SERIAL NO. 27

PHASE I AND II REPORT

RESEARCH AND DEVELOPMENT
FOR
FABRICATING
A
SIMULATED TITANIUM ALLOY Y-RING SEGMENT
FOR THE
S-IC FUEL TANK

PREPARED FOR
GEORGE C. MARSHALL SPACE FLIGHT CENTER
HUNTSVILLE, ALABAMA 35812
CONTRACT NO. NAS8-20533

(30 June 1965 To February 11, 1966)

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FOREWORD

This report covers the work performed by North American Aviation, Los Angeles Division in Phases I and II of NASA Contract NAS8-20533 (Control No. 1-5-30-12546 IF). The purpose of this program is to perform Research and Development for the Fabrication of a Titanium Y-Ring Segment.

This 12-1/2 month contract is sponsored by the Manufacturing Engineering Laboratory (R-ME-1S) of the George C. Marshall Space Flight Center. The program is under the technical direction of Mr. Paul H. Schurer, Technical Program Manager and Mr. Carl Colley, Design Technical Manager. The Program Manager and Project Manager for North American Aviation, Inc., is Mr. Joseph Melill and Mr. Carl J. Muser, respectively. Others who participated in the program and the preparation of this report are: T. E. DeWitt Project Engineer; P. Miskulin and R. Brunken, Diffusion Bonding, R. Rohrberg and D. Harvey, Process Support Tool Design; L. Ecker, Machining; F, Koeller and J. Teeter, Forming; L. Fanelli, Leaching and Chemical Milling, J. Greenspan, G. Keller and J. Riordan, Metallurgy; and Wilson Kearns and K. McDonald, Manufacturing; and F. Janney, C. Phillips and J. Russell, Quality Control.

The studies described in this report were conducted during the period 30 June 1965 and 11 February 1966 and covers Phases I and II of the program

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INTRODUCTION

Space vehicle boosters, like aircraft, are projected into new roles and missions demanding increased performance over the original requirements. Simultaneously, the advances in structural design, state-of-the-art, and materials development are also progressing. It, therefore, becomes necessary to assess these advances and apply them to the benefit of improved systems. Since the Saturn V program was initiated, there have evolved more efficient titanium alloys and new manufacturing techniques. Both of these can advantageously contribute to future programs.

Recently developed titanium alloys such as Ti-8Al-1Mo-1V have been found to possess a unique combination of properties previously not available in a single material. The characteristics of high strength, high toughness, and high modulus of elasticity together with low density, good formability and no loss in strength due to welding have caused design and producibility engineers to strongly consider this new material in place of current more conventional materials. The immediate advantages to be gained are apparent as the ability to design a more efficient, lighter weight structure that can be produced easier and more reliably in the manufacture of hardware.

Within the last six years, studies of solid state diffusion bonding of titanium alloys, have demonstrated that the material can be readily joined by this process, and that joint strengths achieved are equivalent to the parent metal strength with no degradation in toughness as normally associated with welding. This capability leads to the development of a number of methods for diffusion bonding. One of these, the roll bonding process lends itself particularly well to producing long narrow complex shapes in sizes and gages that cannot be produced other than by hogging out from solid materials, which is wasteful of material and very expensive.

One area where these advances can contribute to improved structural efficiency is the Y-Ring that joins the S-IC fuel tank bulkhead to the tank wall. Since the tank wall also acts as a thrust structure to the upper stages, the structural and weight contribution of the Y-Ring to the total system weight is considerable. The prime objective of this program is to combine the advantages of titanium 8Al-1Mo-1V and the advanced manufacturing methods of roll diffusion bonding with modern design concepts to produce an improved Y-Ring. To this end, this program will extend the state-of-the-art of diffusion bonding, forming, and machining of high-strength titanium alloy, and develop the necessary process parameters and design requirements to fabricate two full scale Y-Ring segments. The result will be a reduced weight titanium Y-Ring with increased reliability.

SUMMARY

Phases I and II of a four phase program to perform a research and development program for the development of a Titanium Y-Ring Segment is reported herein and summarized below. This program is to establish design requirements and process parameters for fabricating a simulated Y-Ring Segment, for the S-IC Fuel Tank, from 8Al-1Mo-1V titanium alloy material. The program is to develop a processing technique capable of producing large reduced weight titanium components with increased reliability which can be incorporated into space flight vehicles and extend the state-of-the-art of diffusion bonding, forming and machining high strength titanium alloys.

1 PHASE I - DESIGN AND PROCESS DEVELOPMENT

a. The design for a titanium (8Al-1Mo-1V) head-cylinder attachment member to be fabricated by the roll diffusion bonding process and developed machining techniques has been established and is shown on NAA Drawing 2623-005 (Figure 1).

b. Processing techniques, including diffusion bonding, machining, chemical milling, hot forming, thermal treatment and other related processes, required for fabricating the full scale Y-Ring segments have been developed using sub-scale test components. A complete evaluation of these test components has been made including dimensional evaluation metallographic analysis, physical and mechanical property determinations and non-destructive inspection.

c. Design drawings for all tooling required to fabricate the full-scale Y-Ring segments have been prepared and are shown on NAA Drawing 2623-201 and 2623-202. These designs reflect the pertinent conducted on the sub-scale test components.

2. PHASE II - TOOLING AND FABRICATION PLAN

a. A detailed fabrication plan for the fabrication of two full-scale Y-Ring segments has been prepared and reported in NAA Report 66-87. This plan includes, in detail, the planned inspection and test evaluation programs.

b. Tooling required for the fabrication and inspection of the full-scale Y-Ring segments is being fabricated.

PHASE I

DESIGN

ESTABLISHMENT OF DESIGN

In Phase I, a design for a titanium (8Al-1Mo-1V) head-cylinder-skirt attachment member utilizing roll diffusion bonding and optimized machining techniques was established. This design is shown on NAA Drawing No. 2623-005, Figure 1. This design meets all the requirements of the 2219 aluminum alloy S-1C fuel tank Y-Ring shown on Drawing 60B24290, dated 4/28/64.

DESIGN OF TITANIUM Y-RING

The loading conditions used in the design analysis were furnished by NASA and are shown in Table I. The rebound condition at Station 362 was found to be critical. Additional design criteria which was furnished by NASA are tabulated as follows: (1) Ultimate design pressure equals 1.4 x maximum total pressure. (2) Hydrostatic test pressure is 39.30 psig at Station 698 and 51.44 psig at Station 362. Pressures at points between these stations vary linearly with the distance from the stations. (3) Yield pressure is 105% of hydrostatic test pressure. (4) Yield factor of safety equals 1.1 and ultimate factor of safety equals 1.4, and (5) A 0.280 inch titanium dome thickness adjacent to the Y-Ring.

DESIGN ANALYSIS

During the preliminary design phase six design concepts were proposed for Y-Ring fittings. These concepts used three stiffening methods for the tank wall. These were with stiffeners on the inside of the skin, stiffeners on the outside of the skin and stiffeners on both sides of the skin. These concepts have a potential weight savings of 14% to 42% and are shown in NAA Report 65-582 (Reference a). NASA recommended that the internal stiffening method be used.

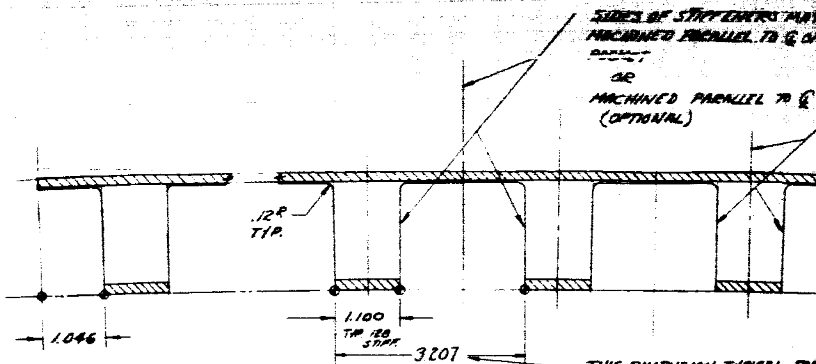
Three variations of internal stiffened Y-Rings were proposed on NAA Drawing 2623-003. Concept "A" with the longitudinal stiffening is structurally the most efficient. However, the producibility of this concept is the least reliable of the three for roll diffusion bonding. Very likely Concept "A" would be machined from a large rolled billet and would be subject to machining limitations similar to the present aluminum Y-Ring. Such a machined fitting would be heavier than Concepts "B" or "C". Both Concepts "B" or "C" are very suitable for roll diffusion bonding. Concept "C" was chosen because it would be more economical to produce and the weight difference is negligible between Concepts "B" and "C". This resulted in the titanium alloy Y-Ring design shown in NAA Drawing 2623-004 (Reference c).

The final Y-Ring design configuration, NAA Drawing 2623-005 (Figure 1), considered various producibility factors relative to the diffusion bonding. Consideration was given to such economic factors as the quantities and sizes of titanium or steel initially required in the layup for making a specific Y-Ring configuration. The structural analysis of the chosen Y-Ring design is given in the following paragraphs.

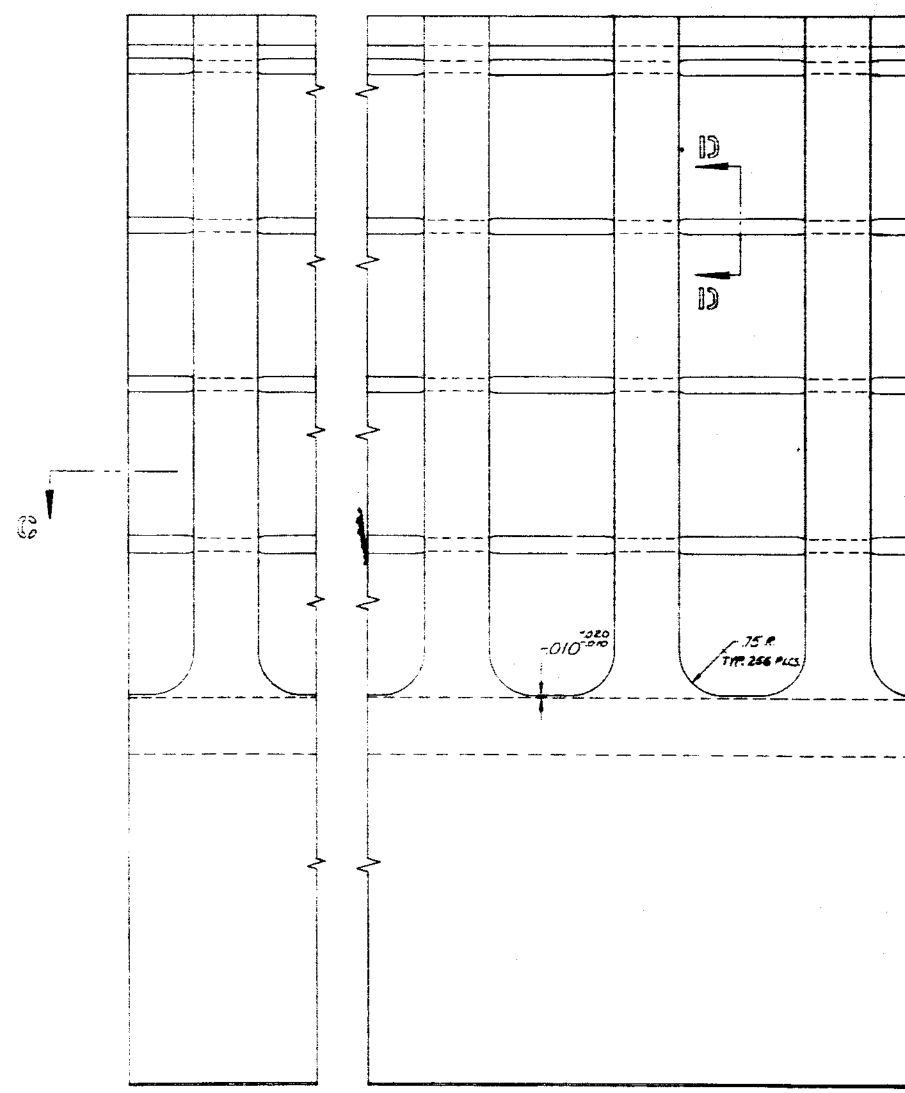
TABLE I

LOADS AND PRESSURES FOR TITANIUM S-IC FUEL TANK

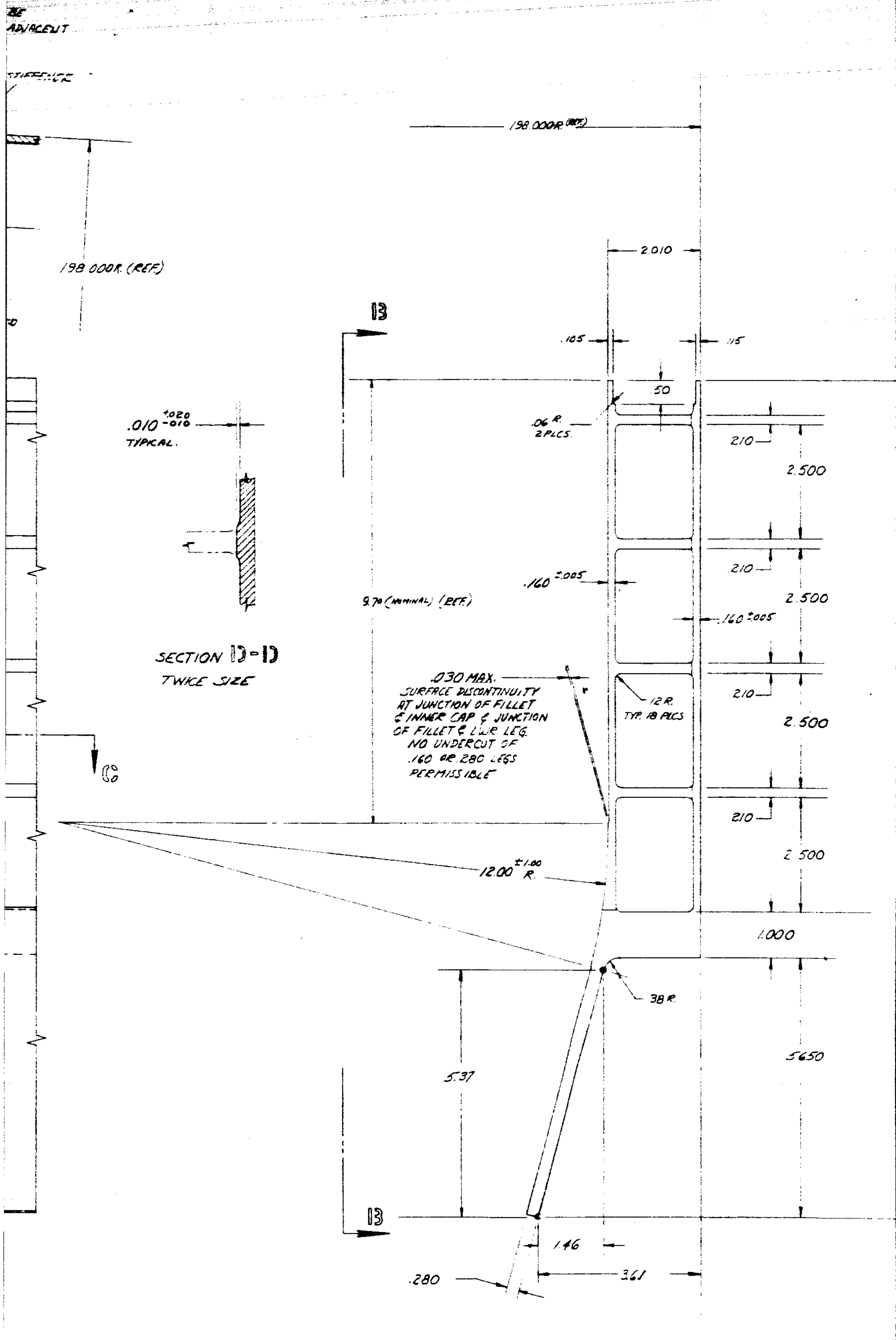
Condition	Sta	Ullage Psig		N_c Ultimate #/in		M x 10 -6 in-#	Pressure Total Psig	
		Fwd	Aft	Fwd	Aft		MAX	MIN
Ground	362	0	0	10540	12230	381	—	—
Wind	698	0	0	9840	10030	351		
Rebound	362	23	0	8290	12500	243	46.8	38.8
	698	0	23	9970	7940	212	34.36	26.36
Q Max	362	24.6	0	8690	12770	181	40.45	34.05
	698	0	24.6	12370	10430	337	31.0	24.6
αQ Max	362	23.3	0	8750	12790	195	41.4	33.65
	698	0	23.3	12340	10550	352	31.0	23.3
Cutoff	362	26.5	0	7840	10650	0	31.0	26.5
	698	0	26.5	9450	7840	0	31.0	26.5



SECTION C-C
FULL SIZE



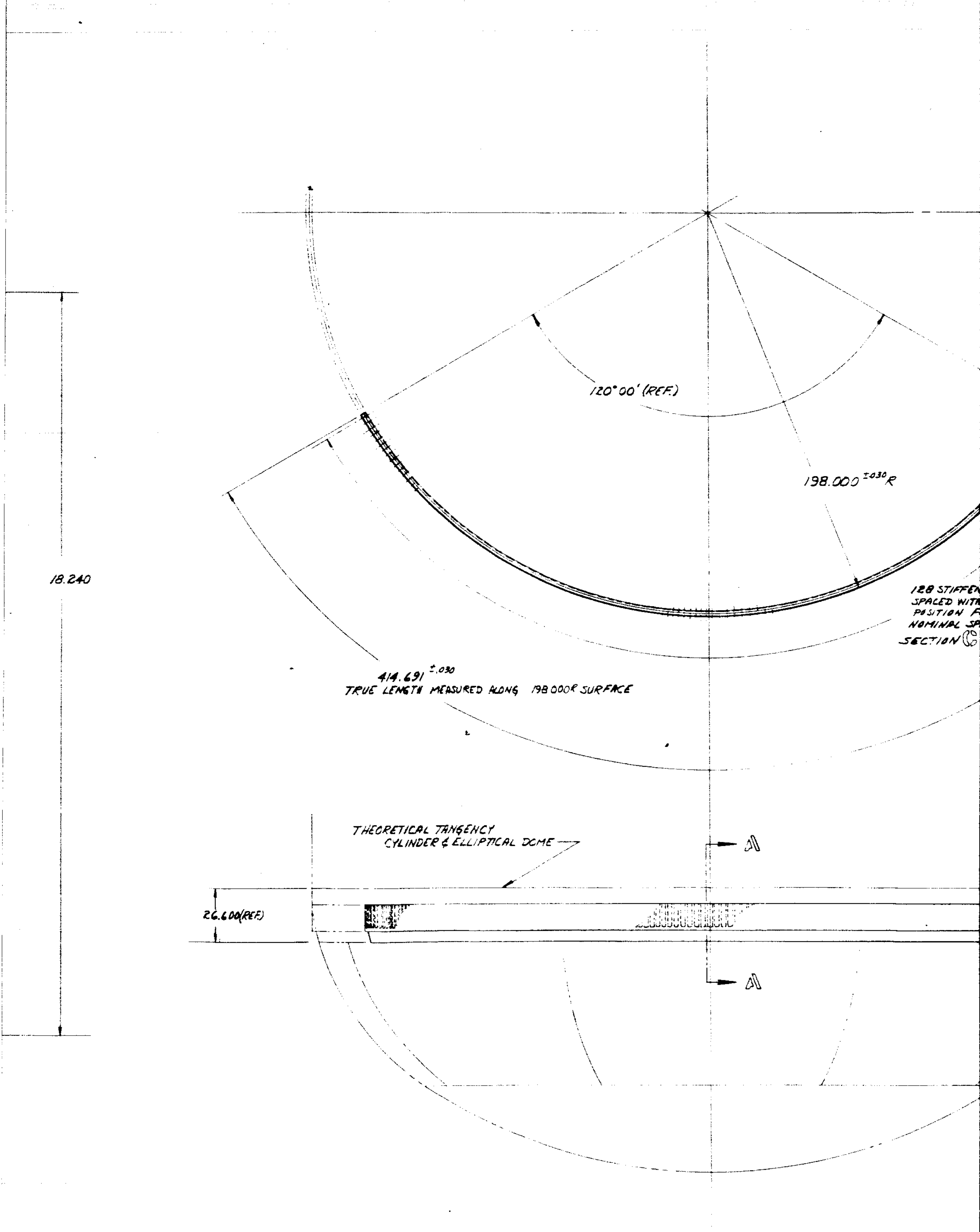
VIEW B-B
FULL SIZE



SECTION A-A

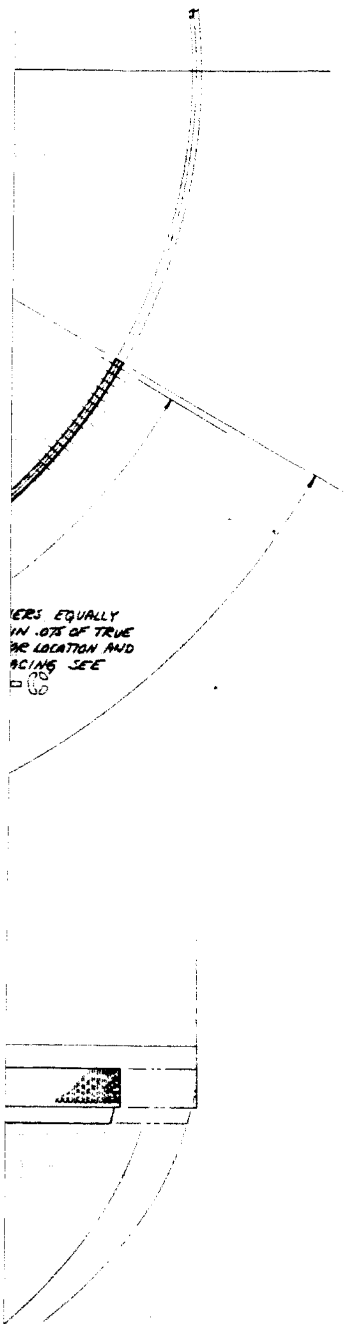
FULL SIZE

5-2


120°00' (REF.)
198.000 ±.030 R
18.240
414.691 ±.030
TRUE LENGTH MEASURED ALONG 198.000R SURFACE
THEORETICAL TANGENCY
CYLINDER & ELLIPTICAL DOME
26.600(REF.)
A
A

REVISIONS

SYM	DESCRIPTION	DATE



MATERIAL ALL ELEMENTS 6AL-4V-1MO TITANIUM ALLOY
COND. A

HEAT TREAT TO COND DA
PER NAA SPEC LA0111-028

FIGURE 1

6. ALL MACHINED SURFACES
5. MACHINED FILLET RADII .062
4. CHEM MILL PER SPEC LA0103-003
3. MACHINE PER SPEC LA0103-004
2. INSPECT PER SPEC MIL-I-6870 (LA0501-007)
1. DIMENSIONS ARE IN INCHES
TOLERANCE ON DIMENSIONS. DECIMALS. 2 PLACE (.XX) ±.03
3 PLACE (.XXX) ±.010

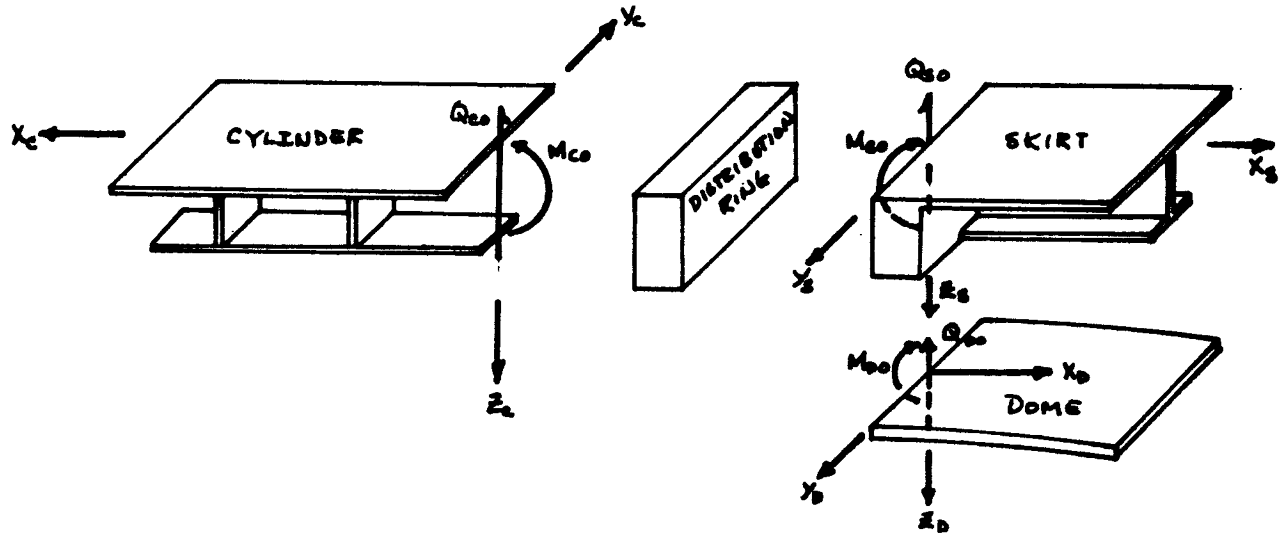
NOTES (UNLESS OTHERWISE NOTED)

1/20	11-15-65	NORTH AMERICAN AVIATION, INC. INTERNATIONAL AIRPORT LOS ANGELES 45, CALIFORNIA
"Y" RING SEGMENT - ROLL DIFFUSION BOND TITANIUM S-IC		2623-005

Structural Analysis of Y-Ring

I. Redundant Analysis

In order to analyze the various designs, an IBM program was written to determine the redundant loads at the intersection of the cylinder, elliptical dome and skirt. The sketches below show the basic elements used for the redundant analysis.



This analysis determines the redundant loads by satisfying the equilibrium equations and compatibility equations at the common juncture.

Equilibrium equations

$$Q_{CO} + Q_{SO} + Q_{DO} = 0$$

$$M_{CO} - M_{SO} - M_{DO} = 0$$

Compatibility equations

$$w_{CO} = w_{SO} = w_{DO}$$

$$\frac{dw_c(o)}{dx_c} = -\frac{dw_s(o)}{dx_s} = -\frac{dw_D(o)}{dx_D}$$

The deflections, w, and slopes, $\frac{dw}{dx}$, are related to the shears, Q, and moments, M, by the following equations:

Semi-infinite cylinder under internal pressure, p, which is used for both the cylinder and skirt

$$w_o = -\frac{pa^2}{Eh} + \frac{-1}{2\beta^3(EI)_x}(\beta M_o + Q_o)$$

$$\frac{dw(o)}{dx} = \frac{1}{2\beta^2(EI)_x}(2\beta M_o + Q_o)$$

$$\beta = \left[\frac{(Eh)_y}{4a^2 (EI)_x} \right]^{1/4}$$

Elliptical dome under internal pressure

$$\omega_o = -\frac{\mu p a^2}{Eh} + \frac{2\lambda}{Eh}(\lambda M_o + a Q_o)$$

$$\frac{d\omega(o)}{dx} = -\frac{2\lambda^2}{Eha}(2\lambda M_o + a Q_o)$$

$$\lambda = \left[3(1-\mu^2)\frac{a^2}{h^2} \right]^{1/4}$$

where the signs are determined by the reference systems for the cylinder and the dome respectively.

The redundant loads determined above were then superposed on the static loads and the stresses and deformations were found at critical points on the structure. The structure was then analyzed by the conventional methods of comparing the stresses with the pertinent general and local instability allowables corresponding to the design concept being studied. This was done for each design concept. The above analysis makes the following assumptions:

(1) The redundants based on semi-infinite, constant-section cylinders and a constant-section dome are considered valid for the variable geometry structure which we actually have.

(2) The deformations of the distribution ring is negligible.

(3) The extensional stiffness in the hoop direction is only a function of the skin gage while the bending rigidity in the longitudinal direction is a function of the total cross-section.

(4) The deflections are small and thus superposition is valid.

II. Strength Check

Configuration "A" of Dwg. 2623-003

1. The basic structure was compared with general instability allowables.

2. The skin was checked for general instability and ultimate failure. The ultimate failure criteria used was to assume that the Mohr's Circle for the loading could not exceed the envelope of the Mohr's Circle for Ftu, Fsu, and the tangent lines drawn between these two. Von Mises' hypothesis that the plastic strain is a function of the octohedral shear stress

$$\tau_{oct.} = K(\sigma_x^2 - \sigma_x \sigma_y + \sigma_y^2)^{1/2}$$

is used to determine the plasticity correction for combined loading.

3. The webs and inner skin were analyzed as a Vierendeel truss using the results of the redundant analysis to determine the external loading. The shear load in each vertical member was found by determining the shear flow due to the redundant analysis. The resultant shear and bending stresses were then compared with their allowables. Since the webs form the stabilizing structure for the inner and outer skins, their axial flexibility was then checked to ensure that they are adequate to give simple support to the facing sheets. The nature of this type of support is such that the outer skin can not attain the support required for panel action and thus must be analyzed as a column. The inner skin was also checked as a column.

NOTE:

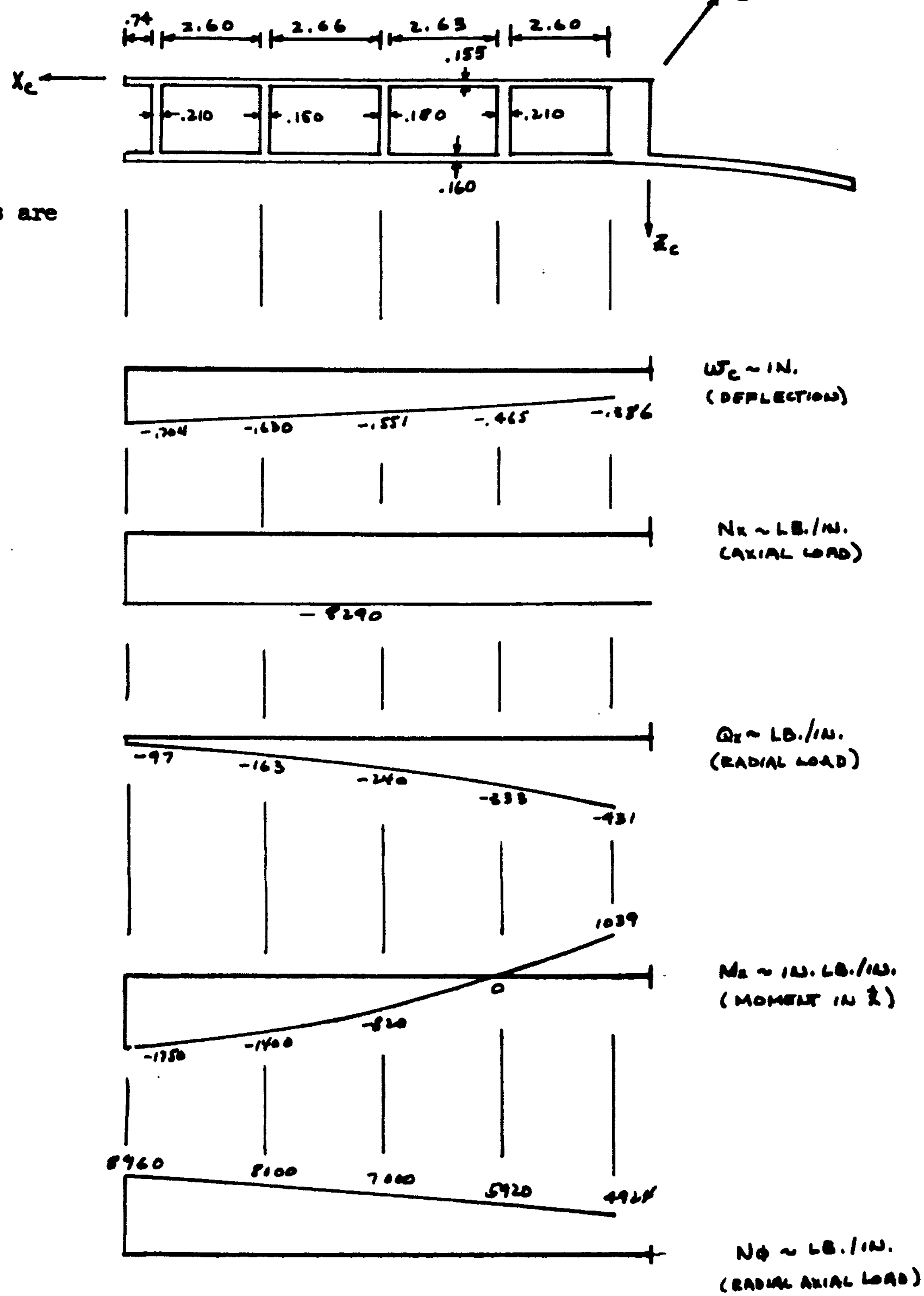
(1) The final structure differed from the structure analyzed below in that:

(1) Distance between webs is 2.50 inches rather than 2.60 or 2.63 inches.
(2) Web thickness is .210 rather than .150, .180 and .210.

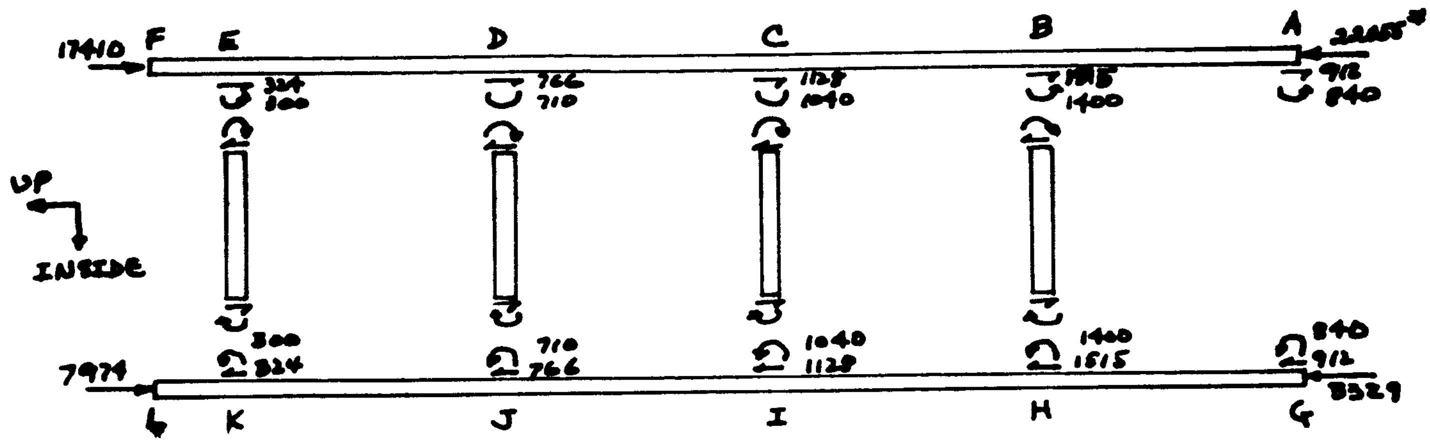
This was done to facilitate fabrication and since this renders our structural analysis somewhat conservative, no further calculations were required.

III. Detail Analysis for Final Design

All loads are ultimate



Based on these loads and deformations the internal loads on each individual component are shown below. These loads represent a 3.062" unit width in the circumferential direction.



Check webs for rigidity to give skins simple support for column loading (Ref. NASA TN D-162)

$$K_{REQ'D} = \frac{2\pi^3 s\ b_i D_i}{a_i^3} \qquad i = c, f$$

$$K_{ACT} = \frac{b_w h_w E}{a_w}$$

Where: Kreq'd and Kact are the required and actual spring constants for the web respectively

hi, ai, and bi are the thickness, length and width of the ith member

i can represent c, w or f which are the outer skin, web and inner cap respectively.

$s = \left(\frac{Dc}{Dt}\right)^{1/2}$ where Dc and Dt are the flexural rigidity of the compression and tension member were the structure to be placed under a bending load.

For the outer skin

$$D_c = \frac{E h_c^3}{12(1-\mu^2)} = \frac{18\times10^6 \times .155^3}{12(1-.3^2)} = 6138 \text{ Lb. in}^2/\text{in.}$$

$$D_T = \frac{1}{3.062}\frac{E h_f^3}{12(1-\mu^2)} = \frac{18\times10^6 \times .160^3}{3.062\times12\times.91} = 2205 \text{ Lb. in}^2/\text{in.}$$

$$S = \left(\frac{D_c}{D_T}\right)^{1/2} = \left(\frac{6138}{2205}\right)^{1/2} = 1.67$$

$$K_{REQ'D} = \frac{2\pi^3 \times 1.67 \times 3.062 \times 6138}{2.81^3} = 87700 \text{ Lb./in.}$$

$$K_{ACT.} = \frac{1\times.150\times18\times10^6}{1.843} = 1465000 \text{ Lb./in.}$$

Thus it can be seen that based on these flexibilities (axial only) the web is more than adequate to support the face sheets. Now checking the web (BH) for shear

$f_s = \frac{3}{2}\frac{V}{A} = \frac{3}{2} \times \frac{1515}{.210} = 10800$ PSI

Fsu = 90000 psi M.S. = HIGH

Check web (BH) for bending

$f_b = \frac{6M}{bh^2} = \frac{6 \times 1400}{1 \times .210^2} = 190500$ PSI

$F_{bc} \cong 1.5 \times F_{ty} = 202500$ PSI M.S. = .06

Check outer skin (AB) for column stress

$\sigma_x = \frac{P}{A} = \frac{22055-912}{3.062 \times .155} = 44500$ PSI (COMP.)

$\sigma_\phi = \frac{N_\phi}{h_c} = \frac{5920}{.155} = 38200$ PSI (TENS.)

$\gamma = \frac{\sigma_\phi}{\sigma_x} = -.858$ $\gamma_i = \sqrt{1-\gamma+\gamma^2} = 1.61$

$\frac{F_{co}}{\eta} = \frac{\pi^2 E}{(L/\rho)^2} = \frac{\pi^2 \times 18 \times 10^6}{\left(\frac{2.81}{.289 \times .155}\right)^2} = 45200$ PSI

$\frac{F_{co}}{\eta}\gamma_i = 72800$ PSI

$F_{co}\gamma_i = 72800$ PSI

$F_{co} = 45200$ PSI M.S. = .02

Check inner skin (KJ) for column stress

$\sigma_x = \frac{7974-324}{1 \times .160} = 47800$ PSI

$\frac{F_{co}}{\eta} = \frac{\pi^2 \times 18 \times 10^6}{\left(\frac{2.81}{.289 \times .160}\right)^2} = 48100$ PSI

$F_{co} = 48100$ PSI M.S. = .01

COMPARATIVE WEIGHT ANALYSIS (TITANIUM VS ALUMINUM)

A weight comparison was made between the aluminum Y-Ring design shown on NASA Drawing 60B2490 dated 4/28/64 and the titanium Y-Ring shown on NAA Drawing 2623-005.

The weight of the titanium 8Al-1Mo-1V Y-Ring was calculated to be 1,412 pounds for the complete circular ring section. The weight of the aluminum 2219 Y-Ring was read as 2,430 pounds.

The width of the two Y-Rings is not the same. For a constant size fuel tank an adjustment was made in the weight of the shorter titanium Y-Ring. The added weight represents the slightly longer cylindrical skin section. The weight comparison is shown in the table below.

WEIGHT COMPARISON

Y-RING	DWG.	WIDTH	WEIGHT	ADJUSTMENT	COMPARABLE WEIGHT	
					COMPLETE RING	ONE SEGMENT
Aluminum	60B24290	23.6"	2430 pounds	0	2430 pounds	810 pounds
Titanium	2623-005	18.24"	1412 pounds	238 pounds	1650 pounds	550 pounds

The titanium Y-Ring shows a 32 percent weight savings as compared to the aluminum Y-Ring. This results in a weight saving of 780 pounds per vehicle.

DEVELOPMENT OF PROCESSING TECHNIQUES

DIFFUSION BONDING

Diffusion bonding is a joining method in which a metallic bond is obtained between two pieces of metal without melting the parent metal (welding) or an intermediate metal (brazing). It is accomplished by the diffusion of atoms across the interface between the two materials being joined.

Diffusion bonding is a two-stage process. The first stage is largely mechanical in nature. During this stage, an initial bond is obtained by bringing the two parts to be joined into intimate contact. This involves plastic deformation to overcome surface asperities, thereby achieving metal-to-metal contact. Several methods of achieving the required metal-to-metal contact are employed: (1) deforming the parent metal by heat and pressure; (2) using an intermediate metal interleaf capable of being deformed by heat and pressure; and (3) using an intermediate metal which forms a eutectic with the parent metal to develop a liquid phase at the joint interface. For titanium, the first method is adequate and no intermediate materials are required.

The second stage of the process is strengthening of the bond by the diffusion of atoms across the interface. This is a function of the mobility of the exchange atoms and is accomplished by holding at elevated temperatures for definite periods of time.

Diffusion bonding was selected as the method of fabricating the titanium Y-Ring segment for the following reasons:

1. Metallurgically sound joints equivalent in strength to the parent materials are obtainable.
2. Difficulty in obtaining sound metallurgical and mechanical properties in the thick sections required for Y-Ring segments.
3. Versatility in design.
4. Ability of titanium to bond to itself without the use of intermediate or filler materials.
5. Reduction in cost by the ability to place titanium structural members in desired locations thus reducing significantly amounts of titanium machining.

SELECTION OF BONDING PROCESS

Significant progress has been made in the state-of-the-art of diffusion bonding and a number of methods have been developed for accomplishing joining under controlled metallurgical conditions. "Roll Bonding", "Creep Controlled Bonding," and "Yield-Strength Controlled Bonding", are three uniquely different processes that have been developed in the evolution of solutions for the material joining problems. Each of these techniques has been recognized as having great potential for application to the fabrication of advanced aerospace hardware. Under industry funded contracts, each of these processes is being carried from the laboratory feasibility stage to the fabrication of selected components applicable to vehicle or engine construction.

The subject program is concerned with the development of roll diffusion bonding to fabricate a titanium Y-Ring segment. Because of the problems associated with procurement of thick section plates of titanium alloys approximately 35 feet long, and of the problems associated with applying the uniform high pressures required for static bonding the long Y-Ring segments, roll diffusion bonding appears at this time, to be the most promising diffusion bonding approach and fabrication technique.

Roll bonding achieves intimate contact of the surfaces to be joined by the large amounts of deformation obtained in passing a heated pack layup through a rolling mill. Normally, a reduction of 60 to 70 percent or more of the pack thickness is achieved. Thus, a major characteristic of roll bonding is high deformation. The pack, consisting of parts and filler tooling, must be layed up in precalculated shapes which will be deformed into the desired configuration during the rolling process.

Roll bonding requires new tooling for each and every part, the tooling being destroyed by chemical leaching which is used to remove the steel from the titanium. Roll bonding is most suited to producing long and narrow parts, since this is the type of product normally rolled at the mill.

SUB-SCALE TEST COMPONENTS FABRICATION

Nine sub-scale Y-Ring segments were roll diffusion bonded to develop the necessary bonding techniques and process techniques to produce the desired Y-Ring configurations. These sub-scale components were one-half the thickness and height of the full-scale Y-Ring and were approximately 4 feet long following rolling. These segments were rolled to develop diffusion bonding, machining, hot forming, thermal treatment and other related processes required for the fabrication of full scale Y-Ring segment. These half-scale thickness and height components were rolled at the U. S. Steel Research Mill in Monroeville, Pennsylvania. The size of all of the packs that were rolled was approximately 6" x 18" x 24". This was the pack size that U. S. Steel Research Mill suggested as the largest size to roll at this time.

The choice of half-scale ring height is based on the fact that full-scale height could not be produced using this facility and an appreciable cost saving was achieved by selecting half-scale.

FABRICATION CONCEPTS

The three fabrication concepts for roll diffusion bonding the Y-Ring designs are shown in Figure 2 . These layup design concepts for the fabrication of the titanium alloy Y-Ring configurations differ in respect to how the internal bulkhead attachment member will be made.

Concept "A" involves machining the attachment member to the final size and required configuration from a large piece of titanium. This method is the easiest but requires the most titanium and machining.

Concept "B" would produce the attachment member in the desired configuration and would be machined to final size without forming. The concept requires less material than Concept "A" but presents a rolling problem to achieve the desired angle and constant material thickness.

Concept "C" could be rolled horizontally and then formed to shape and machined to size in subsequent separate operations. This concept utilizes the smallest amount of titanium and reduces the amount of machining but presents a forming problem.

The layup designs can also be modified by changing the direction of the vertical stiffeners.

The first six packs that were roll diffusion bonded, consisted of two packs of each fabrication concept. In addition, these packs had variations in rib direction.

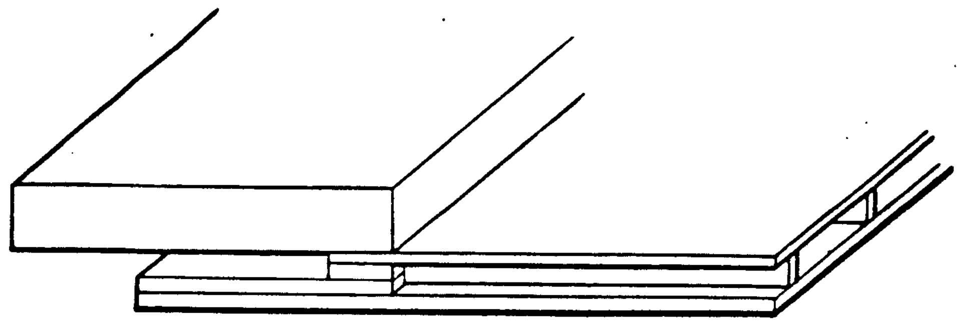
As a result of the analysis of the roll diffusion bonding of the first six packs, fabrication concept "C" with alternate rib configuration was selected and utilized in the roll diffusion bonding of the final three packs.

Review of Fabrication Approaches

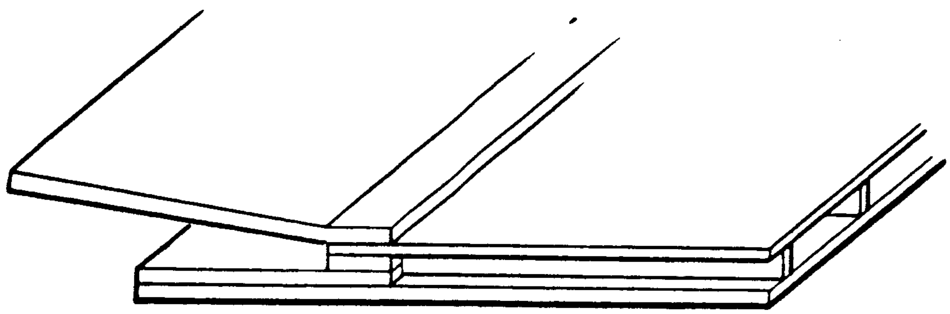
CONCEPT "A"

This concept can be successfully roll diffusion bonded. This concept requires 653 more pounds of titanium per Y-Ring segment than Concept "C", which amounts to 78.5 percent of the final total segment weight.

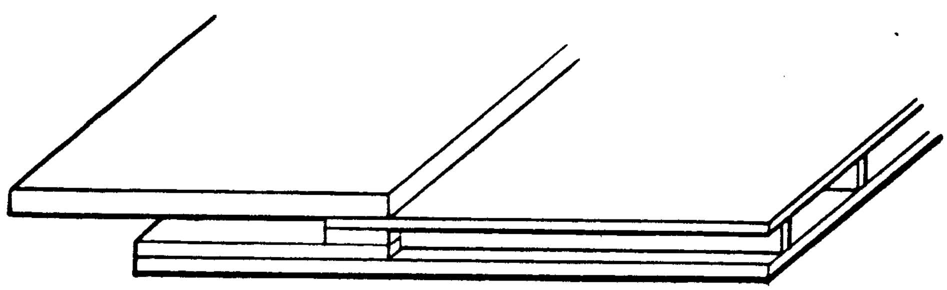
This additional titanium results in additional costs other than the increase in titanium costs; more steel is required in the yoke, the pack rolling weight is increased and the shipping charge is increased. This concept requires extensive machining of the flange after rolling with cost estimates varying between $20,000.00 and $50,000.00



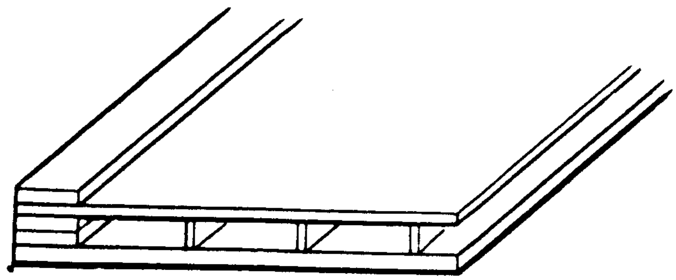
Fabrication Concept - Configuration A



Fabrication Concept - Configuration B



Fabrication Concept - Configuration C



Alternate Rib Design Configuration

Figure 2. Fabrication Layup Concepts

CONCEPT "B"

This concept can also be successfully roll diffusion bonded. The angle of lay-up, 39°19' was reduced to 15° 35'. The required angle is 15° 11'.

This concept also requires extensive machining of the steel and titanium details prior to roll diffusion bonding and requires additional machining and/or forming of the flange to produce the desired contour.

The costs for machining 16 titanium details for the subscale packs increased approximately 140 percent as compared to Concept "A".

CONCEPT "C"

This concept can also be successfully roll diffusion bonded. This concept requires the least amount of titanium and can be successfully formed at costs considerably below machining costs. This concept was therefore selected.

RIB DIRECTION

The direction of the ribs are required to be parallel to the direction of rolling. Ribs perpendicular to the rolling direction collapsed during rolling.

BONDING PROCEDURE

The following is the fabrication sequence used for roll diffusion bonding all of the nine sub-scale components.

The roll bonding process is a method of effecting a diffusion bond between, in this case, titanium details at elevated temperature by the reduction rolling of a pack consisting of the details to be joined and a steel matrix contained within a steel retort. Shaped steel tooling which fills the spaces between the titanium details comprises the matrix. The retort consists of a steel yoke and steel face sheets above and and below which are welded together and evacuated prior to rolling. The pack assembly thus forms a solid type of plate which can then be reduced in a rolling mill at high temperature. The reduction in pack thickness is approximately 67%, which would result in a pack length approximately three times the length of the original pack.

The pack layup assembly is basically as follows. A thick steel plate which forms one surface of the retort is used as a reference plate. A steel picture frame (or yoke) of approximately the same length and width as the plate and the same height as the Y-Ring details is used as the retort edges. The titanium details and steel support tooling are placed within the frame or yoke. Another thick steel plate is positioned over the assembly and forms the opposite retort cover. The two retort covers and frame are then welded to form a sealed retort. A purge tube was inserted through a hole drilled in the end of the frame (so as not to interfere with the rolling operation) and weld sealed to the frame. The sealed retort was evacuated by continuous pumping or pumping plus inert-gas purging during heating to the rolling temperature to remove air and contaminants. Prior to rolling, the purge tube was sealed-off close to the pack by welding and the remainder of the tube removed.

The assembled packs are rapidly transferred from the furnace to the rolling mill for reduction. A reduction of approximately 67% of the initial pack thickness has been found to be necessary to fabricate the length of Y-Ring segments required with the current heating furnaces available at the steel mills.

The important criteria for the successful rolling of the packs are: performing the reduction as fast as possible to retain the heat in the part and accomplishing all of the rolling with no reheats.

The pack is rolled in only one direction. This produces some increase in the pack width and considerable elongation depending upon the percent of reduction. Horizontal details, for example Y-Ring facing sheets, are reduced in thickness by the same factor as the pack is reduced. Vertical details, for example the circumferential stiffeners, are reduced in height by the same factor however their thickness is increased by the action of the sidespread during rolling.

Pack Materials

Throughout the Phase I developmental program, use was made of cold drawn A.I.S.I. C1018 or S.A.E. 1018 steel filler bars whenever possible. The advantages to their use is that they do not require machining and can be procurred to close geometrical tolerances.

All other internal steel tooling was machined from either Merchant Bar Quality M1020 hot rolled flat steel bar or ASTM A-7 hot rolled steel plate. Steel cover plates and yokes were machined from ASTM A-7 hot rolled steel plate. Shim stock was hot rolled 1020 steel sheet per Specification MIL-S-7952.

All titanium was procurred to NAA material specification LB0170-177 for sheet and plate material and material specification LB0170-185 for bar material.

Pack Design Evaluation

The thickness or thicknesses of the upper and lower steel cover plates were investigated for their effect on pack heat retention, configurational accuracy, and diffusion bond quality.

Packs #1 through #6 consisted of conventional yokes and either 3/4 inch or 1 inch cover plates. The yoke height was equal to the height of the Y-Ring segment detail assembly. The four of the first six packs that were rolled between 1805°F and 1850°F had a finishing rolling temperature of from 1630°F to 1740°F. These temperatures were recorded by thermocouples in the side of the yoke at the midplane near the cavity. Since bonding is a function of temperature and becomes increasingly important when the load, or pressure, is applied over a short time, attempts were made in Packs #7, 8 and 9 to increase the finishing temperature. To accomplish this, the cover plate thickness was increased to 1-3/8 inches for Packs #7, 8 and 9 and resulted in a finishing temperature of approximately 1810°F.

Temperature uniformity is also important in roll bonding. Temperature gradients in the pack can cause ununiform metal movement and cooler spots retard bonding. Because the major difficulty in bonding occurred in the stiffened panel portion of the Y-Ring segment and the panel area was not located in the center of the pack with the conventional yoke design, a change in design seemed necessary. As a result, in Packs #7, 8 and 9 an internal steel plate was placed in the cavity below the outer facing sheet. This placed the panel portion of the segment in the center of the pack with an equal thickness of steel above the inner facing sheet and below the outer facing sheet.

Cleaning Procedures

Throughout the Phase I program, all Ti-8Al-1Mo-1V details were cleaned per NAA/LAD Process Specification LA0110-008. This process involves a conditioning of any scale, water rinsing, scale removal, water rinsing, and drying.

Shortly after initiation of the Phase I effort, it was found that the established cleaning procedures for iron and steel were not adequate for roll bonded assemblies. The standard procedures involve alkaline cleaning to remove the last traces of oil and rust followed by water rinsing and oven drying or an alkaline cleaning to remove the last traces of oil, water rinsing, an acid pickle to remove rust and scale, followed by water rinsing and oven drying. It was found that these processes produced a steel part with a thin layer of rust since the water from the rinse solution could not be removed fast enough. Air blowing the parts following rinsing did not prevent rusting of the steel details.

As a result, the cleaning procedure that was established for the Phase I Pack assemblies involved alkaline cleaning to remove all grease and oil from the surfaces, water rinsing, light hand sanding to remove all rust, followed by hand solvent cleaning until no residue is visable Vapor honing was also used in place of the hand sanding operation and served equally well.

Lay-up Tolerances

In order to reduce or eliminate distortion of the Y-Ring segment during rolling, the pack details should fit together as close as possible during lay-up. Void spaces in the cavity will be immediately filled during rolling and can thereby cause undesirable metal movement. It has been shown in this program that detail parts machined to reasonable tolerances, without incuring above average costs, is sufficient. In the packs assembled in this program, the yoke cavity has been approximately .050 inches thicker, wider, and longer than the Y-Ring segment and internal tooling assembly to aid in its placement in the cavity. This "built-in" void space was then filled (the cavity shimmed) to produce a tight fit. It was found in Packs #7, 8 and 9 that of the .050 inch void space built into the cavity dimensions only approximately .020 inches of shim stock could be placed in the cavity to produce a tight fit. The reason for this fact is individual detail machining tolerances and details which are not perfectly straight. The small void space, therefore, that was present during rolling did however, not cause detrimental distortion of the resulting parts. A typical Y-Ring detail and internal steel tooling assembly prior to placement in the yoke cavity is shown in Figure 3 . The small void spaces evident are due to machining tolerances in the individual detail parts.

Figure 4 shows the same assembly, the yoke with lower cover plate welded in place, and the upper cover plate. The yokes for Packs #8 and 9 had slotted circular pins at the corners to produce a rectangular cavity rather than end plates with radii on the edges to mate with a cavity with curved corners as was previously used. This slotted pin technique eliminated the problem of gaps between the plates and the yoke, thereby making assembly easier.

Rolling Variables Determination

Purging Process

In order to achieve complete diffusion bonding in the pack during rolling, the residual air in the pack must be maintained below a critical level. The amount of residual air contained within the pack that can be tolerated is a function of the material being joined. The bonding of titanium and titanium alloys can be accomplished under a more oxidizing atmosphere than can aluminum alloys, for example. Two methods investigated were purging of the pack with inert gas during heatup and continuous evacuation of the pack by pumping during heatup.

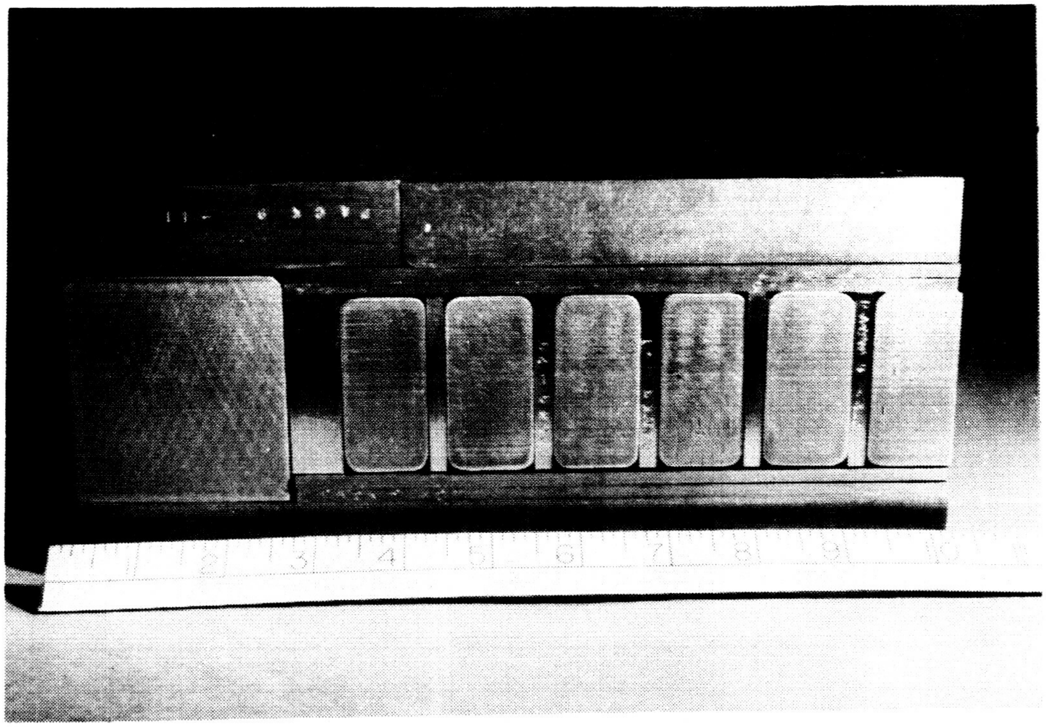


FIGURE 3 Y-RING DETAIL AND INTERNAL TOOLING ASSEMBLY

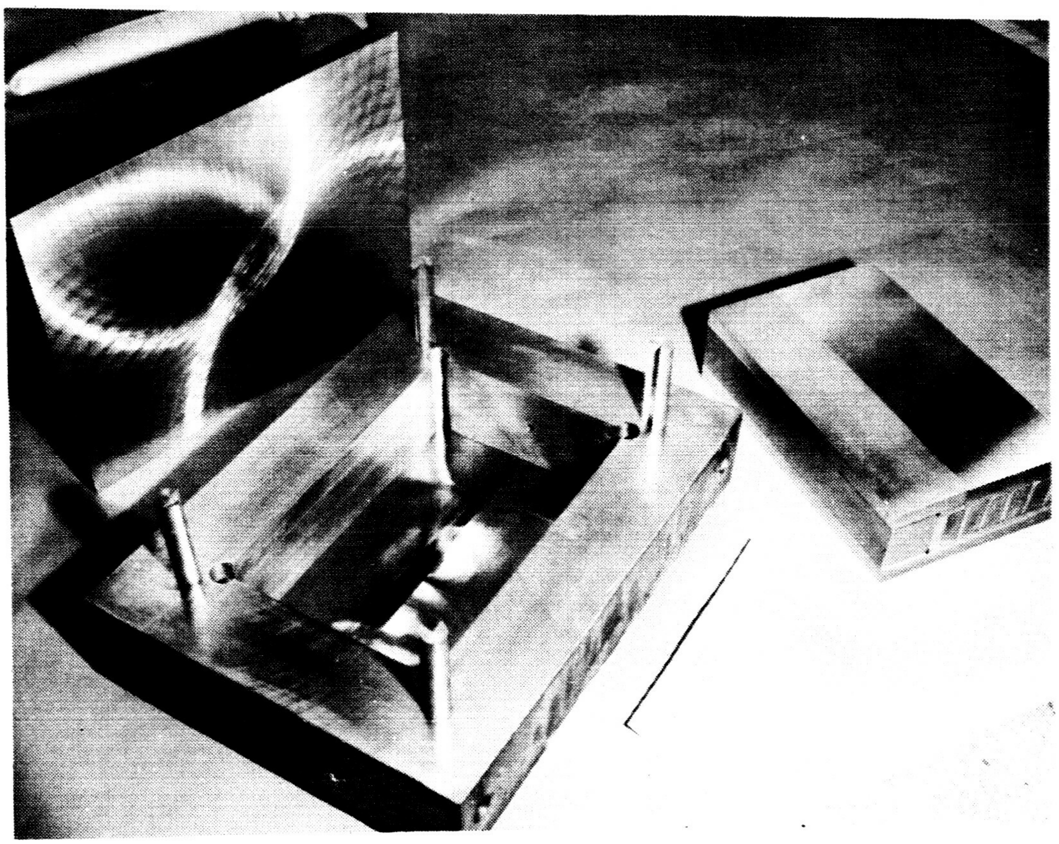


FIGURE 4 CAVITY ASSEMBLY, YOKE, AND COVER PLATES

Table II contains a summary of the outgassing procedures that were used on Packs #1 through #9. Packs #1, 3, 4, 7 and 8 were heated, prior to rolling, to the indicated temperatures in a resistance heated electric ceramic blanket composed of two ceramic platens above and below the pack. The packs were under continual vacuum during heatup except for periodic purging with argon gas. After stabilizing at the selected temperature the packs were allowed to cool to room temperature, maintaining a continuous vacuum in the packs during cooling.

Packs #2, 5, 6, and 9 were allowed to outgas while being heated for rolling at the rolling mill. These packs also were held under continuous vacuum during heat-up to the selected temperature. These packs, however, were not purged with argon gas.

Metallurgical examination of these developmental packs do not show any correlation between bond quality and/or contamination level and the outgasing temperature (within the range investigated). Also no correlation was found between bond quality and/or contamination level and whether or not the packs were purged with argon gas.

Rolling Temperature

During the rolling operation, it is essential that the pack details (titanium alloy details and filler material) be heated to a uniform temperature. An investigation was made to determine the time and temperature required to preheat full-thickness packs to insure uniform heating thoughout the packs.

Except for Pack #1, all developmental packs were heated to the desired rolling temperature as recorded by thermocouples in the yoke at the mid-plane and stabilized at this temperature for a minimum of one hour. These furnace heating times corresponded very closely to a heating time of one hour per inch of thickness. Using this technique, no difficulty was encountered with rolling mill load levels. Pack #1 was heated to 1800°F as measured by similar thermocouples and rolled immediately. The total heating time was five hours for the 6 inch thick pack. The result was mill rolling loads almost two times those predicted. To insure that the pack is uniformly heated to the desired rolling temperature, it is recommended that the heating time should be a minimum of one hour per inch of thickness.

Table II shows the rolling temperature for Packs #1 through 9. Metallurgical examination revealed that the titanium in Packs #1 and 4 exceeded the beta-transus temperature and therefore upon cooling transformed to the acicular alpha-beta morphology rather that the equiaxed alpha-beta structure. The published beta-transus temperature for Ti-8Al-1Mo-1V is 1900° ± 25°F. Although Pack #4 was heated to only 1850°F prior to rolling, it is believed that the titanium heat of deformation is sufficient to raise the temperature and thereby exceed the beta-transus temperature.

Since it is desirable to accomplish the roll diffusion bonding at the highest possible temperature consistant with desired metallurgical properties, a rolling temperature range of 1835°F - 1840°F affords the optimum rolling condition.

PACK NO.	FABRICATION CONCEPT	PURGING TEMP.	PROCEDURE ARGON/FT	CONT.VAC	ROLLING TEMPERATURE BEFORE	AFTER 2ND PASS	AFTER ROLLING	NO. PASSES	COOLING PROCED[illegible]
1	A	1400	Yes	During Cooling	1795°F	1795°F 1890°F	1750°F 1875°F	1 5 [illegible] 10	Air Cool Air Cool
2	A	1800	No	To 1800F (1)	1805°F	1800°F	1700°F	12	Oscillat[illegible] Air
3	C	1485	Yes	During Cooling	1835°F	1830°F	1740°F	10	A.C. to Water Qu[illegible]
4	C	1650	Yes	During Cooling	1850°F	1835°F	1720°F	10	A.C. to water Qu[illegible]
5	B	1845	No	To 1845F (1)	1845°F	1805°F	1830°F	13	Air Cool
[illegible]	B	1800	No	To 1800 (1)	1800°F	1860°F	---	[illegible]	A.C. to [illegible] water [illegible]
7	C	1200	Yes	During Cooling	1835°F	---	---	14	Air Cool
[illegible]	C	1-00	Yes	During Cooling	18-0°F	1825°F	1810°	14	Air Cool
9	C	1600	No	To 1600 (1)	1835°F	---	---	14	Air Cool

TABLE II

PHASE I Y-RING

SUB-SCALE TEST COMPONENTS

ROLLING DATA

...RES	PACK SIZE BEFORE	PACK SIZE AFTER	% REDUCTION
...ed ...ed	6.000"	1.957"	67.39
...ed in	[illegible].000"	1.945"	67.59
...200° ...nched	5.650"	1.830"	67.62
...700° ...nched	5.[illegible]50"	[illegible]	67.62
...d	6.960"	2.330"	66.53
...700° ...nched	[illegible]	2.[illegible]	67.68
...ed	7.223"	2.415"	66.56
...ed	7.207"	2.414"	66.51
...ed	7.226	2.422	66.48

In this temperature range no titanium transformation takes place, diffusion rates necessary to achieve bonding are highest consistant with no transformation, rolling mill reduction schedules are optimized, and differences between the forces necessary to deform titanium and steel are minimized consistant with no titanium phase transformation.

Reduction Schedule

Each Y-Ring segment to be fabricated in Phase III is 414.7 inches long. It is planned to make the final length approximately 430 inches long thereby allowing material for trim and quality control inspection. The Bethlehem Steel Mill is limited at the present time to the rolling of packs 100 inches x 160 inches which means the original component length is limited to approximately 144 inches. In order to increase that length to the required 430 inches, the pack must be reduced approximately 66.5%. No problem is anticipated in the reducing of the packs 66.5%. This reduction percentage was investigated in Phase I.

The U. S. Steel Research Mill at Monroeville, Pennsylvania where the nine developmental packs were rolled is a fully instrumented rolling mill. The rolling mill facility consists of a two-high fully instrumented and automated reversing mill with a maximum separating force of 1,000,000 lbs. In addition, the facility consists of three gas fired, push-out furances shown in Figure 5 . Figure 6 shows a pack in the furnace prior to being pushed out for rolling. The packs are pushed out of the furnace onto a motor driven roller table, Figure 7 and rolled, Figure 8 . During the rolling operation the following are automatically recorded: motor speed, rolling speed, motor volts and amps, rolling horsepower, and a continuous recording of separating force over the full pack length on each reduction pass.

Steel Yoke and Cover Removal

The removal of the low carbon steel tooling hardware: yokes, covers, and tooling bars in which the titanium alloy (Ti-8-1-1) detail parts are laid up and roll bonded consists of several steps:

1. Removal of the yoke frame sides and ends. On small developmental packs these are removed by sawing, radiac cutting, and flame cutting. On large packs, such as the final design configuration for the full scale Y-Ring segment, the edges can be most readily and economically removed by flame cutting off the major portion of the yoke edges and ends and removing the remainder by a machining operation.
2. Removal of the cover plates. After removal of the edges and ends of the pack, the remaining cover plates may be readily removed by

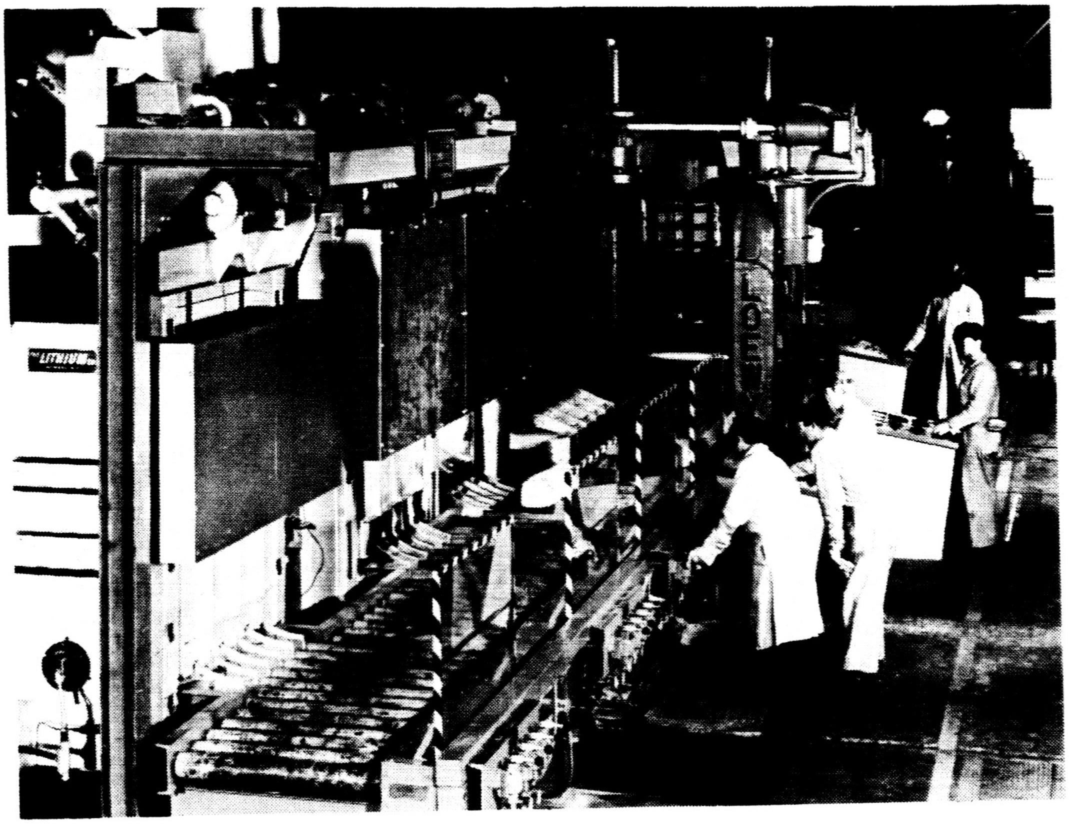


FIGURE UNITED STATES STEEL RESEARCH ROLLING MILL

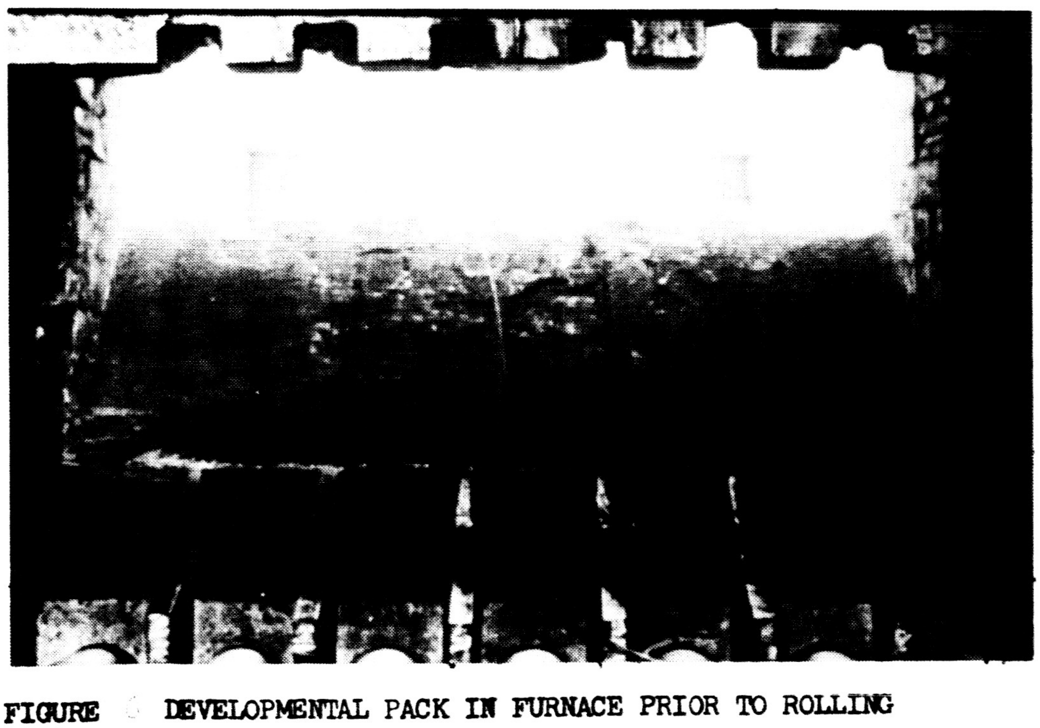


FIGURE DEVELOPMENTAL PACK IN FURNACE PRIOR TO ROLLING

FIGURE - DEVELOPMENTAL PACK PRIOR TO ROLLING

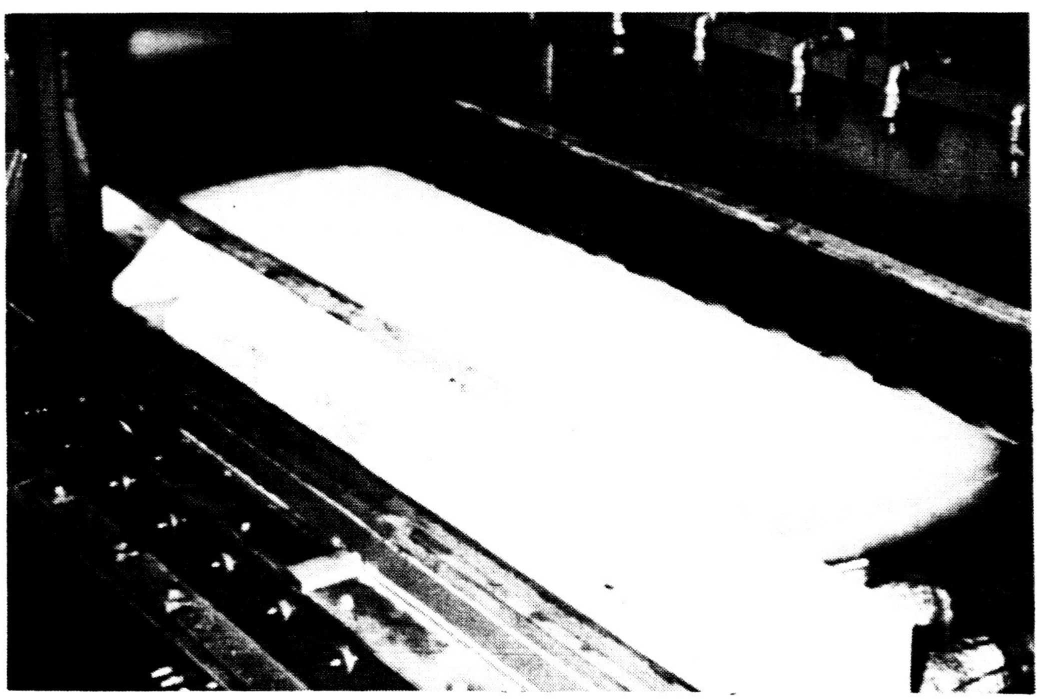


FIGURE DEVELOPMENTAL PACK AFTER ROLLING

simple mechanical means provided they are not interlocked with the titanium part. During the cooling down cycle after roll diffusion bonding or hot forming, a shearing stress is created between the steel covers and the internal titanium part which is caused by the differential shrinkage between the two metals and is normally of sufficiently high magnitude to break the weak bond established during the roll diffusion bonding. Separation of the covers from the pack may also be assisted by the use of a liquid nitrogen blast on the cover surfaces to further increase the shearing stresses tending to break the bond at the steel and titanium alloy interface.

A method has been developed to facilitate the removal of the cover plates, yoke and internal steel tooling following roll bonding. The method, used in Packs #7, #8, and #9 consists of placing a thin strip of titanium foil between the yoke and cover plates and extending beyond the yoke cavity in both directions prior to welding the cover plates to the yoke. Following roll bonding, the pack is flame cut outside of the cavity, along the edges, Figure 9. This removes almost all of the excess steel material around the Y-Ring part. During the flame cutting operation, the cover plates broke loose from the yoke by fracturing the brittle bond between the steel and the titanium foil. Any additional steel along the edges of the part was then removed. Easier removal of this remainer can be done by placing titanium foil along the sides of the yoke cavity. This technique can also be used to separate pieces of internal steel tooling to aid in their removal. This becomes increasingly important as the size and weight of individual steel pieces becomes larger. These techniques will be employed in the roll bonding the full-scale Y-Ring segments.

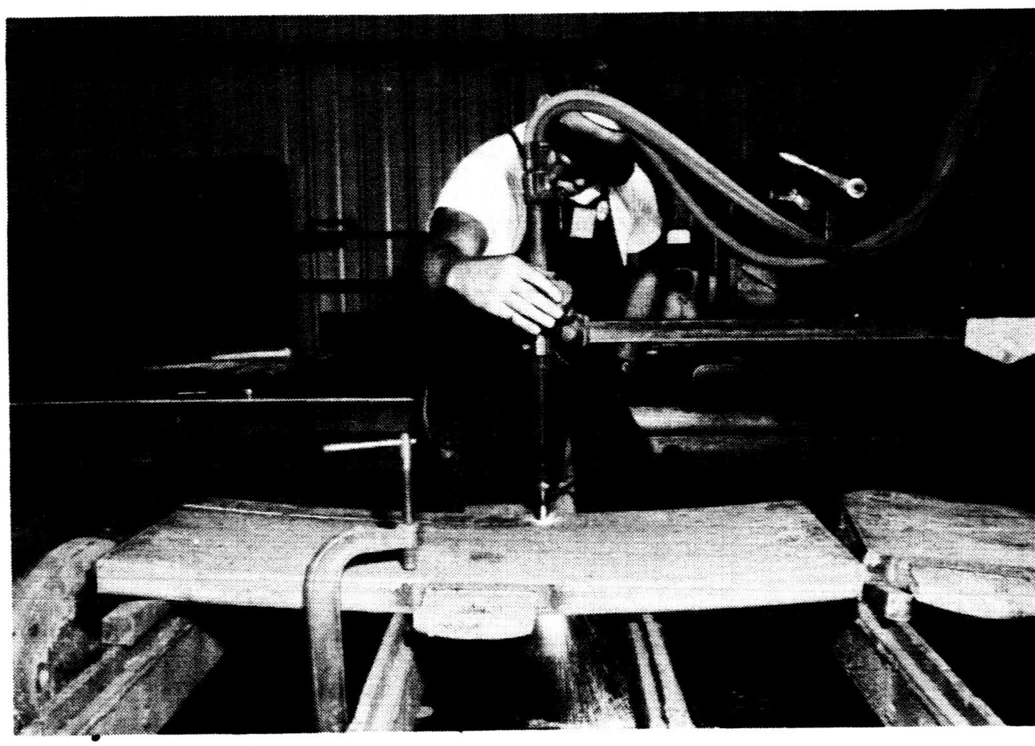


FIGURE 9 FLAME-CUTTING DEVELOPMENTAL PACK

EVALUATION

Dimensional Analysis

Cross-Sectional Geometry

A complete dimensional analysis of #7, #8 and #9 packs and Y-Ring parts revealed close correlation between actual and target dimensions. Complete dimensional data is shown in Table III. Pack #7 was rolled within .005 inches of target thickness and Packs #8 and #9 were rolled within .001 inches of the target dimension. Two dimensions of interest following roll bonding are the flange and rib stiffened panel thickness. The average deviation from the target flange thickness was .006 inches and the average deviation from the target panel thickness was .003 inches.

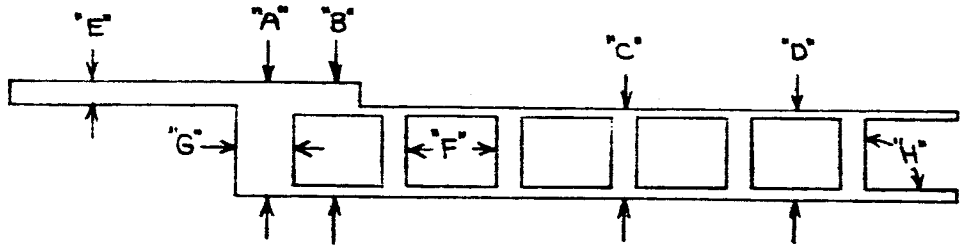
As the dimensional data indicate, the stiffened panel thickness is smaller as measured across the ribs than as measured between the stiffeners. This depression effect was .012 inches, .009 inches, and .007 inches for Packs #7, #8 and #9 respectively. The data indicates that the depression effect is reduced as the rib thickness is increased for the same facing thickness and as the facing thickness is increased for the same rib thickness.

The small deviations from perpendicularity between the ribs and facings occurred in the outside ribs, toward the edge of the pack cavity. The other perpendicularity deviation occurs between the skirt attachment and the facings. These small deviations may be related to side effects during rolling and/or void space in the pack cavity prior to rolling.

The amount of sidespread that occurred in Packs #7, #8 and #9 during rolling ranged from 3.66% to 6.58% depending upon the particular detail measured. Since the Y-Ring is machined and chem-milled following rolling, the only change in dimension due to sidespread that could influence the final Y-Ring geometry is that of the rib separation. The particular amount of sidespread that will occur is a function of many variables: the individual rolling mill characteristics, the reduction schedule, the pack thickness, and pack width to mill width ratio.

Fillet Size

A study was made of various techniques to produce a fillet between the inner and outer facing sheets and the circumferential stiffeners since this is desirable for the transmission of loads. Four techniques were employed: the use of as cold drawn filler bars, breaking the edges of the filler bars with a hand file prior to rolling, machining a chamfer on the bars, and machining a radii on the bars prior to rolling. Figures 10 and 11 are photomicrographs after roll bonding of facing-to-stiffener joints using a cold drawn filler bar on the left hand side and a filler bar with hand filed edges on the right side. Figure 12 is a photomicrograph of a joint produced after roll bonding using a 3/32" x 3/32" chamfer on the filler bar prior to rolling. Figure 13 shows a photomicrograph of a typical fillet produced from an original 5/32" bar radius.



PACK #7

	Head End (Average)	Tail End (Average)	Pack Average	Target Dimensions	Head End (Average)
Pack Thickness			2.415	2.420	
Total Y-Ring Thickness ("A")	1.106	1.118	1.112	1.119	1.118
Total Y-Ring Thickness ("B")	-	1.145	1.145	1.119	1.103
Panel Thickness at Rib ("C")	.798	.813	.805	.810	.804
Panel Thickness Between Rib ("D")	.808	.827	.817	.810	.811
Flange Thickness ("E")	--	.321	.321	.308	.301
Rib Thickness	.157	.159	.158	--	.220
Rib Sidespread				6.04%	
Inner Facing Thickness	.070	.073	.072	.070	.071
Outer Facing Thickness	.070	.068	.069	.070	.072
Rib Separation ("F")	1.058	1.042	1.050	--	1.033
Separation Sidespread				5.20%	
Ring Width ("G")	--	.663	.663	--	.615
Ring Sidespread				--	
Flange Width	4.144	4.118	4.131	--	4.102
Flange Sidespread				6.46%	
Y-Ring Width	--	--	--	--	10.58
Y-Ring Sidespread				--	
Rib Angel ("H")				90°	

TABLE III

PACK #7, #8, #9 DIMENSIONAL ANALYSIS

PACK #8				PACK #9			
Center (Average)	Tail End (Average)	Pack Average	Target Dimensions	Head End (Average)	Tail End (Average)	Pack Average	Target Dimensions
		2.414	2.415			2.422	2.421
1.108	1.122	1.116	1.119	1.173	1.166	1.170	1.178
--	--	1.103	1.119	1.169	1.168	1.168	1.178
.800	.816	.807	.810	.880	.874	.877	.870
.806	.831	.816	.810	.886	.881	.884	.870
--	.307	.304	.308	.305	.307	.306	.308
.218	.223	.220	--	.222	.220	.221	--
			4.75%				5.74%
.071	.073	.072	.070	.106	.104	.105	.100
.071	.071	.071	.070	.102	.100	.101	.100
1.045	1.060	1.046	--	1.032	1.040	1.036	--
			4.80%				3.81%
--	.630	.622	--	.630	.632	.631	--
			3.06%				5.17%
4.160	--	4.131	--	--	4.128	4.128	--
			6.58%				6.50%
10.70	--	10.64	--	10.68	10.65	10.67	--
			5.24%				5.52%
		88°-90°	90°			87°-92°	90°

Figures 10 and 11 indicate a non-uniform fillet using as-cold-drawn filler bars. This same indication is present using filed edge filler bars, however, this can be remedied by close control of the hand filing. Figure 12 shows the resulting joint configuration as a chamfer. This chamfer was approximately 15% of the original bar chamfer.

Machined filler bar radii from 1/8" to 1/4" were investigated and Table IV shows the average results of the resulting fillet radii. The fillets produced were not a perfect radius after roll bonding and the equivalent radius was defined for the purpose of comparative analysis as the perfect radius that produces the measured fillet throat distance; i.e., the distance from the intersection of the rib edge and the inner face sheet surface to the edge of the fillet as measured along a 45° angle. The bar radii did not produce a smooth and fully continuous fillet after rolling, but instead resembled a chamfer. Further examination of the joints after rolling with radiused filler bars revealed notches in the fillet area.

The notch shown in Figure 14 is typical of those found in all three packs. The notches were found almost exclusively at the bottom joints, those near the bottom of the pack as rolled. It is believed that this notch effect is due to the mode of plastic flow in filling the void space caused by the filler bar radii during roll bonding. This suggests that a reduction in the filler bar radii should be made and prior experience indicates that a filler bar radii near 1/32 inches will not produce a notch and will still produce a small fillet at the stiffener-to-facing sheet joint.

End Effects

From examination of the ends of the sub-scale segments, it was found that a void is present after rolling approximately one inch from the end of the parts. It is believed that a separation occurs between the end of the part assembly and the yoke during rolling. When this occurs, steel from the cover plates and the internal tooling bars are forced into the space. As a result, a portion of the rolling force is used in filling this void and not in reducing the thickness of the titanium assembly. The void space was not found to be completely filled following rolling.

This void space allowed uncontrolled deformation of the titanium structure at the ends of the parts. After roll bonding, each end of the sub-scale parts were rounded (bulged outward) approximately 1-inch. Also, at the ends, the two facing sheets are almost pinched together, the outer facing sheet and inner facing curved toward each other to intersect near the mid-plane of the circumferential stiffeners. One facing sheet is observed to be approximately 1/4" longer than the other. This pinching effect occurrs within approximately 1-1/4" of the end of the segment. After this portion of the segment is cut off, it was found that the Y-Ring was thicker at the new ends than planned. The stiffened panel portion of the Y-Ring was found to be from .075 inches to .100 inches thicker at the ends. The flange thickness was found to be from .010 inches to .020 inches thinner at the ends, the Y-Ring width was found to be from .15 inches to .20 inches narrower, and the flange width was found to be essentially the same at the ends as over the remainder of the segment. This void effect is expected to be minimized with increased yoke size.

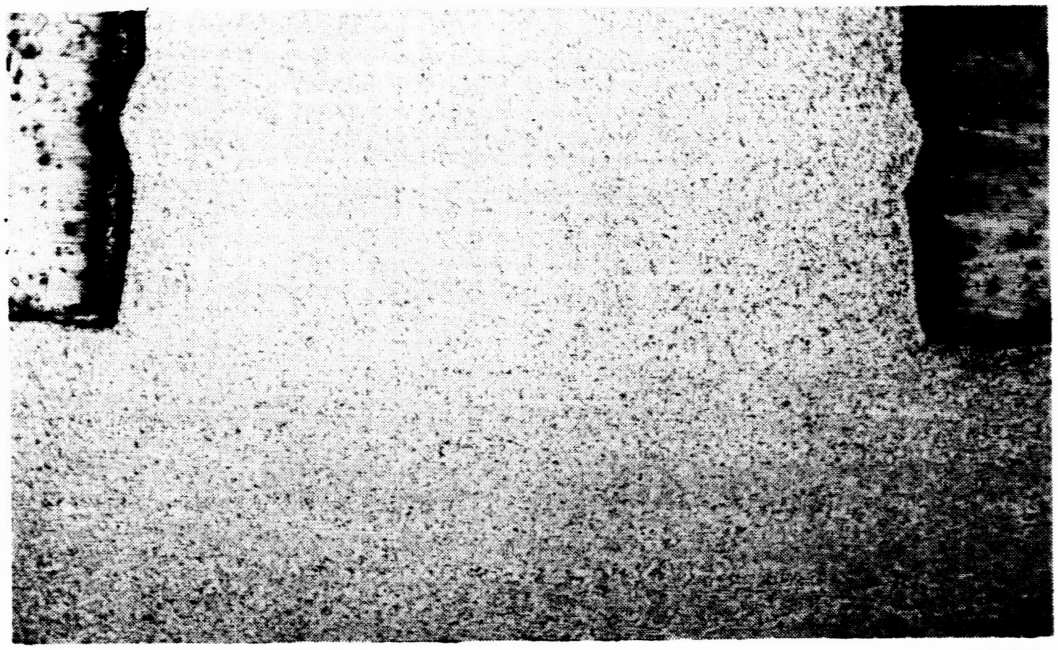


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FIGURE 10 FACING-TO-STIFFENER JOINT USING AS COLD DRAWN AND FILED EDGE FILLER BARS-PACK #2

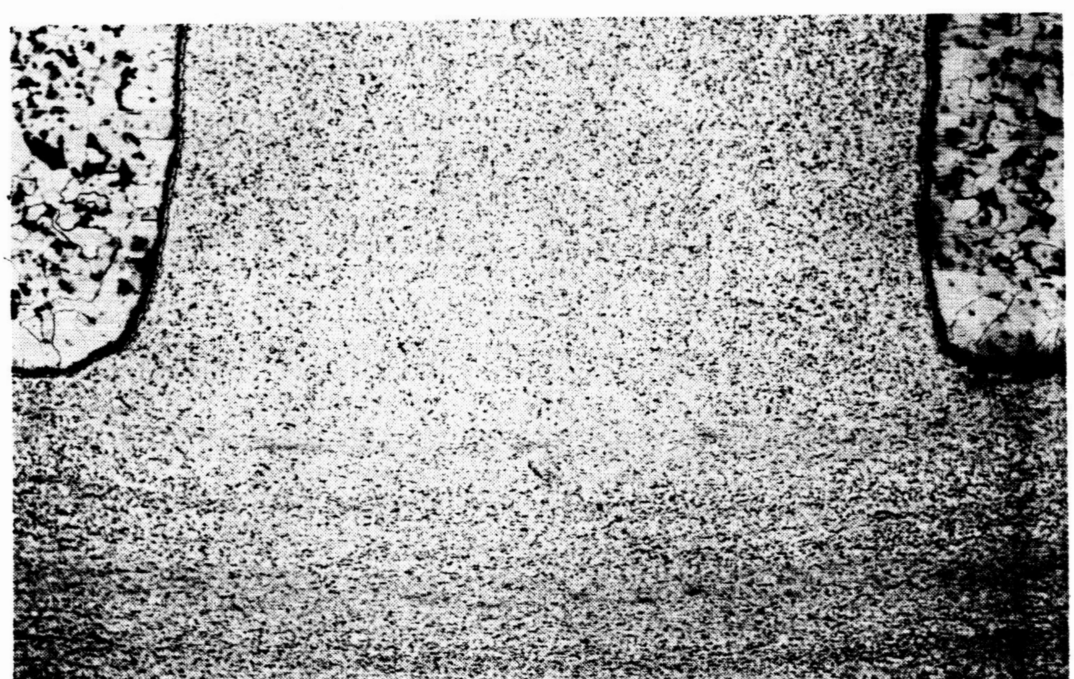

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FIGURE 11 FACING-TO-STIFFENER JOINT USING AS COLD DRAWN AND FILED EDGE FILLER BARS-PACK #2

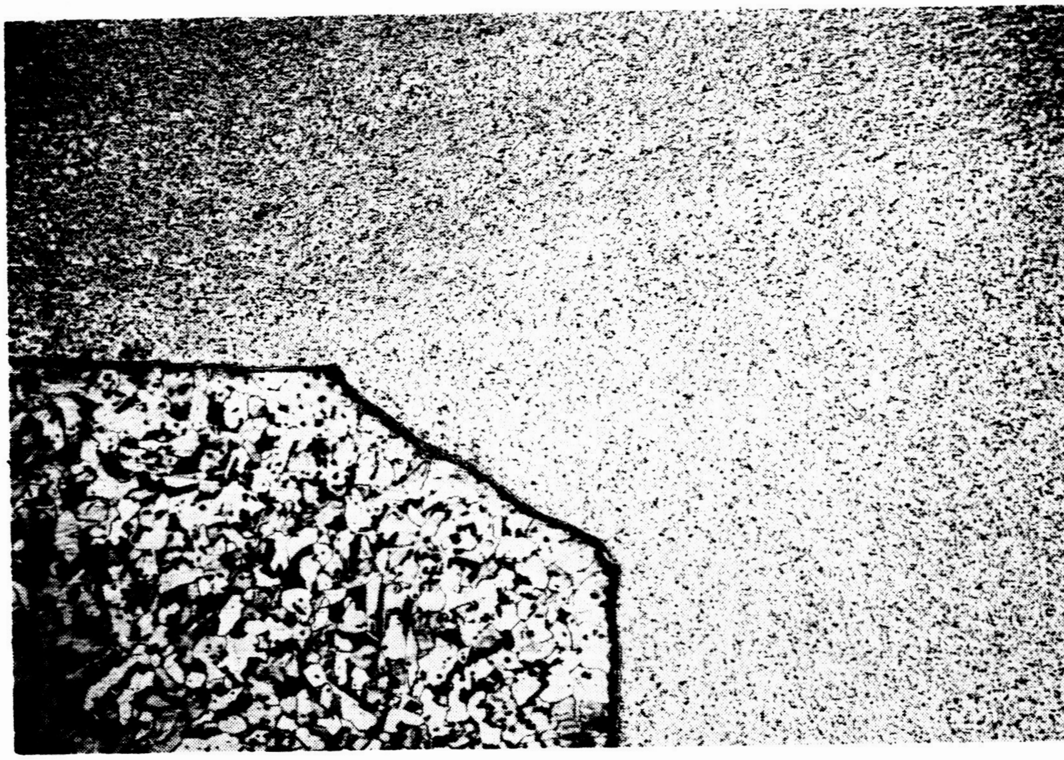

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FIGURE 12 STIFFENER-TO-FACING JOINT USING CHAMFERED FILLER BAR-PACK #2

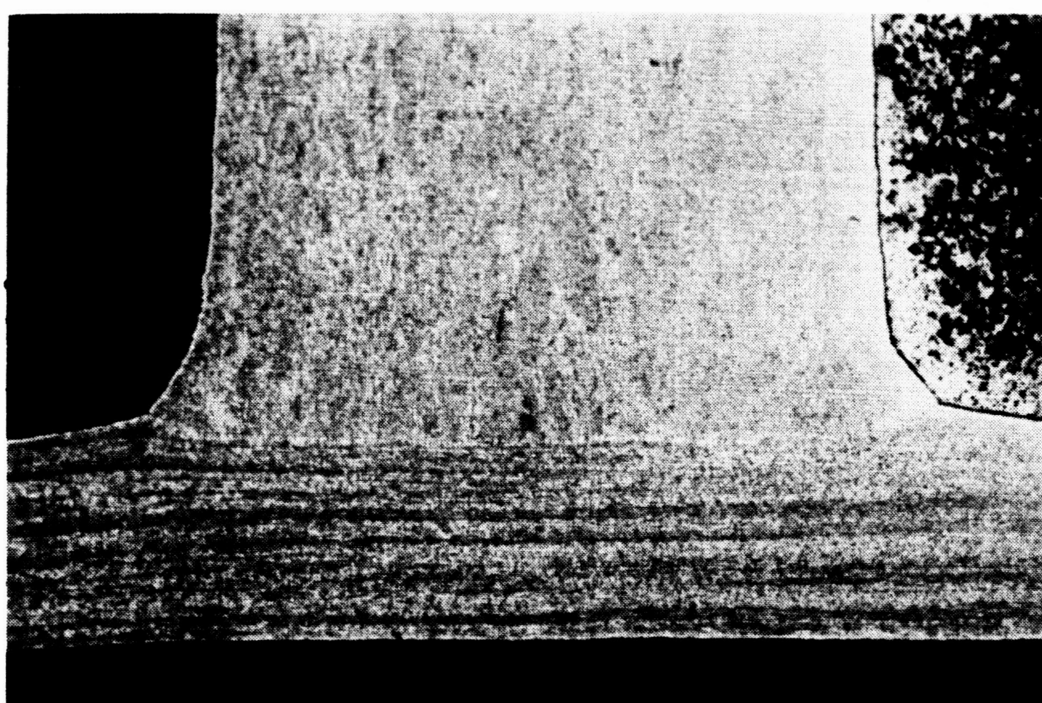

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FIGURE 13 STIFFENER-TO-FACING JOINT USING RADIUSED FILLER BAR-PACK # 8

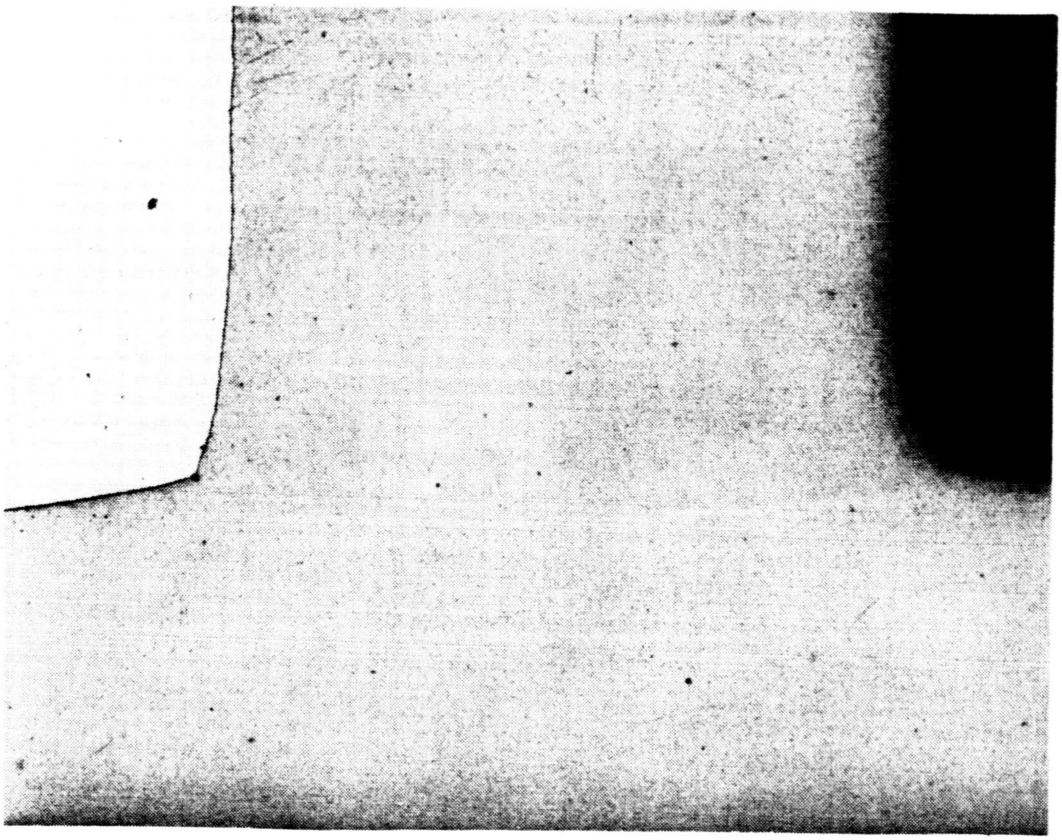
TABLE IV

FILLET RADII ANALYSIS

FILLER BAR RADIUS PRIOR TO ROLLING	FILLET THROAT DISTANCE AFTER ROLLING * (AVERAGE)	EQUIVLANET FILLET RADIUS** (AVERAGE)	PERCENT OF ORIGINAL BAR RADIUS (AVERAGE)
1/4" (.250)	.0325"	.079"	31.5%
3/16" (.1875	.024"	.058"	30.9%
5/32" (.1562)	.0222"	.054"	34.4%
1/8" (.125)	.0175"	.042"	34.0%

* DISTANCE FROM INTERSECTION OF RIB EDGE AND INNER FACE SHEET SURFACE TO EDGE OF FILLET AS MEASURED ON 45° ANGLE.

** THE TRUE RADIUS THAT PRODUCES THE GIVEN THROAT DISTANCE.



14X

FIGURE 14 STIFFENER-TO-FACING JOINT SHOWING NOTCH IN FILLET AREA - PACK 9

Metallurgical Analysis

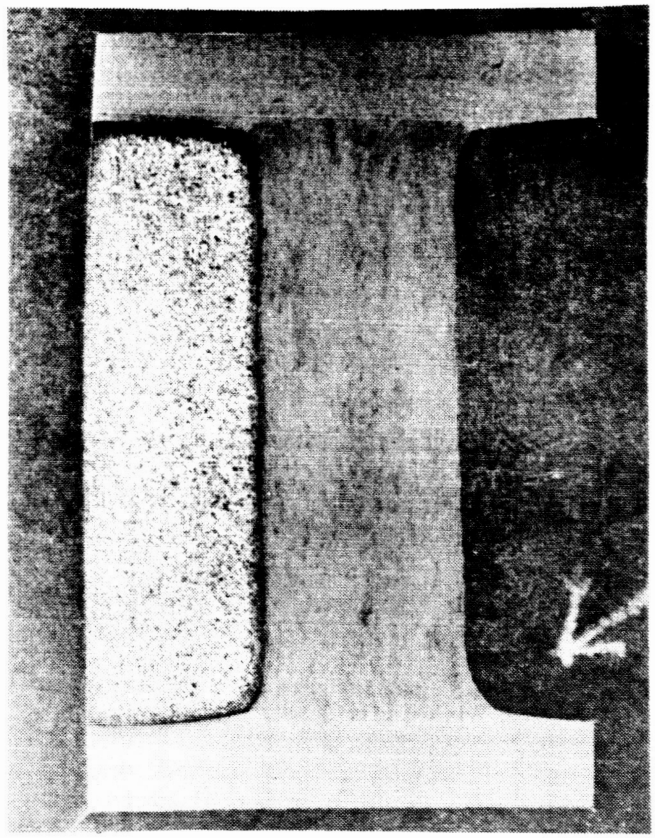
Numerous variables were examined during the fabrication of nine (9) sub-scale Y-Ring parts. One very critical variable proved to be the rolling temperature of the packs. Rolling temperatures from 1795F to 1890F were investigated. Specimens were cut from each of the nine packs and examined metallographically. The examination included overall bond quality, and evidence of contamination, metallurgical phase transformation, and joint configuration.

The optimum rolling temperature was determined to be 1835F and packs 7, 8 and 9 were rolled at this temperature. Figure 15 and 16 are photomicrographs of typical stiffener-to-facing sheet joints and Figure 17 and 18 are photomicrographs of typical laminated joints in the bulkhead and skirt connector portion of the Y-Ring segment. These metallographic specimens were taken from the end of pack 9 and excellent bond quality is evident. The only distinguishable characteristic between the individual titanium details is the difference in parent metal microstructures. Close examination of some of the stiffener-to-facing sheet joints revealed an acicular alpha-beta structure at the bond line, extending from the outside surface. This structure extended up to .020 inches of bond line on each side of the rib. Figures 19 and 20 typify this condition and it is important to note that although this condition existed, diffusion bonding was complete. It is known that iron that is diffused into titanium will effectively lower the titanium alloy's beta-transus temperature, the temperature being lowered with increasing iron content. It is believed that the area where the acicular structure is found is original stiffener and facing sheet surface material that becomes joint area after rolling due to its plastic movement into the void area caused by the filler bar radii.

As a result, iron-rich stiffener and face sheet surfaces, caused by diffusion of iron from the filler bars, that are folded into the void space to form bond area are transformed on heating to a much higher beta phase content than parent material and upon cooling produces a characteristic acicular structure while the reminder of the titanium retains its equiaxed morphology.

Although the acicular structure in the joint area is not desirable, its effect on joint integrity is not known. It is believed that this effect will be eliminated by utilization of smaller filler bar radii.

Pack number 2 was diffusion bonded at a rolling temperature of 1805F and this temperature was determined to be too low upon examination. Figure 21 is a photomicrograph taken in a stiffener-to-facing sheet fillet area near the center of pack 2. This depicts a diffusion bonded joint of excellent quality; however, stiffener-to-facing sheet joints near the ends of pack 2 exhibited complete disbonds and cracks in the bond line as shown in Figure 22.



4X

FIGURE 15 STIFFENER-TO-FACING JOINTS-PACK 9

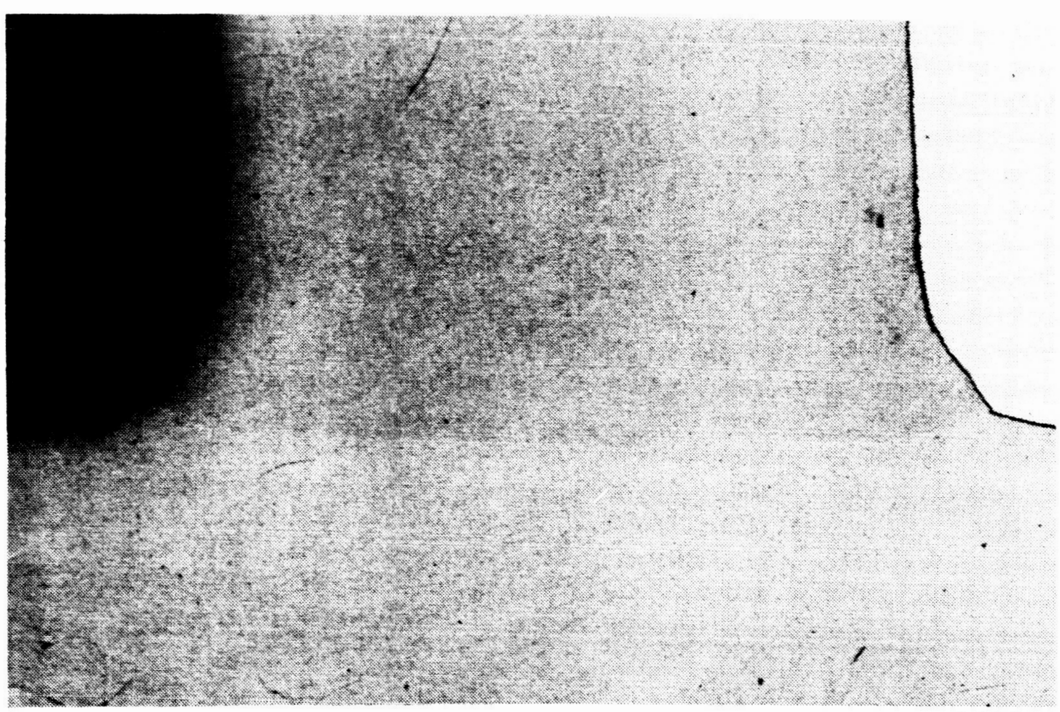


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FIGURE 16 STIFFENER-TO-FACING JOINTS-PACK 9

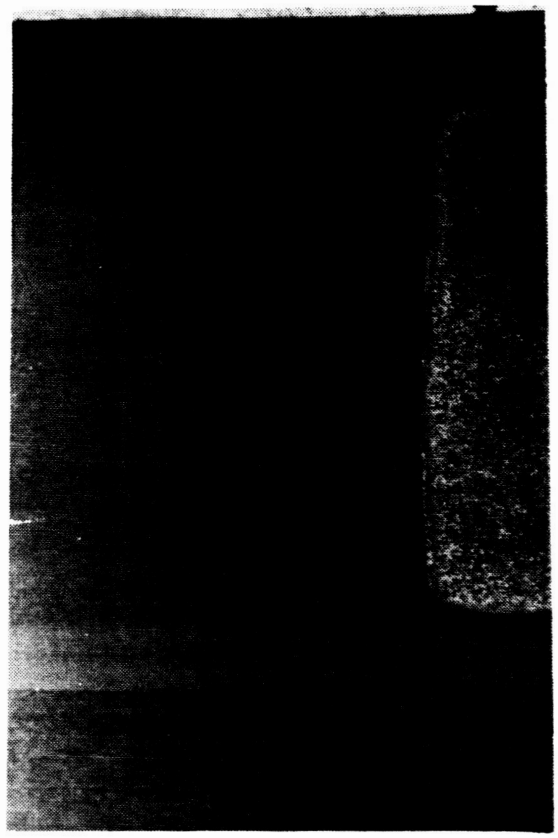

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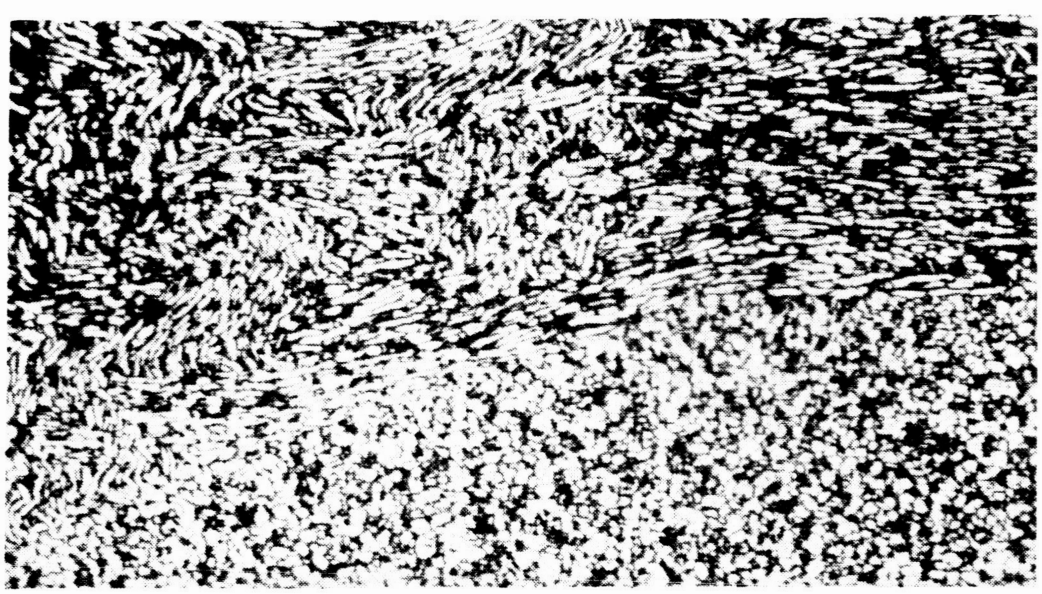
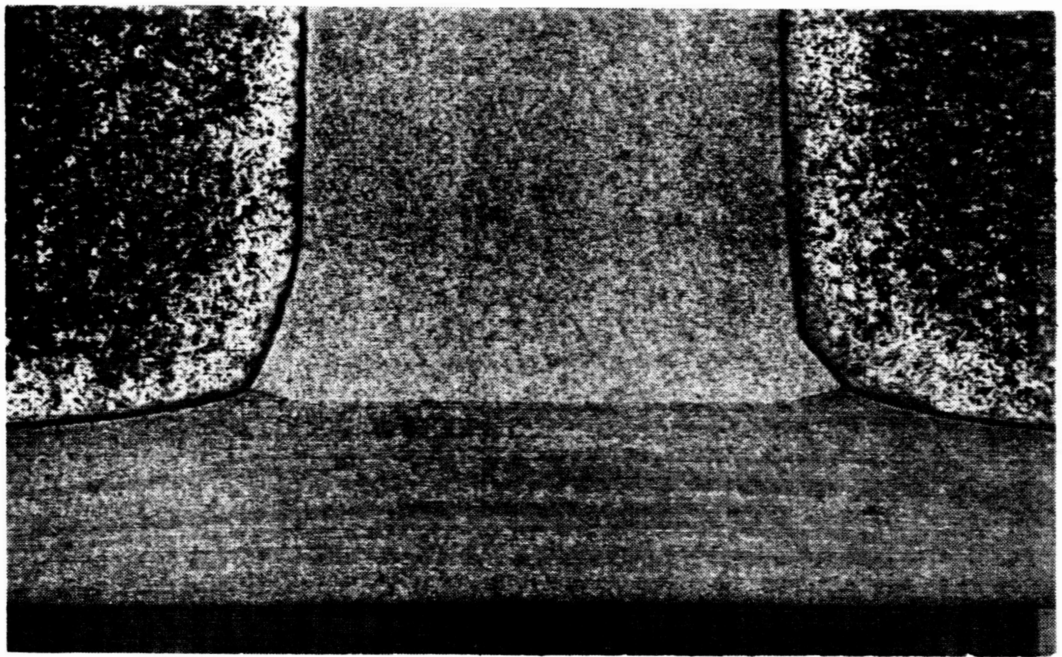
FIGURE 17 BULKHEAD-SKIRT CONNECTOR JOINT AREA-PACK #9



150X

FIGURE 18 INWARD FACING SHEET-TO SKIRT ATTACHMENT MEMBER BOND-PACK #9

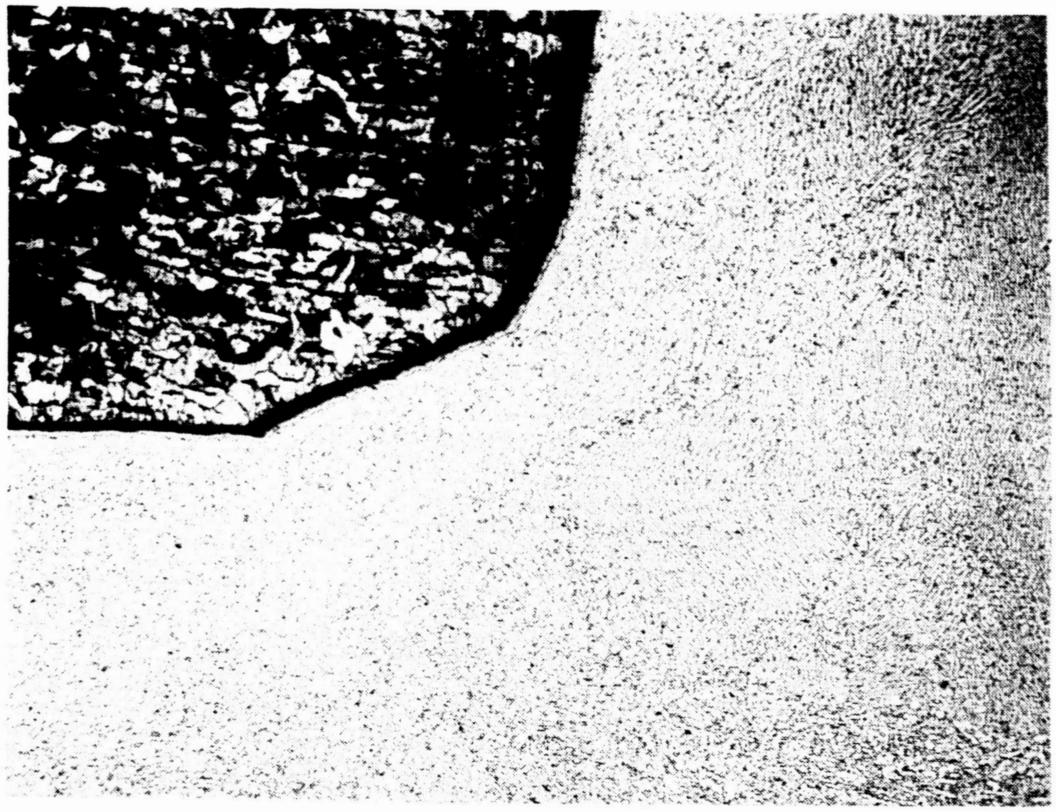


14X

FIGURE 19 STIFFENER-TO-FACING JOINT-PACK #7

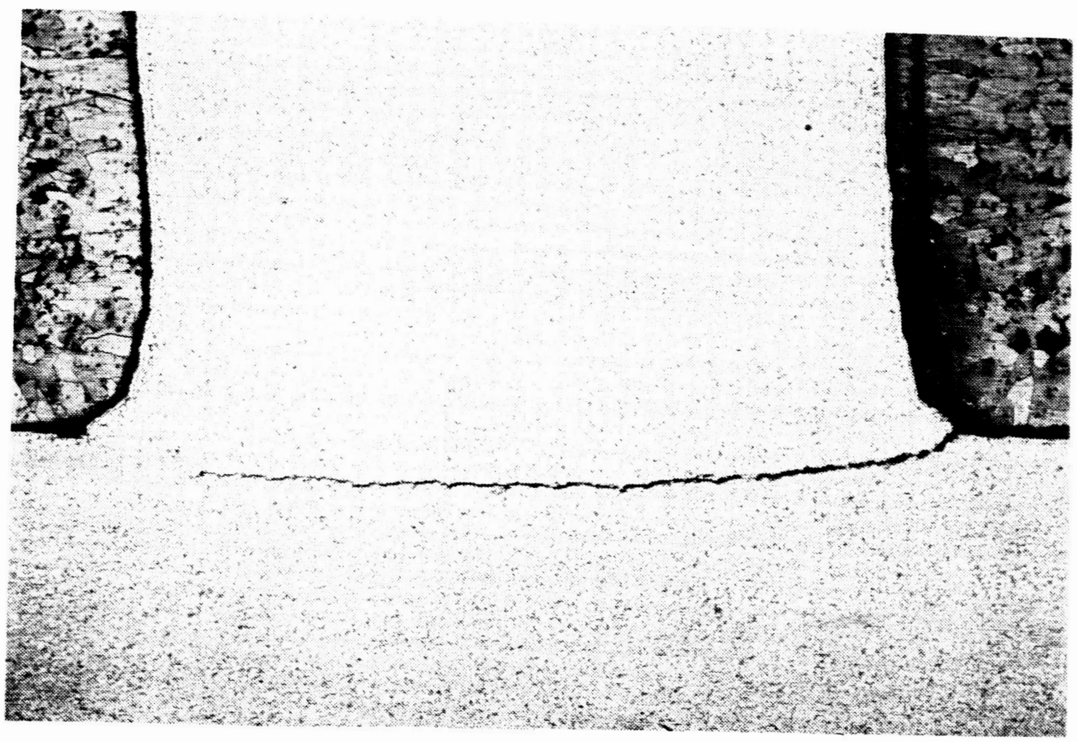
150X

FIGURE 20 SURFACE AND BOND LINE CONTAMINATION - PACK #7



250X

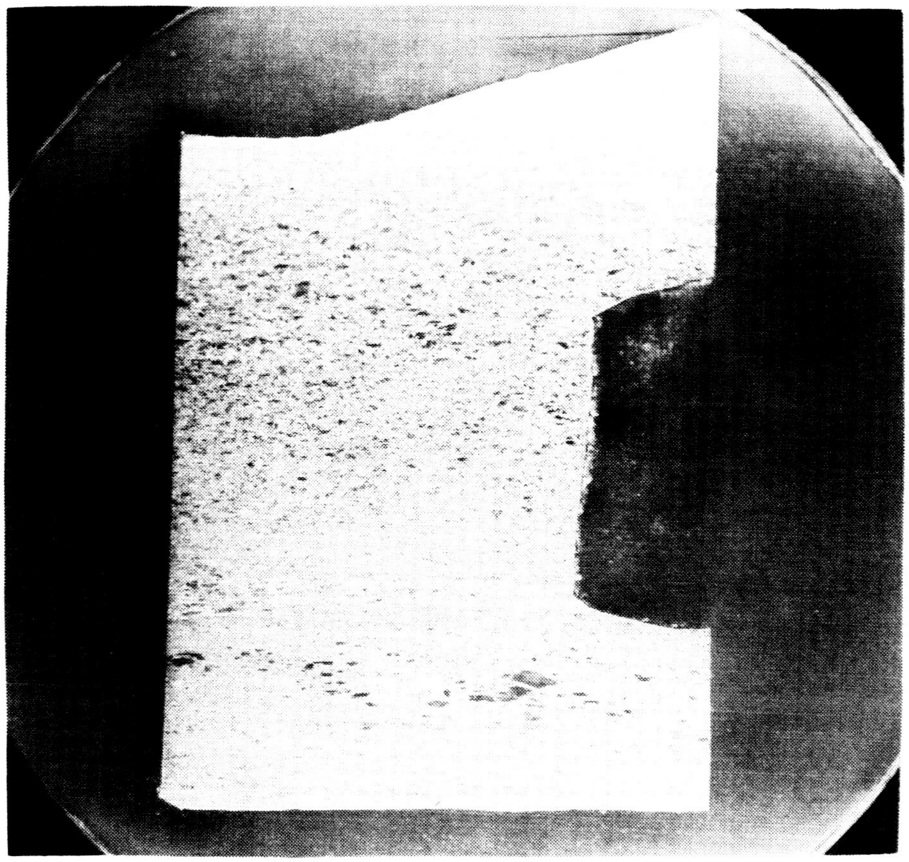
FIGURE 21 STIFFENER-TO-FACING JOINT-PACK [illegible] (CENTER)



150X

FIGURE 22 STIFFENER-TO-FACING JOINT-PACK [illegible] (END)

Pack 6 was diffusion bonded with a rolling temperature of 1890F. This temperature is above the beta-transus temperature of 8-1-1 titanium and upon cooling, the microstructure transforms to an acicular alpha-beta structure which is not as desirable a structure from the elongation and toughness standpoint of the material. Figure 23 is a photomicrograph of the flange joints of pack 6 showing the transformed structure. It should also be noted that rolling at this temperature resulted in an extremely rough titanium surface.



4X

FIGURE 23 FLANGE AREA JOINTS - PACK [illegible]

Physical and Mechanical Properties

In order to determine the amount of interstial element pickup during roll diffusion bonding, analyses were made of hydrogen, oxygen, nitrogen, and carbon contents in the titanium material prior to bonding, after bonding, and after chemical milling. The data is shown in Table V. For the purpose of comparison, the maximum allowables per NAA Ti-8Al-1Mo-1V Material Specification are included. The data shows that no detrimental amounts of these interstial elements are picked up during the roll bonding process. Bend tests conducted on the material following chemical milling clearly indicates no loss in properties due to the presence of contamination. Specimens were bend tested to a 3.7t bend radius without failure. NAA Material Specification LB0170-177 specifies the requirement of a bend without failure equal to 4.5t.

Tests were made from Pack #8 to determine the effect of roll diffusion bonding on the mechanical properties of the parent material. The material that was used for the inner and outer facing sheets and the circumferential stiffeners was tensile tested in the pre-bond condition and tested after rolling. The data is shown in Table VI. The ultimate strength of the rib material was reduced approximately 21,000 psi and the facing material approximately 19,000 psi. The yield strength of the rib material was reduced approximately 19,500 psi and the facing material approximately 18,500 psi. The elongation of the rib material was increased approximately 7% and the facing material approximately 3%. The mechanical properties obtained following roll bonding meet the minimum properties for duplex annealed material as specified in NAA Material Specification LB0170-177.

Tensile tests were made from Packs #2 and #8 to determine bond integrity. Round tensile specimens were machined from the ring and flange area of the Pack #2 Y-Ring segment, the length of the tensile specimen being perpendicular to the circumferential direction of the segment. These tensile specimens incorporated three diffusion bonded joints within their reduced section. The data is tabulated in Table VII. All tensile properties meet NAA-LAD Material Specification for duplex annealed material.

TABLE V

INTERSTITIAL ANALYSES

Pack #8 Stiffener and Facing Material

	As Reported by TMCA (As Received)	Prior to Roll Bonding	After Roll Bonding	After Chemical Milling Facing	After Chemical Milling Rib	Max. Allowable (NAA Spec. LB0170-177)
Hydrogen	.006%	.0044%	.0061%	.0076%	.0048%	.0125%
Oxygen	.108%	.091%	.115%	.104%		.2%
Nitrogen	.011%	.012%	.01%	.021%		.05%
Carbon	.073%	.02%	.04%	.02%		.08%
Aluminum	7.89%	8.15%				7.50-8.50%
Molybdenum	1.20%	1.19%				.75-1.25%
Vanadium	1.05%	.94%				.75-1.25%
Iron	.22%	.18%				.3%

TABLE VI

TENSILE PROPERTIES OF ROLL BONDED Ti-8Al-1Mo-1V

Pack #8 Stiffener and Facing Material (Heat #3960977, Sheet #3637)

	As Reported by TMCA (As Received)	Prior to Bonding	After Bonding Rib	After Bonding Facing	NAA Spec. LB0170-177 Min. Duplex Annealed Properties
Tensile Strength (psi)	153,900 (T) 149,400 (L)	163,700 165,200 160,000	143,100 141,800	145,800 145,000	130,000
Yield Strength (psi)	147,100 (T) 137,200 (L)	154,800 157,700 153,200	137,000 136,500	138,600 136,400	120,000
Elongation (% in. 2")	14 (T) 13 (L)	11.5 9.0	17 17.5	13 --	10

TABLE VII
PACK NO. 2
R. T. TENSILE TESTS OF ROLL BONDED 8Al-1Mo-1V TITANIUM ALLOY
SPECIMEN TYPE - ROUND - TAKEN FROM 1-1/4 THICK SECTION ACROSS BONDS

IDENT	DIAMETER	AREA	LOADS LBS ULT.	LOADS LBS YIELD 1/2 IN	STRESS KIS ULT.	STRESS KIS YIELD 0.2%	RED. DIAMETER	% R.A.	% TEN. EL 4D
1	0.0982	0.00757	1062	988	140.2	130.5	0.080	33.6	12.5
2	.1013	.00806	1111	1027	137.8	127.4	.080	37.6	15
3	.1010	.00801	1093	1012	136.5	126.3	.076	43.3	12.5
4	.1004	.00792	1094	1000	138.1	138.1	.081	34.9	15
5	.1011	.00803	1130	1028	141.0	128.0	.081	35.8	12.5
Average			1098	1011	138.7	130.1		37.0	13.5
MIN. DUPLEX ANNEALED PROPERTIES - NAA Spec. LB0170-177					125.0	115.0		--	10.0

Test specimens in the form of "I" sections were machined from the stiffened panel area of the Pack #2 segment to evaluate joint integrity. Special grips which enabled gripping the two legs (facing sheets) next to the web (circumferential stiffener) were employed for the tests. The numerical test valves (stress) obtained, see Table VIII, varied considerably depending upon the type of failure that occurred. The type of failure that occurred was influenced by bond quality, specimen geometry, and the position of the grips relative to the legs on the test specimen. Some specimens failed in shear with one side of one of the legs shearing off adjacent to the supporting webb. This was due principally to the fact that the loads required to fail the webb area in tension exceeded those required to shear one of the legs. However, the test values obtained, were generally lower than would be expected for this material in shear. This can be explained by the high notch factor occurring in the fracture area which is a result of the leg joining the webb at a 90° angle with a relatively sharp included radius. Another factor which had an influence upon fracture location as well as recorded breaking stress was the grip and its relative position on the test specimen. In some cases, deflections of the legs were permitted which always resulted in a shear failure.

A second type of specimen failure that occurred involved fracture of web material after the initial shear in the leg. Values derived from these tests are not considered quantitative measures of material strength since the secondary failure resulted from outer fiber bending stresses due to specimens cocking after leg failure.

In an attempt to obtain a true tension failure in the webb or bond area, two specimens had a radius machined into the webb area thus reducing the cross section in that area. When these specimens were tested, failure occurred in the web adjacent to one of the legs well away from the reduced section. Here again the high notch factor inherent with a specimen of this geometry was a influencing factor upon fracture location.

Three "I" section specimens were machined from the panel portion of the Pack #8 segment to evaluate the validy of the new roll bonding techniques. For a direct comparison with the Pack #2 results, the webs were machined to the same thickness. These test results are also reported in Table VIII. There were no bond failures and the web stress at fracture was higher. Failure occured by shear through the cap and subsequent failure through the web (tear) near the cap, in two of the three tests.

TABLE VIII
R.T. TENSILE TESTS OF ROLL BONDED 8Al-1Mo-1V TITANIUM ALLOY
"I" Section (Facing Sheets - To Circumferential Stiffeners)

	SPECIMEN IDENT.	WEB. THICK (Ins.)	WEB WIDTH (Ins.)	AREA (In^2)	ULTIMATE LOAD (Lbs)	ULTIMATE WEB STRESS (Psi)	REMARKS
PACK #2							
	5-1 (1)	.047	.498	.0234	1,020	43,600	Bond Failure
	5-2 (1)	.046	.497	.0229	1,790	78,100	Bond Failure
	5-3 (1)	.046	.497	.0229	1,340	58,500	Bending Failure
	4-1 (1)	.047	.509	.0239	1,955	81,900	Bending Failure
	4-2 (1)	.047	.507	.0238	1,080	45,400	Bond Failure
	4-3 (1)	.047	.507	.0238	1,500	63,000	Bending Failure
	Average				1,447	61,750	
	1-1 (1),(2)	.047	.270	.0127	1,520	120,000	Bond Failure
	1-2 (1),(2)	.047	.272	.0128	1,115	87,100	Bond Failure
	Average				1,317	103,550	
PACK #8							
	A (1)	.0450	.5025	.0226	2,555	112,800	Cap Shear Failure
	B (1)	.0453	.5022	.0227	2,555	112,300	Cap Shear Failure
	C (1)	.0462	.5018	.0232	2,500	107,700	Cap Shear Failure
	Average				2,537	110,933	
	PM 1	.0434	.499	.0216	2,980	137,800	Cap Shear Failure
	PM 2	.0436	.500	.0218	2,960	135,600	Cap Shear Failure
	PM 3	.0440	.500	.0220	2,760	125,200	Cap Shear Failure
	Average				2,900	132,870	

NOTES: (1) Nitric Acid Etch, Pickled, No Indication of Cracks Using Die Penetrant
(2) Reduced Width In Web Section.

Three specimens were machined from Pack #8 rib material to the same configuration as the Pack #8 bond test specimens for the purposes of comparison. The test results are also shown in Table . The mode of failure was the same, shear through the cap, although the ultimate load was higher. The parent metal test specimens failed in shear with an average web stress of 132,870 psi however, the ultimate stress of the rib material, from which they were machined was an average 142,850 psi as determined by standard flat-wise tensile specimens, see Table

It should be pointed out that tension tests on roll bonded specimens of the "I" configuration are valuable in evaluating bond intregrity and should be examined from the standpoint of fracture location and mode as well as the load required to produce failure. However, it is questionable if meaningful and quanitative numberical values (stress) result from these tension tests due to the limitations imposed by specimen geometry.

Non-Destructive Testing

After removal from the pack, but with the steel filler bars in place, a section of Pack #2 was evaluated by ultrasonic through transmission, ringing, and high resolution (SPIDER) techniques as well as by penetrant inspection of exposed bonded surfaces.

The through transmission technique using the pulse echo immersion method with a back reflector plate gave unreliable results and was discontinued.

The standard ringing technique appears capable of detecting disbond conditions, but could not differentiate between bonding of the steel filler bars and the bonding of the titanium stiffeners.

The high resolution (SPIDER) technique showed very promising results. This instrument, developed by NAA, showed a feasibility of differentiating between the bonding of steel filler bars and the bonding of the titanium stiffeners. In addition, it was apparently capable of measuring the thickness of the rolled bonded structure and the titanium facing sheets.

The penetrant inspection method, Fluorescent Penestrip, was very effective in revealing disbonds when the rolled diffusion bonded structure containing the defect was exposed to the surface.

Pack #4 had "built-in" bond defects prior to rolling in the skirt attachment area and in several facing-to-stiffener joints. These defects were in the form of machined slots and parting compounds such as aluminum oxide. These defects were to be used to develop non-destructive testing techniques for locating disbonds following roll diffusion bonding.

The Pack #4 Y-Ring segment had vertical stiffeners transverse to the rolling direction and as a result of the distortion of these members during rolling, ultrasonic inspection of this area was not possible. Only the skirt attachment area could be tested.

One half of the segment, following removal from the pack, was tested using various pulse-echo ultrasonic techniques on a Curtiss-Wright Immerscope, Model 424D. Disbond indications were plotted, and three selected sections were cut, polished, etched, and visually examined. Three disbonds were found, and these areas were again ultrasonically tested. Various focused and flat transducers were used by themselves and with collimators and slits. None of these techniques were successful. Signals from the actual disbonds were obtained along with numerous other signals indicating disbonds where there were none. No gating technique could be devised to record only the true disbonds. In some cases, the multiple echoes from actual disbonds would fall in the gate and would not be recorded.

The main cause of these difficulties was assumed to be the surface roughness. Therefore, the surface of a small area on one of the sections was ground smooth. Retesting this area gave satisfactory results. The erroneous signals were eliminated, and the actual "build-in" disbonds could be recorded. The following technique was established and is anticipated for use to inspect the full-scale Y-Ring segments. The beam was focused on the front surface of the structure, and the back surface echo was gated. Loss of the back surface echo was recorded as a disbond somewhere between the front and back surfaces of the part. These areas were then reinvestigated to locate the joint disbonded. This technique was able to detect a 1/16 inch disbond through 1-1/8 inches of titanium.

MACHINING

Machining to the design configuration was conducted on the roll diffusion bonded sub-scale test components to provide parts suitable for forming studies and to explore the basic machining concept which will be used in machining the full scale Y-Ring.

FLANGE MACHINING

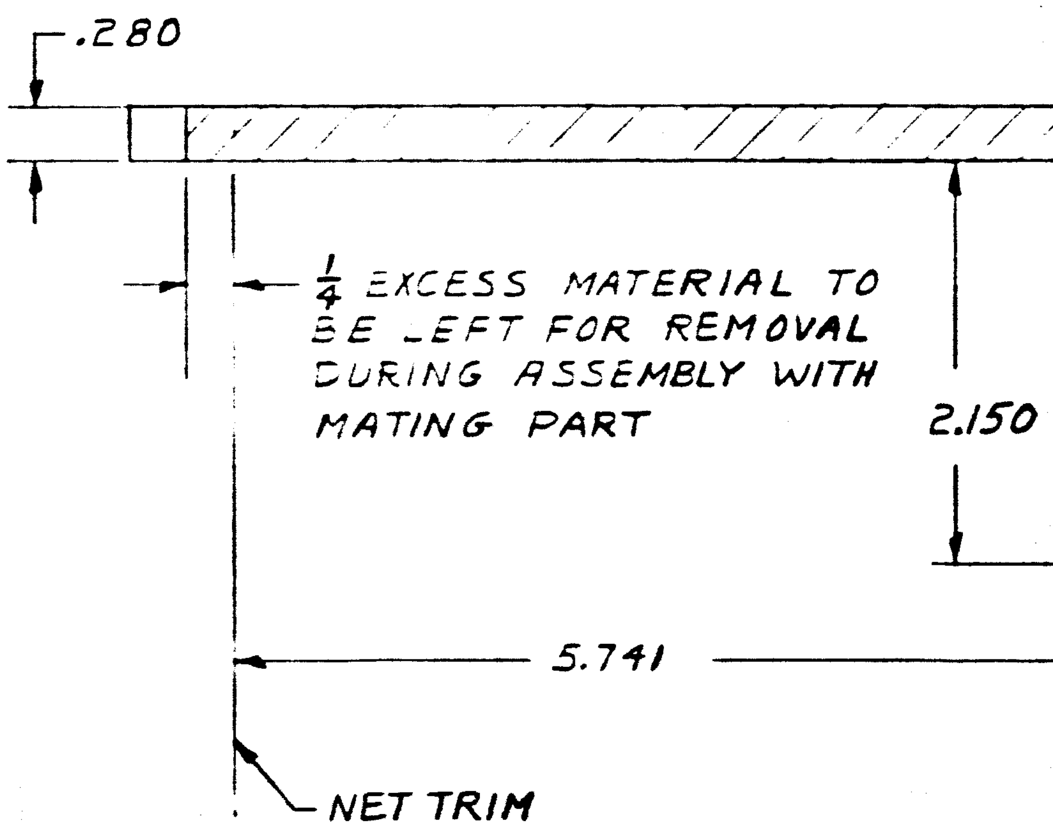
In the initial investigation of the fabrication requirements for the full scale Y-Ring utilizing fabrication concept "A", Figure 2, it was planned to conduct the machining operations after the Y-Ring pack had been roll formed into the 33 foot diameter cylindrical shape. This procedure would have required the cylindrical flange machining to be performed either by the use of a special skate machining fixture or by the use of a large vertical boring mill. A preliminary design of a skate machining fixture was prepared, NAA Drawing No. T10706 (Reference d). Although boring mill facilities of adequate size were not available on the contractors site, two facilities were located capable of performing this operation. The tentative costs of machining the flange by the methods mentioned are tabulated below:

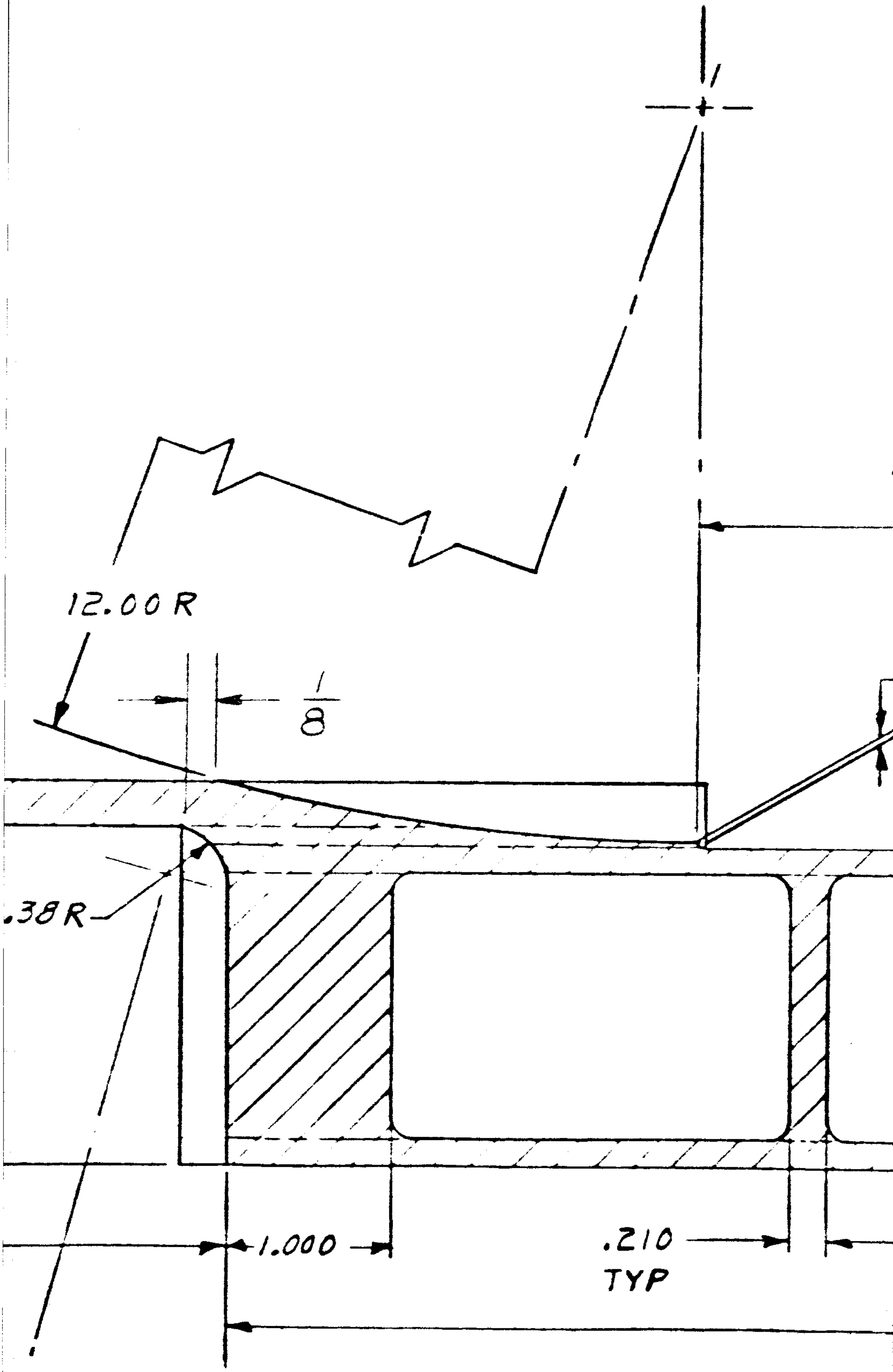
Preliminary Y-Ring Machining Data
(Configuration A)
Machining Flange of Two Full Scale Y-Ring Segments

	Skate Mach. N.A.A. Dwg. T-1070675	Purchased Labor **Source A** (Rough Estimate)	Purchase Labor **Source B** (Rough Estimate)
Tooling	12,000	30,000	
Machining	24,000	20,000	50,000
	36,000	50,000	50,000

Fabrication concept "A" would require procurement of approximately 1475 pounds of titanium for each full scale Y-Ring segment or approximately 650 pounds more titanium than is required for the forming fabrication concept "C" which requires approximately 825 pounds.

As a result of a review of various possible fabrication approaches for the full scale Y-Ring segment, fabrication concept "C" was selected as the most feasible and economical method of fabrication. Since, in this configuration the flange achieves its design thickness requirement during the roll diffusion bonding operation, only cleanup machining is required as shown in Figure 24. This cleanup machining will be performed after the pack covers are removed and while the pack is still in the flat condition. This method of removing the excess titanium in the flange area

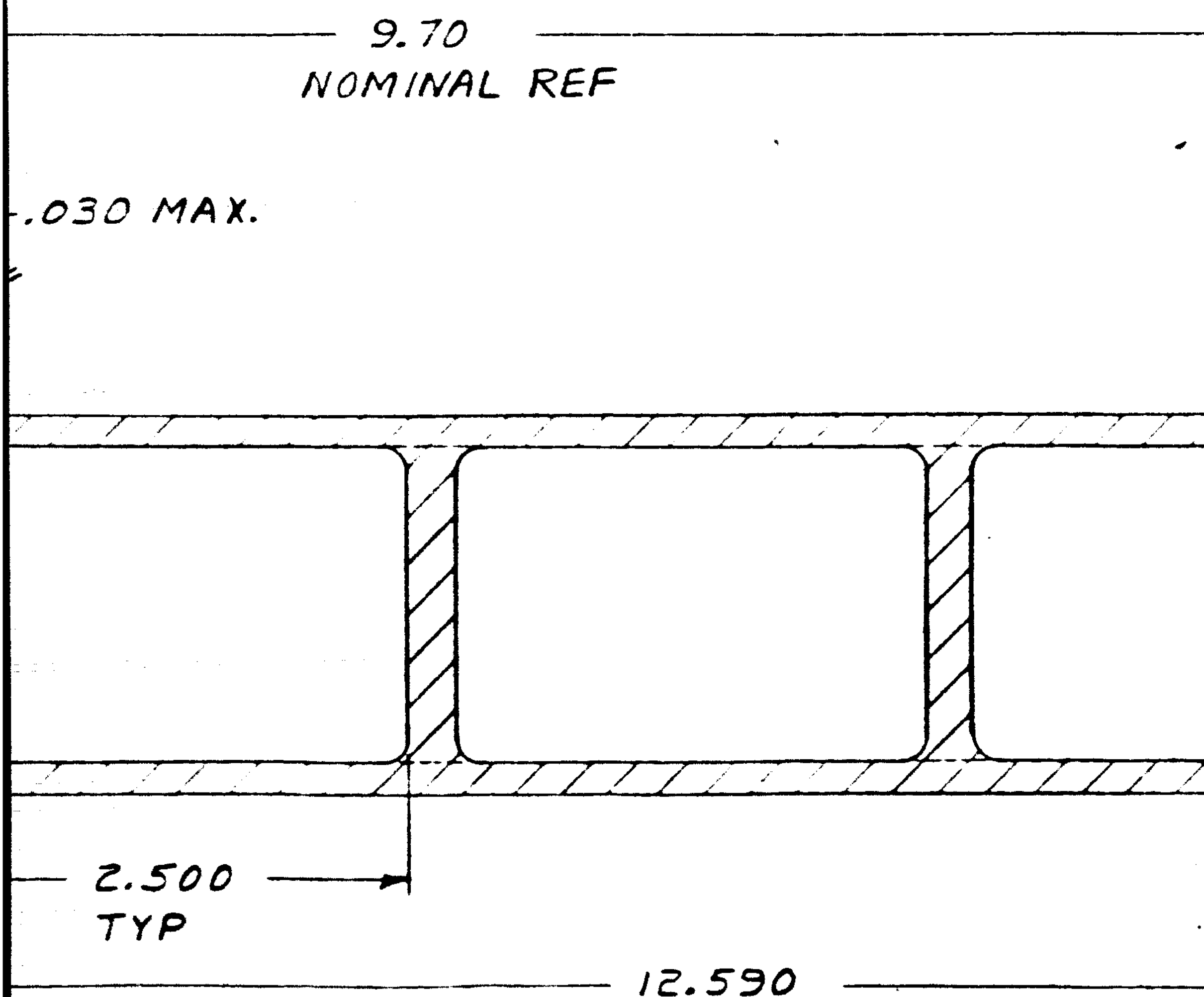

.280
1/4 EXCESS MATERIAL TO BE LEFT FOR REMOVAL DURING ASSEMBLY WITH MATING PART
2.150
5.741
NET TRIM

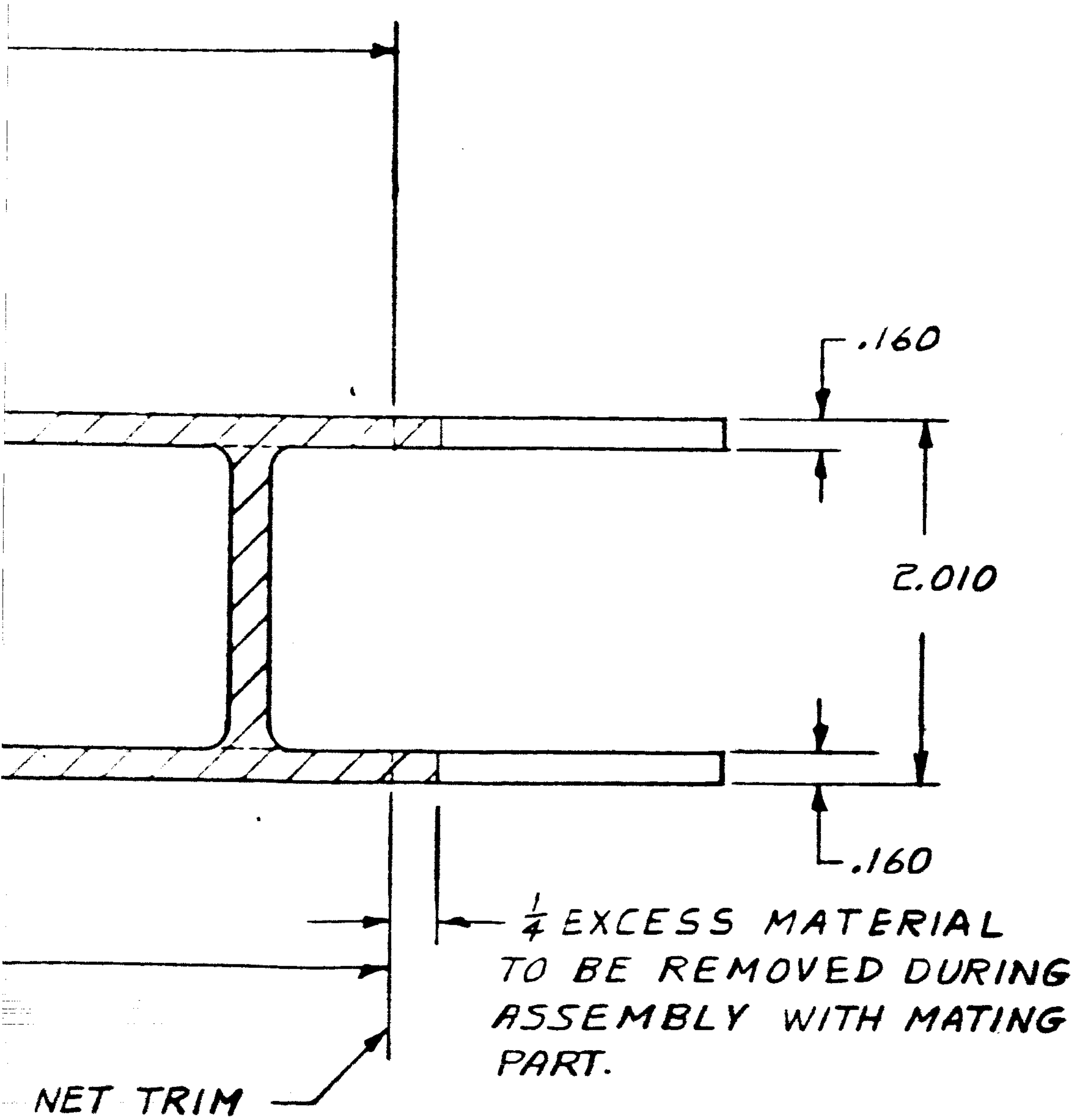


52-3

FIGURE 24

MACHINE TRIM PRIOR TO FORMING




.160
2.010
.160
¼ EXCESS MATERIAL TO BE REMOVED DURING ASSEMBLY WITH MATING PART.
NET TRIM

was chosen because of the considerable saving in machining cost as compared to machining after forming using the skate technique or vertical boring mill method. A demonstration of this machining concept was made on subscale test component specimens which show the feasibility of this method of machining the flange, see Figure 25.

POCKET MACHINING

After forming, the 127 pockets in the full scale Y-Ring will be machined using conventional techniques in a horizontal boring mill. This pocket machining was demonstrated on formed sub-scale components and Figure 26 shows a machined part.

TRIM MACHINING

The flange end and the face sheet ends of the rib stiffened section of the Y-Ring segment will not be machined to a net dimension because of the requirements for excess material. This excess material is necessary to assure proper fitup during the subsequent weld joining required with mating parts. Figure 26 shows 1/4 in. excess material remaining on each end of part which is customary for weld joint fitup requirements.

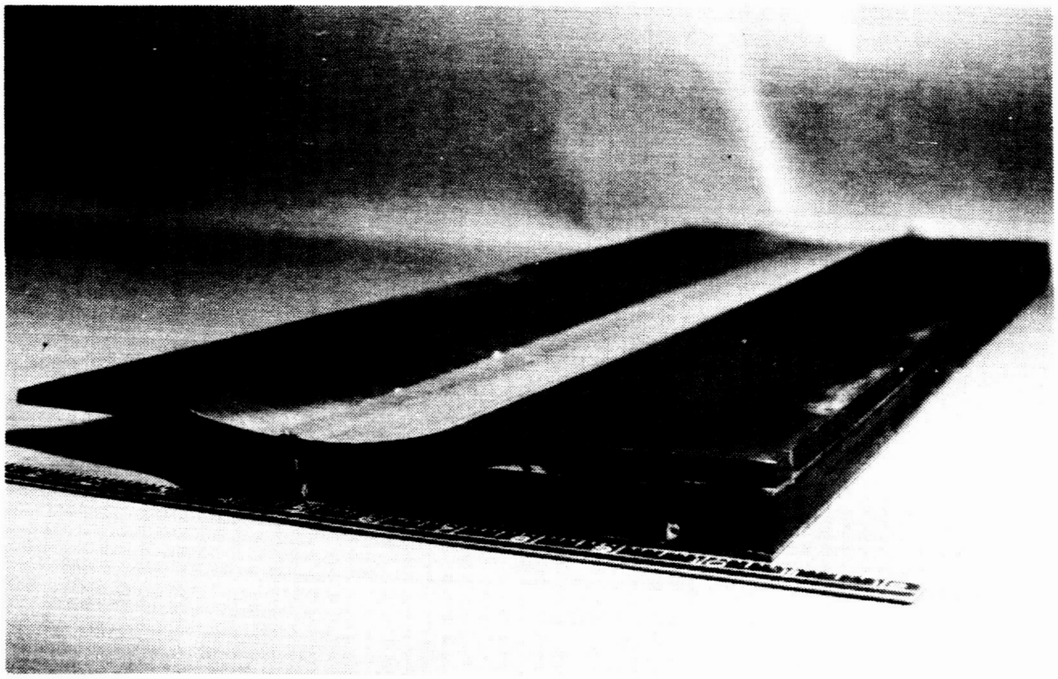


FIGURE 25 MACHINED SUB-SCALE PACK FLANGE RADII

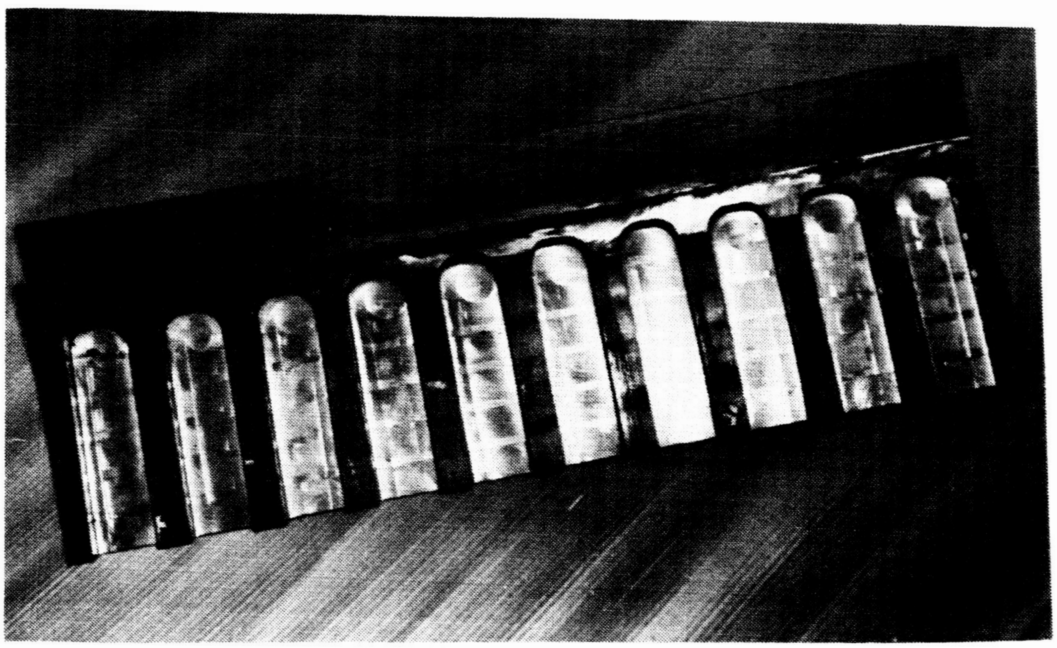


FIGURE 2[illegible] MACHINED POCKETS IN SUB-SCALE PACK

HOT FORMING

Two methods were investigated for achieving the 198-inch radius required by the Y-Ring segment. These methods are (1) Roll contouring of the pack followed by removal of outside steel with subsequent machining of the flange (Configuration "A"), and (2) Hot creep forming of the stripped part at one time or by incremental methods (Configuration "C").

ROLL CONTOURING

Roll contouring of subscale Pack #3 was accomplished at Southwest Welding and Manufacturing Co., located at 3201 W. Mission Road in Alhambra, California. The pack, while still encapsulated in steel, was heated to 1700F in 6-1/2 hours in a gas fired furnace and stabilized at this temperature for 1 hour and 10 minutes.

An overhead gantry crane conveyed the hot part a distance of approximately 200 feet in 1-1/2 minutes to a 14-foot, 25-inch diameter, heavy duty Birch pinch roll. The hot part was fed into the rapid reversing roll and reversed back six times with the idler roll raised incrementally each pass to achieve the desired 198-inch radius. Pack temperature was checked by temp-stick at the conclusion of rolling and found to be between 1300 and 1400F.

CREEP FORMING

The hot creep-form/size operation requires a mated steel punch and die. This tool was designed to be economically manufactured from flame cut 1018C steel plates welded to base plates. Each tool member consisted of two 6-inch thick plates flame cut to the required curvature, welded together for a 12-inch die width, then welded to a base. Six inch thick plates were used to insure contour conformity and surface smoothness which tends to become increasingly more difficult to control as plate thickness increases.

The as-cropped pack measured 2-inches thick, 9-3/4 wide, 37-1/2 inches long, and was fitted with 4 alumel-chromel thermocouples for temperature control during forming.

The machine tool used for hot creep-form/size operations is a Sheriden-Gray hot-size press shown in Figure 27. It is an electrically heated press rated at 75 tons horizontal clamp pressure and 300 tons vertical ram pressure. For this particular contouring operation only the ram pressure was utilized.

The punch and die were loaded into the hot-size press with upper and lower press platens indicating 1200F. After loading the cold die into the press, a soak period of 3 hours was required to restabilize platen temperatures at 1200F. Pack #1 was then loaded into the pre-heated tool and allowed a 1 hour soak period to achieve thermocouple temperatures of approximately 1000F. Initial ram pressure of 25 tons was then applied to commence accelerated creep forming with subsequent build-up of forming load to the maximum 300 tons obtainable by the press.

Subsequent to the contour rolling and after the cover plates were removed, Pack No. 3 was also hot creep formed at NAA on the 300 ton Sheridan-Gray hot-size press to shape the conical flange and the 198 inch radius to the dimensional requirements of the finished Y-Ring design as follows:

The hot-size press was stabilized at 1400F. The part was loaded into a steel weldment/Glasrock tool in an adjacent preparation area. The room temperature tool and part were loaded into the hot-size press and soaked for a 4 hour period to achieve 1400F at the die face. Forming pressure was then applied at a rate of 25 tons every 10 minutes for one hour. At the end of this one hour period, with 150 total tons of ram pressure applied, a visual inspection showed zero gap between the part and form die. The remainder of press capacity, 150 tons was then applied to achieve full forming pressure of 300 tons. The part was subjected to this 300 ton static forming pressure at 1400F for 2-1/2 hours. After removal of ram pressure, and opening of the press, the part to die conformity was excellent as can be seen in Figure 28.

Pack #3 and Pack #9 parts were formed similarly. Each was fitted with thermocouples to record part temperature independent of press and die temperature. The steel weldment/Glasrock tool was charged into the Sheridan-Gray hot size press and allowed to stabilize at 1450F. A stripped subscale part in the straight and flat condition was loaded into the preheated tool. When 1450F was indicated by the part thermocouples, a unit compressive load of 25 tons was applied and held for 5 minutes. An additional 25 tons was applied for each succeeding 5 minute period totaling 150 tons in 30 minutes. This accelerated creep forming phase closed the die gap and a remaining 150 tons, 300 tons total, was applied for an additional 45 minutes. After cool-down and removal of the upper die half, part to die conformity was excellent.

Pack #7 part was subjected to incremental forming techniques after minor modification to the steel weldment/Glasrock tool. An angle iron ramp extending about 24 inches, was affixed to one end of the lower tool member. This ramp supported the flat and straight workpiece in its starting position except for 6 inches of the lead end which was fed into the die as the first increment to be formed. A steel filler, of a thickness equal to the workpiece, filled the balance of the die providing uniform tool loading.

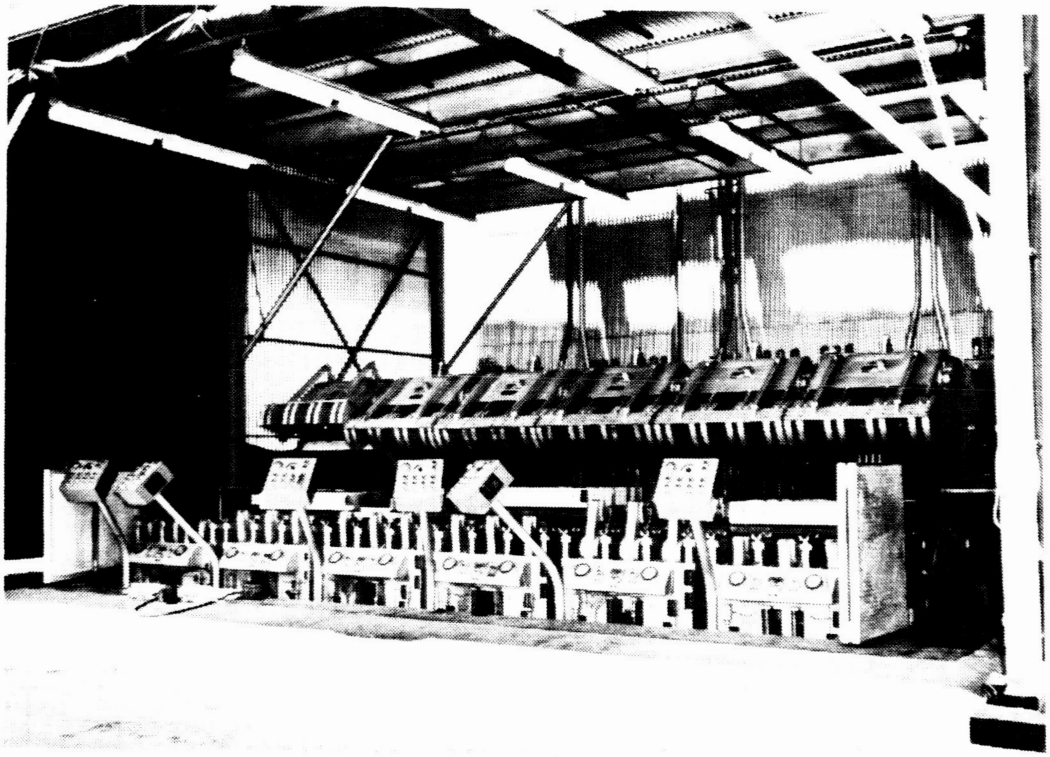


FIGURE [illegible] HOT SIZING PRESSES AT NAA/LAD

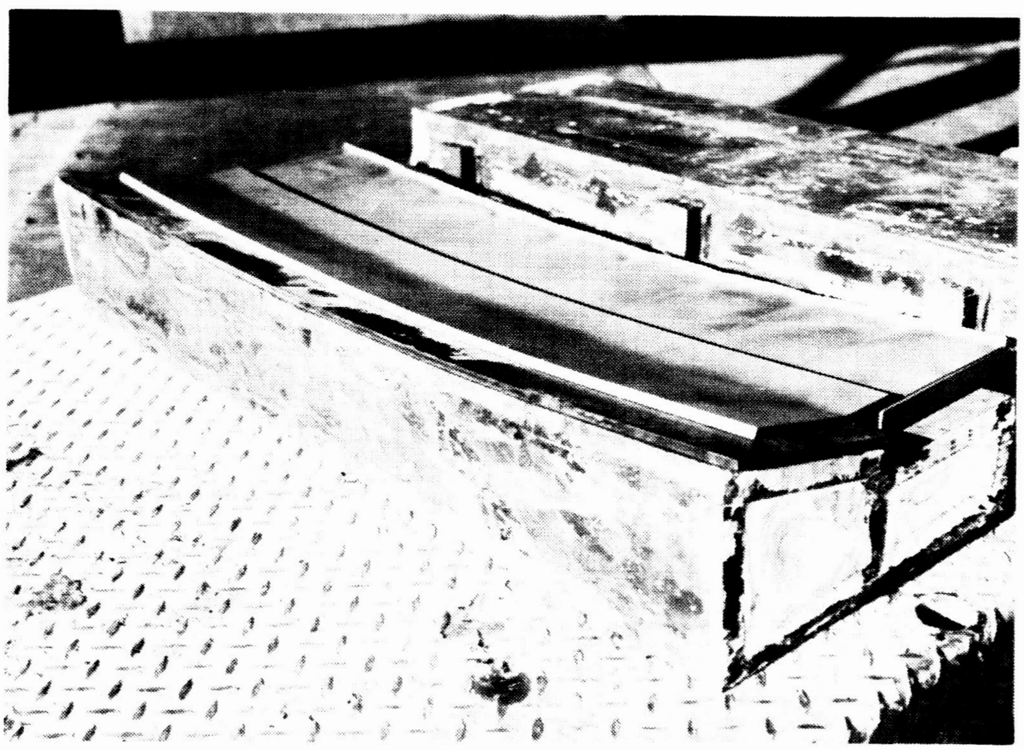


FIGURE [illegible] DOUBLE CONTOURED DEVELOPMENTAL PACK

The modified tool with ramp, filler, and workpiece in position as described, was charged into the Sheridan-Gray hot-size press and stabilized at 1175F. A compressive load of 150 tons was slowly applied over a period of 5 minutes after which the balance of press tonnage, 150 tons, was applied. The total 300 tons load was held for another 5 minutes, released and the part advanced an additional increment of 6 inches moving the filler an equal distance. Repetition of this procedure; 10 minute load periods, 6 inch advances, continued six times until the workpiece was completely fed into the die and the filler plate ejected. 1/4 inch dia. steel rods were attached to the workpiece and to the filler plate, oriented parallel to the line of travel, and allowed to extend from the hot-size press providing physical facility to incrementally advance the work upon die opening. After cool down and removal of the upper die half, the flange to die conformity was excellent.

GLASROCK TOOL

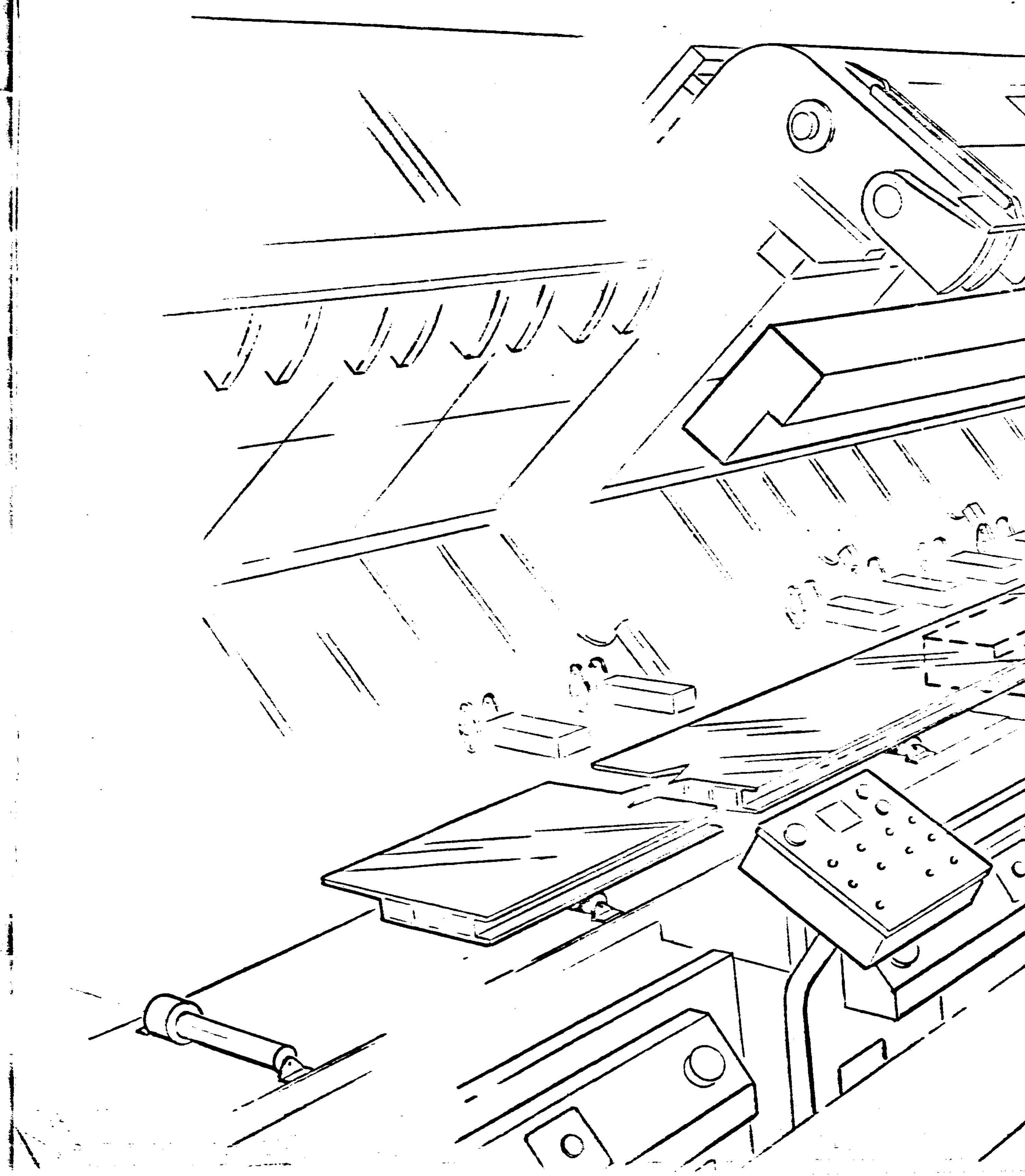
The tool used for forming the conical flange of Pack #1 part, and also the subsequently discussed Pack #3 and Pack #9 parts, is an economically constructed steel weldment/Glasrock combination. Sequence of construction is described as follows; 1) Flat steel plates of 1018-20 HRS, 1/2 inch thick, are flame cut to required flat pattern shapes, 2) Plates requiring contour are rolled to match templates, 3) Plates are clamped together building block fashion in their proper plane relationship and tack welded, 4) Plates are fusion welded together at all joints forming a hollow "box" structure supporting the curved die face, 5) The hollow is filled with castable Glasrock and allowed to harden, and 6) The steel weldment/Glasrock tool is baked at 190F for 12 hours to drive off residual moisture. This tool has performed satisfactorily for many hours under compression loads of 300 tons and temperatures to 1550F.

FULL SCALE Y-RING FORMING

At the conclusion of the fabrication development effort it was readily apparent that the optimum configuration from both the deformation and machining standpoint, is configuration "C" and the optimum procedure is an incremental hot form/size technique. On a continuing developmental basis, the NAA Sheridan-Gray hot-size press is an ideal heat and pressure media for time/temperature/load dependent plastic deformation operations. Based on the successful forming of subscale Y-Ring parts by these techniques, it was decided to apply the same basic fundamentals to forming full scale Y-Ring segments.

The forming tool planned for use on the full scale Y-Ring specimen is a 2 piece HS Meehanite ductile iron casting designed to simultaneously hot form/size the 198-inch radius contour and the conical flange displacement, incrementally as the specimen is "fed" through the die. Figure 29 is a sketch showing this tool mounted in the hot-size press with a specimen having progressed through it several feet. On exit from the hot form/size tool, a handling fixture receives the specimen providing support in the controured condition. Figure 30 is a schematic of this operation, the upper sketch showing hot-size press position with the specimen partially formed, the lower sketch showing incremental advancing position with the die and lower platens lowered to allow "feed in" of another increment. It is planned to form/size at 1450F for a 10 minute period, release load, advance the specimen approximately 6 inches, apply load for 10 minutes, and repeat this cycle for the full specimen length.

Y-RING, HOT CONTOUR



NA-56-104

FORMING CONCEPT

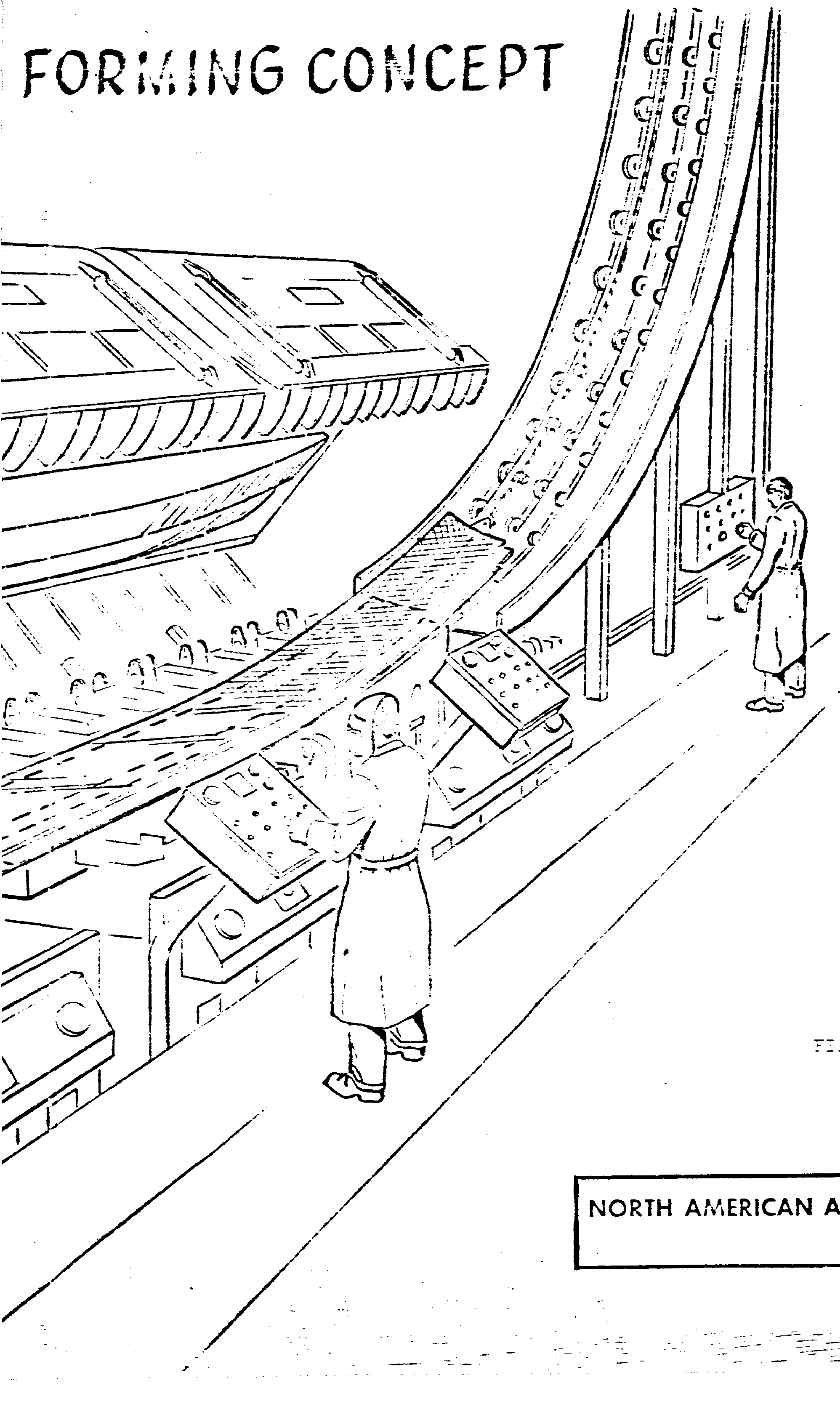
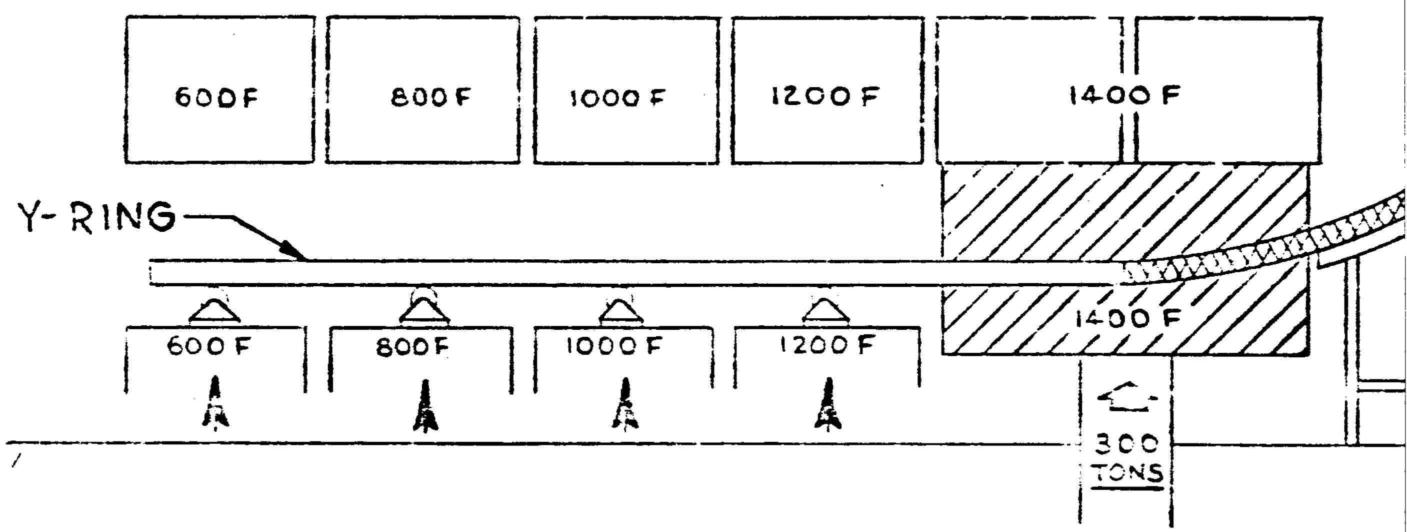


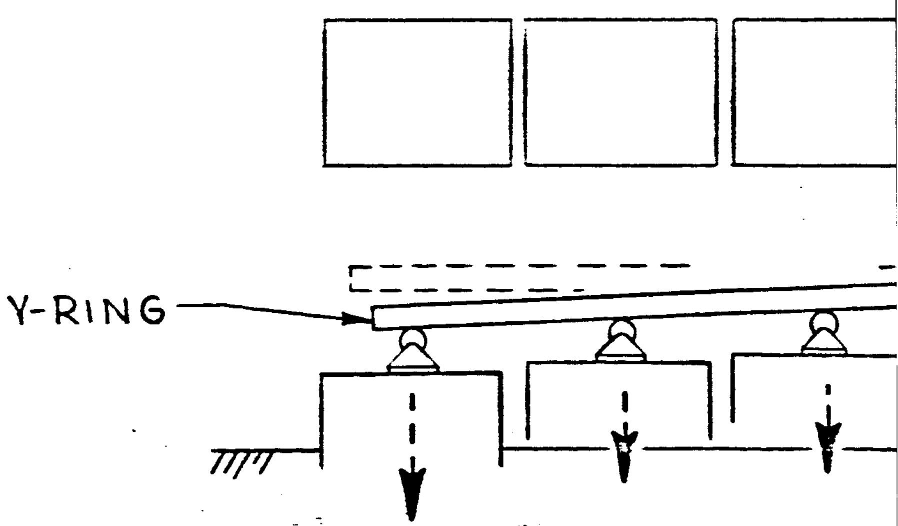
FIGURE 29

NORTH AMERICAN AVIATION, INC.

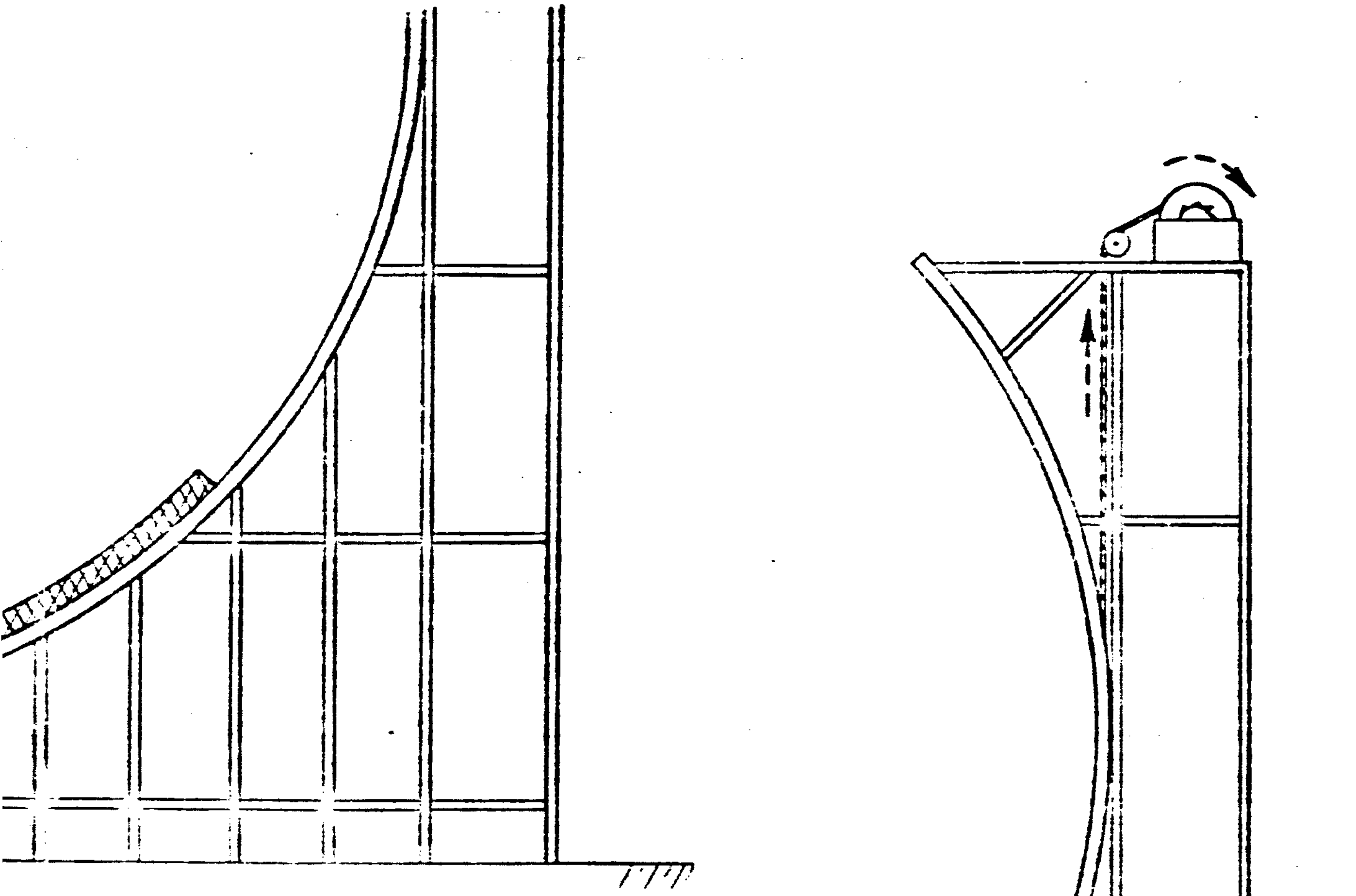
Y-RING, HOT CONTOUR FO

FORMED POSITION

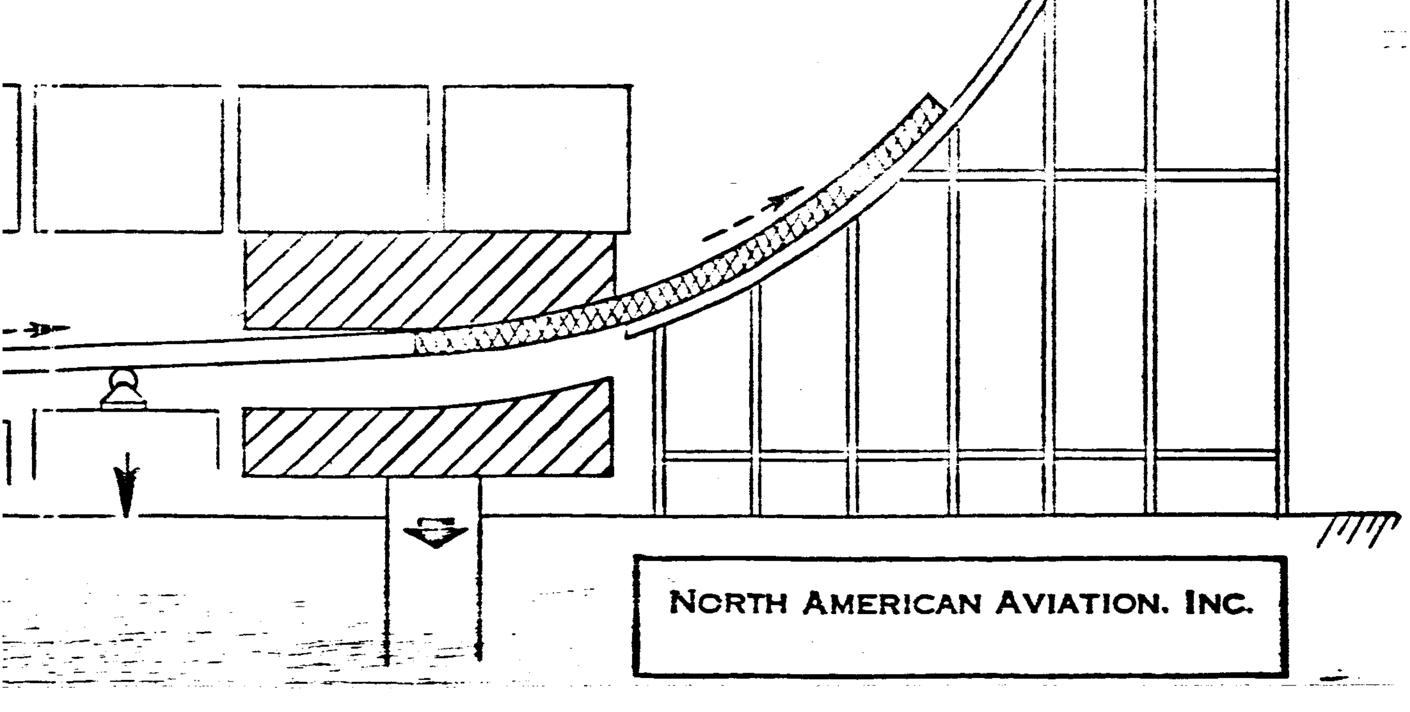




RMING CONCEPT



INCREMENTAL ADVANCING POSITION



NORTH AMERICAN AVIATION, INC.

THERMAL TREATMENT

Ti-8Al-1Mo-1V alloy sheet in the duplex annealed condition exhibits an excellent combination of fracture toughness, strength and weldability. The use of duplex anneled material also permits fusion welding the alloy without cracking and potentially eliminates the need for post weld stress relieving.

The duplex annealing treatment is performed as a two-step operation, involving achievement of metallurgical equilibrium at 1450°F to obtain the desired alpha-beta phase relationship, followed by cooling from 1450°F at a rate sufficient to prevent initiation of the embrittling ordering reaction associated with Ti-8Al-1Mo-1V and other high aluminum titanium alloys. In sheet gages this rate is readily achieved by air cooling. The nature of the time-temperature ordering reaction in high aluminum titanium alloys is such that the material, even if properly duplex annealed, will undergo ordering when reheated to moderately high temperatures for sufficient lengths of time. This effect is shown for Ti-8Al-1Mo-1V in data obtained from Titanium Metals Corporation of America presented in Enclosure 1. Notch tensile tests using NASA sharp notch tensile specimens with a maximum root radius of 0.0001-inch were used to indicate loss in toughness or degree of embrittlement associated with the ordering phenomenon. The time dependency of the ordering reaction is evident from the decreasing values of notch tensile strength shown in parentheses and expressed in KSI at several temperature levels. Selection of a notch tensile strength of 120,000 psi as the criterion for toughness permits developing the curve, as indicated, describing the limiting time and temperatures for heating duplex annealed Ti-8Al-1Mo-1V to prevent initiation of ordering embrittlement. The curve also permits development of the critical cooling rate necessary for cooling the material from the duplex annealing temperature, 1450°F.

From the foregoing it is seen that attainment of duplex annealed properties in the Ti-8Al-1Mo-1V structure necessitates the development of appropriate thermal processing cycles either during or subsequent to bonding due to the erasure of prior thermal history by the high bonding temperatures. This has, however, permitted procurement of raw material in the less expensive mill-annealed condition.

The need for the use of heat in excess of 1000F for substantial lengths of time to form design contours in the post-bonded structure eliminates the practicality of attainment of duplex annealed properties during the bonding cycle since subsequent hot forming would disrupt the duplex annealed condition and order-embrittle the material. This has lead to development of combined hot forming/thermal processing cycles to produce the properties desired.

The approach taken involves heating the roll-bonded pack to the forming temperature, progressively contouring the pack through successive stages of dies and permitting the final formed segment of the structure to cool in air as it emerges from the furnace. The forming temperature, 1450°F, is selected to provide both ease in contouring and the micro-structure associated with duplex annealed Ti-8Al-1Mo-1V. The sequence of 10 minute increments at 1450°F in each die stage is designed to permit soaking at 1450°F to obtain metallurgical stability at temperature and to achieve incremental cooling from 1450°F through the time-critical ordering range, 1000F to 1300F, as indicated in Enclosure 1. It is recognized that a stepwise temperature gruadient will exist between 1450°F and lower temperatures; however, it is believed that 10 minute maximum sojours at intermediate temperature will result in the accumulation of less than 30 minutes, at temperatures in excess of 900F, well within the limit for beginning of ordering embrittlement. Tensile and notch tensile specimens will be taken from the formed pack to determine if duplex annealing has been achieved. If result are negative, it is planned to thermal cycle the part after leeching in the special handling fixture to achieve proper metallurgical condition for the 8-1-1 titanium.

RELATED PROCESSES

FILLER BAR REMOVAL

Removal of internal steel tooling filler bars that are interlocked with the titanium part and are in contact with four titanium surfaces is required. Filler bars are difficult to remove mechanically without risk of damage to the titanium structure. A short section of the sub-scale Y-Ring pack with the machined pockets was subjected to various tests in an attempt to remove the tooling bars. Two types of tests by mechanical means were employed; a sub-zero thermal shock treatment, and an elevated temperature thermal shock test.

Subzero Thermal Shock Test

A specimen approximately 9 inches square, was immersed in liquid nitrogen until temperature stability as indicated by lack of boiling had been reached. The part was then immersed in a bath of hot water at approximately 120F. The cooling and heating cycle was repeated five times, followed each time by tapping the bars to effect removal. No evidence of looseness was noted. After the final liquid nitrogen immersion but before immersion in hot water some of the bars were removed by tapping but not without some damage to the titanium structure.

Elevated Temperature Thermal Shock Test

A section of the machined Y-Ring approximately 9 inches square was subjected to elevated temperature thermal shock tests. The part was supported on a wire between two banks of GE T-3 1000 watt lamps (12 lamps on each side) for a total of 12000 watts. Temperatures were indicated by thermocouples welded to the face of the titanium skin. After reaching the specified temperature of approximately 650F at the surface of the titanium skin, the part was rapidly lowered into a bath of room temperature tap water. It was felt that sudden thermal expansion of the titanium skin relative to cooler internal steel tooling bar would break the bond at the steel titanium interface and facilitate mechanical removal. Four heating and cooling cycles as described above were run followed in each case by mechanical tapping of the steel tooling bars. Only the end bars, could be removed by this method accompanied by rupture of one of the standing flanges from the face sheet.

Leaching

Results of the mechanical extraction methods for removal of tooling bars has indicated that considerable effort would have to be expended to establish a method that is not only feasible, but one which would result in no damage to the titanium part. For these reasons, it was decided to discontinue this method of removal and investigate chemical removal methods. Leaching tests conducted for removal of steel tooling bars after pocket machining indicated that the leaching process is feasible and economical. After pocket machining, a considerable amount of steel surface area is exposed to the nitric acid, and the steel to be removed consists of many short lengths. Both of these factors assist the leaching operation. For the full scale Y-Ring segments, approximately 900 pounds of iron filler bars require removal by chemical leaching.

CHEM-MILLING

The final fabrication operation for the full-scale Y-Ring segment will be the chemical removal of the surface contamination on the titanium resulting from the rolling and hot contour forming operations. The chem-milling is to be performed in accordance with NAA/LAD Process Specification LA0103-003. Numerous samples have been chemically-milled with good results. An allowance of .002 inch thickness for the iron-titanium compound formed during rolling and .003 inch thickness for air contamination from heating has been used with success.

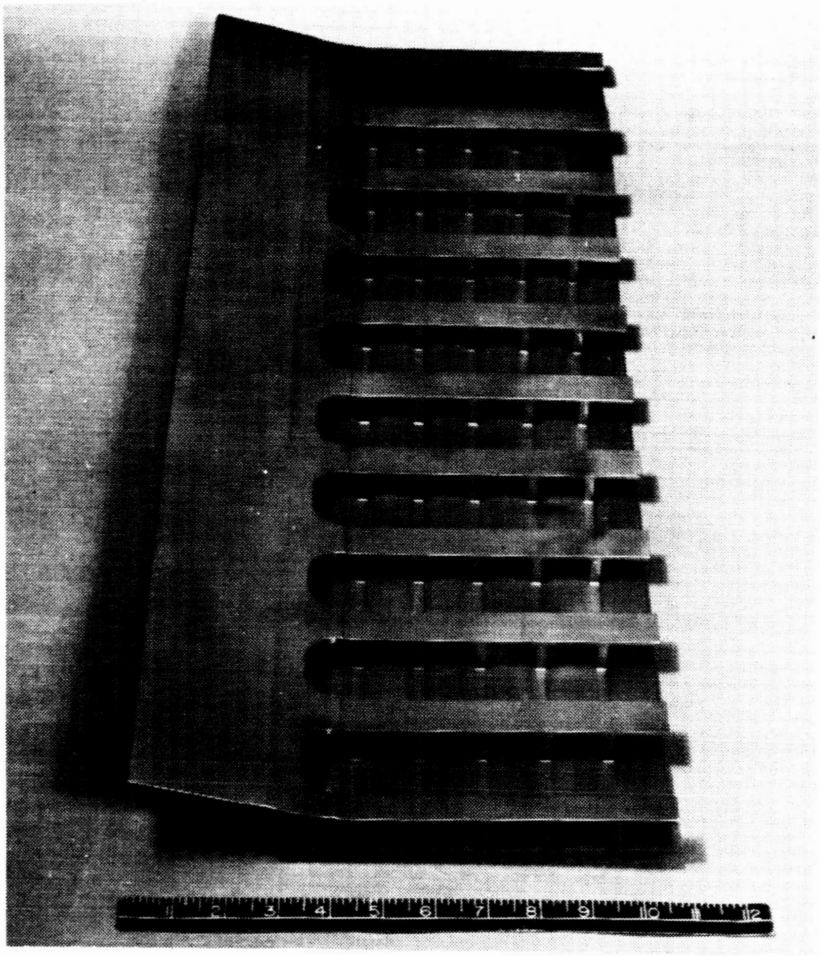


FIGURE 31 COMPLETELY PROCESSED SUB-SCALE Y-RING SEGMENT

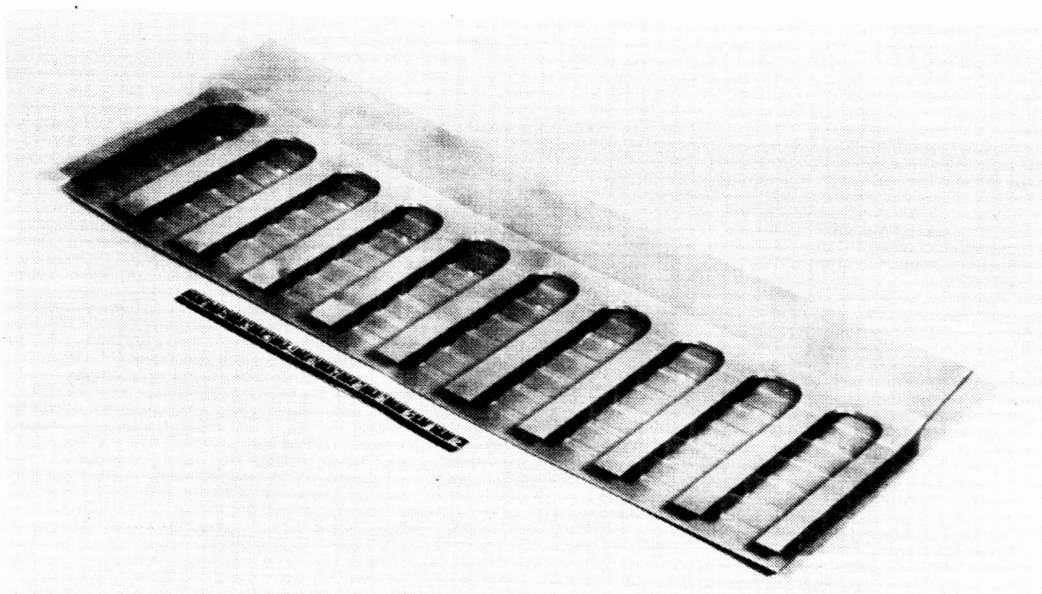


FIGURE 32 COMPLETELY PROCESSED SUB-SCALE Y-RING SEGMENT

TOOL DESIGN DRAWINGS

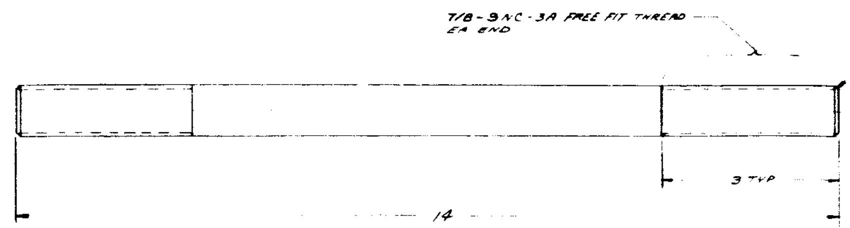
DESIGN DRAWINGS

Design drawings for the tooling required to fabricate the full size Y-Ring segments have been prepared. These drawings, NAA Drawing 2623-201, Hot Forming Die and NAA Drawings 2623-202-1 and 2623-202-2, Special Handling Fixture are shown in Figures 33, 34, and 35. These tools are required for support of the hot forming process which will form, contour and duplex anneal the full scale Y-Ring segments.

The requirements for process support tooling for this application are: (1) Capability of hot forming the flat Y-Ring to a contoured shape (2) Capability of handling, positioning and transporting the contoured Y-Ring for subsequent operations. (3) Minimum tooling costs and (4) Minimum tooling fabrication time. The design philosophy for meeting these requirements is to design multi-purpose tools where possible specifically for this application. Thus a minimum number of tools are required and their functions are oriented only to this application. The design study indicates that two tools will adequately support the requirements.

HOT FORMING DIE

The first tool is a hot forming die. Each Y-Ring segment will be contoured to a 198 inch radius. Several methods were evaluated for accomplishing this task with an incremental hot form/size technique being selected as the most practical and most economical for this particular development effort. The forming concept requires a mated steel die, 6 feet long, capable of maintaining high strength at 1450F, and mounted in the existing Sheridan-Gray Hot-size press at NAA/LAD. Essentially, this tool consists of 3 zones described with their operation as follows, (1) 18-inches of lead in which conforms to the cross-sectional shape of the flat and straight part. This zone accomplishes alignment and pre-heating functions for forming in the subsequent two stages. (2) 18-inches of ramped transition of the .280 inch thick flange from flat to the 13° formed up position. (3) 36-inches of 198 inch contour for the part body and flange completes the die configuration. It is planned to incrementally feed the part from zone 1 into, and through, zones 2 and 3 in approximately 6 inch incremental advances with a forming load of 300 ton applied for about 10 minutes following each advance. The entire tool is heated to 1450F by conduction from the hot size press which has upper and lower heating plattens capable of achieving 1850F. As the workpiece incrementally advances through the contouring tool, it makes its exit into a supporting/handling fixture of light weight construction allowing air-cool at a rate rapid enough to achieve the duplex annealed condition required for subsequent weld joining.



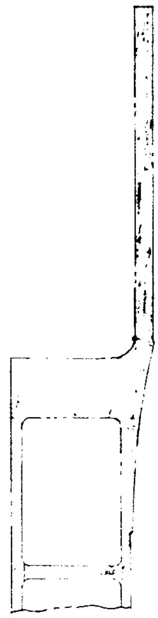
09 CRES STL SHAFT 10 REQD
7/8 DIA X LG TO MAKE

10 CRES STL HEX NUT 20 REQD
7/8-9NC-3A INTERNAL THD

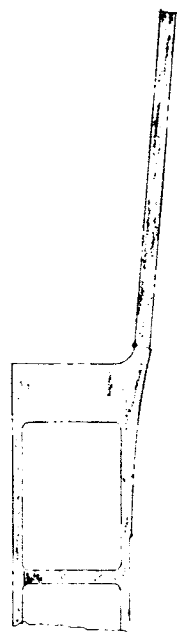
T-262
SCALE:

12

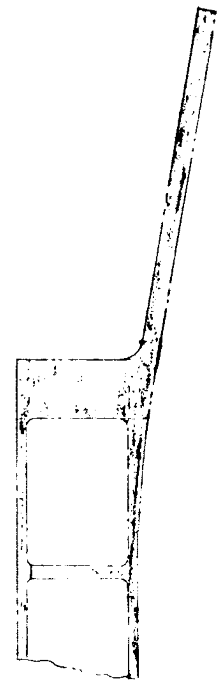
68-1 11



SECTION **E-E** 6
FULL SIZE



SECTION **D-D** 6
FULL SIZE



SECTION **C-C** 6
FULL SIZE

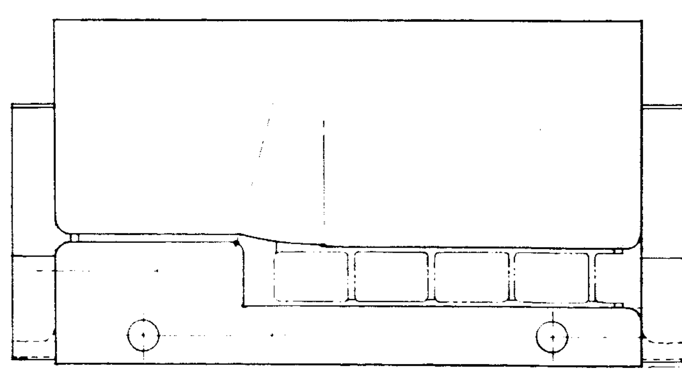
SECT...

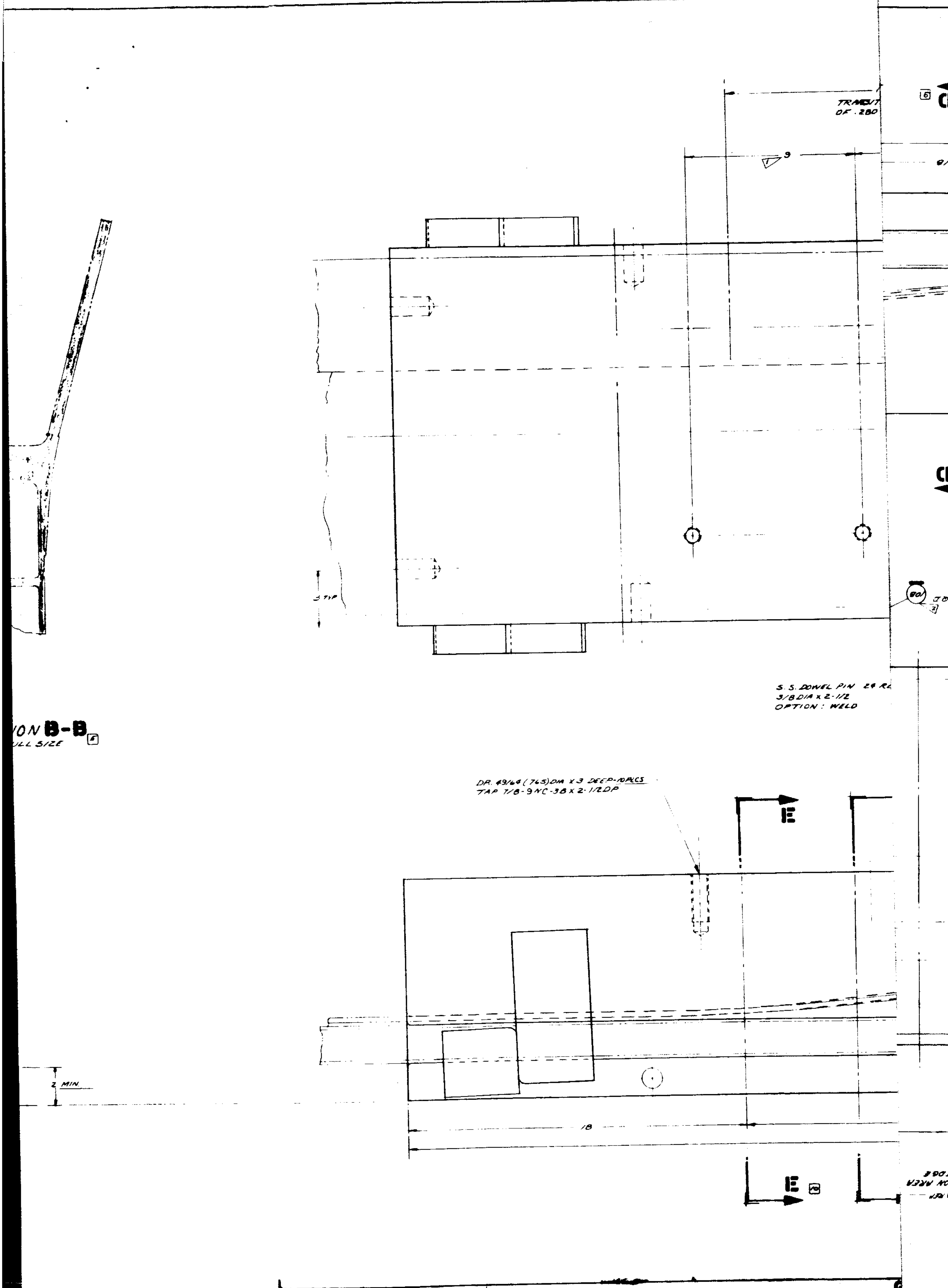
ABOVE SECTIONS (B-B, C-C, D-D, & E-E)
SHOW PART MOVEMENT IN TRANSITION AREA

...MF 45° X 1/16

... DIA

-201
...ULL SIZE



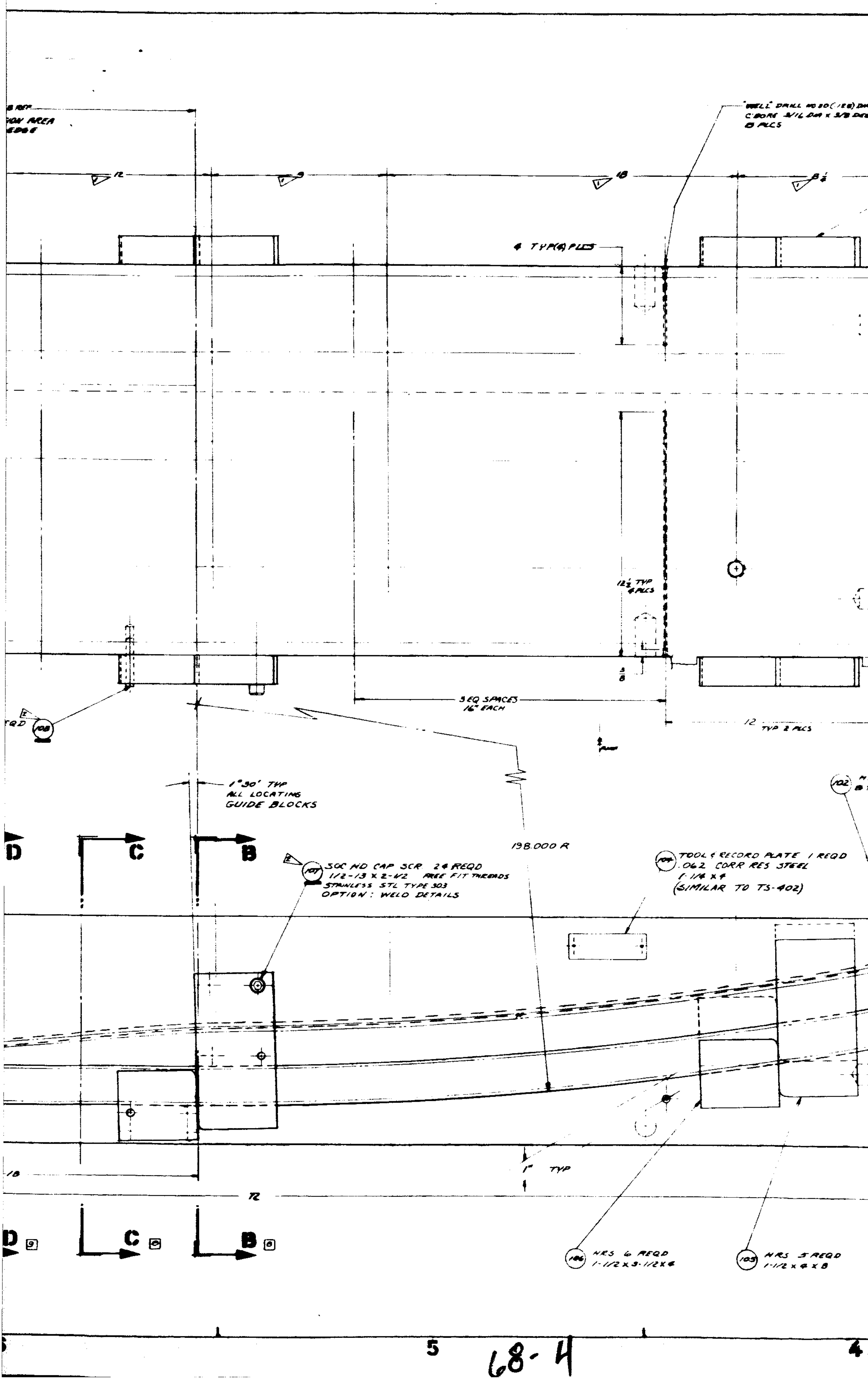


TRAVEL
OF .280
9
S.S. DOWEL PIN 24 R
3/8 DIA x 2-1/2
OPTION: WELD
ON B-B
LL SIZE
DR. 49/64 (.765) DIA x 3 DEEP-10 PLCS
TAP 7/8-9NC-3B x 2-1/2 DP
E
E
3 TYP
2 MIN
18

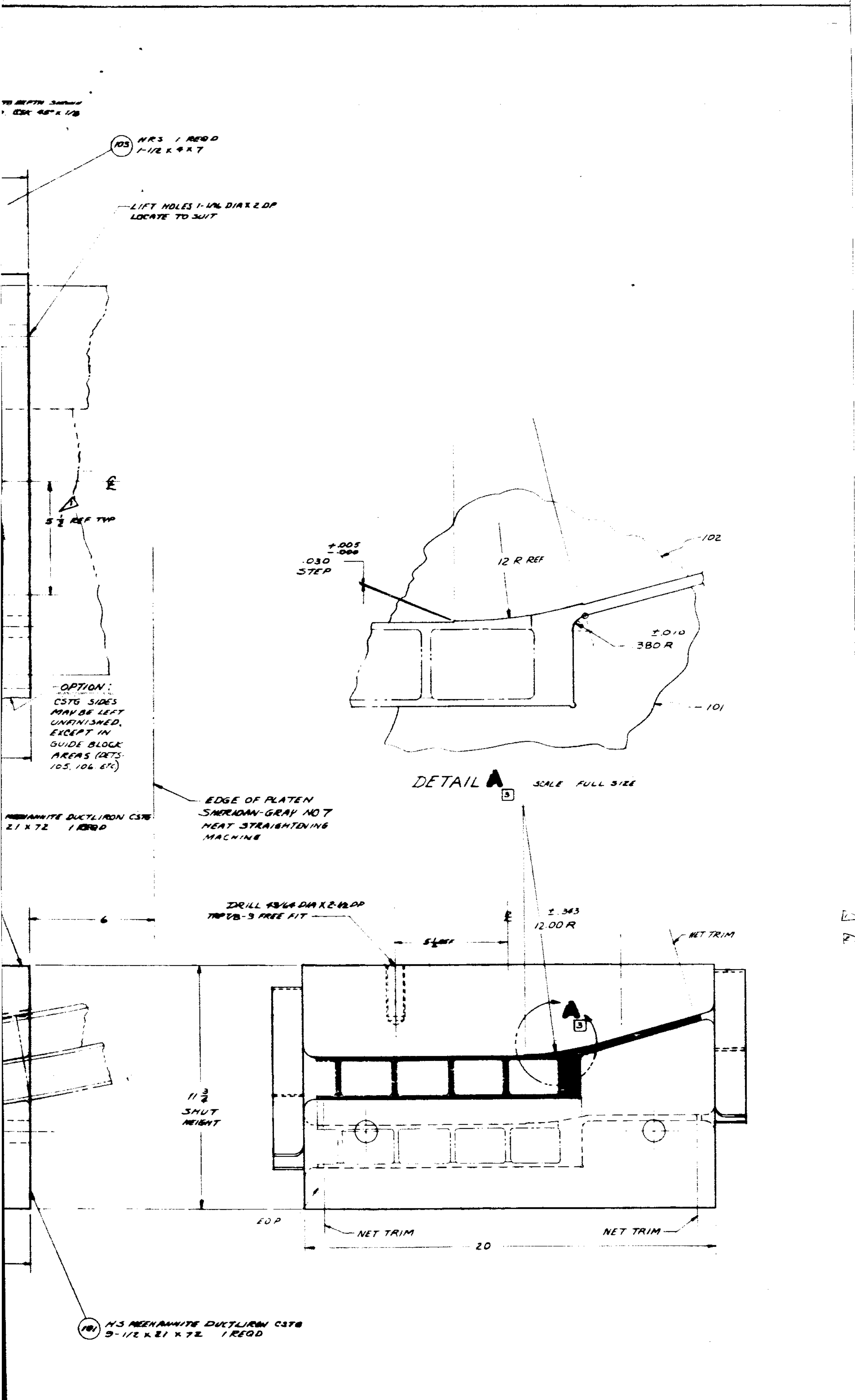
8

7

68-3



C'BORE 3/16 DIA x 3/8 DEEP
8 PLCS
4 TYP(8) PLCS
12¼ TYP
4 PLCS
3 EQ SPACES
16" EACH
12
TYP 2 PLCS
1°30' TYP
ALL LOCATING
GUIDE BLOCKS
198.000 R
107 SOC HD CAP SCR 24 REQD
1/2-13 x 2-1/2 FREE FIT THREADS
STAINLESS STL TYPE 303
OPTION: WELD DETAILS
104 TOOL & RECORD PLATE 1 REQD
.062 CORR RES STEEL
1-1/4 x 4
(SIMILAR TO TS-402)
1" TYP
72
18
106 HRS 6 REQD
1-1/2 x 3-1/2 x 4
105 HRS 5 REQD
1-1/2 x 4 x 8
D
C
B
5
4
68-4



103 HRS 1 REQD 1-1/2 x 4 x 7
LIFT HOLES 1-1/16 DIA x 2 DP LOCATE TO SUIT
5 1/2 REF TYP
OPTION: CSTG SIDES MAY BE LEFT UNFINISHED, EXCEPT IN GUIDE BLOCK AREAS (DETS-105, 106, ETC)
21 x 72 1 REQD
EDGE OF PLATEN SHERIDAN-GRAY NO 7 HEAT STRAIGHTENING MACHINE
+.005 -.000 .030 STEP
12 R REF
102
±.010 .380 R
101
DETAIL A SCALE FULL SIZE
3
DRILL 43/64 DIA x 2-1/2 DP
FREE FIT
±.343 12.00 R
NET TRIM
6
11 3/4 SHUT HEIGHT
EOP
NET TRIM
NET TRIM
20
101 HS MEEHANITE DUCTLIRON CSTG 9-1/2 x 21 x 72 1 REQD

3

ADV INFO

TOOL FUNCTION:

TO HEAT & FORM THE PART TO ENGR. DIMS., INCLUDING THE 198 RADIUS USING SPACED MOVEMENTS THRU THE DIE

OPERATION:

INSERT PART INTO THE FIRST 18 INCHES OF THE DIE (FLAT AREA). THE BALANCE OF THE DIE CAVITY (IN THE 2 INCH THICK AREA) WILL BE SUPPORTED BY SIMULATED "Y" RING PART SEGMENTS

NOTES

1. WORK TO PART PRINT DIMS & HOT FORM TEMPLATE
2. DIE MATL - HS MEEHANITE DUCTLIRON CST6
3. STAMP TYPE OF MATL ON TOOL (NOTE NO.2 REF)
4. ALL WORKING SURFACES OF TOOL THAT CONTACT TITANIUM PART SHALL BE MACHINED TO 125 MICROFINISH. EXCEPT WITHIN THE TANGENT POINTS OF ALL FORMING RADII CONTACTING THE TITANIUM PART SHALL BE 63 MICROFINISH.
5. USING DEPT TO FURNISH THERMOCOUPLE, WIRES & CLIPS
6. BOLT, DOWEL &/OR WELD PER STD. SHOP PRACTICE
7. WEIGHT OF TOOL TO BE STAMPED ON SAME, USING 1/2 INCH HIGH LETTERS - FILL WITH HEAT RESISTANT PAINT, PREFERABLY YELLOW IN COLOR
8. COORD DIMS TO SHERIDAN-GRAY NO 7 HEAT STRAIGHTENING MACHINE IN DEPT-002 LA DIV.
9. MAYBE PURCHASED FROM:
   DUCOMMUN METALS & SUPPLY CO
   AIRCRAFT SALES FORCE
   LOS ANGELES CALIF.

T-2623-201

FIGURE 33

IMPORTANT

THIS TOOL MUST BE COORDINATED WITH THE FOLLOWING

2623-201 Z PLASTER
2623-201 TEMPLATE

110

NORTH AMERICAN AVIATION, INC

HOT FORM DIE

2623-005

"Y" RING SEGMENT

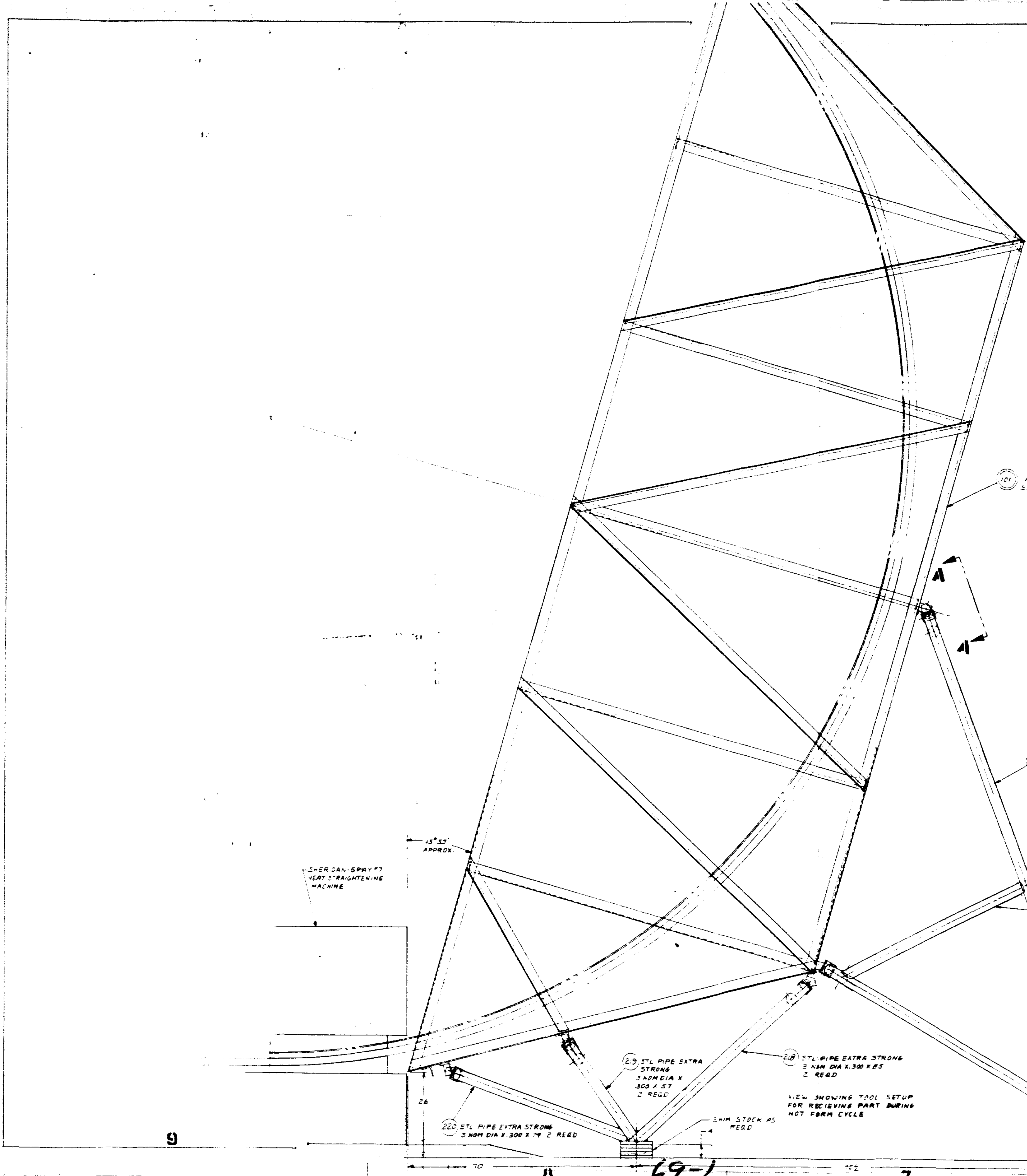
ROLL DIFFUSION BOND TI FRAME S-IC

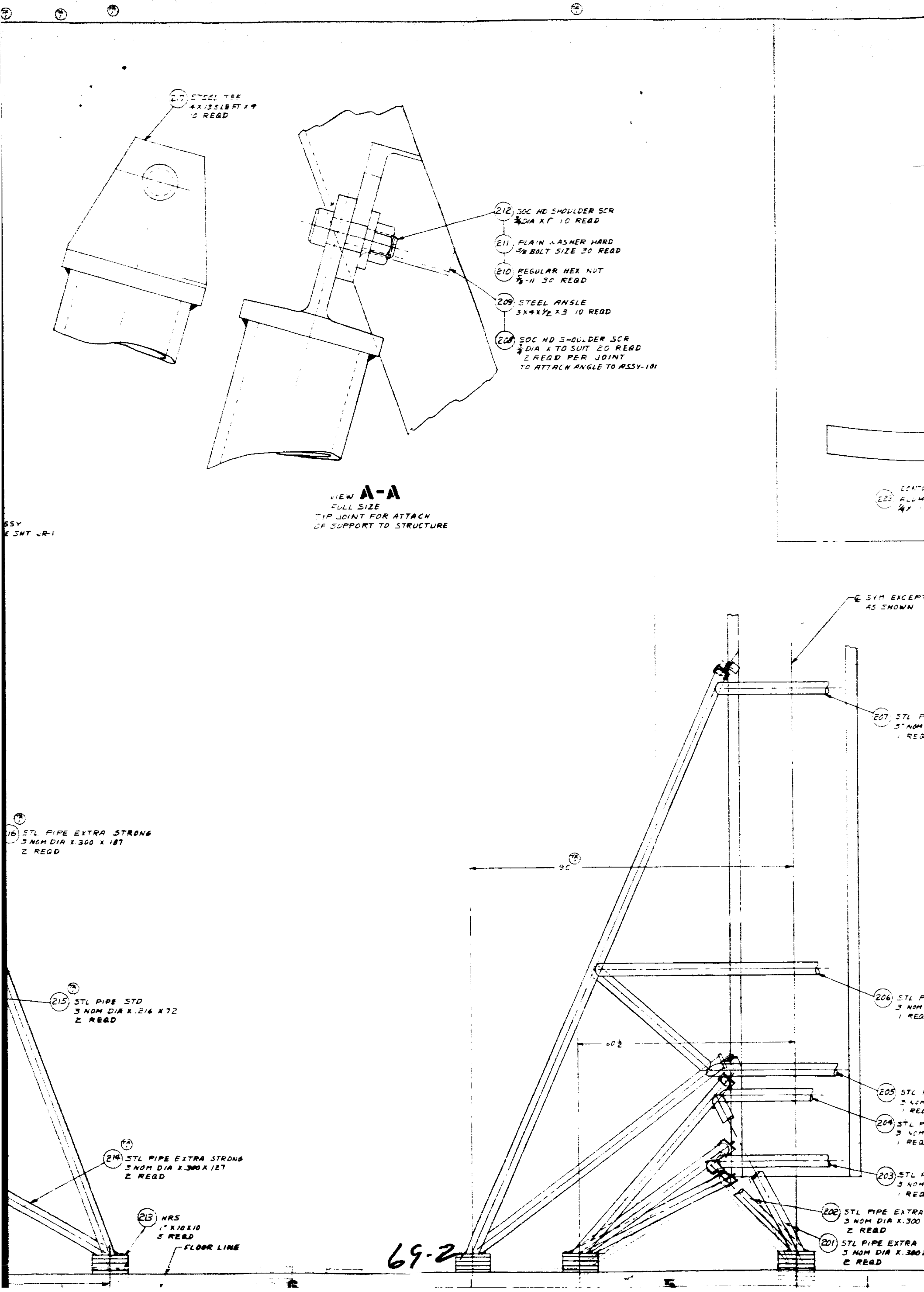
NONE

1

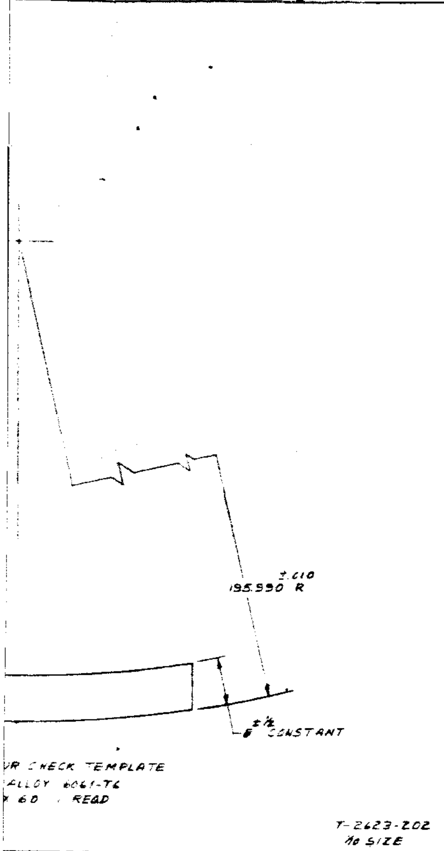
JR-1

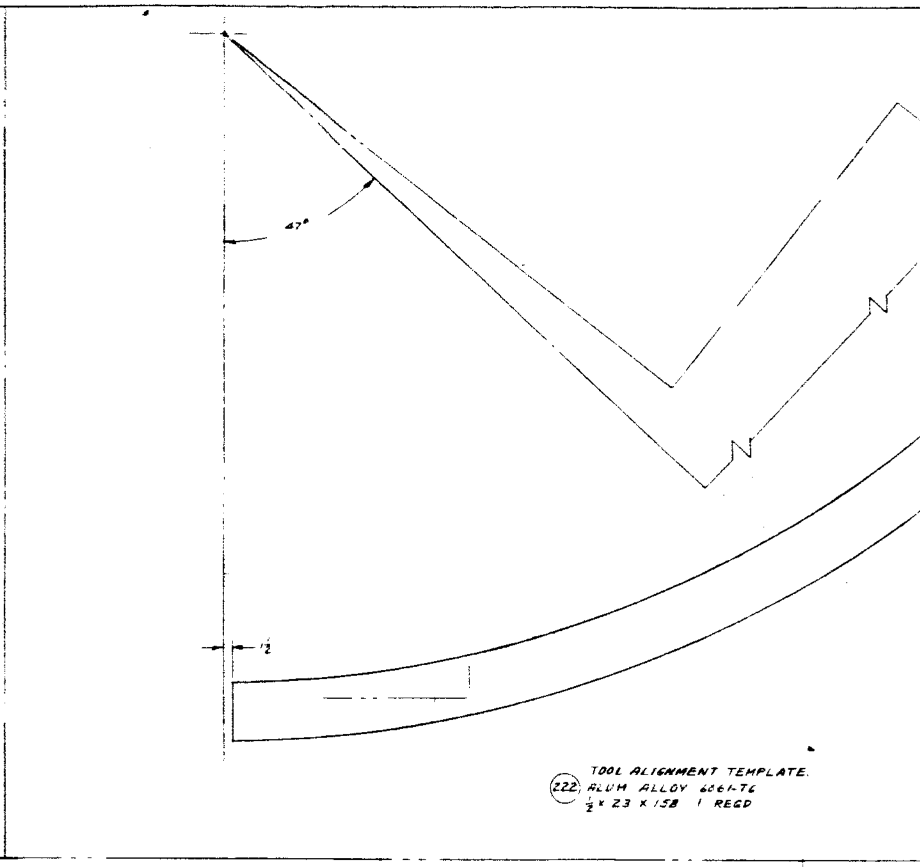
T-2623-201

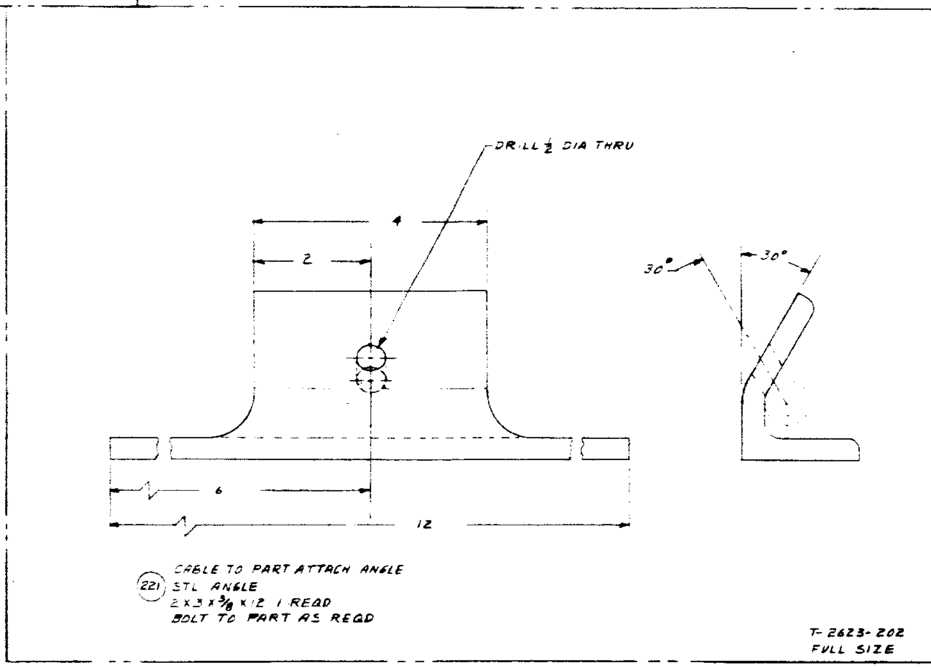

45° 55' APPROX.
SHERIDAN-GRAY #7 HEAT STRAIGHTENING MACHINE
101
A
A
219 STL PIPE EXTRA STRONG 3 NOM DIA X .300 X 57 2 REQD
218 STL PIPE EXTRA STRONG 3 NOM DIA X .300 X 85 2 REQD
220 STL PIPE EXTRA STRONG 3 NOM DIA X .300 X 74 2 REQD
SHIM STOCK AS REQD
VIEW SHOWING TOOL SETUP FOR RECIEVING PART DURING HOT FORM CYCLE
26
4
70
9
8
7
69-1



217 STEEL TEE 4 X 13.5 LB FT X 9 10 REQD
212 SOC HD SHOULDER SCR ⅝ DIA X 1" 10 REQD
211 PLAIN WASHER HARD ⅝ BOLT SIZE 30 REQD
210 REGULAR HEX NUT ⅝-11 30 REQD
209 STEEL ANGLE 3 X 4 X ½ X 3 10 REQD
208 SOC HD SHOULDER SCR ¾ DIA X TO SUIT 20 REQD 2 REQD PER JOINT TO ATTACH ANGLE TO ASSY-101
VIEW A-A
FULL SIZE
TYP JOINT FOR ATTACH OF SUPPORT TO STRUCTURE
SSY
E SHT
223
℄ SYM EXCEPT AS SHOWN
207 STL P
3" NOM
1 REQ
216 STL PIPE EXTRA STRONG 3 NOM DIA X.300 X 187 2 REQD
90
206 STL P
3 NOM
1 REQ
215 STL PIPE STD 3 NOM DIA X.216 X 72 2 REQD
60½
205 STL
1 REQ
204 STL P
3 NOM
1 REQ
214 STL PIPE EXTRA STRONG 3 NOM DIA X.300 X 127 2 REQD
203 STL P
3 NOM
1 REQ
213 HRS 1" X 10 X 10 5 REQD
FLOOR LINE
202 STL PIPE EXTRA
3 NOM DIA X.300
2 REQD
201 STL PIPE EXTRA
3 NOM DIA X.300
2 REQD
69-2







PE STD
DIA X.216 X 46
D

PE STD
DIA X.216 X 112
D

PE STD
DIA X.216 X 50
D

PE STD
DIA X.216 X 44
D

PE STD
DIA X.216 X 48
D

STRONG
43

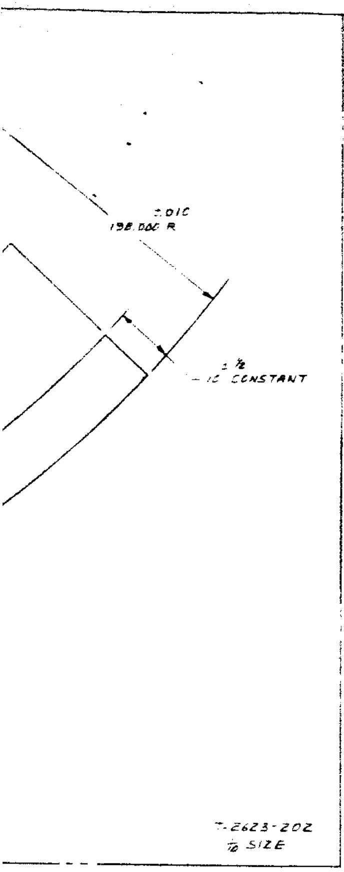
STRONG
73

69-3

4 3

NA-66-104

[illegible]	1	90 WAS [illegible] DET [illegible]	[illegible]	[illegible]		2-8-66
[illegible]		112 WAS 142 DET-214	[illegible]			
6		[illegible] WAS [illegible] DET-215 [illegible]				
6		WAS 79 [illegible] DET-216 [illegible]				
6	4	WAS 216				



GENERAL NOTES:
IS SHEET SHOWS TOOL IN POSITION
IR PART RECEPTION FROM HOT FORM DIE
IRT TO BE PULLED INTO TOOL BY
IBILE CRANE USING ⅜ DIA STL CABLE.
ALE DRAWING FOR NON-CRITICAL DIMS
IT SHOWN.
IPPORT PADS MUST BE ATTACHED
FLOOR WITH MIN OF 2 (¾ DIA MIN)
IG SCREWS PER PAD.
IM SUPPORT PADS TO OBTAIN ALIGNMENT
TH HOT FORM DIE.
E TOOL ALIGNMENT TEMPLATE DET-222
IR ALIGNMENT OF SPECIAL TOOL
HOT FORM DIE

T-2623-202

FIGURE 34

223

NORTH AMERICAN AVIATION, INC.

SPECIAL TOOL

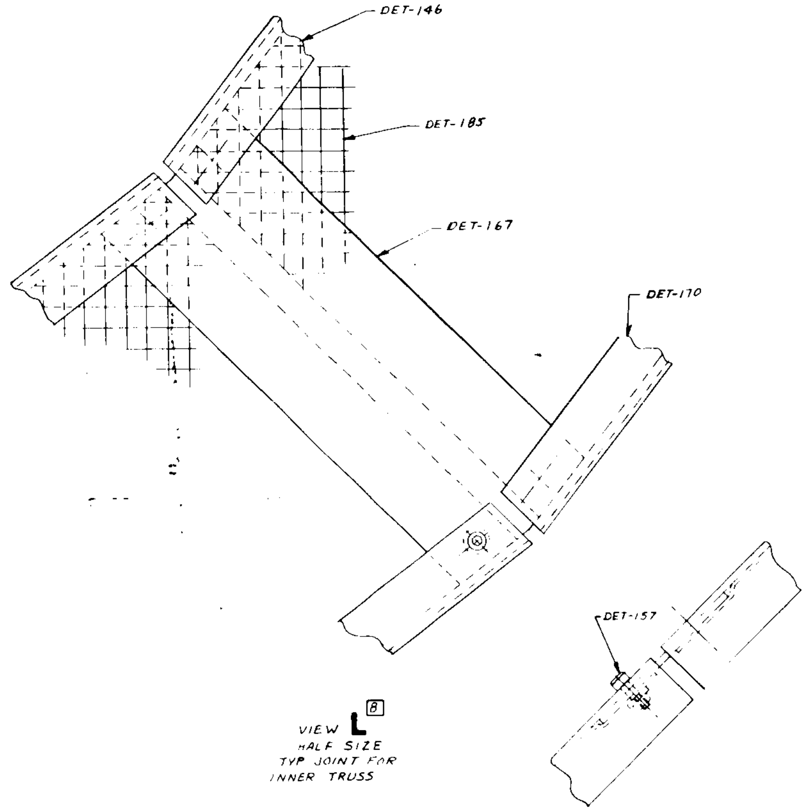
2623-005 | Y- RING SEGMENT ROLL DIFFUSION BOND TITANIUM

SEE SHT JR-1

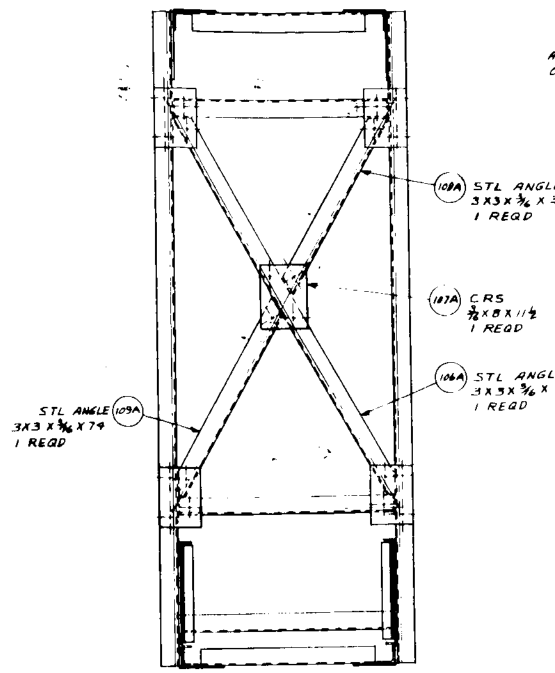
JR-2 | T-2623-202

2

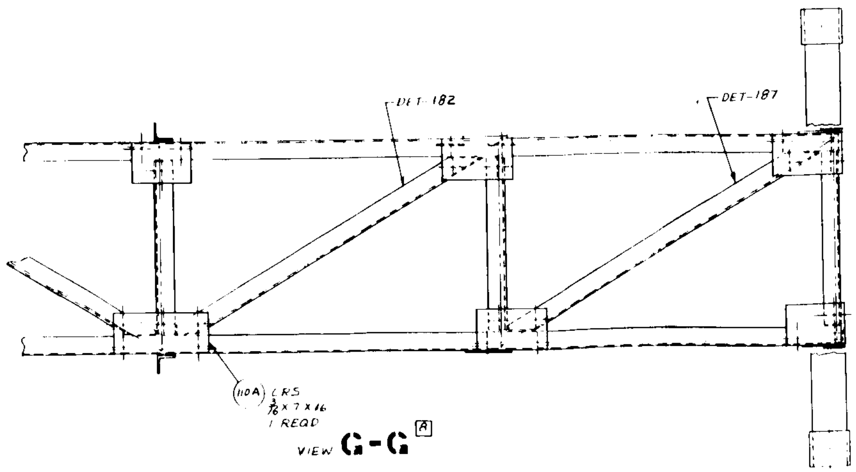
-4/69



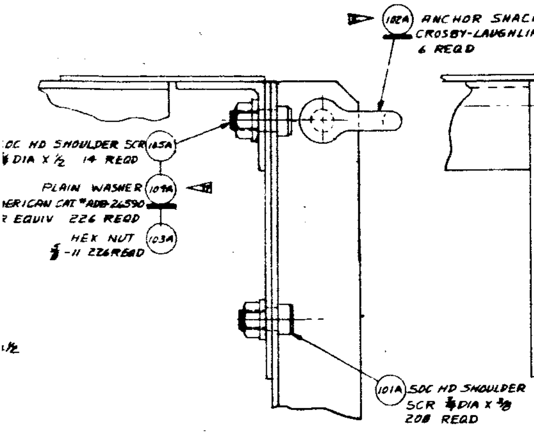
VIEW L [8]
HALF SIZE
TYP JOINT FOR
INNER TRUSS

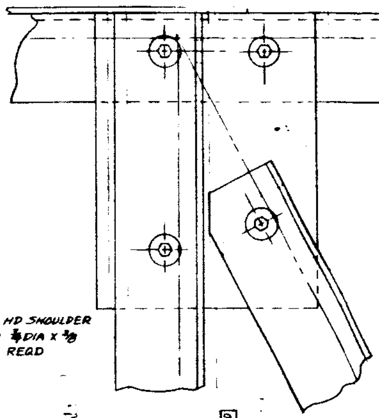


SECTION K-K [9]

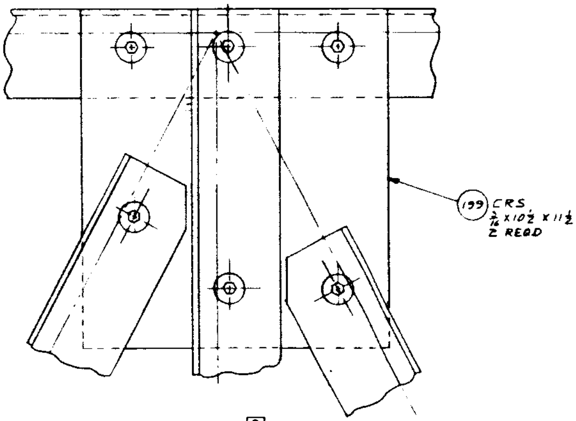


VIEW G-G [A]

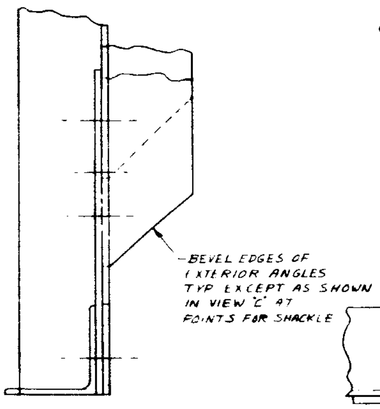


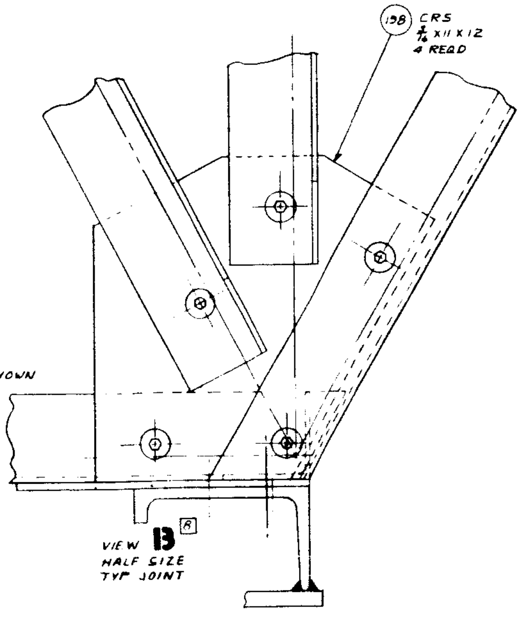


VIEW C [9]
HALF SIZE
TYP JOINT
SHACKLE AT POINTS
CODED ● ONLY

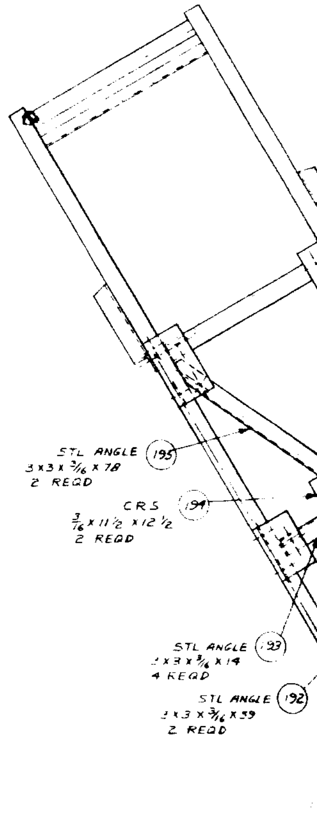


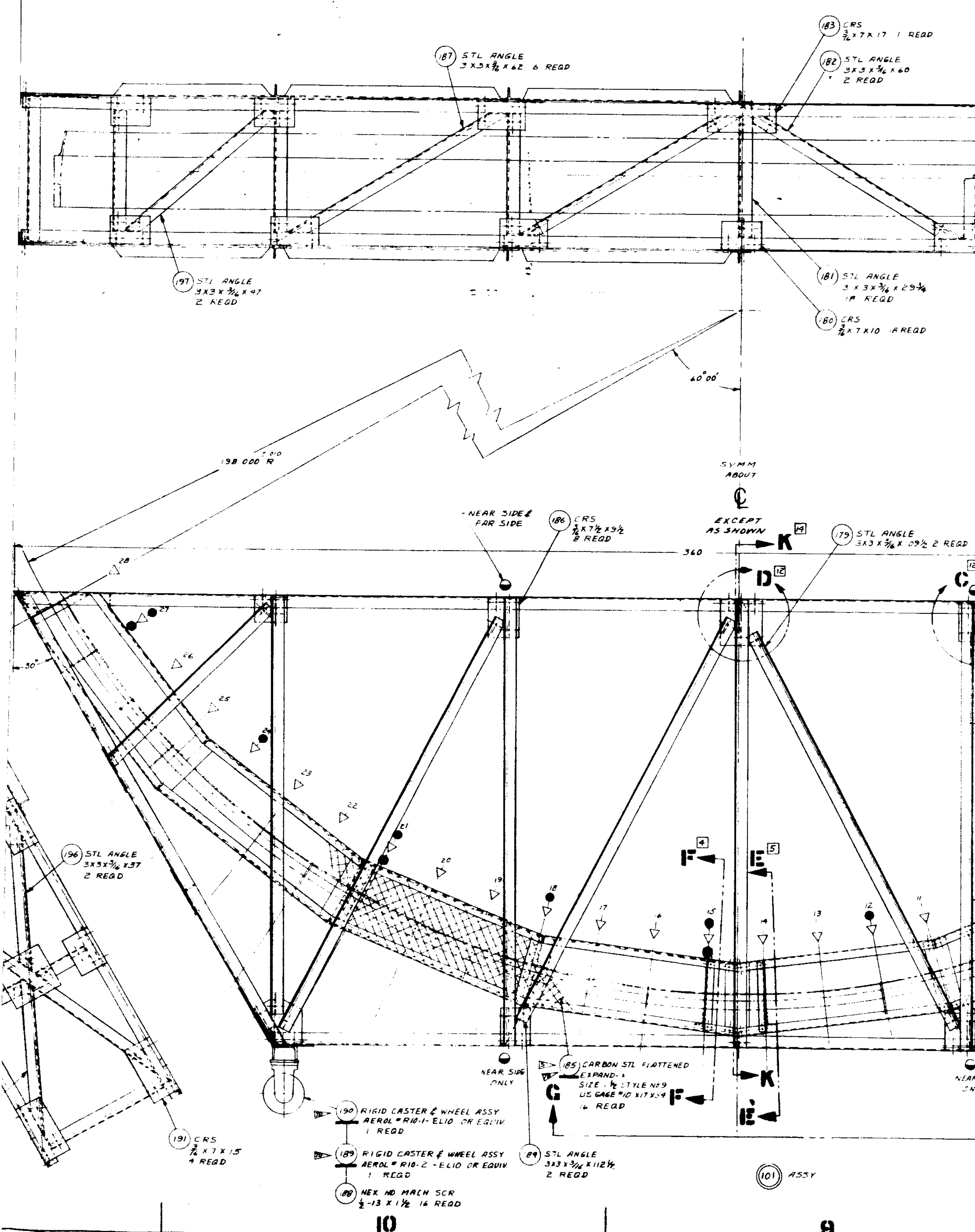
VIEW D [9]
HALF SIZE
TYP JOINT





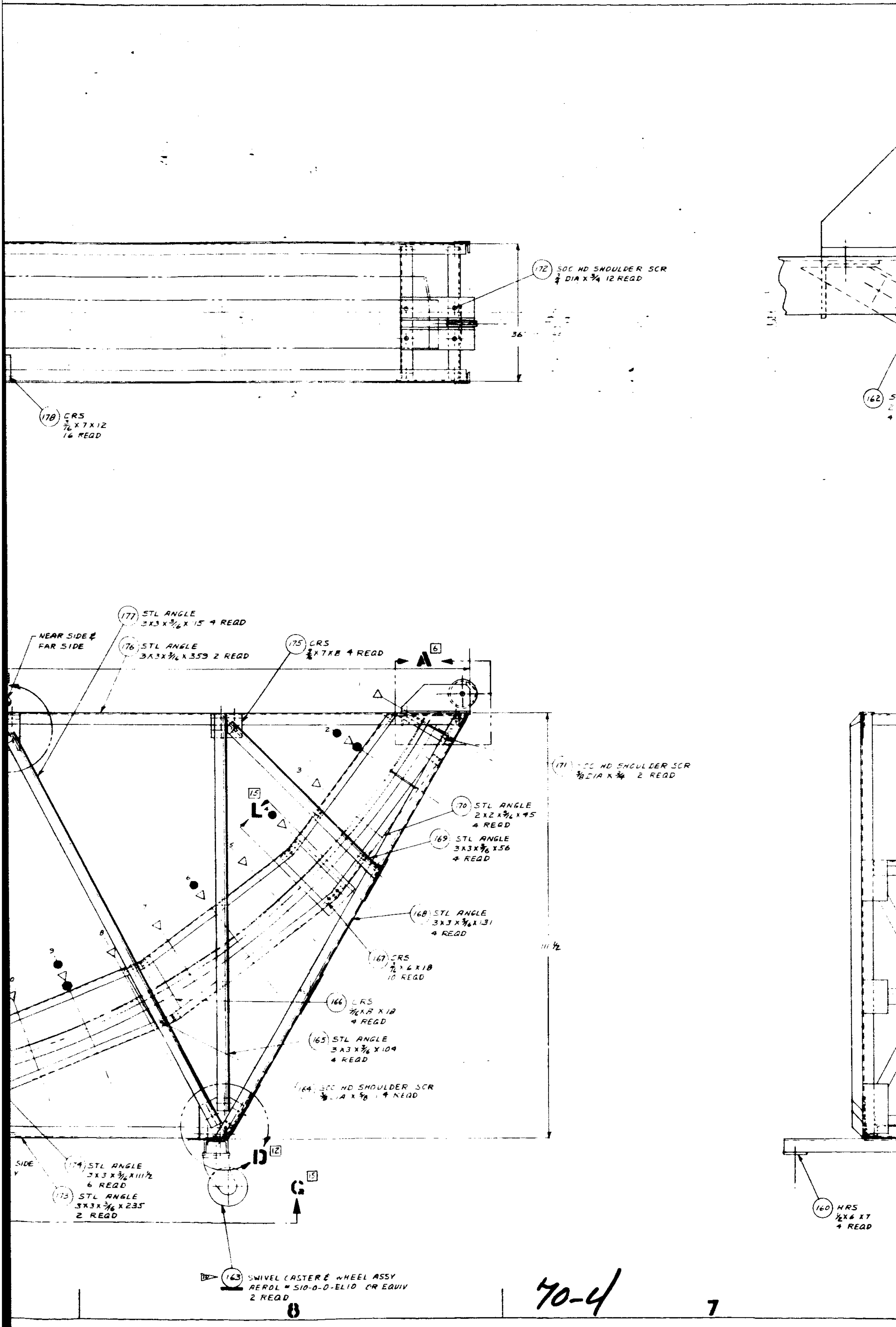
VIEW B [8]
HALF SIZE
TYP JOINT

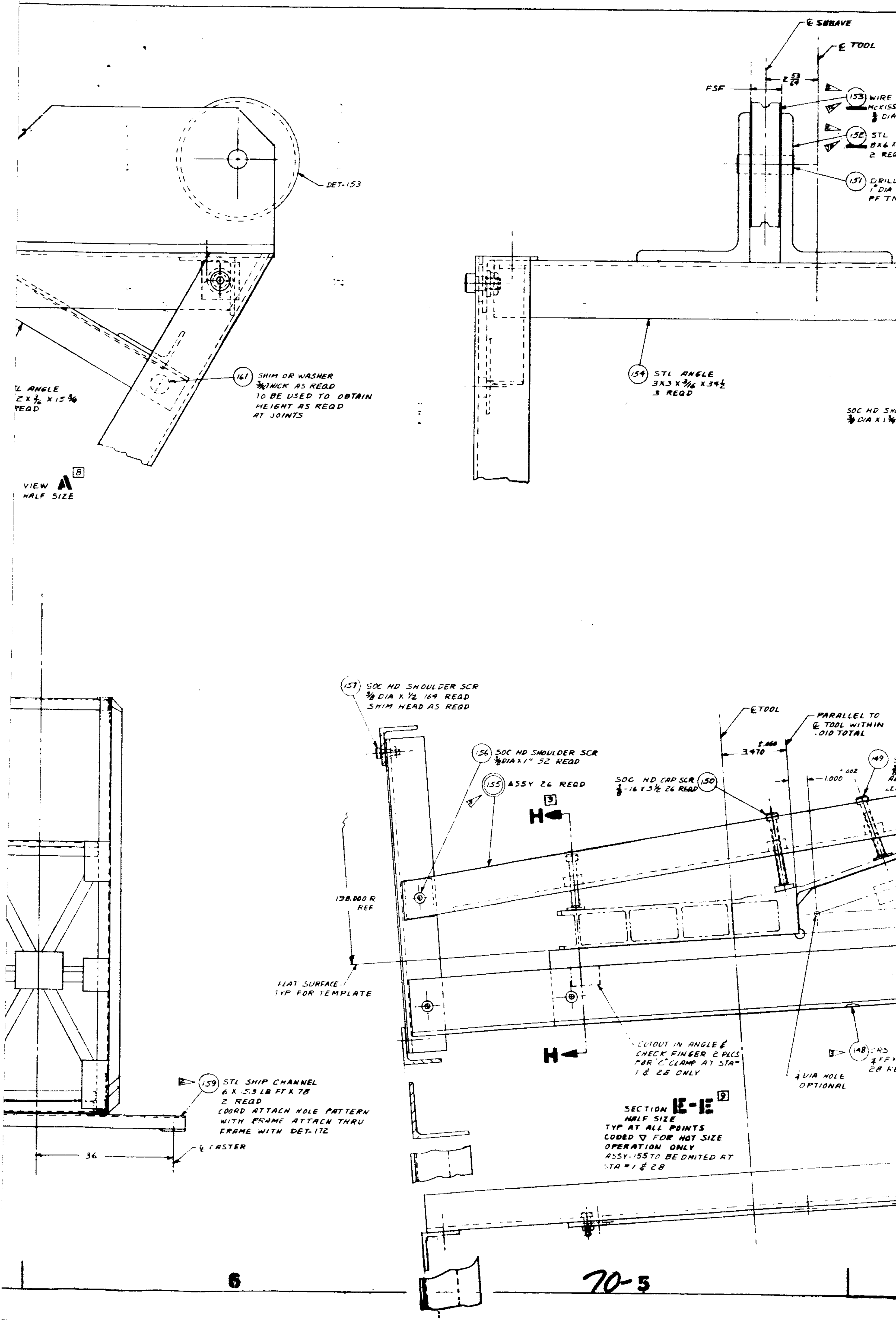




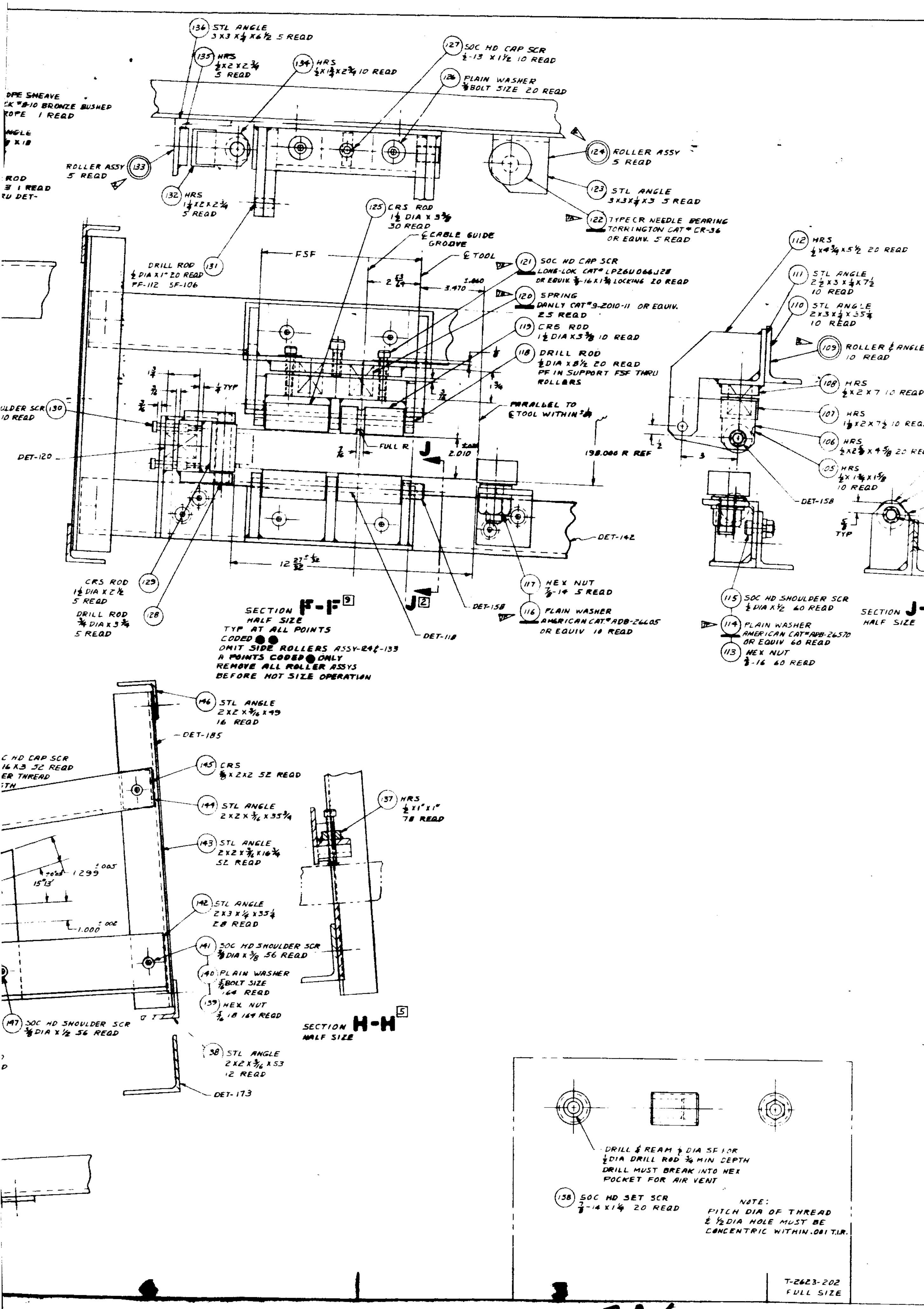
183 CRS 3/16 x 7 x 17 1 REQD
182 STL ANGLE 3x3x3/16 x 60 2 REQD
187 STL ANGLE 3x3x3/8 x 62 6 REQD
197 STL ANGLE 3x3x3/16 x 47 2 REQD
181 STL ANGLE 3x3x3/16 x 29 3/4 18 REQD
180 CRS 3/16 x 7 x 10 18 REQD
60°00'
198.000 R ±.010
SYMM ABOUT ℄ EXCEPT AS SHOWN
NEAR SIDE & FAR SIDE
186 CRS 3/16 x 7 1/2 x 9 1/2 8 REQD
360
K 14
179 STL ANGLE 3x3x3/16 x 109 1/2 2 REQD
D 12
C
30
F 4
E 5
196 STL ANGLE 3x3x3/16 x 37 2 REQD
NEAR SIDE ONLY
185 CARBON STL FLATTENED EXPAND-X SIZE 1/2 STYLE No 9 US GAGE #10 x 17 x 54 16 REQD
G
K
F
E
190 RIGID CASTER & WHEEL ASSY AEROL # R10-1-ELIO OR EQUIV. 1 REQD
189 RIGID CASTER & WHEEL ASSY AEROL # R10-2-ELIO OR EQUIV. 1 REQD
188 HEX HD MACH SCR 1/2-13 x 1 1/2 16 REQD
191 CRS 3/16 x 7 x 15 4 REQD
184 STL ANGLE 3x3x3/16 x 112 1/2 2 REQD
101 ASSY
10
9

70-3


172 SOC HD SHOULDER SCR 3/8 DIA X 3/4 12 REQD
36
178 CRS 7/16 X 7 X 12 16 REQD
162
177 STL ANGLE 3X3 X 3/16 X 15 4 REQD
NEAR SIDE ℄ FAR SIDE
176 STL ANGLE 3X3X3/16 X 359 2 REQD
175 CRS 3/8 X 7 X 8 4 REQD
A 6
171 SOC HD SHOULDER SCR 3/8 DIA X 3/4 2 REQD
170 STL ANGLE 2 X 2 X 3/16 X 45 4 REQD
169 STL ANGLE 3X3X3/16 X56 4 REQD
L 15
168 STL ANGLE 3X3X3/16 X 131 4 REQD
111 1/2
167 CRS 7/16 X 6 X 18 10 REQD
166 CRS 7/16 X 8 X 18 4 REQD
165 STL ANGLE 3 X 3 X 3/16 X 104 4 REQD
164 SOC HD SHOULDER SCR 3/8 DIA X 5/8 4 REQD
D 12
G 15
174 STL ANGLE 3 X 3 X 3/16 X 111 1/2 6 REQD
173 STL ANGLE 3X3X3/16 X 235 2 REQD
160 HRS 1/2 X 6 X 7 4 REQD
163 SWIVEL CASTER & WHEEL ASSY AEROL = S10-0-0-EL10 OR EQUIV 2 REQD
70-4
8
7



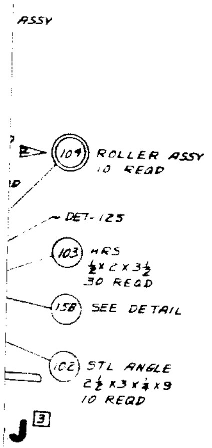
℄ SHEAVE
℄ TOOL
FSF
2 53/64
153 WIRE
McKISS
3/8 DIA
152 STL
8X6 X
2 REQ
151 DRILL
1" DIA
PF TH
DET-153
161 SHIM OR WASHER
3/16 THICK AS REQD
TO BE USED TO OBTAIN
HEIGHT AS REQD
AT JOINTS
L ANGLE
2 X 3/16 X 15 3/4
REQD
VIEW A [8]
HALF SIZE
154 STL ANGLE
3X3 X 3/16 X 34 1/2
3 REQD
SOC HD SH
3/8 DIA X 1 3/4
157 SOC HD SHOULDER SCR
3/8 DIA X 1/2 164 REQD
SHIM HEAD AS REQD
156 SOC HD SHOULDER SCR
3/8 DIA X 1" 52 REQD
155 ASSY 26 REQD
SOC HD CAP SCR 150
1/2-16 X 3 1/2 26 REQD
℄ TOOL
PARALLEL TO
℄ TOOL WITHIN
.010 TOTAL
±.060
3.470
±.002
1.000
149
H [9]
198.000 R
REF
FLAT SURFACE
TYP FOR TEMPLATE
CUTOUT IN ANGLE &
CHECK FINGER 2 PLCS
FOR "C" CLAMP AT STA
1 & 28 ONLY
H
148 CRS
28 RE
1/4 DIA HOLE
OPTIONAL
159 STL SHIP CHANNEL
6 X 15.3 LB FT X 78
2 REQD
COORD ATTACH HOLE PATTERN
WITH FRAME ATTACH THRU
FRAME WITH DET-172
℄ CASTER
36
SECTION E-E [9]
HALF SIZE
TYP AT ALL POINTS
CODED ▽ FOR HOT SIZE
OPERATION ONLY
ASSY-155 TO BE OMITED AT
STA 1 & 28
6
70-5



136 STL ANGLE 3X3X¼X6½ 5 REQD
135 HRS ½X2X2¾ 5 REQD
134 HRS ½X1½X2¾ 10 REQD
127 SOC HD CAP SCR ½-13 X1½ 10 REQD
126 PLAIN WASHER ⅜ BOLT SIZE 20 REQD
ROPE SHEAVE
BRONZE BUSHED
ROPE 1 REQD
ROLLER ASSY 133 5 REQD
124 ROLLER ASSY 5 REQD
123 STL ANGLE 3X3X¼X3 5 REQD
122 TYPE CR NEEDLE BEARING TORRINGTON CAT# CR-36 OR EQUIV. 5 REQD
132 HRS 1½X2X2¾ 5 REQD
125 CRS ROD 1½ DIA X 3⅜ 30 REQD
℄ CABLE GUIDE GROOVE
℄ TOOL
FSF
DRILL ROD 131 ½ DIA X 1" 20 REQD PF-112 SF-106
121 SOC HD CAP SCR LONG-LOK CAT# LP26U066J28 OR EQUIV. ⅜-16X1¾ LOCKING 20 REQD
120 SPRING DANLY CAT# 9-2010-11 OR EQUIV. 25 REQD
119 CRS ROD 1½ DIA X3⅜ 10 REQD
118 DRILL ROD ½ DIA X 8½ 20 REQD PF IN SUPPORT FSF THRU ROLLERS
112 HRS ½X4¾X5½ 20 REQD
111 STL ANGLE 2½X3X¼X7½ 10 REQD
110 STL ANGLE 2X3X¼X35¾ 10 REQD
109 ROLLER & ANGLE 10 REQD
108 HRS ½X2X7 10 REQD
107 HRS 1½X2X7½ 10 REQD
106 HRS ½X2⅝X4⅝ 20 REQD
105 HRS ½X1¾X1⅝ 10 REQD
SHOULDER SCR 130 10 REQD
DET-120
PARALLEL TO ℄ TOOL WITHIN
198.000 R REF
FULL R
2.010
3.470
1.860
DET-142
DET-158
DET-118
12 27/32
CRS ROD 129 1½ DIA X 2½ 5 REQD
DRILL ROD 128 ¾ DIA X 3¾ 5 REQD
117 HEX NUT ⅞-14 5 REQD
116 PLAIN WASHER AMERICAN CAT# ADB-26605 OR EQUIV 10 REQD
115 SOC HD SHOULDER SCR ½ DIA X½ 60 REQD
114 PLAIN WASHER AMERICAN CAT# ADB-26570 OR EQUIV 60 REQD
113 HEX NUT ⅜-16 60 REQD
SECTION F-F 9 HALF SIZE
TYP AT ALL POINTS CODED ●●
OMIT SIDE ROLLERS ASSY-24¢-133 A POINTS CODED ● ONLY
REMOVE ALL ROLLER ASSYS BEFORE HOT SIZE OPERATION
J 2
SECTION J HALF SIZE
146 STL ANGLE 2X2X3/16X49 16 REQD
DET-185
HD CAP SCR 52 REQD THREAD
145 CRS ⅝X2X2 52 REQD
144 STL ANGLE 2X2X3/16X35¾
143 STL ANGLE 2X2X3/16X16¾ 52 REQD
142 STL ANGLE 2X3X¼X35¼ 28 REQD
141 SOC HD SHOULDER SCR ⅜ DIA X⅜ 56 REQD
140 PLAIN WASHER ⅜ BOLT SIZE 164 REQD
139 HEX NUT ⅜-18 164 REQD
147 SOC HD SHOULDER SCR ⅜ DIA X ½ 56 REQD
138 STL ANGLE 2X2X3/16X53 12 REQD
DET-173
137 HRS ½X1"X1" 78 REQD
SECTION H-H 5 HALF SIZE
1.299
1.000
DRILL & REAM ½ DIA SF FOR ½ DIA DRILL ROD ¾ MIN DEPTH DRILL MUST BREAK INTO HEX POCKET FOR AIR VENT
158 SOC HD SET SCR ⅞-14 X1¼ 20 REQD
NOTE: PITCH DIA OF THREAD & ½ DIA HOLE MUST BE CONCENTRIC WITHIN .001 T.I.R.
T-2623-202 FULL SIZE

NA-66-104

2623-005		NO				4-15-65
	1	SEE SHT JR-2				3-8-66



TOOL FUNCTION

RECIEVING FIXTURE FOR HOT FORMED PART.
FEED FIXTURE FOR PROFILE MILL
HOLD PART FOR HOT SIZE OPERATION
INSPECTION FIXTURE.
GENERAL HANDLING & SHIPPING FIXTURE

GENERAL NOTES

1. SCALE DRAWING FOR NON-CRITICAL DIMS NOT SHOWN
2. REMOVE DURING HOT SIZE OPERATION
3. FOR HOT SIZE OPERATION & INSPECTION ONLY REMOVE FOR OTHER OPERATIONS
4. ALL SHOULDER SCRS TO BE SF THRU DET'S & SHIMS UNDER HEADS IF REQD TO OBTAIN CLAMP.
5. TACK OR SPOTWELD 10 ANGLES & PLATES APPROX 3" SPACING BETWEEN WELDS.
6. PART MATERIAL 8AL-1V-1MO TITANIUM ALLOY
7. MAY BE PURCHASED FROM:
   - A. THE TORRINGTON CO.
     4433 CRENSHAW BLVD, LA, CALIF.
   - B. DUCOMMUN METALS & SUPPLY CO.
     4890 S. ALAMEDA ST, LA, CALIF.
   - C. CABLECO
     4333 MAYWOOD AVE, LA, CALIF.
   - D. AEROL CO INC.
     3235 SAN FERNANDO RD, LA, CALIF.
   - E. LONG-LOK CORP.
     4101 REDWOOD AVE, LA, CALIF.
   - F. AMERICAN DRILL BUSHING CO.
     5107 PACIFIC BLVD, LA, CALIF.

T-2623-202

FIGURE 35

110A

NORTH AMERICAN AVIATION INC

SPECIAL TOOL

2623-005 Y-RING SEGMENT ROLL DIFFUSION BOND TITANIUM

D HARVEY 1-5-66

JR-2 | 2

JR-1 | 1/10 & NOTED | T-2623-202

70-7

Utilizing progressive hot forming, one die, approximately 20" wide x 72" long, will accomplish the entire contouring operation. Thus the physical size of the tooling and its support equipment is reduced to a minimum.

SPECIAL HANDLING FIXTURE

The second tool is a special handling fixture that will perform the following operations.

1. Receive the part as it is progressively passes through the hot-forming die.
2. Transport the part to each subsequent operation.
3. Position and hold the part for machining operation.
4. Cradle the part during a possible heat treat operation.
5. Position the part for inspection operations.
6. Cradle the part for shipping.

This fixture is designed as a multipurpose unit specifically for this project. It will perform initially as a receiving fixture for receiving the Y-Ring segment as it progressively moves out of the hot-forming die. The fixture will be attached to the concrete floor with lag bolts to hold it in position. Since the formed Y-Ring segment will come out of the forming die into a vertical position, a mobile crane with a 40 foot boom and a cable will be required to lift it into the vertically-mounted fixture. The cable will run through guide rollers in the fixture and be attached to the leading end of the Y-Ring segment with a bolted-on fitting.

On completion of the forming operation the contoured Y-Ring will be nested in the handling fixture and held in place with clamps. The legs supporting the fixture will then be removed and four large casters mounted on the cross bars. The fixture will be lowered down on the casters into a horizontal position. It will then perform as a shipping fixture to safely move the contoured Y-Ring segment to the various locations required for the subsequent machining, leaching and chem-milling operations. Finally the fixture will be used as a cradle for shipping the completed part to MSFC.

STRUCTURAL ANALYSIS OF SPECIAL HANDLING FIXTURE

The basic parameters that were used in the structural analysis is as follows:

Truss design loads

A. Due to Y-Ring assembly

4g vertical
1g side
1g drag

B. Due to frame assembly

2g vertical
1g side
1g drag

Material properties for frame (1020 steel)

	R.T.	1400°F
Ultimate Tensile Strength	= 60×10^3 psi	9×10^3 psi
Compression Yield Strength	= 36×10^3 psi	4×10^3 psi
Bearing Ultimate	= 90×10^3 psi	10×10^3 psi
Modulus of Elasticity	= 29×10^6 psi	12×10^6 psi

Y-Ring weight and geometry

Weight - Titanium Only = 1625#
Weight - Titanium and Steel = 3630#
Length = 414.7 in.
C.G. such that 60% of weight is currently the critical frame.

The reference system for a frame is as shown below for every point (A thru M).

Loading conditions

A. Y-Ring(full)-R.T.

$\Theta = 75°$
Support at J, L and M

B. Y-Ring (full)-R.T.

Θ 0°
Support at C and E

C. Y-Ring (full)-R.T. to 1400°F

Θ 0°
Supports a H, I, J, K, L

D. Y-Ring (full)-R.T.

$\Theta = \Theta$
Supports at G, L

E. Y-Ring empty

Θ = carried on side
Supports at C, E, I, K

F. Cable pulling Y-Ring load deflected at top to vertical - friction included (otherwise same and Cond. A)

Structural Analytical Procedure

A. Determine load on frame here to Y-Ring at points A, thru M
B. Determine load on frame due to lead weight of frame in terms of W (slight per linear inch) at points A thru M.
C. Place frame and supports in position desired cutting back to statically determined structure where necessary, and determine loads in frame members (AB, BC thru FH).
D. In particular
   1. Due to loading Cond. A., support at M was ignored for first calculations
      RcL=2669+1233 W
      L3x3x3/16 shows
         fa = 2624 psi (C)
         Fco = 6572 Psi
            Margin of safety 1.5

Other members proved to be less critical. Geometric considerations show the loading at M will be up and since this places a tension load on member Cl it can safely be ignored.

2. Due to loading Cond. C at 1400°F

    P at DC = 1328.8# (C)

    A hinge diameter of 3/14" gives

    Fbr = 9450 psi

    Fbru = 1000 psi

    Margin of safety = 0.06

3. Due to loading Cond. F at R.T.

    M.S. was high for compression load on support at J analyzed as a column.

PHASE II

MATERIAL PROCUREMENT

All 8-1-1 titanium materials required for the fabrication of the full-scale Y-Ring segments, and steel matrix tooling, and the non-productive materials required for the fabrication of the manufacturing and inspection tools are being procured to applicable NAA/LAD and government specifications from qualified suppliers. Upon receival, they will be inspected and tested by quality control receiving inspection to assure conformance to materials specification requirements.

FABRICATION PLAN

A detailed fabrication plan for the Fabrication of the Full-Scale Titanium Y-Ring Segments has been prepared. This fabrication plan is reported in NAA Report 66-87 entitled "Fabrication Plan for Fabricating a Simulated Titanium Alloy Y-Ring Segment for the S-1C Fuel Tank". This fabrication plan includes, in detail, the planned inspection and test evaluation program for full scale Y-Ring segments.

TOOLING FABRICATION

Two tools are required for the fabrication of the full scale Y-Ring segments. These tools are required for the hot contour forming, duplex annealing, and handling of the Y-Ring segments. These two tools are the Hot Form Die, and the Special Handling Fixture. These tools are being fabricated to NAA Drawing No's. 2623-201 and 2623-202 respectively.

The hot forming die, NAA Drawing 2623-201, is being fabricated by Murdock, Inc., 15800 S. Avalon Blvd., Compton, California who was the successful bidder.

To facilitate casting and machining of the hot form/size tool 4 "Densite" plaster molds were manufactured by the Tooling Division Plaster Shop. Two of these molds are plaster master tracer patterns, shown in the foreground of Figure 36 . The other two, one of which is shown in the background of Figure 36, are plaster patterns made 1/2-inch oversize in all dimensions of Dwg. T-2623-201 suitable for casting foundry use. Typical foundry procedure is to 1) Ram the plaster patterns up in molding sand, 2) Remove the patterns (they have 3° of draft in side walls to facilitate removal) leaving a pattern shaped cavity, 3) Low temperature bake the molding sand image to drive out mositure, 4) Pour the molten steel, in this case high silicon ductile iron, into the sand cavity to achieve a metallic duplicate of the plaster patterns, and 5) After solidification the sand is broken away exposing the rough casting. The 1/2-inch oversize allows for possible deleterious surface porosity or cooling distortion.

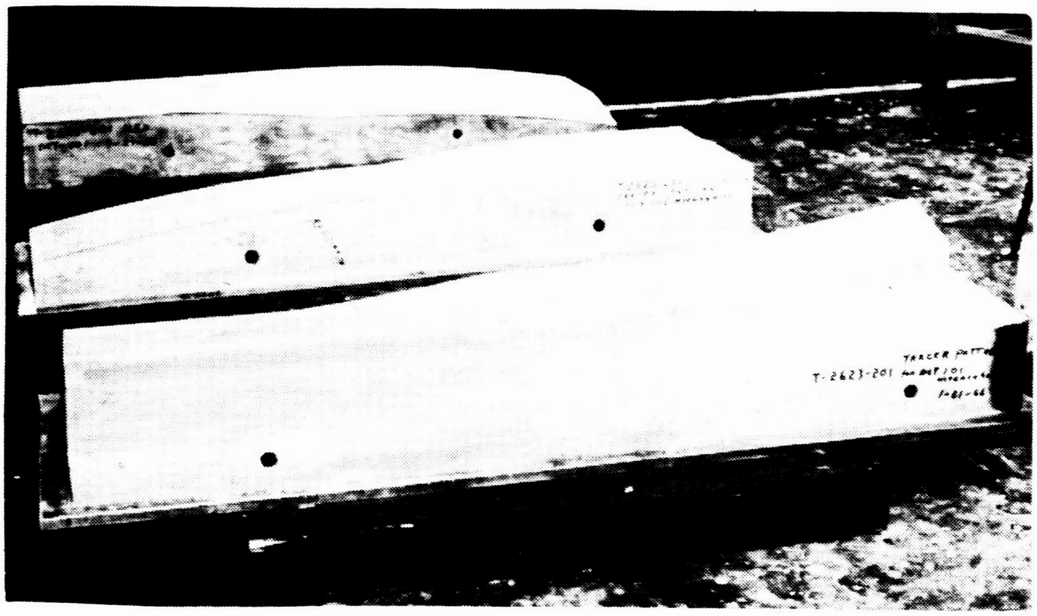


FIGURE 36 "DENSITE" PLASTER MOLDS

The two plaster master tracer patterns are precisely mounted on 1-inch aluminum base plates to establish base reference in relation to each other and the work surfaces of the plaster. The master tracer patterns are manufactured to net dimensions of Dwg. T-2623-201 suitable for application to duplicating machining techniques.

All 4 plasters have been sent to Murdock, Inc. It is planned for Murdock to cast and subsequently plane 1/2-inch from all surfaces except the compounded working surfaces of the tool. Matched working surfaces will be machined by utilizing the tracer patterns as a master surface for follower styles and transfering this image by Keller pattern duplicating machining techniques to the face of the Meehanite tools.

The Special Handling Fixture, NAA Drawing 2623-202, is being fabricated by Mathews Steel Co., Inc., 15534 So. Garfield Ave, Paramount, Calif., who was the successful bidder for this tool. All details are being fabricated including those details required for thermal processing of the Y-Ring, if required.

REFERENCES

(a) NAA-LAD Report 65-582.

(b) NAA Drawing No. 2623-003, "Candidate Y-Ring Assembly Configurations.

(c) NAA Drawing No. 2623-004, "Roll Diffusion Bonding Y-Ring Segment

(d) NAA Drawing No. T10706, "Skate Machining Fixture, Preliminary Design.

NA-66-104

ENCLOSURE 1

JAN 12 1966

Titanium Metals Corporation of America

7223 SYCAMORE STREET
LOS ANGELES, CALIFORNIA 90022
213-723-8567
TLX 06-74212

January 11, 1966

Mr. Julian King
Dept. 56, Group 050
Building 3
North American Aviation, Inc.
International Airport
Los Angeles, California 90009

Dear Julian:

During my recent visit to our West Caldwell facility, Ward Minkler gave me the enclosed report excerpts for you. This was as he had promised to you during a recent visit to North American.

Very truly yours,

TITANIUM METALS CORPORATION OF AMERICA

W H Heil/ch

William H. Heil
Metallurgical Engineer
Technical Service Dept.

WHH/ch

MATERIALS

Ti-8Al-1Mo-1V, Heat D-1237, Sheet No. 5 was used for this study. Typical room temperature tensile results and chemical analyses are shown in Tables I and II.

PROCEDURES

Solution treatments were carried out to a precision of ±5°F whereas temperature control during aging was within ±10°F. All specimen blanks were sandblasted and pickled prior to machining.

NASA sharp notch tensile test specimens (ST 16) with a maximum root radius of 0.0001-inch were used for the notch toughness investigations. Standard 1-inch gage length sheet specimens (ST 3) were used to determine tensile properties. Tensile tests were conducted on a 60,000-pound Riehle screw driven machine, equipped with an O.S. Peters Model MA-SP microformer stress-strain pacer. For the unnotched specimens, stress-strain curves were recorded through the 0.2% yield strength using a 1-inch separable averaging extensometer at a strain rate of 0.005-in/in/min. From yield to fracture, all unnotched tensile specimens were pulled at a constant crosshead speed of 0.10-in/min. The sharp notch tensile test specimens were pulled at a constant crosshead speed of 0.05-in/min until fracture occurred.

Arcweld Model M Creep Machines were utilized for the thermal stress exposures. The exposure procedure consisted of first bringing the furnace to test temperature, then placing the specimen blank, with holding bars attached, into the hot zone. Recovery of temperature was then followed on a Minneapolis-Honeywell Recorder until test temperature was again reached. An additional short time period was then allowed for the temperature to equilibrate before loading. Temperature control during exposure was ±10°F. In each case, the notches were machined into the specimen after exposure.

TABLE I

ROOM TEMPERATURE TENSILE PROPERTIES OF Ti-8Al-1Mo-1V, 1450F(8hrs)FC[1], HEAT D-1237, SHEET NO. 5

Test Direction	UTS Ksi	0.2% YS Ksi	Elongation, % in 2-inches
L	152.1	148.6	16.5
T	154.8	149.2	16.0

(1) Mill results and heat treatment.

TABLE II

CHEMICAL ANALYSES OF Ti-8Al-1Mo-1V; HEAT D-1237, SHEET NO. 5

Al	Mo	V	Sn	Fe	N	C	O	H
7.7	1.2	1.0	---	0.11	0.014	0.027	0.09	0.013

ENCLOSURE 1 (Continued)

RESULTS AND DISCUSSION

The effects of isothermal aging time and temperature on sharp notch properties of Ti-8Al-1Mo-1V are shown in Figure 1. As may be seen, embrittlement was most severe and the rate most rapid at 1100F or 1200F. Significant embrittlement occurred in 100-hours or less at temperatures as low as 600F and as high as 1275F. The choice of 120 Ksi notch strength in defining the curve was arbitrary but well serves the purpose of outlining the embrittlement region. The effects of solution treatment practice were not explored but it is probable that the "TTE" (Time-Temperature-Embrittlement) curve can be shifted horizontally somewhat by solution treatment in the alpha-beta field. However, inasmuch as a water quench from the "alpha" field was used as a base condition, the embrittlement curve reasonably represents the true situation and may be used in selecting heat treat sequences to avoid sharp notch embrittlement.

As shown in Table III, stress at 900F and 1000F increases the embrittlement rate by a factor of four or more, however, at lower temperatures, any effect of stress was small and less definite.

Pre-aging at 900F or 1000F did not prevent embrittlement after subsequent 600F or 800F thermal stress exposure. Rather, pre-aging and subsequent thermal stress exposure appeared to have cumulative effects. These data are given in Table IV.

Finally, a statistical analysis was made of the relationship between the sharp notch and yield strengths of Ti-8Al-1Mo-1V. None of the thermal stress exposures were included in this analysis. The results are summarized in Figure 2 wherein a linear regression line of x (NTS) upon y (YS) was plotted together with $\pm 2\sigma$ limits. As may be readily observed, there was an inverse relationship between yield strength and sharp notch tensile strength. The significance level of this correlation is above 0.001 (highly significant). The practical significance of this analysis is that, on the average, for yield strengths of about 127 Ksi, the sharp NTS/YS ratio would be expected to be below unity half of the time. For yield strengths of 135 Ksi the sharp NTS/YS ratio would be expected to be less than unity 95% of the time.

ENCLOSURE L (Continued)

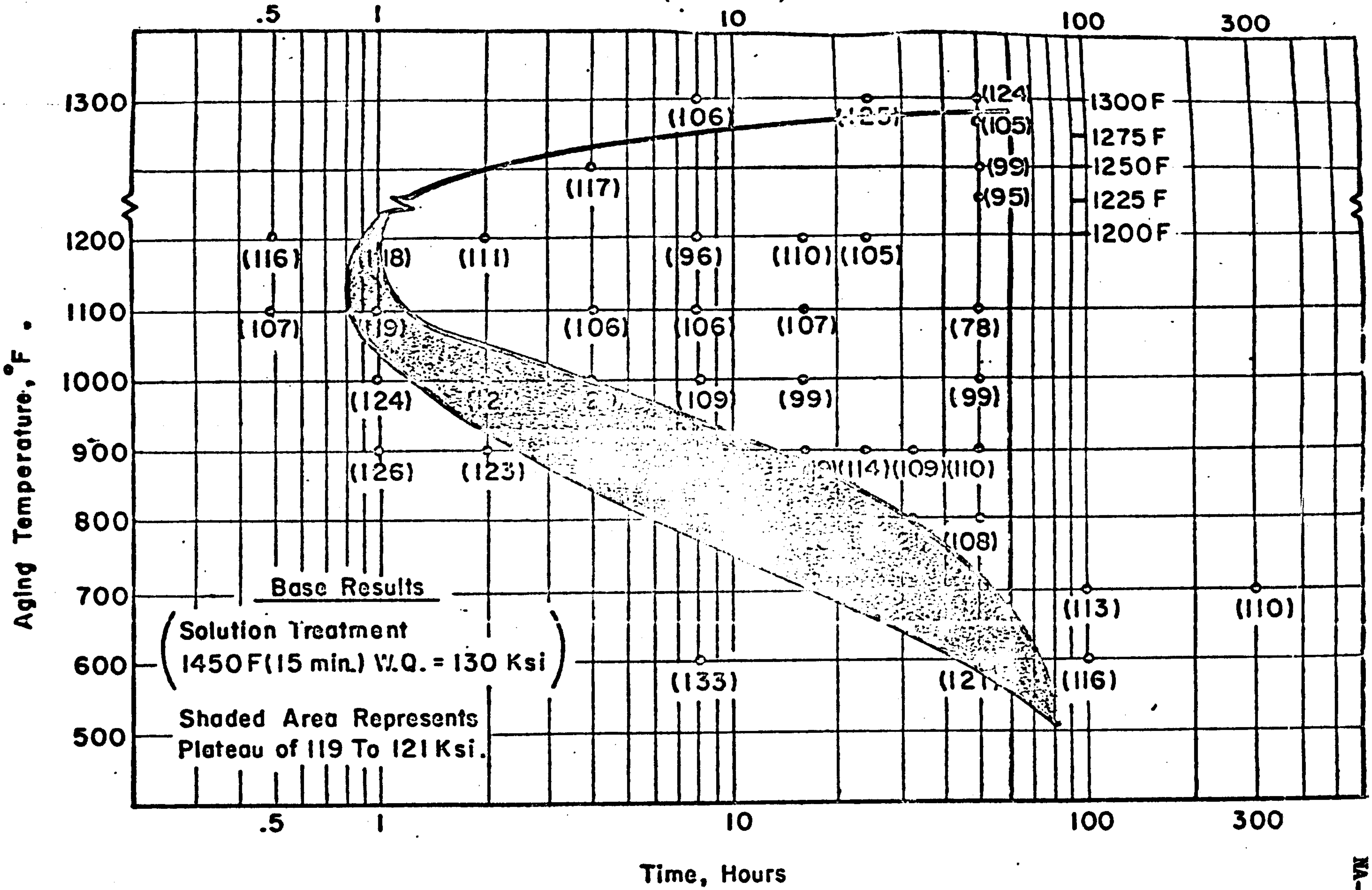


FIGURE I. TIME-TEMPERATURE-EMBRITTLEMENT CURVE FOR Ti-8Al-1Mo-1V, HEAT D-1237, SHEET No.5, L SPECIMENS.