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WRDC-TR-89-3027

SUPERPLASTIC FORMING OF ALUMINUM (TASK C)

T. Renshaw

Fairchild Republic Company
Farmingdale, NY 11735

March 1989

Final Report for Period March 1986 - January 1988

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WRIGHT RESEARCH AND DEVELOPMENT CENTER
AIR FORCE SYSTEMS COMMAND
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R. L. Hinrichsen, Major, USAF
Chief, Structural Concepts Branch

James P. Belloto
Structural Concepts Evaluation Group

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This report covers the work done under Task C of Contract F33615-83-C-3208. An SPF based A-10 nose landing gear door was designed using Supral 220 alloy: The part count for the basic door was reduced to 4 components as compared to 52 for the conventional construction method. The superplastic pan comprising the stiffening structure of the door was assembled to the external skin using the ultrasonic weldbonding process. The SPF based door and a conventional door were supplied to AFFDL for static testing. Test results show that the two doors are approximately equivalent in strength. Economic analysis indicates that the SPF door is less than half the cost of the conventional door for production quantities larger than 100. Keywords: aircraft panels; aircraft doors;

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PREFACE

This report was prepared by Fairchild Republic Company under Contract F33615-83-C-3208 for the Air Force Systems Command, Wright-Patterson Air Force Base, Ohio. Mr. Rod Joblove was the Air Force Program Monitor. Lt. David Krier was the Air Force Test Engineer.

This program was conducted by the Advanced Composites and Materials Technology Department of the Fairchild Republic Company under the direction of Walter B. Trepel, Director. Theodore Renshaw was the Program Manager. Other participants were Scott Mantay and Ken Sandholm from the Design Group; Herman Axelrod from the Structural Analysis Group; Joseph Cardello from the Ground Test Group, and Mark Cetrone from Industrial Engineering.

The efforts of Mr. James P. Belloto and Ms Lisa A. McNeal to achieve a publishable final report are acknowleged in compiling and formatting from the draft final, received as the contractor went out of business. Use of the Macintosh computer system proved invaluable to USAF personnel in economically creating final manuscript from draft sketches.

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SECTION I

INTRODUCTION, BACKGROUND AND OBJECTIVES

1.1 INTRODUCTION

Rising costs of military hardware and increased emphasis on high durability aircraft structures have challenged the aircraft designer and manufacturing research engineer. It has prompted the development of unique manufacturing processes and materials to complement innovative designs.

Fairchild Republic Company (FRC) in its continuing study of advanced processing and materials, has investigated superplastic forming (SPF) through several ongoing programs, as a means of reducing costs, decreasing structural weight and improving design efficiency.

A major effort is now in progress in the United States to develop into manufacturing practice high strength SPF alloys, spearheaded by Air Force supported programs to demonstrate the capability of these alloys in the fabrication of complex structures. However, it was estimated that several years would elapse before there was available in the United States both production quantities of high strength SPF alloys and information on the performance of actual parts fabricated from these alloys.

Superform, Ltd., Worcester, England (and its affiliate, Superform USA, Inc., Riverside, California) has developed and has in production (through Alcan) several superplastic alloys such as the medium strength Supral 100 (bare 2004), Supral 150 (clad 2004), and the high strength Supral 220. This company has developed unique facilities and methods for SPF which have enlarged design freedom over conventional procedures.

The medium strength British alloys have been extensively used in commercial applications and in European aircraft and have been evaluated from test specimens in the United States. There has been little application in United States aircraft except for Fairchild's present applications, primarily due to lack of design information on parts themselves, rather than specimen data. Fairchild is currently using a superplastically formed exhaust duct on the A-10 aircraft.

Fairchild has confined its efforts to the superplastic forming of aluminum alloys, a relatively new arrival in the superplastic forming arena, because aluminum is the dominant structural material for its aircraft. Fairchild studies with superplastic aluminum alloys have provided an extensive background on the current state of the technology and knowledge of the gaps in information requiring study in order to transfer this technology into aircraft usage.

In light of the preceding situation, the Air Force considered it advantageous in 1983 to enter into a contract with Fairchild Republic Company to generate design data on the Supral alloys.

1.2 BACKGROUND TO CONTRACT F33615-83-C-3208

This contract was initiated in mid-1983 for the purpose of carrying out two tasks:

> Task A - to generate a variety of static, fatigue and other property data on alloys Supral 100, Supral 150 and Supral 220.
>
> Task B - to extend the testing of the 220 alloy and to perform tests on alloy (U.K.) DTDXXXA, an Al-Li sheet alloy under development by Alcan.

Task A and a portion of Task B were completed and reported upon in the AFWAL Final Report - Part 1 entitled, "Superplastic Alloys and Data" dated May 1985 (Ref. 1).

Completion of Task B was suspended for a period awaiting a satisfactory SPF version of the Al-Li alloy. With the information that such a version of Al-Li alloy would not become available early enough, it was decided that the remainder of the program should be devoted to a new Task C involving the construction of landing gear doors by the SPF route and by conventional built-up sheet metal. This task was an expansion of a limited program at FRC which revolved around SPF based landing gear doors. The task was also to include an emerging assembly process, ultrasonic weldbonding (Ref. 2), in manufacturing the SPF door.

1.3 OBJECTIVES OF TASK C

Task C was initiated in March 1986 and technical completion was planned for December 1986 with a final approved report due in April 1987.

The objectives of Task C are:

1.3.1 that FRC provide a conventional sheet metal built-up A-10 nose gear door for static testing by AFWAL at WPAFB.

1.3.2 that FRC optimize the design and fabricate an SPF based, Supral 220 alloy A-10 nose gear door using weldbonding assembly methods and deliver the finished door to WPAFB for static testing by AFWAL.

1.3.3 that FRC provide a static test plan for the nose gear doors which will be suitable for use at AFWAL and be coordinated with and approved by AFWAL test engineers.

1.3.4 that FRC shall analyze the static test results and compare the efficiency of the construction of the two doors.

1.3.5 that FRC shall collect and analyze fabrication assembly costs of each door and establish the relative value of each construction method for a fleet of aircraft.

1.3.6 that FRC shall compare the relative weights of the two construction methods.

SECTION II

TECHNICAL DISCUSSION

2.1 PRIOR WORK

The conventional sheet metal, built-up, A-10 nose landing gear door was designed in the early 70's. It is shown mounted on the aircraft in Fig. 1 and in a state of partial assembly in Fig. 2. This conventional construction involved the assembly of 52 components using approximately 500 rivets and other fasteners.

A first SPF version of the door was designed in 1983 as an internal research and development project. The die for the SPF pan was cast in aluminum at Superform, Ltd. in Worcester, England, and a number of pans were formed in different gauges. One of the pans is shown in Fig. 3 and the final weldbonded assembly is shown in Fig. 4. The internal construction of this design is shown in Fig. 5. The internal channels with the large number of clips proved to be unsatisfactory with respect to assembly time. As may be noted in Table 1 where the cost elements of the conventional door are compared to the first SPF design, approximately twenty manhours were required to prefit and drill the clips and channels before the pan could be weldbonded to the outer skin.

The design that was expected to result in a minimal assembly time and cost was found not to be the most efficient SPF design that could be developed. It was therefore a major objective of Task C to develop an optimal design requiring the least assembly time and having the lowest possible part count.

2.2 SPF DOOR DESIGN

The central concept for simplifying the original SPF design was to reconfigure the die so that channels were formed in the pan, the walls and corners of which would provide the structural continuity which had been the function of the original 12 clips. Machined channel fittings would attach to the walls and provide connection to splice members and the hinges.

The structural goal was to design a nose landing gear door reinforced with a superplastically formed inner pan. The objective was to significantly reduce the number of detail parts; thus reducing the manhours required to fabricate the detail parts and assemble the door. The newly designed door was required to be equally strong and stiff as the current production door. The stiffness requirement was a paramount consideration in the design. The leading edge of the door, under airload, could not deflect more than the production door. Excessive deflections of the leading edge could allow air to enter the wheel well compartment and result in a failure of the door and/or surrounding structure. Additionally, the weight of the new door design should be equal to or less than the production door.

Figure 1. Forward Nose Landing Gear Door on the A-10 Aircraft

Figure 2. A-10 Nose Landing Gear Door in Assembly

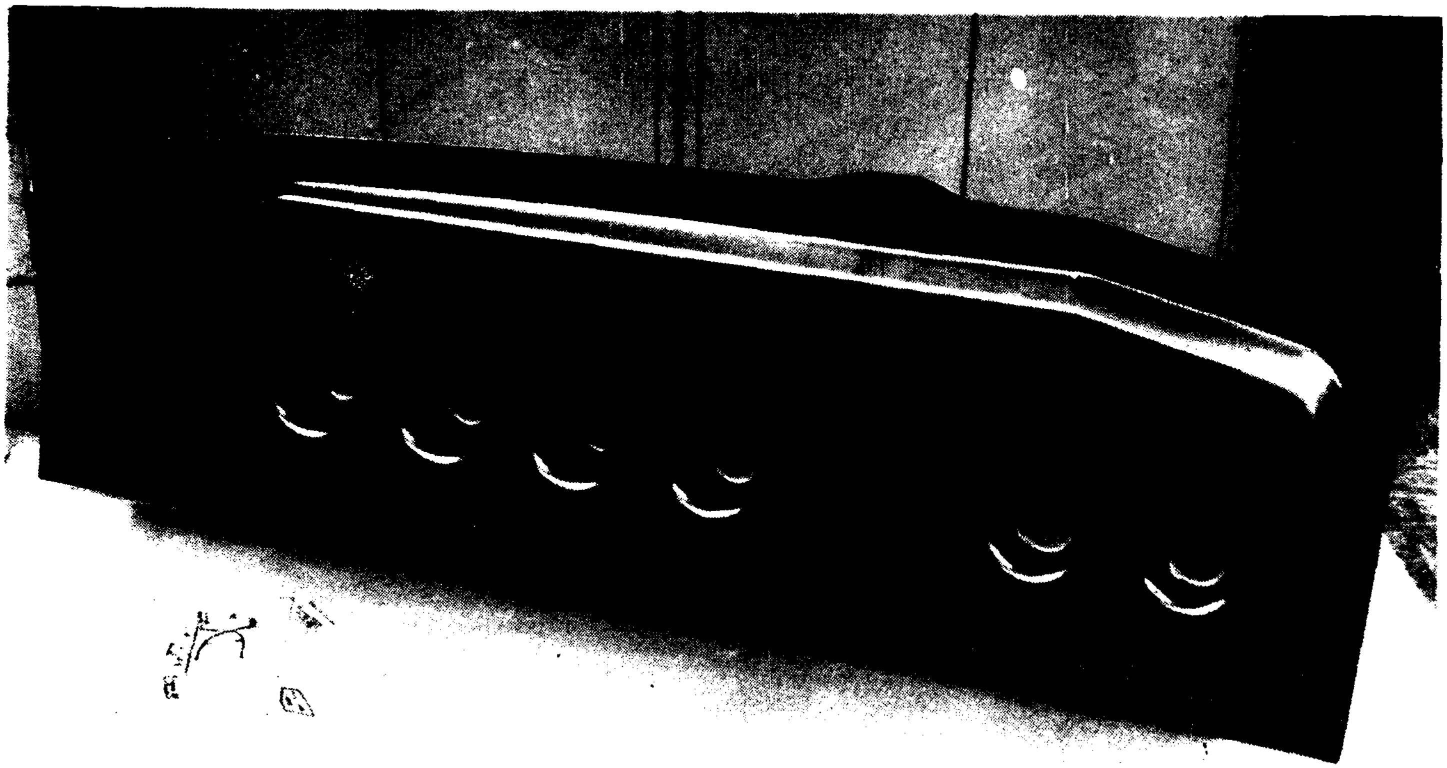


Figure 3. First Version of SPF Pan for the Nose Landing Gear Door

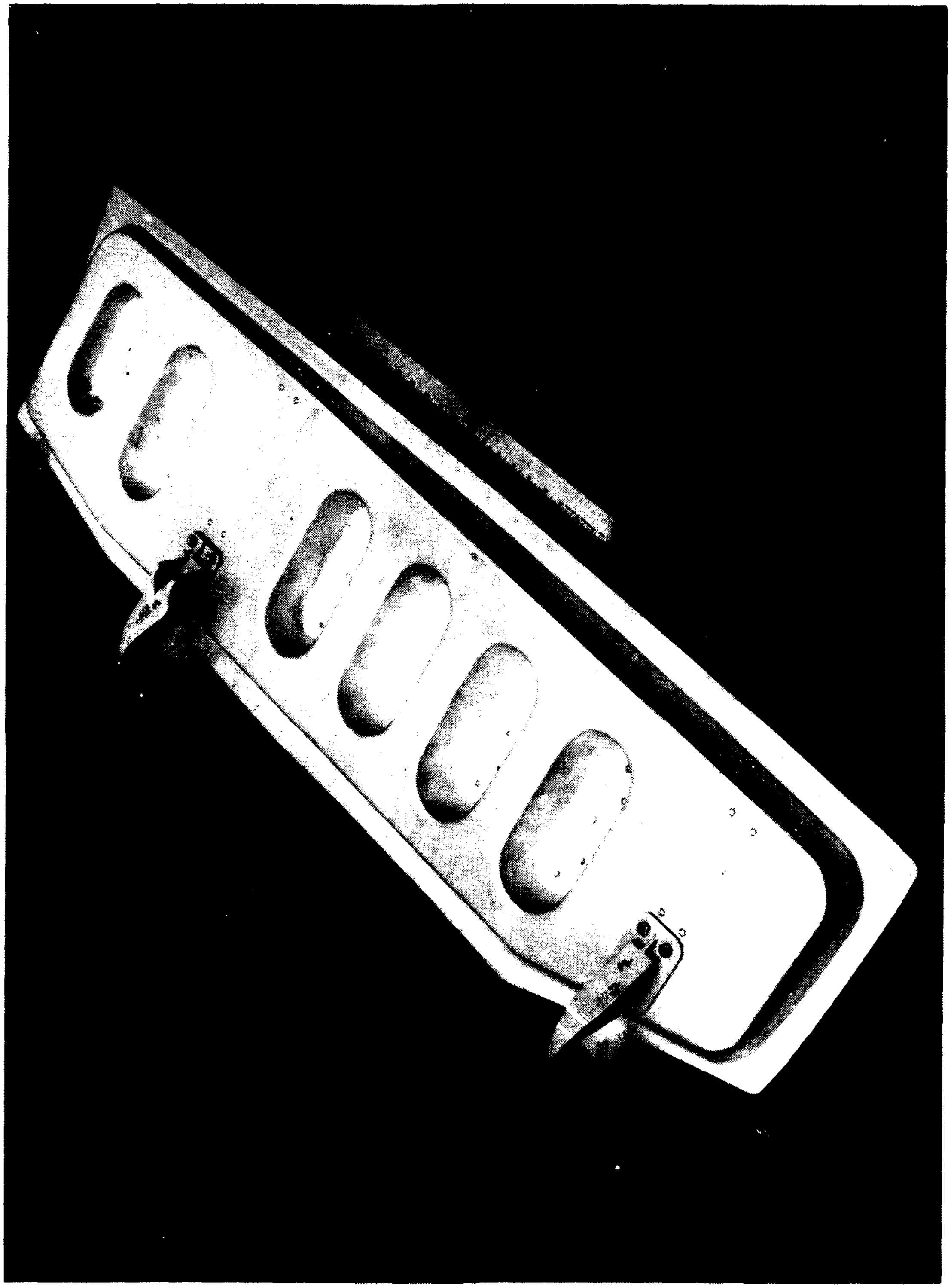


Figure 4. SPF Nose Landing Gear Door Assembled by Weldbonding

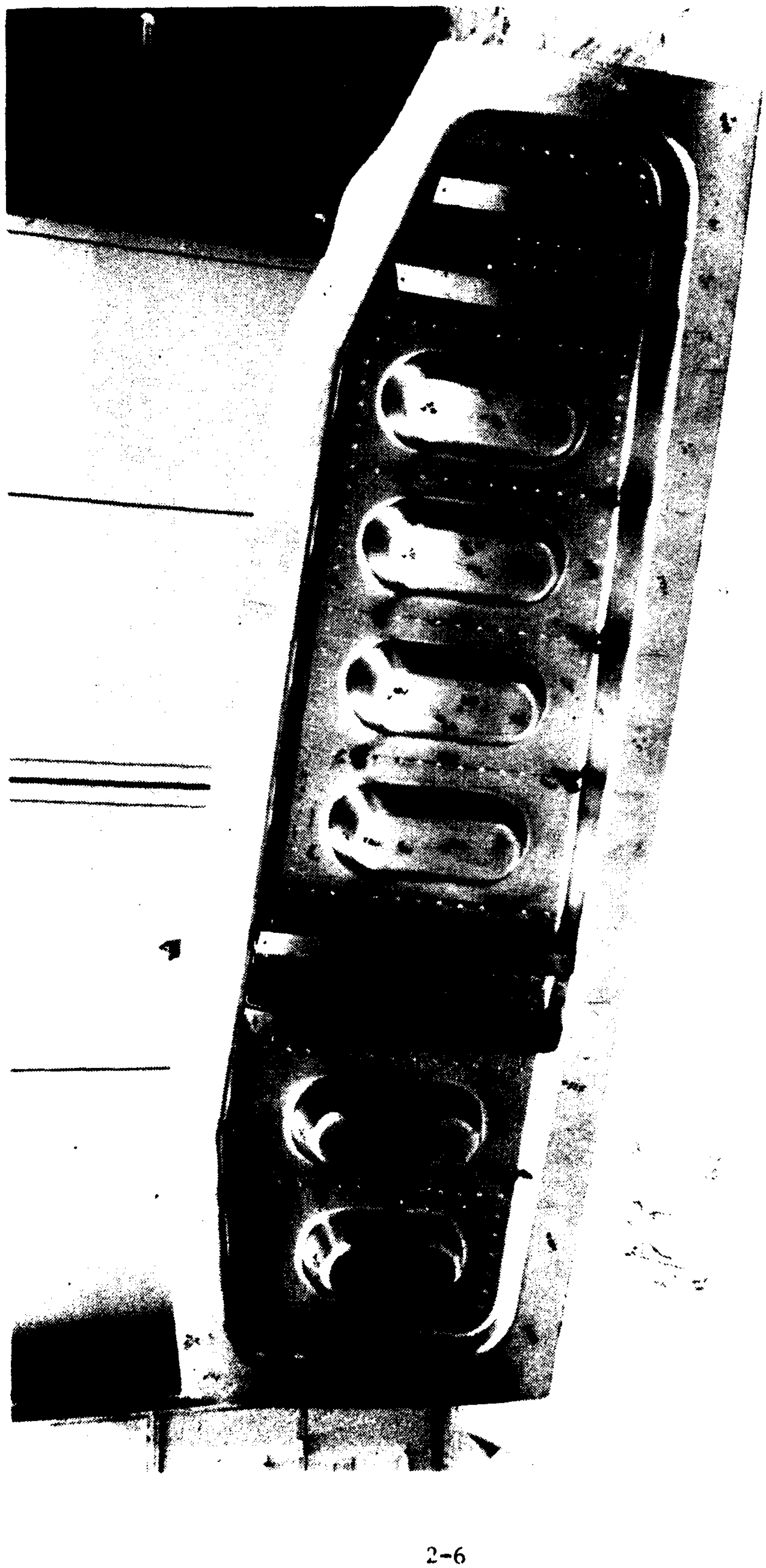


Figure 5. Internal Components of SPF Door

TABLE 1. NOSE LANDING GEAR DOOR COST COMPARISON

	As Manufactured (Conventionally)	First SPF Generic Door
Parts	Inner Pan Outer Skin 50 Component Inner Stiffening Framework 52 Total	Waffle Pan Outer Skin 2 Channel Ribs 12 Clips 16 Total
Recurring Cost	Cost of Preparing 52 Components 50 Hours to Assemble (Skilled Mechanic)	Cost of Preparing 16 Components To Prepare Door for Welding ~20 hours First Trial by Ultrasonic Weldbonding 4 hours First Trial by Resistance Weldbonding 10 hours
Non-Recurring Cost	Assembly Tooling 3689 Hours	SPF Die Cost 465 hours
Weight	13.2 lbs	12.5 lbs
Materials	7075-T6	7075-T6 except waffle pan is Supral 220

A stress analysis was performed on the SPF door. Supral 220 was used as the pan material because of its superior mechanical properties. The pan design effectively provided a longitudinal spar along the inboard and outboard edges of the door with the pan providing shear stiffness. It was determined that a minimum of .064 inch material thickness was required at the caps of the spar section. This dictated a 2mm sheet thickness prior to forming in order to accomodate the expected material thin-out occurring during the SPF process.

The outboard spar was discontinuous at the hinge locations. Continuity was provided by the installation of splice plates at these locations. Machine fittings were required to support the concentrated hinge loads.

The final design concept is shown in Fig. 6. It incorporates the suggestion of Superform USA that the channel not be taken completely across the pan in order to improve the forming action as the sheet is strained into the die contours. The suggestion also simplified the forming requirements of the splice member, reducing it to the requirement for two bends to match the pan/contour rather than four if the channels were carried through the sections. This greatly reduced potential fitting and shimming problems.

While not within the scope of this redesign, it should be noted that for production quantities the hinge could be reconfigured as a machined forging to incorporate the functions of the channel fitting and the splice element. Such a redesign would reduce the part count of the A-10 landing gear door to four components; i.e., 2 hinges, the SPF pan and the external skin.

The final design is detailed in Drawing 160K136160 shown in reduced form in Figs. 7a and 7b. It provides for assembly of the fittings and splice members to the SPF pan with 213 fasteners and attachment of the skin to the pan using ultrasonic weldbonding on the peripheral flanges and in the pockets. Because of the preattached fittings and splice members, the contact surfaces of the pan and skin beneath them were blind fastener bonded rather than weldbonded.

2.3 PRODUCTION OF THE SPF PAN

Upon completion of the design, a quotation was obtained from Superform USA which covered the cost of revising the forming tool, production of 10 SPF pans and the preparation of a qualification report on the properties of one pan. A purchase order was placed with Superform in July 1986.

The Supral 220 alloy, being a new developmental alloy, was not generally available. Superform had anticipated that Alcan, England would cast and roll a heat during August 1986. Subsequently, it was determined that this heat was not properly balanced chemically and therefore could not be accepted as Supral 220 material.

Limitations on casting and rolling facilities delayed the pouring of another heat until early in 1987. That heat was also unsuccessful due to cracking of the mold.

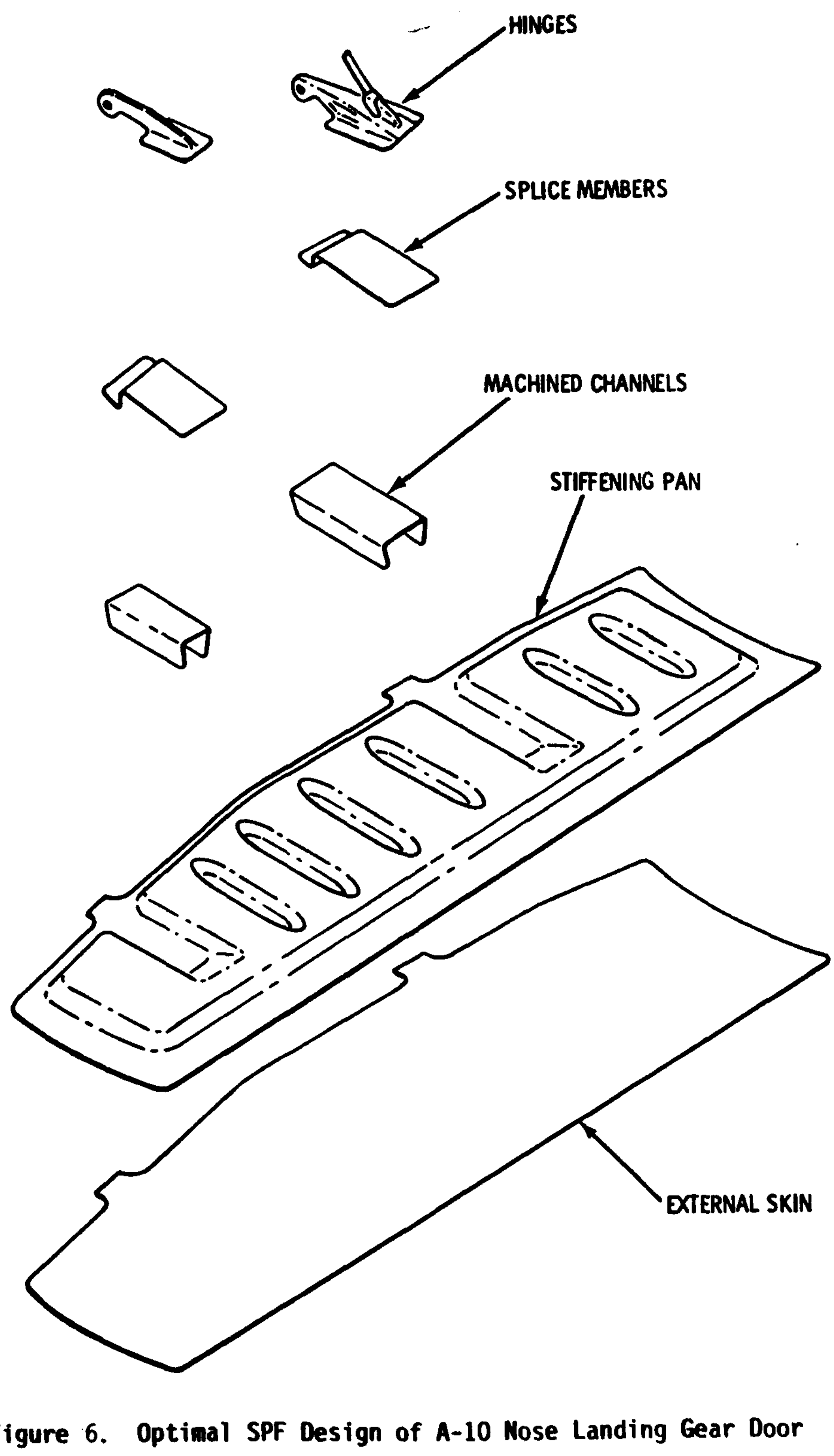


Figure 6. Optimal SPF Design of A-10 Nose Landing Gear Door

Supral 220 finally became available in the spring of 1987. Additional delays were experienced in having the billet rolled into sheet and then having the sheet qualified for mechanical properties and for superplastic forming properties.

Qualified sheet became available to Superform Metals, England in mid-summer. The forming campaign was carried out in July 1987 and the as-formed parts were shipped to Superform, USA, Riverside, CA for heat treatment and evaluation. Appendix A provides detailed information on the forming, heat treating and evaluation of these SPF pans. As may be expected for a large sheet metal structure, the quenching and straightening of the pans was an especially challenging operation in order to maintain contours. Heat treat fixtures were built and fabrication trials and adjustments were made.

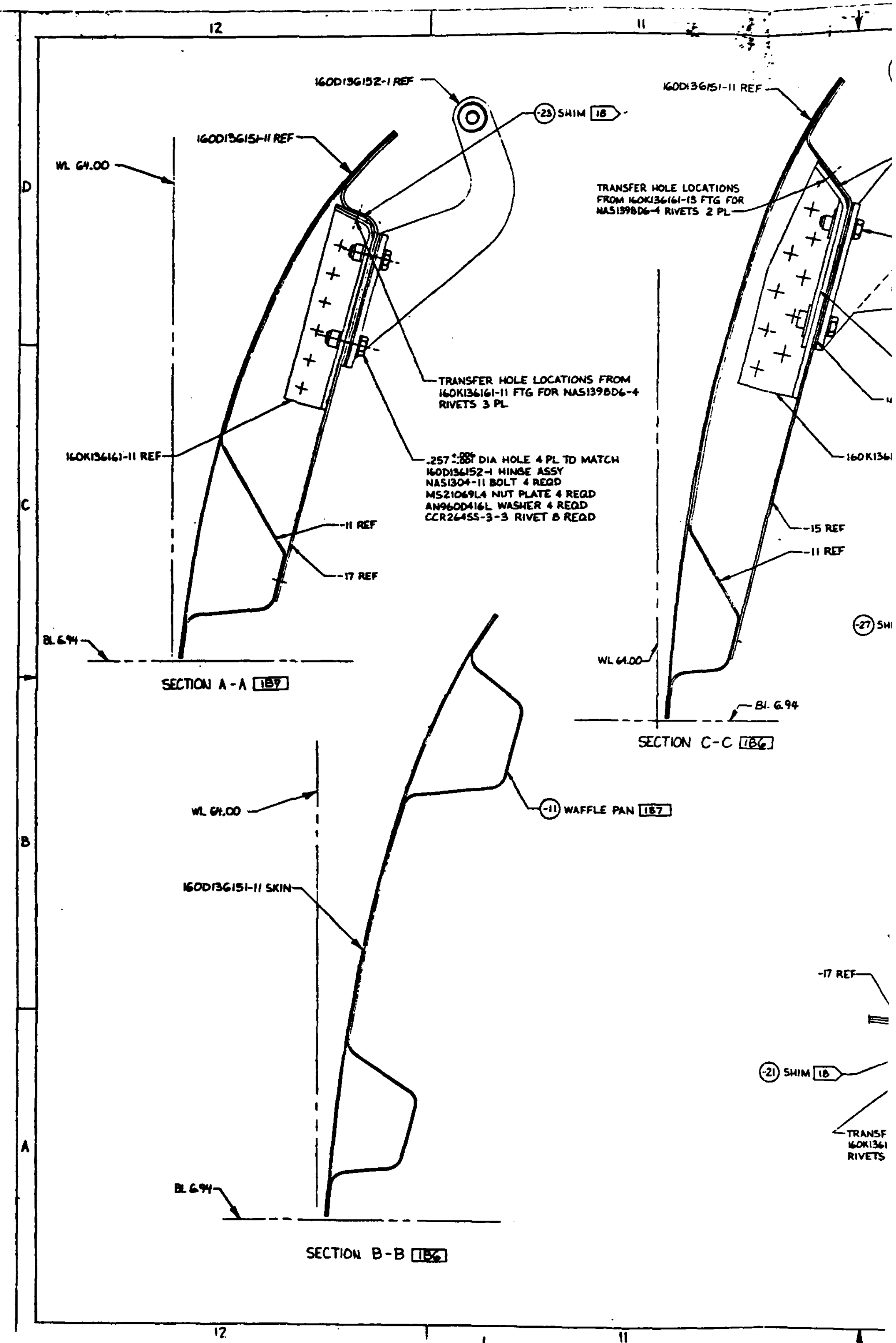
Nine heat treated and straightened pans were received from Superform USA in October 1987 and the Appendix A report was received in November. They advised that straightening was carried out by reference to a thick sheet copy of the die sent from Superform metals.

The pans were mated to both the formed skins and the assembly fixture which reflected the mating fuselage contours and evaluated for fit. It was found that the fits in both cases were poor. The skin and pan could be forced to fit using clamps. In the case of the pan to fuselage contour, it was not possible to bring any of the pans into fit with clamps. The pans had too much error and were too stiff to be brought into contour. It appeared that none of the doors made with these pans could be satisfactorily fitted to aircraft. The pans were otherwise satisfactory and could be used to fabricate a proper test article.

2.4 ASSEMBLY OF THE SPF DOOR

The best fitted combination of pan and skin was selected for preparing the deliverable test door. The second best combination was chosen for weldbonding practice prior to the assembly of the deliverable test door. The best pan was prefitted and drilled for subsequent assembly of the machined fitting, the splice plates and the hinges in accordance with drawing directions.

Both selected sets of pan and skin were then cleaned, deoxidized and given the FPL etch treatment. The interior faying surfaces were coated with the corrosion inhibiting adhesive primer BR-127 (American Cyanamid). The efficacy of these treatment steps was evaluated by preparing lap shear test specimens which reflected these treatments on the materials being bonded. Lap shear strengths between 4400 psi and 4550 psi were obtained on specimens after pressing and curing the film adhesive FM-123 (American Cyanamid) in the lap area. These are acceptable values, and they qualify the adhesive system employed on the doors.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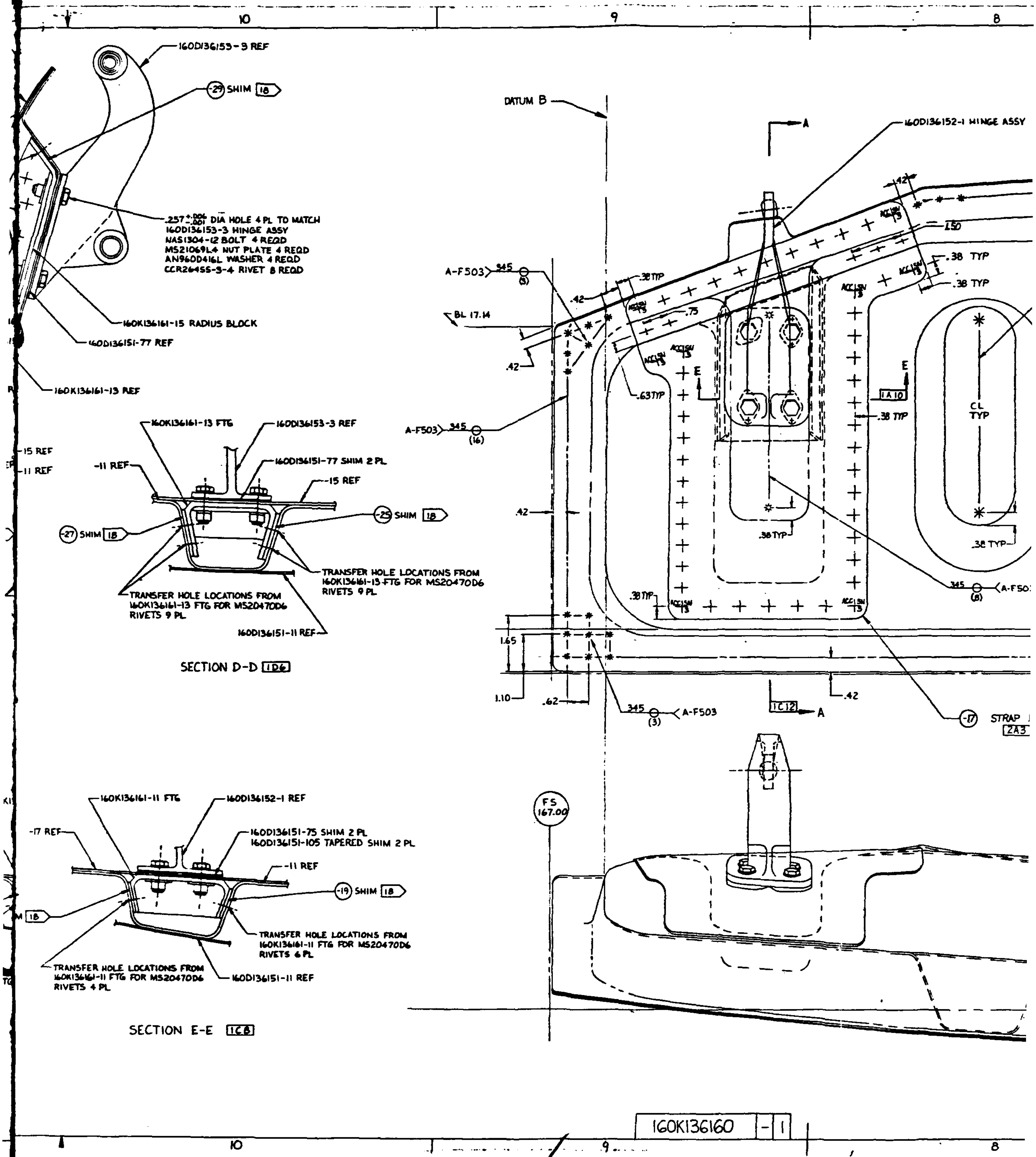

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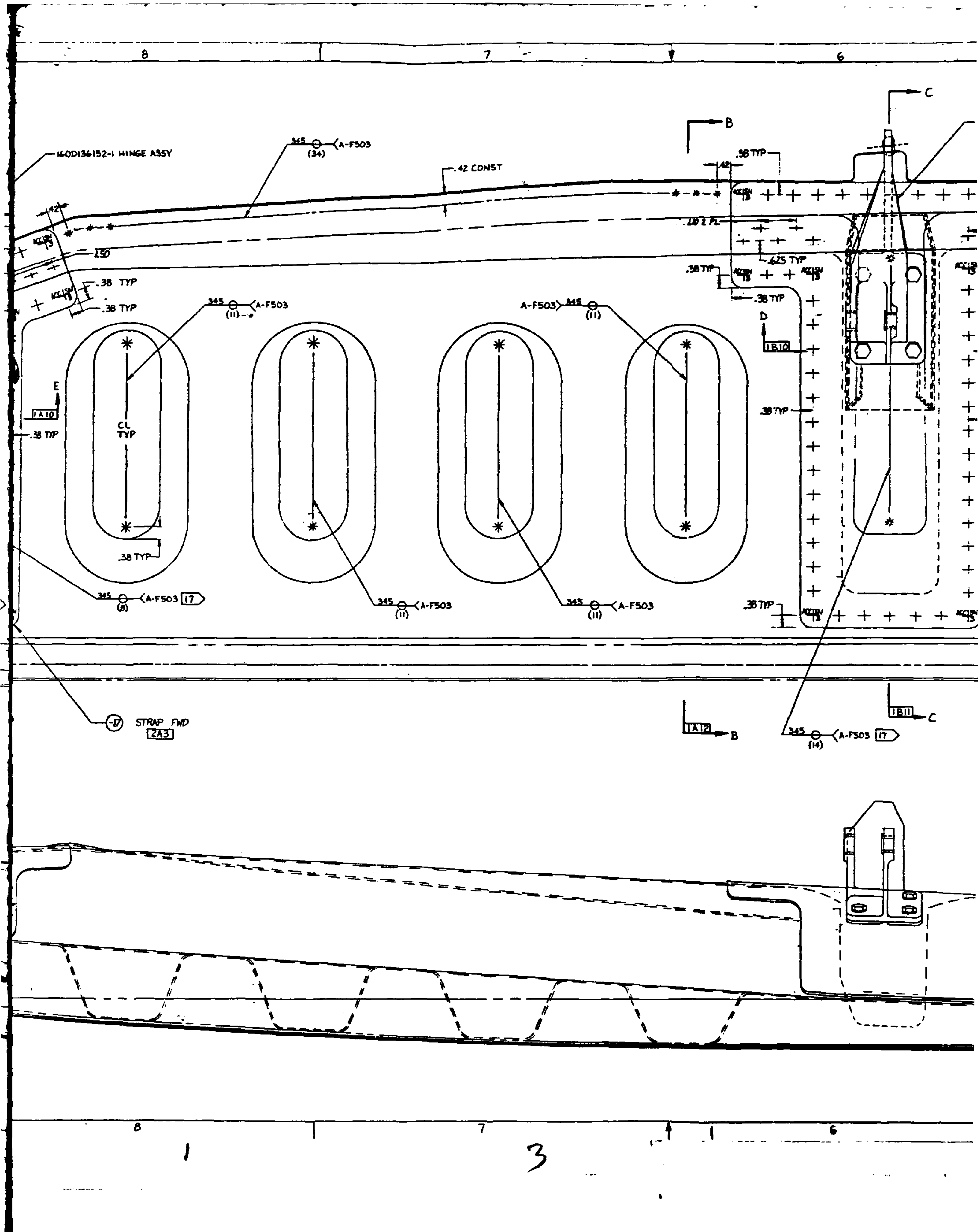

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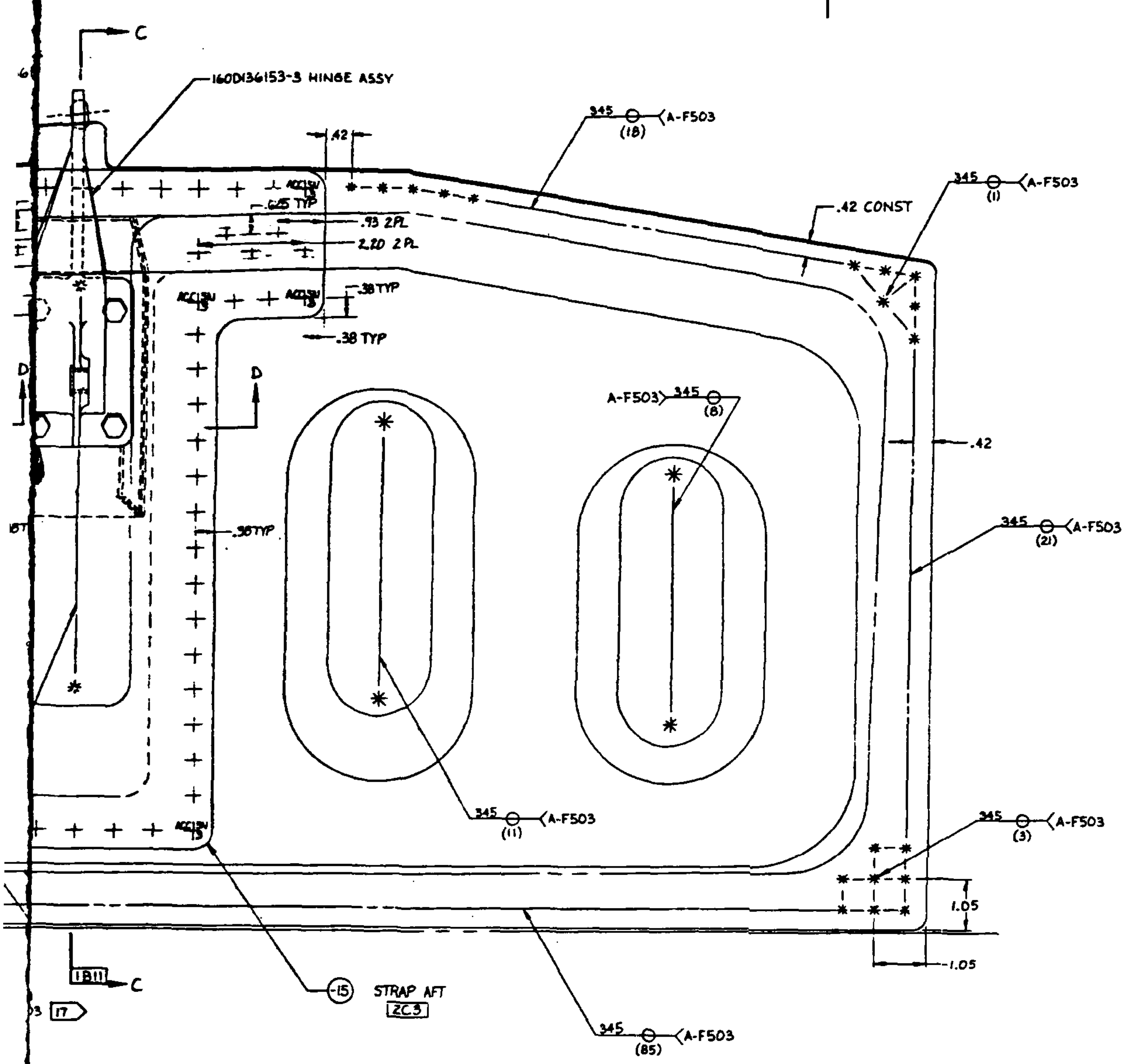

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4	LOFT DATA BOOK
5	ENVIRONMENTAL SEAL
6	COLORS
7	EPOXY ADHESIVE
8	CHEMICAL FILM-ALODI EPOXY-POLYAMIDE PI PRIMER APPL
9	WELD BONDING
10	POLYURETHANE CO
11	BRUSH ALODINE 600
12	METAL CLEANING
13	BRUSH ALODINE 120
14	PRIMER APPL
15	SEALING AND COATING C
16	BOLTS, NUTS AND WASHE
17	WRENCHING TORQUE
18	HONEYCOMB BOND

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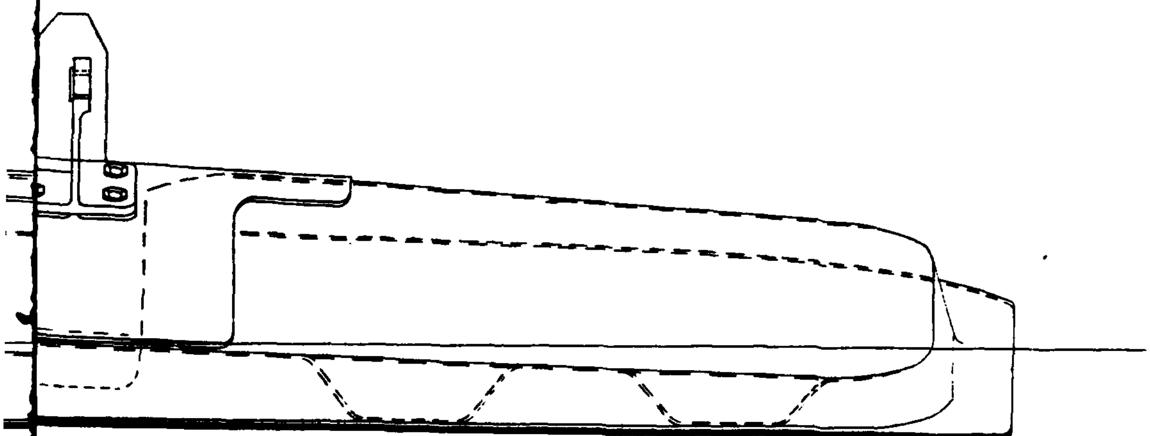

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BASIC CODES

✱ INSTALLATION FASTENER/RIVET

BASIC CODE — DASH NO. FOR DIA; N=MFG-HEAD NEAR SIDE; F=MFG-HEAD FAR SIDE; B=FLUSH BOTH SIDES

S=SINGLE; FIGURE=NO OF SHEETS TO BE JOINED; C=CSK — DASH NO. FOR LENGTH

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FASTENER/RIVET CODE

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TABLE 1 - ASSOCIATED DOCUMENTS

TITLE OR DESCRIPTION	GOVT/IND-SPEC/DOC	FRC SPEC/DOC	NOTE
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ENVIRONMENTAL SEALING	NONE	Z-P102	9
COLORS	FED-STD-595	NONE	12
EPOXY ADHESIVE	NONE	B-F501	8
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WELD BONDING	NONE	A-F503	3
POLYURETHANE COAT	NONE	Z-R901 CODE ZC	
BRUSH ALODINE 600	MIL-C-5541, CL 3	Z-R901 CODE AX	4
METAL CLEANING	NONE	G-R301	
BRUSH ALODINE 1200	MIL-C-5541, CL 1A	Z-R901 CODE BX	
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HONEYCOMB BOND	NONE	S-F501	

DRAWING DEVELOPED FOR SPECIAL PROGRAM TESTS OF ULTRASONIC
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ER CURING BRUSH COAT WITH ALODINE 600 ON EXPOSED METAL
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T INSTALL EXTERNAL FASTENERS ON EXPOSED SURFACES WITH
-S-81733 SEALANT PER Z-P102.
AL FAYING SURFACES OF ALL EXTERIOR DETAIL PARTS NORMAL TO
LT HOLES IN AREA ADJACENT TO BOLT HOLES PER Z-P102.
TRASONIC WELDS MAY BE REPLACED BY NAS1097AD4 RIVETS-FLUSH BOTH SIDES.
PLY TOP COAT, COLOR NO. 31136, INSIGNIA RED PER FED-STD-595.
R REF ONLY LOFT MASTER NO. LM160D136151.
R REF ONLY SEE DWGS 160D136151 DOOR ASSY AND 160K136151 DOOR ASSY-TEST ONLY.
OR TO INSTALLING FASTENERS, GRIP LENGTHS MUST BE CHECKED FOR
RRECTNESS. GRIP LENGTHS MAY VARY DUE TO SHIMMING ALLOWANCES
D THINNING OF PAN IN MANUFACTURE.
→ DENOTES DIMENSION TAKEN FROM BASIC DATUM LINE.
OT WELDS IN BLIND AREAS MAY BE REPLACED BY NAS1398D4A2 RIVETS.
X GAP TO SHIM AFTER DELAMINATION TO BE .003 .
RQUE NAS1304 BOLTS TO 65 - 90 INCH POUNDS PER SP625.
IS ARTICLE NOT FOR FLIGHT PURPOSES.

Figure 7a. Modified Door Ass

QUANTITY REQD	CODE IDENT	PART NO OR IDENTIFYING NO	NOMENCLATURE OR DESCRIPTION	ZONE	STOCK SIZE	MATERIAL / MATERIAL SPECIFICATION / CONDITION VENDOR NAME AND ADDRESS	ASSOCIATE
8		CCR264SS3-4	RIVET				
4		NAS1304-12	BOLT				
5		NAS1398D6A4	RIVET				
117		NAS1398D5A3	RIVET				
4		NAS1304-11	BOLT				
28		MS20470D6	RIVET				
8		MS21069L4	NUT PLATE				
8		CCR264SS-3-3	RIVET				
8		AN960D416L	WASHER				
1		160D136153-3	HINGE ASSY-AFT	1D6			
1		160D136152-1	HINGE ASSY-FWD	1D8			
2		160D136151-105	TAPERED SHIM	1B10			
2		160D136151-77	SHIM	1C10			
2		160D136151-75	SHIM	1B10			
1		160D136151-11	SKIN	1B12			
1		160K136161-15	RADIUS BLOCK	1C10			
1		160K136161-13	FITTING	1C10			
1		160K136161-11	FITTING	1B10			
1		-29	SHIM	1D10	.250 1.60 2.80	AL SH, MIL-S-22499 COMP I CL 2 TYPE I	
1		-27		1C10	.250 1.60 6.00		
1		-25		1C10	.250 1.60 6.00		
1		-23		1D11	.250 1.10 3.25		
1		-21		1A11	.250 1.10 4.10		
1		-19	SHIM	1A10	.250 1.10 4.85	AL SH, MIL-S-22499 COMP I CL 2 TYPE I	
1		-17	STRAP	2A3	.063 15.0 110.0	AL SH, QQ-A-250/12 7075-T6	2, 8
1		-15	STRAP	2C3	.063 15.0 11.0	AL SH, QQ-A-250/12 7075-T6	2, 8
1		-11	WAFFLE PAN	1B11	.080 20.0 60.0	SUPRAL 220	2
		160K136160-1	DOOR ASSY				1 THRU
-1			ASSEMBLIES				

PARTS LIST

PART NUMBER MARKING PER MIL STD 130 (Z-R701)

TEST ONLY

NEXT ASSEMBLY | USED ON | NEXT ASSY | FINAL ASSY | APPLICATION | QUANTITY REQD

DO NOT SCALE DRAWING

MODIFIED LANDING FOR

CONTRACT NO F33615-83-C-5200

J 77751

ASONIC

AL FATTERN DEVELOPED

METAL

G DIMENSIONS.
DIMENSIONS.
MANUFACTURING

ES WITH

ORMAL TC
PIO2.
S-FLUSH BOTH SIDES.
STD-595.

1 DOOR ASSY-TEST ONLY.
HECKED FOR
ALLOWANCES

LINE.
RIVETS.

Figure 7a. Modified Door Assembly -1.

8	CCR264SS3-4	RIVET					
4	NAS1304-12	BOLT					
5	NAS1398D6A4	RIVET					
117	NAS1398D5A3	RIVET					
4	NAS1304-11	BOLT					
28	MS20470D6	RIVET					
8	MS21069L4	NUT PLATE					
8	CCR264SS-3-3	RIVET					
8	AN960D416L	WASHER					
1	160D136153-3	HINGE ASSY-AFT	1D6				
1	160D136152-1	HINGE ASSY-FWD	1D8				
2	160D136151-105	TAPERED SHIM	1B10				
2	160D136151-77	SHIM	1C10				
2	160D136151-75	SHIM	1B10				
1	160D136151-11	SKIN	1B12				
1	160K136161-15	RADIUS BLOCK	1C10				
1	160K136161-13	FITTING	1C10				
1	160K136161-11	FITTING	1B10				
1	-29	SHIM	1D10	.2501.602.80	AL SH, MIL-S-22499 COMP I CL 2 TYPE I		
1	-27		1C10	.2501.606.00			
1	-25		1C10	.2501.606.00			
1	-23		1D11	.2501.103.25			
1	-21		1A11	.2501.104.10			
1	-19	SHIM	1A10	.2501.104.85	AL SH, MIL-S-22499 COMP I CL 2 TYPE I		
1	-17	STRAP	2A3	.0631.5.0110.0	AL SH, QQ-A-250/12 7075-T6	2, 8	2
1	-15	STRAP	2C3	.0631.5.011.0	AL SH, QQ-A-250/12 7075-T6	2, 8	2
1	-11	WAFFLE PAN	1B11	.08020.060.0	SUPRAL 220	2	2, 4, 13, 15
	160K136160-1	DOOR ASSY				1 THRU 20	1 THRU 20
-1		ASSEMBLIES					

PARTS LIST

PART NUMBER MARKING PER MIL STD-130 (2-R701)

TEST ONLY

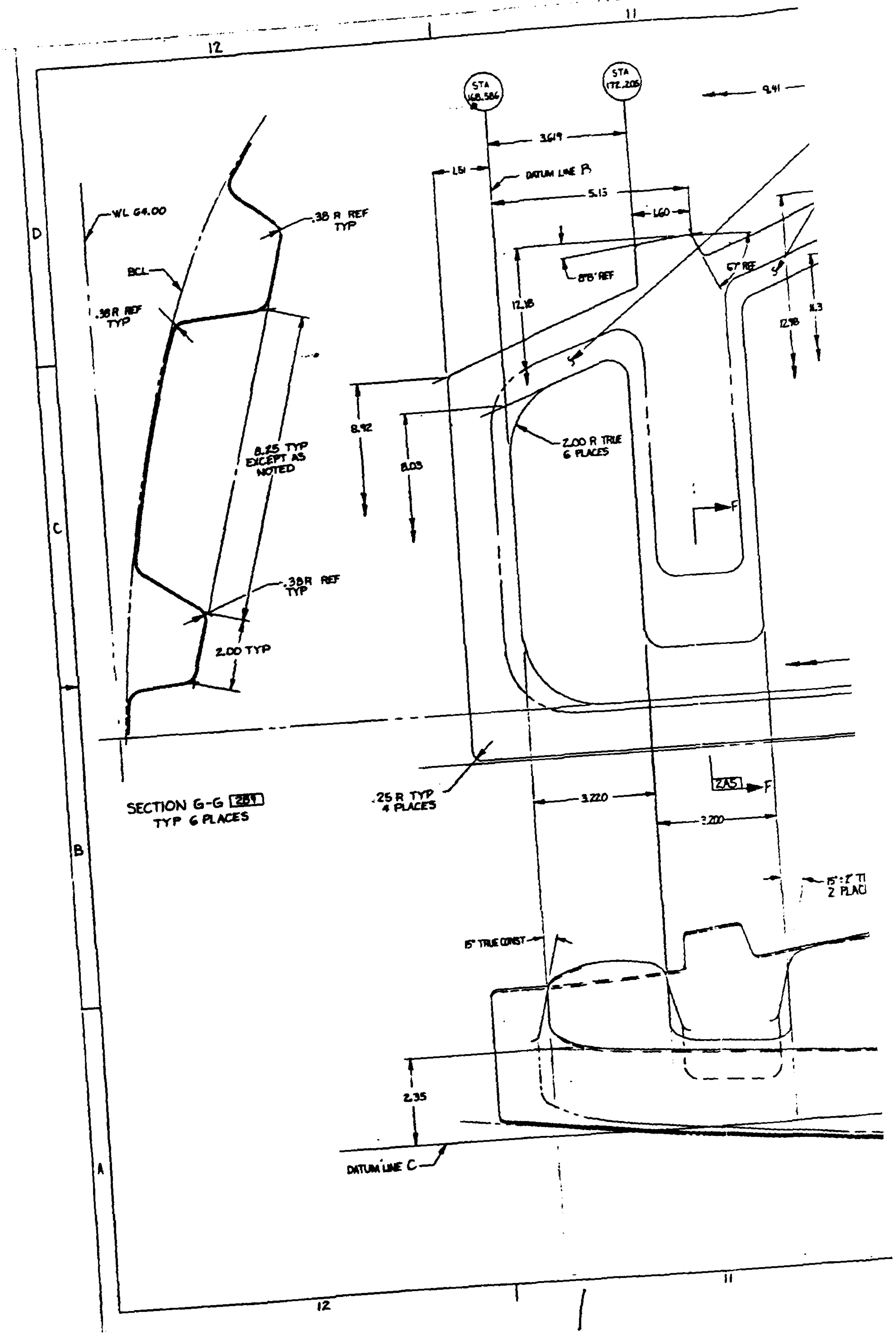
DO NOT SCALE DRAWING

CONTRACT NO F33615-83-C-3240

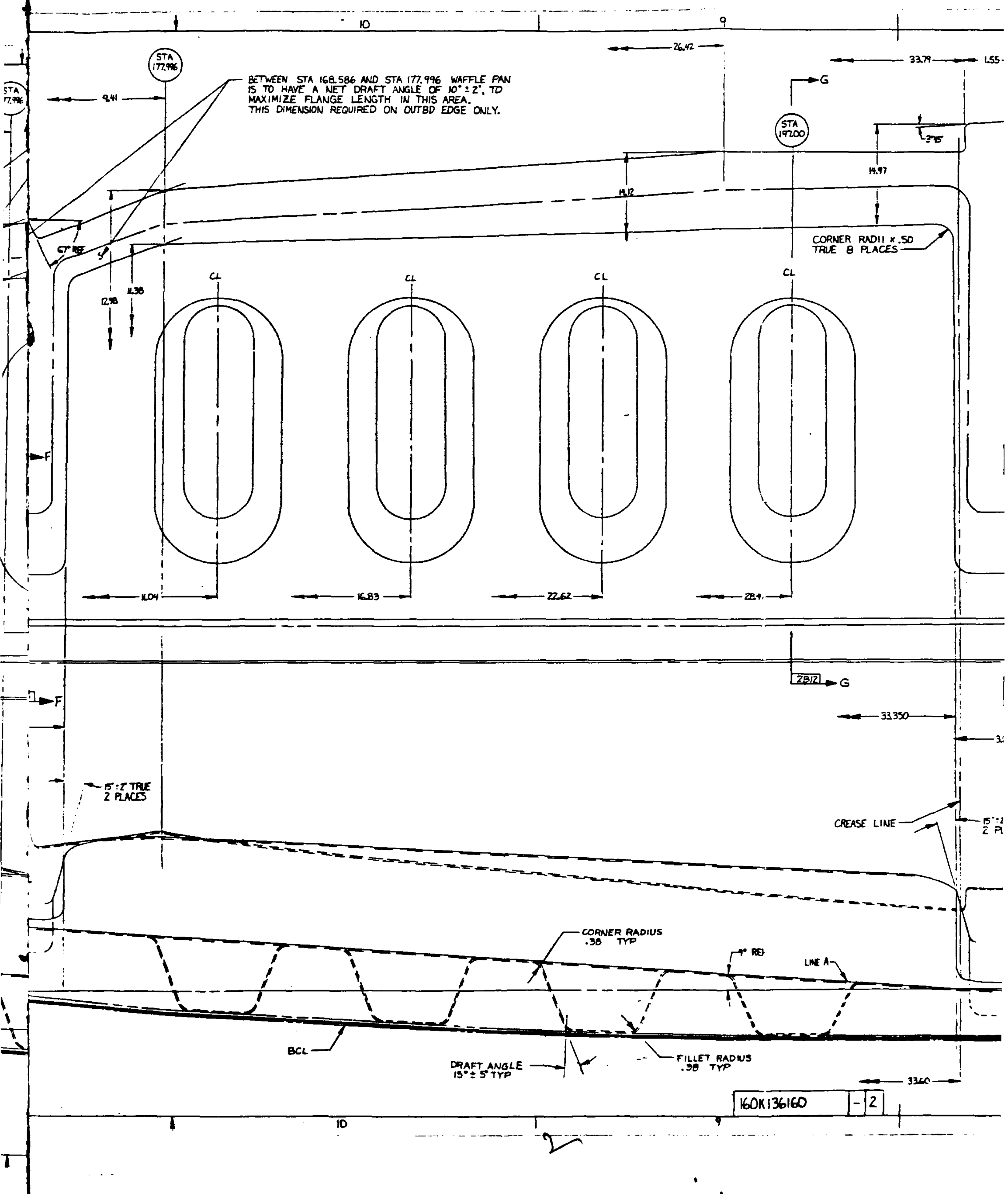
FAIRCHILD

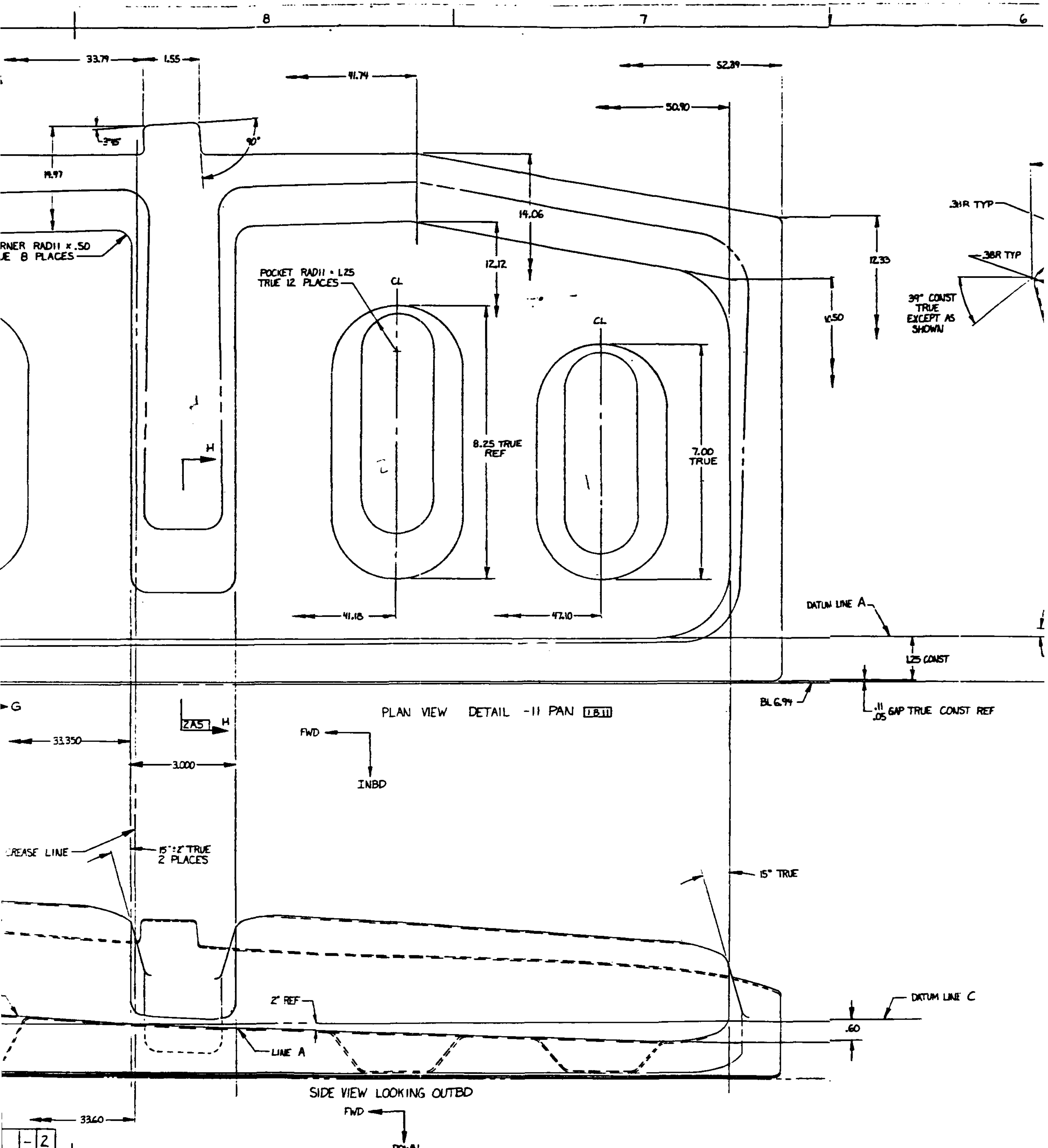
MODIFIED DOOR ASSY - NOSE LANDING GEAR - FWD, NO 2 FOR TEST ONLY

J 77751 160K136160



12
11
STA 168.586
STA 172.205
9.41
3.619
1.51
DATUM LINE B
5.15
1.60
WL 64.00
.38 R REF TYP
BCL
.38 R REF TYP
8.25 TYP EXCEPT AS NOTED
.38R REF TYP
2.00 TYP
12.18
8.92
8.03
2.00 R TRUE 6 PLACES
67° REF
12.98
.25 R TYP 4 PLACES
SECTION G-G
TYP 6 PLACES
3.220
3.200
15° TRUE CONST
2.35
DATUM LINE C
D
C
B
A

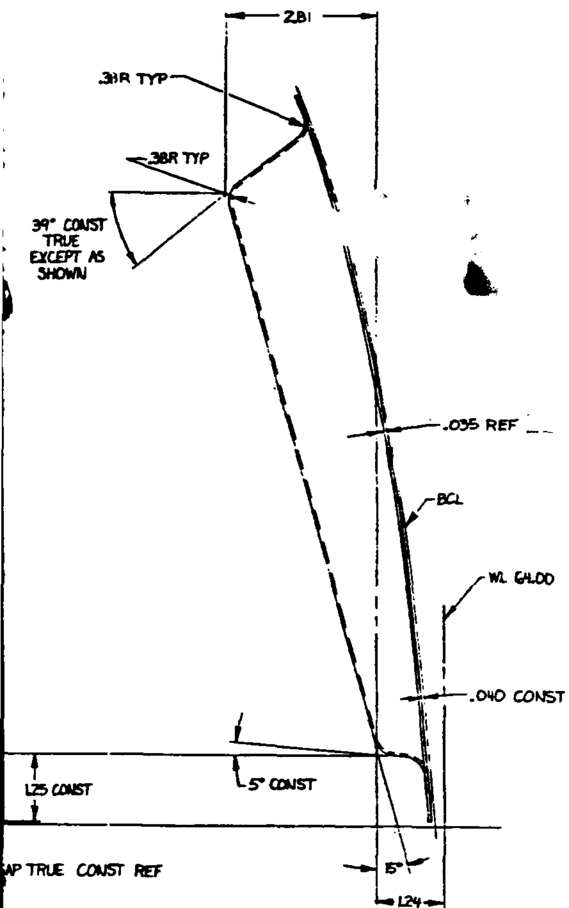

10
9
STA 177.996
BETWEEN STA 168.586 AND STA 177.996 WAFFLE PAN IS TO HAVE A NET DRAFT ANGLE OF 10° ± 2°, TO MAXIMIZE FLANGE LENGTH IN THIS AREA. THIS DIMENSION REQUIRED ON OUTBD EDGE ONLY.
26.42
33.79
1.55
9.41
STA 192.00
G
14.97
14.12
67° REF
CORNER RADII × .50 TRUE 8 PLACES
CL
12.98
11.38
F
11.04
16.83
22.62
28.4
2B12
33.350
15° ± 2° TRUE 2 PLACES
CREASE LINE
CORNER RADIUS .38 TYP
LINE A
BCL
DRAFT ANGLE 15° ± 5° TYP
FILLET RADIUS .38 TYP
33.60
160K136160
2

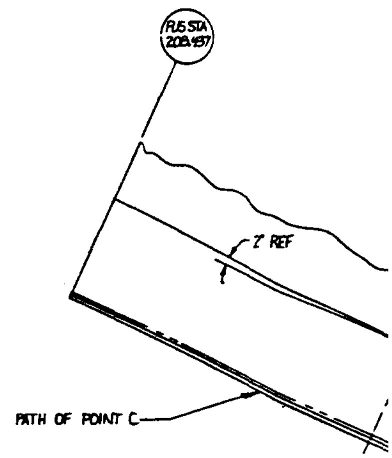


33.79
1.55
41.74
52.39
50.90
3°15'
90°
19.97
14.06
12.12
12.33
10.50
RNER RADII × .50
UE 8 PLACES
POCKET RADII = 1.25
TRUE 12 PLACES
CL
.31R TYP
.38R TYP
39° CONST
TRUE
EXCEPT AS
SHOWN
H
8.25 TRUE
REF
7.00
TRUE
41.18
47.10
DATUM LINE A
1.25 CONST
BL 6.94
.11
.05 GAP TRUE CONST REF
G
2A5
PLAN VIEW DETAIL -11 PAN 1B11
FWD
INBD
33.350
3.000
CREASE LINE
15°±2° TRUE
2 PLACES
15° TRUE
2° REF
DATUM LINE C
.60
LINE A
SIDE VIEW LOOKING OUTBD
FWD
DOWN
33.60

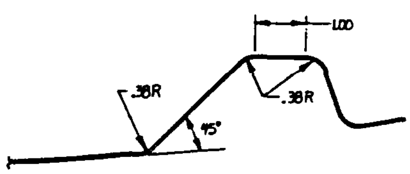
| - | 2 | 8 | 7 | 6 |

3

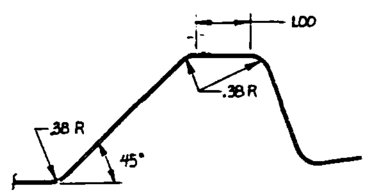




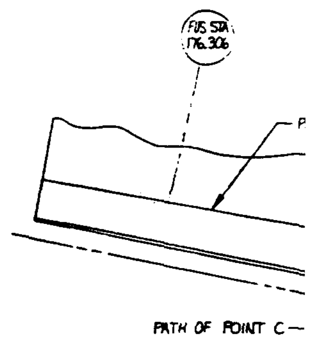
DATUM LINE C



SECTION H-H [2B8]



SECTION F-F [2B11]



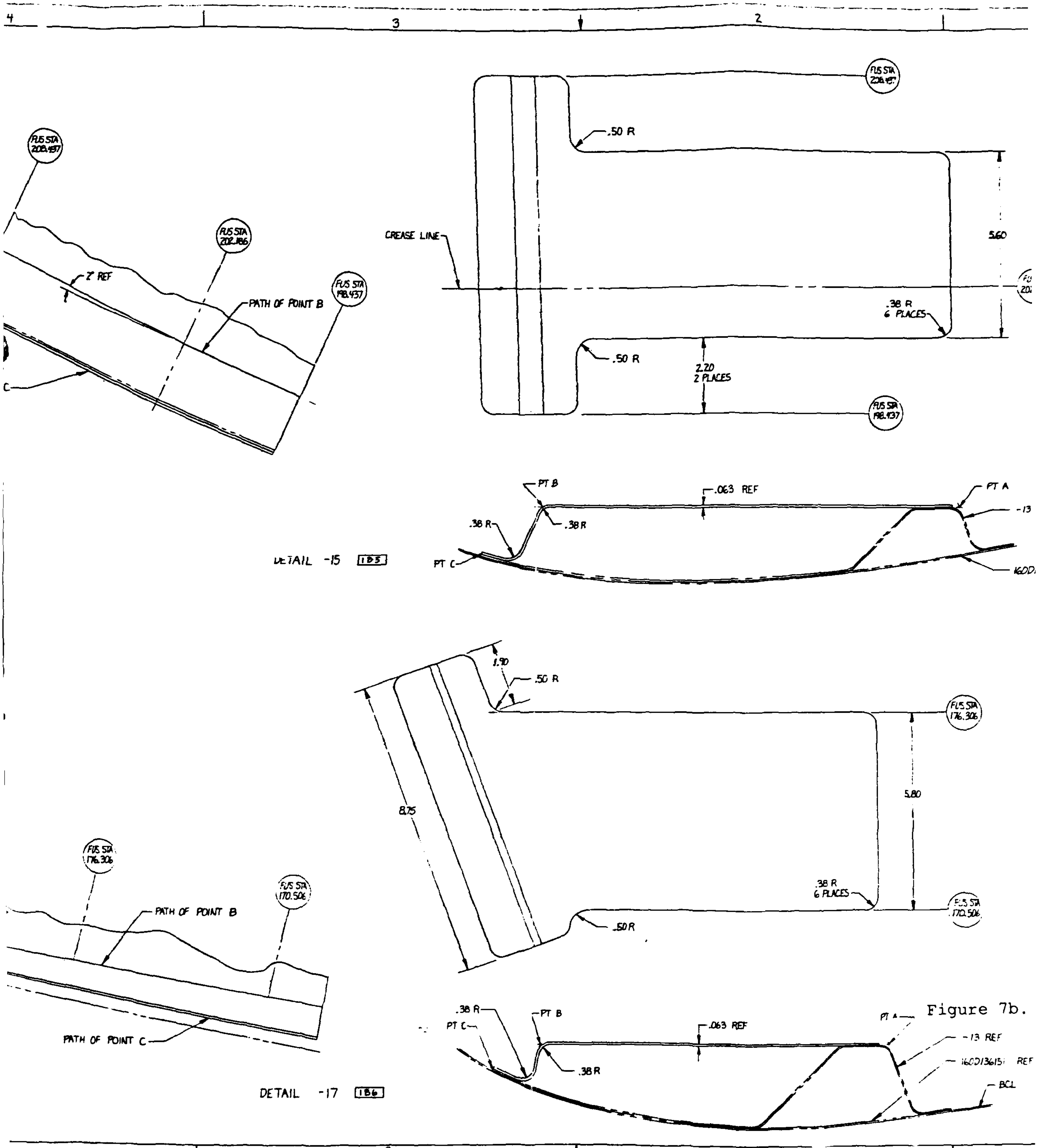

FUS STA 226.437
.50 R
5.60
FUS STA 208.437
FUS STA 202.186
2" REF
PATH OF POINT B
FUS STA 198.437
CREASE LINE
.38 R
6 PLACES
.50 R
2.20
2 PLACES
FUS STA 198.437
PT B
.063 REF
PT A
.38 R
.38 R
DETAIL -15 1B5
PT C
1.90
.50 R
FUS STA 176.306
5.80
8.75
FUS STA 176.306
FUS STA 170.506
PATH OF POINT B
.38 R
6 PLACES
.50 R
PATH OF POINT C
.38 R
PT B
PT C
.063 REF
-13 REF
.38 R
BCL
DETAIL -17 1B6

Figure 7b.

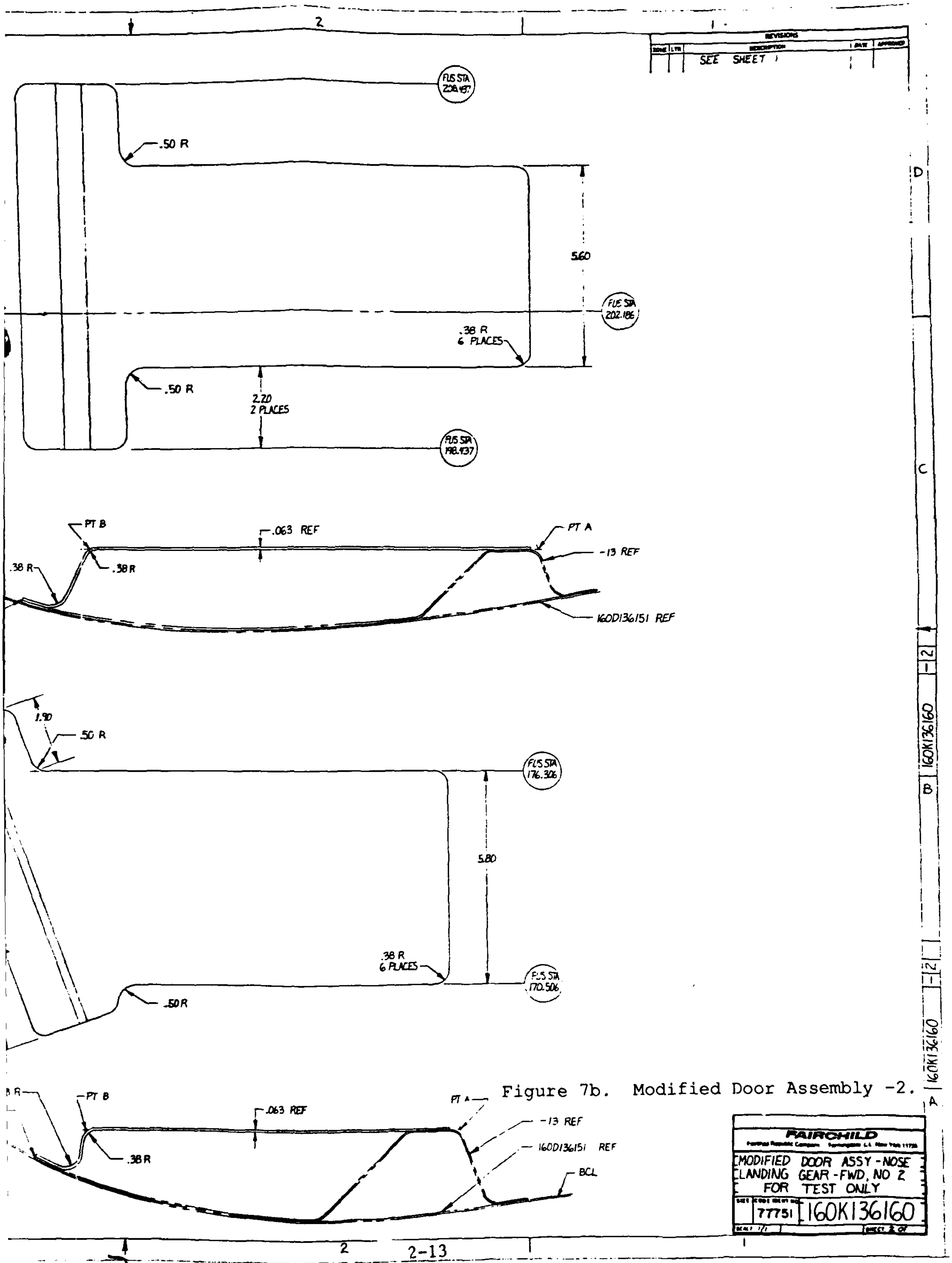


Figure 7b. Modified Door Assembly -2.

The ultrasonic welder (Ref. 2) was set up with tools suitable for the deep pockets on the nose landing gear door and the capacity of the opening on the welder. The anvil which enters the pocket was hardened steel, 1/2" diameter and approximately 5 inches long with a tip radius of 20". The power tip was hardened steel, 3/4" diameter and approximately 1/2" long with a tip radius of 16".

The power, pressure and time controls on each weld cycle were also selected. Within an overall time envelope of 3.3 seconds which includes travel time for the anvil to seat on the workpiece, power was ramped from a 0 level to 4000 watts over 1.4 seconds with a dwell at full power of only .2 seconds. An anvil load of 3800 lbs. is briefly applied prior to the power application to bring the workpieces into contact through the film adhesive. The tip load then drops back to 450 lbs. for the start of the weld cycle, during the first .8 seconds of which it is ramped back again to 3800 lbs. After completion of the weld cycle, pressure was maintained on the workpiece for a number of seconds to assure cooling of the bond line to a solid. Ultrasonic welding practice was in conformance with MIL-STD-1947(MR) (Ref. 3) and FRC Specification A-F503 (Ref. 4)

The selected weld schedule was tested using lap shear specimens of the materials to be welded on the door. With the film adhesive left uncured spot shear strengths of 1000 to 1200 lbs. were regularly obtained. This strength level should be more than adequate for the purpose of fixturing components which will eventually depend upon a cured adhesive bond line for their assembled functional strength.

The weldbonding practice pan was fitted with adhesive film and the exterior skin was mated to it using tooling holes to establish alignment. The 6 pockets were spot welded first with good overall faying surface contact being made in those areas. The skin and pan also made rather good contact along the flange of the straight long side of the door when spot welded. In a few areas, it was necessary to apply clamps to achieve close contact before welding. Heavy clamping was required to bring the end flanges into reasonable contact due to the misfit of the contours of the pan. Spot welding became awkward due to the interference of the clamps. Weld spots in the areas of forced contact held in some areas when the clamps were removed, but in other areas the spots opened up due to the high tension stresses across the weld generated by the poor fit. In order to reasonably complete the weldbond operation, it became necessary to apply rivets in the outside trim areas of the most severe misfits. Rivets are quite strong in tension fields and were able to hold the bond lines in contact. After cure of the adhesive and trimming of the riveted areas some bond line gapping developed in the areas of worst misfit. Tension stresses overcame the adhesives' tensile strength in those areas.

The pan for the deliverable test door had the machined fittings riveted into appropriate grooves and then the splice plates were riveted over the fittings and the grooves. Some 213 fasteners were used in these operations. Thereafter, the film adhesive was applied and the skin was mated to the pan. Again severe misfit problems were encountered which precluded a straightforward weldbonding assembly. Clamps and peripheral riveting were required to close up the bond line interface and to assure adhesive contact to the faying surfaces. With a pitch of 1.75 inches, some 138 ultrasonic spot welds were applied to the faying areas of the skin and pan. Again, after the oven curing of the adhesive and the trimming of excessive peripheral material, areas were found where the bond line was gapping. Those areas of the deliverable test door were locally reinforced with rivets so that the static test of the basic door structure could be made.

The assembled test door was alodined and primed on the exterior surfaces. The hinges were attached and the door was shipped to AFFDL for testing.

2.5 PRODUCTION OF THE STANDARD DOOR

The preparation of the standard A-10 forward nose landing gear door (Part No. 160D136151-1) for comparison testing with the SPF based door posed a problem since the A-10 was out of production. The manufacture of some 52 components and their assembly into a single door would have been exceptionally expensive. Fortunately, the factory received a spares order that included nose gear doors in this time period. The door required for this program was added to the spares requirement in 6-86. It was completed and shipped to AFFDL in 5-87. The internal reinforcement structure within the drop hammer formed pan is shown in Fig. 2. The pre-drilled exterior skin is also visible in the photo. Approximately 500 fasteners are used in the assembly of the door, many being required at awkward angles. A great deal of fitting and shimming is required in assembling these doors; this requires both skill and time.

2.6 COST COMPARISON

The comparative cost data generated for the two doors is presented in Table 2.

The methodology for developing the data is presented in Appendix B which covers the ground rules used, the costs of the door's details, vendor projected costs, assembly costs, and quantity manufacturing factors.

It may be seen in Table 2 that while an SPF based door has higher material costs, it is assembled with a much lower manpower burden than the conventionally manufactured door. Using a nominal wraparound manhour cost of \$40/hr (which will of course vary from shop to shop), it is shown in Table 2 that the SPF approach is less than half the cost of the conventional approach for production quantities larger than 100. In Fig. 8 it is seen that the learning curve for the conventional approach is somewhat steeper than the SPF approach; this effect being related to the much greater manpower application in the former approach.

TABLE 2

A-10 NOSE LANDING GEAR DOOR SPF VS. CONVENTIONAL COST SUMMARY

	CONVENTIONAL ASSEMBLY		SPF	
	A/C #1-100	A/C #1-500	A/C #1-100	A/C #1-500
MATERIAL ($)	47,300	210,000	131,200	543,500
DETAILS (hrs)	2,197	7,375	757	2,617
SPOT WELD (hrs)	230	793	-	-
ULTRASONIC WELD (hrs)	-	-	313	1,102
ASSEMBLY (hrs)	10,170	27,820	1,863	5,096
TOTAL (hrs)	12,597	35,988	2,933	8,815
TOTAL HOURS INCLUDE 25% SUPPORT	15,746	44,985	3,666	11,019
TOTAL ($) / HOURS	47,300 / 15,746	210,000 / 44,985	131,200 / 3,666	543,500 / 11,019
@ $40/hr				
TOTAL COST $	677,140	2,010,200	277,840	984,260
UNIT COST $	6,771	4,020	2,778	1,969

COST RATIO: $(\text{CONVENTIONAL/SPF})_{100\ A/C} = 2.4$

COST RATIO: $(\text{CONVENTIONAL/SPF})_{500\ A/C} = 2.0$

FABRICATION COSTS FOR "PRODUCTION" RUN SPF DOORS ARE LESS THAN HALF OF CONVENTIONAL DOOR COSTS

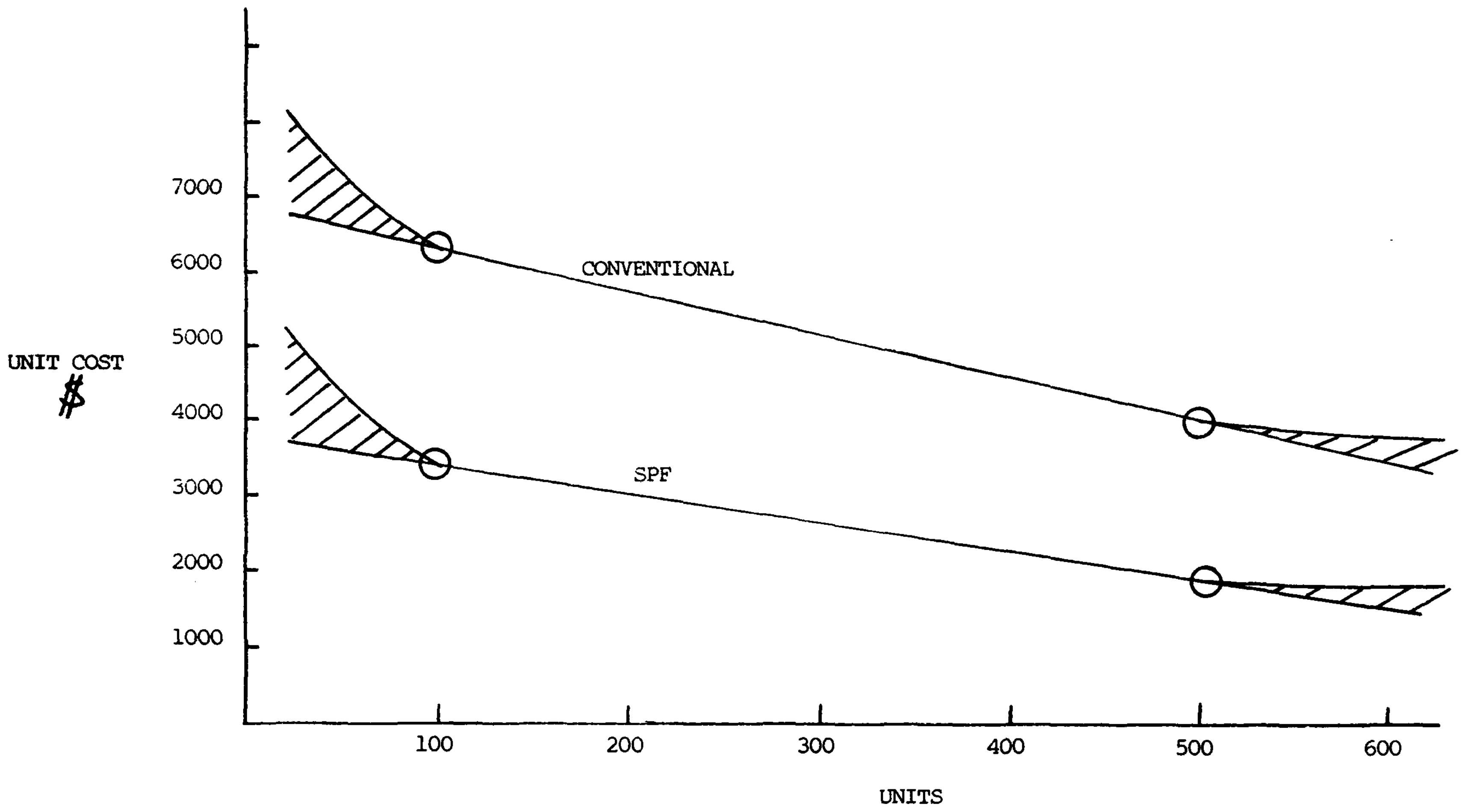


FIGURE 8 - EFFECT OF FLEET SIZE ON DOOR FABRICATION COSTS

2.7 WEIGHT COMPARISON

The weight of the completed doors was provided by AFWAL/FIBTB-WPAFB as follows:

SPF Door - 13.75 lbs.
Production Door - 12.75 lbs.

The SPF door configuration fabricated and tested in this program did not represent a mature production article. In addition, the SPF door as tested was stiffer with respect to deflections measured at critical locations. From a comparable stiffness point of view along with elimination of manufacturing discrepancies, it is projected that a mature production unit SPF door would be on the order of 10% lighter than the conventional door. The decrease in weight of a production SPF door with respect to the door fabricated for this program is attributed to reduction in fasteners, adhesives, pan thickness, and a simplification of the hinge detail into a machined forging concept.

2.8 STATIC TEST PLAN

The static test plan was prepared as a separate Test Information Sheet document. This document is provided as Appendix C .

2.9 STATIC TEST RESULTS

This test program was conducted in accordance with the FRC Test Information Sheet (Test Plan), entitled "Superplastic Forming (Task C)", document number GT002T5807, dated 24 April 1987 (Appendix C). Both A-10 Nose Landing Gear Doors (i.e., the production door and the SPF door) were tested at AFWAL/FIBTB, Wright-Patterson AFB, Ohio. The results presented herein are the results of these tests.

The production door was the first door to be tested under this program. The test was conducted on 2 October 1987 and the SPF door was tested on 19 January 1988.

A summary of the test results, comparing the production door to the SPF door, shows that:

- Both doors exceeded twice ultimate load before failure occurred. The production door failed at 340.9% of limit load (L.L.) and the SPF door failed at 329.3% L.L. In both cases it was the aft hinge and/or its attaching hardware that failed.
- Both doors failed in the area of the aft hinge/interface, see Figs. 9 and 10.
- The strains measured on each door are essentially the same.
- The SPF door appears to be somewhat stiffer than the production door based on the measured deflections.

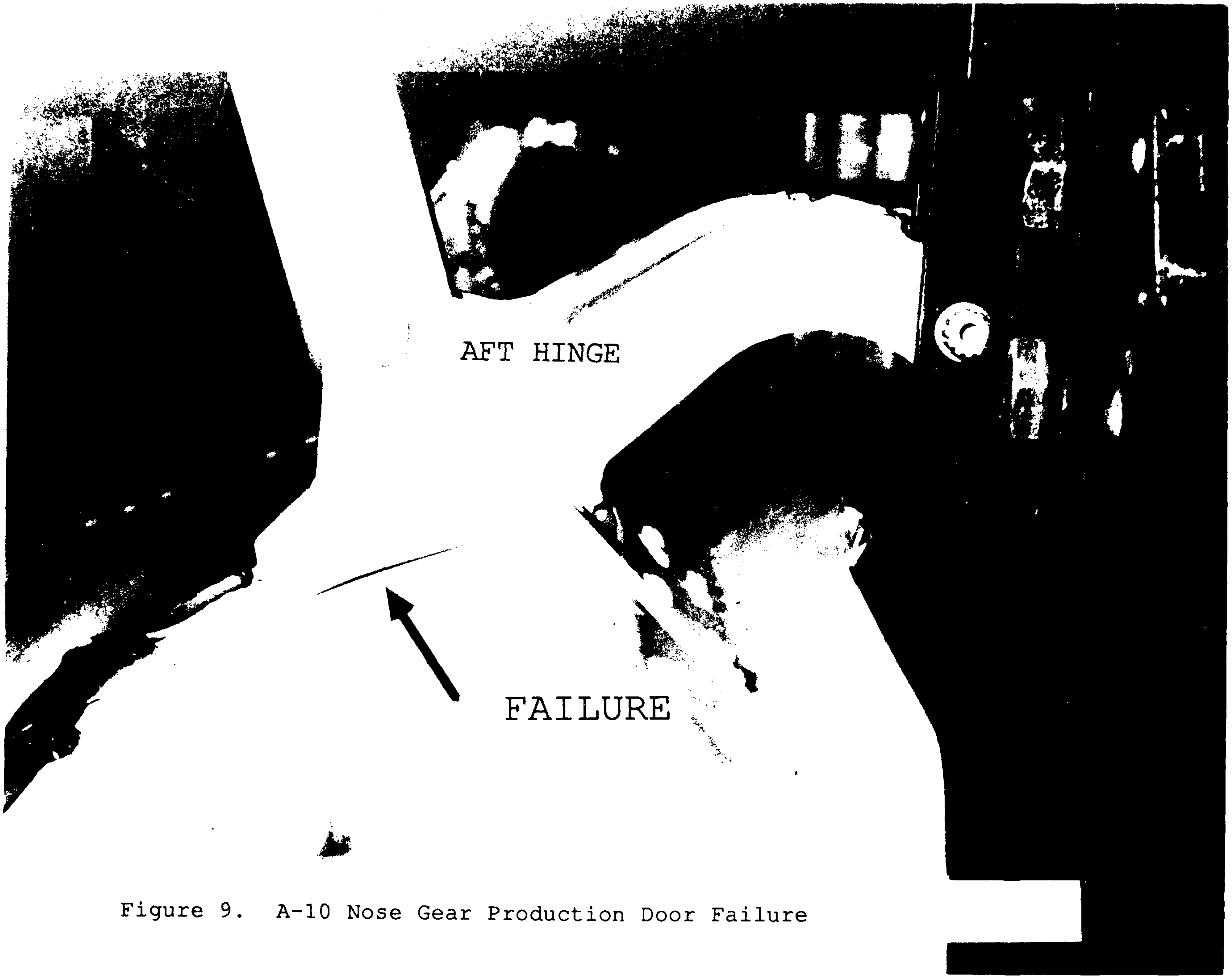


Figure 9. A-10 Nose Gear Production Door Failure

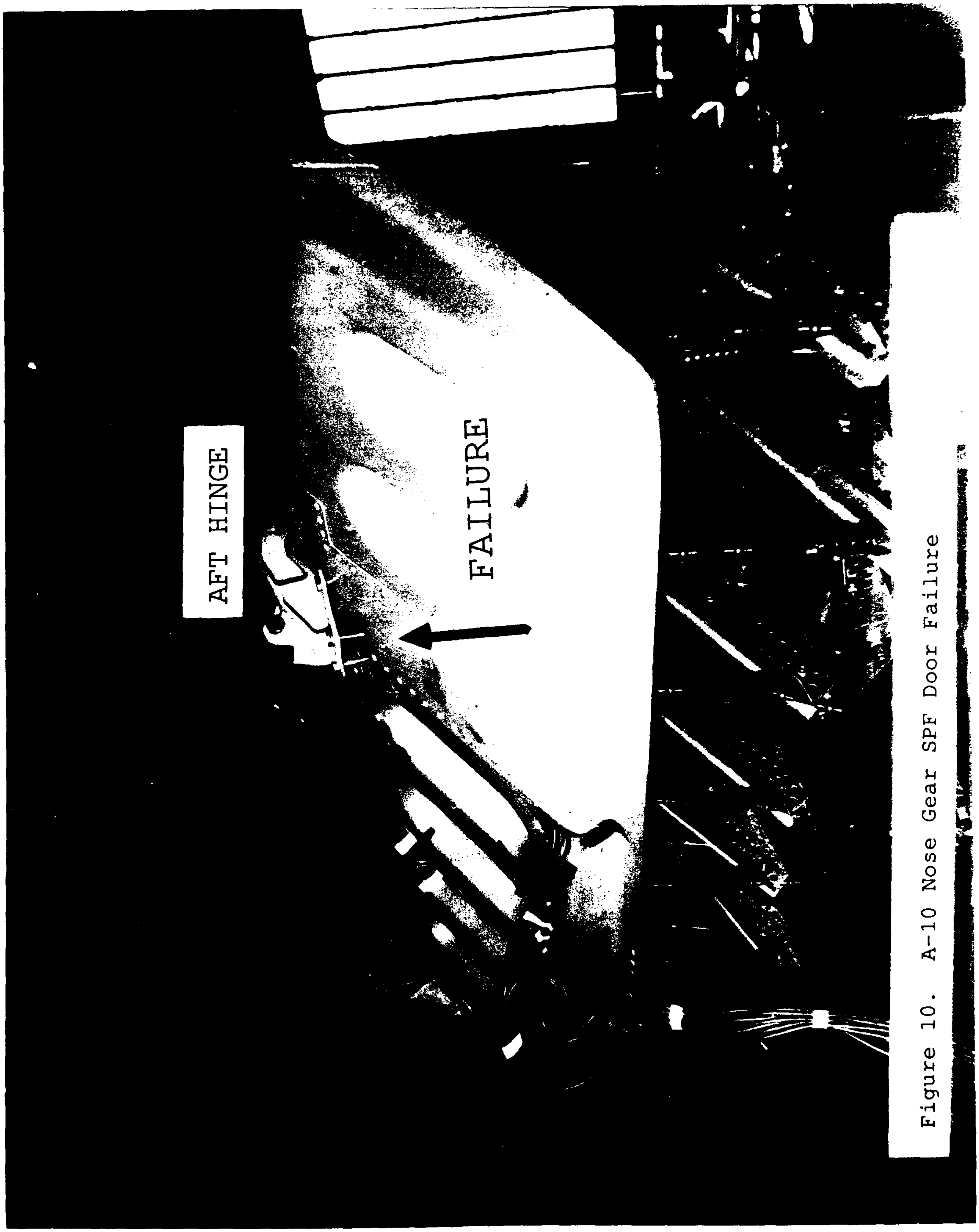


Figure 10. A-10 Nose Gear SPF Door Failure

Each door in turn was mounted to a reusable loading/reaction fixture with the outer skin of the door facing down. With 4" X 4" loading pads bonded to the outer skin of the door, at the locations shown in Fig. 4.1 of the test plan (GT002T5807), the whiffletree was attached to the door's pads. The whiffletree was then attached to a load cell which in turn was attached to a hydraulic loading cylinder. Nine deflection gages were fastened to the door, including one at each hinge location, see Fig. 11. Due to interference, strain gages 3, 5 and 6 on the production door were all relocated (within approximately one inch, in each case, of the original location), see Fig. 12. On the SPF door, strain gages 1, 4, 5 and 6 were relocated approximately one inch forward of the -15 strap shown on drawing 160K136160 (Figure 13).

For the production door, an incremental load was applied up to 100% L.L. The load was then decreased incrementally to zero. The load was then reapplied in increments up to failure, 340.9% L.L. (4390.8 pounds). The mode of failure, as shown in Fig. 9, was buckling of the flange on the aft hinge. As a secondary failure, the aft/inboard attachment bolt cocked forward. The load was then reduced to zero pounds and the test was terminated.

Similarly, the SPF door was incrementally loaded up to approximately 83% L.L. The load was then incrementally decreased to zero. The load was reapplied in increments up to failure, 329.3% L.L. (4241.4 pounds). the failure mode, as shown in Fig. 10, was shearing of the threads of the two inboard bolts on the aft hinge. The load was then reduced to zero pounds and the test was terminated.

Figures 14 through 19 are the actual strain readings (gage numbers 1 through 6) for both doors as submitted by AFWAL/FIBTB, W-PAFB. As shown, the same strain gage number from each door is plotted on the same graph for easy reference. It should be noted however, that strain gage number 5 on the production door is 6.4 inches outboard of B.L. 6.94 as shown on Fig. 12, whereas on the SPF door strain gage 5 is only 2.0 inches outboard of B.L. 6.94. All other gages are within approximately one inch of the same strain gage number on the other door.

The actual deflection readings (numbers 1 through 9) for both doors, as submitted by AFWAL/FIBTB, W-PAFB, are shown in Figs. 20 through 28. As shown, the same deflection gage number from each door is plotted on the same graph for easy reference.

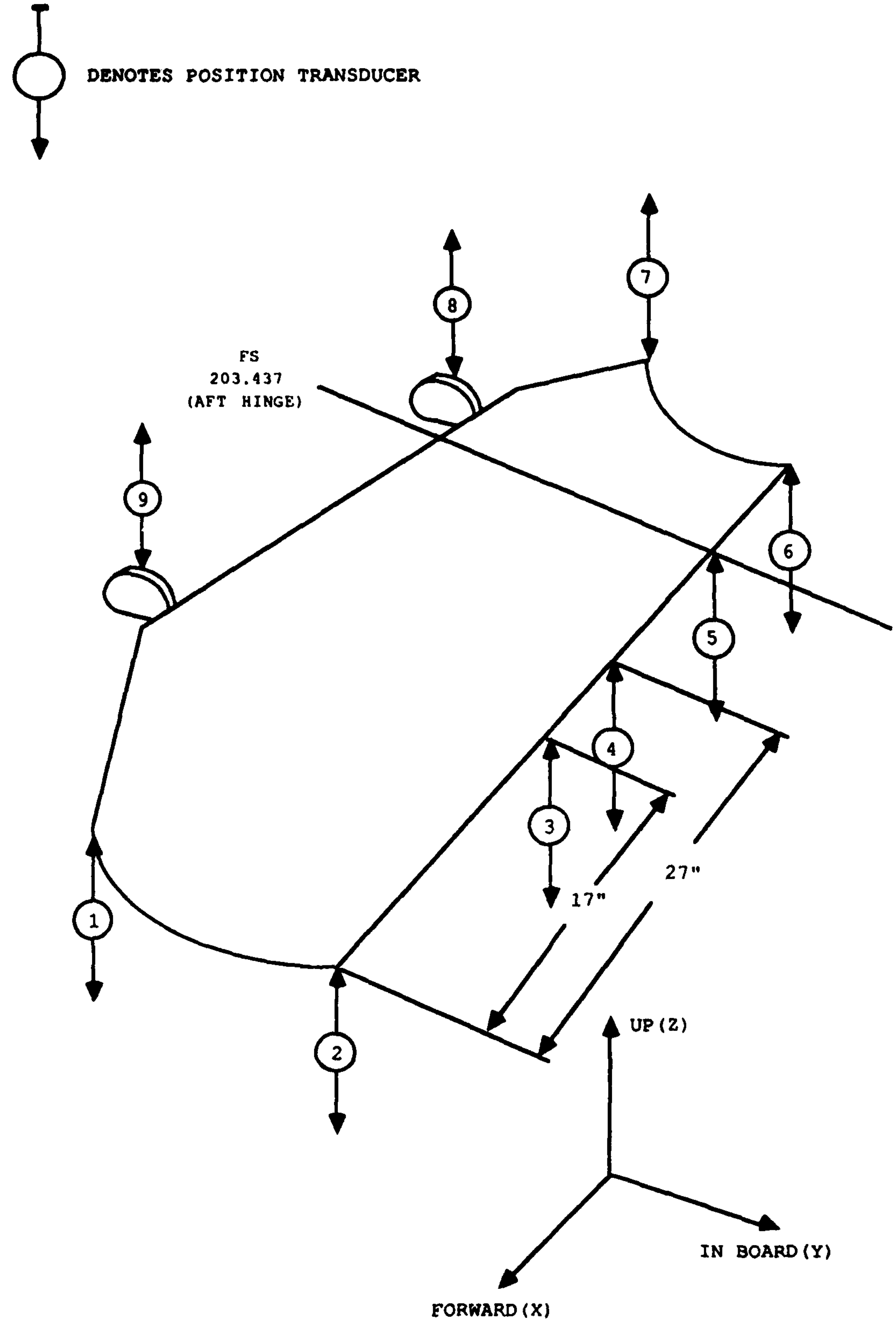


Figure 11. Deflection Gage Locations

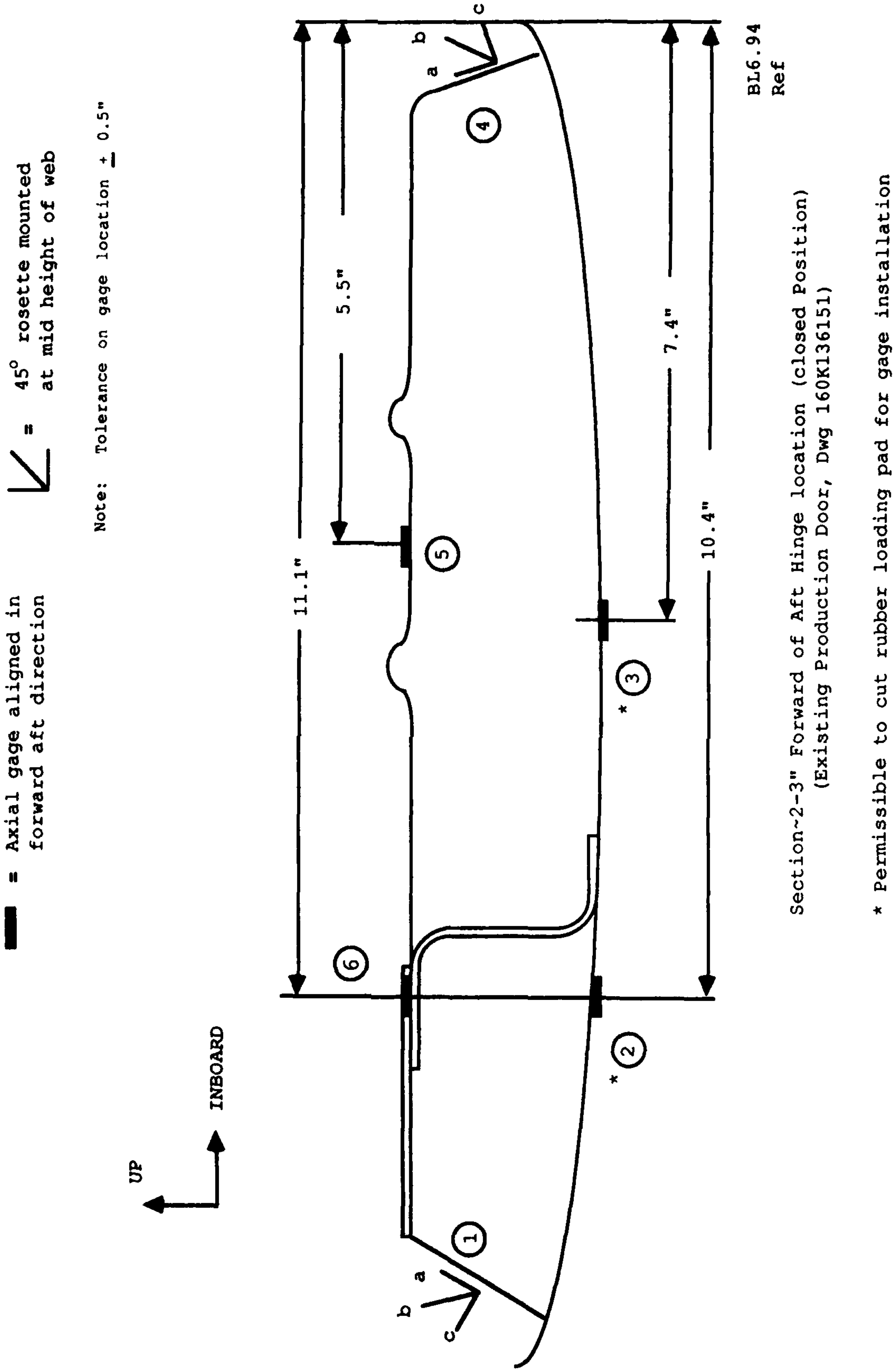


Figure 12. Strain Gage Locations on Existing Production Door

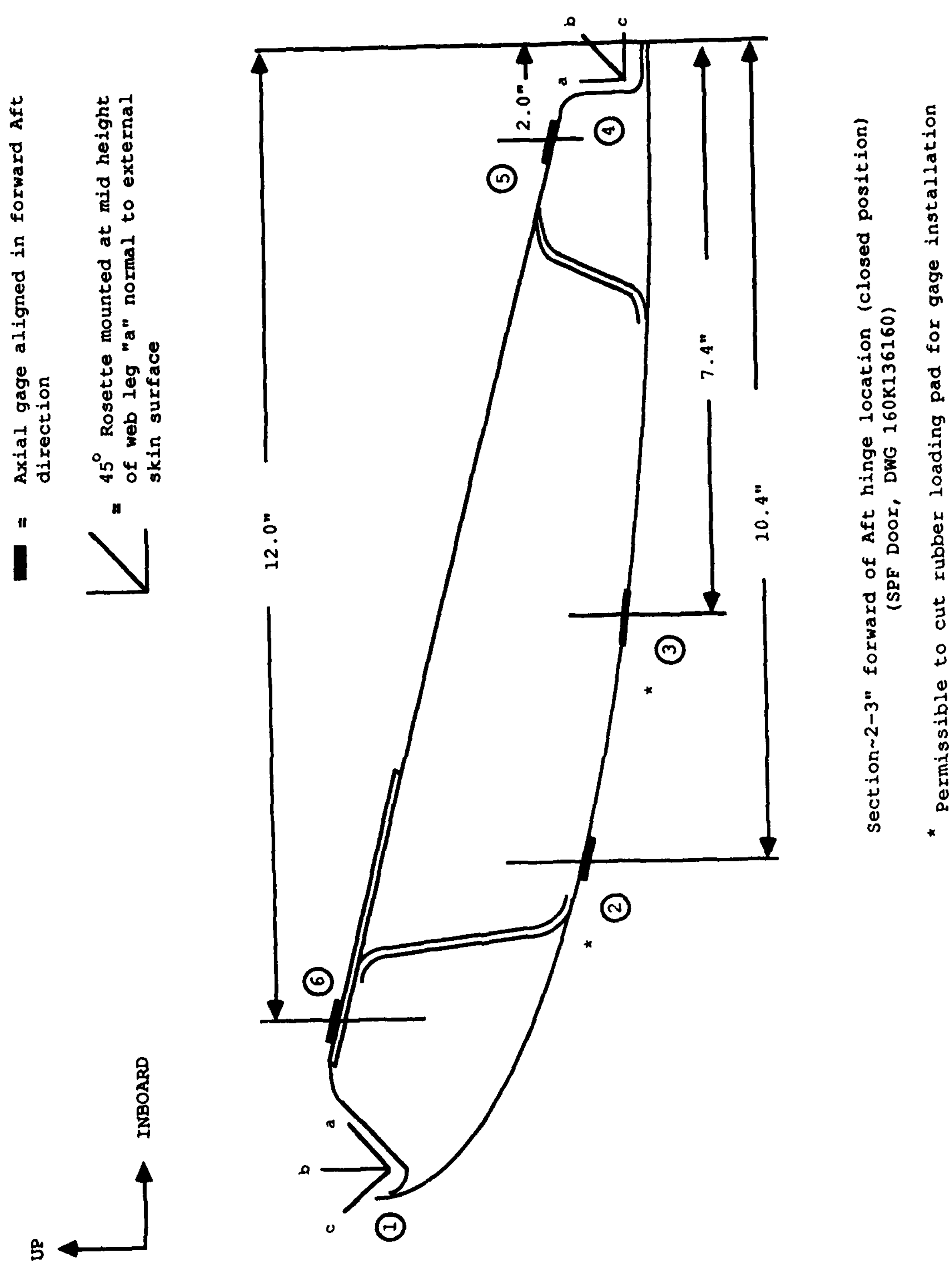


Figure 13. Strain Gage Locations on New SPF Door

320.00

A10NLG DOOR

FIGURE 27 DEFLECTION GAGE NO.8.

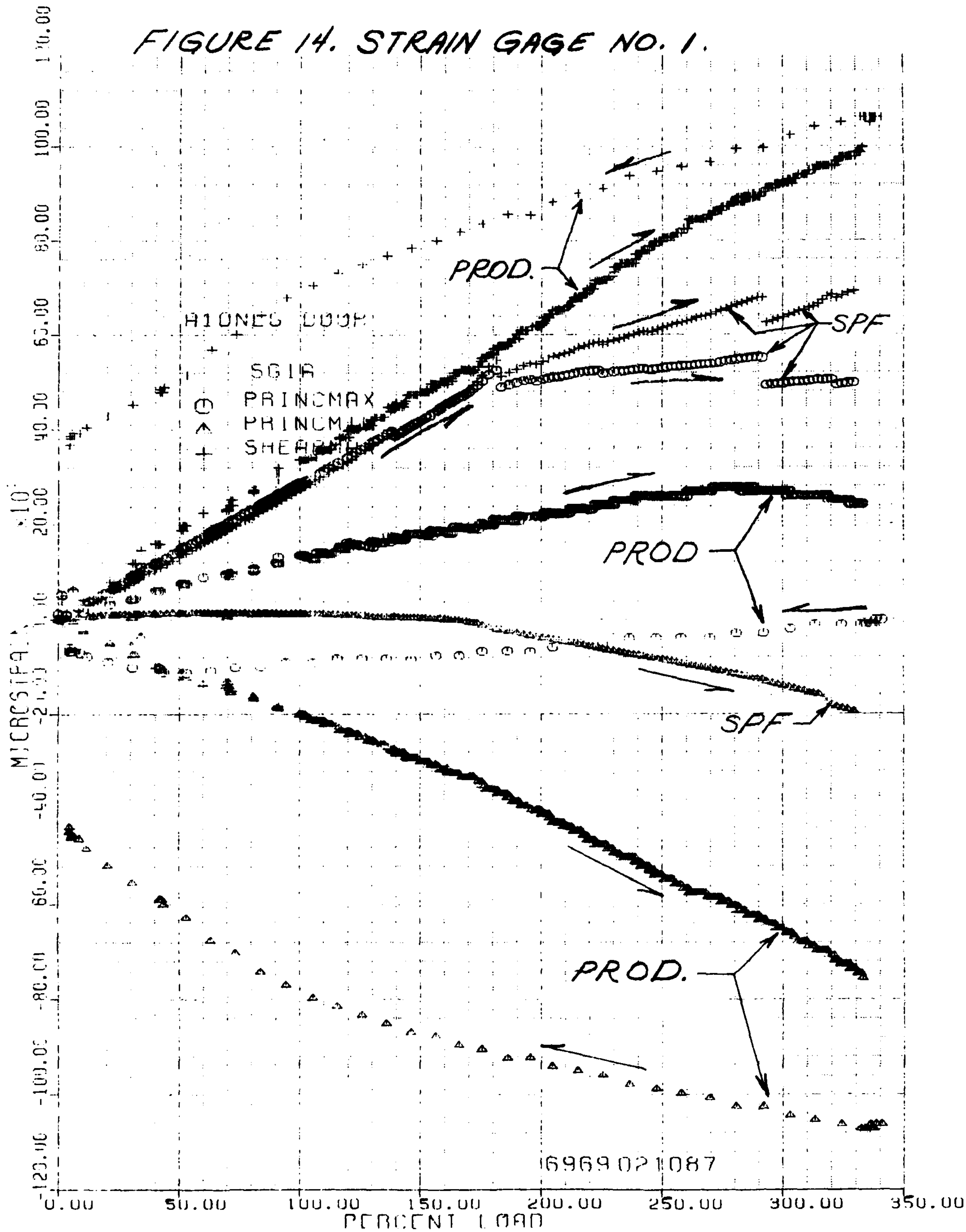


FIGURE 14. STRAIN GAGE NO. 1.
A10NES DOOR
SG1A
PRINCMAX
PRINCMIN
SHEARMAX
PROD.
SPF
PROD
PROD.
SPF
MICROSTRAIN
PERCENT LOAD
6969021087

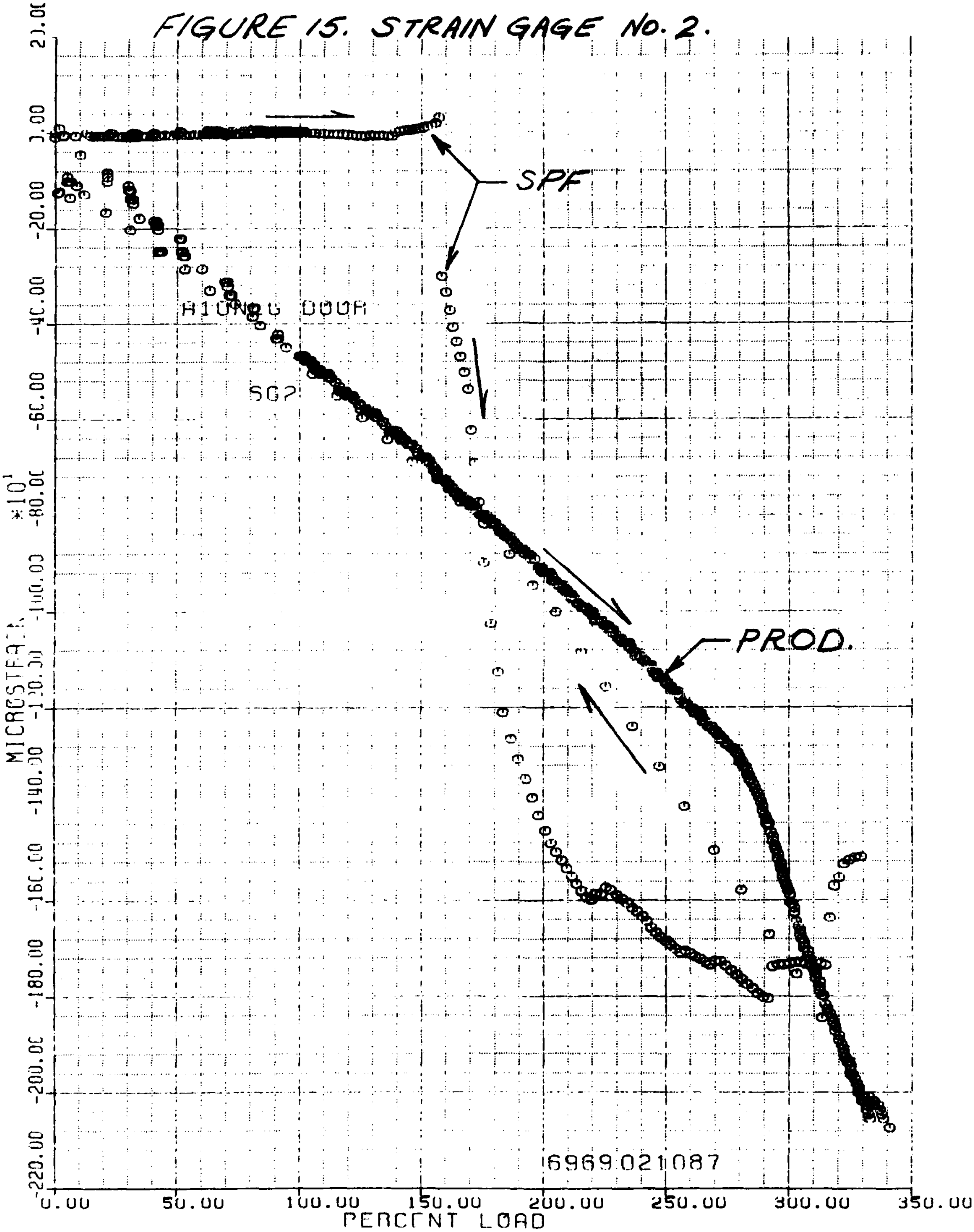
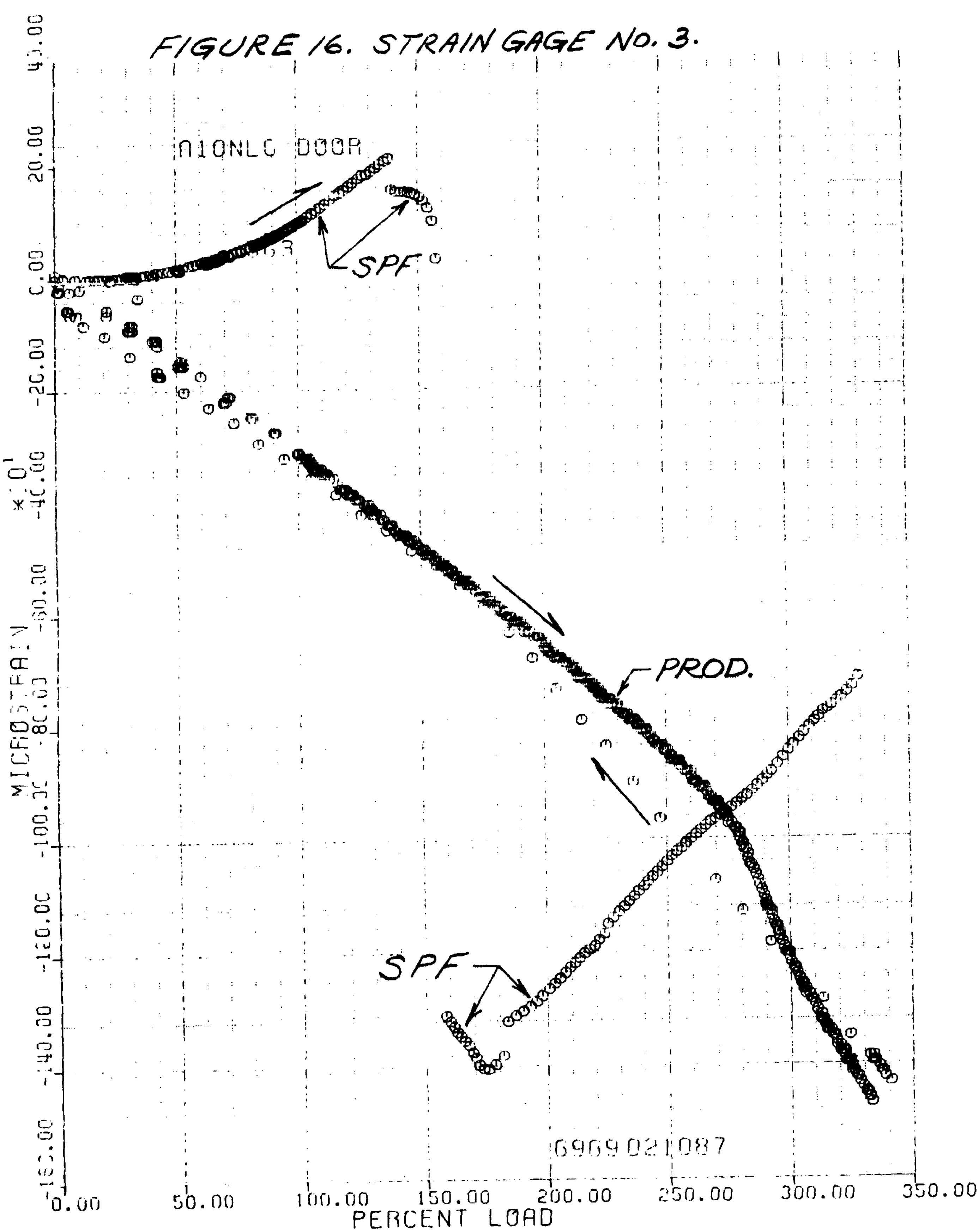


FIGURE 15. STRAIN GAGE No. 2.
SPF
HIDING DOOR
SG2
PROD.
6969021087
MICROSTRAIN *10¹
PERCENT LOAD

FIGURE 16. STRAIN GAGE No. 3.



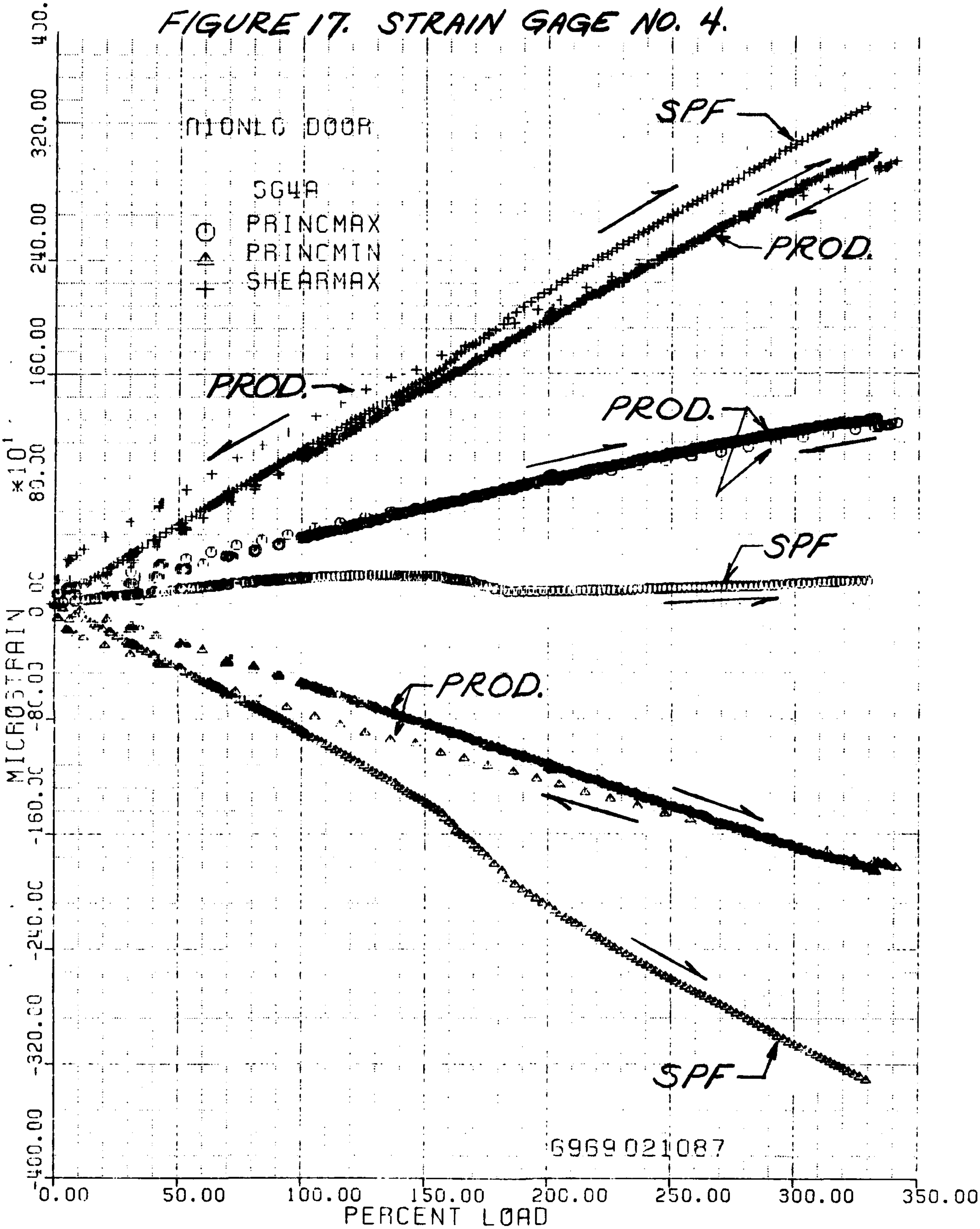


FIGURE 17. STRAIN GAGE NO. 4.
M10NLG DOOR
SG4A
PRINCMAX
PRINCMIN
SHEARMAX
SPF
PROD.
PROD.
PROD.
SPF
PROD.
SPF
G969 021087
MICROSTRAIN *10[1]
PERCENT LOAD

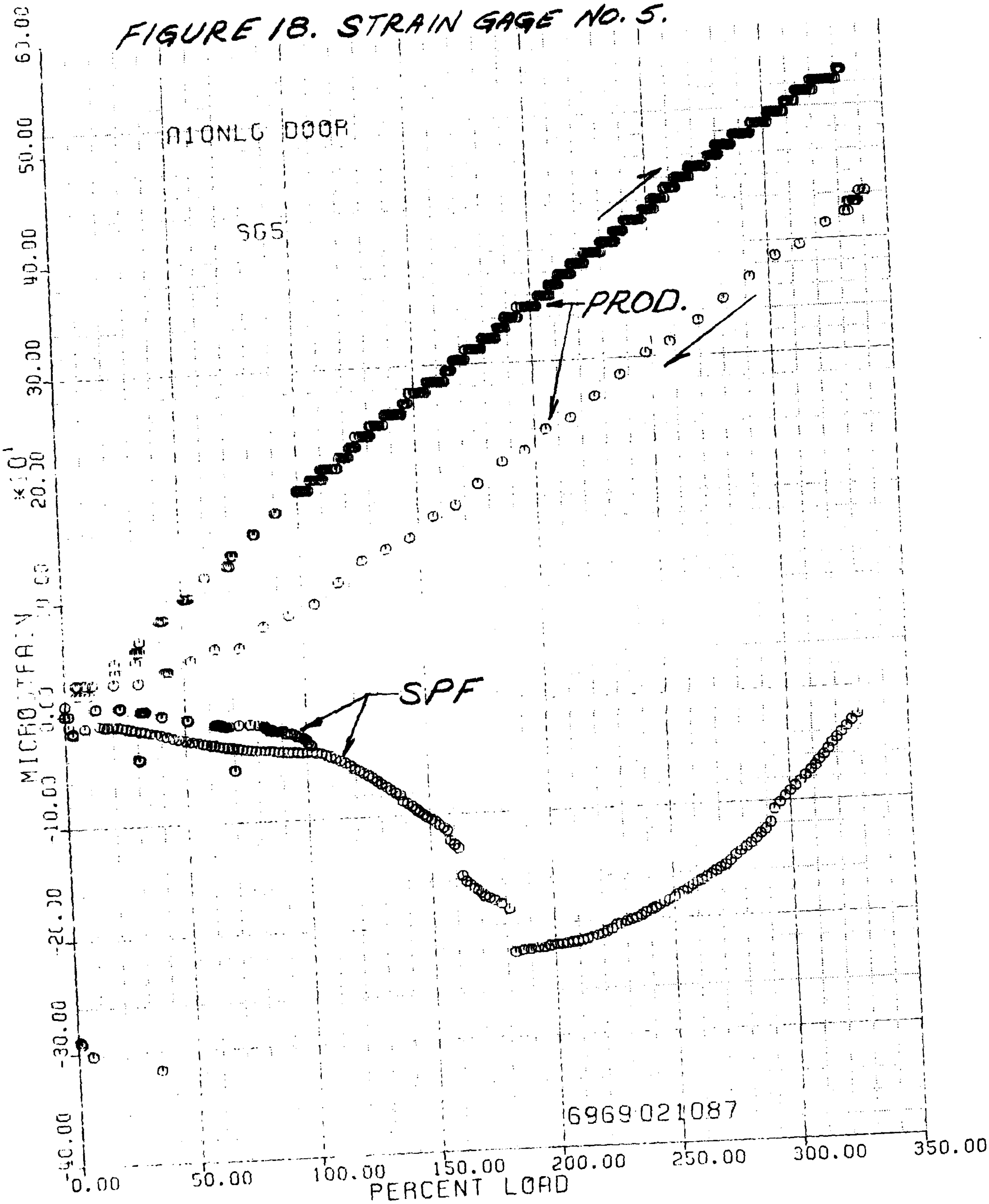
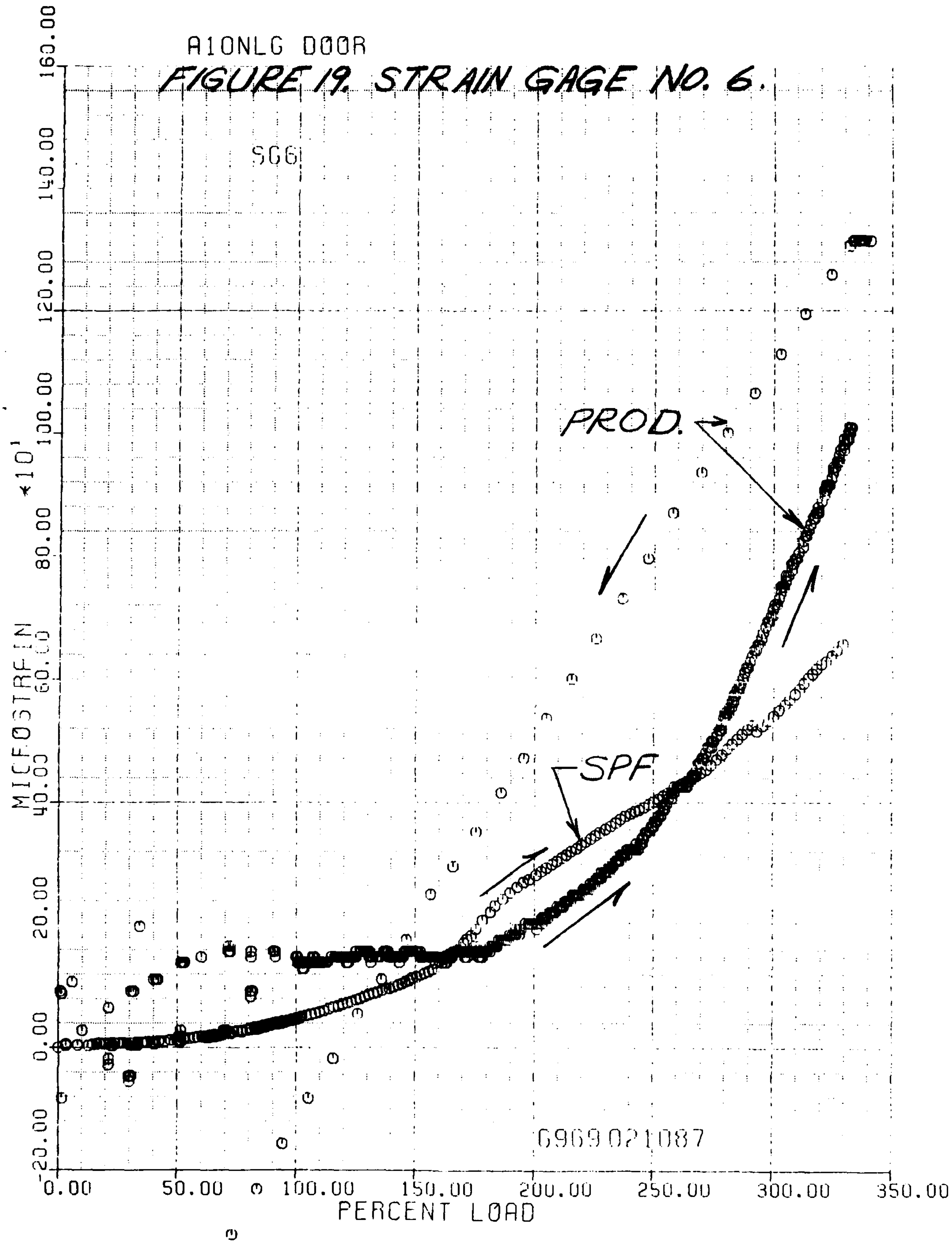


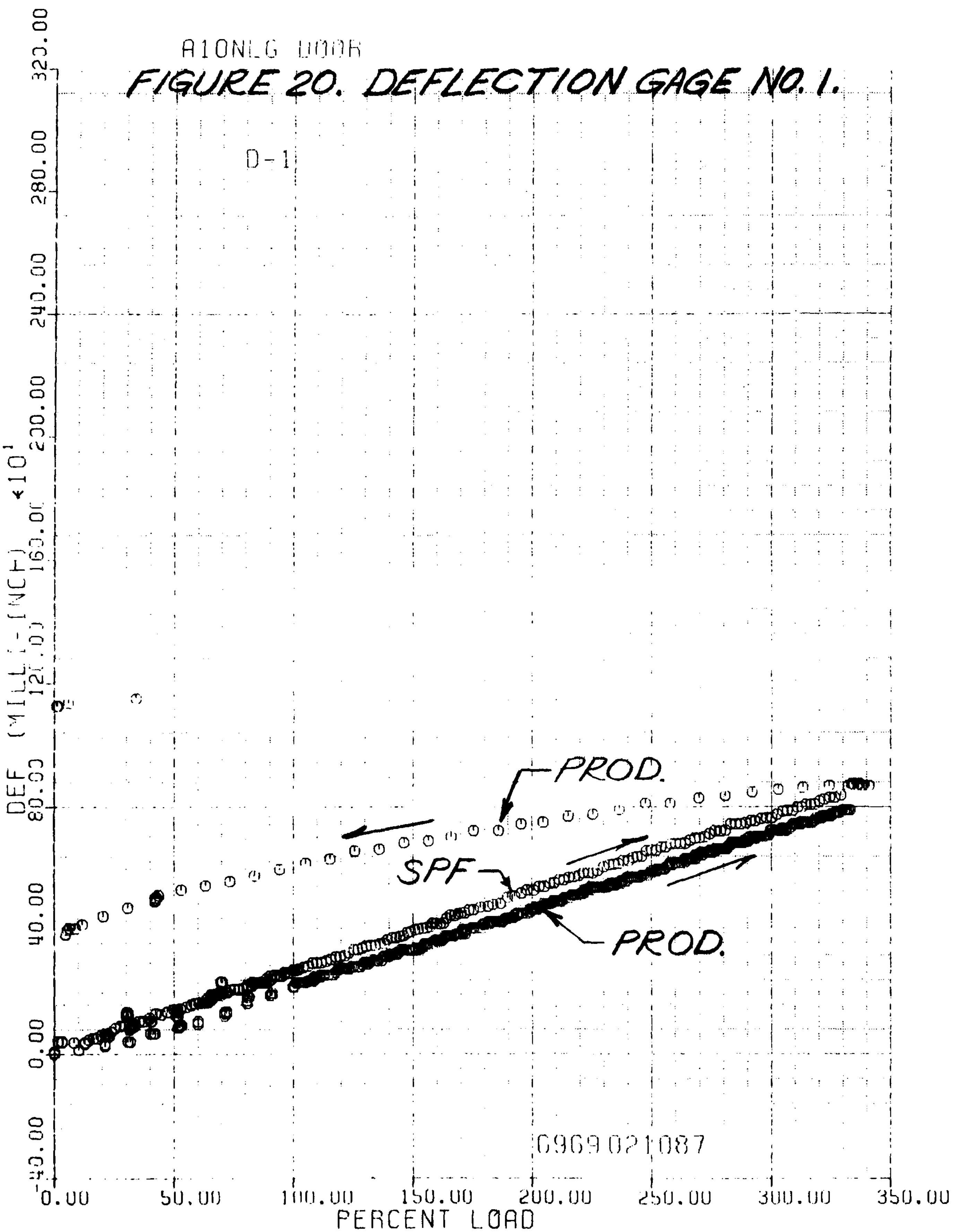
FIGURE 18. STRAIN GAGE NO. 5.
A10NLG DOOR
SG5
PROD.
SPF
MICROSTRAIN
*10¹
PERCENT LOAD
6969021087
0.00
50.00
100.00
150.00
200.00
250.00
300.00
350.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
-10.00
-20.00
-30.00
-40.00



A10NLG DOOR
FIGURE 19. STRAIN GAGE NO. 6.
SG6
PROD.
SPF
MICROSTRAIN *10¹
PERCENT LOAD
6969021087
0.00
50.00
100.00
150.00
200.00
250.00
300.00
350.00
-20.00
20.00
40.00
60.00
80.00
100.00
120.00
140.00
160.00

A10NLG DOOR

FIGURE 20. DEFLECTION GAGE NO. 1.



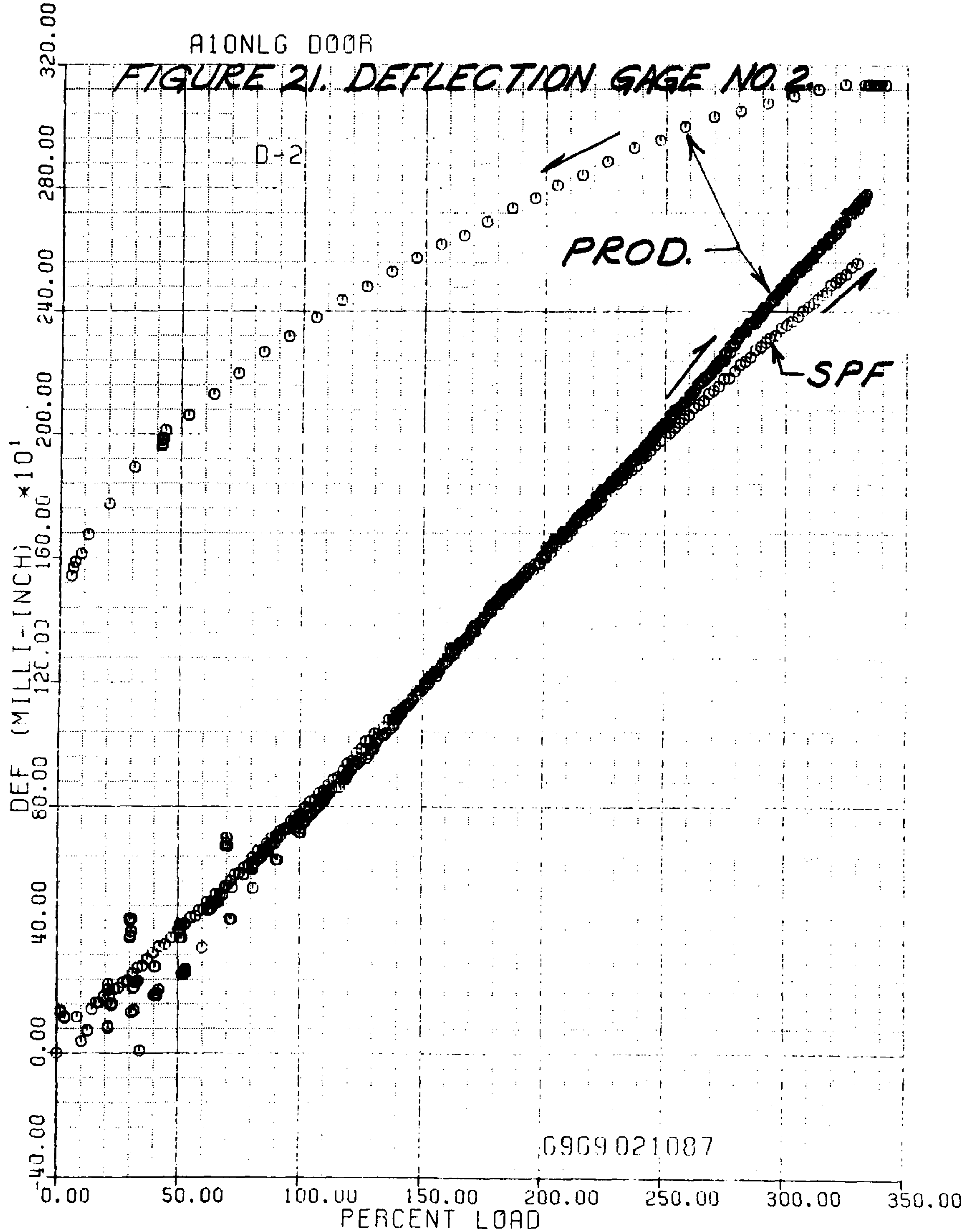
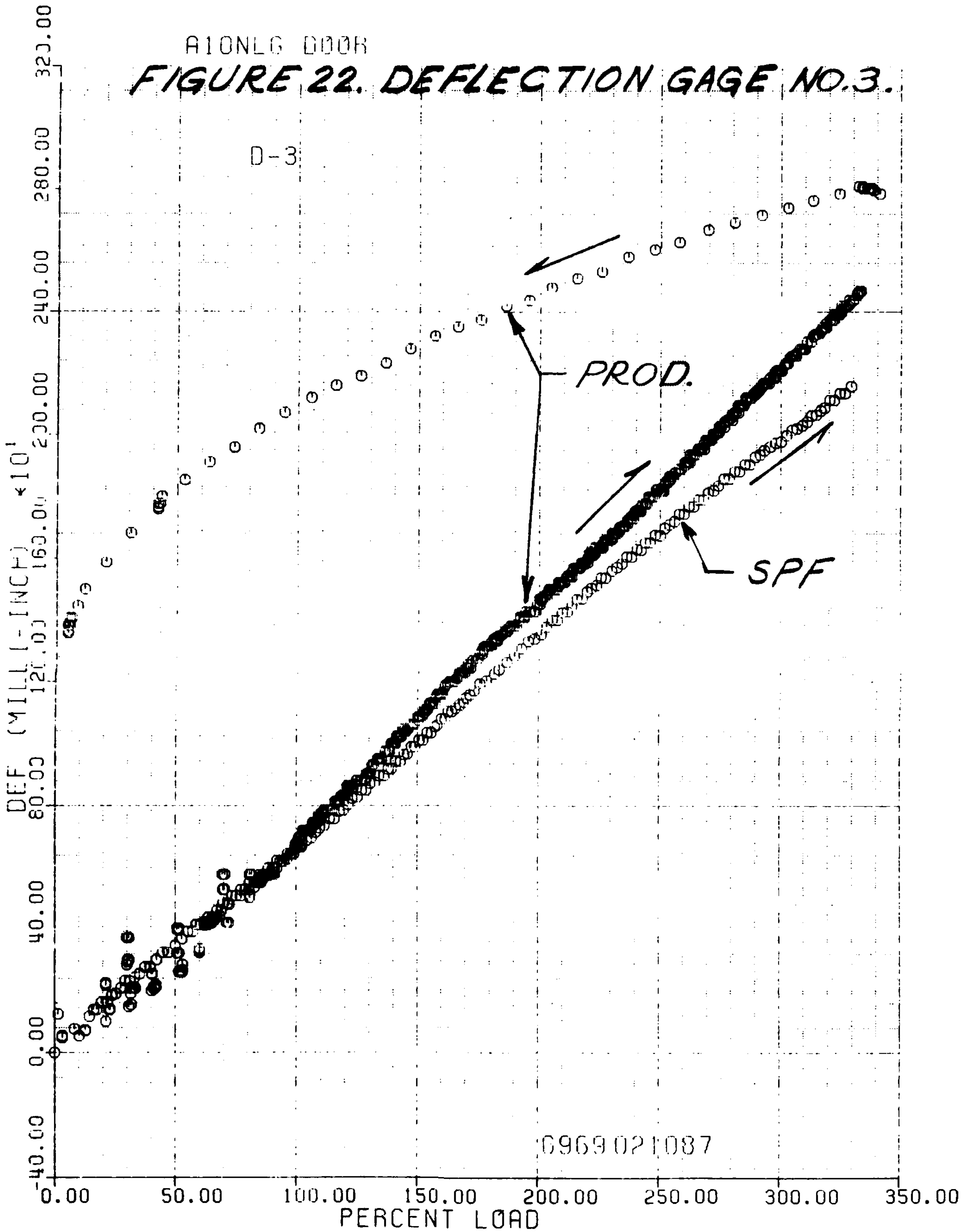
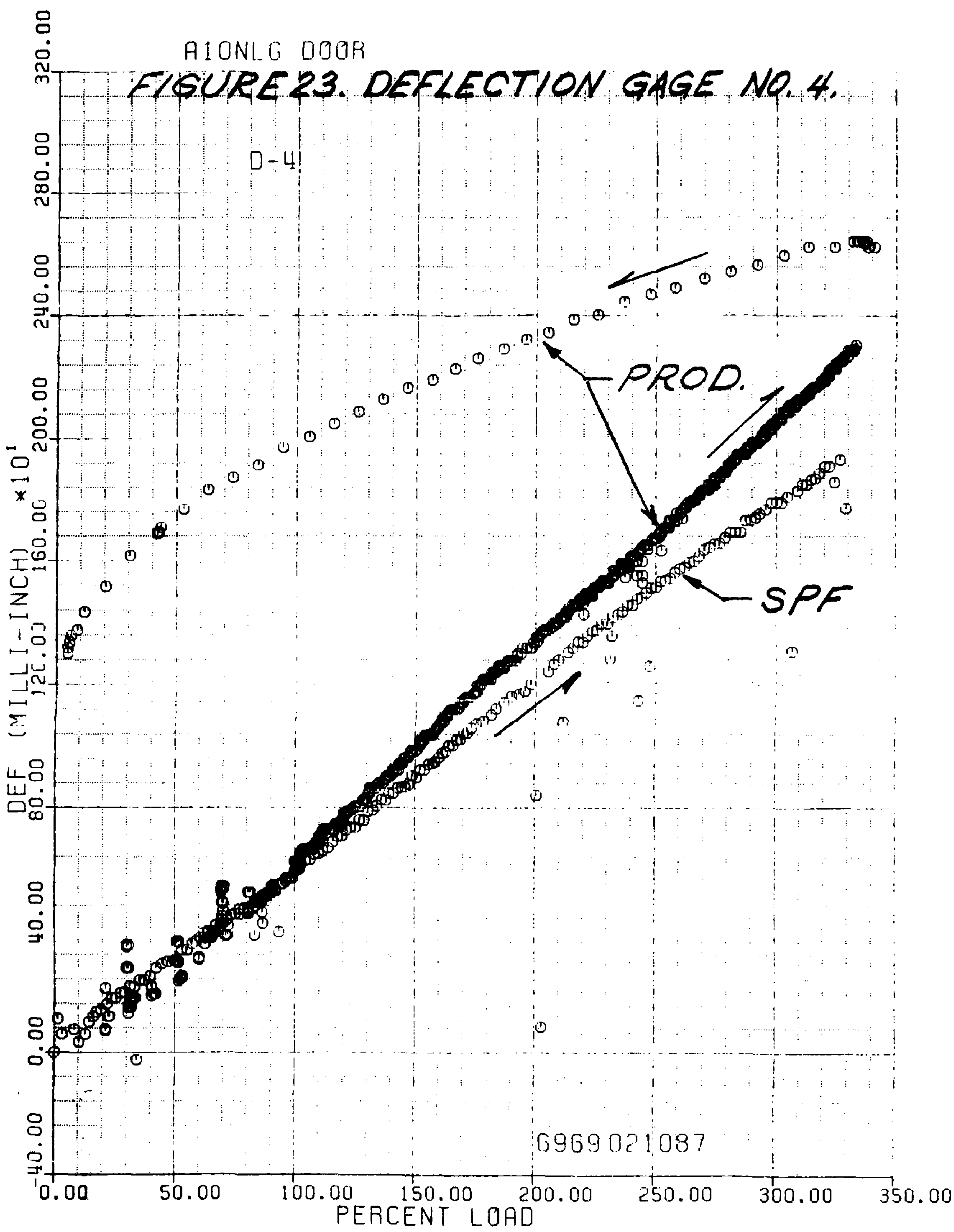
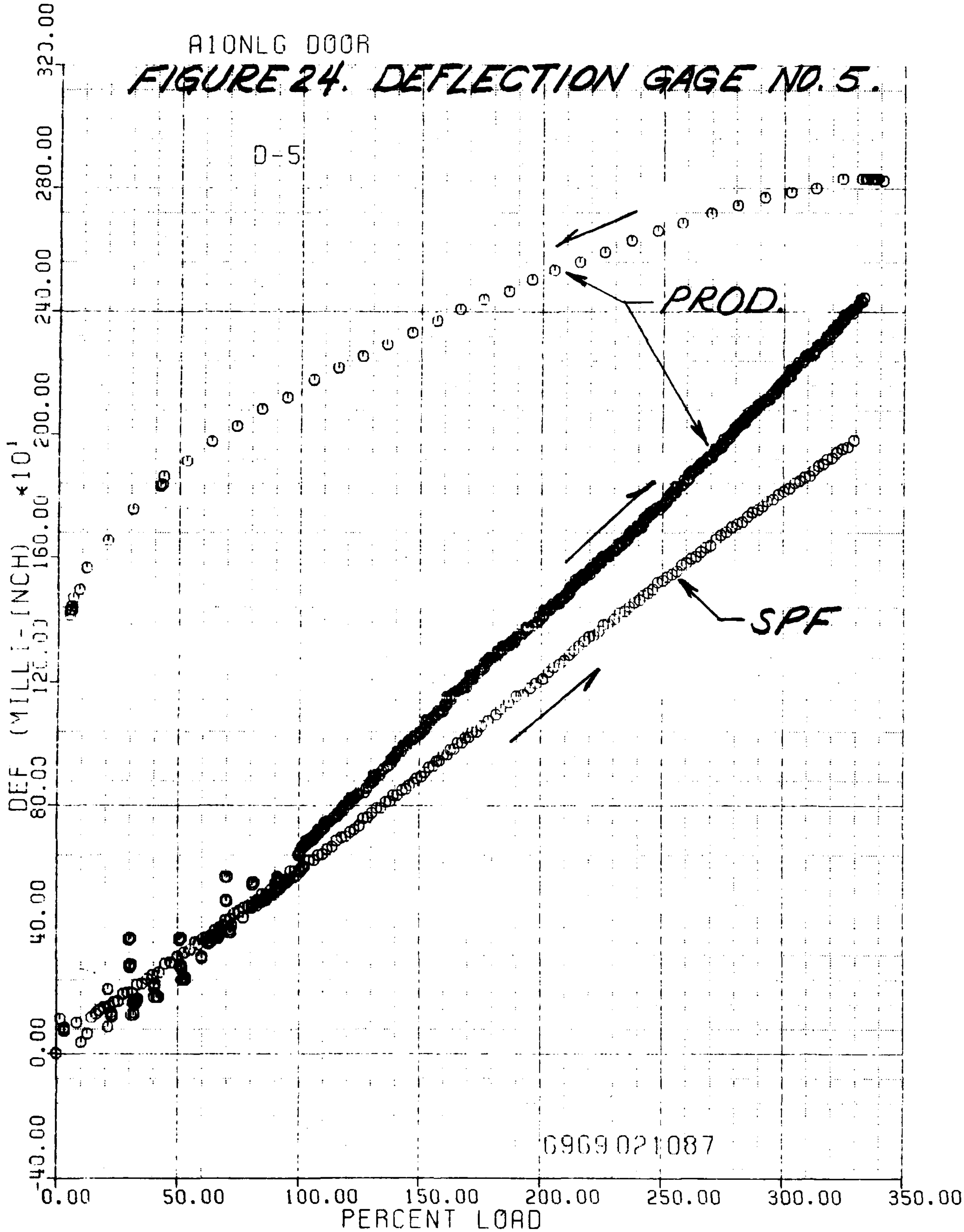


FIGURE 21. DEFLECTION GAGE NO. 2.


AIONLG DOOR
FIGURE 22. DEFLECTION GAGE NO.3.
D-3
PROD.
SPF
DEF (MILLI-INCH) *10^1
320.00
280.00
240.00
200.00
160.00
120.00
80.00
40.00
0.00
-40.00
0.00
50.00
100.00
150.00
200.00
250.00
300.00
350.00
PERCENT LOAD
0969021087


A10NLG DOOR
FIGURE 23. DEFLECTION GAGE NO. 4.
D-4
PROD.
SPF
DEF (MILLI-INCH) *10¹
PERCENT LOAD
6969021087
0.00
50.00
100.00
150.00
200.00
250.00
300.00
350.00
-40.00
0.00
40.00
80.00
120.00
160.00
200.00
240.00
280.00
320.00



A10NLG DOOR
FIGURE 24. DEFLECTION GAGE NO. 5.
D-5
PROD.
SPF
0969 021087
DEF (MILLI-INCH) *10[1]
PERCENT LOAD

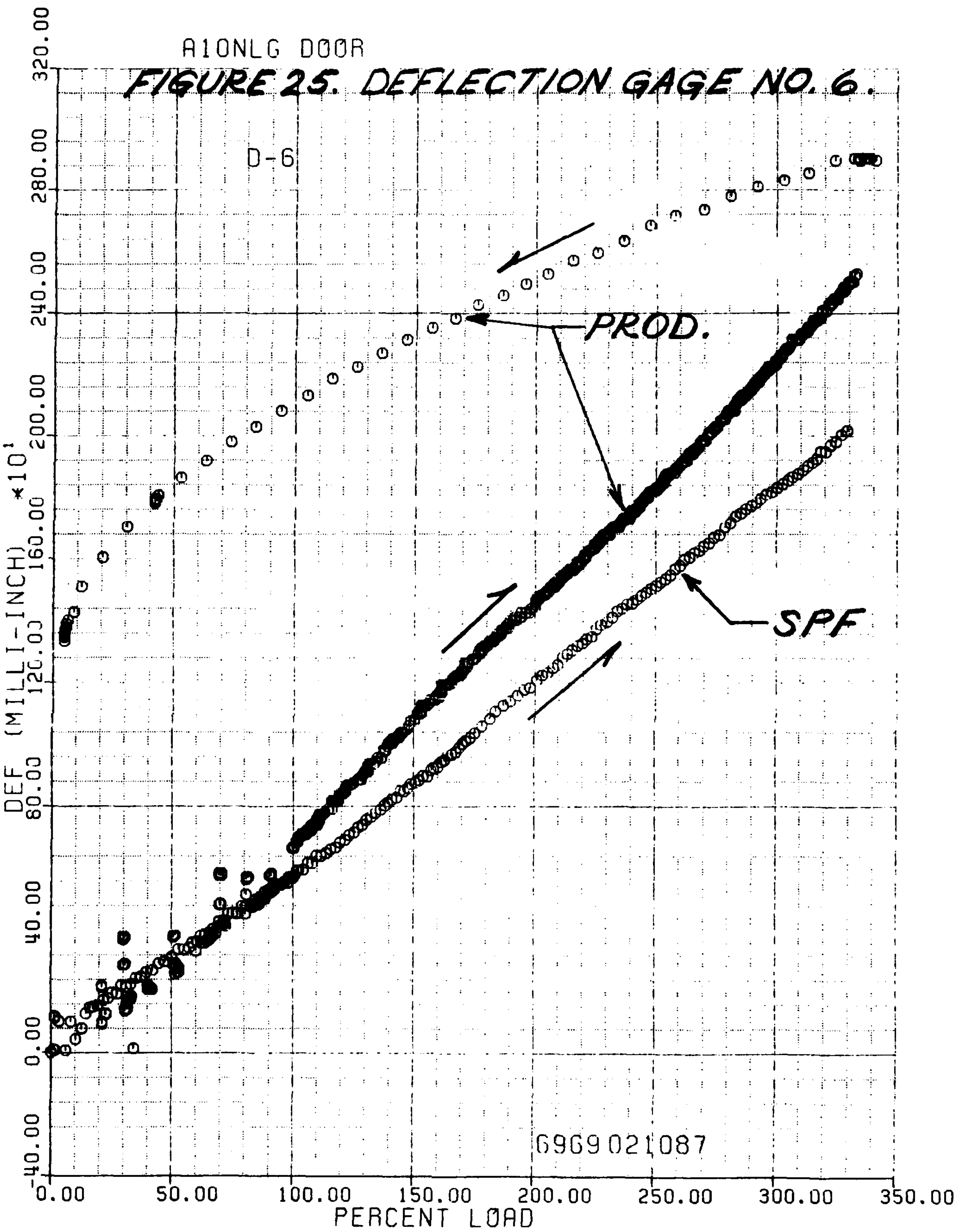
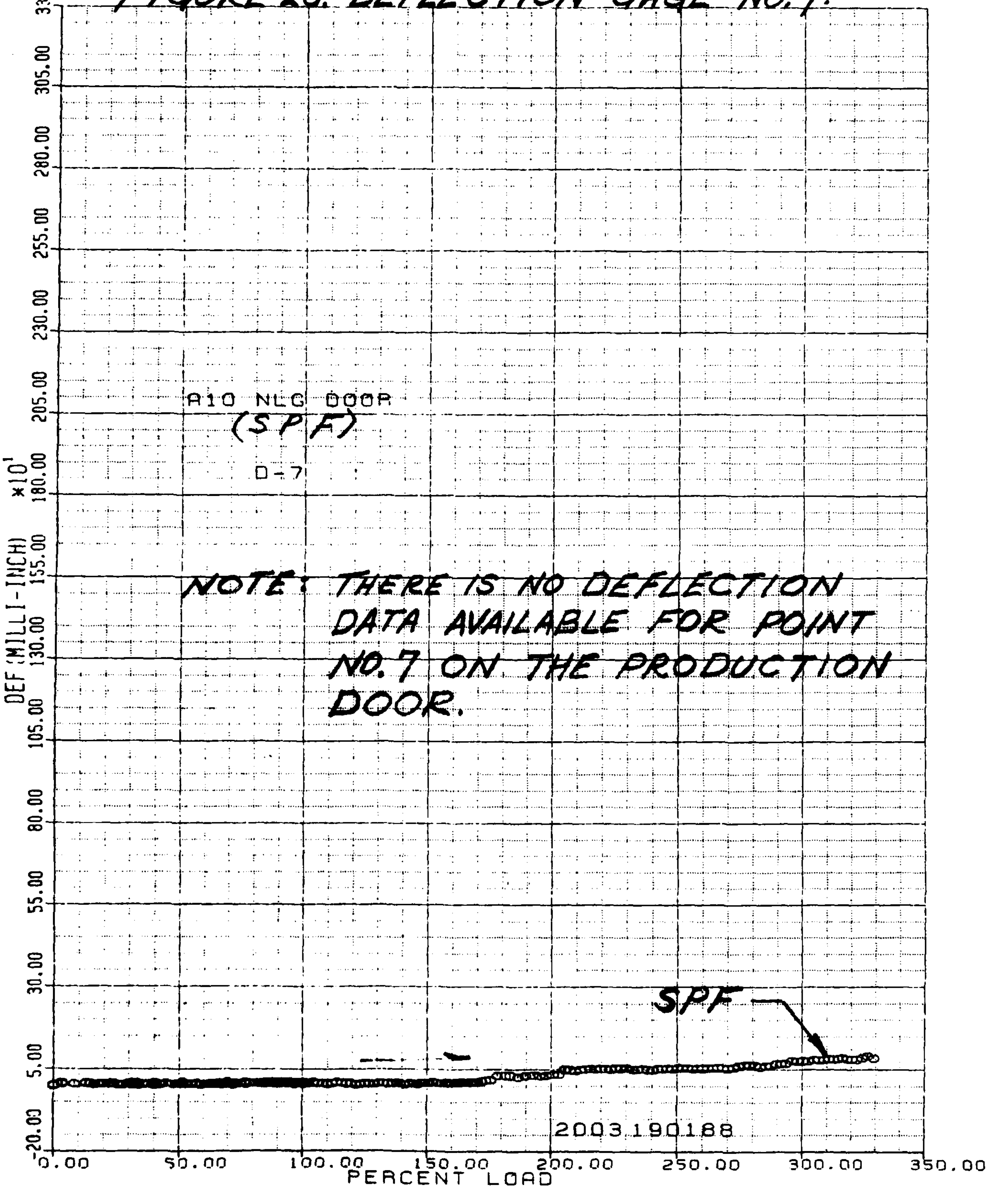
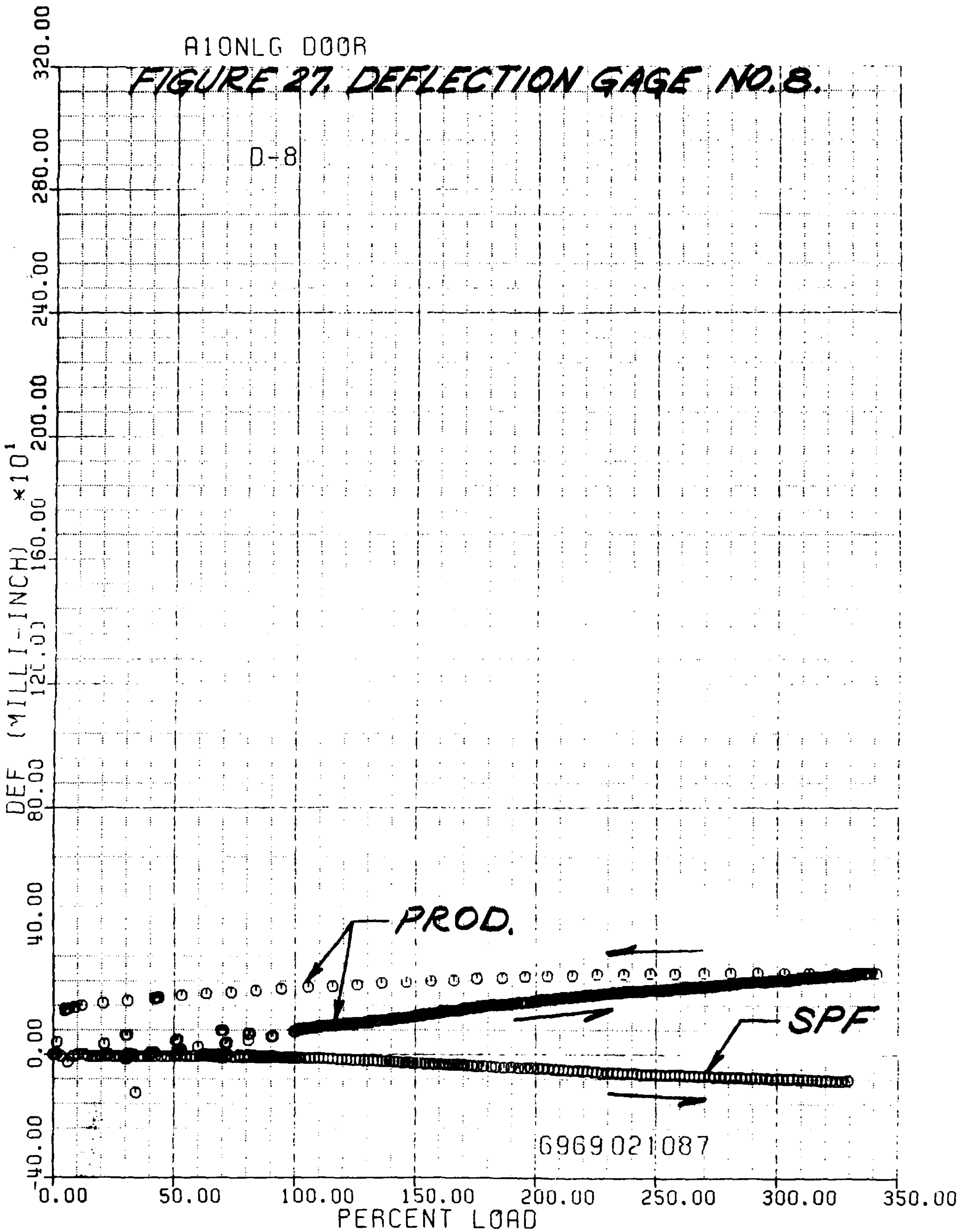
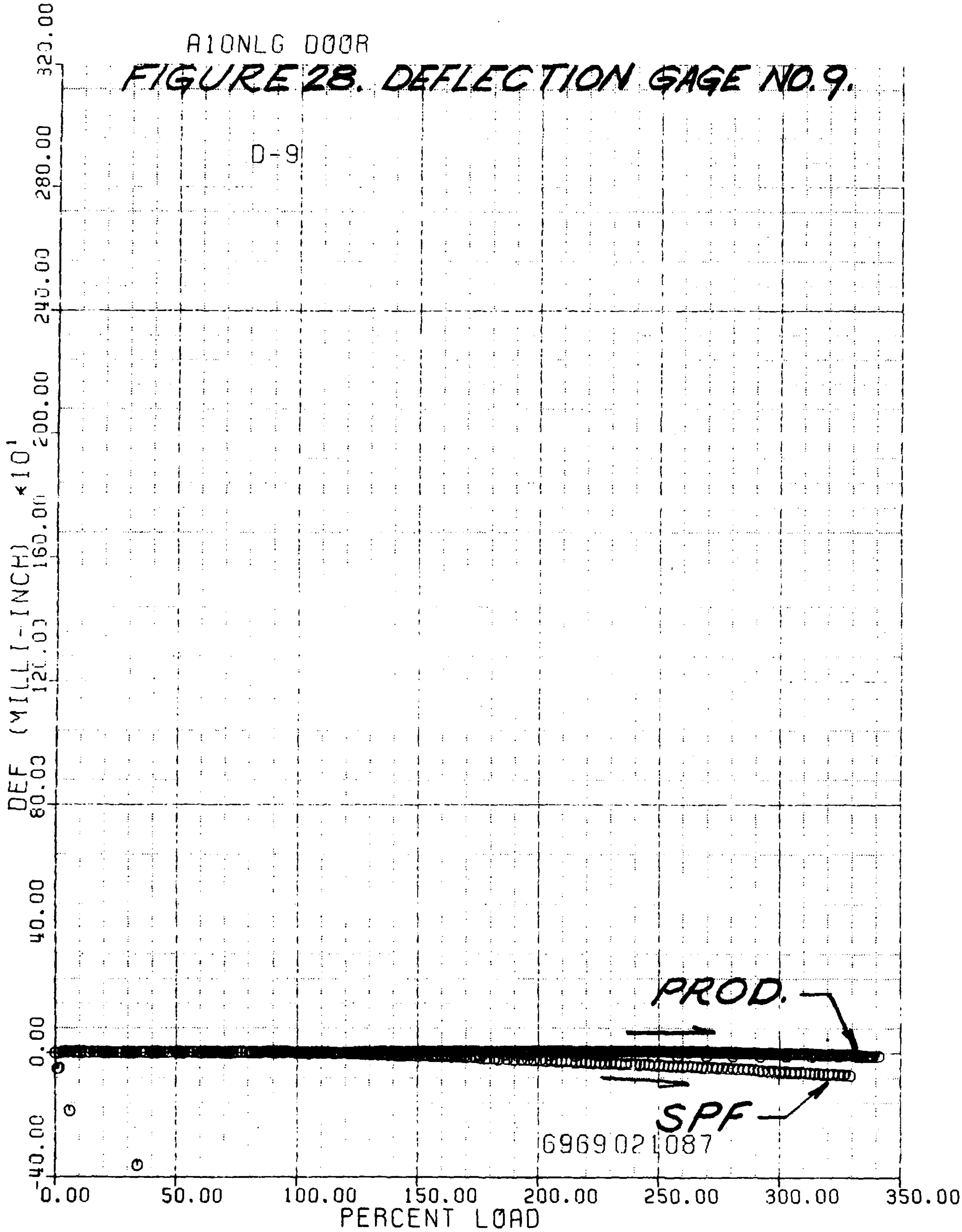

A10NLG DOOR
FIGURE 25. DEFLECTION GAGE NO. 6.
D-6
PROD.
SPF
DEF (MILLI-INCH) *10[1]
PERCENT LOAD
6969021087
-40.00
0.00
40.00
80.00
120.00
160.00
200.00
240.00
280.00
320.00
0.00
50.00
100.00
150.00
200.00
250.00
300.00
350.00

FIGURE 26. DEFLECTION GAGE NO. 7.





A10NLG DOOR
FIGURE 27. DEFLECTION GAGE NO. 8.
D-8
PROD.
SPF
6969021087
DEF (MILLI-INCH) *10¹
PERCENT LOAD


A10NLG DOOR
FIGURE 28. DEFLECTION GAGE NO.9.
D-9
DEF (MILLI-INCH) *10¹
PERCENT LOAD
PROD.
SPF
6969 021087
-40.00
0.00
40.00
80.00
120.00
160.00
200.00
240.00
280.00
320.00
0.00
50.00
100.00
150.00
200.00
250.00
300.00
350.00

SECTION III

CONCLUSIONS

As a result of this program, the following conclusions are drawn:

1. An SPF based door was designed and constructed that was the equivalent of the conventional door in strength and weight.

2. An economic analysis demonstrated that the SPF based door is less than half the cost of a conventional door for production quantities more than 100 units.

3. Serious contour deviations were found on all the SPF pans produced. Such errors could seriously affect the viability of this method of manufacturing. These deviations develop during quenching and they are difficult to eliminate, after the fact, because of the inherent stiffness of three dimensionally shaped pans. The availability of SPF alloys that could be more slowly cooled from the solution treating temperature would alleviate these problems.

4. At this stage of development SPF based designs must be grouped with forgings and castings as long lead items having a developmental phase where iterations of procedures and designs may need to be worked out to obtain a satisfactory product.

RECOMMENDATIONS

1. Expand the current program to include the now maturing Aluminum Lithium superplastically formable alloys. Additional weight savings at little or no increase in fabrication costs for production quantities can be expected.

2. Fabricate one or more new SPF doors to the design tested as part of this program and install them on A-10 aircraft for purposes of flight test evaluation. Long term structural durability, damage tolerance, environmental durability, etc., would be parameters to be evaluated. In addition, repair methodology could be developed and economically compared to those used for conventional as well as composite structures.

SUMMARY

The work conducted in Task C consisted of the fabrication and test of two door components meeting the fit, form, function and structural performance of the A-10A nose landing gear door. One door was fabricated as an exact duplicate of the existing production design (built-up aluminum alloy sheet metal) while the other was an optimized superplastically formed (SPF) design using Supral 220 Alloy (Superform, LTD.) and weldbond assembly methods. In addition, a cost analysis was performed based on economic lot sizes to quantify the expected cost advantage of the SPF door over the existing conventional design.

From a fabrication point of view, it was found that the SPF design will require further refinement in order to better meet contour requirements necessary for assembly and installation fit. These additional trials were not carried out as the door which was produced was sufficiently satisfactory for test and evaluation purposes. Both doors tested approximately the same, exceeding the static strength requirements by a large margin. The SPF door was found to be stiffer, deflecting less at each of the locations measured.

Cost analysis indicates that the SPF door in production quantities of more than 100 units will cost less than half that of the conventional built-up production design door. This conclusion is significant because it indicates that SPF concepts together with weldbond assembly techniques can have wide application to the numerous built-up type structures used in aircraft and aerospace vehicles. From a cost viewpoint, viable comparisons can be made with composite designs which would ordinarily be viewed as the logical replacement concept for built-up structures as well.

Weight comparisons made between the existing A-10 production door (over 700 produced) and the single SPF test unit are premature. It is expected that a mature SPF production door comparable to the existing production door would be approximately 10% lighter. This is based on further design refinements not affecting strength as well as the elimination of initial manufacturing/assembly discrepancies typical of initial production.

APPENDIX A

SUPERFORM SUMMARY REPORT

SUPERFORM USA, INC.

FAIRCHILD REPUBLIC, FARMINGDALE, LONG ISLAND, NEW YORK

PURCHASE ORDER NUMBER: 6-648-441732

SUPERFORM WORK ORDER NUMBER: W086024

Summary report on SPF forming, heat treatment and testing of the modified A10 nose landing gear door made from Supral 220.

1. MANUFACTURE

The female form tool constructed in 1984 under Fairchild purchase order number 9-342779-01 was modified to incorporate integral hinge attachment features to drawing number 160K136160.

The material used to form a batch of ten doors was Supral 220, 2 mm unclad. Its chemical composition was:

PK No. HON220	Si	Fe	Cu	Mn	Mg	Zn	Ge	Zr
	.09	.15	6.05	.046	0.27	0.024	0.16	0.36

The parts were SPF formed at Superform Metals Ltd., Worcester, England on their 8' X 4' press. The forming cycle was the same as reported in "Summary Report" dated September 14, 1984.

The formed unheat treated parts were shipped to Superform USA of Riverside for heat treatment, rough trimming and testing.

Heat treatment was carried out by Aerospace Heat treatment of Paramount, California to the following schedule:

Solution treat by heating uniformly at a temperature of 977 degrees, plus 0 degrees F, minus 10 degrees F, for 60 minutes, plus or minus 10 minutes and quench rapidly in an aqueous solution of Quindella PA (or approved equivalent) not exceeding 30% at a temperature not exceeding 40 degrees C. Artificially age by heating uniformly at a temperature of 355 degrees F for 16 hours, plus or minus 1 hour.

Note: Hand correction was carried out where necessary to remove heat treatment distortion between solution treatment and aging. Heat treatment parameters are summarized in subsection 1 of this appendix (A.1).

The heat treated parts were hand trimmed to approximately 1" oversize to final trim.

2. TESTING

One formed and heat treated part was subjected to a detailed thickness survey. The minimum thickness found was .024" located at the root radius of the pan features 1 through 6 (see subsection 2 of this appendix, A.2). This represents 238% equivalent strain.

Samples were cut from the same door and subjected to mechanical and metallurgical testing at Durkee Testing Laboratories, Inc. of Paramount, California. (See subsection A.3) Sample locations are shown in Figure A3-1. Note: locations T1, T2 and MO are not on the final trimmed part.

Yield, UTS and elongation values were obtained for unstrained material (T1) and five SPF locations.

Cavitation was determined at three locations; M1, M2 and M3. Volume fraction cavitation at locations M1 and M2 were determined metallurgically at 200X and at M3 by density method. Zero strained specimen MO was used as reference for density measurement. See figures A3-2 and A3-3.

Isolated blisters were evident on some of the doors after solution treament. One such blister close to location M2 was sectioned. See Figure A3-4.

3. REMARKS

The modified design door formed successfully. Heat treatment was remarkable for the emergence of isolated large (3/16" diameter) blisters. Cavitation levels at the greatest strain regions were high at around 7%. The metallurgraphic sections shown in Figures A3-2 and A3-3 do not appear worse than those shown in 1984 Summary Report (Appendix 2) in regard to the extent of cavitation. Cavity shape is more rounded in the heat treated samples as would be expected.

Mechanical testing has revealed a fall-off in properties with increasing strain. It is expected that such depletion of properties with strain can be eliminated by the application of appropriate cavity suppression back pressure forming techniques.

The occurrence of isolated blisters appears to be associated with hydrogen gas and localized oxide films. This may have arisen from porosity in the experiment block which failed to "heal" when rolled from block to sheet. This defect will be investigated further.

APPENDIX A.1

SUMMARY OF HEAT TREATMENT INFORMATION

HEAT TREATMENT INFORMATION

QUANTITY	DESCRIPTION	SPECIFICATIONS / ORIGINAL CONDITION / FINAL CONDITION	HEAT TREATMENT: SOLUT HT TREAT time, temp	HEAT TREATMENT: QUENCH GLYCOL time, temp	ELECTRICAL CONDUTIVITY: RESULTS OF I.A.C.S
1	A-10 Door Panel	MIL-H-6008 F/1, AMS-2770-D, SCQ-2	50 min 975 F	10 s GLYCOL 22 % F	-
		220-0			
		220-W			
2	A-10 Door Panels	MIL-H-6008 F/1, AMS-2770-D, SCQ-2	50 min 975 F	7 s 22% UCON F	-
		220-0			
		220-W			
2	A-10 Door Panels	MIL-H-6008 F/1, AMS-2770-D, SCQ-2	50 min 975 F	10 s GLYCOL 22 % F	-
		220-0			
		220-W			
2	A-10 Door Panels	MIL-H-6008 F/1, AMS-2770-D, SCQ-2	50 min 975 F	9 s 22% F	-
		220-0			
		220-W			

HEAT TREATMENT INFORMATION

QUANTITY	DESCRIPTION	SPECIFICATIONS / ORIGINAL CONDITION / FINAL CONDITION	HEAT TREATMENT: SOLUT HT TREAT (time, temp)	HEAT TREATMENT: QUENCH GLYCOL (time, temp)	ELECTRICAL CONDUTIVITY: RESULTS OF I.A.C.S
2	A-10 Door Panels	MIL-H-6008 F/1, AMS-2770-D, CUST P.O.SCQ-2	60 min 977 F	9 s 22 % F	-
		220-0			
		220-W			
1	A-10 Door Panel	MIL-H-6088 F/1, AMS-2770-D, SCQ-2	60 min 977 F	9 s GLYCOL 22 % F	-
		220-0			
		220-W			
6	A-10 Door Panels	MIL-H-6088 F/1, AMS-2770-D, CUST P.O., SCQ-2	16 hrs 355 F	No Quench	37.1 - 39.0
		220-0			
		220-W			
4	A-10 Door Panels	MIL-H-6088 F/1, AMS-2770-D, CUST P.O., SCQ-2	16 hrs 355 F	No Quench	36.0 - 39.2
		220-0			
		220-W			

APPENDIX A.2

THICKNESS SURVEY

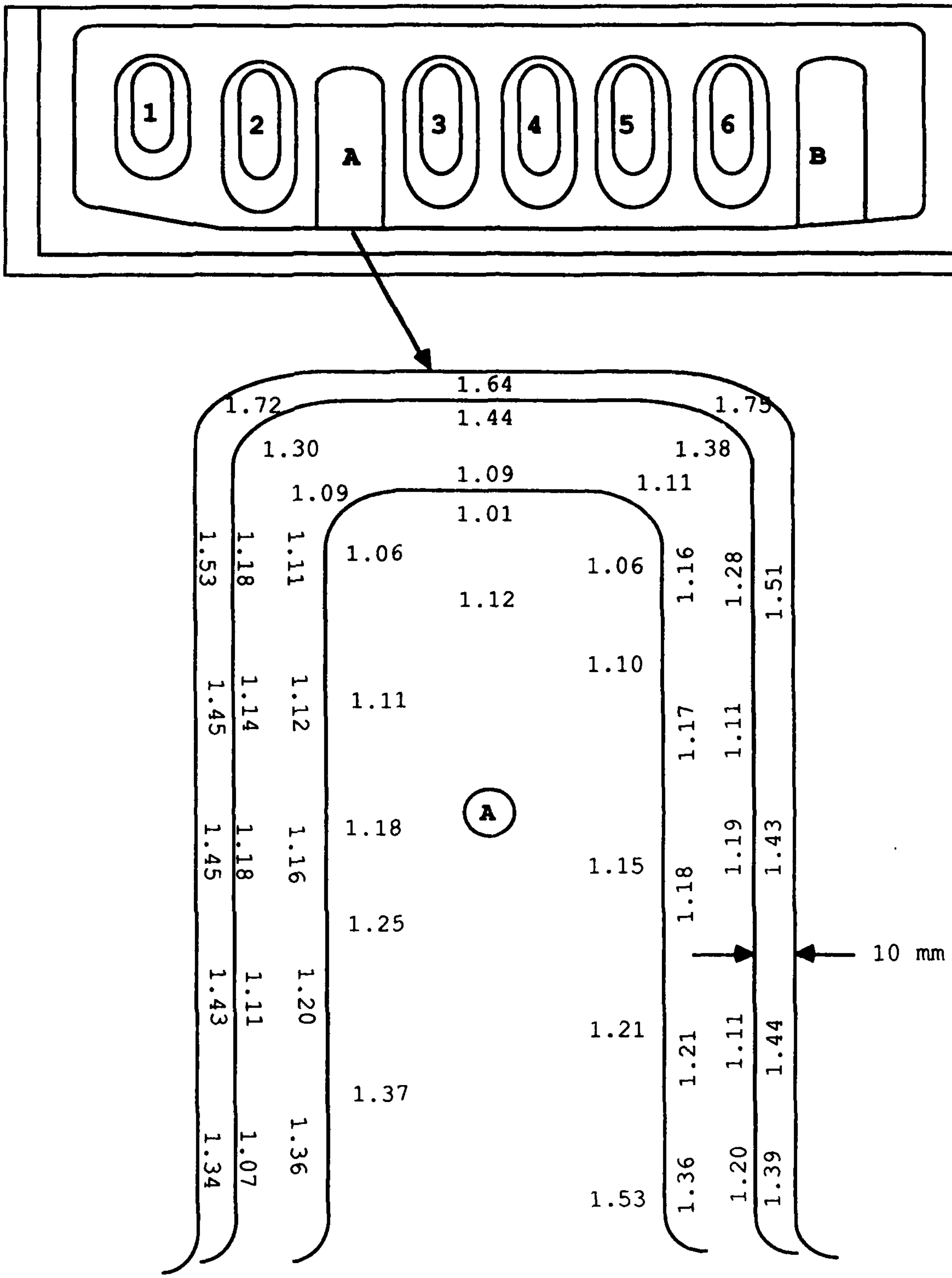


Figure A2-1: Development of Pan A Showing Local Thickness Achieved

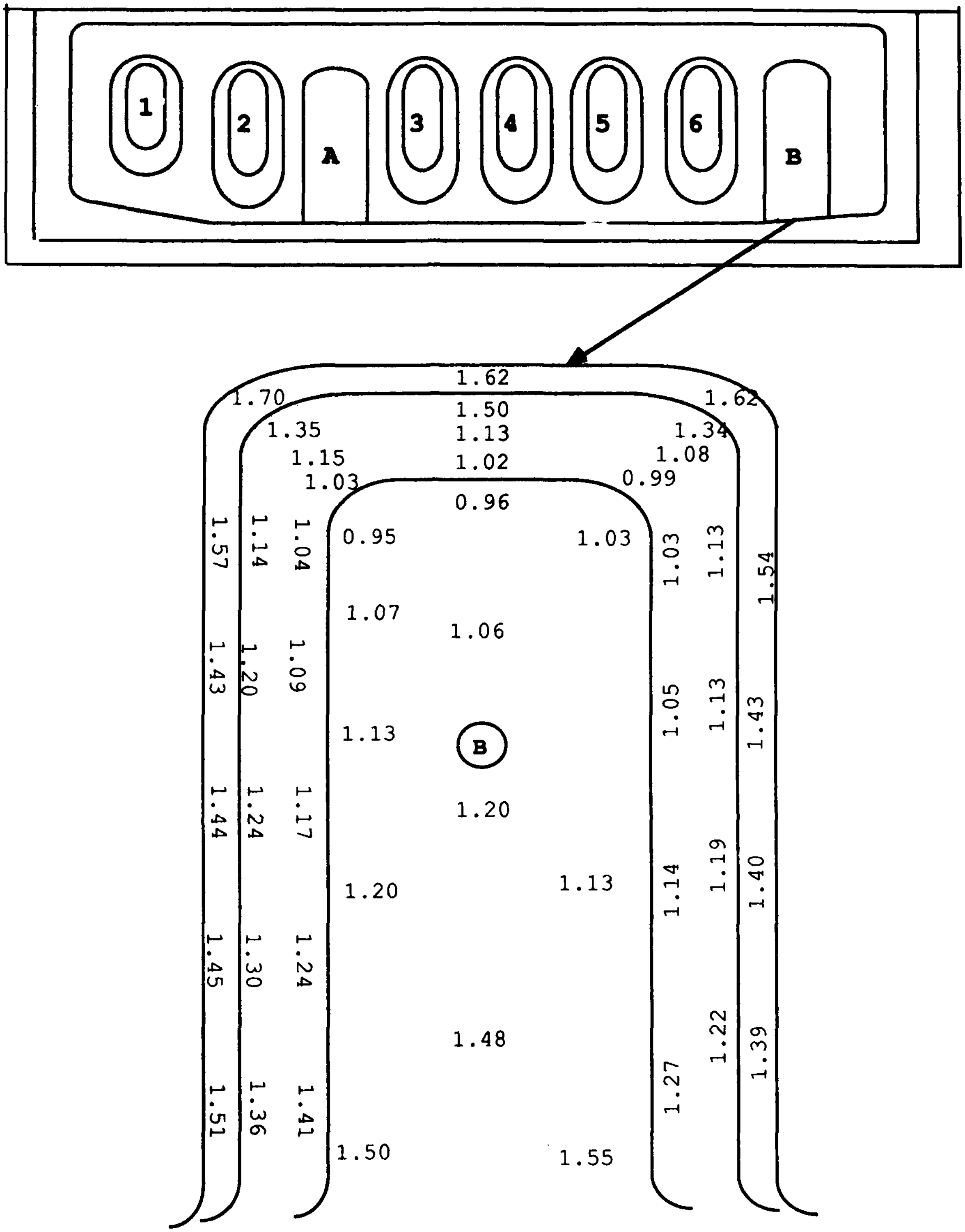


Figure A2-2: Development of Pan B Showing Local Thickness Achieved

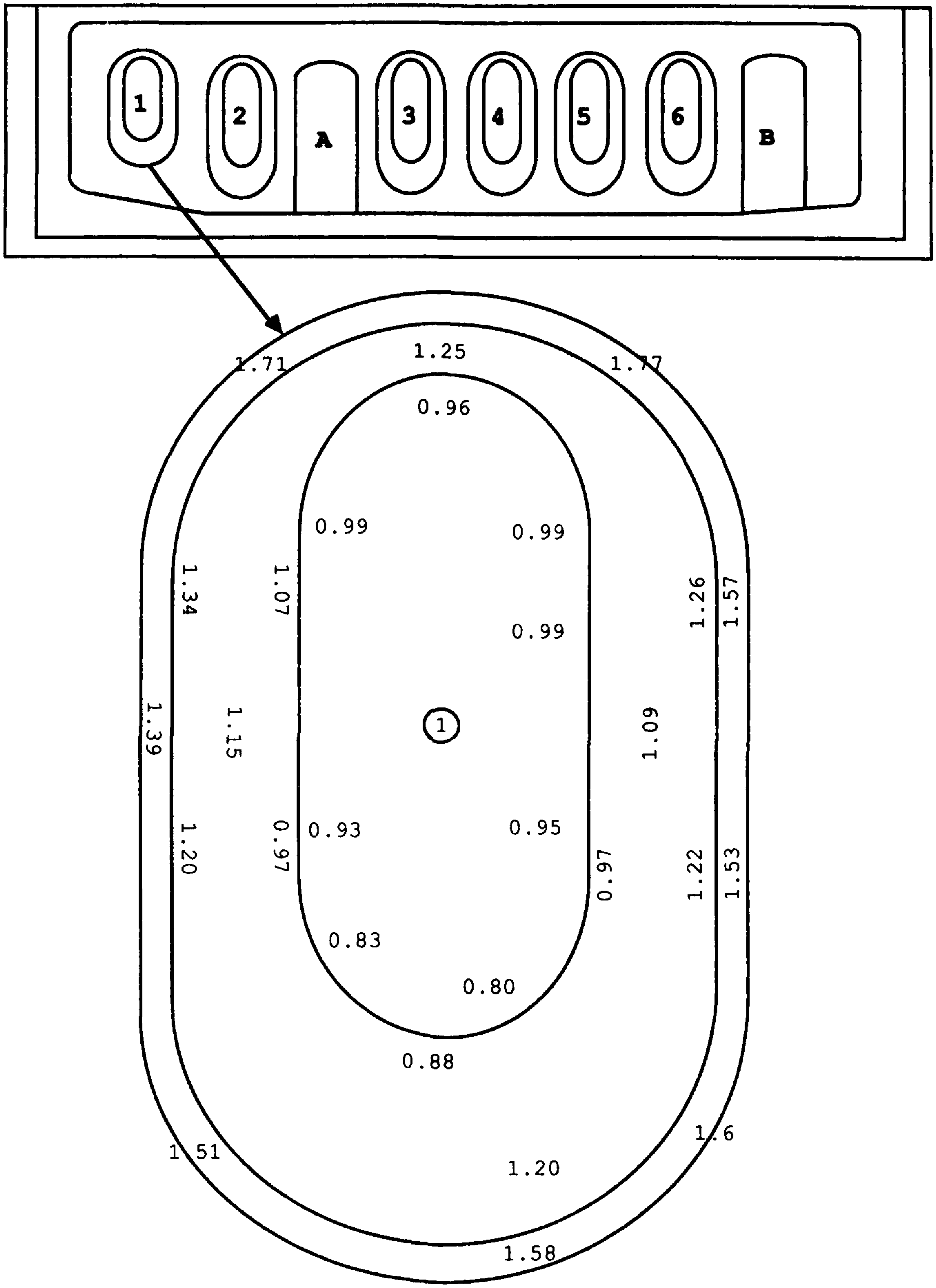


Figure A2-3: Development of Pan 1 Showing Local Thickness Achieved

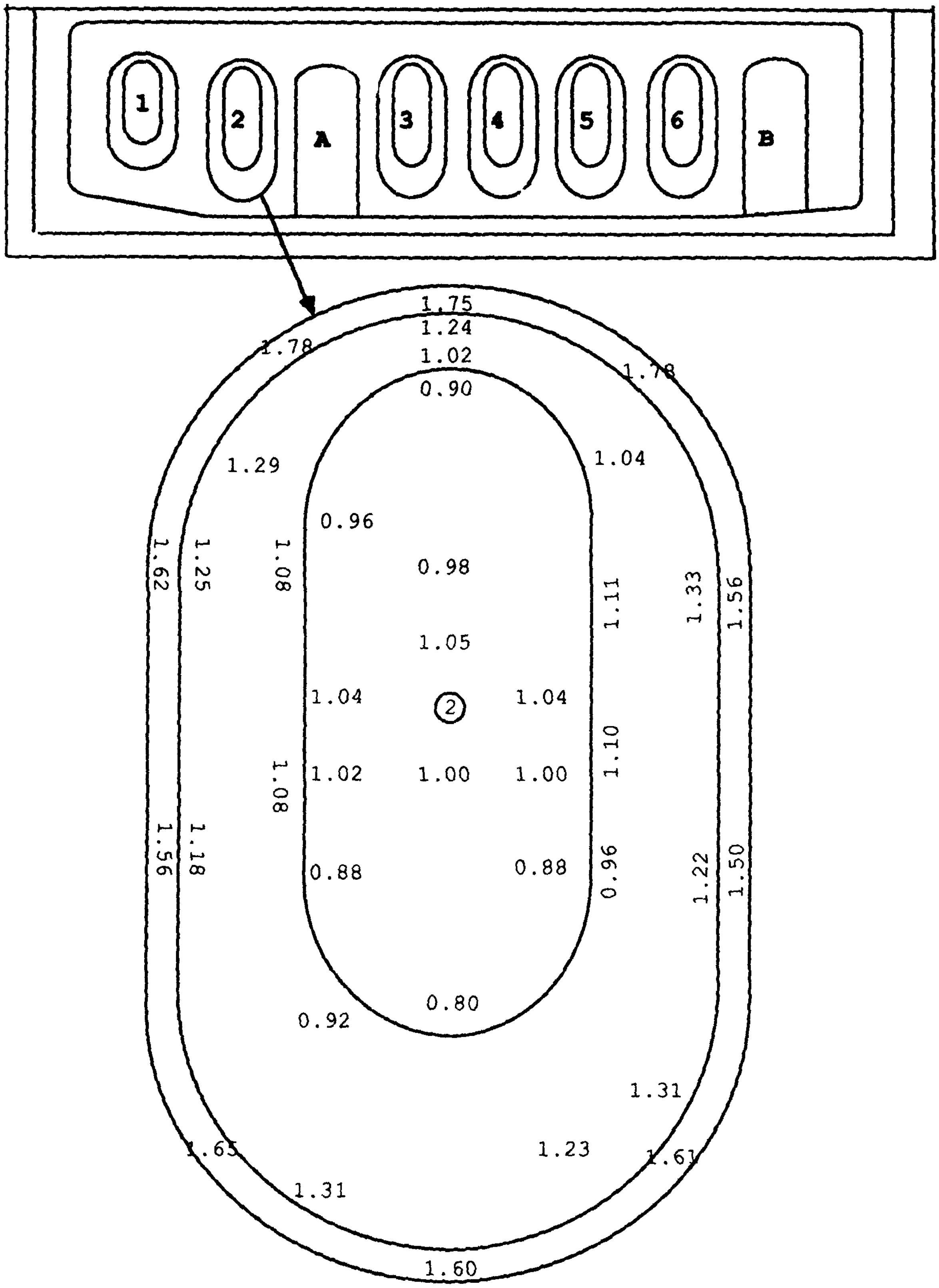


Figure A2-4: Development of Pan 2 Showing Local Thickness Achieved

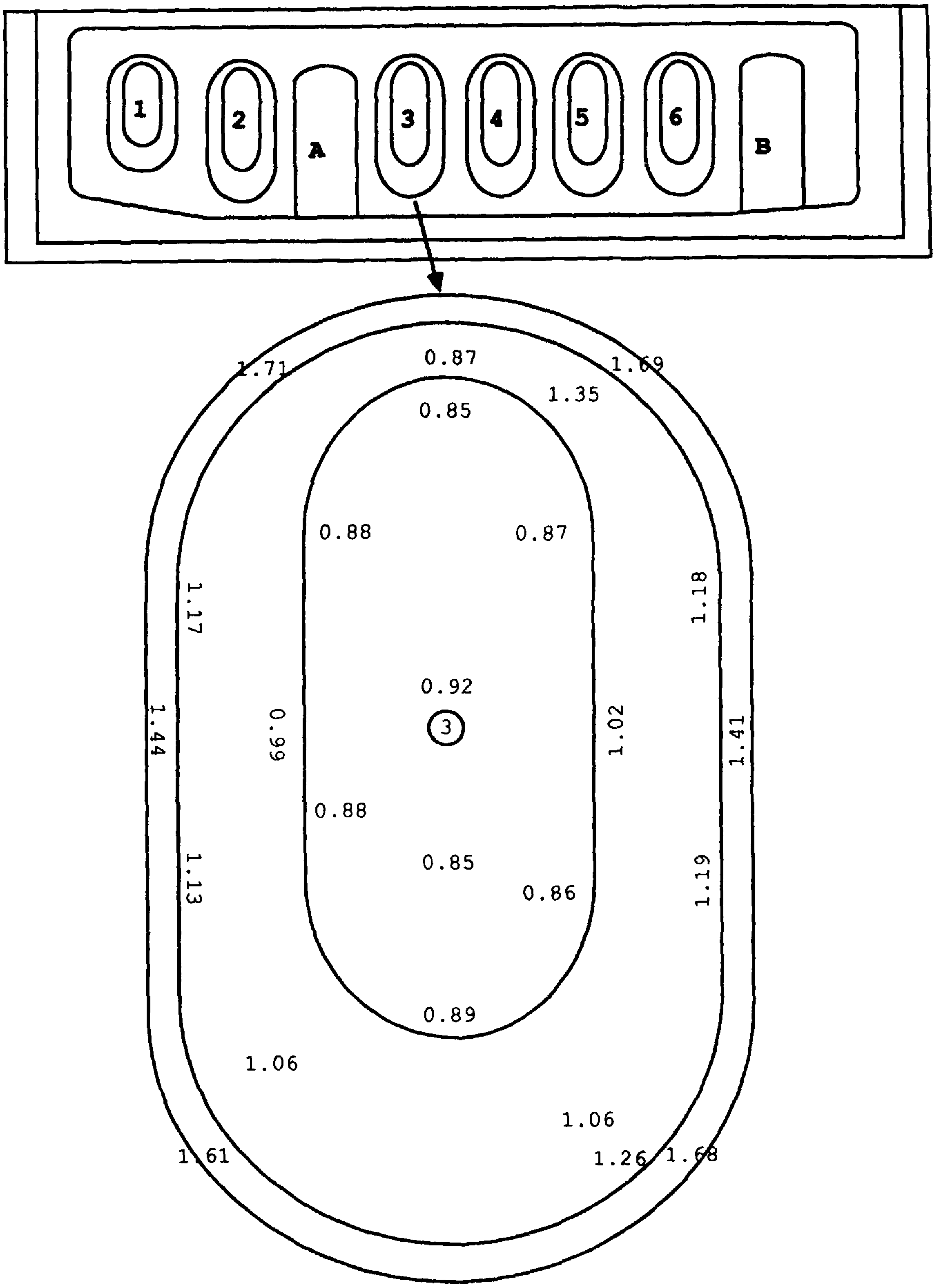


Figure A2-5: Development of Pan 3 Showing Local Thickness Achieved

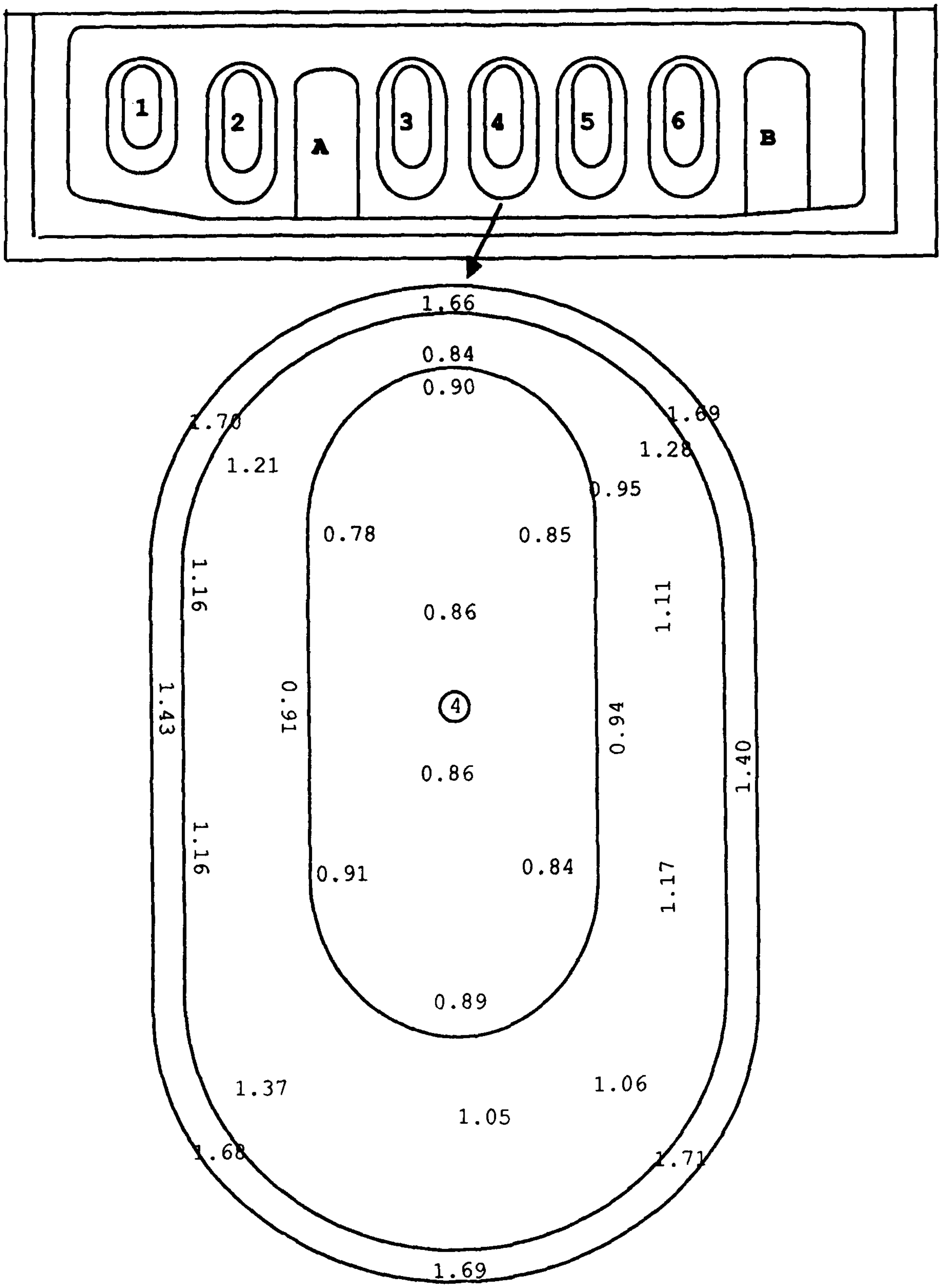


Figure A2-6: Development of Pan 4 Showing Local Thickness Achieved

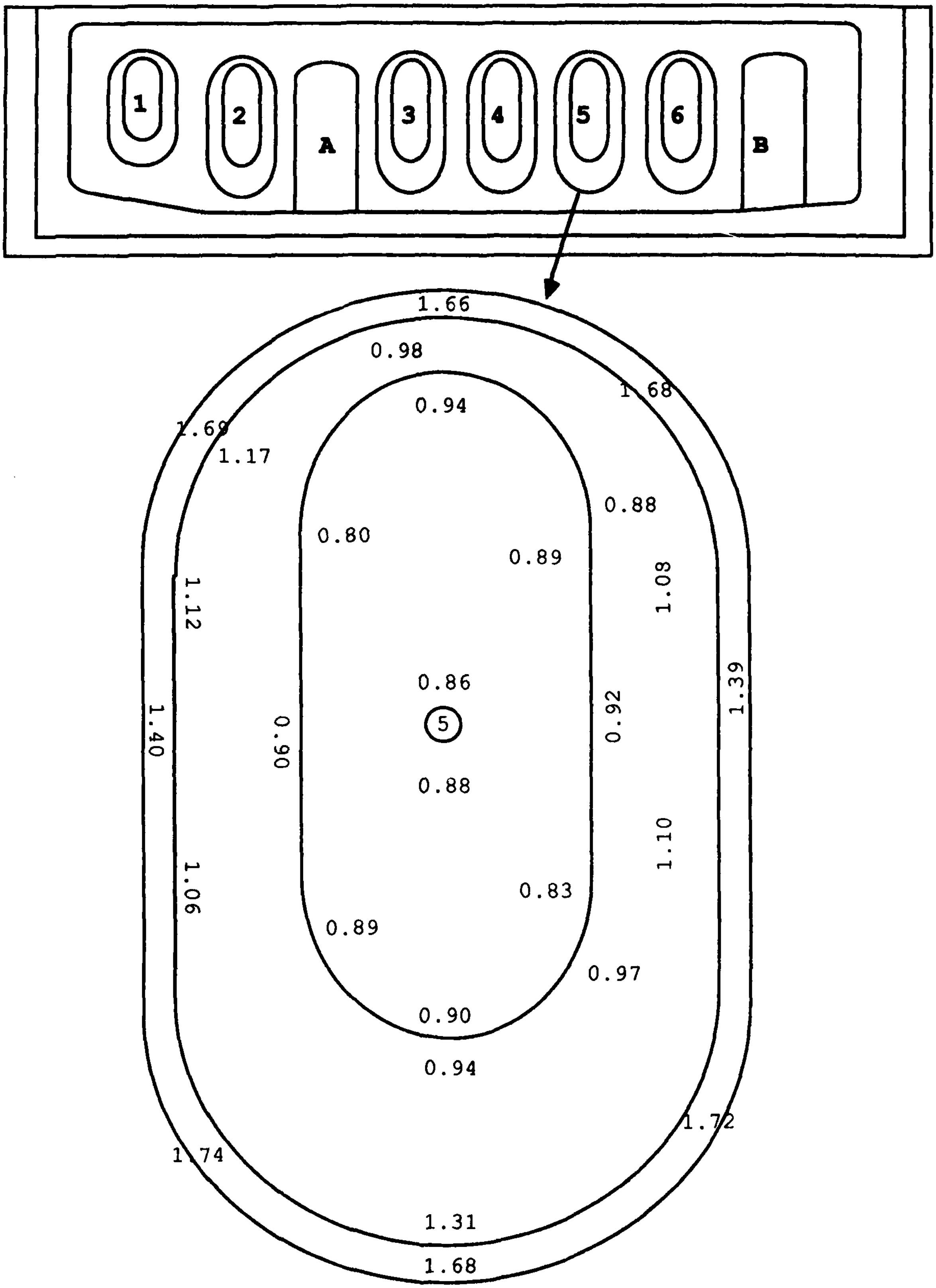


Figure A2-5: Development of Pan 5 Showing Local Thickness Achieved

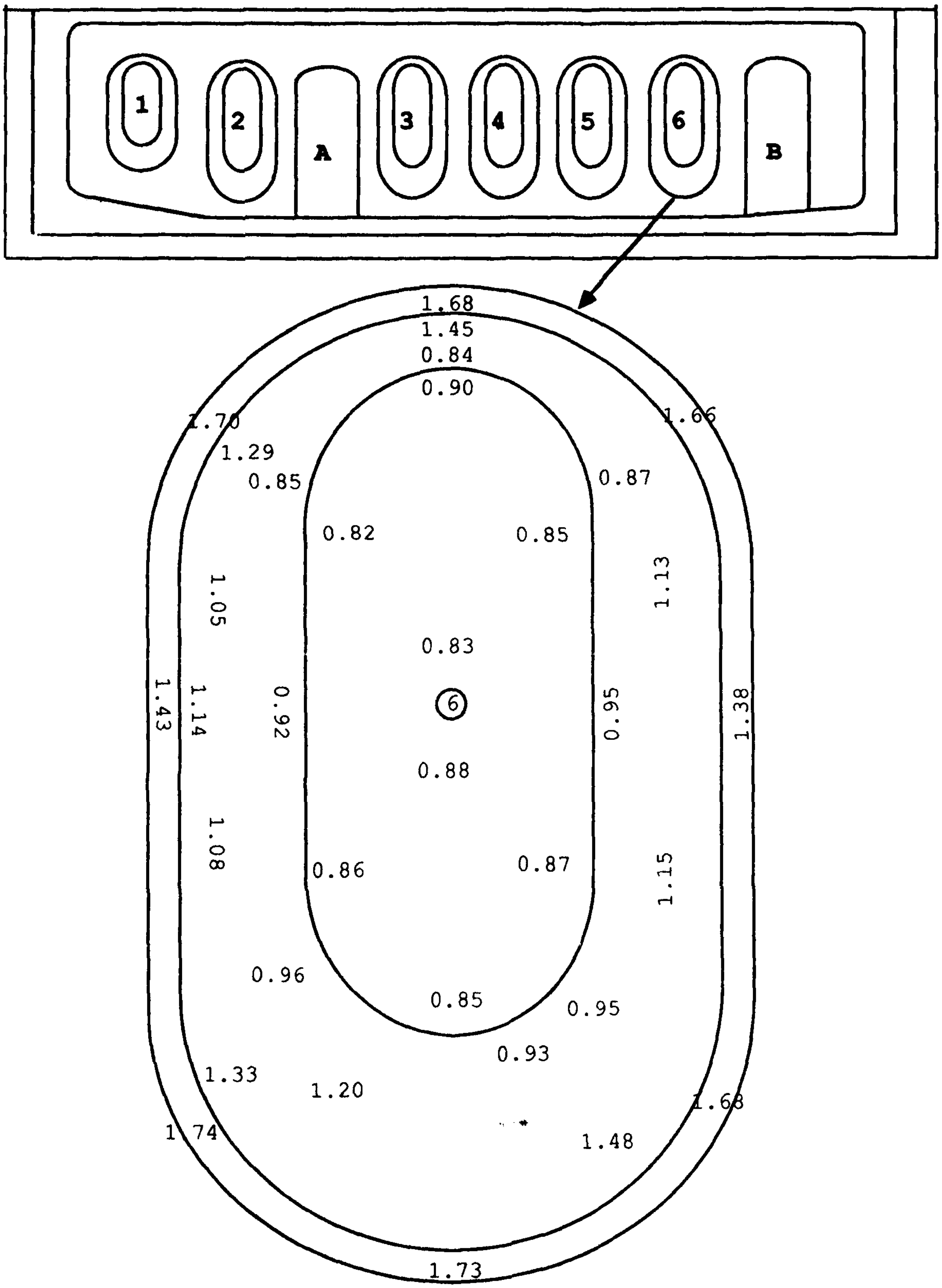


Figure A2-6: Development of Pan 6 Showing Local Thickness Achieved

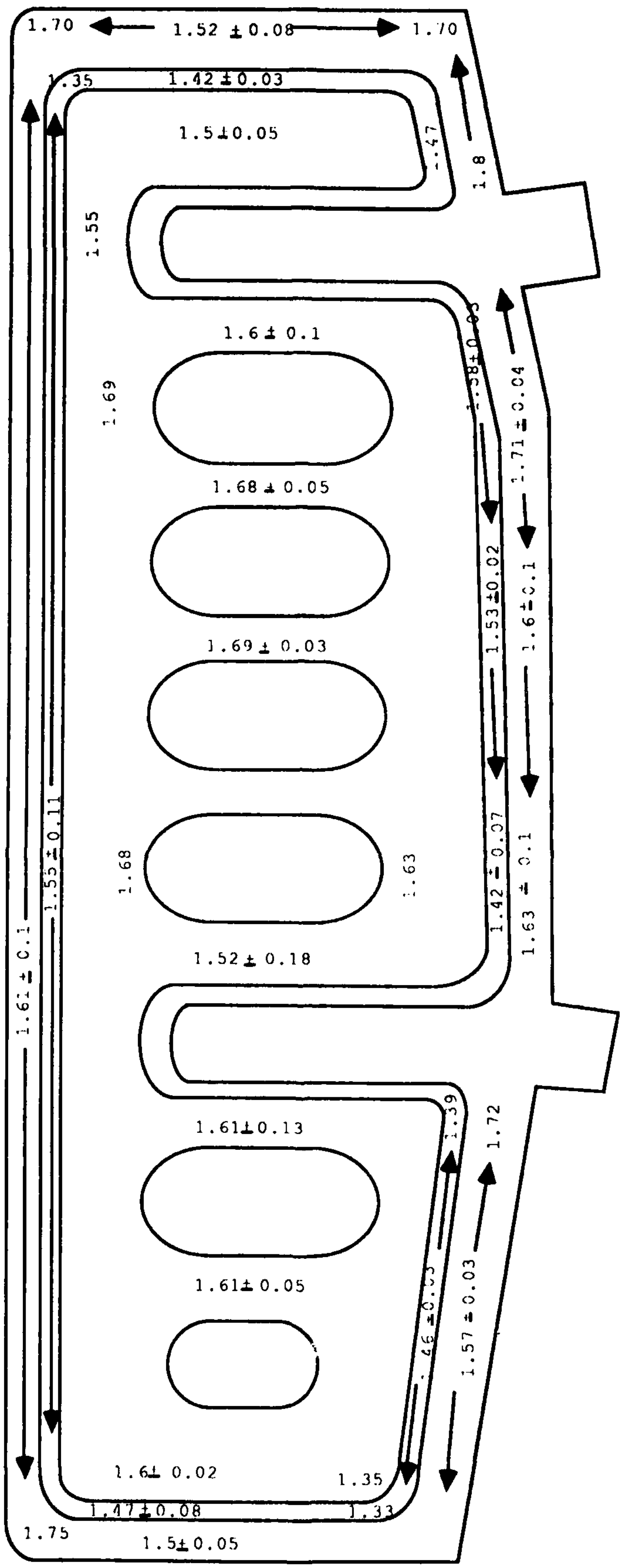


Figure A2-7: Thickness Survey of Entire Door

APPENDIX A.3

PROPERTIES SUMMARY

MECHANICAL PROPERTIES REPORT

	ACTUAL SIZE	ACTUAL AREA	ACTUAL LOAD, lbs	Yld S, psi	ACTUAL LOAD, lbs	Ult S, psi	ELONG 2 in.	ELONG %
T1	.081/.502	.0407	2630	64600	2925	71900	.22	11.0
T2	.066/.502	.0331	2100	63400	2320	70100	.22	11.0
T3	.059/.502	.0296	1880	63500	2100	70900	.15	7.5
T4	.045/.500	.0225	1260	56000	1475	65600	.12	6.0*
T5	.041/.501	.0205	1180	57600	1285	62700	.04	2.0*
T6	.032/.251	.00803			387	48200	.02**	2.0

*Fractured close to the radius of gage length
**Elongation in 1.0"

METALLURGICAL TEST REPORT

Identification:
Two (2) Supral 220 Test Specimen A10 Door Panel SPF Formed from Material Lot HON220

	M1	M2
Volume % of Cavitation:	7.94	4.76
Largest Void Size:	.0023"X.0065"	.0009"X.0014"
Cross Section Thickness:	.015"	.018"

Microstructure:

Large bubble observed in M2 sample. Excessive amount of cavitation observed in both specimens M1 and M2.

CHEMISTRY TEST REPORT

Identification: Two (2) Test Specimens
MO - Initial and M3 - Formed
A-10 Door Panel SPF Formed
from Material Lot HON220
Material: Aluminum

$$\text{Density} = \frac{\text{Wt. of Sample in Air}}{\text{Wt. of Sample in Air} - \text{Wt. of Sample in Water}}$$

	MO-Initial	M3-Formed
Wt of Sample in Air	4.3766	3.0223
Wt. of Hook in Air	.1902	.1902
Wt. of Sample and Hook in Water	3.0125	2.0544
Wt. of Hook in Water	.1804	.1804
Wt. of Sample in Water	2.8321	1.8740

Density Results: MO-Initial=2.83, M3-Formed=2.63

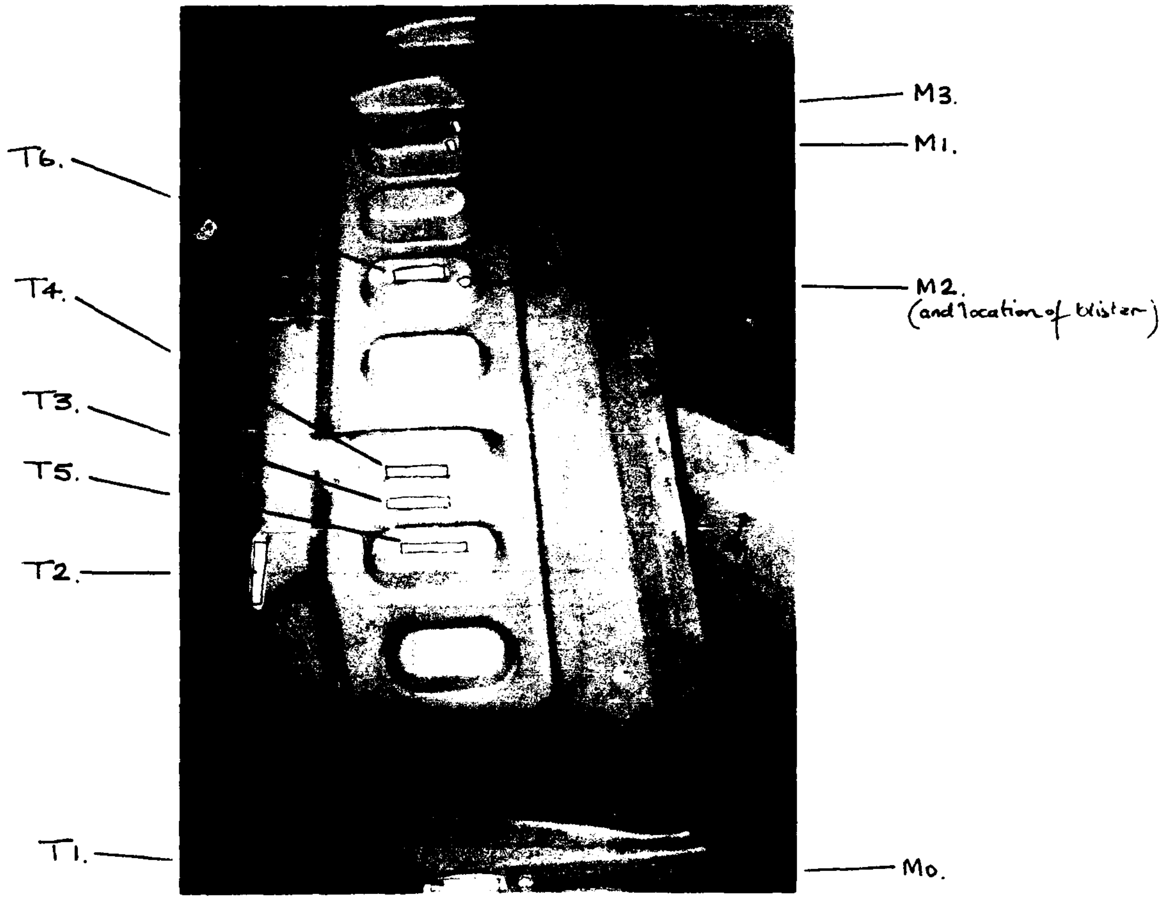


Figure A3-1. Location of Mechanical and Metallurgical Test Specimens

Figure A3-2. Cavitation in Supral 220-T6 at location M1

Figure A3-3. Cavitation in Supral 220-T6 at location M2

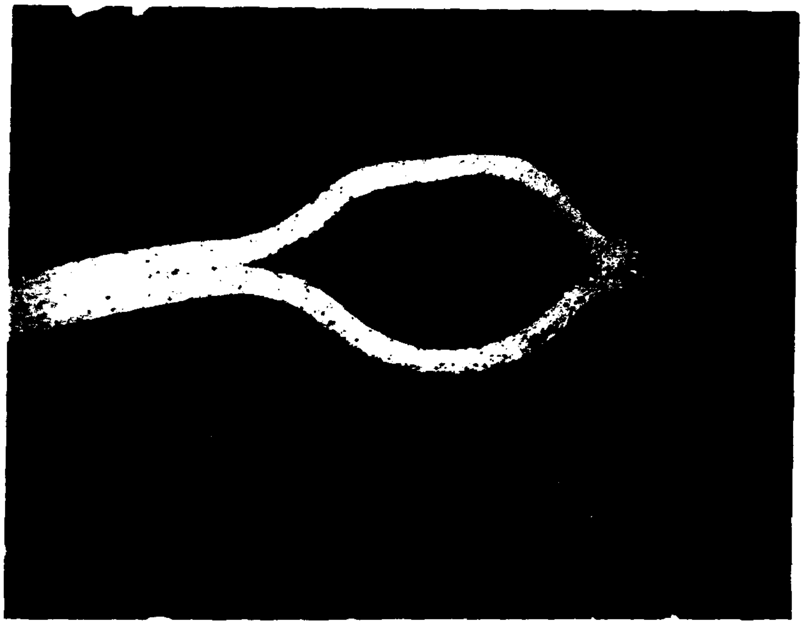
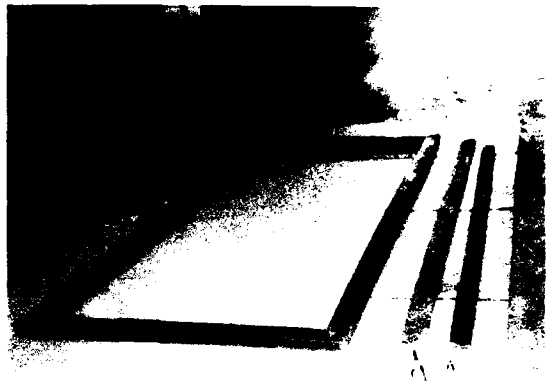
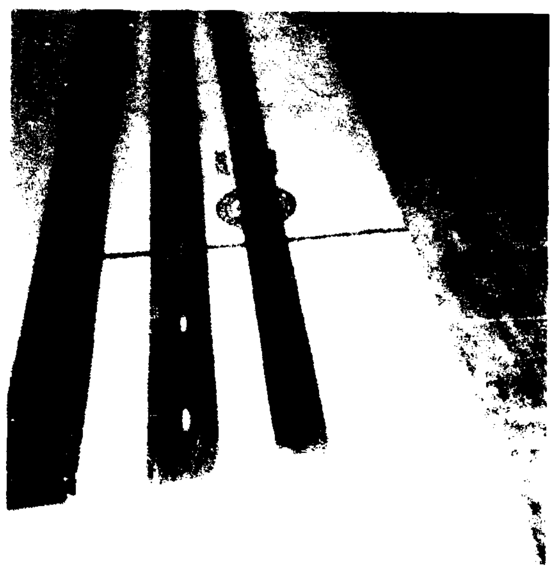


Figure A3-4. Center line blister at location M2 (10X)

APPENDIX A.4

HEAT TREATMENT FRAMES





APPENDIX B

COSTING PRACTICE AND COMPARATIVE COSTS

APPENDIX B

COSTING PRACTICE AND COMPARATIVE COSTS

1. The data in Table 2, Section 2.6 was developed using the data contained herein.

2. Table B-1 lists the ground rules applied in this study. Note that non-recurring tooling costs were not included since they were equivalent for both assembly methods.

3. Table B-2 provides definitions of the principal terms utilized in industry standard procedures for cost analysis.

4. Table B-3 presents the cost data for the detail parts utilized in the two doors. The data for the conventional door is historical data developed during manufacture of the A-10 aircraft. The SPF door data is from vendor estimates and shop standards.

5. Table B-4 includes vendor data on the SPF pan and extrapolated data to develop costs of 100 units.

6. Table B-5 summarizes the assembly steps and associated time values for the SPF/based door. This table utilizes ultrasonic weld bond data generated during time studies made for the A-10 fuel cell access doors assembled for service testing (Ref. 2).

7. Table B-6 lists the application of industrial engineering factors to the assembly of the two doors.

TABLE B-1

SPF VERSUS CONVENTIONAL ASSEMBLY COST SUMMARY (GROUND RULES)

- COST DATA PROVIDED FOR (A/C #1-100 & A/C #1-500)
- MATERIAL DOLLARS CALCULATED BASED ON ACTUAL BUY HISTORY AND MATERIAL CURVES
- SPF VENDOR QUOTE EXTRAPOLATED FOR PRICING (SEE ATTACHMENT II)
- CONVENTIONAL A-10 STANDARD DATA BASED ON HISTORICAL FILES (SEE ATTACHMENT I)
- SPF ASSEMBLY METHOD ESTIMATED UTILIZING PREDETERMINED TIME VALUES (SEE ATTACHMENT III)
- MATERIAL HANDLING, OVERHEADS, G&A OMITTED FOR CLARITY.
- APPLICABLE STANDARD FACTORS AND CURVES DEFINED IN ATTACHMENT IV
- SUPPORT FACTOR INCLUDES INDUSTRIAL ENGINEERING, MANUFACTURING ENGINEERING AND INSPECTION.
- TOOLING COSTS OMITTED (ESTIMATED CONVENTIONAL VS. SPF EQUAL)

TABLE B-2

A-10 SPF VS CONVENTIONAL COMPARATIVE STUDY

In establishing the comparative costs for this study, the term "STANDARD" or "STANDARD AT 1000" is used to describe the BASE STANDARD or ultimate unit of time which is required by an experienced operator to produce one unit of manufacture. This standard is made up of two parts and expressed in Decimal Hours.

- Set-Up (S/U) - which is the per lot time required to set equipment and workplace for manufacture of a particular part.
- Run Time (Run) - which is the required per piece time to perform a specific operation of manufacture.

After the BASE STANDARD has been established, it is necessary to apply factors to the Set-Up and Run Time to account for various conditions that prevail during the manufacturing process. This is done to project "BASE STANDARD" to the level of actual time expected to manufacture.

Generally, these factors are summarized into three categories which are applied as percentage above the BASE STANDARD.

- Set-Up Factor - which is historical shop data applied only to the set-up. (Set-Up is not curved since it occurs infrequently, and is not subject to learning).
- Non-Standard - which is any operation not covered by the STANDARD (missing operation, rework, prorates, etc.).
- Realization - which is shop performance applied to assembly standards based on historical data.

Finally, factored BASE STANDARDS are curved, which is the industry accepted method of determining costs of units that are produced in consecutive order, showing a reduction in labor cost every time another unit is produced. Factors that contribute to learning include: Tooling, Methods Improvement, Training, Improved Design for Production, etc. Learning Curve Values are calculated based on learning (%) historical data for similar type work.

TABLE B-3a. A-10 NOSE LANDING GEAR DOOR SPF DATA

160D136151 (ORIGINAL DOOR)

PART NUMBER	DETAIL STD. S/U	DETAIL STD. RUN	RAW MATERIAL $
136151-11 Skin	1.30	1.104	26.57
-13 Pan	5.72	0.900	30.71
-15 Former	1.05	0.151	3.73
-17 Former	1.54	0.173	0.57
-19 Former	1.30	0.178	0.59
-21 Former	1.26	0.214	0.21
-23 Inter.	0.55	0.263	1.69
-25 Inter.	1.37	0.295	0.63
-27 Inter.	1.41	0.273	0.36
-29 Tee	0.79	0.374	12.33
-31 Tee	0.71	0.260	4.00
-33 Brkt.	1.40	0.215	0.35
-35 Brkt.	0.60	0.115	1.61
-37 Brkt.	0.60	0.137	1.54
-39 Stringer	1.30	0.223	0.35
-43 Brkt.	0.94	0.137	0.26
-45 Brkt.	1.22	0.138	0.38
-47 Brkt.	0.50	0.038	1.19
-49 Brkt.	0.58	0.046	1.19
-51 Brkt.	0.58	0.052	2.04
-53 Brkt.	0.50	0.042	1.21
-55 Brkt.	0.50	0.038	1.21
-57 Brkt.	0.50	0.038	1.11
-59 Brkt.	0.50	0.042	1.23
-63 Brkt	0.63	0.065	1.23
-65 Brkt.	0.50	0.038	1.23
-67 Stringer	0.54	0.115	2.67
-69 Stringer	1.73	0.373	3.57
-71 Stringer	1.37	0.255	0.59
-73 Stringer	1.56	0.223	0.28
-75 Shim(2)	0.10	0.010	1.84
-77 Shim(2)	0.10	0.010	2.40
-79 Radius Blk.	0.73	0.031	0.06
-81 Radius Blk.	0.67	0.026	0.07
-83 Radius Blk.	1.22	0.030	0.07

160K136160 (SPF DOOR)

PART NUMBER	DETAIL STD. S/U	DETAIL STD. RUN	RAW MATERIAL $
136153-3 Ftg.	1.32	0.31	156.27
136152-1 Ftg.	0.53	0.118	38.15
136151-105 Shim(2)	0.10	0.010	2.12
136151-77 Shim	0.10	0.01	2.40
136151-75 Shim	0.10	0.01	1.84
136151-11 Skin	1.30	1.104	26.57
136161-15 Rad Blk.	1.01	0.035	0.08
136161-13 Ftg.	1.25	0.35	150.0
136161-11 Ftg.	1.25	0.35	150.0
136161-29 Shim	0.10	0.015	2.12
-27 Shim	0.10	0.019	2.76
-25 Shim	0.10	0.019	2.76
-23 Shim	0.10	0.015	2.12
-21 Shim	0.10	0.015	2.12
-19 Shim	0.10	0.015	2.12
-17 Strap	1.30	0.242	1.78
-15 Strap	1.30	0.242	1.78
-11 Pan	-	-	$\frac{100}{705}$ $\frac{500}{475}$
CCR264SS3-4 Rvt. (8)			1.36
NAS1304-12 Bolt (4)			0.96
NAS1398D6A4 Rvt. (5)			2.00
NAS1398D5A3 Rvt. (117)			46.8
NAS1304-11 Bolt (4)			0.96
MS2106914 N/P (8)			4.00
CCR264$$-3-3 Rvt. (8)			1.36
AN960D416L Washer(8)			0.08
4 Sq ft Adhesive Film			4.00

TABLE B-3b. A-10 NOSE LANDING GEAR DOOR SPF DATA

160D136151 (ORIGINAL DOOR)				160K136160 (SPF DOOR)			
PART NUMBER	DETAIL STD.		RAW MATERIAL $	PART NUMBER	DETAIL STD.		RAW MATERIAL $
	S/U	RUN			S/U	RUN	
136151-85 Radius Blk.	1.22	0.034	0.07				
-87 Radius Blk.	1.22	0.034	0.10				
-88 Radius Blk.	1.22	0.034	0.10				
-89 Radius Blk.	0.93	0.028	0.10				
-91 Radius Blk.	0.90	0.059	0.10				
-93 Brkt.	0.50	0.038	1.23				
-95 Brkt. (6)	0.50	0.246	7.38				
-99 Brkt.	0.39	0.039	2.04				
-100 Brkt.	0.39	0.039	1.19				
-101 Brkt.	0.47	0.039	1.19				
136152-1 Ftg.	0.53	0.118	38.15				
136153-1 Ftg.	1.32	0.31	156.27				
RV1203-4-3 Rvt. (11)			4.40				
CCR264SS-3-6 Rvt. (16)			2.72				
AN960D416 Washer (8)			0.08				
NAS1304-11 Bolt (8)			1.92				
MT2C428K N/P (8)			4.00				
RV1203-4-2 Rvt. (356)			142.40				
TOTAL	45.46	7.65	472.50	TOTAL	10.16	2.88	100: 1311.51; 500: 1096.51

TABLE B-4

A-10 NOSE LANDING GEAR DOOR SPF DATA (160K136160-11 SPF PAN)

	QTY.	COST ($)	COST($)/PIECE	% REDUCTION	Heat Treat Per Piece	Total Cost Per Piece ($)
VENDOR PRICE DATA	10	8,650	865.0	-	73	938
	15	11,400	760.0	12%	-	
	20	14,210	710.5	18%	-	
	500	237,500	475.0	45%	Included	475
EXTRAPOLATED DATA	100	-	650.0	25%	55	705

TABLE B-5

SPF ASSEMBLY METHOD	STD. AT 1000 S/U	RUN
1. Prep. Fixture/Get Kit		0.15
2. Locate - 11 Pan in ASF		0.025
3. Locate 13161-11 & -13 Fittings and Shim		0.084
4. Trans. Drill from Pilots (28) holes C/T - 11 Pan	0.016	0.185
5. Locate -15 & -17 Straps, 136153-3 & 136152-1 Hinges and Shim		0.134
6. Trans. Drill (122) hls. from Splice Plates C/T -11 Pan	0.024	0.805
7. Trans. Drill 8 hls. from 136153-3 & 136152-1 Hinges C/T Straps and 136161-11 & -13 Fittings	.016	0.053
8. Disassemble		0.182
9. DBR	0.008	0.158
10. Instl. Nutplates in 13616-11 & -13 Fittings	0.008	0.136
11. Bolt 136153-3 & 136152-1 Hinges C/T 136161-15 & -17 Straps and 136161-11 & -13 Fittings		0.2
12. Reassemble Hinges, Straps and Fittings C/T - 11 Pan		0.182
13. Wet Instl. (28) Jo-Bolts in Pan C/T 136161-11 & -13 Fittings	0.008	0.224
14. Wet Instl. (122) Olympic Blind Rvts. in Straps C/T -11 Pans		0.976
15. Drill (41) hls. below Fittings	0.016	0.271
16. Clean Assembly and Apply Adhesive Film on Faying Surface of -11 Pan		0.250
17. Loc. 136151-11 Skin		0.025
18. Weld Bond (138) places C/T -11 Pan	0.051	0.104
19. Wet Instl. (41) Olympic Blind Rvts.	0.008	0.328
20. Clean Assembly		0.050
21. I.D. Part #		0.017
TOTALS	0.154	5.54

TABLE B-6

A-10 NOSE LANDING GEAR DOOR SPF VS. CONVENTIONAL COST SUMMARY (RAW DATA)

	APPLICABLE CURVE	OTHER FACTORS	CONVENTIONAL ASSEMBLY		SPF	
			A/C #1-100	A/C #1-500	A/C #1-100	A/C #1-500
MATERIAL (AVG. $/A/C)	95%	-	473	420	1312	1087
			S/U	RUN	S/U	RUN
DETAILS (BASE STD. HRS.) INCL. PAINT	RUN ONLY 80% 1-68 90% 69-UP	S/U - 1.9 NON-STD.-1.27	45.46	7.65	10.16	2.88
SPOT WELD (BASE STD. HRS.)	85%	S/U - 2.2 NON-STD.-1.27	0.440	0.775	-	-
ULTRASONIC WELD (BASE STD. HRS.)	85%	S/U - 2.2 NON-STD.-1.27	-	-	0.325	1.104
ASSEMBLY	75% 1-200 85% 200-UP	NON-STD.-1.1 REALIZATION - 1.25	23.27		4.26	

TEST INFORMATION SHEET

SUPERPLASTIC FORMING (TASK C)

SUPPLEMENT TO CONTRACT NO. F33615-83-C-3208

STATIC TESTING OF

A-10A FORWARD FAIRING NOSE LANDING GEAR DOORS

TABLE OF CONTENTS

LIST OF TABLES AND FIGURES

1.0 INTRODUCTION

This Test Information Sheet presents the detail loading, instrumentation and data requirements for each of two (2) different structurally designed A-10A forward fairing nose landing gear doors.

One of the nose landing gear doors is a replica of the most recent production version door as installed on in-service production A-10A aircraft. This door is of conventional sheet stiffened aluminum alloy construction as depicted on drawing 160K136151. The second door utilizes a conventional aluminum alloy skin stiffened by a weld bonded monolithic superplastically formed element fabricated from Supral 220 alloy. This door represents the optimized SPF designs for Task C of the subject contract, and is depicted on drawing 160K136160. The testing outlined here will be for static testing of both doors. The testing will be conducted in the Structural Test Laboratory at Wright-Patterson Air Force Base, in accordance with this plan.

2.0 OBJECTIVE

The objectives of these tests are to compare the structural efficiency of the superplastically formed (SPF), Supral 220 alloy door with the more conventionally designed production door. The existing production door will represent the baseline from which qualitative comparisons are made through analysis of the test results. The criteria for the comparison will be (1) to demonstrate that the application of limit load on either door will not produce detrimental yielding of the structure nor will the application of ultimate load produce failure or unacceptable structural deformations, and (2) the stiffness of the SPF door is functionally acceptable when compared to the production door.

3.0 DESCRIPTION OF TEST ARTICLES

Two (2) structurally different A-10 forward fairing nose landing gear doors will be tested. One door is the currently designed production door and the second is an optimally designed weld bonded SPF door. Both doors have the same geometry, hinge and actuator locations. The doors are interchangeable with respect to the test fixture installation as well as the aircraft.

4.0 LOADING PROCEDURE

Each test article will be placed in a reusable test fixture capable of supporting and reacting the hinge and actuating rod loads. The test article is 15.37 inches wide and 53.98 inches long and will be essentially mounted horizontally in the test fixture by its hinges and actuating clevis, which is an integral part of the aft hinge.

The critical design condition is the door closure airload condition. ($V=450$ KTS, $N_z=7.33g$). This condition produces a uniformly distributed suction pressure of 1.54 psi limit and 2.31 psi ultimate. The air load pressure is applied normal to the door surface resulting in an equivalent total load of 1288 lbs limit and

1931 lbs ultimate.

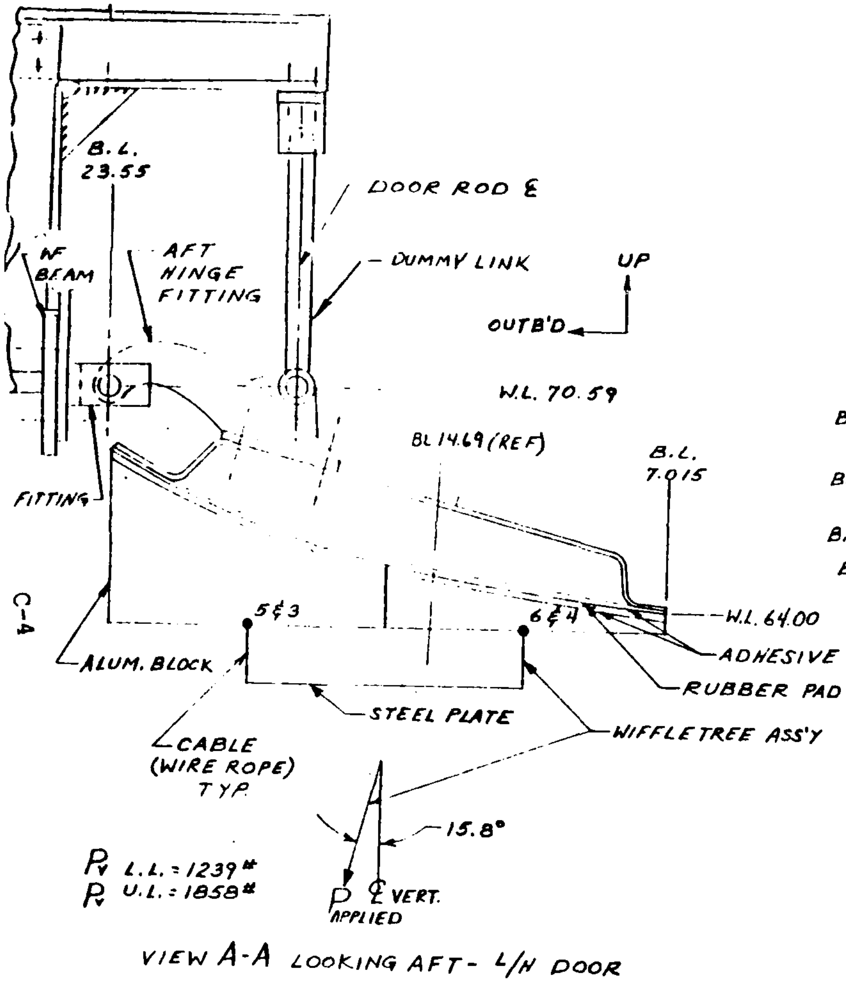
Sufficient tension pads to represent the uniform air pressure are attached to the outer skin and will be loaded by a wiffle tree arrangement as shown in Figure C-1. Load will be applied by a hydraulic cylinder mounted between the support/reaction fixture and the wiffle tree assembly. Details of the loading requirements and fixtures to be used are provided in C.1 of this appendix.

The test load will be applied incrementally as follows: 10%, 30%, 50%, 70%, 90% and 100% of limit load. Having demonstrated structural integrity at limit load, the load will be reduced incrementally to 90%, 50%, 30% and 0% of limit load, to show no permanent deformation after application of limit load. Limit load will then be reapplied and then increased to ultimate load in increments of 10%. Continuation to failure will be accomplished in 10% increments of load.

Applied actuator loads must be held within an error of ±3% of the required percent limit load value. At 100% limit load and 150% limit load (ultimate load), the applied loading must be held for three seconds.

TABLE C.1 - APPLIED TEST LOADS

% LIMIT LOAD	ACTUATOR APPLIED LOAD (lbs)
0	0
10	123
30	136
50	644
70	902
90	1169
100 (LIMIT LOAD)	1288
110	1417
120	1546
130	1674
140	1803
150 (ULTIMATE LOAD)	1931
160	2061
170	2190
180	2318
190	2447
200	2576
210	2705
220	2834
230	2962
240	3092
250	3220
260	3349
270	3478
280	3606
290	3735
300	3864



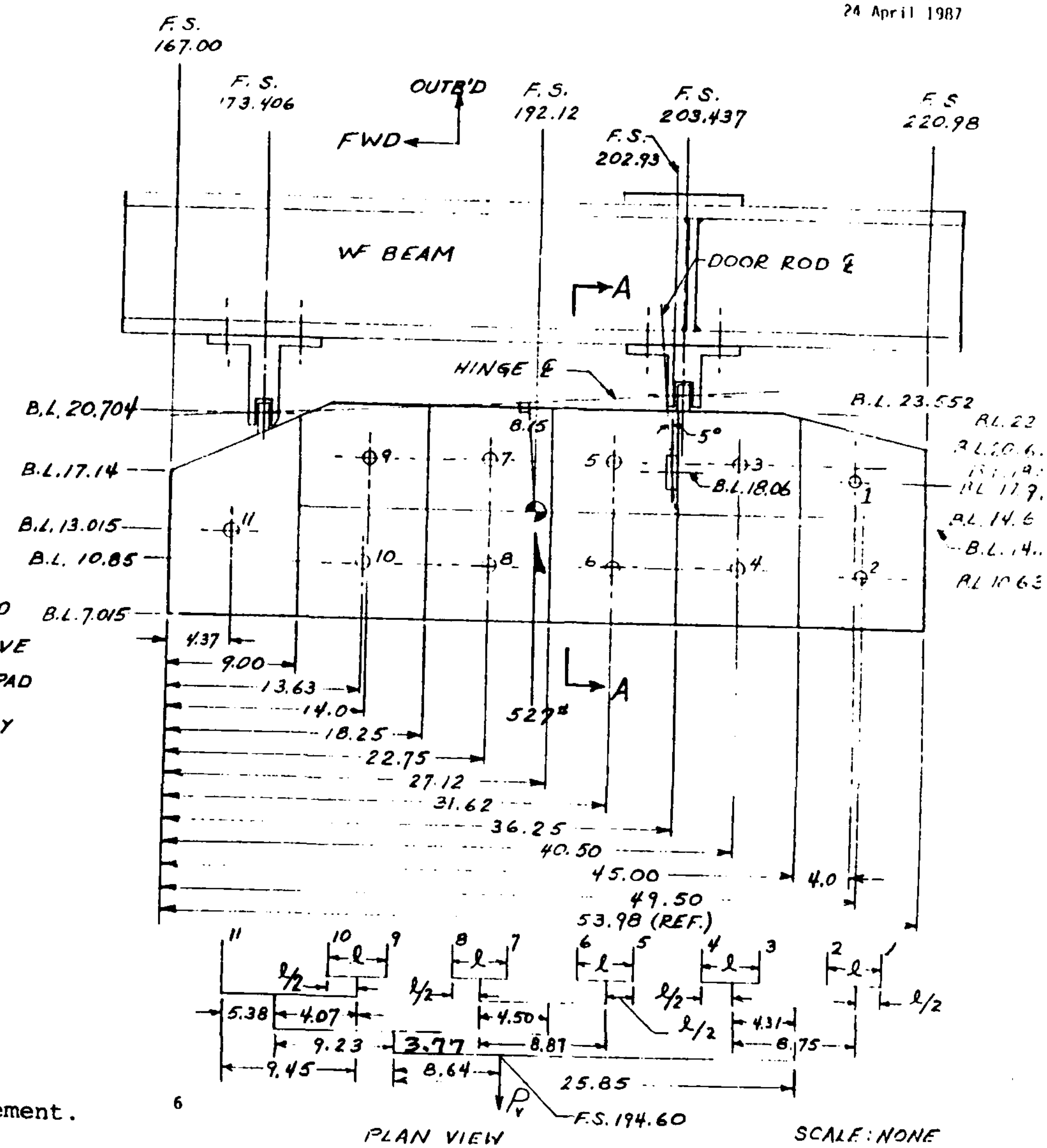


Figure C-1. Wiffle Tree Loading Arrangement.

5.0 INSTRUMENTATION

Application of the test load will be measured by a load cell mounted between the wiffle tree assembly and the hydraulic loading cylinder. Minimum load cell rating shall be 500 lbs.

Seven position transducers will be installed for each test set up to measure deflection normal to the external initial position of the outer skin surface. The locations shown in Figures 11, 12 and 13 are along the longitudinal edge of the door as well as at the leading and trailing edge corners. The position transducer readings will be used to assess whether any permanent set occurred during loading to limit load.

Six wire resistant strain gages will be installed on each door in order to measure strains induced by bending and torsion under the action of the applied loads. The locations shown in Figures 11, 12 and 13 are at the section of maximum bending and shear. The strain readings will be used to assess whether any permanent set occurred during loading to limit load. In addition, the readings will be used in the analysis of the failure mode during the failing load portion of the tests.

6.0 DATA REQUIREMENTS

Deflection and strains will be measured at the locations described in section 5.0 for each incremental loading up to limit load and for each incremental decrease in load to 0.

7.0 MISCELLANEOUS

The test articles defined in section 3.0 are supplied by FRC. Strain gage instrumentation is not supplied by FRC. Load fixtures, load cell, hydraulic cylinders, wiffle tree structure, position transducers and door attaching hardware are all suppplied by the WPAFB Structural Test Laboratory. The test articles do not include the door drive rod which attaches to the aft door hinge clevis. A dummy link attached to the door hinge at one end and the load fixture at the other end will be required in its place. The dummy link is considered part of the test fixturing supplied by the Air Force.

8.0 REFERENCES

(a) Report SA160R9172 - Nose Loading Gear Fairings and Uplock Stress Analysis A-10A

(b) Report MP002V6245 - Interim Technical Progress Report No. 3 for Supreplastic Forming (Task C), Supplement to Contract No. F33615-83-C-3208

(c) FRC Drawing 160D136151 - Door Assembly Nose Landing Gear Fwd.

(d) FRC Drawing 160D136100 - Installation - NLG Doors, Mechanism & Uplock

(e) FRC Drawing 160K136160 - Modified Door Assy - Nose Landing Gear FWD No. 2, for test only.

APPENDIX C.1

DETAIL TEST SET UP AND LOADING INFORMATION

a) LOAD FIXTURE DESIGN, LOADS (See Figure C1-1)

(Recommend a factor of safety = 3.0 be applied to ultimate load for fixture design)

ITEM	COMPONENT	REACTION LOAD LBS ULTIMATE (APPLIED TO FIXTURE)
FORWARD HINGE	R_{Fy}	-199
	R_{Fx}	0
	R_{Fz}	-455
AFT HINGE	R_{Ay}	-328
	R_{Ax}	295
	R_{Az}	1967
ROD LOAD	P_R	3383
DOOR ROD FITTING	R_{Ry}	0
	R_{Rx}	-295
	R_{Rz}	-3370

+ R_{Fy}, R_{Ay} = SIDE DIRECTION, INBOARD

+ R_{Fx}, R_{Ax} = LONGITUDINAL, FWD

+ R_{Fz}, R_{Az} = UP

+ P_R = TENSION

b) ATTACHING HARDWARE

- Forward Hinge - NAS 464P4 Bolt and MS17826-4 Nut or equivalent, 0.250 inch diameter 160 ksi heat treat hardware (AN960PD416 washers or equivalent, as required).

- Aft Hinge - NAS 464P6 Bolt and MS17826-6 Nut or equivalent, 0.312 inch diameter 160 ksi heat treat hardware (AN 960PD516 washers or equivalent, as required).

- Drive Rod - NAS 464P6 Bolt and MS17826-6 Nut or equivalent 0.375 inch diameter 160 ksi heat treat hardware (AN960PD616 washers or equivalent, as required).

- Bushings - Appropriate bushing types (i.e. S5005) should be installed in fixture clevises to prevent clamp-up on fitting/fixture Lugs.

c) DOOR POSITION

The door is mounted in the closed position in some attitude as it would be on the aircraft. Fig C1-2 shows the mounting geometry using the hinge points and forward and aft door edges as the reference points to establish the closed position. After selection of the verticle location of the fixture mount point for the drive rod (dummy link), the length of the dummy link can be established. When installed, the link maintains the door in the correct closed position. Referring to Figure C-1, the wiffle tree loading system is shown relative to the door in the closed position.

d) FIXTURE DETAILS

The wiffle tree arrangement (Figure C-1) is arranged in such a way to provide eleven (11) discrete loading points. Attachment to the door structure for each loading point is by means of a rubber pad bonded to the external skin surface. Each rubber pad in turn is bonded to an aluminum plate which contains a threaded insert to piuck up as cable for attachment to the wiffle tree beam. Using an average of approximately 80 sq inches of pad area with a 75% effective factor to account for load concentration for each pad, the pad flatwise tension strength in bonding to the door surface must be capable of approximately a minimum of 20 psi at failing load (approximately 5000 lb) with a Factor of Safety of two (2) included.

Accountability for the dead weight of the fixturing should be made when computing applied loads if the fixture weight is a significant percentage of the limit load.

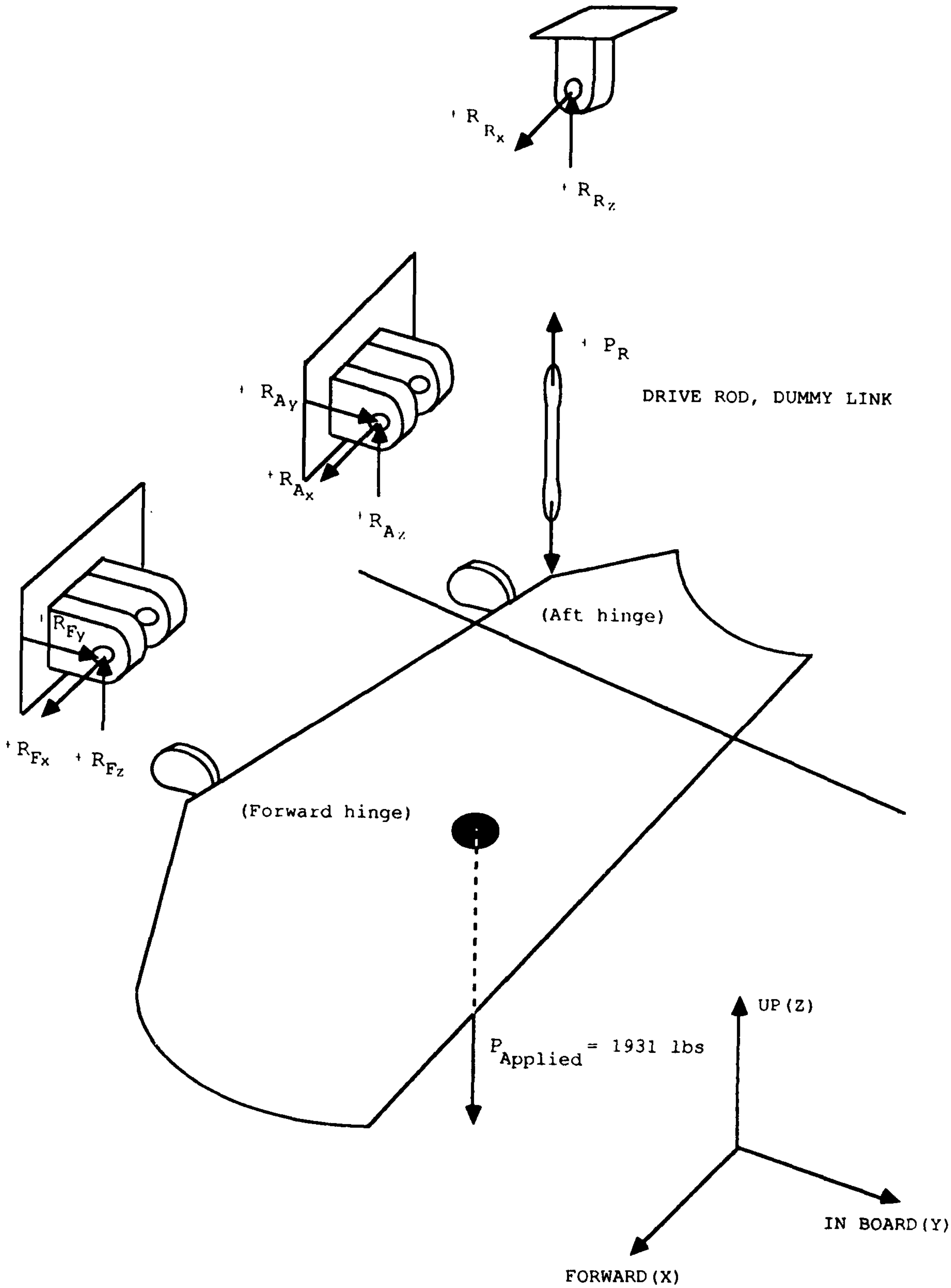


Figure C1-1. Sign Convention for Loads Applied to Fixture

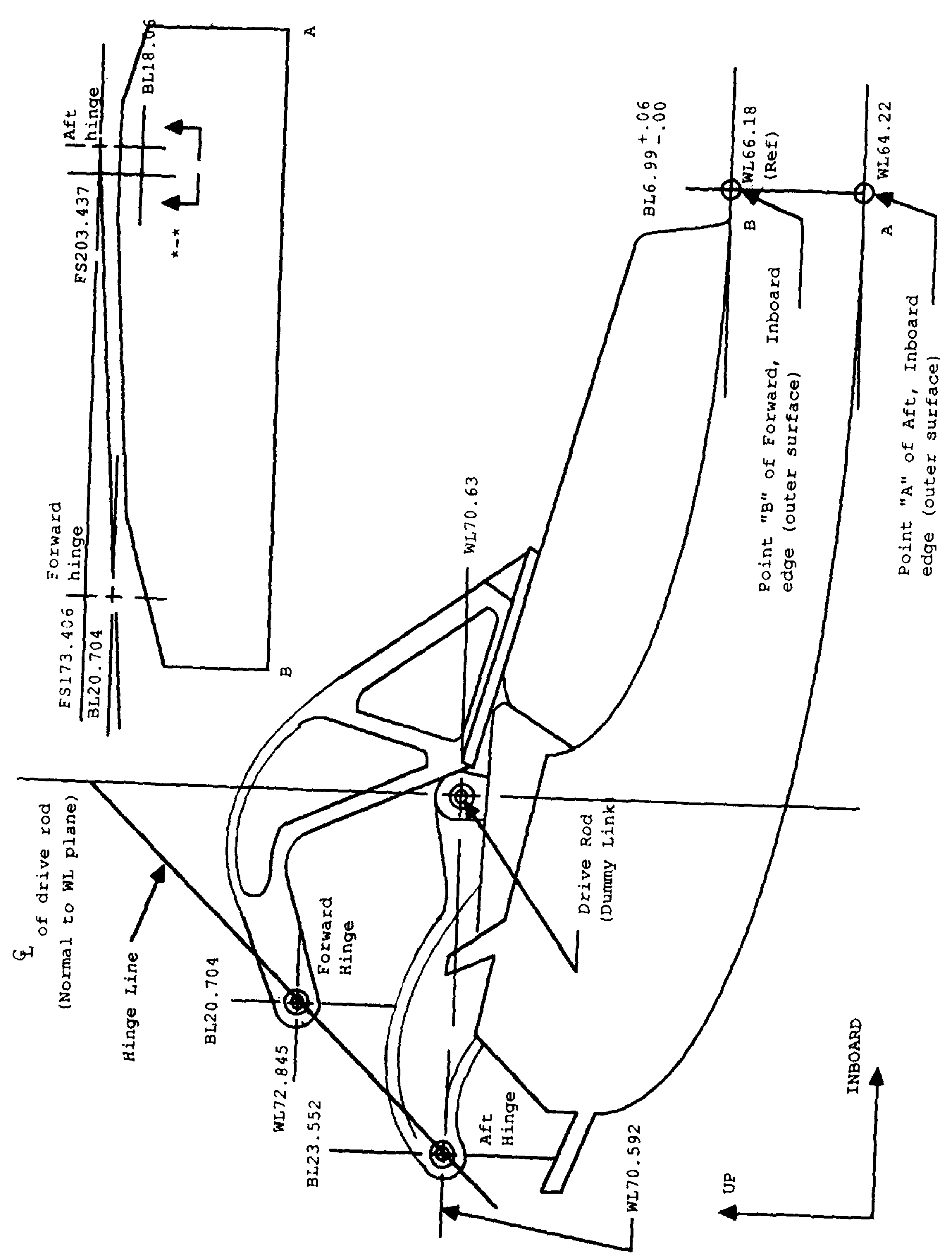


Figure C1-2a. Door Mounting Geometry AFT Door in Closed Position (Ref FRC DWG 160D136151)

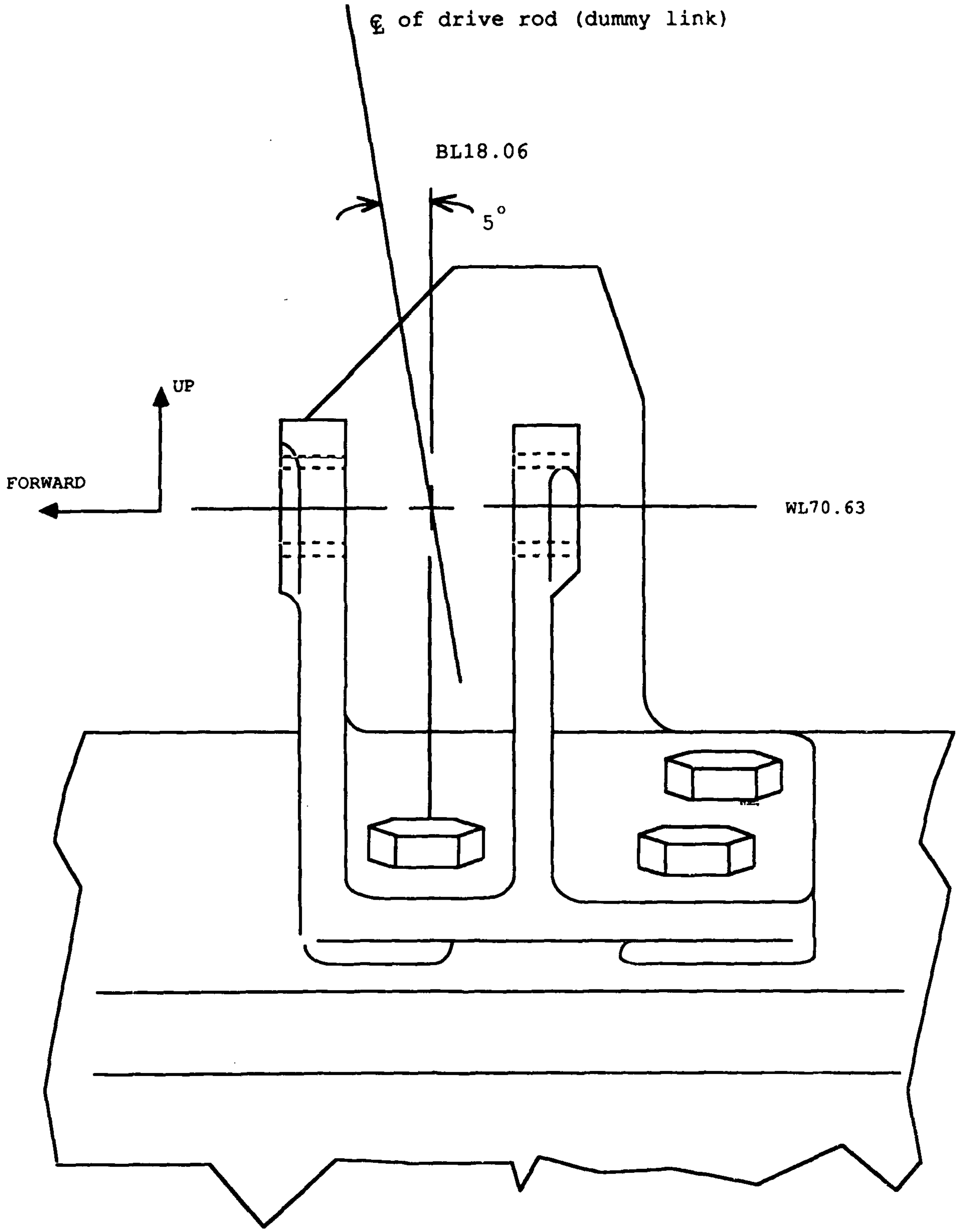


Figure C1-2b. View Looking Outboard

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