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REPORT NO. CASD-NAS-74-029
CONTRACT NAS 8-30665

(NASA-CR-120365) ROOM TEMPERATURE STRETCH FORMING OF SCALE SPACE SHUTTLE EXTERNAL TANK DOME GORES. VOLUME 1: TECHNICAL Final Report (General Dynamics/Convair) 47 p HC $5.50 CSCL 22B G3/31
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ROOM TEMPERATURE STRETCH FORMING OF SCALE SPACE SHUTTLE EXTERNAL TANK DOME GORES

VOLUME I ✦ TECHNICAL
FINAL REPORT

GENERAL DYNAMICS
Convair Division

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VOLUME I ✦ TECHNICAL

FINAL REPORT

June 1974

Submitted to
National Aeronautics and Space Administration
GEORGE C. MARSHALL SPACE FLIGHT CENTER
Science and Engineering Laboratory
Huntsville, Alabama 35812

Prepared by
GENERAL DYNAMICS CONVAIR DIVISION
P.O. Box. 80847
San Diego, California 92138

FOREWORD

This report was prepared by General Dynamics Convair Division under Contract NAS8-30665 (Exhibit B) "Room Temperature Stretch Forming of Scale Space Shuttle External Tank Dome Gores" for the George C. Marshall Space Flight Center of the National Aeronautics and Space Administration. The work was administered by M. A. Oliver (A & PS-PR-RD) and monitored by Messrs. E. D. Minter (S & E-PE-MWP) and V. H. Yost (S & E-PE-MWP). C. L. Bennett was the program manager.

Volume I (technical) of the report was prepared by R. D. Blunck and D. E. Krantz, and the report was approved by C. L. Bennett. The production flow chart and tooling requirements were contributed by R. E. Bruce.

Volume II of the report contains the cost study estimates required under this contract. The cost estimates were prepared by L. J. Pierce, J. A. Cherry and E. N. Yeaton, and the report was prepared by D. E. Krantz.

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SUMMARY

This document is the final technical report on "Room Temperature Stretch Forming of Scale Space Shuttle External Tank Dome Gores" under Contract NAS 8-30665 (Exhibit B). It gives an account of the performed tests, the results, and an analysis of the results. It also gives an account of a production cost study. The technical material is presented in Volume I of the report, and the cost study data is presented in Volume II.

The Phase I objective of the program was to prove the feasibility of room temperature stretch forming of approximate one-third scale bulkhead gores from premachined 2219-T37 aluminum alloy blanks. Three gores were successfully formed to an approximate one-third-scale, 12-gore, 355.6-cm (140-in.) diameter polar cap configuration of a typical 838.7-cm (330.2-in.) diameter bulkhead, thereby demonstrating feasibility. The three gores were shipped to NASA MSFC and received by NASA, MSFC on June 21, 1974.

The Phase II cost study objectives were to: a) prepare a typical full-scale production STFM die design, and determine the cost of all tooling required to manufacture seven gore configurations at the required production rates, and, b) determine the production cost per gore for the seven configurations at the required production rates to manufacture, package, and ship these gores to NASA's Michoud Assembly Facility. All of the Phase II objectives were achieved.

SECTION 1

INTRODUCTION

This report is an account of activities and data gathered in the Room Temperature Stretch Forming of One-third Scale External Tank Bulkhead Gores for Space Shuttle study, and a tooling design and production cost study.

The objectives of the studies were to:

a. Stretch form (at room temperature) three approximately one-third-scale external tank (ET) dome gores from single sheets of 2219-T37 aluminum alloy, for Marshall Space Flight Center testing and evaluation.

b. Design a full-scale production die, and determine the cost of all tooling required to manufacture, using the room-temperature stretch forming (RTSF) process, ET dome gores at the required production rates.

c. Determine the cost per gore, at the required production rates, to manufacture, package, and ship these gores to NASA's Michoud Assembly Facility.

The program was divided into phases and tasks:

Phase I - Manufacture, Documentation, and Delivery of Three One-third-Scale Room Temperature Stretch Formed External Tank Dome Gores

Of particular concern in this study is the amount of material that must be trimmed away after room temperature stretch forming. Reusable ends were welded on two gores before forming, demonstrating material reduction possibilities. The 12 gore 355.6 cm (140 in.) polar cap configuration was scaled down approximately one-third and used for the stretch forming test.

Phase II - Production Die Design, Tooling Cost Study, and Production Cost Study

Task A - Production Die Design

Task B - Tooling Cost Study

Task C - Production Cost Study

SECTION 2

PHASE I - ROOM TEMPERATURE STRETCH FORMING OF ONE-THIRD-SCALE EXTERNAL TANK BULKHEAD GORE

2.1 ROOM TEMPERATURE STRETCH FORMING

The bulkhead gore for the Space Shuttle External Tank is described by an ellipse rotated about its minor axis.

The longitudinal stretch forming process consists of two stages. The first is a wrapping or single-curvature bending of the blank over the die, where the blank is in contact with the crown of the die over the entire length. To impart this curvature permanently to the blank, the steps shown in Figure 2-1 must occur.

For thin materials, such as those being considered for the bulkhead gores, the strain required to accomplish this action is small in comparison with the strain required during the second stage of forming.

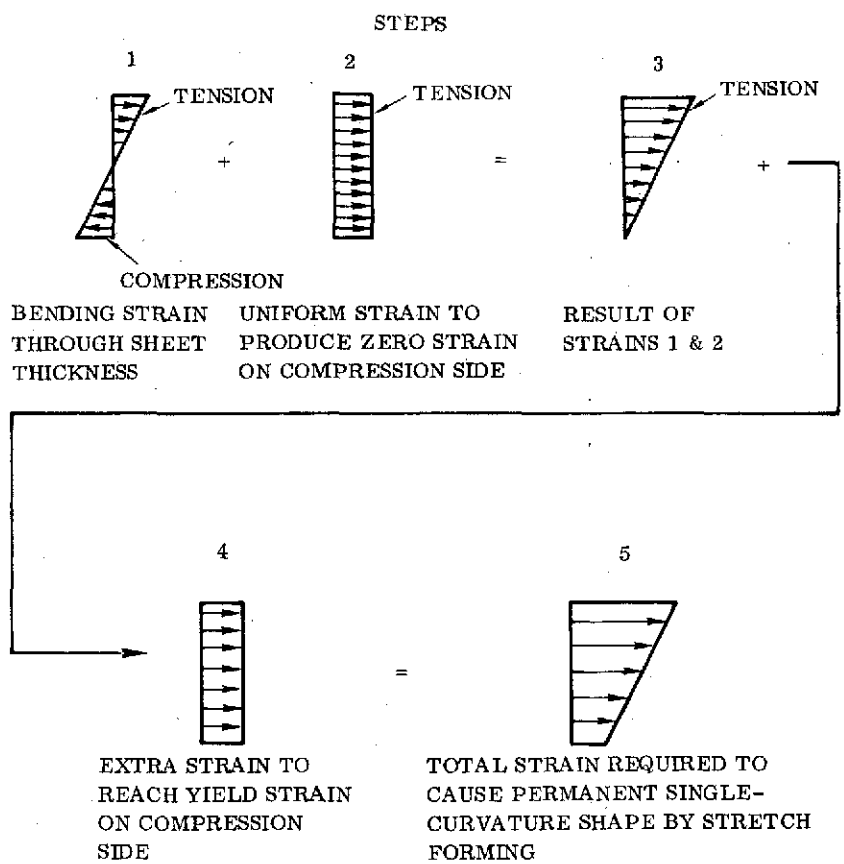


Figure 2-1. Single-Curvature Bending

The second stage consists of stretching the material in contact with the die crown area and allowing the side material to drop down with respect to the crown. Elongation required to accomplish this forming is dependent on the die radius in the stretch form direction and the height differential between the crown and the edge of the part as shown in Figure 2-2.

The last point along the edge to touch the die has the least elongation. If the stretch forming process were stopped just as this point touched, the elongation at this point would be zero. With the unloading of the blank, this point would spring away from the die. To avoid this springback, the part must be further stretched to reach the material yield strain in the edge element.

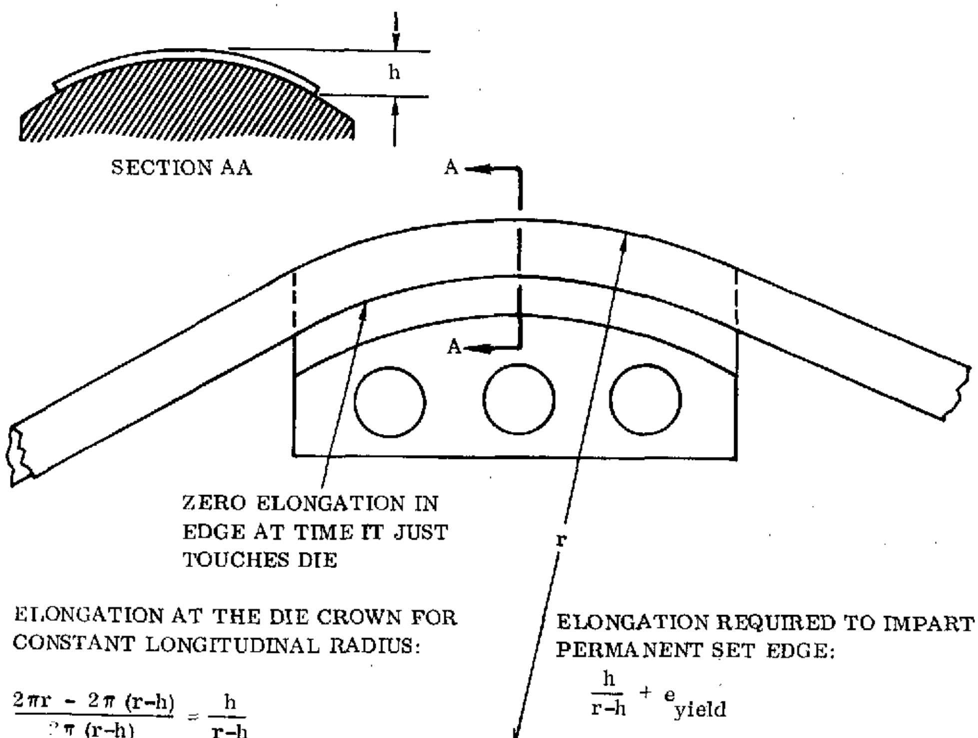
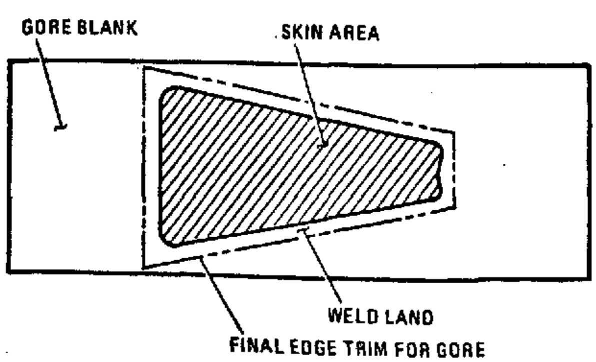
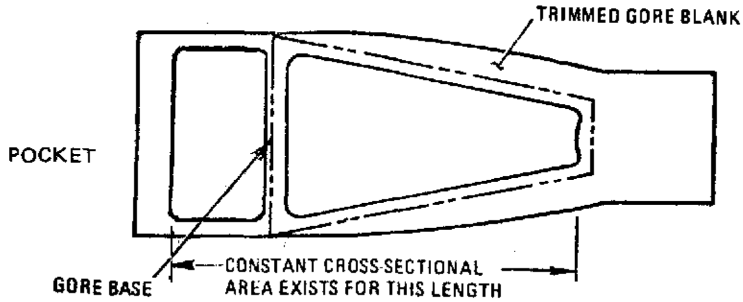


Figure 2-2. Compound-Curvature Forming



To reduce fabrication costs and decrease stretch-pull tonnage requirements, the blanks are premachined. Basic blank thickness is determined by the maximum required weld land thickness. The blank is then machined, in the flat, to produce the gore skin-weld shape and thickness.



Further machining is required to produce a relatively constant cross-sectional area throughout the stretch form length, and a pocket is machined at the base end having the same cross-sectional area.

The purpose of this pocketed area at the base of the gore is to allow the material to stretch in this area, thereby in effect, allowing a small amount of material draw to occur in the center of the gore base end. If this pocket is not machined in the blank, no material draw will occur during stretch forming, and the amount of stretch in the center at the base end will be slightly higher. Previous gore stretch forming tests with and without the machined pocket have proven this to be true.

2.2 LONGITUDINAL STRETCH FORMING MACHINE CAPABILITY AT CONVAIR

The stretch forming press used to stretch form the three one-third-scale test gores was a 500-ton Sheridan-Gray stretch press that is located at Building 5, Column C-16 at the Kearny Mesa Plant, San Diego. It's versatility is shown in the following data:

Maximum Tensile Force	500 ton
Jaw Width	254 cm (100 inches) in seven segments
Jaw Travel	91.44 cm (36 inches) each jaw
Distance Between Jaws	243.84 cm (96 inches) minimum 1259.84 cm (496 inches) maximum

(The six outboard segments can be positioned to curve the jaws.)

Strain Rates	5.08 to 101.60 cm (2 to 40 inches) per minute
Number of Die Tables	3 (usually used together)
Die Table Size	60.96 cm (20 inches) by 254 cm (100 inches) each
Longitudinal Die Table Capacity	182 cm (72 inches) minimum 1097.28 cm (432 inches) maximum
Die Table Vertical Travel	91.44 cm (36 inches)

2.3 NUMERICAL CONTROL (N/C) MACHINING OF GORE BLANKS

The gore blanks were machined from 2219 aluminum alloy on hand at Convair. Two of the sheets were mill processed 2219-T37 0.635 cm (0.250 in.) thick by 152.4 cm (60 in.) wide by 304.8 cm (120 in.) long. The third sheet was 2219-T87 0.635 cm (0.25 in.) by 121.92 cm (48 in.) by 365.76 cm (144 in.). The third sheet was re-solution treated, quenched, and stretched 7% before machining. Although this sheet meets MIL-A-8920 minimum properties, it is not typical of mill supplied 2219-T37 material. Limited tensile data available indicates mill supplied 2219-T37 has 3 to 5% more available elongation than the material in the third sheet.

The blanks were milled to a scale factor of 838.7 cm (330.2 in.) full-size dome diameter divided by 304.8 cm (120 in.) Atlas dome diameter or SF=2.75. Thus the blanks are 36.3% of the full-scale gore. All dimensions were held to this scale except the thickness dimensions. It was decided that the minimum thickness of the scaled gores should be 0.070 inch to avoid the possibility of failure due to reduced elongation in thin sheets; therefore, the scale factor used for the material thickness is the minimum full-size LO_2 tank skin thickness of 0.297 cm (0.117 in.) divided by 0.178 cm (0.070 in.) or SF = 1.67. The tapered weld land thicknesses were also scaled down using the 1.67 SF. Thus, all blank thickness dimensions are 59.8% of full size.

A flat layout drawing of the one-third-scale LO_2 tank gore was given to the Numerical Control (N/C) Department for preparation of the N/C program. Figure 2-3 shows the gore blank layout giving both flat dimensions and thicknesses. The blanks were held in place with a vacuum chuck plate on a Giddings and Lewis skin mill at USAF Plant 19. Multiple passes were made to ensure quality of finish. During the milling of the first blank (Sheet C), N/C programming error was encountered and the tape had to be revised. Some hand blending was done on Sheet C because of this error but was not necessary on Sheets A and B after tape revision. Figure 2-4 shows Sheet C being milled at USAF Plant 19, San Diego.

2.4 WELD STRENGTH VERIFICATION TESTS AND GORE BLANK WELDING

Four tensile bars were fabricated and tested of transverse hand welded 2219-T37 aluminum 0.635 cm (0.25 in.) thick taken from excess material of Blanks A and B. The purpose of these tests was to verify that the yield-ultimate weld strength was much greater than the stress applied to the gore welds during stretch forming. It was calculated that the stress on the weld during gore stretch forming will be approximately 1195.27 kg/cm^2 (17,000 psi), while the results of these tensile tests showed an average ultimate strength of 2812.4 kg/cm^2 (40,000 psi) in the weld area, and an average yield strength of 1617.13 kg/cm^2 (23,000 psi); therefore, weld failure should not occur.

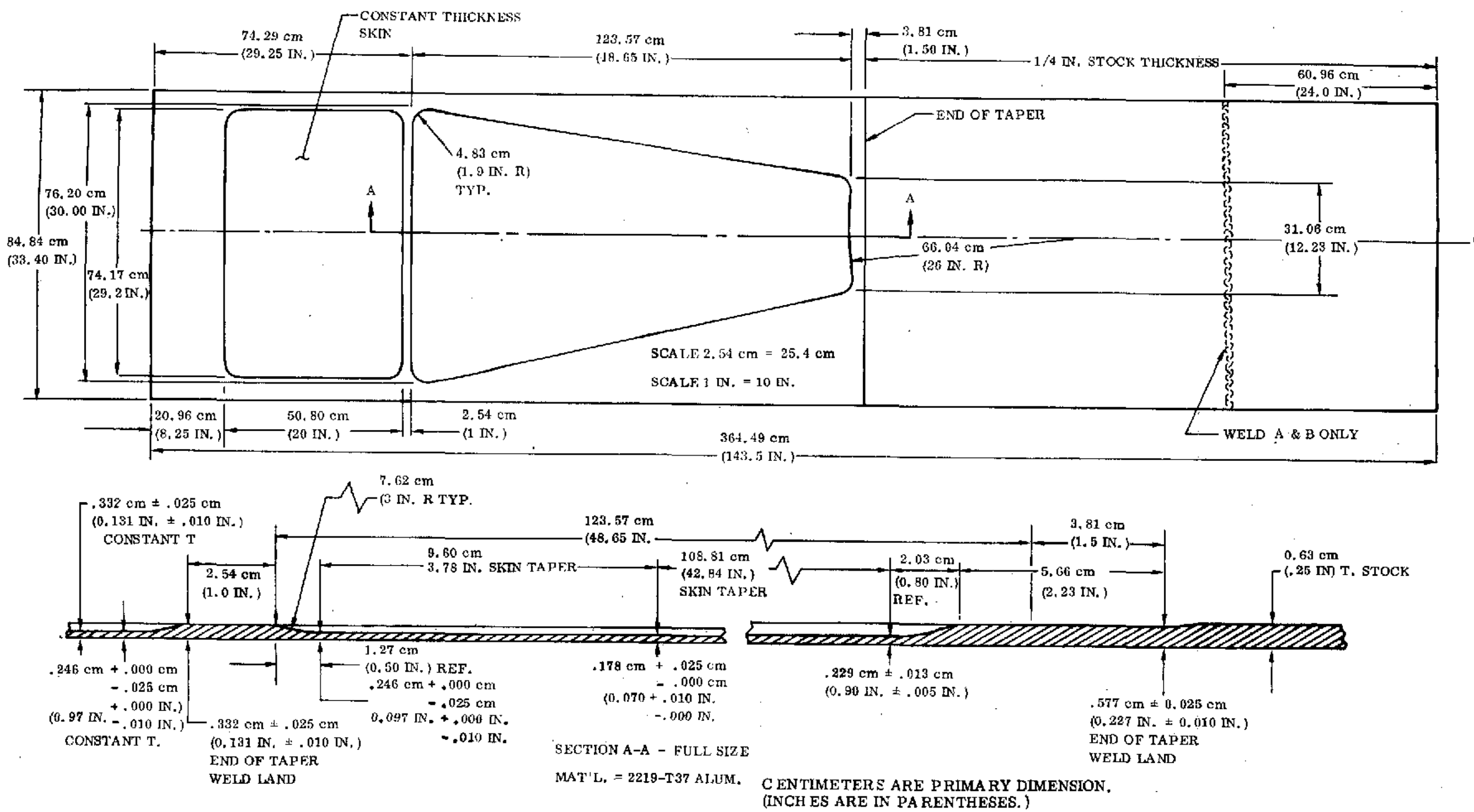


Figure 2-3. STFM Blank for 12-Gore LO_2 Bulkhead

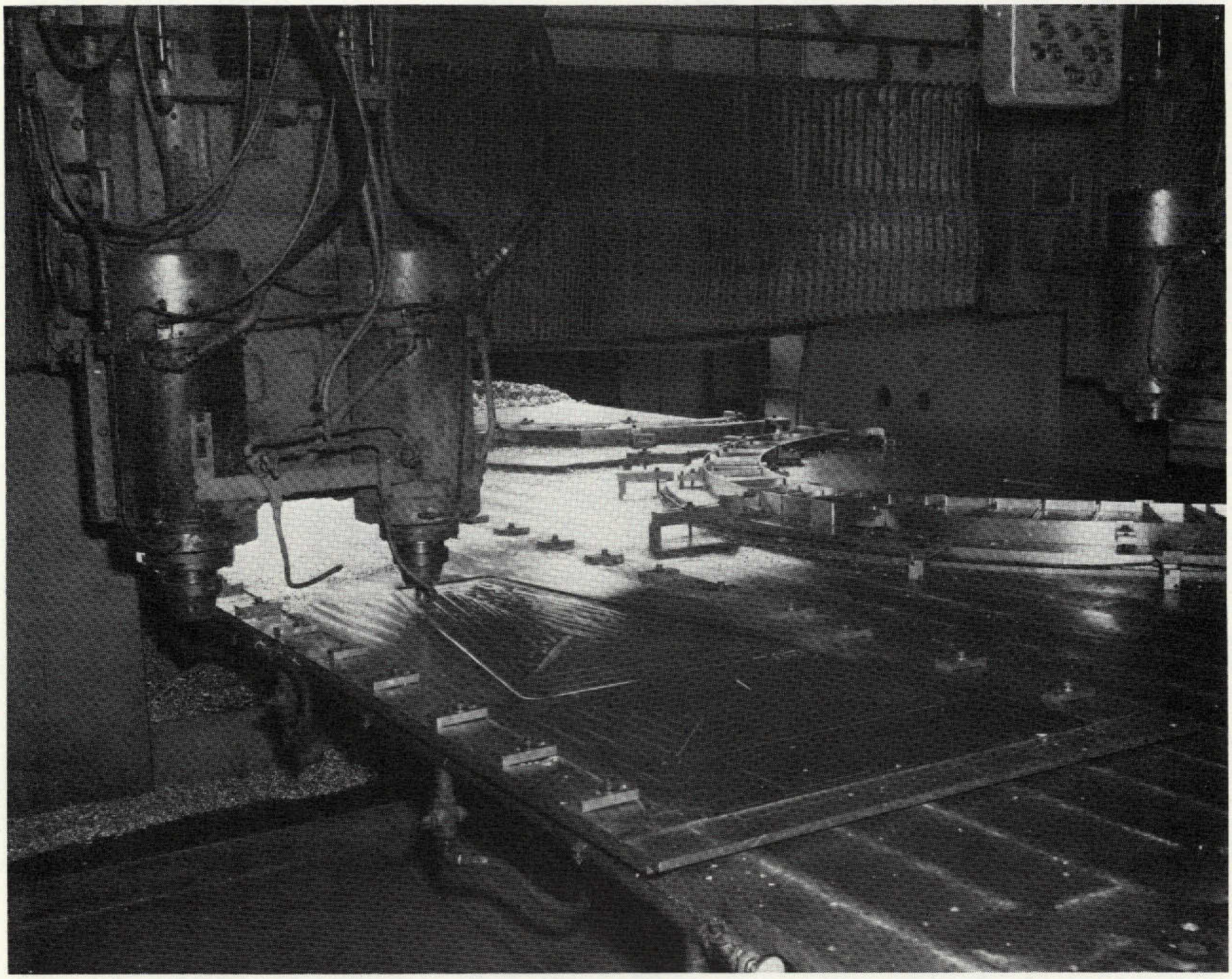


Figure 2-4. Gore Blank Sheet C on Skin Mill - USAF Plant 19

A 60.96-cm (24-in.) wide strip of cutoff material from Blanks A and B was welded onto gore Blanks A and B using the same edge preparation and hand welding technique that were used for the tensile specimens. The grain direction of the welded-on strips was perpendicular to the gore blank grain direction. Figure 2-3 shows the location of the weld on the gore blanks.

2.5 PRE-FORMING THICKNESS INSPECTION

Following the milling operation a grid system was marked on each gore blank. This system, shown in Figure 2-5, was made up of inspection locations in a 10.16 by 10.16 cm (4 by 4 in.) grid. Additional inspection locations were marked as required for added accuracy, and each location was identified by a station and line number. The thickness of material at each inspection location was determined with a Panametrics Model 5221 ultrasonic gauge, using both the delay line transducer and broad band contact transducer, and random readings were verified by a sheet metal micrometer. Table 2-1 shows the results of this pre-forming thickness inspection for all three blanks.

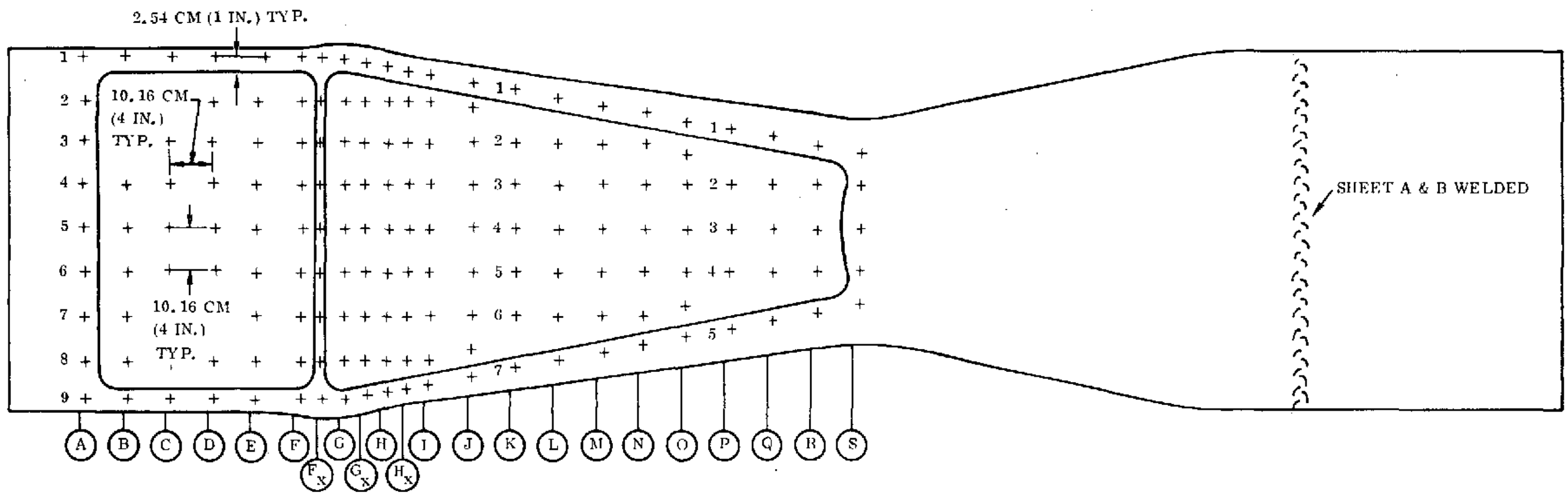


Figure 2-5. Thickness Inspection Locations

Table 2-1. Pre-forming Thickness Inspection, Sheets A, B, and C

Gore Blank	Line		A	B	C	D	E	F	Fx	G	Gx	H	Hx	I	J	K	L	M	N	O	P	Q	R	S
			Station																					
Blank A	1	mm	3.52	3.44	3.42	3.44	3.48	3.45	3.40	3.50	3.59	3.73	3.83	3.89	4.02	4.27	4.45	4.69	4.83	5.00	5.16	5.31	5.59	5.69
		(in.)	(.139)	(.135)	(.134)	(.135)	(.137)	(.136)	(.134)	(.138)	(.141)	(.147)	(.151)	(.153)	(.158)	(.168)	(.175)	(.184)	(.190)	(.197)	(.203)	(.209)	(.220)	(.224)
	2	mm	3.55	2.46	2.46	2.48	2.49	2.51	3.40	2.21	2.22	2.13	2.13	2.17	2.20	2.24	2.26	2.26	2.31	2.31	2.32	2.33	2.35	5.74
		(in.)	(.140)	(.097)	(.097)	(.097)	(.098)	(.099)	(.134)	(.087)	(.087)	(.084)	(.084)	(.085)	(.086)	(.088)	(.089)	(.089)	(.091)	(.091)	(.091)	(.092)	(.092)	(.226)
	3	mm	3.51	2.41	2.48	2.46	2.51	2.50	3.43	2.27	2.21	2.12	2.15	2.11	2.17	2.26	2.26	2.30	2.30	2.35	2.29	2.29	2.32	5.69
		(in.)	(.138)	(.095)	(.097)	(.097)	(.099)	(.098)	(.135)	(.089)	(.087)	(.083)	(.084)	(.083)	(.085)	(.089)	(.089)	(.090)	(.090)	(.092)	(.090)	(.090)	(.091)	(.224)
	4	mm	3.44	2.45	2.48	2.49	2.51	2.51	3.51	2.36	2.22	2.12	2.15	2.20	2.12	2.15	2.17	2.21	2.20	2.22	2.24	2.27	2.30	5.72
		(in.)	(.135)	(.096)	(.097)	(.098)	(.099)	(.099)	(.138)	(.093)	(.087)	(.083)	(.084)	(.086)	(.083)	(.084)	(.085)	(.087)	(.086)	(.087)	(.088)	(.089)	(.090)	(.225)
	5	mm	3.41	2.45	2.48	2.49	2.51	2.50	3.48	2.31	2.21	2.12	2.11	2.18	2.21	2.15	2.13	2.15	2.16	2.21	5.08	5.28	5.46	5.69
		(in.)	(.134)	(.096)	(.097)	(.098)	(.099)	(.098)	(.137)	(.091)	(.087)	(.083)	(.083)	(.086)	(.087)	(.084)	(.084)	(.084)	(.085)	(.087)	(.200)	(.208)	(.215)	(.224)
	6	mm	3.43	2.43	2.45	2.46	2.45	2.49	3.44	2.26	2.18	2.10	2.04	2.13	2.15	2.04	2.10	2.11	2.16	2.21				
		(in.)	(.135)	(.095)	(.096)	(.097)	(.096)	(.098)	(.135)	(.089)	(.086)	(.082)	(.080)	(.084)	(.084)	(.080)	(.082)	(.083)	(.085)	(.087)				
	7	mm	3.44	2.41	2.44	2.44	2.45	2.46	3.34	2.25	2.13	2.06	2.06	2.04	2.06	4.19	4.37	4.57	4.76	4.94				
		(in.)	(.136)	(.095)	(.096)	(.096)	(.096)	(.097)	(.131)	(.088)	(.084)	(.081)	(.081)	(.080)	(.081)	(.165)	(.172)	(.180)	(.187)	(.194)				
	8	mm	3.49	2.44	2.44	2.45	2.46	2.44	3.38	2.24	2.16	2.06	2.06	2.03	2.01									
		(in.)	(.137)	(.096)	(.096)	(.096)	(.097)	(.096)	(.133)	(.088)	(.085)	(.081)	(.081)	(.080)	(.079)									
	9	mm	3.51	3.45	3.29	3.31	3.31	3.31	3.24	3.35	3.45	3.58	3.62	3.68	3.87									
		(in.)	(.138)	(.136)	(.129)	(.130)	(.130)	(.130)	(.127)	(.132)	(.136)	(.141)	(.142)	(.145)	(.152)									
Blank B	1	mm	3.50	3.40	3.30	3.35	3.39	3.34	3.30	3.42	3.50	3.67	3.75	3.77	4.00	4.28	4.43	4.70	4.83	4.99	5.16	5.31	5.59	5.69
		(in.)	(.138)	(.134)	(.130)	(.132)	(.133)	(.131)	(.130)	(.134)	(.138)	(.144)	(.147)	(.148)	(.157)	(.168)	(.174)	(.185)	(.190)	(.196)	(.203)	(.209)	(.220)	(.224)
	2	mm	3.57	2.44	2.46	2.46	2.48	2.50	3.35	2.24	2.24	2.11	2.16	2.12	2.20	2.22	2.24	2.25	2.30	2.31	2.31	2.35	2.35	5.75
		(in.)	(.140)	(.096)	(.097)	(.097)	(.097)	(.098)	(.132)	(.088)	(.088)	(.083)	(.085)	(.083)	(.086)	(.087)	(.088)	(.088)	(.090)	(.091)	(.091)	(.092)	(.092)	(.226)
	3	mm	3.48	2.41	2.45	2.44	2.48	2.48	3.43	2.25	2.20	2.08	2.12	2.07	2.18	2.25	2.26	2.29	2.30	2.33	2.29	2.31	2.33	5.75
		(in.)	(.137)	(.095)	(.096)	(.096)	(.097)	(.097)	(.135)	(.088)	(.086)	(.082)	(.083)	(.081)	(.086)	(.088)	(.089)	(.090)	(.090)	(.092)	(.090)	(.091)	(.092)	(.226)
	4	mm	3.43	2.43	2.44	2.46	2.49	2.50	3.47	2.31	2.22	2.08	2.13	2.17	2.11	2.13	2.16	2.20	2.21	2.21	2.22	2.25	2.30	5.77
		(in.)	(.135)	(.095)	(.096)	(.097)	(.098)	(.098)	(.136)	(.091)	(.087)	(.082)	(.084)	(.085)	(.083)	(.084)	(.085)	(.086)	(.087)	(.087)	(.087)	(.088)	(.090)	(.227)
	5	mm	3.40	2.40	2.45	2.45	2.46	2.49	3.45	2.26	2.21	2.08	2.12	2.15	2.22	2.12	2.13	2.16	2.17	2.20	5.03	5.26	5.49	5.64
		(in.)	(.134)	(.094)	(.096)	(.096)	(.097)	(.098)	(.136)	(.089)	(.087)	(.082)	(.083)	(.084)	(.087)	(.083)	(.084)	(.085)	(.085)	(.086)	(.198)	(.207)	(.216)	(.222)
	6	mm	3.35	2.37	2.43	2.44	2.45	2.44	3.43	2.25	2.18	2.06	2.07	2.11	2.12	2.03	2.06	2.08	2.16	2.16				
		(in.)	(.132)	(.093)	(.095)	(.096)	(.096)	(.096)	(.135)	(.088)	(.086)	(.081)	(.081)	(.083)	(.083)	(.080)	(.081)	(.082)	(.085)	(.085)				
	7	mm	3.40	2.38	2.41	2.41	2.41	2.33	3.28	2.20	2.10	2.01	2.03	2.04	2.01	4.15	4.37	4.57	4.73	4.94				
		(in.)	(.134)	(.093)	(.095)	(.095)	(.095)	(.092)	(.129)	(.086)	(.082)	(.079)	(.080)	(.080)	(.079)	(.163)	(.172)	(.180)	(.186)	(.194)				
	8	mm	3.48	2.40	2.38	2.41	2.41	2.41	3.28	2.20	2.13	2.01	2.02	1.98	1.99									
		(in.)	(.137)	(.094)	(.093)	(.095)	(.095)	(.095)	(.129)	(.086)	(.084)	(.079)	(.079)	(.078)	(.078)									
	9	mm	3.52	3.40	3.25	3.30	3.34	3.30	3.33	3.39	3.48	3.59	3.64	3.68	3.85									
		(in.)	(.138)	(.134)	(.128)	(.130)	(.131)	(.130)	(.131)	(.133)	(.137)	(.141)	(.143)	(.145)	(.151)									
Blank C	1	mm	3.48	3.33	3.30	3.38	3.43	3.40	3.35	3.40	3.50	3.60	3.71	3.78	4.01	4.19	4.37	4.57	4.75	4.90	5.08	5.21	5.54	5.44
		(in.)	(.137)	(.131)	(.130)	(.133)	(.135)	(.134)	(.132)	(.134)	(.138)	(.142)	(.146)	(.149)	(.158)	(.165)	(.172)	(.180)	(.187)	(.193)	(.200)	(.205)	(.218)	(.214)
	2	mm	3.48	2.21	2.18	2.21	2.24	2.24	3.35	2.08	2.11	2.01	2.03	2.01	2.06	2.13	2.18	2.18	2.16	2.24	2.29	2.26	2.31	5.44
		(in.)	(.137)	(.087)	(.086)	(.087)	(.088)	(.088)	(.132)	(.082)	(.083)	(.079)	(.080)	(.079)	(.081)	(.084)	(.086)	(.086)	(.085)	(.088)	(.090)	(.089)	(.091)	(.214)
	3	mm	3.45	2.18	2.21	2.24	2.21	2.24	3.38	2.18	2.13	2.06	2.03	2.06	2.08	2.16	2.18	2.21	2.24	2.26	2.21	2.24	2.26	5.46
		(in.)	(.136)	(.086)	(.087)	(.088)	(.087)	(.088)	(.133)	(.086)	(.084)	(.081)	(.080)	(.081)	(.082)	(.085)	(.086)	(.087)	(.088)	(.089)	(.087)	(.088)	(.089)	(.215)
	4	mm	3.38	2.21	2.21	2.24	2.24	2.24	3.45	2.26	2.13	2.06	2.03	2.08	2.06	2.08	2.08	2.11	2.16	2.18	2.18	2.24	2.26	5.44
		(in.)	(.133)	(.087)	(.087)	(.088)	(.088)	(.088)	(.136)	(.189)	(.084)	(.081)	(.080)	(.082)	(.081)	(.082)	(.082)	(.083)	(.085)	(.086)	(.086)	(.088)	(.089)	(.214)
	5	mm	3.35	2.18	2.21	2.21	2.24	2.24	3.43	2.26	2.13	2.03	2.06	2.06	2.11	2.06	2.06	2.08	2.13	2.16	5.05	5.23	5.44	5.46
		(in.)	(.132)	(.086)	(.087)	(.087)	(.088)	(.088)	(.135)	(.089)	(.084)	(.080)	(.081)	(.081)	(.183)	(.081)	(.081)	(.082)	(.084)	(.085)	(.199)	(.206)	(.214)	(.215)
	6	mm	3.33	2.16	2.18	2.18	2.18	2.24	3.40	2.21	2.11	2.01	2.01	2.03	2.06	1.98	2.01	2.06	2.08	2.11				
		(in.)	(.131)	(.085)	(.086)	(.086)	(.086)	(.088)	(.134)	(.187)	(.083)	(.079)	(.079)	(.080)	(.081)	(.078)	(.079)	(.081)	(.082)	(.083)				
	7	mm	3.38	2.16	2.16	2.16	2.16	2.16	3.40	2.18	2.08	2.01	1.98	2.01	2.01	4.11	4.32	4.52	4.70	4.88				
		(in.)	(.133)	(.085)	(.085)	(.085)	(.085)	(.085)	(.134)	(.086)	(.082)	(.079)	(.078)	(.079)	(.079)	(.162)	(.170)	(.178)	(.185)	(.192)				
	8	mm	3.43	2.16	2.16	2.16	2.16	2.16	3.33	2.16	2.11	2.01	1.96	1.93	1.91									
		(in.)	(.135)	(.085)	(.085)	(.085)	(.085)	(.085)	(.131)	(.085)	(.083)	(.079)	(.077)	(.076)	(.075)									
	9	mm	3.45	3.38	3.30	3.28	3.28	3.28	3.20	3.25	3.38	3.53	3.60	3.71	3.91									
		(in.)	(.136)	(.133)	(.130)	(.129)	(.129)	(.128)	(.126)	(.128)	(.133)	(.139)	(.142)	(.146)	(.154)									

FOLDOUT FRAME 1

FOLDOUT FRAME 2

2.6 TRIMMING OF GORE BLANKS

Average thicknesses for each station were calculated using the results of the pre-forming thickness inspection. Knowing average thicknesses, width of the pocket, and average weld-land width and thickness, a standard cross-sectional area was determined for each gore blank. The weld-land cross-sectional area for each station was varied to maintain constant cross-sectional area from Station B through R, with the exclusion of Station Fx. Table 2-2 shows average pocket and weld-land thicknesses and widths for each station of each gore blank. The same cross-sectional area is maintained over the length of the gore to provide uniform elongation during the forming process. During the milling of Blanks A and B one edge was trimmed too close to the milled pocket to permit the desired land width of 5.08 cm (2 in.) to be maintained. This error decreased the cross-sectional area for these two blanks, and thus reducing the width of the weld land.

2.7 ELONGATION GRIDDING OF GORE BLANKS

A 5.05 cm (1.99 in.) elongation inspection circle was scribed about each thickness inspection location. A circular grid system was chosen over a square grid system because it is nondirectional. A circle is always correctly oriented to furnish the maximum elongation directly. During forming, the circles are deformed into ellipses where strain is high, and the major axes of these ellipses indicate the direction of maximum strain. Elongation in the longitudinal and transverse directions was determined by this deformation. Figure 2-6 shows the trim lines on the left and right of the photo, the thickness inspection locations, and elongation inspection circles. Figure 2-7 shows the location of each elongation circle and call-out of station and line numbers.

2.8 ONE-THIRD-SCALE GORE DIE AND SUBSTRUCTURE

An existing Atlas bulkhead gore die at General Dynamics Convair Division, San Diego, was used to produce the approximately one-third-scale gores required for test and evaluation. The stretch form die was placed atop a substructure shown in Figure 2-8. This structure was needed to obtain the vertical height necessary for the operation. The majority of the vertical height was obtained by using an existing die support and the remaining structure was constructed of six I-beams that were welded together for stability.

2.9 STRETCH FORMING OF ONE-THIRD-SCALE GORES

The die and substructure were centered and secured in place for forming, and the three gores were successfully stretch formed the morning of June 6, 1974. The sequence in which the gores were formed was: Gore C, Gore B, and Gore A.

Table 2-2. Weld-Land Width Data

			Station																					
			A	B	C	D	E	F	Fx	G	Gx	H	Hx	I	J	K	L	M	N	O	P	Q	R	S
Blank A	Average Pocket Thickness	mm	0	2.44	2.46	2.46	2.49	2.49	0	2.26	2.18	2.11	2.11	2.13	2.13	2.16	2.18	2.21	2.24	2.26	2.29	2.29	2.31	0
		(in.)	0	(.096)	(.097)	(.097)	(.098)	(.098)	0	(.089)	(.086)	(.083)	(.083)	(.084)	(.084)	(.085)	(.086)	(.087)	(.088)	(.089)	(.090)	(.090)	(.091)	0
	Pocket Width	cm	0	74.24	74.24	74.24	74.27	74.30	0	74.50	73.00	71.27	69.49	67.56	63.88	61.00	56.52	52.83	49.15	45.39	41.66	37.97	34.24	0
		(in.)	0	(29.23)	(29.23)	(29.23)	(29.24)	(29.25)	0	(29.33)	(28.74)	(28.06)	(27.36)	(26.60)	(25.15)	(23.70)	(22.25)	(20.80)	(19.35)	(17.87)	(16.40)	(14.95)	(13.48)	0
	Average Weld-land Thickness	mm	3.48	3.45	3.35	3.38	3.40	3.38	3.40	3.43	3.53	3.66	3.73	3.78	3.96	4.24	4.42	4.62	4.80	4.98	5.13	5.31	5.54	5.72
		(in.)	(.137)	(.136)	(.132)	(.133)	(.134)	(.133)	(.134)	(.135)	(.139)	(.144)	(.147)	(.149)	(.156)	(.167)	(.174)	(.182)	(.189)	(.196)	(.202)	(.209)	(.218)	(.225)
	Weld-land Width	cm	2.72	2.72	2.51	2.44	2.21	2.16	3.28	4.42	5.61	6.78	7.16	7.34	7.98	8.08	8.53	8.86	9.27	9.60	10.03	10.41	10.67	10.67
		(in.)	(1.07)	(1.07)	(.99)	(.96)	(.87)	(.85)	(1.29)	(1.74)	(2.21)	(2.67)	(2.82)	(2.89)	(3.14)	(3.18)	(3.36)	(3.49)	(3.65)	(3.78)	(3.95)	(4.10)	(4.20)	(4.20)
Blank B	Average Pocket Thickness	mm	0	2.41	2.44	2.44	2.46	2.46	0	2.24	2.18	2.06	2.08	2.08	2.11	2.16	2.16	2.18	2.24	2.24	2.26	2.31	2.34	0
		(in.)	0	(.095)	(.096)	(.096)	(.097)	(.097)	0	(.088)	(.086)	(.081)	(.082)	(.082)	(.083)	(.085)	(.085)	(.086)	(.088)	(.088)	(.089)	(.091)	(.092)	0
	Pocket Width	cm	0	74.30	74.30	74.32	74.35	74.37	0	74.52	72.95	71.22	69.49	67.62	63.86	60.25	56.54	52.83	49.17	45.42	41.71	37.95	34.29	0
		(in.)	0	(29.25)	(29.25)	(29.26)	(29.27)	(29.28)	0	(29.34)	(28.72)	(28.04)	(27.36)	(26.62)	(25.14)	(23.72)	(22.26)	(20.80)	(19.36)	(17.88)	(16.42)	(14.94)	(13.50)	0
	Average Weld-land Thickness	mm	3.40	3.28	3.33	3.35	3.33	3.33	3.38	3.40	3.51	3.63	3.71	3.73	3.94	4.22	4.39	4.65	4.78	4.95	5.11	5.28	5.54	5.72
		(in.)	(.134)	(.129)	(.131)	(.132)	(.131)	(.131)	(.133)	(.134)	(.138)	(.143)	(.146)	(.147)	(.155)	(.166)	(.173)	(.183)	(.188)	(.195)	(.201)	(.208)	(.218)	(.225)
	Weld-land Width	cm	2.58	2.58	2.37	2.25	2.04	2.09		4.26	5.28	6.77	6.82	7.30	7.68	7.80	8.24	8.52	8.91	9.35	9.78	10.12	10.32	10.32
		(in.)	(1.02)	(1.02)	(.93)	(.89)	(.80)	(.82)	(1.25)	(1.68)	(2.08)	(2.67)	(2.69)	(2.87)	(3.03)	(3.07)	(3.24)	(3.36)	(3.51)	(3.68)	(3.85)	(3.98)	(4.06)	(4.06)
Blank C	Average Pocket Thickness	mm	0	2.18	2.18	2.21	2.21	2.21	0	2.18	2.11	2.03	2.01	2.03	2.03	2.08	2.11	2.13	2.16	2.18	2.24	2.24	2.26	0
		(in.)	0	(.086)	(.086)	(.087)	(.087)	(.087)	0	(.086)	(.083)	(.080)	(.079)	(.080)	(.080)	(.082)	(.083)	(.084)	(.085)	(.086)	(.088)	(.088)	(.089)	0
	Pocket Width	cm	0	74.17	74.17	74.17	74.17	74.17	0	74.81	72.72	71.12	69.54	67.46	63.83	60.17	56.36	52.71	49.05	45.42	41.61	36.10	34.29	0
		(in.)	0	(29.20)	(29.20)	(29.20)	(29.20)	(29.20)	0	(29.06)	(28.63)	(28.00)	(27.38)	(26.56)	(25.13)	(23.69)	(22.19)	(20.75)	(19.31)	(17.88)	(16.38)	(15.00)	(13.50)	0
	Average Weld-land Thickness	mm	3.40	3.35	3.30	3.33	3.35	3.33	3.38	3.33	3.45	3.56	3.66	3.76	3.96	4.17	4.34	4.55	4.72	4.90	5.05	5.23	5.49	5.44
		(in.)	(.134)	(.132)	(.130)	(.131)	(.132)	(.131)	(.133)	(.131)	(.136)	(.140)	(.144)	(.148)	(.156)	(.164)	(.171)	(.179)	(.186)	(.193)	(.199)	(.206)	(.216)	(.214)
	Weld-land Width	cm	5.33	5.33	5.31	5.13	5.05	5.03	5.16	5.31	6.30	7.49	7.77	8.05	8.43	8.59	8.99	9.25	9.58	9.86	10.19	10.57	10.69	10.69
		(in.)	(2.10)	(2.10)	(2.09)	(2.02)	(1.99)	(1.98)	(2.03)	(2.09)	(2.48)	(2.95)	(3.06)	(3.17)	(3.32)	(3.38)	(3.54)	(3.64)	(3.77)	(3.88)	(4.01)	(4.16)	(4.21)	(4.21)

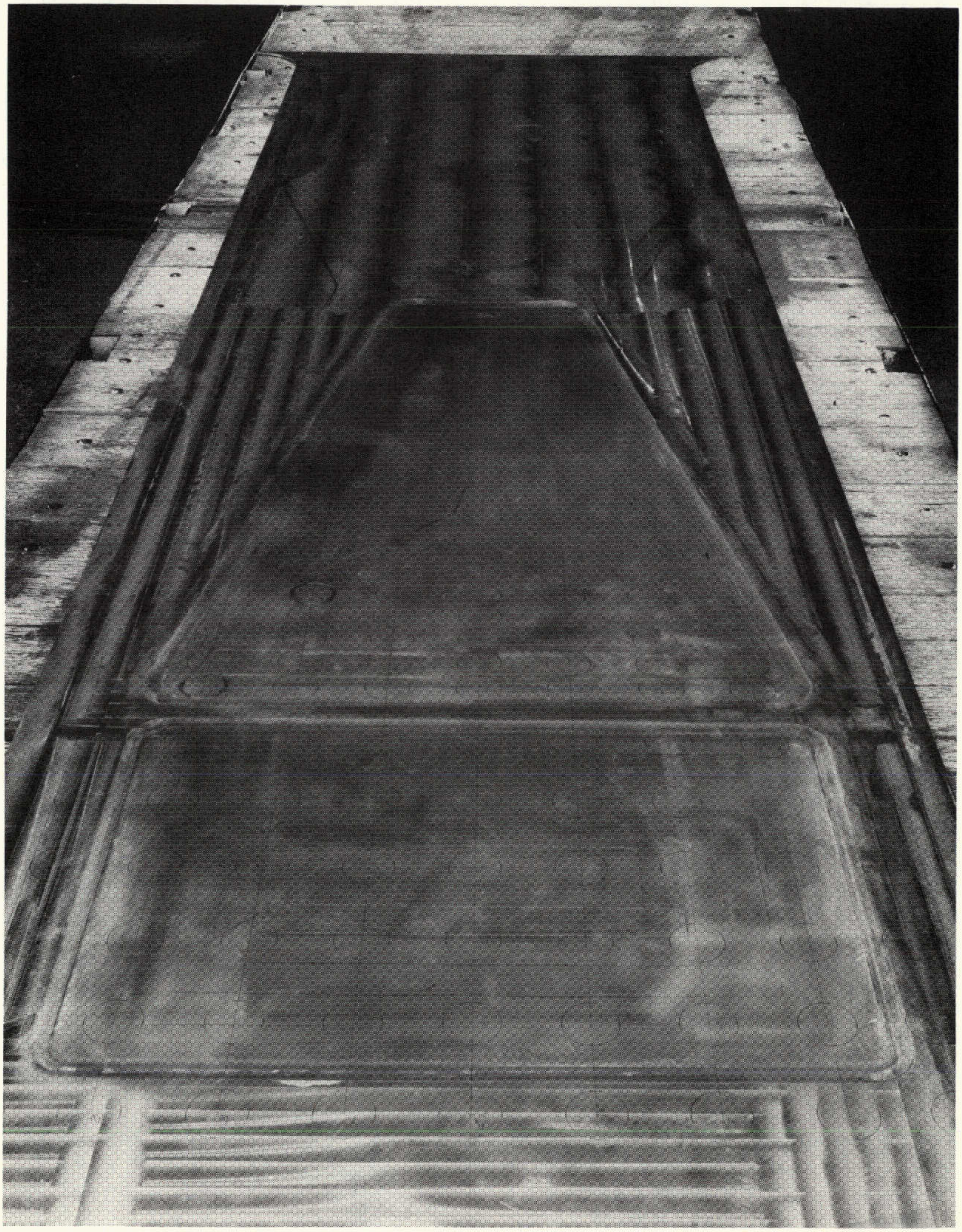


Figure 2-6. Untrimmed Gore Blank

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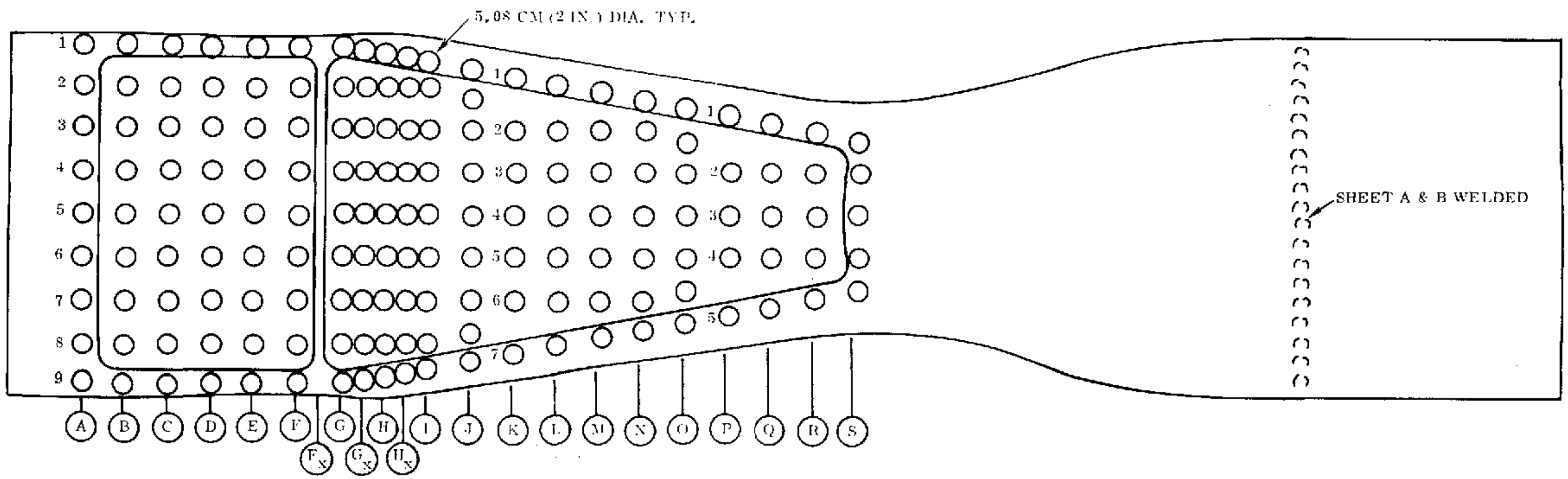

Figure 2-7. Elongation Inspection Locations

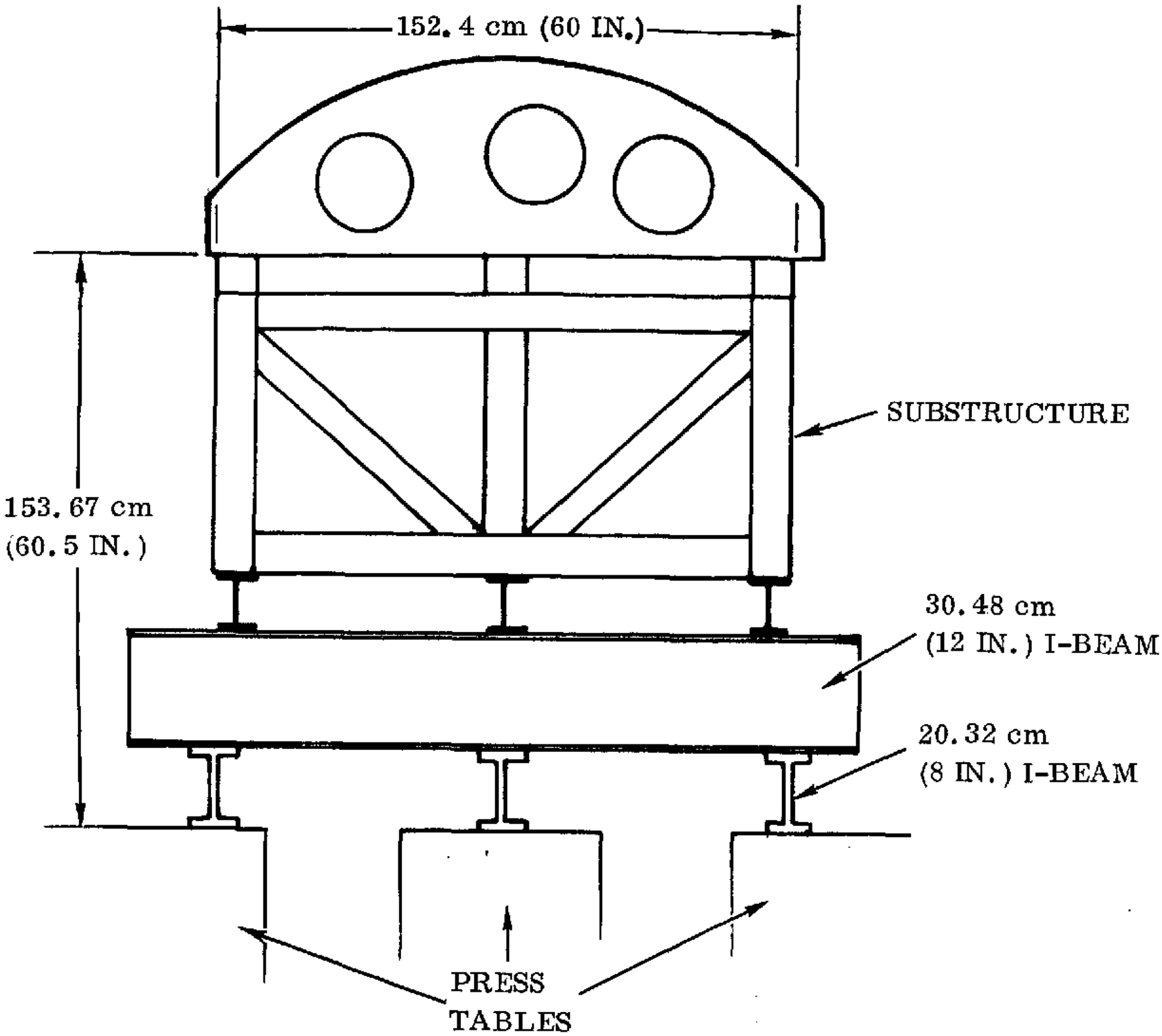

Figure 2-8. Die Substructure

2.9.1 TEST SETUP. The die was coated with a special drawing compound Oakite 21 to decrease friction between the gore blank and die during forming. With the stretch press tables in the down position, the first gore blank was placed in position on the die (see Figure 2-9). The jaws of the press were then moved into place for gripping of the gore blank ends. Premachined aluminum spacers were placed in the jaws on either side of the gore blank to ensure even gripping, and the blank ends were placed in the jaws and gripping pressure applied. The tables were slowly raised to a forming position of 86.36 cm (34 in.) above the down position and the jaws were positioned for forming. Figure 2-10 shows the beginning of stretch forming of Blank C and the press tables in the raised or forming position.

2.9.2 TEST. The 500-ton Sheridan Gray stretch forming machine was programmed in advance for a 5% overall gore and pocket elongation. This value was chosen as the optimum, based on previous experience in stretch forming similar gores.

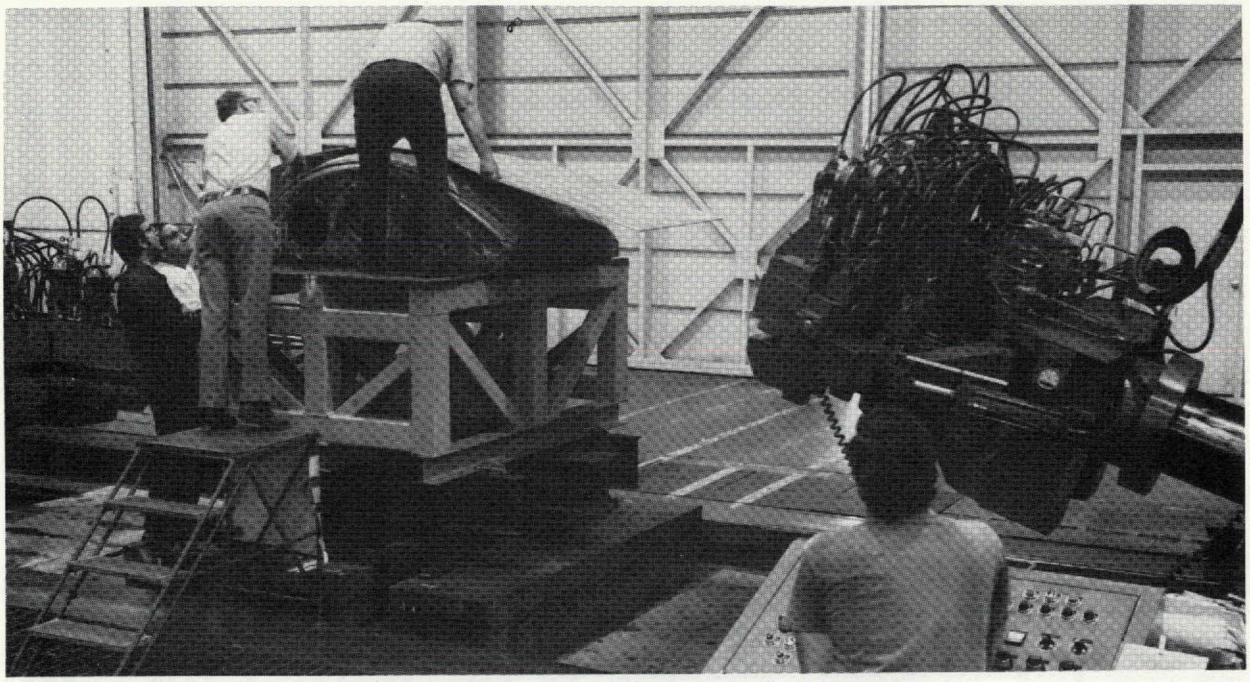

Figure 2-9. Placing Gore Blank on Die

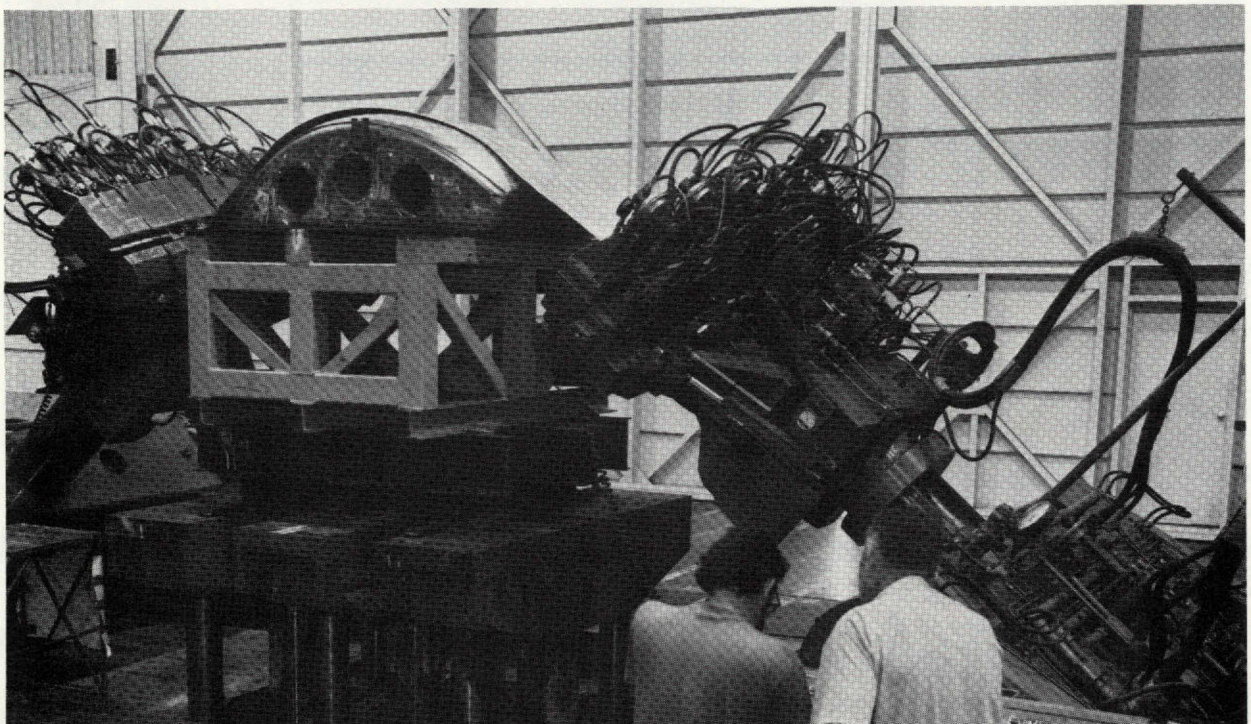

Figure 2-10. Gore Blank at Start of Stretch Forming

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A total of 8.57 cm (3.37 in.) of stretch was desired in the gore and pocket length. Sixty percent, or 5.13 cm (2.02 in.) was programed for the narrow end of the gore, the left jaw, and 40% or 3.43 cm (1.35 in.) was programed for the base end, the right jaw. This shifting of the overall travel of the two jaws was done to help shift elongation out of a critical area that will be noted later. Figure 2-11 is the setup sheet for Blank C and Figure 2-12 gives the setup for gore Blanks B and A. Gore Blank C, being the first to be formed, and also not being typical of mill supplied 2219-T37 material, was stopped before reaching full programed elongation. This is shown in the setup sheet, Figure 2-11. The left jaw traveled its full programed length of 3.30 cm (1.3 in.) but the right jaw traveling only 3.30 cm (1.3 in.) was short of its full travel by 2.03 cm (0.8 in.).

The forming of Blank C was stopped at this time and the blank was removed from the die. Figure 2-13 shows a concave bow across the weld-land between the gore and pocket. Two factors contributed to this bow, the major factor being the discontinuing of the programed 5% elongation. This halting of the forming process prevented the gore from being drawn completely down on the die at the base end; thus, forming was incomplete. The second factor was the bending effect of the jaws on the base end of the gore blank. The outside jaw segments were tilted 13 degrees each to conform to the contour of the die. The jaw angles can be seen in Figure 2-10 and the effect to the gripping area of the gore blank can be seen in Figure 2-13 at the base end.

Blank B was the second to be formed followed by Blank A, each using the same loading procedures as previously described. To ensure the desired blank and die contact, the press tables were raised another 2.54 cm (1 in.) to 88.9 cm (35 in.), and Blanks B and A were formed at this new level. To further ensure a good forming, Blanks B and A were allowed to be formed the full programed 5%. Figure 2-14 shows the successfully formed gore and the transverse weld across the gore blank. The welds in gore Blanks A and B appeared to be unaffected by the stretch forming.

2.9.3 POST-FORMING INSPECTION. Following the forming of the three gore blanks a post-forming inspection was performed. The thickness of each inspection location was again recorded using the same inspection procedures as in the pre-inspection. This data is shown in Table 2-3, with the difference of thickness between the pre-inspection and post inspection listed in Table 2-4.

Gore A was trimmed and placed against the stretch form die face to check contour. This is shown in Figure 2-15. Gores B and C were left untrimmed but were also checked for contour. Gore A had a 1.27 cm (0.5 in.) gap at the base end, as seen in Figure 2-16, and a 0.079 cm (0.031 in.) gap at the nose. Gore B in the untrimmed condition also had a 1.27 cm (0.5 in.) gap at the base, but an 0.635 cm (0.125 in.) gap at the nose. Gore C, not stretched the full 5% elongation, had a 1.905 cm (0.75 in.) gap at the base end and a 1.27 cm (0.5 in.) gap at the nose.

GENERAL DYNAMICS
Convair Aerospace Division

Date: June 6, 1974

500 TON SHERIDAN GRAY STRETCH FORMING MACHINE
SET-UP SHEET

1/3 Scale R&D LO_2 330.2 In. dia.

Part No. ET Gore DC NC 1/3 scale STFM # Atlas Die

Die Weight 11,500 lb Die Location on Tables Centered

Sheet Length 143.5 in. Part Width 33.5 in. Thickness 0.08 in. - 0.22 in.

Material Type 2219-T37 Aluminum

Carriage Position Readout L. H. 000 R. H. 7.4

Die Table Position Readout 000

Tension Cylinder Readouts

Stretch Rate approx. 1 in./min. each jaw

Left Cylinder	Right Cylinder
Post 8.3 Load 7.0 Program 7.0	Program 23.3 Load 23.3 Post 24.6
Stretch Programmed 1.3	Stretch Programmed 1.3

Total Stretch Both Cylinders Combined 2.6 Programmed

Prestretch Put on R. H. Cylinder 0 Add to Post Readout 0

Jaw Angle Up L. H. 40° Jaw Angle Up R. H. 40°

Oscillation L. H. 0 Oscillation R. H. 0

Centroid L. H. 0 Centroid R. H. 0

Radius Settings L. H. Jaw Front to Back. Jaw Pressure 9,000 psig

0 0 13 0 13 0 0

Radius Settings R. H. Jaw Back to Front. Jaw Pressure 14,000 psig

0 0 13 0 13 0 0

Rotation L. H. 0 Rotation R. H. 0

Post (Stretch) Dial Settings L. H. 3% R. H. 3%

Load (Return) Dial Settings L. H. 25% R. H. 25%

Die Table Height Settings Up Reading 34 in.

" " " " Down Reading 34 in.

" " " " Program Setting 34 in.

" " " " Post Setting 34 in.

" " " " Speed Dial Setting 25%

Die Table Use: Center Table yes #1 & #3 Tables yes

Figure 2-11. Blank C Stretch Press Setup

Date: June 6, 1974

500 TON SHERIDAN GRAY STRETCH FORMING MACHINE
SET-UP SHEET

Part No. 1/3 Scale R&D LO_2 ET Gore   DC NC 330.2 in. dia. 1/3 scale   STFM # Atlas Die

Die Weight 11,500 lb   Die Location on Tables centered

Sheet Length 143.5 in.   Part Width 33.5 in.   Thickness 0.08 in. - .22 in.

Material Type 2219-T37 Aluminum

Carriage Position Readout   L. H. 000   R. H. 7.4

Die Table Position Readout 000

Tension Cylinder Readouts
Stretch Rate approx. 1 in/min. each jaw

Left Cylinder   Right Cylinder

Post 8.3 Load 7.0 Program 7.0   Program 22.4 Load 22.4 Post 24.5

Stretch Programmed 1.3 in.   Stretch Programmed 2.1 in.

Total Stretch Both Cylinders Combined 3.3 in. Programmed

Prestretch Put on R. H. Cylinder 0   Add to Post Readout 0

Jaw Angle Up L. H. 40-1/2°   Jaw Angle Up R. H. 40-1/2°

Oscillation L. H. 0   Oscillation R. H. 0

Centroid L. H. 0   Centroid R. H. 0

Radius Settings L. H. Jaw Front to Back.   Jaw Pressure 9,000 psig

0 0 0 0 0 0 0

Radius Settings R. H. Jaw Back to Front.   Jaw Pressure 14,000 psig

0 0 0 0 0 0 0

Rotation L. H. 0   Rotation R. H. 0

Post (Stretch) Dial Settings L. H. 3%   R. H. 3%

Load (Return) Dial Settings L. H. 25%   R. H. 25%

Die Table Height Settings   Up Reading 35 in.
" " " "   Down Reading 35 in.
" " " "   Program Setting 35 in.
" " " "   Post Setting 35 in.
" " " "   Speed Dial Setting 25%

Die Table Use: Center Table yes   #1 & #3 Tables yes

Figure 2-12. Blank A and B Stretch Press Setup

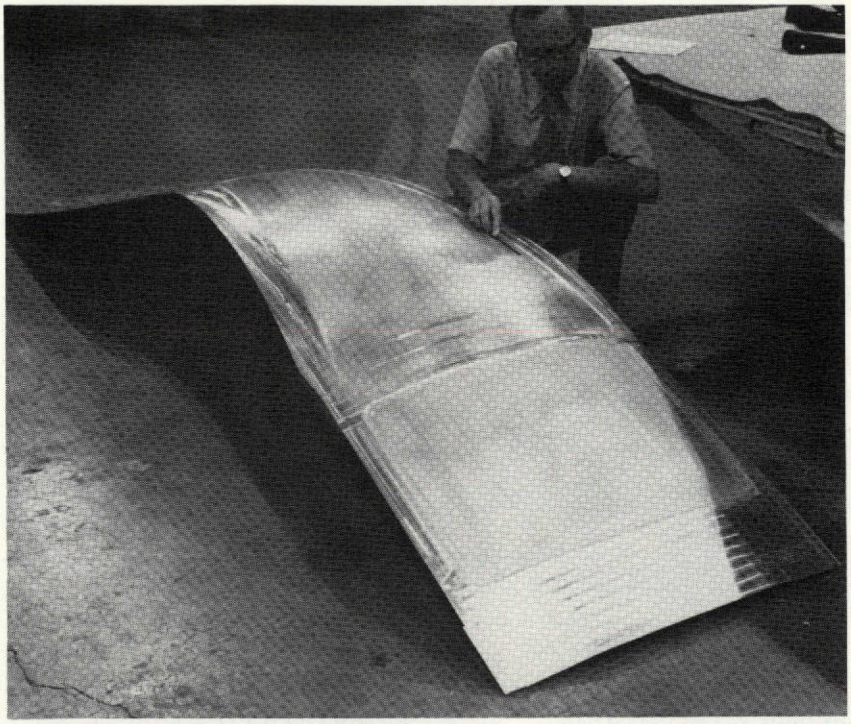

Figure 2-13. Gore Blank C After Forming

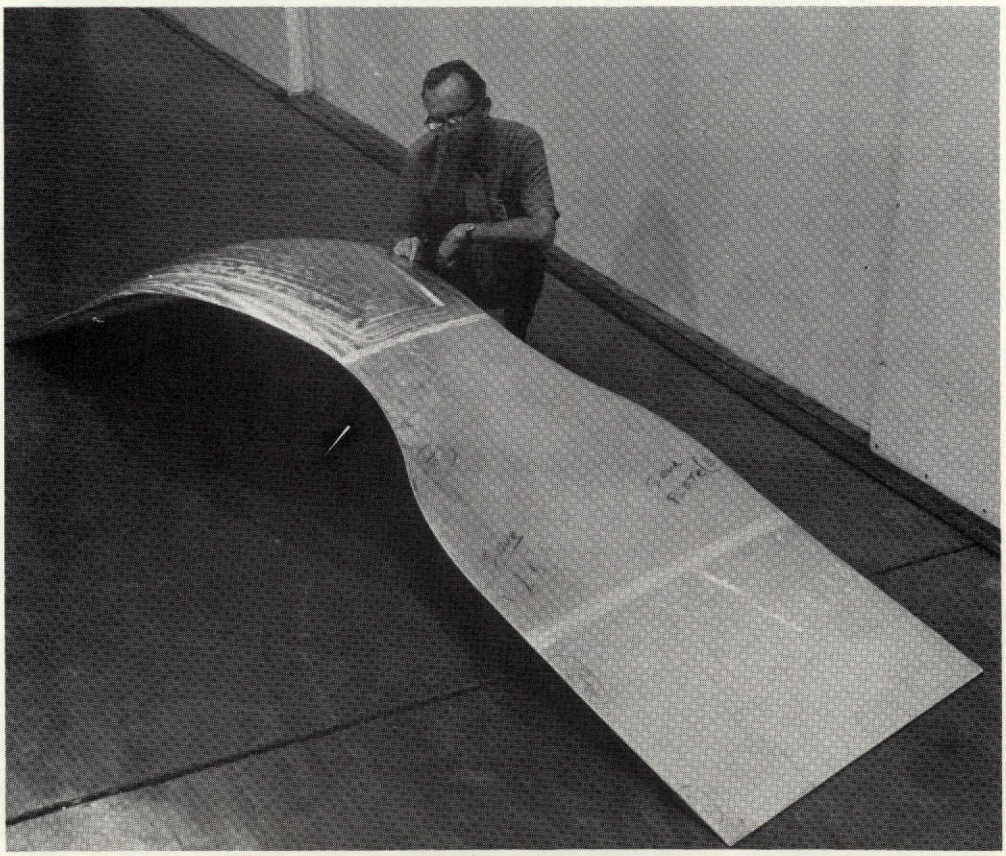

Figure 2-14. Gore Blank B Showing Weld

Table 2-3. Post-forming Thickness Inspection, Sheets A, B, and C

Gore Blank	Line		Station A	B	C	D	E	F	Fx	G	Gx	H	Hx	I	J
Blank A	1	mm	3.50	3.35	3.35	3.38	3.38	3.20	3.35	3.54	3.57	3.72	3.81	3.86	4.01
		(in.)	(.138)	(.132)	(.132)	(.133)	(.133)	(.126)	(.132)	(.139)	(.140)	(.146)	(.150)	(.152)	(.158)
	2	mm	3.53	2.40	2.43	2.45	2.44	2.44	3.39	2.13	2.17	2.07	2.08	2.12	2.15
		(in.)	(.139)	(.094)	(.095)	(.096)	(.096)	(.096)	(.133)	(.084)	(.085)	(.081)	(.082)	(.083)	(.084)
	3	mm	3.50	2.36	2.43	2.43	2.46	2.48	3.43	2.21	2.11	1.98	2.07	2.01	2.08
		(in.)	(.138)	(.093)	(.095)	(.095)	(.097)	(.097)	(.135)	(.087)	(.083)	(.078)	(.081)	(.079)	(.082)
	4	mm	3.44	2.41	2.41	2.45	2.49	2.50	3.50	2.30	2.12	1.97	2.03	2.08	2.02
		(in.)	(.135)	(.095)	(.095)	(.096)	(.098)	(.098)	(.138)	(.090)	(.083)	(.077)	(.080)	(.082)	(.079)
	5	mm	3.40	2.40	2.43	2.44	2.49	2.49	3.48	2.26	2.11	1.98	2.02	2.06	2.15
		(in.)	(.134)	(.094)	(.095)	(.096)	(.098)	(.098)	(.137)	(.089)	(.083)	(.078)	(.079)	(.081)	(.084)
	6	mm	3.42	2.48	2.41	2.41	2.43	2.49	3.44	2.22	2.11	1.93	2.01	2.01	2.06
		(in.)	(.134)	(.097)	(.095)	(.095)	(.095)	(.098)	(.135)	(.087)	(.083)	(.076)	(.079)	(.079)	(.081)
	7	mm	3.43	2.39	2.39	2.40	2.41	2.45	3.34	2.18	2.03	1.96	1.98	1.97	1.99
		(in.)	(.135)	(.094)	(.094)	(.094)	(.095)	(.096)	(.131)	(.086)	(.080)	(.077)	(.078)	(.077)	(.078)
	8	mm	3.48	2.44	2.41	2.41	2.43	2.39	3.37	2.18	2.10	2.01	1.99	1.98	1.96
		(in.)	(.137)	(.096)	(.095)	(.095)	(.095)	(.094)	(.132)	(.086)	(.082)	(.079)	(.078)	(.078)	(.077)
	9	mm	3.50	3.40	3.25	3.30	3.28	3.17	3.15	3.35	3.43	3.56	3.58	3.63	3.81
		(in.)	(.138)	(.134)	(.128)	(.130)	(.129)	(.125)	(.124)	(.132)	(.135)	(.140)	(.141)	(.143)	(.150)
Blank B	1	mm	3.52	3.32	.325	3.33	3.32	3.12	3.14	3.40	3.49	3.63	3.72	3.72	3.98
		(in.)	(.138)	(.130)	(.128)	(.131)	(.130)	(.123)	(.123)	(.134)	(.137)	(.143)	(.146)	(.146)	(.156)
	2	mm	3.56	2.39	2.43	2.44	2.43	2.40	3.34	2.15	2.17	2.06	2.11	2.08	2.13
		(in.)	(.140)	(.094)	(.095)	(.096)	(.095)	(.094)	(.131)	(.084)	(.085)	(.081)	(.083)	(.082)	(.084)
	3	mm	3.47	2.37	2.40	2.40	2.43	2.44	3.43	2.18	2.11	1.94	2.03	1.98	2.11
		(in.)	(.136)	(.093)	(.094)	(.094)	(.095)	(.096)	(.135)	(.086)	(.083)	(.076)	(.080)	(.078)	(.183)
	4	mm	3.43	2.37	2.39	2.41	2.45	2.49	3.48	2.26	2.13	1.90	2.01	2.07	2.01
		(in.)	(.135)	(.093)	(.094)	(.095)	(.096)	(.098)	(.137)	(.089)	(.084)	(.075)	(.079)	(.081)	(.079)
	5	mm	3.39	2.36	2.40	2.40	2.44	2.46	3.44	2.21	2.12	1.90	2.01	2.02	2.12
		(in.)	(.133)	(.093)	(.094)	(.094)	(.096)	(.097)	(.135)	(.087)	(.083)	(.075)	(.079)	(.079)	(.083)
	6	mm	3.34	2.35	2.37	2.39	2.43	2.43	3.43	2.18	2.08	1.89	1.94	1.98	2.03
		(in.)	(.131)	(.092)	(.093)	(.094)	(.095)	(.095)	(.135)	(.086)	(.082)	(.074)	(.076)	(.078)	(.080)
	7	mm	3.40	2.35	2.36	2.35	2.37	2.30	3.25	2.15	2.03	1.90	1.93	1.94	1.94
		(in.)	(.134)	(.092)	(.093)	(.092)	(.093)	(.090)	(.128)	(.084)	(.080)	(.075)	(.076)	(.076)	(.076)
	8	mm	3.48	2.36	2.36	2.37	2.37	2.31	3.27	2.16	2.11	1.93	1.96	1.93	1.94
		(in.)	(.137)	(.093)	(.093)	(.093)	(.093)	(.091)	(.128)	(.085)	(.083)	(.076)	(.077)	(.076)	(.076)
	9	mm	3.49	3.35	3.19	3.30	3.28	3.07	3.29	3.38	3.45	3.55	3.60	3.65	3.76
		(in.)	(.137)	(.132)	(.125)	(.130)	(.129)	(.121)	(.129)	(.133)	(.136)	(.139)	(.142)	(.143)	(.148)
Blank C	1	mm	3.47	3.35	3.30	3.37	3.39	3.34	3.35	3.40	3.52	3.59	3.68	3.77	3.99
		(in.)	(.136)	(.132)	(.130)	(.132)	(.133)	(.131)	(.132)	(.134)	(.138)	(.141)	(.145)	(.148)	(.157)
	2	mm	3.48	2.18	2.17	2.20	2.21	2.21	3.37	2.10	2.11	1.96	2.01	1.97	2.06
		(in.)	(.137)	(.086)	(.085)	(.086)	(.087)	(.087)	(.132)	(.082)	(.083)	(.077)	(.079)	(.077)	(.081)
	3	mm	3.44	2.18	2.18	2.21	2.21	2.21	3.38	2.13	2.10	1.98	1.96	1.99	2.04
		(in.)	(.135)	(.086)	(.086)	(.087)	(.087)	(.087)	(.133)	(.084)	(.082)	(.078)	(.077)	(.078)	(.080)
	4	mm	3.38	2.20	2.20	2.21	2.22	2.22	3.45	2.21	2.07	1.96	1.96	2.01	1.99
		(in.)	(.133)	(.086)	(.086)	(.087)	(.087)	(.087)	(.136)	(.087)	(.081)	(.077)	(.077)	(.079)	(.078)
	5	mm	3.35	2.20	2.18	2.21	2.21	2.21	3.44	2.24	2.08	1.94	1.94	1.98	2.04
		(in.)	(.132)	(.086)	(.086)	(.087)	(.087)	(.087)	(.135)	(.088)	(.082)	(.076)	(.076)	(.078)	(.080)
	6	mm	3.33	2.17	2.17	2.17	2.18	2.18	3.42	2.17	2.08	1.94	1.92	1.94	2.01
		(in.)	(.131)	(.085)	(.085)	(.085)	(.086)	(.086)	(.134)	(.085)	(.082)	(.076)	(.075)	(.076)	(.079)
	7	mm	3.38	2.15	2.15	2.15	2.15	2.16	3.39	2.15	2.06	1.94	1.92	1.93	1.96
		(in.)	(.133)	(.184)	(.184)	(.184)	(.184)	(.185)	(.133)	(.084)	(.081)	(.076)	(.075)	(.076)	(.077)
	8	mm	3.43	2.17	2.15	2.16	2.15	2.16	3.33	2.11	2.03	1.97	1.93	1.91	1.85
		(in.)	(.135)	(.085)	(.084)	(.085)	(.084)	(.085)	(.131)	(.083)	(.080)	(.077)	(.076)	(.075)	(.073)
	9	mm	3.45	3.35	3.29	3.27	3.27	3.24	3.22	3.20	3.37	3.50	3.59	3.68	3.87
		(in.)	(.136)	(.132)	(.129)	(.128)	(.128)	(.127)	(.126)	(.126)	(.132)	(.138)	(.141)	(.145)	(.152)

Gore Blank	Line		Station K	L	M	N	O	P	Q	R	S
Blank A	1	mm	4.18	4.36	4.60	4.75	4.90	5.03	5.08	5.36	5.56
		(in.)	(.164)	(.171)	(.181)	(.187)	(.193)	(.198)	(.200)	(.211)	(.219)
	2	mm	2.17	2.21	2.16	2.26	2.26	2.26	2.26	2.26	5.69
		(in.)	(.085)	(.087)	(.085)	(.089)	(.089)	(.089)	(.089)	(.089)	(.224)
	3	mm	2.21	2.17	2.20	2.25	2.29	2.21	2.20	2.22	5.66
		(in.)	(.087)	(.085)	(.086)	(.088)	(.090)	(.087)	(.086)	(.087)	(.223)
	4	mm	2.08	2.10	2.15	2.08	2.16	2.18	2.21	2.22	5.69
		(in.)	(.082)	(.082)	(.084)	(.082)	(.085)	(.086)	(.087)	(.087)	(.224)
	5	mm	2.10	2.07	2.07	2.08	2.17	5.00	5.10	5.31	5.59
		(in.)	(.082)	(.081)	(.081)	(.082)	(.085)	(.197)	(.201)	(.209)	(.220
	6	mm	1.99	2.04	2.06	2.11	2.13				
		(in.)	(.078)	(.080)	(.081)	(.083)	(.084)				
	7	mm	4.11	4.29	4.50	4.65	4.80				
		(in.)	(.162)	(.169)	(.177)	(.183)	(.189)				
	8	mm									
		(in.)									
	9	mm									
		(in.)									
Blank B	1	mm	4.22	4.36	4.61	4.70	4.85	5.03	5.08	5.31	5.51
		(in.)	(.166)	(.171)	(.181)	(.185)	(.191)	(.198)	(.200)	(.209)	(.217)
	2	mm	2.16	2.18	2.18	2.22	2.25	2.25	2.24	2.24	5.66
		(in.)	(.085)	(.086)	(.086)	(.087)	(.088)	(.088)	(.088)	(.088)	(.223)
	3	mm	2.17	2.20	2.20	2.22	2.26	2.20	2.20	2.24	5.64
		(in.)	(.085)	(.086)	(.086)	(.087)	(.089)	(.086)	(.086)	(.088)	(.222)
	4	mm	2.07	2.08	2.13	2.13	2.15	2.13	2.16	2.21	5.64
		(in.)	(.081)	(.082)	(.084)	(.084)	(.084)	(.084)	(.085)	(.087)	(.222)
	5	mm	2.04	2.06	2.08	2.11	2.13	4.92	5.08	5.23	5.46
		(in.)	(.080)	(.081)	(.082)	(.083)	(.084)	(.193)	(.200)	(.206)	(.215)
	6	mm	1.96	1.99	2.03	2.10	2.11				
		(in.)	(.077)	(.078)	(.080)	(.082)	(.083)				
	7	mm	4.06	4.27	4.46	4.65	4.78				
		(in.)	(.160)	(.168)	(.175)	(.183)	(.188)				
	8	mm									
		(in.)									
	9	mm									
		(in.)									
Blank C	1	mm	4.18	4.34	4.55	4.72	4.90	5.07	6.18	5.38	5.41
		(in.)	(.164)	(.171)	(.179)	(.186)	(.193)	(.199)	(.204)	(.212)	(.213)
	2	mm	2.11	2.15	2.17	2.13	2.20	2.26	2.22	2.26	5.44
		(in.)	(.083)	(.084)	(.085	(.084)	(.086)	(.089)	(.087)	(.089)	(.214)
	3	mm	2.10	2.12	2.16	2.21	2.24	2.18	2.20	2.17	5.44
		(in.)	(.082)	(.083)	(.085)	(.087)	(.088)	(.086)	(.086)	(.085)	(.214)
	4	mm	2.02	2.03	2.07	2.12	2.16	2.16	2.20	2.22	5.41
		(in.)	(.079)	(.080)	(.081)	(.083)	(.085)	(.085)	(.086)	(.087)	(.213)
	5	mm	1.98	2.02	2.04	2.10	2.13	5.02	5.21	5.38	5.44
		(in.)	(.078)	(.079)	(.080)	(.082)	(.084)	(.197)	(.205)	(.212)	(.214)
	6	mm	1.96	1.98	2.03	2.06	2.10				
		(in.)	(.077)	(.078)	(.080)	(.081)	(.082)				
	7	mm	4.10	4.29	4.48	4.67	4.85				
		(in.)	(.161)	(.169)	(.176)	(.184)	(.191)				
	8	mm									
		(in.)									
	9	mm									
		(in.)									

Table 2-4. Thickness Difference, Sheets A, B, and C

Gore Blank	Line		Station A	B	C	D	E	F	Fx	G	Gx	H	Hx	I	J	K	L	M	N	O	P	Q	R	S
Blank A	1	mm	.015	.086	.063	.063	.101	.254	.051	.038	.025	.013	.025	.025	.013	.089	.089	.089	.076	.102	.127	.229	.229	.127
		(in.)	(.0006)	(.0034)	(.0025)	(.0025)	(.004)	(.010)	(.002)	(.0015)	(.001)	(.0005)	(.001)	(.001)	(.0005)	(.0035)	(.0035)	(.0035)	(.003)	(.004)	(.005)	(.009)	(.009)	(.005)
	2	mm	.020	.063	.063	.025	.051	.076	.015	.076	.051	.063	.051	.051	.051	.063	.051	.102	.051	.051	.063	.076	.089	.051
		(in.)	(.0008)	(.0025)	(.0025)	(.001)	(.002)	(.003)	(.0005)	(.003)	(.002)	(.0025)	(.002)	(.002)	(.002)	(.0025)	(.002)	(.004)	(.002)	(.002)	(.0025)	(.003)	(.0035)	(.002)
	3	mm	.005	.051	.051	.038	.051	.025	0	.063	.102	.140	.076	.104	.089	.051	.089	.102	.051	.063	.076	.089	.102	.025
		(in.)	(.0002)	(.002)	(.002)	(.0015)	(.002)	(.001)	0	(.0025)	(.004)	(.0055)	(.003)	(.004)	(.0035)	(.002)	(.0035)	(.004)	(.002)	(.0025)	(.003)	(.0035)	(.004)	(.001)
	4	mm	0	.038	.051	.038	.025	.015	0	0.063	.102	.152	.114	.114	.102	.063	.076	.063	.114	.063	.051	.056	.076	.025
		(in.)	0	(.0015)	(.002)	(.0015)	(.001)	(.0005)	0	(.0025)	(.004)	(.006)	(.0045)	(.0045)	(.004)	(.0025)	(.003)	(.0025)	(.0045)	(.0025)	(.002)	(.0022)	(.003)	(.001)
	5	mm	.010	.025	.051	.051	.025	.015	0	.051	.102	.140	.089	.127	.063	.051	.063	.076	.076	.038	.076	.178	.152	.102
		(in.)	(.0004)	(.001)	(.002)	(.002)	(.001)	(.0005)	0	(.002)	(.004)	(.0055)	(.0035)	(.005)	(.0025)	(.002)	(.0025)	(.003)	(.003)	(.0015)	(.003)	(.007)	(.006)	(.004)
	6	mm	.010	.038	.038	.051	.025	0	0	.038	.076	.165	.038	.127	.089	.051	.051	.051	.051	.076				
		(in.)	(.0004)	(.0015)	(.0015)	(.002)	(.001)	0	0	(.0015)	(.003)	(.0065)	(.0015)	(.005)	(.0035)	(.002)	(.002)	(.002)	(.002)	(.003				
	7	mm	.015	.025	.051	.038	.025	.015	0	.063	.102	.102	.076	.076	.063	.076	.076	.076	.114	.140				
		(in.)	(.0006)	(.001)	(.002)	(.0015)	(.001)	(.0005)	0	(.0025)	(.004)	(.004)	(.003)	(.003)	(.0025)	(.003)	(.003)	(.003)	(.0045)	(.0055)				
	8	mm	.015	0	.025	.038	.038	.051	.015	.051	.063	.051	.063	.051	.051									
		(in.)	(.0005)	0	(.001)	(.0015)	(.0015)	(.002)	(.0005)	(.002)	(.0025)	(.002)	(.0025)	(.002)	(.002)									
	9	mm	.005	.051	.038	.015	.038	.140	.089	0	.025	.025	.038	.051	.063									
		(in.)	(.0002)	(.002)	(.0015)	(.0005)	(.0015)	(.0055)	(.0035)	0	(.001)	(.001)	(.0015)	(.002)	(.0025)									
Blank B	1	mm	.127	.089	.051	.025	.076	.218	.165	.013	.013	.038	.025	.051	.028	.063	.076	.089	.127	.127	.127	.229	.279	.178
		(in.)	(.0005)	(.0035)	(.002)	(.001)	(.003)	(.0086)	(.0065)	(.0005)	(.0005)	(.0015)	(.001)	(.002)	(.0011)	(.0025)	(.003)	(.0035)	(.005)	(.005)	(.005)	(.009)	(.011)	(.007)
	2	mm	.127	.051	.038	.025	.051	.102	.013	.089	.063	.051	.051	.038	.066	.063	.051	.063	.076	.063	.063	.114	.114	.089
		(in.)	(.0005)	(.002)	(.0015)	(.001)	(.002)	(.004)	(.0005)	(.0035)	(.0025)	(.002)	(.002)	(.0015)	(.0026)	(.0025)	(.002)	(.0025)	(.003)	(.0025)	(.0025)	(.0045)	(.0045)	(.0035)
	3	mm	.013	.038	.054	.038	.051	.038	0	.063	.089	.140	.089	.092	.076	.076	.063	.063	.076	.076	.089	.114	.102	.114
		(in.)	(.0005)	(.0015)	(.0021)	(.0015)	(.002)	(.0015)	0	(.0025)	(.0035)	(.0055)	(.0035)	(.0036)	(.003)	(.003)	(.0025)	(.0025)	(.003)	(.003)	(.0035)	(.0045)	(.004)	(.0045)
	4	mm	0	.051	.051	.051	.038	.016	.013	.051	.089	.178	.127	.102	.102	.063	.076	.063	.076	.063	.089	.089	.089	.127
		(in.)	0	(.002)	(.002)	(.002)	(.0015)	(.0006)	(.0005)	(.002)	(.0035)	(.007)	(.005)	(.004)	(.004)	(.0025)	(.003)	(.0025)	(.003)	(.0025)	(.0035)	(.0035)	(.0035)	(.005
	5	mm	.013	.038	.054	.051	.025	.025	.013	.051	.089	.178	.116	.127	.102	.076	.076	.076	.063	.063	.114	.178	.254	.178
		(in.)	(.0005)	(.0015)	(.0021)	(.002)	(.001)	(.001)	(.0005)	(.002)	(.0035)	(.007)	(.0046)	(.005)	(.004)	(.003)	(.003)	(.003)	(.0025)	(.0025)	(.0045)	(.007)	(.010)	(.007)
	6	mm	.013	.025	.051	.051	.025	.013	0	.063	.102	.165	.127	.127	.189	.076	.063	.051	.063	.051				
		(in.)	(.0005)	(.001)	(.002)	(.002)	(.001)	(.0005)	0	(.0025)	(.004)	(.0065)	(.005)	(.005)	(.0035)	(.003)	(.0025)	(.002)	(.0025)	(.002)				
	7	mm	0	.028	.051	.063	.038	.038	.025	.054	.063	.102	.102	.102	.063	.089	.102	.114	.089	.165				
		(in.)	0	(.0011	(.002)	(.0025)	(.0015)	(.0015)	(.001)	(.0021)	(.0025)	(.004)	(.004)	(.004)	(.0025)	(.0035)	(.004)	(.0045)	(.0035)	(.0065)				
	8	mm	0	.038	.016	.038	.038	.102	.025	.038	.025	.076	.063	.051	.051									
		(in.)	0	(.0015)	(.0006)	(.0015)	(.0015)	(.004)	(.001)	(.0015)	(.001)	(.003)	(.0025)	(.002)	(.002)									
	9	mm	.023	.051	.063	0	.063	.229	.038	.013	.025	.051	.038	.038	.089									
		(in.)	(.0009)	(.002)	(.0025)	0	(.0025)	(.009)	(.0015)	(.0005)	(.001)	(.002)	(.0015)	(.0015)	(.0035)									
Blank C	1	mm	.013	.013	0	.025	.025	.063	0	.013	.013	0	.013	.025	.025	.013	.025	.025	.025	0	0	.025	.152	.025
		(in.)	(.0005)	(.0005)	0	(.001)	(.001)	(.0025)	0	(.0005)	(.0005)	0	(.0005)	(.001)	(.001)	(.0005)	(.001)	(.001)	(.001)	0	0	(.001)	(.006)	(.001)
	2	mm	0	.013	.025	.013	.013	.013	0	0	0	.038	.025	.025	.013	.038	.038	.025	.025	.038	.025	.025	.038	0
		(in.)	0	(.0005)	(.001)	(.0005)	(.0005)	(.0005)	0	0	0	(.0015)	(.001)	(.001)	(.0005)	(.0015)	(.0015)	(.001)	(.001)	(.0015)	(.001)	(.001)	(.0015)	0
	3	mm	0	0	.013	.013	.013	.013	0	.051	.038	.063	.076	.063	.038	.051	.051	.051	.026	.038	.025	.026	.076	.025
		(in.)	0	0	(.0005)	(.0005)	(.0005)	(.0005)	0	(.002)	(.0015)	(.0025)	(.003)	(.0025)	(.0015)	(.002)	(.002)	(.002)	(.001)	(.0015)	(.001)	(.001)	(.003)	(.001)
	4	mm	0	0	.013	.013	.013	.025	0	.051	.063	.089	.089	.063	.076	.063	.051	.051	.025	.025	.025	.025	.013	.025
		(in.)	0	0	(.0005)	(.0005)	(.0005)	(.001)	0	(.002)	(.0025)	(.0035)	(.0035)	(.0025)	(.003)	(.0025)	(.002)	(.002)	(.001)	(.001)	(.001)	(.001)	(.0005)	(.001)
	5	mm	0	.013	.025	.013	.013	.025	0	.013	.051	.089	.102	.089	.051	.063	.038	.038	.025	.013	.025	.025	.051	.025
		(in.)	0	(.0005)	(.001)	(.0005)	(.0005)	(.001)	0	(.0005)	(.002)	(.0035)	(.004)	(.0035)	(.002)	(.0025)	(.0015)	(.0015)	(.001)	(.0005)	(.001)	(.001)	(.002)	(.001)
	6	mm	0	.013	.013	.013	.013	.025	.013	.051	.025	.076	.089	.089	.051	.038	.025	.025	.025	.013				
		(in.)	0	(.0005)	(.0005)	(.0005)	(.0005)	(.001)	(.0005)	(.002)	(.001)	(.003)	(.0035)	(.0035)	(.002)	(.0015)	(.001)	(.001)	(.001)	(.0005)				
	7	mm	0	0	.013	.013	.013	0	0	.038	.038	.051	.063	.063	.038	.013	.025	.025	.025	.025				
		(in.)	0	0	(.0005)	(.0005)	(.0005)	0	0	(.0015)	(.0015)	(.002)	(.0025)	(.0025)	(.0015)	(.0005)	(.001)	(.001)	(.001)	(.001)				
	8	mm	0	.013	0	0	.013	0	0	.051	.013	.025	.038	.038	.038									
		(in.)	0	(.0005)	0	0	(.0005)	0	0	(.002)	(.0005)	(.001)	(.0015)	(.0015)	(.0015)									
	9	mm	0	.013	.013	.013	.013	0	.025	.038	.013	.013	.013	.025	.025									
		(in.)	0	(.0005)	(.0005)	(.0005)	(.0005)	0	(.001)	(.0015)	(.0005)	(.0005)	(.0005)	(.001)	(.001)									

FOLDOUT FRAME

Figure 2-15. Gore A on Die

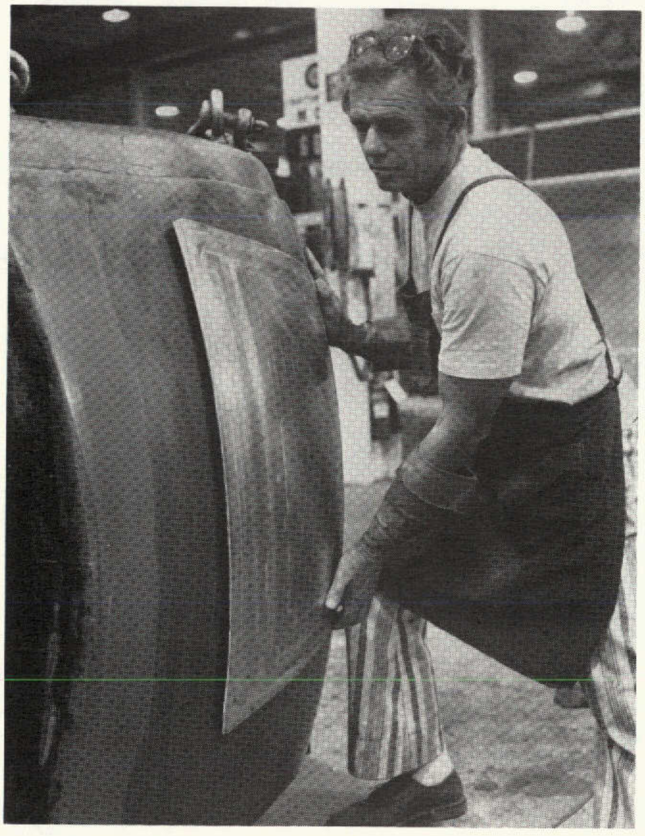

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Figure 2-16. Gore A Showing Springback

The large gap at the base end of all the formed gores was caused by a limitation of the stretch press. This limitation is the 45-degree maximum rotation of the jaws in the vertical plane, which prevented the part from being stretched tightly against the die at the base end. If the jaws could have been raised to a 50- to 55-degree angle, contact with the die could have been achieved.

Each elongation inspection circle was checked, using a scale and magnifying glass, and recorded. The percent of elongation in the longitudinal and transverse directions were calculated by comparing the initial circle diameters to the ellipse major and minor axis lengths. Figure 2-17 shows typical elliptical distortion of the inspection circles that took place on Gore B during the forming operation. Stations Gx, H, and Hx had the greatest elongation. This is shown in Table 2-5. The percent of elongation for each blank is shown in Table 2-6. For clarification of the high areas of elongation a pictorial, or elevation type drawing of the longitudinal elongation was prepared for each blank (Figures 2-18, 2-19, and 2-20). The incomplete elongation in gore Blank C can be readily seen in the comparison of these figures. The data for the transverse elongation was also recorded and is found in Tables 2-7 and 2-8.

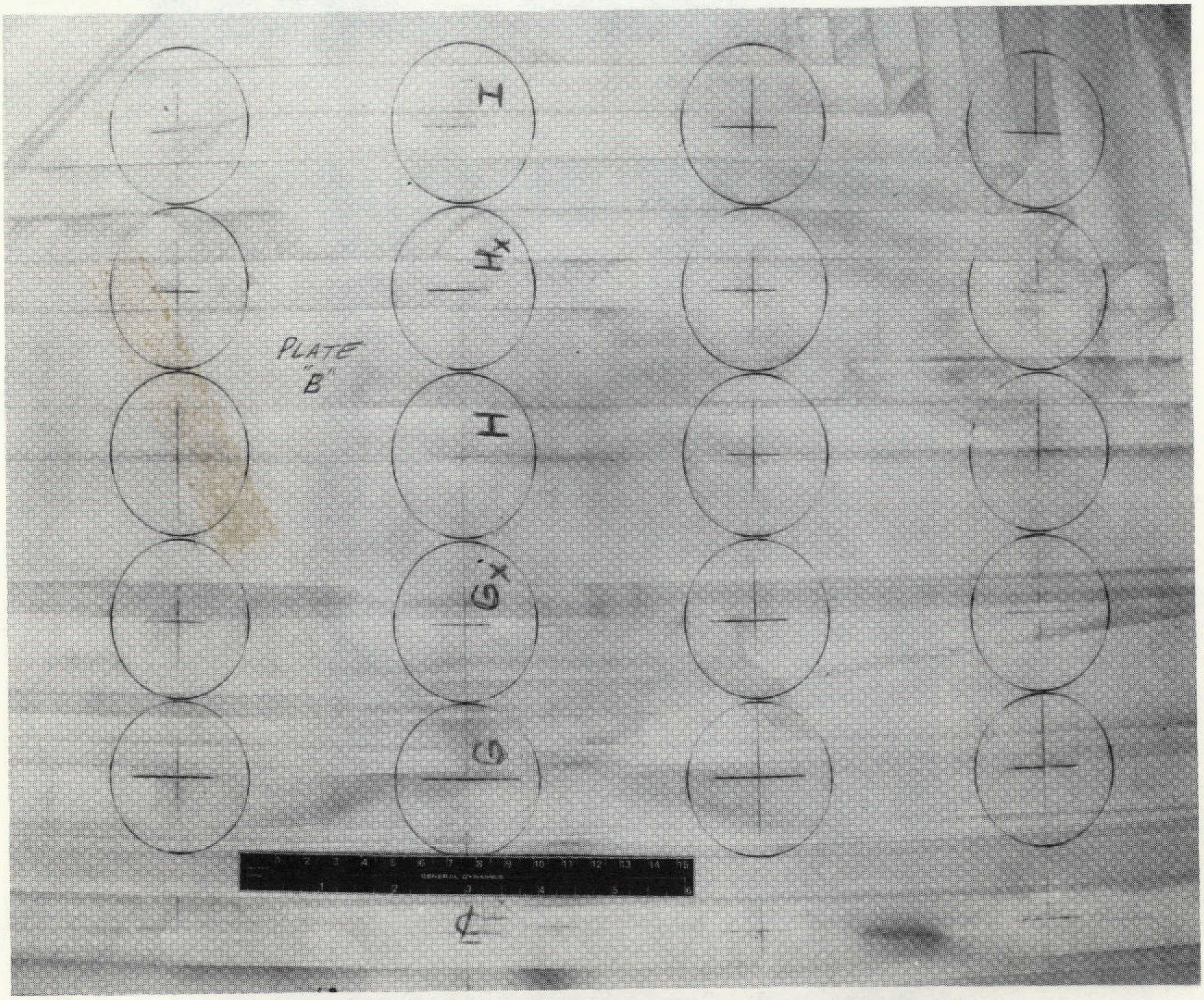

Figure 2-17. Gore Blank B Elliptical Inspection Circles

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Table 2-5. Circular Grid Measurements, Longitudinal, Sheets A, B, and C

Gore Blank	Line		Station																					
			A	B	C	D	E	F	Fx	G	Gx	H	Hx	I	J	K	L	M	N	O	P	Q	R	S
Blank A	1	mm	50.8	52.1	51.6	51.8	52.3	55.1	-	51.1	51.3	51.3	51.3	51.3	51.8	52.6	52.3	52.1	52.1	52.3	52.6	52.8	52.8	51.8
		(in.)	(2.00)	(2.05)	(2.03)	(2.04)	(2.06)	(2.17)	-	(2.01)	(2.02)	(2.02)	(2.02)	(2.02)	(2.04)	(2.07)	(2.06)	(2.05)	(2.05)	(2.06)	(2.07)	(2.08)	(2.08)	(2.04)
	2	mm	50.8	52.6	51.8	52.1	52.6	52.3	-	53.1	53.1	52.8	52.6	52.6	52.6	52.8	52.8	53.3	52.6	52.8	53.3	53.8	53.6	50.8
		(in.)	(2.00)	(2.07)	(2.04)	(2.05)	(2.07)	(2.06)	-	(2.09)	(2.09)	(2.08)	(2.07)	(2.07)	(2.07)	(2.08)	(2.08)	(2.10)	(2.07)	(2.08)	(2.10)	(2.12)	(2.11)	(2.00)
	3	mm	50.5	52.1	52.1	51.8	51.8	51.1	-	53.1	54.1	54.6	53.8	53.8	53.6	53.1	53.3	53.8	53.1	52.8	53.3	53.8	53.6	50.8
		(in.)	(1.99)	(2.05)	(2.05)	(2.04)	(2.04)	(2.01)	-	(2.09)	(2.13)	(2.15)	(2.12)	(2.12)	(2.11)	(2.09)	(2.10)	(2.12)	(2.09)	(2.08)	(2.10)	(2.12)	(2.11)	(2.00)
	4	mm	50.5	52.1	52.1	51.8	51.6	51.1	-	52.6	54.4	55.4	55.6	54.6	54.4	53.3	53.3	52.8	54.4	53.1	53.1	53.3	53.1	50.5
		(in.)	(1.99)	(2.05)	(2.05)	(2.04)	(2.03)	(2.01)	-	(2.07)	(2.14)	(2.18)	(2.19)	(2.15)	(2.14)	(2.10)	(2.10)	(2.08)	(2.14)	(2.09)	(2.09)	(2.10)	(2.09)	(1.99)
	5	mm	50.8	51.8	52.1	52.1	51.1	50.8	-	52.6	54.4	56.1	56.1	55.4	53.6	53.3	53.1	53.8	54.1	53.1	52.1	52.1	52.3	50.8
		(in.)	(2.00)	(2.04)	(2.05)	(2.05)	(2.01)	(2.00)	-	(2.07)	(2.14)	(2.21)	(2.21)	(2.18)	(2.11)	(2.10)	(2.09)	(2.12)	(2.13)	(2.09)	(2.05)	(2.05)	(2.06)	(2.00)
	6	mm	50.5	51.6	52.1	52.1	51.3	51.1	-	52.3	54.1	55.9	55.6	54.9	53.8	52.8	52.8	53.1	52.8	53.3				
		(in.)	(1.99)	(2.03)	(2.05)	(2.05)	(2.02)	(2.01)	-	(2.06)	(2.13)	(2.20)	(2.19)	(2.16)	(2.12)	(2.08)	(2.08)	(2.09)	(2.08)	(2.10)				
	7	mm	50.5	51.6	51.6	51.8	51.8	51.1	-	52.8	54.1	54.6	54.4	53.6	53.3	51.8	52.1	52.3	52.8	53.1				
		(in.)	(1.99)	(2.03)	(2.03)	(2.04)	(2.04)	(2.01)	-	(2.08)	(2.13)	(2.15)	(2.14)	(2.11)	(2.10)	(2.04)	(2.05)	(2.06)	(2.08)	(2.09)				
	8	mm	50.5	51.6	51.6	51.8	52.1	52.3	-	52.6	52.8	52.8	52.6	52.6	52.8									
		(in.)	(1.99)	(2.03)	(2.03)	(2.04)	(2.05)	(2.06)	-	(2.07)	(2.08)	(2.08)	(2.07)	(2.07)	(2.08)									
	9	mm	50.5	51.1	51.3	51.3	52.1	54.9	-	51.1	51.1	51.3	51.3	51.6	51.8									
		(in.)	(1.99)	(2.01)	(2.02)	(2.02)	(2.05)	(2.16)	-	(2.01)	(2.01)	(2.02)	(2.02)	(2.03)	(2.04)									
Blank B	1	mm	50.5	51.8	51.8	51.3	52.3	-	-	51.3	51.3	51.3	51.6	51.6	51.6	52.1	52.3	52.3	52.8	53.3	53.3	53.3	53.6	52.3
		(in.)	(1.99)	(2.04)	(2.04)	(2.02)	(2.06)	-	-	(2.02)	(2.02)	(2.02)	(2.03)	(2.03)	(2.03)	(2.05)	(2.06)	(2.06)	(2.08)	(2.10)	(2.10)	(2.10)	(2.11)	(2.06)
	2	mm	50.8	52.3	51.8	52.1	52.6	53.3	-	53.8	53.3	52.8	52.3	52.6	52.3	52.6	52.8	52.8	53.1	53.3	53.6	54.6	54.4	50.8
		(in.)	(2.00)	(2.06)	(2.04)	(2.05)	(2.07)	(2.10)	-	(2.12)	(2.10)	(2.08)	(2.06)	(2.07)	(2.06)	(2.07)	(2.08)	(2.08)	(2.09)	(2.10)	(2.11)	(2.15)	(2.14)	(2.00)
	3	mm	50.8	52.1	52.1	52.1	52.1	51.6	-	53.1	54.6	54.9	54.4	54.1	53.1	53.1	53.1	53.6	53.3	53.3	53.8	54.6	53.8	50.8
		(in.)	(2.00)	(2.05)	(2.05)	(2.05)	(2.05)	(2.03)	-	(2.09)	(2.15)	(2.16)	(2.14)	(2.13)	(2.09)	(2.09)	(2.09)	(2.11)	(2.10)	(2.10)	(2.12)	(2.15)	(2.12)	(2.00)
	4	mm	50.8	51.6	52.3	52.3	51.3	51.3	-	52.3	55.4	56.4	55.4	54.6	54.1	53.3	53.3	53.3	53.3	53.6	54.1	54.4	53.8	50.8
		(in.)	(2.00)	(2.03)	(2.06)	(2.06)	(2.02)	(2.02)	-	(2.06)	(2.18)	(2.22)	(2.18)	(2.15)	(2.13)	(2.10)	(2.10)	(2.10)	(2.10)	(2.11)	(2.13)	(2.14)	(2.12)	(2.00)
	5	mm	50.5	51.6	52.3	52.3	51.3	51.1	-	52.3	54.9	56.4	55.4	55.1	53.8	53.8	53.6	53.3	53.6	53.3	53.3	52.6	52.8	51.6
		(in.)	(1.99)	(2.03)	(2.06)	(2.06)	(2.02)	(2.01)	-	(2.06)	(2.16)	(2.22)	(2.18)	(2.17)	(2.12)	(2.12)	(2.11)	(2.10)	(2.11)	(2.10)	(2.10)	(2.07)	(2.08)	(2.03)
	6	mm	50.8	51.6	52.1	52.1	51.3	51.3	-	52.8	54.4	55.4	55.1	55.1	53.8	53.8	53.3	53.1	53.3	53.3				
		(in.)	(2.00)	(2.03)	(2.05)	(2.05)	(2.02)	(2.02)	-	(2.08)	(2.14)	(2.18)	(2.17)	(2.17)	(2.12)	(2.12)	(2.10)	(2.09)	(2.10)	(2.10)				
	7	mm	50.8	51.6	51.8	52.1	51.8	51.3	-	52.6	53.8	54.1	54.1	54.4	53.6	52.3	52.6	52.6	52.3	53.1				
		(in.)	(2.00)	(2.03)	(2.04)	(2.05)	(2.04)	(2.02)	-	(2.07)	(2.12)	(2.13)	(2.13)	(2.14)	(2.11)	(2.06)	(2.07)	(2.07)	(2.06)	(2.09)				
	8	mm	50.5	51.6	51.8	51.6	52.1	52.6	-	52.3	52.3	52.6	52.6	52.3	53.1									
		(in.)	(1.99)	(2.03)	(2.04)	(2.03)	(2.05)	(2.07)	-	(2.06)	(2.06)	(2.07)	(2.07)	(2.06)	(2.09)									
	9	mm	50.5	51.1	51.6	51.6	52.1	54.9	-	51.1	51.1	51.6	51.3	51.6	52.3									
		(in.)	(1.99)	(2.01)	(2.03)	(2.03)	(2.05)	(2.16)	-	(2.01)	(2.01)	(2.03)	(2.02)	(2.03)	(2.06)									
Blank C	1	mm	50.8	50.8	51.1	-	50.8	50.8	-	50.5	50.8	50.8	51.1	-	51.1	51.1	51.1	50.8	50.8	51.1	51.1	51.3	51.3	51.1
		(in.)	(2.00)	(2.00)	(2.01)	-	(2.00)	(2.00)	-	(1.99)	(2.00)	(2.00)	(2.01)	-	(2.01)	(2.01)	(2.01)	(2.00)	(2.00)	(2.01)	(2.01)	(2.02)	(2.02)	(2.01)
	2	mm	50.8	51.1	51.3	51.1	50.8	51.1	-	51.6	51.3	51.6	51.8	52.1	51.8	51.6	51.8	51.6	51.3	51.6	51.6	51.8	51.8	50.8
		(in.)	(2.00)	(2.01)	(2.02)	(2.01)	(2.00)	(2.01)	-	(2.03)	(2.02)	(2.03)	(2.04)	(2.05)	(2.04)	(2.03)	(2.04)	(2.03)	(2.02)	(2.03)	(2.03)	(2.04)	(2.04)	(2.00)
	3	mm	50.5	51.3	51.3	51.3	51.1	51.1	-	51.6	51.8	52.8	52.8	52.6	52.3	52.3	51.8	52.1	51.6	51.6	51.6	52.1	52.1	50.8
		(in.)	(1.99)	(2.02)	(2.02)	(2.02)	(2.01)	(2.01)	-	(2.03)	(2.04)	(2.08)	(2.08)	(2.07)	(2.06)	(2.06)	(2.04)	(2.05)	(2.03)	(2.03)	(2.03)	(2.05)	(2.05)	(2.00)
	4	mm	50.5	51.1	51.1	50.8	51.1	51.1	-	51.3	52.1	53.6	53.3	53.1	52.8	52.8	52.1	52.1	51.8	51.8	51.1	51.3	51.6	50.8
		(in.)	(1.99)	(2.01)	(2.01)	(2.00)	(2.01)	(2.01)	-	(2.02)	(2.05)	(2.11)	(2.10)	(2.09)	(2.08)	(2.08)	(2.05)	(2.05)	(2.04)	(2.04)	(2.01)	(2.02)	(2.03)	(2.00)
	5	mm	50.5	51.1	51.1	50.8	50.8	51.1	-	51.6	52.1	53.6	53.6	53.3	52.8	52.3	52.1	51.8	51.6	51.6	50.8	51.1	-	50.8
		(in.)	(1.99)	(2.01)	(2.01)	(2.00)	(2.00)	(2.01)	-	(2.03)	(2.05)	(2.11)	(2.11)	(2.10)	(2.08)	(2.06)	(2.05)	(2.04)	(2.03)	(2.03)	(2.00)	(2.01)	-	(2.00)
	6	mm	50.5	51.1	51.1	50.8	51.1	51.1	-	51.3	51.8	53.3	53.3	53.1	52.8	51.8	51.6	51.6	51.3	51.1				
		(in.)	(1.99)	(2.01)	(2.01)	(2.00)	(2.01)	(2.01)	-	(2.02)	(2.04)	(2.10)	(2.10)	(2.09)	(2.08)	(2.04)	(2.03)	(2.03)	(2.02)	(2.01)				
	7	mm	50.5	51.1	50.8	50.8	51.1	51.1	-	51.3	51.3	52.3	52.6	52.8	52.3	51.1	51.3	51.1	-	51.1				
		(in.)	(1.99)	(2.01)	(2.00)	(2.00)	(2.01)	(2.01)	-	(2.02)	(2.03)	(2.06)	(2.07)	(2.08)	(2.06)	(2.01)	(2.02)	(2.01)	-	(2.01)				
	8	mm	50.5	51.1	50.8	50.8	50.8	50.8	-	50.8	51.1	51.3	51.6	51.8	52.1									
		(in.)	(1.99)	(2.01)	(2.00)	(2.00)	(2.00)	(2.00)	-	(2.00)	(2.01)	(2.03)	(2.03)	(2.04)	(2.05)									
	9	mm	-	-	50.5	-	-	50.5	-	50.5	50.5	50.8	50.8	51.1	51.3									
		(in.)	-	-	(1.99)	-	-	(1.99)	-	(1.99)	(1.99)	(2.00)	(2.00)	(2.01)	(2.02)									

Table 2-6. Percent Longitudinal Elongation, Sheets A, B, and C

Gore Blank	Line	Station A	B	C	D	E	F	Fx	G	Gx	H	Hx	I	J	K	L	M	N	O	P	Q	R	S
	1	.5	3	2	2.5	3.5	9.5	-	1	1.5	1.5	1.5	1.5	2.5	4	3.5	3	3	3.5	4	4.5	4.5	2.5
	2	.5	4	2.5	3	4	3.5	-	5	5	4.5	4	4	4	4.5	4.5	5.5	4	4.5	5.5	6.5	6	.5
	3	0	3	3	2.5	2.5	1	-	5	7	8	6.5	6.5	6	5	5.5	6.5	5	4.5	5.5	6.5	6	.5
	4	0	3	3	2.5	2	1	-	4	7.5	9.5	10	8	7.5	5.5	5.5	4.5	7.5	5	5	5.5	5	0
Blank A	5	.5	2.5	3	3	1	.5	-	4	7.5	11	11	9.5	6	5.5	5	6.5	7	5	3	3	3.5	.5
	6	0	2	3	3	1.5	1	-	3.5	7	10.5	10	8.5	6.5	4.5	4.5	5	4.5	5.5				
	7	0	2	2	2.5	2.5	1	-	4.5	7	8	7.5	6	5.5	2.5	3	3.5	4.5	5				
	8	0	2	2	2.5	3	3.5	-	4	4.5	4.5	4	4	4.5									
	9	0	1	1.5	1.5	3	8.5	-	1	1	1.5	1.5	2	2.5									
	1	0	2.5	2.5	1.5	3.5	-	-	1.5	1.5	1.5	2	2	2	3	3.5	3.5	4.5	5.5	5.5	5.5	6	3.5
	2	.5	3.5	2.5	3	4	5.5	-	6.5	5.5	4.5	3.5	4	3.5	4	4.5	4.5	5	5.5	6	8	7.5	.5
	3	.5	3	3	3	3	2	-	5	8	8.5	7.5	7	5	5	5	6	5.5	5.5	6.5	8	6.5	.5
	4	.5	2	3.5	3.5	1.5	1.5	-	3.5	9.5	11.5	9.5	8	7	5.5	5.5	5.5	5.5	6	7	7.5	6.5	.5
Blank B	5	0	2	3.5	3.5	1.5	1	-	3.5	8.5	11.5	9.5	9	6.5	6.5	6	5.5	6	5.5	5.5	4	4.5	2
	6	.5	2	3	3	1.5	1.5	-	4.5	7.5	9.5	9	9	6.5	6.5	5.5	5	5.5	5.5				
	7	.5	2	2.5	3	2.5	1.5	-	4	6.5	7	7	7.5	6	3.5	4	4	3.5	5				
	8	0	2	2.5	2	3	4	-	3.5	3.5	4	4	3.5	5									
	9	0	1	2	2	3	8.5	-	1	1	2	1.5	2	3.5									
	1	.5	.5	1	-	.5	.5	-	0	.5	.5	1	-	1	1	1	.5	.5	1	1	1.5	1.5	1
	2	.5	1	1.5	1	.5	1	-	2	1.5	2	2.5	3	2.5	2	2.5	2	1.5	2	2	2.5	2.5	.5
	3	0	1.5	1.5	1.5	1	1	-	2	2.5	4.5	4.5	4	3.5	3.5	2.5	3	2	2	2	3	3	.5
	4	0	1	1	.5	1	1	-	1.5	3	6	5.5	5	4.5	4.5	3	3	2.5	2.5	1	1.5	2	.5
Blank C	5	0	1	1	.5	.5	1	-	2	3	6	6	5.5	4.5	3.5	3	2.5	2	2	.5	1	-	.5
	6	0	1	1	.5	1	1	-	1.5	2.5	5.5	5.5	5	4.5	2.5	2	2	1.5	1				
	7	0	1	.5	.5	1	1	-	1.5	2	3.5	4	4.5	3.5	1	1.5	1	-	1				
	8	0	1	.5	.5	.5	.5	-	.5	1	2	2	2.5	3									
	9	-	-	0	-	-	0	-	0	0	.5	.5	1	1.5									

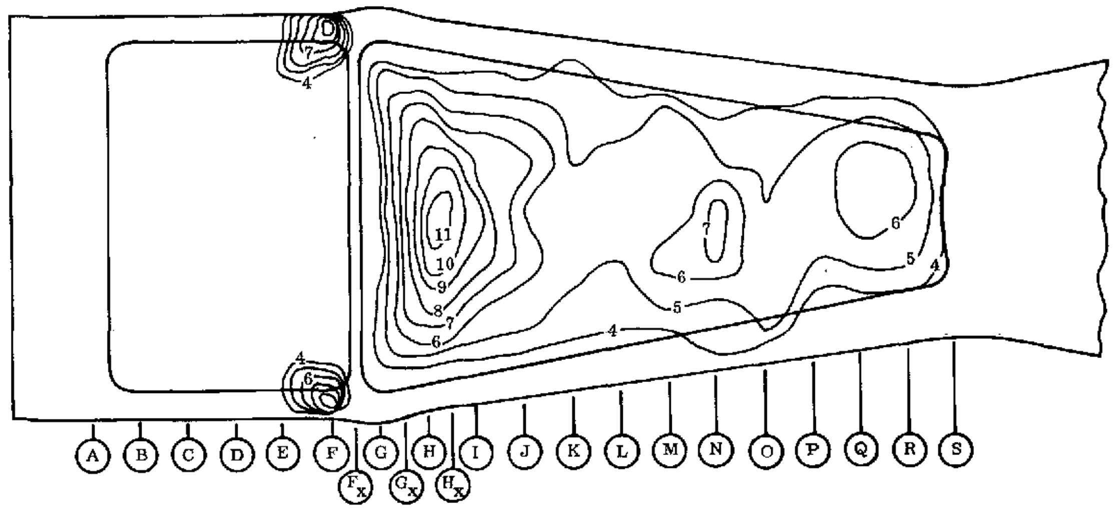

Figure 2-18. Longitudinal Elongation Distribution, Sheet A

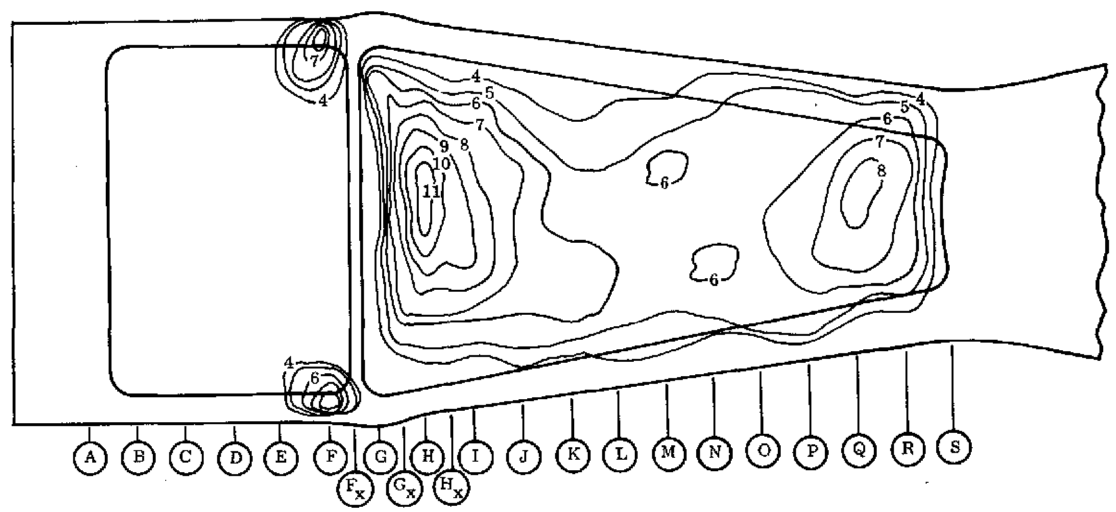

Figure 2-19. Longitudinal Elongation Distribution, Sheet B

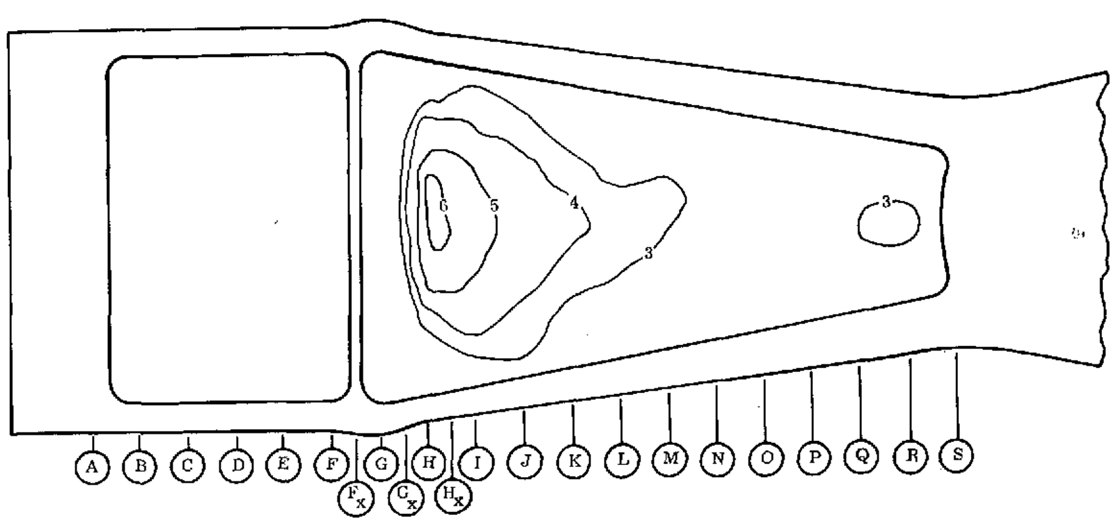

Figure 2-20. Longitudinal Elongation Distribution, Sheet C

Table 2-7. Transverse Elongation, Sheets A, B, and C

Gore Blank	Line		Station																					
			A	B	C	D	E	F	Fx	G	Gx	H	Hx	I	J	K	L	M	N	O	P	Q	R	S
Blank A	1	mm	-	-	-	-	-	-	-	-	50.8	50.5	50.5	50.0	50.0	50.1	50.3	50.3	50.3	50.3	49.8	50.1	50.1	50.3
		(in.)	-	-	-	-	-	-	-	-	(2.00)	(1.99)	(1.99)	(1.98)	(1.98)	(1.97)	(1.98)	(1.98)	(1.98)	(1.98)	(1.96)	(1.97)	(1.97)	(1.98)
	2	mm	50.8	50.3	50.3	50.5	50.35	50.5	-	50.1	50.1	50.3	50.0	50.0	50.0	50.1	50.3	50.1	50.3	50.1	49.8	49.8	50.1	50.8
		(in.)	(2.00)	(1.98)	(1.98)	(1.99)	(1.98)	(1.99)	-	(1.97)	(1.97)	(1.98)	(1.97)	(1.97)	(1.98)	(1.97)	(1.98)	(1.97)	(1.98)	(1.97)	(1.96)	(1.96)	(1.97)	(2.00)
	3	mm	50.8	50.3	50.5	50.3	50.5	50.5	-	50.3	49.8	50.1	50.0	50.0	50.0	50.1	50.1	50.1	50.1	50.1	50.1	49.8	50.1	50.8
		(in.)	(2.00)	(1.98)	(1.99)	(1.98)	(1.99)	(1.99)	-	(1.98)	(1.96)	(1.97)	(1.97)	(1.97)	(1.97)	(1.97)	(1.97)	(1.97)	(1.97)	(1.97)	(1.97)	(1.96)	(1.97)	(2.00)
	4	mm	50.8	50.3	50.5	50.3	50.8	50.5	-	50.3	50.1	49.8	49.0	49.0	49.0	50.1	50.1	50.1	49.8	50.1	50.1	50.1	50.3	50.8
		(in.)	(2.00)	(1.98)	(1.99)	(1.98)	(2.00)	(1.99)	-	(1.98)	(1.97)	(1.96)	(1.96)	(1.96)	(1.96)	(1.97)	(1.97)	(1.97)	(1.96)	(1.97)	(1.97)	(1.97)	(1.98)	(2.00)
	5	mm	50.8	50.5	50.5	50.5	50.8	50.8	-	50.3	50.1	49.8	49.0	49.0	50.0	50.1	50.3	50.1	49.8	50.1	50.3	50.3	50.3	50.5
		(in.)	(2.00)	(1.99)	(1.99)	(1.99)	(2.00)	(2.00)	-	(1.98)	(1.97)	(1.96)	(1.96)	(1.96)	(1.97)	(1.97)	(1.98)	(1.97)	(1.96)	(1.97)	(1.98)	(1.98)	(1.98)	(1.99)
	6	mm	50.8	50.8	50.5	50.5	50.8	50.8	-	50.1	50.1	49.8	49.0	49.0	50.0	50.3	50.3	50.1	50.3	50.1				
		(in.)	(2.00)	(2.00)	(1.99)	(1.99)	(2.00)	(2.00)	-	(1.97)	(1.97)	(1.96)	(1.96)	(1.96)	(1.97)	(1.98)	(1.98)	(1.97)	(1.98)	(1.97)				
	7	mm	50.8	50.8	50.3	50.5	50.8	50.8	-	50.1	50.1	49.8	50.0	50.0	50.0	50.3	50.3	50.3	50.1	50.1				
		(in.)	(2.00)	(2.00)	(1.98)	(1.99)	(2.00)	(2.00)	-	(1.97)	(1.97)	(1.96)	(1.97)	(1.97)	(1.97)	(1.98)	(1.98)	(1.98)	(1.97)	(1.97)				
	8	mm	50.8	50.8	50.3	50.3	50.5	50.5	-	50.1	50.1	50.3	50.0	50.5	50.0									
		(in.)	(2.00)	(2.00)	(1.98)	(1.98)	(1.99)	(1.99)	-	(1.97)	(1.97)	(1.98)	(1.98)	(1.99)	(1.98)									
	9	mm	-	-	-	-	-	-	-	-	-	50.0	50.0	50.5	50.5									
		(in.)	-	-	-	-	-	-	-	-	-	(1.98)	(1.98)	(1.99)	(1.99)									
Blank B	1	mm	-	-	-	-	-	-	-	-	50.8	50.8	50.8	50.8	50.8	50.8	50.3	50.5	50.3	50.3	50.5	50.3	50.1	50.5
		(in.)	-	-	-	-	-	-	-	-	(2.00)	(2.00)	(2.00)	(2.00)	(2.00)	(2.00)	(1.98)	(1.99)	(1.98)	(1.98)	(1.99)	(1.98)	(1.97)	(1.99)
	2	mm	50.8	50.5	50.8	50.5	50.3	50.3	-	50.1	50.1	50.3	50.3	50.3	50.3	50.5	50.3	50.3	50.3	50.3	49.8	49.5	50.1	51.1
		(in.)	(2.00)	(1.99)	(2.00)	(1.99)	(1.98)	(1.98)	-	(1.97)	(1.97)	(1.98)	(1.98)	(1.98)	(1.98)	(1.99)	(1.98)	(1.98)	(1.98)	(1.98)	(1.96)	(1.95)	(1.97)	(2.01)
	3	mm	51.1	50.8	50.5	50.5	50.5	50.5	-	50.3	49.8	49.8	49.8	50.1	50.3	50.3	50.3	50.3	50.1	50.1	49.8	49.5	50.1	50.8
		(in.)	(2.01)	(2.00)	(1.99)	(1.99)	(1.99)	(1.99)	-	(1.98)	(1.96)	(1.96)	(1.96)	(1.97)	(1.98)	(1.98)	(1.98)	(1.98)	(1.97)	(1.97)	(1.96)	(1.95)	(1.97)	(2.00)
	4	mm	50.8	50.8	50.3	50.3	50.8	50.5	-	50.5	50.1	49.8	49.8	50.1	50.1	50.1	50.1	50.1	50.3	50.1	50.1	49.8	50.1	50.8
		(in.)	(2.00)	(2.00)	(1.98)	(1.98)	(2.00)	(1.99)	-	(1.99)	(1.97)	(1.96)	(1.96)	(1.97)	(1.97)	(1.97)	(1.97)	(1.97)	(1.98)	(1.97)	(1.97)	(1.96)	(1.97)	(2.00)
	5	mm	50.8	50.8	50.3	50.5	50.8	50.8	-	50.3	50.1	49.8	49.8	49.5	50.1	50.1	50.3	50.1	50.1	50.1	50.3	50.5	50.5	50.8
		(in.)	(2.00)	(2.00)	(1.98)	(1.99)	(2.00)	(2.00)	-	(1.98)	(1.97)	(1.96)	(1.96)	(1.95)	(1.97)	(1.97)	(1.98)	(1.97)	(1.97)	(1.97)	(1.98)	(1.99)	(1.99)	(2.00)
	6	mm	51.1	50.8	50.5	50.8	50.8	50.8	-	50.3	50.1	50.1	50.1	49.8	50.1	50.1	50.3	50.3	50.3	50.5				
		(in.)	(2.01)	(2.00)	(1.99)	(2.00)	(2.00)	(2.00)	-	(1.98)	(1.97)	(1.97)	(1.97)	(1.96)	(1.97)	(1.97)	(1.98)	(1.98)	(1.98)	(1.99)				
	7	mm	51.1	50.8	50.8	50.5	50.5	50.8	-	50.3	50.3	50.1	50.1	50.1	50.3	50.3	50.3	50.5	50.5	50.3				
		(in.)	(2.01)	(2.00)	(2.00)	(1.99)	(1.99)	(2.00)	-	(1.98)	(1.98)	(1.97)	(1.97)	(1.97)	(1.98)	(1.98)	(1.98)	(1.99)	(1.99)	(1.98)				
	8	mm	50.8	50.5	50.8	50.5	50.5	50.5	-	50.3	50.3	50.3	50.8	50.3	50.3									
		(in.)	(2.00)	(1.99)	(2.00)	(1.99)	(1.99)	(1.99)	-	(1.98)	(1.98)	(1.98)	(2.00)	(1.98)	(1.98)									
	9	mm	-	-	-	-	-	-	-	-	50.5	50.5	-	-	50.3									
		(in.)	-	-	-	-	-	-	-	-	(1.99)	(1.99)	-	-	(1.98)									
Blank C	1	mm	-	-	-	-	-	-	-	-	50.3	50.5	50.3	50.5	50.3	-	50.8	50.5	50.5	50.5	50.5	50.5	50.8	50.8
		(in.)	-	-	-	-	-	-	-	-	(1.98)	(1.99)	(1.98)	(1.99)	(1.98)	-	(2.00)	(1.99)	(1.99)	(1.99)	(1.99)	(1.99)	(2.00)	(2.00)
	2	mm	50.5	50.8	50.5	50.5	50.5	50.8	-	50.5	50.3	50.5	50.3	50.5	50.3	50.3	50.5	50.5	50.5	50.5	50.5	50.5	50.5	50.5
		(in.)	(1.99)	(2.00)	(1.99)	(1.99)	(1.99)	(2.00)	-	(1.99)	(1.98)	(1.99)	(1.98)	(1.99)	(1.98)	(1.98)	(1.99)	(1.99)	(1.99)	(1.99)	(1.99)	(1.99)	(1.99)	(1.99)
	3	mm	50.8	50.5	50.5	50.5	50.5	50.5	-	50.5	50.5	50.3	50.5	50.3	50.3	50.3	50.3	50.5	50.5	50.5	50.5	50.5	50.5	50.5
		(in.)	(2.00)	(1.99)	(1.99)	(1.99)	(1.99)	(1.99)	-	(1.99)	(1.99)	(1.98)	(1.99)	(1.98)	(1.98)	(1.98)	(1.98)	(1.99)	(1.99)	(1.99)	(1.99)	(1.99)	(1.99)	(1.99)
	4	mm	50.5	50.5	50.5	50.8	50.8	50.8	-	50.5	50.5	50.5	50.5	50.5	50.3	50.3	50.5	50.5	50.5	50.3	50.5	50.5	50.5	-
		(in.)	(1.99)	(1.99)	(1.99)	(2.00)	(2.00)	(2.00)	-	(1.99)	(1.99)	(1.99)	(1.99)	(1.99)	(1.98)	(1.98)	(1.99)	(1.99)	(1.99)	(1.98)	(1.99)	(1.99)	(1.99)	-
	5	mm	50.5	50.8	50.5	50.5	50.5	50.5	-	50.8	50.5	50.5	50.5	50.5	50.5	50.3	50.3	50.5	50.5	50.5	50.5	50.5	50.5	-
		(in.)	(1.99)	(2.00)	(1.99)	(1.99)	(1.99)	(1.99)	-	(2.00)	(1.99)	(1.99)	(1.99)	(1.99)	(1.99)	(1.98)	(1.98)	(1.99)	(1.99)	(1.99)	(1.99)	(1.99)	(1.99)	-
	6	mm	50.5	50.5	50.8	50.8	50.8	50.8	-	50.5	50.5	50.5	50.5	50.5	50.3	50.5	50.5	50.5	50.5	50.5				
		(in.)	(1.99)	(1.99)	(2.00)	(2.00)	(2.00)	(2.00)	-	(1.99)	(1.99)	(1.99)	(1.99)	(1.99)	(1.98)	(1.99)	(1.99)	(1.99)	(1.99)	(1.99)				
	7	mm	50.8	50.8	50.8	50.8	50.8	50.8	-	50.8	50.5	50.5	50.5	50.5	50.3	50.5	50.5	50.5	50.5	50.5				
		(in.)	(2.00)	(2.00)	(2.00)	(2.00)	(2.00)	(2.00)	-	(2.00)	(1.99)	(1.99)	(1.99)	(1.99)	(1.98)	(1.99)	(1.99)	(1.99)	(1.99)	(1.99)				
	8	mm	50.8	50.8	50.8	50.8	50.8	50.8	-	50.8	50.5	50.8	50.5	50.5	50.5									
		(in.)	(2.00)	(2.00)	(2.00)	(2.00)	(2.00)	(2.00)	-	(2.00)	(1.99)	(2.00)	(1.99)	(1.99)	(1.99)									
	9	mm	-	-	-	-	-	-	-	-	50.5	-	50.3	50.3	50.5									
		(in.)	-	-	-	-	-	-	-	-	(1.99)	-	(1.98)	(1.98)	(1.99)									

FOLDOUT FRAME

FOLDOUT FRAME

Table 2-8. Percent Transverse Elongation and Compression, Sheets A, B, and C

Gore Blank	Line	Station A	B	C	D	E	F	Fx	G	Gx	H	Hx	I	J	K	L	M	N	O	P	Q	R	S
Blank A	1	-	-	-	-	-	-	-	-	.5	0	0	-.5	-.5	-1	-.5	-.5	-.5	-.5	-1.5	-1	-1	-.5
	2	.5	-.5	-.5	0	-.5	0	-	-1	-1	-1.5	-1	-1	-.5	-1	-.5	-1	-.5	-1	-1.5	-1.5	-1	.5
	3	.5	-.5	0	-.5	0	0	-	-.5	-1.5	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1.5	-1	.5
	4	.5	-.5	0	-.5	.5	0	-	-.5	-1	-1.5	-1.5	-1.5	-1.5	-1	-1	-1	-1.5	-1	-1	-1	-.5	.5
	5	.5	0	0	0	.5	.5	-	-.5	-1	-1.5	-1.5	-1.5	-1	-1	-.5	-1	-1.5	-1	-.5	-.5	-.5	0
	6	.5	.5	0	0	.5	.5	-	-1	-1	-1.5	-1.5	-1.5	-1	-.5	-.5	-1	-1.5	-1				
	7	.5	.5	-.5	0	.5	.5	-	-1	-1	-1.5	-1	-1	-1	-.5	-.5	-.5	-1	-1				
	8	.5	.5	-.5	-.5	0	0	-	-1	-1	-.5	-.5	0	-.5									
	9	-	-	-	-	-	-	-	-	-	-.5	-.5	0	0									
Blank B	1	-	-	-	-	-	-	-	-	.5	.5	.5	.5	.5	.5	-.5	0	-.5	-.5	0	-.5	-1	0
	2	.5	0	.5	0	-.5	-.5	-	-1	-1	-.5	-.5	-.5	-.5	0	-.5	-.5	-.5	-.5	-1.5	-2	-1	1
	3	1	.5	0	0	0	0	-	-.5	-1.5	-1.5	-1.5	-1	-.5	-.5	-.5	-.5	-1	-1	-1.5	-2	-1	.5
	4	.5	.5	-.5	-.5	.5	0	-	0	-1	-1.5	-1.5	-1	-1	-1	-1	-1	-.5	-1	-1	-1.5	-1	.5
	5	.5	.5	-.5	0	.5	.5	-	-.5	-1	-1.5	-1.5	-2	-1	-1	-.5	-1	-1	-1	-.5	0	0	.5
	6	1	.5	0	.5	.5	.5	-	-.5	-1	-1	-1	-1.5	-1	-1	-.5	-.5	-.5	0				
	7	1	.5	.5	0	0	.5	-	-.5	-.5	-1	-1	-1	-.5	-.5	-.5	0	0	-.5				
	8	.5	0	.5	0	0	0	-	-.5	-.5	-.5	.5	-.5	-.5									
	9	-	-	-	-	-	-	-	-	0	0	-	-	-.5									
Blank C	1	-	-	-	-	-	-	-	-	-.5	0	-.5	0	-.5	-	.5	0	0	0	0	0	.5	.5
	2	0	.5	0	0	0	.5	-	0	-.5	0	-.5	0	-.5	-.5	0	0	0	0	0	0	0	0
	3	.5	0	0	0	0	0	-	0	0	-.5	0	-.5	-.5	-.5	-.5	0	0	0	0	0	0	0
	4	0	0	0	.5	.5	.5	-	0	0	0	0	0	-.5	-.5	0	0	0	-.5	0	0	0	-
	5	0	.5	0	0	.5	0	-	.5	0	0	0	0	0	-.5	-.5	0	0	0	0	0	0	-
	6	0	0	.5	.5	.5	.5	-	0	0	0	0	0	-.5	0	0	0	0	0				
	7	.5	.5	.5	.5	.5	.5	-	.5	0	0	0	0	-.5	0	0	0	0	0				
	8	.5	.5	.5	.5	.5	.5	-	.5	0	.5	0	0	0									
	9	-	-	-	-	-	-	-	-	0	-	-.5	-.5	0									

The percent of elongation for the centerline of each blank is graphically represented in Figure 2-21 to show the line of greatest elongation in each blank. Figure 2-21 also includes the average elongation for the weld-lands of each station. Limited test data indicate typical elongations of 18.5% to 21% are available for mill supplied 2219-T37 aluminum, but the available uniform elongation is normally 60% of the total elongation, based on Convair's experience. Thus 11.1% to 12.6% maximum elongation is desired. For this reason a limit of 11% elongation is shown on Figure 2-21. Blank B having a maximum elongation at station H of 11.5% exceeds the limit desired.

A minimum elongation of 1% is desired in all edge or weld-land elements to prevent springback, thus ensuring a good set in these elements (see 1% limit line in Figure 2-21). The Blank C falling below the 1% minimum elongation limit in the edge elements, was caused by the termination of the stretch forming program for this blank. Blank C should have been stretched further to set the edge elements, while blanks A and B were satisfactory.

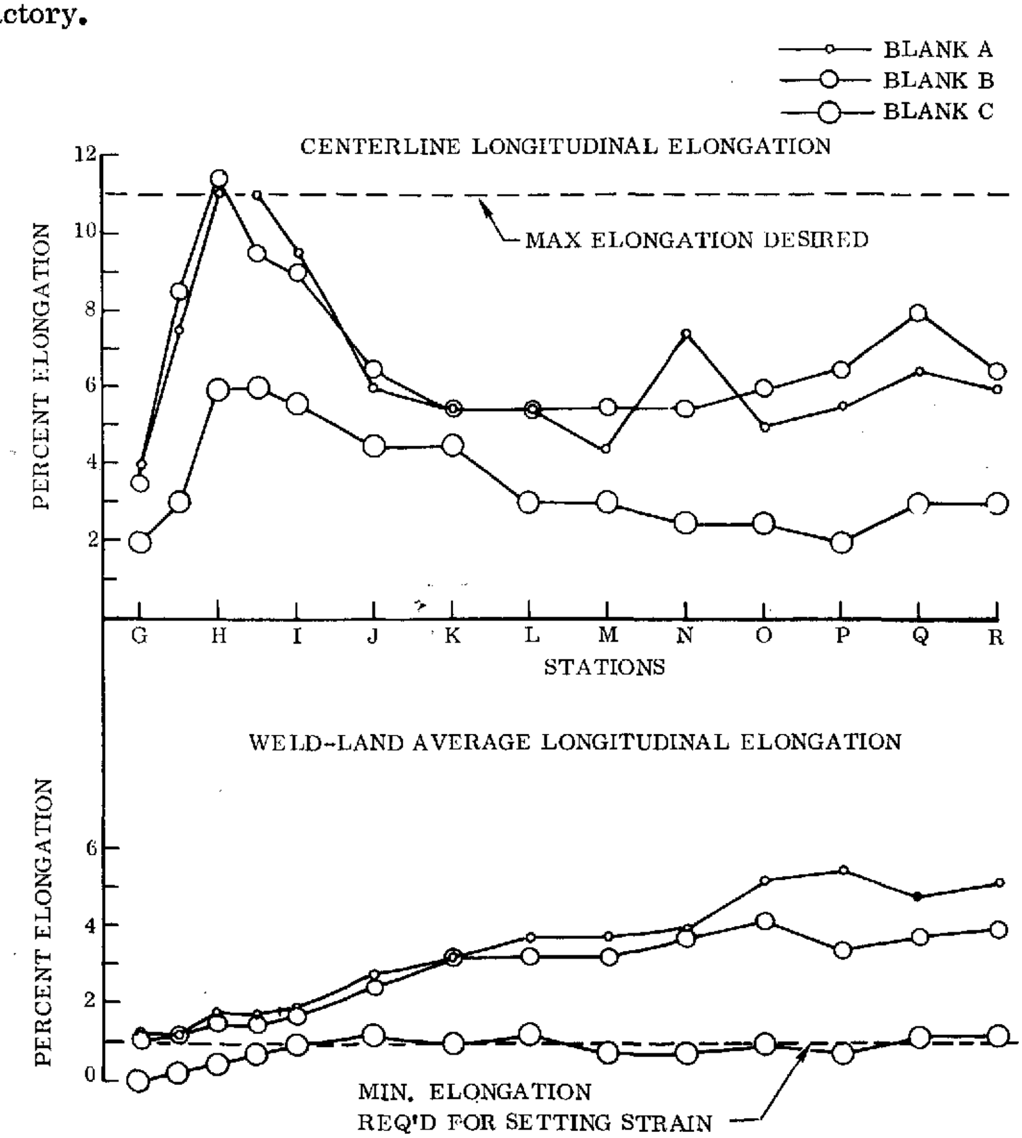

Figure 2-21. Centerline and Weld-Land Longitudinal Elongation

2.10 PACKAGING AND SHIPPING

The three gores plus all cutoff material from the gore blanks were packaged in a single wooden box for shipment by truck to NASA/MSFC, Alabama. The box was custom made with two contour-matching vertical supports proportionally located on the box base to support the full width of the compound contoured gores. The gores were installed in the box with the concave sides down. The ends of the gores were fitted against blocks on the box to prevent shifting. The parts were separated with cushioning material for protection, and secured to the base by steel strapping over the vertical support locations. Parent material that was trimmed off of the edges of each blank before forming was strapped to the base under the parts. Each piece of this trim material and each gore was identified with its corresponding blank number for identification by both impression stamping and marking pen. The approximate dimensions of the wooden shipping box were 99.06 cm (39 in.) high by 96.52 cm (38 in.) wide by 365.76 cm (144 in.) long. The box was shipped to MSFC via Leeway Freight Lines on 11 June 1974.

2.11 CONCLUSIONS

The conclusions reached are as follows:

1. The successful room temperature STFM of the three 2219-T37 one-third-scale gores show that the gores of a 12-gore configuration blukhead can be fabricated using this process.
2. If the stretch press jaws could have been rotated to a greater vertical angle, it is believed that the gores would have been formed completely to the die at the base end without difficulty, and the amount of stretch could possibly be reduced.
3. It may be possible to stretch form gores to an 11- or 10-gore bulkhead configuration if the amount of stretch can be reduced; however, available uniform material elongation is the governing factor. An 11- or 10-gore bulkhead configuration could result in a much higher scrap rate (> 5%).

SECTION 3

PHASE II - PRODUCTION DIE DESIGN, TOOLING COST STUDY, AND PRODUCTION COST STUDY

3.1 GENERAL INFORMATION

The designs and costs in Phase II were to be compiled, if possible, for all of the following configurations:

1. Production of LH_2 Tank Dome gores per MMC Dwg. 82600202000 (200 in. cap, 12 gores).
2. Production of LH_2 Tank Dome gores per MMC Dwg. 82600202001 (140 in. cap, 12 gores).
3. Production of LO_2 Tank Dome gores, no MMC Dwg. available (200 in. cap, 8 gores).
4. Production of LO_2 Tank Dome gores per MMC Dwg. 82600203500 (140 in. cap, 8 gores).
5. Production of 12 gores for MMC LH_2 Dome Configuration (one-half an ellipsoid with major and minor axes of 165.1 and 123.825 in. rèspectively) but with the optimum size of cap based on GD/C studies.
6. Production of 8 gores for the MMC LO_2 Dome Configuration (one-half an ellipsoid with major and minor axes of 165.1 and 123.825 in. respectively) but with optimum size cap based on GD/C studies.
7. Production of 12 gores for the MMC LO_2 Dome Configuration (one-half an ellipsoid with major and minor axes of 165.1 and 123.825 in. respectively) but with optimum size cap based on GD/C studies.
8. Production of the least number of gores for the MMC LH_2 Tank Dome with the 200 in. diameter cap that can be made with existing stretch presses in the country and the material sizes available. See MMC Dwg. 82600202000.
9. Production of the least number of gores for the MMC LH_2 Tank Dome with the 140 in. diameter cap that can be made with existing stretch presses in the Country and the material sizes available. See MMC Dwg. 82600202001.
10. Production of the least number of gores for the MMC LO_2 Tank Dome with the 200 in. diameter cap that can be made with existing stretch presses in the Country and the material sizes available. See MMC Dwg. 82600203500.
11. Production of the least number of gores for the MMC LO_2 Tank Dome with the 140 in. diameter cap that can be made with existing stretch presses in the Country and the material sizes available. See MMC Dwg. 82600203500.

12. Production of the least number of gores for the MMC LH_2 Dome configuration and the optimum size cap based on GD/C studies.

13. Production of the least number of gores for the MMC LO_2 Dome configuration and the optimum size cap based on GD/C studies.

This list of 13 configurations was reduced to seven configurations because: a) previous experience showed that the minimum number of gores per bulkhead that can be formed is 10, and, b) duplication of configurations occurred after establishing the least number of gores for the desired polar cap diameters. The seven configurations and their numerical identification which will be used throughout the Phase II study are as follows:

Configuration 1
LH_2 tank bulkhead gores
200-in.-diameter cap, 12 gores per bulkhead (NASA 1)
Ref. Dwg: MMC82600202000

Configuration 2
LH_2 tank bulkhead gores
140-in.-diameter cap, 12 gores per bulkhead (NASA 2)
Ref. Dwg: MMC 82600202001

Configuration 3
LH_2 tank bulkhead gores
120-in.-diameter cap, 12 gores per bulkhead (NASA 5)
Ref. Dwg: MMC82600202001

Configuration 4
LO_2 tank bulkhead gores
120-in.-diameter cap, 12 gores per bulkhead (NASA 7)
Ref. Dwg: MMC82600203500

Configuration 5
LH_2 tank bulkhead gores
200-in.-diameter cap, 10 gores per bulkhead (NASA 8)
Ref. Dwg: MMC82600202000

Configuration 6
LO_2 tank bulkhead gores
200-in.-diameter cap, 10 gores per bulkhead (NASA 10)
Ref. Dwg: MMC82600203500

Configuration 7
LO_2 tank bulkhead gores
140-in.-diameter cap, 12 gores per bulkhead (NASA 11)
Ref. Dwg: MMC82600203500

3.2 STRETCH FORM DIE DESIGN

A preliminary design for a typical production stretch form die capable of forming two parts simultaneously (Siamese forming) was prepared.

The preliminary STFM die design and die support structure design is shown in Figure 3-1 (Drawing MRD C00191802). The overall gore die dimensions are based on a 12-gore LO_2 or LH_2 bulkhead configuration with a 304.8 cm (120-in.) diameter polar cap. This configuration requires the largest gore die. The end of part (EOP) locations for 355.6 cm (140-in.) diameter and 508 cm (200-in.) diameter polar cap sizes are also shown on the die drawing for reference.

The Siamese method of stretch forming was chosen because previous cost studies at Convair showed a 15 to 20% material cost savings as compared to single gore stretch forming. The Siamese method is cheaper not only because of reductions in the amount of aluminum scrap cutoff material, but also because of reduced machining and setup time, stretch forming and setup time, and handling.

The Siamese stretch form die design consists of two separate stretch form dies mounted on a tall substructure. The substructure, of 15.24-cm (6-in.) square steel tubing, would be fabricated as three separate weldments and bolted together. Each section would weigh less than 4535.9 kg (5 tons) so that an existing 4535.9-kg (5-ton) overhead crane could be used to assemble the substructure on the stretch press bed. The jaws of the 453,592.3 kg (500-ton) Convair stretch press can presently be raised to only a 45-degree angle, but the press jaws can be readily modified to permit raising a full 90-degree angle as shown in the tool drawing.

The design concept of the two stretch form dies is based on a low cost design recently developed at Convair and proven on large production DC-10 skin stretch form dies. This method of fabricating large stretch form dies is believed to be the lowest cost method in use in the industry today. The die fabrication method consists of the following steps:

1. Fabricate a female plaster master of the desired gore shape.
2. Layup a 1.27 cm (1/2-in.) thick high-dens ty fiberglass die face within the plaster master.
3. Fabricate a weldment structure of I-beams as shown, and install in position above the fiberglass die face.
4. Fill the die cavity with a commercial lightweight aerated concrete and allow to harden for 30 days to achieve maximum concrete strength. A lightweight concrete is used to reduce the die weight to within the capacity of existing handling equipment. This concrete can be formulated with a density as low as 72.1305 gm/m^3 (45 lb/ft^3), as compared to the normal concrete density of approximately 232.4205 gm/m^3 (145 lb/ft^3). Although the compression strength of the 72.1305 gm/m^3

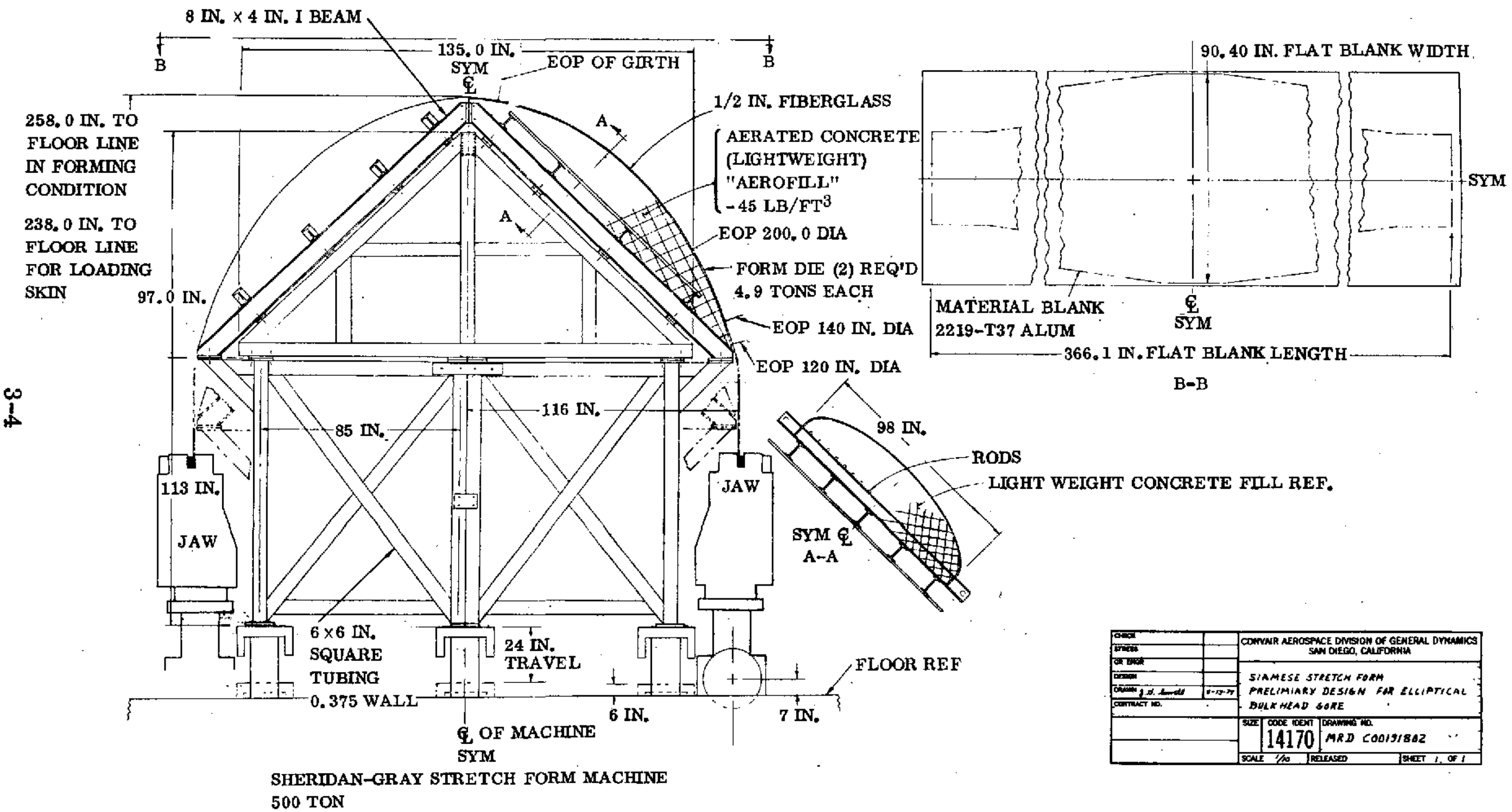

Figure 3-1. Siamese Stretch Form Preliminary Design for Elliptical Bulkhead Gore

($45\ lb/ft^3$) concrete is less than normal concrete, this concrete has proven satisfactory in large STFM dies forming aluminum parts on a production basis as large and as thick as the subject gores.

The completed STFM dies, weighing approximately 4445.2 kg (4.9 tons) each, will then be installed on the substructure using the existing 4535.9 kg (5-ton) overhead hoist and bolted in position ready for stretch forming.

A discrepancy exists between the supplied Martin Co. drawings and the NASA RFQ with respect to the contour dimensions of the LO_2 and LH_2 bulkheads. The drawings show that the inside dimensions, half ellipsoids having inside major and minor axes of 419.05 cm (165.1 in.) and 314.51 cm (123.825 in.) respectively, of the LO_2 and LH_2 bulkheads are the same, but, the NASA contract Scope of Work states that the outside dimensions of the two bulkheads are the same. If the NASA Scope of Work statement is correct, then a removable die cover sheet will be stretch formed of approximate 0.508 cm (0.20 in.) thick aluminum to shim the die surface out to the required mold line contour for the stretch forming of LH_2 tank gores. This cover sheet cost is included in the Tooling Cost Study (see Volume II - Cost Study).

3.3 TOOLING COST STUDY

The tooling costs for the seven different configurations is discussed in Volume II - Cost Study.

3.4 PRODUCTION FLOW CHART

The production flow chart showing the major operations and tools in a proposed manufacturing plan for any of the seven bulkhead gore configurations is shown in Figure 3-2. A simplified version of the production flow chart is shown in Figure 3-3.

The estimated average flow hours for each operation are shown on these charts. The production rates at each station can be established from the fabrication rate and lot plan shown in Figure 3-4.

3.5 PRODUCTION COST STUDY

The cost studies for bulkhead gores manufacturing are contained in Volume II of this report.

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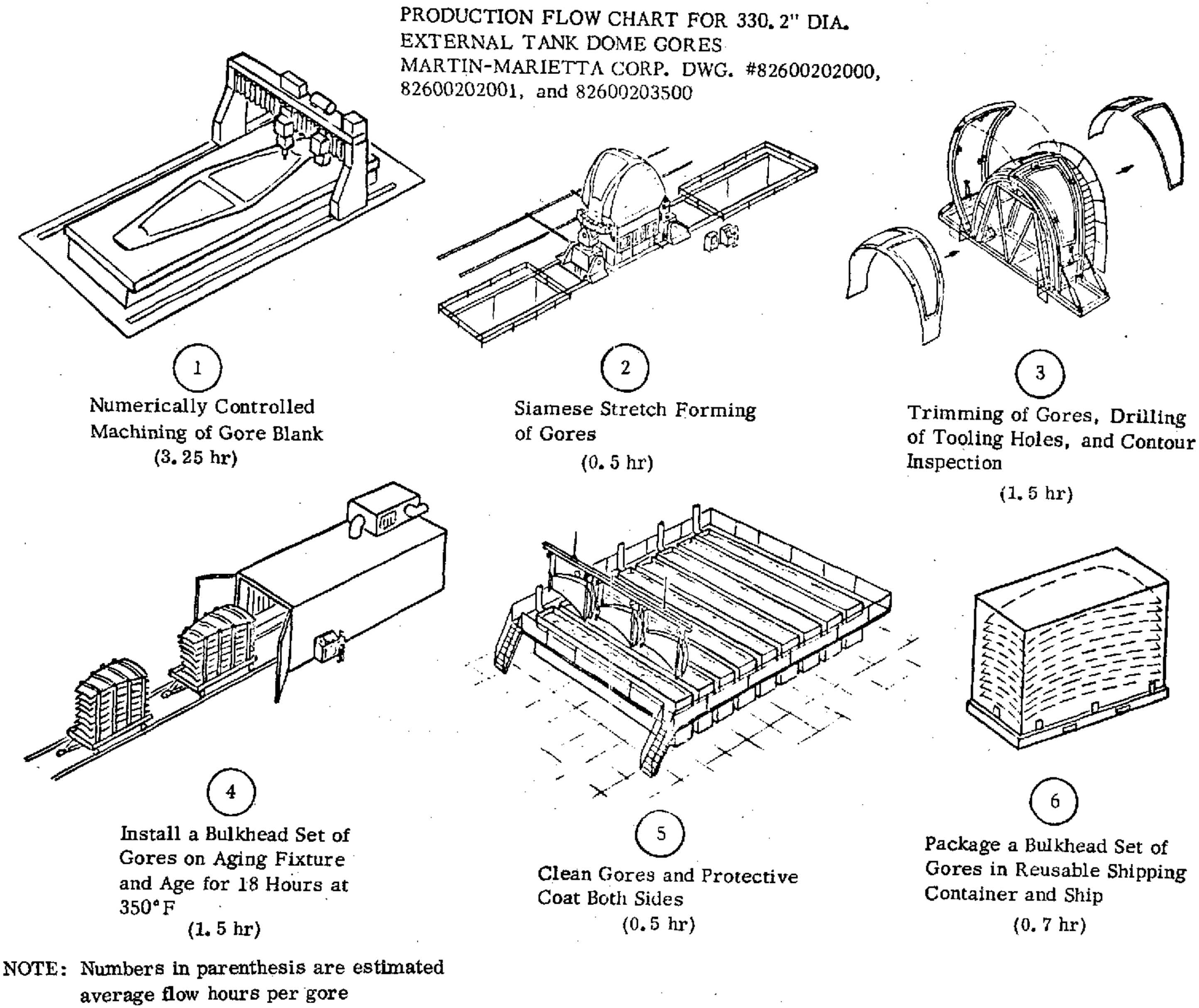


Figure 3-3. Simplified Production Flow Chart

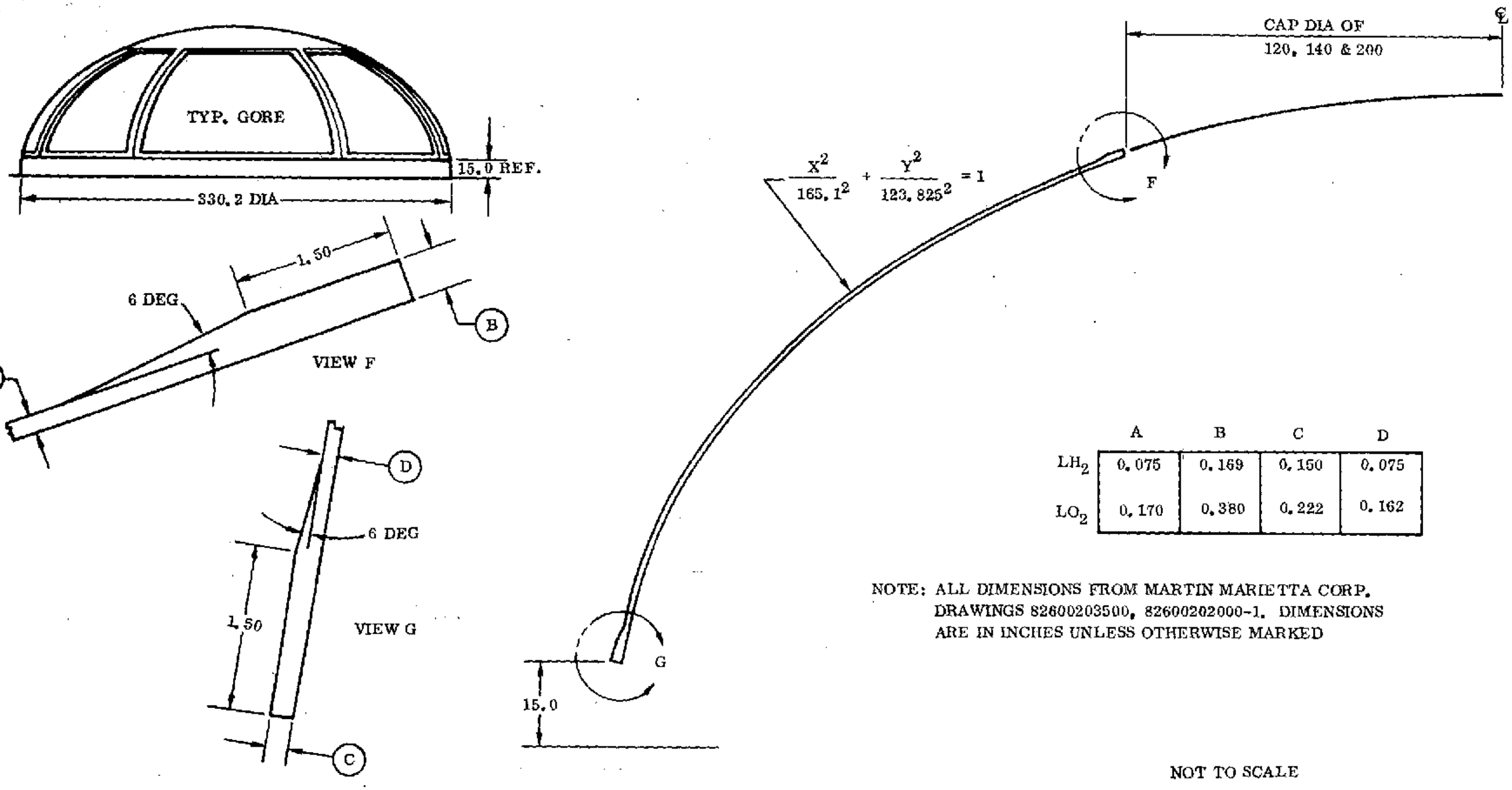
SHUTTLE EXTERNAL TANK DOME GORES
FABRICATION RATE & LOT PLAN
CM 74-2002A

13 MAY 1974

	PROGRAM YEAR 1	2	3	4	5	6	7	8	9	10	11	12	13
LO_2 TANK (10 GORE PLAN)													
DELIVERY REQUIREMENTS	20	30	80	150	240	320	400	600	600	600	600	600	240
CUM	20	50	130	280	520	840	1240	1840	2440	3040	3640	4240	4480
MANUFACTURING RATE	10 10	20 20	20 20 20 30	30 30 30 60	60 60 60 60	60 90 90 90	90 90 90 120	150 150 150 150	150 150 150 150	150 150 150 150	150 150 150 150	150 150 150 150	150 70
CUM COMPLETIONS	20	60	150	300	540	870	1260	1860	2460	3060	3660	4260	448[illegible]
LOTS PER YEAR	2	2	4	5	8	11	13	20	20	20	20	20	8
CUM LOTS TOTAL	2	4	8	13	21	32	45	65	85	105	125	145	153
LOT SIZE	10	20	3-20 1-30	30	30	30	30	30	30	30	30	30	6-30 2-20
LH_2 TANK (10 GORE PLAN)													
DELIVERY REQUIREMENTS	40	60	160	300	480	640	800	1200	1200	1200	1200	1200	480
CUM	40	100	260	560	1040	1680	2480	3680	4880	6080	7280	8480	8960
MANUFACTURING RATE	20 20	40 40	40 40 40 60	60 60 60 120	120 120 120 120	120 180 180 180	180 180 180 240	300 300 300 300	300 300 300 300	300 300 300 300	300 300 300 300	300 300 300 300	300 140
CUM COMPLETIONS	40	120	300	600	1080	1740	2520	3720	4920	6120	7320	8520	896[illegible]
LOTS PER YEAR	2	2	4	5	8	11	13	20	20	20	20	20	8
CUM LOTS TOTAL	2	4	8	13	21	32	45	65	85	105	125	145	151
LOT SIZE	20	40	3-40 1-60	60	60	60	60	60	60	60	60	60	6-60 2-40
LO_2 TANK (12 GORE PLAN)													
DELIVERY REQUIREMENTS	24	36	96	180	288	384	480	720	720	720	720	720	288
CUM	24	60	156	336	624	1008	1488	2208	2928	3648	4368	5088	5176
MANUFACTURING RATE	12 12	24 24	24 24 24 36	36 36 36 72	72 72 72 72	72 108 108 108	108 108 108 144	180 180 180 180	180 180 180 180	180 180 180 180	180 180 180 180	180 180 180 180	180 64
CUM COMPLETIONS	24	72	180	360	648	1044	1512	2232	2952	3672	4392	5112	5176
LOTS PER YEAR	2	2	4	5	8	11	13	20	20	20	20	20	8
CUM LOTS TOTAL	2	4	8	13	21	32	45	65	85	105	125	145	153
LOT SIZE	12	24	3-24 1-36	36	36	36	36	36	36	36	36	36	6-36 2-24
LH_2 TANK (12 GORE PLAN)													
DELIVERY REQUIREMENTS	48	72	192	360	576	768	960	1440	1440	1440	1440	1440	576
CUM	48	120	312	672	1248	2016	2976	4416	5856	7296	8736	10176	10752
MANUFACTURING RATE	24 24	48 48	48 48 48 72	72 72 72 144	144 144 144 144	144 216 216 216	216 216 216 288	360 360 360 360	360 360 360 360	360 360 360 360	360 360 360 360	360 360 360 360	360 168
CUM COMPLETIONS	48	144	360	720	1296	2088	3024	4464	5904	7344	8784	10224	10752
LOTS PER YEAR	2	2	4	5	8	11	13	20	20	20	20	20	8
CUM LOTS TOTAL	2	4	8	13	21	32	45	65	85	105	125	145	153
LOT SIZE	24	48	3-48 1-72	72	72	72	72	72	72	72	72	72	6-72 2-48
	1	2	3	4	5	6	7	8	9	10	11	12	13
	PROGRAM YEAR												

Figure 3-4. Production Rate and Lot Plan

APPENDIX
COLD STRETCH FORMED BULKHEAD GORE DRAWING



	A	B	C	D
LH_2	0.075	0.169	0.150	0.075
LO_2	0.170	0.380	0.222	0.162

NOTE: ALL DIMENSIONS FROM MARTIN MARIETTA CORP. DRAWINGS 82600203500, 82600202000-1. DIMENSIONS ARE IN INCHES UNLESS OTHERWISE MARKED

NOT TO SCALE

COLD STRETCH FORMED BULKHEAD GORE