on production forgings, castings, or extrusions, prior to approval of pre-production samples by ACF Industries, shall be at the supplier's risk unless otherwise specified.
- (i) Special Shaped Extrusions - Extrusions for which a die design has been established for ACF Industries.

[illegible]

PIECE PARTS, ASSEMBLIES, AND SUB-ASSEMBLIES REQUIREMENTS

CATEGORY AND INDEX NO.	DESCRIPTION	CERTIFICATION REQUIREMENTS (TO BE SUPPLIED TO ACF)	IDENTIFICATION
8.1. PRODUCTS BEING SUPPLIED TO ACF	8.1.1. Piece Parts, Assemblies, and Sub-Assemblies	Furnish to ACF a certificate of compliance as defined in paragraph 5.2.2. and such certifications as required by paragraphs 8.2. and 8.3. below. If TMS (Tool Made Sample) is specified, see ACF Specification 6-300072 for requirements.	As required by purchase order.
8.2. MATERIALS USED IN PRODUCTS SUPPLIED TO ACF	8.2.1. Raw Material Except Forgings, Castings, and Extrusions	Furnish with the initial lot certificate of compliance (paragraph 8.1.) copies of raw material certifications as required in Section 7. For subsequent lots with no change in raw material, i.e., <u>no change in heat, lot, batch, etc.</u> , furnish only the certificate of compliance (paragraph 8.1.). However, retain on file and available for inspection, by the buyer, certifications covering the entire quantity of material.	Material shall be identified as required in Section 7 and must be identifiable to the raw material supplier's certification at all times.
	8.2.2. Supplier Procured Forgings, Castings, and Special Shaped Extrusions	Unless otherwise specified, submit for ACF approval two (2) pre-production samples (per Section 7) and certified test reports furnished by the raw material supplier. Verification testing and/or other evaluations will be conducted at ACF Industries, Albuquerque. Testing may be performed by an independent laboratory approved, in writing, by ACF Industries for each purchase order involved. Obtain the necessary production test samples as defined in Section 7 and submit samples and raw material supplier's certified test report as defined above. The ACF Purchasing Department will furnish a copy of the Quality Control and Inspection certification report, AL-546, for all materials submitted. The ACF Certification Lot Number must appear on the certificate of compliance (paragraph 8.1.).	<u>Prior to ACF Approval</u> The identification required in Section 7 shall be maintained. <u>After ACF Approval</u> An ACF Certification Lot Number will be supplied by the ACF Purchasing Department and material must be identifiable to this number at all times.
	8.2.3. ACF Supplied Materials	When raw materials are supplied by ACF Industries, reference the ACF Certification Lot Number on the product certificate of compliance (paragraph 8.1.). The ACF Purchasing Department will furnish a copy of the Quality Control and Inspection certification report, AL-546, for all material furnished.	Material furnished by ACF will be identified with an ACF Certification Lot Number. Physical identification need not be maintained; however, material must be identifiable to this number at all times.
	8.2.4. Off-the-Shelf Hardware	Furnish with the initial lot certificate of compliance (paragraph 8.1.) copies of hardware supplier's certification as required in Section 9. For subsequent lots with <u>no change in hardware supplier</u> , furnish only the product certificate of compliance (paragraph 8.1.). However, retain on file and available for inspection, by the buyer, certifications covering all hardware used.	Unless otherwise specified, marking for identification shall be as specified in Section 9.
8.3. PROCESSING OF MATERIALS USED IN PRODUCTS SUPPLIED TO ACF	8.3.1 Processing, Testing, and Other Services	When processing, testing, or other services are performed to an applicable specification, the certification required by the applicable specification shall be submitted with the certificate of compliance as follows: 1. If performed at your facility, certify as required by paragraph 5.2. 2. If performed by a subcontractor, furnish with the initial lot copies of the subcontractor's certification. For subsequent lots with no change in processing, i.e., <u>no change in process, methods, subcontractor, etc.</u> , furnish only the certificate of compliance (paragraph 8.1.). However, retain on file and available for inspection, by the buyer, certifications covering all lots submitted.	As required by the applicable specification (paragraph 4.4.).

9. HARDWARE (OFF-THE-SHELF) REQUIREMENTS

CATEGORY AND INDEX NO.	DESCRIPTION	CERTIFICATION REQUIREMENTS (TO BE SUPPLIED TO ACF)	IDENTIFICATION
9.1. HARDWARE	9.1.1. ACF 800,000 AN, AND, MS, NAS, etc.	Furnish to ACF a certificate of compliance as defined in paragraph 5.2.2.	Unless otherwise specified, marking for identification shall be as specified in the applicable procurement specification(s) or standard(s).
ISSUE	G	CLASSIFICATION	
TITLE		UNCLASSIFIED	
VENDOR QUALITY CONTROL AND SAMPLE REQUIREMENTS		MFG AGENCY NUMBER	Sheet 10 of 10
		6-000004	

SUBJECT In-Process Material Identification And Control	DATE ISSUED 12/12/63	DATE EFFECTIVE 12/12/63	NUMBER 620-002
	PAGE NO. 1 OF 4	SUB-PAGE NO. OF	REVISION NUMBER

APPLICABLE TO

Departments 302, 541, 543

GENERAL PURPOSE

To establish responsibility and control of material and piece part identification during production

<u>SECTION</u>	<u>TITLE</u>	<u>PAGE</u>
I.	General	2
II.	Definition	2
III.	Procedure	3

PURPOSE OF CURRENT REVISION

To update procedure and change procedure number from 541-002 to 620-001.

SUPERSEDES

FORMS AND EXHIBITS

Form AL-1209, Production Material Issue Card
Form AL-1205, Route Card, Exhibit 1

QUALITY
POLICIES AND PROCEDURES

CONTINUATION SHEET

SUBJECT In-Process Material Identification And Control	DATE EFFECTIVE 12/12/63		NUMBER 620-002
	PAGE 2	SUB-PAGE NO. 1	OF 1

I. GENERAL

- A. This procedure applies to all raw material and piece parts that are certified by ACF with exception of the following:
1. "Off-the-shelf" items such as AN, MS, AND, and NAS hardware or parts, and standard commercial hardware.
 2. Noncritical items not requiring serialization.
 3. Products that require more stringent material identification and control where the methods to be employed are specified on applicable engineering drawing, product and/or quality specifications.
- B. Material identification and certification requirements for raw materials furnished by ACF to an outside vendor or procured by an outside vendor for fabrication of production parts are outlined in latest revision of ACF Specification 6-000004.

II. DEFINITIONS

- A. Raw Material - Any material from which something may be made, such as sheet, plate, bar, rod, billet, forgings, castings, extrusions, paint, adhesives, polyurethane components, bulk rubber, synthetic rubber, and material of like nature.
- B. ACF Certification Lot - All raw material and piece parts requiring ACF certification, received by ACF at one time, that has some identifying characteristic(s) such as heat number, heat treat lot number, batch number, melt number, lot number, cure date, date of manufacture, or similar identification that would imply that material has uniform chemical and/or physical properties.

(Definitions continued)

SUBJECT In-Process Material Identification And Control	DATE EFFECTIVE 12/12/63	FORM 620-003 PAGE 3 OF 1
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II. DEFINITIONS (continued)

C. ACF Certification Lot Number - The number employed to identify each item within ACF Certification Lot and the key for identification of lotted material (before and after fabrication into a finished product) with vendor and/or ACF Certification. This ACF Certification Lot Number further provides a means of isolating defective material that may unintentionally be introduced into production. ACF Certification Lot Number consists of two parts:

1. Sequential alphabetical prefix that indicates year that ACF Certification Lot Number was assigned.
2. Sequential number to indicate a specific ACF Certification Lot.

EXAMPLE:

III. PROCEDURE

Responsibility

Quality Control and
Inspection
(Vendor Inspection)

Action

1. Upon receipt of raw material and/or piece parts, segregates, lots, and inspects material to latest revision of ACF Specification 6-000003.
2. Assigns ACF Certification Lot Number(s) to each piece, part, or quantity of each lot per latest revision of ACF Specification 6-000003.
3. Disposes of inspected material as follows:

Certified Items sent to Production Stores or General Stores in accordance with Procedure 741-002, Receiving Inspection.

Rejected Items handled in accordance with Procedure 549-002, Disposition of Non-Conforming Vendor Production Material.

SUBJECT In-Process Material Identification And Control	DATE EFFECTIVE		NUMBER
	12/12/63		620-002
	PAGE	SUB-PAGE	REVISION NO.
	4	NO	OF

III. PROCEDURE (continued)

Responsibility

Action

Production Stores

4. Verifies that material issued fulfills requirement(s) of Form AL-1209, Production Material Issue Card, and ACF Certification Lot Number(s) is shown on Form AL-1209. If omitted, writes it on the form.

Shop Expediter

5. Upon receipt of material, verifies that it is from the same ACF Certification Lot(s) as indicated on Form AL-1209, and enters ACF Certification Lot Number in "Material Certification No." space on appropriate Form AL-1205, Route Card. (See Exhibit 1)
6. Makes certain that any material to be returned to Stores has proper ACF Certification Lot Number applied.

Production

7. (Shop personnel who perform such tasks as painting, welding, bonding):

Makes certain material being used such as paint, adhesives, and weld wire have an ACF Certification Lot Number properly applied.

When material is used write ACF Certification Lot Number in space on Form AL-1205 allocated for that operation being performed. (See Exhibit 1).

ROUTE CARD								SHEET 1 OF 1	BY <i>John</i>		
ALBUQUERQUE DIVISION ASF INDUSTRIES <small>COMPANY</small> ALBUQUERQUE, NEW MEXICO U. S. ATOMIC ENERGY COMMISSION CONTRACT NO. AT-(22-1)-1583				PART NO.		S.C. ISSUE		PART DESCRIPTION			
				5-XXXXXX-001			Section "B" Subassembly		Dwg. No.		
				MATERIAL DESCRIPTION						Qty.	
				MATERIAL UNIT QUANTITY						P.O. No.	
☐ YES ☒ NO		INSPECTION TRAVELER		SERIALIZATION				START WEEK 48 DATE WRITTEN 5/10/63 DATE DES'D. 6/20/63			
				☐ I.S. NO. ☐ S.C.S. NO. ☐ PRIOR ☐ OTHER ☐ NONE							
REMARKS											
MATERIAL CERTIFICATION NO. F-126											
INSPECTOR	OPER. NO.	DEPT.	MACH. SER.	STD. NR. PR.	S.U. NOS.	MACH. NO.	OPERATION DESCRIPTION		LOAD TIME		
A	2	XXX	XXXX	1.50	000	XXXX	Machine				
Machine 1, D. and O. D. See P. D.											
INSPECTOR	OPER. NO.	DEPT.	MACH. SER.	STD. NR. PR.	S.U. NOS.	MACH. NO.	OPERATION DESCRIPTION		LOAD TIME		
B	11	XXX	XXXX	1.20	000	XXXX	Weld				
Weld 4 studs (5-XXXXXX-000) per 4-XXXXXX. Certification number of study F-331 See P. D. Weld 11 per F-3356											
INSPECTOR	OPER. NO.	DEPT.	MACH. SER.	STD. NR. PR.	S.U. NOS.	MACH. NO.	OPERATION DESCRIPTION		LOAD TIME		
C	13	XXX	XXXX	1.50	000	XXXX	Machine				
Finish machine. See P. D.											
INSPECTOR	OPER. NO.	DEPT.	MACH. SER.	STD. NR. PR.	S.U. NOS.	MACH. NO.	OPERATION DESCRIPTION		LOAD TIME		
D	16	XXX	0000	2.50	000	XXXX	Bond.				
Clean, assemble, and bond per Note #2 using Gilbrath Teflon Adhesive. Adhesive F-3126											
INSPECTOR	OPER. NO.	DEPT.	MACH. SER.	STD. NR. PR.	S.U. NOS.	MACH. NO.	OPERATION DESCRIPTION		LOAD TIME		
E	21	XXX	XXXX	1.00	000	XXXX	Weld				
Assemble and weld per P. D. Weld 20 per F-3329											
INSPECTOR	OPER. NO.	DEPT.	MACH. SER.	STD. NR. PR.	S.U. NOS.	MACH. NO.	OPERATION DESCRIPTION		LOAD TIME		
F	47	XXX	0000	1.20	000	0000	Paint				
Apply paint per 6-XXXXXX. Paint F-2568											
INSPECTOR	OPER. NO.	DEPT.	MACH. SER.	STD. NR. PR.	S.U. NOS.	MACH. NO.	OPERATION DESCRIPTION		LOAD TIME		
G											
INSPECTOR	OPER. NO.	DEPT.	MACH. SER.	STD. NR. PR.	S.U. NOS.	MACH. NO.	OPERATION DESCRIPTION		LOAD TIME		
H											
INSPECTOR	OPER. NO.	DEPT.	MACH. SER.	STD. NR. PR.	S.U. NOS.	MACH. NO.	OPERATION DESCRIPTION		LOAD TIME		
I											
INSPECTOR	OPER. NO.	DEPT.	MACH. SER.	STD. NR. PR.	S.U. NOS.	MACH. NO.	OPERATION DESCRIPTION		LOAD TIME		
J											
INSPECTOR	OPER. NO.	DEPT.	MACH. SER.	STD. NR. PR.	S.U. NOS.	MACH. NO.	OPERATION DESCRIPTION		LOAD TIME		
K											
INSPECTOR	OPER. NO.	DEPT.	MACH. SER.	STD. NR. PR.	S.U. NOS.	MACH. NO.	OPERATION DESCRIPTION		LOAD TIME		
L											

AA-1000 (REV. 6/58)

UPON COMPLETION, RETURN TO PRODUCTION PLANNING & CONTROL

ALBUQUERQUE DIVISION

— ACF INDUSTRIES

ALBUQUERQUE, NEW MEXICO

STANDARD

1. PURPOSE

1.1. The purposes of this standard are as follows:

1.1.1. To establish a uniform, in-plant certification lot system for all raw material, piece parts, subassemblies, and assemblies procured by ACF Industries for fabrication of products deliverable to the Atomic Energy Commission.

1.1.2. To establish a uniform method of applying ACF Certification Lot Numbers to materials and products.

2. SCOPE

2.1. This standard shall apply to all raw material and, when applicable, purchased piece parts, subassemblies, and assemblies that are required by the applicable procurement specifications to be certified by ACF.

3. DEFINITIONS AND MARKING TERMS

3.1. Definitions of commodity forms, shapes, and sizes (examples: bar, forging, billet, pound, gallon) shall be those in common use.

3.2. Raw material shall be any material from which something may be made such as sheet, plate, bar, rod, billet, forgings, castings, extrusions, paint, adhesives, polyurethane, rubber, synthetic rubber, and material of like nature.

3.3. A finished product shall be any ACF manufactured piece part, subassembly, or assembly to be bought from ACF by the Atomic Energy Commission.

3.4. ACF Certification Lot - all material included in 2.1. that is received by ACF at one time that has some identifying characteristic(s) such as a heat number, heat treat lot number, batch number, melt number, lot number, cure date, date of manufacture, or similar identification that would imply that the material has uniform chemical and/or physical properties.

3.5. ACF Certification Lot Number

3.5.1. The ACF Certification Lot Number is employed to identify each item within the ACF Certification Lot and is the key for identification of materials mentioned in 2.1.

CUSTOMER'S REFERENCE NUMBER		CLASSIFICATION			
		UNCLASSIFIED			
DATE 11/15/63	REV A B	PREPARED	INITIAL	DEPT	TITLE
		APPROVED			APPLICATION OF ACF
		APPROVED			CERTIFICATION LOT NUMBERS
		APPROVED			NUMBER
		APPROVED			6-000003-B
		APPROVED			
		APPROVED			
		RELEASED			

SHEET 1 of 12

(before and after fabrication into a finished product) with the vendor and/or ACF certification. This certification lot number further provides a means of isolating defective material that may unintentionally be introduced into production.

3.5.2. The ACF Certification Lot Number consists of two parts: (1) a sequential alphabetical prefix that indicates the year that the ACF Certification Lot Number was assigned and, (2) a sequential number to indicate a specific ACF Certification Lot.

Example:

3.5.3. ACF Certification Lot Numbers from one (1) through ten thousand (10,000) shall be used for items mentioned in 2.1. and numbers over ten thousand (10,000) shall be used for in-process testing and other miscellany.

4. DETERMINATION OF AN ACF CERTIFICATION LOT

4.1. All raw material and other material mentioned in 2.1. shall be placed in one of three groups for determining ACF Certification Lots: (1) ferrous metals, (2) nonferrous metals, (3) non-metals.

4.2. For any material to be designated as one ACF Certification Lot all pieces, parts, or quantities shall conform to Tables I, II, or III unless otherwise stated in the procurement specifications. The ACF Certification Lot Number shall be applied to the material as designated in the last column of the tables.

4.3. All markings shall be applied so there will be no harmful effect on the material nor its performance. In all cases the material shall be carefully marked so that the numbers can be easily found, easily read, and will remain with the material under normal ACF handling and storage.

5. METHODS OF APPLYING ACF CERTIFICATION LOT NUMBERS TO THE MATERIAL

5.1. Method A - impression stamp the ACF Certification Lot Number using a steel die-impact stamp of standard vertical type. Three type sizes may be used, 1/8", 1/4", or 1/2". The largest applicable type shall be used unless otherwise specified.

5.2. Method B - rubber stamp the ACF Certification Lot Number using Ideal Type 80 Ink for metal and Ideal Type 70 Ink for non-metals. One-eighth (1/8) inch, 1/4" or 1" stamps of standard vertical type shall be used with either black or yellow ink. The color most easily seen on the material shall be used. If the surface to be stamped is dirty it shall be properly cleaned so the ink will adhere to the material.

TITLE

APPLICATION OF ACF CERTIFICATION LOT NUMBERS

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5.3. Method C - on a 1" X 2", 23 gage aluminum tag with 1/8" holes 1/8" from the center of each end, apply the ACF Certification Lot Number per Method A with the 1/4" stamp. Attach the tag as specified.

5.4. Method D - using a vibro-etch or electro-etch pen, write the ACF Certification Lot Number on the material neatly and legibly.

5.5. Method E - using 1/8", 1/4", or 1" stencils, spray or brush the ACF Certification Lot Number on the material. The largest applicable stencil shall be used unless otherwise specified. Use the color of ink (only yellow or black) that shows up best on the material. The following kinds of ink shall be used for the indicated type of material:

Porous Material (paper, wood, fiber board, etc.) - (1) Marsh Spray Stencil Ink or (2) Ideal (Type F) stencil Ink to be applied with a brush.

Nonporous Material (mainly metal) - Marsh Spray Stencil Ink.

6. AUTHORITY FOR MARKING

6.1. Methods of marking and the location of the markings on the material shall be in accordance with this specification unless otherwise instructed in the applicable engineering drawing.

TITLE APPLICATION OF ACF CERTIFICATION LOT NUMBERS	CLASSIFICATION UNCLASSIFIED	
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TABLE I - FERROUS METALS

TO BE DESIGNATED AN ACF CERTIFICATION LOT, ALL OF THE MATERIAL CONSIDERED MUST MEET EACH REQUIREMENT THAT IS INDICATED BY THE X'S IN THIS TABLE	REC'D UNDER THE SAME PURCHASE ORDER	REC'D IN THE SAME SHIPMENT	HAVING SAME HEAT, MELT, OR LOT NUMBER	HAVING SAME P/N OR ALL THE SAME SIZE	APPLICATION OF ACF CERTIFICATION LOT NUMBERS
Sheet (Under 1/8") and Plate (1/8" and Over)	X	X	X		Apply per Method A on each edge of each rectangular plate. One impression shall be placed 1" from one corner and others at intervals of not more than 3 ft. Impressions shall be staggered in relation to those on the opposite side as illustrated in Figure #1. Edges of lengths over 2 ft. long shall have at least two impressions. For rectangular sheet material with a surface area exceeding 4 sq. ft. apply per Method E at each corner and at the center on one surface (Figure #2). The corner stamps shall be 6" from the two sides. Sheet with 4 sq. ft. of surface or less shall be stamped once near each corner. Disks and other non-rectangular shapes shall be stamped once on each piece; Method A on plate edges and Method E on sheet surfaces. Sheet and plate that cannot be marked as stated above shall have <u>three</u> tags, per Method C, nailed to the skid or attached to the container so as to remain with the material a reasonable length of time. (Note: Comply with 4.3.)
Bar, Rod, and Billet EXTRUDED SHAPES	X	X	X		When size and shape permits, impression stamp the ACF Certification Lot Number, per Method A, on each end of each piece (Figure #5). Pieces that are too small to stamp on the end with a 1/8" stamp shall be stamped at each end (Figure #3) on another surface per Method A. No part of these impressions shall be more than 1" from the end of the piece. Pieces that are too small for the application of a 1/8" impression shall be securely bound together with wire and four tags attached with wire per Method C. Three tags shall be attached at
(1) Commercial Shapes	X	X	X		
(2) Special Shapes	X	X	X	X	
TITLE APPLICATION OF ACF CERTIFICATION LOT NUMBERS					CLASSIFICATION UNCLASSIFIED NUMBER 6-000003-B SHEET 4 OF 12

TABLE I - FERROUS METALS (Page 2)

O BE DESIGNATED AN ACF CERTIFICATION LOT, ALL OF THE MATERIAL CONSIDERED MUST MEET EACH REQUIREMENT THAT IS INDICATED BY THE X's IN THIS TABLE	REC'D UNDER THE SAME PURCHASE ORDER	REC'D IN THE SAME SHIPMENT	HAVING SAME HEAT, MELT OR LOT NUMBER	HAVING SAME P/N OR ALL THE SAME SIZE	APPLICATION OF ACF CERTIFICATION LOT NUMBERS
					evenly spaced intervals to different individual pieces and the fourth tag wired around the entire bundle (Figure #4).
<u>NONEXTRUDED TUBE</u>					All tube with end surfaces of adequate size and shape shall be impression stamped per Method A on each end of each piece (Figure #5). Other tubular material shall be stamped per Method A on the outer surface at each end unless the application should result in an apparent distortion of the tube. No part of these impressions shall be more than 1" from the end of the tube (Figure #3). If tube that cannot be impression stamped are large enough they shall be marked per Method E, 1" from each end and at intervals no greater than 3 feet. Material that cannot be marked in either of the above mentioned ways shall be marked at each end per Method D. No part of these impressions shall be greater than one inch from the end.
(1) Commercial Tube	X	X	X		
(2) Special Tube	X	X	X	X	
Forgings and Pressings	X	X	X	X	Die forgings and any partially machined forgings shall be stamped per Method E with the position of the number near the vendor's markings. Ring rolled and hand forged pieces shall be stamped once on each end per Method A. Within a given lot all pieces shall be marked in the same relative position.
Castings	X	X	X	X	All castings shall be marked per Method B or E. The position of the number shall be at the inspector's discretion, but each piece within a lot shall be marked in the same relative position.

TITLE	CLASSIFICATION	
	UNCLASSIFIED	
APPLICATION OF ACF CERTIFICATION LOT NUMBERS	NUMBER	
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TABLE I - FERROUS METALS (Page 3)

TO BE DESIGNATED AN ACF CERTIFICATION LOT, ALL OF THE MATERIAL CONSIDERED MUST MEET EACH REQUIREMENT THAT IS INDICATED BY THE X'S IN THIS TABLE	REC'D UNDER THE SAME PURCHASE ORDER	REC'D IN THE SAME SHIPMENT	HAVING SAME HEAT, MELT OR LOT NUMBER	HAVING SAME P/N OR ALL THE SAME SIZE	APPLICATION OF ACF CERTIFICATION LOT NUMBERS
Weld Rod, Wire, and Electrode	X	X	X	X	Spools and containers that are to remain with the material during use shall be marked per Method B or E unless they are sealed from the atmosphere in a plastic container in which case the outer container shall be marked per Method B or E. Coils and uncovered bundles shall be tagged with wire per Method C. All other material shall be in a container with the container marked per Method B or E.
Bolts, Nuts, Rivets, and Other Hardware	X	X		X	Each container shall be marked per Method B or E near the vendor's identification.
TITLE APPLICATION OF ACF CERTIFICATION LOT NUMBERS	CLASSIFICATION UNCLASSIFIED		NUMBER 6-000003-B		SHEET 6 OF 12

TABLE II - NONFERROUS METALS

TO BE DESIGNATED AN ACF CERTIFICATION LOT, ALL OF THE MATERIAL CONSIDERED MUST MEET EACH REQUIREMENT THAT IS INDICATED BY THE X'S IN THIS TABLE	APPLICATION OF ACF CERTIFICATION LOT NUMBERS					
	REC'D UNDER THE SAME PURCHASE ORDER	REC'D IN THE SAME SHIPMENT	MATERIAL OF SAME P/N OR SAME SIZE AND ALLOY CONDITION	MATERIAL OF THE SAME MELT OR MANUFACTURE LOT	MATERIAL OF THE SAME HEAT TREAT LOT	
Sheet (under 1/8") and Plate (1/8" and over)	X	X	X	X*	X*	Apply per Method A on each edge of each rectangular plate. One impression shall be placed 1" from one corner and others at intervals of not more than 3 ft. Impressions shall be staggered in relation to those on the opposite side as illustrated in Figure #1. Edges of lengths over 2 ft. long shall have at least two impressions. For rectangular sheet material with a surface area exceeding 4 sq. ft. apply per Method E at each corner and at the center on one surface (Figure #2). The corner stamps shall be 6" from the two sides. Sheet with 4 sq. ft. of surface or less shall be stamped once near each corner. Disks and other nonrectangular shapes shall be stamped once on each piece, Method A on plate edges and Method E on sheet surfaces. Sheet and plate that cannot be marked as stated above shall have three tags, per Method C, nailed to the skid or attached to the container so as to remain with the material a reasonable length of time. (Note: comply with 4.3.)
Bar, Rod, and Billet EXTRUSIONS	X	X	X		X*	When size and shape permits, impression stamp the ACF Certification Lot Number, per Method A, on each end of each piece (Figure #5).
(1) Commercial Shapes	X	X	X			
(2) Special Shapes	X	X	X	X	X	
TITLE						CLASSIFICATION
APPLICATION OF ACF CERTIFICATION LOT NUMBERS						UNCLASSIFIED
						NUMBER
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TABLE II - NONFERROUS METALS (Page 2)

TO BE DESIGNATED AN ACF CERTIFICATION LOT, ALL OF THE MATERIAL CONSIDERED MUST MEET EACH REQUIREMENT THAT IS INDICATED BY THE X's IN THIS TABLE	REC'D UNDER THE SAME PURCHASE ORDER	REC'D IN THE SAME SHIPMENT	MATERIAL OF SAME P/N OR SAME SIZE AND ALLOY CONDITION	MATERIAL OF THE SAME MELT OR MANUFACTURE LOT	MATERIAL OF THE SAME HEAT TREAT LOT	APPLICATION OF ACF CERTIFICATION LOT NUMBERS

Pieces that are too small to stamp on the end with a 1/8" stamp shall be stamped at each end (Figure #3) on another surface per Method A. No part of these impressions shall be more than 1" from the end of the piece. Pieces that are too small for the application of a 1/8" impression shall be securely bound together with wire and 4 tags attached with wire per Method C. Three tags shall be attached at evenly spaced intervals to different individual pieces and the 4th tag wired around the entire bundle (Figure #4).

Nonextruded Tube X X X

All tube with end surfaces of adequate size and shape shall be impression stamped per Method A on each end of each piece (Figure #5). Other tubular material shall be stamped per Method A on the outer surface at each end unless the application should result in an apparent distortion of the tube. No part of these impressions shall be more than 1" from the end of the tube (Figure #3). If tube that cannot be impression stamped are large enough they shall be marked per Method E, 1" from each end and at intervals no greater than 3 ft. Material that cannot be marked in either of the above mentioned ways

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TABLE II - NONFERROUS METALS (Page 3)

TO BE DESIGNATED AN ACF CERTIFICATION LOT, ALL OF THE MATERIAL CONSIDERED MUST MEET EACH REQUIREMENT THAT IS INDICATED BY THE X'S IN THIS TABLE	APPLICATION OF ACF CERTIFICATION LOT NUMBERS					
	REC'D UNDER THE SAME PURCHASE ORDER	REC'D IN THE SAME SHIPMENT	MATERIAL OF SAME P/N OR SAME SIZE AND ALLOY CONDITION	MATERIAL OF THE SAME MELT OR MANUFACTURE LOT	MATERIAL OF THE SAME HEAT TREAT LOT	
						shall be marked at each end per Method D. No part of these impressions shall be greater than 1" from the end.
FORGINGS						
(1) Not Heat Treated	X	X	X			Die forgings and any partially machined forgings shall be stamped per Method E with the position of the number near the vendor's markings. Ring rolled and hand forged pieces shall be stamped once on each end per Method A. Within a given lot all pieces shall be marked in the same relative position.
(2) Heat Treatable	X	X	X		X	
CASTINGS						
(1) Not Heat Treated	X	X	X	X		All castings shall be marked per Method B or E. The position of the number shall be at the inspector's discretion, but each piece within a lot shall be marked in the same relative position.
(2) Heat Treatable	X	X	X	X	X	
Weld Wire, Rod, Bar and Electrode	X	X	X	X*	X*	Spools, rods, wire, etc. that are to remain with the material during use shall be marked per Method B or E unless they are sealed from the atmosphere in a plastic container in which case the outer container shall be marked per Method B or E. Coils and uncovered bundles shall be tagged with wire per Method C. All other material shall be in a container with the container marked per Method B or E. (Note: comply with 4.3.)
TITLE						CLASSIFICATION
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TABLE II - NONFERROUS METALS (Page 4)

TO BE DESIGNATED AN ACF CERTIFICATION LOT, ALL OF THE MATERIAL CONSIDERED MUST MEET EACH REQUIREMENT THAT IS INDICATED BY THE X'S IN THIS TABLE	REC'D UNDER THE SAME PURCHASE ORDER	REC'D IN THE SAME SHIPMENT	MATERIAL OF SAME P/N OR SAME SIZE AND ALLOY CONDITION	MATERIAL OF THE SAME MELT OR MANUFACTURE LOT	MATERIAL OF THE SAME HEAT TREAT LOT	APPLICATION OF ACF CERTIFICATION LOT NUMBERS

Bolts, Nuts, Rivets, and Other Hardware X X X

Each container shall be marked per Method B or E near the vendor's identification.

* When applicable

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TABLE III - NONMETALS

TO BE DESIGNATED AN ACF CERTIFICATION LOT, ALL OF THE MATERIAL CONSIDERED MUST MEET EACH REQUIREMENT THAT IS INDICATED BY THE X'S IN THIS TABLE	MATERIAL REC'D UNDER THE SAME PURCHASE ORDER	MATERIAL REC'D IN THE SAME SHIPMENT	MATERIAL WITH THE SAME LOT NUMBER, BATCH NUMBER, CURE DATE OR DATE OF MANUFACTURE	MATERIAL OF THE SAME P/N OR SAME SIZE AND SHAPE	APPLICATION OF ACF CERTIFICATION LOT NUMBERS
All liquid nonmetallic material received for Captions 03, 46, 61, or 63 to make up all or part of a finished product	X	X	X		All liquid material shall be marked per Method B or E on each individual container, (Example: drums, cans, jars, bottles, tubes, etc.). Each container within an ACF Certification Lot shall be stamped in the same relative position such as on the side of cans, on jar labels, and/or near the vendor's identification. (Note: comply with 4.3.)
All nonliquid, non-metallic material received for Captions 03, 46, 61, or 63 that will make up all or part of a finished product	X	X	X		Bulk material such as polyethelene pellets, dry resin and carbon black shall be marked per Method B or E (in an obvious position) on each individual container within an ACF Certification Lot. Material other than bulk shall be marked per Method B or E directly on the material when permitted. If marking on the material is not permitted, then the containers shall be marked per Method B or E. (Note: comply with 4.3.)
All raw material received for Caption 47 requiring ACF Certification.	X	X	X	X	Each part shall be marked per Method B or E or if the parts cannot or should not be marked, the individual containers shall be marked per Method B or E. (Note: comply with 4.3.)

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ARROWS INDICATE POSITION OF NUMBERS

Figure #1

Figure #2

Figure #3

Figure #5

Figure #4

TITLE

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ultrasonic standard for plate, extrusions and forgings

1. SCOPE

This ultrasonic standard covers the normal guaranteed quality level for aluminum alloy plate, extrusions, and forgings in the alloys and sizes specified in Table 1. It is not intended to be a process or inspection procedure standard, nor does it require ultrasonic inspection by the vendor unless specifically required by the order or contract.

2. DEFINITIONS

Following are the definitions of the aluminum alloy products covered by this ultrasonic standard:

Plate. A solid section rolled to a thickness of 0.250 in. or heavier in rectangular form and with either sheared or sawed edges.

Extrusion. A product formed by pushing the material through an orifice in a die.

Die Forging. A forging that is formed to the required shape and size by working in impression dies.

Hand Forging. A forging worked between flat or simply shaped dies by repeated strokes and manipulation of the piece.

3. ORDERING INFORMATION

When ultrasonic inspection of finished material is required of the vendor, orders or contracts shall include the following:

- Sampling requirements (Section 7).
- Engineering drawings (Section 8).
- Discontinuity class limits if other than those listed in Table 1.
- Requirements for material or techniques not covered by this standard (Section 6).

4. MANUFACTURE

The vendor shall control the quality level defined herein by intermediate ultrasonic inspection and/or other control procedures.

5. ULTRASONIC DISCONTINUITY LIMITS

Material furnished in any temper shall conform to the requirements of Table 1 when inspected in accordance with Section 8. The limits, specified in Table 1, are not applicable after plastic deformation introduced into the material subsequent to delivery.

The discontinuity class limits are as follows:

Class A Areas:

- Indications from a single discontinuity shall not

exceed the response from a $\frac{5}{64}$ in. diameter flat-bottomed hole at the estimated discontinuity depth.

- Multiple indications in excess of the response from a $\frac{3}{64}$ in. diameter flat-bottomed hole at the estimated discontinuity depth shall not have their indicated centers closer than 1 in.
- Indications from a single discontinuity equal to or greater than the response from a $\frac{3}{64}$ in. diameter flat-bottomed hole at the estimated discontinuity depth shall not be more than 1 in. in length.
- Multiple discontinuities shall not be of such size or frequency as to reduce the back reflection pattern to 50 percent or less of the back reflection pattern of normal material of the same geometry, with the crystal parallel to the front and back surfaces to insure that the loss of back reflection is not caused by surface roughness or part geometry variation.

Class B Areas:

- Indications from a single discontinuity shall not exceed the response from an $\frac{8}{64}$ in. diameter flat-bottomed hole at the estimated discontinuity depth.
- Multiple indications in excess of the response from a $\frac{5}{64}$ in. diameter flat-bottomed hole at the estimated discontinuity depth shall not have their indicated centers closer than 1 in.
- Indications from a single discontinuity equal to or greater than the response from a $\frac{5}{64}$ in. diameter flat-bottomed hole at the estimated discontinuity depth shall not be more than 1 in. in length.
- Multiple discontinuities shall not be of such size or frequency as to reduce the back reflection pattern to 50 percent or less of the back reflection pattern of normal material of the same geometry, with the crystal parallel to the front and back surfaces to insure that the loss of back reflection is not caused by surface roughness or part geometry variation.

Class C Areas (may apply to noncritical areas and to some areas not covered by Table 1):

Indications from a single discontinuity shall not exceed the response from an $\frac{8}{64}$ in. diameter flat-bottomed hole at the estimated discontinuity depth.

6. REQUIREMENTS FOR ALLOYS OR SIZES NOT SPECIFICALLY COVERED

Discontinuity limits for alloys or sizes not covered by this standard or discontinuity limits other than those specified in Table 1 shall be as agreed upon between the purchaser and the vendor at the time of quotation and/or order acceptance.

7. SAMPLING

When ultrasonic inspection is required of the vendor, the size of the sample in number or percentage of pieces in a lot must be specified.

8. INSPECTION

When ultrasonic inspection is performed, conformance with the requirements of Section 5 shall be determined by ultrasonic inspection using pulsed longitudinal waves. Inspection of cylindrical parts or areas of sections containing fillets may be performed using shear waves, but in such cases the technique shall be as agreed upon between the purchaser and the vendor at the time of quotation and/or order acceptance.

When ultrasonic inspection is required of the ven-

dor, inspection shall be conducted as specified herein. For section thicknesses or weights outside the limits shown in Table 1, or for discontinuity classes other than those specified in Table 1, discontinuity limits shall be as negotiated and as shown on zoned engineering drawings of the material. The engineering drawings shall indicate those areas which are noncritical and/or which are to be removed by machining.

9. EQUIPMENT AND TECHNIQUE

The ultrasonic equipment and technique used shall be capable of performing the inspection as governed by this standard. Those frequencies and sensitivities which provide the best determination of discontinuities in the inspected parts shall be used. Inspection shall be conducted by the immersion method or its equivalent. Initial scanning shall be performed perpendicularly to the inspection surface, except for die forgings, on which initial scanning shall be performed perpendicularly to the parting plane wherever possible. Angular manipulation shall be used to obtain maximum response from individual discontinuities.

TABLE 1. ULTRASONIC DISCONTINUITY LIMITS^①

PRODUCT	ALLOY	SIZE			DISCONTINUITY CLASS ^②
		THICKNESS in.	MAXIMUM WEIGHT PER PIECE lb	MAXIMUM WIDTH TO THICKNESS RATIO	
Plate	2014	0.500-1.499 1.500-3.000 3.001-4.500	2,000 2,000 2,000		B A B
	2219				
	2024				
	7075				
	7178				
Extrusions	7079	0.375 and over 0.375-1.499 1.500 and over	600 600 600	10 to 1 10 to 1 10 to 1	B B A
	2014				
	2219				
	2024				
	7075				
Die Forgings	7178	0.375-4.000	300		B
	7079				
	2014				
	2219				
	7075				
Hand Forgings	7079	1.0-8.0	600		A
	2014				
	2219				
	7075				
	7079				

^①Discontinuities in excess of those listed in this Table shall be allowed if it is established that they will be removed by machining or that they are in noncritical areas.

^②The discontinuity class limits are defined in Section 5.

10. STANDARDIZATION OF INSTRUMENT

Water travel distance from crystal to part shall be such that the second front reflection shall not appear between the first front and back reflections. The water travel for both standardization and inspection shall be the same distance within plus and minus $\frac{1}{2}$ in.

Discontinuities will be compared to recognized ultrasonic standard reference blocks containing flat-bottomed holes of standard diameters at the same depths as the indicated discontinuities, within plus and minus $\frac{1}{16}$ in. for depths up through $\frac{1}{4}$ in.; within plus and minus $\frac{1}{8}$ in. for depths over $\frac{1}{4}$ through 1 in.; within plus and minus $\frac{1}{4}$ in. for depths over 1 through 3 in.; and within plus and minus $\frac{1}{2}$ in. for depths over 3 in. Standard blocks now recognized are those supplied by Alcoa Research Laboratories and by Automation Industries, Inc. (formerly Ultrasonic Testing and Research Laboratories). As calibration data become available, individual reference blocks shall meet the requirements of the American Society for Testing and Materials Recommended Practice E127 for

Fabricating and Checking Aluminum Alloy Ultrasonic Standard Reference Blocks.

11. MARKING

When ultrasonic inspection by the vendor is required, aluminum mill products so inspected by the vendor will be stamped as follows:

12. REJECTION

Unless otherwise specified in the order or contract, material not conforming to the ultrasonic limits specified in Table 1 shall, after verification by the vendor of nonconformance, be subject to rejection.

SUBJECT Supplier Facility Certification	DATE ISSUED 5/25/64 PAGE No. 1 of 3	DATE EFFECTIVE 5/25/64 SUB-PAGE No. OF	NUMBER 660-002 REVISION NUMBER R 1									
APPLICABLE TO												
GENERAL PURPOSE <p>To establish policy and responsibilities for certification of supplier facilities engaged in certain manufacturing and testing processes requiring specialized equipment, procedures, and personnel.</p> <table border="1"> <thead> <tr> <th><u>SECTION</u></th> <th><u>TITLE</u></th> <th><u>PAGE</u></th> </tr> </thead> <tbody> <tr> <td>I.</td> <td>Policy</td> <td>2</td> </tr> <tr> <td>II.</td> <td>Procedure</td> <td>2</td> </tr> </tbody> </table>				<u>SECTION</u>	<u>TITLE</u>	<u>PAGE</u>	I.	Policy	2	II.	Procedure	2
<u>SECTION</u>	<u>TITLE</u>	<u>PAGE</u>										
I.	Policy	2										
II.	Procedure	2										
PURPOSE OF CURRENT REVISION <p>To clarify areas of supplier's operation requiring certification, and add Rover Program to booklet distribution.</p>												
SUPERSEDES <p>Supersedes Procedure 660-002, issued 3-20-64.</p>												
FORMS AND EXHIBITS <p>Form AL-857, Quality Control Purchase Instructions.</p>												

SUBJECT Supplier Facility Certification	DATE EFFECTIVE 5/25/64		NUMBER 660-002
	PAGE 2	SUB-PAGE NO 1 OF 1	REVISION NO. R 1

I. POLICY

- A. ACF issues certifications to those facilities for which process certifications are required by engineering drawings, including all referenced ACF, customer, federal, military, DOD, and society specifications.
- B. Facilities - For purposes of this procedure, facilities are divided into two groups:
1. Suppliers of raw materials which are subjected to in-plant verification testing and certification. These suppliers are not issued written facility certifications (unless specifically required), but are considered certified so long as ACF verification testing indicates compatibility between ACF and supplier test results.
 2. Suppliers of fabricated assemblies, sub-assemblies, components, and piece parts which are tested and verified at source of manufacture. These suppliers are issued written certifications for approved processes such as heat treating, plating, chemical analysis, environmental testing, resistance welding, fusion welding, nondestructive testing, etc.
- C. Recognition of Certification - A booklet listing certifications and certification period of personnel, and/or procedures is issued at least quarterly and is used by inspectors to determine certification status of suppliers. Letters of certification per paragraph II. 4., are official addendums to certification booklet.
- D. Parts and materials processed by facilities not possessing required certifications are subject to rejection.

II. PROCEDURE

ResponsibilityActionQuality Control
Engineering

1. Determines processes requiring (personnel and/or procedure) certifications and notes requirements in appropriate space on Form AL-857, Quality Control Purchase Instructions.

Special
Engineering

2. Notifies Purchasing and Vendor Inspection, in writing, of requirements for process certification when sole responsibility for program, including procurement requisitioning, falls within their area.

6. Reviews all items submitted for acceptance for conformance to this procedure.

ACF FINAL INSPECTION ACCEPTANCE TAG

ENGINEERING ITEM

ACF DRAWING NUMBER AND REVISION

DEVIATION APPROVAL NUMBER

MATERIAL CERTIFICATION NUMBER

SERIAL NUMBER

ACF
INSPECTOR

DATE

AL 815 A (REV. 9-64)

ENGINEERING ITEM

ACF DWG. NO. AND REVISION

DEVIATION NUMBERS

MAT. CERT. NO.

SERIAL NUMBER

ACF INSPECT.

DATE

ALBUQUERQUE DIVISION
ACF INDUSTRIES
INCORPORATED
ALBUQUERQUE, NEW MEXICO

MFG. AGENCY NO.

PROCESS STANDARD

6-9919100

DWG. NO.

9919100

MARKING, GENERAL METHODS

1. GENERAL

1.1. Scope

This standard covers the requirements for information and identification marking of products. This standard supplements, but does not take precedence over, the marking requirements on drawings.

1.2. Classification

The marking classes and methods covered by this standard are listed in Table I. The marking class shall be called out on the drawing. If a specific marking method is desired it shall be called out on the drawing, otherwise the method is optional within the specified class.

TABLE I. Marking Classes and Methods

Class	Description	Method
A-1	Ink w/o covercoat	A. Stamp B. Stencil C. Silk Screen
A-2	Ink with covercoat	A. Stamp B. Stencil C. Silk Screen D. Mechanical Guide
A-3	Ink w/o covercoat	A. Freehand
B-1	Paint w/o covercoat	A. Stencil B. Silk Screen
B-2	Paint with covercoat	A. Stencil B. Silk Screen
C-1	Impression	A. Die Impact
C-2	Impression	A. Freehand
C-3	Impression	A. Sand Blast (a)
C-4	Impression	A. Roll Die
D-1	Hot Stamp w/o covercoat	A. Heated Die and Foil
D-2	Hot Stamp with covercoat	A. Heated Die and Foil
E-1	Engrave w/o fill	A. Chemical or Electro-Chemical Etch B. Mechanical
E-2	Engrave with fill	A. Chemical B. Mechanical
F-1	Surface Conversion	A. Electro-Chemical
G-1	Integral	A. Embossed (Raised) B. Recessed
H-1	Indirect	A. Bag B. Tag C. Tape (b) D. Heat-Shrinkable Sleeve (b) E. Embossing Tape (b) F. Box

(a) For aluminum surfaces .080 and thicker only.

(b) Only when specified.

Examples: A-2-B Ink Marking, with Covercoat, Stencil
E-1-B Engrave Marking, without Fill, Mechanical
H-1 Indirect Marking, either Bag, Tag, or Box
H-1-D Indirect Marking, Heat-shrinkable Sleeve only

Typical Drawing Call-Out: Mark (1) per 9919100, Class (2). (Specify method and/or character size when required.)

- (1) Insert applicable identification requirements. Manufacturing agency part no. will be marked only when specifically requested.
(2) Insert applicable class designation from Table I.

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APPROVAL AUTHORITY

BX C. J. Camp
GE

LSB, D. Pontler DL 674 11054

SAL, D. Selteneich RP 088 13054

SCP, E. Jockle, Jr. RE 598 13054

CV E. D. Rhoades GC 21 05054

MH J. M. Higgins BS 107 12054

UC H. J. MacDonald DL 275 06074

COORDINATED

Change Authorization EGN 7101284

Issue: F

Issue Date: July 20, 1964

Page 1 of 12 db

6-9919100

1.3. Definitions

1.3.1. Research and Development Serial Number

Research and development serial numbers are specified in one of two ways:

- a. When issue control of drawings is in effect, the serial number is the letter X followed by the issue of the drawing to which the part is made, followed by a dash and a number to indicate the order of manufacture; e.g., XA-1, XA-2, XB-1, etc.
- b. When issue control is not in effect, the serial number is the letter X followed by a dash and a number to indicate the order of manufacture; e.g., X-1, X-2, etc.

1.3.2. AEC Code Designation

The AEC code designation is as specified; e.g., SA79, CF1062, MC107A, W101-1T₃, etc. There shall be no separation (space or dash) between the letters and numbers.

1.3.3. Part Number (P/N)

The part number consists of the basic six digit number, a dash, and the applicable suffix as shown in the P/N block of the drawing; e.g., 127199-01, 221735-03, 350221-021, etc., composed as follows:

a. Basic Six Digit Number

The basic number is the number that identifies the part, e.g., 127199, 221735, 350221, etc. (It has been previously referred to as Drawing Number (DWG. NO.))

b. Suffix (SUF)

The suffix is a two or three digit number as specified, preceded by a dash; e.g., -01, -03, -021, etc. The manufacturing agency part number is applicable only if specifically required.

1.3.4. Manufacturing Number (MFG NO.)

The manufacturing number is the combination of the manufacturer's code and one or more of the following elements: a serial number, a date code, and a lot or batch number, as specified.

a. Manufacturer's Code

The manufacturer's code is the three letter code assigned by the design agency. Examples are OAC, ACX, and BEN. Suppliers will request their code letters from the buyer's purchasing department. (Note: This term has been previously defined as "Manufacturing Supplier's Identification Designation.")

b. Serial Number

The serial number is a four or five digit number assigned in the order of manufacture unless a random serial number is specified on the drawing or otherwise required by security regulations. A zero may be used as the first digit to obtain five digits. Serial numbers shall not be duplicated on the same part unless the manufacturer's code, the date code, or the lot/batch number changes.

c. Date Code

The date code may be Type I or Type II as defined below. Type I shall be used unless Type II is specifically called out.

Type I - A letter (A through L) for the month of the year followed by the last digit of the calendar year. For example, "H2" indicates August, 1962.

Type II - A three digit number, the first of which is the last digit of the calendar year, followed by the number of the week of that year. If the number of the week is a single digit, it shall be preceded by a zero. For example, "302" indicates the second week of 1963; "240" indicates the fortieth week of 1962.

d. Lot or Batch Number

A lot or batch number is applicable if shown on the drawing. The number shall be a two digit number, 01 thru 99, or a three digit number, 001 thru 199, assigned in sequence of manufacture. Lot or batch numbers shall not be duplicated unless the date code changes.

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e. Examples

The elements of the MFG NO. are separated by dashes as shown in the following examples:

OAC-2654-H2

BBN-06345-103-01

1.3.5. Mark/Mod Identification

The mark/mod identification consists of an abbreviation for mark (MK), the system number, a dash and the modification number e.g., MK 3-2 (Mark 3, Mod 2), MK 8-0 (Mark 8, Mod 0). Note that when the modification is zero, the number '0' is entered.

1.3.6. Alterations Number (ALTS)

The alterations number consists of the word 'ALTS' and a number or 'ALTS' and a series of numbers separated by commas, e.g., ALTS 0, ALTS 4, 290. Note that when no ALTS have been incorporated, the number '0' is entered.

1.3.7. Mark/Mod Serial Number (SERIAL)

The mark/mod serial number consists of the word 'SERIAL' and a three to seven digit number. The number is assigned to the production agency by AEC/ALO. Examples are SERIAL 793, SERIAL 1234567.

1.3.8. Other Designations

Designations other than those defined above shall be as specified on the drawing.

2. DOCUMENTS

2.1. Required Documents

The following document is a requirement to the extent stated elsewhere in this standard:

Federal Standard

No. 595

Colors

2.2. Reference Documents

Reference documents are listed in Section 6.

3. REQUIREMENTS

3.1. Designations

Product shall be identified by one or more of the designations defined in 1.3 as specified on the drawing.

3.2. Materials

Any marking material may be used providing it meets requirements Sections 3.3.4 and 3.7 of this standard. Marking materials and covercoat shall be compatible with the surface being marked and with each other. Section 6 carries a list of materials and equipment found to be satisfactory for many uses.

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3.3. Features

3.3.1. Location and Orientation (Wires and Cables)

Unless otherwise specified on the drawing, the location of markings on electrical cables and hook-up wires shall be as indicated below

a. Electrical Cables

All designations shall be marked on the cable body twice, $180^\circ \pm 20^\circ$ apart. On assemblies including connectors, markings shall read away from the connectors when practicable.

b. Hook-Up Wires

Designations shall be either circumferential or parallel to the axis of the wire.

3.3.2. Character Style

Unless otherwise noted in this paragraph, all characters shall be uppercase (capital) vertical gothic, either normal, medium, condensed, or extra condensed.

a. Freehand

Characters shall be freehand approximations of vertical gothic.

b. Class F-1

Characters may be any type commercially available.

3.3.3. Character Dimensions

3.3.3.1. Vertical Height

Unless otherwise noted below, the overall vertical height of characters shall be as specified in Table II. When character height is not specified on the drawing, the largest height practicable, not to exceed 1.10 inch, shall be used and shall conform to Table II

TABLE II. Height Tolerances

<u>Vertical Height, Inch</u>	<u>Tolerance, inch</u>
0.06	$\pm .02$
0.12	$\pm .04$
0.19	$\pm .04$
0.25	$\pm .06$
0.50	$\pm .06$
0.75	$\pm .08$
1.00 and larger	$\pm 10\%$

a. Freehand

No height requirement applies

b. Hook-up Wire

Height of characters on hook-up wire shall be as large as practicable, consistent with wire size and legibility

c. Heat-Shrinkable Sleeving

Except for hook-up wire applications, height of characters on heat-shrinkable sleeving shall be 0.09 inch minimum and 0.19 inch maximum after shrinking the sleeve in place

3.3.3.2. Depth Dimensions

a. Die Impact

Depth of characters shall be 0.03 inch maximum.

b. Sand Blast

Depth of characters shall be 0.002 to 0.005 inch below the surface of the metal

c. Vibrating Tool

Depth of characters shall be the minimum consistent with legibility

d. Hot Stamp

Maximum depth of characters shall be 25% of the original material thickness or 0.03 inch, whichever is less.

e. Roll Die

Typical depth of characters after any required plating is 0.0025 inch

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3.3.3.3. Engraved Dimensions

Engraved characters shall have dimensions as given in Table III. The height dimension is measured to the center lines of the grooves. Height tolerances given in Table II shall apply.

TABLE III. Dimensions of Engraved Characters

Height, Inch	Minimum Groove Width, Inch	Maximum Groove Depth, Inch
0.06	0.01	0.03
0.12	0.02	0.03
0.19	0.02	0.03
0.25	0.05	0.03
0.50	0.09	0.03

* Or 25% of the original material thickness of the marked surface, whichever is less.

3.3.3.4. Surface Conversion

Surface conversion markings shall be the minimum thickness consistent with legibility and permanence.

3.3.4. Color

The color of marking materials shall be one listed in Table IV that contrasts with the color of the material being marked or with the background color when marking clear or translucent materials.

TABLE IV. Colors

Color	Fed Std 595 Number
White	37875 or 27875
Yellow	33538 or 23538
Black	37038 or 27038
Red	11105 or 21105
Purple*	37144

*Applies to silicone marking ink only. The color will vary according to the color of the silicone rubber marked.

3.4. Marking Methods

Unless otherwise specified on the drawing, the following marking methods shall be used.

3.4.1. Ink

Ink markings may be applied by stamp, stencil, silk screen, or freehand (marking pen) or with a mechanical lettering guide.

3.4.2. Paint

Paint markings may be applied by silk screen or stencil.

3.4.3. Impression

a. Die Impact

Die impact markings shall be applied with male metal dies to properly back-supported surfaces before application of final surface finishes. Die edges shall be rounded to minimize displacement of material above the surface being marked. Marked surfaces shall not be distorted or flattened by the marking dies.

b. Freehand

Freehand markings may be applied with an electro-mechanical or pneumatic vibrating tool.

c. Sandblast

The area to be marked shall be covered with an adhesive-backed stencil paper into which the marking designations have been cut. Sandblasting shall be directed over the surface of the stencil until the specified depth of characters has been obtained. The stencil paper shall be capable of withstanding the sandblasting.

d. Roll Die

Roll die marking shall be applied by rolling the specified characters into the metal prior to plating. Proper pressure shall be used to obtain characters meeting the legibility requirements. A mandrel or other backing fixture shall be used to prevent distortion of the marked surface.

3.4.4. Hot Stamp

Markings shall be stamped with heated male metal dies over colored marking foils directly on the surface to be marked. Marking machine manufacturer's instructions should be observed as closely as possible.

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3.4.5. Engraved

Engraved markings may be made by mechanical means, chemical etch, or electro-chemical etch. When used, residual etching solutions shall be neutralized and removed from the surface immediately after completion of the etching. When filling is specified, excess filling compound shall be removed from the surrounding area.

3.4.6. Surface Conversion

Surface conversion markings shall be applied by an electro-chemical process. Residual processing solution shall be neutralized and removed from the surface immediately after completion of the marking process.

3.4.7. Integral

Integral markings shall be produced by casting or molding embossed (raised) or recessed characters.

3.4.8. Indirect

The following requirements concerning the use of boxes, bags, and tags apply only to parts shipped outside the manufacturer's plant. Indirect markings for internal use are left to the manufacturer's discretion.

3.4.8.1. Boxes, Bags, and/or Tags

Products requiring indirect marking may be identified by any applicable method of Class A-1, A-2, A-3, B-1, or D-1 using any one of the following methods:

- a. Direct marking of a box or bag into which the product(s) is inserted.
- b. Marking a pressure-sensitive label which is affixed to the outside of a box or bag containing the product(s)
- c. Marking a tag, which is either tied to the product or inserted into a transparent box or bag with the product(s).

3.4.8.2. Tape

The tape shall be as specified on the drawing. The required markings shall be applied by either Class A-1 or D-1 on the tape at uniform intervals. Marking interval on wires and cables shall be at least twice around the periphery. On electrical cables with extruded jackets, the tape shall be wrapped 1-1/2 to 2 turns without spiralling around the cable. The markings may be covercoated after installation of the tape. For cables jacketed with transparent polyvinyl chloride, the tape shall be wrapped 1 to 2 turns around a single conductor, then 1-1/2 to 2 turns without spiralling around the entire wire bundle before installation of the jacket.

3.4.8.3. Heat-Shrinkable Sleeve

The required markings shall be applied to the sleeve per Class D-1. It is recommended that the markings be applied before installation of the sleeve. Markings may not be divided but shall appear as a group on any piece of sleeving. Marking shall be at least one-half inch less than the sleeving length. After installation, the sleeving shall be shrunk in place using a hot-air gun.

3.4.8.4. Embossed Tape

The adhesive-backed embossing tape shall be as specified on the drawing. The required markings shall be applied to the tape in accordance with the manufacturer's instructions.

3.5. Surface Conditions

Surfaces to be marked shall be cleaned and dried as necessary to provide for permanency and adhesion of marking materials without damage to the product.

3.6. Legibility

All characters shall be fully developed and clearly legible. All characters, except treehand, shall be uniformly spaced and aligned.

3.7. Adhesion

When tested per paragraph 4.2., Class A-1, A-2, A-3, B-1, D-1, D-2 and E-2 markings shall not smear, chip or loosen.

3.8. Rework of Marking

Marking damaged during processing or handling at the product manufacturing agency may be reworked provided the original marking method and marking materials are used. If damaged marking cannot be satisfactorily restored per above, the Design Agency shall be contacted by the prime manufacturing contractor for appropriate instruction.

4. QUALITY PROVISIONS**4.1. Visual Inspection**

All markings shall be visually inspected for conformance to the requirements of this standard.

4.2. Adhesion and Smear

All specified markings shall be capable of being rubbed a total of 20 strokes in one direction only with a clean dry thumb using normal firm pressure, with no evidence of smearing.

5. PACKAGING AND HANDLING

Not applicable.

6. NOTES

6.1. Reference Documents

The following list of specifications and comments have been compiled to aid in the use of this standard.

GG-M-117, Felt Tip, Fountain Type Marker

A fountain-type marking pen for use in freehand marking. Available as a valve control feed, an adjustable feed, and a gravity feed.

GG-S-747, Hand Operated Stencil Cutting Machines

GG-S-749, Electrical Stencil Cutting Machines

Stencil cutting machines available in 1, 3/4, 1/2 and 1/4 inch cutting sizes.

H-B-621, Stencil Brush

A fountain type brush for use in stenciling. Available as a straight and L-head.

PPP-T-0066, Vinyl Plastic Film, Pressure-Sensitive Adhesive Tape

A tape used where a printed legend and the properties of a vinyl plastic tape are required. Type II (white or yellow) tapes are used as a marking surface.

QQ-T-25, Wire Identification Marking Foil

A transfer foil used with marking machines (MIL-M-4528 and MIL-M-15991) to transfer colors to wires and cables.

TT-E-489, Gloss Enamel

A silk screen enamel supplied as air drying or baking types.

TT-I-544, Felt Tip Marker Ink

An ink for use in felt tip marking pens for freehand marking.

TT-I-558, Stencil Marking Ink

An ink for use on non-porous surfaces with stencil board and stencil brush.

TT-I-559, Stencil Marking Ink

An ink for use on porous surfaces with stencil board and stencil brush.

TT-P-98, Flat Stencil Paint

A paint for use on porous surfaces with stencil board and stencil brush. Gives a much thicker film than stencil ink.

TT-V-121, Water-resisting Spar Varnish

A protective waterproof covercoat for markings.

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UU-P-543, Oil Board Paper for Stencils

A high quality impregnated paper used as stencil material.

MIL-L-73, Lacquer, Lusterless

An exterior finish coat on primed metal surfaces. Used as a stencil lacquer.

MIL-E-74, Enamel, Lusterless, Quick Drying

A fast drying finish coat on unprimed metal surfaces. Used as a silk screen enamel.

MIL-L-6805, Lacquer, Camouflage

A finish coat on primed or pretreated metal surfaces. Used as a stencil lacquer.

MIL-L-11195, Lacquer, Lusterless, Hot Spray

A finish coat on primed or phosphated metal surfaces. Used as a stencil lacquer.

AMS 3633, Heat-Shrinkable, Irradiated Polyolefin, Electrical Insulation, Plastic Tubing

A thin-wall flexible tubing whose diameter can be reduced to a predetermined size by application of heat. Black tubing is used as a marking surface.

6.2. Materials

The following materials and marking equipment have met the requirements of this standard for most applications. Their use is not a requirement and is not a guarantee that markings will meet the requirements of this standard.

a. Ink

<u>Type</u> <u>Stamp Pad Ink</u>	<u>Supplier</u> <u>(See 6.4)</u>	<u>Covercoat</u> <u>(See b.2.c)</u>
No. 15 Black	A	1
No. 1 Black	B	1, 2
No. 127 1/2 Black	C	1, 2
G-1000 Black	D	1
RK-1 Black (on non-absorbent)	D	1
No. 3 Yellow	B	1
No. 127 1/2 Yellow	C	1, 2
No. 127 1/2 White	C	1, 2
No. 3 Red	B	1, 2
No. 127 1/2 Red	C	1, 2
G-1000 Red (on non-absorbent)	D	1
<u>Roll Out Ink For Stamps</u>		
No. 41 WE Black	A	3, 4
No. 45 WE Black	A	3, 4
No. Q-51 Black	F	1, 3
JV-7406 Black	E	None
No. 43 WE Yellow	A	3, 4
No. 47 WE Yellow	A	3
No. Q-58 Yellow	F	1, 3
JV-7407 Yellow	E	None
No. 42 WE White	A	4
No. 46 WE White	A	4
No. X-146 White	F	1, 3
KX-8655	E	5

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Silk Screen Ink

No. N-252 Black	F	4
No. N-224 Yellow	F	3
No. N-185 White	F	3
No. N-366 Red	F	3

Type <u>Stencil Ink</u>	Supplier (See 6.4)	Covercoat (See 6.2.c)
8-PG-1 Black (on non-absorbent surfaces)	D	1, 2
K-1 Black (on absorbent surfaces)	D	1, 2
8-PG-5 Yellow (on non-absorbent surfaces)	D	1, 2
9-PG-5 Yellow (on absorbent surfaces)	D	1, 2
8-PG-3 White (on non-absorbent surfaces)	D	1, 2
9-PG-3 White (on absorbent surfaces)	D	1, 2
8-PG-2 Red (on non-absorbent surfaces)	D	1, 2
9-PG-2 Red (on absorbent surfaces)	D	1, 2

Freehand Ink

T-102 Black Flo-master (on absorbent and non-absorbent surfaces)	G	None
T-1 Black (on absorbent and non-absorbent surfaces)	D	None
T-102 Yellow Flo-master (on absorbent and non-absorbent surfaces)	G	None
T-6 Yellow (on absorbent and non-absorbent surfaces)	D	None
Opaque White Flo-Master (on non-absorbent surfaces)	G	None
T-20 White (on non-absorbent surfaces)	D	None
T-102 Red Flo-master (on absorbent and non-absorbent surfaces)	G	None
T-2 Red (on absorbent and non-absorbent surfaces)	D	None

Special Ink

GK-6646 Purple (on silicones)	E	None
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b. Paint

Type <u>Silk Screen Enamels</u>	Supplier (See 6.4)	Covercoat (See 6.2.c)
59-111 Black	H	1, 2, 3
PE-70 Black	I	1, 2, 3
59-130 Yellow	H	1, 2, 3
PE-20 Yellow	I	1, 2, 3
59-112 White	H	1, 2, 3
PE-10 White	I	1, 2, 3
59-104 Red	H	1, 2, 3
PE-54 Red	I	1, 2, 3

Stencil Lacquers

246-2048 Black	J	1, 2
246-067 Yellow	J	1, 2
246-1 White	J	1, 2

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c. Protective Coatings

<u>Covercoats</u>	<u>Supplier (See 6.4.)</u>
AN-12 Clear Plastic (1)	D
No. 1202 Clear Glyptal (1)	K
No. 1303 Clear Coating (1)	L
RK-302 Clear Varnish (1)	J
No. 1202 Clear Lacquer (2)	J
Orange Shellac Varnish (3)	J
White Shellac Varnish (4)	J
CORROCOTE 1295 (on neoprene)	U
U-87 (5)	X

NOTE Numbers in brackets indicate covercoat compatibility with inks, enamels, and lacquers of 6.2.a and 6.2.b.

d. Marking Foils

<u>Type</u>	<u>Use</u>	<u>Supplier (See 6.4)</u>
DH 61 Black	On Polyvinyl Chloride Insulation and Tape	M
DH 68 Black		M
DH 63 White		M
DH 50 White		M
K-36 Black		N
K-286 Black		N
K-39 White		N
K-289 White		N
NH 81 Black	On Polyethylene	M
K-36 Black		N
K-286 Black		N
K-289 White		N
NH 90 White		M
K-39 White		N
DH 48 Black	On Polyamide (Nylon)	M
DH 68 Black		M
K-46 Black		N
DH 46 White		M
DH 50 White		M
K-39 White		N
KT-28-E Black	On Polytetrafluoroethylene (Teflon)	N
KT-26-E White	On Polytetrafluoroethylene (Teflon)	N
K-39 White	On Neoprene	N
K-289 White	On Neoprene	N
K-49 White	On Heat Shrinkable AMS 3633 Sleeving	N

e. Filling Compounds

<u>Fillers</u>	<u>Supplier (See 6.4)</u>
811 B10 Black	0
811 W8 White	0
104 Red	0

f. Paper Products

<u>Adhesive Paper Label</u>	<u>Supplier (See 6.4)</u>
60 lb. Satin Sasson With S-201 Extra Heavy Adhesive	Y
<u>Stencil Paper</u>	
2510 White Adhesive Backed	Z

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Tags

Tensalex

AA and AB

Whitetuff

AC

6.3 Equipment

Class Reference	Equipment	Supplier (See 6.4)
A-1, A-2	RM 50 stamp pad	D
A-1, A-2	RM 20 roller	D
A-1, A-2	FB-25, FB-26, FB-80, 90-L fountain brushes	D
A-1, A-2, B-1	Models R, S, H and Q manual stencil cutter	D
A-1, A-2, B-1	Models ER, ES, EH and ED electric stencil cutter	D
A-3	Models AD-0, DC-OD and KS freehand markers and felts and cleaner	G
A-3	Models 77, 99 and M-3 freehand markers and felts and cleaners	D
D-1, D-2	Foil Marking Machine, Model KW-7 and accessories	N
C-2	Thor Air Pen No. 116	P
	Vibro-Graver	Q
C-4	Marking machine and accessories	AD
E-1, E-2	Mico Engraver	R
F-1	Marking Machine and accessories	S
F-1	Marking Machine and accessories	T
H-1-E	Dymo-Mite Tape Writer and tapes	W

6.4. Supplier Addresses

Home offices for suppliers cited in this standard are as follows

A. General Printing Ink Co. East Rutherford, N. J.	J. E. I. duPont de Nemours Co. Wilmington 98, Delaware
B. Phillip Process Co. 50 Commercial Street Rochester 14, N. Y.	K. General Electric Company 1 River Road Schenectady 5, N. Y.
C. The Pannier Corporation 501 Pannier Building Pittsburgh, 12, Pa.	L. Krylon, Incorporated Norristown, Pa.
D. Marsh Stencil Machine Co. 100 Marsh Building Belleville, Illinois	M. M. Swift & Sons, Inc. 10 Love Lane Hartford, Connecticut
E. Markem Machine Company 40 Putnam Street Keene, New Hampshire	N. Kingsley Machine Co. 850 Cahuenga Blvd. Hollywood 38, California
F. Bernhard Meiners, Inc. New York 6, N. Y.	O. Cook Paint & Varnish Co. 1412 Knox North Kansas City, Missouri
G. Esterbrook Pen Company 200 Cooper Camden 1, N. J.	P. Thor Power Tool Company Aurora, Illinois
H. Naz-Dar Company 463 Milwaukee Avenue Chicago 10, Illinois	Q. Burgess Vibrocrafters, Inc. Grayslake, Illinois
I. Advance Process Supply Co. 2317 W. Huron Street Chicago, Illinois	R. Mico Instrument Company 81 Trowbridge Street Cambridge 38, Mass
	S. Electro-Mark Corporation 7.20 Carnegie Avenue Cleveland 3, Ohio

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- T. Lectroetch Company
 14925 Elderwood Ave.
 Cleveland 12, Ohio
- U. Chemical Coating and Engineering Company
 Media, Pa.
- V. (Vendor deleted. Do not use)
- W. Dymo Company
 Berkeley 10, California
- X. Sterling Varnish Company
 Haysville, Pa.
- Y. Bermingham & Prosser
 715 May St.
 Kansas City, Mo.
- Z. Mystic Adhesive Products Co.
 2635 N. Kildare Ave.
 Chicago, Illinois
- AA. Dennison Manufacturing Co.
 Framingham, Mass.
- AB. Cupples-Hesse Envelope Company
 5002 Penrose St.
 St. Louis 15, Mo.
- AC. American Tag Company
 6151 S. State Street
 Chicago 21, Illinois
- AD. Noble & Westbrook Mfg. Co.
 East Hartford 8, Connecticut

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CERTIFICATION FORM

ASSEMBLY DATA

ACF Drawing No.	Rev.	Serial No.

Part Name:

Drawing No. & Rev:

Ref. Drawing No. & Rev:

Serial Number:

CERTIFICATION:

This certifies that the unit with the above serial number has been manufactured, tested and inspected in accordance with all applicable drawings and specifications, and that all requirements thereof have been fulfilled except as listed below.

ALBUQUERQUE DIVISION
ACF INDUSTRIES, INC.
ALBUQUERQUE, NEW MEX.

Authorized Representative

Date

AEC Authorized Repr.

Date

REMARKS & DEVIATIONS:

PROCESS DATA

--

RECORDED DATA

--

PREPARATION AND USE OF CERTIFICATION FORM - FORM AL-900KA APPROVED: T. A. GILTNER, MANAGER	DATE ISSUED 6/9/65	NUMBER IQC - 195
	PAGE 1 OF 4	REVISION NUMBER 02

1.0 SCOPE

- 1.1 This procedure delineates the preparation and use of the Certification Form - Form AL-900KA.
- 1.2 This form is used as an inspection report to indicate:
 - 1.2.1 ACF and, when applicable AEC acceptance
 - 1.2.2 Customer and/or engineering approved deviations from specifications or drawings
 - 1.2.3 Waiver of and/or changes to inspection requirements
 - 1.2.4 Recorded data as required by customer
- 1.3 Customer requirement for this report is released by the purchase order or Engineering Release/Change Form, Form AL-823 (Rover only).
- 1.4 Shop requirements are included in the production order, Process Description Packet, Inspection Traveler and/or Shipper.
- 1.5 Field Inspection requirements are included on the Quality Control Purchase Instructions, Form AL-857 or the ER/C Form AL-823 (Rover only).
- 1.6 The AL-900KA written for an assembly shall include a list of discrepancies for all components as well as those on the final assembly.

2.0 General

- 2.1 The shop inspector will complete three copies of the AL-900KA when required by the Process and/or Inspection Traveler. All three copies should be presented to AEC for signature before distribution, when AEC inspection is required by process. (only two copies required for non-AEC parts).
 - 2.1.1 When an ER/C is used to approve discrepancies, a copy of the ER/C must be available at the time of preparation of the AL-900KA.

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DEPARTMENT INSTRUCTION

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2.1.2 When preparing AL-900KA for an assembly, contact Quality Control Records Section for copy of required components AL-900KA's.

2.1.3 Transfer discrepancies from component AL-900KA to final assembly, AL-900KA.

2.1.4 Send two copies of completed form to Quality Control Records Section. One copy is to be presented to AEC with the C of I when AEC inspection is required.

2.2 The shipping inspector will contact Quality Control Records Section for the AL-900KA. If not available, contact the Quality Control Engineer. One copy of the AL-900KA is to be shipped with the material, when required by the Shipper.

2.3 The Field Inspector will complete the AL-900KA when required by the AL-857 or ER/C Form AL-823.

3.0 Instructions - See Fig. 1

Block 1 Part Name - As shown in name block of drawing.

Block 2 Drawing No. & Rev.
The ACF drawing number, print revision letter, plus the latest change date marked up on the print and signed by the authorized engineer.

Block 3 Ref. Drawing No. & Rev.
The customer drawing number, print revision letter, plus all change ER/C numbers (4-digit) if applicable.

- a. This may be found on the print or Traveler.
- b. Only Rover change ER/C 4-digit numbers are the drawing update that must be reported in this block.
- c. The marked up print change dates signed by the authorized engineer, but without any ER/C number, are only in-process manufacturing changes to the ACF print and are reported by date only in Block #2, Not in Block #3.

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- Block 4** **Serial Number**
Record 5- digit serial number of all parts covered by the AL-900KA. Use N/A if parts are not serialized and list number of pieces instead. (S/N of components are listed in Block #7). Also list any special customer serial number.
- Blocks 5,6,7** **ACF Drawing No., Rev. and Serial No.**
List all components except hardware. Place an asterisk in front of all part numbers for which a deviation approval number, i.e. EU, EO, ER/C, etc., appears on the AL-815A or for deviations listed on component AL-900KA and added per 9.a. The correct revision letter and serial number are obtained from the acceptance tag, AL-815A and/or certification form, AL-900KA. (For Rover, only, do not report EU approvals)
- Block 8** **Recorded Data**
List and record information required by print, process traveler or other appropriate document.
- Block 9** **Remarks and Deviations**
- a. Transfer discrepancies from components AL-900KA to assembly AL-900KA and identify by part number.
 - b. List all discrepancies with approval authority.
 - c. List only discrepancies approved by ER/C and the ER/C number for Rover AL-900KA's.
 - d. List EO No.'s. if applicable, and what inspection requirements were changed or waived.
- Block 10,11** **Authorized Representative, Date**
Signed and dated by Inspector, Inspection Foreman or Quality Control Engineer as applicable.
- Blocks 12,13** **AEC Authorized Representative, Date**
Have all copies signed and dated by AEC only when AEC submittal is required. Use N/A when AEC submittal is not required.

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DEPARTMENT INSTRUCTION

SUBJECT PREPARATION AND USE OF CERTIFICATION FORM - FORM AL-900KA	DATE ISSUED 6/9/65	NUMBER IQC - 195
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APPROVED: T. A. GILTNER, MANAGER

CERTIFICATION FORM			
ASSEMBLY DATA			Part Name: (1)
ACF Drawing No.	Rev.	Serial No.	Drawing No. & Rev: (2)
(5)	(6)	(7)	Ref. Drawing No. & Rev: (3)
			Serial Number: (4)
			CERTIFICATION: This certifies that the unit with the above serial number has been manufactured, tested and inspected in accordance with all applicable drawings and specifications, and that all requirements thereof have been fulfilled except as listed below. ALBUQUERQUE DIVISION ACF INDUSTRIES, INC. ALBUQUERQUE, NEW MEX.
PROCESS DATA			(10) (11)
			Authorized Representative Date
			(12) (13)
			AEC Authorized Repr. Date
RECORDED DATA			REMARKS & DEVIATIONS:
(8)			(9)

AL-900-KA

Figure 1

ALBUQUERQUE DIVISION

— QCF INDUSTRIES

ALBUQUERQUE, NEW MEXICO

GENERAL TEST SPECIFICATION

1. SCOPE

- 1.1. Scope. This specification prescribes certification tests for ACF-Albuquerque welders and welding operators engaged in production welding with electric arc fusion welding processes.
- 1.2. Classification. In accordance with the provisions of this specification, the following classifications shall be established and maintained.
 - 1.2.1. Unrestricted Welder. Unrestricted welders have successfully demonstrated their ability to manually produce Class I welds in the vertical, flat and overhead positions and are certified for all position welds with the required alloy group and associated process.
 - 1.2.2. Partially Restricted Welder. Partially restricted welders have successfully demonstrated their ability to manually produce Class I welds in the flat position and are certified for only welds with the required alloy group and associated process in the flat position.
 - 1.2.3. Restricted Welder. Restricted welders have not demonstrated their ability to pass the certification tests for either unrestricted or partially restricted welder. Restricted welders are restricted to the welding of non-critical welds, where weld defects will not result in potential failure of the completed product.
 - 1.2.4. Welding Operator. Welding operators shall be certified unrestricted or partially restricted welders who have also successfully demonstrated their ability to produce Class I mechanized welds with the same alloy group and associated mechanized welding process, in accordance with the provisions of this specification. In the case of submerged-arc welding, the operator shall first obtain his unrestricted or restricted welder's metal arc-coated electrode certification.

2. APPLICABLE DOCUMENTS

- 2.1. The following documents form a part of this specification.

CUSTOMER'S REFERENCE NUMBER		CLASSIFICATION			
		Unclassified			
DATE	8/3/60	INITIAL	DEPT	TITLE WELDER AND WELDING OPERATOR CERTIFICATION TESTS	
		PREPARED	401		
		PREPARED			
		APPROVED	401	NUMBER 6-300005-A	
		APPROVED	301		
		APPROVED	542		
APPROVED		SHEET 1 OF 21			
RELEASED	542				
REV	A				

CERTIFICATION SHEET

ASME, Boiler & Pressure Vessel Code, Section VIII, Appendix IV.
MIL-T-5021A.

3. REQUIREMENTS FOR CERTIFICATION

3.1. Application for Certification. The applicant shall be provided with the required application forms (Figure 1) and unwelded test plates by the welding inspector. The forms will be executed in triplicate and will indicate class of certification to be performed, welding process, alloy group, and joint number. Upon completion of the certification test, the applicant will fill in the required information, sign the forms, and return them along with the welded joints to the welding inspector.

3.1.1. Demonstration of Proficiency. To achieve certified status, the welders and welding operators shall demonstrate their skill by satisfactorily welding the joints in the designated alloy group using the desired process.

3.1.2. Joint Quality. The joints shall be tested and shall meet required specified properties as described in section 3.3.

3.1.3. Eligibility. No welder or welding operator shall be permitted to perform any welding operation that requires certification until such certification has been issued in accordance with the provisions of this specification.

3.1.3.1. Welding Procedure Specifications. For special applications covered by welding procedure specifications, welders and welding operators shall be certified in accordance with this specification and shall also require the additional training necessary to enable them to comply with the provisions of the procedure specification.

3.1.3.2. Welders and welding operators who have been certified to weld a given alloy are also certified for the other various alloys in that same group.

3.1.4. Alloy Groups. For the purposes of certification, the various alloys shall be included in the following groups.

<u>Alloys</u>	<u>Groups</u>
Carbon steel and alloy steel	I
Corrosion and heat-resistant alloys	II
Copper and nickel alloys	III
Aluminum alloys	IV
Magnesium alloys	V

3.1.4.1. For Alloy Group III, Copper and Nickel Alloys, test plates can be either those indicated in Figures 5, 6, 7, 8 and 9, or sections from an actual production part that can be subjected to the required tests.

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- 3.1.5. Welding Processes. This specification applies to the following electric arc welding processes.

- a. Metal arc coated electrode (manual)
- b. Tungsten inert gas (manual)
- c. Metal inert gas (manual)
- d. Submerged arc (mechanized)
- e. Tungsten inert gas (mechanized)
- f. Metal inert gas (mechanized)

3.2. Preparation of Welded Joints

3.2.1. Materials

- 3.2.1.1. Base metal. The material used for the certification tests will be indicated on the individual joint drawings (see Figures 5-11) and will conform to the typical alloys used in production.
- 3.2.1.2. Weld filler material. The welding rods or electrodes shall conform to those used for production applications.
- 3.2.1.3. Test supervision. All test specimens shall be welded under supervision of an agent of the Welding Engineering Section of the Development and Test Engineering Department and/or representative of the Quality Control and Inspection Department.

3.2.2. Welder and Welding Operator Certification, Alloy Groups and Joints

- 3.2.2.1. All welders and welding operators. Certification tests shall consist of the joints and alloy groups indicated in Tables I, II and III.

3.2.3. Weld Joints

- 3.2.3.1. Number of joints required. For unrestricted and partially restricted welders and operators, only one weld joint is required for each position as indicated in Tables I, II and III.

- 3.2.4. Weld Joint Specifications. Weld joint specifications such as materials, tensile values, specimen sizes, etc., are called out on the individual joint drawings, Figures 5-11.

3.3. Examination and Tests of Welded Joints

3.3.1. Applicable Tests

- 3.3.1.1. Visual examination. The exposed surfaces of all the welded joints shall be visually examined for weld quality. The weld beads shall be smooth, free from surface defects, and blend smoothly into the base plates.

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Lack of these qualities shall be sufficient cause for rejection. Cracks of any type will be cause for rejection. All completed certification test plates shall be subjected to visual examination.

- 3.3.1.2. Radiographic examination. All completed certification test plates shall be subjected to radiographic examination. The porosity standards shown in Figures 12, 13 and 14 apply to all joints (1, 2, 3, 4, 5, 6, and 7) and indicate acceptable levels of porosity. Porosity or inclusions in excess of that indicated in Figures 12, 13 and 14 shall be sufficient cause for rejection. Cracks of any type, insufficient penetration, or lack of fusion, will be cause for rejection.
- 3.3.1.3. Tensile test requirements. Tensile specimens shall be considered satisfactory only when failure occurs at or above the minimum specified ultimate tensile strengths. The surfaces of tensile specimen fractures shall be free from defects in excess of those permitted in this specification.
- 3.3.2. Rejection and Retest. When the welder or welding operator fails on one joint, he shall be permitted to submit two other specimens of the same joint. If either of these specimens fails to meet the requirements specified for that joint, the welder or operator shall be disqualified. If re-examination is desired after the above tests, the welding operator shall be required to submit a complete series of qualification tests.
- 3.3.3. Report of Tests. Upon successful completion of the specified tests, the Inspection Test Report, Figure 12, shall be completed in triplicate and signed by the Quality Control Supervisor.

4. CERTIFICATION AND MAINTENANCE OF RECORD

- 4.1. Certificate. If the application form and test reports are satisfactory, the welding inspector shall issue a certificate, Figure 16, and forward it to the welder or welding operator. The welding inspector's signature on the certificate will indicate that the applicant has satisfactorily fulfilled all the requirements for the indicated classification.
- 4.2. Maintenance of Status. Certified status of the welders and operators shall be maintained by successfully completing re-examination tests every six months. However, the cognizant inspection authority may require re-examination testing whenever there is reason to question proficiency or workmanship.
- 4.2.1. Re-examination. All certified welders and operators shall be re-examined every six months.

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- 4.2.1.1. Unrestricted welders shall be required to weld one joint in any of the positions indicated in Table I, using the associated welding process.
- 4.2.1.2. Partially restricted welders shall be re-examined by repeating the certification tests using the alloy groups, welding processes, and joints indicated in Table II.
- 4.2.1.3. Welding operators shall be re-examined by repeating the certification tests using the alloy groups, welding processes, and joints indicated in Table III.
- 4.3. Failure to Pass Re-examination Test. In the event a welder or operator fails to pass the six-month re-examination test, he will be allowed two additional sets of test plates for that alloy group and associated process. If either of the specimens fails to meet the requirements for that joint, the welder or operator shall be disqualified and shall be required to undergo a period of additional training before being eligible for re-certification.

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APPLICATION FOR EXAMINATION OF WELDERS AND WELDING OPERATORS

Name of Applicant _____ Date _____

Certification Applying For _____ Alloy Group _____

Welding Process _____ Joint No. _____

Dept. _____ Supervisor _____

Employee No. _____ Specimen Serial No. _____

Base Metal Specification _____ Filler Material Spec. _____

Dia. of Filler Material _____ Specification _____

Test Plate Information (If data does not apply, leave space blank)

Pass No. (indicate torch or backing side)	1	2	3	4	5	6	7	8	Remarks
Tungsten dia.									
Cup size									
Torch gas type and flow (CFH)									
Backing gas type and flow (CFH)									
Voltage									
Amperage									
Travel speed (IPM)									
Wire speed (IPM)									
Type of current									

Signature of Applicant _____

Signature of Test Supervisor _____

FIGURE 1

TITLE WELDER AND WELDING OPERATOR CERTIFICATION TESTS	CLASSIFICATION unclassified	
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TABLE I

**DESIGNATED JOINTS, WELDING POSITIONS, AND APPLICABLE
PROCESSES FOR THE VARIOUS ALLOY GROUPS FOR
UNRESTRICTED WELDER CERTIFICATION**

Alloy Group To Be Certified In	Applicable Processes To Be Certified In	Applicable Joints Figs. 5 & 6	Welding Positions *	No. of Joints Req'd For Ea. Position
I	a	1	O, V, F	1
	c	1	O, V, F	1
	b	2	O, V, F	1
II	a	1	O, V, F	1
	c	1	V, F	1
	b	2	O, V, F	1
III	a	1	F, V	1
	c	1	F, V	1
	b	2	F, V	1
IV	c	1	F, V	1
	b	2	F, V	1
V	c	1	F, V	1
	b	2	F, V	1

* O - Overhead

V - Vertical

F - Flat

FIGURE 2

TITLE WELDER AND WELDING OPERATOR CERTIFICATION TESTS	CLASSIFICATION unclassified	
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TABLE II

DESIGNATED JOINTS, WELDING POSITIONS, AND APPLICABLE PROCESSES FOR THE VARIOUS ALLOY GROUPS FOR PARTIALLY RESTRICTED WELDER CERTIFICATION

Alloy Group To Be Certified In	Applicable Processes To Be Certified In	Applicable Joints Figs. 5 & 6	Welding Position	No. of Joints Req'd For Ea. Position
I	a	1	flat	1
	c	1	flat	1
	b	2	flat	1
II	a	1	flat	1
	c	1	flat	1
	b	2	flat	1
III	a	1	flat	1
	c	1	flat	1
	b	2	flat	1
IV	c	1	flat	1
	b	2	flat	1
V	c	1	flat	1
	b	2	flat	1

FIGURE 3

TITLE WELDER AND WELDING OPERATOR CERTIFICATION TESTS	CLASSIFICATION unclassified	
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TABLE III

**DESIGNATED JOINTS, WELDING POSITIONS, AND APPLICABLE
PROCESSES FOR THE VARIOUS ALLOY GROUPS FOR
WELDING OPERATOR CERTIFICATION**

Alloy Group To Be Certified In	Applicable Processes To Be Certified In	Applicable Joints Figs. 6-11	Welding Position	No. of Joints Req'd For Ea. Position
I	d	3	flat	1
	e	4	flat	1
	f	5	flat	1
II	d	3	flat	1
	e	4	flat	1
	f	5	flat	1
III	d	3	flat	1
	e	4	flat	1
	f	5	flat	1
IV	e	4	flat	1
	f	6	flat	1
V	e	4	flat	1
	f	7	flat	1

FIGURE 4

TITLE WELDER AND WELDING OPERATOR CERTIFICATION TESTS	CLASSIFICATION unclassified	
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JOINT NO. 1

BUTT JOINT IN PLATE (TENSILE TEST)

Warping to be held to a minimum. The sample should be cut into tensile test specimens with a minimum of three to be tested. See table below for materials and minimum tensile requirements.

Applicable Processes	a, c	a, c	a, c	a, c	a, c
Alloy Group	I	II	III	IV	V
Material	SAE 1020	304 SS	to be specified	6061-T6	AZ31B
Min. UTS psi	55,000	75,000		24,000	35,000

Minimum of 2 passes, maximum of 5.

FIGURE 5

TITLE

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JOINT NO. 2

BUTT JOINT IN PLATE (TENSILE TEST)

Warping to be held to a minimum. The sample should be cut into tensile test specimens with a minimum of three to be tested. See table below for materials and minimum tensile requirements.

Process	b	b	b	b	b
Alloy Group	I	II	III	IV	V
Material	SAE 1020	304 SS	to be specified	6061-T6	AZ31B
Min. UTS psi	55,000	75,000	specified	24,000	35,000

Minimum of 2 passes.

FIGURE 6

TITLE
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A - A

JOINT NO. 3

BUTT JOINT IN PLATE (RADIOGRAPH SPECIMEN)

Warping to be held to a minimum. Grind weld bead flush on both sides to aid radiograph interpretation.

Applicable Process	d	d	d
Alloy Groups	I	II	III
Material	SAE 1020	304 SS	to be specified

Minimum of 4 passes, maximum of 8.

FIGURE 7

TITLE

WELDER AND WELDING OPERATOR
CERTIFICATION TESTS

CLASSIFICATION

unclassified

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JOINT NO. 4

BUTT JOINT IN PLATE (RADIOGRAPH SPECIMEN)

Warping to be held to a minimum. Grind weld bead flush on both sides to aid radiograph interpretation.

Applicable Process	e	e	e	e	e
Alloy Group	I	II	III	IV	V
Material	SAE 1020	304 SS	to be specified	6061-T6	AZ31B

Maximum of 2 passes.

FIGURE 8

TITLE WELDER AND WELDING OPERATOR CERTIFICATION TESTS	CLASSIFICATION unclassified	
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A - A

JOINT NO. 5

BUTT JOINT IN PLATE (RADIOGRAPH SPECIMEN)

Warping to be held to a minimum. Grind weld bead flush on both sides to aid radiograph interpretation.

Applicable Process	f	f	f
Alloy Group	I	II	III
Material	SAE 1020	304 SS	to be specified

Minimum of 4 passes.

FIGURE 9

TITLE WELDER AND WELDING OPERATOR CERTIFICATION TESTS	CLASSIFICATION unclassified	
	NUMBER 6-300005-4	SHEET 14 OF 21

A - A

JOINT NO. 6

BUTT JOINT IN PLATE (RADIOGRAPH SPECIMEN)

Warping to be held to a minimum. Grind weld bead flush on both sides to aid radiograph interpretation.

Applicable Process	f
Alloy Group	IV
Material	6061-T6

Minimum of 4 passes.

FIGURE 10

TITLE WELDER AND WELDING OPERATOR CERTIFICATION TESTS	CLASSIFICATION unclassified	
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JOINT NO. 7

BUTT JOINT IN PLATE (RADIOGRAPH SPECIMEN)

Warping to be held to a minimum. Grind weld bead flush on both sides to aid radiograph interpretation.

Applicable Process	f
Alloy Group	V
Material	AZ31B

Minimum of 4 passes.

FIGURE 11

TITLE WELDER AND WELDING OPERATOR CERTIFICATION TESTS	CLASSIFICATION unclassified	
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WELDING CERTIFICATION TEST REPORT

Name of Applicant _____ Date _____

Joint No. 1 2 (circle) Position _____

Alloy Group _____ Material _____

Process _____ Specimen Serial No. _____

Tensile Specimens	1	2	3	Remarks	Initials
Visual					
X-Ray					
Area, in ²					
Ultimate load, lbs.					
Ultimate stress, psi					
Location of fracture					

Joint No. 3 4 5 6 (circle)

Alloy Group _____ Material _____

Process _____ Specimen Serial No. _____

			Remarks	Initials
Visual				
X-Ray				

Quality Control Supervisor

FIGURE 12

TITLE WELDER AND WELDING OPERATOR CERTIFICATION TESTS	CLASSIFICATION unclassified	
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POROSITY CHARTS

SCATTERED

Assorted Scattered

Max dimension 25% T

Max dimension 15% T

Max dimension 10% T

ALIGNED

Single - max dimension 25% T

3 to 6 per group - max dimension 15% T

3 to 8 per group - max dimension 10% T

Plate 1/4 in. or less
Specimens shown are 1/4 in. thick

FIGURE 13

TITLE

WELDER AND WELDING OPERATOR
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POROSITY CHARTS

SCATTERED

ALIGNED

Plate over 1/4 in. to 1/2 in. thick
Specimens shown are 1/2 in. thick

FIGURE 14

TITLE

WELDER AND WELDING OPERATOR
CERTIFICATION TESTS

CLASSIFICATION

unclassified

NUMBER

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POROSITY CHARTS

SCATTERED

ALIGNED

Plate over 1/2 in. to 1-1/4 in.
Specimens shown are 1-1/2 in. thick

FIGURE 15

<p>TITLE</p> <p>WELDER AND WELDING OPERATOR CERTIFICATION TESTS</p>	<p>CLASSIFICATION</p> <p>unclassified</p> <p>NUMBER</p> <p>6-300005-A</p> <p>SHEET 20 OF 21</p>
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WELDING CERTIFICATION AUTHORIZATION ACF-ALBUQUERQUE

Name _____ Date _____

Signature of Certified Personnel

In accordance with ACF Specification _____, the above
has successfully demonstrated his ability to produce Class I welds
in alloy group _____ using the _____
process and is a certified _____.

Quality Control Supervisor

(front side)

(reverse side)

Date	Welding Inspector's Signature
_____	_____
_____	_____
_____	_____
_____	_____
_____	_____
_____	_____
_____	_____
_____	_____
_____	_____
_____	_____
_____	_____
_____	_____
_____	_____
_____	_____
_____	_____

FIGURE 16

TITLE

WELDER AND WELDING OPERATOR
CERTIFICATION TESTS

CLASSIFICATION

unclassified

WORKING

6-300005-A

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ALBUQUERQUE DIVISION

ACF INDUSTRIES

INCORPORATED

ALBUQUERQUE, NEW MEXICO

1. SCOPE

1.1 This standard covers the requirements for process control, inspection, and acceptance of Class I welds in aluminum alloys whose as-welded thickness are 0.060 inch and over (see 3.4). For definitions of terminology used in this standard, see 6.1.

1.2 Welding shall be done by the inert-gas-shielded metal arc process using a consumable electrode or the inert-gas-shielded tungsten arc process. Use of manual, semiautomatic, and automatic techniques are within the scope of this standard.

2. APPLICABLE DOCUMENTS

2.1 The following documents form a part of this standard:

Military Standard

MIL-STD-410, "Certification of Penetrant Inspection Personnel"

Military Specifications

MIL-I-6866, "Inspection Penetrant, Method of"

MIL-T-5021, "Tests, Aircraft Welding Operators' Certification"

Other Specifications

American Society of Mechanical Engineers, Boiler and Pressure Vessel Code, Section VIII and Section IX.

3. REQUIREMENTS

3.1 Qualification and Approval of Welding Procedures. --The Buyer shall approve the welding procedure as formulated by the Supplier before production of the ordered weldments, except when waived on the product drawing. Approval of the welding procedure by the Buyer does not relieve the Supplier of his responsibility in producing acceptable weldments.

CUSTOMER'S REFERENCE NUMBER		INITIAL	DEPT.	DATE	CLASSIFICATION	
400215		PREPARED	CVF	542	3/62	UNCLASSIFIED
		PREPARED				
ACF DATE 3/16/62 REV. A		APPROVED	JLD	301	3/62	TITLE CLASS I WELDS IN ALUMINUM ALLOYS
		APPROVED	JCG	301	3/62	
		APPROVED	JEF	401	3/62	
		APPROVED	RHG	542	3/62	
		APPROVED				NUMBER 6-400215-A
		APPROVED				
		APPROVED				
		APPROVED				
	RELEASED	RWB	542	3/62	ISSUE	SHEET 1 OF 13

3.1.1 For approval of the welding procedure(s), the Supplier shall complete Form A (see Appendix B) for each of the following variables: (1) type of weld (butt, fillet, etc.), (2) specified weld size where differences exceed 1/8 inch, (3) combination of parent metals, (4) filler metal, and (5) welding process used. These forms, in triplicate, shall be sent to the Buyer for approval, if the Buyer doubts that the chosen procedure will produce weldments that meet all the drawing requirements, qualification tests shall be required before approval is made.

3.1.2 Only approved procedures shall be used for fabrication of weldments. Any change in the variables listed in Appendix B is considered a changed procedure. If the procedure is changed or a change is desired, approval of the new procedure is required prior to its use.

3.2 Qualification of Welders and Welding Operators. -- Welders and welding operators using manual, semiautomatic, and automatic equipment shall pass qualification tests and be certified as follows:

3.2.1 Welders using manual or semiautomatic equipment shall qualify under one of three agencies: (1) Air Force, per MIL-T-5021, Class A only, (2) ASME Boiler and Pressure Vessel Code, Section IX, for applicable metal thickness alloy, and process, or (3) the Buyer's qualification tests described in Appendix A.

3.2.2 Welding operators for automatic welding equipment shall be tested in accordance with requirements of the ASME Boiler and Pressure Vessel Code, Section IX.

3.3 Marking. -- Each part that has passed radiographic inspection shall be permanently marked X; each part that has passed penetrant inspection shall be permanently marked P. Impression stamping shall be used only when permitted and then only in the area designated by the product drawing.

3.4 Machining. -- Machining after welding shall not reduce the as-welded material thickness by more than 10 percent.

4. QUALITY ASSURANCE PROVISIONS

4.1 Inspection and testing specified herein and on the product drawing shall be the responsibility of the Supplier.

4.1.1 Suppliers shall have adequate laboratory and testing facilities for conducting both qualification and quality control tests, or shall subcontract these tests to a commercial testing laboratory approved by the Buyer.

4.2 Weldments shall be inspected after any heat treatment and prior to machining (except as required in Appendix C) or surface finishing operations that might obscure defects.

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4.3 Inspection. -- Unless otherwise specified on the product drawing, the inspection requirements for Class I welds shall be: (1) 100 percent visual, (2) 100 percent penetrant, and (3) 100 percent radiographic inspection of each weldment. Radiographic and penetrant inspection shall be in accordance with Appendix C of this standard and MIL-I-6866 respectively. Visual inspection shall be as defined in Section 6 of this standard. Penetrant inspection personnel shall be certified in accordance with MIL-STD-410.

4.3.1 Nondestructive testing and inspection methods not mentioned herein or on the product drawing may be substituted only with the written approval of the Buyer, but may be used in addition to those mentioned, without approval.

4.4 Defects. -- Imperfections that exceed the limits specified in Table I shall be considered defects.

4.4.1 Under referee circumstances, the Buyer reserves the right to require removal of a portion of any doubtful weld for testing or metallographic examination. This portion can be removed by trepanning or other suitable method.

4.5 Repair of Defects. -- Repair of defects is permissible to the extent specified in 4.5.1 if the repaired weldment, the repair weld itself, and adjacent parent metal meet the requirements of the original weldment. A repaired weldment shall be reinspected in the same manner as the original weldment.

4.5.1 Welds may be repaired if the total length of the repairs does not exceed 10 percent of the total footage of welding in the weldment. If defective welding exceeds 10 percent, permission to repair the weldment shall be obtained from the Buyer.

4.6 Records. -- Unless otherwise specified, the Supplier shall maintain the following records for at least one year after completion of welding.

- a. Qualification of welding procedure
- b. Qualification and certification of welders or welding operators
- c. Radiographs, macrographs, or micrographs, etc.
- d. Inspection records
- e. Test data (mechanical, proof, pressure, etc.)
- f. Certification of penetrant inspection personnel

5. PREPARATION FOR DELIVERY

5.1 Not applicable

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6. NOTES

6.1 Definitions

Buyer. -- An AEC integrated contractor responsible for procurement of the product.

Crater. -- A depression at the termination of a weld bead.

Crater Crack. -- A crack in the crater of a weld bead.

Incomplete Fusion. -- Fusion which does not occur over the entire base metal surfaces exposed for welding.

Inadequate Joint Penetration. -- Joint penetration which is less than that specified.

Lot. -- A lot shall consist of those weldments submitted for inspection at one time.

Overlap. -- Protrusion of weld metal beyond the bond at the toe of the weld.

Porosity. -- Gas pockets or spherical voids in metal.

Qualification. -- Tests to demonstrate ability of a person (welder or welding operator) or a particular welding process to produce sound and acceptable welds.

Supplier. -- A contractor to a Buyer.

Throat of Fillet Weld (Theoretical). -- The distance from the beginning of the root of the joint perpendicular to the hypotenuse of the largest right triangle that can be inscribed within the fillet weld cross-section.

Throat of Fillet Weld (Actual). -- The shortest distance from the root of a fillet weld to its face.

Undercut. -- A groove melted into the base metal adjacent to the toe of a weld and left unfilled by weld metal.

Visual Inspection. -- Close visual examination of welds and adjacent parent metal, with the aid of magnification not exceeding 10X, for cracks, undercuts, overlaps, unfilled craters, pock marks, contour, smoothness, regularity, general workmanship, appearance, and conformity to dimensional size specified on the product drawing.

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Welder. -- One who is capable of performing a manual or semi-automatic welding operation.

Welding Operator. -- One who operates automatic welding equipment.

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Imperfection	Limit								
Cracks in weld bead	Unacceptable								
Cracks in parent metal	Unacceptable								
Crater cracks	Unacceptable								
Incomplete fusion	Unacceptable								
Inadequate joint penetration	Unacceptable								
Porosity	Porosity may be scattered, aligned, or a combination of both. The maximum size and population of porosity as seen on the radiographic film shall be in accordance with Appendix D. Porosity in welds of plate over 1-1/4 inches thick shall be as specified in Appendix IV of Section VIII of the ASME Boiler and Pressure Vessel Code.								
Inclusions	Inclusions shall be added to porosity and subjected to the requirements of Appendix D. No inclusion having a maximum dimension greater than twice its minimum dimension is acceptable. The maximum dimension of an inclusion shall be considered its diameter. (See Note 1)								
Undercut	Unacceptable								
Overlap	Unacceptable								
Convexity of butt welds either side (reinforcement height maximum)	<table> <tr> <th>Weld Size</th><th>Convexity</th></tr> <tr> <td>Up to 0.125</td><td>0.050 inch</td></tr> <tr> <td>0.125 to 0.500</td><td>25% of weld size</td></tr> <tr> <td>0.500 and over</td><td>0.125 inch</td></tr> </table>	Weld Size	Convexity	Up to 0.125	0.050 inch	0.125 to 0.500	25% of weld size	0.500 and over	0.125 inch
Weld Size	Convexity								
Up to 0.125	0.050 inch								
0.125 to 0.500	25% of weld size								
0.500 and over	0.125 inch								
Concavity	Unacceptable in butt welds. In fillet welds, actual throat shall be not less than theoretical throat for specified weld size.								
Fillet weld size limits	Specified weld size (leg)+50%, -0%								
Note 1 -- Tungsten spatter that can be removed from the surface of the weld shall not be considered as inclusions.									
TITLE CLASS I WELDS IN ALUMINUM ALLOYS	CLASSIFICATION UNCLASSIFIED								
	<table> <tr> <td>NUMBER 6-400215-A</td><td>SHEET 6 OF 13</td></tr> </table>	NUMBER 6-400215-A	SHEET 6 OF 13						
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APPENDIX A

Qualification and Certification of Welders and Welding Operators

1. The Buyer' qualification tests are patterned after MIL-T-5021, Class A, as follows:
 - 1.1 The qualification tests shall be administered by the Buyer.
 - 1.2 The welder shall be qualified for each welding process shown in MIL-T-5021 that he will be using.
 - 1.3 The welder shall be qualified for Group IV alloys as shown in MIL-T-5021.
 - 1.4 Two test weldments of Joint No. 5 and one test weldment of Joint No. 6 shall be made in the flat position. Joint No. 5 may use tensile test bars instead of bend bars, and the minimum tensile strength will be determined for each alloy group, thickness, condition and temper. Joint No. 6 is tested by sectioning. Joint No. 7 may be required at the discretion of the Buyer.
2. Certification. -- Certification of welders will be made by the Buyer by letter to the Supplier and by issuing a card (SC-7689-F) to the welder or welding operator. All records of qualification tests that the Supplier has on file shall be available to the Buyer, and he shall decide on the validity of existing qualifications and what additional qualification tests may be required.
3. Maintenance of Status. -- Welders and welding operators will be certified for six months. At expiration, the certification may be renewed if the welder or welding operator has been continuously producing acceptable welds per his qualification. Requalification tests shall be required (1) when the welder has not used the specific process for a period of three months, (2) when the welder has not welded the specific alloy group for a period of three months, or (3) when in the judgement of the Buyer, the quality of the welder's work falls below standard. Requalification tests shall be chosen by the Buyer as individually required. Qualification testing and certification of welders by the Buyer does not certify welders for other Government agencies.

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APPENDIX B*

QUALIFICATION OF WELDING PROCEDURES

Manufacturer's Name _____ Date _____
 Address _____
 Name of Part _____ Dwg No. _____
 Purchase Order No. _____ Welding Spec. No. _____
 Material Base _____ Spec. _____
 Description of Welds Covered by this Form _____
 (Butt, Fillet, Size, Location)

Welding Process _____
 (Metal Arc, Inert Gas Shielded Tungsten Arc., etc)
 Technique _____ Position _____
 (Manual, Semi-Automatic, etc.) (Flat, Vert., Horizontal)

Electrode - Class _____ Size _____ Spec. _____

Filler Rod - Comp _____ Size _____ Spec. _____

Shielding Gas _____ Backup Gas _____

Flux _____ Type Current _____
 (AC, DCRP, etc)

Weld Preparation _____
 (Flame cut, Machined, etc.)

Beads Layers and Sequence of Welding (make sketch)

Preheat Temp. _____ Interpass Temp. _____

Brief Description of Heat Treatment Procedures After Welding _____

Signed _____ Title _____

*Preprinted forms similar to above are available from the Buyer.

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APPENDIX C⁽¹⁾

TECHNIQUE FOR RADIOGRAPHIC EXAMINATION OF WELDED JOINTS

1. All welds requiring complete examination shall be examined throughout their length by the X-ray method of radiography.
2. All welded joints that are to be radiographed shall be prepared as follows: The weld ripples or weld surface irregularities, on both sides if applicable, shall be removed by any suitable mechanical process to a degree such that the resulting radiographic contrast due to any remaining irregularities will not mask or be confused with any defect. Also the weld surface shall merge smoothly into the plate surface.
3. Single-welded butt joints made the equivalent of double-welded butt joints may be radiographed without the removal of the backing strip, provided the backing strip image will not interfere with the interpretation of the resultant radiographs.
4. The weld shall be radiographed with a technique which will indicate the size of imperfections equal to or greater than two per cent of the thickness of the base metal.

(Diameters of holes are 2, 3, and 4 times the thickness of penetrameter but not less than 0.010 in.)

Fig. 1 - Dimensions of penetrameters

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5. As a check on the radiographic technique employed, penetrameters as herein described shall be used in the following manner to determine whether the requirements of Paragraph 4 of this Appendix are being met.

- (a) The penetrameters shall be placed on the side nearest the radiation source except when complying with the provisions given in Paragraph 7.
- (b) At least one penetrameter shall be used for each exposure, to be placed at one end of the exposed length, parallel and adjacent to the weld seam, with the smallest hole at the outer end. When there is any difference between the angularity of the radiation at the two ends, the penetrameter shall be placed at the end of maximum angularity. In special cases, the inspector may require the use of a penetrameter at each end of the exposed region.
- (c) The material of the penetrameter shall be aluminum or aluminum alloy. If the filler metal is of the same composition as the base metal, the penetrameter may be placed adjacent to the weld; otherwise it shall be placed on the deposited weld metal.
- (d) The thickness of the penetrameter shall not be more than 2 percent of the thickness of the plate being radiographed, but for sheet need not be less than 0.005 inch. When the penetrameter is placed adjacent to the weld seam and the weld reinforcement and/or backing strip is not removed, a shim of the same alloy as the backing strip shall be placed under the penetrameter such that the total thickness being radiographed under the penetrameter is the same as the total thickness through the weld, including backing strip when used and not removed.
- (e) In each penetrameter, there shall be three holes of diameters equal respectively to two, three, and four times the penetrameter thickness, but not less than 0.010 inch. The smallest hole shall be distinguishable on the radiograph.
- (f) Each penetrameter shall carry numbers at least $\frac{3}{32}$ inch high which identify the material or alloy of which it is made and indicate the minimum thickness of plate (to two significant figures) for which it may be used.
- (g) The images of these identifying numbers shall appear clearly on the radiograph.

6. The film during exposure shall be as close to the surface of the weld as practicable. If possible, this distance shall not be greater than 1 inch. In any event, the following ratio shall be satisfied.

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$$\frac{\text{Distance from source of radiation to weld surface toward radiation}}{\text{Distance from weld surface toward radiation to film}} = \frac{\text{At least 7}}{1}$$

7. Penetrameters may be placed on the film side of the joint provided the manufacturer can satisfy the inspector that the technique employed in doing the work is known to be adequate.
8. All radiographs shall be free from excessive mechanical processing defects that would interfere with proper interpretation of the radiograph.
9. Identification markers, the images of which will appear on the film, shall be placed adjacent to the weld, and their locations shall be accurately marked on the outside surface near the weld, so that a defect appearing on the radiograph may be accurately located.
10. The job number or serial number, the seam, and the manufacturer's identification symbol or name shall be plainly indicated on each film.
11. The radiographs shall be submitted to the inspector with such information regarding the radiographic techniques as he may request.

(1) Information in this appendix was taken from Paragraph UW-51 of Section VIII of the ASME Code, through the courtesy of the American Society of Mechanical Engineers.

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APPENDIX D - LIMITS OF POROSITY PLUS INCLUSIONS
PER LINEAR INCH OF WELD

ALUMINUM SHEET - 0.060 to 1/8 INCH THICK

If the range of diameters in any linear inch of weld is:*	then the max population for each diameter increment within the range is:**			
	0.010" to 17%T	17%T to 30%T	30%T to 40%T	40%T and over
0.010" to 17%T	13	0	0	0
0.010" to 30%T	5	4	0	
0.010" to 40%T	3	2	2	

ALUMINUM SHEET - 1/8 to 1/4 INCH THICK

If the range of diameters in any linear inch of weld is:*	then the max population for each diameter increment within the range is:**				
	0.010" to 10%T	10%T to 15%T	15%T to 20%T	20%T to 25%T	25%T and over
0.010" to 10%T	20	0	0	0	0
0.010" to 15%T	9	5	0	0	
0.010" to 20%T	5	3	2	0	
0.010" to 25%T	4	2	2	1	

*(T) is the specified weld size.

**Substitution. -- Two smaller imperfections may be substituted for every allowable larger imperfection that is missing; and conversely, one larger imperfection may be substituted for every two allowable smaller imperfections that are missing. No re-substitution of imperfections is allowed.

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APPENDIX D - LIMITS OF POROSITY PLUS INCLUSIONS PER LINEAR INCH OF WELD

ALUMINUM PLATE - 1/4 to 1/2 INCH THICK

If the range of diameters in any linear inch of weld is:*	then the max population for each diameter increment within the range is:**			
	2%T to 5%T	5%T to 7%T	7%T to 12%T	12%T and over
2%T to 5%T	28	0	0	0
2%T to 7%T	10	9	0	
2%T to 12%T	7	4	3	

ALUMINUM PLATE - 1/2 to 1-1/4 INCH THICK

If the range of diameters in any linear inch of weld is:*	then the max population for each diameter increment within the range is:**			
	2%T to 3%T	3%T to 4%T	4%T to 6%T	6%T and over
2%T to 3%T	40	0	0	0
2%T to 4%T	16	10	0	
2%T to 6%T	8	6	4	

*(T) is the specified weld size.

**Substitution.--Two smaller imperfections may be substituted for every allowable larger imperfection that is missing; and conversely, one larger imperfection may be substituted for every two allowable smaller imperfections that are missing. No re-substitution of imperfections is allowed.

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ALBUQUERQUE DIVISION
ASF INDUSTRIES
ALBUQUERQUE, NEW MEXICO

PROCESS STANDARD

GENERAL MANUFACTURING REQUIREMENTS

MFG. AGENCY NO.

6-9900000

DWG. NO.

9900000

Drawing Call-Out: Limits of acceptable workmanship are defined in 9900000.

COORDINATED

<u>APPROVAL AUTHORITY</u>	<u>INITIAL COORDINATED ISSUE</u>	<u>RELEASE STATUS</u>	<u>CHANGE AUTHORITY</u>	<u>RELEASE DATE</u>
BY <u>J. H. Kuehnle</u> <i>JKK / JH</i>	<u>B</u>	<u>Active</u>	<u>ECN 7104658</u>	<u>1-8-65</u>
SC <u>P. E. Jockle, Jr. BA 283 14124</u>	<u>B</u>			
LS <u>V. M. Field LL 1320 23114</u>	<u>B</u>			
SA <u>L. D. Seltenreich PP 30 04124</u>	<u>B</u>			
GE _____				
MM <u>A. L. Thibodeaux LS 034 23114</u>	<u>C</u>			
PI <u>W. D. Martin LP 72 11124</u>	<u>D</u>			
SU <u>Ray Taylor NR 14 04124</u>	<u>D</u>			
CV <u>E. E. Rhodes BC 31 04124</u>	<u>C</u>			
UC <u>H. J. MacDonald LC 160 12084</u>	<u>D</u>			
OR <u>F. S. McGuiness LC 315 30114</u>	<u>E</u>			

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GENERAL MANUFACTURING REQUIREMENTS

1. GENERAL

1.1. Scope

This standard supplements, but does not supersede, drawings and specifications by:

- (a) Defining those limits of workmanship that normally are left to common understanding,
- (b) Defining certain drawing terms and callouts to establish mutual understanding.
- (c) Providing callout of Government, industry, or society standards that control physical dimensions, materials or manufacturing processes not normally specified.
- (d) This standard does not apply to commercial "off-the-shelf" or catalog (800000 number) items.

1.2. Definitions

1.2.1. Design Agency

An AEC integrated contractor responsible primarily for the design, development and evaluation of products. The following are Design Agencies.

Univ. of Calif., Los Alamos Scientific Laboratory, Los Alamos, New Mexico
Sandia Corp., Livermore Laboratory, Livermore, California
Univ. of Calif., Lawrence Radiation Laboratory, Livermore, California
Sandia Corp., Sandia Laboratory, Albuquerque, New Mexico

1.2.2. Production Agency (Manufacturing Agency)

An AEC integrated contractor responsible primarily for the manufacture and/or procurement of products. The following are Production Agencies

The Bendix Corporation, Kansas City Division, Kansas City, Missouri
ACF Industries Inc., Albuquerque Division, Albuquerque, New Mexico
Mason and Hanger, Silas Mason Co., Inc., Burlington AEC Plant, Burlington, Iowa
Mason and Hanger, Silas Mason Co., Inc., Pantex Plant, Amarillo, Texas
Dow Chemical Co., Rocky Flats Division, Denver, Colorado
General Electric Co., Pinellas Peninsula Plant, St. Petersburg, Florida
Monsanto Research Corp., Mound Laboratory, Miamisburg, Ohio
Mason and Hanger, Silas Mason Co., Inc., Fort Campbell, Kentucky
Mason and Hanger, Silas Mason Co., Inc., Medina Facility, San Antonio, Texas
Union Carbide Corporation, Nuclear Division, Y12 Plant, Oak Ridge, Tennessee

The following also may function as Production Agencies.

Univ. of Calif., Los Alamos Scientific Laboratory, Los Alamos, New Mexico
Sandia Corp., Livermore Laboratory, Livermore, California
Univ. of Calif., Lawrence Radiation Laboratory, Livermore, California
Sandia Corp., Sandia Laboratory, Albuquerque, New Mexico

1.2.3. Buyer

An organization purchasing materials, parts, components, apparatus, or services.

1.2.4. Supplier

An organization selling materials, parts, components, apparatus, or services.

1.2.5. "C*", "M"

These symbols govern certain engineering relationships only between the Design Agency and the Production Agency that are not applicable to a Supplier. The symbol applies to the specific numbered requirement to which it is applied and to any subnumbered portions of the requirement.

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2. DOCUMENTS

2.1. Required Documents

The following documents are requirements to the extent stated elsewhere in this standard:

National Bureau of Standards

Handbook H28	Screw Thread Standards for Federal Services
Part I	Unified; American; American National, and National Miniature Threads
Part II	Pipe Threads, Including Dry Seal Pipe Threads, Etc.
Part III	Acme, Stub Acme, and Buttress Threads, Etc.

Military Standards

MIL-STD-9	Screw Thread Conventions and Methods of Specifying
MIL-STD-12	Abbreviations for Use on Drawings and in Technical Type Publications
MIL-STD-15	Electrical and Electronic Symbols
MIL-STD-20	Welding Terms and Definitions
JAN-STD-19	Welding Symbols

Military Specifications

MIL-C-5541	Chemical Films for Aluminum and Aluminum Alloys
MIL-T-5544	Thread Compound, Anti Seize, Graphite Petroleum

American Standards Association Standards

ASA B1.10	Unified Miniature Screw Threads
ASA B5.30	Knurling
ASA B46.1	Surface Texture

2.2. Procurement of Specifications and Standards

2.2.1. Production Agency's Publications

Copies of Production Agency-published specifications and standards may be obtained through the Production Agency's purchasing department.

2.2.2. Federal and Military Publications

The Department of Defense Index of Specifications and Standards lists the unclassified Federal, Military, and departmental specifications, standards, and related standardization documents that are used by the Department of Defense, and may be purchased from the Superintendent of Documents, U.S. Government Printing Office, Washington 25, D.C.

The DOD Index of Specifications and Standards, and related standardization documents is comprised of three (3) separate parts as follows:

- Part I - An Alphabetical Listing
- Part II - A Numerical Listing
- Part III - A Federal Classification Listing

Included in each of the three listings are detailed instructions for the procurement of those specifications and standards indexed.

2.2.3. Industry and society specifications and standards frequently used may be obtained as follows:

NAS (NAS 525, etc.)	Aerospace Industries Association 1725 DeSalle N.W. Washington 6, D.C.
ASTM (ASTM B16, etc.)	American Society for Testing and Materials 1916 Race Street Philadelphia 3, Pennsylvania
AMS (AMS 3685, etc.)	Society of Automotive Engineers 485 Lexington Avenue New York 17, New York

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2.2.3. (Continued)

ASA
(ASA B18.3, etc.)

American Standards Association
70 East 45th Street
New York 17, New York

SAE

Society of Automotive Engineers
485 Lexington Avenue
New York 17, New York

- 2.2.4. When copies of specifications required for a specific product cannot be obtained through sources given, assistance may be obtained by contacting the Production Agency's purchasing department.

3. DIMENSIONAL INTERPRETATION REQUIREMENTS

3.1. Free-State Variations

If material flexibility or normal internal material stresses can be expected to cause parts to be out of tolerance, the Supplier shall obtain appropriate inspection procedures from the Production Agency prior to the manufacture of parts.

3.2. Sheet Metal Bends

The angularity tolerance for sheet metal bends is $\pm 0^\circ 30'$ for material thicker than 0.064 inch and $\pm 2^\circ$ for thinner material.

3.3. Threaded Holes

The perpendicularity or normality of threaded holes in flat or curved surfaces shall be within $1^\circ 0'$. However, this tolerance must not allow the feature to exceed the limits of location specified on the drawing.

3.4. Concentricity of Machined or Molded Diameters

Any two diameters having a common axis (including hole countersinks, counterbores and spot faces) shall be concentric within a total indicator reading (TIR) of one-half the arithmetic sum of the diameter tolerances (see Figure 1). The axis of the diameter having the smallest tolerance shall be the reference axis for all related diameters. If tolerance values are equal, the diameter having the longest axis shall be used as the datum reference.

$$\text{Concentricity of A} = 1/2 (0.010 + 0.004) = 1/2 (0.014) = 0.007 \text{ TIR}$$

$$\text{Concentricity of B} = 1/2 (0.020 + 0.004) = 1/2 (0.024) = 0.012 \text{ TIR}$$

FIGURE 1

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3.5. Counterbores, Spotfaces and Countersinks

The depth of counterbores and spotfaces in curved surfaces shall be measured from the lowest point on the rim as shown in Figures 2(a) and 2(b). On flat surfaces when the axis is not perpendicular to the surface depth is the minimum distance from the rim to the bottom as shown in Figure 2(c).

The diameter of countersinks in curved surfaces shall be measured across the diameter from the lowest point on the rim in a plane perpendicular to the hole axis. See Figure 2(d). This method of measurement also applies to the diameter of countersinks when their axis is not perpendicular to a flat surface (see Figure 2(e)).

FIGURE 2

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3.6. Parallelism

Surfaces of a part shown as parallel on a drawing shall be parallel within $0^{\circ}30'$. However, this tolerance must not allow the part to exceed the limits of size specified on the drawing.

3.7. Squareness

Surfaces of a part shown as a right angle on a drawing shall be square within $0^{\circ}30'$. However, this tolerance must not allow the part to exceed the limits of size specified on the drawing.

3.8. Location and Size of Features

Dimensions specified for all elements of a feature control only the size and shape of the feature. Locating dimensions specified for the feature control only the position of the feature. The feature size tolerances and locating dimension tolerances shall be considered separately, except when maximum material condition is specified.

3.9. Measurements at Maximum Material Condition

The surface finish shall be within the limits of size at maximum material condition.

3.10. Measurement of Dimensions Over Coated Surfaces

Dimensions apply over metallic platings, dry film lubricants, electrochemical, and chemical-film coatings. Care should be taken to insure that the finish is not damaged by measuring equipment. Where painted finishes are specified, dimensions apply without paint. Paint will be removed when verification of dimensions is necessary. Paint removed to permit gaging shall be replaced (see 5.9 and 5.10).

(E) 3.11. Location of Features on Centerlines

When a feature is shown on the centerline of a part and is located in one direction only, (C dimension, Figures 3, 4 and 5), the centerline of that feature shall coincide with the centerline of the part within a tolerance equal to one-half the tolerance of the dimension defining the size of the part. When two or more size dimensions apply, the smallest tolerance shall control location of the related features. Location of any such feature closer than 0.005 is not required.

Three examples are shown following

FIGURE 3

In Figure 3 the centerline of the hole shall be located within one-half the tolerance of diameter A on either side of the centerline of diameter A. $1/2 (0.040) = 0.020$

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FIGURE 4

In Figure 4 the centerline of slot B shall be located on the part centerline within one-half the tolerance of width A, or 0.010 on either side of the centerline of width A.

FIGURE 5

In Figure 5, the centerline of diameter A is the reference centerline for hole shown.

3.12. Tooling Locations Designated by Datum-Targets

Where Datum-Targets are designated as shown in Figure 6 and located by untoleranced dimensions, the following shall apply:

- (a) Tooling features in fabrication tools and inspection fixtures that make contact with the part and which represent "datum-targets" on the drawing shall be located within ± 0.005 from the untoleranced dimensions specified. See Figure 6a.
- (b) Such features representing area contacts may vary from the area (indicated by corresponding diameter) size to 25% less area. For example, a specified 0.500 diameter area as in Figure 6b would have tooling diameter limits of 0.500 maximum and 0.433 minimum as shown.

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FIGURE 6 (a)

FIGURE 6 (b)

3.13. Stock Material Tolerances

When the part drawing specifies nominal cross-sectional dimensions for material used to fabricate the part, but does not specify tolerances for these dimensions, the widest tolerances applicable to the material, form, and process shall be used.

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4. SURFACE TEXTURE REQUIREMENTS

Surface texture requirements are expressed by symbols on the drawings. These symbols shall be interpreted and the texture measurements performed in accordance with ASA B46.1 Standard. The following interpretation shall apply:

4.1. Surface Roughness Number

The surface roughness number specified shall be interpreted as the arithmetical average (AA System).

The conversion formula is as follows:

$$AA = 0.9 \text{ RMS}$$

4.2. Texture Measuring Instruments

- 4.2.1. Unless otherwise specified, instruments used to measure surface roughness shall be adjusted to the following roughness width cutoff requirements:

Single-Stroke Distance Permitted By Part Surface (*)	Required Roughness-Width Cutoff
0.150 or more	0.030
0.149 thru 0.050	0.010
0.049 thru 0.015	0.003
0.015 thru 0.005	0.001 (**)

(*) Distance applies in direction that will give maximum roughness reading.

(**) Obtainable with instruments that are set at 0.003 roughness width cut off by reducing stroke speed to one-third of standard stroke speed.

- 4.2.2. When the surface roughness specified is $63\sqrt{\text{ }}$ or rougher, visual and tactile comparison of the actual part surface with commercial roughness comparison specimens such as the General Electric Company "Roughness Comparison Specimens" (Catalog No. 8651831 series) is acceptable in lieu of measurement by electronic instrumentation. Emphasis should be placed on feel rather than sight in using these specimens.

- 4.2.3. When the surface roughness specified is less than $63\sqrt{\text{ }}$, acceptable measurement is by electronic instrumentation. On inaccessible area or areas where finishes should not be touched by a stylus, a surface replica should be made and measurements taken therefrom. Replica specimens may be made using material such as 'Replica Kit' by Taylor Hobson Company.

4.3. Applicability

- 4.3.1. Surface texture requirements apply over metallic platings, electrochemical and chemical film coatings (e.g., Iridite, Anodize, Alodine, Bonderite, metallic plating, etc. or application of resin bonded dry film lubricants). Surface texture requirements apply before the application of painted organic surface finishes.
- 4.3.2. Flaws in surfaces having specified surface texture limits are to be excluded from surface texture measurements (see 5.11).
- 4.3.3. Surface texture measurements are to be taken in the area and direction that will result in the maximum reading.
- 4.3.4. Surface texture limits given in general note form do not apply to the cut edges of sheet metal, to the surfaces of screw threads, to the walls of punched or drilled holes, or to the mold or flash lines of molded plastic parts.
- 4.3.5. If a finishing method is not specified, part surfaces may be finished by any process that will produce a surface finish within the specified texture limits.
- 4.3.6. Unless otherwise specified, maximum surface roughness for surfaces of countersinks, counterbores, spotfaces, thread reliefs, heads and shanks of bolts and screws shall be $125\sqrt{\text{ }}$. Maximum surface roughness for all other machined surfaces shall be $250\sqrt{\text{ }}$. The maximum surface roughness of compression molded plastic parts shall be $32\sqrt{\text{ }}$ on all as-molded surfaces.

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5. MANUFACTURING REQUIREMENTS

5.1. Formed Parts

Final material thickness may be "as formed" for areas of parts affected by forming processes such as bending, drawing, or stretching.

5.2. Fillets

When two machined surfaces on a part intersect so as to form an angle exterior to the part of less than 180 degrees, there shall be a blending fillet of 0.002 to 0.015 at the intersection of the two surfaces as illustrated in Figures 7(a) and 7(b).

FIGURE 7

5.3. Turning Centers

Turning centers are permissible.

5.4. Grind Relief

Ground diameters that terminate at a shoulder may be provided with a relief. The ground diameter, or both the ground diameter and the shoulder, may be relieved within the limits shown in Figure 8.

FIGURE 8

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5.5. Plain Holes

5.5.1. Blind Holes

The depth specified for blind holes is the full cylindrical diameter and does not include the depth of drill point penetration. The drill point shall not penetrate or deform the material surface opposite the mouth of the hole (see Figure 9).

FIGURE 9

5.5.2. Gaging Hole Diameters

The size of a hole is within required limits when accepted by "GO" and "NOT GO" plug gages of appropriate size without reasonable evidence during plug gaging that the hole is out of round in excess of the diameter limits. Performance of a variable measurement (micrometer, etc.) normally will be required only for the specific holes that are suspect as a result of the "GO" and "NOT GO" gaging. Bell-mouthed holes are acceptable if the "NOT GO" gage does not enter more than one-third the nominal length of the hole (see Figure 10).

FIGURE 10

5.5.3. Holes in Molded Plastic Parts

Holes may be cored in the mold or added by subsequent machining. Holes shall be within specified limits (see 5.5.2) to the required depth.

5.5.4. Hole Quality

The walls of holes shall be clean cut and shall present a good machined surface. Hole edges shall be free from burrs and shall not be ragged, chipped, or torn. These requirements are subject to visual inspection only and are to be evaluated in terms consistent with the characteristics of the material and with the method used to produce the hole.

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5.6. Counterbores and Spotfaces

The sharp corners produced at the bottom of both counterbores and spotfaces by standard tools are satisfactory. Spotfacing shall provide a 75 percent minimum bearing area around holes, must be visible on the part surface, and shall not be deeper than 0.015. Dimension 0.015 applies per "Depth" in Figure 2 "Concave Curved Surfaces".

5.7. Removing Burrs and Sharp Edges

All burrs and sharp edges shall be removed to the extent that material fragments are not visible and sharpness cannot be felt. Either a 0.010 (max.) x 45° (approx.) chamfer or a 0.010 max. radius round is satisfactory treatment in breaking edges and deburring. Only those edges that appear to exceed these limits upon visual inspection need be measured for conformance to these dimensions. If it is necessary to break sharp edges or to deburr after application of chemical surface treatment, the bared metal shall be touched up as required by paragraph 5.9. Flash on molded plastic parts that does not cause the part to exceed maximum dimensional limits need not be removed.

5.8. Use of Holes Called for on Assembly Drawings

Where holes are called out on assembly drawings, they may be inserted in the detail parts, either full size or less than full size, as required to facilitate manufacture. Inspection of such holes is not required, however, until final assembly, at which point the holes must meet all assembly drawing requirements.

5.9. Repair of Finishes and Metallic Coatings

5.9.1. Repairs Prohibited

5.9.1.1. Any finish repair process that reduces the base material to less than the allowable minimum material condition defined on the drawing is not permissible.

5.9.1.2. Repair of major damage or damage to functional (e.g., mechanical load bearing, electrical conducting surface, seal surface, alignment surface) areas is not permitted.

NOTE: Function shall be determined on the basis of relationship of the surface to the total complex of components of which it forms a part.

5.9.2. Repairs Permitted

Repair of minor damage in non-functional areas is permitted to the extent indicated below.

5.9.2.1. Metallically coated surfaces may be repaired only if specifically authorized by the Design Agency.

5.9.2.2. Electrochemically treated or chemical treated aluminum surfaces shall be touched up by application of a freshly prepared chromate chemical treatment using materials specified in MIL-C-5541 applied as recommended by the producer of the touch-up material.

5.9.2.3. Electrochemically treated or chemical treated magnesium surfaces shall be touched up by application of a freshly prepared solution of Dow 19.

5.9.2.4. In touching-up painted finishes, use shall be made of the same preparation, sequence, number of coatings, and materials as specified for the original finish. Paint touch-up must be substantially smooth with respect to the surrounding original finish and shall be within the color range specified for the original finish but need not otherwise be an exact color match with the original finish.

5.10. Paint-Free and Contaminant-Free Surfaces

5.10.1. Hole surfaces and screw-thread surfaces shall be free of foreign materials that would adversely affect the function of the part. Strippable coatings may be applied during fabrication and processing of individual parts to surfaces specified to be "paint free". These coatings must be removed prior to assembly.

5.10.2. When painting of parts and assemblies is specified, the following shall apply:

5.10.2.1. Screw thread surfaces, holes for locating pins, and holes having a tolerance less than normal for drilled holes of the size specified, shall be paint-free.

5.10.2.2. Clearance holes for fasteners, hardware and mating of metal parts normally shall not be painted, but may have evidence of paint to an extent that will not interfere with correct assembly.

5.10.2.3. Countersinks, counterbores, spotfaces and holes for weight reduction, ventilation, routing of wiring and plumbing, safety wiring, grommets, and similar exposed or loose-fitting conditions, shall be painted.

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5.11. Surface Flaws

Acceptance of parts having surface flaws shall be at the discretion of the Production Agency and shall be based upon the function of the part. If any doubt exists as to the effect of a flaw on part function, the question shall be referred to the Design Agency.

Flaws are surface irregularities and imperfections that occur at one place, or at relatively infrequent intervals in contrast to the normal irregularities produced by the surface finishing operations. Flaws include surface conditions such as scratches, cuts, dents, cracks, checks, pits, blow holes, bumps, ridges, and similar marks and imperfections. Flaws are usually caused by handling or are inherent in the material from which an item is manufactured.

5.12. Rework and Repair of Parts and Assemblies

Rework is permissible if the method used is one of completing regular work rather than changing the nature of the product. Examples are retapping undersize threads, re-turning of oversize diameters, etc.

Repairs that add material to the part or that employ a technique abnormal to the production process are not permissible. Examples are welding cracks and other flaws, plugging of off location or oversize holes, filling of voids in encapsulations or metal castings.

5.13. Deformation of Die-Cut or Sheared Metal Parts

Die-cut or sheared metal parts may vary from a theoretical sharp corner by as much as 25 percent of material thickness. For limits applicable to holes see 5.5.2.

5.14. The symbol $\propto$ indicates that the surface so designated shall be a machined surface. The symbol $\nless$ does not control the surface texture, which is defined in paragraph 4.

6. THREADED PART REQUIREMENTS

6.1. General

6.1.1. Form and Class of Fit

All threads shall conform to the requirements of Handbook H28 Parts I, II, or III, or of ASA B1.10, whichever applies to the particular thread size, form and class of fit specified.

6.1.2. Appearance

All threads must be free from burrs, nicks, and rough or chattered surfaces.

6.1.3. Gaging

6.1.3.1. Measurement Over Wires

Thread wires and measurement indicators may be used.

6.1.3.2. "Go" Gages

When "go" gages are used, the product shall allow the "go" gage to enter or to be entered the specified full length or depth of the thread.

6.1.3.3. "Not Go" Gages

Threads are acceptable as within material limits if, when plug and ring thread gages are used, the "not go" plug gage does not enter or the "not go" ring gage is not entered. Threads may be accepted if all complete threads can enter in or be entered by the "not go" gage provided a definite drag results from metal-to-metal contact on or before the third turn of entry. For holes having three or fewer turns, the drag must occur on or before the first one-half turn of actual thread engagement. "Not go" gaging procedures for extremely ductile materials shall be as agreed upon between the Design Agency and the Production Agency. Neither working nor final inspection "not go" gages should be forced after the drag is definite.

6.1.3.4. Three-Roll Indicating-Type Gage Readings

When this type gage is used on Class 2A or 3A external threads, the gage reading may exceed the basic pitch diameter not more than 1/8 turn of the screw providing the maximum gage reading does not exceed the basic pitch diameter by more than 50 percent of the difference between basic pitch diameter and minimum 2A or 3A pitch diameter, as applicable (see 6.2.3).

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6.1.3.5. Threads in Installed Commercial Threaded Parts

Thread size and class of fit callouts may appear on assembly drawings in conjunction with installed commercial threaded parts. Unless such callouts are modified by reference to specific notes on the assembly drawing, the size and class of fit shown are for information purposes only and the commercial part thread limits shall be governed by the limits of the commercial part drawing specified on the assembly drawing.

6.1.4. Anti-Seize Compound

When aluminum or magnesium threads are to be in contact with threads of any metal, the surfaces of the internal thread may be coated prior to assembly with an anti-seize compound meeting the requirements of MIL-T-5544, except where electrical conductivity is a factor or where out-gassing in a sealed container would be deleterious or when an assembly wrench torque based upon dry (non-lubricated) threads is specified.

6.1.5. Assembly

When two or more threaded fasteners are used to attach a part, a sequential tightening pattern shall be established that will equalize fastener load throughout the part.

6.1.6. Torque Wrenches

6.1.6.1. When torque limits are specified for threaded assemblies or fasteners, the torque wrench used shall be selected so that the limits specified for each feature will fall within approximately the middle 75 percent of the wrench scale.

6.1.6.2. A procedure for the routine periodic calibration and repair of all torque wrenches used to assemble items to specified limits shall be established and maintained.

6.1.6.3. Torque wrench readings shall be taken in a direction that will tighten the part.

6.2. External Threads

6.2.1. Thread Length

Dimensions of axial thread length shown on product drawings indicate minimum required length of complete threads. When the dimensioned thread length terminates at a shoulder and an undercut is not specified, the two threads next to the shoulder may be incomplete.

6.2.2. Chamfer

The leading end of externally threaded parts shall be chamfered. The resulting incomplete threads are included in the measurement of thread length but must not exceed two pitches in length.

6.2.3. Coated Class 2A Threads

Class 2A threads to which metallic plating, chemical-film coatings, resin bonded dry film lubricants, or any combination thereof have been applied may be gaged with Class 3A "go" gages in determining conformance to maximum size limits.

6.2.4. External Acme Threads

The feather edge at the start of the thread shall be removed to the actual minor diameter to a width equal to one-half the crest width (see Figure 11).

FIGURE 11

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6.3. Internal Threads

6.3.1. Thread Depth

Dimensions of axial thread depth shown on product drawings indicate minimum required depth of complete threads.

6.3.2. Chamfer

The leading ends of internal threads shall be chamfered as shown in Figure 12. Both ends of through-tapped holes shall be chamfered except where the far side is not accessible. The incomplete threads resulting from chamfering are included in the measurement of complete threads, but must not exceed one pitch in depth, from the surface adjacent to the hole.

FIGURE 12

6.3.3. Hole Preparation and Tapping

6.3.3.1. Hole diameter prior to tapping shall be controlled so that the minor diameter of the finished threads are within the limits specified in Handbook H28.

6.3.3.2. For blind holes, the drill point shall not penetrate or deform the material surface opposite the mouth of the hole.

6.3.3.3. Cold forming thread taps such as Besly "X-Press" taps may be used in lieu of metal cutting taps. A slight groove may appear along the thread crest (see Figure 13) as a result of the metal flowing action of these taps. The groove is acceptable if the overall thread crest height conforms to 6.3.3.1.

FIGURE 13

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6.3.4. Internal Acme Threads

The feather edge at the start of an internal acme thread shall be removed to the actual major diameter to a width equal to one-half the crest width (see Figure 14). This treatment applies to both ends of through-tapped holes except where far side is not accessible.

FIGURE 14

6.3.5. Plated Internal Threads

If plating of internal threads is required on the product drawing, thickness of such plating shall be as specified. If not required on the product drawing, plating in internal threaded holes is acceptable. In either case, the threads shall meet the dimensional limits given in Handbook H28 for the class of fit specified.

7. METAL HEAT TREATMENT REQUIREMENTS

M 7.1. (Applicable to Production Agencies Only)

E When necessary to facilitate fabrication, parts made from heat-treatable alloys for which material is specified in terms of the final temper or condition required may be fabricated from raw stock of a temper or condition different from the final temper and then heat-treated to the specified temper or condition.

7.2. In-process heat treatment shall conform to the requirements of the applicable heat treatment process standards or specifications.

7.3. After the completion of in-process heat-treatment, sample parts from each heat-treat lot shall be tested to determine that the material properties influenced by heat-treatment do conform to the applicable Material Standard or Specification requirements. If tests of actual parts are impractical, suitable samples of the same alloy and starting condition as the parts shall be heat-treated with the lot and tested for conformance to the applicable requirements.

7.4. Parts specified to be made from work-hardened temper of non-heat treatable alloys must be fabricated from material of the required temper or condition.

M 7.5. (Applicable to Sandia Corporation and BKC procurement only)

Thermal treatments such as hot forming, stress-relieving, drying, bonding and baking, other than those specifically permitted by the product drawings, shall not be used.

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8. IDENTIFICATION MARKING

8.1. Product Identification

When the size and/or spacing of identification marking is specified without a tolerance, the markings shall be approximately as specified. Regardless of their actual size the markings shall be complete and entirely legible.

8.2. "In-Process" Marking

"In-process" markings may be visible at the time of acceptance of a part or assembly provided the marking will not cause confusion with any specified marking nor degrade the functional properties.

9. REQUIREMENTS FOR PROTECTION AND IDENTIFICATION OF RAW MATERIAL, PARTS AND ASSEMBLIES

- 9.1. All parts and assemblies shall be protected from accumulation of foreign matter, corrosion, physical damage or deterioration. This requirement shall apply to all manufacturing operations from receipt of raw material to completion of a finished product, to products held in any storage area and to products prepared for shipment.

- 9.1.1. Protective measures used during processing, fabricating and packaging must not only guard against obvious damage and deterioration but also against the creation of latent conditions that may later cause unsatisfactory performance, accelerated deterioration, or malfunction.

9.1.2. Raw Material and Parts

Raw material and parts at all levels of production shall be kept adequately segregated and identified at all times. Parts shall be transported in a manner which will assure adequate protection from damage.

9.1.3. Stock Room

All items such as raw material, parts, subassemblies, assemblies, tools, etc. not in immediate use, shall be adequately packaged, identified and when feasible, catalogued and neatly stored.

9.2. Cleanup of Parts and Assemblies

All finished parts and subassemblies shall be adequately cleaned before final assembly. Final assembly and necessary subassembly shall be performed in an environment appropriate to the type of product. All parts and assemblies shall be thoroughly cleaned to remove foreign and manufacturing waste material such as

Superfluous hardware, wire and insulation clippings.

Chips, filings, abrasives, machining lubricants.

Soldering, brazing and welding fluxes, solder droppings, weld spatter, slag and welding rod ends.

Drippings of lubricants, adhesives and sealing compounds.

Paint droppings, splatter and overspray.

Residues from liquid baths used in plating and chemical treatments.

Temporary tags and packaging.

9.3. Packaging of Parts with Metallic Coatings

- 9.3.1. Parts plated with silver or gold over silver shall be free from human handling residues and packaged in a manner that will prevent mechanical damage and tarnishing. Packaging adjacent to the parts shall provide a positive barrier between the plated surfaces and tarnish-producing atmospheres and materials. However, semi-permeable films such as polyethylene may be used for the barrier material if an inner layer of tarnish-inhibiting paper is used to completely cover the part surfaces. Tarnish producing materials, including rubber, paper products not treated with tarnish-inhibiting chemicals and pressure-sensitive tape, shall not be placed inside the barrier.

- 9.3.2. Tin and tin-lead coated parts intended for subsequent soldering shall be packaged in a manner that will provide a positive barrier between the part surfaces and oxidizing atmospheres and materials. This requirement does not apply to tinned wire leads on transformers, resistors, etc.

- 9.3.3. Parts having other metallic coatings shall be protected by suitable packaging that will prevent contamination, deterioration and mechanical damage.

9.4. Care and Handling of Electron Tubes

- 9.4.1. Where possible, tubes shall be kept in the cartons or packages in which they were received from the tube manufacturer. When removed from its packaging, each tube shall be protected from contact with other tubes, parts, tools and other items that might damage its glass surfaces.

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- 9.4.1.1. All tubes and the trays, cartons, benches and equipment where tubes are to be stored, used or inspected shall be kept free of grit and abrasive materials.
- 9.4.1.2. Pliers or any other tool that might scratch or abrade tube surfaces shall not be used to aid the installation of tubes into sockets or clamps.
- 9.4.1.3. The glass surfaces of tubes shall be free from evidence of scratches, abrasion and similar damage that is visible without magnification. Immediately prior to installation, each tube shall be inspected for the presence of these defects.
- 9.4.2. Any tube that has been dropped or otherwise subjected to unusual impact shall either be rejected or retested for conformance to all applicable electrical property requirements.
- 9.4.3. Any tube that has been operated electrically with its elements improperly connected because of faulty indexing of tube pins at installation, incorrect test equipment settings, circuit wiring errors, or similar causes shall be rejected.
- ⑨ 9.4.4. The pins of all miniature tubes shall be visually inspected immediately before installation of the tube. If the pins are severely bent, the tube shall be rejected. A pin straightener shall be used on all tubes that are not rejected in this inspection (installation of the tube into the straightener at three positions, spaced 90 degrees apart, is required).
- Tubes with pins that are pitted, scratched, or otherwise damaged so as to reduce the diameter more than 25 percent shall be rejected.

10. DRAWING SYMBOLS AND ABBREVIATIONS

- 10.1. The following standards apply to drawing symbols and abbreviations used on drawings and are to be interpreted in accordance with their instructions.
- 10.1.1. Knurling
- ASA Standard B5.30 Knurling
- Note - When depressed knurling is specified, the knurling shall be produced by a single male (raised-point) diamond pattern knurl that will produce a female (depressed point) pattern on the work. Depressed knurling is the reverse of conventional raised-point knurling and requires special knurls.
- 10.1.2. Welding
- JAN-STD-19, Welding Symbols
MIL-STD-20, Welding Terms and Definitions
- 10.1.3. Electronic Symbols
- MIL-STD-15, Electrical and Electronic Symbols
- 10.1.4. Abbreviations
- MIL-STD-12, Abbreviations for Use on Drawings and in Technical Type Publications
- 10.1.5. Screw Threads
- MIL-STD-9, Screw Thread Conventions and Methods of Specifying

11. TOLERANCES AND MEASUREMENTS

- 11.1. Tolerances
- 11.1.1. Absolute Tolerances

Tolerances expressed on drawings and specifications are absolute values. The term "absolute" means that the intent of the tolerances is that the true values of characteristics, not merely the measured values, shall be within the tolerances stated.

An acceptable degree of conformance of product to the intent of absolute tolerances is required. To judge the degree of conformance, consideration shall be given to the inherent measurement uncertainty in relation to the specified tolerances. Information concerning production process distribution (both centering and dispersion), if available, may also be used in determining conformance.

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11.1.2. Measurement Limits (When Measuring System is Specified)

When the method and/or accuracy of measurement or the measurement equipment are specified by the product requirements, adequate allowance for measurement uncertainty has been made in establishing the measurement limits. Specified measurement equipment may include equipment such as universal measuring machines and will not be limited to gages designed for particular parts. In such cases a part will be considered conforming to design intent if the measurement is within the specified limits. The absolute tolerance requirement of 11.1.1 does not apply under these conditions.

- 11.1.3. In comparing measured (observed) values with the stated tolerances, it is not permissible, in order to reflect conformance, to round the digit in the decimal place one place beyond the last place in the stated tolerance.

11.2. Measurement Temperatures

11.2.1. Mechanical

Mechanical dimensions of all materials are specified at a temperature of 68°F (20°C). If referee measurements are required, the measurement shall be made at 68°F (20°C), or adjusted to 68°F (20°C) to account for differences in thermal expansion or contraction in the material of the gage and/or parts. The tolerance on the 68°F temperature is controlled by the degree of accuracy required for the measurement being made.

11.2.2. Electrical Measuring

When the temperature for an electrical measurement for a product is not specified, the required product value is normally considered to be based on a measurement taken at a nominal temperature of 23°C. Electrical measuring instruments and standards are normally calibrated at a temperature of 23°C. There are certain exceptions to this norm, e.g. standard resistors usually are calibrated at 25°C.

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If measurements are not taken at the above temperatures an appropriate correction should be made to adjust the calibrated values to the use temperature. Where available data indicates such compensations cannot be made, it may be necessary to move the product and measuring instruments and/or standards into a suitable environment.

11.3. Measuring Instrument Calibration

- 11.3.1. The accuracy of the measuring instruments, gages and testers used for inspection and testing of products shall be maintained by frequent checking or recalibration.

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- 11.3.2. All measuring instruments, gages and testers furnished by the Design Agency or furnished by the Production Agency to a supplier shall be checked and calibrated in accordance with their accompanying procedures.

- 11.3.3. Adequate calibration records shall be maintained for all measuring instruments, gages and testers used by Suppliers and their sub-contractors. These records shall be available for inspection by the Production Agency.

12. USE AND INTERPRETATION OF SPECIFICATIONS AND STANDARDS

12.1. Effective Issue of Specifications and Standards

When the issue of a Federal, Military, or Society specification or standard is not specified in the product documentation, the issue used shall be the one in effect on the date of invitation for bids or any later issue.

12.2. Replacement Specifications and Standards

12.2.1. Federal, Military, and Society Specifications

When a specification or standard is cancelled, or obsoleted, automatic use of a replacement document(s) is not permissible. Utilization of any replacement document shall occur only through change in product documentation.

12.2.2. Design Agency and/or Production Agency Specifications and Standards

Design Agency and/or Production Agency specifications and standards that have been inactivated for new design or for new applications shall be adhered to until the product documentation is changed.

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12.3. Paragraph References

When any requirement includes reference to a specification paragraph number, all numbered paragraphs subordinate to the referenced number also shall apply.

Example	Referenced Paragraph =	3.
		3.1
		3.2
	Also Applicable =	3.2.1
		3.2.2
		3.3
		etc.

12.4. Raw Materials

12.4.1. Acceptance Requirements

Raw (stock) materials shall be inspected and tested at least once in accordance with the applicable material standards or specifications. Testing of raw material shall be performed by a capable laboratory operated by the buyer, the supplier, the material manufacturer or by an independent laboratory found capable by any of the above. When the tests are performed by other than the buyer, the required data shall accompany the material. When acceptance data are required from the supplier, the buyer shall so specify in his purchase order. The material shall be accepted when the buyer determines that the data show conformance of the material to the requirements. If acceptance testing has been done by a laboratory other than the buyer or an AEC integrated contractor laboratory, the validity of the data supplied shall be periodically verified by tests performed by the buyer or by a different laboratory selected by the buyer. Verification data may be exchanged among AEC integrated contractors. Submittal of certification to the Design Agency is required only if specifically requested.

12.4.2. Supplier Certification for Parts and Assemblies

12.4.2.1. (Applicable to BKC Only)

Each shipment of parts and assemblies to Bendix shall be accompanied by a certification signed by a responsible member of the Supplier's organization. The certification shall state that all raw (stock) material used in the production of the parts or assemblies was inspected and tested in accordance with the applicable material standards and found to conform to them.

12.4.2.2. (Applicable to BKC Only)

The certifications for parts, but not assemblies, shall include the following when applicable, the identification number of all batches of thermosetting molding compounds used in the parts, the identification number of all batches of rubber used in the parts and the quantitative inspection and test data for each batch that is required by the applicable material standard. When rubber parts, but not assemblies that include rubber parts are furnished directly to a Buyer, the rubber part manufacturer also shall furnish Bendix the test slabs and buttons required by the applicable material standard.

12.4.3. Material Procurement (Applicable to BKC Only)

Raw (stock) material may be purchased to the Government, ASTM, AMS, or other published or proprietary specifications referenced in the material standard without reference to the applicable material standard in the purchase order, but shall be inspected and tested in accordance with the applicable material standard and shall conform to its requirements.

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13. DESIGN AGENCY - SUPPLIER COMMUNICATIONS

All communications between the Design Agency and the Supplier shall be through the Production Agency.

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ALBUQUERQUE DIVISION
ACF INDUSTRIES
INCORPORATED
 ALBUQUERQUE, NEW MEXICO
MANUFACTURING PROCEDURE

1. SCOPE

- 1.1 This process specification covers a method of cleaning ferrous and non-ferrous alloys for general dirt and soil removal.

2. APPLICABLE REFERENCES

- 2.1 Electroplating Engineering Handbook, by A. K. Graham.
 2.2 Protective Coatings for Metals, by Burns & Bradley.

3. MATERIALS AND EQUIPMENT

- 3.1 Two tanks, 2200-gallon operating capacity.
 3.2 Turco Aviation Cleaner or equivalent non-etching alkaline cleaner for reactive metals.
 3.3 Miscellaneous hooks and racks for holding parts.
 3.4 Untreated water.
 3.5 Clean, compressed air.

4. PROCEDURE

- 4.1 Parts to be cleaned are placed in hooks or racks and suspended in hot cleaner solution from 5-15 minutes or until soils and dirt have been satisfactorily removed.
 4.2 Some mechanical scrubbing of the parts may be necessary in the case of stubborn soils.
 4.3 Parts are transferred as quickly as possible into water rinse. Agitate in this water rinse until all cleaner solution is removed from parts.

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		PREPARED			
ACF	REV.			DATE	TITLE GENERAL CLEANING OF FERROUS AND NON- FERROUS ALLOYS NUMBER 6-000012-B ISSUE B
				12/7/60	
				4/20/65	
		APPROVED	CHD	4/12	
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		APPROVED	WLB	451	
		APPROVED	WLB	542	
		APPROVED			
		APPROVED			
		RELEASED	WLB	542	

- 4.4 Remove parts from rinse tank and allow to air-dry or dry with stream of clean, compressed air.

5. GENERAL INSTRUCTIONS

- 5.1 The soils encountered in general manufacturing processes are many and varied. The cleaner used in this process is a mild, alkaline type which will do no harm to reactive metals such as aluminum and magnesium. Therefore, some stubborn dirt may require longer immersion time and some mechanical scrubbing.
- 5.2 It is not the intent of this process to produce a "chemically clean" surface. This is for general purposes only.
- 5.3 The analysis and control of this solution is the responsibility of the Chemical Engineering Section. No changes in conditions, materials, or concentrations are to be made without the approval of this section.

6. SOLUTION MAINTENANCE AND CONTROL

6.1 Alkaline Cleaner

Material: Turco Aviation, or equivalent.
 Concentration: 6 oz./gal.
 Temperature: 170° F - 180° F.

- 6.1.1 To make up new solution, fill tank 3/4 full with warm water. Add 750 lbs. Turco Aviation Cleaner, slowly with agitation. Fill tank to operating level and agitate to assure complete mixing. Adjust temperature.

6.2 Water Rinse

- 6.2.1 Free-running tap water, amount of flow to be determined by need.

7. SAFETY

- 7.1 The material used in this process is caustic in nature. Contact with skin and clothing should be avoided as much as possible. In case of contact, flush with copious amounts of water. Get medical attention if necessary.

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GENERAL CLEANING OF FERROUS AND
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