NA-65-1043

PHASE I REPORT

TITANIUM S-IC SKIN SECTION

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

GEORGE C. MARSHALL SPACE FLIGHT CENTER

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PHASE I REPORT

TITANIUM S-IC SKIN SECTION

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

GEORGE C. MARSHALL SPACE FLIGHT CENTER

PREPARED BY

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PROJECT MANAGER

APPROVED BY

G. B. LEWIS
PROGRAM MANAGER

DATE 10 December 1965

NO. OF PAGES 28

NORTH AMERICAN AVIATION, INC. / LOS ANGELES DIVISION
INTERNATIONAL AIRPORT • LOS ANGELES, CALIFORNIA 90009

FOREWORD

The studies, activities, and accomplishments described in this report were made in the Phase I time period of the development program, from 29 June to 10 December 1965. This work constitutes part of the requirements of NASA/MSFC Contract No. NAS8-20530, "Titanium S-IC Skin Section."

35224

ABSTRACT

This report describes the engineering studies and design effort, the fabrication of roll diffusion bonded test packs, and the laboratory testing and analysis of the titanium panels produced in the test packs. Design drawings, fabrication and test data, and photographs are included.

SUMMARY

In its continuing effort to improve the structural design and reliability of the Saturn vehicle, NASA/MSFC is conducting an extensive research and development effort intended to promote the state-of-the-art in fabrication techniques for high-strength titanium alloys.

The program governed by Contract No. NAS8-20530 has the objective of establishing design requirements and process parameters for fabricating simulated skin sections, for the S-IC fuel tank, from 8Al-1Mo-1V titanium alloy. This is a four-phase program scheduled to be completed in the 10-month period from 29 June 1965 to 29 April 1966.

The specific technique being developed in this program is roll diffusion bonding. In this process, component parts made of titanium are assembled and encased within a carbon steel pack assembly and subjected to high-pressure rolling at elevated temperature. The fusion results in an integral titanium panel which is then removed from its steel enclosure by mechanical and/or chemical means.

During Phase I of the program, the primary task was to design, make, and test six subscale titanium panels, approximately 15-3/4 by 55 inches, representative in cross-section of the full-scale panels to be made in Phase III. Additional tasks in Phase I included the completion of the engineering design for the full-scale panel, preparation of a process specification for roll diffusion bonding, and the design of any special tooling required for Phase III. This reports presents an account of these tasks and their results.

As mutually agreed in a program review with representatives from NASA/MSFC on 29 July, the six test panels were scheduled to be made in successive sets of two so that information obtained from the first pair could be applied to the second pair, and from the second to the third pair. Consequently, four test panels have been completed and analyzed, and the fifth and sixth panels are, at this date, ready to be rolled at the steel mill. Data pertinent to the first four panels are included in this report. Information on the last two panels will be included in a supplement to this report, scheduled for completion on 21 January 1966.

Principal conclusions derived from Phase I effort to date are:

1. Excellent roll diffusion bonded joints have been produced, meeting or surpassing strength requirements, as evidenced by results of tensile and crippling tests, by penetrant inspection, and by metallographic examination.

2. Successful crack-free test welds indicate that unaided air cooling of a pack after rolling resulted in duplex annealed properties in the titanium.

3. The thermal shock process for separating the steel from the titanium caused severe cracking in the titanium. Thermal shock, in which the pack is frozen to about -120°F and then plunged into near-boiling water, will not be used again in this program.

4. Minor surface cracks in the titanium are attributable to a combination of effects caused by water quenching, rolling pressures, and iron-titanium embrittling contamination.

5. Steel filler bars should be machined to remove contaminated surface material, should be carefully radiused on edges which contact titanium joints, and must be meticulously clean when placed in the pack assembly.

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LIST OF ILLUSTRATIONS

PROGRAM ORGANIZATION

PROGRAM PLANNING

Upon confirmation of the contract award, organization of a project team under the direction of Program Manager George B. Lewis was immediately accomplished. At the initial meeting of the team on 8 July, the purpose and scope of the program were outlined, copies of the General Order, the Plan of Action, and the Schedule were distributed, and each team member was requested to evaluate his department's responsibilities, contribute constructive criticism and comments, and submit an estimate of hours for his department's effort in the program.

The information subsequently obtained from the team was analyzed, revisions to the original plan were made, and allocations of hours were determined and distributed on 15 July.

As mentioned in the Summary, a revision of the plan of action was made following NASA/MSFC approval at a review on 29 July. Accordingly, a new schedule chart (figure 1) was prepared and distributed. This schedule reflects the concept of progressive development in making and evaluating test panels. As agreed in the 29 July review, a decision on whether to proceed with the fifth and sixth panels was scheduled after preliminary evaluation of the second pair of test packs.

SCHEDULE POSITION

All of the tasks established for Phase I in the plan of action and schedule chart have been accomplished, and the program has been maintained on schedule.

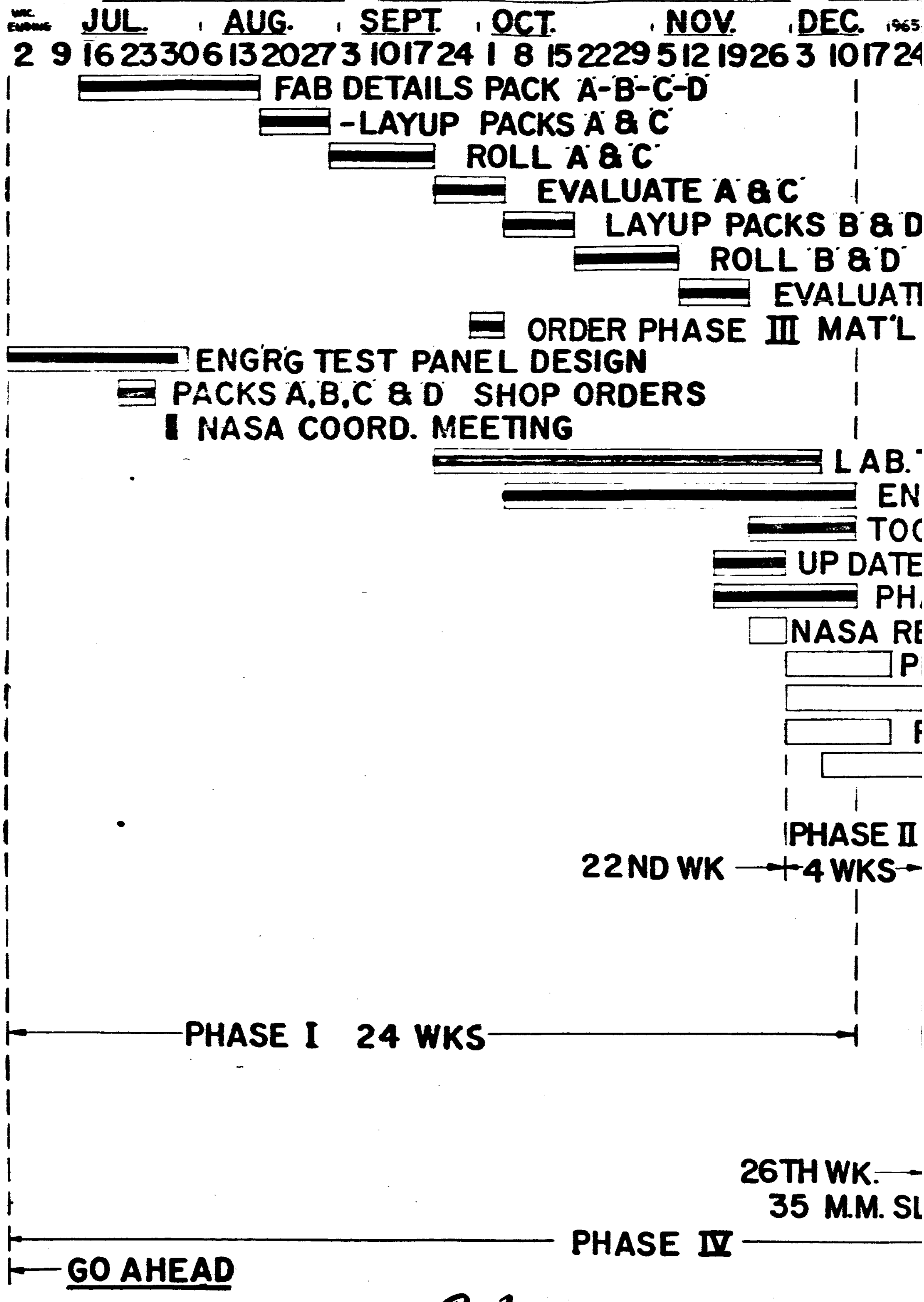
Roll diffusion bonding of the fifth and sixth packs is scheduled for 13 and 14 December. Completion of laboratory tests is scheduled for 14 January and the Phase I Report Supplement is to be completed by 21 January.

Initiation of Phases II and III of the program is not being affected by the supplementary effort in Phase I.

BUDGET CONTROL

Total expenditure of funds during Phase I has been controlled within allocations, with the exception that the commitment for titanium material for Phase III, amounting to $21,741.32, is reflected in November costs. See figure 2.

TITANIUM S-IC SKIN SECTION -G.O.



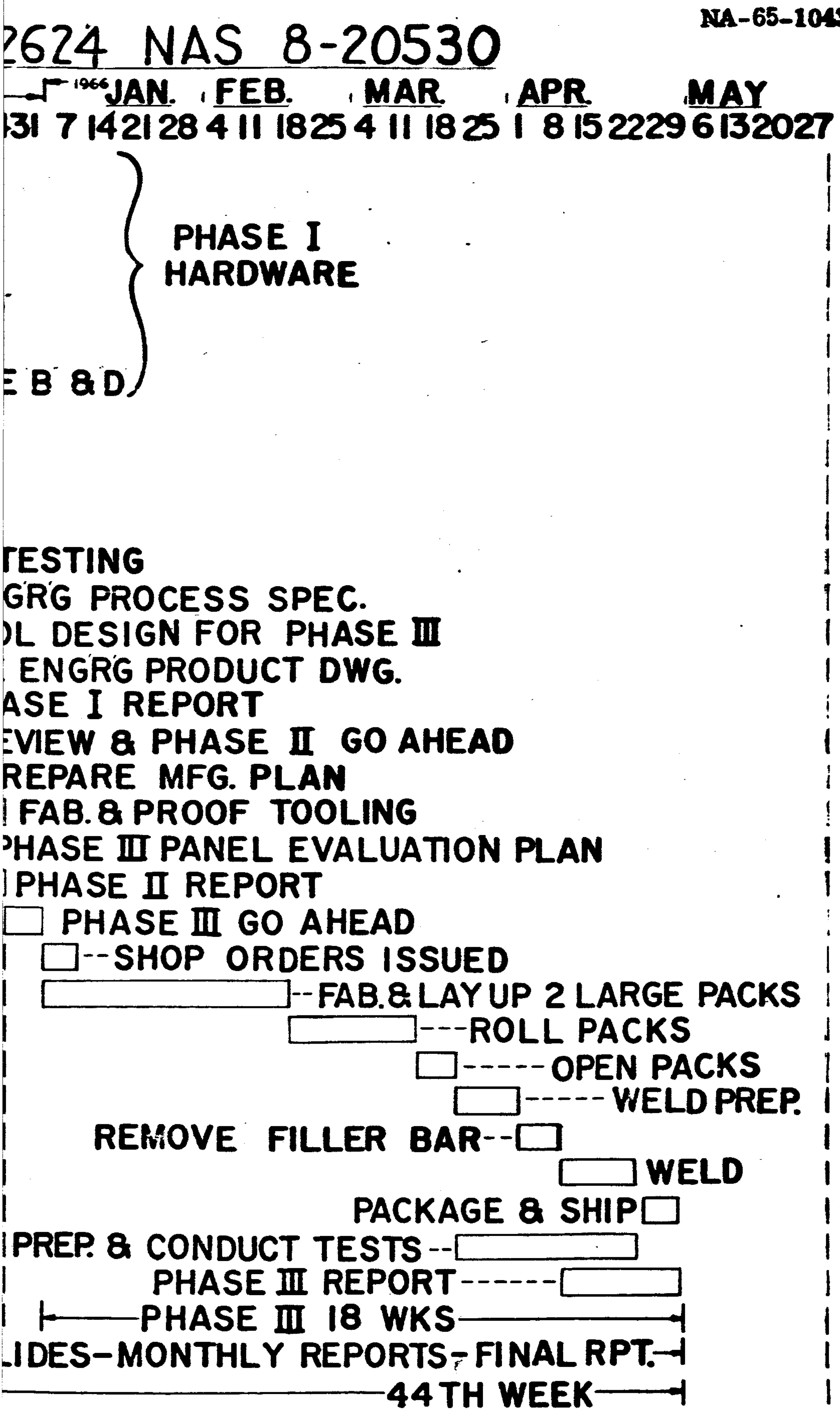
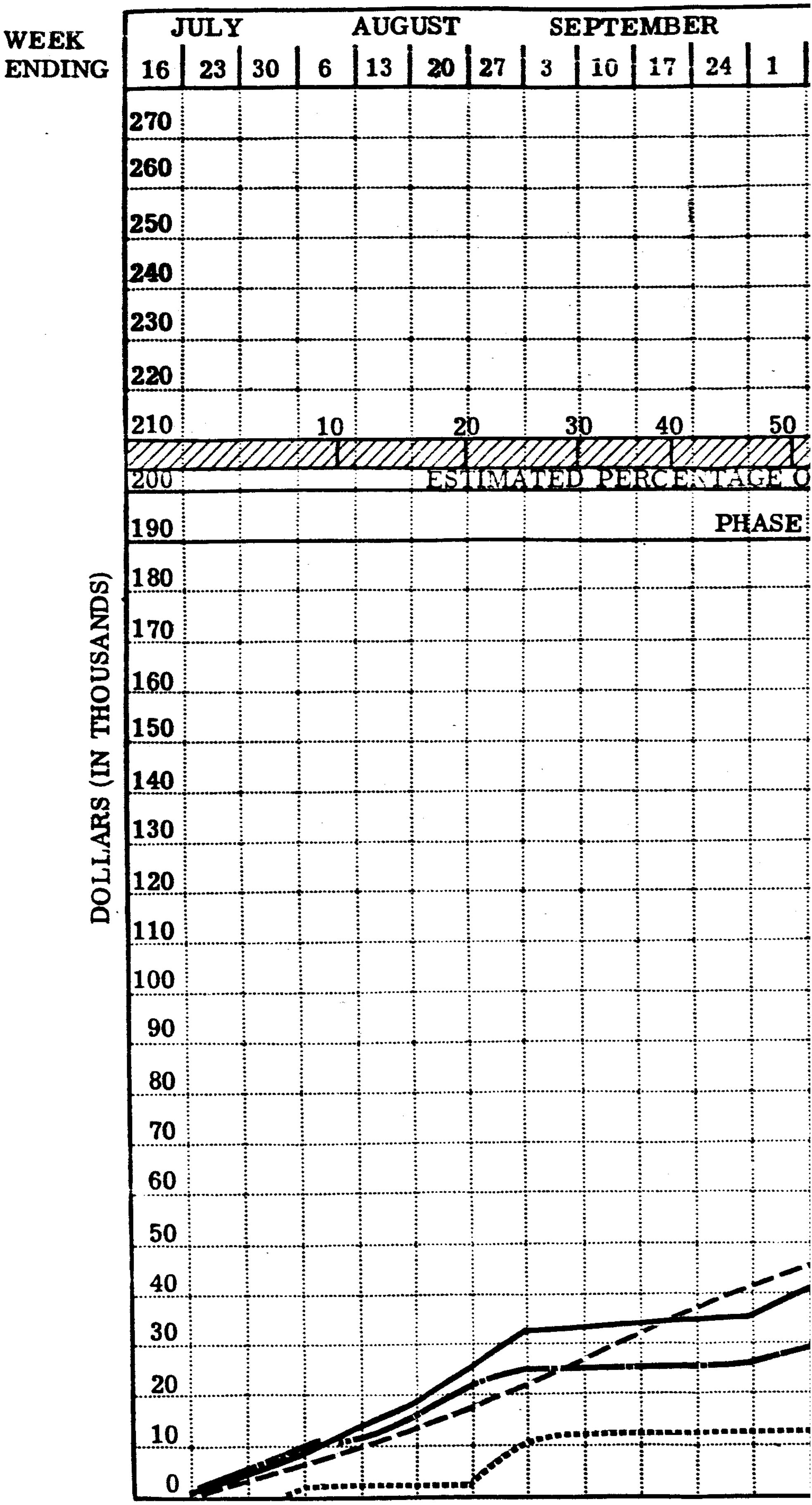
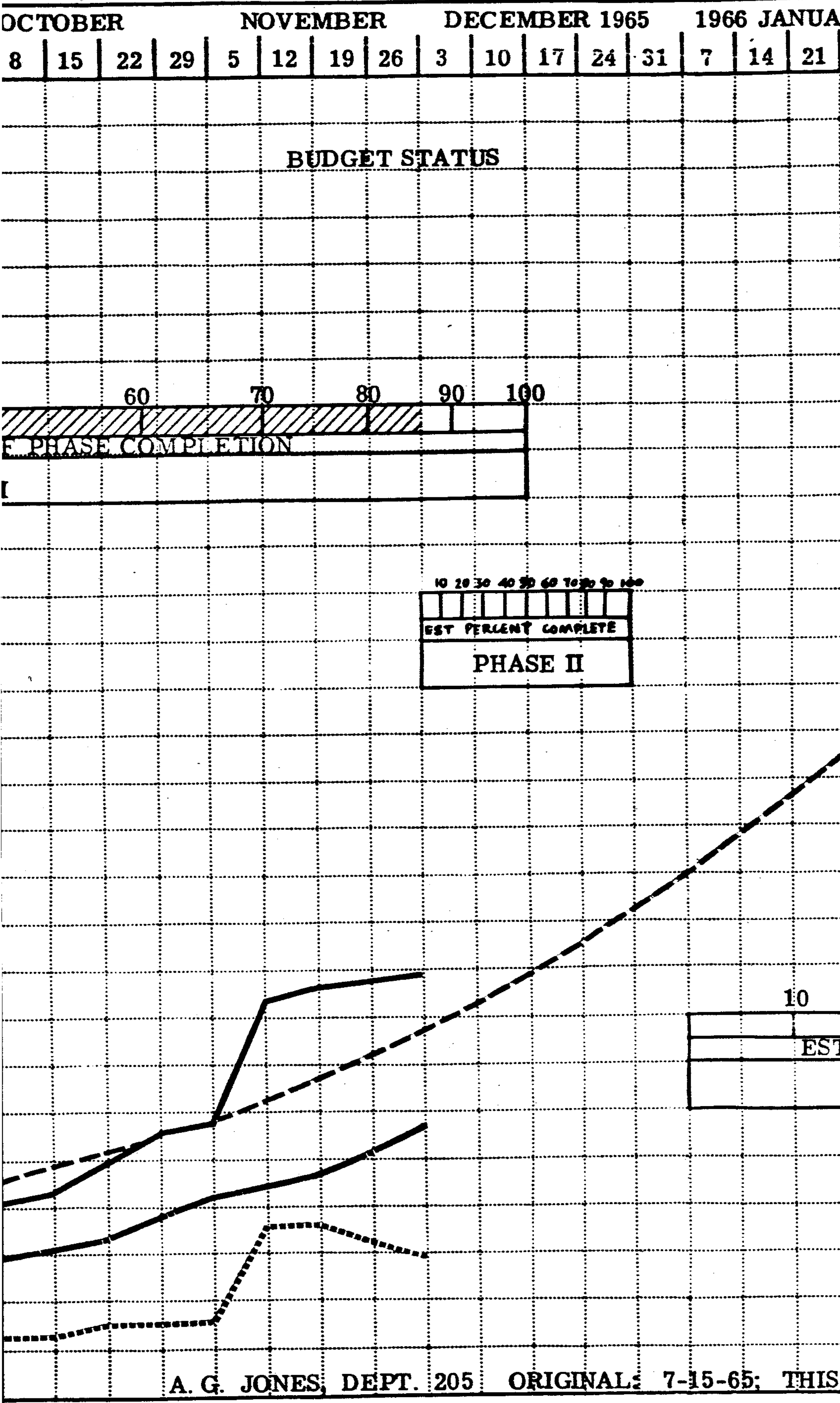


Figure 1. Schedule Chart

TITANIUM S-IC SKIN SECTION G.O. 2624

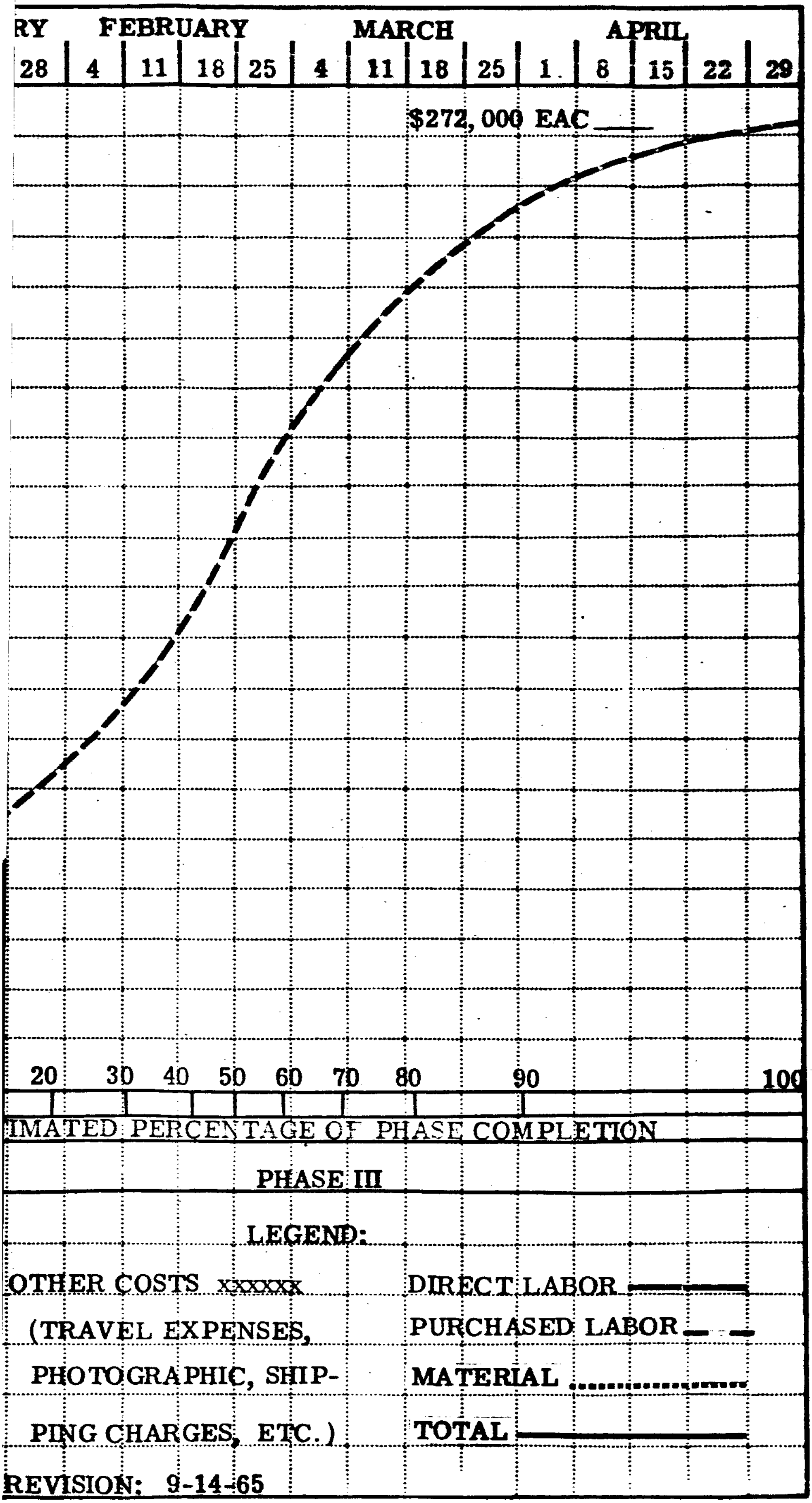


FORM 2000-P



A. G. JONES, DEPT. 205 ORIGINAL: 7-15-65; THIS

NA65-1043
DATE: 12-7-65



As the activity in Phase I has progressed, the emerging picture of hours expenditures has made possible a more realistic view of program needs. Consequently, allocations to the various participating departments have been revised, keeping the total within the established budget.

ENGINEERING SUMMARY

Engineering input during Phase I has consisted of design concept studies and analyses, final design of the full-scale panel to be produced in Phase III, information concerning materials and processes applicable to the program, assistance in static diffusion bonding of one test pack, preparation of a roll diffusion bonding process specification, and structures laboratory tests on panel specimens.

A detailed description of Engineering's activities during Phase I is presented in Appendix A.

Results of Production Development Laboratory tests also are included in Appendix A.

FABRICATION OF TEST PANELS

IDENTIFICATION OF TEST PANELS

At the beginning of Phase I it was decided that the test panels would be identified by number and letter to assure clear understanding among personnel engaged in the program as to which panel was being referred to in any discussion or correspondence.

Accordingly, the following identifications, in chronological order of fabrication, were established:

Pack Assembly No.	Engineering Configuration No.	Common Reference
2624-001-A	1	Pack A
2624-002-C	2	Pack C
2624-001-B	1	Pack B
2624-002-D	2	Pack D
2624-002-E	2	Pack E
2624-002-F	2	Pack F

Designs of the two basic pack configurations are shown in figures 3 and 4. Evaluation of the first four packs led to the adoption of Engineering Configuration No. 2 for both Packs E and F.

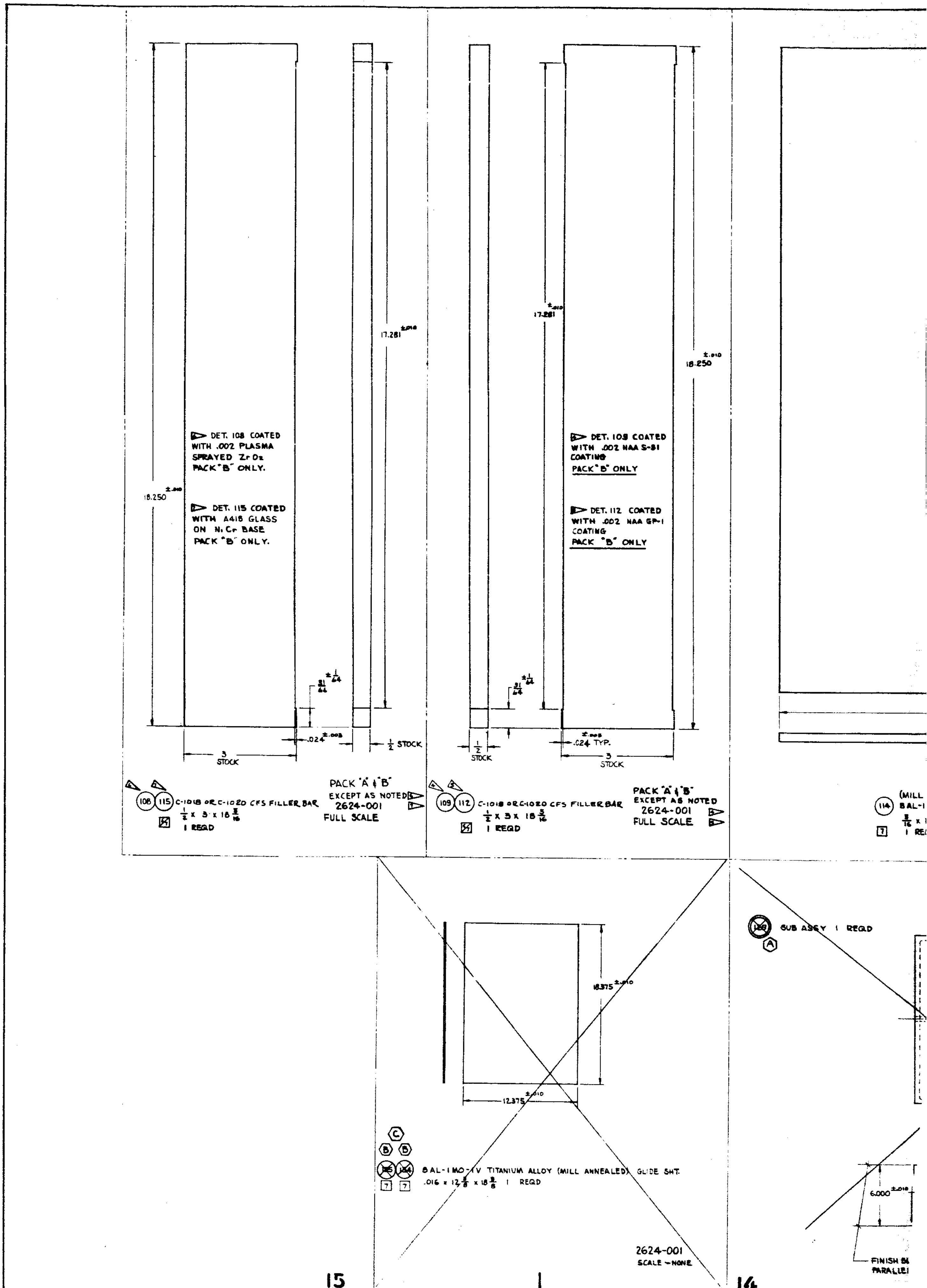
FABRICATION OF TEST PACKS

Detailed information on the fabrication of Packs A, B, C, and D is contained in the monthly progress reports submitted to NASA/MSFC on the 15th of each month, beginning in August. These reports, in chronological order, bear the following reference numbers: 65LA12347-277, 65LA13044-56, 65LA13173-56, and 65LA13598-056.

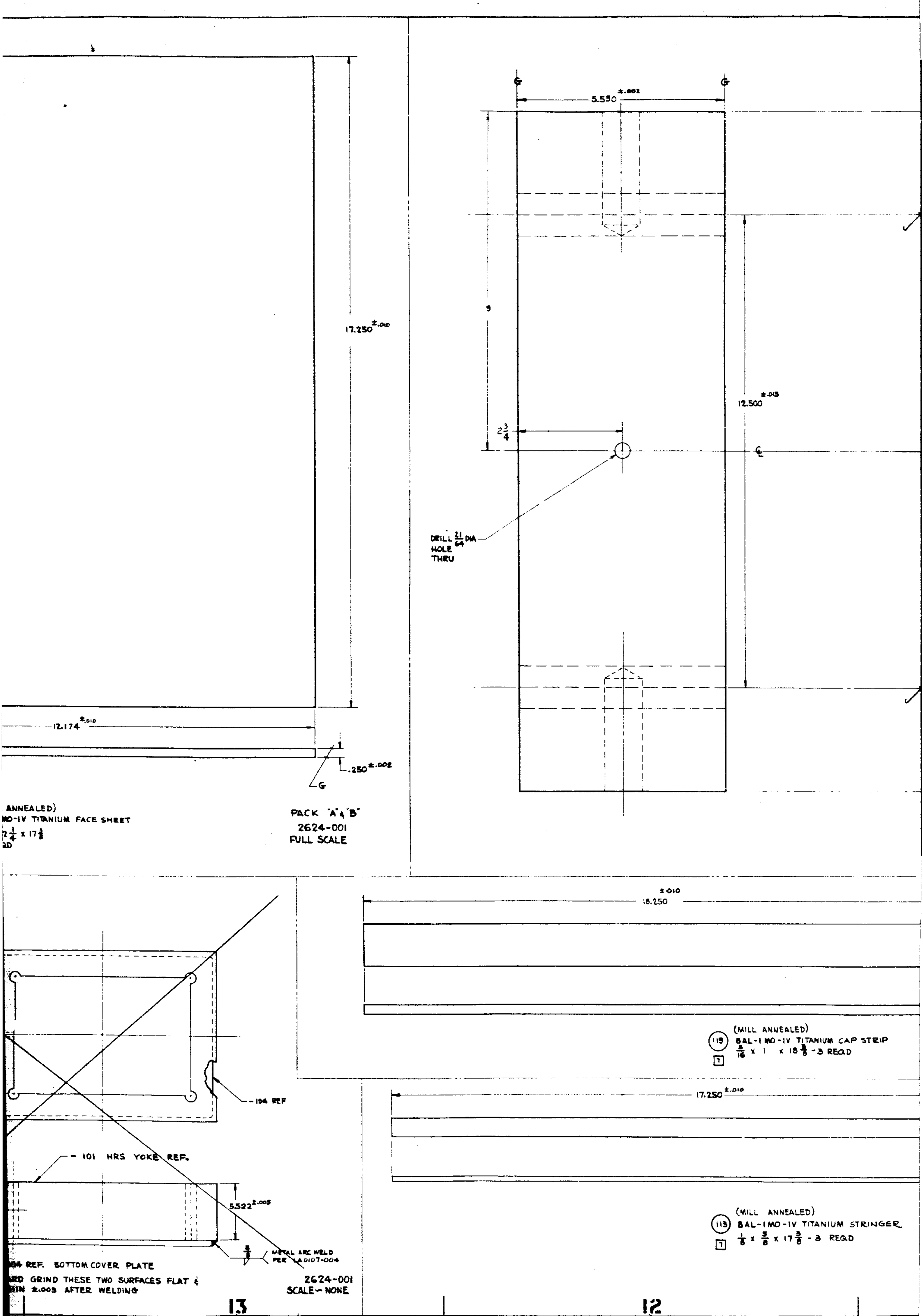
Highlights of the manufacturing of the first four test panels are presented in the following paragraphs.

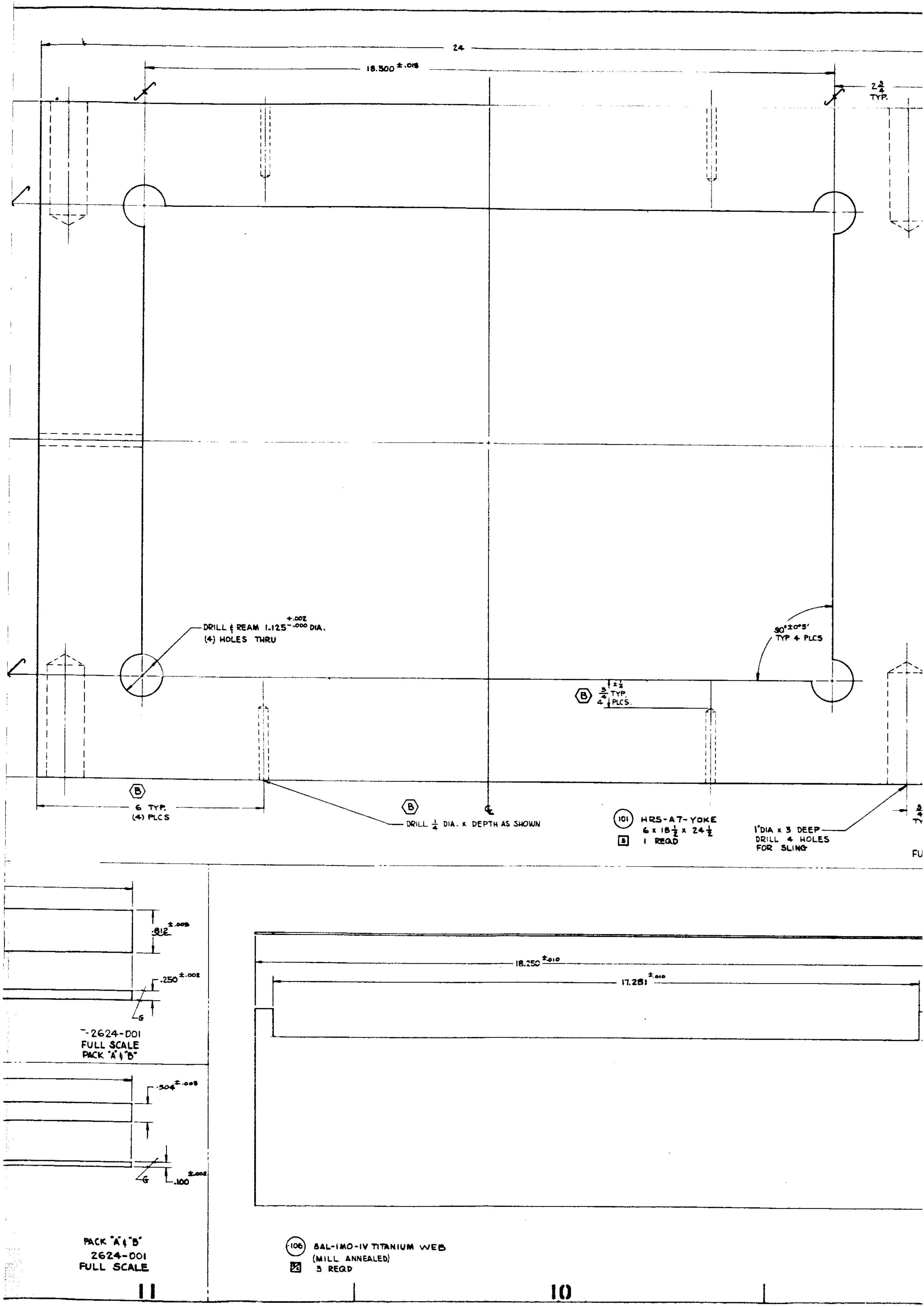
Fabrication of details and the layup assembly operations for Pack A were typical of all of the test packs; therefore, the illustrations of sequential steps in the fabrication of Pack A serve to depict the operations for the test pack group.

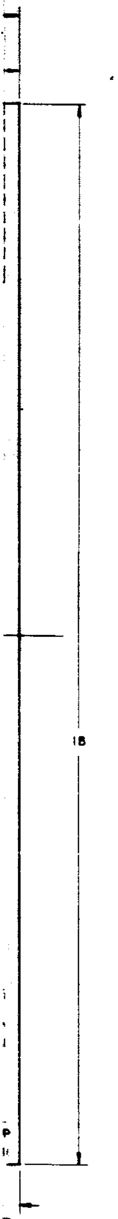
Figure 5 shows the steel filler bars and shims ready to be cleaned and processed prior to assembly. In figure 6, the component parts have been fitted into the yoke, and strips of mild steel foil are being tack-welded in



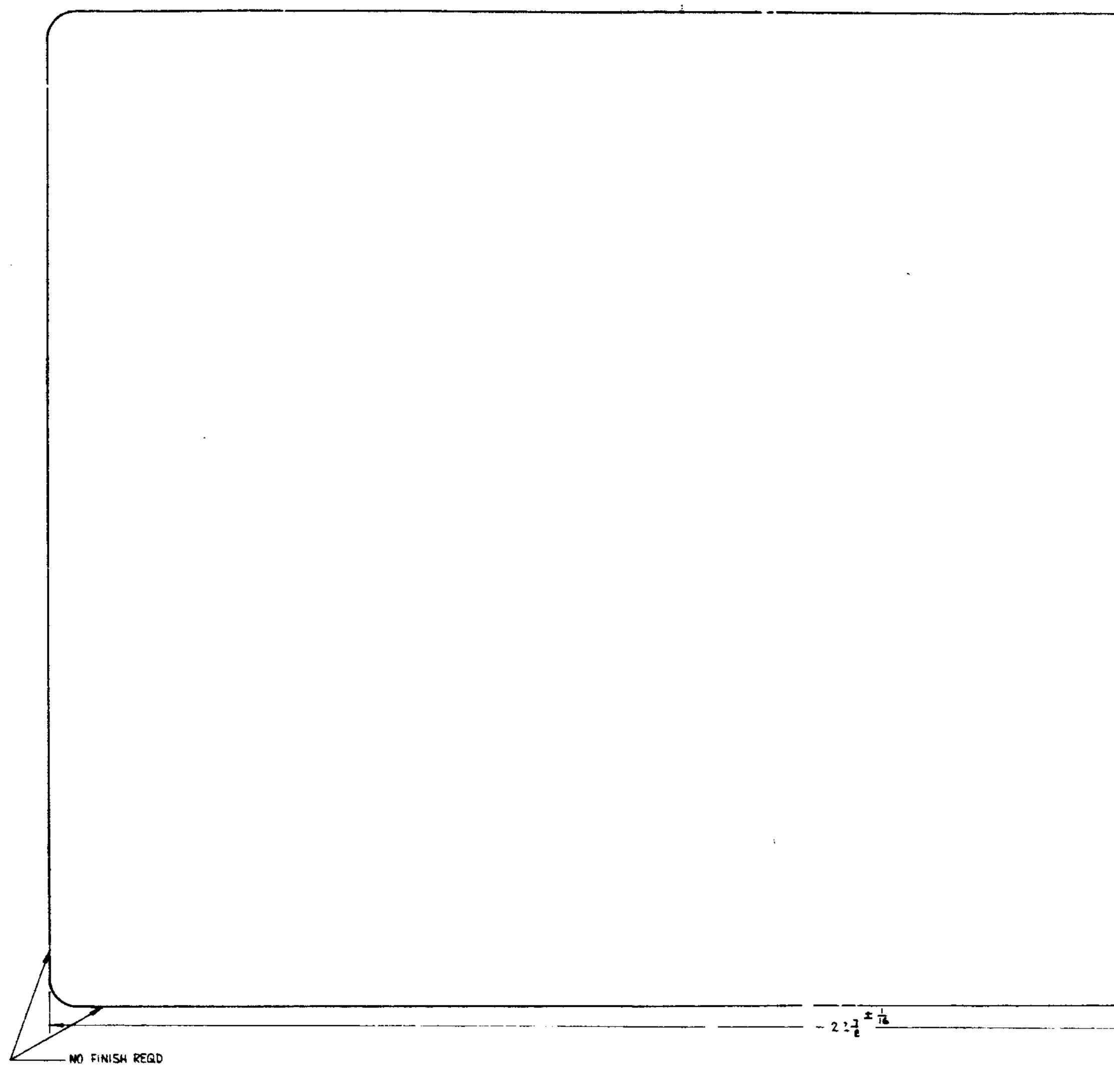
18.250 ±.010
17.281 ±.010
DET. 108 COATED WITH .002 PLASMA SPRAYED ZrO2 PACK "B" ONLY.
DET. 115 COATED WITH A418 GLASS ON NiCr BASE PACK "B" ONLY.
31/64 ±1/64
.024 ±.003
1/2 STOCK
3 STOCK
108 115 C-1018 OR C-1020 CFS FILLER BAR
1/2 x 3 x 18 3/16
1 REQD
PACK "A" & "B" EXCEPT AS NOTED
2624-001
FULL SCALE
DET. 109 COATED WITH .002 NAA S-81 COATING PACK "B" ONLY
DET. 112 COATED WITH .002 NAA GP-1 COATING PACK "B" ONLY
.024 ±.003 TYP.
109 112 C-1018 OR C-1020 CFS FILLER BAR
1/2 x 3 x 18 3/16
1 REQD
PACK "A" & "B" EXCEPT AS NOTED
2624-001
FULL SCALE
114
SUB ASSY 1 REQD
A
18.375 ±.010
12.375 ±.010
C
B B
6AL-1MO-1V TITANIUM ALLOY (MILL ANNEALED) GLIDE SHT.
.016 x 12 3/8 x 18 3/8 1 REQD
7 7
2624-001
SCALE - NONE
6.000 ±.010
15
14

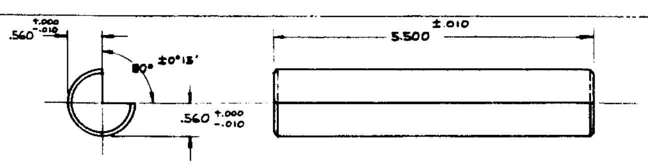

5.550 ±.002
17.250 ±.010
12.174 ±.010
.250 ±.002
ANNEALED)
MO-IV TITANIUM FACE SHEET
PACK "A" & "B"
2624-001
FULL SCALE
9
2 3/4
12.500 ±.015
DRILL 21/64 DIA HOLE THRU
±.010
18.250
(MILL ANNEALED)
119 8AL-1MO-1V TITANIUM CAP STRIP
5/16 x 1 x 18 3/8 - 3 REQD
17.250 ±.010
(MILL ANNEALED)
113 8AL-1MO-1V TITANIUM STRINGER
1/8 x 5/8 x 17 3/8 - 3 REQD
104 REF
101 HRS YOKE REF.
5.522 ±.005
METAL ARC WELD PER LA0107-004
REF. BOTTOM COVER PLATE
GRIND THESE TWO SURFACES FLAT &
±.005 AFTER WELDING
2624-001
SCALE — NONE
13
12


24
18.500 ±.015
2 3/4 TYP.
DRILL & REAM 1.125 +.002 -.000 DIA.
(4) HOLES THRU
90°±0°5'
TYP 4 PLCS
B
3/4 ±1/4 TYP.
4 PLCS.
B
6 TYP.
(4) PLCS
B
DRILL 1/4 DIA. x DEPTH AS SHOWN
101 HRS-A7-YOKE
6 x 18 1/2 x 24 1/2
1 REQD
1" DIA x 3 DEEP
DRILL 4 HOLES
FOR SLING
.812 ±.005
.250 ±.002
G
-2624-D01
FULL SCALE
PACK "A" & "B"
.504 ±.005
G
.100 ±.002
PACK "A" & "B"
2624-D01
FULL SCALE
18.250 ±.010
17.281 ±.010
106 6AL-1MO-1V TITANIUM WEB
(MILL ANNEALED)
3 REQD
11
10



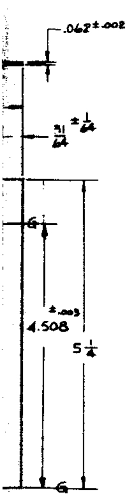
PACK "A" & "B"
2624-001
LL SCALE



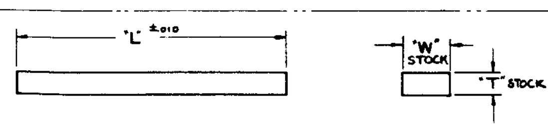


(102) C-1018 OR C-1020 CFS PLUG
$1\frac{1}{8}$ DIA X $5\frac{1}{2}$
5 4 REQD

PACK "A" & "B"
2624-001
FULL SCALE



PACK "A" & "B"
2624-001
FULL SCALE

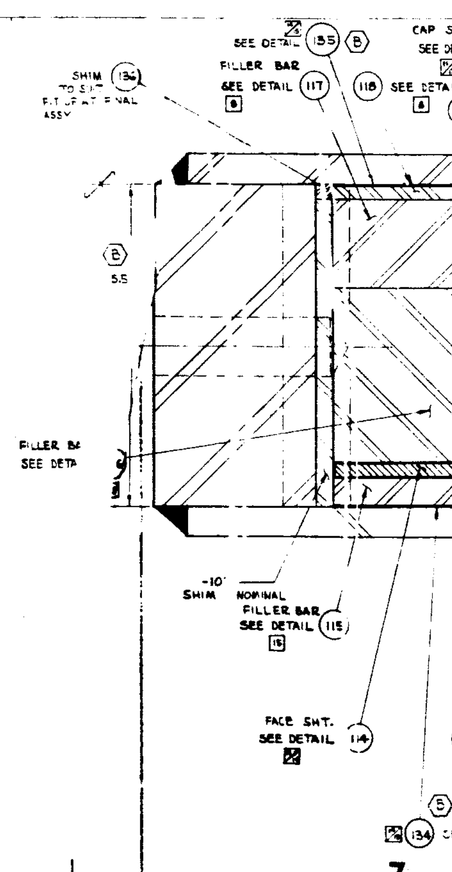


DET. NO.	T	W	L	NO. REQD
-120	$1\frac{1}{2}$	3	18.250	1
~~-122~~	~~$1\frac{1}{2}$~~	~~3~~		~~1~~
-117	$1\frac{1}{2}$	3		1
-125	$1\frac{1}{2}$	3		1
~~-110~~	~~3~~	~~3~~		~~1~~
-111	3	3		1
-105	3	3		1
-116	3	3		1
-118	$\frac{1}{4}$	$2\frac{1}{2}$		1
-121	$\frac{1}{4}$	$2\frac{1}{4}$		1
-124	$\frac{1}{4}$	$2\frac{1}{2}$		1
-123	$\frac{1}{4}$	$2\frac{1}{4}$		1
-126	$\frac{1}{4}$	$\frac{1}{8}$	18.250	2

SEE SHT. #2 OF 2 FOR
DETAILS -105 & -116 USED ON PACK "B"

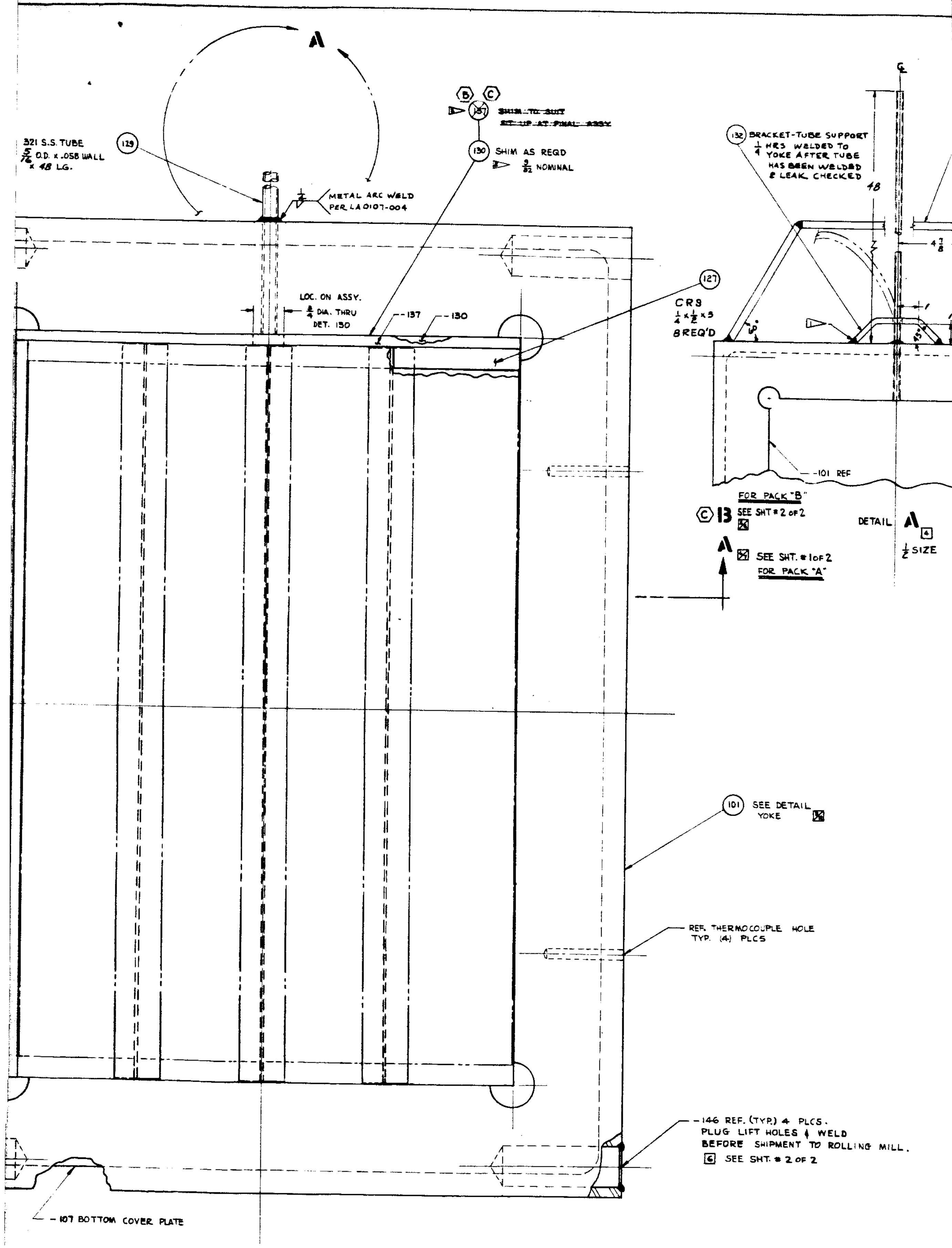
MT'L· C-1018 OR C-1020 COLD FINISHED STEEL FILLER BARS
SEE TABULATION ABOVE
FOR DET'S AS NOTED

PACK "A" & "B"
EXCEPT AS NOTED
2624-001
FULL SCALE

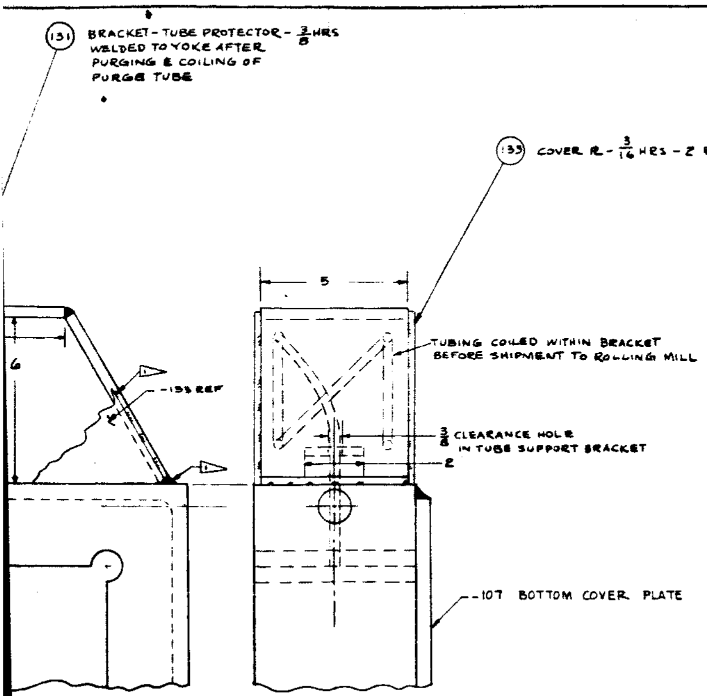


9 8 7

7-4



(PLAN VIEW) DETS. 104, 118, 121, 123 & 124 OMITTED
FOR CLARITY
PACK "A" & "B" EXCEPT AS NOTED



REVISIONS

LTR	ZONE	CHANGE	APP	DATE
A	13-14	DELETED -128	GJM	8-11-65
B	10	ADDED DRILL $\frac{1}{4}$ DIA. X DEPTH AS SHOWN.	NM	8-11-65
	11	ADDED DIMS $\frac{3}{4}$ & 6 TYP. (4) PLCS.		
		ADDED WELD SYMBOL & SPEC. AS NOTED.	NM	8-11-65
	14-15	ADDED DETS 134 & 135	NM	8-23-65
	7-8	ADDED DIM. 5.514		
	2-4	$\frac{3}{4}$ DIA. WAS $\frac{1}{2}$ DIA.	NM	8-23-65
	2-4-5	ADDED DETS 136 & 137	NM	8-24-65
C		ADDED TITANIUM FOIL AS A PARTING AGENT AND CONTAMINATE ADSORPTION DEVICE.	NM	10-5-65
	8-9	OBS. DETAILS 110, 122 134, 135, 136 & 137, FOR PACK "B".		
	5-6	ADDED DETS 138 THRU 146 SEE SHT #2 OF 2		
	3-5	ADDED SECTION "BB" & SHT #2 OF 2 FOR PACK "B"	NM	10-5-65

GENERAL NOTES!

1. WELD PER STD SHOP PRACTICE EXCEPT AS NOTED.
2. FRACTIONAL TOL. $\pm\frac{1}{32}$, EXCEPT AS NOTED.
   DECIMAL TOL. $\pm$.010, EXCEPT AS NOTED.

(B) 3. DET. 103, 130, 136 & 137 AS REQ'D AT TIME OF LAYUP. DRILL $\frac{3}{4}$ DIA HOLE IN -130 SHIM & LOC. AT ASSY.

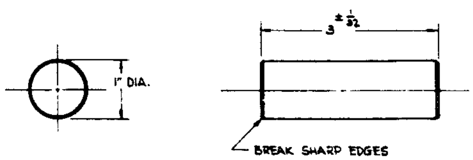
(C) 4. CODED THUS ▷ DENOTES PACK "B"

SCALE: FULL & NOTED	DR. H. MORIWAKI DATE 7-17-65 CHECKED	NORTH AMERICAN AVIATION, INC. INTERNATIONAL AIRPORT LOS ANGELES 45, CALIFORNIA
PACK ASSY - CONFIGURATION # 1 S-IC ROLL DIFFUSION BOND TEST PANEL		2624-001

2

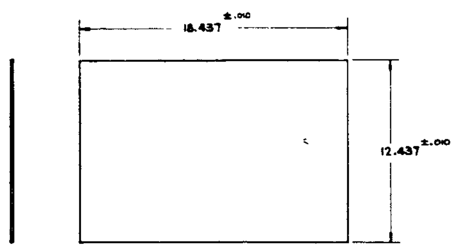
SHT # 1 OF 2

Figure 3 Pack A Assembly Drawing



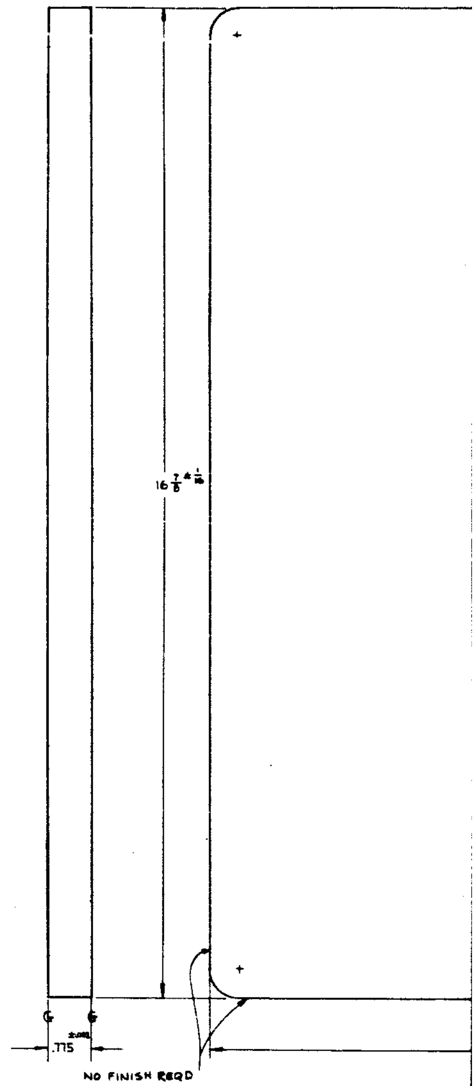
(D) (131) CRS PLUG
1" DIA x 3   4 REQD
[5]

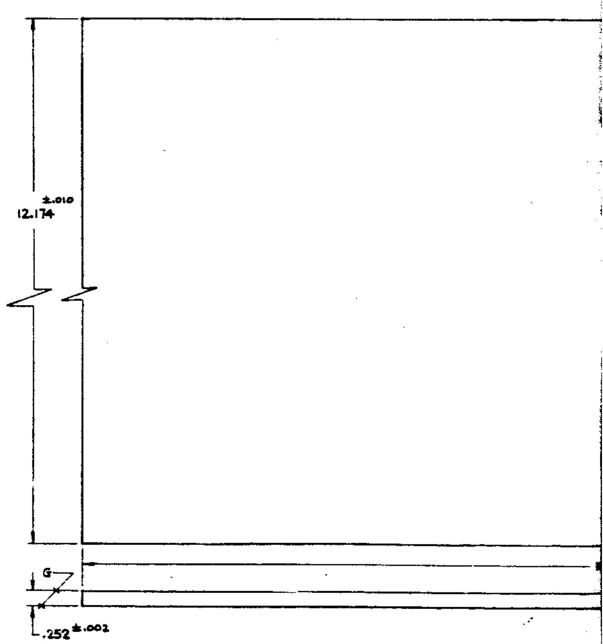
2624-002
SCALE – FULL



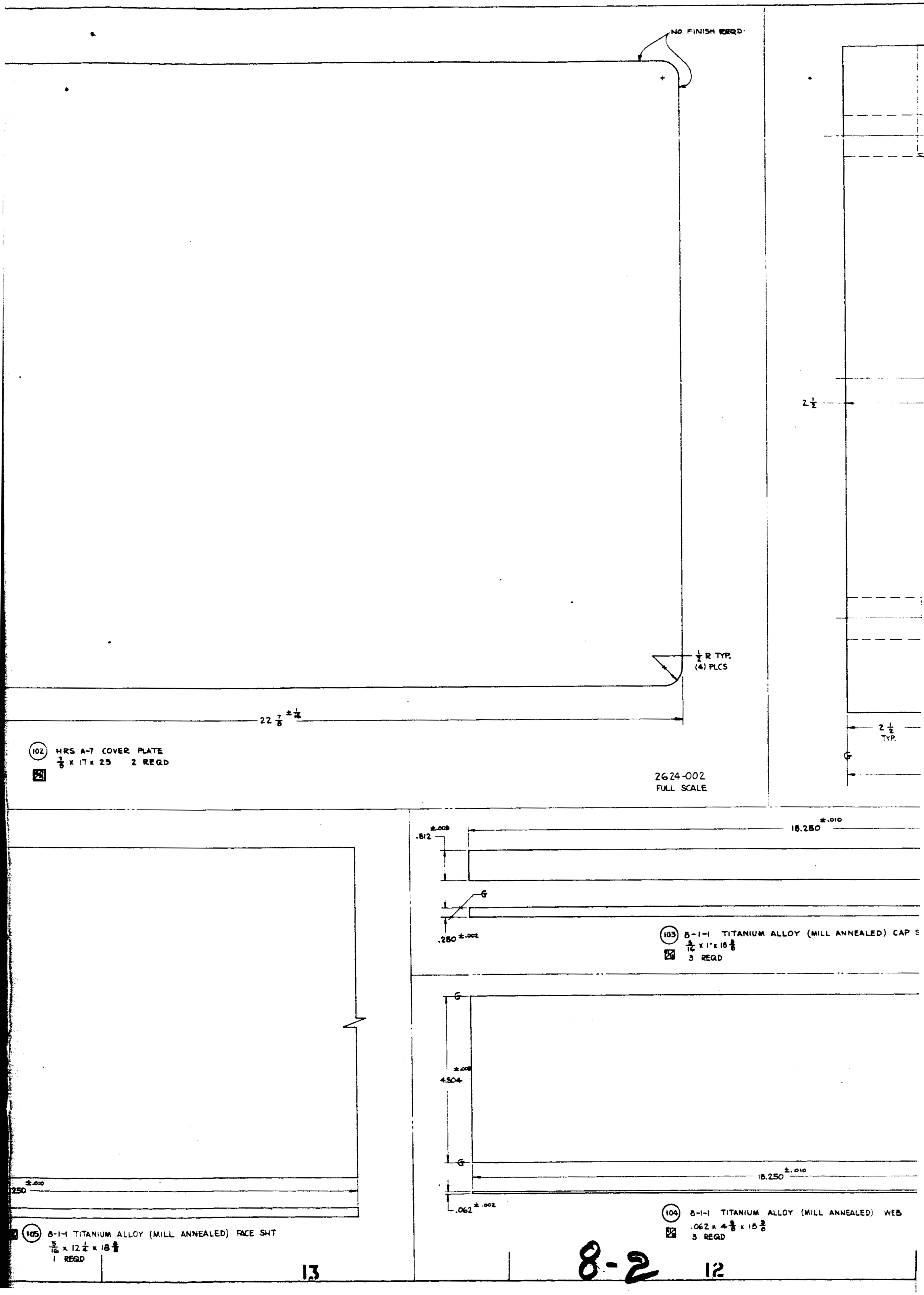
(B) (129) 8AL-1MO-1V (MILL ANNEALED) TI. GLIDE SHT.
.016 x 12 1/2 x 18 7/16   1 REQD
[10]

2624-002
SCALE – NONE



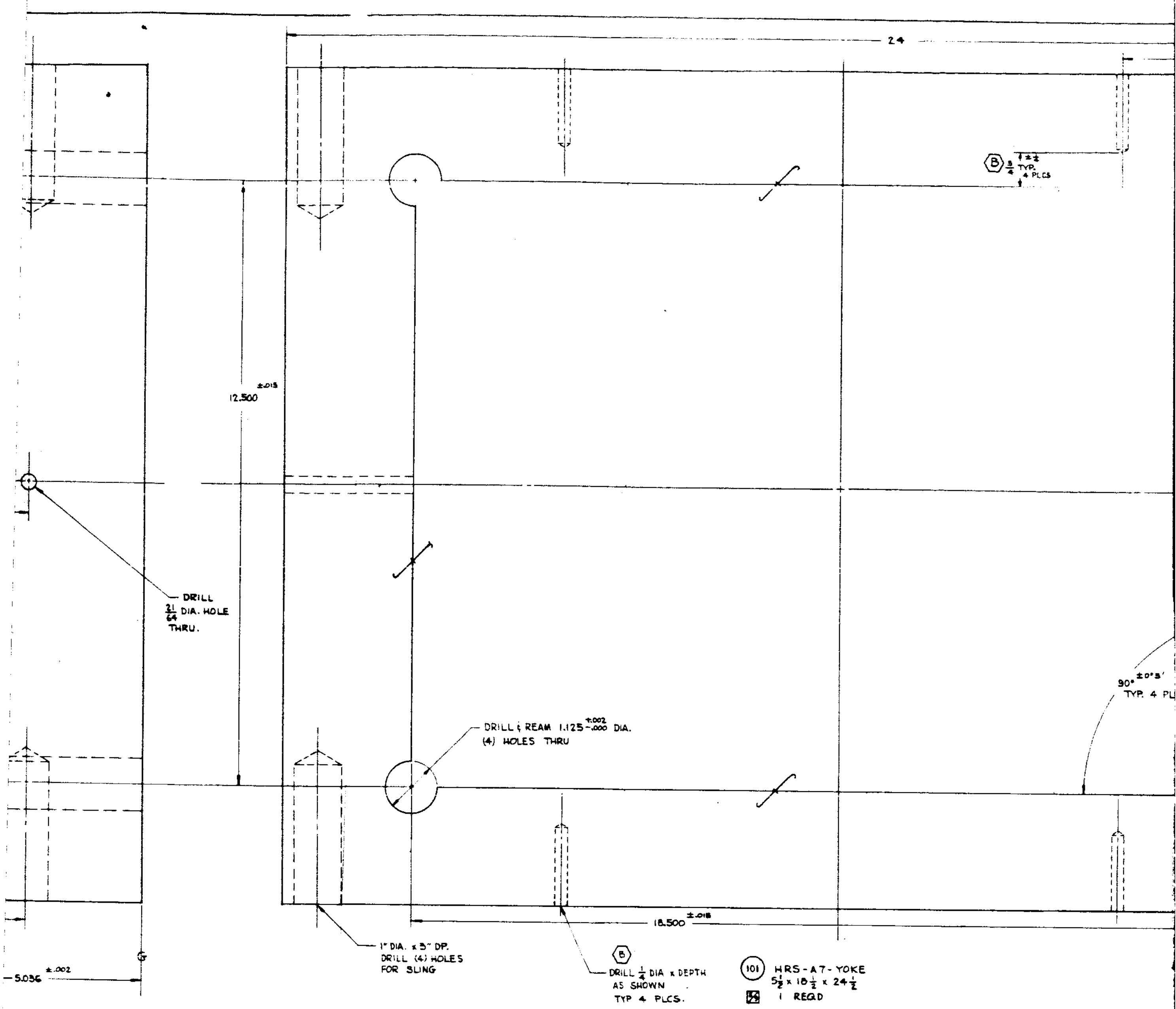


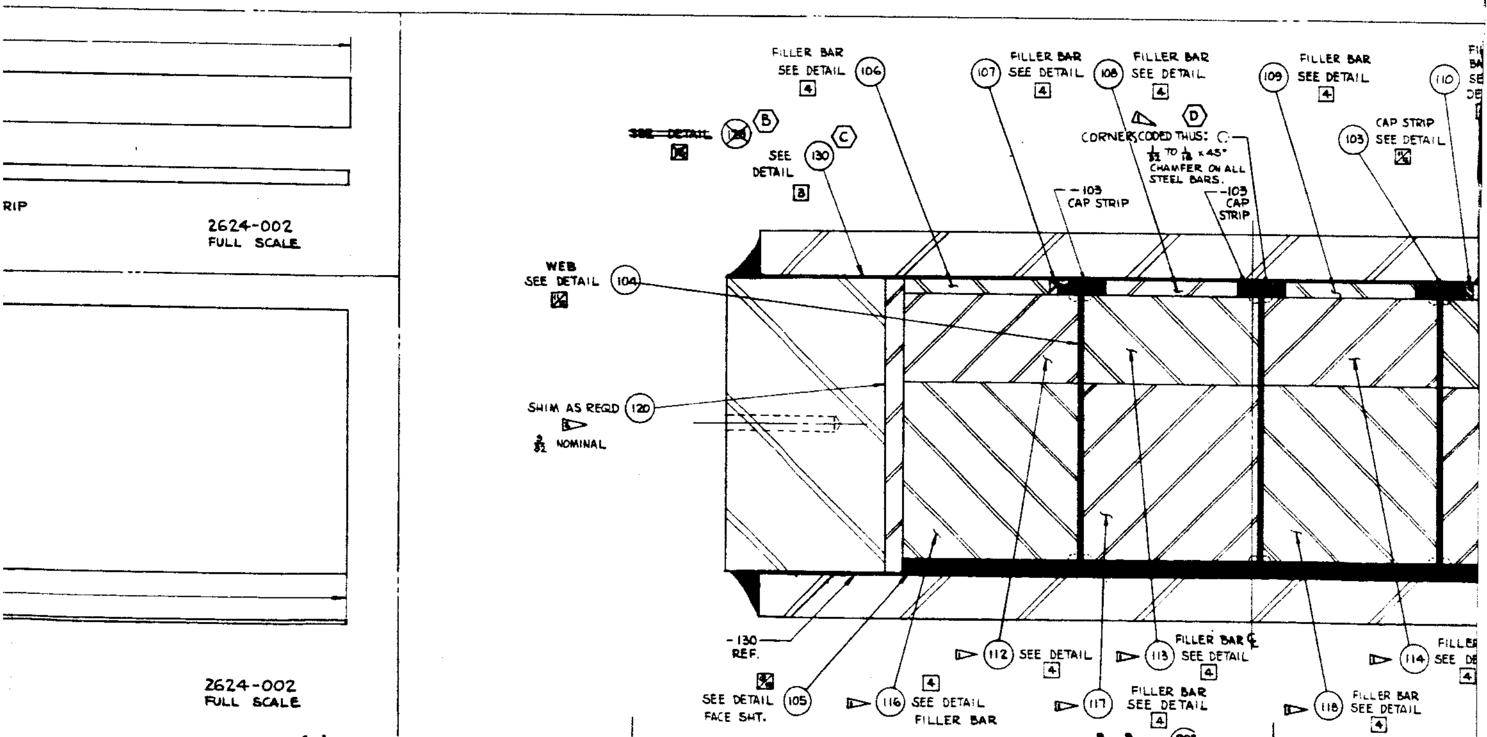
8-1

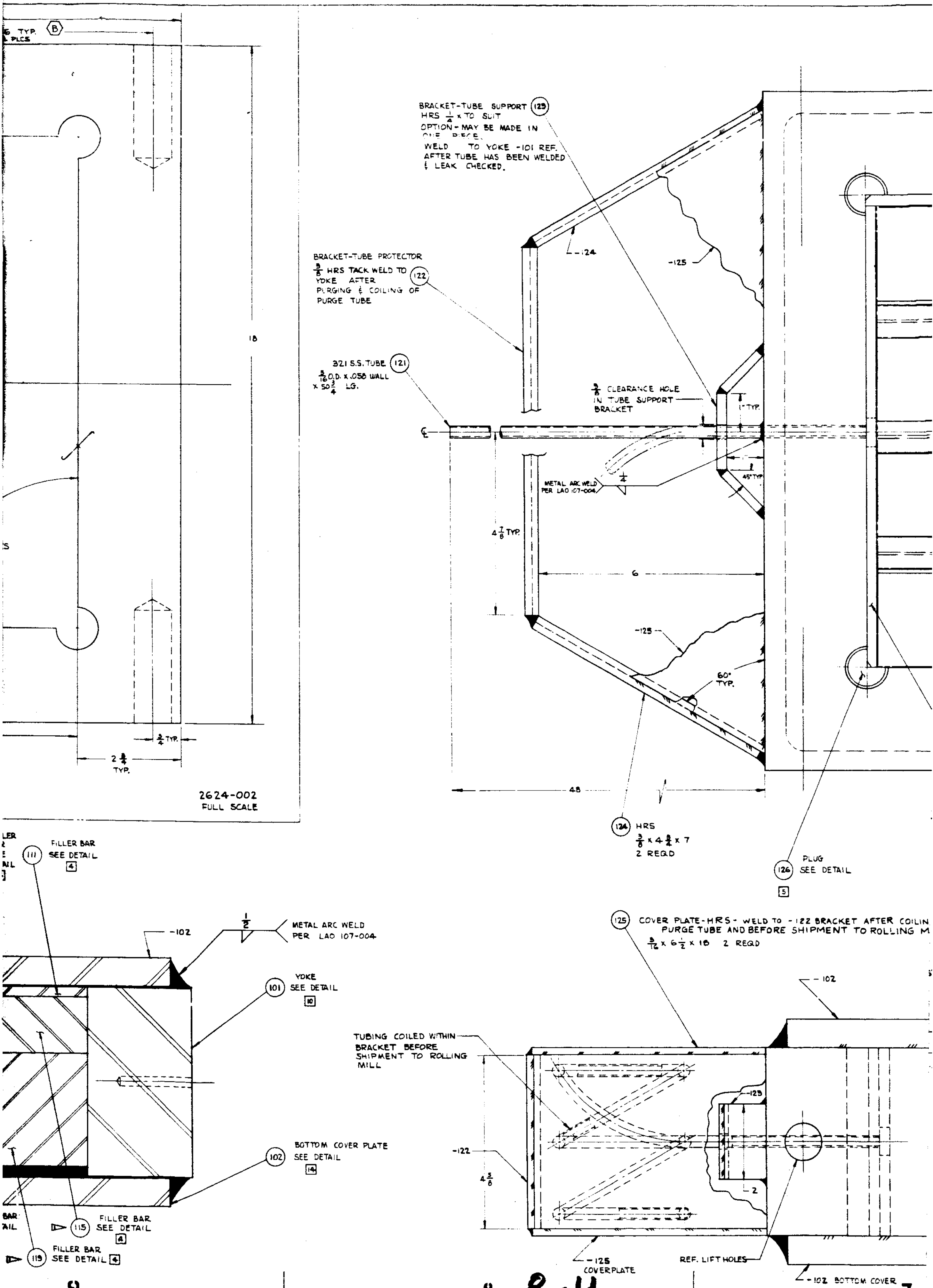


NO FINISH REQD
1/2 R TYP.
(4) PLCS
22 7/8 ±1/16
(102) HRS A-7 COVER PLATE
1/8 x 17 x 23 2 REQD
2624-002
FULL SCALE
2 1/2
2 1/2
TYP.
.812 ±.005
18.250 ±.010
.250 ±.002
(103) 8-1-1 TITANIUM ALLOY (MILL ANNEALED) CAP S
3/16 x 1" x 18 3/8
3 REQD
4.504 ±.005
18.250 ±.010
.062 ±.002
(104) 8-1-1 TITANIUM ALLOY (MILL ANNEALED) WEB
.062 x 4 5/8 x 18 3/8
3 REQD
250 ±.010
(105) 8-1-1 TITANIUM ALLOY (MILL ANNEALED) FACE SHT
3/16 x 12 1/4 x 18 3/8
1 REQD
13
12

8-2

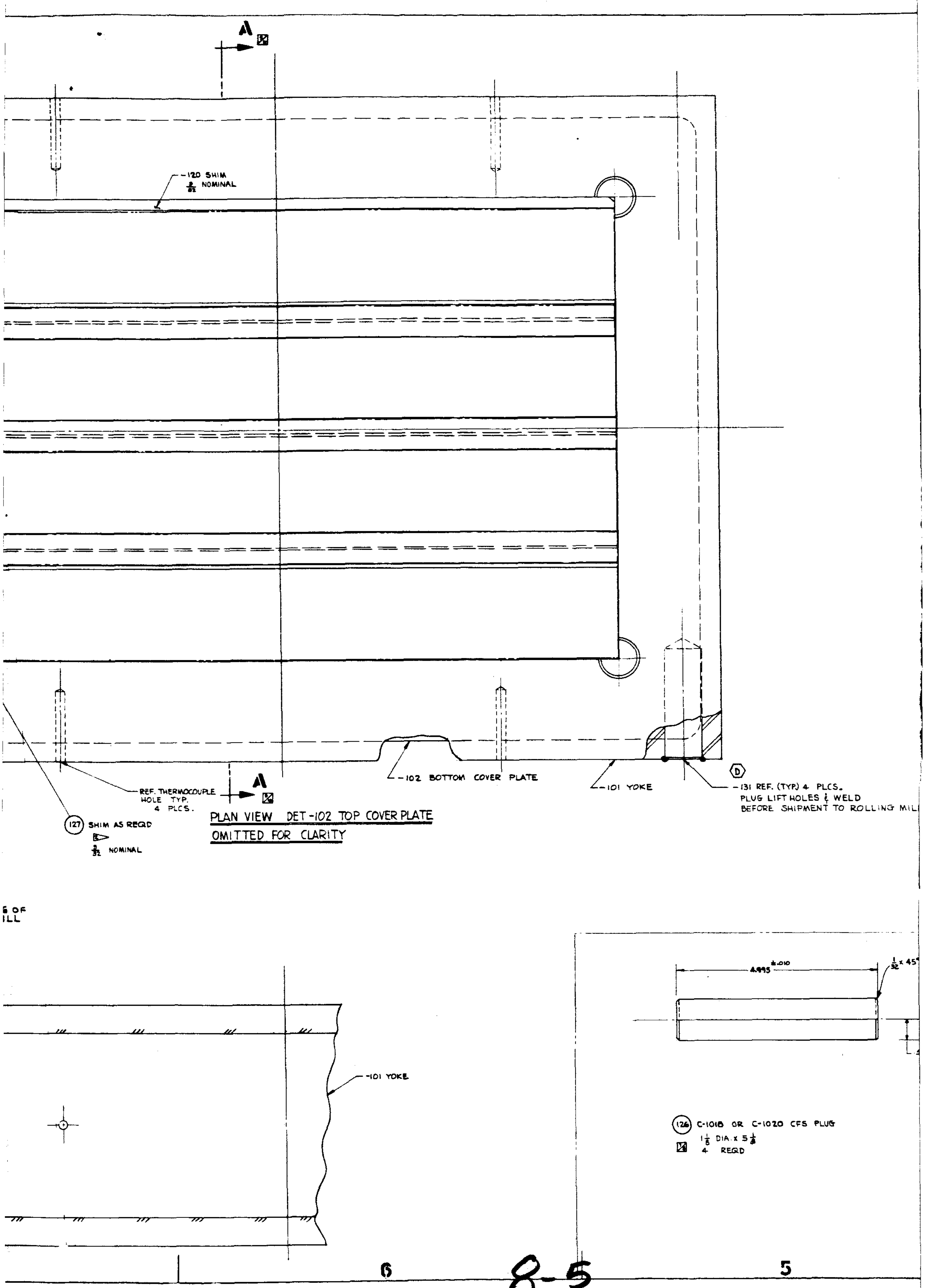

24
B 3/4 ±1/4 TYP. 4 PLCS
12.500 ±.015
DRILL 21/64 DIA. HOLE THRU.
90° ±0°5' TYP. 4 PL
DRILL & REAM 1.125 +.002 -.000 DIA. (4) HOLES THRU
1" DIA. x 3" DP. DRILL (4) HOLES FOR SLING
18.500 ±.015
5.036 ±.002
B DRILL 1/4 DIA x DEPTH AS SHOWN TYP 4 PLCS.
101 HRS-A7-YOKE 5 1/2 x 18 1/2 x 24 1/2 1 REQD

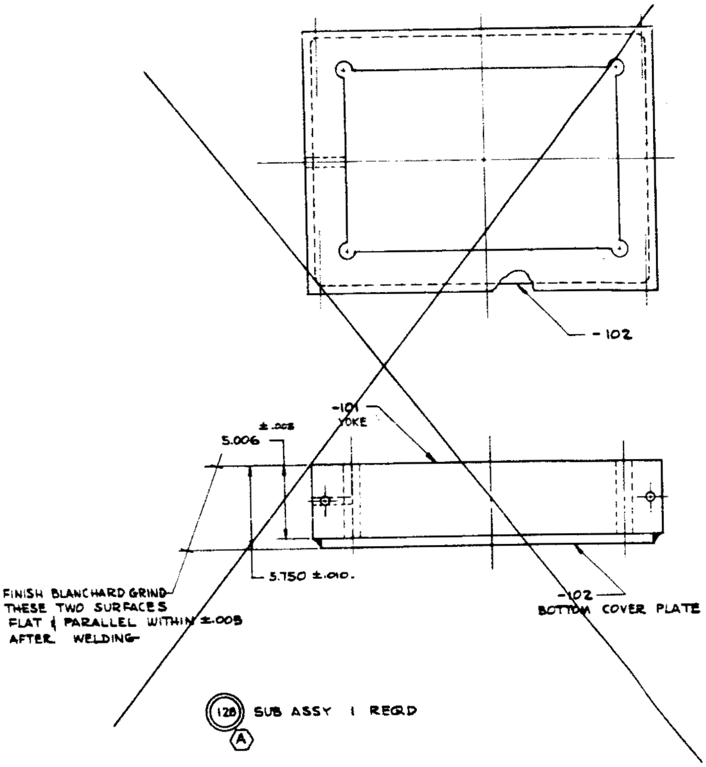

2624-002 FULL SCALE
2624-002 FULL SCALE
11
FILLER BAR SEE DETAIL 106 4
FILLER BAR SEE DETAIL 107 4
FILLER BAR SEE DETAIL 108 4
FILLER BAR SEE DETAIL 109 4
110
SEE DETAIL 128 B
SEE DETAIL 130 C 8
CORNERS CODED THUS: 1/32 TO 1/16 x 45° CHAMFER ON ALL STEEL BARS. D
CAP STRIP SEE DETAIL 103
-103 CAP STRIP
-103 CAP STRIP
WEB SEE DETAIL 104
SHIM AS REQD 120 3/32 NOMINAL
-130 REF.
SEE DETAIL FACE SHT. 105
116 SEE DETAIL FILLER BAR 4
112 SEE DETAIL 4
117 FILLER BAR SEE DETAIL 4
113 FILLER BAR SEE DETAIL 4
118 FILLER BAR SEE DETAIL 4
114 FILLER SEE DETAIL 4
10 SECTION AA 90° CCLOCKWISE



TYP. (B)
PLCS
18
$\frac{3}{4}$ TYP.
$2\frac{3}{4}$ TYP.
2624-002
FULL SCALE
BRACKET-TUBE SUPPORT (123)
HRS $\frac{1}{4}$ x TO SUIT
OPTION - MAY BE MADE IN ONE PIECE.
WELD TO YOKE -101 REF. AFTER TUBE HAS BEEN WELDED & LEAK CHECKED.
-124
-125
BRACKET-TUBE PROTECTOR
$\frac{3}{8}$ HRS TACK WELD TO YOKE AFTER PURGING & COILING OF PURGE TUBE (122)
321 S.S. TUBE (121)
$\frac{3}{16}$ O.D. x .058 WALL x $50\frac{3}{4}$ LG.
$\frac{3}{8}$ CLEARANCE HOLE IN TUBE SUPPORT BRACKET
1" TYP.
METAL ARC WELD PER LAO 107-004
$\frac{1}{4}$
45° TYP.
$4\frac{7}{8}$ TYP.
6
-125
60° TYP.
48
(124) HRS
$\frac{3}{8}$ x $4\frac{3}{4}$ x 7
2 REQD
(126) PLUG SEE DETAIL 5
(111) FILLER BAR SEE DETAIL 4
-102
$\frac{1}{2}$
METAL ARC WELD PER LAO 107-004
(101) YOKE SEE DETAIL 10
(102) BOTTOM COVER PLATE SEE DETAIL 14
(115) FILLER BAR SEE DETAIL 4
(119) FILLER BAR SEE DETAIL 4
(125) COVER PLATE-HRS - WELD TO -122 BRACKET AFTER COILIN PURGE TUBE AND BEFORE SHIPMENT TO ROLLING M
$\frac{3}{16}$ x $6\frac{1}{2}$ x 18 2 REQD
-102
TUBING COILED WITHIN BRACKET BEFORE SHIPMENT TO ROLLING MILL
-123
-122
$4\frac{5}{8}$
2
-125 COVER PLATE
REF. LIFT HOLES
-102 BOTTOM COVER

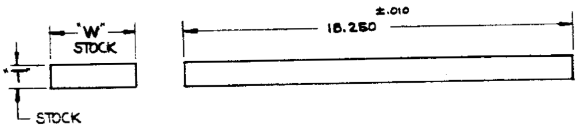
9 8 8-4 7


A
-120 SHIM
$\frac{3}{32}$ NOMINAL
REF. THERMOCOUPLE HOLE TYP. 4 PLCS.
127 SHIM AS REQD
$\frac{3}{32}$ NOMINAL
PLAN VIEW DET-102 TOP COVER PLATE
OMITTED FOR CLARITY
-102 BOTTOM COVER PLATE
-101 YOKE
D
-131 REF. (TYP) 4 PLCS.
PLUG LIFT HOLES & WELD
BEFORE SHIPMENT TO ROLLING MIL
-101 YOKE
4.995 ±.010
$\frac{1}{32}$ x 45°
126 C-1018 OR C-1020 CFS PLUG
$1\frac{1}{8}$ DIA. x $5\frac{1}{8}$
4 REQD
6
5



(128) SUB ASSY 1 REQD

(A)

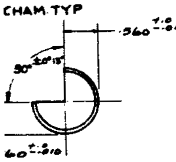


	DET. NO.	"T"	"W"	NO. REQD
	106	$\frac{1}{4}$	$2\frac{1}{2}$	1
	107		$\frac{1}{8}$	
	108		$2\frac{1}{4}$	
	109		$2\frac{1}{4}$	
	110		$\frac{1}{8}$	
	111	$\frac{1}{4}$	$2\frac{1}{2}$	
▷	112	$1\frac{1}{2}$	3	
▷	113			
▷	114			
▷	115	$1\frac{1}{2}$		
▷	116	3		
▷	117			
▷	118			
▷	119	3	3	1

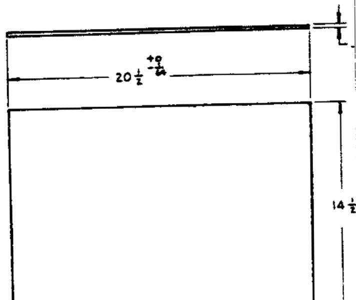
(106) THRU (119) C-1018 OR C-1020 COLD FINISH STEEL FILLER BARS

▷ SEE SECTION "AA" [K] FOR SPECIAL INSTRUCTION FOR DETS. AS NOTED.

2624-002
SCALE — NONE



2624-002
NO SCALE



(C)

(130) COM. PURE TI. FOIL
.004 x $14\frac{1}{2}$ x $20\frac{1}{2}$
[10] 2 REQD

4

3

8-6

REVISIONS

LTR	ZONE	CHANGE	APP	DATE
A	4	DELETED -128	GJR	8-4-6[illegible]
B	9-10	ADDED DRILL $\frac{1}{4}$ DIA. X DEPTH AS SHOWN. ADDED DIM. $\frac{3}{4}$ & 6 TYP. 4 PLCS.	MM	8-11-65
	2-3	$\frac{3}{4}$ DIA. WAS $\frac{1}{2}$ DIA.	MM	8-23-65
	10-15	ADDED DET. 129		
C	10 3-10	OBS. DET. -129 ADDED DET. -130 FOR PACK "D"	MA	10-7-65
D	9-10	$\frac{1}{32}$ TO $\frac{1}{16}$ X 45° CHAMFER WAS $\frac{1}{16}$ X $\frac{1}{32}$ X 45°	MM	10-19-65
	5-15	ADDED DET. 131	MM	10-26-65

GENERAL NOTES:

1. MATERIAL OF PART- 8-1-1 TITANIUM ALLOY (MILL ANNEALED)
2. WELD PER STD. SHOP PRACTICE, EXCEPT AS NOTED.
3. B DET.- 120 & -127 AS REQD AT TIME OF LAY UP. DRILL $\frac{3}{4}$ DIA. HOLE IN -127 SHIM & LOC. AT ASSY.
4. FRACTIONAL TOL. $\pm\frac{1}{32}$, EXCEPT AS NOTED. DECIMAL TOL. $\pm$ .010, EXCEPT AS NOTED.

.004 STOCK

2624-002
SCALE – NONE

8-7

SCALE: FULL & NOTED	DR. N. MORIWAKI DATE 7-28-65 CHECK G.J.R. [illegible]	NORTH AMERICAN AVIATION, INC. INTERNATIONAL AIRPORT LOS ANGELES 45, CALIFORNIA
PACK ASSY- CONFIGURATION #2 S-IC ROLL DIFFUSION BOND TEST PANEL		2624-002

2

Figure 4. Pack C Assembly Drawing

SHT. # 1 OF 1
PACK "D"

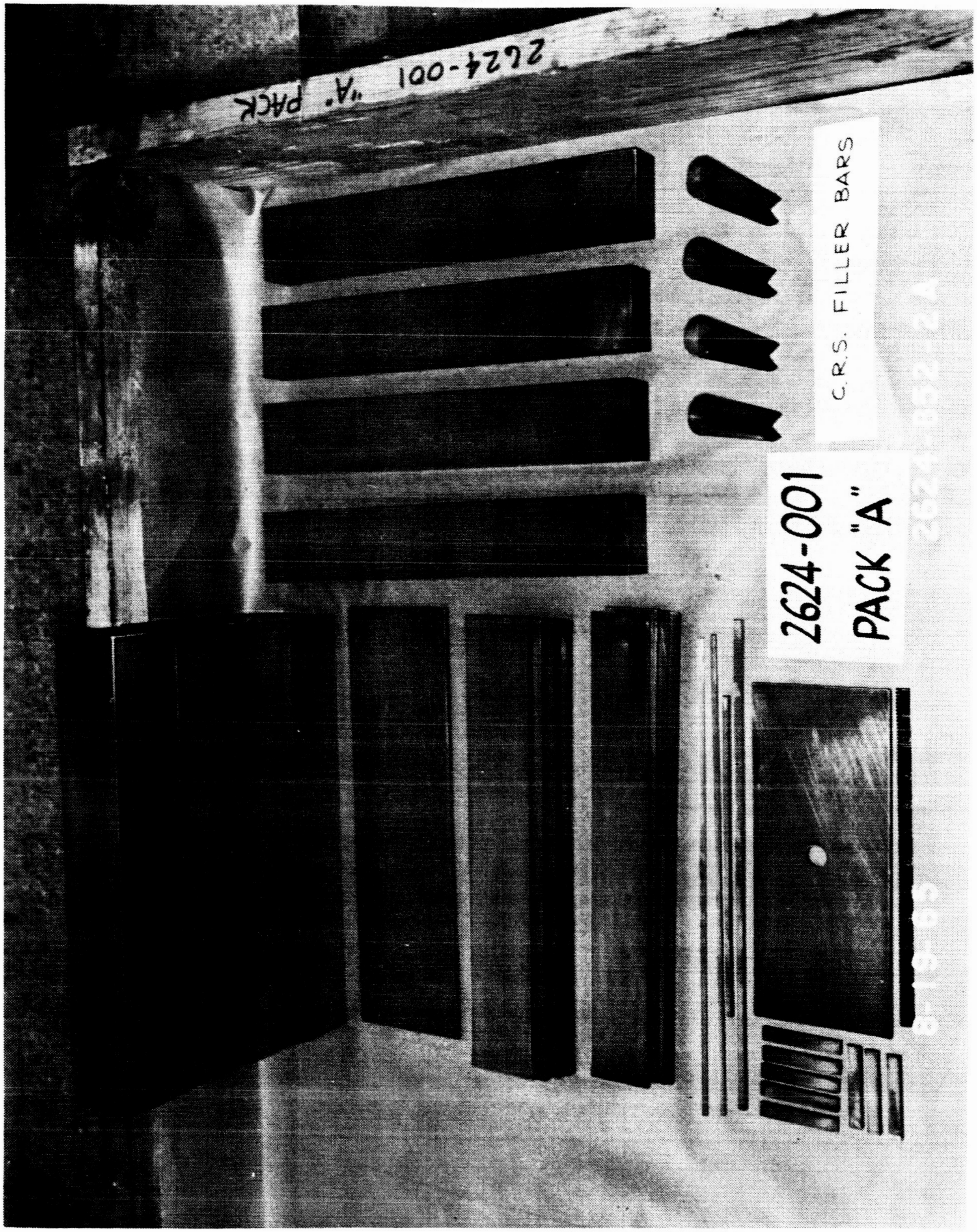


Figure 5. Steel Filler Bars for Pack A

Figure 6. Layup of Pack A

place to provide planned defects as controls in subsequent laboratory analysis of the titanium panel.

After the pack has been completely welded and a purge tube has been installed, a hot purging cycle is initiated during which the pack is heated to approximately 1700°F and thoroughly purged. Figure 7 shows the pack being prepared for the hot purging operation, which requires about 16 hours.

In the first four packs, the 1018 steel filler bars were used as received except for the ends being milled square and to length. The bars were simply cleaned and processed before being laid into the pack assembly. For Packs E and F, the filler bars have been machined completely, based on evidence that the cleaner surfaces will minimize the iron-titanium contamination which, according to laboratory reports, contributed to surface cracking in the titanium panels produced from the first four packs.

As an additional precaution to assure cleanliness, the steel filler bars for Packs E and F were wiped dry immediately after machining, dimensionally inspected, and tightly wrapped in VPI (Vapor Phase Inhibited) treated paper, MIL-P-34208, Type 1, Class 1, Style B. When unwrapped just prior to layup the bars were shiny clean, with no trace of surface stains or discoloration.

In an experiment to try to determine the deformation patterns in the steel and titanium during rolling, a grid pattern was machined into selected steel filler bars of the Pack B components. See figure 8.

The results of the experiment are illustrated by figure 9, which shows that the grid pattern, when transferred into the titanium from the steel, remained constant in the horizontal facesheet but assumed a bow in the vertical member. The deformation is in the direction of the pressure produced in the initial rolling pass.

This flow pattern also was evidenced by the appearance of Pack B itself after rolling, and it is considered that the apparent movement of material in the standing member might be a contributing cause of the unsatisfactory bonding at the extreme ends of the titanium panels.

HOT ROLLING OPERATIONS

Rolling of the test packs to effect diffusion bonding has been performed by the U. S. Steel Applied Research Laboratory, Monroeville, Pennsylvania. The packs have been heated to approximately 1800°F, soaked for an hour, then discharged onto the rolling mill conveyor bed.

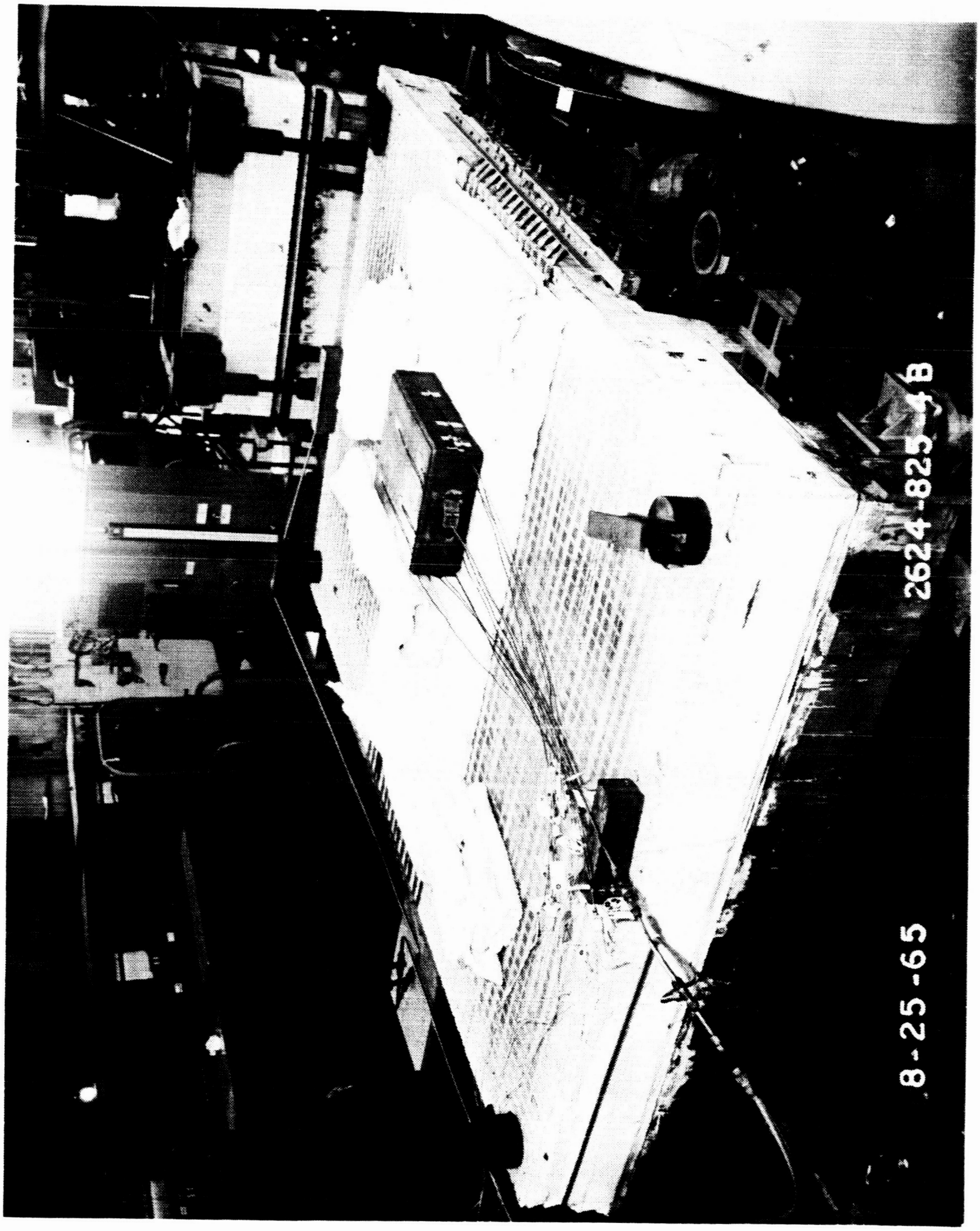


Figure 7. Preparing Pack for Hot Purging

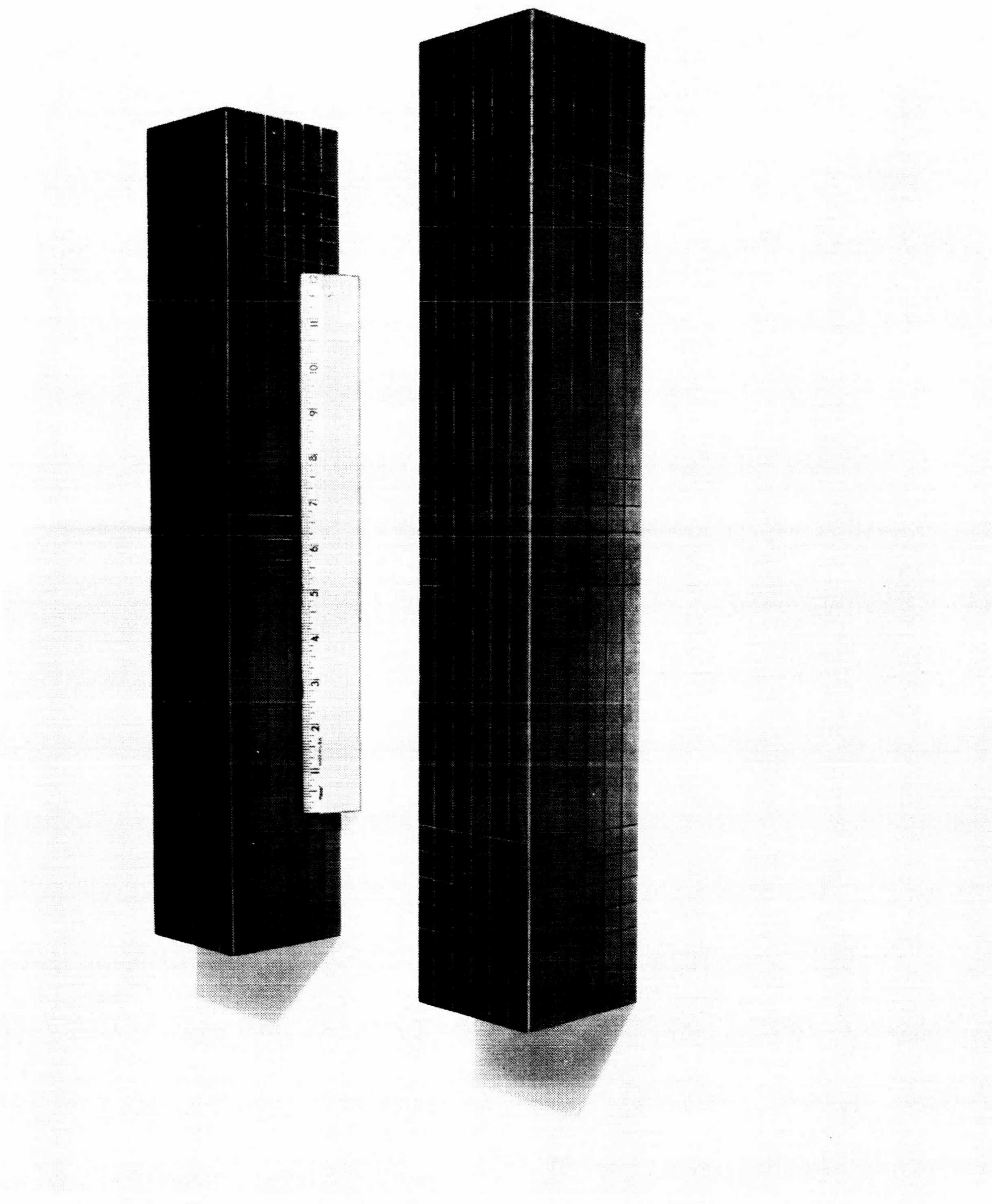


Figure 8. Grid Pattern Machined in Filler Bars

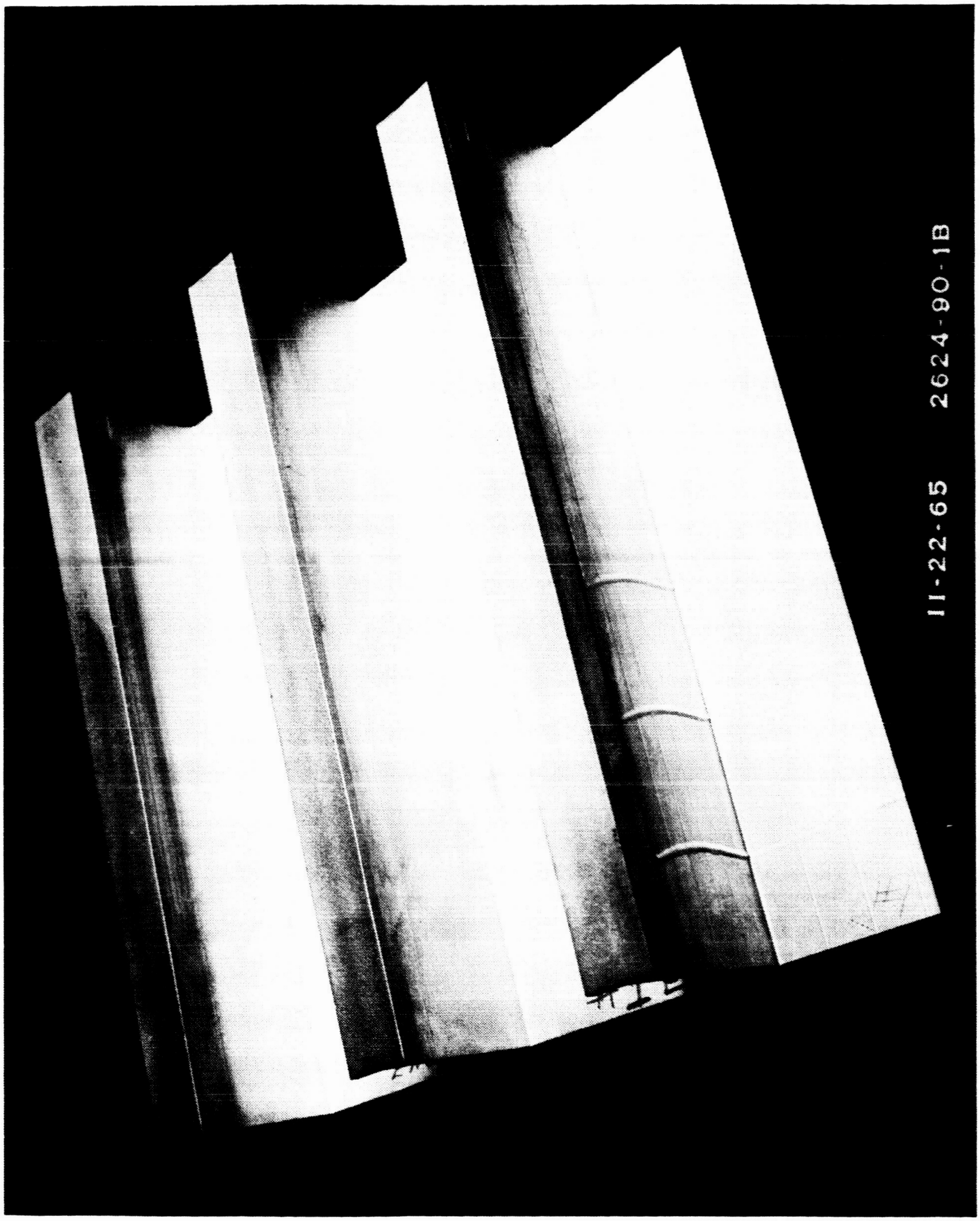


Figure 9. Grid Pattern Transferred Into Titanium

Programmed rolling to achieve the desired 60 percent reduction in thickness has been accomplished in from 10 to 16 passes per pack in an elapsed time of from 2 to 3 minutes. Figure 10 shows U. S. Steel's rolling data on Packs A and C.

A problem of major concern in the rolling operations has been the tendency of the packs to curl up or down. The laboratory mill is not equipped with leveler rolls. Consequently, when Pack A indicated turn-up during rolling it had to be quickly transferred to a flat-platen press, flattened, and returned to the rolling mill for continuation of the series of passes before the temperature dropped below 1600°F.

When Pack D curled during rolling, the turn-up was so severe that the operation was aborted. The pack had to be reheated to 1800°F, subjected to straightening operations, then again heated to rolling temperature for completion of the 60 percent reduction. This deviation from the planned rolling sequence produced disastrous results in the bonding of the titanium.

Packs B and C remained flat during rolling, and the bond joints were of good quality.

Another phase of the rolling process which has not yet been completely resolved is the heating and cooling of the packs.

In NAS8-20530, the packs have been heated to 1800°F for rolling. In other roll diffusion bonding development programs, rolling temperatures range from 1750°F to more than 1900°F. A thorough study and comparison of conditions and results should yield data of universal value in this field of development.

The cool-down rate of the packs has a direct bearing on the welding characteristics of the 8Al-1Mo-1V titanium panels in subsequent fabrication operations. Tests have shown that crack-free, quality welds can be made in material which is in the duplex annealed condition. Duplex annealing is accomplished by reducing the temperature of the titanium from 1450°F to 900°F within one hour.

This can be accomplished by water quenching the packs. However, the shock of water quenching can be a cause of titanium surface cracks. Air cooling might produce duplex annealed properties in the titanium, as evidenced by two experimental developments.

Pack No. 5 in the Y-Ring Program (NASA/MSFC Contract No. NAS8-20533) was cooled in still air after rolling. Thermocouples were inserted into the pack to provide temperature readings as the pack cooled. The recordings show that the cool-down from 1450°F to 900°F occurred in approximately 23 minutes.

Pack A in the S-IC Skin Section Program was air-cooled. On 24 November a section of the titanium panel was used in a welding experiment in

EXPERIMENTAL TITANIUM-ALLOY PACKS FOR S-1C TANK
ROLLED FOR NORTH AMERICAN AVIATION, INC

Sample No.	Pass No.	Time From Furnace to Pass, sec	Temperature, F* 1	Temperature, F* 2	Rolling Speed (fpm)	Total Peak Separating, Force, (lb)	Rolling (hp)
A	1	58	-	-	113	428,000	203
	2	73	-	-	108	534,000	286
	3	85	-	-	69	650,000	242
	4	100	1770	1800	83	622,000	323
	5	113	1800	1810	70	622,000	252
	6	126	1800	1810	87	594,000	321
	7	136	1800	1810	86	572,000	262
	8	204	1730	1730	97	506,000	292
	9	217	1730	1739	90	588,000	263
	10	230	1710	1710	104	566,000	334
C	1	32	-	-	100	547,000	290
	2	45	-	-	93	600,000	359
	3	56	-	-	95	570,000	295
	4	69	-	1800	95	575,000	337
	5	79	-	1810	96	556,000	281
	6	107	-	1820	100	534,000	320
	7	116	-	1820	96	533,000	269
	8	136	-	1810	104	497,000	295
	9	150	-	1790	101	495,000	259
	10	163	-	-	108	466,000	280
	11	173	-	-	109	428,000	235
	12	186	-	-	117	394,000	209
	13	200	-	-	120	322,000	170

* Measured with thermocouples buried in steel yoke (thermocouples not at equilibrium temperatures during first several passes).

September 10, 1965

Figure 10. Rolling Data on Packs A and C

which three round discs were punched out of the face space, fitted back into the holes, and hand TIG fusion welded. To date, no cracks have appeared in or adjacent to the weld areas.

Further development work is planned to establish the feasibility of air cooling as a method which will result in duplex annealed titanium.

SEPARATING THE TITANIUM AND STEEL

Experiments conducted at NAA/LAD prior to the awarding of NAS8-20530 indicated that thermal shock would serve as a technique for separating the titanium panel from the steel filler bars after a pack had been roll diffusion bonded.

The results of the thermal shock process on Pack C showed that the method is unsatisfactory. Severe destructive cracking, plus panel deformation, were attributed to the sudden stresses to which the pack was subjected when, at -120^{o}F, it was plunged into 204^{o}F water.

Pack A was put through the same process. Although the results were not nearly as drastic, the operation failed to separate the steel from the titanium. The pack was later chemically processed to leach out the steel. See figure 11.

Leaching is now considered to be the most practical method of removing steel from packs without damage to the titanium, and this process is planned for Packs E and F as well as for the Phase III packs.

APPLICATION OF ACCUMULATED KNOWLEDGE

Throughout Phase I there has been a continuing effort to develop methods and processes of fabrication which will be applicable to the full-scale Phase III packs.

Knowledge, both negative and positive, gained from the fabrication and testing of the first four packs has been assimilated for application in the making of Packs E and F.

Two new pack assembly designs, as shown in figure 12, were prepared, incorporating the features which were deemed to be advantageous.

These features include:

1. Completely machined filler bars, with radiused edges in contact with the titanium joints.

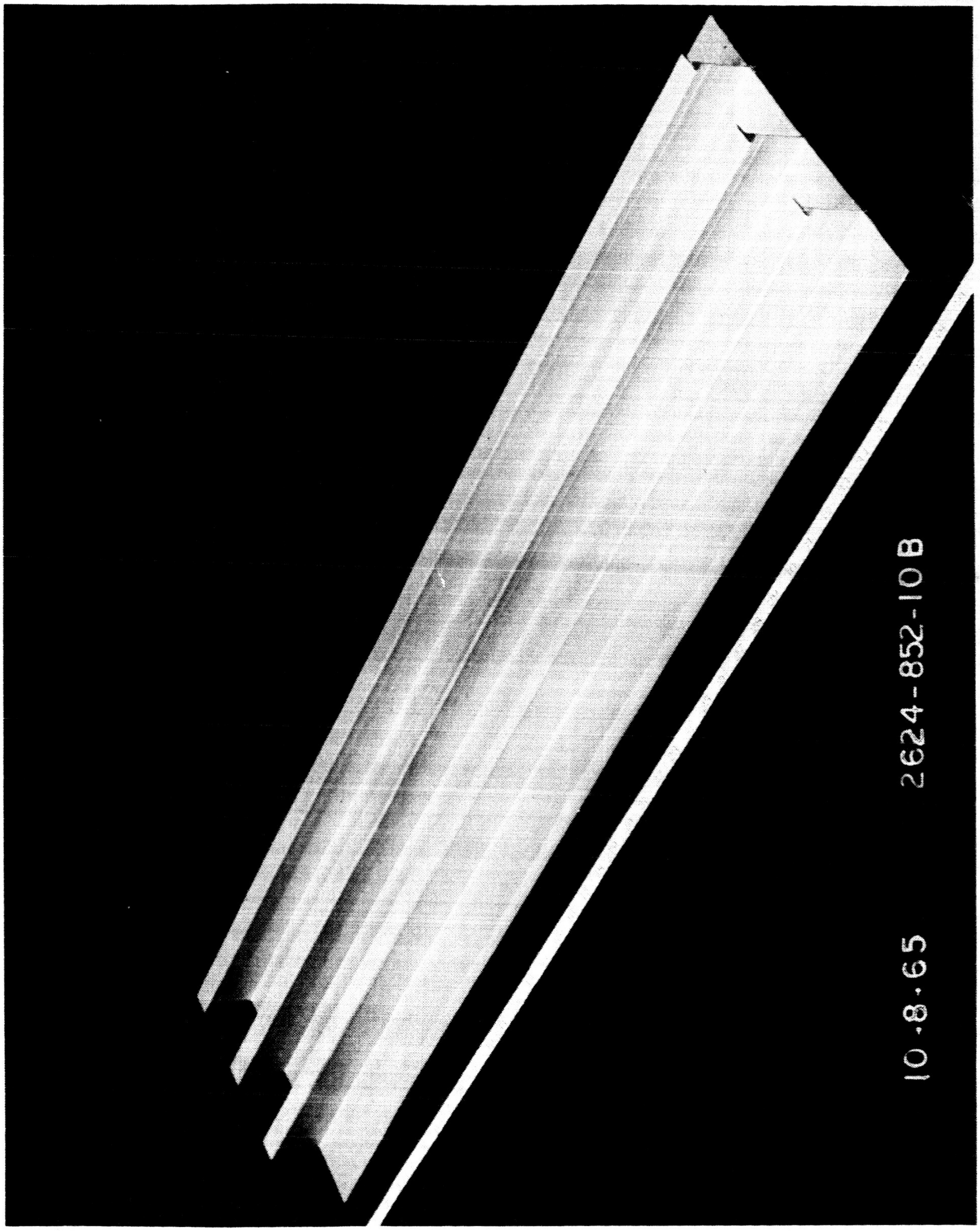
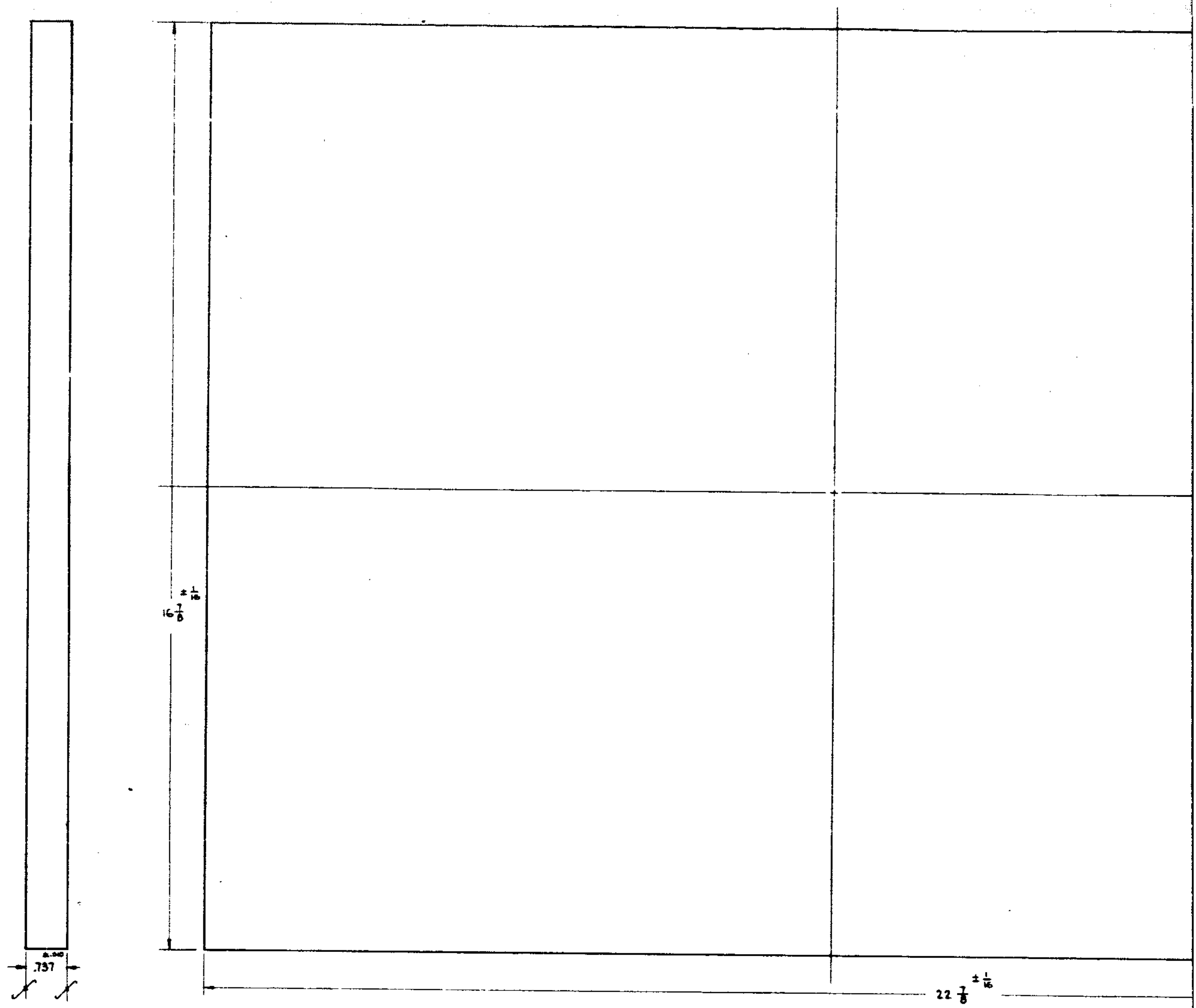
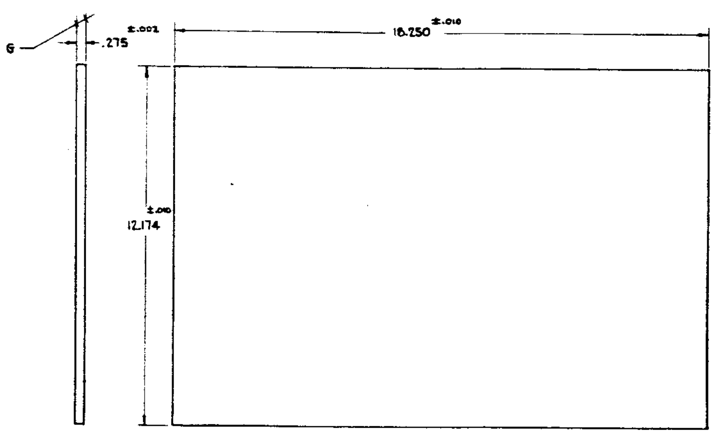


Figure 11. Test Panel After Steel Leaching

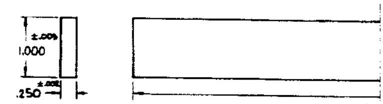


(102) HRS AT COVER PLATE
[7] $\frac{7}{8}$ x 17 x 23   2 REQD

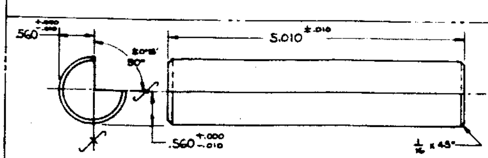


(110) 8-1-1 TITANIUM ALLOY (MILL ANNEALED) FACE SHT
[8] $\frac{5}{16}$ x $12\frac{1}{4}$ x $18\frac{3}{8}$ 1 REQD

2624-002



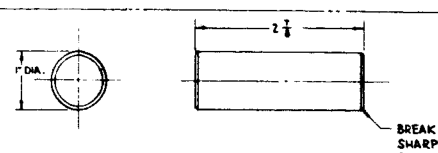
(105) 8-1-1 TITANIUM ALLOY (MILL ANNEALED) CAP STRIP
.250 x $1\frac{1}{8}$ x $18\frac{3}{8}$
[6] 3 REQD



(116) C-1018 OR C-1020 CFS PLUG
$1\frac{1}{8}$ DIA. x $5\frac{1}{8}$ LG.
4 REQD

2624-002
FULL SCALE

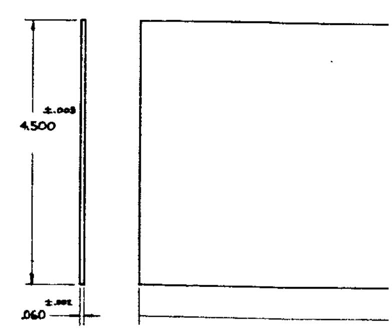
11



(112) CRS PLUG
1" DIA x 3   4 REQD

2624-002
FULL SCALE

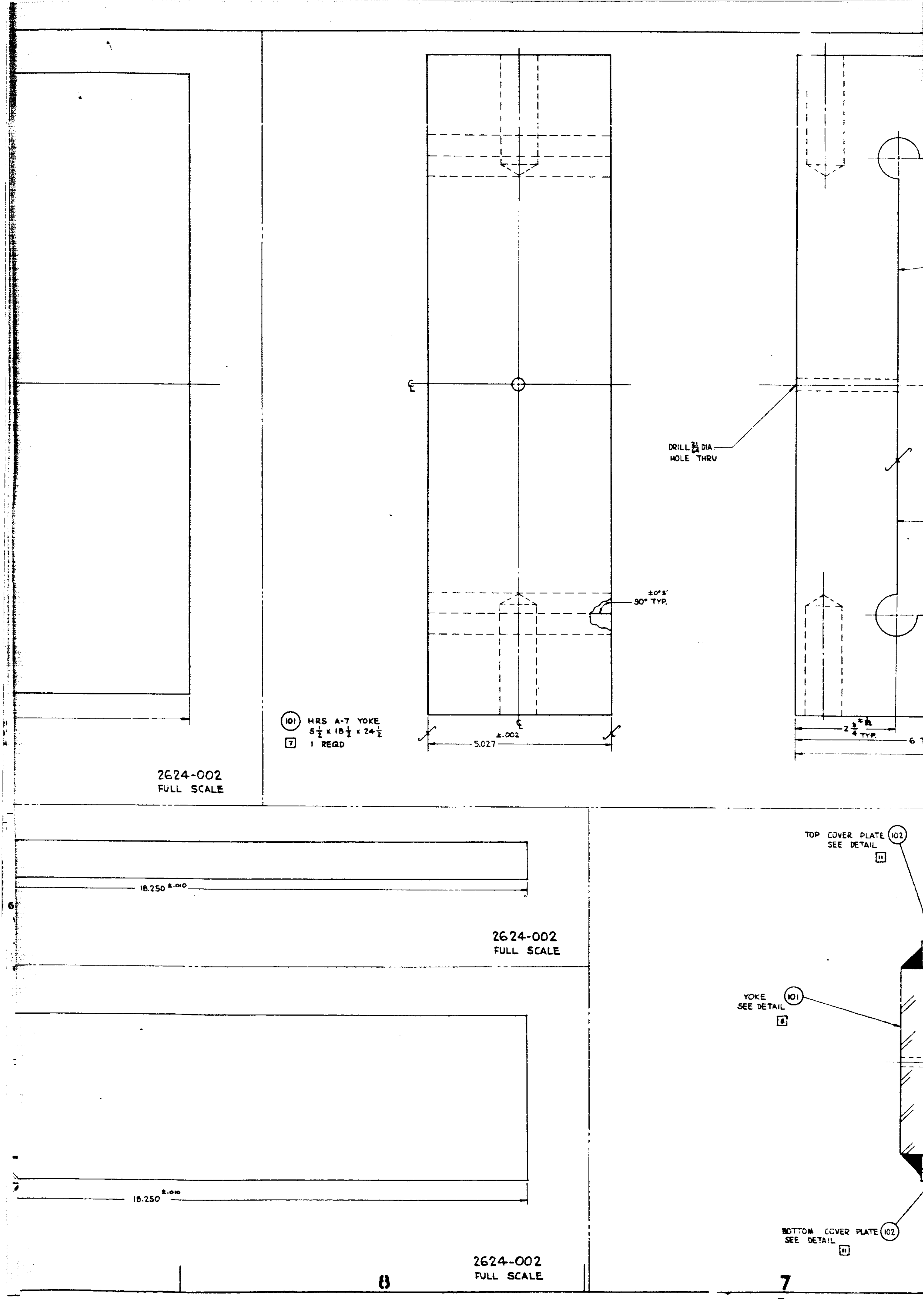
10

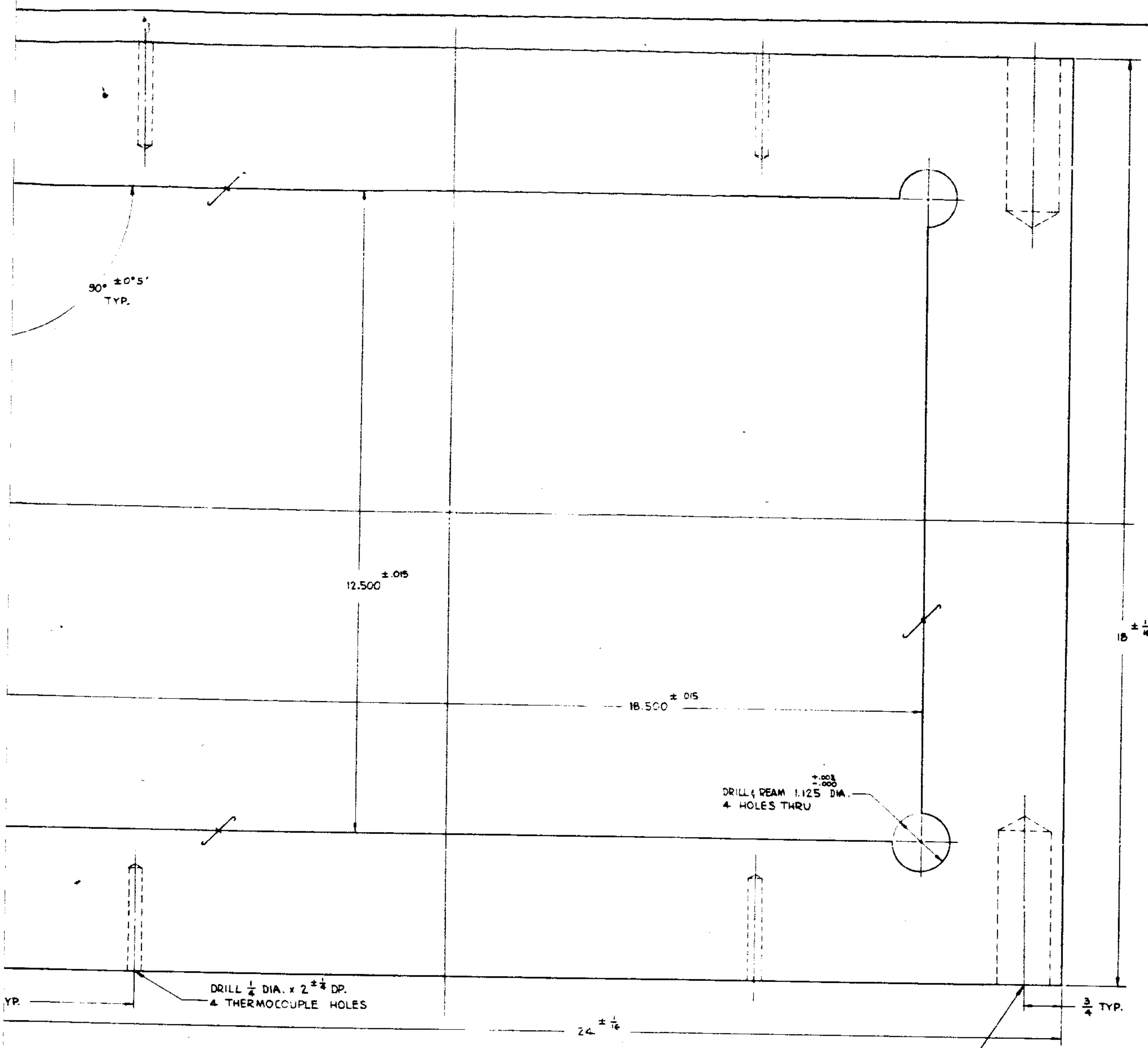


(108) 8-1-1 TITANIUM ALLOY (MILL ANNEALED) WE
[6] .060 x 4 [illegible] x 18 [illegible]
3 REQD

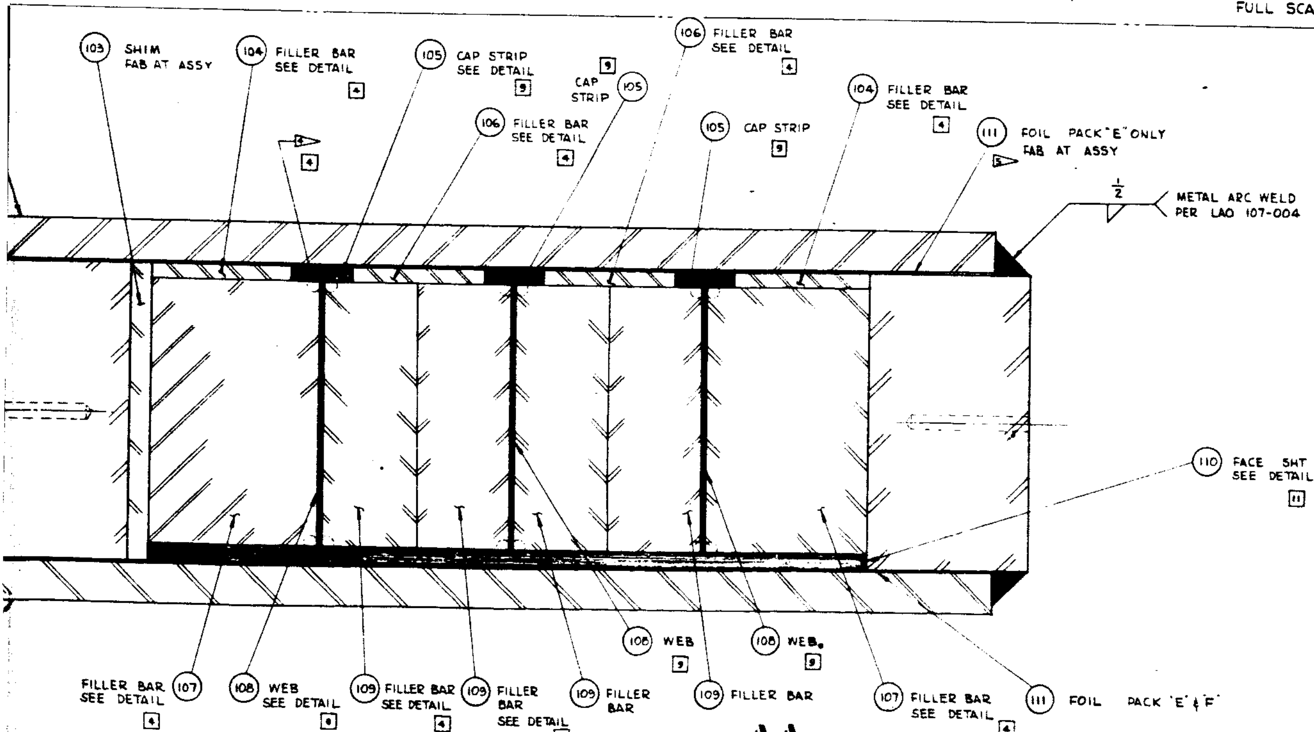
9

19-1


2624-002
FULL SCALE
101 HRS A-7 YOKE
5 1/2 x 18 1/2 x 24 1/2
7 1 REQD
±.002
5.027
±0°5'
90° TYP.
DRILL 31/64 DIA.
HOLE THRU
2 3/4 TYP.
18.250 ±.010
2624-002
FULL SCALE
TOP COVER PLATE 102
SEE DETAIL
11
YOKE 101
SEE DETAIL
8
18.250 ±.010
BOTTOM COVER PLATE 102
SEE DETAIL
11
2624-002
FULL SCALE
8
7



2624-002
FULL SCALE

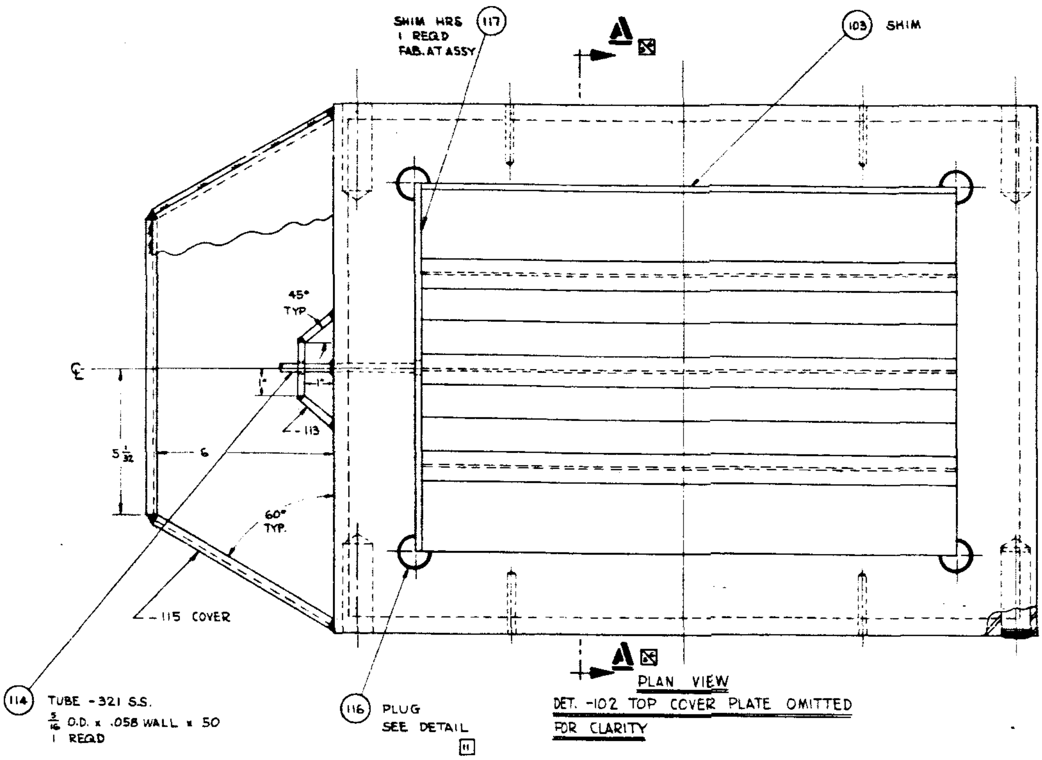


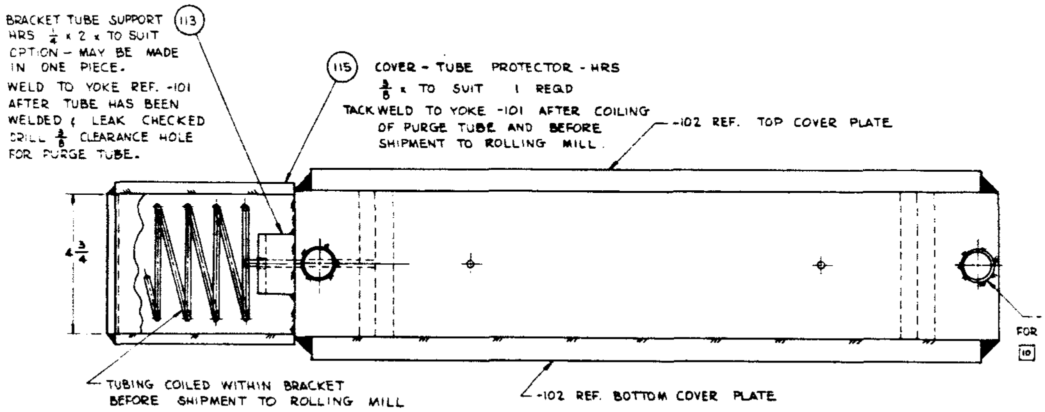
SECTION AA 3
FULL SCALE

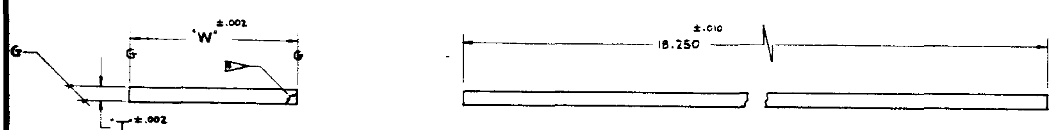
6

5

19-3







104
106
107
109

C-1018 OR C-1020 COLD FINISH STEEL BAR

DET.	REQ'D	T	W
104	2	.245	2.548
106	2	.245	2.239
107	2	4.482	2.818
109	4	4.482	1.589

NOTE:

1. ALL CORNERS MUST BE 90° ±0°5'
2. $\frac{1}{32}{}^{+\frac{1}{64}}_{-0}$ RADIUS ON ALL FILLER BARS AT CORNERS CODED THUS ◯ SEE SECTION AA

2624-002
PACK "E" & "F"
SCALE - NONE

4 3

19-4

REVISION				
LTR	ZONE	CHANGE	APP	DATE
E	5	OBS. SHT. # 1 OF 2 SHT. # 2 OF 2 ADDED FOR PACK "E" & "F" EXCEPT AS NOTED SEE CODE ▶ REF. DET. 111		[illegible]

GENERAL NOTES

1. MATERIAL OF PART - 8-1-1 TITANIUM ALLOY (MILL ANNEALED)
2. WELD PER STD. SHOP PRACTICE, EXCEPT AS NOTED.
3. DET'S -103 & -117 AS REQD AT TIME OF LAY UP.
   DRILL $\frac{3}{4}$ DIA. HOLE THRU -117 SHIM, LOC. AT ASSY.
4. FRACTIONAL TOL. $\pm\frac{1}{32}$, EXCEPT AS NOTED.
   DECIMAL TOL. ±.010, EXCEPT AS NOTED.
5. PACK "E" & "F", EXCEPT AS NOTED ▶ $\boxed{E}$ REF. DET. 111

REF.
12 PLUG
LING HOLE

19-5

SCALE: HALF & NOTED	DR. N. MORIWAKI DATE 11-26-65	NORTH AMERICAN AVIATION, INC. INTERNATIONAL AIRPORT LOS ANGELES 45, CALIFORNIA
PACK ASSY - CONFIGURATION #2 S-IC ROLL DIFFUSION BOND TEST PANEL		2624-002

[redacted]

Figure 12. Pack E and Pack F Assembly Design

SHT. # 2 OF 2

2. Filler bars assembled side by side instead of being stacked, to avoid lateral shifting and consequent markoff on the titanium standing members.

3. Packs dimensioned to allow for removal of 0.002 inch from all surfaces of bonded titanium panel by grit shot blasting and the Chem-Mill process to eliminate iron-titanium embrittling contamination.

4. Commercially pure titanium foil included to serve as a getter and to implement separation of the cover plates.

A full report on the fabrication and testing of Packs E and F will be included in the supplement to the Phase I report, scheduled for release on 21 January 1966.

APPENDIX

APPENDIX A Report No. Na-65-1004, "S-IC Skin Panel Structural Analysis, Contract No. NAS8-20530."