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CALIFORNIA DIVISION
BURBANK, CALIFORNIA

Lockheed Aircraft Corporation
Burbank, California

Report No. LR 13221
Dated: September 8, 1958

FINAL ENGINEERING REPORT
DEVELOPMENT OF FORGING WAFFLE-TYPE
INTEGRALLY STIFFENED SKIN PANELS
CONTRACT AF 33(600)22372


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FOREWORD

This Final Engineering Report has been prepared by the Lockheed Aircraft Corporation, California Division, Burbank, California, as part of the USAF Contract AF 33(600)-22372, Development of Forging Waffle-Type Integrally Stiffened Skin Panels, entered into by the USAF Materiel Command and the Lockheed Aircraft Corporation on September 5, 1952.

The planning of the basic waffle-type forging development program, direction, coordination and evaluation of the results were performed by personnel of the Lockheed Aircraft Corporation, Production Engineering Department. The construction of dies and performance of tests were conducted by the Wyman-Gordon Company, Worcester, Massachusetts, as the subcontractor to the Lockheed Aircraft Corporation.

The data herein is concerned with two phases of the subject contract. The first phase consisted of a survey of applicable existing air-frame designs, the selection of a part producible on existing forging facilities and preparation of engineering data relative to the part selected. The second phase included design and construction of necessary forging tools, design of ejector mechanisms, development of forging techniques, study of die design to produce complete forgings, and production of sufficient number of test forgings to evaluate forging characteristics, mechanical and metallurgical properties.

ABSTRACT

This report outlines and presents the results of a program for the development of waffle-type forging techniques for producing high strength light weight metal alloy integrally stiffened skin panels. This program was conducted by Lockheed Aircraft Corporation under the sponsorship of the Industrial Resources Branch of the Air Materiel Command.

As a result of an extensive survey and analysis of current and future airframe applications, the Pylon Tank Side Panel (REF. LAC 127593) on the YC-130 airplane was selected for development. Complete engineering data including drawing, stress analysis, weight analysis, and the procedure and results of structural tests are reported.

Technical information on forging techniques, blocker die design, finish die design, ejector system employed and die heater requirements are included. Basic data for low draft angle light metal alloy forgings obtained from small scale test work showing the influence of pressure, temperature, dwell time, blank thickness, web thickness, fillet radii, and stiffener height and thickness is also contained in this report.

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OBJECT

The evident advantages in reduced fabricating costs, in improved mechanical properties, and in obtaining irregular plan form shapes make forging appear to be a very promising method of producing integrally stiffened panels. The object of this investigation was to establish the feasibility of press forging waffle-type integrally stiffened skin panels from high strength light weight metal alloys.

SUMMARY AND CONCLUSIONS

1. The forged panels produced under this program demonstrated the practicability of forging waffle-type integrally stiffened skin panels. The limitations on this type of design are controlled primarily by the maximum press capacity available. The forging techniques developed during this program are not restricted to integrally stiffened panels with waffle-type stiffener design, but are equally applicable to panels with other stiffener patterns.
2. Most of the deficiencies experienced in this panel forging program were due to certain inadequacies in the tooling and accessories rather than being inherent in the technique itself. The difficulties encountered in maintaining adequate die temperatures had a limiting effect on developing full rib heights. An adequately designed internal die heating system, as presented in Appendix VIII, will eliminate this deficiency in future development programs. It is also possible to allow the ribs to flow to unrestricted height and, in a subsequent operation, machine the tops of the ribs to the desired height.
3. The improved structural efficiency and reduction in weight obtained in integrally stiffened structures, as compared with multiple-piece fabricated structures, indicates the need for perfecting this production technique.
4. Stiffener height obtained during forging operations was a direct function of stiffener thickness, forging temperature, forging pressure, and dwell time. Maximum stiffener height, without introducing detrimental defects in the skin surface (suck-in), was established as a direct function of blank thickness.
5. The original design of the lower forging die ejection system did not provide adequate support for the high temperatures and high pressures of forging applied on the knockout pins. The resulting plastic set necessitated redesigning the knockout pins, to be made from high-strength hot-work tool steel, for the final panel forging tryouts. No significant difficulties were encountered with the redesigned knockout pins during the final tryouts. However, improvements would be required in the actuating system, using tapered wedges operated by a horizontal hydraulic cylinder, before attempting further development work. Consideration should be given to the use of a series of lifting bars, operated by the lower platen cylinder, to raise the ejector pins.
6. The multiple-piece interlocking die insert design selected for this forging program proved to be satisfactory. The difficulties, encountered in previous integrally stiffened panel forgings, with underfilled panel edges were eliminated by use of closed-die construction restricting metal flow around the edges of the panel. Complete edge filling was obtained.

7. The multiple-piece insert provides several advantages over the alternately proposed strip-type insert. Particularly important advantages are ease of repair of damaged insert segments and ease of alteration to conform with forging design changes.
8. Striking unblocked blanks in the finish forging dies resulted in incomplete and defective forgings due to excessive flow of metal from the center of the flat blank. Producing finished forgings directly from flat plate stock was not practical. At least one blocking operation prior to finish forging is necessary to reduce lateral metal flow and the resulting metal-flow defects. Underfilled blocked pieces usually resulted in underfilled forgings from the finish dies. Proper blocker configuration is essential to successful forging operations.
9. The best forged panels were produced from fully-formed blocked blanks at temperatures from 730° to 800° F. The heavier forging pressure of 7700 tons produced more nearly filled pieces than did the 4400 ton load. However, extracting the forging from the die cavity without excessive warpage or fracture was difficult due to heavy flash formed between the insert segments by the excessively high forging pressure. Forging pressures should be high enough to completely fill the die cavity but not high enough to force excessive flash between the die insert segments. The optimum combination of temperature and pressure is necessary to produce satisfactory forgings.
10. The "suck-in" type of defect occurring on the skin side of the forged panels became more frequent as the web thickness approached the rib thickness. The tests showed that a 0.25 inch thick forged web with 0.12 inch thick ribs was sufficiently free from defects for an airframe skin. Where required, thinner skins can be machined from the 0.25 inch thickness in order to avoid excessive defects. Forging web thicknesses less than 0.12 inch often resulted in an open "buckling" defect in place of "suck-in". The occurrence of detrimental metal flow defects can be eliminated by restricting the forged web thickness to a minimum of approximately twice the rib thickness.
11. Restriking underfilled forgings approached satisfactory results only when the piece was etched to clear the rib cavities and machined to a uniform rib height. The restruck rib retained its etched thickness except where newly extruded in the die. If this condition is acceptable within dimensional tolerances on a specific production part, restriking in this manner is an effective production technique.
12. Increasing horizontal fillet radii contributed only slightly to improved forging characteristics, as shown by small size specimen investigations. A 1/16 inch radius proved adequate in the panel forging tests. It is felt that larger fillet radii contribute toward increased occurrence of "suck-in" defects.

RECOMMENDATIONS

The development program completed under this Contract demonstrated the practicability of forging integrally stiffened surface structures. The potential savings in machine time and labor costs possible by the use of single piece integrally stiffened structures in place of multiple-piece fabricated structures should establish the desirability of continued research and development effort towards this goal.

1. Further development work to establish optimum forging techniques for producing integrally stiffened panels is recommended in order to bring this method into full production usefulness.
2. The scope of further investigations should be enlarged to include other structural airframe and missile materials such as high strength steels, corrosion and heat resistant alloys and titanium alloys. The need for developing methods for economically fabricating these new materials into useable configurations is urgent.
3. Although the multiple-piece interlocking die inserts in combination with the closed die design performed satisfactorily, it is recommended that the design be modified to provide for unrestricted rib height to assist complete filling and, in a subsequent operation, machine the tops of the ribs to the final desired height.
4. A suitable internal die heating system should be employed in place of external strip heaters in order to maintain proper die temperatures throughout normal forging runs without the use of supplementary heating sources.
5. Further refinement of the ejection system incorporated in the present dies is recommended. The knockout pin design employed in the final forging tryouts functioned satisfactorily. However, redesign of the tapered wedges actuating the pins is recommended to provide optimum operating conditions.
6. In order to eliminate forging defects, the minimum forged web thickness should not be less than twice the rib thickness. Where required, thinner webs can be obtained by subsequently machining the as-forged web to the desired thickness.
7. Forging of flat, unblocked blanks is not recommended. At least one blocking stage to properly distribute the material and reduce lateral metal flow to a minimum is required to produce completely filled, defect free forged panels.
8. Restriking of underfilled forgings is not generally recommended unless an etching operation has been performed so the forging will clear the rib cavities in the die and the superficial step at the juncture of the etched rib and the newly extruded rib surface can be tolerated.

BACKGROUND

Design Standards

Standard draft angles and web thicknesses required by currently used handbook data would indicate that forging of structurally efficient integrally stiffened skin panels is impracticable. These standards, however, apply specifically to hammer forging practice. Information contained in numerous reports and in technical literature on press forging of conventional parts has little or no application to forging of integrally stiffened parts.

Production Experience

Since 1945 the Lockheed Aircraft Corporation has been actively engaged in the development and production of integrally stiffened structures. Such structures incorporate the surface sheet and the required internal stiffeners into a one-piece unit. These panels may be produced by machining from plate, extruding, or press forging. Current models being produced at Lockheed utilize machined and extruded integrally stiffened panels.

The excessive size of some integrally stiffened panels used on current Lockheed models makes it imperative that they be machined from plate stock on equipment specifically designed for this kind of production. Currently available extruded integrally stiffened sheet is limited in width by the capacity of the extruding presses and is limited to parallel stiffeners.

Previous Research

In 1946 a preliminary investigation determined that it was possible to press forge a structurally efficient integrally stiffened section of selected configuration. Based on these preliminary test results, a research program for forging integrally stiffened panels was completed in 1950 under Air Force Contract W33-039-AC 22032. Results of this program (1)* established the feasibility of press forging parallel-ribbed, structurally efficient, integrally stiffened panels from high strength light weight metal alloys.

*Numbers in parenthesis refer to references listed in the bibliography.

Current Program

The next logical step in the development of forged integrally stiffened structures was the production of panels with stiffener elements in two directions forming a waffle-type pattern. Intersecting stiffeners presented additional forging problems of metal flow not encountered in parallel stiffener design. The nature of metal flow at stiffener intersections was not known, particularly with regard to what stiffener heights could be obtained and what forging defects would develop. The most serious defect normally occurring when forging integrally stiffened panels from relatively thin blanks had been a lap-type defect commonly referred to as "suck-in". Various blocker die configurations to provide necessary material in the area of the stiffeners were used to eliminate "suck-in".

Forging Tool Design

Die design, suitable for low draft angle waffle-type forgings, presented several problems. An economically efficient part ejection system had to be developed and an adequate heating method had to be designed which would maintain the required temperature of the forging dies. Alternate insert designs were considered. Blocker die studies were conducted to insure complete filling of the finish die. The size of the final forged part was limited by the 18,000 ton maximum press size available when this program was initiated.

FORGING DEVELOPMENT PROGRAM

In 1952 Lockheed Aircraft Corporation entered into Contract No. AF 33(600)-22372 with the Air Materiel Command to develop a forging technique for the production of waffle-type integrally stiffened skin panels. Although considerable prior work to develop techniques for producing close tolerance light alloy forgings had been conducted, many forging problems relative to the production of thin skin integrally stiffened surface structures remained to be answered. This development program provided answers to many of these problems.

Engineering Design, Analysis, and Testing:

- (a) A survey was made of existing air frame designs for possible application of the waffle grid type integrally stiffened panel.
- (b) A suitable part was selected for development that could be produced, using existing forging facilities.
- (c) Complete engineering data was prepared relative to the part selected, including:
 - (1) stress analysis of the selected part.
 - (2) weight analysis, comparing current design with the one and two-piece forged designs.
 - (3) analysis and selection of the most suitable material, either aluminum or magnesium alloy.
 - (4) adequate structural tests of simulated elements to prove the structural integrity of the proposed design.

Forging Technique Development:

- (a) Design and construction of necessary forging tools.
- (b) Development of ejector mechanisms for part removal.
- (c) Development of forging techniques, including evaluation of the "suck-in" problem, blocker studies and study of the effect of press and die deflections.
- (d) Study of methods of die design to insure complete filling around the outer edges of the panel.
- (e) A sufficient number of test forgings were produced to evaluate the forging characteristics, metallurgical and mechanical properties of the forged panels.

ENGINEERING DESIGN, ANALYSIS, AND TESTING.

1. Survey of Existing Air Frame Designs:

A total of 14 possible applications were considered under this survey. Four parts on the Model C-121, two parts on the F-94C, one part on the T-33 and seven parts on the YC-130 airplanes were considered. Consideration was given to the potential future production of the aircraft, maximum size of the panel under consideration, possible weight savings and the type of loading to which the panel would be subjected. A summary of the parts considered in this survey is contained in Table I.

The tank pylon side panel for the YC-130 airplane was selected for development under this contract for the following reasons:

- (a) Present built-up structure was required to carry relatively high shear loads.
- (b) Panel was a surface structure, readily accessible from the outside of the aircraft for inspection and service.
- (c) Although the total plan area of the side panel required a press considerably larger than that available for this research, it was found that the forging size could be reduced by designing a symmetrical, common forging that could be used to make fore and aft sections of one complete side panel.
- (d) Data obtained under this development program would provide necessary information for the design of a one-piece forged panel producible on one of the presses built under the Air Force Heavy Press Program.

2. Engineering Data:

- (a) Forging Design: The largest forging presses available at the initiation of this program were: one 16,500 ton press located at the Air Force facilities pilot plant, Adrian, Michigan; a 16,500 ton press located at the Alcoa Cleveland Works; and an 18,000 ton press in operation at Wyman-Gordon Company in North Grafton, Massachusetts.

The YC-130 tank pylon side panel has a projected plan area of approximately 1380 square inches. Available information

PART NO.	TITLE	MODEL	QUANTITY PER AIRCRAFT	MAXIMUM DIMENSION (inch)	AREA IN FORGING PLANE (inch ²)	ESTIMATED WEIGHT		MATERIAL	DIRECT LOADING	SHEAR LOADING lb/in.	OTHER LOADS	REMARKS
						CONVENTIONAL	WAFFLE					
337445	Beam Inst'l.-- Interceptal F.S. 697	YC 130	1L-1R	40x8	320	8.00	6.00	75S-T6		450		Loading Small
338633	Access Door-- C.V.U. STA. 283-351.9	YC 130	1L-1R	70x18	1260	not obtained		75S-T6 Al. Alloy	83,000T 94,000T	880 790		Production Airplane Calls for 78ST. Shear Loads Small-- Severe End Loading
338634	Access Door-- O.V.U. STA. 351.8-421.2	YC 130	1L-1R	70x18	1260			75S-T6 Al. Alloy	140,400C Max. Conditions (Inboard)	856		
338636	Access Door-- O.V.U. STA. 491.5-557.75	YC 130	1L-1R	58x18	1224			75S-T6 Al. Alloy				
33864	Access Door-- O.V.U. STA. 163-197	YC 130	1L-1R	39x18	702			75S-T6 Al. Alloy				
338320	Access Door-- C.S. STA. 179-200	YC 130	1L-1R	11x22	242			75S-T6 Al. Alloy	44,000C 28,000T	1,200 1,500		Small--No Particular Problems
342342	Box Beam Assy-- Tank Pylon	YC 130	2L-2R	58x15	870	28.00	27.30	75S-T6 Al. Alloy	60,500T 37,000C Low ~ 5000T/C	500 750 3,100		High Shear Loading--Replacement of built up construction. Interesting Problems. Highly Accessible, Primary-Secondary Structure
312597	Door Assy-- Baggage Comp Access	1049 B	2	18x19	340	not obtained		75S-T6 Al. Alloy			7.74 PSI Pressure	On Cargo Floor-- Size & Loads too Small
312804	Panel Assy-- Wing Joint Access	1049 A, B & C	1L-1R	21x12	252			75S-T6 Al. Alloy	30,000T PSI C	800 200		Shear Load Small--Panel Small
312806	Panel Assy-- O.V. Fuel Tank Access	1049 A	1L-1R	55x12	660			75S-T6 Al. Alloy	35,000T PSI C	900 300		Shear Loading Small
312808	Panel Assy-- O.V. Fuel Tank Access	1049 A	1L-1R	60x12	720			75S-T6 Al. Alloy	24,000T PSI C	700 300		Shear Loading Small
174860	Instal.-- Tank Panel V.S. 34-63 CTR	T 33	1L-1R	28x14	392			75S-T6 Al. Alloy	10,695T	978		
450129	Panel Inst'l.-- Wing Aft Inb'd. Lower	F 94 C	1L-1R	81x22x16	1515			75S-T6 Al. Alloy	10,800 PSI Diaph. Tension	482	23,900 PSI	Bending Load Due to Normal Press. 29.8 PSI
450984	Panel Inst'l.-- V.S. 34.5-61 Lower Tank END	F 94 C	1L-1R	27x15	405			75S-T6 Al. Alloy		1016		Diaphragm Air Pressure Also Present

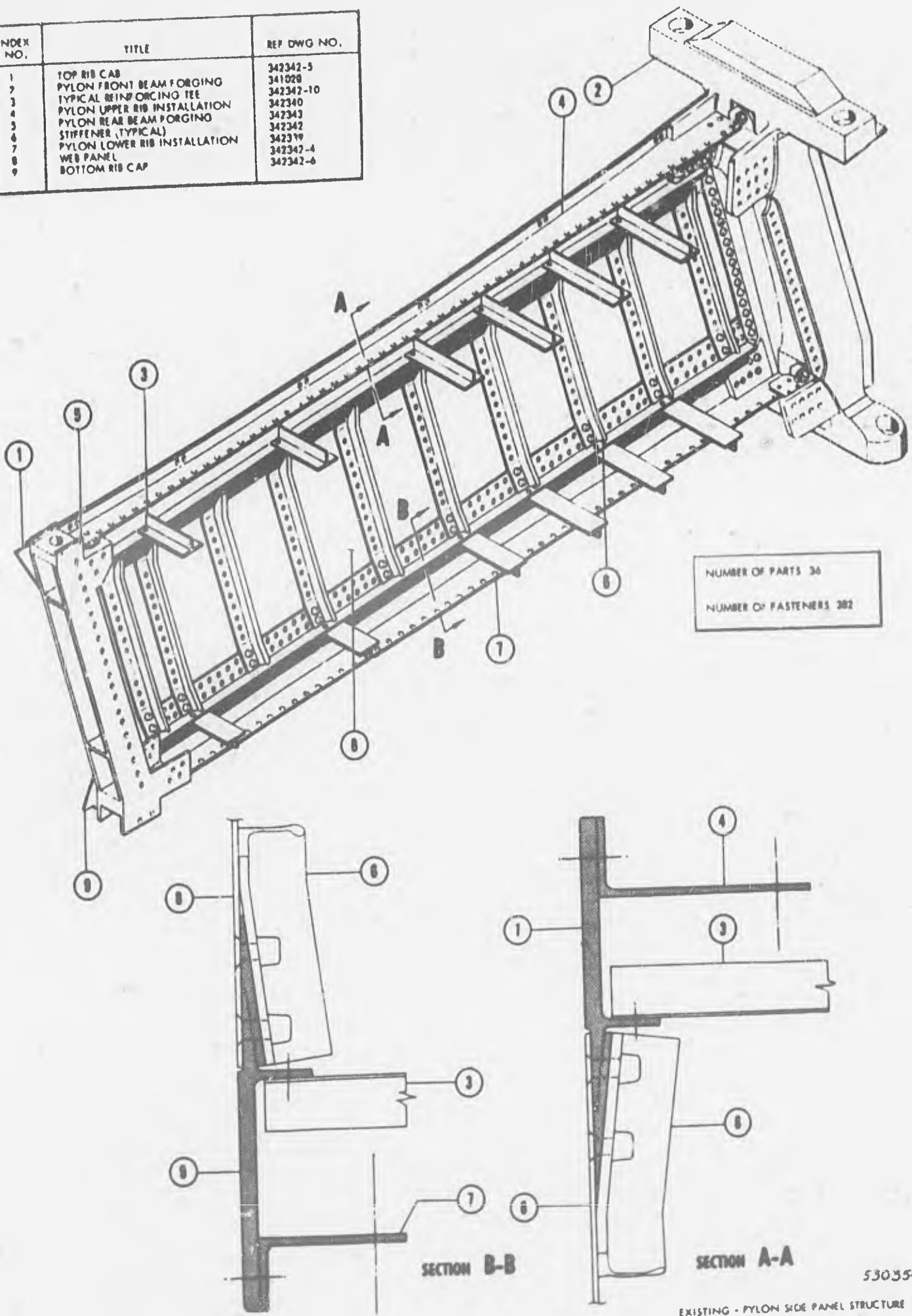
TABLE I. PARTS SURVEY SUMMARY

on forging pressure requirements indicated that the largest panel that could be forged on existing facilities was about 700 square inches. The engineering study indicated that the tank pylon could be split into two parts thus reducing the plan area of each half to approximately 710 square inches. By the use of temperatures in the range of 800°F, it was felt that a forging of this size could be produced on the 18,000 ton Mesta press at the Wyman-Gordon Company.

One common forging was designed so that a fore and aft panel could be made by relatively simple machine operations. Thus, two forgings would be required for each complete side panel. Machined part drawings for the fore and aft panels were prepared. Figures 1, 2, and 3 show the existing structure, the proposed forged structure and the location of the completed panel on the aircraft.

- (b) Stress Analysis: A complete stress analysis was prepared substantiating the use of a 45° waffle grid type shear panel for the YC-130 tank pylon. The analysis (Appendix I) consisted of a check on the general instability of the panel, buckling of the webs, compression in the ribs, and critical attachments.
- (c) Weight Analysis: Due to the limited press forging capacity available for this work and the resultant two-piece design, the required joint imposed a small weight penalty on the forged panel. The design of any production panel would be based on the use of the proposed Air Force heavy presses, permitting the use of a one-piece panel eliminating the necessity of a center joint. It was therefore decided to prepare the weight analysis (Appendix II) by comparing the present built-up structure with the proposed two-piece design and the probable one-piece production design. The weight saving for the two-piece forged panel was calculated to be 2.8 pounds per airplane. The saving for the one-piece forged panel was 10.4 pounds per airplane, using four panels per airplane.
- (d) Structural Test: Very little information was available that could be used in the analysis of this type of structure. A study was undertaken to establish design parameters for a waffle grid structure. Based on this analysis, a panel was designed for the structural test. One panel was machined from 7075-T6 aluminum alloy plate and subject to extensive tests. Upon completion of these tests, a second panel with modified stiffener height was machined from 7075-T6 aluminum alloy plate and subjected to the same extensive tests. The results of the study (Appendix III) to establish design

INDEX NO.	TITLE	REF DWG NO.
1	TOP RIB CAP	342342-5
2	PYLON FRONT BEAM FORGING	341020
3	TYPICAL REINFORCING TEE	342342-10
4	PYLON UPPER RIB INSTALLATION	342340
5	PYLON REAR BEAM FORGING	342343
6	STIFFENER (TYPICAL)	342342
7	PYLON LOWER RIB INSTALLATION	342339
8	WEB PANEL	342342-4
9	BOTTOM RIB CAP	342342-6

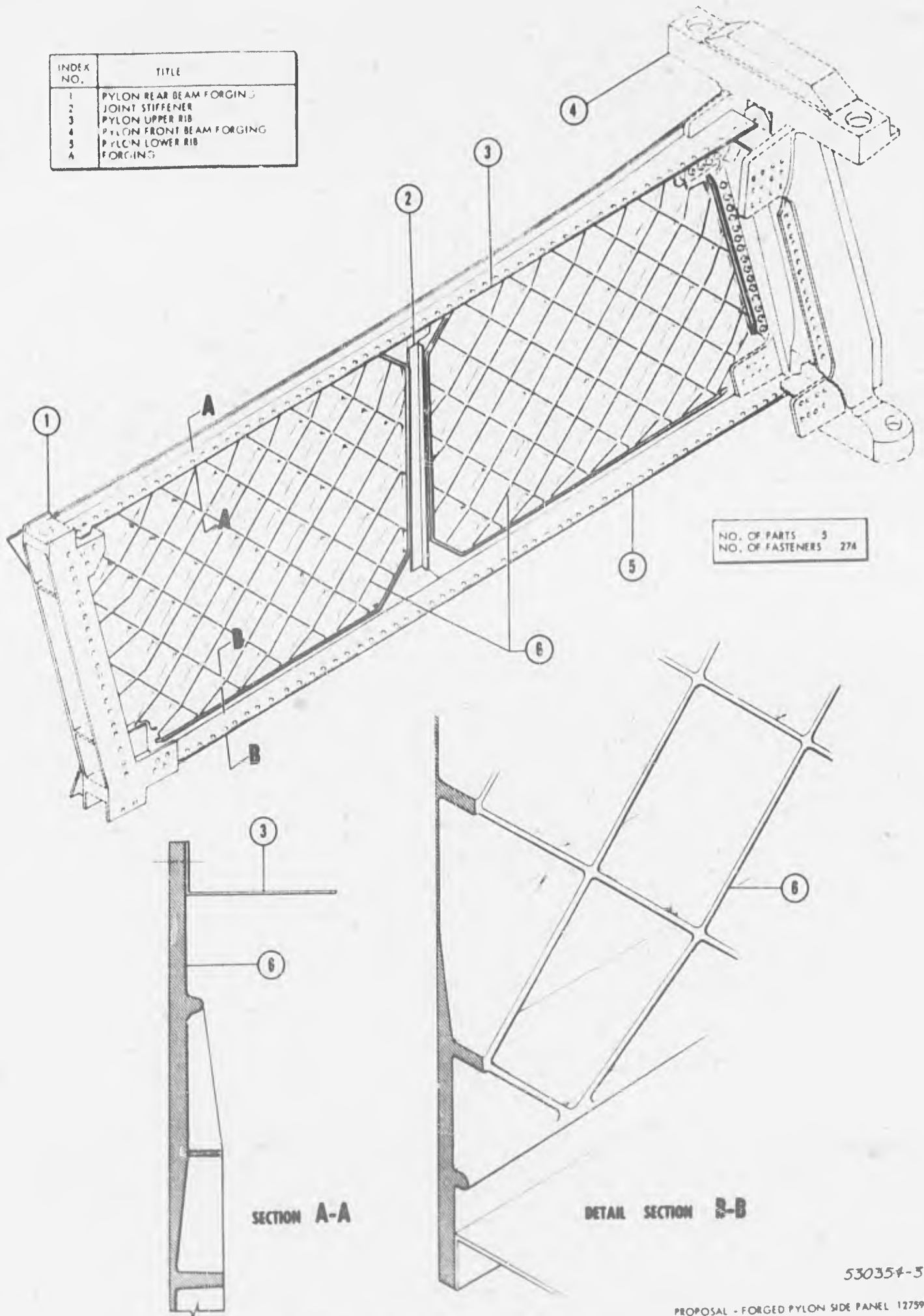


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EXISTING - PYLON SIDE PANEL STRUCTURE 127991

Figure 1. Existing - Pylon Side Panel Structure

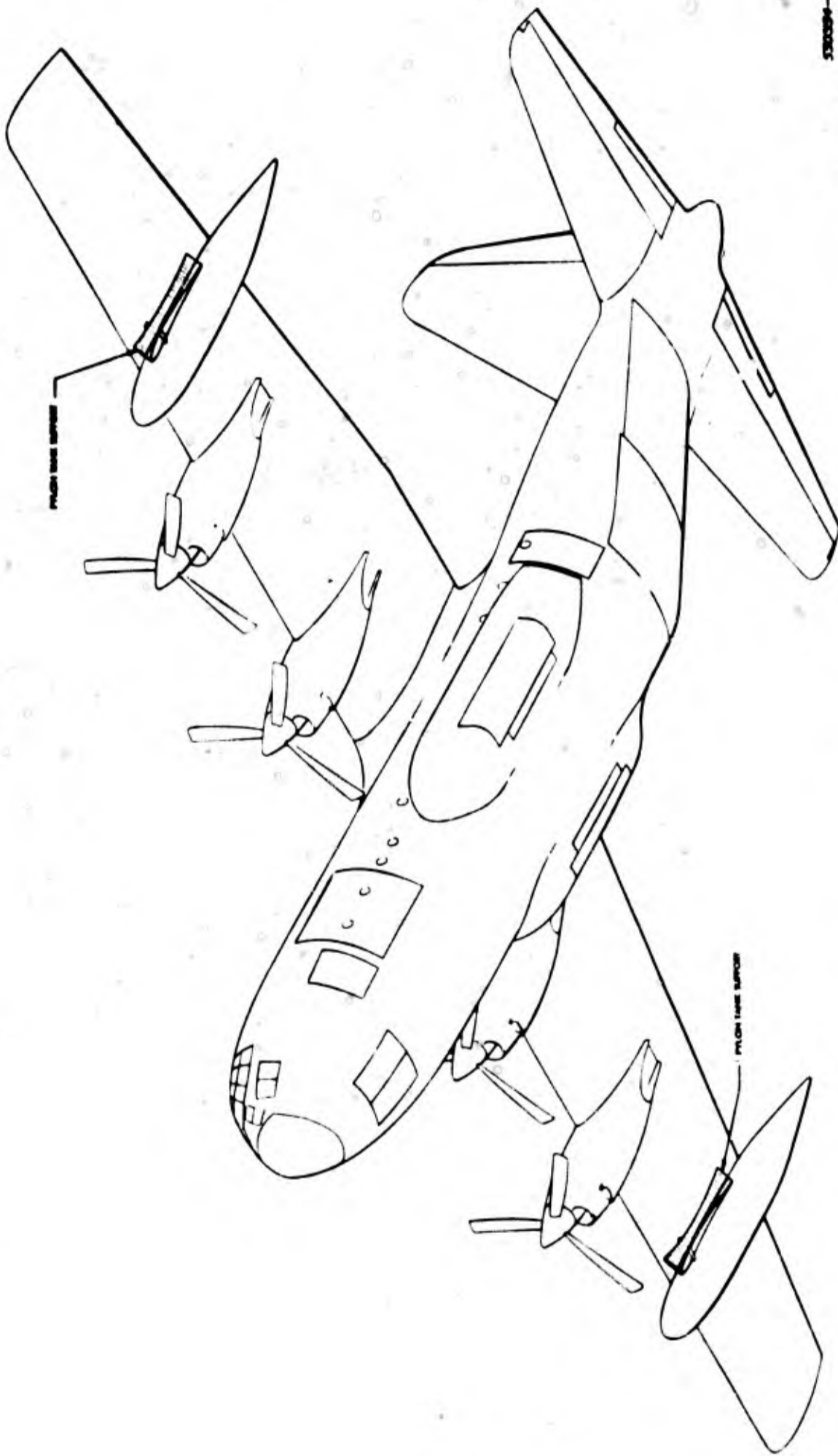
INDEX NO.	TITLE
1	PYLON REAR BEAM FORGING
2	JOINT STIFFENER
3	PYLON UPPER RIB
4	PYLON FRONT BEAM FORGING
5	PYLON LOWER RIB
6	FORGING



530354-5

PROPOSAL - FORGED PYLON SIDE PANEL 127593

Figure 6. Proposal - Forged Pylon Side Panel



3300000-4
LOCATIONS - Pylon Tank Support 1978

Figure 3, Location - Pylon Tank Support

parameters and the results of structural tests of two machined panel sections showed:

- (1) That panels stiffened by an integral waffle grid can be used very efficiently as compression and shear panels.
- (2) Excellent correlations were obtained between measured and calculated critical shear flows and stress distribution between ribs and webs of the tested panels.

FORGING DEVELOPMENT

Initial Forging Research Investigations

In order to investigate specific forging characteristics in connection with the forged panel operations at the Wyman-Gordon Company, small size 7075 aluminum alloy and 5052 magnesium alloy specimens were forged at the Lockheed Engineering Research Laboratories on a 300 ton hydraulic press. These specimens were of two types; one type for part extraction tests and a second type for tests other than part extraction.

A symmetrical three-inch square specimen with a box-shaped rib configuration, 1.50 inches between centers, was used on part extraction tests. Except for the half-scale rib spacing these specimens were the same size as a comparable section of the full forging. The forging tool was made up of a nine-piece tool steel die insert, a 4340 steel die holder, and a tool steel punch. Alternate extraction mechanisms were incorporated in the punch and center die insert. Appendix IV show details of specimens and tools.

A symmetrical 3.125 inch square specimen with a cross-shaped rib configuration was used on tests other than part extraction. These specimens were the same size as a comparable section of the full forging. The forging tool was made up of a four-piece tool steel die insert assembled in a two-piece tool steel container which, in turn, was held in a steel plate outer retainer ring. Figures 5, 6, and 7, show details of these specimens and tools.

So as to simulate, as closely as possible, the metal flow that would occur in the full forged panel, the dies for both specimen types were designed to confine the test forging on all sides to prevent lateral metal escape. The dies were heated electrically to 800°F. Flat forging blanks, machined approximately 0.010 inches smaller than the die cavity, were lubricated on all surfaces with colloidal graphite and preheated in closed dies under low pressure. After completion of the press stroke, the die was disassembled and the forged test section removed.

Forged Panel Development Program

A forged panel representing approximately one-third of the area of the full-size part to be forged was designed and produced at the Wyman-Gordon Company, the forging subcontractor, as a means of establishing techniques for producing satisfactory forgings of the entire part. A drawing of this forged panel is presented in Figure 4. This program of die development, forging tryouts, and the results of these tests are the major concern of this report.

These panels were forged from 7075 aluminum alloy on tools designed and constructed by the Wyman-Gordon Company. Forging pressures were provided by a hydraulic forging press operating at two pressure stages, 7700 tons and 4400 tons. These pressures proved to be adequate for the planned forging program.

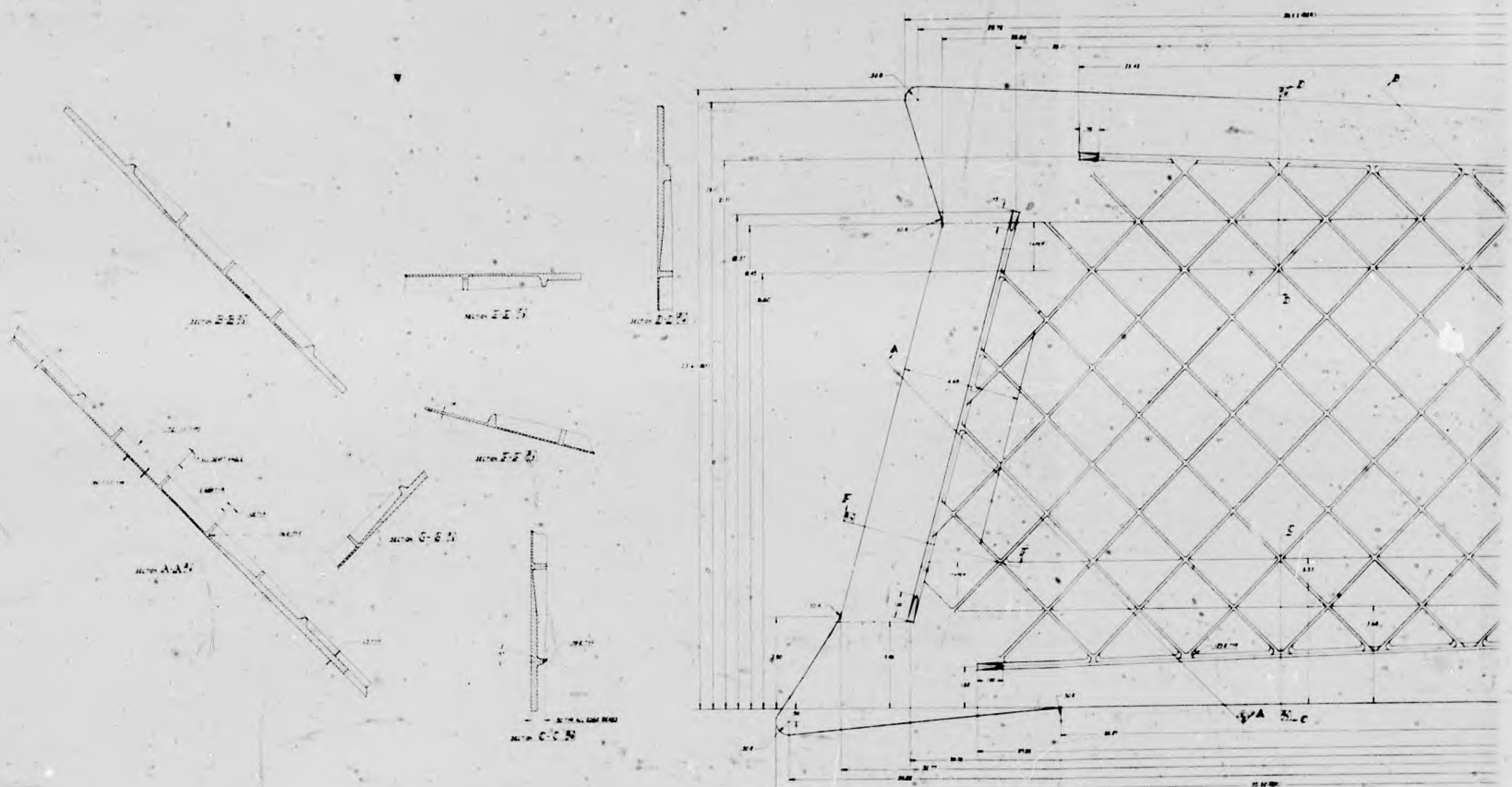
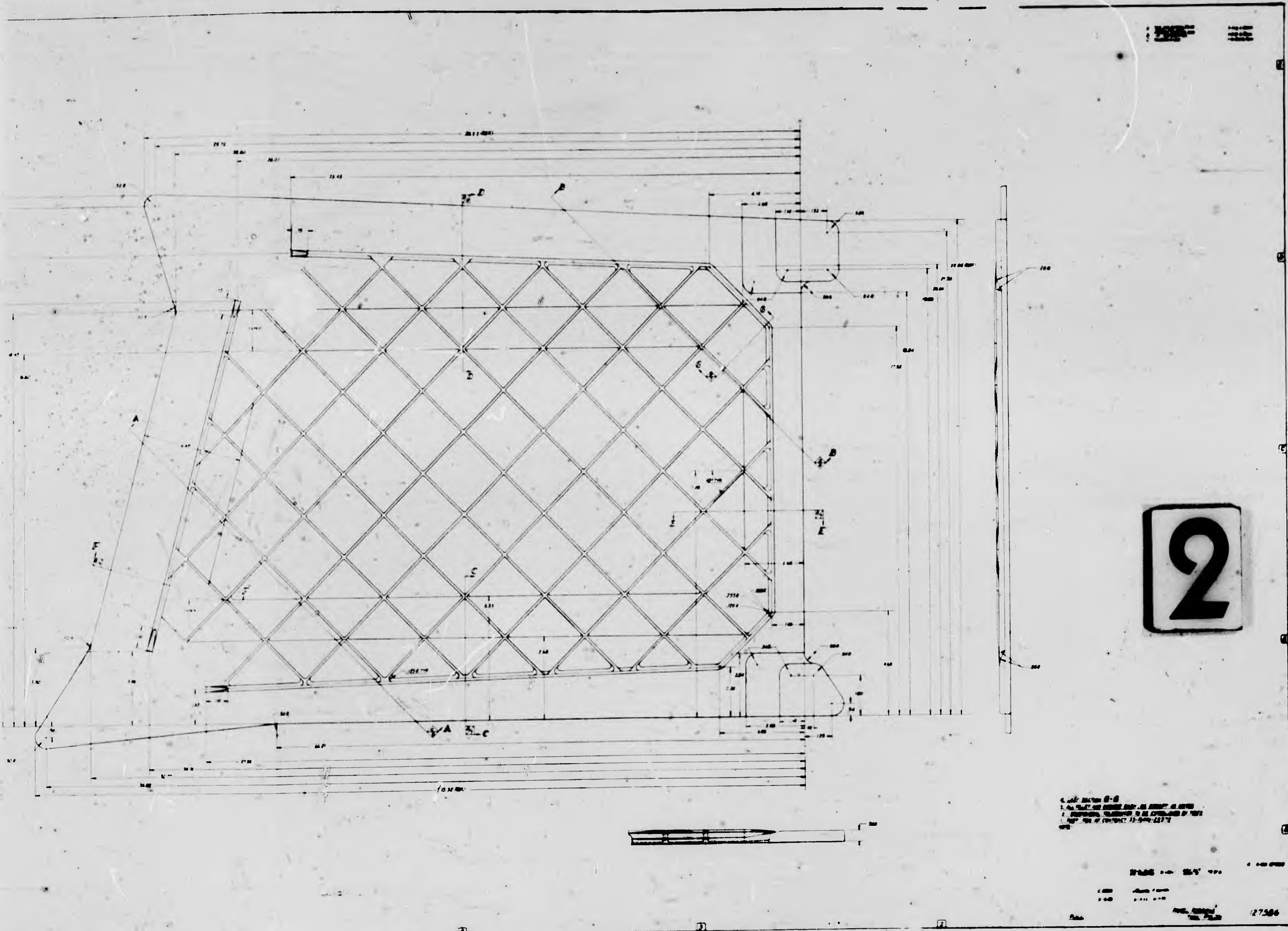


FIGURE 4.

1



2

1. ALL DIMENSIONS IN METERS
 2. ALL DIMENSIONS ARE TO CENTER UNLESS OTHERWISE SPECIFIED
 3. ALL DIMENSIONS ARE TO BE CHECKED BY THE CONTRACTOR

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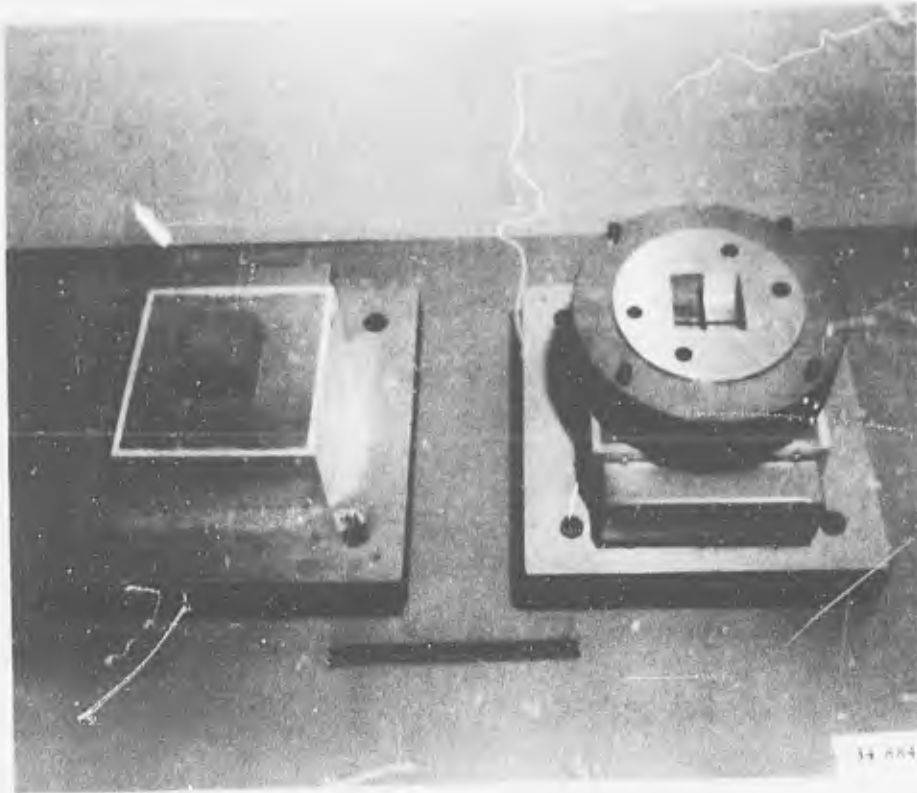


Figure 5. Electrically Heated Tools for Initial Forging Research - Upper Punch and Lower Die.

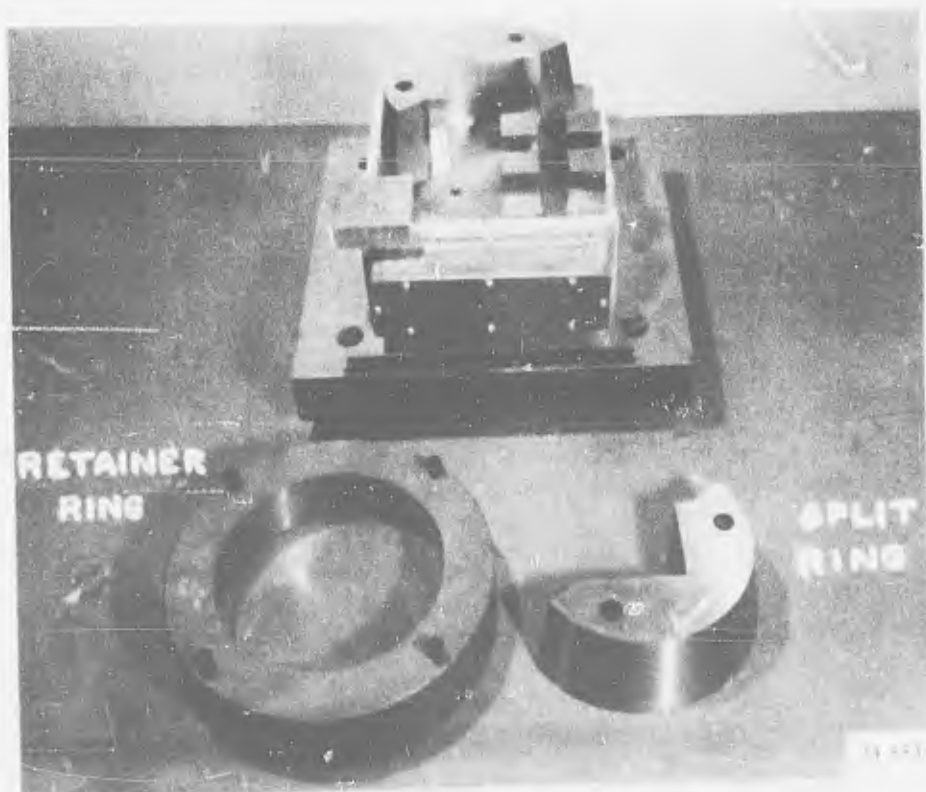


Figure 6. Segmented Lower Die for Initial Forging Research - Inserts, Split Ring and Retainer Ring.

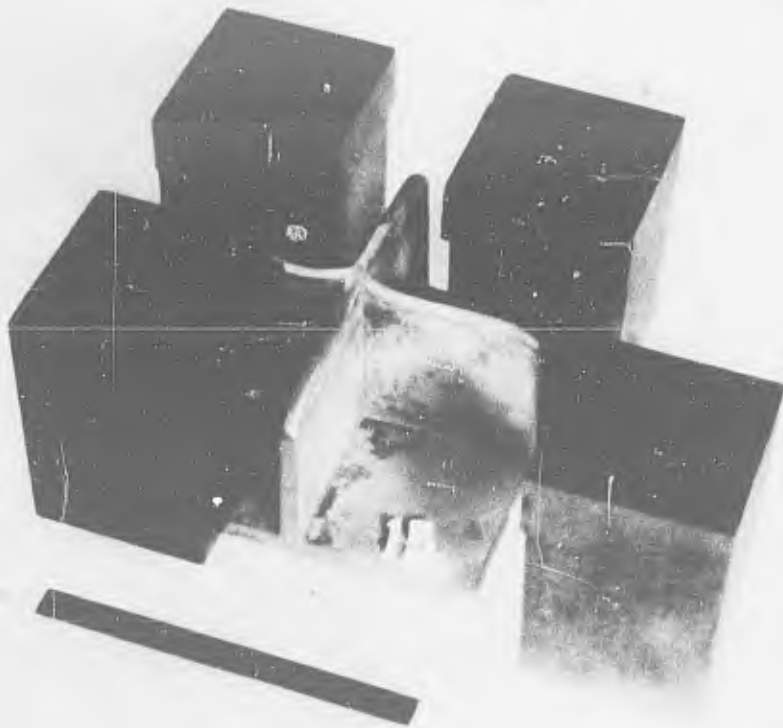
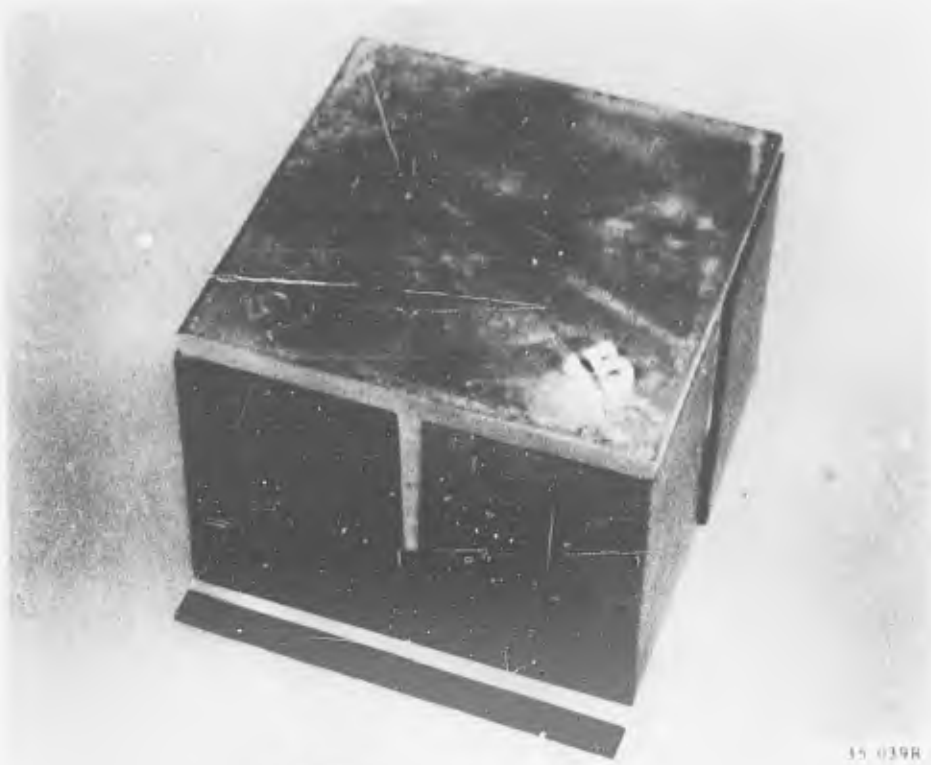


Figure 7. Small Size Specimen and Die Inserts for Initial Forging Research - Assembled and Disassembled Views.

DESIGN AND CONSTRUCTION OF FORGING TOOLS

Die Materials

1. The die inserts were made from annealed Potomac "M" tool steel, heat treated to a hardness of Rockwell C45-49.
2. The hold down bars, wedges, knockout pins, and keys were made from 4340 steel.
3. The upper die was Heppenstall special analysis A double temper steel.
4. The hardplate and bottom die holder were annealed EIS-T-721 Thermoneal.

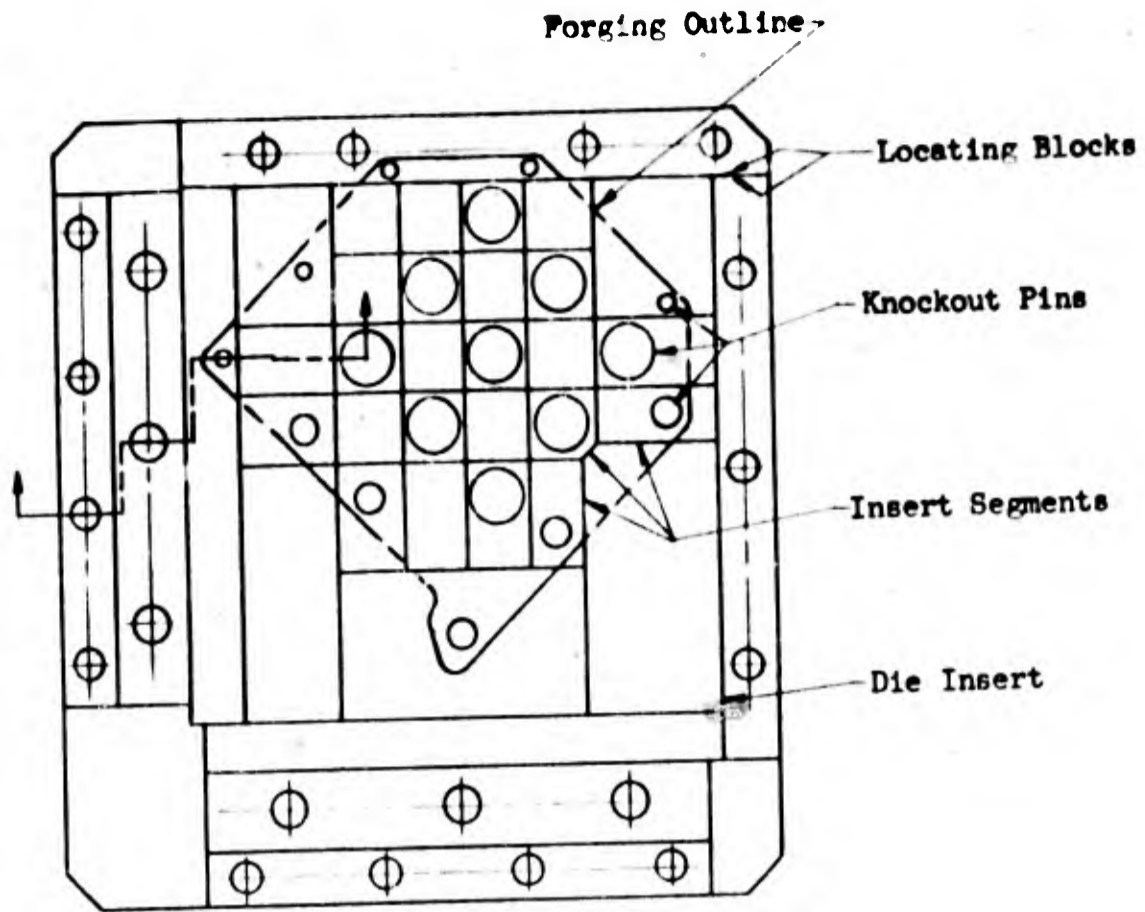
Die Insert

Two insert systems were considered in the design of the lower die. The first system was a series of one-piece strip inserts with slots cut across for rib cavities. The second system, the one adopted, was a multiple-piece die insert, one piece for each forging recess. The multiple-piece insert was selected on the basis of ease of machining and polishing, rapid replacement of damaged pieces, and quicker cleanup of effects of sticking during the break-in period. A small scale representation of the insert segmentation is shown in Figure 8.

The insert pieces which were square, rectangular, or wedge-shaped were held in place through a stepped locking system and through bolts attaching alternate overlapping pieces directly to the hardplate. Figure 11 illustrates the method of locking insert pieces in place. A wedge system on two sides clamping against a shoulder on opposite sides restrained the insert pieces from shifting laterally. The clamping action of this wedge system is shown in Figures 8, 9, and 10.

Waffle Pattern

The waffle pattern of the full-size forged part was incorporated in the forged panel dies. Zero-degree straight-sided rib cavities provided a rib depth of 1.50 inches and a rib thickness of 0.12 inches with .03 inch fillet radii.



BOTTOM DIE - PLAN

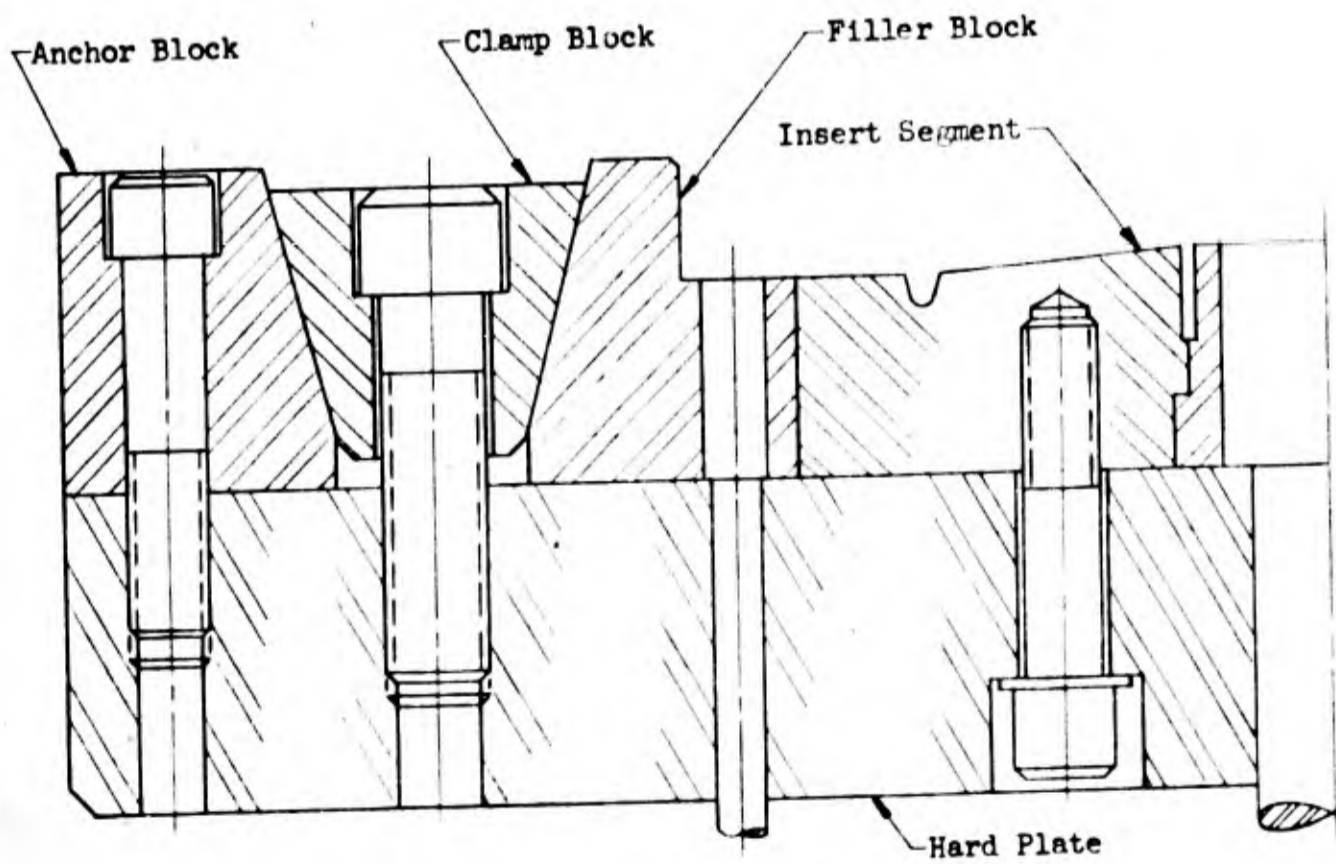


FIGURE 8. BOTTOM DIE INSERT SEGMENTS AND CLAMPING ACTION

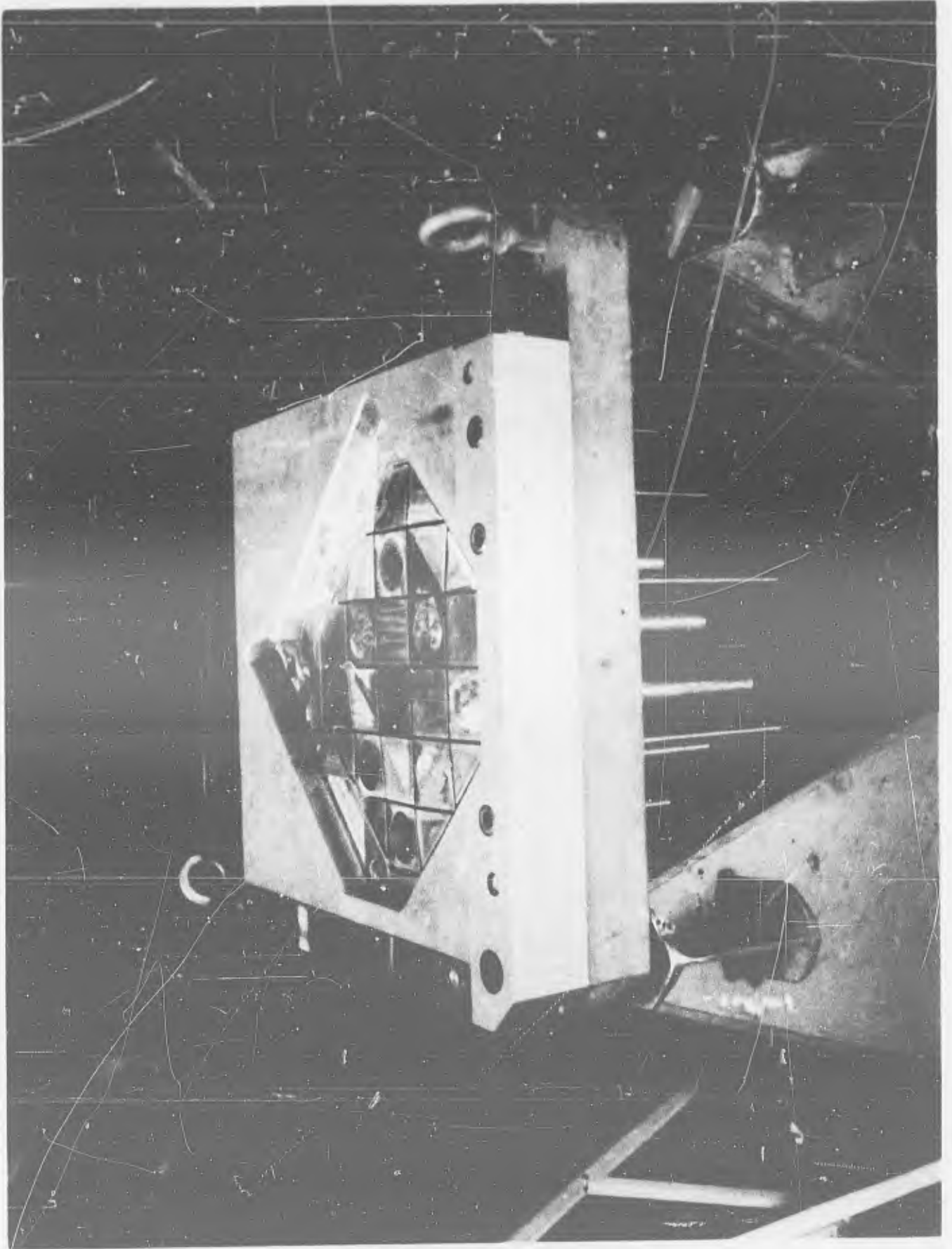


Figure 9. Die Insert Assembly Showing Arrangement of Knockout Fins.

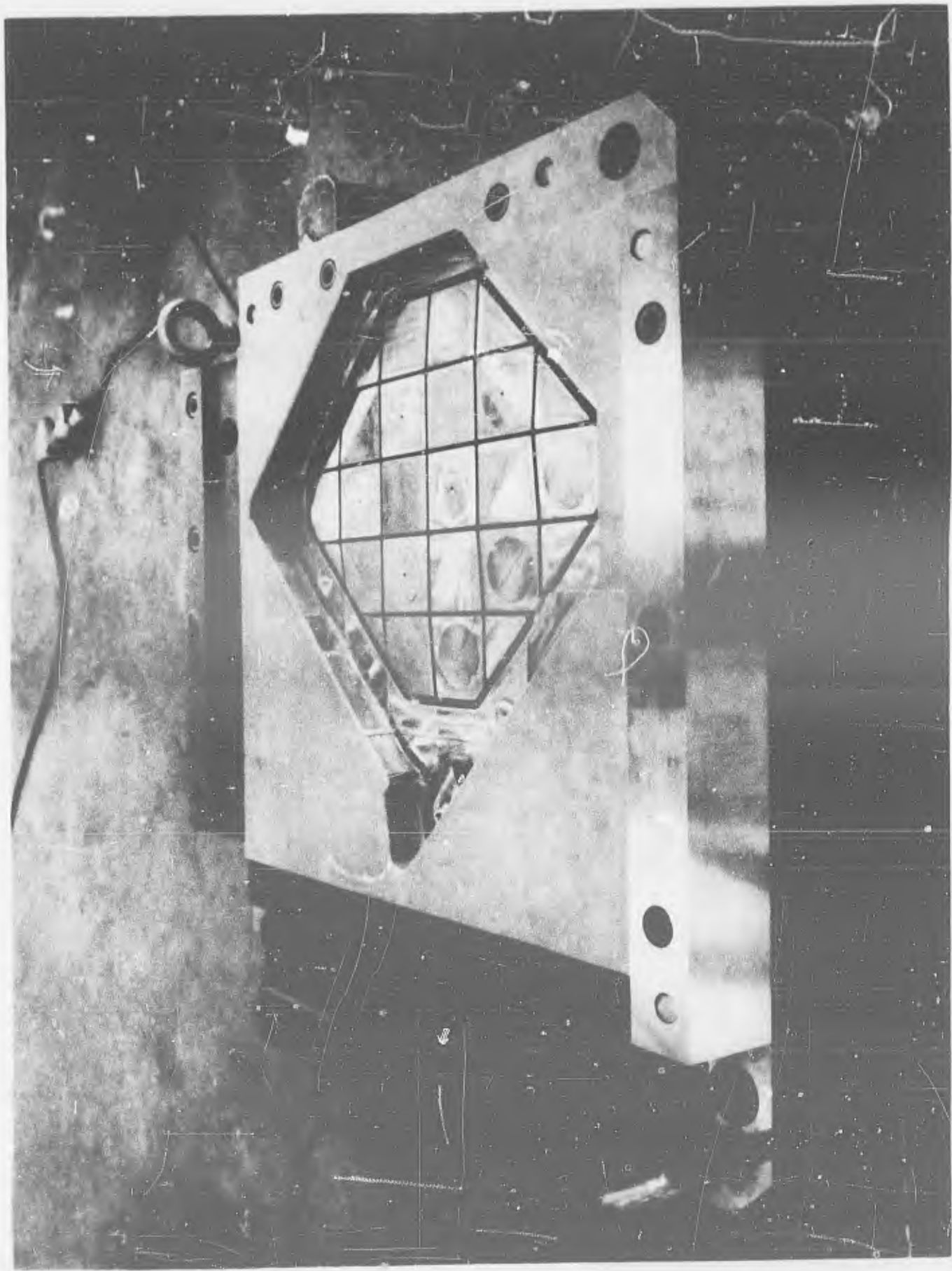


Figure 10. Die Insert Assembly Showing the Two Wedges Which Hold Inserts in Position Preventing Lateral Spread.

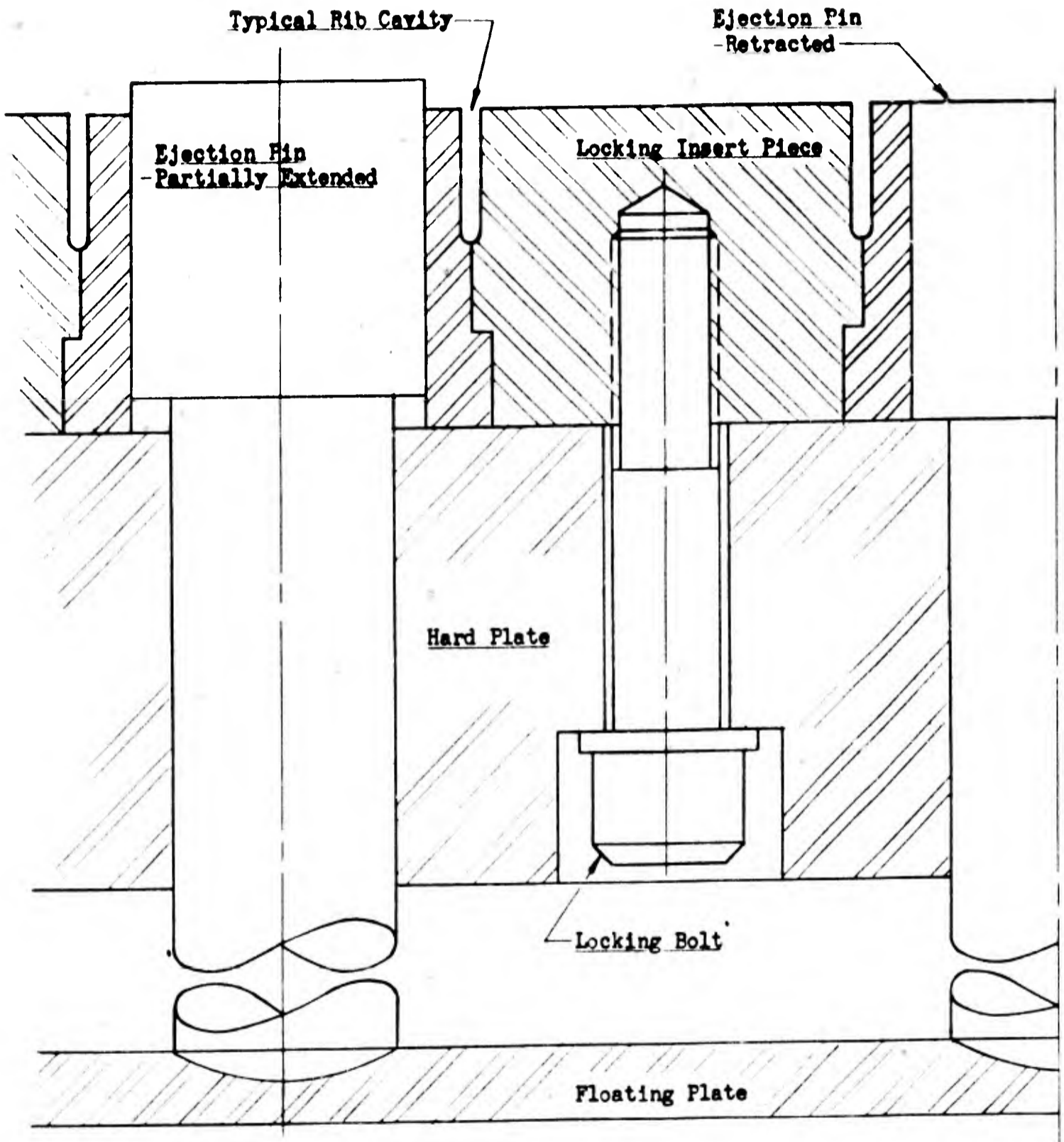


Figure 11. - Section Through Bottom Die Showing Insert Locking Ejection System

Previous forged panel research programs observed an incomplete filling of the die around the outer edges of the panel due to a pressure drop caused by unrestricted metal escape. This problem was eliminated in the present program by providing a closed die to restrict metal escape at the edges. The closed die construction is shown in Figures 9 and 10.

Die Heating

Prior to a forging run the dies were preheated to 700° F in a furnace. In order to reduce heat transfer to the press, a sheet of transite was placed under the bottom of the die. Exterior strip heaters were attached to the edge of the die holder. This method of heating provided a temperature of about 1000° F at the heater attachments. However, this produced a heat barrier only and did not replace heat lost at the die impression. It was necessary to add heat periodically through the use of a gas ring. This combination of two heat sources also proved to be unsatisfactory. The external electrical die heaters are shown in Figures 12 and 13.

Ejection System

The zero-degree draft angle on the rib cavity sides necessitated an ejection system in order to extract the forged panel from the bottom die. The ejection system incorporated in the bottom die assembly consisted mainly of conventional round knockout pins centered in alternate insert pieces so located that a pin was adjacent to one side of each rib in the waffle pattern. Ten additional knockout pins were spaced around the edge of the die impression. The knockout pins were lifted by tapered wedges actuated horizontally by a side hydraulic cylinder. A general view of the knockout pin locations is shown in Figure 9.

A discussion of the development of the ejection system will be given in a following section of this report.

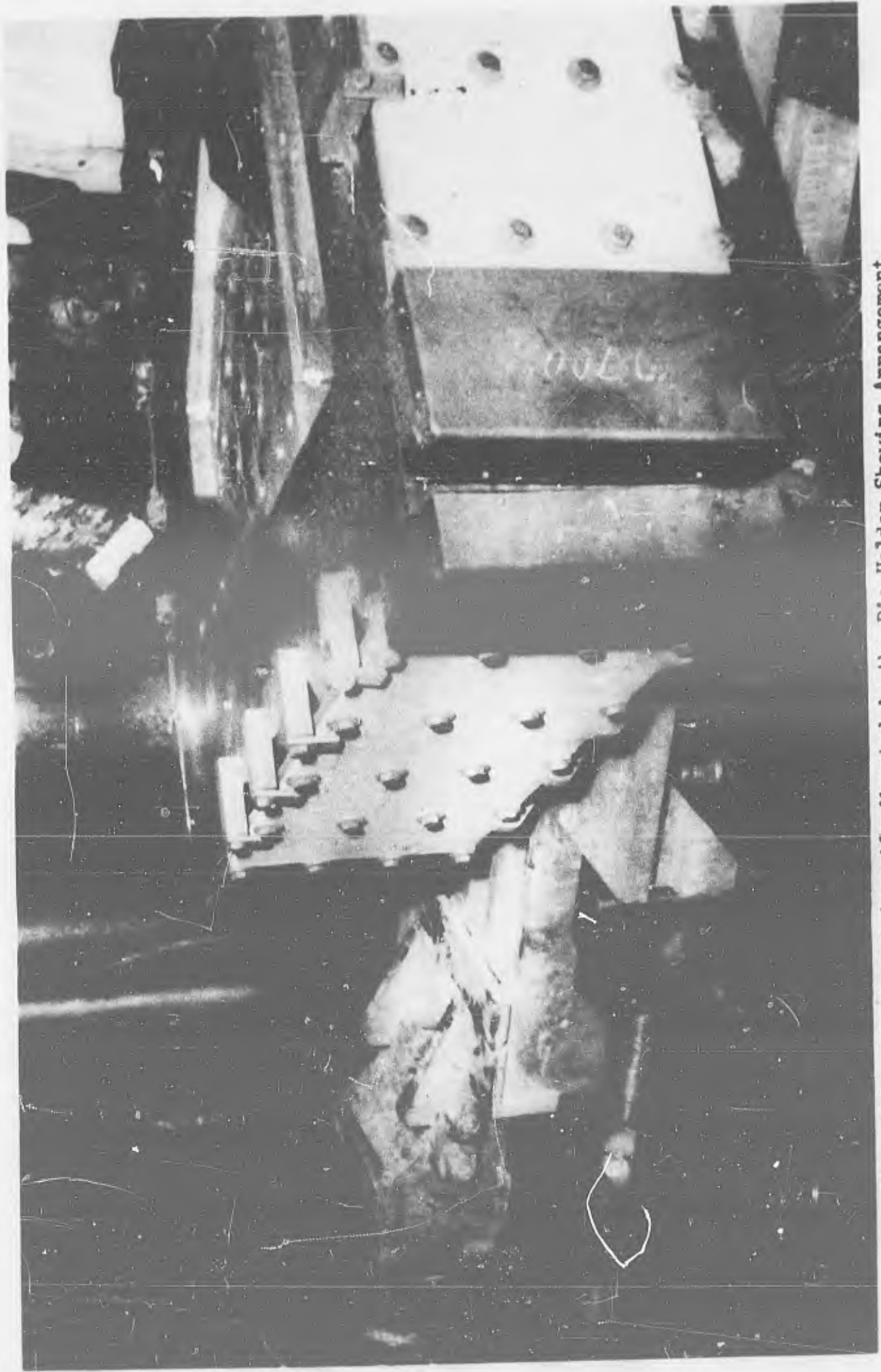


Figure 12. Die Insert, Assembly Mounted in the Die Holder Showing Arrangement of Electrical Heaters Around Periphery of Holder.

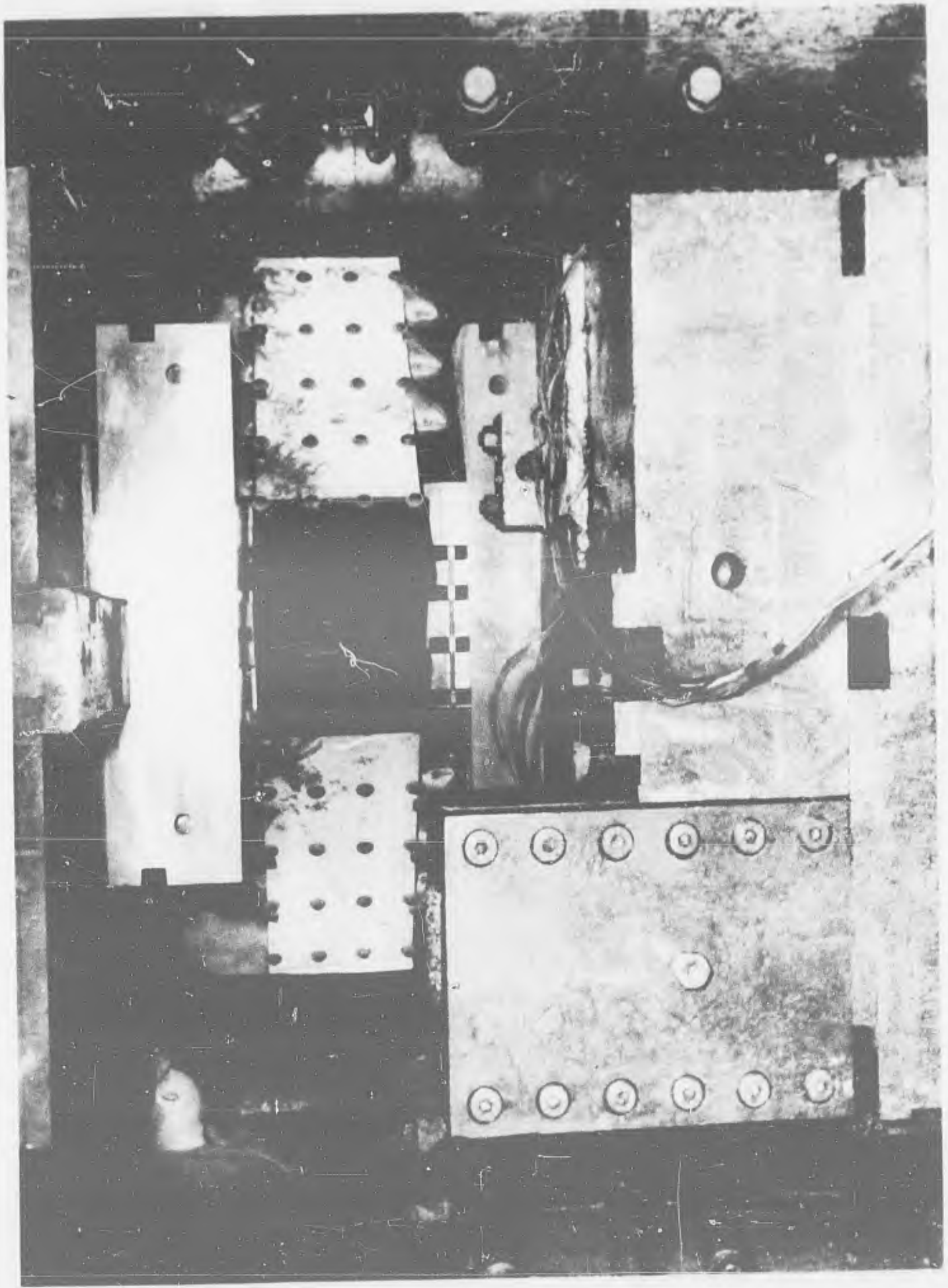


Figure 13. Dies Mounted in 7700 Ton Hydraulic Forging Press.

DEVELOPMENT OF EJECTION MECHANISM

Requirements

The ejection system to be employed in the removal of the zero-degree draft angle forged panels from the bottom die had to economically eject finished forgings without distortion or fracture. This requirement meant that enough pressure would have to be distributed over sufficient area to prevent damage to the panel on ejection without being too complex or costly. In addition the system would have to be structurally sound under forging pressures.

Ejection Mechanisms Considered

Six types of ejection mechanisms were considered as follows:

1. Movable center die insert.
2. Conventional round knockout pin.
3. Round knockout pin with drafted square ejector cap.
4. Edge-lifting plate.
5. Dovetail lifting-lug in upper die.
6. Round lifting-lug in upper die.

Research Investigations

One of the Lockheed Metallurgical Research investigations, (Appendix IV), using small size 7075 aluminum alloy specimens was concerned with testing several methods of ejection. The results of this investigation recommended the use of maximum diameter round knockout pins in combination with round lifting lugs forged onto the skin surface of the panel.

Round knockout pins were incorporated in the forged panel dies since their use was adaptable to more types of design than the lifting lugs. The knockout-pin ejection system was evaluated using a flat upper die, with the alternate choice of machining lifting lugs into the upper die if the pins should fail to perform properly. The knockout pins performed satisfactorily in most respects and were employed in the forged panel tools throughout the test runs. Details of the ejection system are shown in Figures 9, 11, 12, 14, and 15.

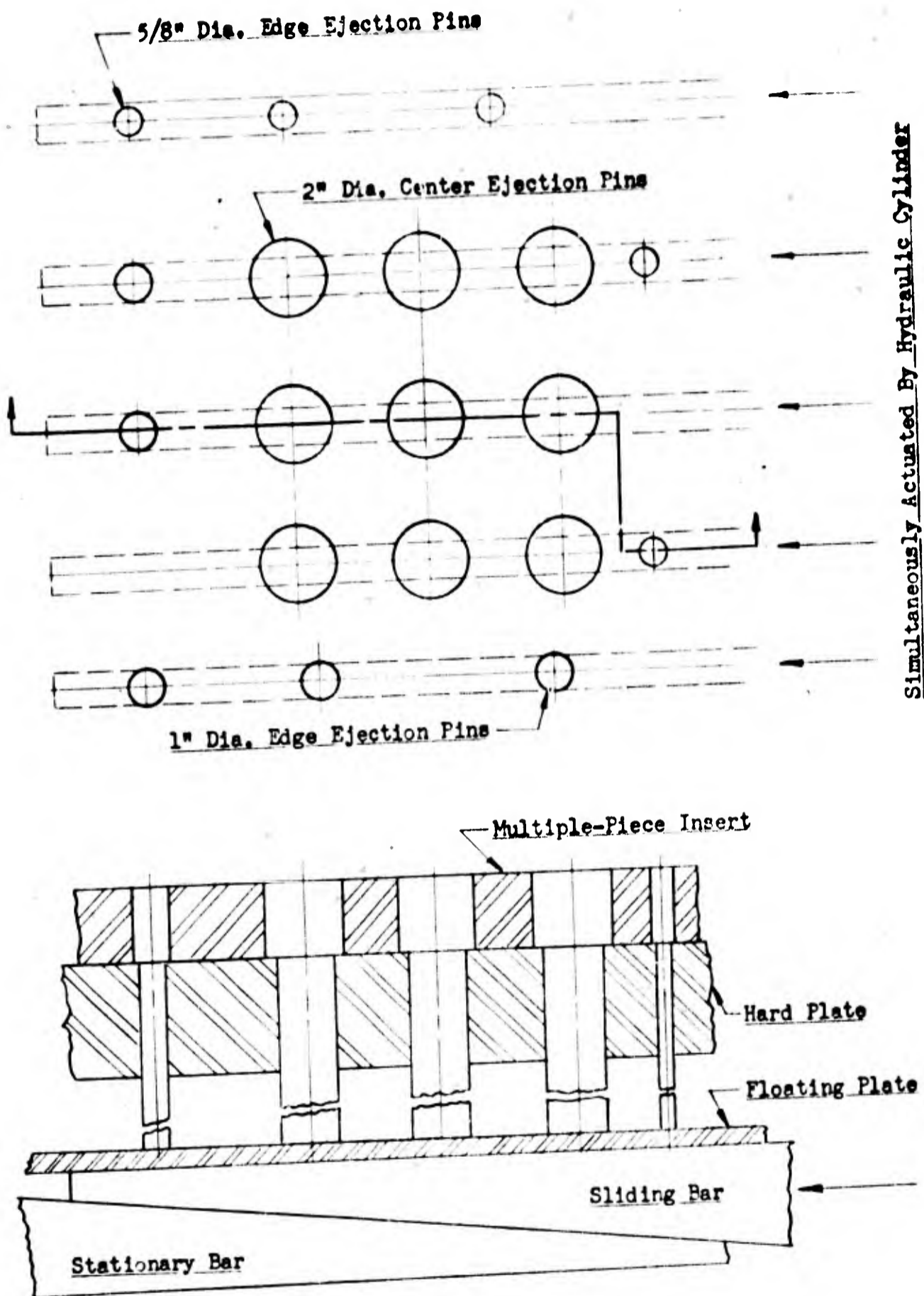


Figure 14. - Ejection Fin System

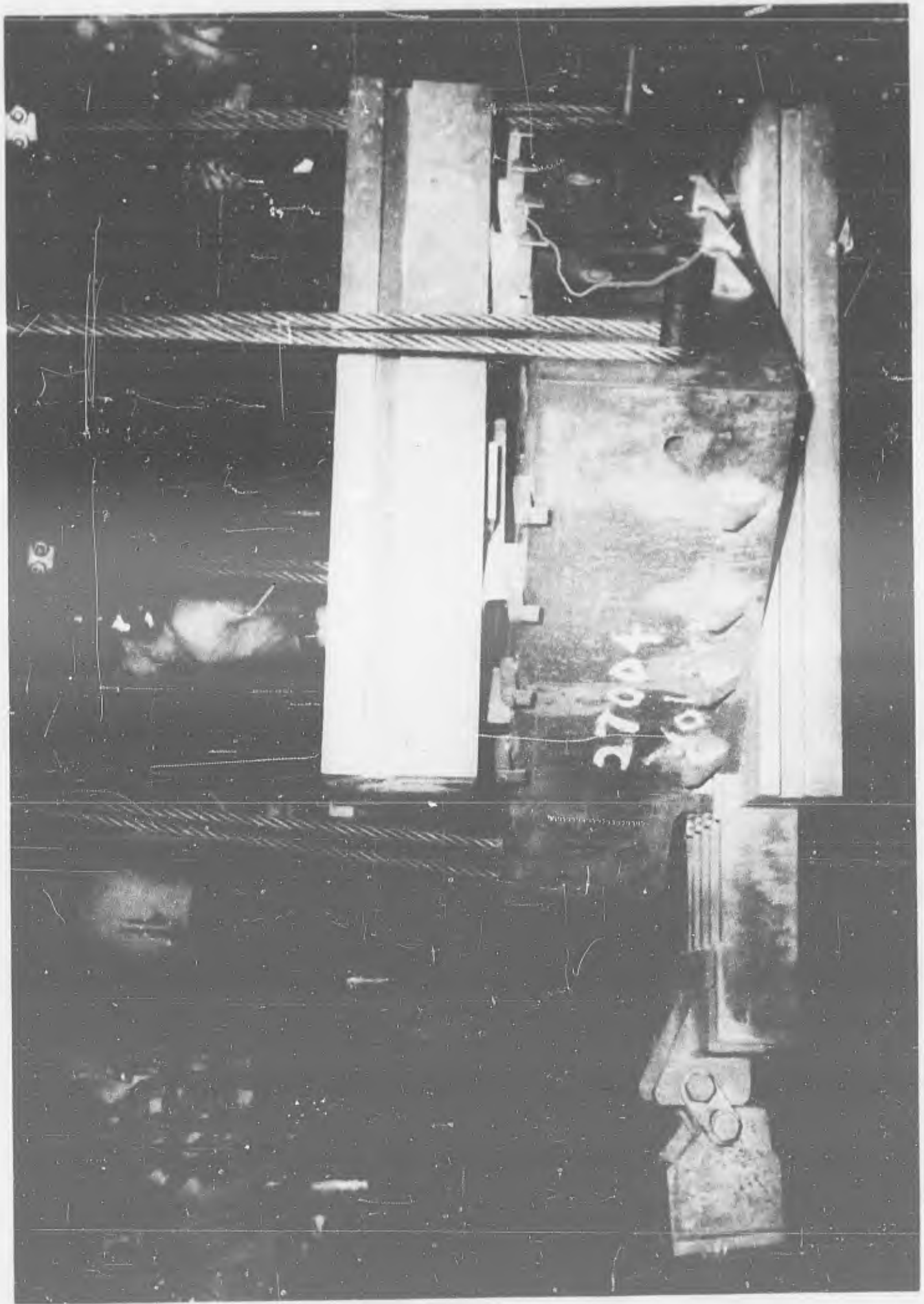


Figure 15. Upper and Lower Die Blocks and Knockout Wedges.

Difficulties Encountered

The knockout-pin ejection system design did not function without certain difficulties. As the first few pieces were forged, increasing difficulty was encountered with the pins sticking in the extended position. Excessive force was required to return the pins to retracted position. The dies were then disassembled to correct this problem. The ejector pins had been upset and the hardplate had taken a compressive permanent set where the pins were seated on the hardplate. This was apparently due to insufficient bearing area at this point to withstand the forging pressure load carried by the pins. The difficulties in malfunction of the knockout-pins could, in part, be attributed to the lack of any positive retraction mechanism outside of the weight of the pins.

The upset on the pins, .015 inch on a 2 inch diameter, was ground off and undercut another .015 inch. The permanent set on the hardplate, .005 inch depressions, was removed by grinding .008 inch from the hardplate thickness. The ejection pins for the final forging run were made from "Thermold J" alloy (Cyclops Steel Corporation) in order to resist the forging temperatures and pressures.

DEVELOPMENT OF FORGING TECHNIQUES

Blocker Die Design

Use of a blocker die to gather metal in positions as required in the finish die was found to be necessary. Tests proved that plate stock pressed directly in the finish die would not produce a filled part unless the plate was $3/4$ inch thick or greater. There were also indications that the use of plate stock always introduced defects at rib junctions.

The use of an intervening plate, incorporating the upper surface of the blocker configuration and the bottom finish die in combination, to forge a blocked piece, was considered as a means of simplifying the blocking operations. However, because of the importance of proper and precise volumetric distribution of material in the blocked piece prior to finish operation, it was decided to provide a separate set of blocking tools in place of the intervening plate technique.

The blocker was designed with a small flash gutter around the contour of the part, as shown in Figure 16, and with dies closing face to face with no plug extension similar to the extension in the finish tools. The blocker dies employed two types of rib and web configuration so that the best design could be determined after the finish operation on the preliminary forgings.

The blocker impression was based on the volume required by the finished forging with the web thickness added. The minimum web thickness of the finished part was a function of the minimum produced in the blocker. The blocker tools were designed to produce .060 inch minimum web thickness and a 0.300 inch maximum thickness.

Forging Defects

The most serious defect encountered in the forging operations was a lap-type defect, commonly known as "suck-in". Another defect related to "suck-in" and referred to as "marking" was superficial and not considered serious from a structural standpoint. "Marking" occurred on the forged panel surface opposite to the rib locations resulting from the metal flow into the ribs from the web on both sides under forging pressures.

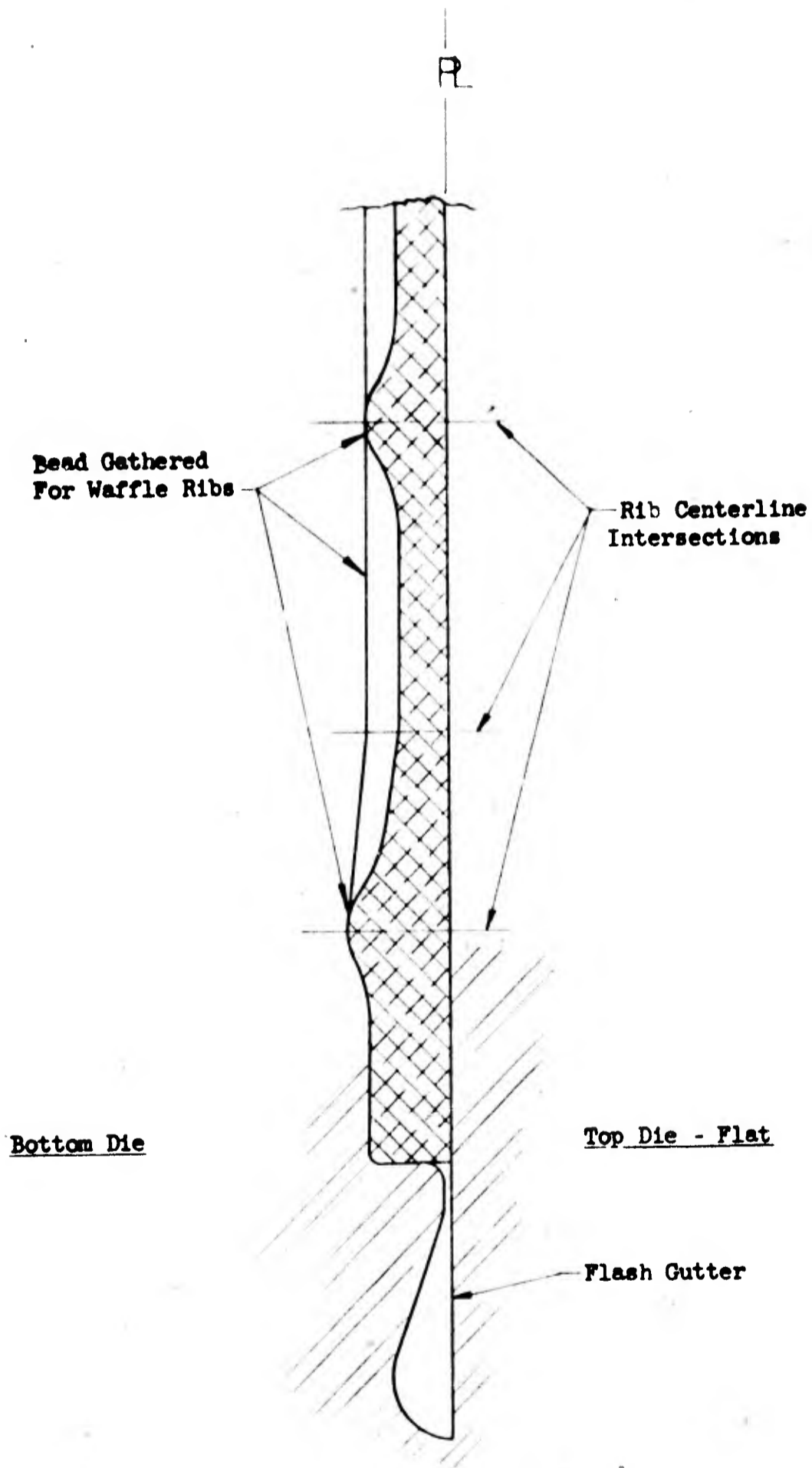


Figure 16. - Edge Section Through Blocked Piece.

As the web of the finished panel was forged thinner, "suck-in" occurred on the panel surface opposite the ribs. "Suck-in" was an open break in the surface of sufficient depth to cause serious structural weakness. In extreme cases this "suck-in" effect resulted in an apparent buckling of the panel surface into the rib cavity. Blocked parts less than 0.30 inch thick resulted in "suck-in" and incomplete rib height on the finished forging.

A third forging defect, referred to as "peel-down" occurred when panels were re-run in the finish die in an attempt to increase the rib height. Since this operation was unsuccessful, this defect was not of serious consequence. The metal was peeled off the ribs and collected at the web fillet causing a lap-type defect.

Lockheed Research tests on small size specimens (2) indicate some limitations to be imposed on forging operations to reduce the above mentioned defects to a minimum. These tests, made on single operation parts, showed that a forged skin thickness 0.250 inch or greater would be sufficiently free from defects for an airframe skin. Thinner skin thicknesses should be machined from .250 inch minimum thickness to avoid defects. Figure 17 shows the relationship between blank thickness, minimum stiffener height and occurrence of defects as determined by the above tests. Figures 23, 24, and 25 show micrographs of sections cut through typical defects in the small size specimens.

Stiffener Height and Thickness

Forging tests (2) (3) on small size 7075 aluminum alloy and 5052 magnesium alloy specimens were performed at Lockheed Engineering Research Laboratories for the purpose of establishing relationships between stiffener dimensions and forging temperatures, forging pressures, dwell time, blank thickness, and occurrence of defects.

Minimum stiffener height was determined for numerous magnitudes of the above variables. Figures 18, 19, 20, and 21 present plotted values for the above relationships. The minimum stiffener height was not measured at the edge of the section due to some loss of height generally occurring as a result of die friction. Forged panel operations at the Wyman-Gordon Company brought out the importance of proper blocker operations in obtaining full stiffener heights in the finish dies. On practically all blocked pieces where the blocked beads were not fully formed, the corresponding stiffeners did not reach full height on the finish dies. Figure 22 shows a typical small size specimen and macrographs of sections resulting from the above mentioned forging tests.

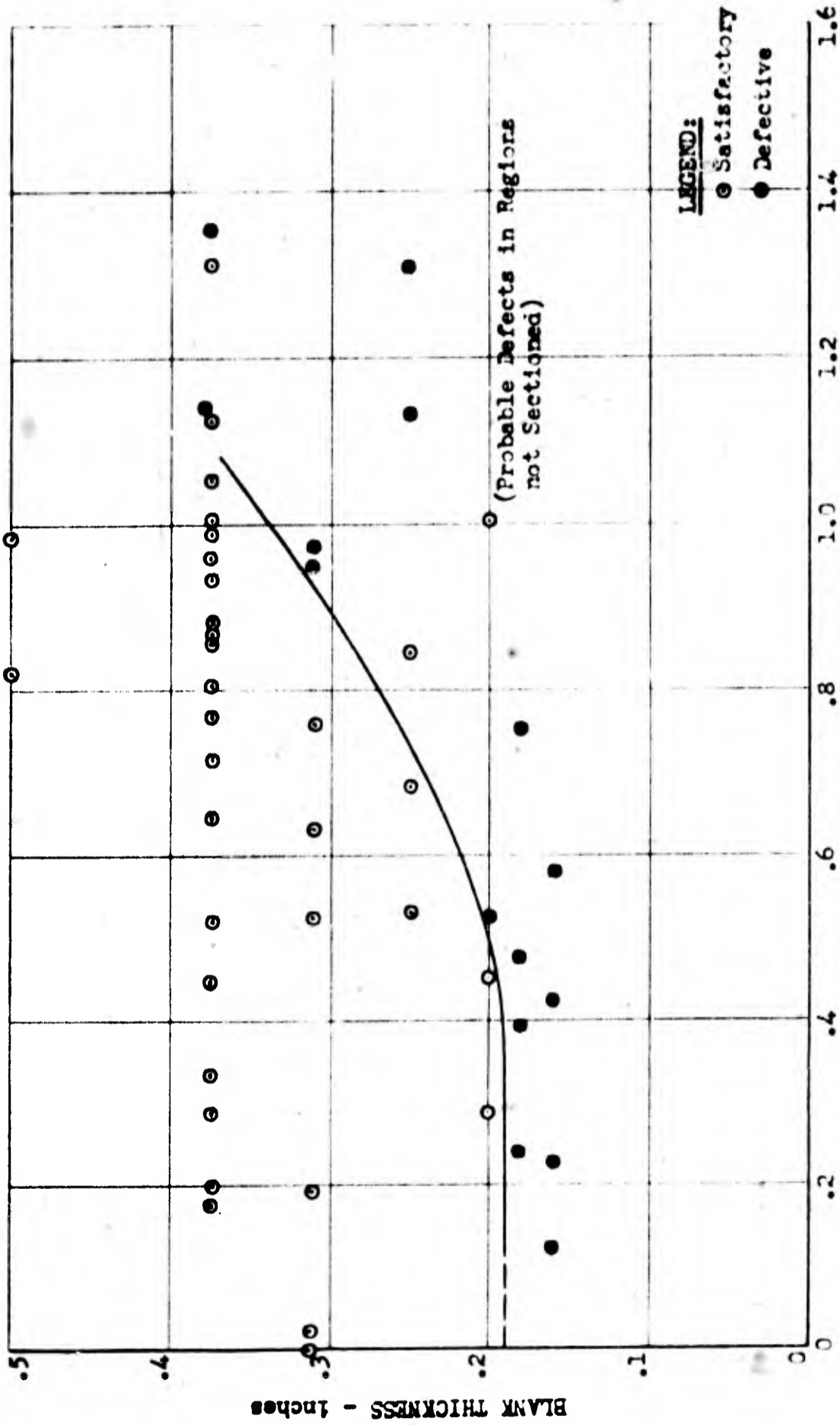


Figure 17. The Effect of Minimum Rib Height for Various Blank Thicknesses on the Occurrence of Forging Defects in 75S Aluminum Alloy Single Operation Waffle Forging Test Parts.

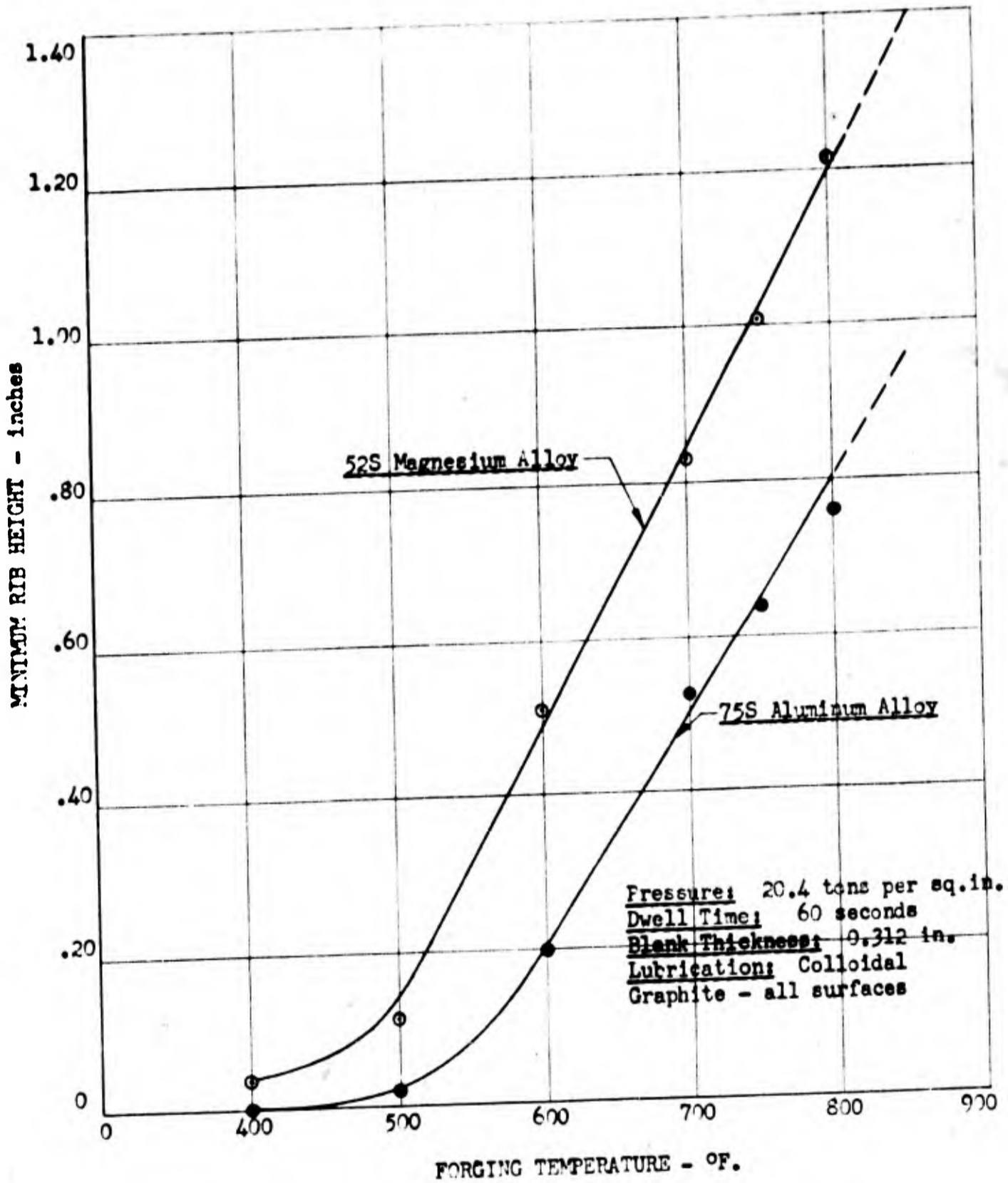


Figure 18. The Relationship between Rib Height and Forging Temperature for 75S Aluminum and 52S Magnesium Alloys with Pressure, Dwell Time, Blank Thickness, and Lubrication Constant.

⊙ Indicates:

Temperature: 800° F.
Pressure: 30.6 tons per sq.in.
Blank Thickness: 0.375 in.

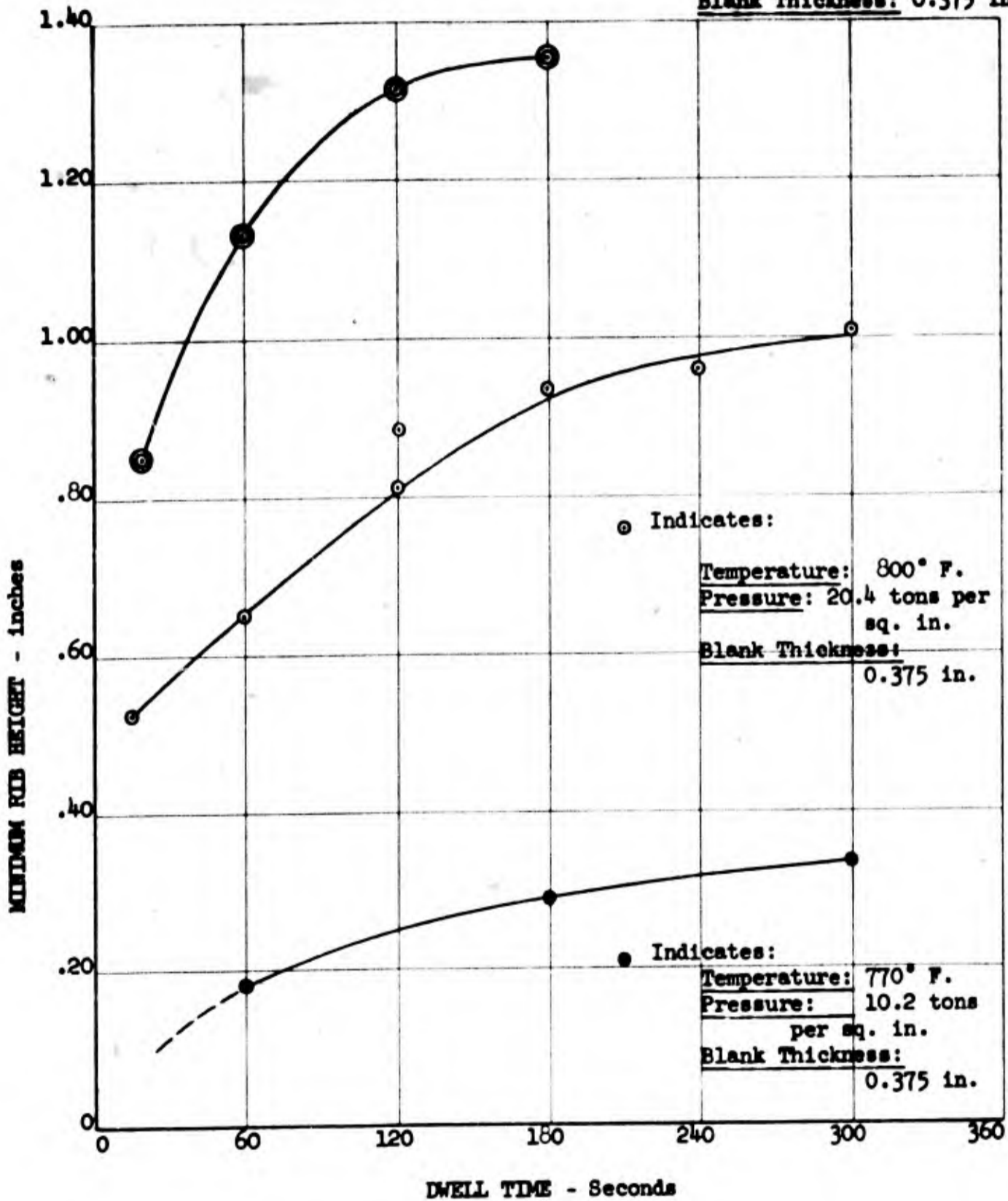


Figure 19. The Relationship between Dwell Time and Rib Height for 75S Aluminum Alloy with Temperature, Pressure, Blank Thickness and Lubrication Constant.

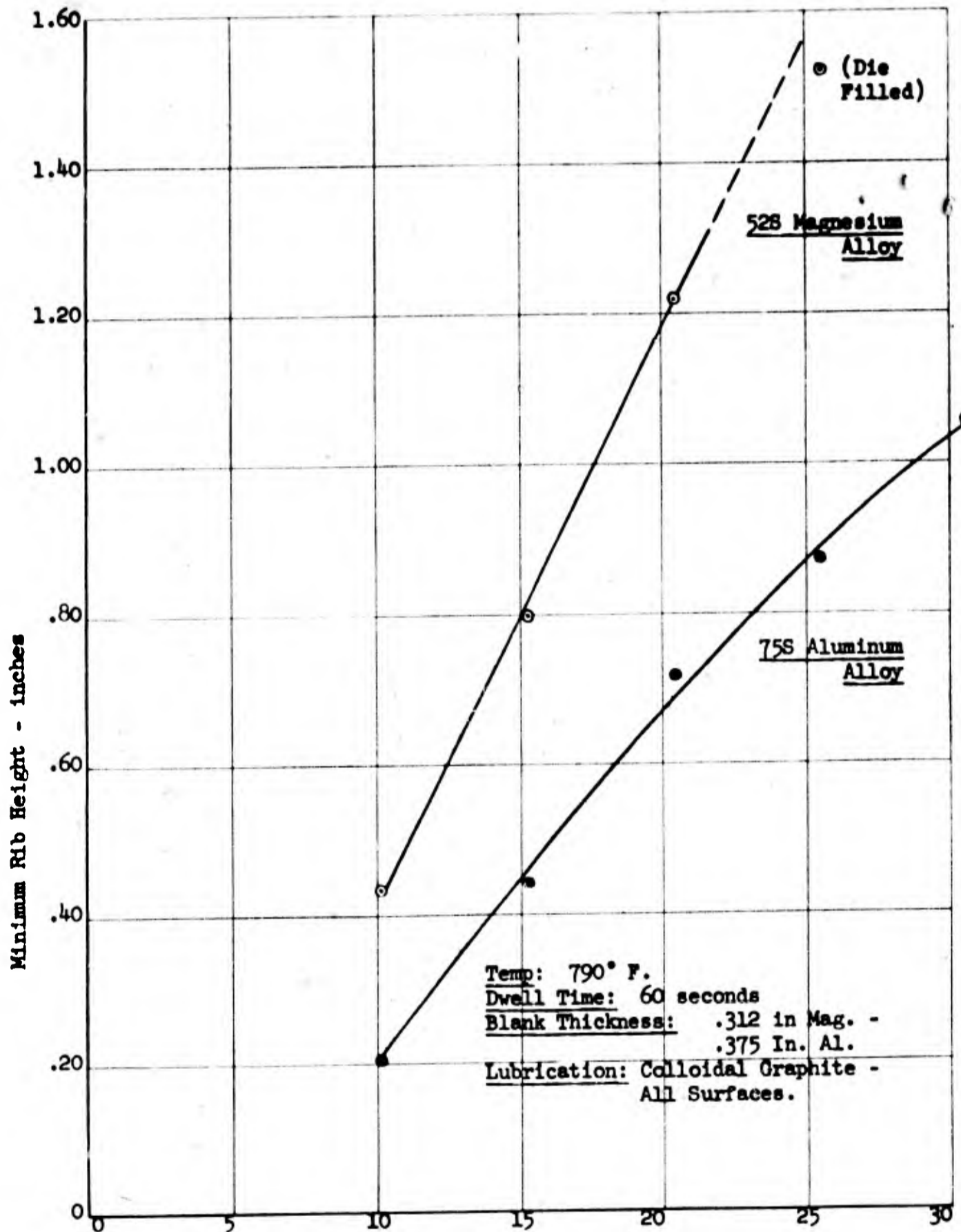


Figure 20. The Relationship between Forging Pressure and Minimum Rib Height for 75S Aluminum and 52S Magnesium Alloy Test Parts with Temperature, Dwell Time, Blank Thickness, and Lubrication Constant.

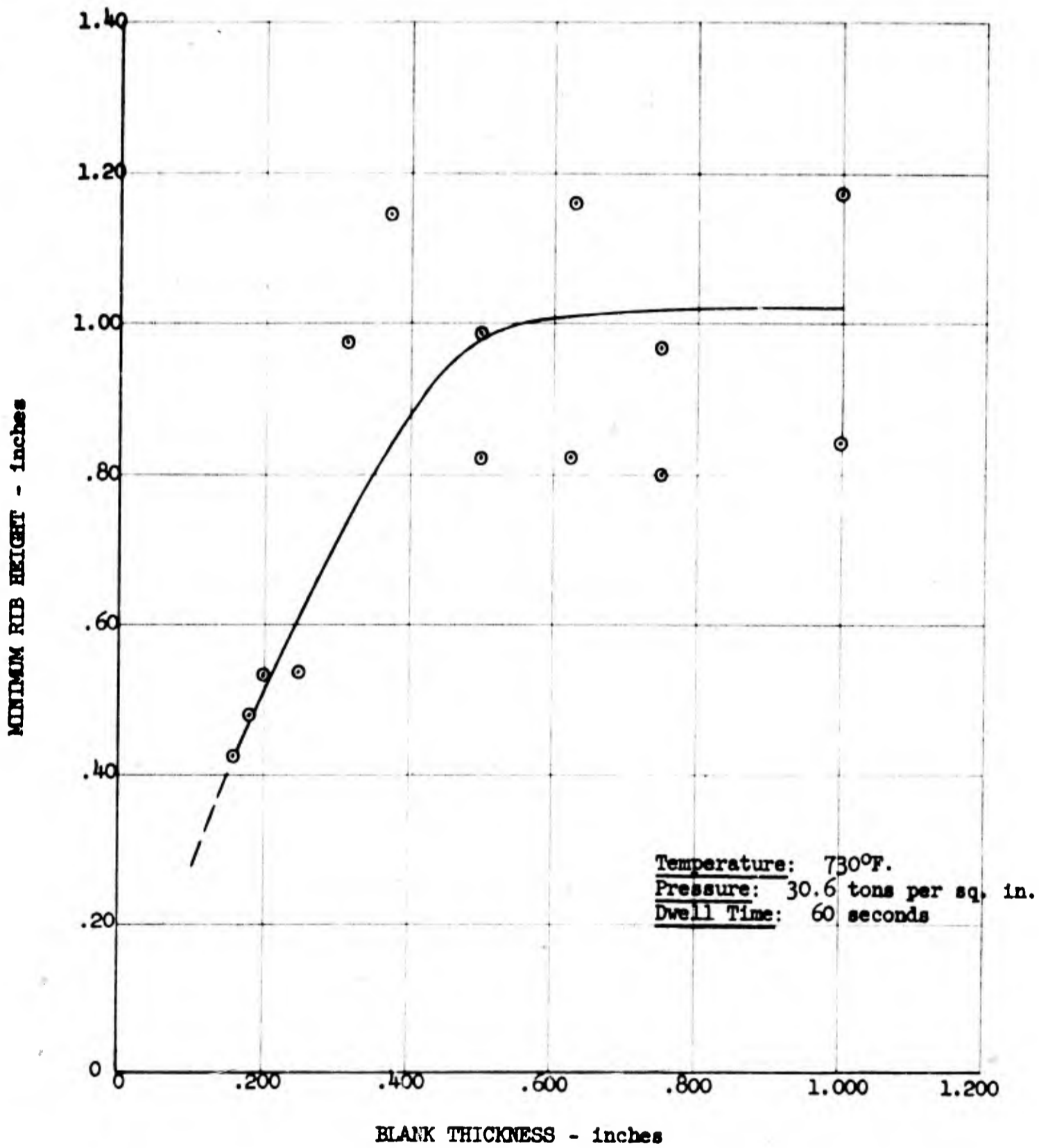
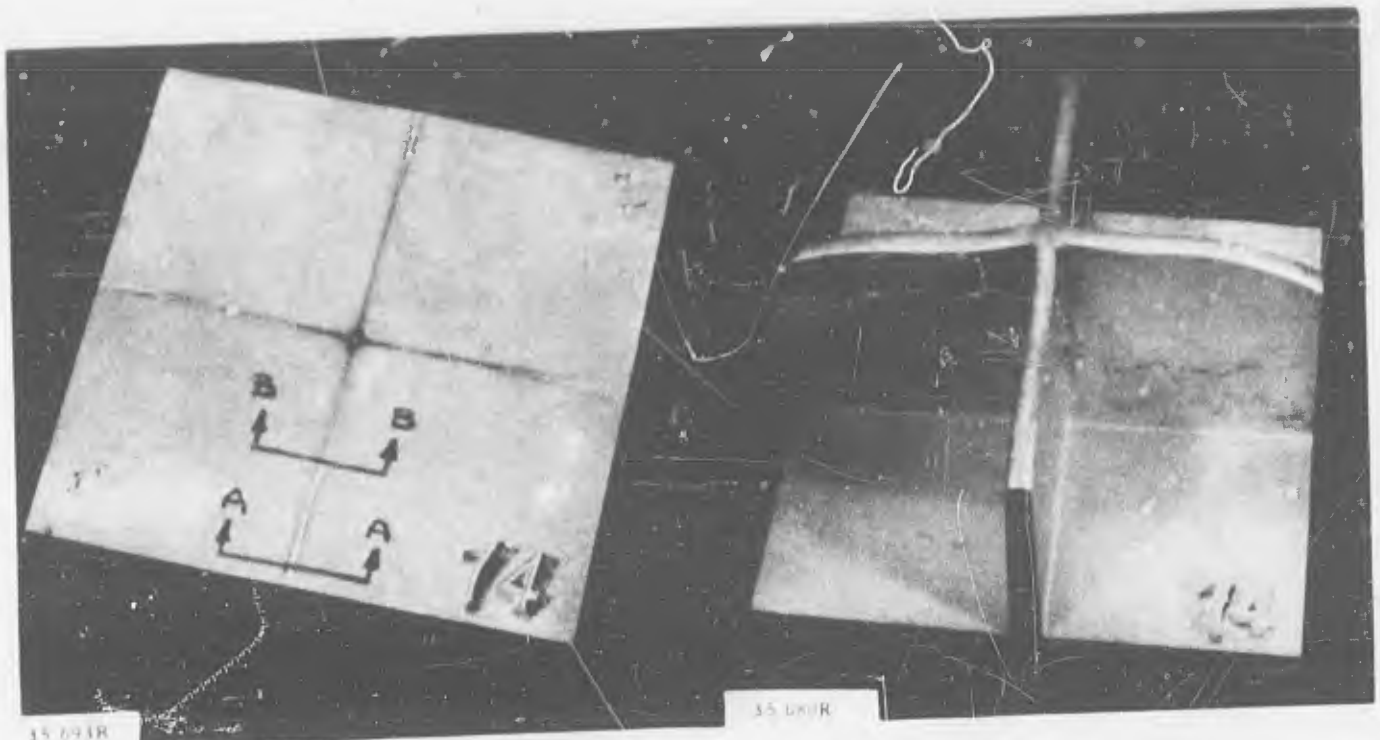
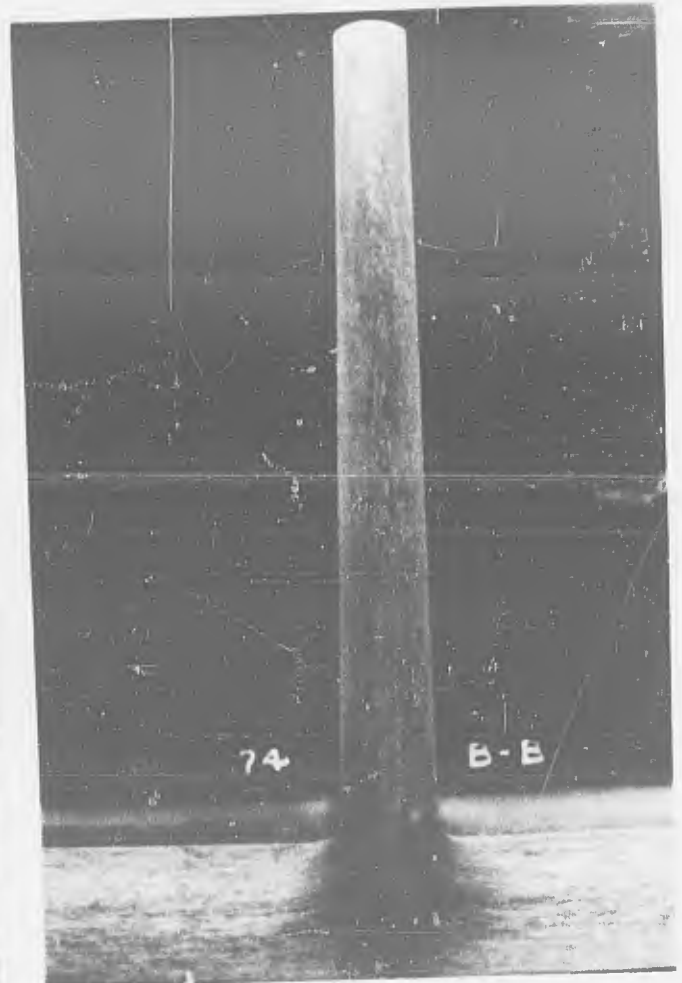


Figure 21. The Relationship between Rib Height and Original Blank Thickness for 75S Aluminum Alloy with Temperature, Pressure, Dwell Time, and Lubrication Constant.



35 091R

35 091R



Blank Thick: 0.375 in. Forging Temp: 800°F.
Skin Thick: 0.232 in. Forging Pressure: 30.6 tons per sq. in.
Min. Rib Height: 1.350 in. Dwell Time: 180 seconds
Defects: Microlap

Figure 22. 75S Aluminum Alloy Waffle Forging
Small Size Specimen No. 74

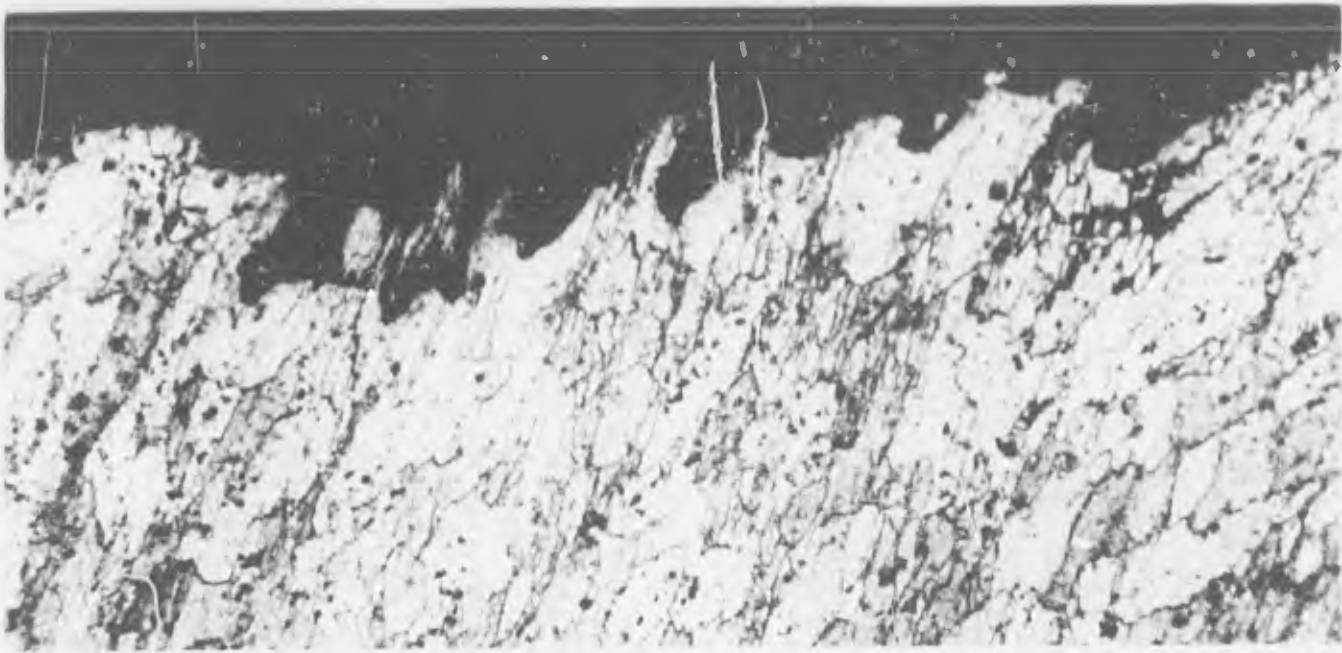


Figure 23. Micrograph Illustrating Sectional Aspects of Skin Surface Roughness in Area Exhibiting "Marking" Opposite Stiffeners. 200X

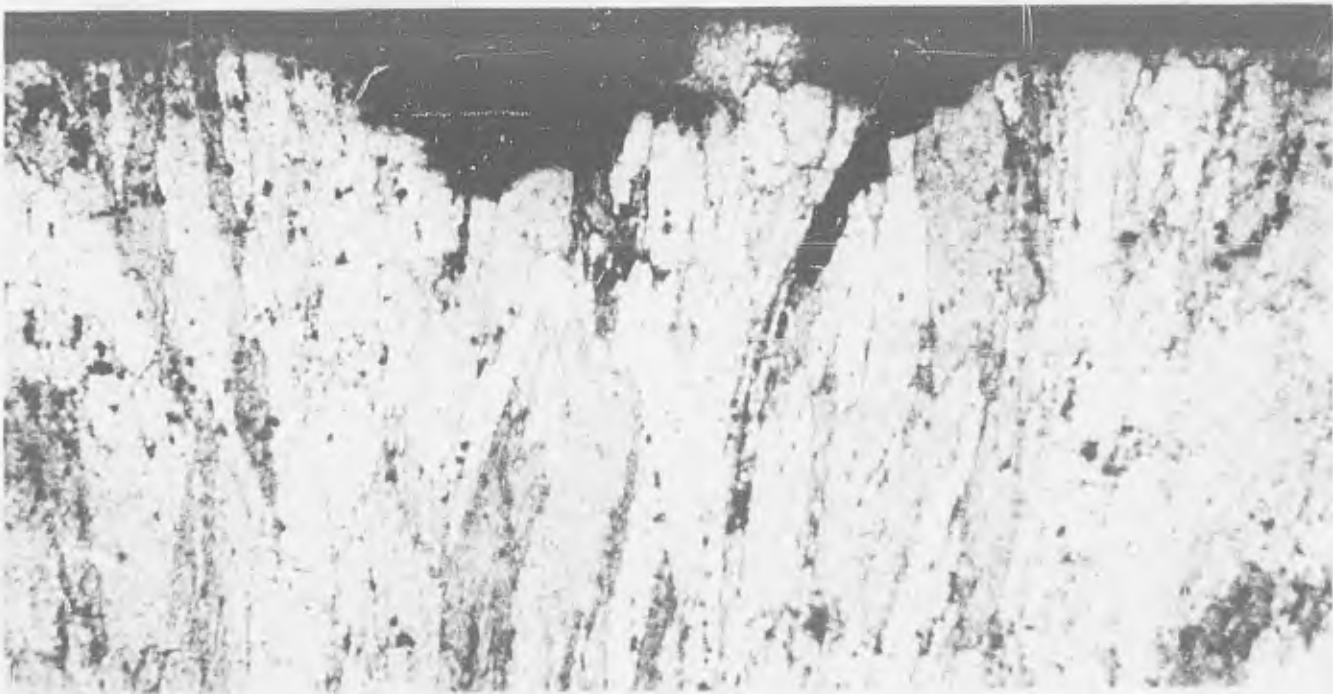


Figure 24. Micrograph Illustrating Sectional Aspects of Skin Surface Roughness and Small Forging Discontinuity of the "Suck-in" Type in Area Exhibiting "Marking" Opposite Stiffener. 200X



Figure 25. Micrograph Illustrating Sectional Aspects of Skin Surface Roughness and Moderately Deep Forging Discontinuity of the "Suck-in" Type in Area Exhibiting "Marking" Opposite Stiffener Centerline. - 200X

Stiffener thickness had a direct effect on the height to which a rib could be raised from a flat blank when other variables remained constant. The occurrence of defects, such as "buckling" and "suck-in" as shown in the above noted forging tests, (3), signified a limiting factor in the production of single operation forgings having tall stiffeners and relatively thin skins. The "buckling" type defects occurred when the stiffener thickness to forging blank thickness ratio became large (more than 1.0, approximately). The tests indicated thin blanks require higher pressure than thick blanks to produce ribs of similar proportions. Also, thin ribs required more pressure than thick ribs to produce stiffeners of the same height from blanks of the same thickness. With a given rib thickness, a thicker blank results in a decreased frequency of occurrence of defects.

Forging Temperature

An optimum forging temperature range determined for the forged panel operations at the Wyman-Gordon Company was 730° F to 800° F. Below 730° F the rib development was incomplete. Above 800° F the knockout pins in the ejection system caused excessive warpage in extracting a forged panel with 0.350 inch web thickness.

Results of tests (4) conducted by the Lockheed Engineering Research Laboratories agreed fairly well with the above temperature limits as far as effects on forming of the forged panels are concerned. Forging operations performed at temperatures under 850° F resulted in no significant surface or metallurgical defects. Defects of the "hot tear" type accompanied by evidence of intergranular melting were found in stiffener tips of parts forged at 900° F and 950° F. Accelerated corrosion tests on these specimens produced intergranular attack in areas previously shown to be damaged by overheating. Specimens forged at 850° F exhibited greatly increased stiffener height compared with parts forged at 800° F.

Lubricant

The lubricant used in forming the forged panels at the Wyman-Gordon Company was Kerns Forging Compound, Number 4247.

Horizontal Fillet Radii

Small size specimens with increasing horizontal fillet radii, from .030 to 0.375 inch, were forged from 7075 aluminum alloy blanks varying from 0.200 to 1.00 inch in thickness at the Lockheed Engineering Research Laboratories (Appendix V). The scope of this research did not permit the determination of exact limits of maximum obtainable stiffener heights for sound parts forged from various blank thicknesses with various horizontal fillet radii. However, it did indicate that slight improvement in forging characteristics accompanied increased fillet radii within the range investigated.

The results of these tests are plotted and compared with previously obtained values (Figure 17) for .030 inch fillet radii in Figure 1 of Appendix V. Photomicrographs illustrating grain flow structure and defects in the small size specimens are shown in Figures 11 thru 18 of Appendix V.

Flow Across Rib Cavities

Forging tests (Appendix V) on small size 7075 aluminum alloy specimens were performed at Lockheed Engineering Research Laboratories in order to determine the possibility of shear failure at the rib base due to lateral flow of metal across the rib cavity. Undersize blanks were forged so as to result in a flow of metal across the rib cavity as well as into the rib cavity. No defects due to lateral flow occurred in any of specimens forged from undersize blanks. This lack of defects was explained as being due to the metal not filling the narrow rib cavity until the blank had expanded to its full width. Final stages of the forging stroke appeared to have produced flow conditions similar to those for full sized blanks of the same volume. It was reasoned that shear discontinuities will only occur across the base of stiffeners when the lateral and vertical openings are proportioned to permit simultaneous forging flow in both directions.

Restriking Incomplete Parts

Attempts to restrike underfilled forgings in the finish dies at the Wyman-Gordon Company proved this operation to be impractical. The first restrikes resulted in a "peel down" accumulating metal in the fillet radius at the base of the ribs as shown in Figure 35. In order to avoid "peel down" in subsequent restrikes the tops of the ribs were all ground off to a constant height and .005 inch thickness was removed from the rib sides by a 7% caustic soda solution etch. This method proved unsatisfactory because, although the ribs developed full height, the etched thickness did not upset to full size. The ribs were full thickness only where they were newly extruded from the web.

PANEL FORGING TESTS

This development program was originally conceived with the object of determining the forging techniques required to solve the metal flow problems encountered in the production of forged thin skin, waffle-type ribbed panels. The importance of proper metal distribution was recognized and consideration was originally given to the use of an intervening blocker plate in conjunction with the finish forging dies. The use of the intervening plate was considered in order to reduce the cost of the blocking operations. However, as previously stated, it was decided that separate blocker dies would prove to be more efficient in producing good finished forgings.

The panel forging tests were performed on a 7700 ton press at the Wyman-Gordon Company, with forging pressures of 4400 tons and 7700 tons. A general view of the forging tools in position on the press is shown in Figure 13. External electrical strip heating units were installed on the sides of the bottom die holder and a sheet of transite was placed under the bottom of the die. The knockout pin ejector system was actuated through tapered wedges connected to a horizontal hydraulic cylinder as shown in Figure 12.

Initial Forging Tryouts

Ten of the twelve forging blanks for the initial forging tryouts were blocked to web thicknesses of 0.33 to 0.49 inch prior to the finish forging operations. The remaining two blanks, made of 0.75 inch thick plate stock profiled to fit the finish die cavity, were not blocked so as to determine the possibility of eliminating the blocking operation. Several of the blocked pieces were underfilled in various areas, the poorest being used as initial trial pieces to condition the new finish dies.

The finish dies were heated to 700° F prior to forging operations. However, the external strip heaters were inadequate, allowing the die temperature to drop to 620° F when the first run was stopped after forging four pieces under a pressure of 4400 tons. During the first run part extraction was readily accomplished but increasing difficulties were encountered in retracting the ejection knockout pins. Dry graphite was applied to the knockout pins to facilitate retraction. A summary of these initial tryouts is shown on Table II.

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PART NUMBER	PRESS LOAD	DWELL TIME	STOCK TEMP. PRIOR TO FORGING	STOCK TEMP. AFTER FORGING	DIE TEMP.	EJECTOR LOAD SLIDE CYLINDER	REMARKS
NUMBER	TONS	SEC.	°FAHRENHEIT	°FAHRENHEIT	°FAHRENHEIT	TONS	
7	Weight of Moving Cross Head	---	775°	---	700°	0	This blocker was hit only with weight of head in order to "break in" the finish dies. A very slight mark was made on the blocker, piece was put back in furnace.
9	4400	20	775°	---	---	0	The blocker had been made out of 10" square stock, small amount of underfills in blocker.
10	4000 to 4400	60	775°	---	620°	0	The blocker had been made out of 10" square
4	4000 to 4400	60	760°	610°	620°	0	The blocker had been made out of plate stock machined to .50 panel with .75 local pad.

Table II. Data Sheet - Initial Tryouts

Modifications Prior To Second Tryouts

As a result of the experience and difficulties encountered in the initial forging tryouts, the tooling was disassembled. Disassembly revealed upset on the ejection pins and compressive permanent set on the hard plate, where the pins were bearing on the plate, due to forging temperatures and pressures. The pins and hardplate were reworked, as previously noted, to remove the damage.

The ejector system was also reworked to provide greater stroke to facilitate removal of pieces from the die. The method of coupling the ejector system to the side cylinder was simplified to permit a more rapid assembly in order to decrease the die installation time and reduce the resultant heat losses which occurred when transferring the dies from the furnace to the press.

The plan form of the blank was enlarged to reduce the lateral flow of metal that was occurring in the finish dies.

Thermocouples were installed at the deepest part of the impression on the lower side of the hardplate and in a lift pin hole approximately ten inches from the punch plug. A gas ring heater was decided upon as a means of periodically supplementing the inadequate external electric strip heaters so as to maintain a die temperature above 700° F.

Second Forging Tryouts

Twenty-one blanks prepared for the second forging tryouts were of three types:

- (a) Ten blanks were in the "as blocked" condition with web thicknesses from 0.26 to .32 inch.
- (b) Eight defect-free blocked parts were machined to web thicknesses of .050 to 0.225 inch so as to evaluate the effect of web thickness on the occurrence of defects.
- (c) Three blanks were machined from plate stock to evaluate the effects of blocker configuration on forgeability. Two of these plates were sculptured to provide an approximate distribution of material over the panel area. The remaining blank was only profiled to fit the die cavity and was of a constant 0.76 inch thickness.

Thickness measurements indicated in (a) and (b) above were taken at locations indicated in Figure 26 and are listed in Table III.

After forging the fourth panel in this series of tests, difficulty was again encountered in retraction of the large knockout pins. After forging each succeeding panel the pins had to be forced down into position by placing an aluminum blank on the pins and forcing them down with the weight of the press head. Eight blocked blanks, (a) above, and two blanks machined from plate stock, (c) above, were forged during this series of tests before the run was stopped because of the above difficulties with the ejection system.

The use of the gas ring heater to supplement the external electric strip heaters did not maintain temperatures above 700° F as expected. Although the gas burner, placed directly over the inserts, would raise the insert temperature it could not be maintained for any reasonable period of time.

All panels produced from sound blocked blanks showed various degrees of underfill at the tops of the ribs. There was no consistency or pattern in the location of this underfilled condition. Piece No 6, shown in Figure 27, forged from a block blank, illustrates a typical panel with 0.35 inch minimum web thickness and with underfill, up to 3/8 inch, on approximately 50% of the interior rib edges.

Both panels forged from plate stock without a blocking operation showed indications of "suck-in" in the vertical fillet radii at rib intersections, and an underfilled condition in the area of the tapered web and ribs. Both of these conditions can be attributed to the severe flow of excess metal from the center of the panel to the edges which must occur when the relatively thin center web has not been previously blocked to proper thickness. This condition would be improved by allowing the ribs to form to unrestricted height and thereby providing for disposal of excess web material. The excess rib height could be removed by a simple machining operation after forging.

One panel, piece No. 291 shown in Figure 28, forged from the 0.76 inch thick plate stock showed somewhat better filling over the entire panel than the second panel, piece No. 281 shown in Figure 29, forged from 0.50 inch plate stock. The extremely high forging pressures that were developed can be detected by the presence of heavy flash at the tips of the ribs in the center of piece No. 281, Figure 29.

The importance of maintaining adequate die temperature is shown by pieces No. 201 and No. 241 in Figures 30 and 31. Dimensionally

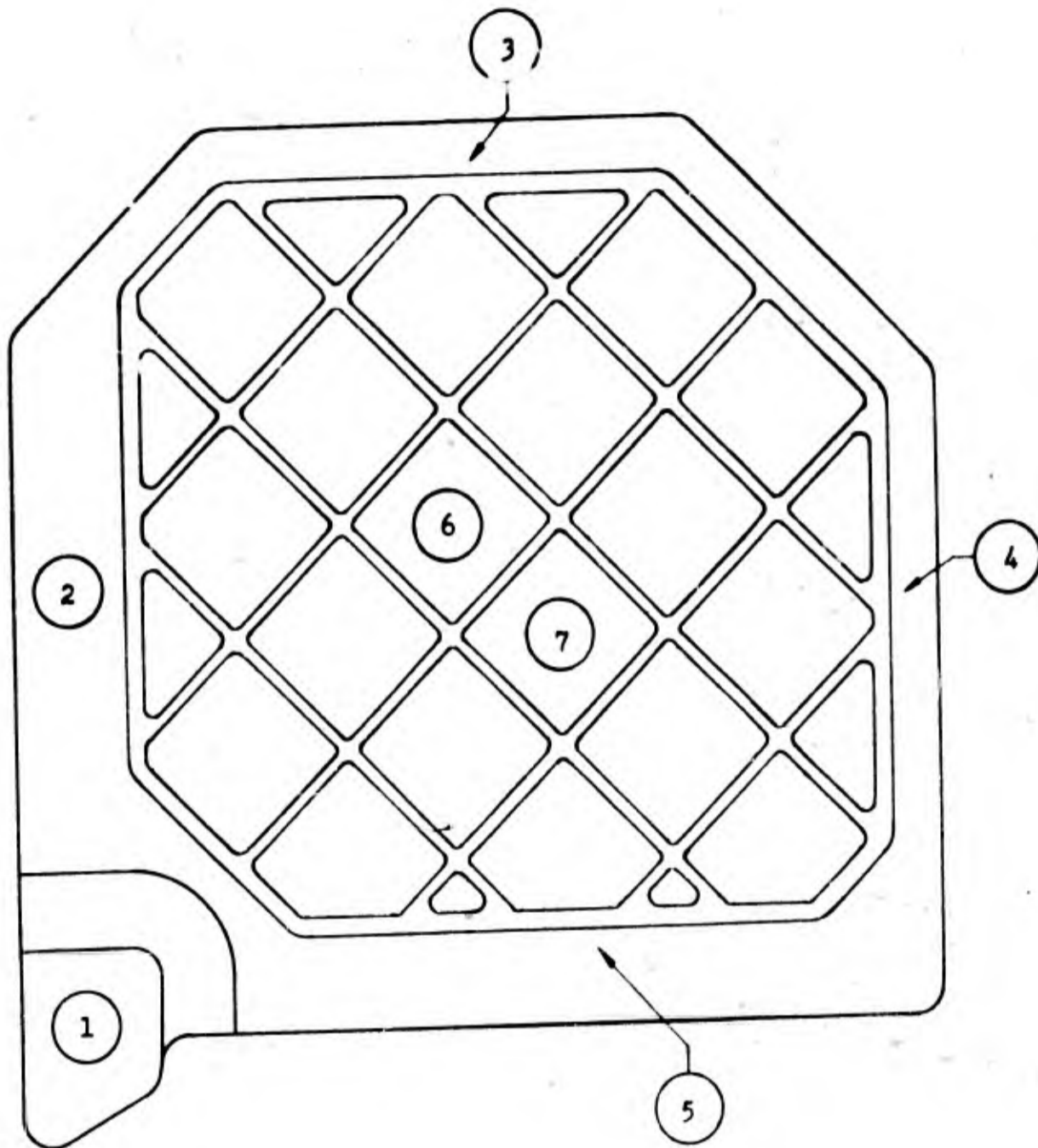


Figure 26. Location of Web Thickness Measurements (Ref. Table III)

"AS BLOCKED" - DEFECT FREE

<u>Piece Number</u>	<u>Web</u>	<u>Piece Number</u>	<u>Web</u>
161	.34 to .36	251	.33
15	.33 to .34	231	.35
241	.33 to .35	201	.33
221	.35	271	.32
6	.35	211	.34

DEFECT FREE BLOCKERS MACHINED TO DIFFERENT WEB THICKNESSES

<u>Piece Number</u>	<u>Location</u>						
	<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>5</u>	<u>6</u>	<u>7</u>
171	.724	.439	.440	.440	.442	.225	.225
181	.729	.443	.440	.444	.446	.230	.230
5	.685	.396	.397	.384	.396	.180	.180
11	.685	.408	.407	.406	.412	.210	.210
12	.654	.403	.400	.407	.407	.200	.200
191	.593	.333	.325	.338	.317	.110	.110
2	.526	.248	.268	.271	.255	.055	.060
1	.533	.259	.258	.254	.258	.050	.050

BLANKS PROFILED FROM PLATE STOCK TO FIT FINISH DIES
WEB THICKNESS MACHINED TO THICKNESSES LOCATIONS
SHOWN IN FIGURE 26

<u>Piece Number</u>	<u>Location</u>						
	<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>5</u>	<u>6</u>	<u>7</u>
261	.721	.524	.510	.526	.492	.5.5	.515
281	.739	.518	.499	.511	.521	.515	.515
291	.760	Constant					

Table III. Web Thickness Data - Second Tryouts.

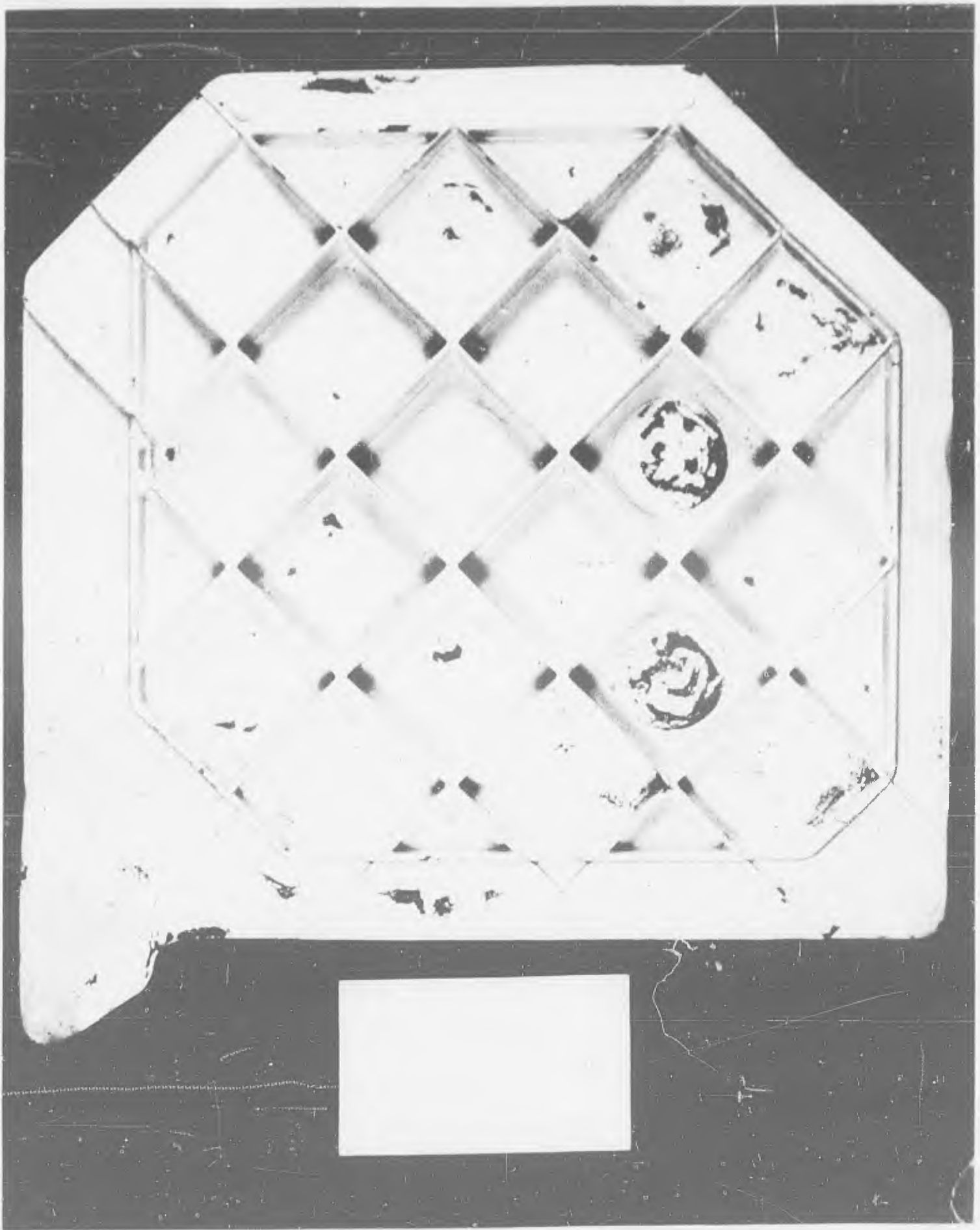


Figure 27

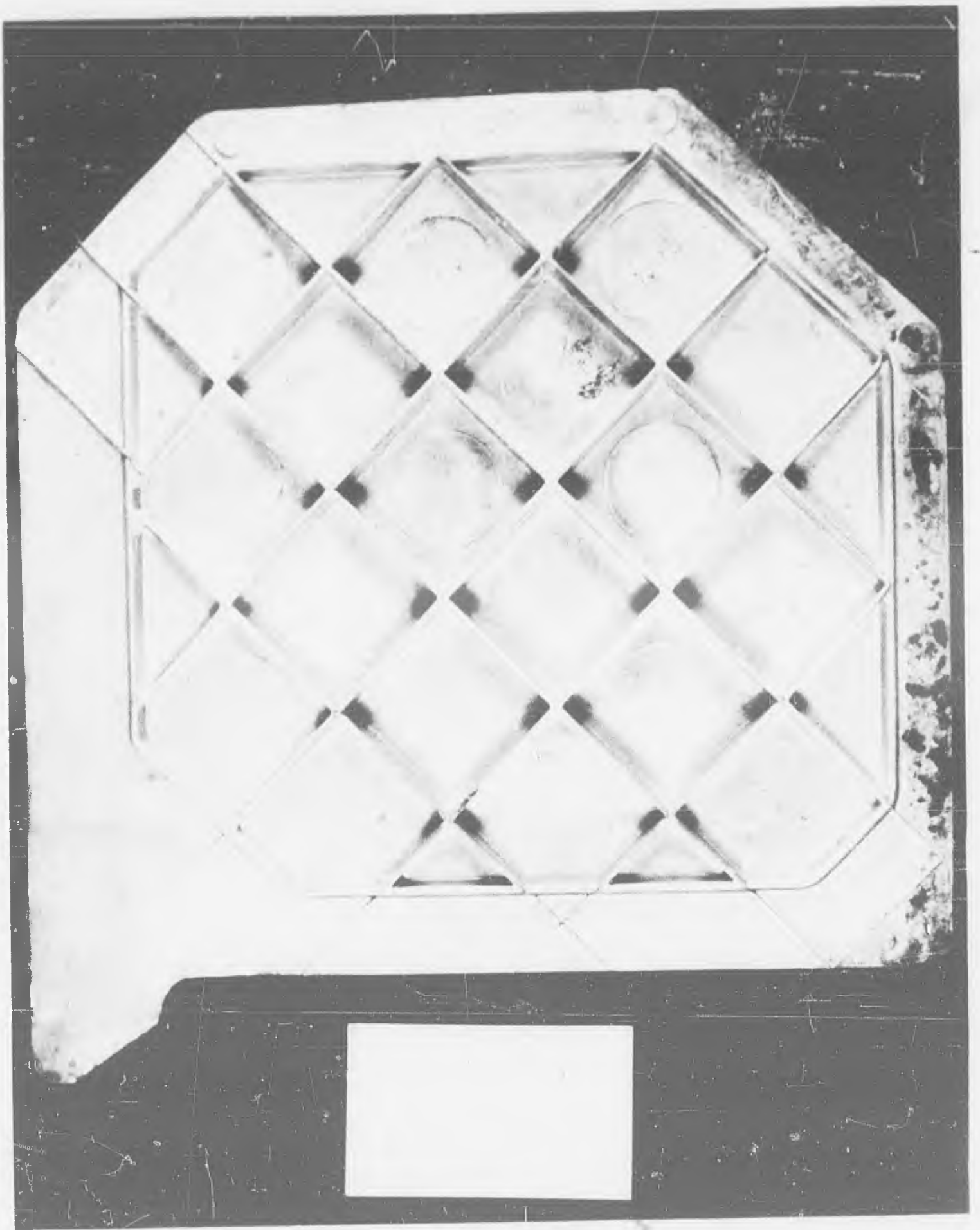


Figure 28

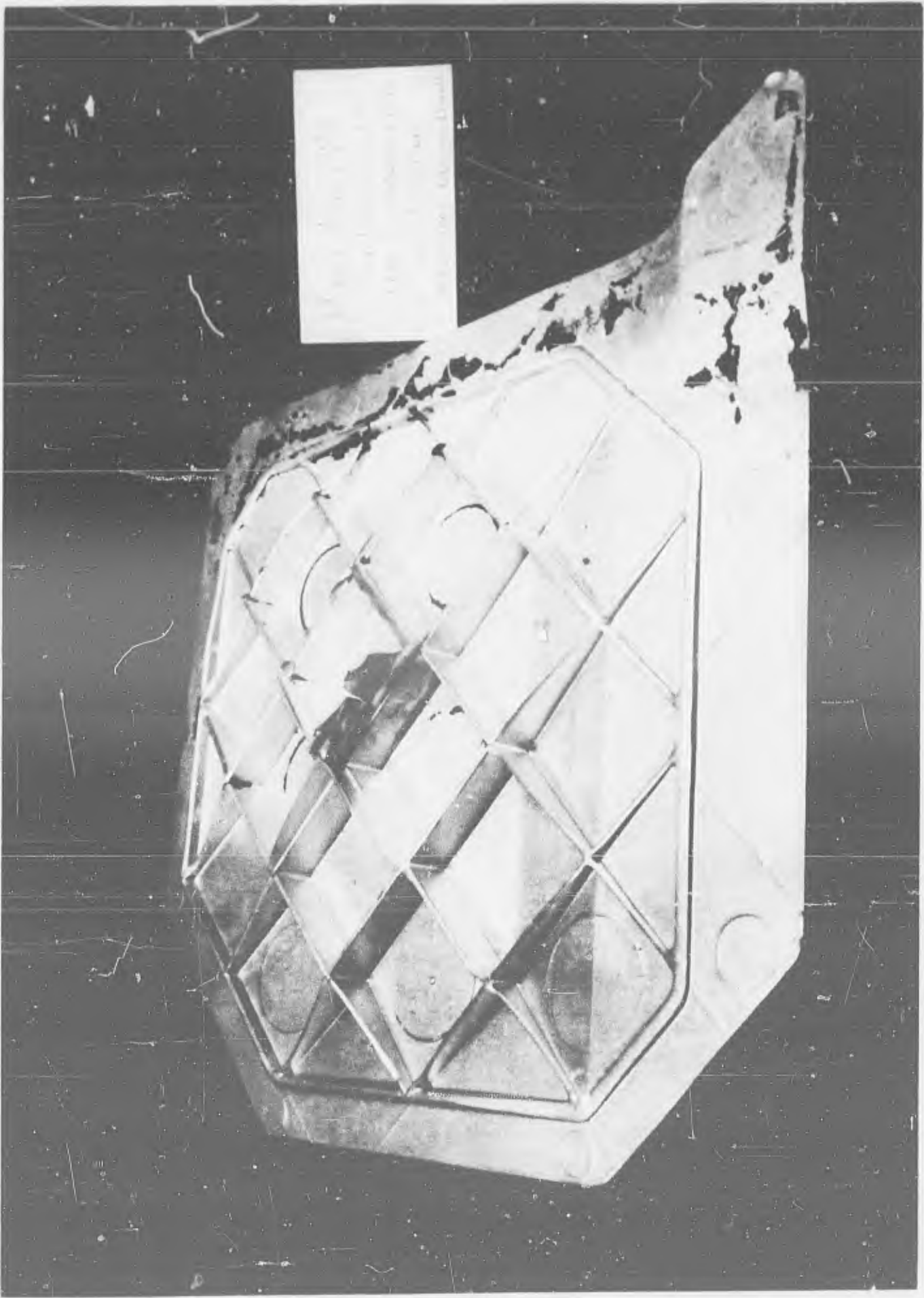


Figure 29

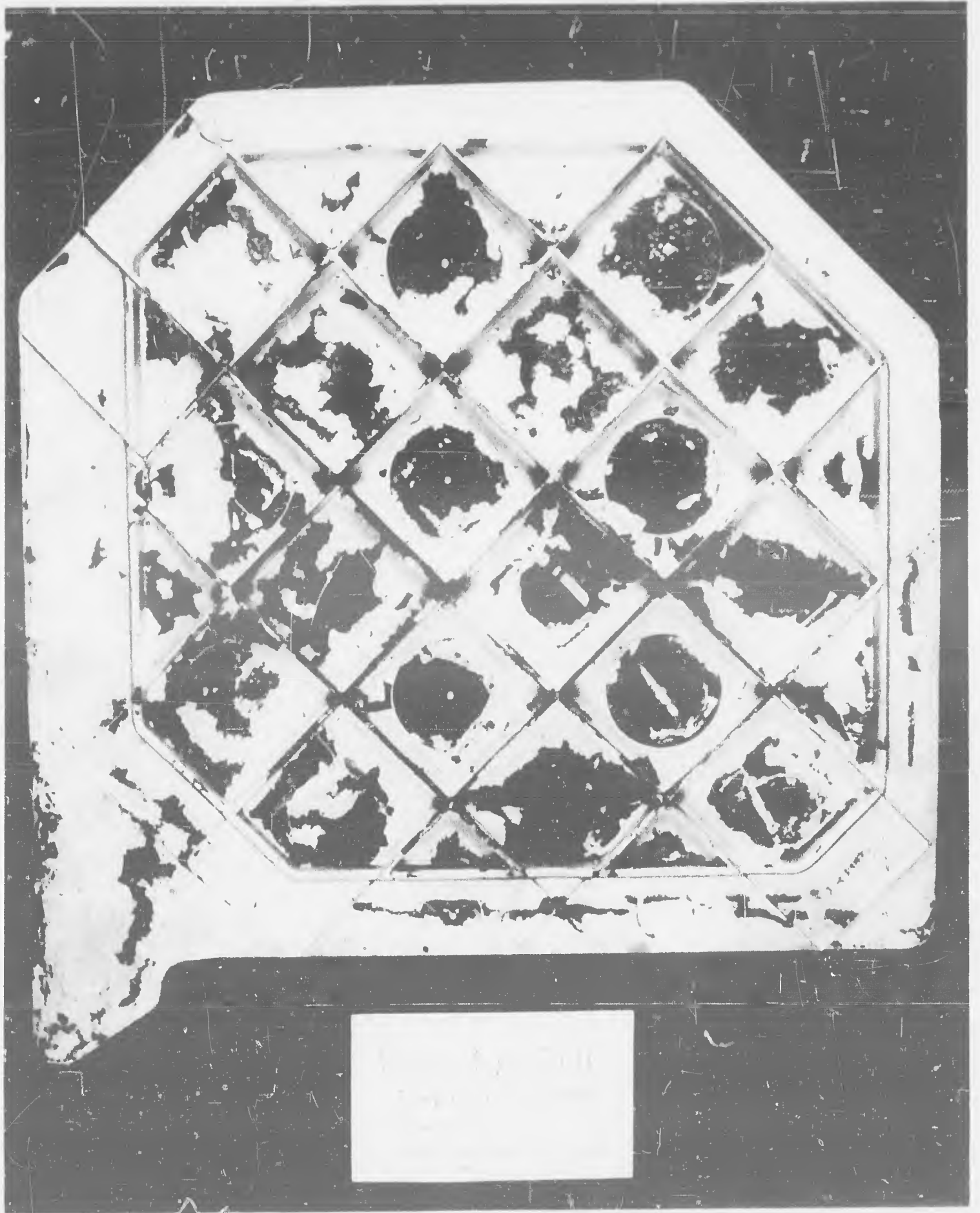


Figure 30

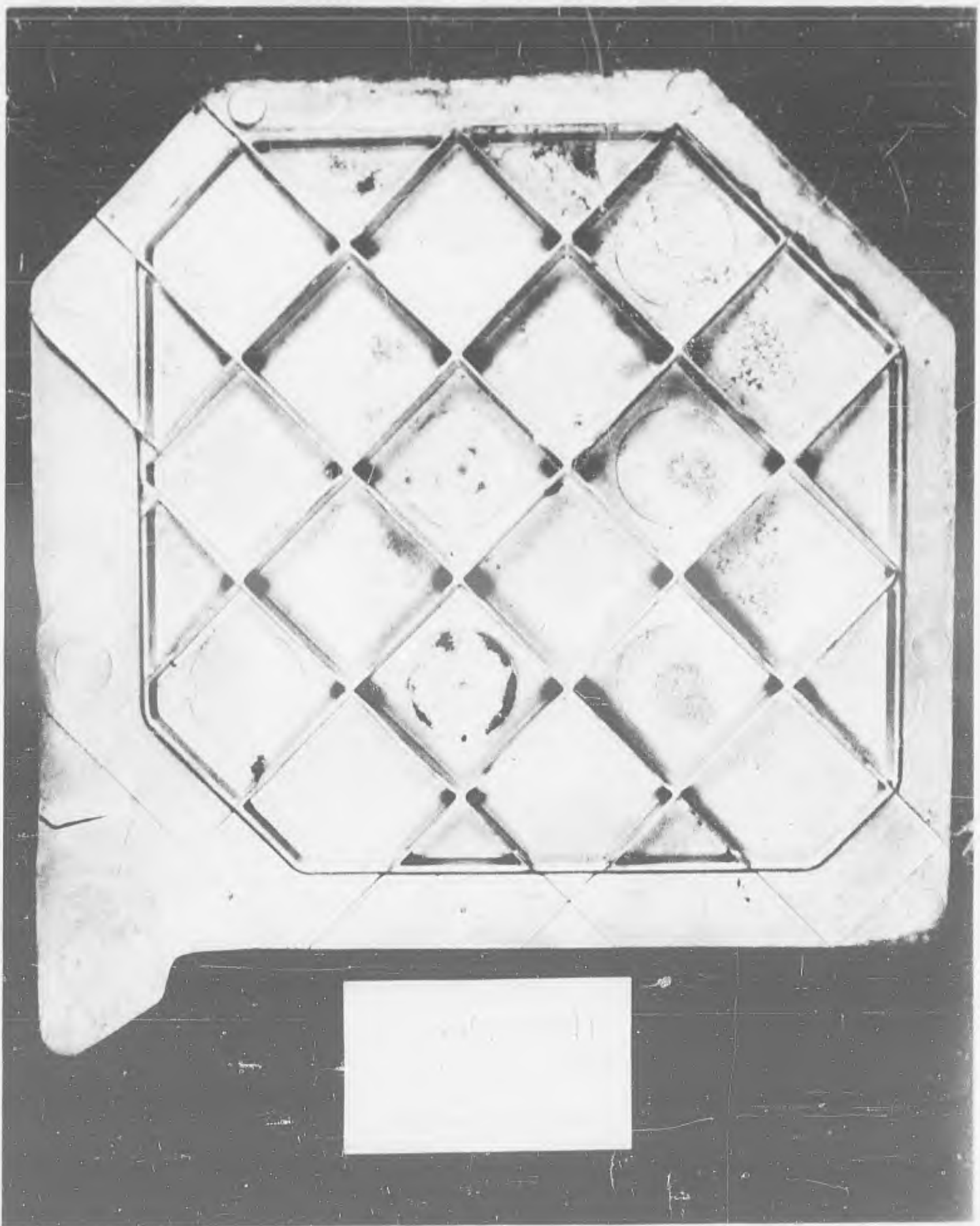
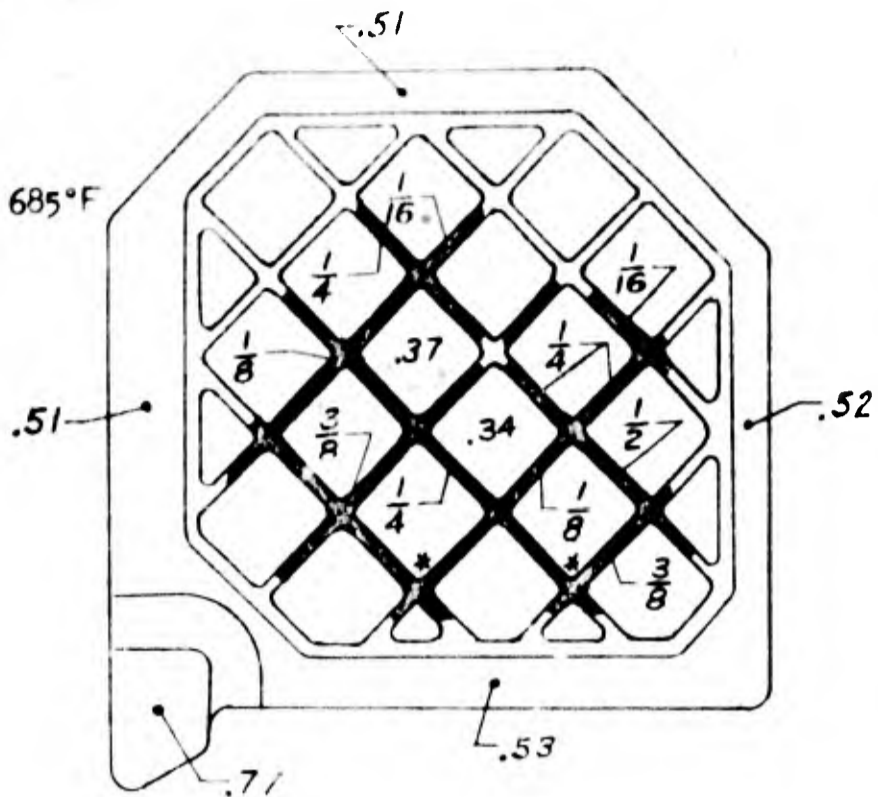


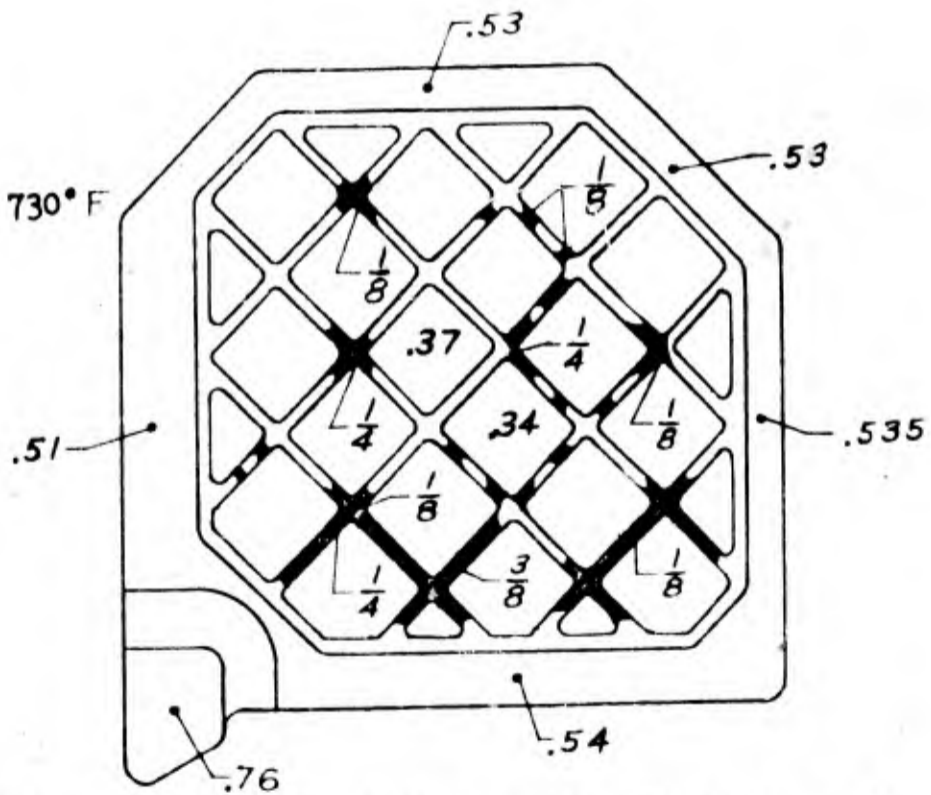
Figure 31

Piece No. 201
 Temp. Bottom Die 685°F
 From Blocker
 4400 Tons
 60 Sec. Dwell



* Indicates Forging Defect (suck-in)

Piece No 241
 Temp. Bottom Die 730°F
 From Blocker
 4400 Tons
 60 Sec. Dwell



Note: Shading and fractions indicate location and extent of underfill in inches. Decimals indicate web thickness.

Figure 32. Effect of Die Temperature on Underfill on Pieces #201 and #241.

these two blocked panels were identical except for a difference of up to .020 inch in web thickness. Figure 32 illustrates a comparison of the web thickness and rib underfill on these two panels. Piece No. 201, Figure 30, forged at 685° F shows decidedly less filling and also indication of "suck-in" defects.

Details of the forging conditions for the panels produced during the second forging tryouts are summarized in Table IV.

Modifications Prior to Final Tryouts

A review of the problems encountered during the second trials indicated that modification of the blocker and finish dies would be required. The blocker die was reworked to adjust the distribution of metal as indicated by the results of the second forging tryouts.

The difficulties encountered in retraction of the ejection knockout pins, as a result of plastic flow under the high temperatures and high pressures of the forging operations, indicated redesign of the pins. The knockout pins were replaced with new pins made from "Thermold J" alloy obtained from the Cyclops Steel Corporation. The use of this high-strength hot-work tool steel reduced the retraction difficulties encountered in previous tryouts.

Final Forging Tryouts

The primary objectives of the final forging tryouts were decided upon as being to:

- (a) Produce a sound, completely filled forged panel with a web thickness of approximately 0.30 inch.
- (b) Determine the minimum web thickness that could be produced without introducing metal-flow defects.

Twenty-one blanks were prepared for the final forging tryouts. Seventeen were blocked pieces, seven of which were machined to various web thicknesses. The remaining four blanks were finished forgings from the second tryouts with underfilled ribs. Two of these four blanks had rib underfill up to 3/8 inch. The other two had the ribs machined to a uniform 1/2 inch height. A list of these blanks and the condition of each is presented in Table V.

Part Number	Press Load 100 Ton	Dwell Sec.	Temperature (°F)				Ejector Load Side Cyl.	Remarks
			Stock		Dies			
			Before Forge	After Forge	Bottom	Top		
161	44-40	60	780	650	780	720	Blocked piece with .35 web.	
15	44-40	60	780	640 620	760	730	Blocked piece with .33 web.	
241	44-40	60	780	780	730	760	Blocked piece with .34 web.	
221	44-40	60	790	660	720	750	Pins struck & forged down with weight of head. Blocked piece with .35 web.	
6	44-40	60	790	670	710	740	Blocked piece with .35 web.	
251	44-40	60	790	650	710	740	Blocked piece with .33 web.	
231	44-40	60	790	630	690	740	Blocked piece .35 web.	
201	44-40	60	790	630	685	740	Blocked piece .33 web.	
161	44-40	120	770	750	700	770	Restrike of piece which was ground after first finish.	
291	44-40	120	790	680	700	770	Plate (.76 Thick) Profiled to fit finish die.	
261	44-40	60	790	640	690	760	Plate profiled to fit finish dies with web area machined to .51 and corner tab .76 thick. Weight of head would not push pins down. Run stopped.	

Table IV. Data Sheet - Second Tryouts

Old Blockers		
#211	.34 web	filled
#271	.32	filled
Old Blockers Machined to Various Web Thicknesses		
#11	.210 web	unfilled tab
#12	.200	unfilled corner
#191	.110	filled
#1	.050	filled
New Blockers		
#21	.410 web	unfilled 90° corner
#31	.360	filled
#41	.370	filled
#51	.340	filled
#61	.395	unfilled 90° corner
#71	.350	filled
#81	.350	unfilled 90° corner
#91	.340	filled
New Blockers Machined to Various Web Thicknesses		
#101	.250 web	filled
#102	.250	filled
#103	.188	filled
Finished Pieces With .005 Etched off Surface for Restrike		
#231	.360 web	3/8 maximum unfill
#6	.350	3/8 maximum unfill
Finished Pieces Machined and Etched for Restrike		
#201	.340 web	1/2 inch leveled ribs
#221	.360	1/2 inch leveled ribs

Table V. Condition of Pieces - Final Tryouts

The difficulties encountered in retraction of the ejection knockout pins in previous forging tryouts did not recur during the final forging tryouts. However, some difficulty did occur in actuating the tapered wedges with the hydraulic cylinder. Maintaining die temperatures above 700° F by means of the gas ring heater in combination with the external electric strip heaters again proved to be impractical. At one time during forging operations the exterior of the die was at 1000° F while the insert dropped from 700° F to 540° F. The gas ring heater was applied without success, so the die had to be returned to the furnace to restore forging temperatures. Forging results became appreciably worse with each drop in die heat.

After the eighteenth piece, the forging pressure was increased from 4400 tons, used on all previous tryouts, to 7700 tons on the remaining three pieces, No. 91, 51 and 101. The pressure on piece No. 91 was increased only momentarily to 7700 tons after one minute at 4400 tons. The final piece, No. 101, run at 7700 tons, threw heavy flash into the space between the insert segments and was difficult to eject. The knockout pins very nearly pushed up through the back side of the piece as shown in Figure 33. The opposite side of Piece No. 101 is shown in Figure 34. When this last piece was removed, the flash remaining between the insert segments made the die unsuitable for additional work.

The attempts to restrike finish forgings with underfilled ribs proved unsuccessful. Figure 35 shows an enlarged view of the "peel down" resulting from restriking Piece No. 161, during the second forging tryouts without etching. However, the ribs filled fairly well with a maximum underfill of 1/8 inch at one spot only. Piece No. 201, shown in Figure 36 was etched and machined to a uniform rib height before restriking. The ribs bottomed almost completely with a maximum underfill of 1/16 inch at the center of the panel. Although no "peel down" occurred, none of the ribs regained full thickness except where newly extruded from the web, as is illustrated in Figure 36.

Data on final forging tryouts are listed in Table VI. One of the nearest to completely filled panels produced during the three forging runs is shown in Figure 36, Piece No. 201.

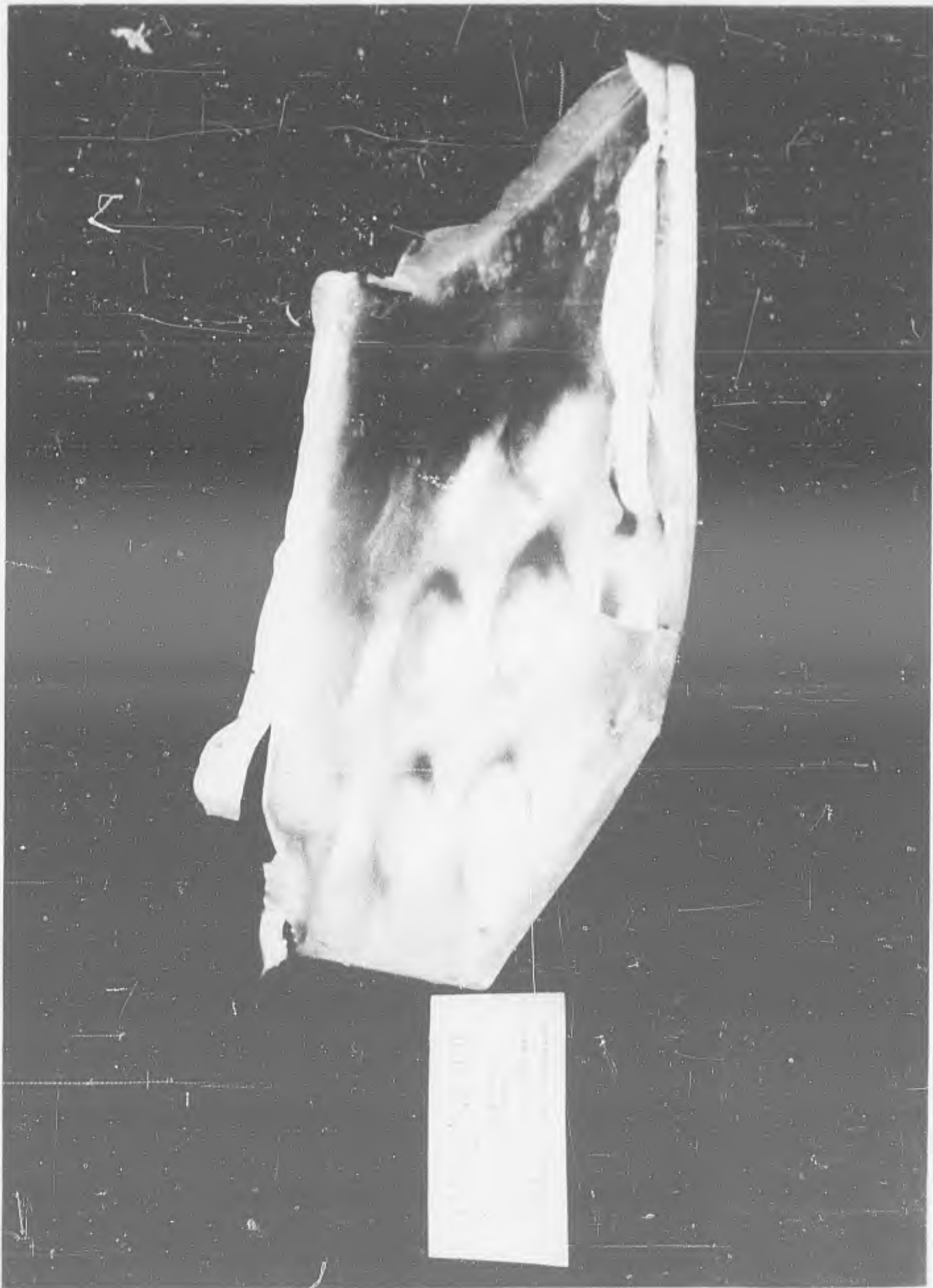


Figure 33



Figure 34

Piece No. 161

Temp. Bottom Die 700°

2nd Finish from Blocker

4400 Tons 120 Sec. Dwell



Figure 35

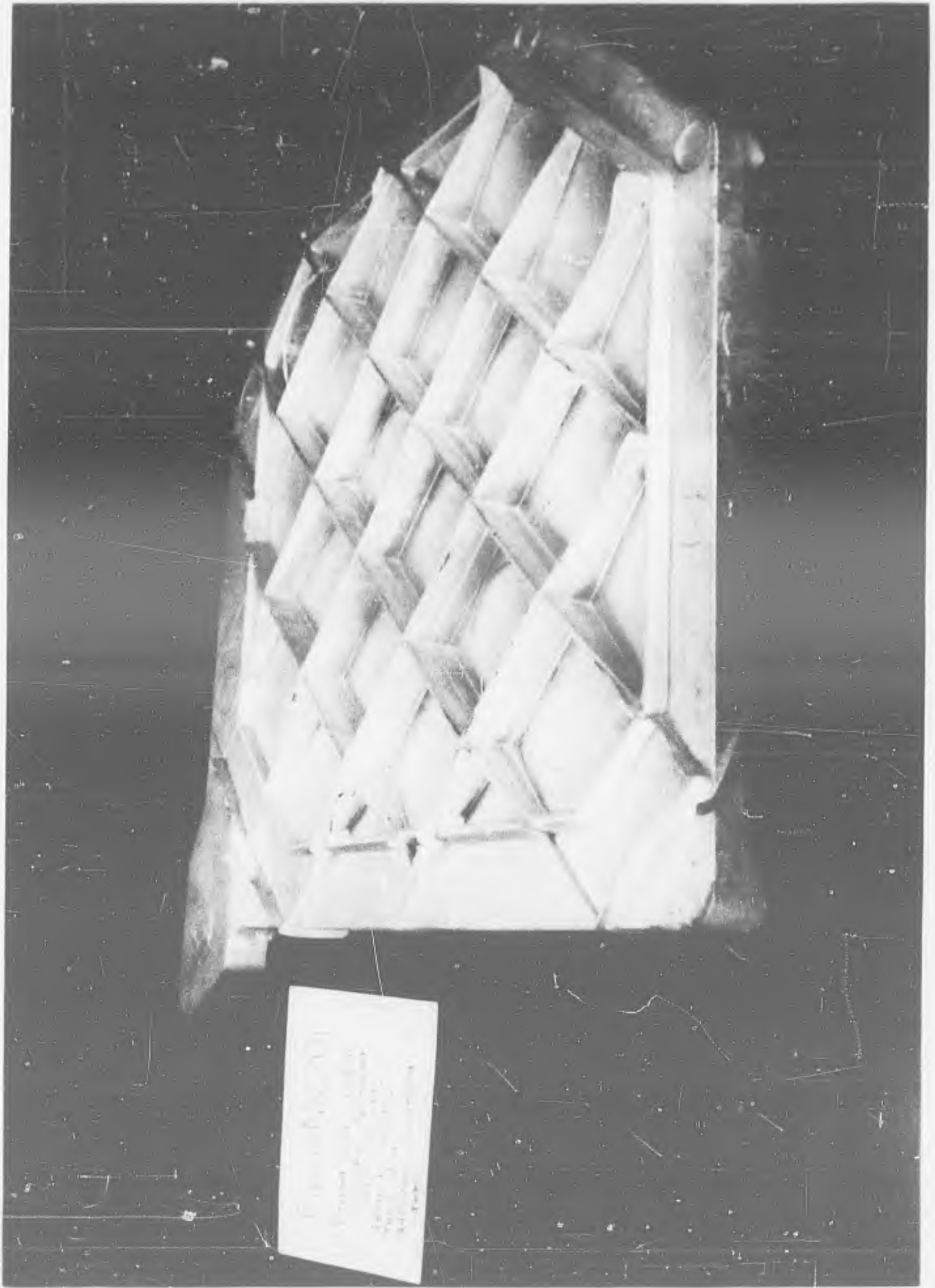


Figure 36

Part Number	Tonnage 100's	Dwell Sec's	Temperature °F		
			Stock Before	Stock After	Bottom Die
61	44	60	760	--	540
21	44	60	760	--	800
81	44	120	760	660	725
221	44	120	760	660	675
211	44	120	760	720	810
271	44	120	760	700	725
31	44	120	760	--	725
71	44	120	770	--	825
41	44	120	770	--	810
201	44	120	770	710	800*
102	44	120	770	690	830
6	44	120	770	660	730
231	44	120	770	670	710*
103	44	120	770	660	690
11	44	120	770	650	675
12	44	120	770	665	690
191	44	120	770	650	670
1	44	120	770	630	650
91	44	60	770	--	630*
	77	Inst.			
51	77	60	770	--	610*
101	77	60	770	--	670*

*These Temperatures Estimated.

Table VI. Data Sheet - Final Tryouts

FORGING CHARACTERISTICS, METALLURGICAL AND MECHANICAL PROPERTIES

Investigations into metallurgical and mechanical properties were conducted by both the Lockheed Aircraft Corporation (Appendix VI) and the Wyman-Gordon Company (Appendix VII). Photomicrographs in Appendix VI, Figures 2 through 8, show the grain flow in various sections of the panel. Tensile properties from representative sections of the forging are listed in Appendix VII, Tables I and II. Figures 9 and 10 of Appendix VI show variations in hardness before and after heat treatment by means of hardness traverses.

The Lockheed investigations showed:

1. A normal grain structure with no visible forging defects.
2. The material could be heat treated to the desired strength level.
3. Uniform hardness before and after heat treatment.

Wyman-Gordon Company Metallurgical tests (Appendix VII) confirmed the above mentioned Lockheed test results in addition to including a chemical analysis showing conformance with specification QQ-A-367c. The effect of grain structure on ultimate tensile strength was shown by comparing results of tensile specimens from the web crossed by ribs with specimens from the flange area. The specimens from the flange area averaged approximately 5000 psi higher in ultimate tensile strength than did the specimens crossed by ribs.

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APPENDIXES

APPENDIX I

STRESS ANALYSIS

OF

YC-130 TANK PYLON WAFFLE GRID SHEAR PANEL

REPORT NO. _____

DATED _____

LOCKHEED AIRCRAFT CORPORATION

BURBANK, CALIFORNIA



TITLE

STRESS ANALYSIS
OF
YC-130 TANK PYLON WAFFLE GRID SHEAR PANEL

SUBMITTED UNDER

AIR FORCE CONTRACT AF 33(600)-22372 -
DEVELOPMENT OF FORGING WAFFLE-TYPE
INTEGRALLY STIFFENED SKIN PANELS

MODEL YC-130 REFERENCE _____

PREPARED BY J. Perlmutter GROUP _____
J. Perlmutter

CHECKED BY L. C. Coombs APPROVED BY _____
L. C. Coombs

NO. PAGES _____ NO. PICTURES _____

NO. DRAWINGS _____

REVISIONS

DATE	REV. BY	PAGES AFFECTED	REMARKS
13 Nov 53	J.P.	all	Analysis revised per structural data contained in L.R. 9425.
			67

Prepared	J. PERLMUTTER	DATE	5-4-53	LOCKHEED AIRCRAFT CORP.	Page	1	TEMP.	FORM.	
Checked	Combs	DATE	5-5-53	TITLE	TANK PYLON				
Approved				WAFFLE GRID SHEAR PANEL				Model	YC-130
								Report No.	

INTRODUCTION

THIS ANALYSIS IS WRITTEN FOR THE PURPOSE OF SUBSTANTIATING THE USE OF A 45° WAFFLE GRID TYPE CONSTRUCTION SHEAR PANEL ON THE YC-130 TANK PYLON.

THE ANALYSIS IS BASED ON THE DESIGN PARAMETERS ESTABLISHED IN L.R. 9425, APPENDIX A, AND CONSISTS OF A CHECK ON THE GENERAL INSTABILITY OF THE PANEL, BUCKLING OF THE WEBS, COMPRESSION IN THE RIBS, AND CRITICAL ATTACHMENTS.

A DIAGRAM OF THE SHEAR PANEL WITH ALL THE REQUIRED DIMENSIONS IS SHOWN ON PAGE 2. THE PANEL IS MADE UP OF TWO INTERCHANGEABLE 75S-T6 DIE FORGINGS, WHICH INCLUDE THE REQUIRED CAP MATERIAL AS AN INTEGRAL PART OF THE FORGING.

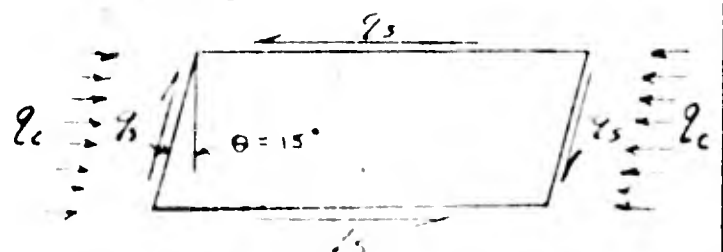
LOADS

THE CRITICAL LOADING CONDITION WHICH GIVES THE MAXIMUM SHEAR FLOW IN THE PANEL IS A SIDE DRIFT LANDING COND.

$$q_s = 2200 \text{ LB/IN. (ULT.)}$$

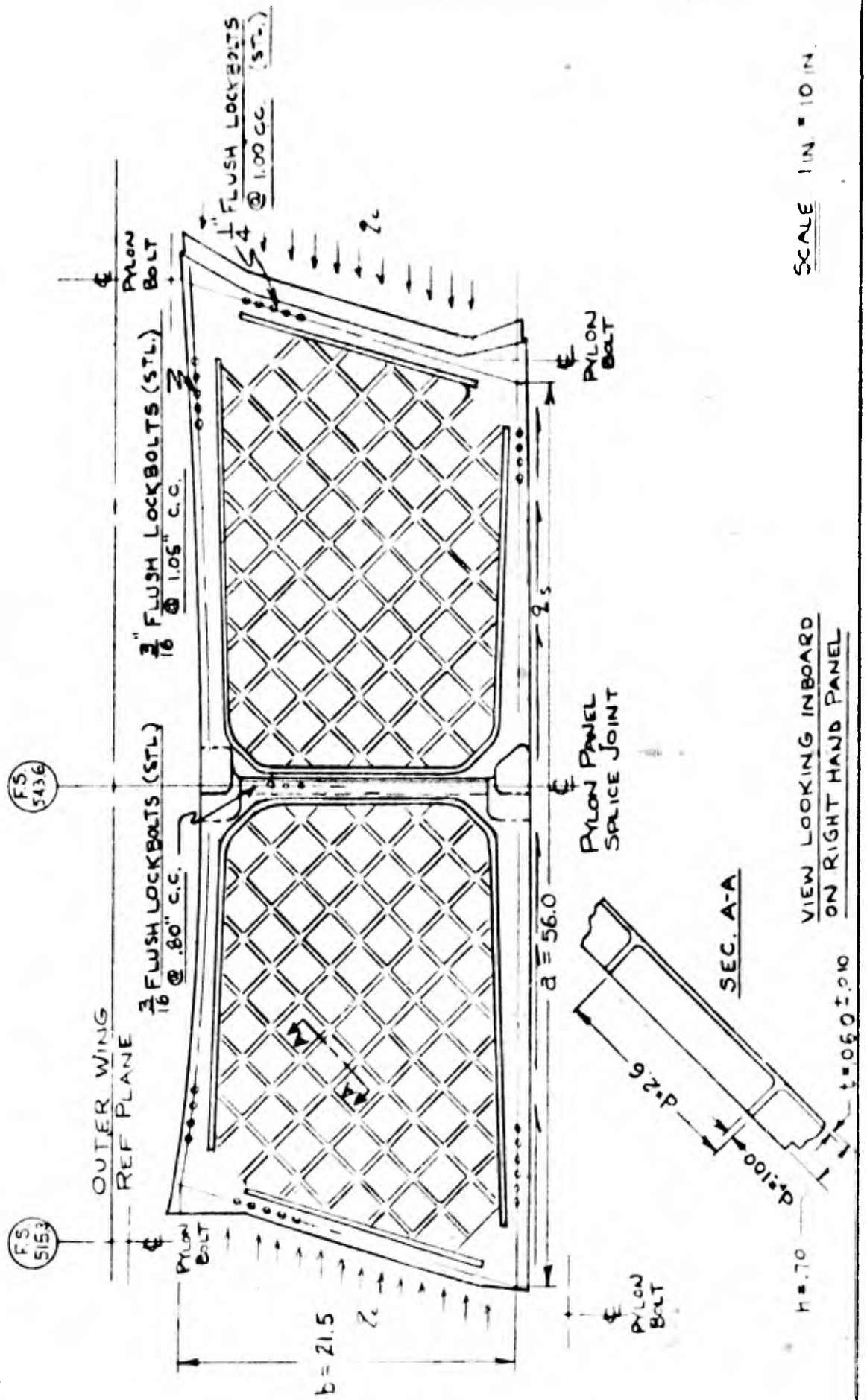
SINCE THE PANEL IS NOT RECTANGULAR IN SHAPE, A COMPRESSION LOAD (q_c) IS INTRODUCED. THE PANEL IS THEREFORE ANALYZED FOR COMBINED SHEAR AND COMPRESSION.

$$\begin{aligned} q_c &= q_s \sin \theta \\ &= 2200 \times 0.2598 \\ &= 570 \text{ LB/IN.} \end{aligned}$$



Prepared	J. PERLAUTER	DATE	4-29-53	LOCKHEED AIRCRAFT CORP.	Page	2	TEMP	FORM	
Checked	Coombs	5-5-53	TITLE		TANK PYLON	Model	YC-130		
Approved			WAFFLE GRID SHEAR PANEL		Report No.				

DIAGRAM OF SHEAR PANEL
 (REF. DWG. # 127590, 127589 & 127586)
 MAT: 755-T6 AL. AL. FORG.



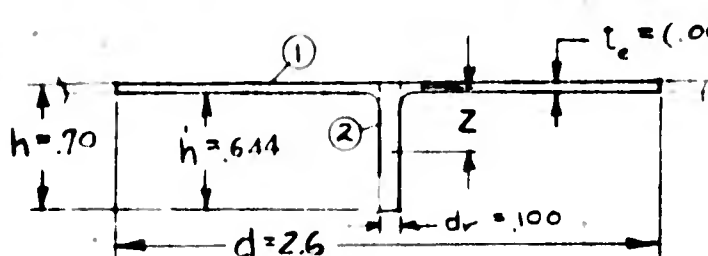
SCALE 1 IN. = 10 IN.

VIEW LOOKING INBOARD
ON RIGHT HAND PANEL

SEC. A-A

Prepared	J. PERLMUTTER	DATE 4-30-53	LOCKHEED AIRCRAFT CORP.	Page	TEMP. 3	PERM.
Checked	Combs	5-5-53	TITLE TANK PYLON	Model YC-130		
Approved			WAFFLE GRID SHEAR PANEL	Report No.		

MOMENT OF INERTIA PER UNIT OF PANEL



ASSUMED NOMINAL
THICKNESS
REF. SM 75

$$z = \frac{h - t_e}{2} = \frac{.70 - .0555}{2} = .322 \text{ IN.}$$

$$A_1 = (2.60 - .10) \cdot .0555 = .1388 \text{ IN.}^2$$

$$A_2 = .70 \times .10 = .070 \text{ IN.}^2$$

$$I_1 = \frac{A_1 t_e^3}{12} = \frac{.1388 \times .0555^3}{12} = .00004 \text{ IN.}^4$$

$$I_2 = \frac{A_2 h^3}{12} = \frac{.070 \times .70^3}{12} = .00286 \text{ IN.}^4$$

$$I_T = I_1 + I_2 + \frac{A_1 A_2}{A_1 + A_2} z^2 = .00004 + .00286 + \frac{.1388 \times .070}{.1388 + .070} \times .322^2 = .00772 \text{ IN.}^4$$

$$I_x = I_y = \frac{I_T}{d} = \frac{.00772}{2.6} = .00297 \text{ IN.}^4/\text{IN.} \text{ IN X AND Y DIRECTION.}$$

CRITICAL SHEAR FLOW BASED ON GENERAL INSTABILITY OF PANEL

$$\frac{b}{d} = \frac{21.5}{56.0} = .384$$

(REF. PG. 2)

$$D_3 = .62 EI_x$$

(REF. LR. 9425)

$$\text{FOR } \frac{D}{D_3} = 1.62, \quad K = 45.5 \text{ FOR INFINITE LONG PLATE}$$

(REF. LR. 9425)

$$\text{FOR ASPECT RATIO} = .384$$

$$K = \frac{5.40}{4.84} \times 45.5 = 51$$

(REF. SM. 33b)

$$q_{scr} = 51 \frac{EI_x}{b^2} = \frac{51 \times 10.5 \times 10^6 \times .00297}{21.5^2} = 3440 \text{ LB/IN.}$$

$$q_s = 2200 \text{ LB/IN.}$$

(REF. PG. 1)

$$R_s = \frac{q_s}{q_{scr}} = \frac{2200}{3440} = .640$$

Prepared	J. PARL MUTHAR	DATE	11-12-53	LOCKHEED AIRCRAFT CORP.	Page	4	TEMP.	PERM.
Checked	Combs	DATE	11-13-53	TITLE	TANK PYLON			
Approved				WAFFLE GRID SHEAR PANEL	Model	YC-130		
					Report No.			

CRITICAL COMPRESSION LOAD BASED ON GENERAL INSTABILITY OF PANEL

$$q_{ccr} = .75 \times 45.5 \frac{EI_x}{b^2} = \frac{34.1 \times 10.5 \times 10^6 \times .00297}{21.5^2} = 2300 \text{ LB/IN.}$$

$$q_c = 570 \text{ LB/IN.} \quad (\text{REF. PG. 1})$$

$$R_c = \frac{q_c}{q_{ccr}} = \frac{570}{2300} = .248$$

M.S. FOR COMBINED LOADING (GENERAL INSTABILITY)

$$M.S. = \frac{1}{.5R_c + \sqrt{(.5R_c)^2 + R_s^2}} - 1 = \frac{1}{.5 \times .248 + \sqrt{(.5 \times .248)^2 + .640^2}} - 1 = \underline{\underline{+.29 M.S.}}$$

INITIAL BUCKLING SHEAR STRESS IN WEB BETWEEN RIBS

$$\left. \begin{aligned} b' &= d - d_r = 2.6 - .10 = 2.50 \text{ IN.} \\ t_e &= .0555 \text{ IN.} \end{aligned} \right\} \quad (\text{REF. PG. 3})$$

$$\sqrt{K} = 2.91 \text{ FOR } b/a = 1.0 \quad (\text{REF. SM 33b})$$

$$\left(\frac{b}{t}\right)_e = \frac{b'}{t_e \sqrt{K}} = \frac{2.5}{.0555 \times 2.91} = 15.5$$

$$F_{0.7} = 66000 \text{ PSI ASSUME FOR 75 ST6 DIE FORGING}$$

$$K_2 = \sqrt{\frac{F_{0.7}}{E}} = \sqrt{\frac{66000}{10.5 \times 10^6}} = .0793$$

$$K_3 = K_2 \sqrt{61} = .0793 \times 7.82 = .062$$

$$n = 20$$

$$B = K_3 \left(\frac{b}{t}\right)_e = .062 \times 15.5 = .960$$

$$\frac{F}{F_{0.7}} = .84 \quad (\text{REF. SM 80a fig 1})$$

$$F_{scr} = .61 F_{0.7} \left(\frac{F}{F_{0.7}}\right) = .61 \times 66000 \times .84 = 33800 \text{ LB/IN}^2$$

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Approved					Model	YC-130		
					Report No.			

INITIAL BUCKLING COMP. STRESS IN WEB BETWEEN RIBS

$$\left. \begin{aligned} b &= 2.50 \text{ IN.} \\ t_w &= 0.555 \text{ IN.} \end{aligned} \right\} \text{ (REF. PG. 4)}$$

$$\sqrt{k} = 3.02 \text{ FOR } b/a = 1.0 \text{ (REF. SM. 33b)}$$

$$\left(\frac{b}{t_w}\right) = \frac{b}{t_w \sqrt{k}} = \frac{2.50}{0.555 \times 3.02} = 14.9$$

$$K_2 = .0793 \text{ (REF. PG. 4)}$$

$$n = 20$$

$$F_{0.7} = 66000 \text{ LB/IN}^2 \text{ (REF. PG. 4)}$$

$$B = K_2 \left(\frac{b}{t_w}\right) = .0793 \times 14.9 = 1.18$$

$$\frac{F}{F_{0.7}} = .71 \text{ (REF. SM 80a)}$$

$$F_{cr} = F_{0.7} \times \left(\frac{F}{F_{0.7}}\right) = 66000 \times .71 = 46900 \text{ LB/IN}^2$$

SHEAR STRESS APPLIED IN WEB

$$q_s = 2200 \text{ LB/IN. (REF. PG. 1)}$$

$$f_{sw} = \frac{q_s/t_w}{1 + \frac{h^2 d^2 E}{2 d t_w G}} = \frac{2200/0.555}{1 + \frac{644 \times 10 \times 10.5 \times 10^6}{2 \times 2.60 \times 0.555 \times 3.9 \times 10^4}} = 24800 \text{ LB/IN}^2$$

$$R_s = \frac{f_{sw}}{F_{cr}} = \frac{24800}{33800} = .735$$

COMPRESSION STRESS APPLIED IN WEB

$$q_c = 570 \text{ LB/IN. (REF. PG. 1)}$$

$$f_{cw} = \frac{q_c}{1.60 t_w} = \frac{570}{1.60 \times 0.555} = 6430 \text{ LB/IN}^2$$

$$R_c = \frac{f_{cw}}{F_{cr}} = \frac{6430}{46900} = .137$$

M.S. FOR COMBINED LOADING (BUCKLING IN WEB)

$$M.S. = \frac{1}{.5 R_c + \sqrt{(.5 R_c)^2 + K_s^2}} - 1 = \frac{1}{.5 \times .137 + \sqrt{(.5 \times .137)^2 + .735^2}} - 1 = \underline{\underline{+.24 \text{ M.S.}}}$$

Prepared	J. R. [unclear]	DATE	11-12-53	LOCKHEED AIRCRAFT CORP.	Page	6	TEMP.	FORM	
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Approved				WAFFLE GRID SHEAR PANEL				Model	YC-130
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ALLOWABLE CRIPPLING STRESS IN RIB (REF SM 80a)

$$F_{0.7} = 66000 \text{ LB/IN}^2 \quad (\text{REF FS 4})$$

$$K_2 = .0793$$

$$K_5 = K_2 / .0682 = .0793 / .0682 = 1.162$$

$$n = 20$$

$$b/t = h/d_r = 644/100 = 6.44$$

$$B = K_5 B_{2+5RT} = 1.162 \times .86 = 1.00 \quad (\text{REF SM 80a FIG 4})$$

$$F/F_{0.7} = 0.825 \quad (\text{REF SM 80a FIG 1})$$

$$F_{cc} = F_{0.7} (F/F_{0.7}) = 66000 \times .825 = 54500 \text{ LB/IN}^2$$

COMPRESSION STRESS IN RIBS DUE TO SHEAR LOAD

$$f_{cR} = [q_s - f_{ste}] \frac{d}{d_r h} = [2200 - 24800 \times .0555] \frac{26}{10 \times 644} = 33100 \text{ LB/IN}^2$$

COMPRESSION STRESS IN RIBS DUE TO COMP. LOAD.

$$f_{cR_2} = [q_c - f_{cste}] \frac{d}{d_r h \sqrt{2}} = [570 - 6430 \times .0555] \frac{26}{10 \times 644 \times 1.41} = 6100 \text{ LB/IN}^2$$

M.S. FOR COMBINED LOADING (CRIPPLING IN RIB)

$$M.S. = \frac{F_{cc}}{f_{cR_1} + f_{cR_2}} - 1 = \frac{54500}{33100 + 6100} - 1 = \underline{\underline{+.31 M.S.}}$$

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Checked	Combs	5-5-53	TITLE TANK PYLON	Model YC-130		
Approved			WAFFLE GRID SHEAR PANEL	Report No.		

ATTACHMENT OF PANEL TO AFT BEAM

1/4" FLUSH STL. LOCKBOLTS @ 1.00" C.C. CRITICAL IN BEARING ON .081 PANEL.

$$q = 2200 \text{ LB/IN.}$$

(REF. PG 1)

$$q_A = 2250 \text{ LB/IN.}$$

(REF. SM.73b)

$$\text{M.S. (BRG.)} = \frac{q_A}{q} - 1 = \frac{2250}{2200} - 1 =$$

+ .02 M.S.

ATTACHMENT OF PANEL TO UPPER RIB

3/16" FLUSH STL. LOCKBOLTS @ 1.05" C.C. CRITICAL IN SHEAR

$$q = 2200 \text{ LB/IN.}$$

(REF. PG. 1)

$$q_A = \frac{2690}{1.05} = 2530 \text{ LB/IN.}$$

(REF. SM.99a)

$$\text{M.S. (SHEAR)} = \frac{q_A}{q} - 1 = \frac{2530}{2200} - 1 =$$

+ .15 M.S.

SPLICE ATTACHMENT

3/16" FLUSH STL. LOCKBOLTS @ .80" C.C. CRITICAL IN BEARING ON .125 PANEL.

$$q = 2200 \text{ LB/IN.}$$

(REF. PG. 1)

$$q_A = \frac{2126}{.80} = 2660 \text{ LB/IN.}$$

(REF. SM73a)

$$\text{M.S. (BRG.)} = \frac{q_A}{q} - 1 = \frac{2660}{2200} - 1 =$$

+ .21 M.S.

APPENDIX II

WEIGHT ANALYSIS

OF

YC-130 TANK PYLON WAFFLE GRID SHEAR PANEL

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	J. A. Olds	5-5-53				
Checked	C. F. Saunders	5-5-53	TITLE	Model		
			TANK TOLON BOX BEAM STRUCTURE	Report No.		
Approved						

WEIGHT ANALYSIS

The weight analysis (Pg.) consists of comparing a built-up section with a two-piece waffle forging and a one-piece waffle forging. The two-piece waffle forging conforms with Contract No. AF 33(600)-22372, and the one-piece waffle forging proposal is based on the availability of a larger type press at a later date. The weight saving for the two-piece waffle is 2.8#/ airplane, and the saving for the one-piece waffle is 10.4#/ airplane.

A further weight reduction is possible pending outcome of structural tests.

<u>ITEM</u>	<u>BUILT-UP SECTION</u>	<u>TWO PIECE WAFFLE</u>	<u>ONE PIECE WAFFLE</u>
Skin	7.3	27.1	25.4
Stiffeners	4.4	Integral Stiffeners	Integral Stiffeners
Caps	12.6		
Doublers	3.0		
Bolts & Nuts	.7	.2	-
Totals	28.0	27.3	25.4

APPENDIX III

LOCKHEED REPORT 9425

SHEAR TESTS OF WAFFLE-GRID PANELS

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CHECKED			TITLE SHEAR TESTS OF WAFFLE-GRID PANELS	MODEL General
APPROVED				REPORT NO. 9425

ABSTRACT

Two waffle grid panels, similar except for rib height, were tested as shear webs, measurements being made of strain, deflection, and buckling under load. The test results were compared with analytical predictions to determine the applicability of the method of analysis of this type of structure outlined in the appendix. Excellent agreement was obtained.

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INTRODUCTION

Studies made by NACA and tests conducted by Lockheed Aircraft Corporation indicate that panels stiffened by an integral waffle grid can be used very efficiently as compression and shear panels. With the initiation of the Air Force heavy forging press program this type of structure becomes feasible.

To study the design criteria for waffle grid panels, a panel similar to the side panels on the YC-130 pylon tank was selected for investigation.

OBJECT

1. To provide experimental information on the critical buckling stress and stress distribution of waffle-grid type panels loaded as shear webs.
2. To compare the test results with the analytical data obtained from the analysis described in the appendixes.

CONCLUSIONS

1. The critical shear flows for the panels tested are given in Table 1, page 6.
2. The distribution of stress between the ribs and web is given in the curves, Figs. 9 through 14, pages 15 through 20.
3. Excellent correlations were found between
 - (a) Measured and calculated (per Appendix A) critical shear flows for the tested panels.
 - (b) Measured and calculated (per Appendix C) stress distribution between ribs and webs of the tested panels.

TEST SPECIMENS

Two waffle grid panels were machined from 75S-T6 plate in accordance with the drawings shown in Figs. 1 and 2, pages 7 and 8. The two panels differed principally in the height of the ribs (and hence in moments of inertia).

Panel Number	Rib Height (inches)	Skin Thickness (inches)	I _x (per inch)	I _y (per inch)
1	.48	.060	.00132 in ³	.00132 in ³
2	.34	.060	.000536 in ³	.000536 in ³

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Panel No. 1 had a machining flaw which was corrected by cementing doublers to both sides of the damaged rib (see Fig. 17, page 23).

The edges of Panel No. 2 were modified slightly to facilitate machining.

Neither of these differences was believed to influence the behavior of the panels.

TEST EQUIPMENT

Fig. 3, page 9, is a drawing of the shear jig used for testing both panels. The salient features of the jig are:

1. All four corners are pin jointed with the centers of the pins in line with the attachment bolts.
2. Knife edge contact between the jig members and the panel to provide simple support of the panel.
3. Tapered loading bars to provide approximately equal straining between attachment bolts. (It was considered impractical to use a 42 to 1 taper on the long members as would be necessary to insure equal straining between attachments.)

The jig was mounted in the laboratory's 400,000 pound Southwark-Emery test machine so as to apply tensile loads on diagonally opposite corners of the jig (see Fig. 15, page 21).

INSTRUMENTATION

Four ARI rosette-type (45° diagonal) electric strain gages were used on each panel. These were located back to back on the skin along the centerline at the positions shown in Fig. 15, page 21. The diagonal gage on each rosette was placed parallel to the long side of the panel. (Thus, the two major legs of each gage were spotted nearly parallel to the principal stresses.)

In addition, eight A-11 linear electric strain gages were placed back to back along the ribs as shown in Fig. 16, page 22. Two pairs of these gages were attached to ribs tested in compression; the other two pairs were affixed to tension ribs.

From these gages the maximum shear stress in the web and the tensile and compressive stresses in the ribs were determined at two typical areas on the panels sufficiently remote from the edges of the panel to avoid edge effects.

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Dial gages were located as shown in Figs. 15 and 16, pages 21 and 22, to measure the depth of buckles. Two other dial gages were arranged to measure the lateral movement of one long side of the jig with respect to the other (see Figs. 15 and 16).

TEST PROCEDURE

Each panel was loaded in small increments of the calculated critical shear flow. At each load, strain data were recorded by the electric strain gages and dial gages were read. At several points the load was reduced to zero to check for and measure permanent set in the panels.

During the loading, running plots of (1) jig strain vs. gross load, (2) rib compressive strains (as recorded by the electric gages) vs. gross load, and (3) deflections normal to the surface of the panel (as observed from dial gages located as shown in Figs. 4 and 5, pages 10 and 11, vs. gross load were made and continually checked for signs of initial buckling. In addition, the reflections of various straight objects (ring stand rod, edge of test machine pillar, fluorescent light, etc.) from the flat skins of the panels were watched for distortions that would indicate initial buckling.

Both panels were loaded to failure.

Fig. 15 shows panel No. 1 in the test machine before testing. Fig. 16 shows panels 1 and 2 after bucklings while still in the test machine. Figs. 17, 18, and 19, pages 23, 24, and 25, show the failed panels after dismounting from the jig.

TEST RESULTS

Initial Buckling: The critical shear flow for each panel was of primary interest. Table 1, page 6, gives the measured and calculated critical shear flow for each panel.

The calculated critical shear flow for each panel was computed by the method described in Appendix A of this report.

The measured critical shear flow was determined in each of the following ways:

- (1) Direct Visual Observations: For panel No. 1 this method produced good, definite results because the panel buckled suddenly. For panel No. 2, however, the observed critical shear

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flow is probably a little high. As the plot of panel deflections vs. load (Fig. 5, page 11) shows, the panel deformed gradually starting with the application of the first load increment. Thus, the first visual signs of buckling were obscured by the gradual deformation of the panel and it is probable that additional load increments were applied to the panel before the buckling was detected.

- (2) Abrupt Change in Slope of Panel Deflection Vs. Shear Flow Curve: Fig. 4, page 10, consists of three such curves for panel No. 1. At least one of these curves changes slope with sufficient abruptness to provide a reasonably sensitive indication of the critical shear flow. Similar curves (Fig. 5, page 11) for panel No. 2 change slope too, gradually, to provide a satisfactory indication of initial buckling.
- (3) Zero-Slope Tangent to Load Vs. Compressive Strain Curve: Back-to-back strain gages mounted on a panel to read compressive strains indicate increasing compressive strains for increasing loads up to the critical load at which initial buckling occurs. One gage then begins reporting smaller strains. Eventually it reports tensile strains. This reversal is due to bending caused by buckling putting one side of the panel in tension. Ref. (1) states that initial buckling occurs at the point where compressive strain begins to fall off with increasing load. That is, if strain is plotted vs. shear flow, initial buckling occurs where the slope of the curve is zero. Fig. 6, page 12, is such a plot for two sets of strain gages located at different places on the skin of panel No. 2. The zero-slope tangents to these curves indicate the critical shear flows were 1100 and 1230 lbs. per inch, respectively.

Fig. 7, page 13, is a similar plot for a strain gage located on one of the ribs which was in compression. The zero-slope tangent indicates the critical shear flow was 1070 lbs. per inch.

Since both panels were specifically designed to fail by general instability, these critical shear flows are not merely local deformations.

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The zero-slope tangent method of detecting initial buckling was applied to panel No. 1, as shown in Fig. 8, page 14. Since the first buckle virtually destroyed the panel, it was impossible to get strain data for loads above those that produced initial buckling. The method, nonetheless, appears applicable. It predicts critical shear flow of 2500 lbs. per inch.

Stress Distribution: Figs. 9 and 10, pages 15 and 16, are plots of web shear stresses (as measured by the rosette gages) vs. shear flow applied to the section of the panel where the gages were located.

Figs. 11, 12, 13 and 14, pages 17, 18, 19 and 20, are similar plots of the rib tensile and compressive strains (as measured by electric strain gages) vs. shear flow applied to the section of the panel where the gages were located.

Included on these plots are calculated curves based on the stress distribution equations developed in the Appendix C. Reasonably good correlation was found between calculated and measured stress distributions.

WITNESSES

The tests described in this report were witnessed by the following representatives of Lockheed Aircraft Corporation: F.C. Piper, J.I. Perlmutter, E.B. Read, A.F. Ensrud.

REFERENCES

1. Lundquest, E.E., and Schuette, E.H., "Critical Stresses for Plates," page 8, NACA Advance Restricted Report No. 3J27, October, 1943.

Test Request: AAF Contract 33(600)-22372 for the development of waffle type integrally stiffened panels.

Data Presented:

I.N. 138501	by T.J. Stapleton, M.W. Mueller,	7-10-53
138502	by T.J. Stapleton,	7-10-53
138503	by T.J. Stapleton, M.W. Mueller,	7-21-53
138504	by T.J. Stapleton, M.W. Mueller,	7-21-53
138514	by M.W. Mueller,	8-19-53
138515	by M.W. Mueller,	8-19-53
138516	by M.W. Mueller,	8-19-53
138517	by M.W. Mueller,	8-19-53

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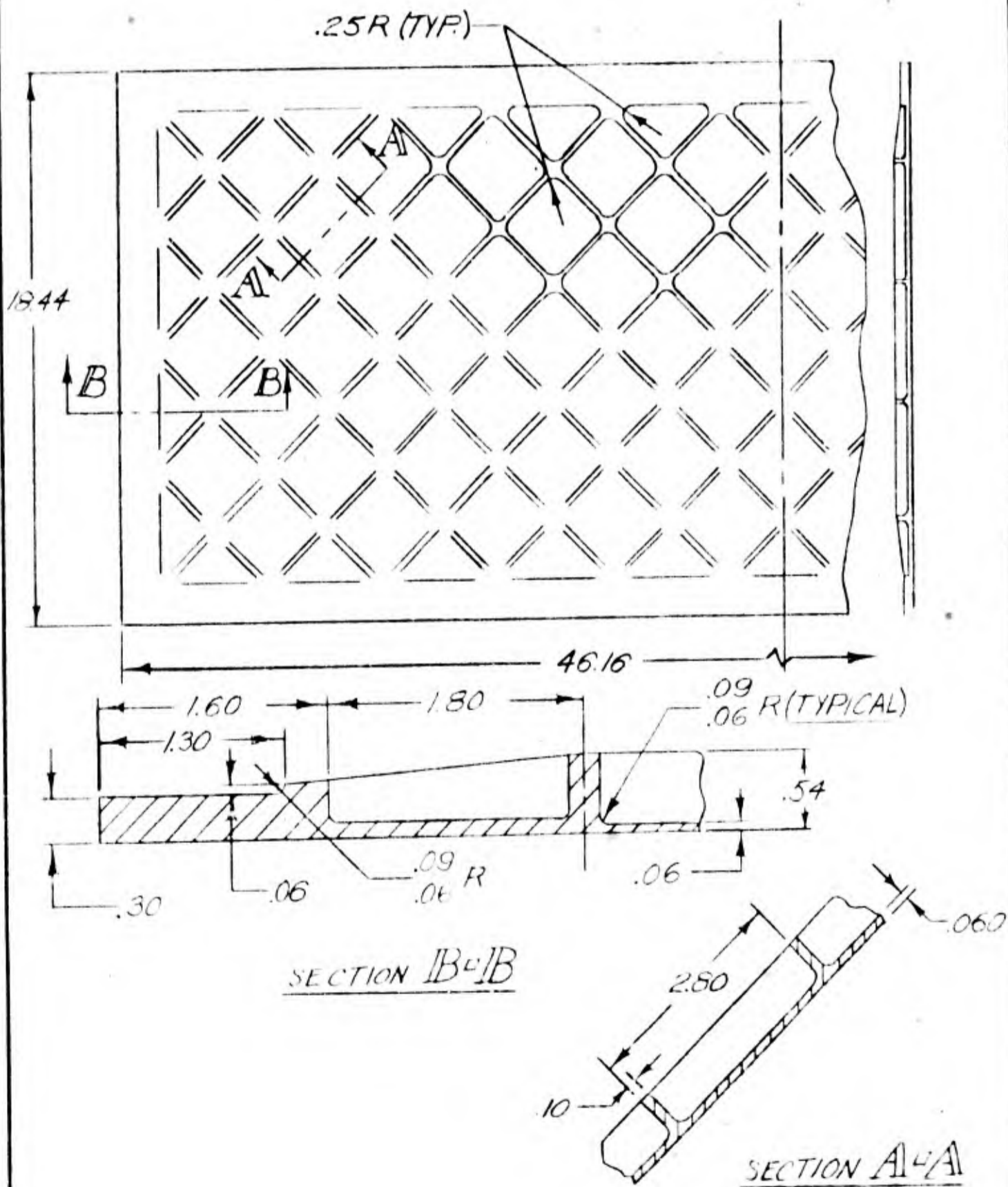
TABLE 1

SUMMARY OF DATA ON CRITICAL SHEAR FLOW

	Panel No. 1 q _{cr} (lbs/inch)	Panel No. 2 q _{cr} (lbs/inch)
<u>Calculated (See Appendix B)</u>	2460	1085
<u>Zero-Slope Tangent Method</u>		
(a) Web Gages		
(1) Top of panel	2500	1100
(2) Bottom of panel	--	1230
(b) Rib Gages	--	1090
<u>Direct Observation Method</u>	2525	--
<u>Panel Deflection Method</u>	2440	--

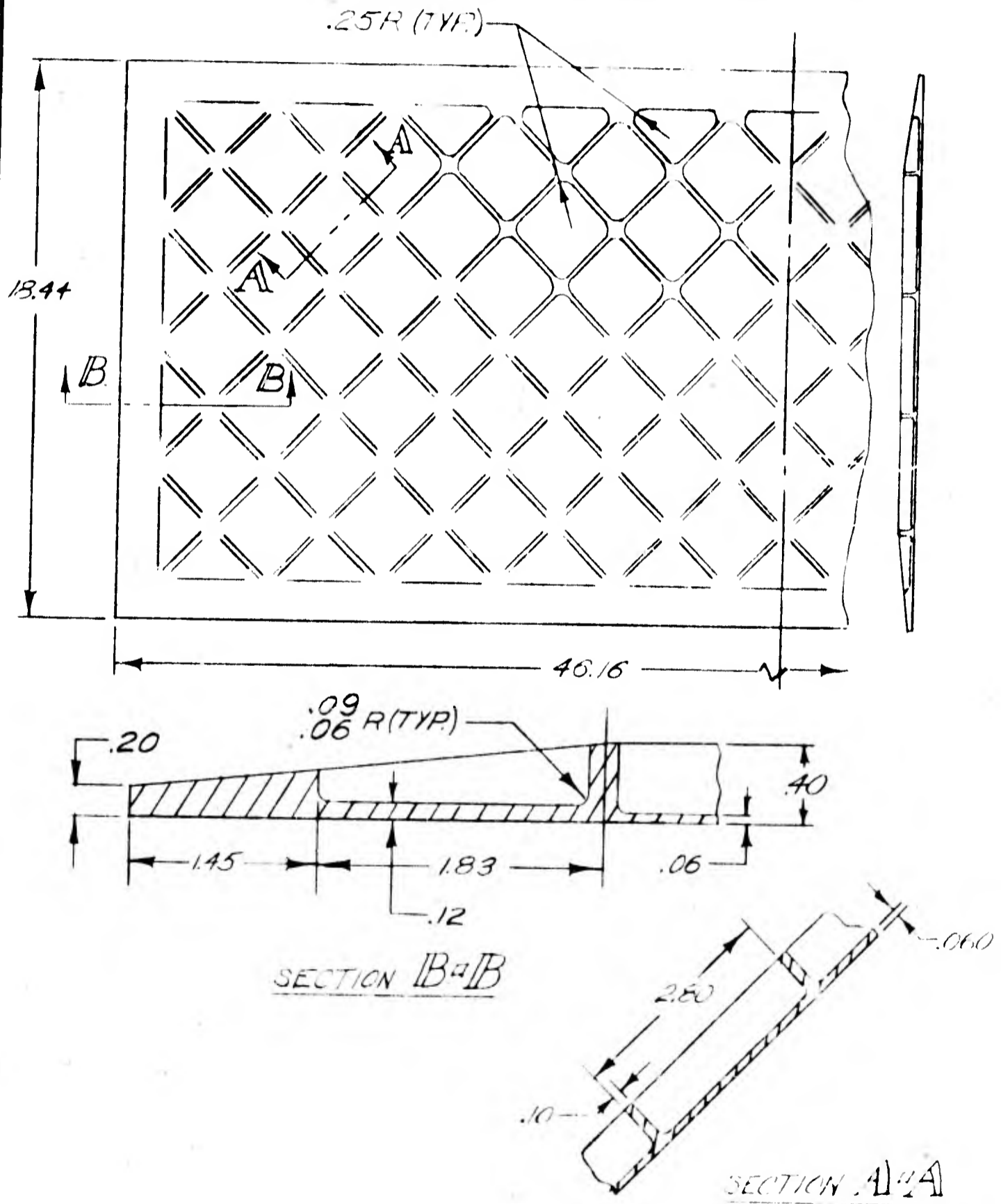
PREPARED	NAME	DATE	LOCKHEED AIRCRAFT CORP.	PAGE 7
CHECKED	M. W. MILLER		TITLE	DESIGN PARAMETERS OF A WAFFLE GRID SHEAR PANEL -
APPROVED			MODEL YC-130 PYLON TANK SIDE PANELS	REPORT NO 9425

Fig. 1
Details of Proposed Test Panel No. 1

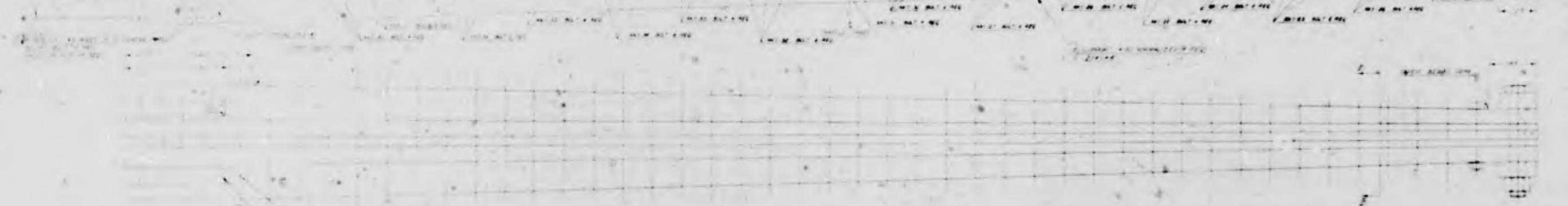
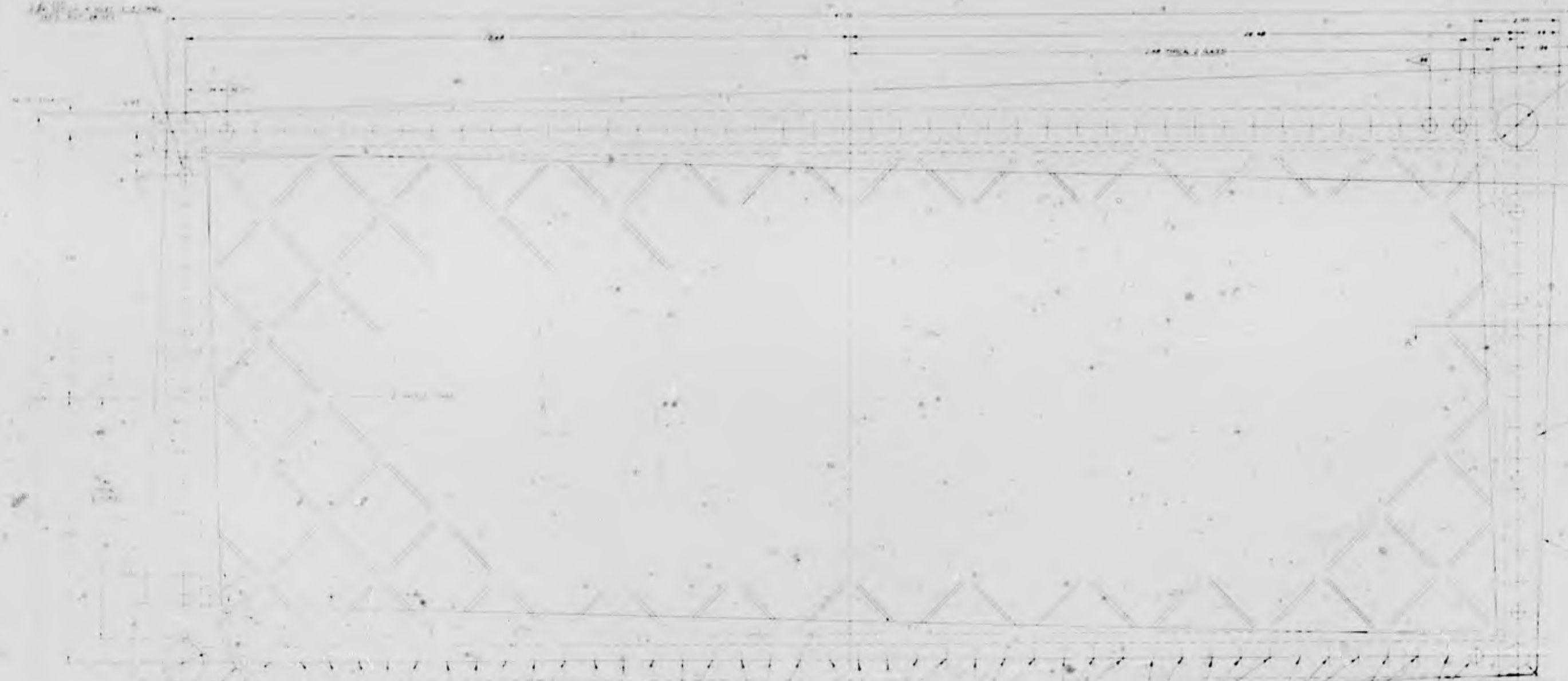
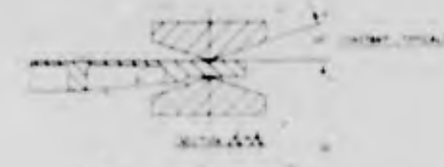


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Fig. 2 - Details of Proposed Test Panel No. 2



1





2

Fig. 3
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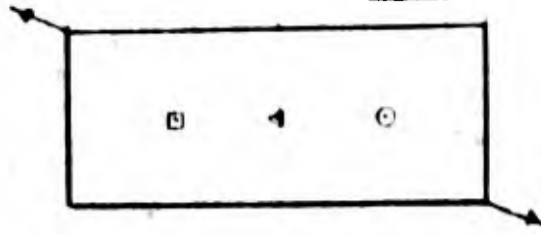
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PREPARED BY M. Mueller
 DATE 7-10-53
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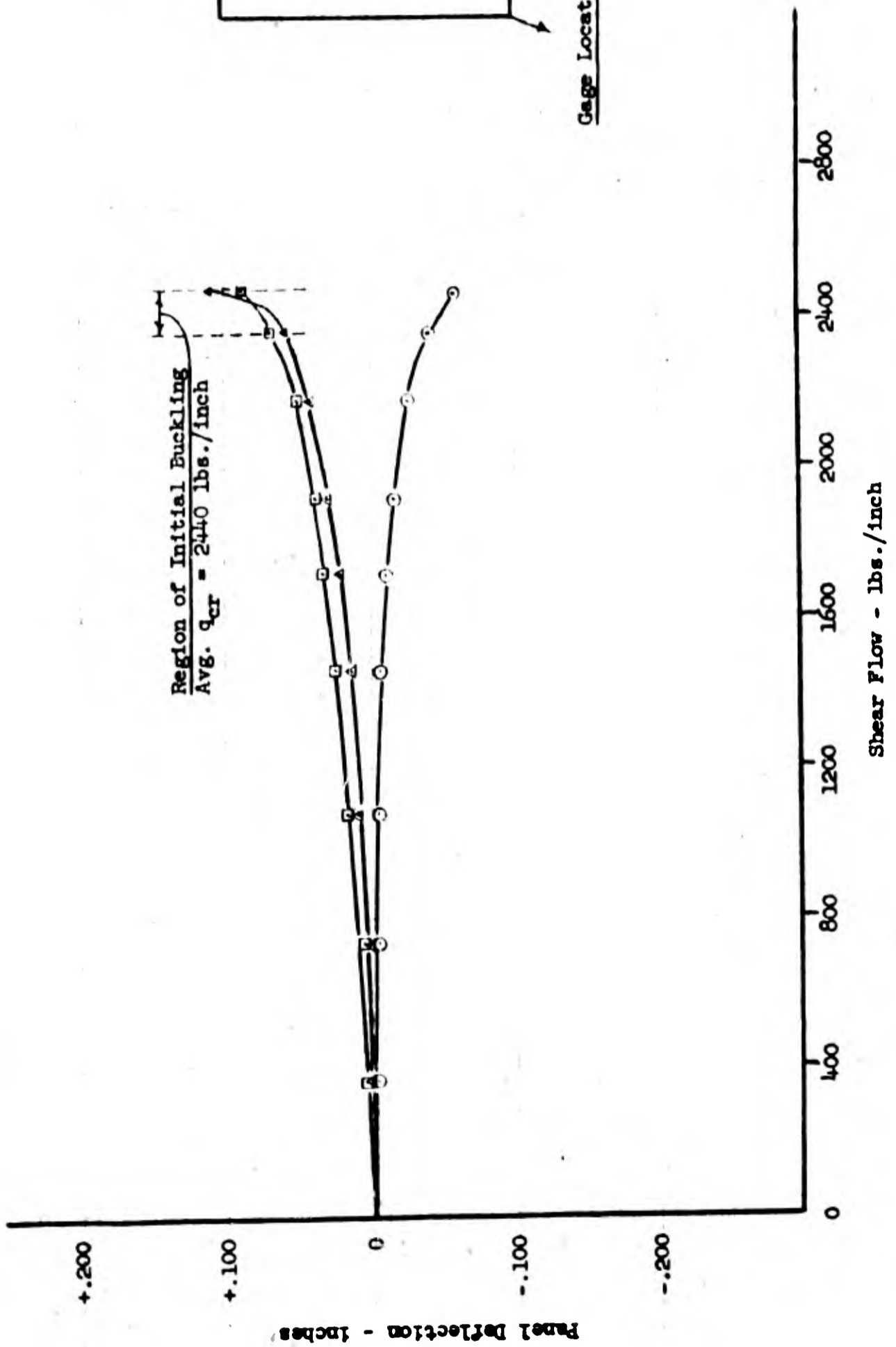
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Fig. 4



Gage Locations

Panel No. 1



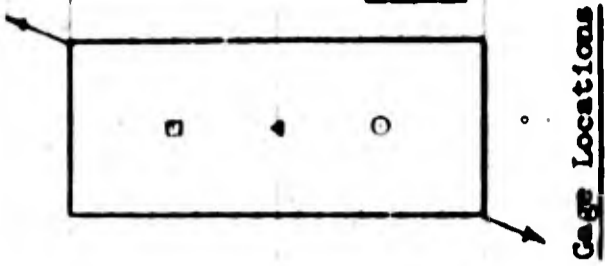
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Fig. 5

Panel No. 2



FORM 5278 B

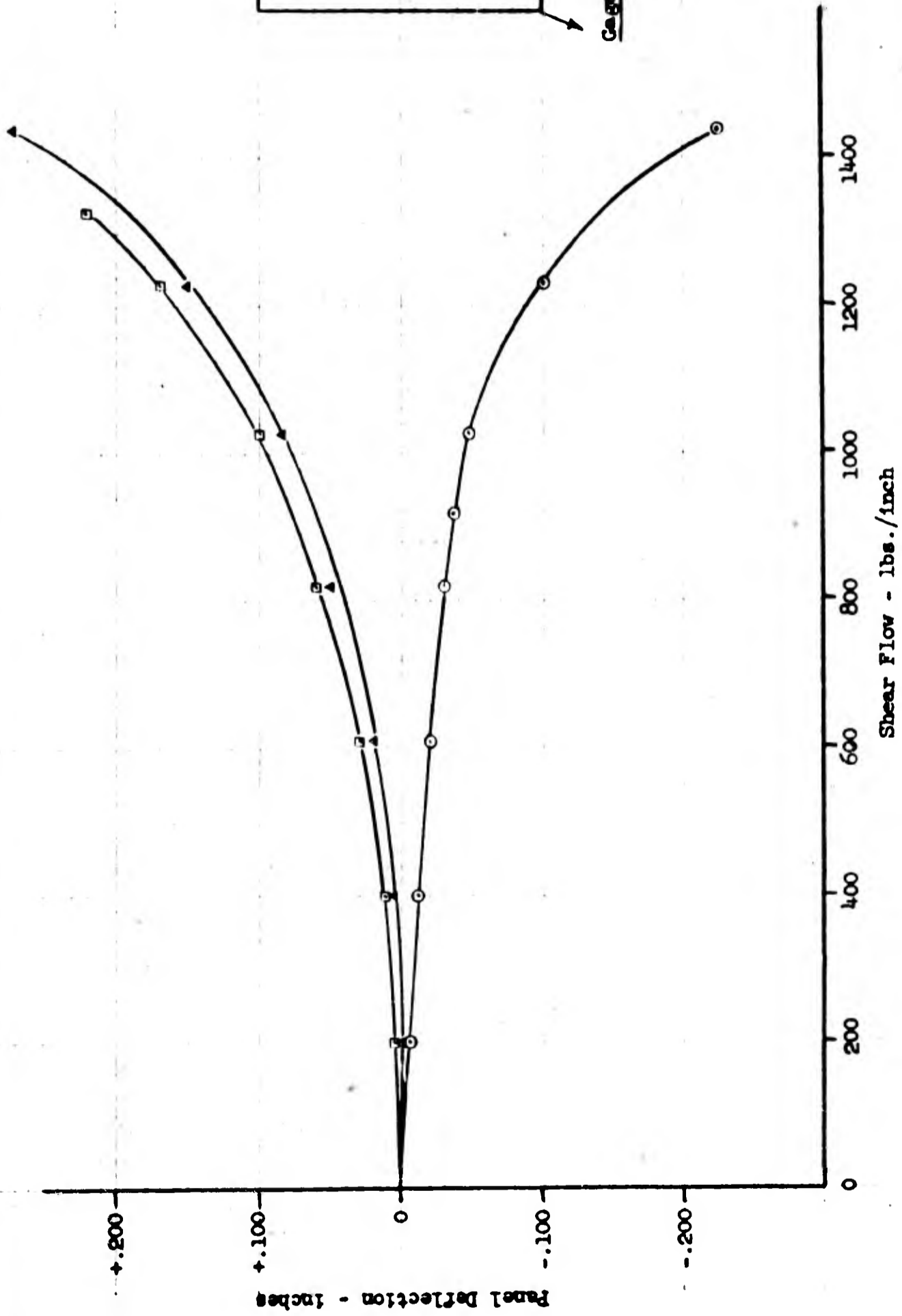


Fig. 6

Panel No. 2

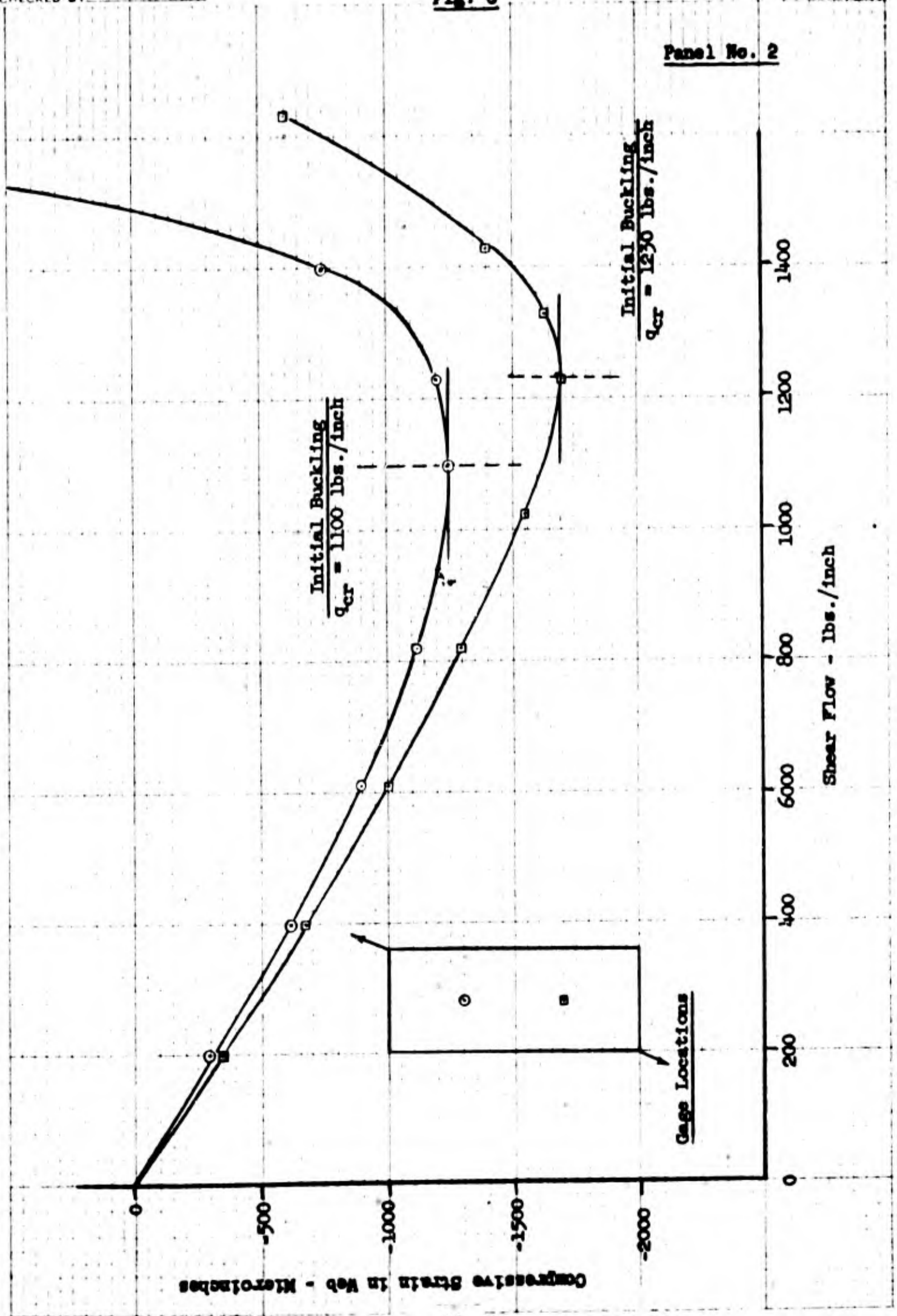
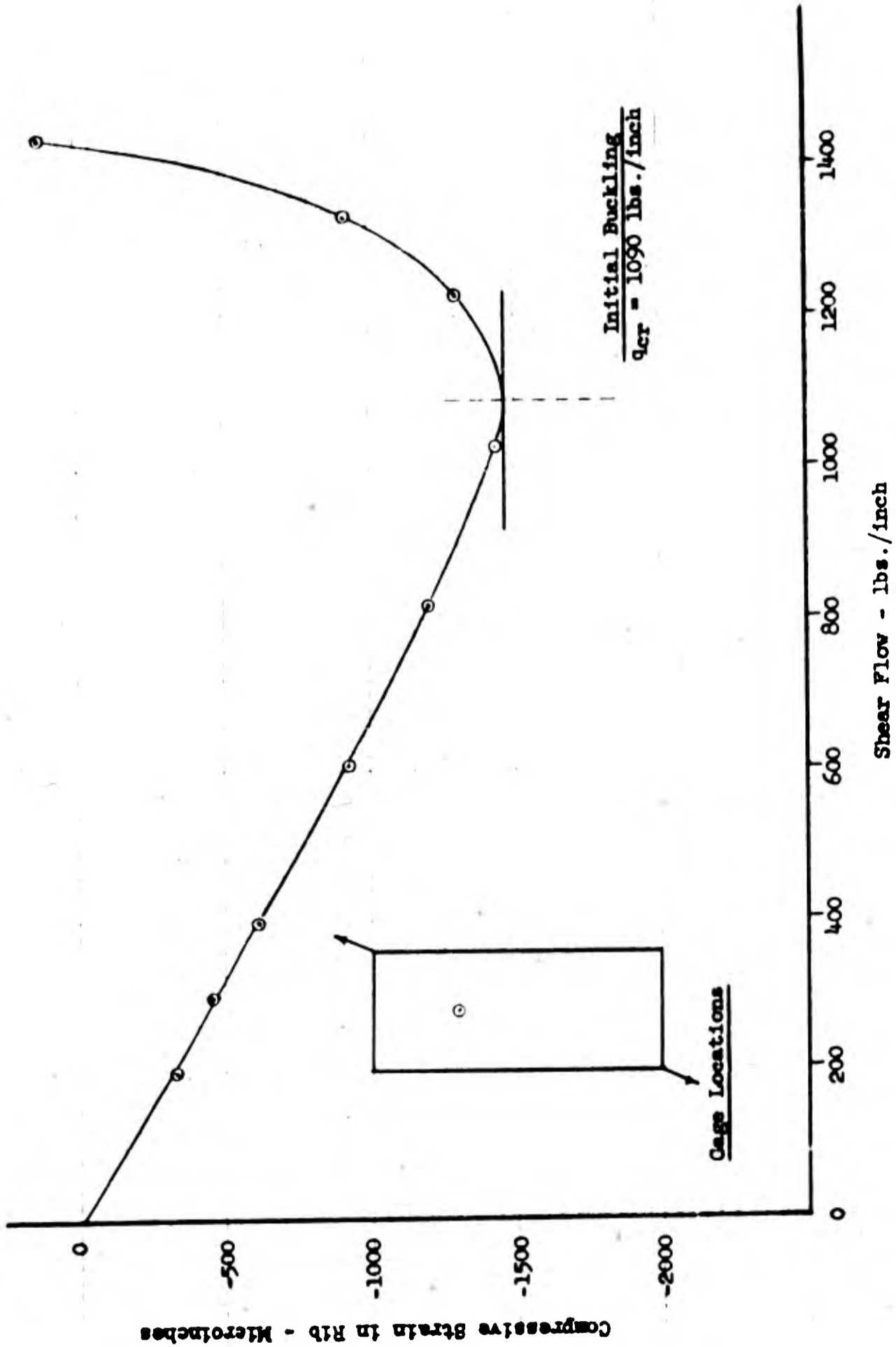


Fig. 7

Panel No. 2

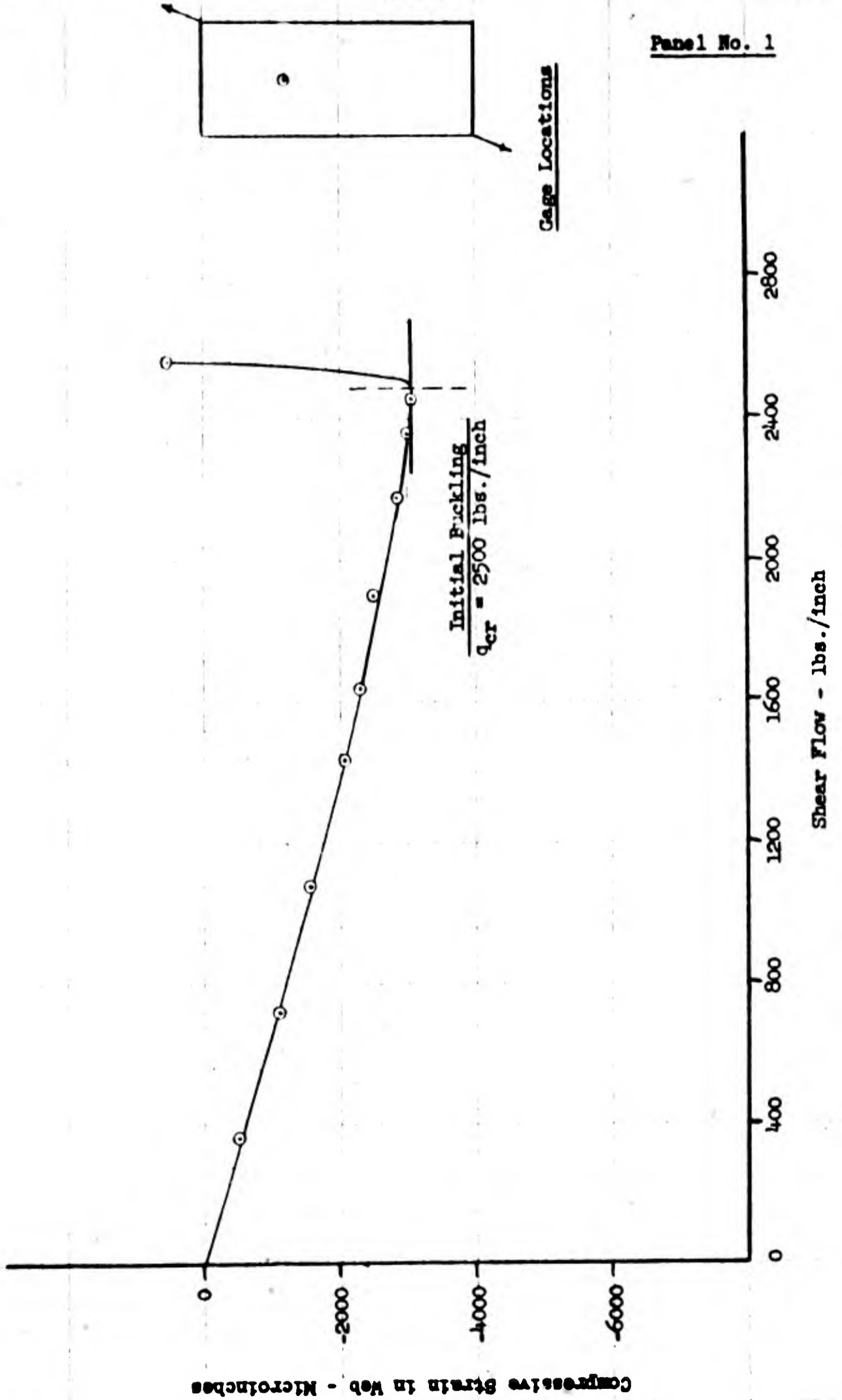


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Fig. 8

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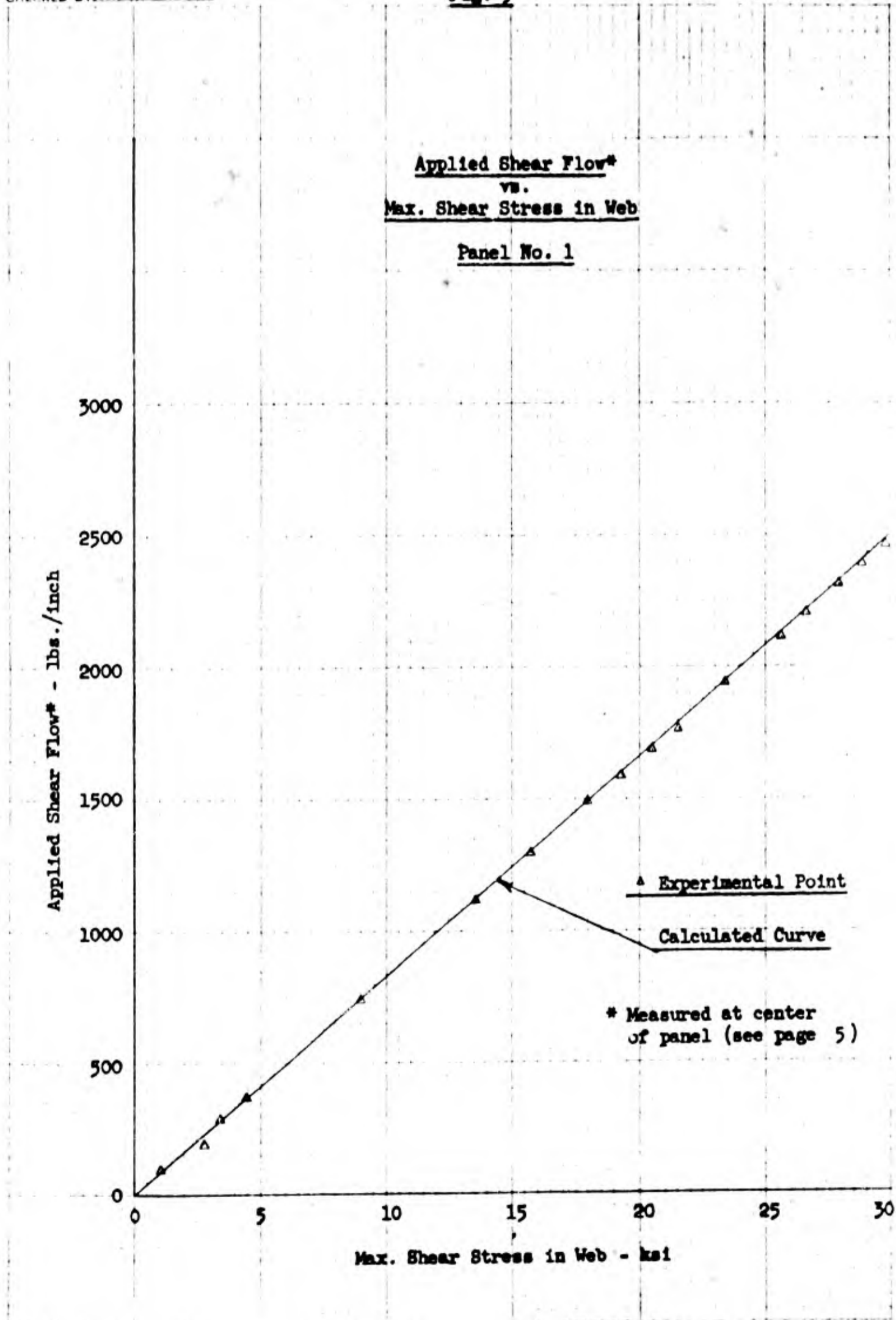
Panel No. 1



FORM 5278 B

Fig. 9

Applied Shear Flow*
vs.
Max. Shear Stress in Web
Panel No. 1



* Measured at center of panel (see page 5)

FORM 3278 B

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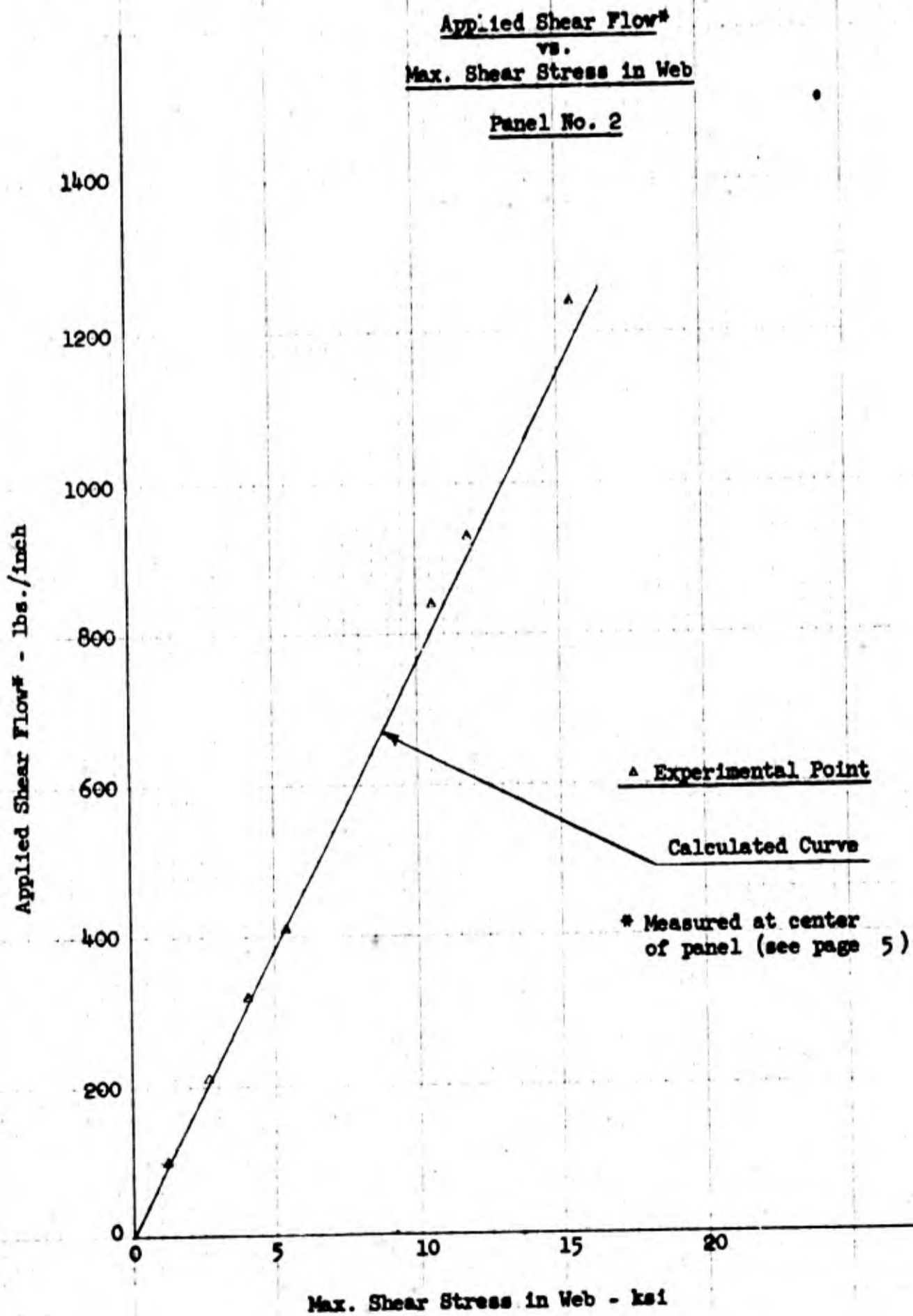
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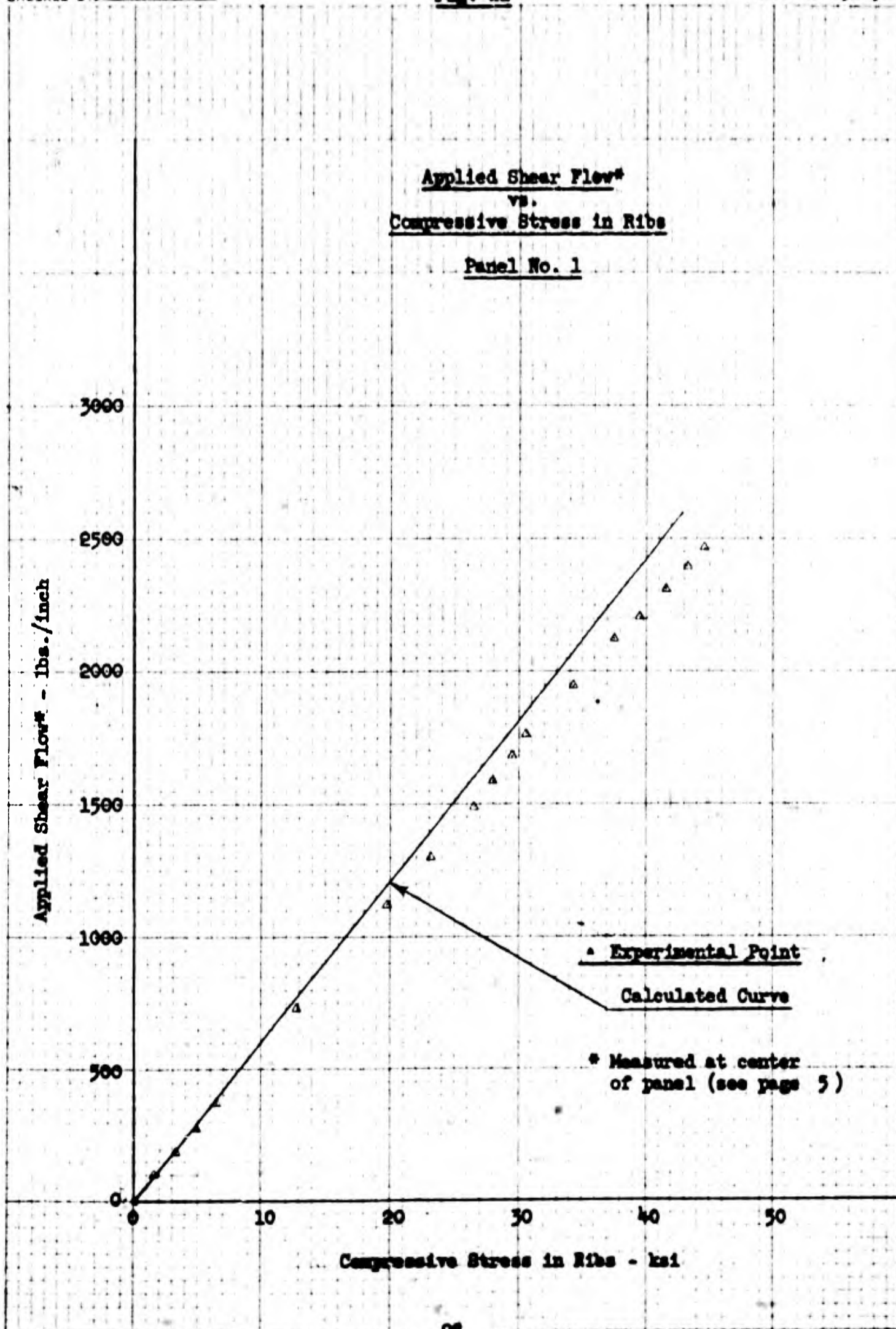
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FORM 5278 B

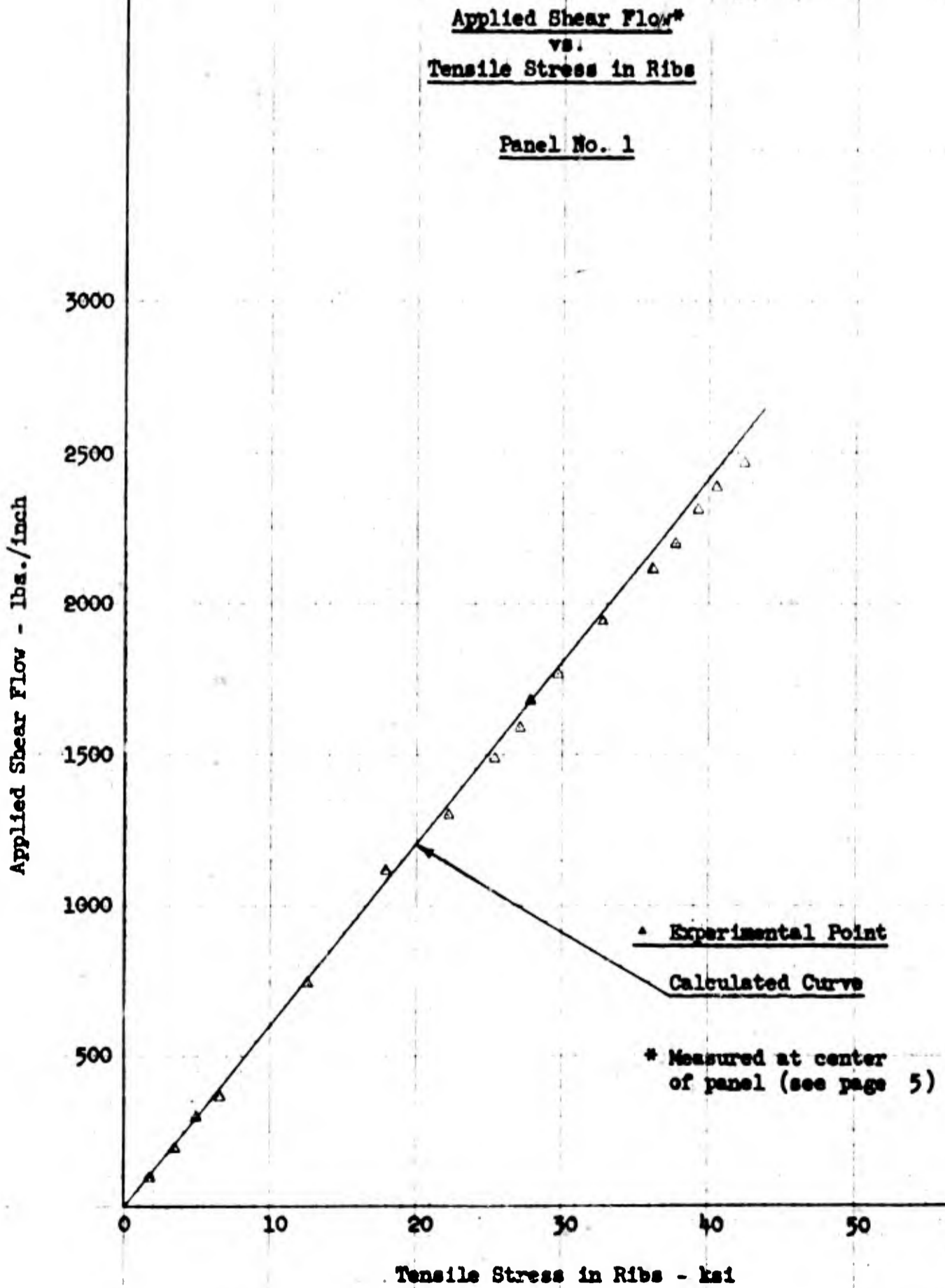
Fig. 11

Applied Shear Flow*
vs.
Compressive Stress in Ribs

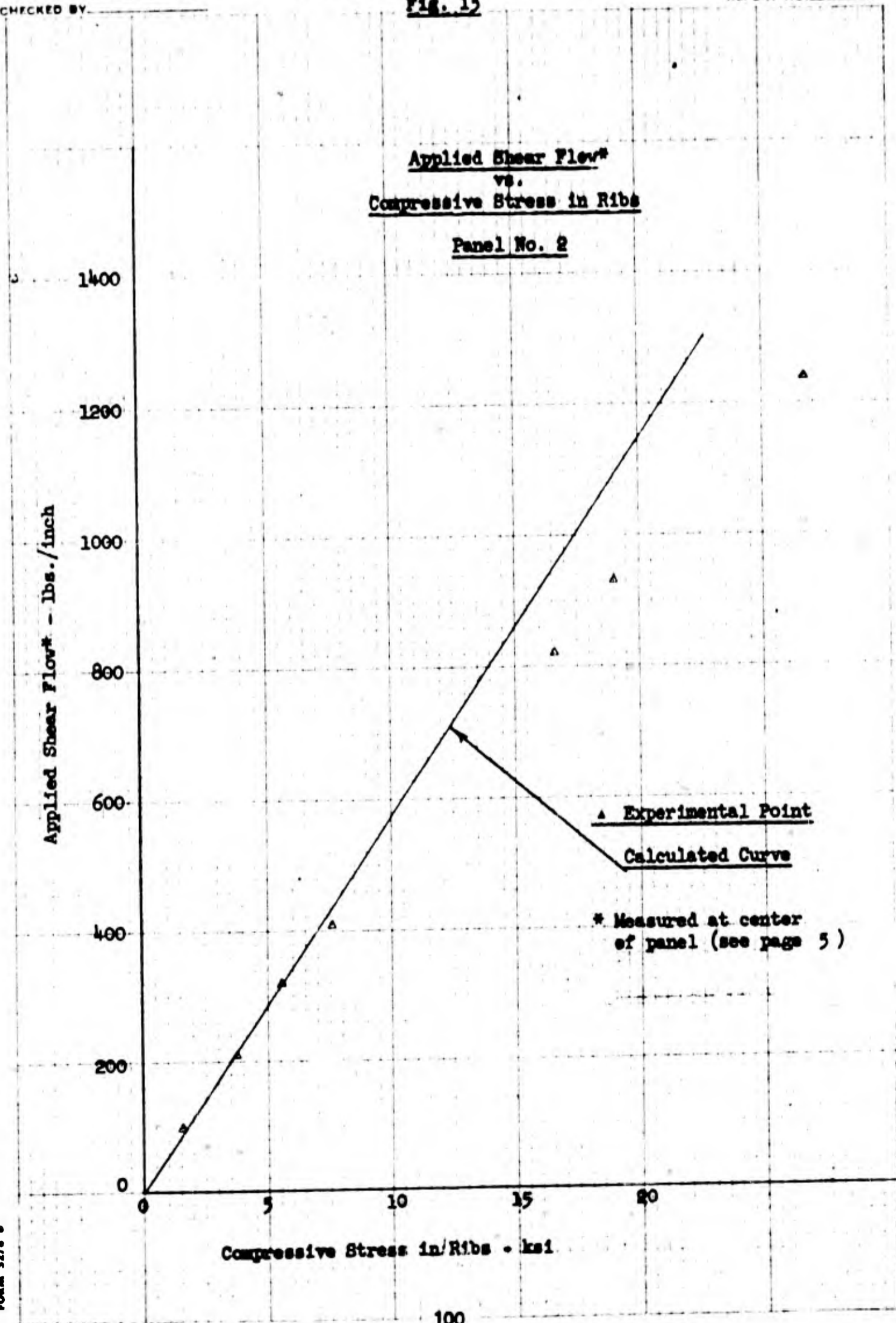
Panel No. 1

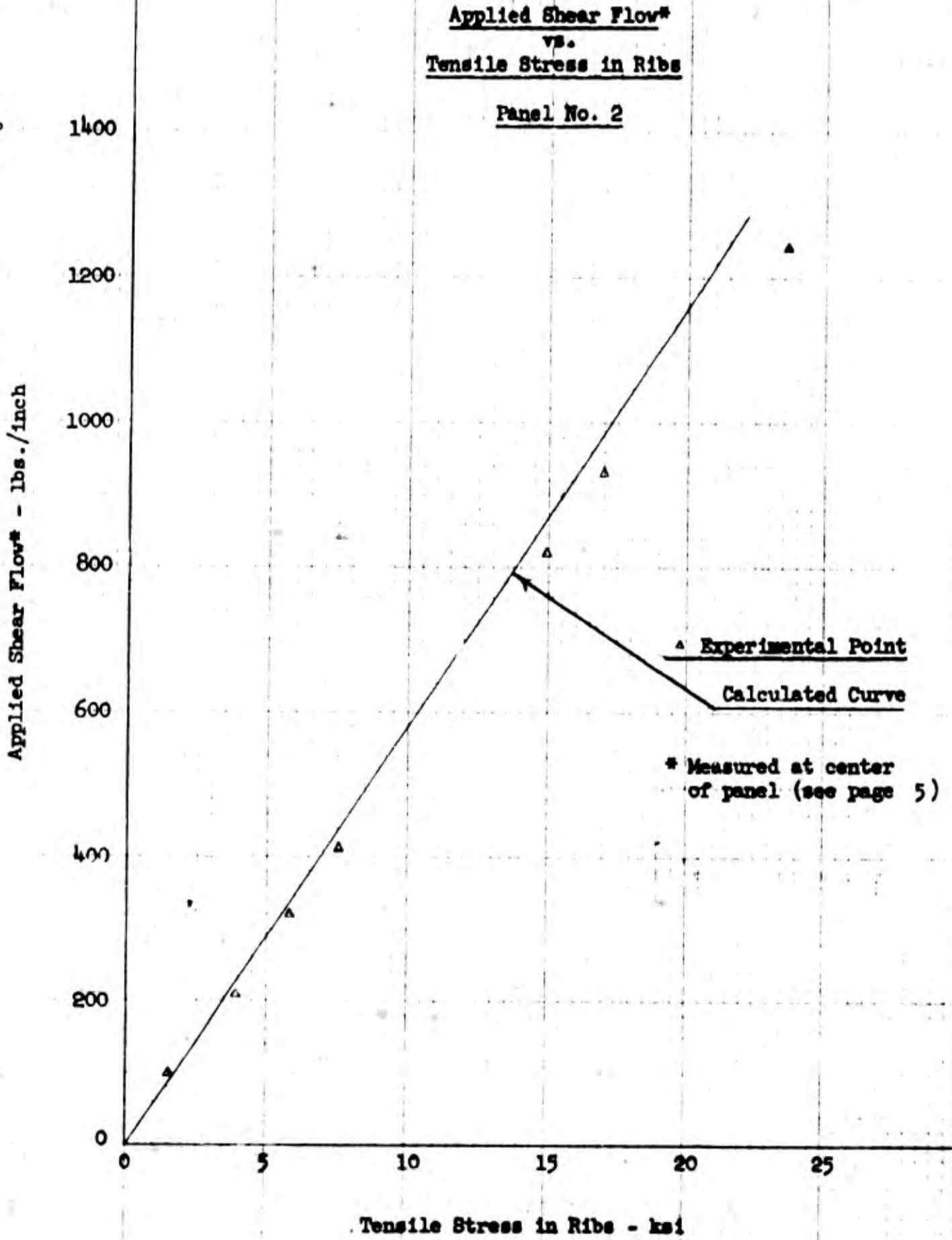


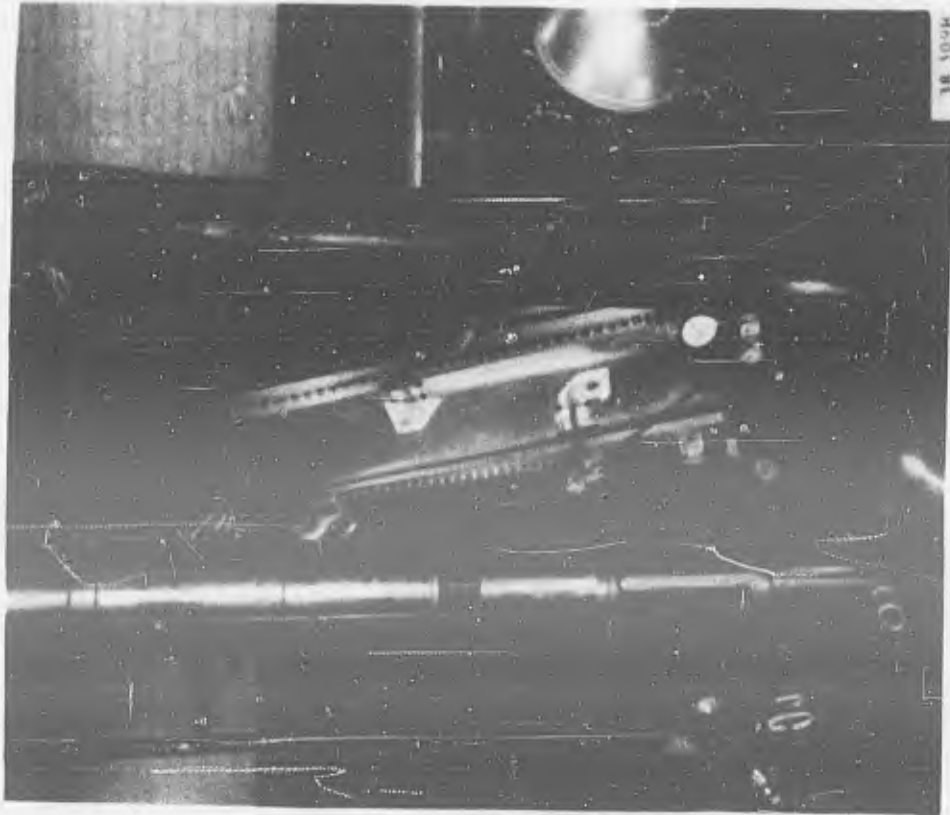
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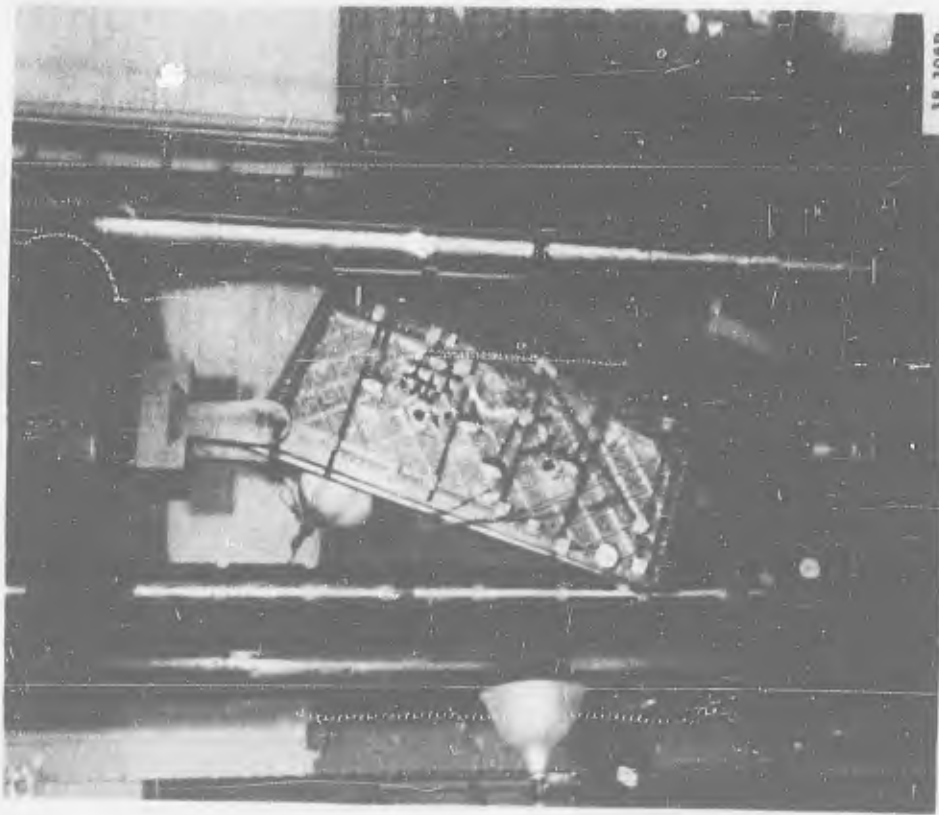
Applied Shear Flow*
vs.
Compressive Stress in Ribs
Panel No. 2







38 309K



38 308R

Fig. 15 - Front and back views of panel No. 1 in 400,000-lb. test machine ready for loading. Note back-to-back location of rosette-type electric strain gages.

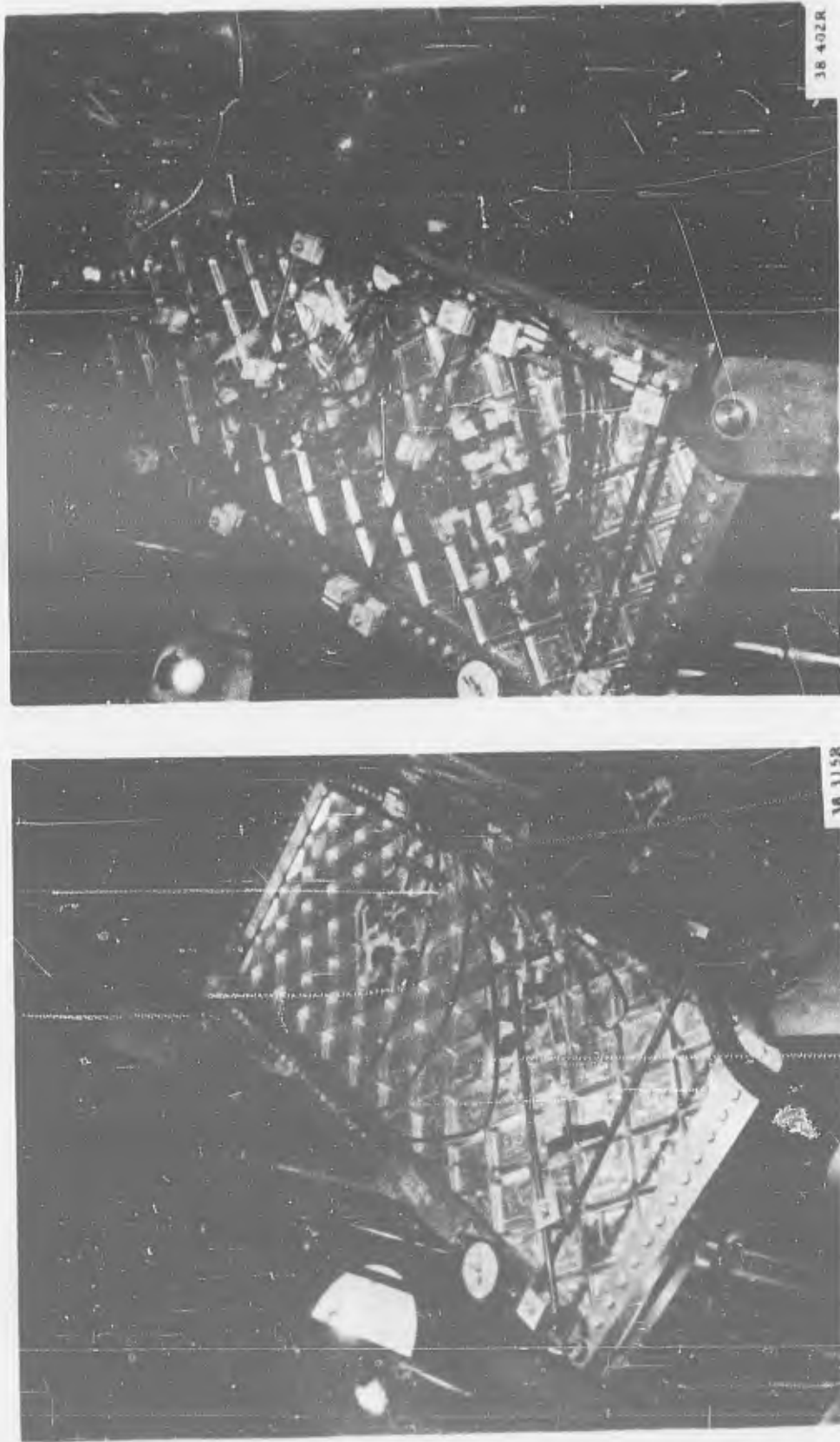
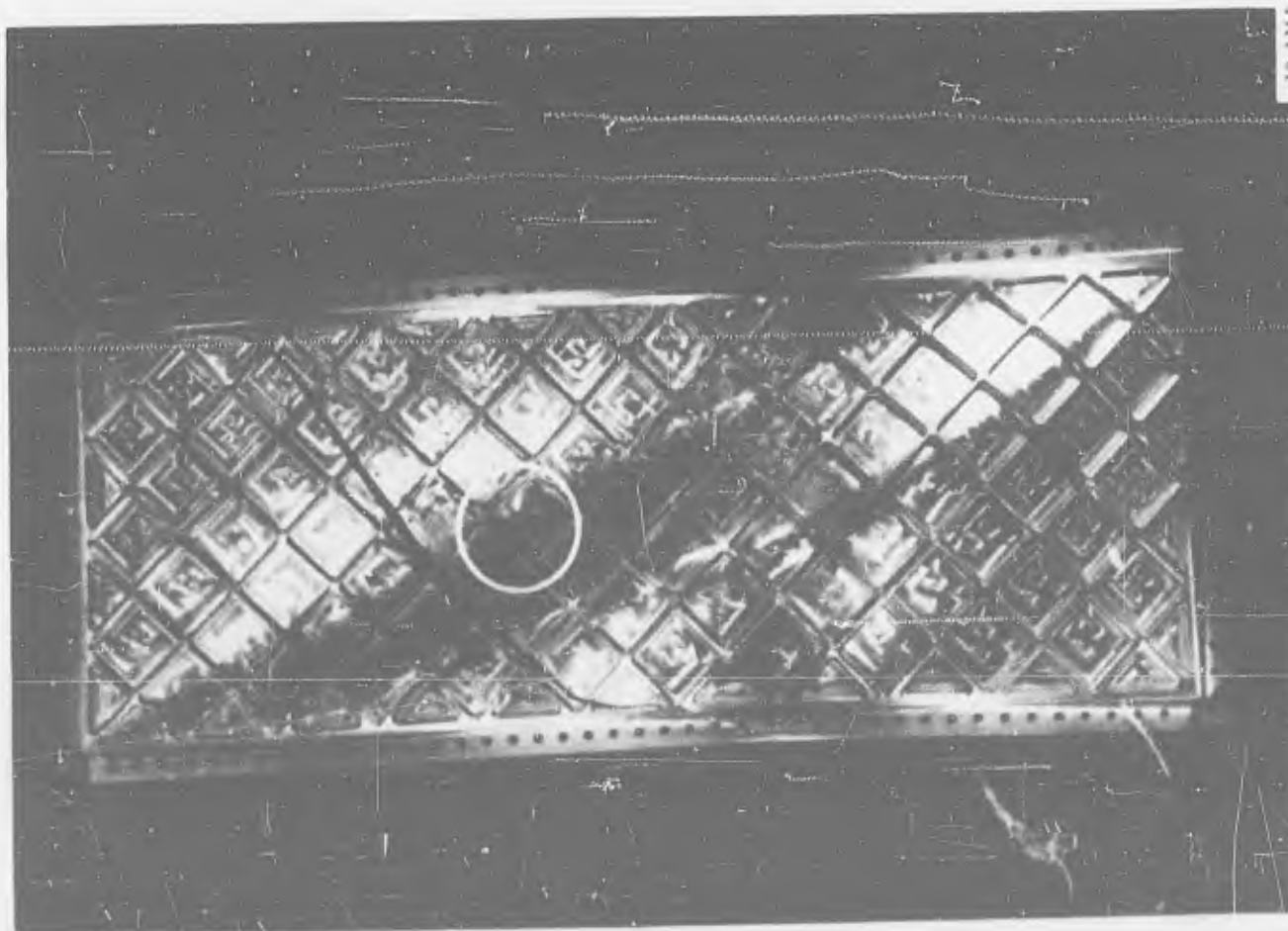


Fig. 16 - Panel No. 1 (left) and panel No. 2 (right) after critical buckling. Linear electric strain gages can be seen on the ribs four "square" inward from the ends of the panels.

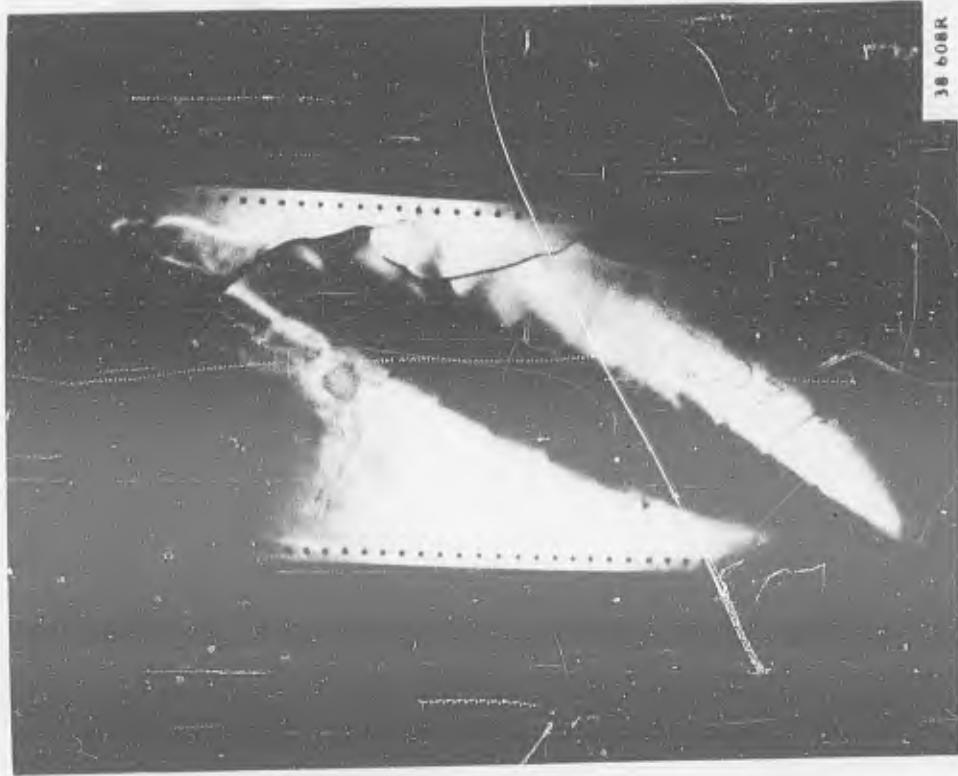


38 3278

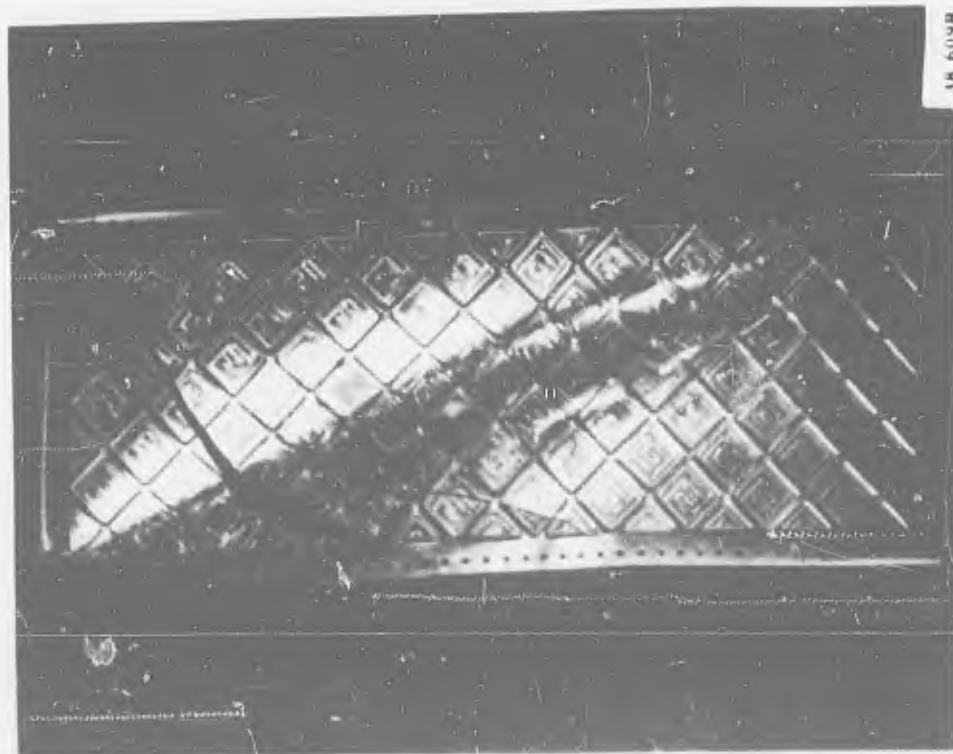


38 3265

Fig. 17 - Front and back views of panel No. 1 after failure. Circle shows location of damaged rib repaired with doublers.



38 608R



38 609R

Fig. 18 - Front and back views of panel No. 2 after failure.

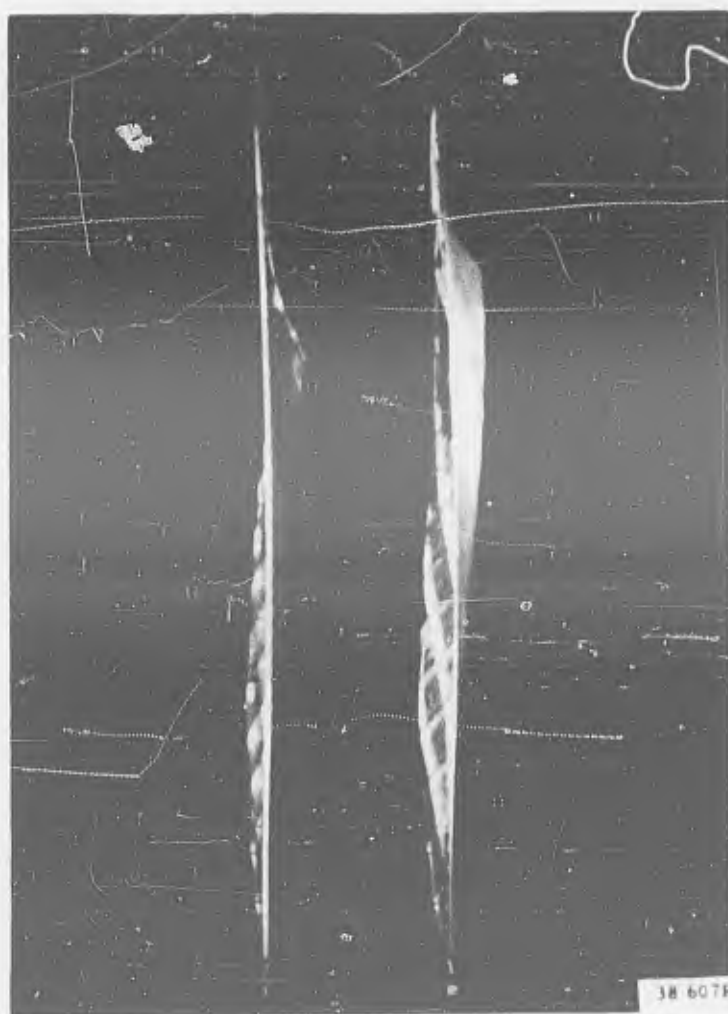


Fig. 19 - Edge views of panels 1 and 2 after failure.

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APPENDIX A

ANALYSIS OF A SHEAR PANEL WITH
INTEGRAL WAFFLE-GRID STIFFENING

The equation for equilibrium of an element in an isotropic or orthotropic plate subjected to a shear flow q may be written in this form (Ref. A-1).

$$\frac{\partial^2 M_x}{\partial x^2} + 2 \frac{\partial T_{xy}}{\partial x \partial y} + \frac{\partial^2 M_y}{\partial y^2} = + 2 q \frac{\partial^2 w}{\partial x \partial y} \quad (1)$$

where (see Fig. A-1)

M_x and M_y indicate internal moments on a plate element of unit length in the x and y directions, respectively.

T_{xy} is the internal twisting moment acting on a plate element of unit width.

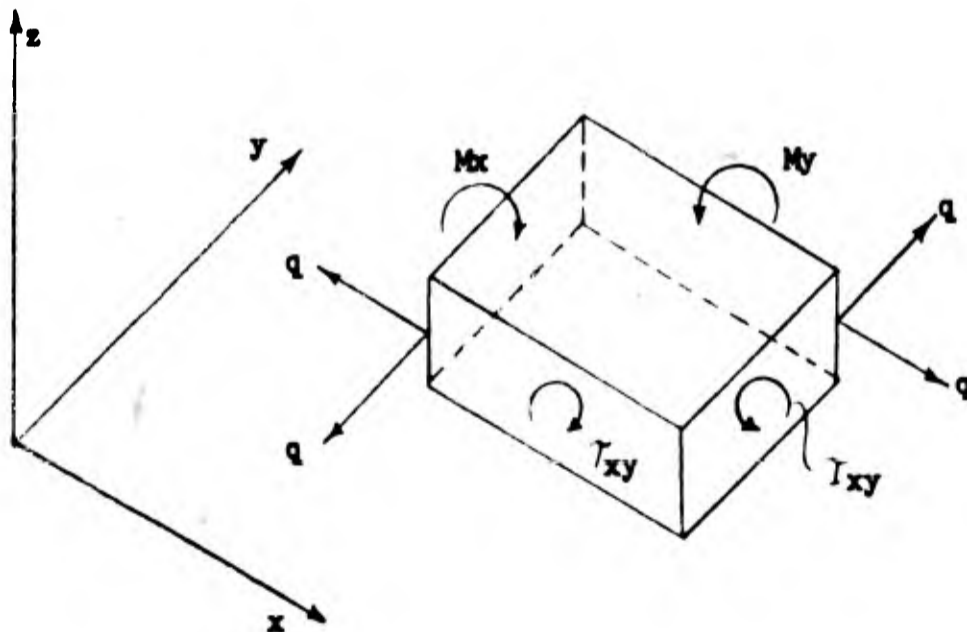


Fig. A-1

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According to the small deflection theory, it is permissible to set the curvatures of a plate

$$\frac{\partial^2 w}{\partial x^2} = -\frac{M_x}{EI_x} + \nu_y \frac{M_y}{EI_y} \quad (2)$$

$$\frac{\partial^2 w}{\partial y^2} = -\frac{M_y}{EI_y} + \nu_x \frac{M_x}{EI_x}$$

and the twist

$$\frac{\partial^2 w}{\partial x \partial y} = -\frac{T_{xy}}{2GI_{xy}} \quad (3)$$

where w denotes the displacement of any point of the plate in the Z direction. The term $2GI_{xy}$ represents the average torsional rigidity of the plate in the x and y directions.

With the following abbreviations for the flexural and torsional stiffness of the plate in inch-pounds

$$D_1 = \frac{EI_x}{1 - \nu_x \nu_y}$$

$$D_2 = \frac{EI_y}{1 - \nu_x \nu_y}$$

$$D_3 = \frac{1}{2} (\nu_x D_2 + \nu_y D_1) + 2GI_{xy}$$

the differential equation for the orthotropic plate subjected to shear takes the general form

$$D_1 \frac{\partial^4 w}{\partial x^4} + 2D_3 \frac{\partial^4 w}{\partial x^2 \partial y^2} + D_2 \frac{\partial^4 w}{\partial y^4} = -2q \frac{\partial^2 w}{\partial x \partial y} \quad (4)$$

Timoshenko (Ref. A-2) points out that in the analysis of stiffened plates it is usually permissible to set Poisson's ratios ν_x and ν_y equal to zero. The average torsional stiffness is then

$$D_3 = 2GI_{xy}$$

This value is difficult to obtain analytically, but can easily be determined by test (see Appendix B).

For a panel with equal bending and torsional stiffness in the x and y direction the bending stiffness is

$$D - D_1 = D_2 = EI$$

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where I indicates the moment of inertia per linear inch in the x or y direction.

Eq. 4 has been solved by E. Seydel (Ref. A-3) giving the critical shear flow in an orthotropic plate of infinite length and width b as

$$q_{CR} = \frac{\kappa EI}{b^2} \quad (5)$$

The coefficients k for different ratios

$$\alpha = \frac{D}{D_3}$$

vary from 1 to ∞ and can be taken from Fig. A-2, page 29.

If the panel has a finite aspect ratio, k is multiplied by k_1/k_2 where k_1 and k_2 are fixity coefficients for a flat plate: k_1 is associated with the given aspect ratio, k_2 is associated with an infinite aspect ratio. Values of k_1 and k_2 are available in such publications as Lockheed Stress Memo 33 or NACA TN 1222.

The method described here is applied in Appendix B to the two waffle-grid panels that form the basis of this report.

REFERENCES

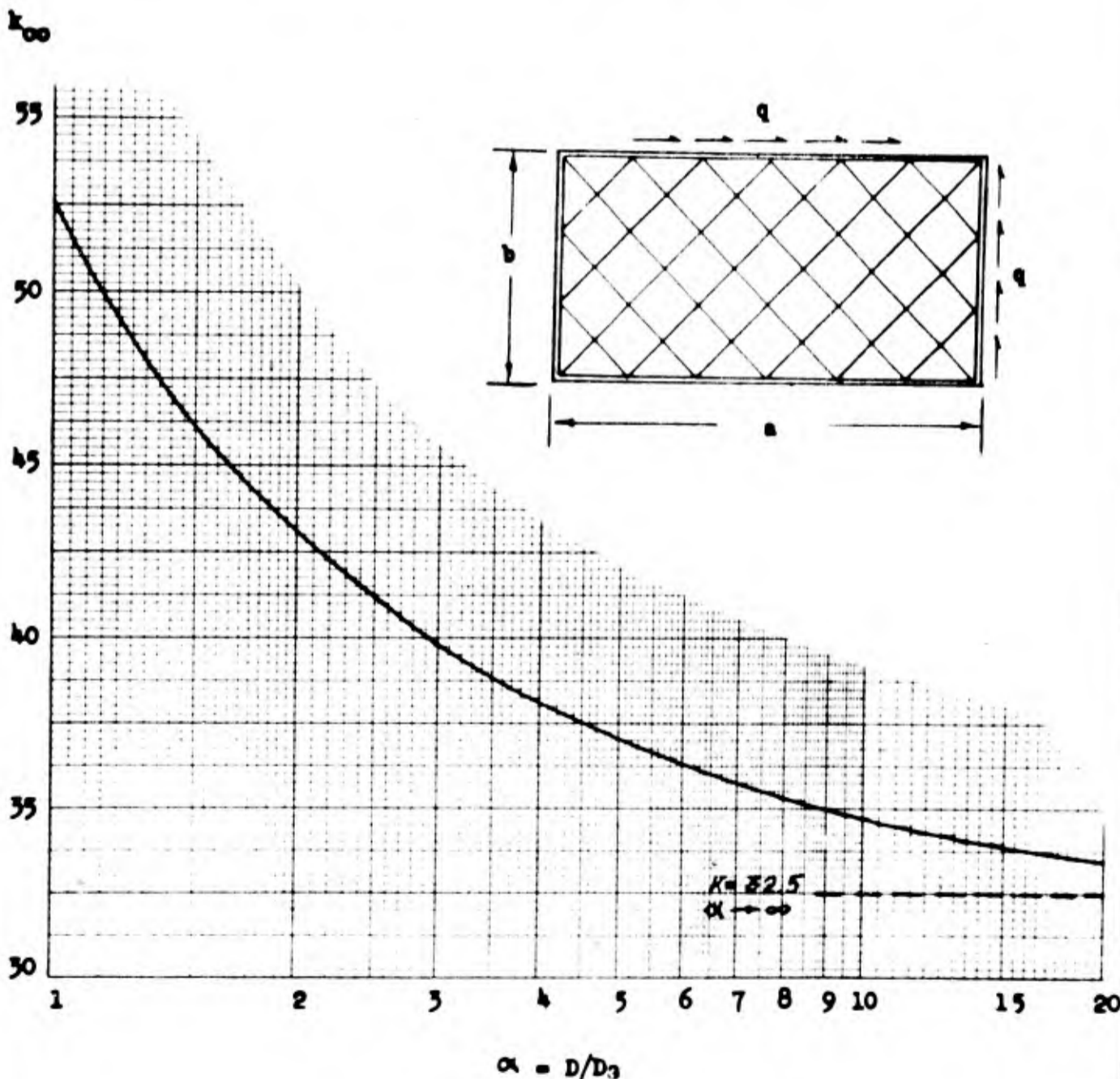
- (A-1) Timoshenko, S., "Theory of Elastic Stability," First Edition, p. 305, McGraw-Hill, (New York, 1936)
- (A-2) Ibid, p. 381
- (A-3) Seydel, Edgar, "Beitrag zur Frage des Ausbeuleus von versteiften Platten bei Schubbeanspruchung," Luftfahrtforschung, Vol. 8, July 21, 1930, p. 71.

Critical Shear Flow for a Panel with
Integral Waffle-Grid Stiffening

(Infinite Aspect Ratio $\frac{a}{b} = \infty$)

$$q_{cr} = k \frac{D}{b^2}$$

Directions: Determine D and D_3 experimentally. Enter diagram with $\alpha = D/D_3$ and find k_{∞} . For a panel with finite aspect ratio multiply k_{∞} by ratio of equivalent coefficients for a simple shear plate (S.M.55).



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APPENDIX B

EXPERIMENTAL DETERMINATION OF ELASTIC CONSTANTS

Panel No. 1

The flexural stiffness D may be determined experimentally by loading the plate, as shown in Fig. B-1.

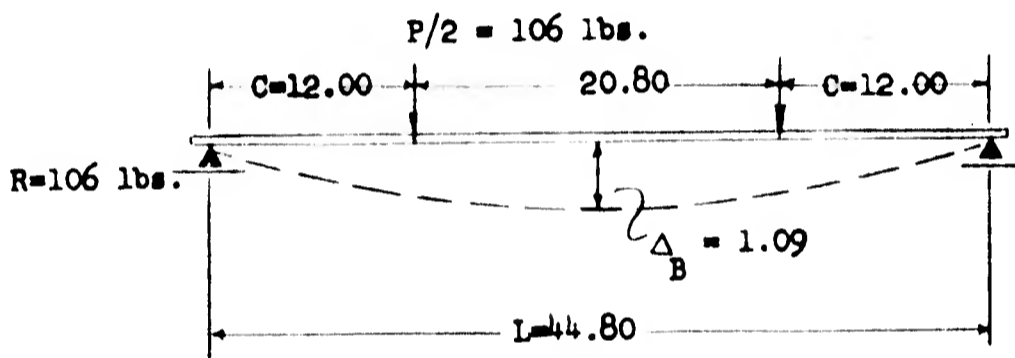


Fig. B-1

According to the elementary theory the deflection in the center of the panel is

$$\Delta_B = \frac{Rc}{EIb} \left[\frac{3l^2 - 4c^2}{12} \right]$$

$$\Delta_B = \frac{2723 R}{EIb}$$

In panel No. 1, $b = 18.44$ (overall width), $\Delta_B = 1.09$
 $p/2 = R = 106$ lbs. This gives an experimental value of the flexural stiffness per linear inch in the x and y direction of

$$D = EI = \frac{2723 \times 106}{1.09 \times 18.44} = 14,300 \text{ in-lbs.}$$

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The torsional rigidity is determined by cutting a square panel from the plate and loading it according to Fig. B-2, page 33.

The deflection Δ_T for a 3.95 inch square panel was measured for a load $P = 75$ lbs. as $\Delta_T = .033$ inch.

Therefore, from the simple relationship

$$D_3 = \frac{T_{xy}}{\frac{\partial^2 w}{\partial x \partial y}} = \frac{Pa^2}{4 \Delta_T} \quad (6)$$

it follows that

$$D_3 = \frac{75 \cdot 3.95^2}{4(.033)} = 8,850 \text{ in-lbs.}$$

For a ratio

$$\alpha = \frac{D}{D_3} = \frac{14,300}{8,850} = 1.62$$

Fig. A-2, page 29, gives $k = 45.5$ for a panel of infinite aspect ratio. Adjustment for the finite aspect ratio* of the panel

$$\frac{b}{a} = \frac{17.2}{44.8} = .384$$

the coefficient k changes to (TN 1222)(Ref. B-1)

$$k = \frac{5.40}{4.84} (45.5) = 51$$

Then, according to Eq. 5, the critical shear flow in the panel becomes

$$q_{cr} = \frac{(51)(14,300)}{(17.2)^2} = 2460 \text{ lbs/in.}$$

Panel No. 2

The measured bending deflection at the center of panel No. 2 due to a vertical loading of p equal to 60 lbs. was $\Delta_b = .62$ in. Thus, the flexural stiffness per linear inch in the x or y direction is

$$D = EI = 6,300 \text{ in-lbs.}$$

*In determining the flexural rigidity of the panel the overall width $b = 18.44$ was used. Here only the portion of the panel in shear is used and $b = 17.2$

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Using the same k as above, the critical shear flow for panel No. 2 is

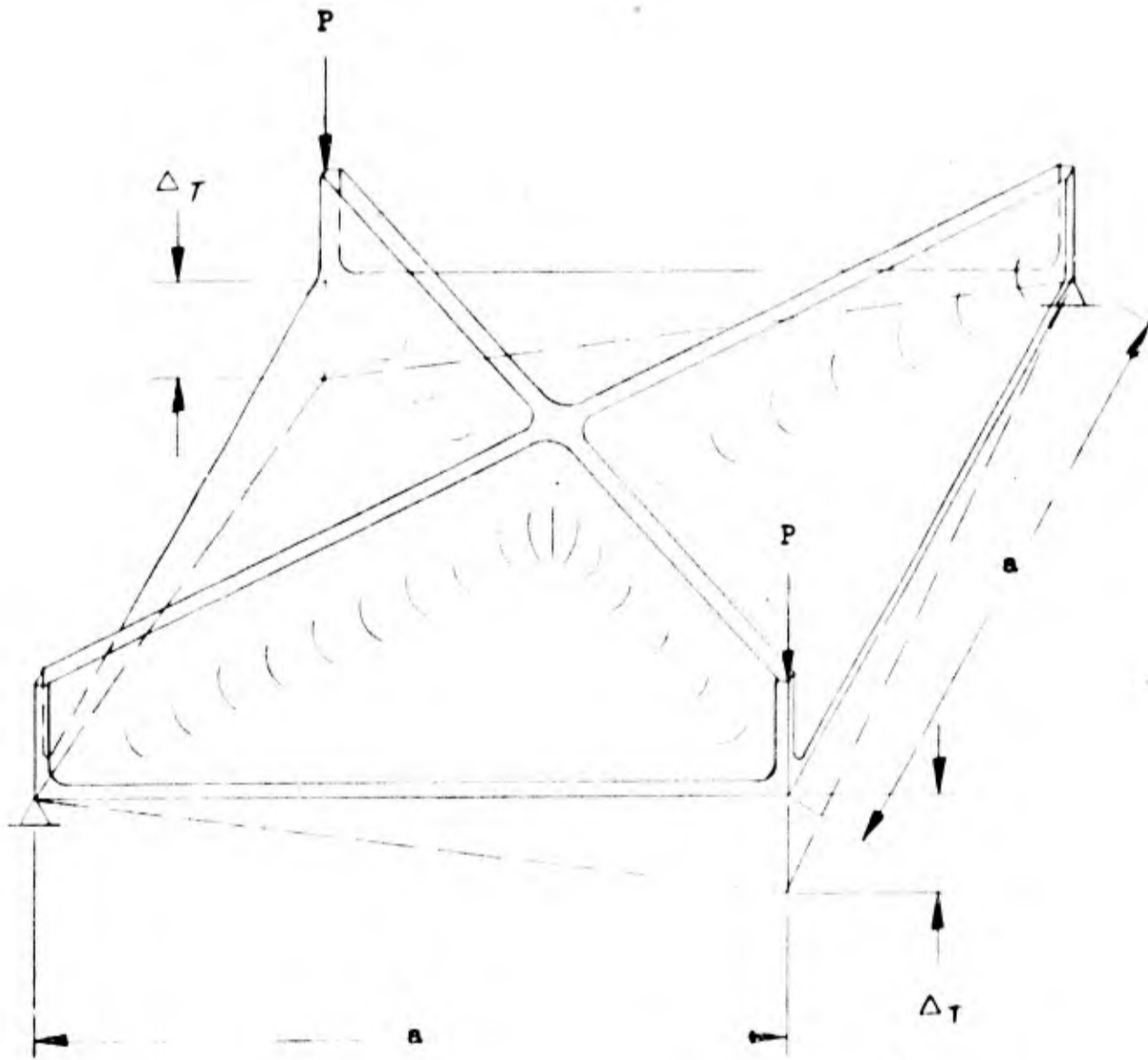
$$q = \frac{(51)(6,300)}{(17.2)^2} = 1085 \text{ lbs/in.}$$

REFERENCES

- (B-1) Stein, M., and Neff, J., "Buckling Stresses of Simply Supported Rectangular Flat Plate in Shear," NACA TN 1222, p. 11 (Washington, March, 1947).

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FIG B-2



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APPENDIX C*

APPROXIMATE STRESS DISTRIBUTION IN PANEL

The requirement of consistent deformations makes it possible to approximate the distribution of shear flow between the web and ribs of the panel.

Consider Fig. C-1.

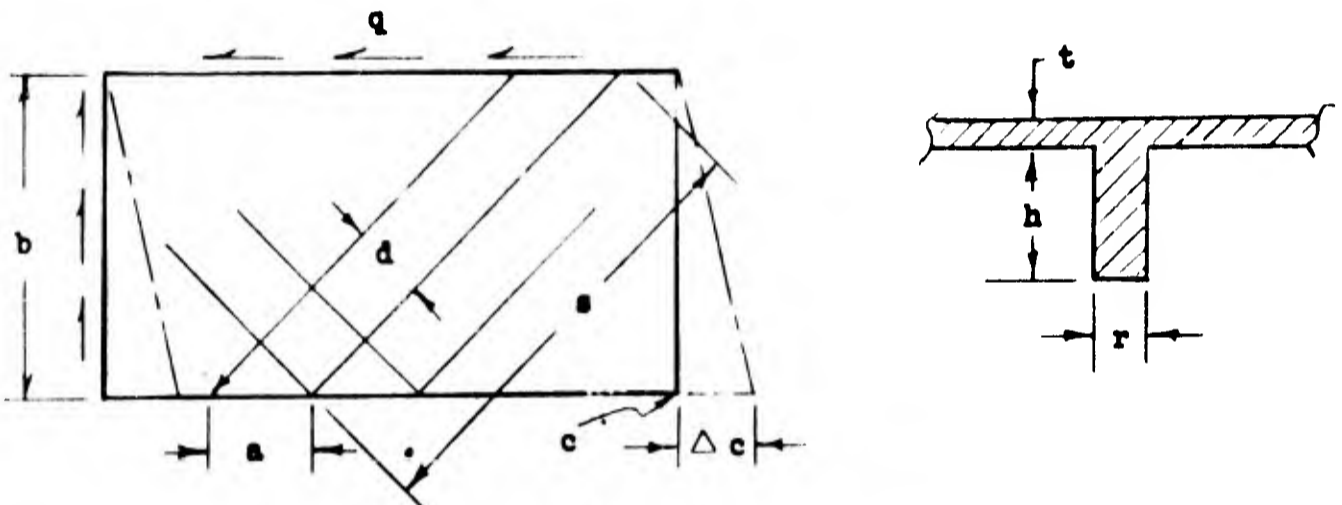


Fig. C-1

The translation of the point c due to shear deformation in the web is given by

$$\Delta_c^w = \frac{q_w' b}{t G} \quad (1)$$

where

q_w' = shear flow in web (i.e., in the area $h \times r$, Fig. B-1)

G = shear modulus

The translation of the same point c due to change in length of the ribs is

$$\Delta_c^r = \frac{1.41 P_s}{A E} \quad (2)$$

*Appendix C paraphrases the work of A. F. Ensrud in Ref. C-1.

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where

P = load per rib in pounds

A = area of rib below web

= $h \times r$

S = length of rib between supports

Let q_r denote the portion of the shear flow which is taken by the part of the rib which extends below the web, then with

$$P = q_r d$$

$$\text{and } A = hr = \frac{t'd}{2} \quad (3)$$

where

t' = equivalent sheet thickness equal to the part of the ribs extending below the web

it follows for the translation of the point c

$$\Delta_c^R = q_r d \frac{b(1.41)^2}{t'(d/2)E} = \frac{4 q_r b}{t' E} \quad (4)$$

$$\text{Setting } \Delta_c^W = \Delta_c^R \quad (5)$$

the shear flow in the web is

$$q_w = \frac{q}{1 + \frac{t' E}{4 t E}} = \frac{q}{1 + \frac{h r E}{2 t E}} \quad (6)$$

and the portion of the shear flow taken by the ribs is

$$q_r = \frac{q}{1 + \frac{4 t E}{t' E}} = \frac{q}{1 + \frac{4 t E}{h r E}} \quad (7)$$

Eqs. (6) and (7) were used to calculate the shear flow distribution on the curves, Figs. 9 through 14.

REFERENCES

- (C-1) Ensrud, A. F., "Design Parameters of a Waffle-Grid Shear Panel - Model YC-130 Pylon Tank Side Panels," 3-27-53.

APPENDIX IV

LOCKHEED REPORT 10432

DEVELOPMENT OF FORGING TECHNIQUES FOR 75S ALUMINUM

ALLOY WAFFLE GRID TYPE INTEGRALLY STIFFENED PANELS

PART EXTRACTION TESTS

A B S T R A C T

This report contains the results of a series of miscellaneous tests conducted to determine the relative merits of several methods for extracting waffle grid type integrally stiffened skin panels from the dies on completion of the forging process. This work was done by the Factory Coordination Group and the Metallurgical Research Group at the request of the Production Engineering Department Manager.

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BACKGROUND:

The work described herein is a continuation of the integrally stiffened wing panel forging studies covered by the following Lockheed Reports:

1. L.R. No. 5942, "Preliminary Press Forging Investigation", by Wm. Schroeder, D. A. Webster and H. W. Grebe, dated 12-12-46.
2. L.R. No. 6202, "Progressive Forging of Integrally Stiffened Sheet", by Wm. Schroeder, dated 7-25-47.
3. L.R. No. 6833, "Progressive Forging of Integrally Stiffened Sheet - 9.6 inch Die", by Wm. Schroeder, dated 1-3-49.
4. L.R. No. 6919, "Progress Report - First Phase - Research Program for Forging Integrally Stiffened Panels", by G. W. Papen, dated 3-14-49.
5. L.R. No. 6955, "Research Program for Forging Integrally Stiffened Panels - Progress Report No. 2", by G. W. Papen, dated 4-11-49.
6. L.R. No. 7192, "Report on Results of Second Phase of Integrally Stiffened Panel Forging Research Program", by G. W. Papen, dated 11-10-49.
7. L.R. No. 7192, Vol. 2, "Supplementary Report on Results of Second Phase of Integrally Stiffened Panel Forging Research", by Wm. Schroeder, dated 2-15-50.
8. L.R. No. 7192, Vol. 3, "Final Report on Results of Second Phase Integrally Stiffened Panel Forging Research Program", by Wm. Schroeder, dated 3-17-50.
9. L.R. No. 7768, "Final Report on Research Program for Forging Integrally Stiffened Panels", by Wm. Schroeder and G. W. Papen, dated 12-20-50.
10. L.R. No. 8746, "Development of Forging Techniques for 75S Aluminum and 52S Magnesium Alloy Waffle Type Integrally Stiffened Panels - Phase I - Effects of Temperature, Pressure, Dwell Time and Blank Thickness on Stiffener Height and Occurrence of Forging Defects", by F. C. Pipher and H. B. Wiley, dated 8-26-52.
11. L.R. 9069, "Development of Forging Techniques for 75S Aluminum and 52S Magnesium Alloy Waffle Type Integrally Stiffened Panels - Phase II - Effects of Stiffener Thickness on the Forgeability of Integrally Stiffened Waffle Type Panels from 52S Magnesium and 75S Aluminum Alloys", by W. A. Brown and H. B. Wiley, dated 12-31-52.

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BACKGROUND: - contd.

12. L.R. No. 9214, "Development of Forging Techniques for 75S Aluminum and 52S Magnesium Alloy Waffle Type Integrally Stiffened Panels - Phase III - Effects of 800 to 950°F Fabrication Temperature on Stiffener Height and Microstructure of 75S Aluminum Alloy Parts", by W. A. Brown and H. B. Wiley, dated 6-18-53.
13. L.R. No. 9425, "Shear Tests of Waffle Grid", by M. W. Mueller, A. F. Ensrud and T. J. Stapleton.
14. L.R. No. 9567, "Development of Forging Techniques for 75S Aluminum Alloy Waffle Grid Type Integrally Stiffened Panels - Horizontal Fillet Radii, Flow Across Die Cavities, Mechanical Properties, by H. B. Wiley, dated 1-4-54.

NOMENCLATURE:

1. WAFFLE GRID: Uniformly spaced integral skin panel stiffeners intersecting at right angles (see Fig. 10, L.R. 8746).
2. DOVETAIL LIFTING LUGS: Integral lugs forged into the upper skin surface of the part by undercut recesses in the punch having the cross sectional shape illustrated in Figs. 4 and 5.
3. ROUND LIFTING LUGS: Same as 2 (above) but with round cross section as shown in Fig. 6.
4. DRAFT ANGLE: Angle of taper built into forging die cavities to facilitate part extraction (see Fig. 7).
5. EXTRUSION TYPE LANDS: Overhang of die inserts to produce extruded ribs (unconfined) as shown for insert assemblies 4 and 5, Fig. 7.
6. MUSHROOM CAP EJECTOR: To provide maximum contact area between ejector and part the standard cylindrical pin type knockout was enlarged to include the entire top of the insert as shown for assemblies 3 and 4, Fig. 7.
7. EXTRACTION FORCE: Force required to remove part from die after forging.
8. BOTTOMED FORGINGS: Parts which completely fill the forging die cavity.

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OBJECT:

1. To evaluate the relative merits of dovetail and round lifting lugs as a means of extracting integrally stiffened waffle grid skin panels from the forging dies.
2. To determine the feasibility of using conventional and "mushroom" type "knockouts" as a means of ejecting forgings from the dies.
3. To measure the extraction forces required for removal of parts from the dies.

SUMMARY:

On the basis of the following detailed observations, it is indicated that the round lifting lug punch (Fig. 6) in combination with the 7° draft "mushroom" cap emergency ejector insert assembly No. 4 (Figs. 7 and 13) with 1° rib cavity draft or in combination with draftless nonextrusion type insert assembly No. 6 (Fig. 8) having maximum diameter round knockout emergency ejectors should be employed for full scale parts and that minimum "as forged" skin thickness should be approximately 0.35 inches:

1. The "dovetail" lifting lug design is not suitable for extraction of parts forged with 1° draft ribs and the removal forces for draftless nonextrusion type parts may become sufficiently high due to "sticking" to cause lug failures in some instances.
2. The round lifting lug design provides adequate strength for removal of 1° or 0° rib draft parts but increasing distortion will result for skin thicknesses less than approximately .35 inches.
3. The 7° draft "mushroom" cap ejector functions satisfactorily but increasing distortion may be expected as skin thicknesses are reduced below approximately .35 inches.
4. Extraction forces for draftless waffle grid forgings will range from 100 to approximately 200 pounds per linear inch of stiffener and values for similar parts with 1° draft may be as much as twice the forces for draftless parts.
5. Marking and part distortion produced by conventional round ejector pins is more severe than the distortion resulting from the use of "mushroom" type cap ejection.

PROCEDURE AND RESULTS:

In order to more nearly reproduce the conditions which will exist during extraction of contemplated full size waffle grid panels (Lockheed Report No. 8746, Fig. 10) from the forging dies, small scale tests were conducted on 3.00 inch square parts modified to provide one complete grid with 1/2 scale rib spacing but with full scale rib height and rib thickness. A photograph of the die block and No. 1 center insert assembly is shown in Fig. 1 and Print No. 127645, from which these parts were made, is presented in Fig. 3.

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PROCEDURE AND RESULTS: - contd.

Initial testing was accomplished using the 127645 (Fig. 3) lower die with the No. 1 flat punch, the No. 2 (Fig. 4) single "dovetail" punch, the No. 3 (Fig. 5) double "dovetail" punch and the No. 4 (Fig. 6) double lifting lug punch. Photographs of the No. 2, 3 and 4 punches are shown in Figs. 1 and 2.

It may be noted from the print shown in Fig. 3 that the die cavity above the rib forming inserts is provided with 7° draft angle to prevent sticking of the parts in this region and to eliminate "edge effects" from the results of part extraction tests. The center insert was also constructed so that it could be driven out from the underside of the die to permit part removal in the event of extraction lug failure or for parts forged without lifting lugs.

Fig. 7 contains sectional drawings of the various inserts (Nos. 1 through 5) used to test the feasibility of removing parts by means of several proposed "knockout" mechanisms for 1° draft ribs (Nos. 1 through 3) and for draftless ribs (Nos. 4 and 5). An additional draftless insert No. 6 (Fig. 8) was also provided by removing the lands from the No. 5 inserts. The No. 6 inserts permit removal of "bottomed" forgings having draftless ribs.

The details of all forging tests conducted for parts 1E through 34E are included in Table I. The No. 2 single dovetail punch was used with the die illustrated in Figs. 1 and 3 with the 1° draft (No. 2, Fig. 7) inserts to forge part No. 28E (Tabulation No. 1 of Table I). Extraction was not successful due to bending of the interlocking forged material in the dovetail recess of the punch. Further testing of the single lifting lug design was abandoned in favor of double lugs capable of exerting twice the extraction force.

The No. 3 double "dovetail" lifting lug punch (Figs. 1 and 5) was tested in the die shown in Figs. 1 and 3 using the 1° draft No. 2 (Fig. 7) inserts to make parts 29E and 30E (Tab. Nos. 2 and 3, Table I) illustrated in Fig. 9. Extraction of these forgings was also unsuccessful due to bending of the "dovetail" edges.

The No. 4 circular section double lifting lug punch (Figs. 2 and 6) was developed to provide a thicker section in the region where bending failures occurred in the "dovetail" parts. Testing was accomplished with the same die and inserts to produce forgings 31E and 32E (Tab. Nos. 4 and 5 of Table I) illustrated in Fig. 10. Extraction was successful but slight distortion resulted.

The parts shown in Figs. 11 and 12 (Specimens 19E through 26E) were fabricated using the draftless No. 6 (Fig. 8) inserts which were made by removing the extrusion lands from the No. 5 inserts. The lower extraction forces required for draftless forgings permitted satisfactory removal with both type lifting lugs with the exception of part No. 24E for which the double "dovetail" lifting device failed. It may also be noted (Fig. 11) that parts 25E and 26E were forged to the full depth of the die.

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PROCEDURE AND RESULTS: - contd.

Details of the No. 4 inserts, employing a "mushroom" cap ejector in the center component, are shown in Fig. 13. This maximum area "knockout" device was developed to permit part removal with less distortion than encountered with the conventional round ejector pins. Parts 27E, 33E, and 34E (Tab. Nos. 14, 15 and 16) shown in Figs. 14, 15 and 16 were made and removed from the die with the No. 4 insert. The 5° draft used for Part No. 27E was found inadequate for satisfactory removal of the forging from the ejector cap. The draft angle was increased to 7° for parts 33E and 34E and sticking of the part to the cap was eliminated.

In order to measure the extraction forces required for grid type forgings, the die was modified to include a lifting plate and dynamometers as shown in Figs. 17 and 18. Sectional aspects are presented in Fig. 19 while details of the various components are illustrated in Figs. 20 through 24. It may also be noted in the sectional sketch (Fig. 19) that provisions were made for actuation of the knockout pin by means of a tapered drift bar and that the die cavity and punch were modified to provide a lifting shoulder around the edge of the forged part.

Figs. 25, 26 and 27 contain photographs of parts made with the die illustrated in Fig. 19. The details of these tests are recorded in Table I, Tabulation Nos. 17 through 33.

Fig. 28 shows the extremely severe distortion produced in several forgings as the result of "sticking" of the parts in the die. This acute condition developed after part deformation developed during extraction to the extent that "keying" or "locking" of the forging in the die occurred and the parts had to be cut, chiseled or pried from the cavity.

CONCLUSIONS:

1. The "dovetail" type lifting lugs (Figs. 4 and 5) have insufficient strength to withdraw test parts (Fig. 9) having 1° draft stiffeners.
2. The round lifting lug design (Fig. 6) was satisfactory for the removal of test parts (Fig. 10) having 1° draft stiffeners. However, very slight skin distortion was evident for these parts.
3. With one exception (part No. 24E), the double "dovetail" extraction lug design was satisfactory for the withdrawal of forgings (Fig. 11) having 0° draft stiffeners made in dies not containing the extrusion type lands at the top of the rib cavities.
4. The round lug design was also satisfactory for removal of draftless parts (Figs. 11 and 12).
5. The "mushroom" cap ejector (Fig. 13) could not be readily removed from the part (Fig. 14) when used with 5° cap draft and 1° rib draft.

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CONCLUSIONS: - contd.

6. The "mushroom" cap ejector functioned satisfactorily with 7° cap draft for parts with 1° stiffener draft.
7. Extraction forces for draftless parts made with extrusion type inserts incorporating lands at the upper portion of the rib cavities (Assembly No. 5, Fig. 7) ranged from 1,100 to 2,200 lbs. for part Nos. 1E through 5E (Table I, Tab. Nos. 17 through 21) shown in Fig. 25. The lifting plate die used for these tests is illustrated in Figs. 17 through 24.
8. Extrusion type draftless parts (No. 5 inserts) removed with the round ejector pins show objectionable marking and distortion for rib heights exceeding .50 inches (Figs. 25 and 26), Table I, Tab. Nos. 22 through 30.
9. Extraction forces for forgings having 1° rib draft exceeded the 3,000 pound capacity of the dynamometers used for part removal (Table I, Tab. Nos. 31, 32 and 33; Figs. 26 and 27).

TABLE I
FORGING TEST DATA FOR 7075 (75) ALUMINUM ALLOY WAFFLE GRID TYPE INTERNALLY STIFFENED VIBRO PANEL SMALL SCALE PARTS

Tabulation No.	Specimen No.	Blank Thickness (in.)	Flange Number	Insert Number	RD Draft (Degrees)	Purging Temperature (°F)	Purging Load (Tons)	Drill Time (Sec.)	Rib Height (in.)	Skin Thickness (in.)	Remarks	Distortion
1	29E	.625	2	2	1	700	250	60	1.00	.295	Single dovetail lifting lug failed - extracted with knockout.	Moderate
2	29E	"	3	"	1	"	"	"	"	.291	Double dovetail lifting lug failed - extracted with knockout.	"
3	30E	.375	"	"	1	800	"	"	"	.095	Double dovetail lifting lug failed - extracted with knockout.	Strong
4	31E	.625	4	"	1	"	200	"	1.10	--	Round lifting lugs extracted part satisfactorily.	Very slight
5	32E	"	"	"	1	"	"	"	1.20	--	"	"
6	21E	.500	3	6	0	"	100	30	.70	.299	Double dovetail lugs extracted part satisfactorily.	Slight
7	22E	"	"	"	0	"	150	"	1.42	.185	"	"
8	23E	"	"	"	0	790	125	"	1.17	.189	"	"
9	24E	.625	"	"	0	780	200	"	1.20	.302	" failed	Moderate
10	25E	.750	"	"	0	680	300	60	1.50	.340	extracted part satisfactorily.	"
11	19E	.500	4	"	0	800	100	30	.55	.431	Round lifting lugs partially filled - extraction satisfactory.	None
12	20E	"	"	"	0	"	125	60	1.10	.249	Round lifting lugs extracted part satisfactorily.	"
13	26E	.750	"	"	0	700	300	"	.85	.302	"	Very slight
14	27E	.625	1	3	1	750	250	"	.85	.302	5° mushroom knockout stuck in part - difficult removal after .004" etch.	Very slight
15	33E	"	1	3a	1	780	"	30	.95	.361	7° mushroom knockout satisfactory removal.	Slight
16	34E	.250	1	3a	1	750	250	60	.85	.075	7° mushroom knockout satisfactory removal.	Moderate
17	1E	.500	5	5	0	800	75	60	.48	.262	1,100 lbs. extraction force.	None
18	2E	"	"	"	0	"	100	"	"	.234	2,200 "	"
19	3E	"	"	"	0	"	125	"	.60	.227	2,000 "	"
20	4E	"	"	"	0	"	"	"	.70	.215	1,900 "	"
21	5E	.500	5	5	0	850	75	180	.90	.196	1,900 lbs. extraction force.	Slight
22	6E	"	"	"	0	"	"	300	.80	.216	Part ejected with knockout.	Severe
23	7E	.625	"	"	0	700	25	120	.35	.334	"	None
24	8E	.500	"	"	0	"	100	180	"	"	"	"
25	10E	"	"	"	0	"	50	60	.40	.262	"	"
							125	180	"	"	"	Moderate
							50	60	.58	.228	"	"
							150	180	"	"	"	"
26	11E	.500	5	5	0	600	75	60	.30	.267	Part ejected with knockout.	Slight
							175	180	"	"	"	"
27	12E	"	"	"	0	"	75	60	.50	.243	"	Very slight
							200	180	"	"	"	"
28	13E	"	"	"	0	"	75	60	.87	.205	"	Moderate
							250	180	"	"	"	"
29	14E	"	"	"	0	550	100	60	.87	.186	"	"
							300	180	"	"	"	"
30	15E	"	"	"	0	525	100	60	.50	.237	"	None
							300	180	"	"	"	"
31	16E	.500	5	5	1	800	200	30	.63	.247	3,000+ extraction force	Moderate
32	17E	"	"	"	1	"	300	"	1.00	--	" (Part missing)	"
33	18E	"	"	"	1	"	250	"	.65	.238	"	Moderate

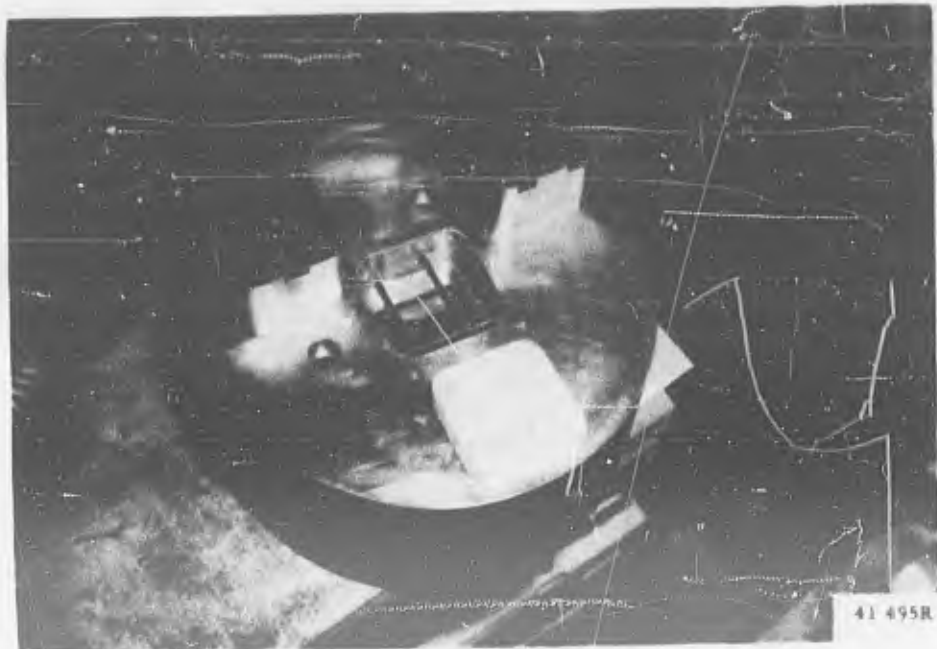


Fig. 1 - Photograph showing die retainer ring with removable rib forming inserts (see Print No. 127645 - Fig. 3), single and double "dovetail" lifting lug punches (see Prints No. 127643 and 127644 - Fig. 4 and 5) and .625 x 3.0 x 3.0 inch 7075 (75S) aluminum alloy forging blank. These components were used for the "dovetail" lifting lug extraction tests.



43 887R

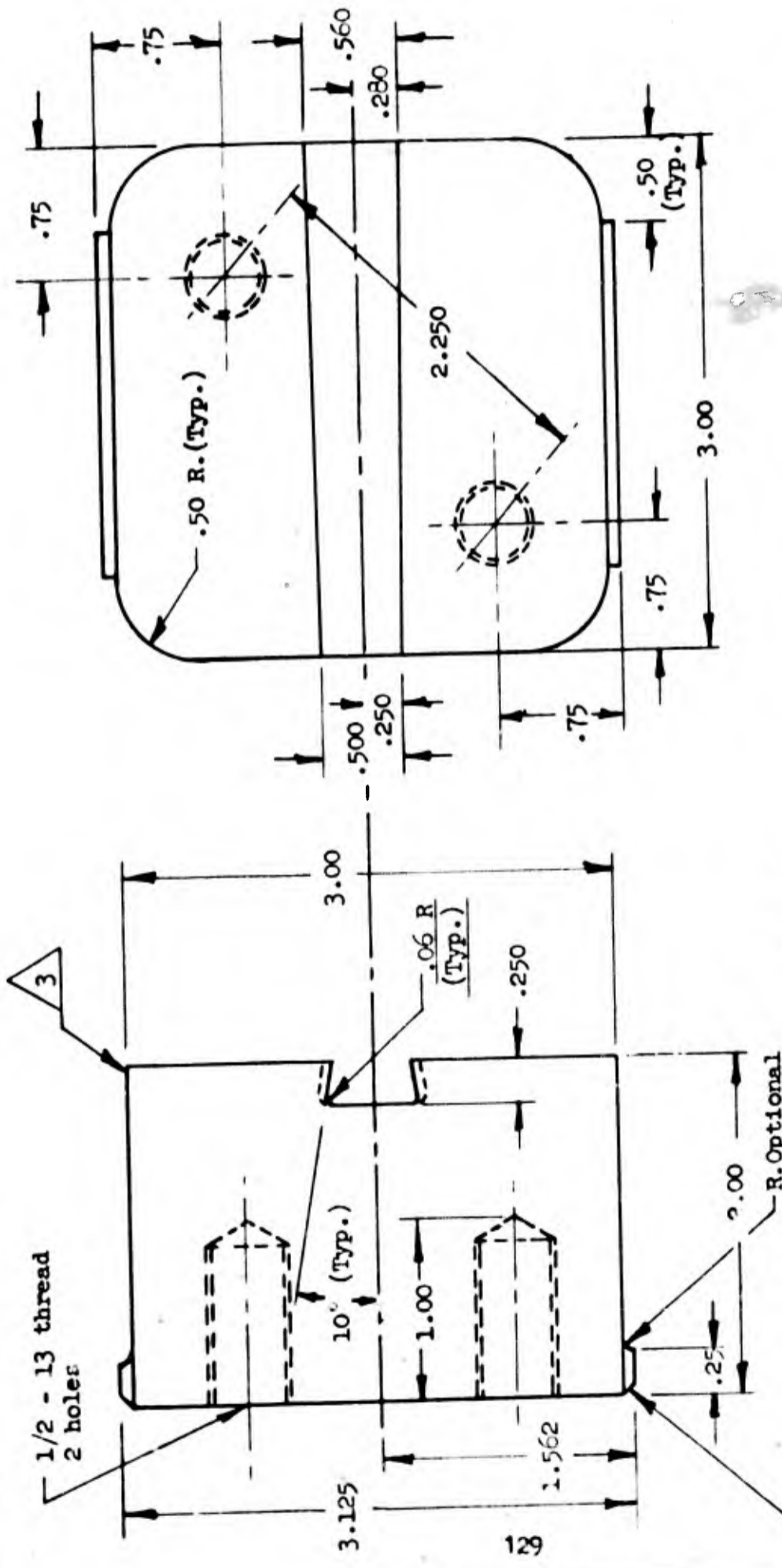


METALLURGICAL RESEARCH.

Fig. 2 - Close view of the No. 4 double circular lifting lug punch (see Print No. 127648, Fig. 6).

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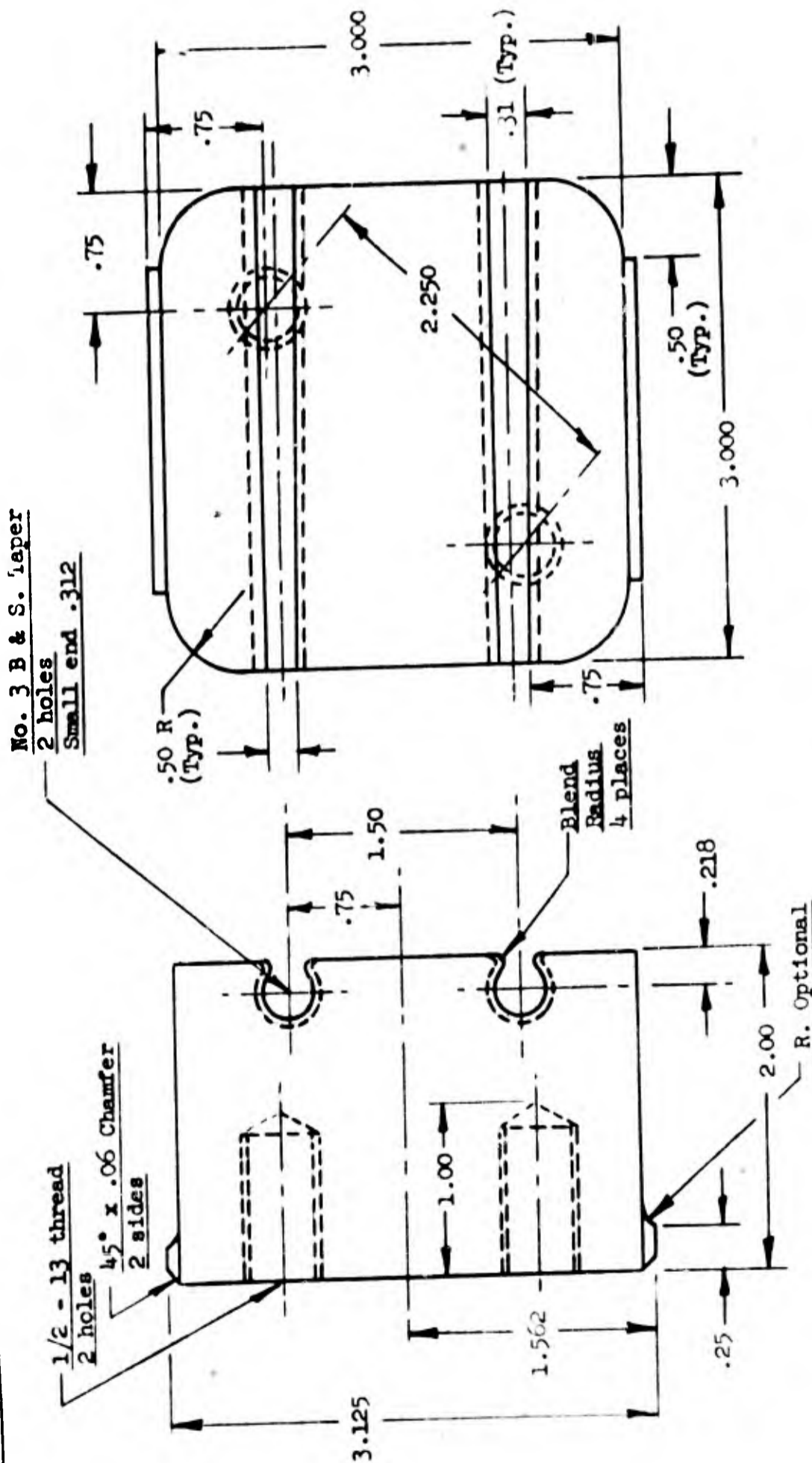


- NOTE:
1. Break sharp corners.
 2. This tool for Contract AF33(600)-22372.
 3. This area may be cleared on final fitting with lower die.

Fig. 4 - Single "Dovetail" extraction punch with recess dimensions as proposed by Wyman-Gordon - traced from Print No. 127643.

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No. 3 B & S. taper
 2 holes
 Small end .312

1/2 - 13 thread
 2 holes
 45° x .06 Chamfer
 2 sides

NOTE: 1. Break sharp corners. 2. This tool for Contract AF33(600)-22372.
 Fig. 6 - Cylindrical lug extraction punch - traced from Print No. 127648.

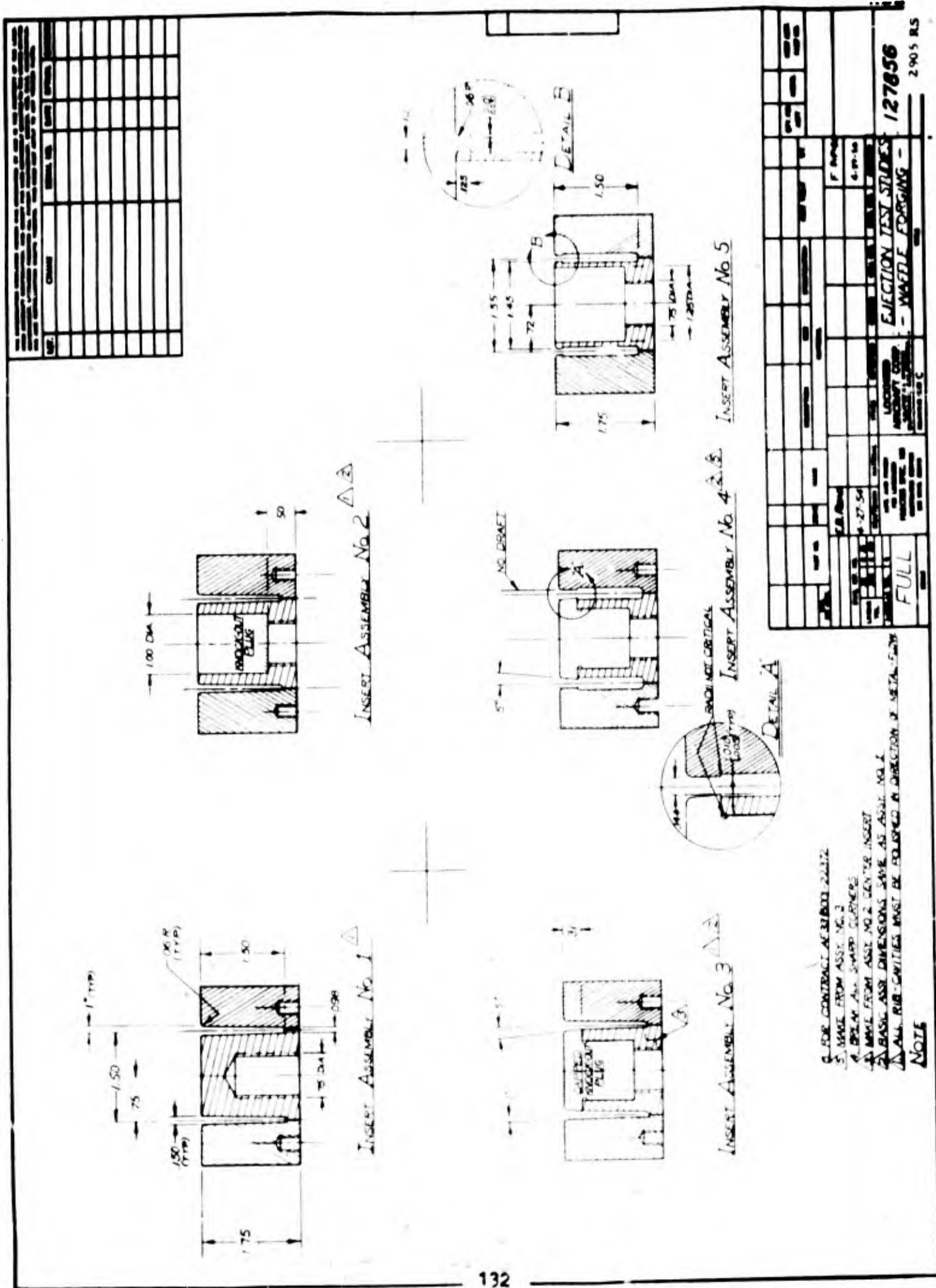


Fig. 7 - Sectional aspects of the die insert Nos. 1 through 5.

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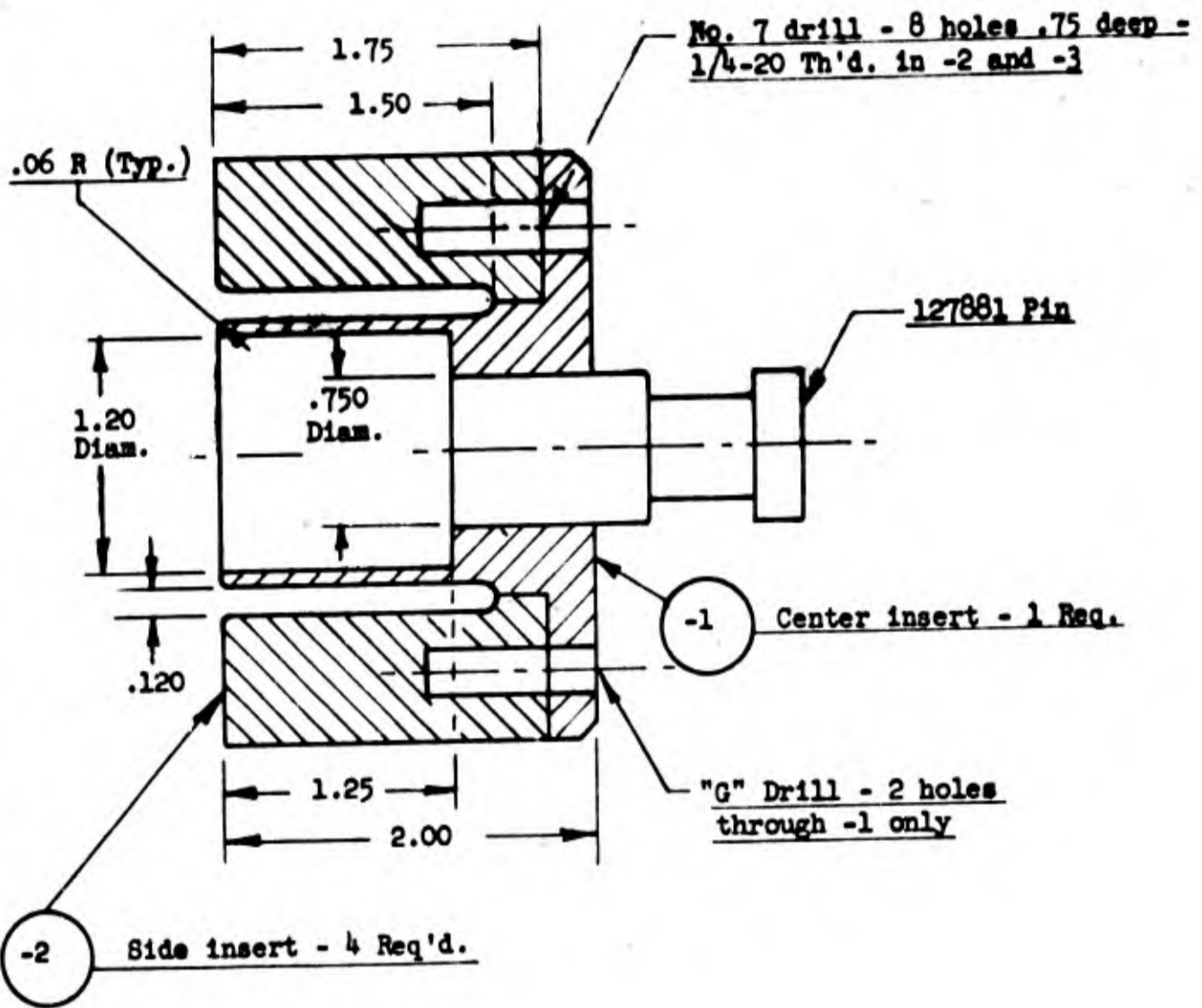


Fig. 8 - Nonextruding type insert assembly No. 6.

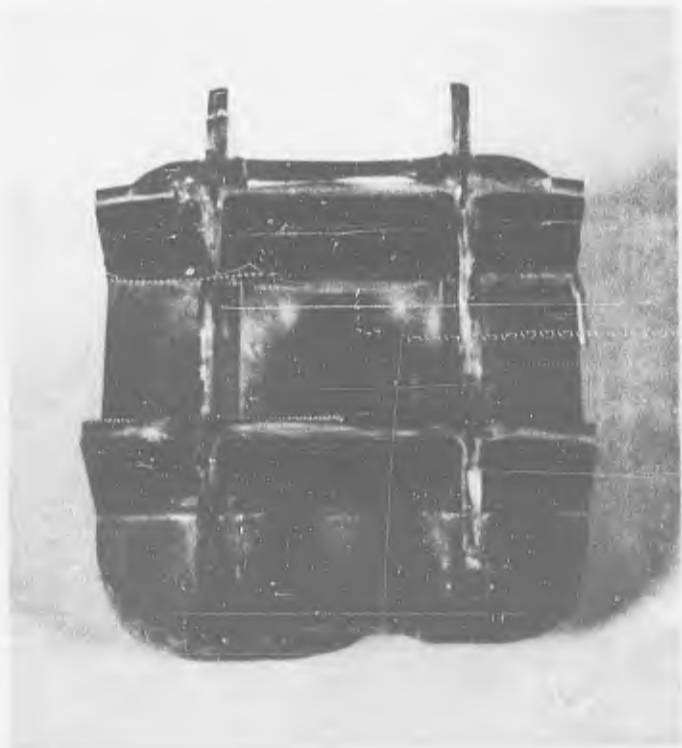
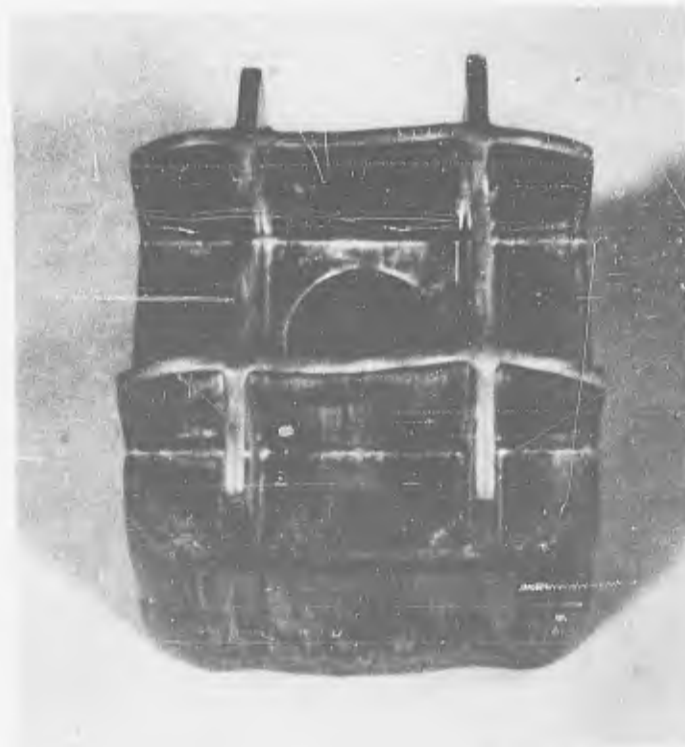
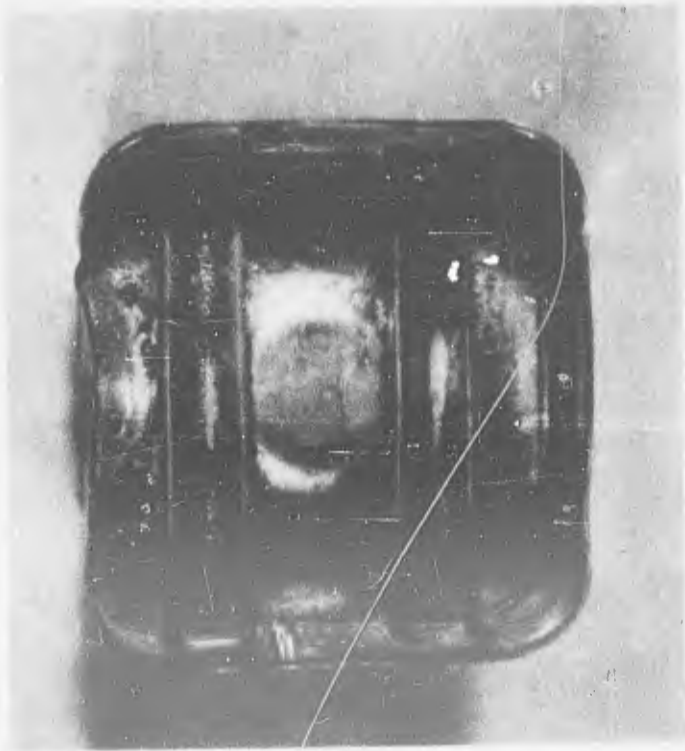


Fig. 9 - Upper and lower views of 7075 (75S) aluminum alloy forgings 29E (left) and 30E (right) made with the No. 2 insert assembly (see Fig. 7) and the double dovetail lifting lug punch (see Fig. 5). Extraction was not successful due to deformation of the lug overhang and subsequent use of the knockout pin produced severe distortion. (For forging details, see Table 1, Nos. 2 and 3).

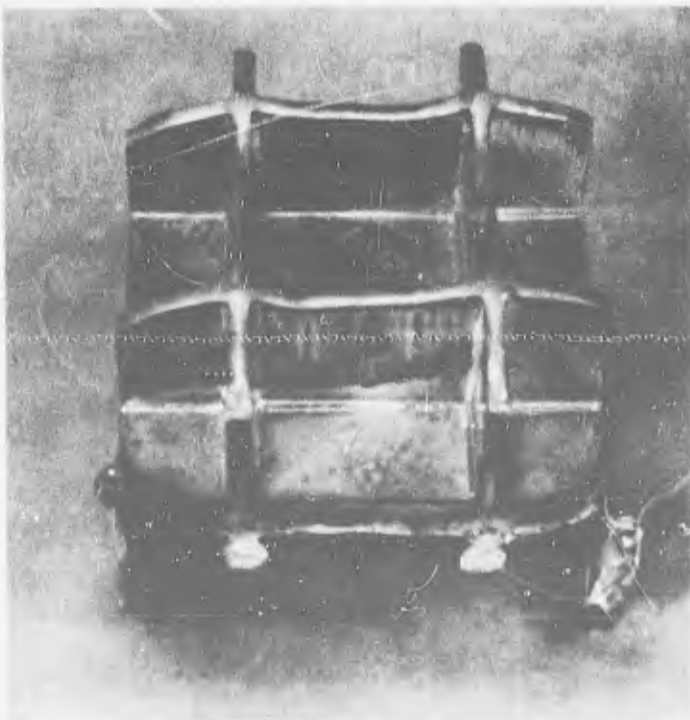
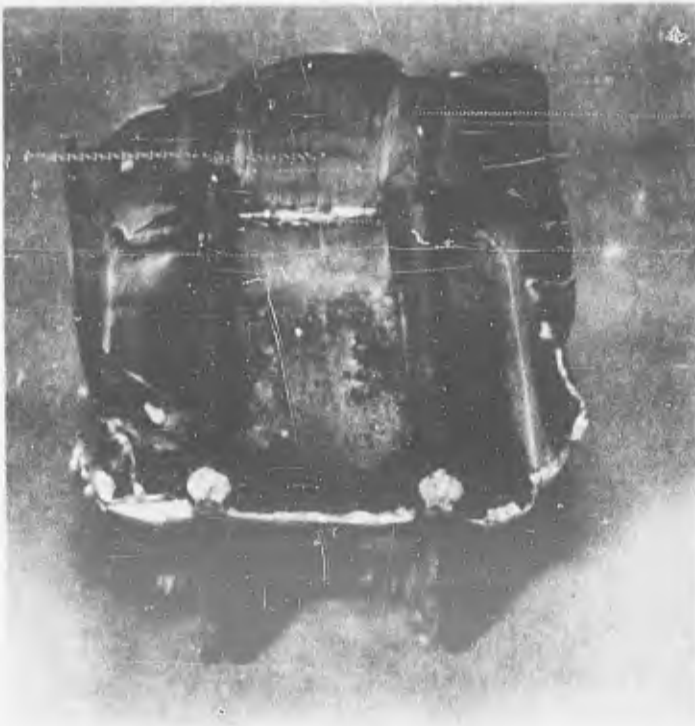
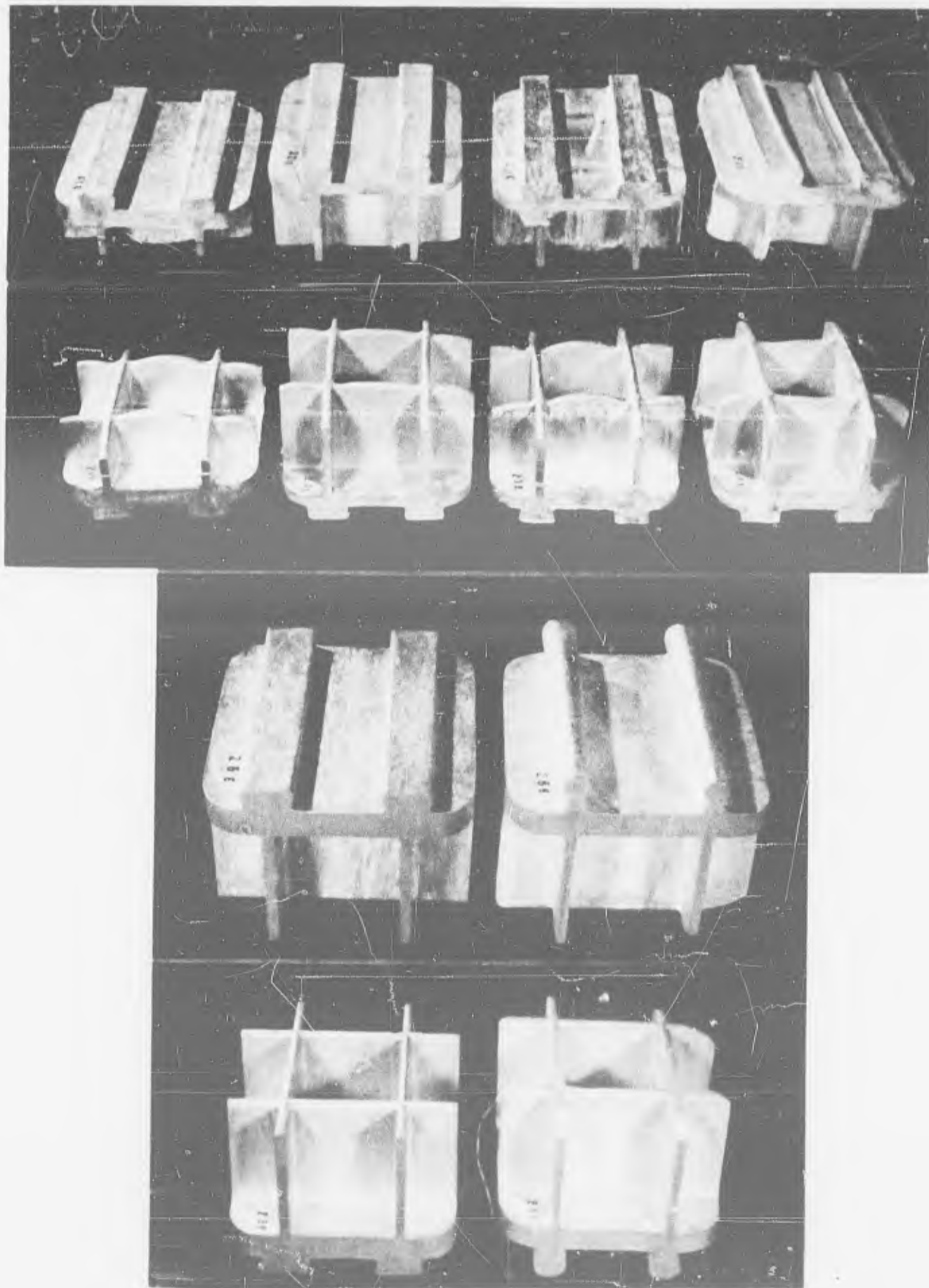
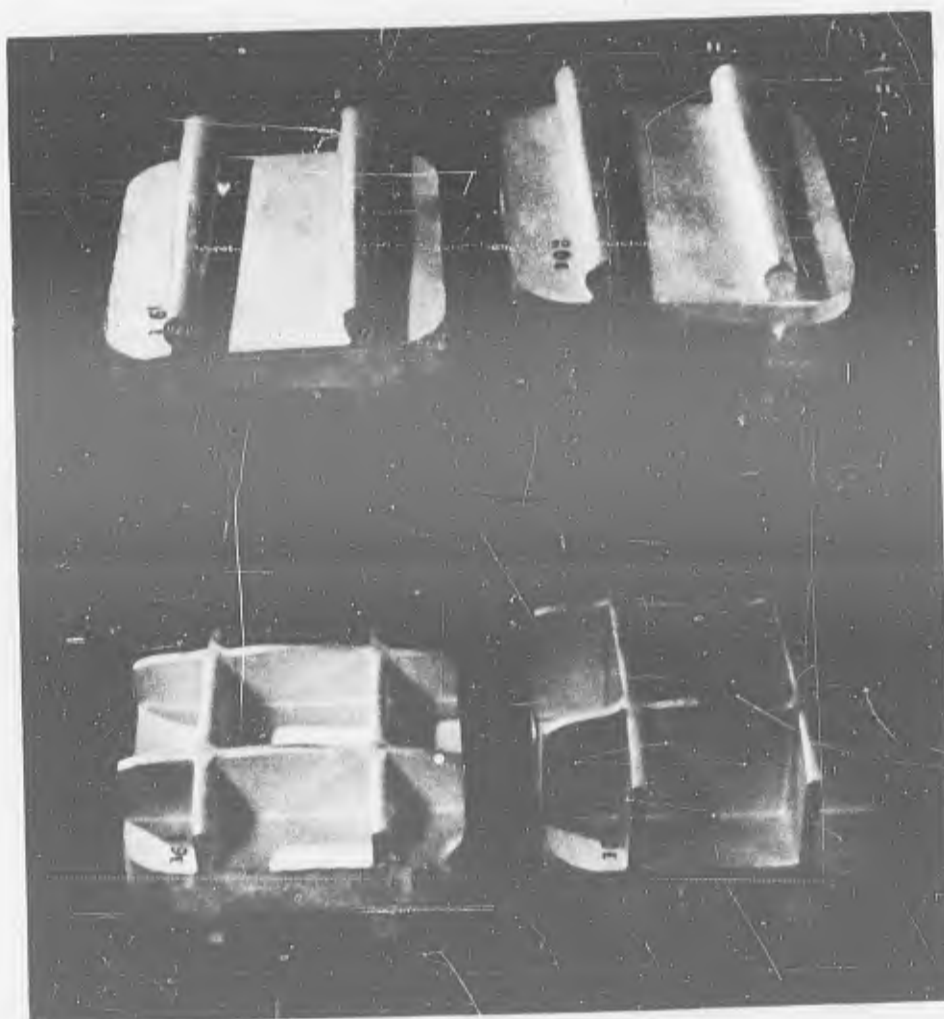


Fig. 10 - Upper and lower views of 7075 (75S) aluminum alloy forgings 31E (left) and 32E (right) made with the No. 1 insert assembly (see Fig. 7) and the round lifting lug punch (see Fig. 6). Extraction was satisfactory but produced slight distortion. (For forging details, see Table I, Nos. 4 and 5.)



METALLURGICAL RESEARCH.

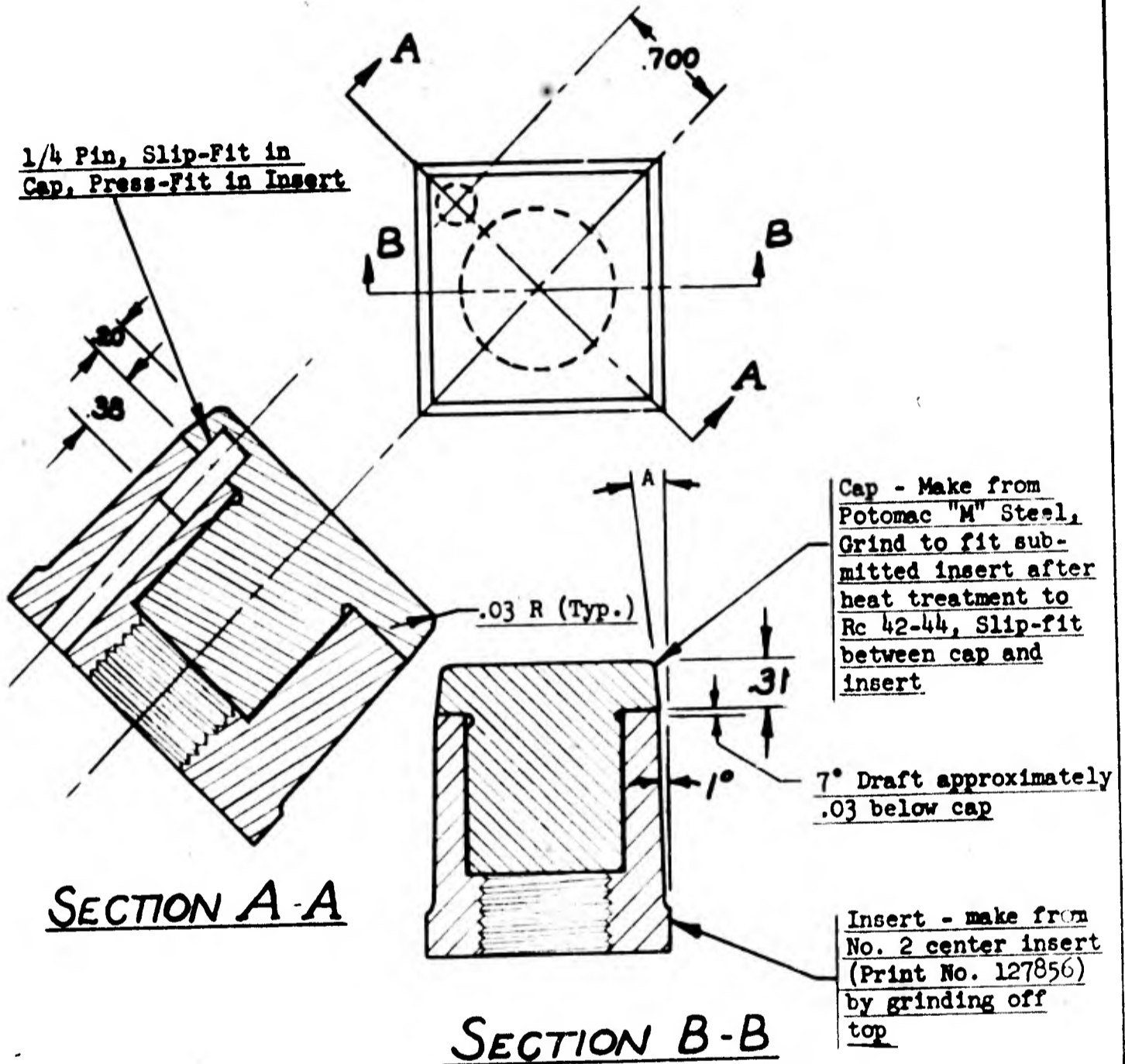
Fig. 11 - Upper and lower views of 7075 (75S) aluminum alloy forgings 21E through 26E made with the No. 6 draftless inserts and double lifting lug punches No. 3 and 4. (For forging details, see Table I, Nos. 6, 7, 8, 9, 10, and 13.)



 METALLURGICAL RESEARCH.

Fig. 12 - Upper and lower views of 7075 (75S) aluminum alloy forgings 19E and 20E made with the No. 6 draftless inserts and the No. 4 round lifting lug punch. (For forging details, see Table I, Nos. 11 and 12.)

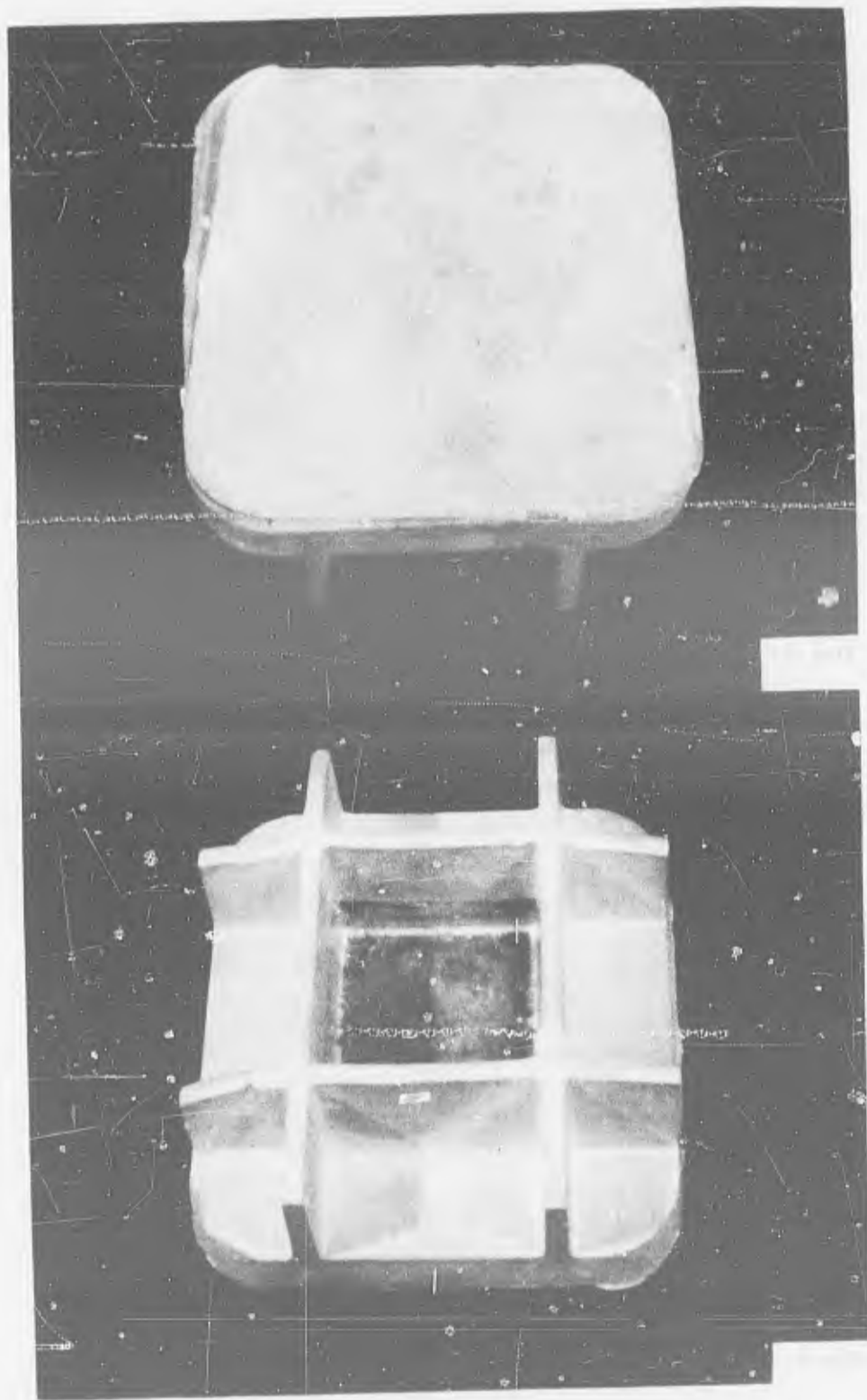
Contract AF33(600)-22372



NOTE: Overall height of assembly to be same as inserts now installed in waffle forging die in the 300 ton press.

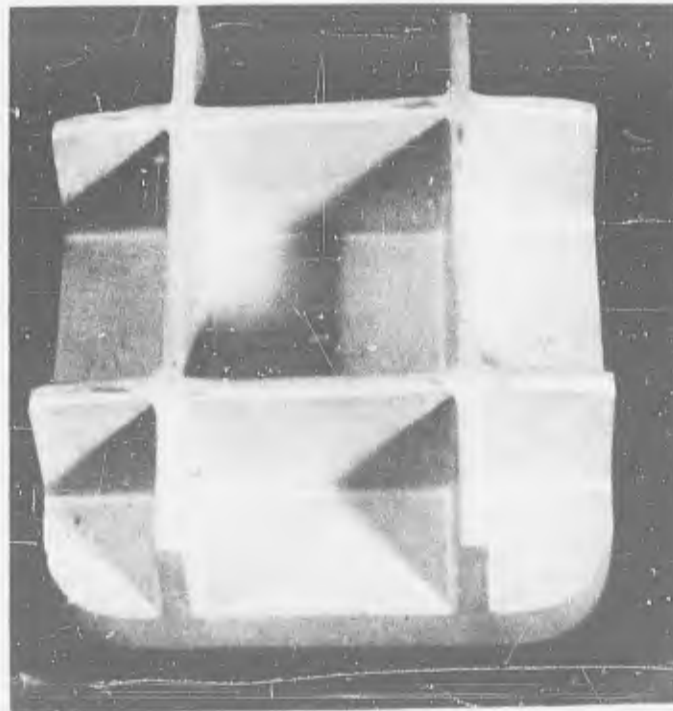
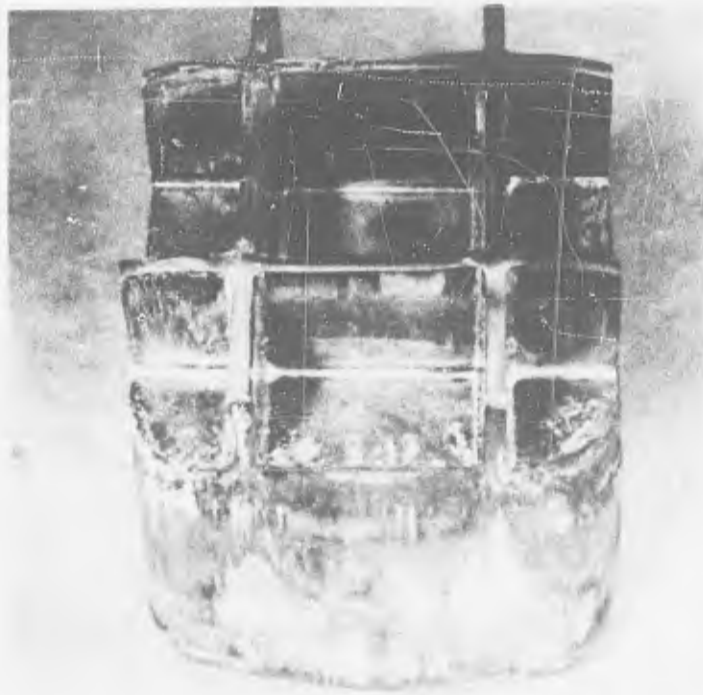
- A = 5° on No. 3 insert
- A = 7° on No. 3a insert

Fig. 13 - Mushroom cap ejector center insert.



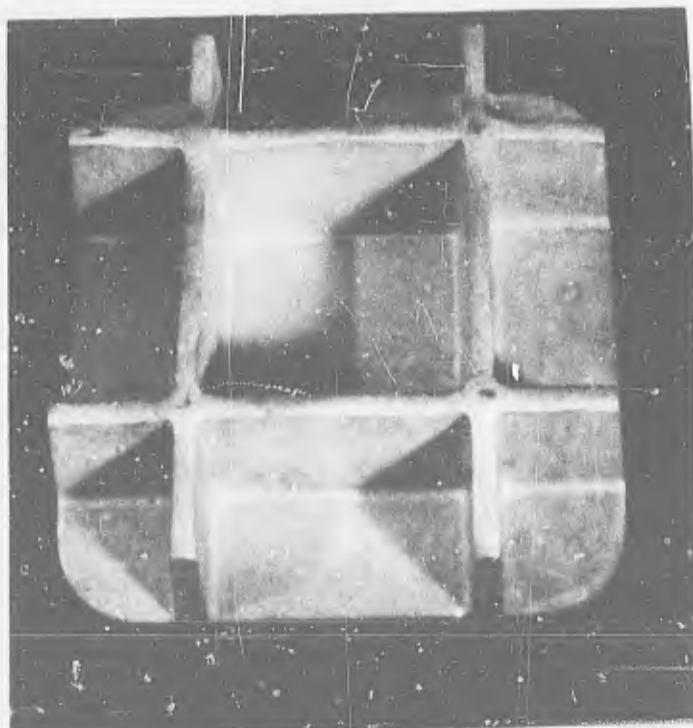
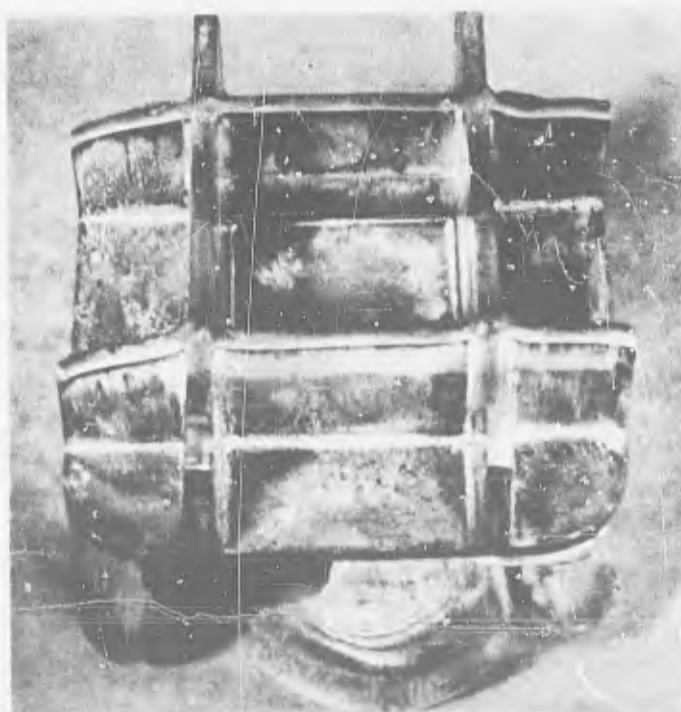
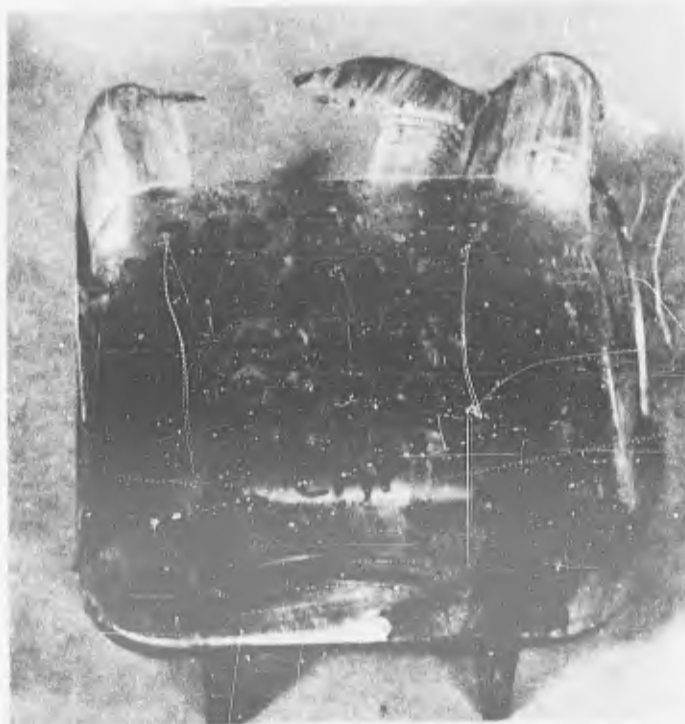
 METALLURGICAL RESEARCH.

Fig. 14 - Upper and lower views of 7075 (75S) Aluminum alloy forging 27E made with a flat punch and the No. 3 (5° cap draft) insert assembly (see Fig. 7 and 13). Part was removed from die with cap remaining in the center grid. Separation was accomplished with difficulty following .004 inch deep caustic etch. (For forging details, see Table I, No. 14.)



 METALLURGICAL RESEARCH.

Fig. 15 - Upper and lower views of 7075 (75S) aluminum alloy forging 33E "as forged" (left) and following flash removal and caustic etch (right). Part was made with a flat punch and the No. 3a (7° cap draft) insert assembly (see Figs. 7 and 13). Ejection was satisfactory but with slight distortion. (For forging details, see Table I, No. 15).




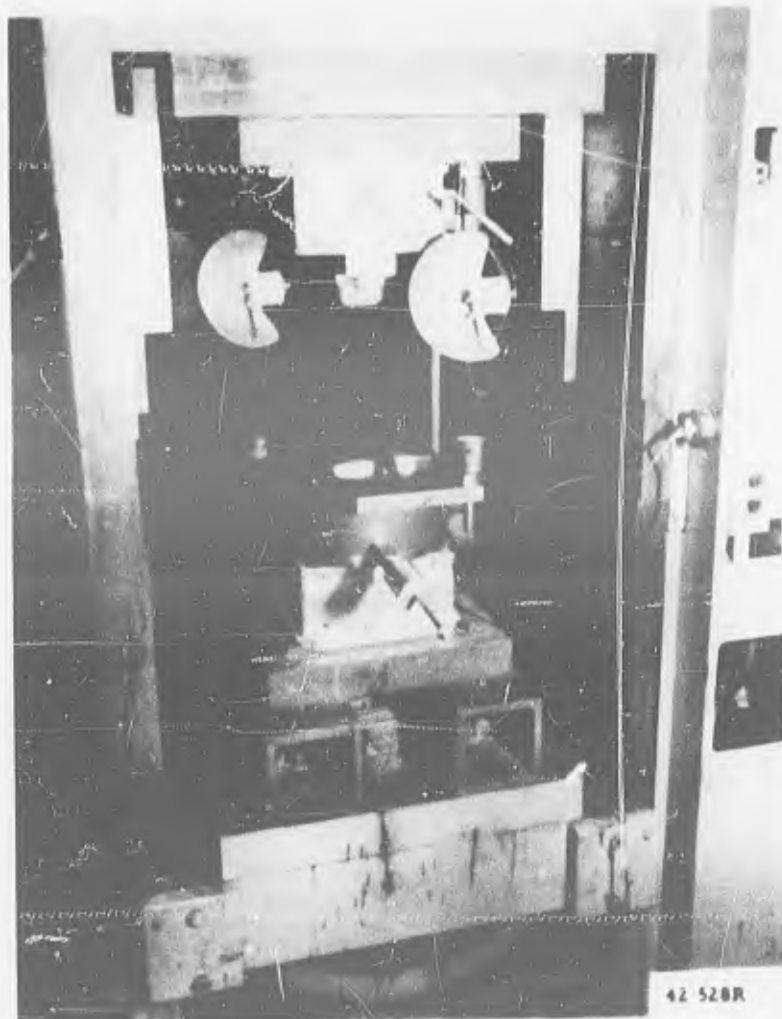
 METALLURGICAL RESEARCH.

Fig. 16 - Upper and lower views of 7075 (75S) aluminum alloy forging 34E "as forged" (left) and following flash removal and caustic etch (right). 7° "mushroom" cap ejection was satisfactory. (For forging details, see Table I, No. 16.)



LOCKHEED METALLURGICAL RESEARCH.

Fig. 17 - General view of 300 ton hydro-press with lifting plate dies installed. Note dynamometers used for measurement of part extraction forces.

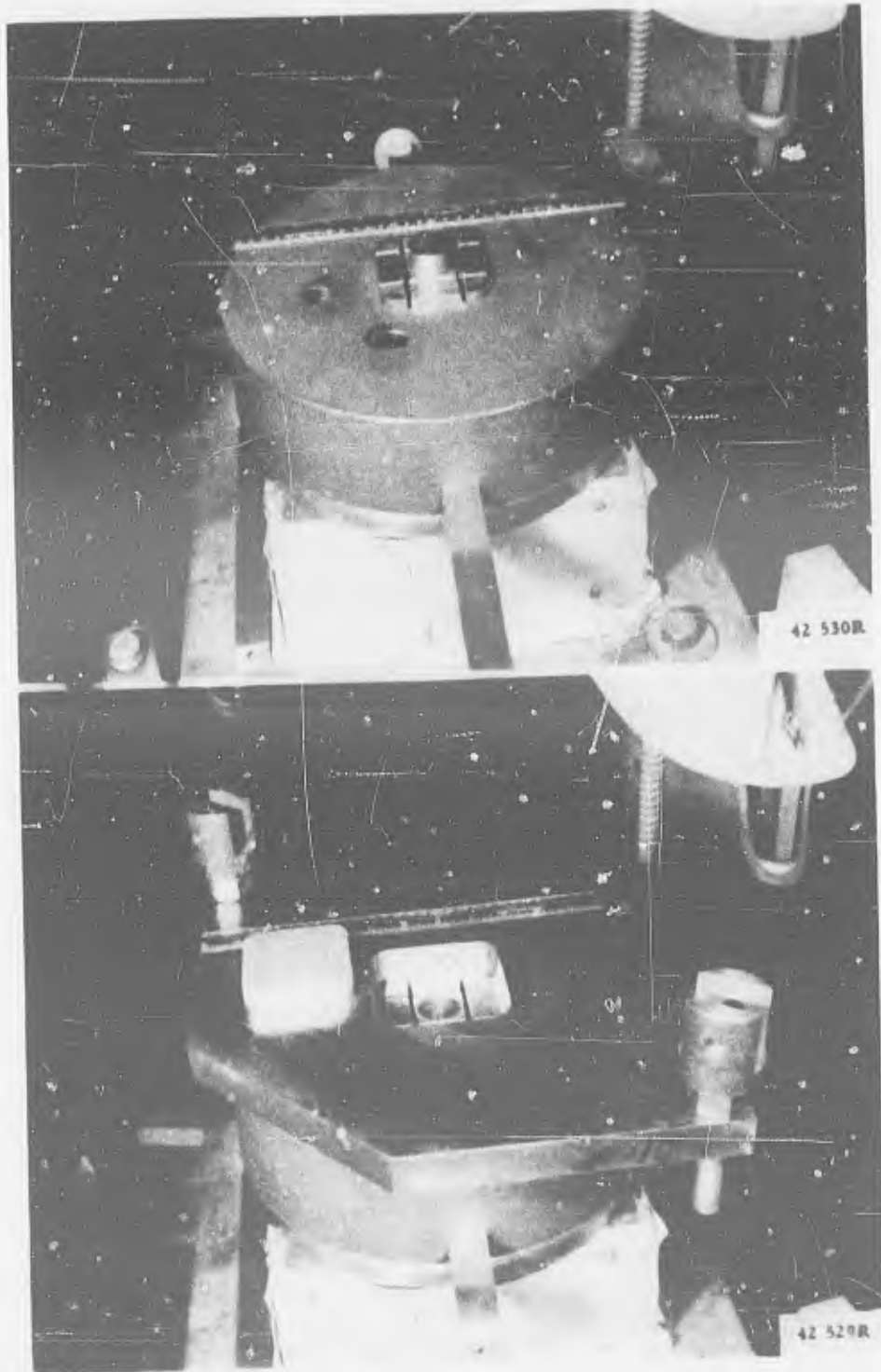
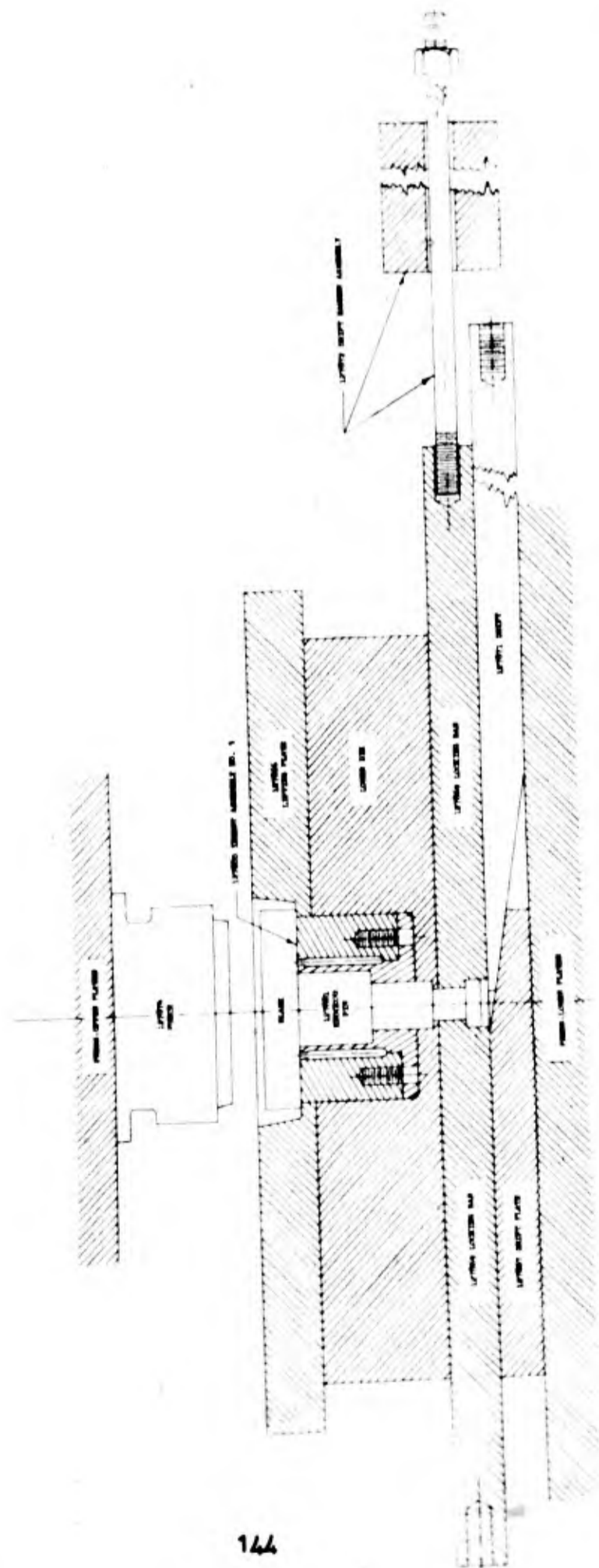


Fig. 18 - Close view of lifting plate die with plate removed (above) and with plate in position (below).



2902 RS

Fig. 19 - Sectional sketch showing relationship of die components for lifing plate tests conducted to measure part extraction forces.

PREPARED	NAME E. B. READ	DATE 5-27-54	LOCKHEED AIRCRAFT CORP.	PAGE 8
ENGINEERED	Traced by H. B. Wiley	12-13-54	TITLE: Print No. 127874 - Ejection Tests - Upper Die No. 5 - A. F.	MODEL: General
APPROVED	J. C. BERGER	5/28/54	Contract 33(600)-22372	REPORT NO. 10432

Material: 4340 steel - H.T. 180,000 - 200,000 psi Ft_u - 1 required

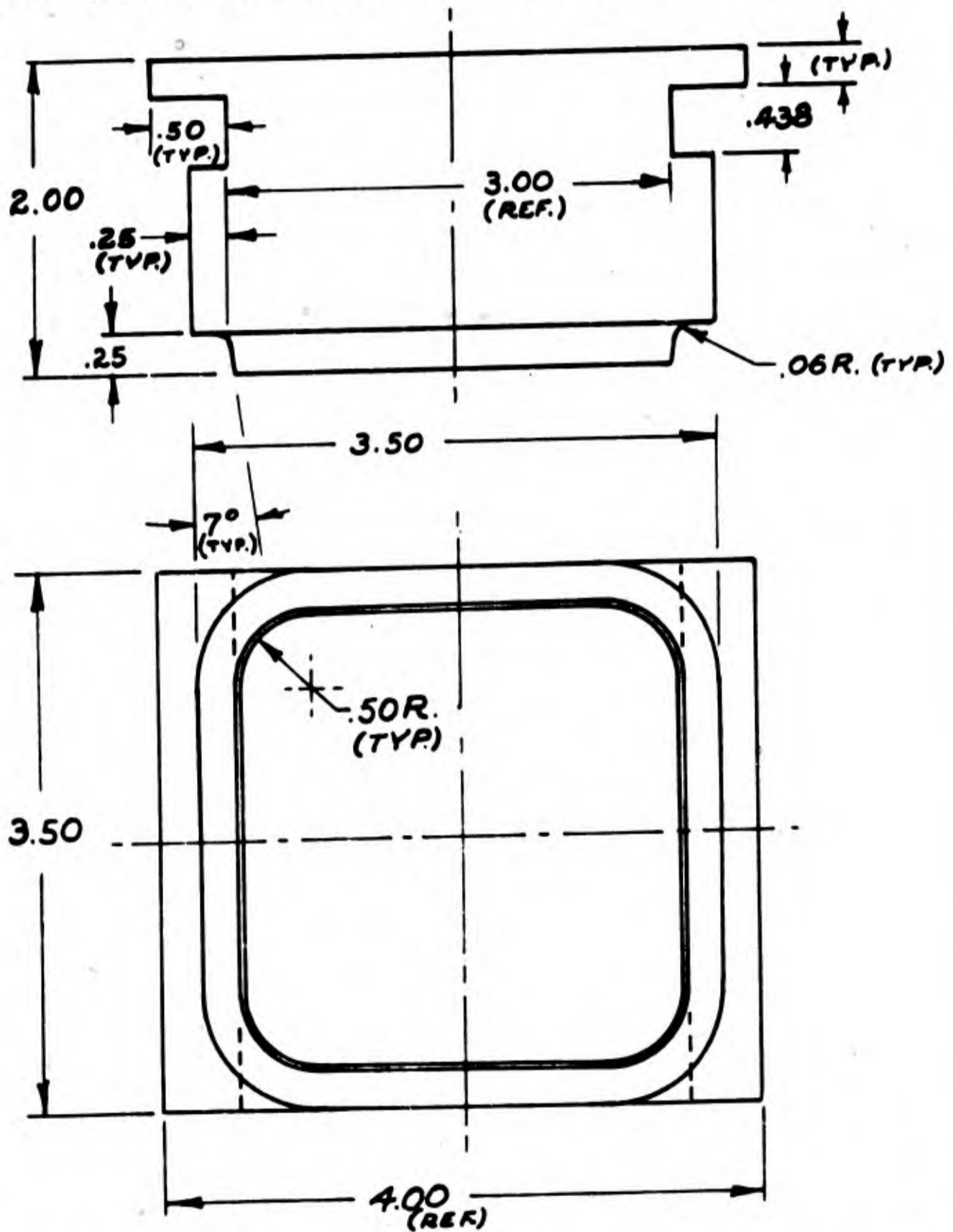
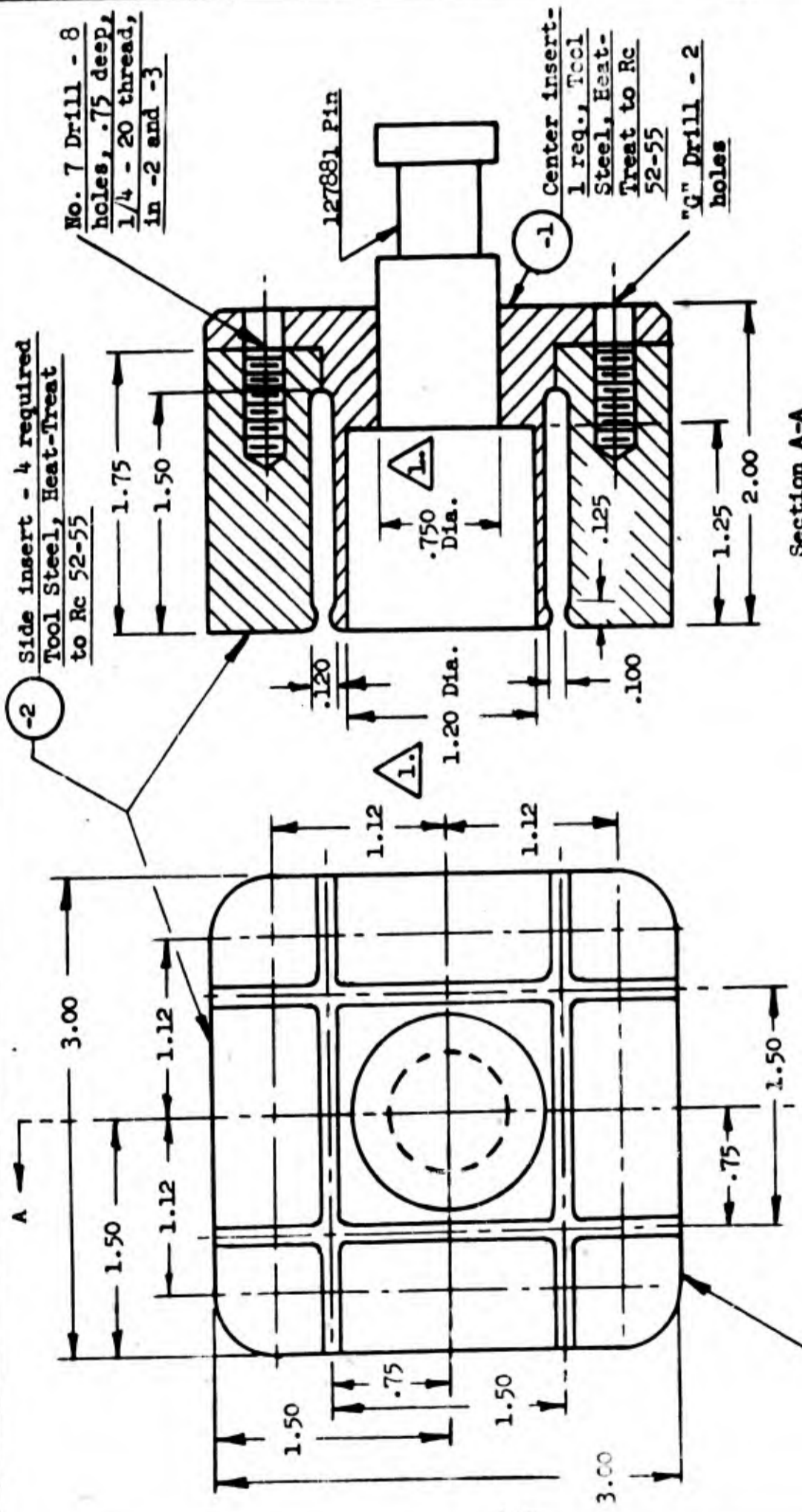


Fig. 20 - Flat punch with shoulder used to provide stiffening pad around edge of skin to prevent distortion during part extraction.



Section A-A

- NOTE:**
- 1. Sliding fit with 127881 pin.
 - 2. For Contract AF 33(600)-22375

- 3 Corner insert - 4 required Tool Steel, Heat-Treat to Rc 52-55

Fig. 22 - Ejection Tests - Insert assembly No. 5, traced from Print 127880.

PREPARED	NAME E. B. READ	DATE 5-27-54	LOCKHEED AIRCRAFT CORP.	PAGE V
CHECKED	Traced by H. B. WILEY	12-13-54	TITLE: Print No. 127069 - Ejection Tests - Insert Lock No. 1 - A.F.	MODEL General
APPROVED	J. C. BORGER	5-28-54	Contract 33(600)-22372	REPORT NO. 10,432

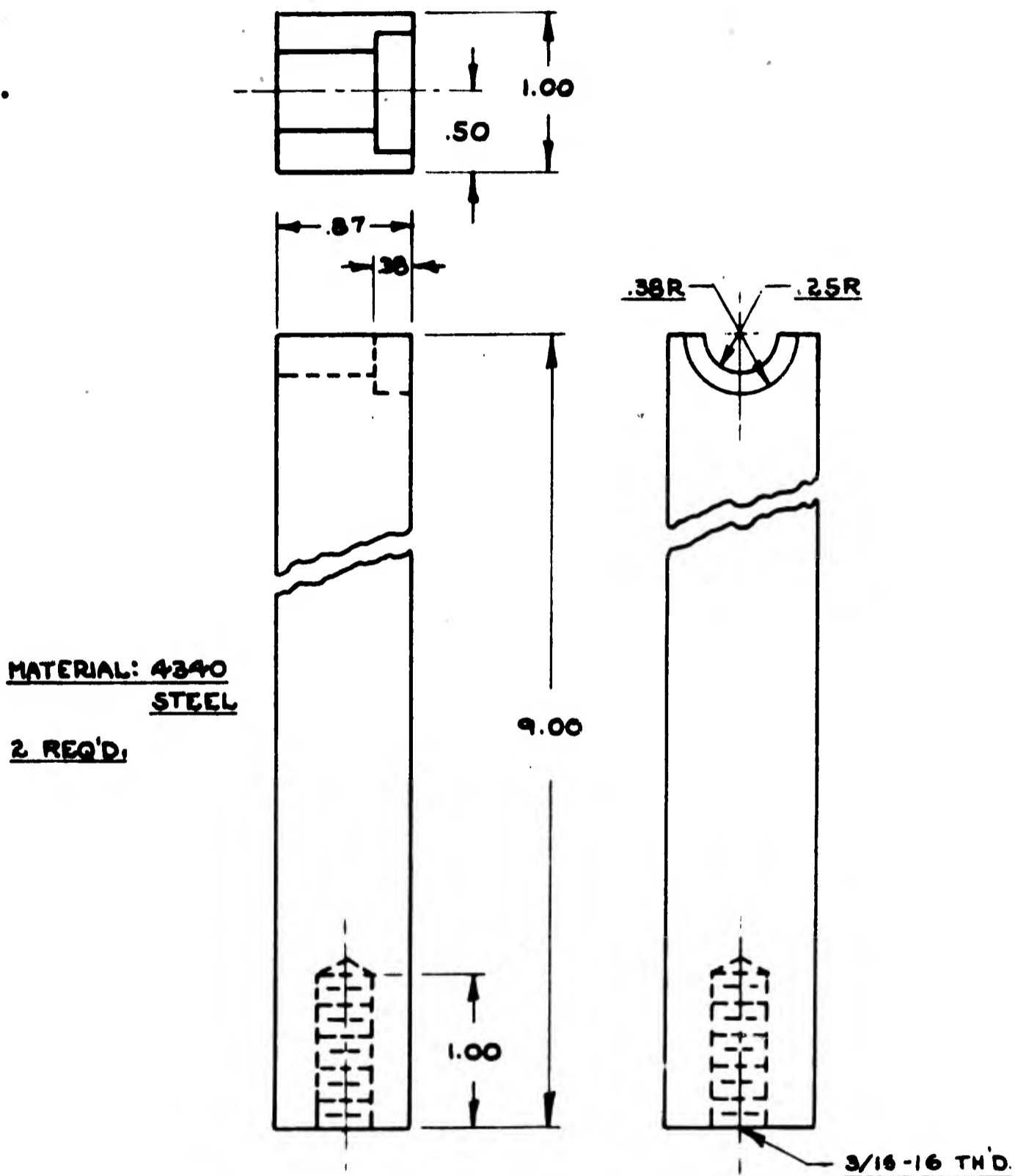


Fig. 23 - Detail of ejection pin lock.

PREPARED	NAME E. B. READ	DATE 5-27-54	LOCKHEED AIRCRAFT CORP.	PAGE W
EMBOSSED	Traced by A.B. Wiley	12-13-54	TITLE: Print No. 127371 - Ejection Tests - Lower Drift - A.F. Contract 33(600)-22372	MODEL General
APPROVED	J.C. BORGER	5-28-54		REPORT NO. 10,432

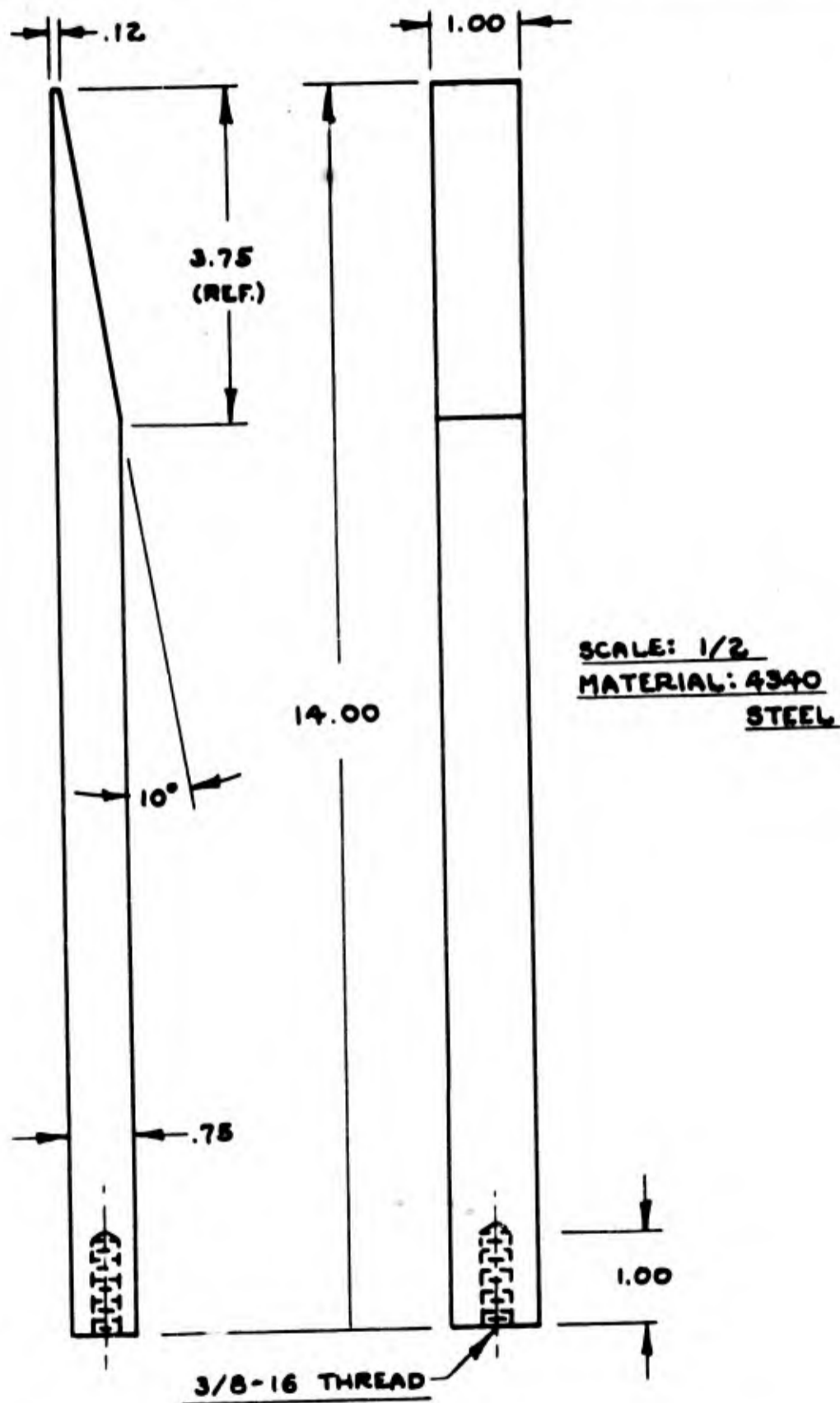
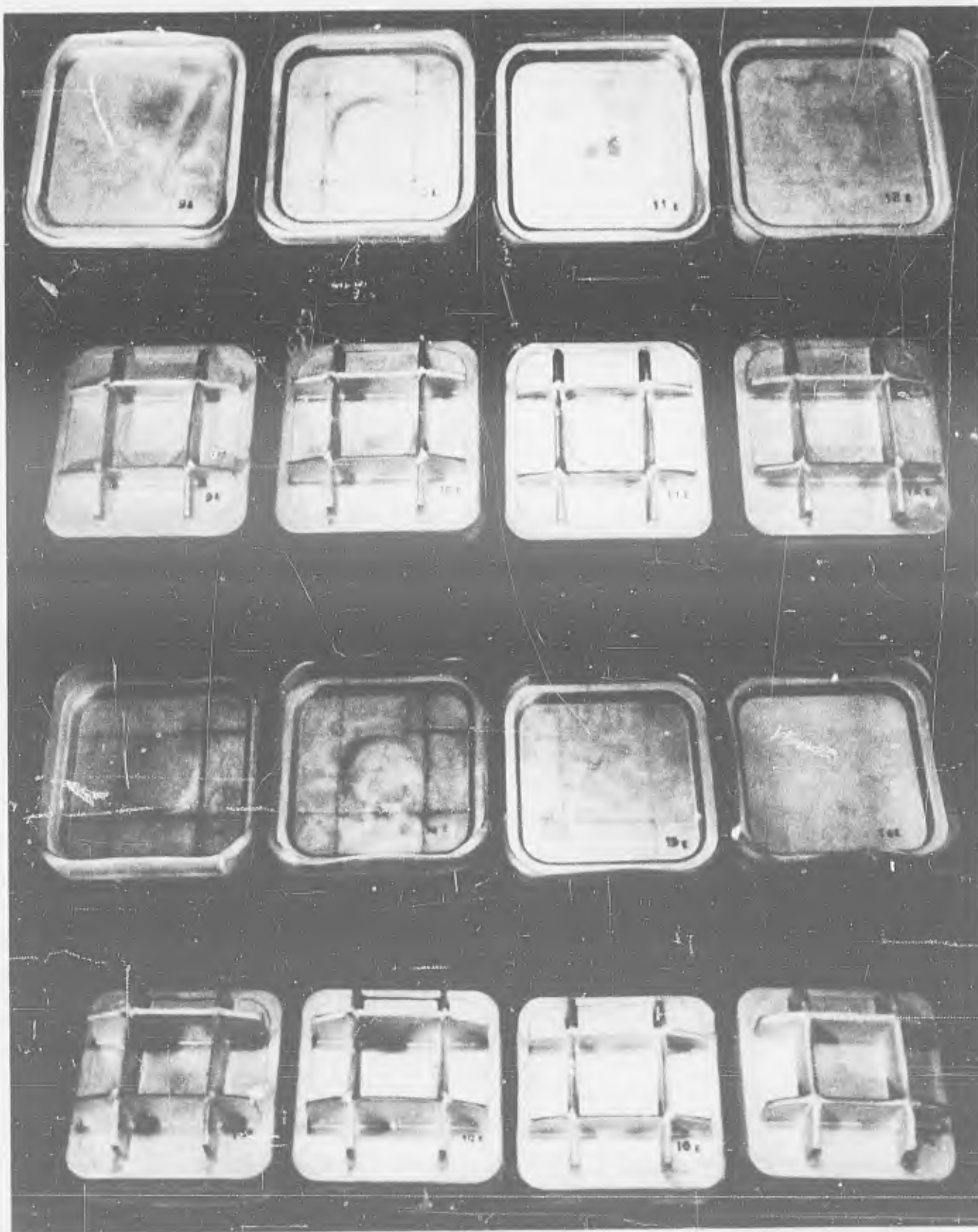


Fig. 24 - Detail of drift bar.



 METALLURGICAL RESEARCH.

Fig. 25 - Upper and lower views of 7075 (75S) aluminum alloy forgings 1E, 2E, 3E, 4E, 5E, 6E, and 8E made with the No. 5 punch (see Fig. 20), the No. 5 die inserts (see Fig. 7) and the lifting plate extraction device (Figs. 17, 18, 19, and 21.) For forging details, see Table I, Nos. 17 through 23.



 METALLURGICAL RESEARCH.

Fig. 26 - Upper and lower views of 7075 (75S) aluminum alloy forgings 9E through 16E made with the No. 5 punch (Fig. 20), the No. 5 die inserts (Fig. 7) and the lifting plate extraction device (Figs. 17, 18, 19, and 21). For forging details, see Table No. 1, Nos. 24 through 31.

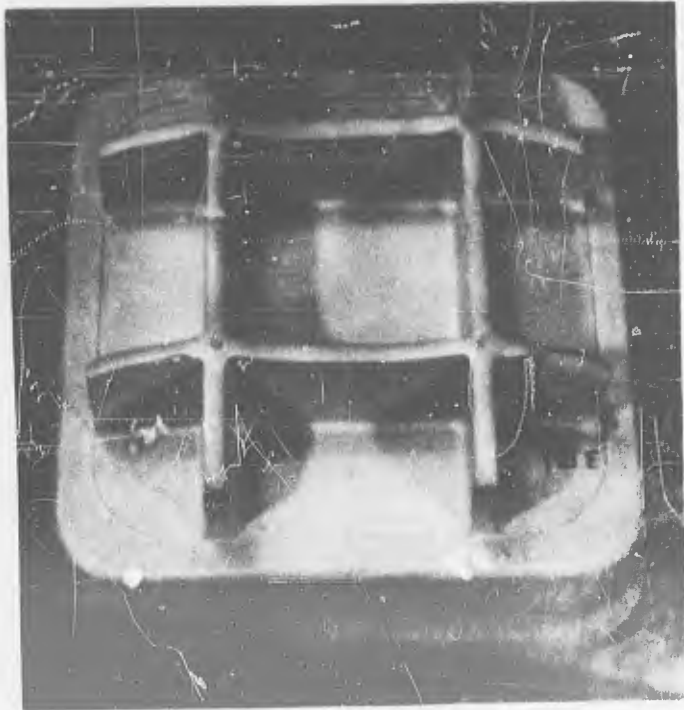
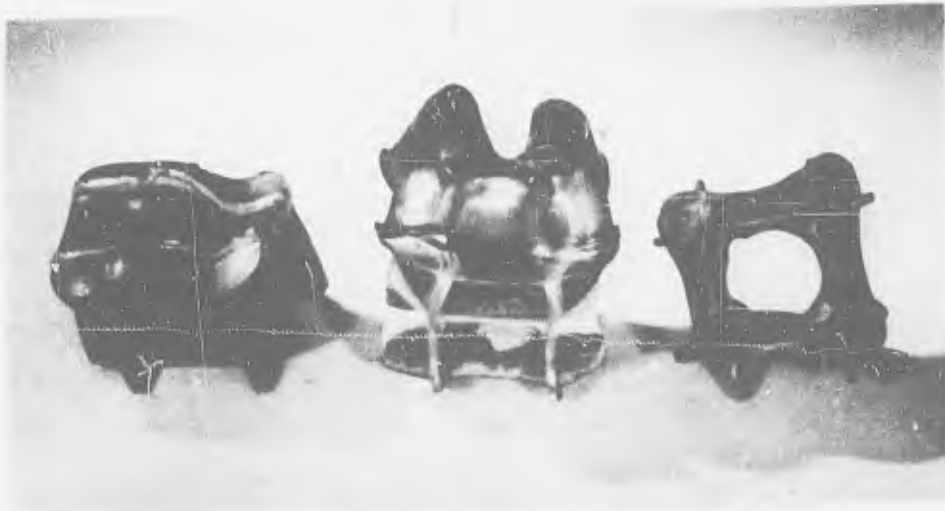


Fig. 27 - Upper and lower views of 7075 (75S) aluminum alloy forging 18E made with the No. 5 punch (Fig. 20), the No. 5 die inserts (Fig. 7) and the lifting plate extraction device (Figs. 17, 18, 19, and 20). For forging details, see Table I, No. 33.



METALLURGICAL RESEARCH.

Fig. 28 - General view of several parts showing severe distortion produced by sticking of one end or the center area during extraction.

APPENDIX V

LOCKHEED REPORT 9567

DEVELOPMENT OF FORGING TECHNIQUES FOR 75S ALUMINUM

ALLOY WAFFLE GRID TYPE INTEGRALLY STIFFENED PANELS

HORIZONTAL FILLET RADII--FLOW ACROSS DIE CAVITIES

MECHANICAL PROPERTIES

UNCLASSIFIED

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4 OF 5

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UNCLASSIFIED

A B S T R A C T

This report contains the results of tests conducted to determine the effects of horizontal fillet radii ranging from 0.030 to 0.375 inches on the forging characteristics of waffle grid type integrally stiffened 75S aluminum alloy test parts. Included are data for similar specimens showing the effects of lateral forging flow across die cavities. Tensile strength properties of heat treated and aged (75S-T6) skin material in areas containing transverse forged ribs are also presented.

This investigation was conducted at the request of the Production Design Engineering Department to provide information to be used for a portion of Air Force Contract AF33(600)-22327, "Development of Forged Waffle Type Integrally Stiffened Skin Panels", Phase II.

LOCKHEED AIRCRAFT CORPORATION
BURBANK, CALIFORNIA

REPORT NO. 9567
MODEL General
PART DATED 1

OBJECT:

- 1). To determine the effects of horizontal fillet radius variation on the forging characteristics and soundness of 75S aluminum alloy waffle grid type integrally stiffened skin panel test parts.
- 2). To establish the combined effects of horizontal fillet radius variation and lateral metal flow across forging die cavities on the soundness of 75S aluminum alloy integrally stiffened waffle grid type test specimens.
- 3). To obtain preliminary data indicating the mechanical properties of integrally stiffened wing panel skins in areas containing transverse forged ribs.

SUMMARY:

- A). Although the scope of the tests performed for this investigation does not permit the determination of exact limits of maximum obtainable rib heights for sound parts forged from various blank thicknesses with various horizontal fillet radii, it is indicated (Fig. 1) that slight improvement in forging characteristics accompanies increasing fillet radii within the range investigated (.030 to .375 inch).
- B). The use of undersized forging blanks permitting metal flow to occur in a direction parallel to the plane of the skin (Fig. 2) did not produce laps, seams, shear failures or other discontinuities at the junction of the skin and stiffener in any of the specimens prepared for this study. An asymmetrical rib tip form and forging flow pattern was produced in most cases in sections parallel to the direction of lateral flow (Figs. 13 through 18) and decreased rib heights resulted in "starved" areas (Figs. 6 through 10). In the most pronounced cases, the finished parts did not completely fill the die cavity in the direction of the free edge.
- C). The results of tensile tests (Table II) show that the yield stress and ultimate strength of the 75S-T6 integrally stiffened forged skins in areas containing transverse stiffeners (Fig. 19) compare favorably with the following Alcoa specified values* for 75S-T6 die forgings:

Yield Stress 65,000 psi
Ultimate Strength 75,000 psi
Elongation in 2 inches 10% (with grain)

*Alcoa Aluminum and Its Alloys, 1950, Table 31

SUMMARY: - cont.

The slightly low elongation values obtained for the test parts are attributed to the effects of coupon geometry for specimens containing the integrally forged rib and to the presence of essentially "short transverse" grain structure in the center of the specimens from which the ribs had been removed.

BACKGROUND:

The work described herein is a continuation of the integrally stiffened wing panel forging studies covered by the following Lockheed Reports:

1. L.R. No. 5942, "Preliminary Press Forging Investigation", by Wm. Schroeder, D. A. Webster and H. W. Grebe, dated 12-12-46.
2. L.R. No. 6202, "Progressive Forging of Integrally Stiffened Sheet", by Wm. Schroeder, dated 7-25-47.
3. L.R. No. 6833, "Progressive Forging of Integrally Stiffened Sheet - 9.6 inch Die", by Wm. Schroeder, dated 1-3-49.
4. L.R. No. 6919, "Progress Report - First Phase - Research Program for Forging Integrally Stiffened Panels", by G. W. Papen, dated 3-14-49.
5. L.R. No. 6955, "Research Program for Forging Integrally Stiffened Panels - Progress Report No. 2", by G. W. Papen, dated 4-11-49.
6. L.R. No. 7192, "Report on Results of Second Phase of Integrally Stiffened Panel Forging Research Program", by G. W. Papen, dated 11-10-49.
7. L.R. No. 7192, Vol. 2, "Supplementary Report on Results of Second Phase of Integrally Stiffened Panel Forging Research:", by Wm. Schroeder, dated 2-15-50.
8. L.R. No. 7192, Vol. 3, "Final Report on Results of Second Phase Integrally Stiffened Panel Forging Research Program", by Wm. Schroeder, dated 3-17-50.
9. L.R. No. 7768, "Final Report on Research Program for Forging Integrally Stiffened Panels", by Wm. Schroeder and G. W. Papen, dated 12-20-50.

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BACKGROUND: - cont.

10. L.R. No. 8746, "Development of Forging Techniques for 75S Aluminum and 52S Magnesium Alloy Waffle Type Integrally Stiffened Panels - Phase I - Effects of Temperature, Pressure, Dwell Time and Blank Thickness on Stiffener Height and Occurrence of Forging Defects", by F. C. Pipher and H. B. Wiley, dated 8-26-52.
11. L.R. 9069, "Development of Forging Techniques for 75S Aluminum and 52S Magnesium Alloy Waffle Type Integrally Stiffened Panels - Phase II - Effects of Stiffener Thickness on the Forgeability of Integrally Stiffened Waffle Type Panels from 52S Magnesium and 75S Aluminum Alloys", by W. A. Brown and H. B. Wiley, dated 12-31-52.
12. L.R. No. 9214, "Development of Forging Techniques for 75S Aluminum and 52S Magnesium Alloy Waffle Type Integrally Stiffened Panels - Phase III - Effects of 800 to 950°F Fabrication Temperature on Stiffener Height and Microstructure of 75S Aluminum Alloy Parts", by W. A. Brown and H. B. Wiley, dated 6-18-53.
13. L.R. No. 9425, "Shear Tests of Waffle Grid", by M. W. Mueller, A. F. Ensrud and T. J. Stapleton.

The present investigation, involving the use of small scale (3.125 inch square) test parts, was initiated to provide preliminary data which may be useful for future part and die design for full scale 75S aluminum alloy waffle grid type integrally stiffened wing panel forgings scheduled for fabrication under the referenced Air Force Contract.

TOOLING:

The electrically heated forging dies, .030 inch horizontal fillet radius waffle grid inserts and automatic temperature control equipment described and illustrated in L.R. 8746 were used in the Lockheed Engineering Research Laboratory 300 ton hydropress with three additional sets of inserts (Fig. 3) to produce the parts required for this investigation.

PROCEDURE AND RESULTS:

GENERAL:

The forgings produced for this series of tests (Specimens 197 through 234 - Figs. 4 through 10) were made using the technique described in L.R. 8746.

PROCEDURE AND RESULTS:

GENERAL: - cont.

All surfaces of the blanks and working areas of the dies were lubricated with colloidal graphite (dispersion No. 2404, Acheson Colloids Corporation, Port Huron, Michigan). The flat blanks were preheated to 800°F in the forging dies under low pressure and fabricated with either 200 or 300 tons load applied for 60 seconds.

HORIZONTAL FILLET RADII:

Specimens 187 through 201 and 228 through 230 illustrated in Figs. 4, 5 and 10 were forged from flat 3.125 inch square, 75S aluminum alloy blanks, .200 to 1.000 inch thick, to obtain preliminary information indicating the effects of various horizontal fillet radii on fabricating characteristics and the occurrence of defects in waffle grid type integrally stiffened skin panel test parts. The data obtained and related forging conditions for the specimens prepared are outlined in Table I. The results are plotted and compared with previously obtained values for .030 inch horizontal fillet radii (L. R. 8746) in Fig. 1.

Photomicrographs illustrating grain flow structure and defects in the sections prepared (B-B of Figs. 4, 5 and 10) are presented in Figs. 11, 12, 13, 17 and 18.

LATERAL FLOW ACROSS STIFFENER CAVITIES:

To obtain preliminary information indicating the permissible lateral flow for waffle grid type integrally stiffened forgings having various horizontal fillet radii, undersized blanks were prepared and forged as shown in Fig. 2.

Specimens 202 through 227, illustrated in Figs. 6 through 9, were produced under the conditions and with the results listed in Table I.

Inasmuch as the use of undersized blanks alone did not cause shear failure at the rib base for any parts in the above series, specimens 231 through 234 were forged under more severe conditions using undersized blanks and a separate punch undercut .125 in. which allowed material to escape vertically at the part edge and produce the skin surface "flash" shown in the lower photograph of Fig. 10. The results and related forging conditions for these parts are presented in Table I. Photomicrographs illustrating defects, asymmetrical rib tip form and asymmetrical flow patterns for all parts made with undersized blanks are shown in Figs. 13 through 17.

PROCEDURE AND RESULTS: - cont.

MECHANICAL PROPERTIES:

To provide preliminary data indicating the probable strength and elongation values which may be expected for integrally stiffened 75S-T6 aluminum alloy forged skins in areas containing transverse stiffeners, tensile tests were conducted by the Lockheed Process Control Laboratory* on a series of 1.00 inch gage length coupons (Table II) machined from forged test parts from the positions shown in the upper photograph of Fig. 10.

The tensile specimens were cut from sound parts having various horizontal fillet radii and relatively thin "as forged" skin thicknesses obtained from this and previous studies (L.R. 8746) and were tested both with and without the stiffeners as indicated in Table II and illustrated in Fig. 19. All coupons were reduced to approximately .055 inches in thickness by machining away the skin surface.

DISCUSSION:

HORIZONTAL FILLET RADII:

The results of previous studies involving the use of .030 inch fillet radii have shown that "suck in" type defects similar to those present in Specimens 187, 188 and 189 of Fig. 11 are the limiting factor preventing fabrication of integrally stiffened parts with sufficiently thin "as forged" skins for structurally efficient wing panels. It was therefore considered possible that the change of forging flow conditions accompanying use of fillet radii larger than .030 inch might increase "suck in" tendencies and result in even less desirable skin thickness limits than heretofore determined. Although the data obtained from Specimens 187 through 201 are not sufficient to provide a family of curves showing the occurrence of defects for each fillet radius investigated, the preliminary information plotted in Fig. 1 is considered significant inasmuch as no increase in minimum forgable skin thickness is indicated for radii as large as .375 inch.

LATERAL FLOW ACROSS STIFFENER CAVITIES:

It is known that in the design of dies for conventional forgings special consideration is required to avoid internal shear in finished parts resulting from excessive metal flow across

* Process Control Laboratory Reports 23060 and 23562.

DISCUSSION:

LATERAL FLOW ACROSS STIFFENER CAVITIES: - cont.

rather than into rib or stiffener cavities. Since the use of undersized blanks for full scale integrally stiffened panel forgings will allow an undetermined amount of lateral flow across the base of stiffeners located near and parallel to the part edges, it was indicated that the effects of this condition should be investigated. However, test part blanks as much as 1.125 inch under size were forged as illustrated in Fig. 2 without occurrence of the shear type failures associated with somewhat similar metal flow patterns in conventional forgings. In an attempt to produce a more severe condition, a floating punch having .125 inch cut from one side was machined and used with undersized blanks in the 3.125 inch square cavity of the test die to allow metal escape in the direction of lateral flow (Fig. 10). This attempt was also unseccessful in producing the predicted shear failures at the base of the test part stiffeners.

The immunity of the specimens fabricated to defects resulting from lateral flow is believed due to the ratio of the rib and skin thicknesses as well as the relative thinness of both members. In the case of the parts made with full sized punch which did not allow escape of forging material on die closure (Fig. 2) it appears that because of the narrow rib opening afforded by the part design, lateral flow in the plane of the skin was nearly completed before filling of the stiffener cavity started. Thus truncation of the rib tip took place during the early stages of the forging punch stroke but the remainder of the rib filled the stiffener cavity after the undersized blank had moved laterally to fill or nearly fill the skin portion of the die cavity. Final stages of the forging stroke appear to have produced flow conditions similar to those for full sized blanks of the same volume.

The specimens made with the undersized punch which did not provide "trapping" of the blank material at the part edge in the direction of lateral flow appear to have been affected by the thinness of the skin and escape aperture. The internal flow friction increases quite rapidly with decrease in skin thickness (L.R. 5942) and it is believed that in this case the friction forces acted in much the same manner as the completely closed die to greatly reduce lateral movement and promote flow into the stiffener cavity during the final portion of the forging stroke.

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DISCUSSION:- cont.

On the basis of the foregoing observations it is reasoned that shear discontinuities will only occur across the base of stiffeners when the lateral and vertical openings are proportioned to permit simultaneous forging flow in both directions. Since the subject parts are limited by "suck in" defects to as forged skin thicknesses greater than rib thicknesses it would appear that lateral flow will proceed almost to completion in closed dies before the stiffeners acquire appreciable height.

HBW:bls

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TABLE I
INTEGRALLY STIFFERED WAFFLE GRID TYPE FORGING TEST DATA FOR 75S ALUMINUM ALLOY PARTS
MADE AT 800°F WITH PRESS PRESSURE APPLIED FOR 60 SECONDS

Speci- man Number	Horizontal Fillet Radius (in.)		Blank Dimensions		Press Load (Tons)	Forged Skin Thick- ness (in.)	Rib Height		D E F E C T S			Part Quality	
	.120	"	Thick- ness (in.)	Width (in.)			Max. (in.)	Min. (in.)	Visual Inspection	Metallographic Inspection			Part Quality
										Macro (25X)	Micro (200X)		
187	.120	"	.200	Full	300	.0812	1.17	0.98	Lap	--	Unsound		
188	"	"	.250	"	"	.1457	1.08	1.00	"	--	"		
189	"	"	.375	"	"	.2116	1.48	1.48	None	None	Sound		
190	"	"	.500	"	"	.3394	1.35	1.17	None	Rough	"		
191	.250	"	.250	"	"	.1022	1.26	1.10	None	None	"		
192	"	"	.312	"	"	.1938	1.19	1.08	"	"	"		
193	"	"	.375	"	"	.2635	1.36	1.21	"	"	"		
194	"	"	.500	"	"	.3650	1.35	1.18	"	"	"		
195	"	"	.500	"	200	.4142	0.85	0.76	"	"	"		
196	"	"	.625	"	"	.4942	1.20	1.08	"	"	"		
197	"	"	1.00	"	"	.8683	1.18	1.10	"	"	"		
198	.375	"	.312	"	"	.1888	1.04	0.88	Marking	Roughness	"		
199	"	"	.375	"	"	.2594	1.00	0.92	"	None	"		
200	"	"	.500	"	"	.3788	1.20	1.08	None	"	"		
201	"	"	1.000	"	"	.8557	1.23	1.17	"	"	"		
202	.030	"	.250	2.50	300	.1275	0.83	0.60	Strong Marking	Lap	Unsound		
203	"	"	.312	"	"	.1568	1.10	0.88	"	Roughness	Sound		
204	"	"	.375	"	"	.1883	1.22	1.00	"	"	"		
205	"	"	.312	2.00	"	.1057	0.92	0.68	"	Lap	Unsound		
206	"	"	.375	"	"	.1452	1.04	0.61	Marking	Roughness	Sound		
207	"	"	.500	"	"	.2148	1.06	0.83	None	None	"		
208	.120	"	.250	2.50	200	.1065	0.87	0.54	Strong Marking	Lap	Unsound		
209	"	"	.312	"	"	.1730	0.84	0.62	Marking	Roughness	Sound		
210	"	"	.500	"	"	.3235	0.74	0.65	"	None	"		
211	"	"	.625	"	"	.3931	0.88	0.75	None	"	"		

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TABLE I - cont.
INTEGRALLY STIFFENED WAFFLE GRID TYPE FORGING TEST DATA FOR 75S ALUMINUM ALLOY PARTS
MADE AT 800°F WITH PRESSURE APPLIED FOR 60 SECONDS

Specimen Number	Horizontal Fillet Radius (in.)	Blank Dimensions		Press Load (Tons)	Forged Skin Thickness (in.)	Rib Height		D E F E C T S				Part Quality
		Thickness (in.)	Width (in.)			Max. (in.)	Min. (in.)	Visual Inspection	Metallographic Inspection		Sound	
									Macro (25X)	Micro (200X)		
212	.120	.312	2.00	200	.1245	0.78	0.47	Marking	None	None	Sound	
213	"	.375	"	"	.1620	0.80	0.60	"	Roughness	"	"	
214	"	.625	"	"	.2959	0.98	0.73	None	"	"	"	
215	"	.750	"	"	.3877	0.85	0.70	"	"	"	"	
216	.250	.312	2.50	300	.1383	1.03	0.85	Marking	"	"	"	
217	"	.500	"	"	.2785	1.21	1.01	None	Roughness	"	"	
218	"	.625	"	"	.2466	1.50	1.50	"	"	"	"	
219	"	.375	2.00	"	.1382	1.24	0.58	Marking	None	"	"	
220	"	.625	"	"	.1857	1.27	0.85	None	"	"	"	
221	"	.750	"	"	.3364	1.33	1.14	"	"	"	"	
222	.375	.500	2.50	200	.2816	0.98	0.83	"	"	"	"	
223	"	.625	"	"	.3515	1.16	0.84	"	"	"	"	
224	"	1.000	"	"	.6755	1.06	0.82	"	"	"	"	
225	"	.625	2.00	"	.2645	1.17	0.83	"	"	"	"	
226	"	.750	"	"	.3273	1.31	0.90	"	"	"	"	
227	"	1.000	"	"	.5032	1.01	0.92	"	"	"	"	
228	.250	.200	Full	300	.107	1.20	0.85	Marking	Open Fold	Lap	Unsound	
229	.375	.200	"	200	.113	0.60	0.52	"	Roughness	Roughness	Sound	
230	"	.250	"	"	.135	0.75	0.65	"	None	None	"	
231	"	.312	2.00	"	.091	1.08	0.24	"	Roughness	Roughness	"	
232	"	.375	"	"	.115	1.18	0.15	None	None	None	"	
233	"	.500	"	"	.162	1.15	0.30	"	"	"	"	
234	.120	.500	"	"	.203	1.18	0.57	"	"	"	"	

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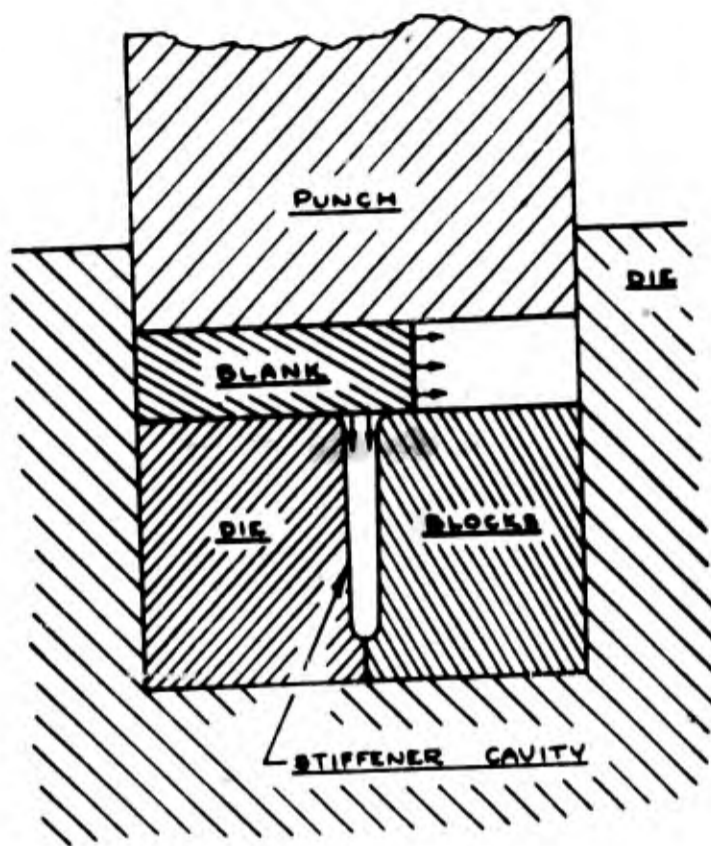
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TABLE II
TENSILE PROPERTIES OF FORGED 75S-T6 ALUMINUM ALLOY WAFFLE GRID TYPE INTEGRALLY STIFFENERD SKIN PANEL TEST PARTS
IN PANELS CONTAINING TRANSVERSE RIBS (DATA FROM PROCESS CONTROL LABORATORY REPORTS 23060 AND 25982)

Forging Number	Coupon Number	As Forged Skin Thickness (in.)	Horizontal Fillet Radius (in.)	Yield Stress (KSI)	Ultimate Strength (KSI)	ELONGATION IN				Stiffener
						.50 Inches	1.00 Inches	.50 Inches Across		
								Break %	Stiffener %	
49	1	.228	.030	69.7	74.0	-	-	9.0	9.0	On coupon
49	2	"	"	70.6	79.1	-	-	9.0	9.0	Machined away
49	3	"	"	76.7	81.8	7.0	6.0	-	-	On coupon
76	1	.270	"	70.2	79.3	-	-	10.0	10.0	Machined away
76	2	"	"	69.1	79.1	-	-	10.0	0.0	On coupon
76	3	"	"	74.8	80.0	6.0	5.0	-	-	Machined away
190	1	.339	.120	66.4	70.6	-	-	8.0	4.0	On coupon
190	2	"	"	70.3	78.9	-	-	10.0	4.0	Machined away
190	3	"	"	76.7	83.1	12.0	10.0	-	-	On coupon
191	1	.102	.250	79.5	84.1	-	-	11.0	4.0	Machined away
191	2	"	"	73.2	83.3	-	-	10.0	4.0	On coupon
191	3	"	"	79.1	83.0	6.0	4.5	-	-	Machined away
192	1	.194	"	71.2	84.6	-	-	9.0	4.0	On coupon
192	2	"	"	Lost	-	-	-	-	-	Machined away
192	3	"	"	79.8	83.1	7.0	4.5	-	-	On coupon
193	1	.189	.375	75.5	81.8	-	-	9.0	0.0	Machined away
193	2	"	"	70.4	74.8	-	-	5.0	0.0	On coupon
193	3	"	"	73.7	77.1	7.0	6.0	-	-	Machined away
199	1	.259	"	80.5	84.5	-	-	11.0	0.0	On coupon
199	2	"	"	78.9	84.1	-	-	12.0	-	Machined away
199	3	"	"	77.4	82.7	9.0	6.5	-	-	Machined away

* Shoulder Failure.
 ** Failure and Stiffener in Same Gage Length.



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Fig. 2 - Sketch illustrating simultaneous forging flow across and into stiffener cavity obtained by use of undersized blanks.

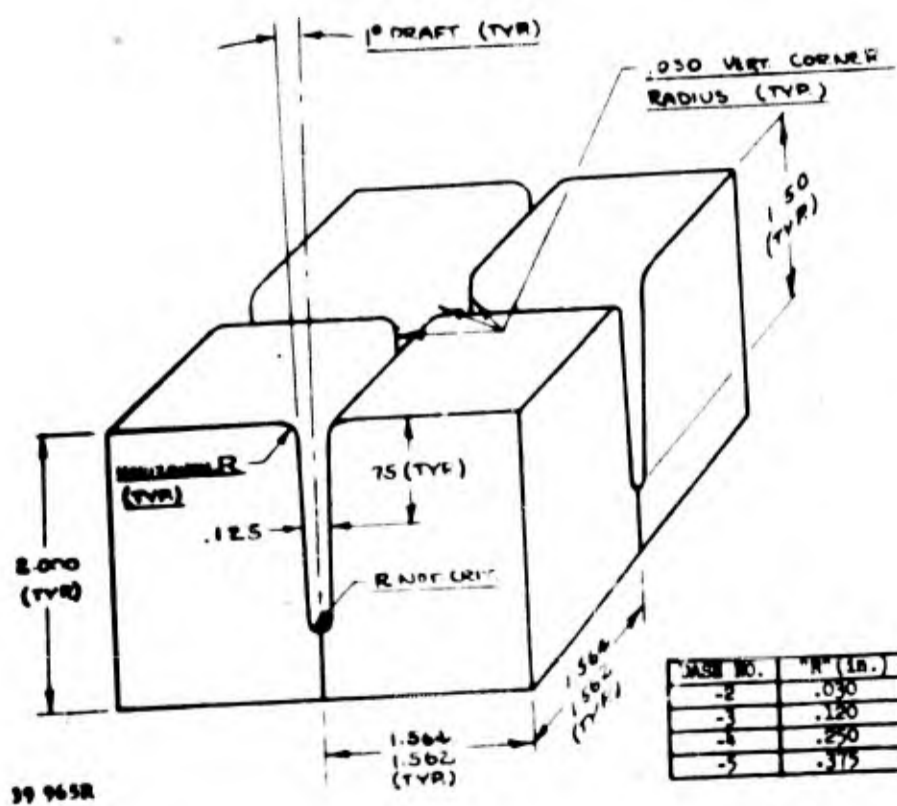
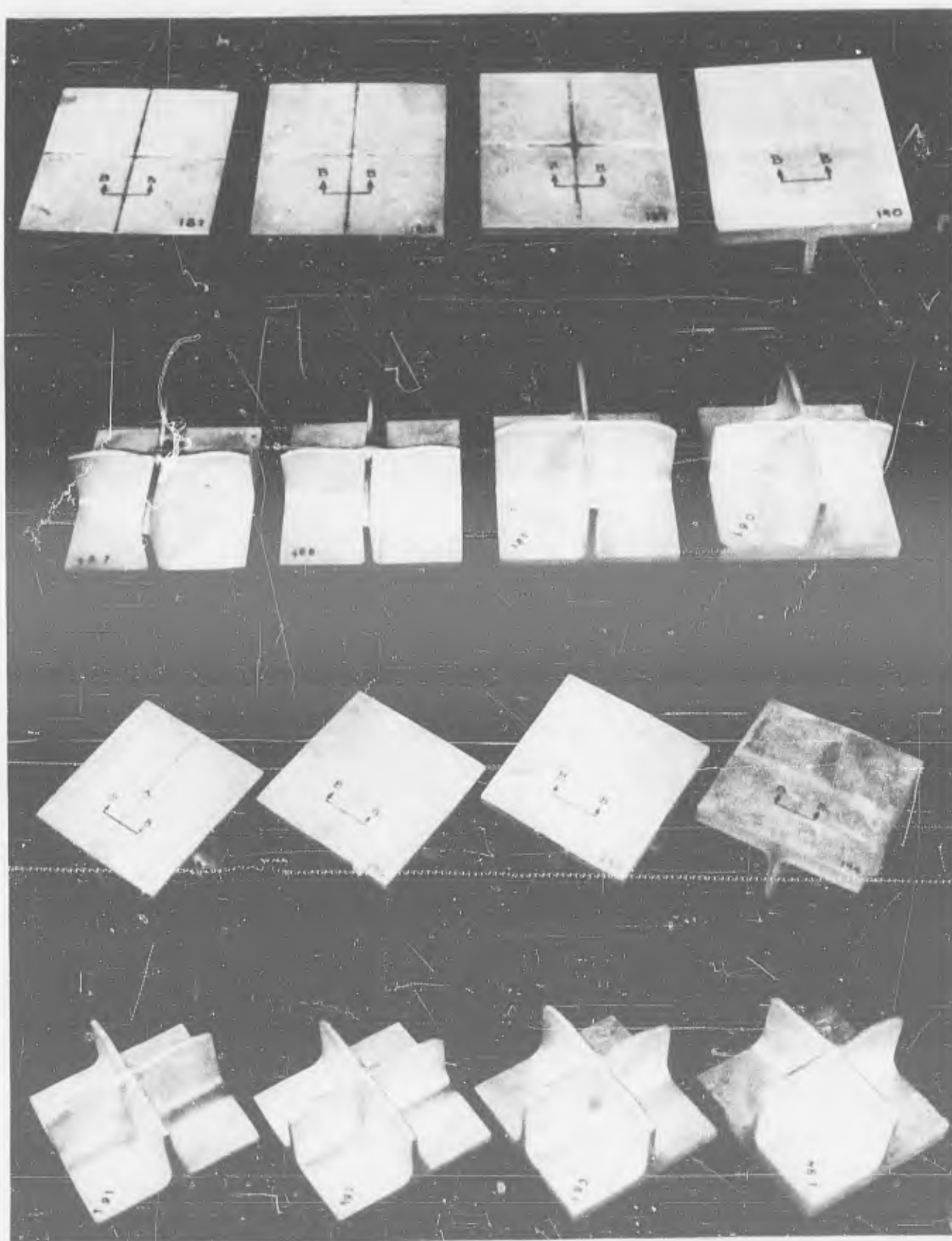
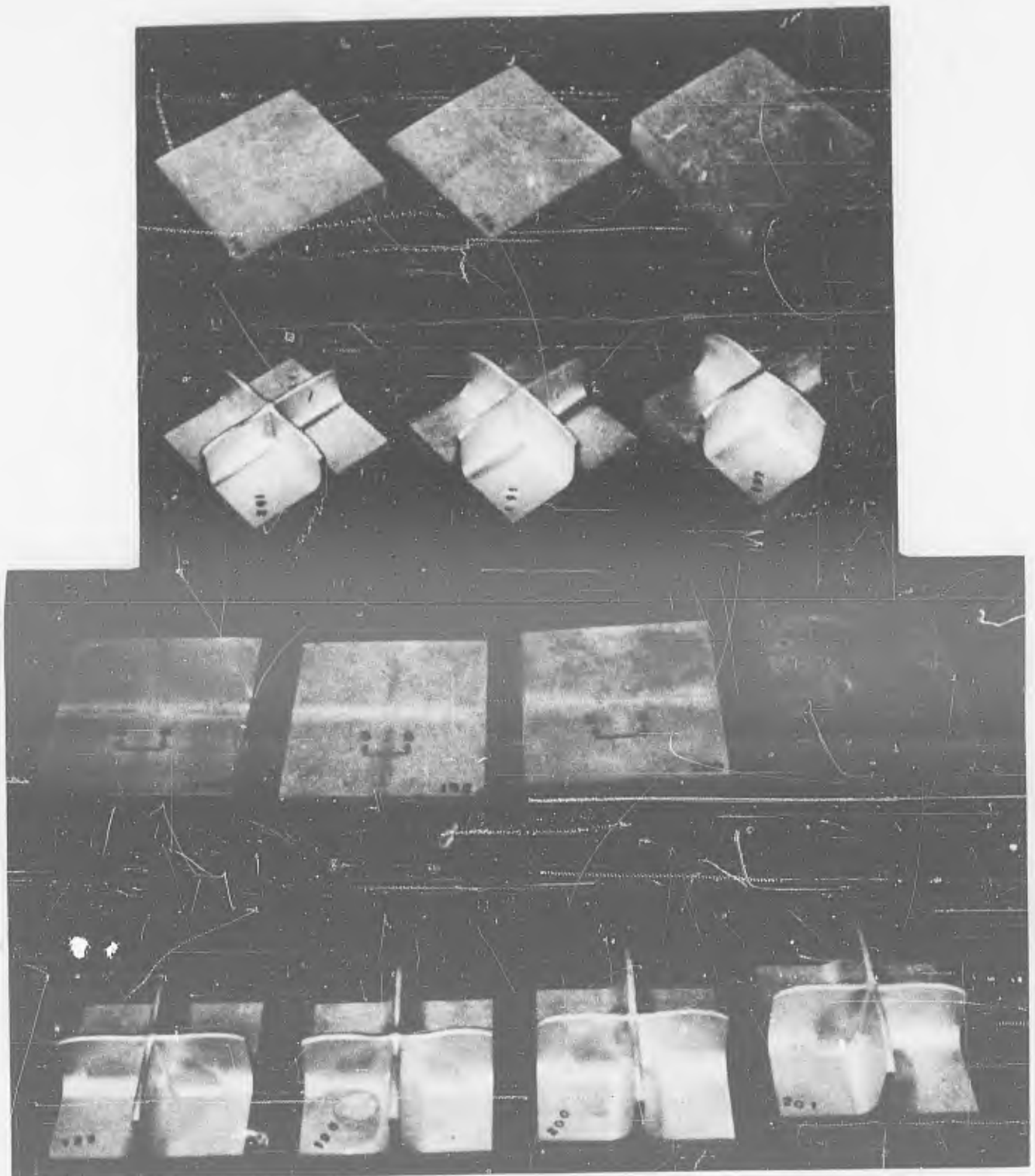


Fig. 3 - Forging die insert blocks used to produce test parts (Potomac "M" Tool Steel heat treated to 230,000 to 250,000 psi ultimate tensile strength).



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Fig. 4 - Upper and lower views of 75S aluminum alloy waffle forging Specimens 187 through 190 made with .120 inch horizontal fillet radii and Specimens 191 through 194 made with .250 inch horizontal fillet radii using 30.6 tons per square inch pressure applied for 60 seconds at 800° F.



 METALLURGICAL RESEARCH.

Fig. 5 - Upper and lower views of 75S aluminum alloy waffle forging Specimens 195 through 197 made with .250 inch horizontal fillet radii and Specimens 199 through 201 made with .375 inch horizontal fillet radii using 20.4 tons per square inch pressure applied for 60 seconds at 800° F.

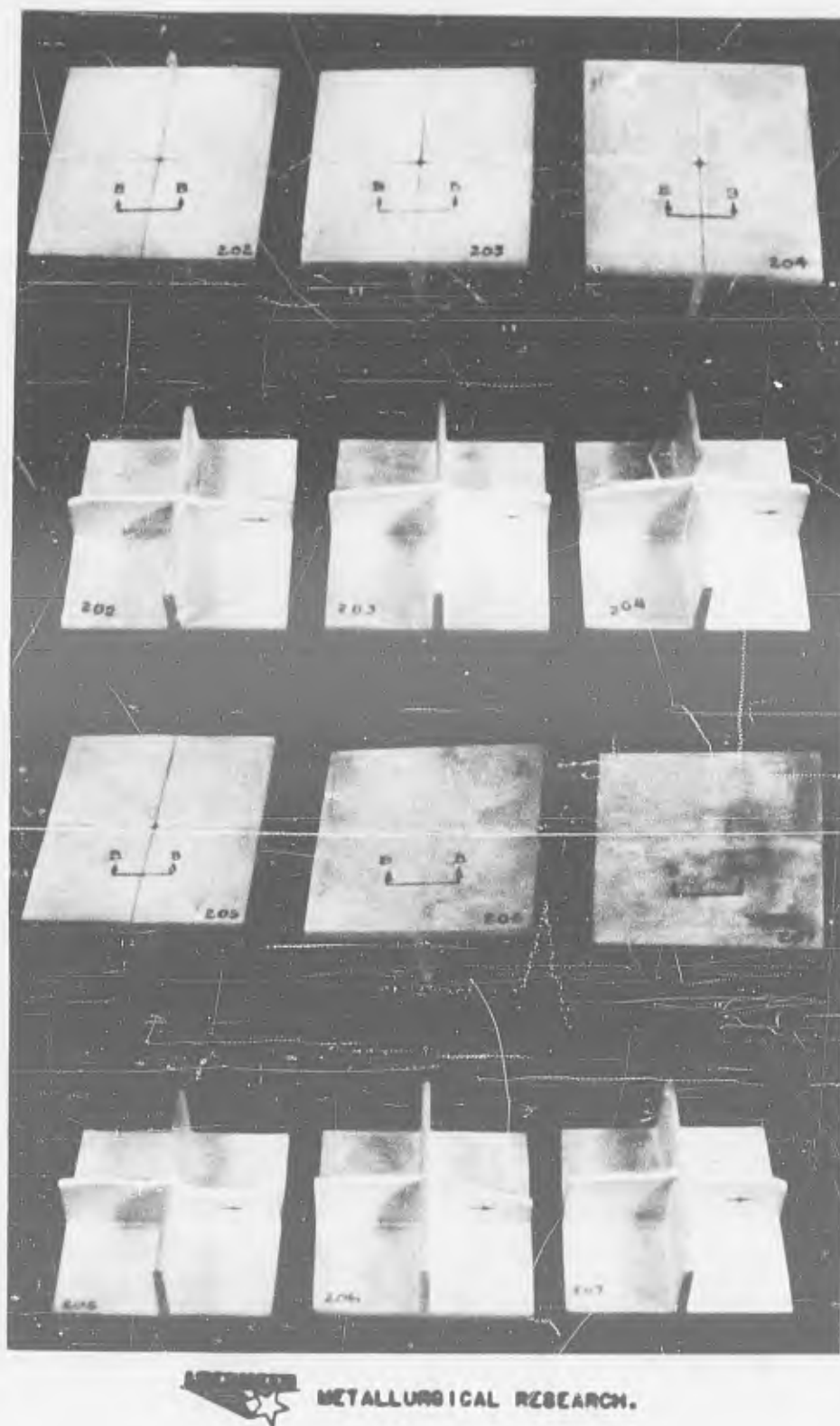
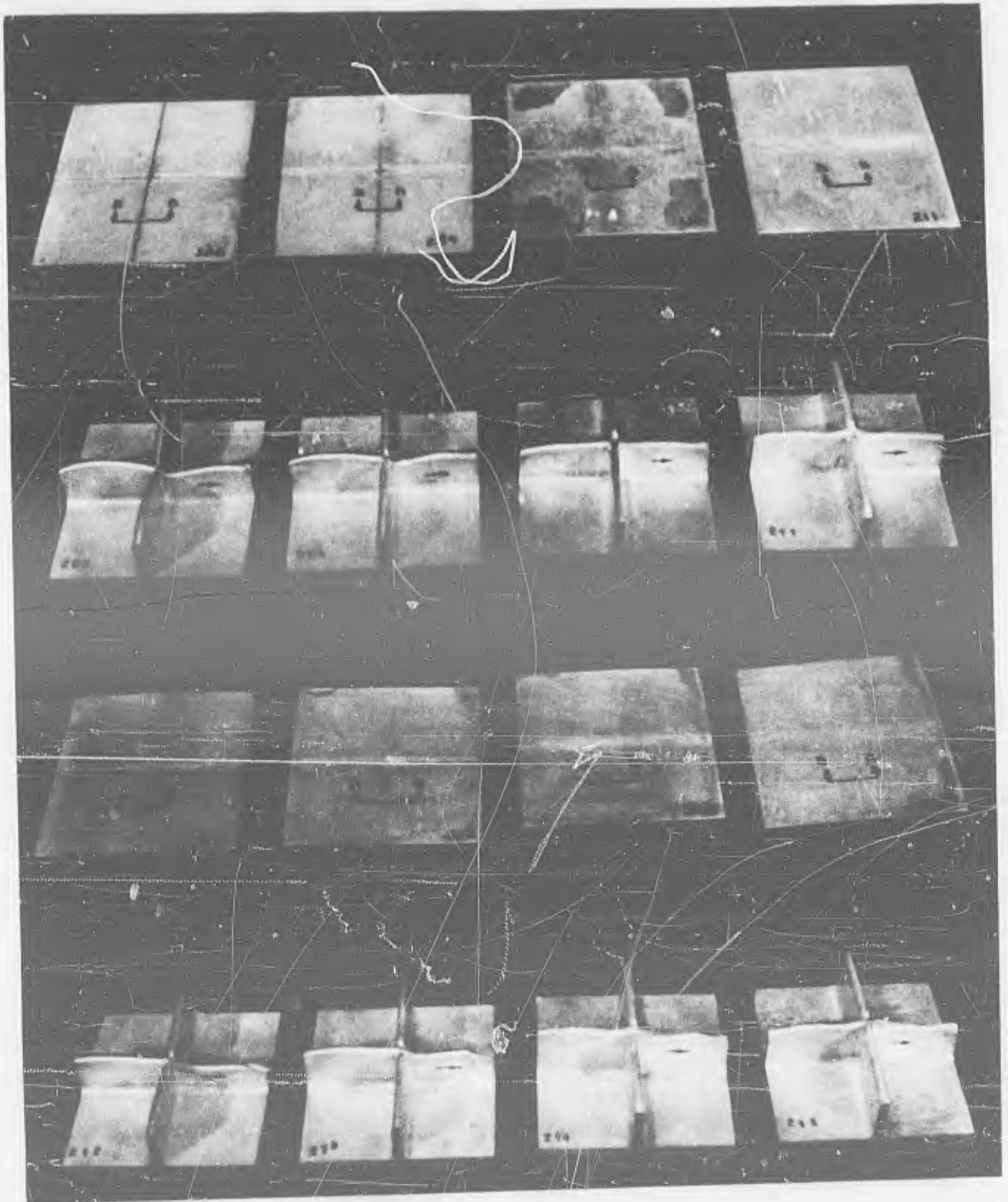
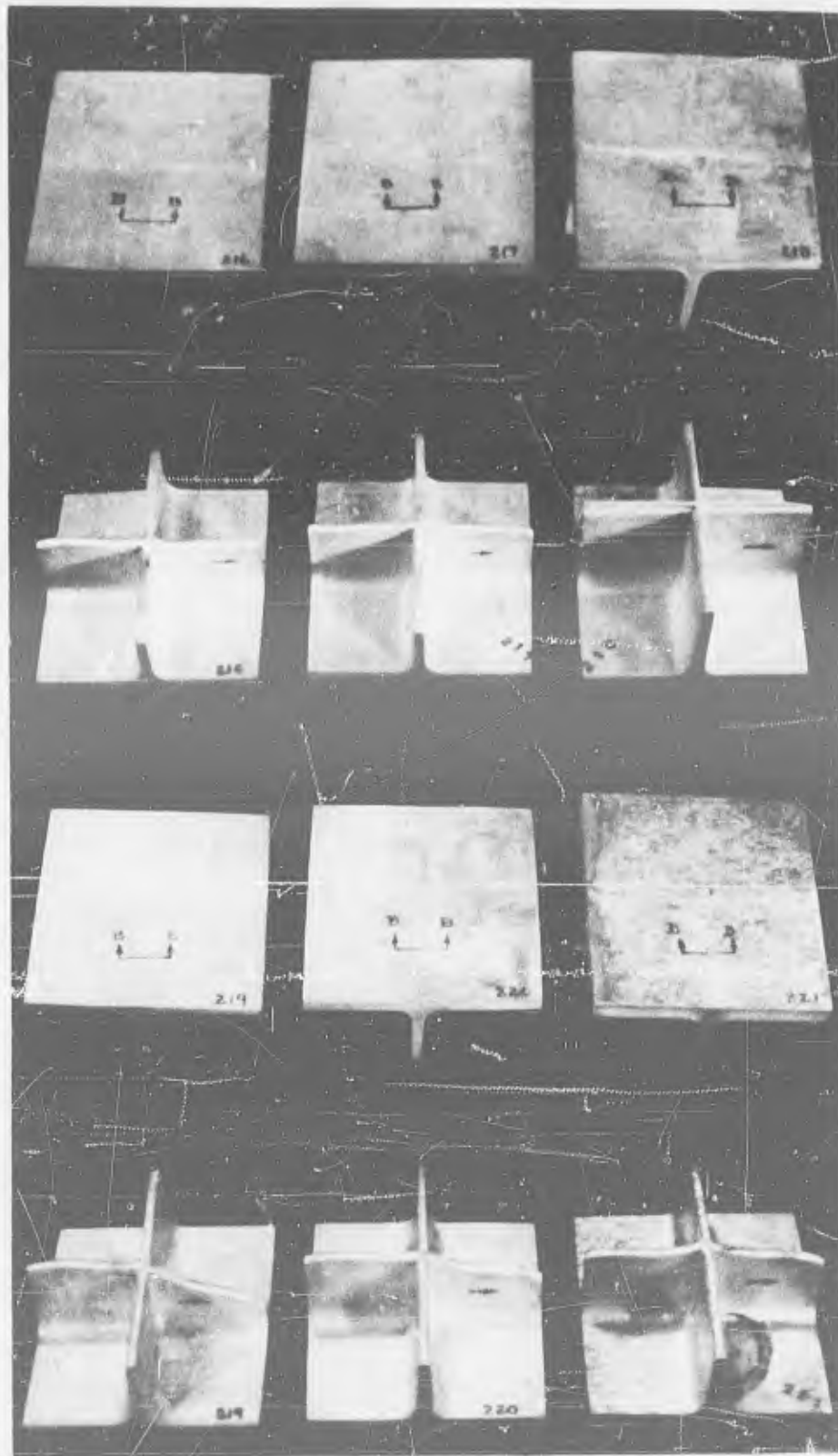


Fig. 6 - Upper and lower views of 75S aluminum alloy waffle forging Specimens 202 through 207 made with .030 inch horizontal fillet radii using 30.6 tons per square inch pressure applied for 60 seconds at 800° F. Direction of lateral flow is indicated by arrows on stiffeners.



 METALLURGICAL RESEARCH.

Fig. 7 - Upper and lower views of 75S aluminum alloy waffle forging Specimens 208 through 215 made with .120 inch horizontal fillet radii using 20.4 tons per square inch pressure applied for 60 seconds at 800° F. Direction of lateral flow is indicated by arrows on stiffeners.

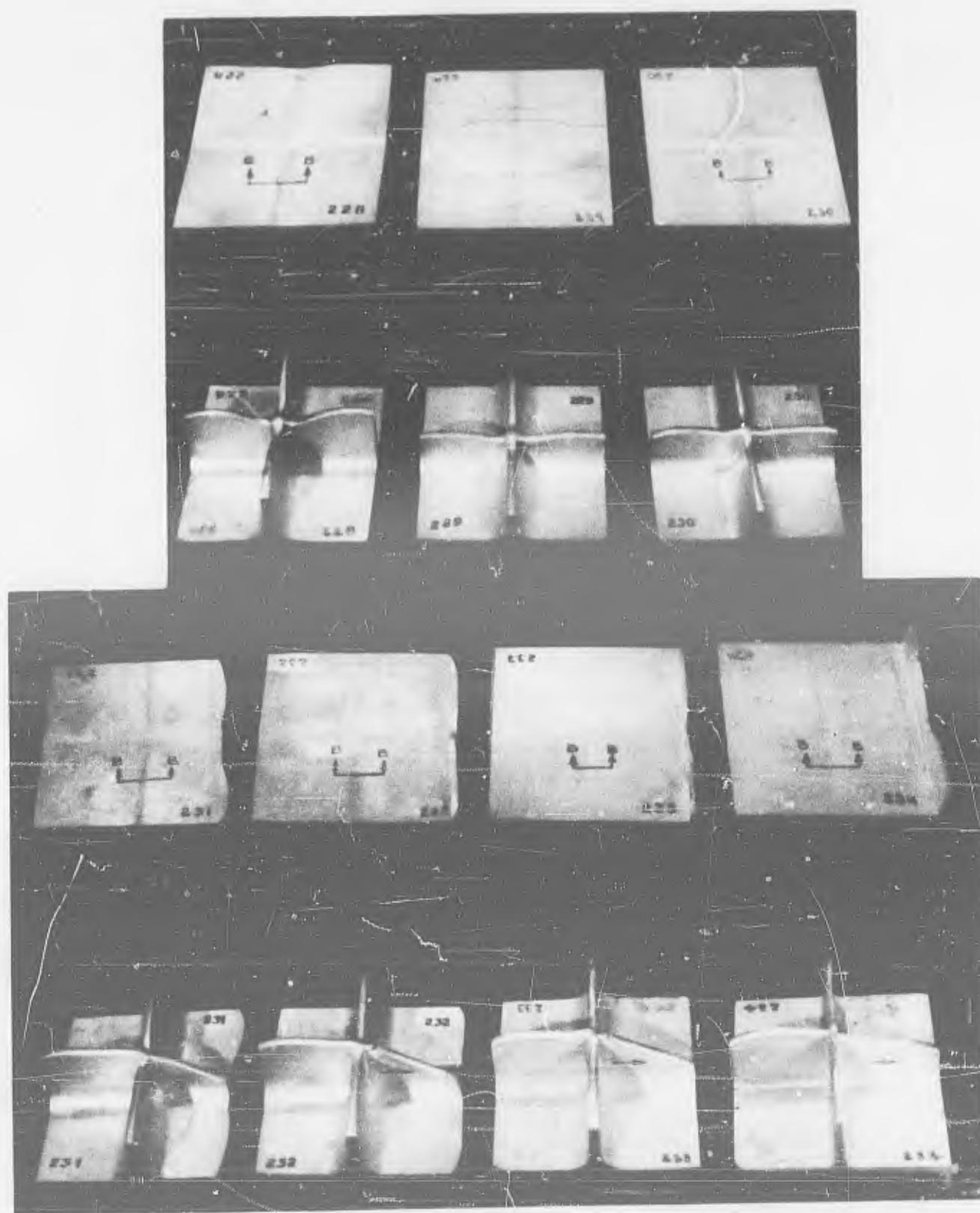


METALLURGICAL RESEARCH.

Fig. 8 - Upper and lower views of 75S aluminum alloy waffle forging Specimens 216 through 221 made with .250 inch horizontal fillet radii using 30.6 tons per square inch pressure applied for 60 seconds at 800° F. Direction of lateral flow is indicated by arrows on stiffeners.

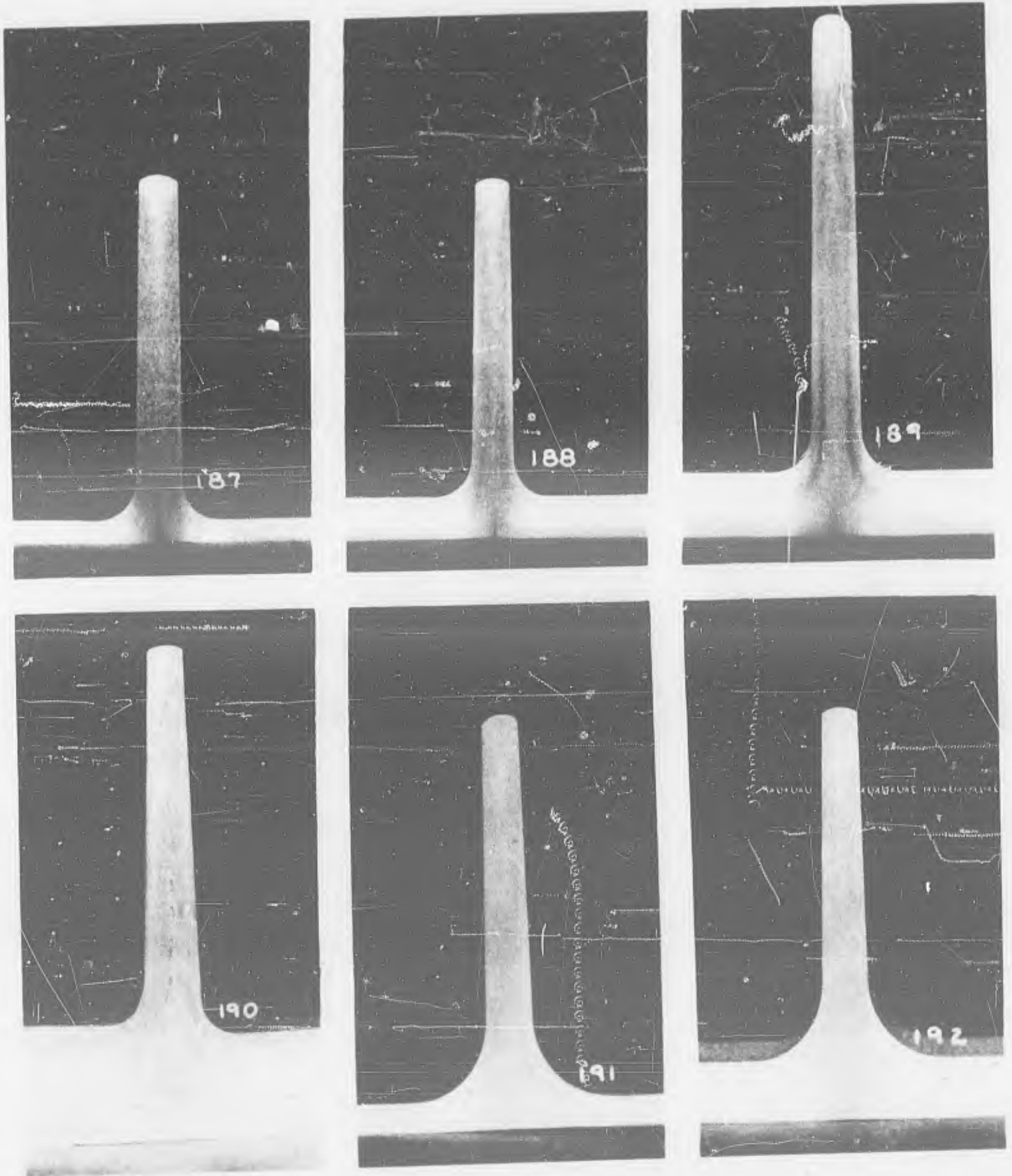


Fig. 9 - Upper and lower views of 75S aluminum alloy waffle forging Specimens 222 through 227 made with .375 inch horizontal fillet radii using 20.4 tons per square inch pressure applied for 60 seconds at 800° F. Direction of lateral flow is indicated by arrows on stiffeners.



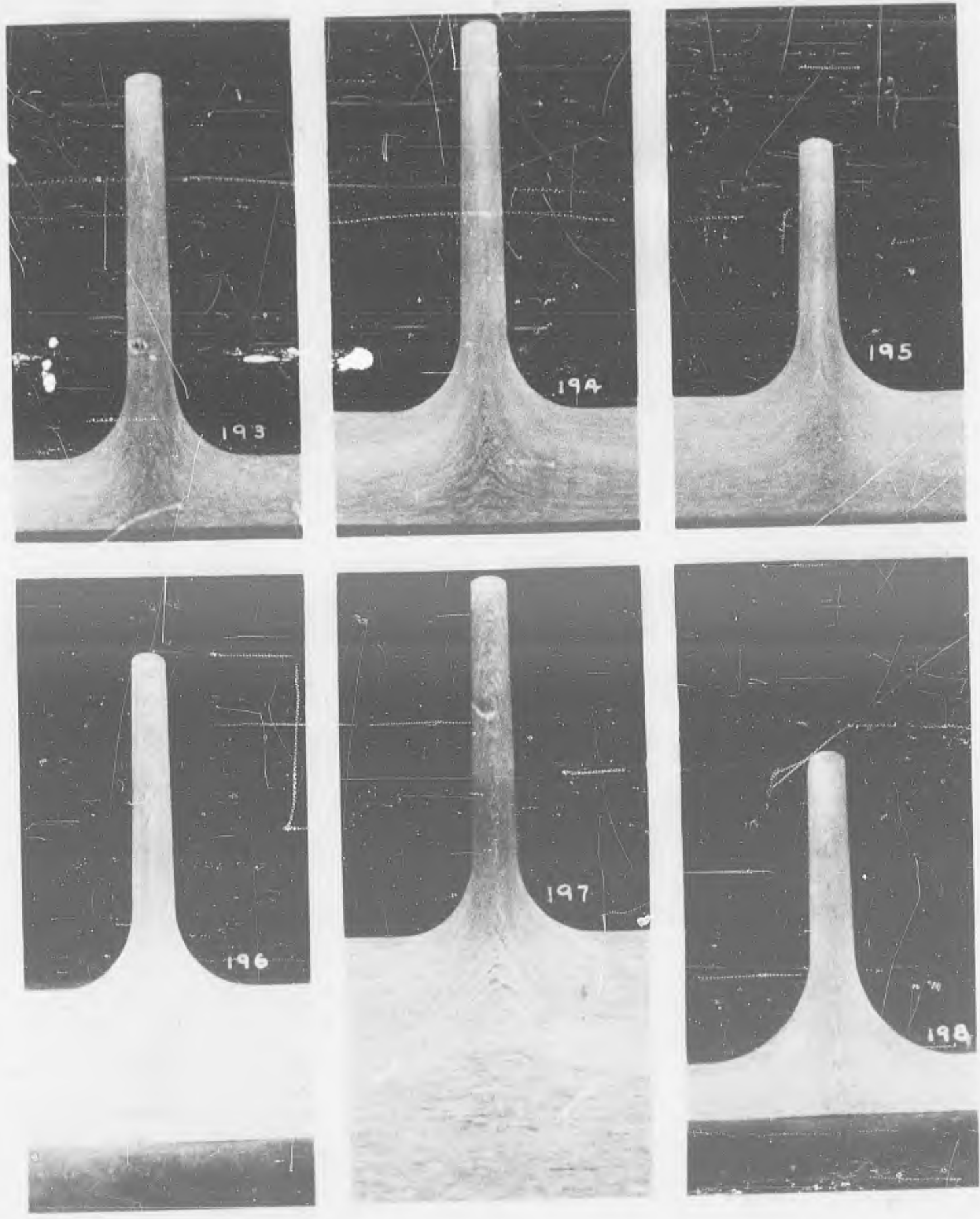
METALLURGICAL RESEARCH.

Fig. 10 - Upper and lower views of 75S aluminum alloy waffle forging Specimens 228 through 234 made with various horizontal fillet radii and press pressures (see Table I) applied for 60 seconds at 800° F. Arrows on stiffeners in lower photograph indicate direction of lateral flow.



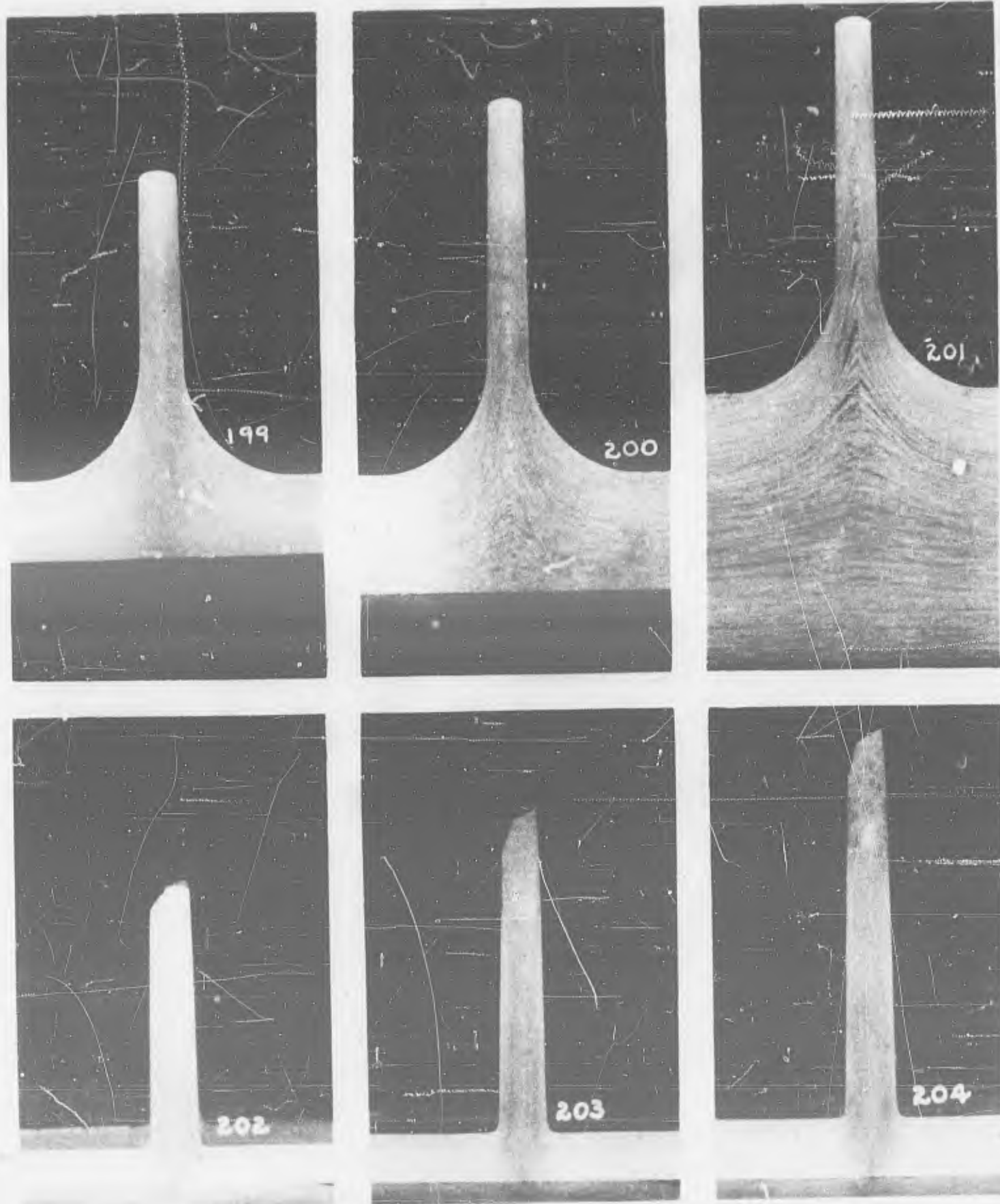
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Fig. 11 - Macrographs illustrating sectional aspects of Specimens 187 through 192 (approximately 2-1/2X).



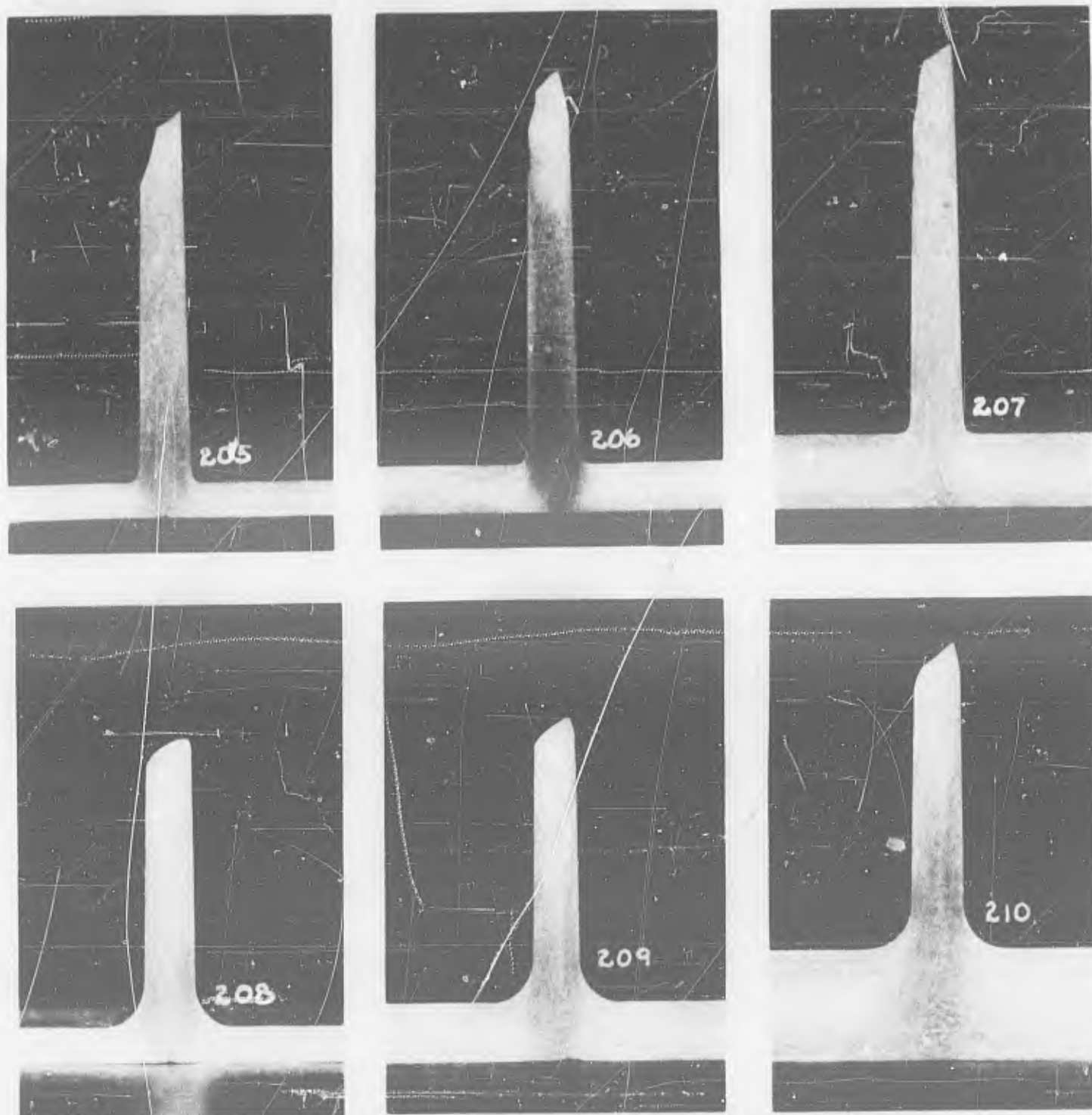
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Fig. 12 - Macrographs illustrating sectional aspects of Specimens 193 through 198 (approximately 2-1/2X).



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Fig. 13 - Macrographs illustrating sectional aspects of Specimens 199 through 204 (approximately 2-1/2X).




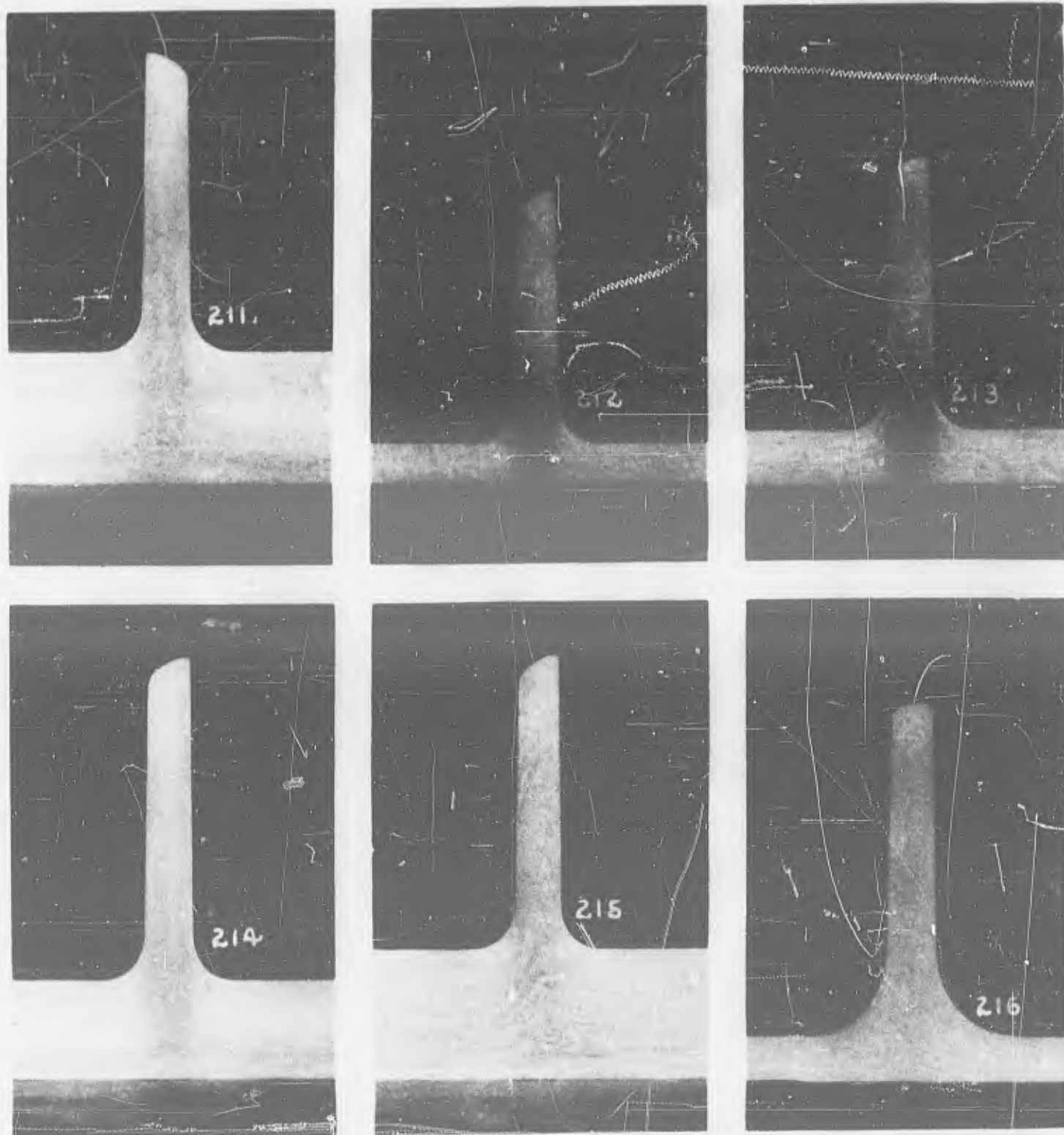
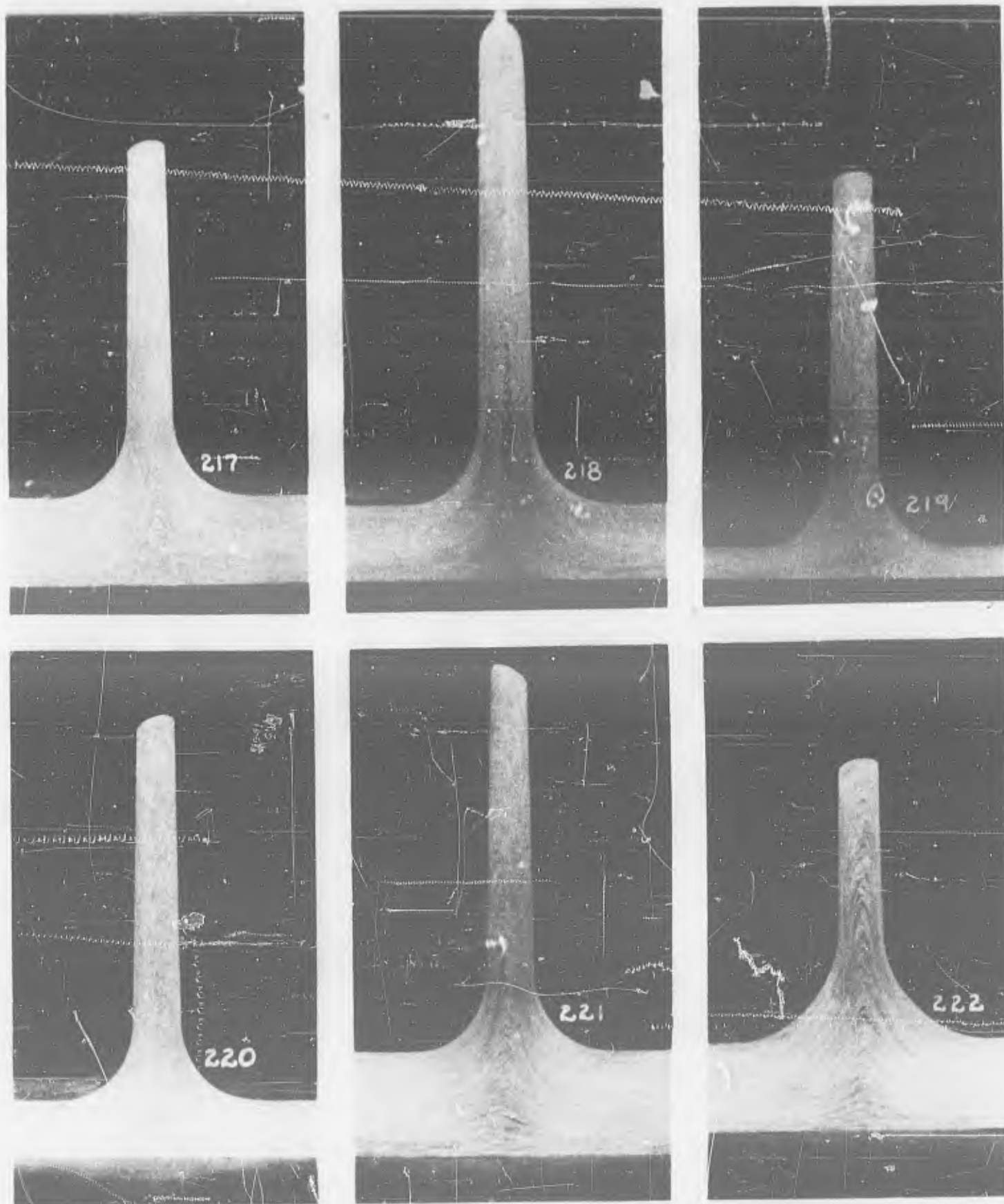
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Fig. 14 - Macrographs illustrating sectional aspects of Specimens 205 through 210 (approximately 2-1/2X).



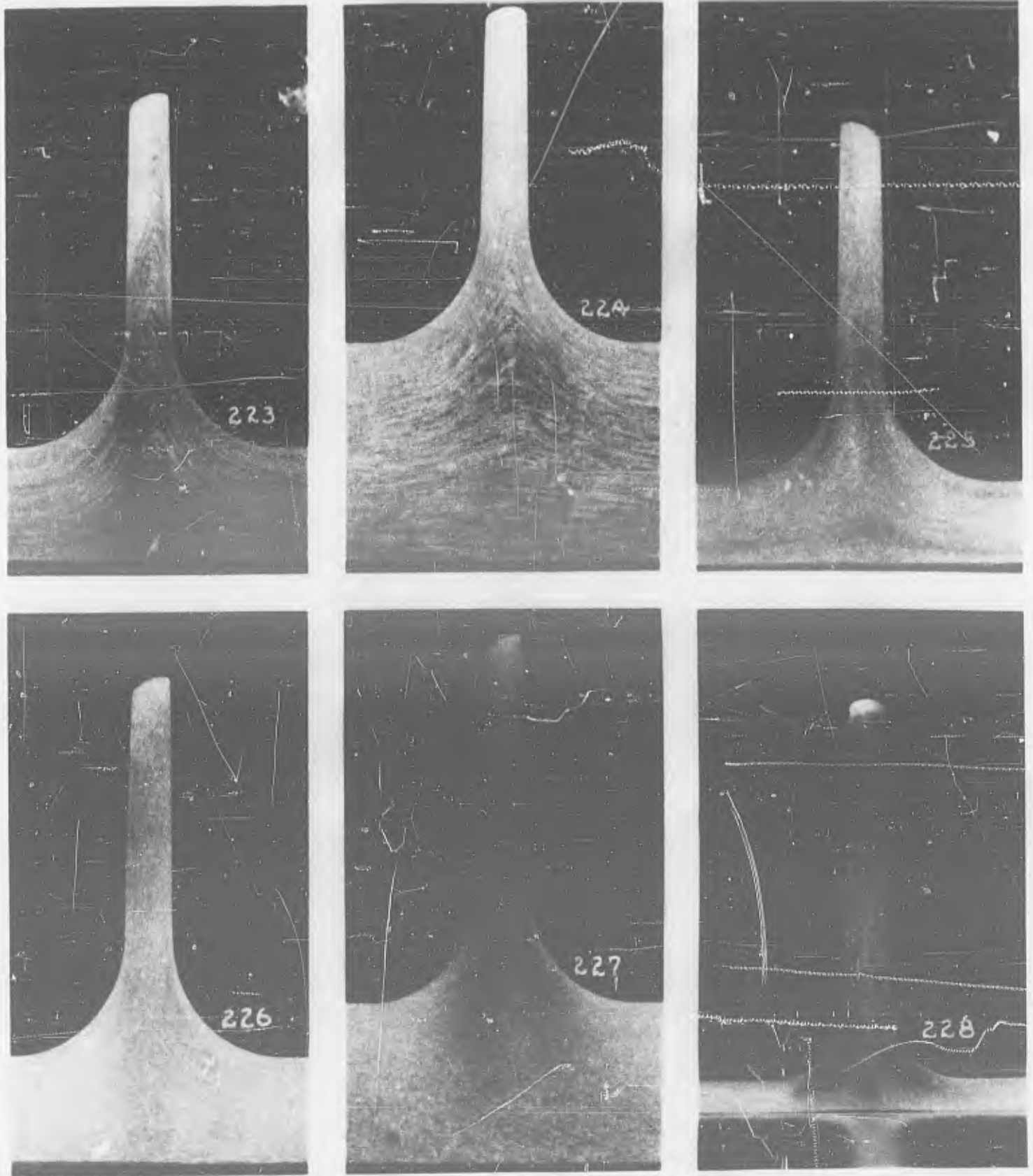
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Fig. 15 - Macrographs illustrating sectional aspects of Specimens 211 through 216 (approximately 2-1/2X).



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Fig. 16 - Macrographs illustrating sectional aspects of Specimens 217 through 222 (approximately 2-1/2X).




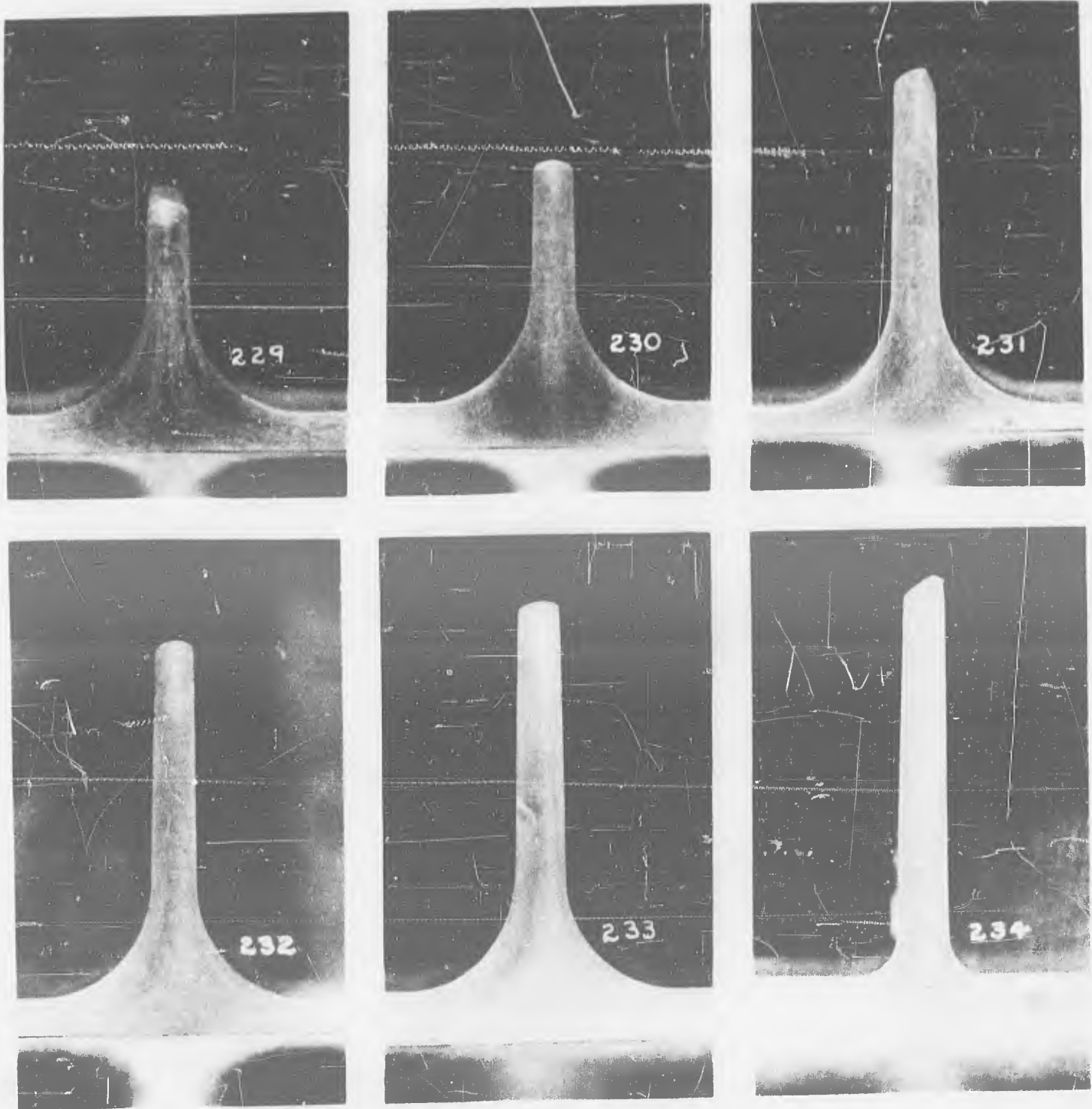
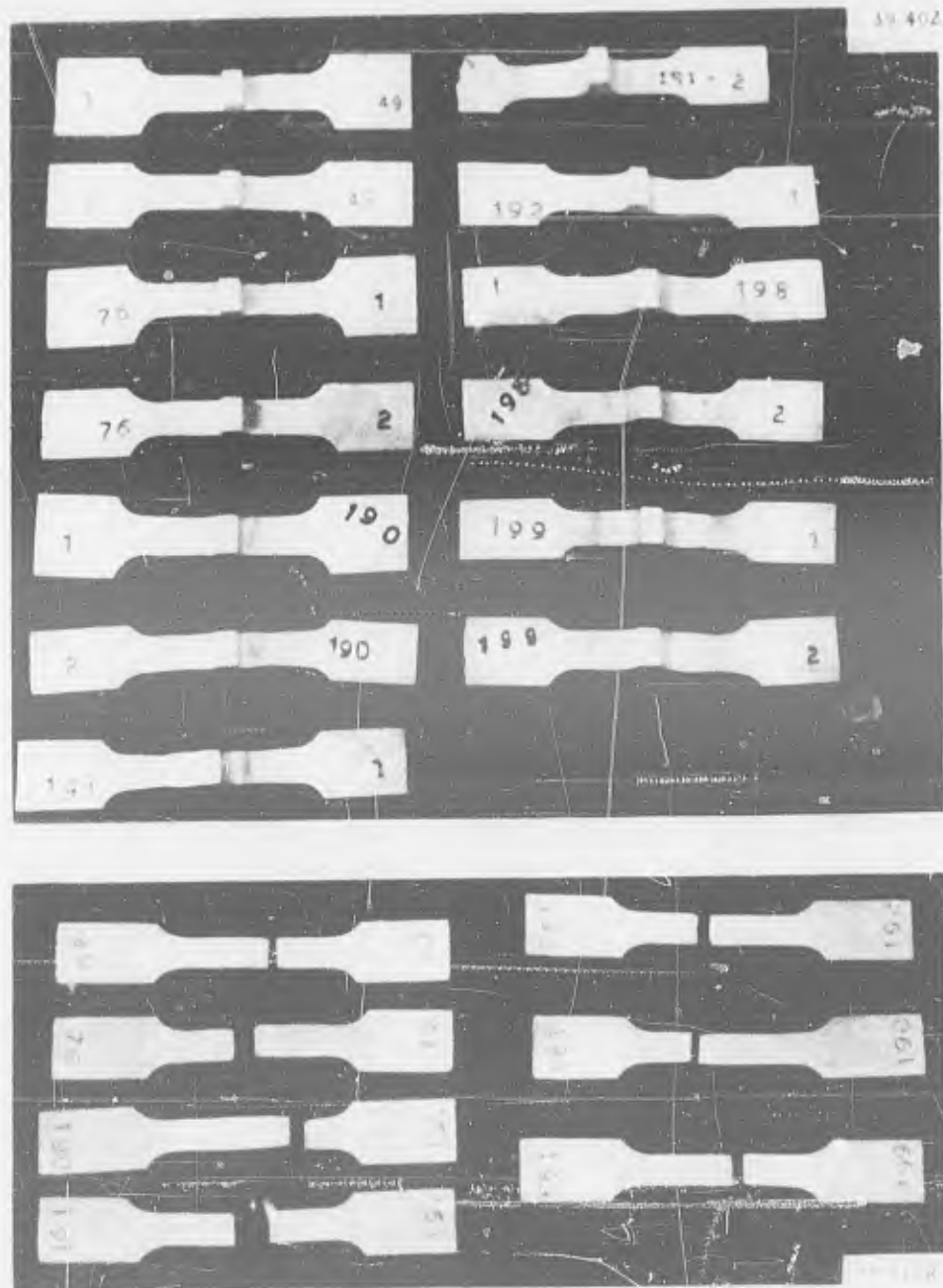
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Fig. 17 - Macrographs illustrating sectional aspects of Specimens 223 through 228 (approximately 2-1 2X).



 METALLURGICAL RESEARCH.

Fig. 18 - Macrographs illustrating sectional aspects of Specimens 229 through 234 (approximately 2-1/2X).



LOCKHEED METALLURGICAL RESEARCH.

Fig. 19 - Failed 1.00 inch gage length 75S-T6 aluminum alloy tensile coupons machined from waffle grid type integrally stiffened skin panel test parts in areas containing transverse ribs. Thickness of all specimens was reduced to approximately .055 inches by machining skin surface.

Upper photograph: Stiffeners remain on coupons.

Lower photograph: Stiffeners machined away.

APPENDIX VI

METALLURGICAL-CHEMICAL RESEARCH MEMORANDUM NO. 1761

METALLURGICAL INVESTIGATION OF WAFFLE FORGINGS

LOCKHEED AIRCRAFT CORPORATION

METALLURGICAL-CHEMICAL RESEARCH MEMORANDUM NO. 1761

METALLURGICAL INVESTIGATION OF WAFFLE FORGINGS

Investigation: R. I. Batista *R I Batista* September 19, 1956
Authorization: Request of the Production Engineering Department
W.O. 2-4168, EWA 4572
Checked by: H. B. Wiley *H B Wiley*
Approved by: E. H. Burkart *E H Burkart*, J. M. Gerschler *J M Gerschler*
Attention of: G. W. Papen/H. B. Sipple, F. C. Pipher/A. W. Ernestus,
J. F. McBrearty/E. H. Spaulding
Reference: IDC, J. M. Gerschler from H. W. Benjamin, dated
3-13-56, Subject - Waffle Forgings.

SUBJECT PARTS:

Four experimental waffle forged panels made at the Wyman-Gordon Company, Worcester, Massachusetts. Material - 7075 aluminum alloy.

OBJECT:

- 1). To prepare macro sections showing the grain flow in various sections of the panels.
- 2). To obtain the tensile properties from representative sections of the forgings.
- 3). To determine the uniformity of hardness before and after heat treatment by means of hardness traverses.

SUMMARY:

- A). Examination of macro sections revealed a normal grain structure with no visible forging defects.
- B). Tensile tests showed that the material could be heat treated to the desired strength level.
- C). Hardness traverses indicated uniform hardness before and after heat treatment.

PROCEDURE AND RESULTS:

Fig. 1 illustrates the forged panels as received, showing the location of the macro and tensile specimens. A list of the specimens is given in Table I.

PROCEDURE AND RESULTS: - cont.

TABLE I

Type of Specimen	Number
Vertical Macro Sections	M1 - M5
Horizontal Macro Sections	M6 - M7
Skin Tensile Coupons	1 - 7
Stiffener Tensile Coupons	8 - 9
Skin and Stiffener Coupons	10, 11, 12
Standard .25 inch Tensile Coupons	T1 - T2

Photomicrographs illustrating the grain flow are shown in Figs. 2 - 8. The macro sections revealed a sound structure with no forging or other metallurgical defects.

Tensile specimens were machined from the first two panels received and sent out for heat treatment to the T-6 condition. The results of the tensile tests from these specimens gave low values which were assigned to the effects of faulty heat treatment.

Two new panels were supplied, tensile specimens machined, and the heat treatment performed under rigid controls. The results from this group of specimens compare favorably with the Alcoa specification values and are presented in Table II.

Hardness traverses were made across macro section M-1 of the first two panels received. Uniform hardness across the sections was indicated both before and after heat treatment. The results of the hardness tests are shown graphically in Figs. 9 and 10.

RIB:bls
Attach Photos (8)

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TABLE II

Identification	Strength ksi	Yield Strength 2% Offset ksi	% Elongation in 1/2 inch	Reduction of Area - %
1B	80.1	73.2	12	
1C	81.1	74.3	9	
2B	80.4	73.4	11	
2C	81.5	74.1	10	
3B	79.0	72.5	12	
3C	82.6	75.4	10	
4B	79.3	73.2	6	
4C	79.5	72.6	8	
5B	81.4	74.4	12	
5C	78.6	72.0	8	
6B	79.2	72.9	11	
6C	81.9	74.9	10	
7B	80.1	74.6	6	
7C	79.4	72.5	8	
8B	77.6	71.9	8	
8C	78.6	71.4	11	
9B	78.0	71.8	8	
9C	79.7	72.2	11	
10B	84.2)	These specimens had stiffeners across the gage lengths preventing determination of yield strength and % elongation.		
10C	76.3)			
11B	76.9)			
11C	75.1)			
12B	81.3)			
12C	80.4)			
T1B	85.2	77.7	11.5	23.2
T1C	86	78.1	10	14.7
T2B	89.8	80.2	10	13.0
T2C	89.6	81.6	10	22.3
Alcoa Specification	75.0	65.0	7 - 10	

PREPARED BY: N.I. Batista
 DATE: _____
 CHECKED BY: _____

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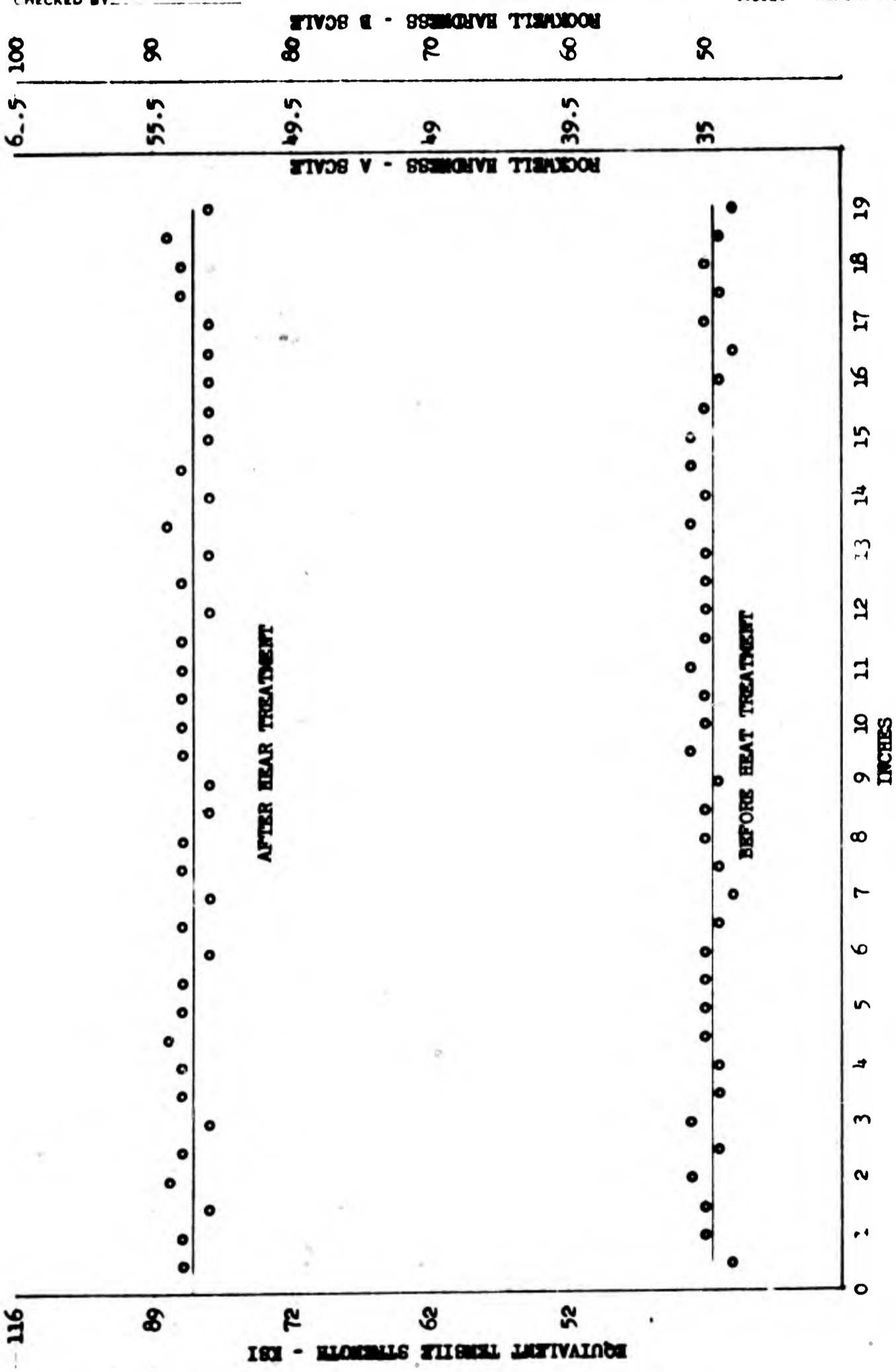


Fig. 9 - Graphs showing results of hardness traverses on specimen M-1 before and after heat treatment.

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 CHECKED BY _____

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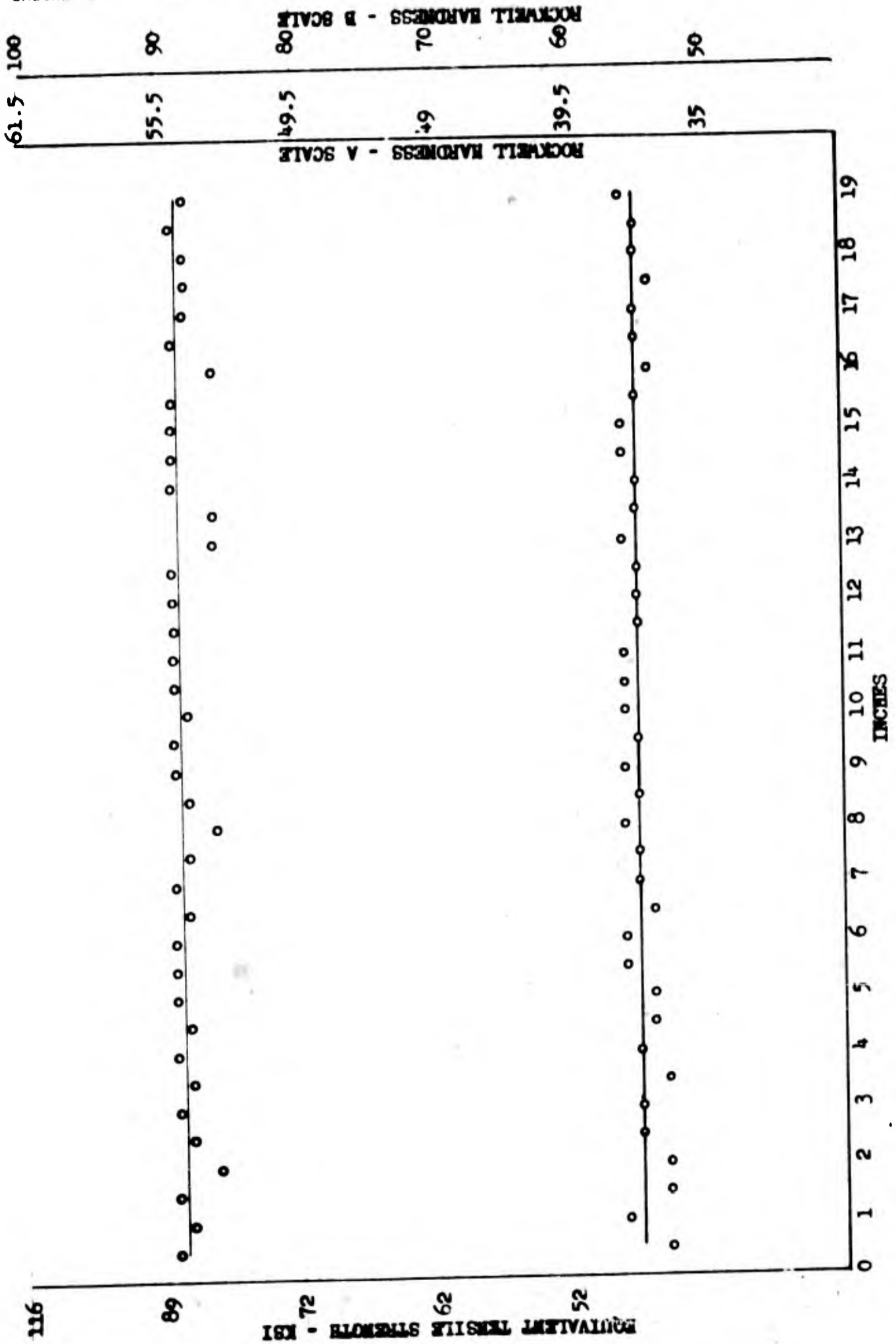


Fig. 10 - Graphs showing results of hardness traverses on specimen M-1A before and after heat treatment.

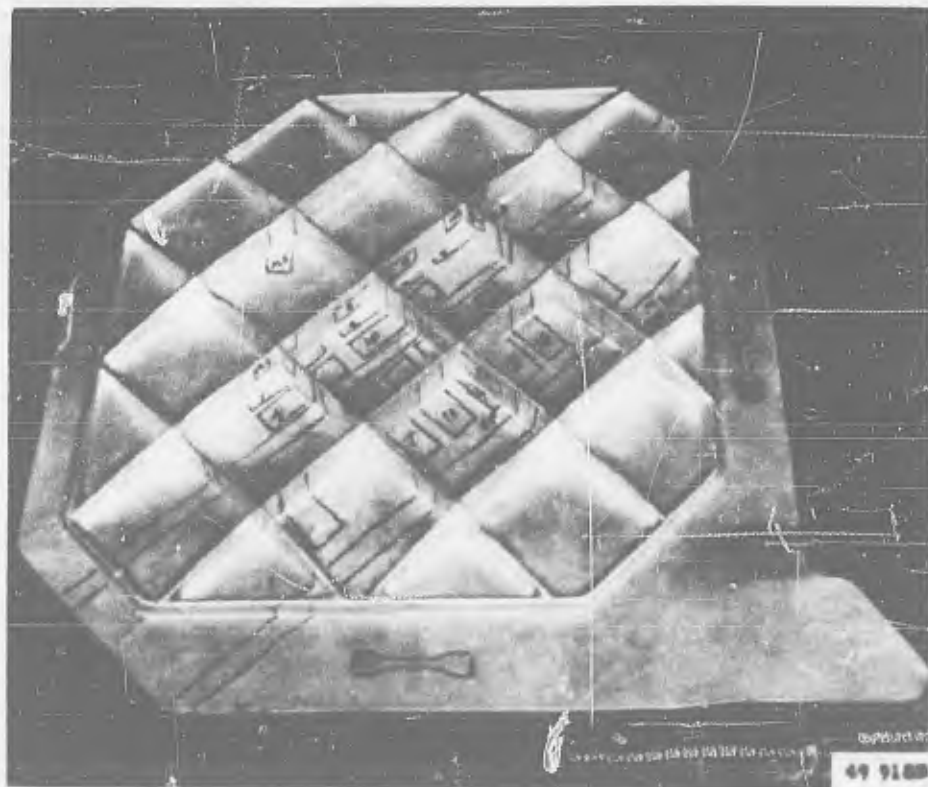
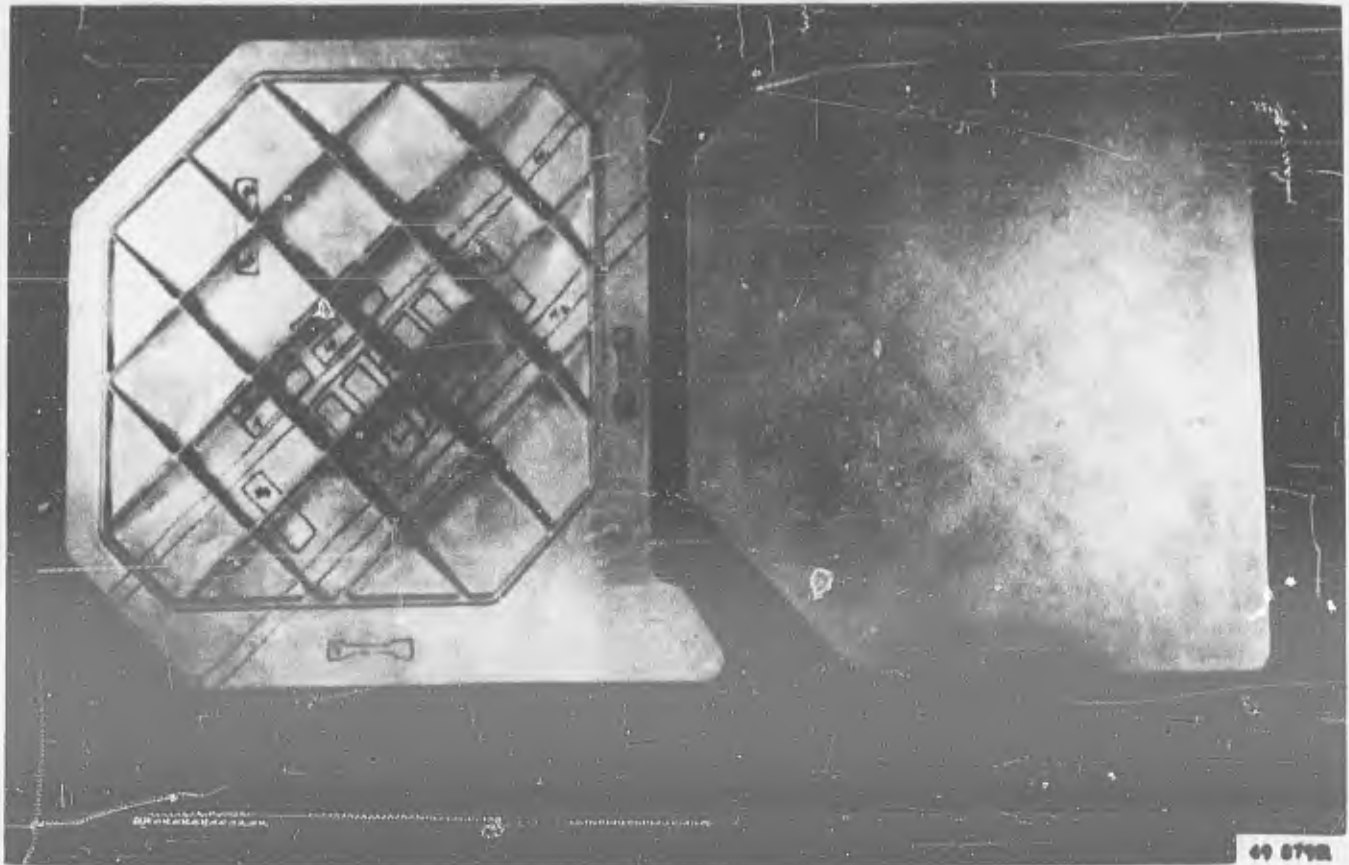


Fig. 1 - Typical panels as received showing location and identification of macro and tensile specimens.

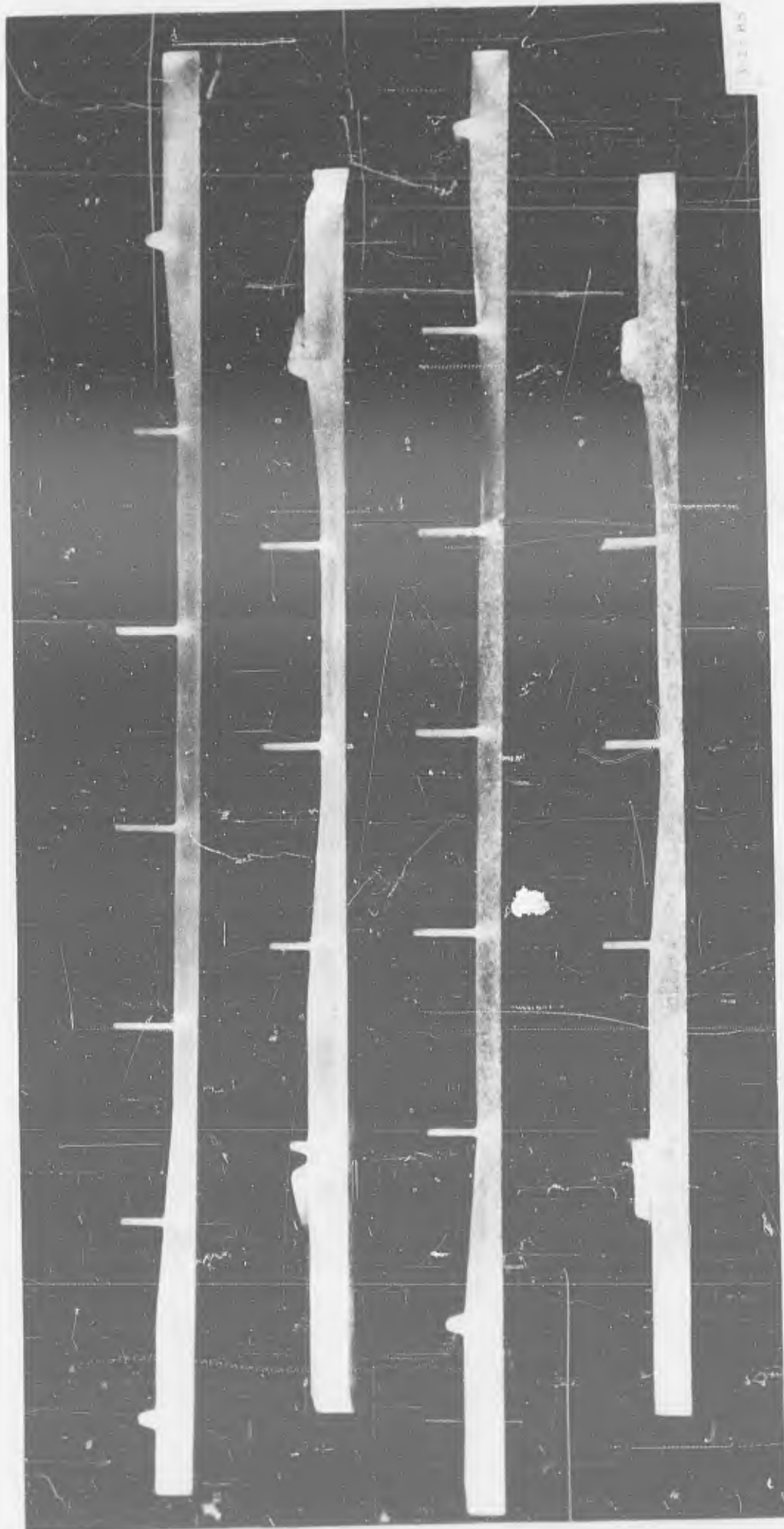
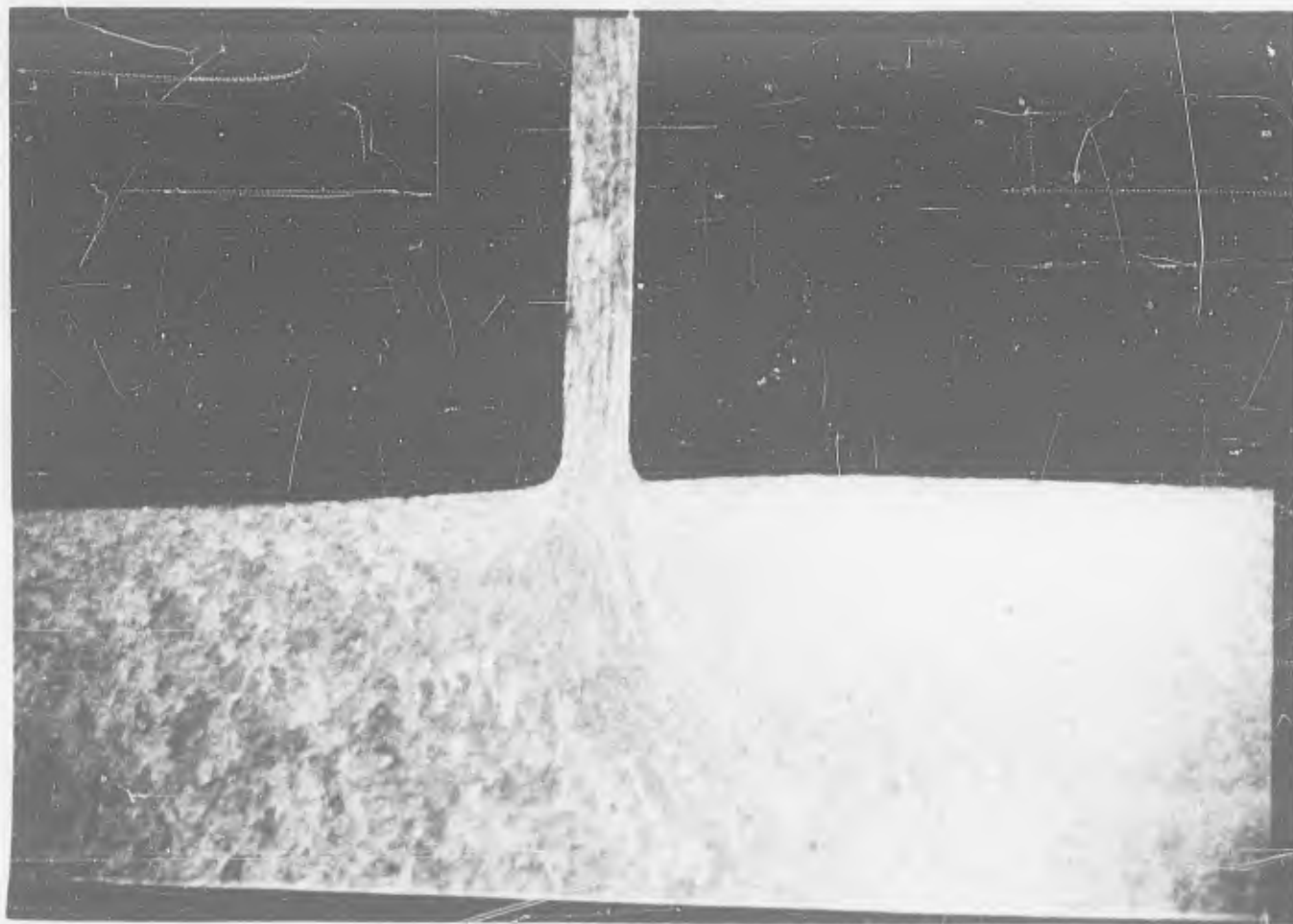
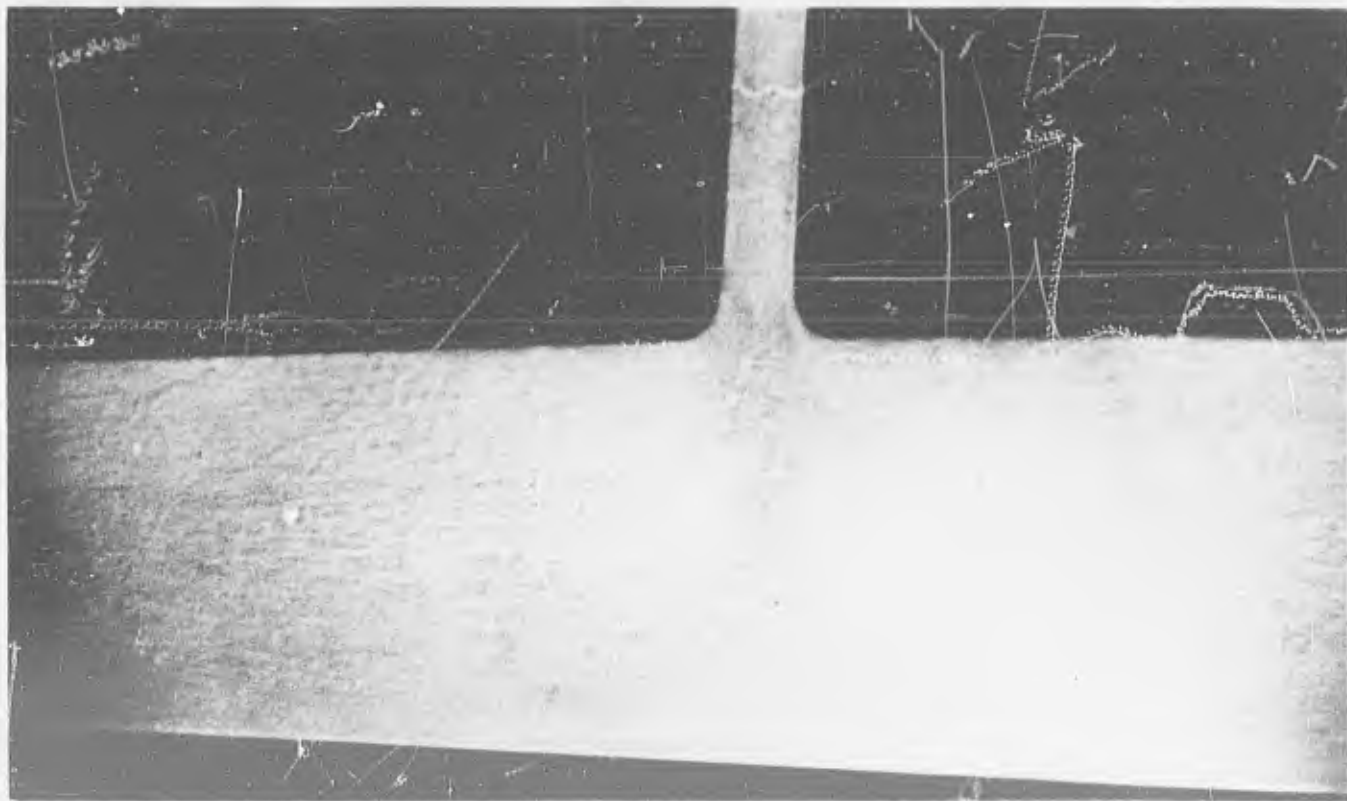


Fig. 2 - Photomicrographs of sections normal to stiffeners and skin showing forged structure.

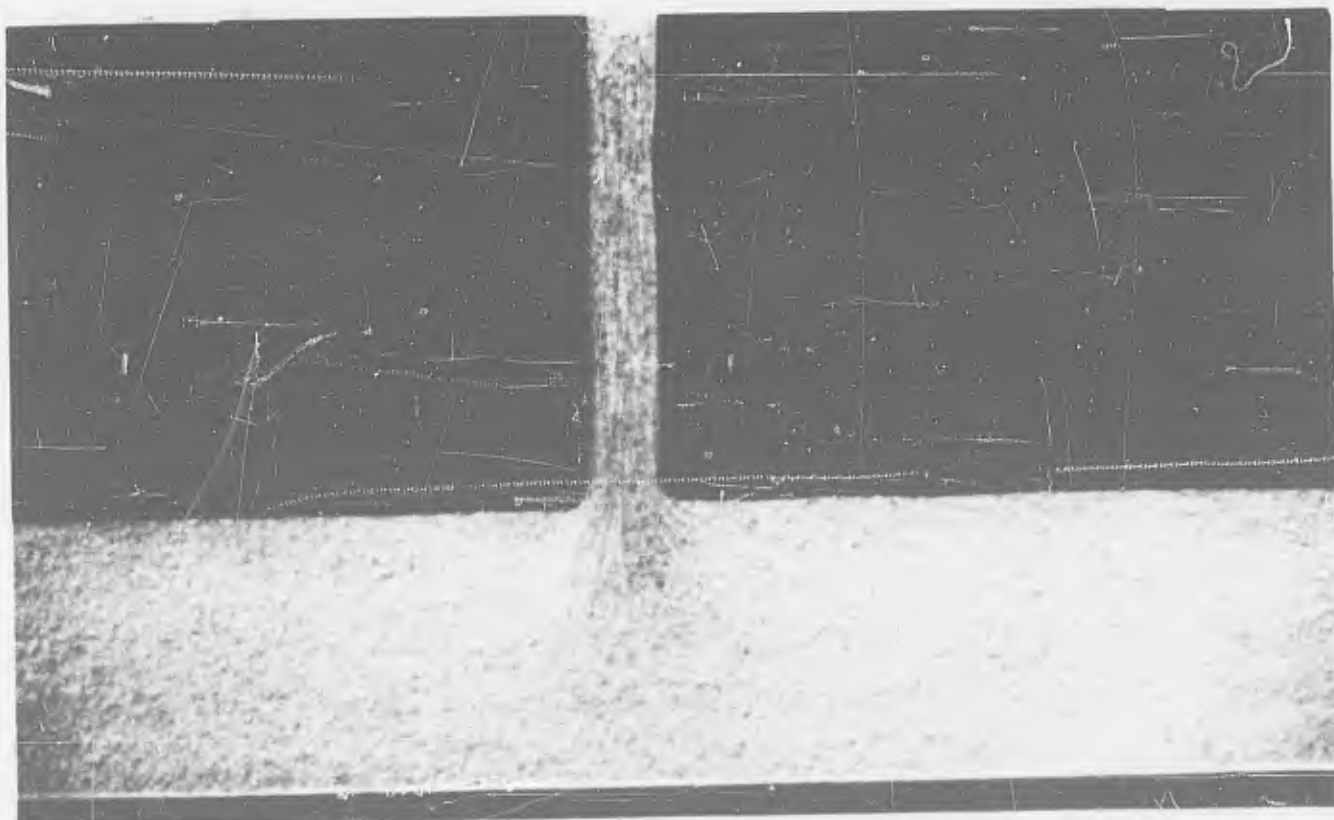
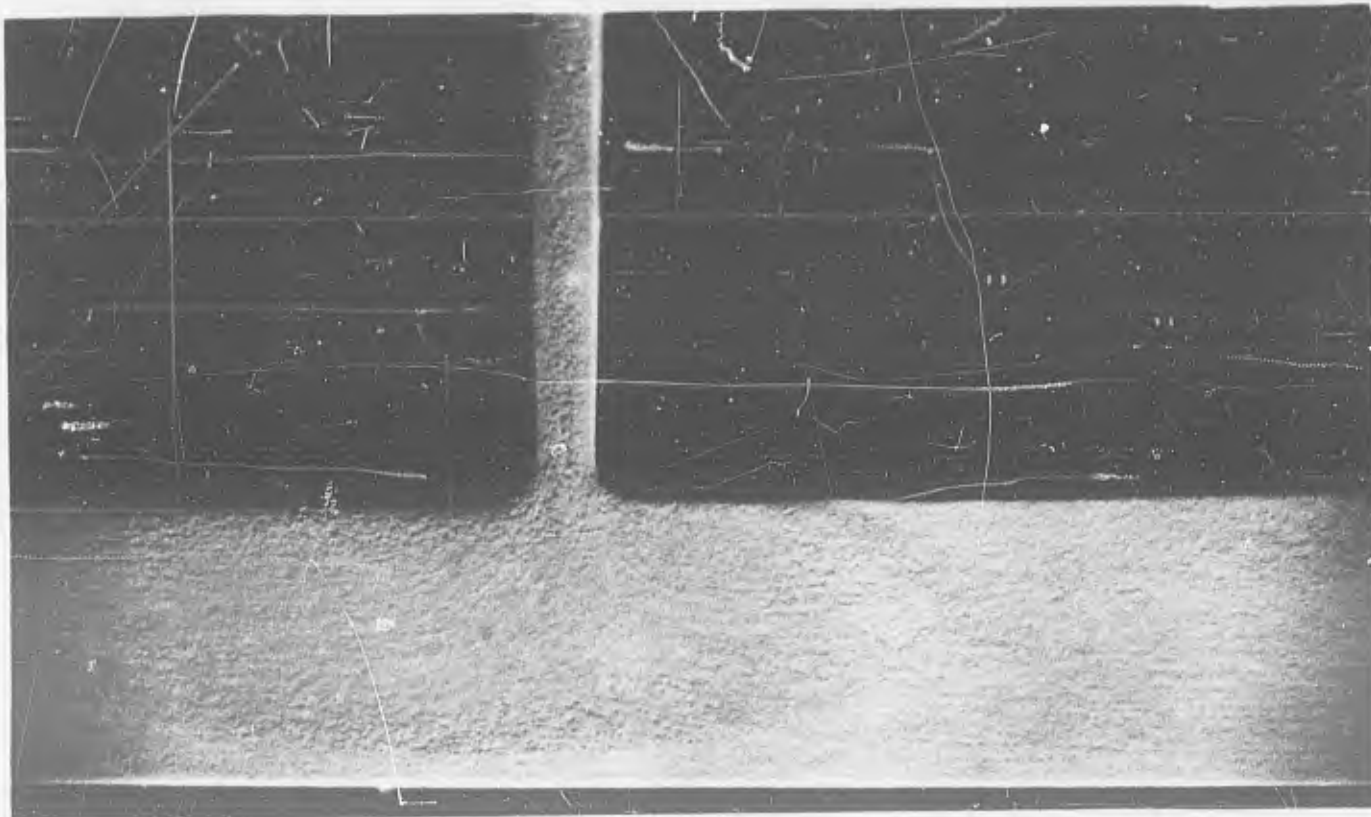
Top - Specimen M1
Specimen ML-A
Specimen M2
Bottom - Specimen M2-A



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Fig. 3 - Photomicrographs of sections normal to stiffener and skin.

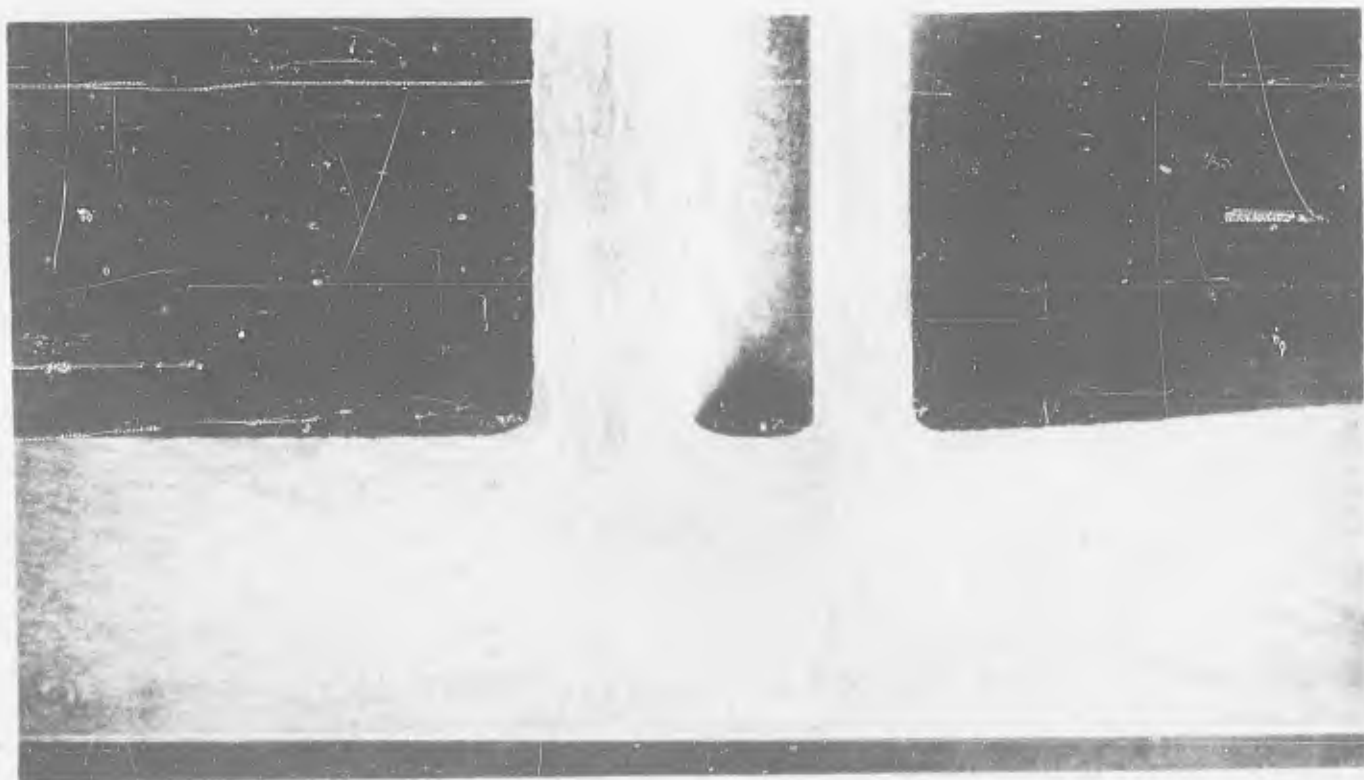
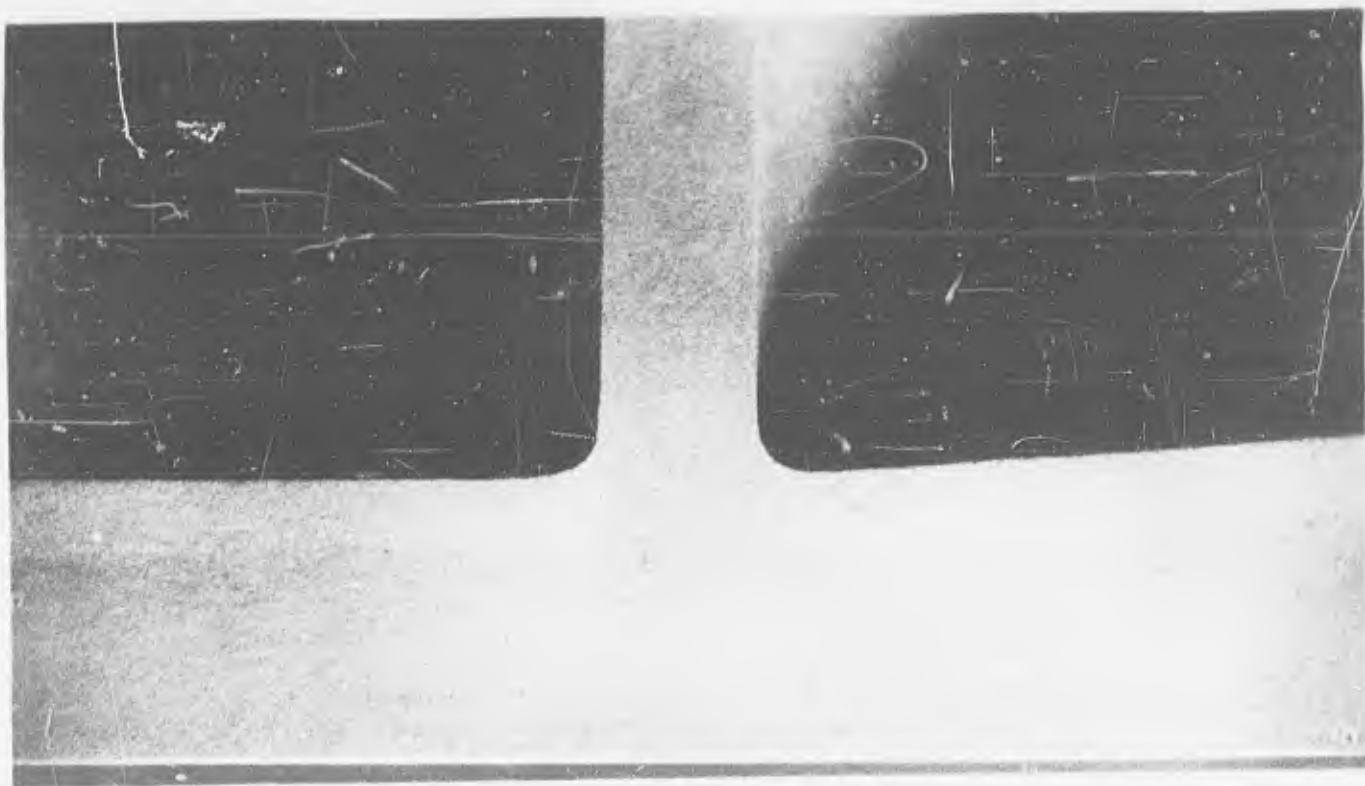
Top - M3
Bottom - M3A
192



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Fig. 4 - Photomicrographs of sections normal to stiffener and skin.

Top - M4
Bottom - M4A



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Fig. 5 - Photomicrograph of section normal to skin and stiffener.
Top - M5

Photomicrograph of section 45° to stiffeners and normal
to skin.

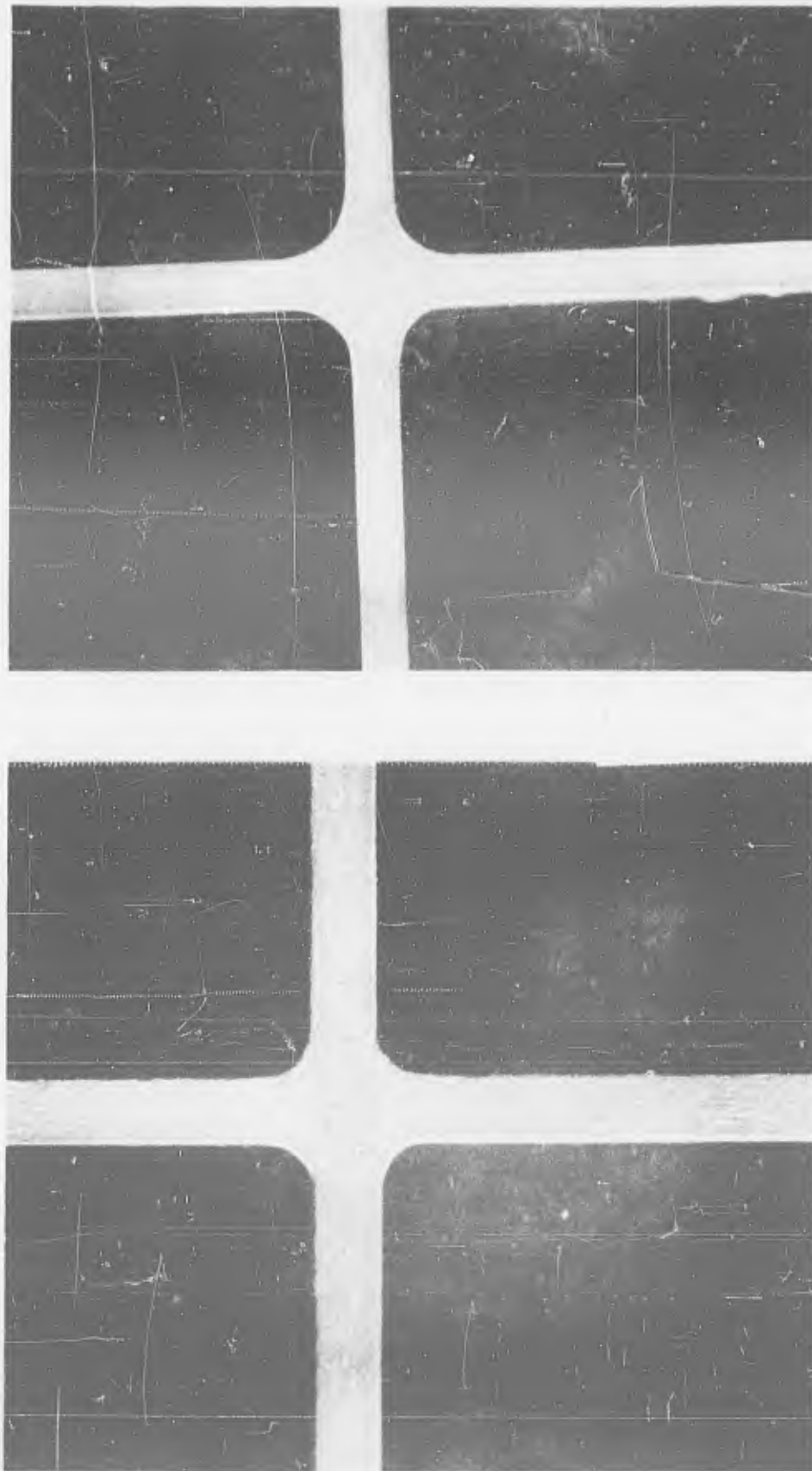
Bottom - M5A



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Fig. 6 - Photomicrographs of sections normal to skin and
45° to stiffeners.

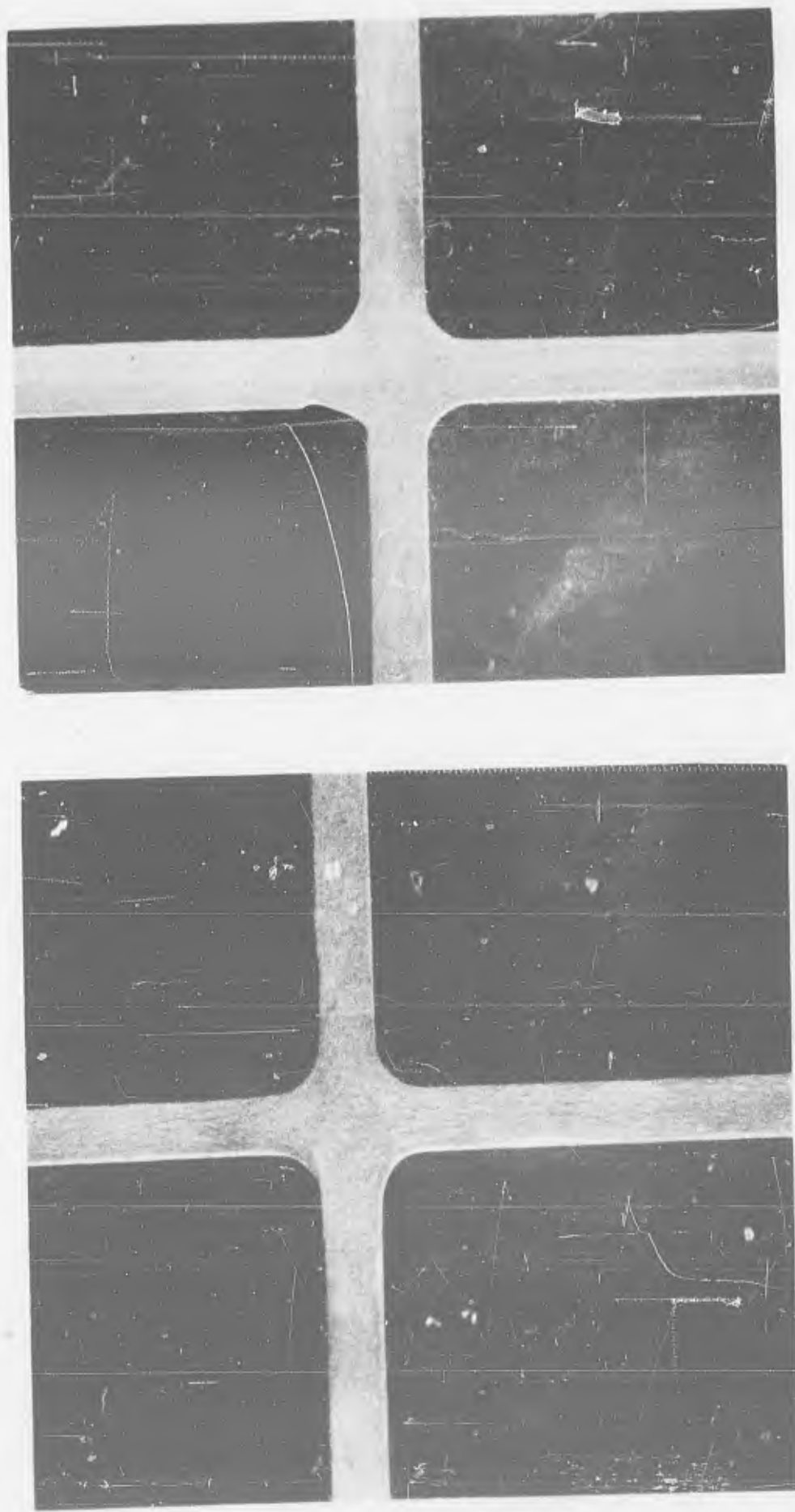
Top - M5
Bottom - M5A
195



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Fig. 7 - Photomicrographs of sections parallel to skin.

Top - M6
Bottom - M6A



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Fig. 8 - Photomicrographs of sections parallel to skin.

APPENDIX VII

ROUTINE METALLURGICAL INVESTIGATION

LAB. NO. 5523

WYMAN-GORDON COMPANY

WYMAN-GORDON COMPANY

WK/Jeg

ROUTINE METALLURGICAL INVESTIGATION

DATE REC'D 8/12/55

REPORTED BY *W. L. Kuczyński*

DATE COMP'D 9/20/55

APPROVED BY *[Signature]*

SUBJECT: Metallurgical Report

NAME OF PART	Experimental Waffle	MATERIAL	7075	CONDITION	T6
CUSTOMER & NO.	Lockheed, 127606	W-G NO.	27,004	CODE NO.	---
SOURCE & HEAT NO.	Alcoa	ANALYSIS NO.	1169	SERIAL NO.	15

INTRODUCTION:

This metallurgical investigation was conducted on one experimental waffle forging, WG 27004 forged to QQ-A-367 specifications and supplements Wyman-Gordon Engineering and Development Report Number 20.

CHEMISTRY:	$\frac{Cu}{\text{Max.}}$	$\frac{Mn}{\text{Max.}}$	$\frac{Wg}{\text{Max.}}$	$\frac{P}{\text{Max.}}$	$\frac{Si}{\text{Max.}}$	$\frac{Ni}{\text{Max.}}$	$\frac{Cr}{\text{Max.}}$	$\frac{Zn}{\text{Max.}}$	$\frac{Ti}{\text{Max.}}$	Al
Specification QQ-A-367c	1.2-2.0	.30	2.1-2.9	.70	.50		0.18-0.40	5.1-6.1	.20	Bal.
Part	1.64	1.08	2.53	.30	.11		0.25	5.47	.03	Bal.

EXAMINATION & RESULTS

- The spectrographic analysis sample was obtained from a section of the base in the approximate center of the forging. Results are as shown above.
- Horizontal and vertical macro cross sections illustrate the grainflow patterns in various locations of the forging. See Figures 2, 3, 4, 5, 6 and 7. The macro specimens were removed from the general areas indicated in Figure 1.
- Brinell hardness impressions (10mm ball - 1000 kg load) were made on macro cross section (D). Results are within a narrow range of BHN 159-165. Section (D) is shown in Figure 1. Brinell indentation positions and values are shown in Figure 8.
- The .250" Standard Round Tension Tests were cut from the base of the forging with the stiffener junction being located in the center of the 1" gage length. See Figure 11. Locations of the .250" tension tests are shown in Figure 9. Rectangular tension test specimens (B-C-D) as shown in Figure 9 were cut and machined so as to position the stiffener intersection at the center of the 2" gage length. Test results are tabulated in Tables I and II. Tensile fracture and grainflow may be seen in Figure 10.

EXAMINATION & RESULTS (Continued)

5. Micro specimens were taken from the center of the stiffener intersection (horizontal plane) and a single stiffener (vertical plane). Locations are shown in Figure 12. Figures 13, 14, 15 and 16 illustrate the microstructures in their respective areas.

CONCLUSIONS

1. Chemical analysis conforms to QQ-A-367 specification.
2. Macro examination shows a satisfactory grainflow with the flow lines following the contour of stiffeners.
3. Brinell hardness results (BHN 159-165) were uniform and consistently high throughout the cross section.
4. Mechanical properties of the flat tensiles and .250" round tension tests meet or exceed the QQ-A-367 specifications.
5. Micro-specimens show a uniform, fine grained, normal structure.

TABLE I

Mechanical Strength Properties of
Standard Round Tension Test Specimen with 1-in. Gage Length
Material: 7075 Condition: T6

<u>Test Specimen</u>	<u>Yield Strength psi</u>	<u>Ultimate Strength psi</u>	<u>Elongation %</u>
1L	72,000	84,400	9.0
2L	69,700	80,900	9.0
T1	72,600	83,400	13.0
T2	72,800	83,200	10.0
1	66,900	77,500	13.0
2	66,500	78,300	12.0
3	66,700	76,500	7.0
4	67,300	75,000	5.0
5	68,300	78,500	13.0
6	66,500	77,500	13.0
7	64,400	80,400	9.0
8	65,800	75,600	8.0
9	68,900	79,500	11.0
10	69,700	79,300	9.0
11	64,800	73,500	11.5
12	68,300	77,900	13.0
13	66,900	78,500	13.0

TABLE II

Mechanical Strength Properties of
Standard Rectangular Tension Test Specimen with 2-in. Gage Length

Material: 7075

Condition: T6

B	72,000	78,200	3.0
C	71,200	76,400	3.0
D	72,000	76,800	4.0

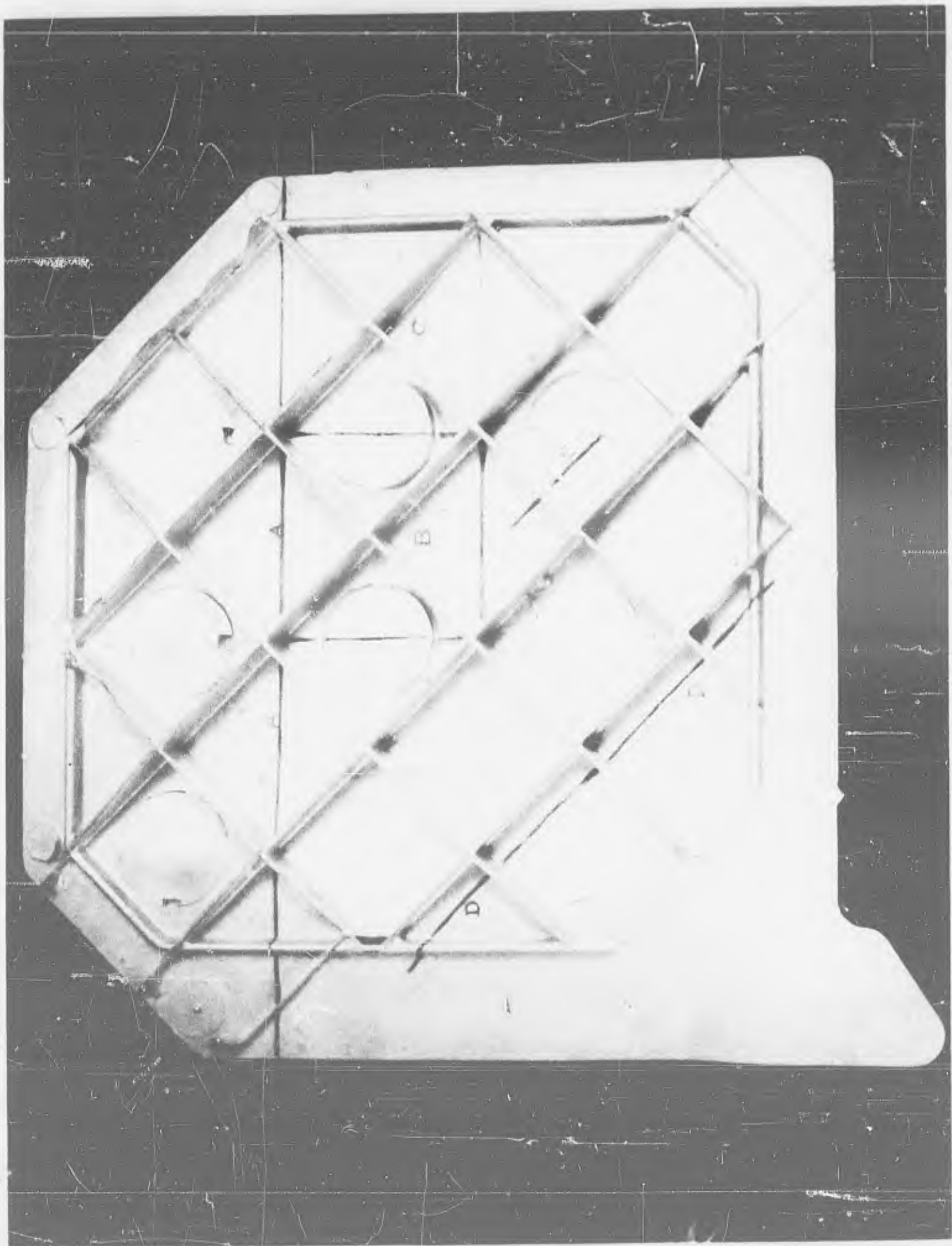


FIGURE 1, X3/4 Micro Specimen Locations and Cutting Planes

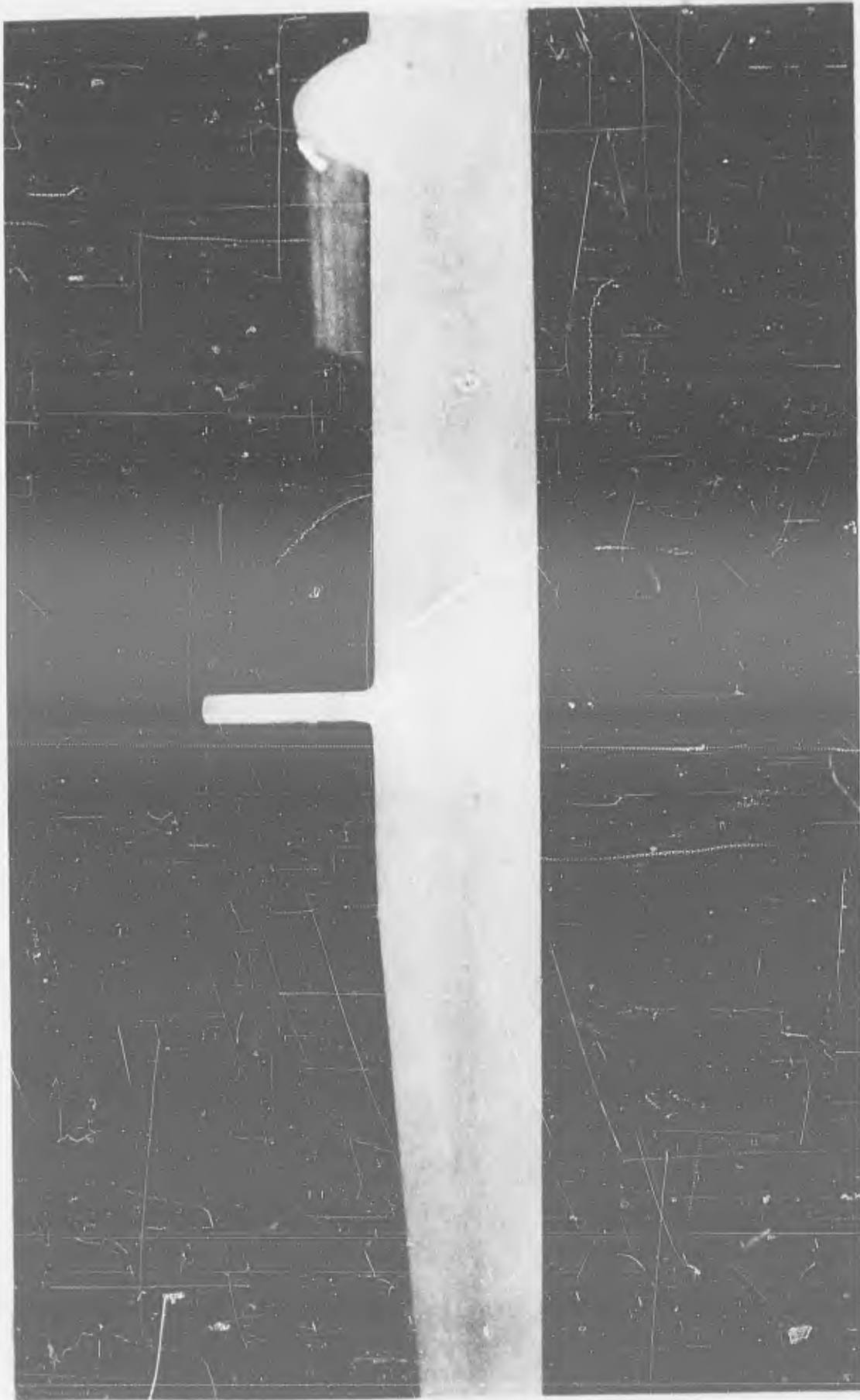


FIGURE 2, X2

Macrograph of cross section 'D' in Figure 1.

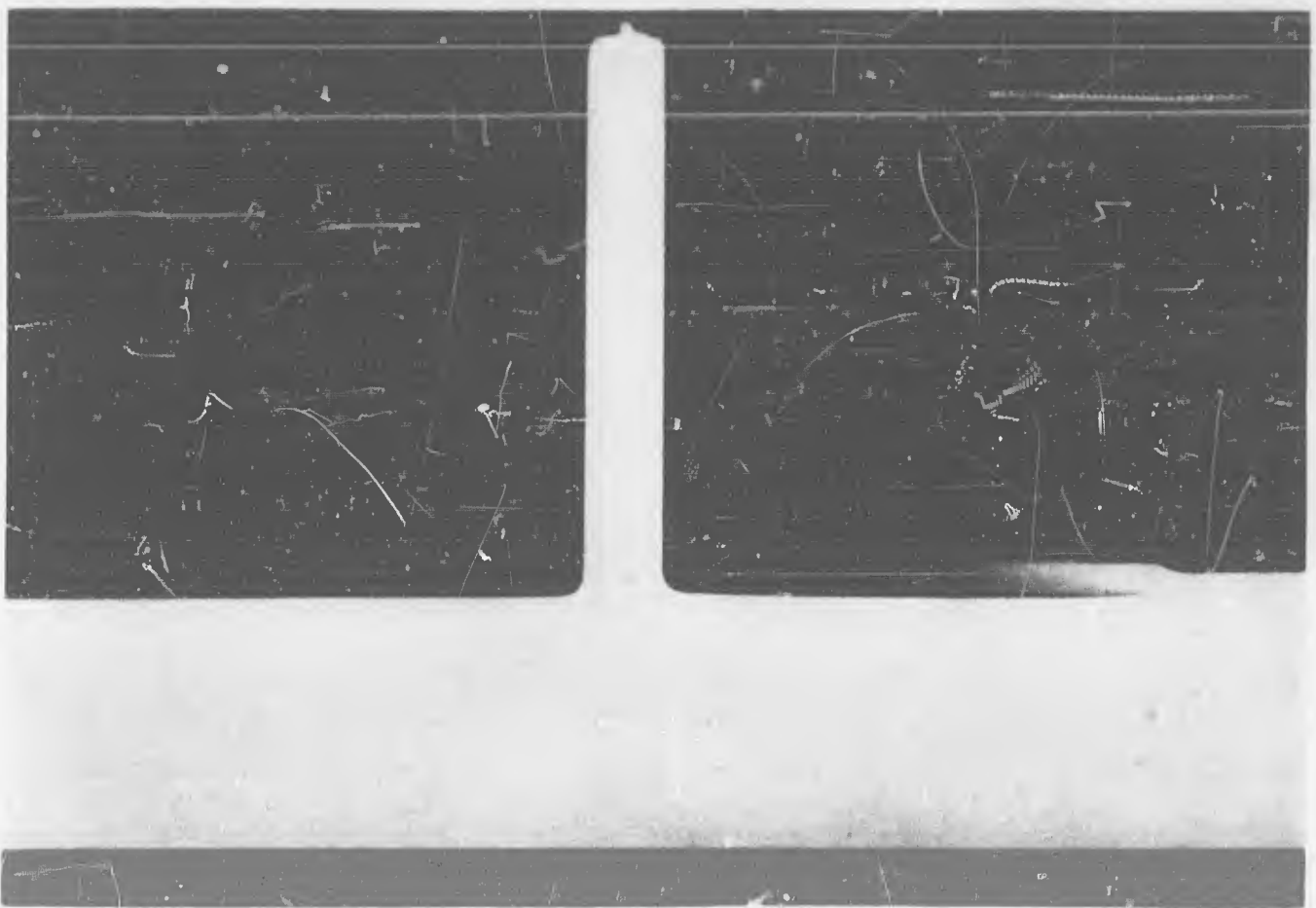


FIGURE 3, X3 Etchant 10% Caustic
Section: Stiffener and Base Location 'E' - Figure 1

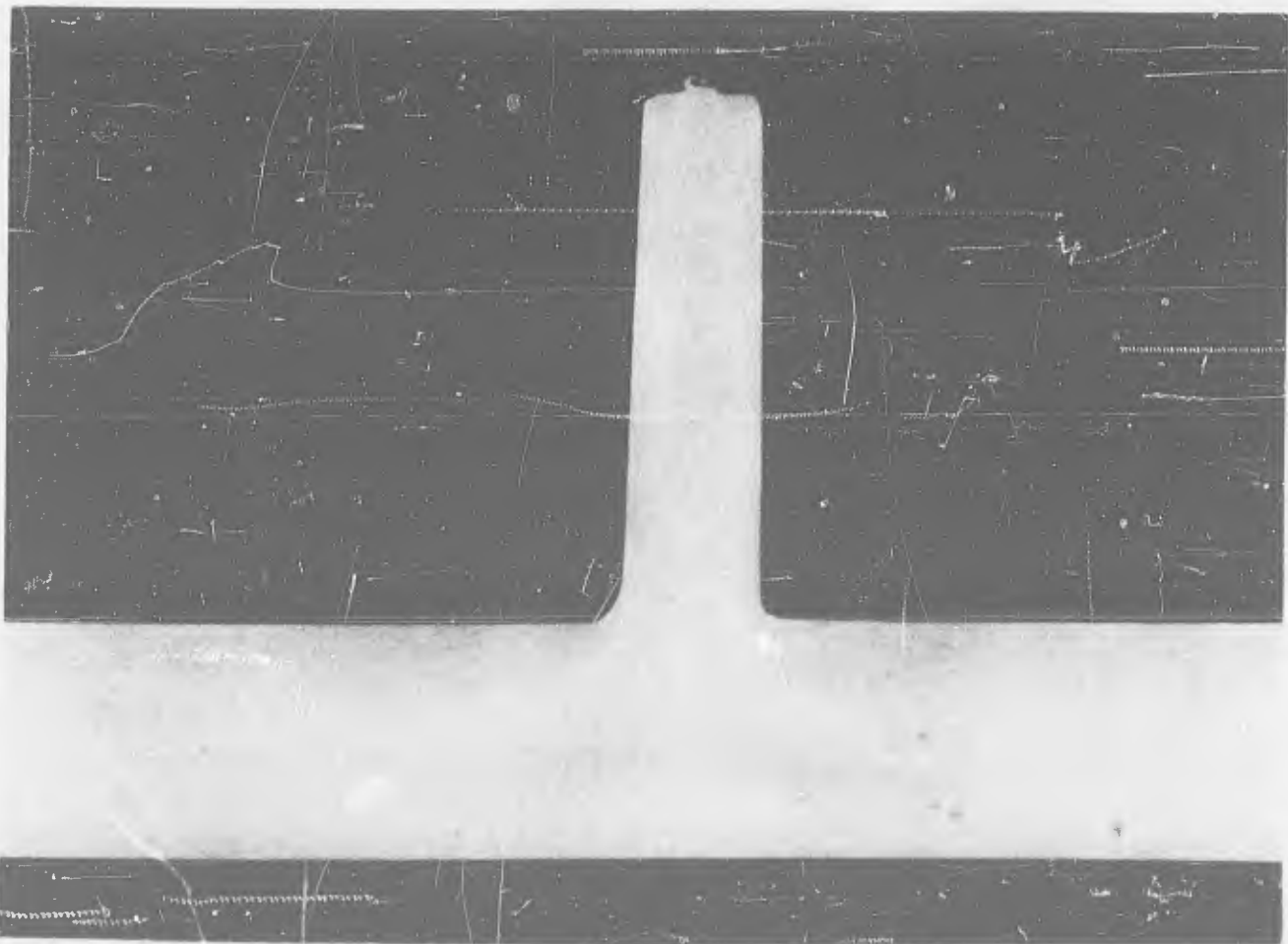


FIGURE 4, X3 Etchant 10% Caustic
Section: Stiffener Intersection and Base Location 'A' - Figure 1

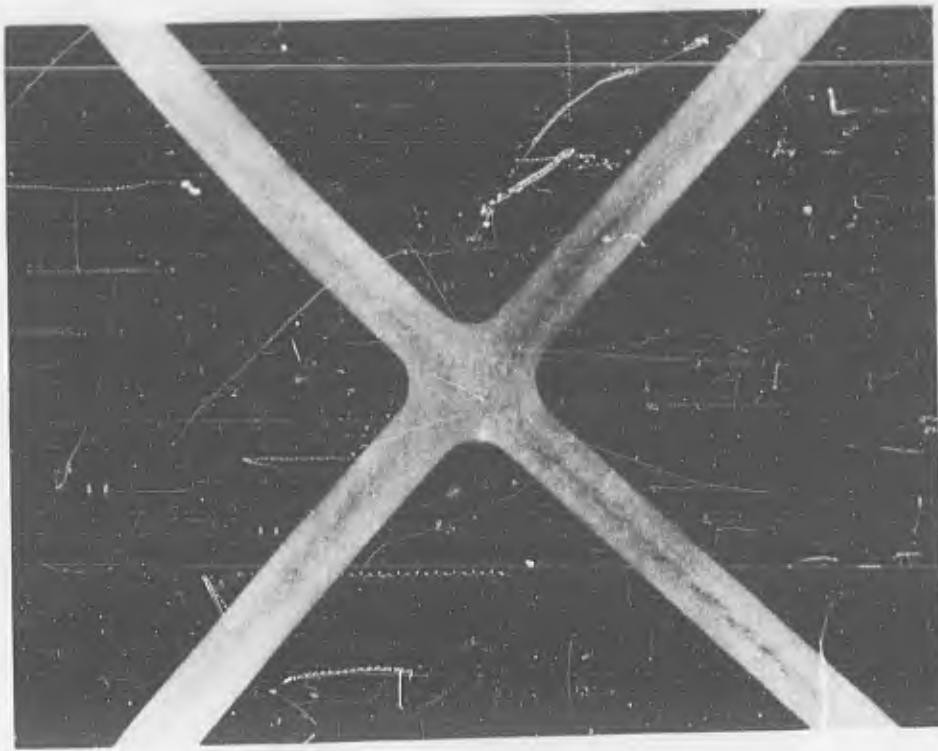


FIGURE 5, $\times 1\frac{1}{2}$ Etchant 10% Caustic
Section: Horizontal cross section of stiffener and intersection.
Location 'B' - Figure 1

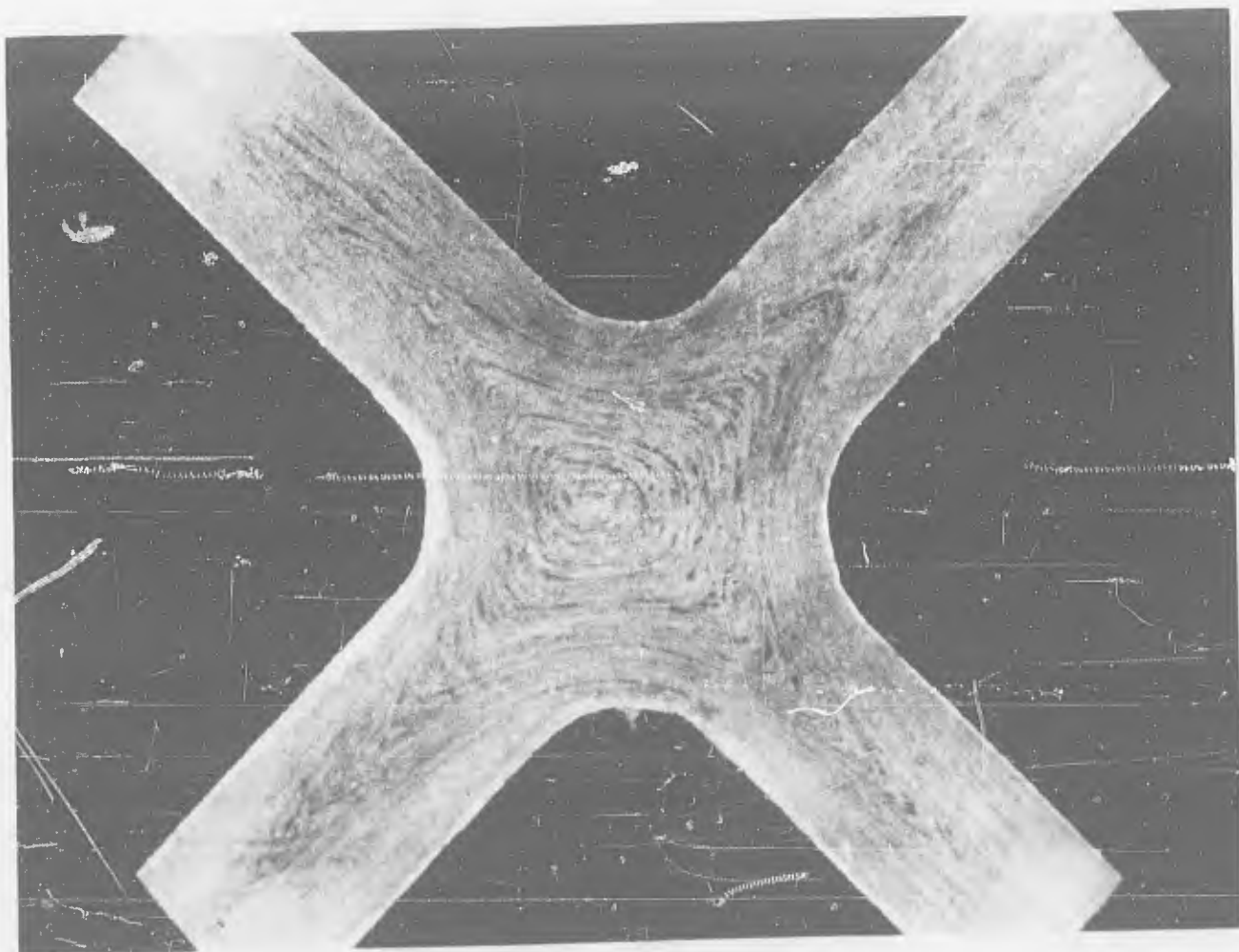


FIGURE 6, $\times 10$ Etchant - Modified Keller's
Section: Horizontal cross section of stiffener and intersection.
Enlargement of Figure 5.

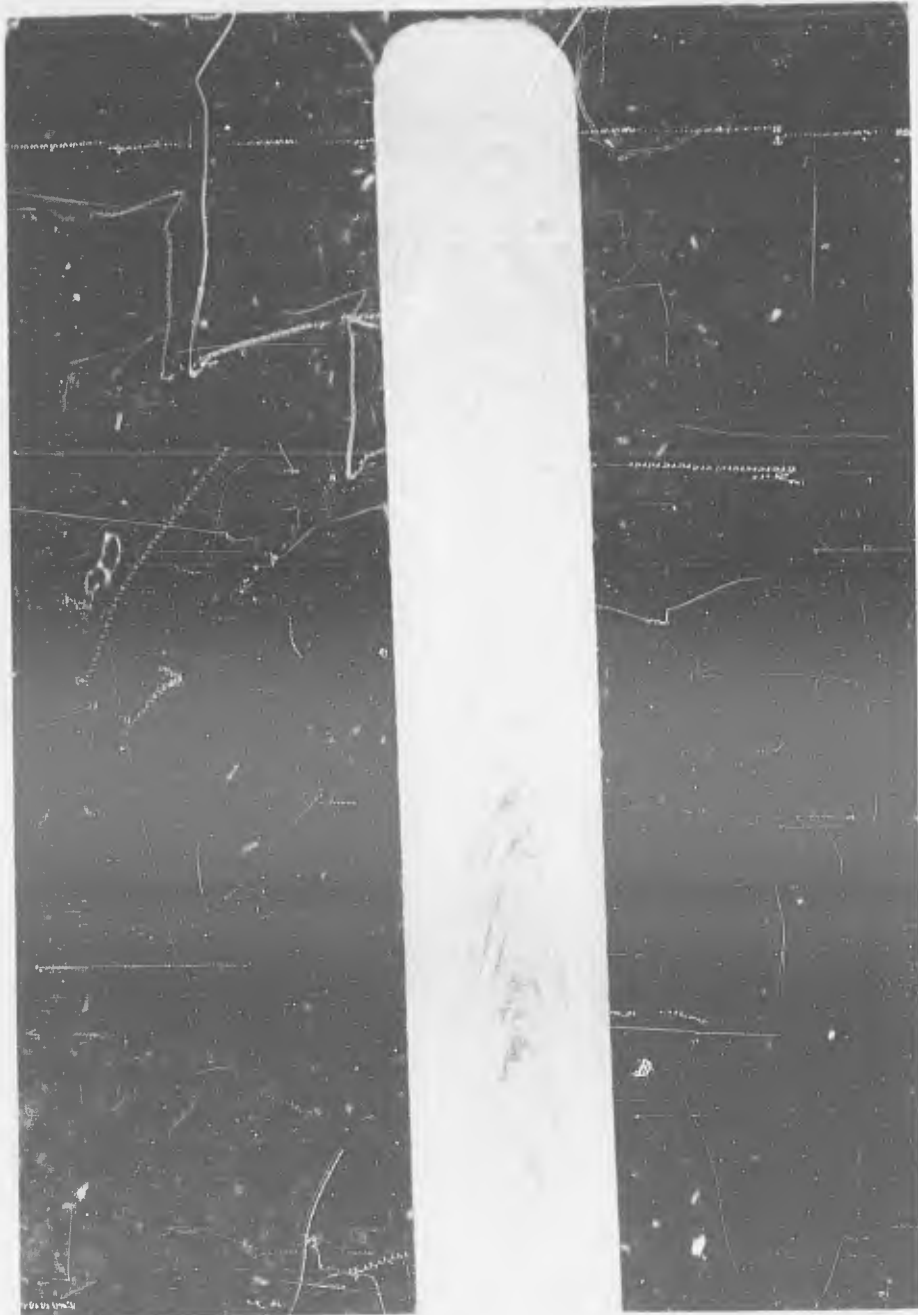


FIGURE 7, X10 Etchant: Modified Keller's
Section: Vertical cross section of stiffener.

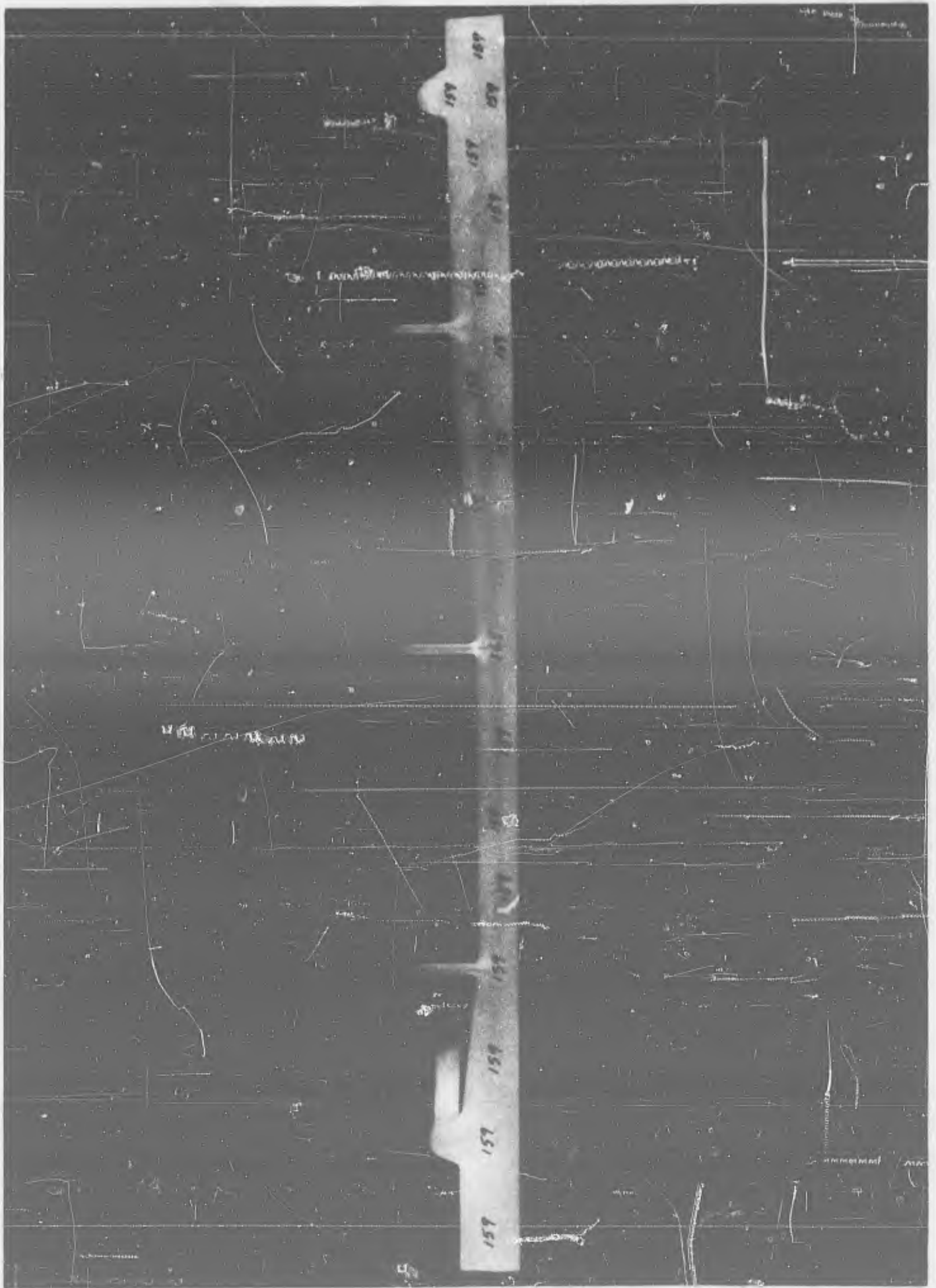


FIGURE 8, X3/4 Brinell Hardness Results and Impression Locations

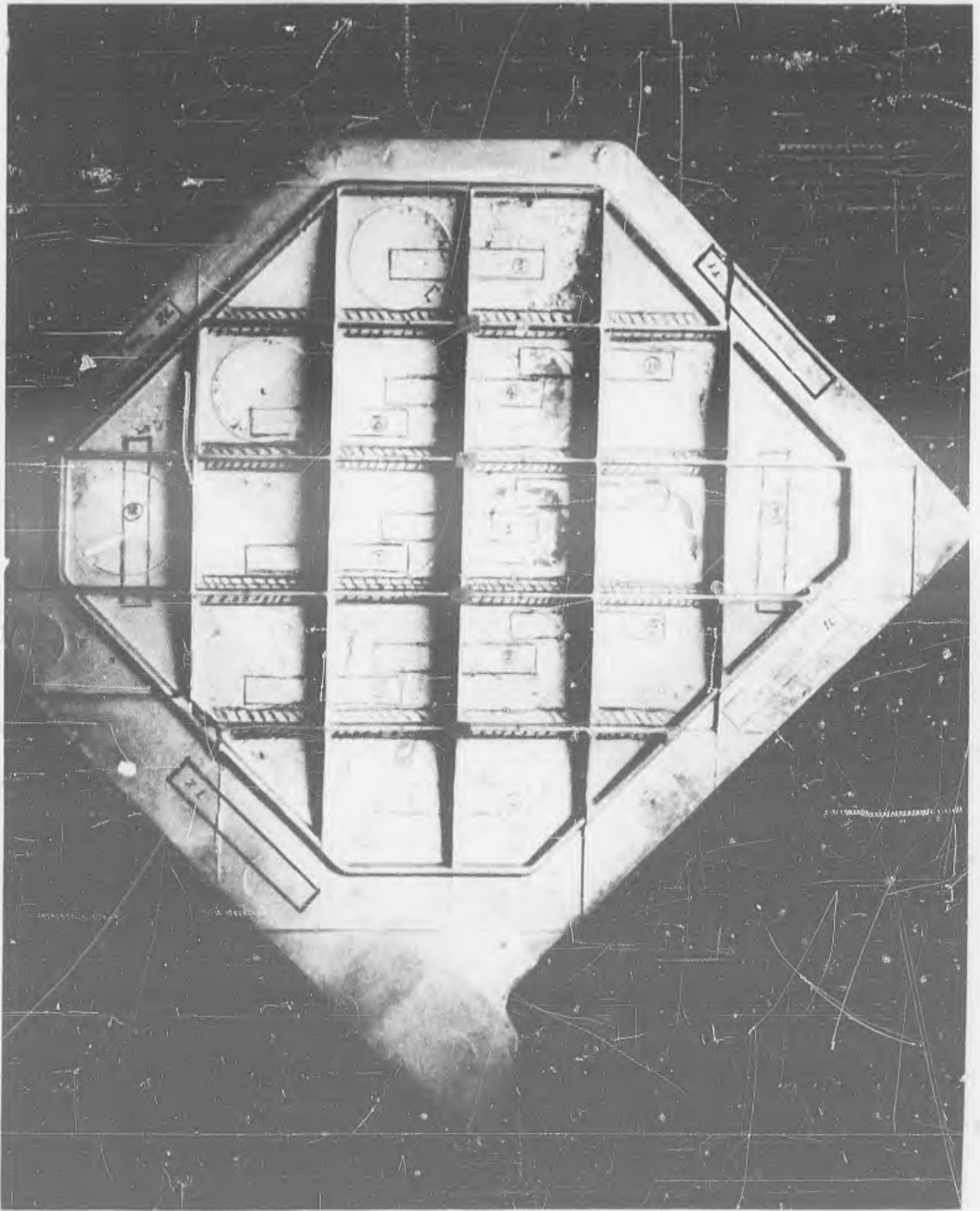
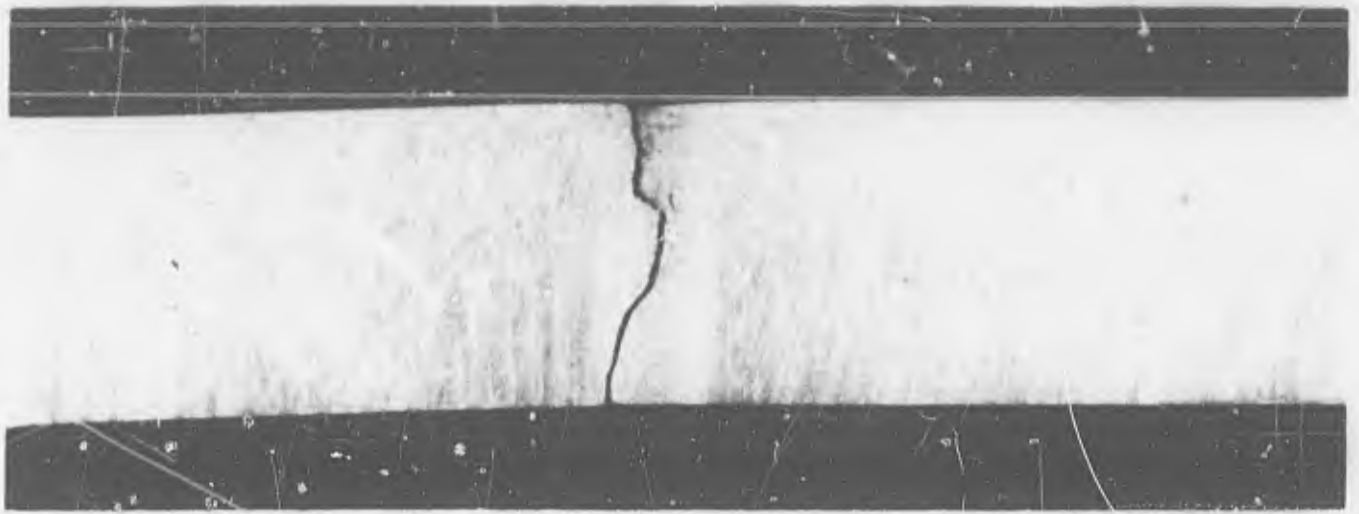
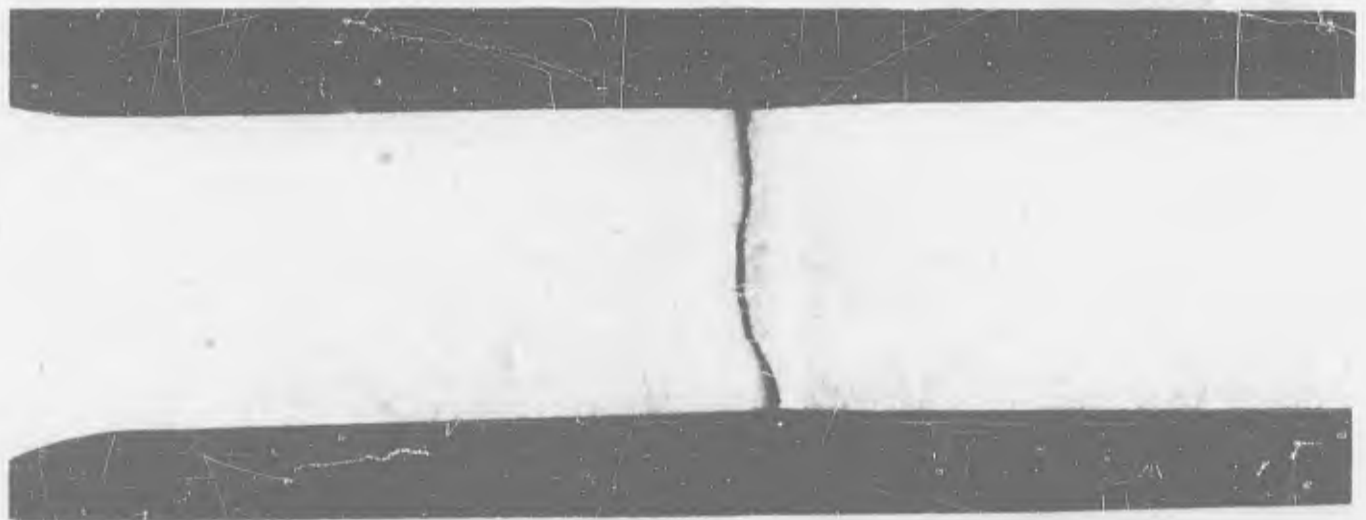
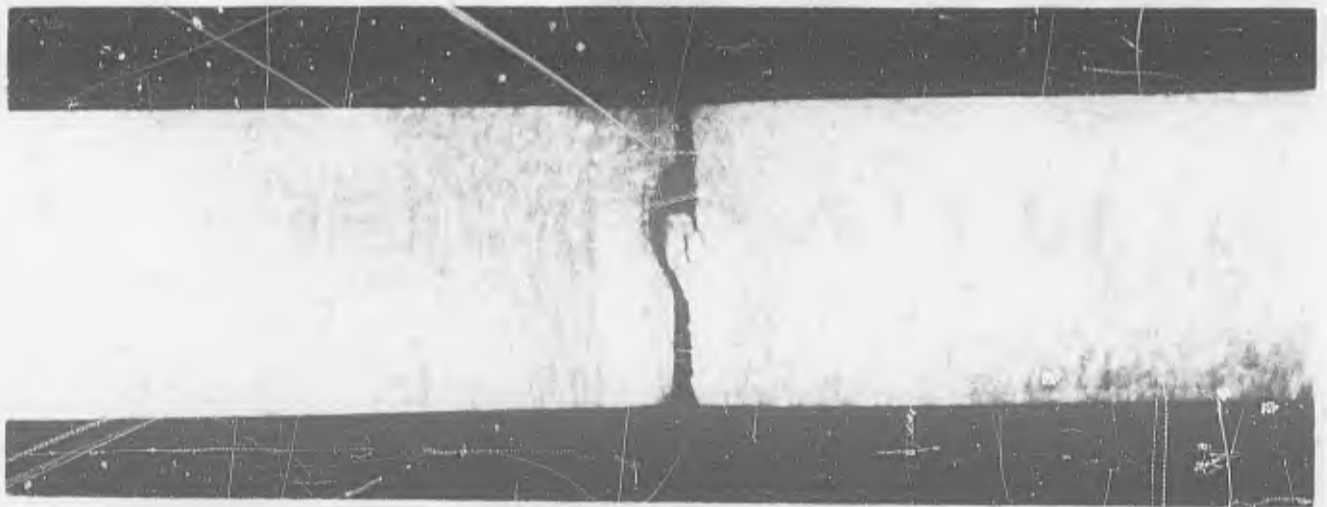


FIGURE 9, X3/4 ensile Locations and Grainflow
Orientation.



B



D

FIGURE 10, X3 Etchant 10% Caustic
Macrostructure of 'flat tensile' specimens showing
fractures occurring at stiffener intersection.

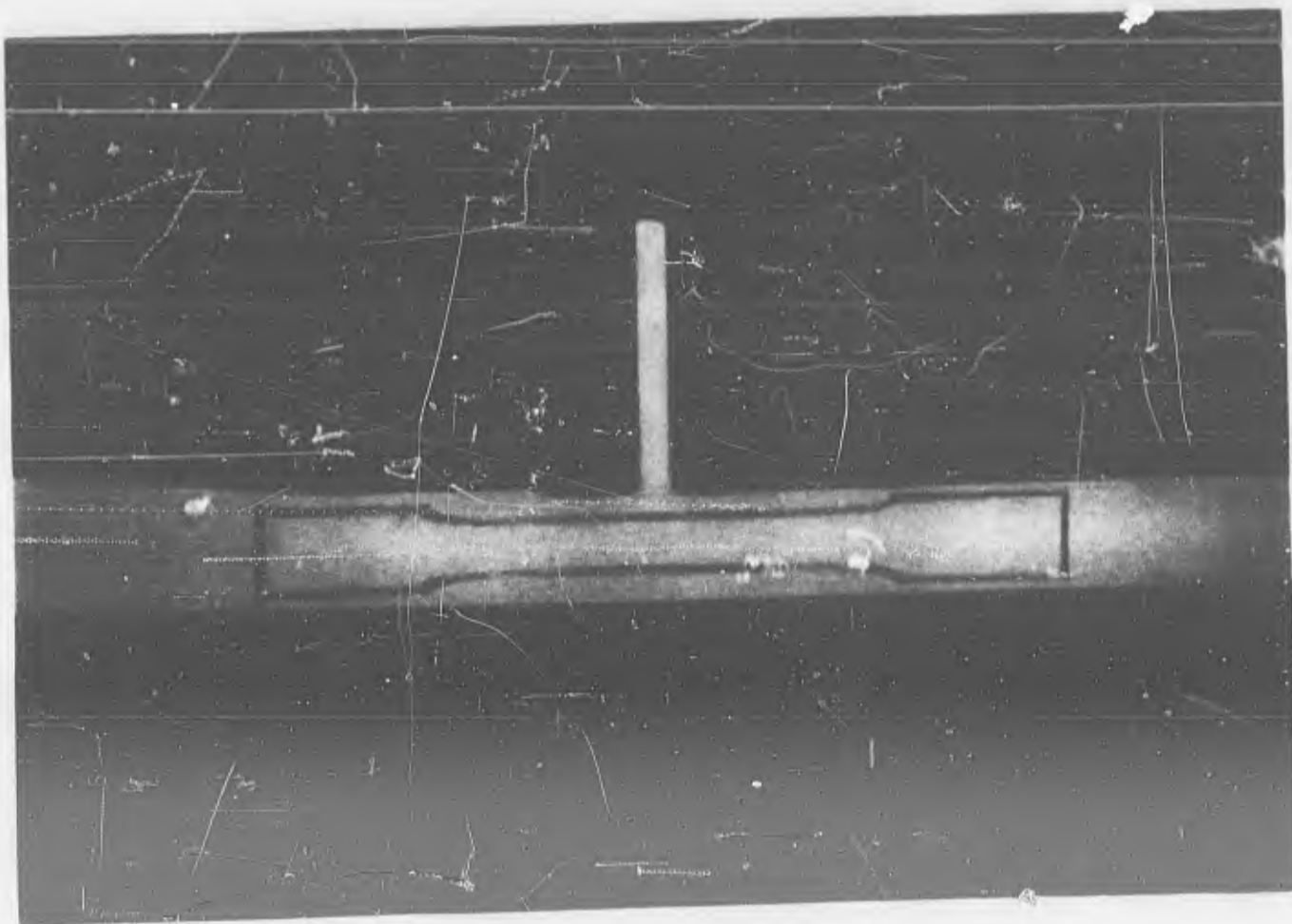


FIGURE 11, $X1\frac{1}{2}$
.250" Round Tensile Location relative to stiffener.
Tests 1 through 11.

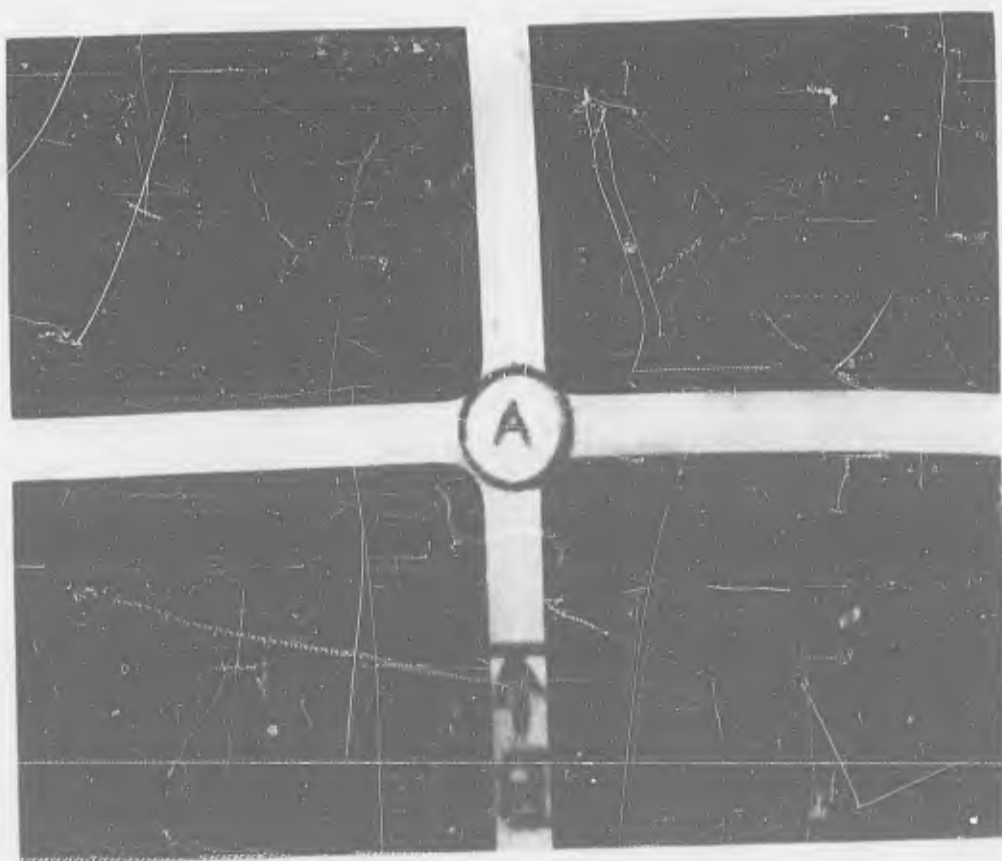


FIGURE 12, $X1\frac{1}{2}$
Micro specimen locations.

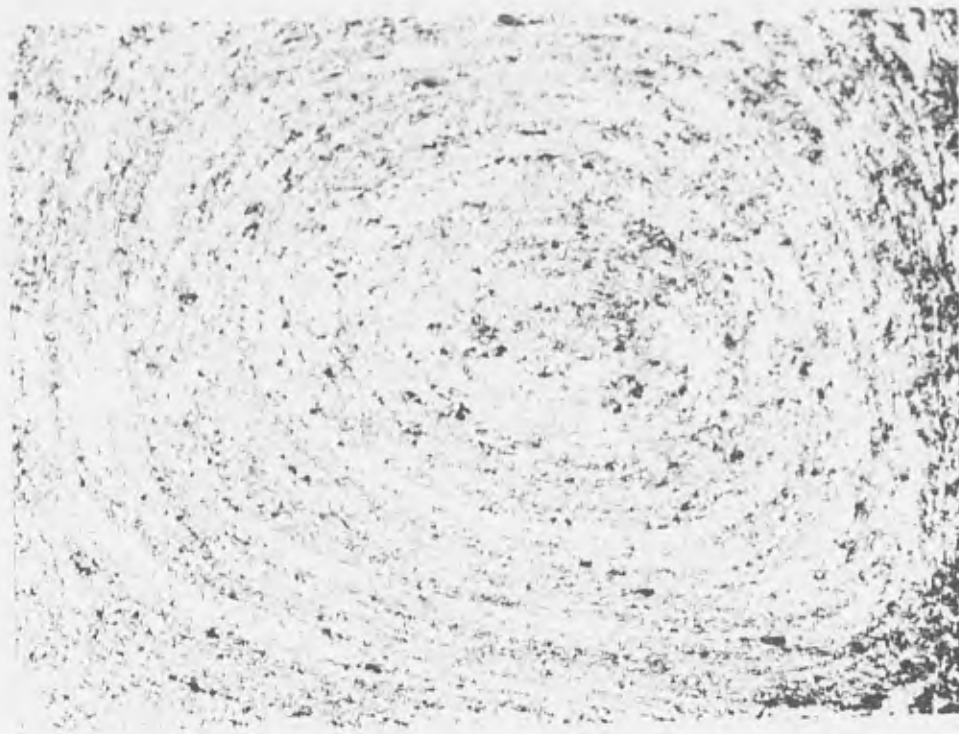


FIGURE 13, X50 Etchant - Modified Keller's
Micro: 'A' Section: Center of Stiffener Intersection (Horizontal plane)



FIGURE 14, X100 Etchant - Modified Keller's
Micro: 'A' Section: Stiffener area adjacent to intersection center.
(Horizontal plane)



FIGURE 15, X50 Etchant - Modified Keller's Micro 'B'
Section: Stiffener area midway between base and top of stiffener.
(Vertical plane)



FIGURE 16, X50 Etchant - Modified Keller's
Typical microstructure of base (Vertical plane)

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**FOR
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5 OF 5

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APPENDIX VIII

ANALYSIS OF PROPOSED DIE HEATING
REQUIREMENTS FOR THE 83" OCTAGON
x 35" DEPTH DIE BLOCK.

ANALYSIS OF PROPOSED DIE HEATING
REQUIREMENTS FOR THE 83" OCTAGON
x 35" DEPTH DIE BLOCK.

A theoretical analysis of the energy requirements to maintain the 83" octagon x 35" depth die block for production of a full-size 127586 Forged Panel was made by Lockheed and showed a deficiency of approximately 37KW. For this analysis, it was assumed that the entire die block would be maintained at 800°F; a platen temperature of 700°F; 1/4" bottom insulation and 1.0" side insulation. The insulation material to have a K value of 1.0. This analysis was submitted to Wyman-Gordon for their review and comments.

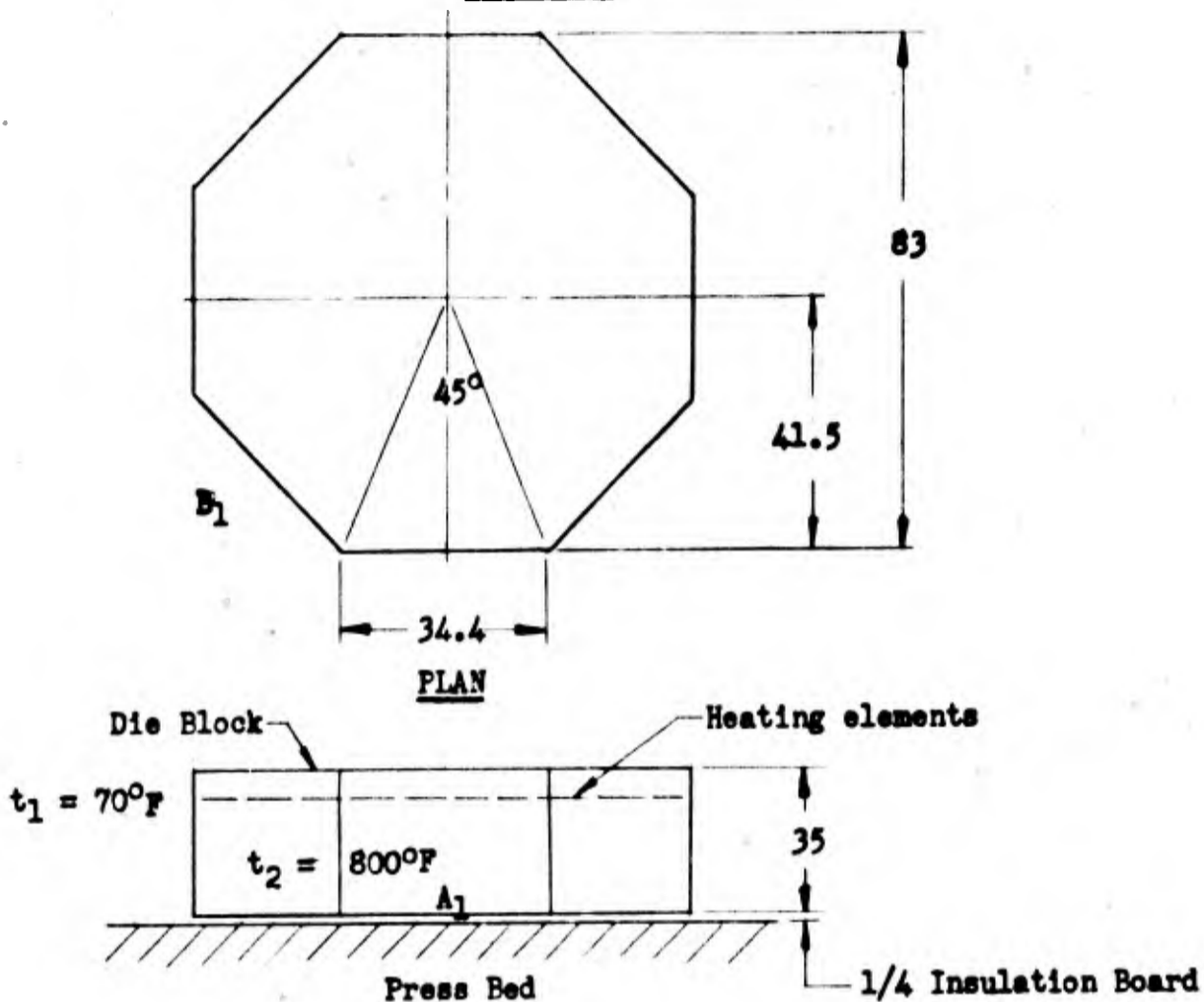
Wyman-Gordon concurred with Lockheed's method of analysis, but did not believe that it was proper to consider maintaining the entire holder at 800°F. Based on their experience, a temperature gradient will exist from the insert temperature to a lower temperature at the surface of the holder. In the Wyman-Gordon analysis, it was assumed the vertical sides of the holder would be radiating at 500°F. The bottom surface was also considered to be at this temperature. The upper surface was assumed to be radiating at an average temperature of 700°F. One inch thick insulation will be used on vertical surfaces and 1/2" bottom insulation with the press platen assumed to be operating at 200°F. The above conditions substantially reduce the power requirements.

To substantiate the temperature assumptions Wyman-Gordon submitted their analysis, and summary test data obtained from a 55" octagon x 22" depth die block identified as "E" Yoke in the following tabular summary:--

	<u>Installed Capacity (KW)</u>	<u>Lockheed Analysis (KW)</u>	<u>Wyman-Gordon Analysis (KW)</u>	<u>Test Data</u>
WAFFLE DIES	73	98.6	55.7	--
"E" YOKE	54.4	55.5	31.3	32.8 KWH/Hr

LOCKHEED ANALYSIS OF PROPOSED DIE HEATING

OF WAFFLE



ELEVATION

Assuming die block heated to 800°F and clamped down to press bed with 1/4 insulation board at bottom, heat losses are as follows:

q_1 = B.T.U./sec. lost through bottom insulation and

$$= \frac{K \times A_1 \times (t_2 - t_1)}{L \times 3600} \text{ B.T.U./sec. where } K \approx 1.0 \text{ B.T.U./ft}^2/\text{°F}/\text{in}/\text{HR}$$

q_{2r} = losses in watts by radiation from top surface and

$$= e \times 5.07 \times (T_2^4 - T_1^4) \times 10^{-10} \times A_1 \text{ where } e = .79 \text{ for steel}$$

q_{2v} = losses in watts by natural convection from top surface and

$$= .0938 (t_2 - t_1)^{1.25} \times 1.1 \times A_1 \text{ (factor of 1.1 for top surface)}$$

$$q_{3r} = \text{Losses in watts by radiation from sides and} \\ = e \times 5.07 \times (T_2^4 - T_1^4) \times 10^{-10} \times B_1 \text{ where } e = .79 \text{ for steel}$$

$$q_{3v} = \text{losses in watts by natural convection from side surface and} \\ = .0938 (t_2 - t_1) \frac{1.25}{x} B_1$$

Referring to figure 1, we have:

$$\text{Top surface} = \text{Bottom surface} = A_1 = 1/2 \times 34.4 \times 41.5 \times 8 = 5700 \text{ in}^2 \\ \underline{39.7 \text{ ft}^2}$$

$$\text{Side area} = B_1 = 34.4 \times 35 \times 8 = 9630 \text{ in}^2 = \underline{67 \text{ ft}^2}$$

$$\text{Wt.} = 39.7 \times 2.92 \times 490 = \underline{56,600 \text{ lb}} = \underline{28.3 \text{ Tons}}$$

Using dimensions of die block in formulae for losses, we have:

$$q_1 = \frac{K \times A_1 (t_2 - t_1)}{L \times 3600} = \frac{1 \times 39.7 \times 730 \times 4}{3600} = 32.2 \text{ B.T.U./sec or } \underline{34 \text{ KW.}}$$

$$q_{2r} = e \times 5.07 \times (T_2^4 - T_1^4) \times 10^{-10} \times A_1 = .79 \times 5.07 \times [(459.6 \\ + 800)^4 - (459.6 + 70)^4] \times 10^{-10} \times A_1 \\ = 4 \times 2.44 \times 10^2 \times 39.7 = \underline{38.7 \text{ KW.}}$$

$$q_{2v} = .0938 \times 730 \frac{1.25}{x} 1.1 \times 39.7 = \underline{15.5 \text{ KW.}}$$

$$q_{3r} = 38.7 \times \frac{67}{39.7} = \underline{65.4 \text{ KW.}}$$

$$q_{3v} = .0938 \times 730 \frac{1.25}{x} 67 = \underline{23.8 \text{ KW.}}$$

Total KW. requirement for keeping die at temp. with bottom insulated only

$$= 34 + 38.7 + 15.5 + 65.4 + 23.8 = \underline{177.4 \text{ KW.}}$$

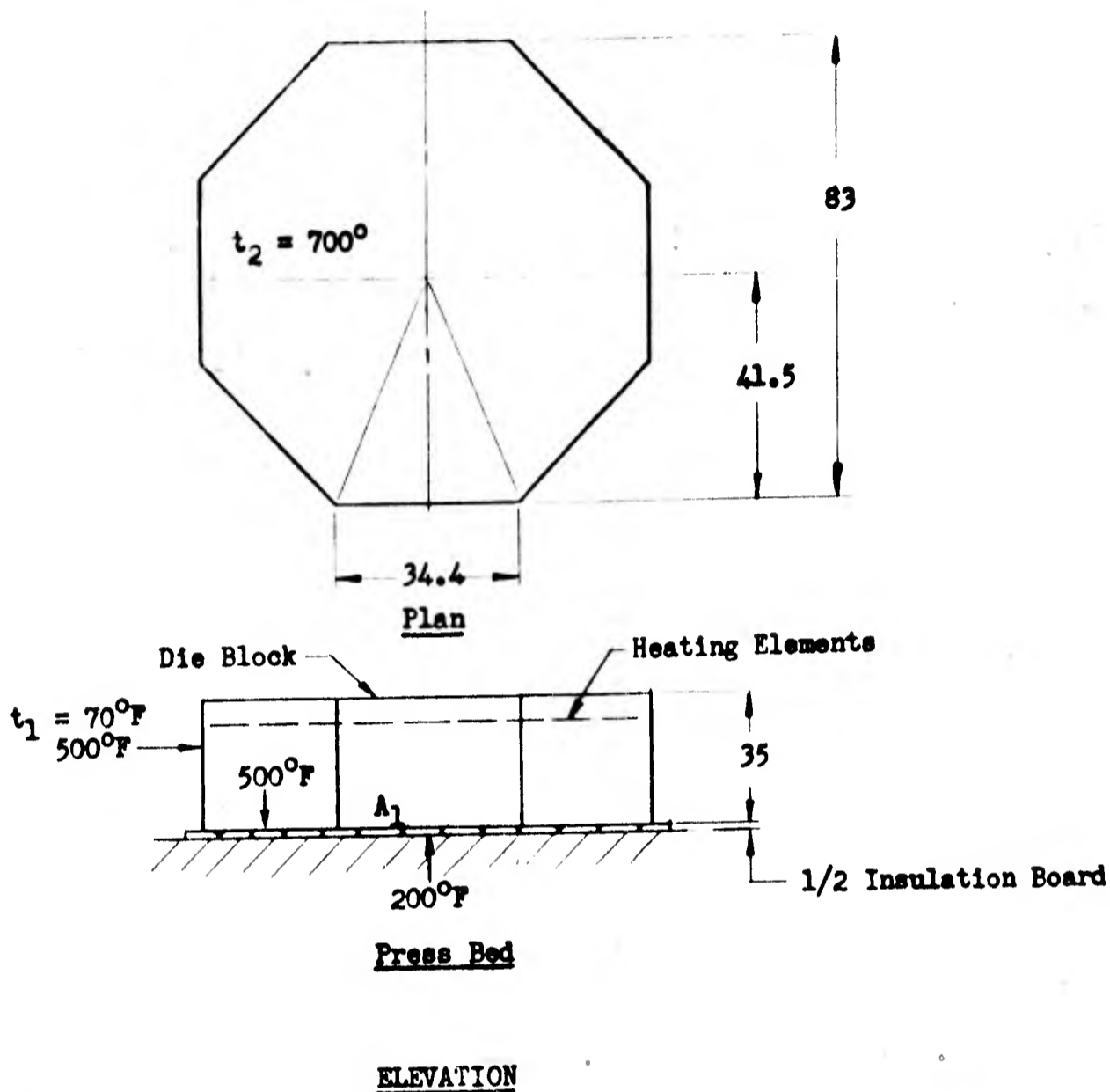
By insulating all vertical surfaces of die we can reduce the sum of $q_{3r} + q_{3v} = q_3 = 89.2 \text{ KW.}$ to the following figure, using $K = 1.0$ for insulation material, 1 in. thick

$$q_3' = \left(\frac{1 \times 67 \times 730}{3600} \right) \times 1.055 = \underline{14.3 \text{ KW.}}$$

Total losses by insulating sides and bottom.

$$= q_1 + q_{2r} + q_{2v} + q_3' = 34 + 38.7 + 15.5 + 14.3 = \underline{102.5 \text{ KW.}}$$

**WYMAN-GORDON ANALYSIS OF PROPOSED DIE HEATING
OF WAFFLE**



Assuming die block heated as shown above (500°F at bottom and sides, average of 700°F on top surface to maintain 800°F in center of block) and clamped down to press bed with 1/2" insulation board at bottom, heat losses are as follows:

$$q_1 = \text{B.T.U./sec. lost through bottom insulation and}$$

$$= \frac{K \times A_1 \times (t_2 - t_1)}{L \times 3600} \text{ B.T.U./sec, where } K = 1.0 \text{ B.T.U./ft}^2/\text{°F/in/hr.}$$

$$q_{2r} = \text{losses in watts by radiation from top surface and}$$

$$= e \times 5.07 \times (T_2^4 - T_1^4) \times 10^{-10} \times A_1 \text{ where } e = .79 \text{ for steel}$$

$$q_{2y} = \text{losses in watts by natural convection from top surface and} \\ = .0938 (t_2 - t_1) \frac{1.25}{x} 1.1 \times A_1 \text{ (factor of 1.1 for top surface)}$$

$$q_{3r} = \text{losses in watts by radiation from sides and} \\ = e \times 5.07 \times (T_2^4 - T_1^4) \times 10^{-10} \times B_1 \text{ where } e = .79 \text{ for steel.}$$

$$q_{3v} = \text{losses in watts by natural convection from side surface and} \\ = .0938 (t_2 - t_1) \frac{1.25}{x} B_1$$

Referring to Figure 1, we have:

$$\text{Top surface} = \text{Bottom surface} = A_1 = 1/2 \times 34.4 \times 41.5 \times 8 = 5700 \text{ in}^2 \\ = \underline{39.7 \text{ ft}^2}$$

$$\text{Side Area} = B_1 = 34.4 \times 35 \times 8 = 9630 \text{ in}^2 = \underline{67 \text{ ft}^2}$$

$$\text{Wt.} = 39.7 \times 2.92 \times 490 = \underline{56600\#} = \underline{28.3 \text{ Tons}}$$

Using dimensions of die block in formulae for losses, we have:

$$q_1 = \frac{K \times A_1 (t_2 - t_1)}{L \times 3600} = \frac{1 \times 39.7 \times 300 \times 2}{3600} = 6.6 \text{ B.T.U./sec. or } \underline{7.0 \text{ KW.}}$$

$$q_{2r} = e \times 5.07 \times (T_2^4 - T_1^4) \times 10^{-10} \times A_1 = .79 \times 5.07 \times [(459.6 + 700)^4 \\ - (459.6 + 70)^4] \times 10^{-10} \times A_1 \\ = 4 \times 1.73 \times 10^2 \times 39.7 = \underline{27.4 \text{ KW.}}$$

$$q_{2v} = .0938 \times 630 \frac{1.25}{x} 1.1 \times 39.7 = \underline{12.9 \text{ KW.}}$$

$$q_{3r} = e \times 5.07 (T_2^4 - T_1^4) \times 10^{-10} \times B_1 = .79 \times 5.07 \times [(459.6 + 500)^4 \\ - (459.6 + 70)^4] \times 10^{-10} \times B_1 \\ = 4 \times .769 \times 10^2 \times 67 = \underline{20.6 \text{ KW.}}$$

$$q_{3v} = .938 \times 430 \frac{1.25}{x} 67 = \underline{12.3 \text{ KW.}}$$

Total KW. requirement for keeping die at temperature with bottom insulated only.

$$= 7.0 + 27.4 + 12.9 + 20.6 + 12.3 = \underline{80.2 \text{ KW.}}$$

By insulating all vertical surfaces of die we can reduce the sum of $q_{3r} + q_{3v} = q_3 = 32.9$ KW. to the following figure, using $K = 1.0$ for insulation material, one inch thick.

$$q'_3 = \frac{(1 \times 67 \times 430)}{3600} \times 1.055 = \underline{8.4 \text{ KW}}$$

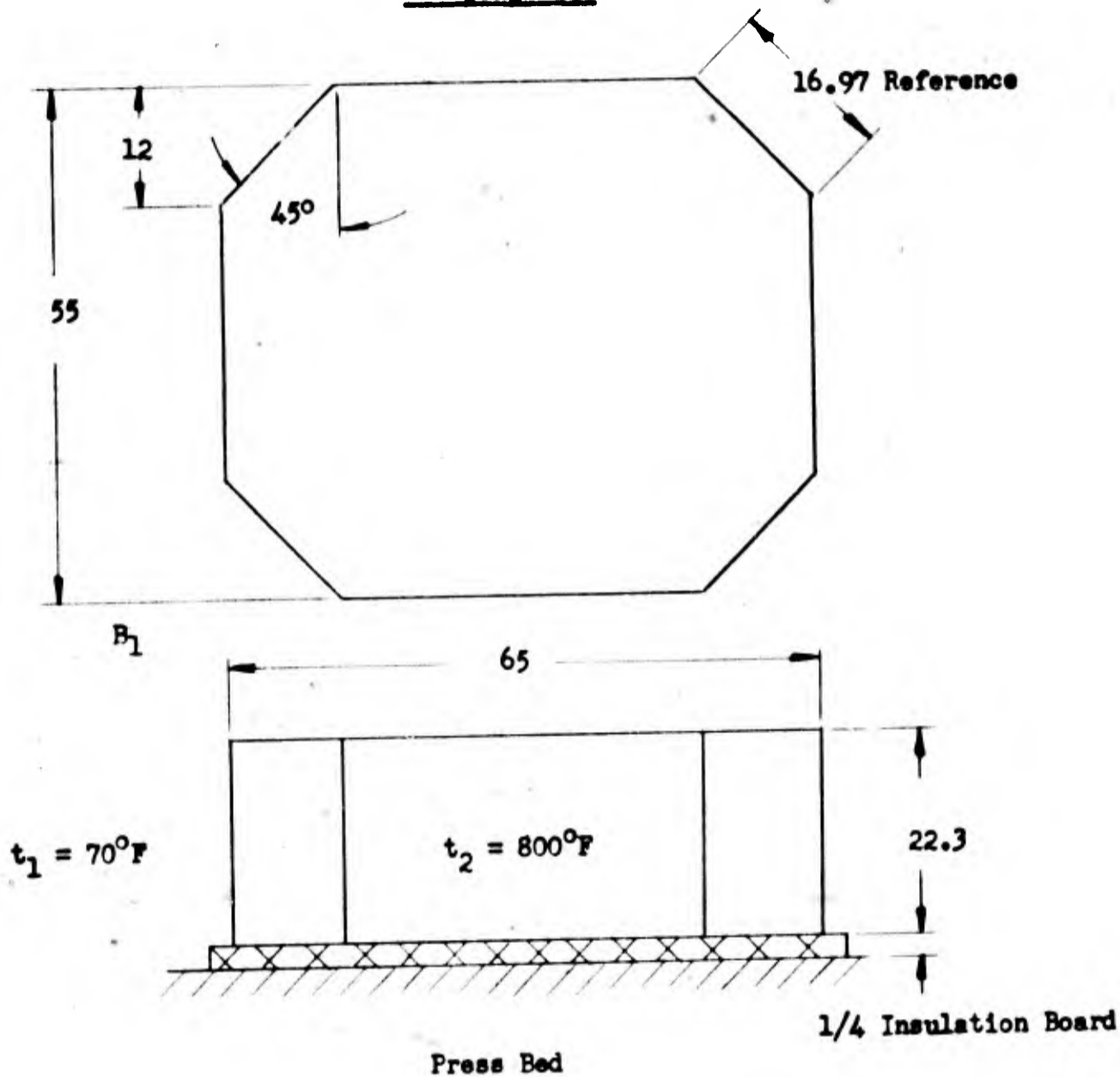
Total losses by insulating sides and bottom

$$= q_1 + q_{2r} + q_{2v} + q'_3 = 7.0 + 27.4 + 12.9 + 8.4 = \underline{55.7 \text{ KW}}$$

Lockheed's calculation for 800°F die was 102.5 KW; their recommended capacity was 110 KW. By ratios $\frac{110}{102.5} \times 55.7 = 59.8$

LOCKHEED ANALYSIS OF PROPOSED DIE HEATING

"E" YOKE DIES



Calculations for proposed die heating of above, using Lockheed method (Sheets 1 and 2).

$$\text{Top Surface} = \text{Bottom Surface} = A_1 = 65 \times 55 - \frac{(12 \times 12 \times 4)}{2} = 3287 \text{ in}^2 = \underline{22.8 \text{ ft}^2}$$

$$\text{Side Area} = B_1 = (41 \times 2) + (31 \times 2) + (16.97 \times 4) \times 22.3 = 4725 \text{ in}^2 = \underline{32.8 \text{ ft}^2}$$

$$\text{Wt.} = 22.8 \times 1.86 \times 490 = 20,781 \# = 10.39 \text{ Tons} \\ (\text{Scale Weight act. } 19,600 \#)$$

Using dimensions of die block in formulae for losses, we have:

$$q_1 = \frac{K \times A_1 (t_2 - t_1)}{L \times 3600} = \frac{1 \times 22.8 \times 730 \times 4}{3600} = 18.49 \text{ B.T.U./sec.} = \underline{19.46 \text{ KW}}$$

$$t_2 = 800^\circ \text{ F}$$

$$t_1 = 70^\circ \text{ F}$$

$$q_{2r} = e \times 5.07 \times (T_2^4 - T_1^4) \times 10^{-10} \times A_1 = .79 \times 5.07 \times ((459.6 + 800)^4 - (459.6 + 70)^4) \times 10^{-10} \times A_1$$

$$= 4 \times 2.44 \times 10^2 \times 22.8 = \underline{22.3 \text{ KW}}$$

$$q_{2v} = .0938 \times 730 \frac{1.25}{x} \times 1.1 \times 22.8 = \underline{8.9 \text{ KW}}$$

$$q_{3r} = 22.3 \times \frac{32.8}{22.8} = \underline{32.11 \text{ KW}}$$

$$q_{3v} = .0938 \times 730 \frac{1.25}{x} \times 32.8 = \underline{11.67 \text{ KW}}$$

Total KW. requirement for keeping die at temperature with bottom insulated only.

$$= 19.5 + 22.3 + 8.9 + 32.1 + 11.7 = \underline{94.5 \text{ KW}}$$

By insulating all vertical surfaces of die we can reduce the sum of $q_{3r} + q_{3v} = q_3 = 43.8 \text{ KW}$. to the following figure, using $K = 1.0$ for insulation material, 1 inch thick.

$$q_3' = \frac{(1 \times 32.8 \times 730)}{3600} \times 1.055 = \underline{7.0 \text{ KW}}$$

Total losses by insulating sides and bottom.

$$= q_1 + q_{2r} + q_{2v} + q_3' = 19.5 + 22.3 + 8.9 + 7.0 = \underline{57.7 \text{ KW}}$$

From G.E. publication Page 11, Figures 1 and 2 (G.E.A. 5097A) the combined loss (radiation + convection) from a heated vertical steel surface = 8 watts/in² at 800°F. A factor of 1.1 apply to horizontal surfaces.

Using data from publication, we have:

1. Radiation and convection loss from top surface

$$= 8 \times 22.8 \times 1.1 \times 144 = \underline{28.9 \text{ KW}}$$

2. Loss through side insulation with $K = 1.0$

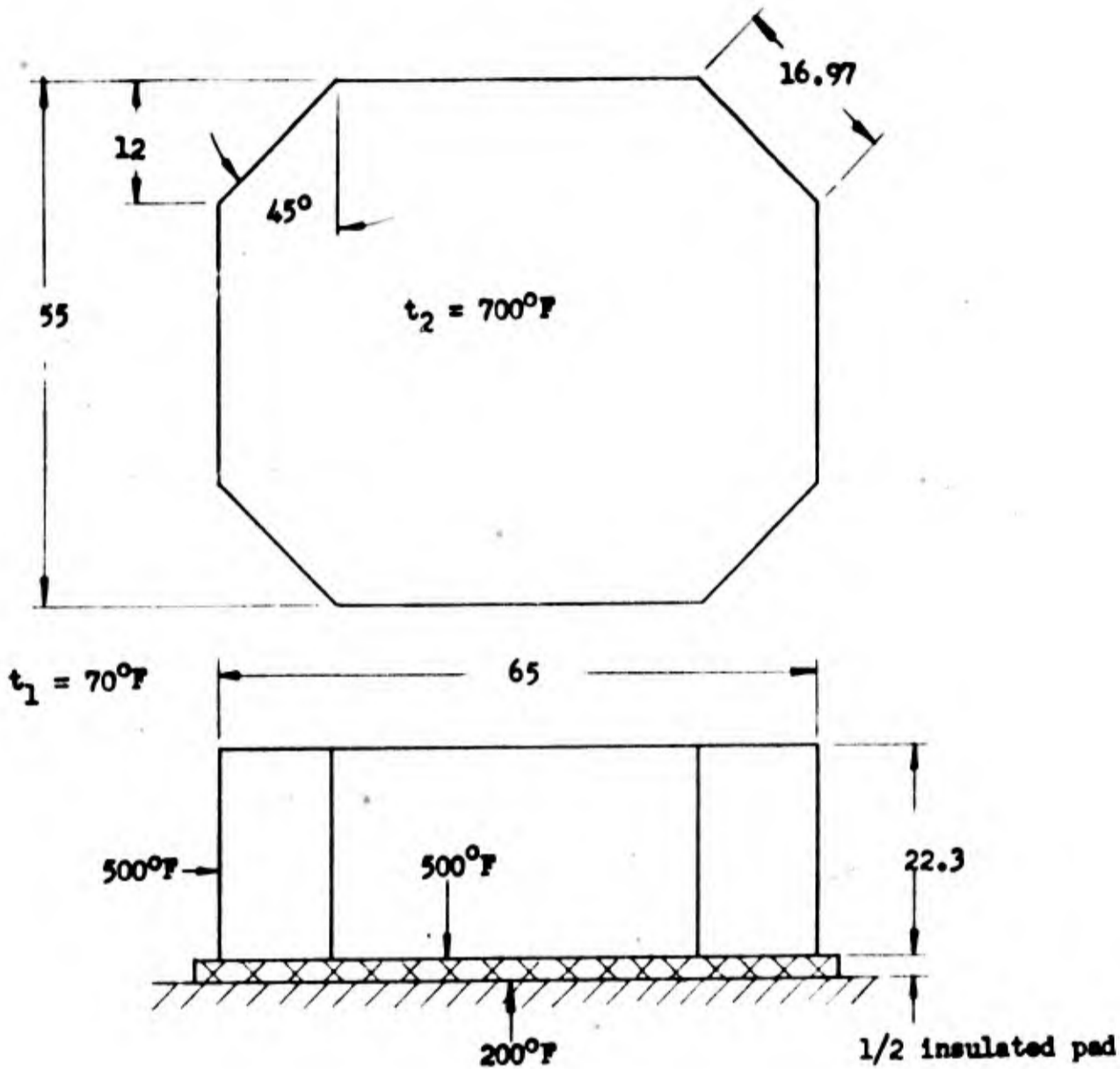
$$= \frac{1 \times 32.8 \times 730}{3600} \times 1.055 = \underline{7.0 \text{ KW}}$$

3. Loss through 1/4" bottom insulation same as above = 19.5 KW.

$$\text{Total loss} = \underline{55.4 \text{ KW}}$$

WYMAN-GORDON ANALYSIS OF PROPOSED DIE HEATING OF

"F" YOKE DIES



Calculations for proposed die heating of above, using Lockheed method
(Sheets 1 & 2)

Top surface = bottom surface

$$= A_1 = 65 \times 55 - \left(\frac{12 \times 12}{2} \times 4 \right) = 3287 \text{ in}^2 = \underline{22.8 \text{ ft}^2}$$

$$\text{Side Area} = B_1 = [(41 \times 2) + (31 \times 2) + (16.97 \times 4)] \times 22.3 = 4,725 \text{ in}^2 = \underline{32.8 \text{ ft}^2}$$

$$\text{Wt.} = 22.8 \times 1.86 \times 490 = 20,781\# = \underline{10.39 \text{ tons}}$$

$$(\text{Scale Wt.} = 19,600\#)$$

$$q_1 = \frac{K \times A_1 (t_2 - t_1)}{L \times 3600} = \frac{1 \times 22.8 \times 300 \times 2}{3600} = 3.8 \text{ BTU/Sec.} = \underline{4.0 \text{ KW.}}$$

$$\begin{aligned} q_{2r} &= e \times 5.07 \times (T_2^4 - T_1^4) \times 10^{-10} \times A_1 \\ &= .79 \times 5.07 \times [(459.6 + 700)^4 - (459.6 + 70)^4] \times 10^{-10} \times A_1 \\ &= 4 \times 1.73 \times 10^2 \times 22.8 = 15,777.6 = \underline{15.8 \text{ KW.}} \end{aligned}$$

$$\begin{aligned} q_{2v} &= .0938 \times 630^{1.25} \times 1.1 \times 22.8 \\ &= .0938 \times 3,156 \times 1.1 \times 22.8 = 7,423.7 = \underline{7.4 \text{ KW.}} \end{aligned}$$

$$\begin{aligned} q_{3r} &= e \times 5.07 \times (T_2^4 - T_1^4) \times 10^{-10} \times B_1 \\ &= .79 \times 5.07 \times [(459.6 + 500)^4 - (459.6 + 70)^4] \times 10^{-10} \times B_1 \\ &= 4 \times .769 \times 10^2 \times 32.8 = 10,090 = \underline{10.0 \text{ KW.}} \end{aligned}$$

$$\begin{aligned} q_{3v} &= .0938 \times 430^{1.25} \times 32.8 \\ &= .0938 \times 1,958 \times 32.8 = 6,024 = \underline{6.0 \text{ KW.}} \end{aligned}$$

Total KW. required for keeping die at temp. with bottom insulated only.

$$= 4.0 + 15.8 + 7.4 + 10.0 + 6.0 = \underline{43.2 \text{ KW.}}$$

By insulating all vertical surfaces of die, we can reduce the sum of $q_{3r} + q_{3v} = q_3 = 16.0 \text{ KW.}$ to the following figure, using $K = 1.0$ for insulation material, 1 in. thick.

$$q_3' = \frac{1 \times 32.8 \times 430}{3600} \times 1.055 = \underline{4.1 \text{ KW.}}$$

Total losses by insulating sides and bottom

$$= q_1 + q_{2r} + q_{2v} + q_3'$$

$$= 4.0 + 15.8 + 7.4 + 4.1 = \underline{31.3 \text{ KW.}}$$

TOTAL LOSS

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