ASD TR 7-556 (XXIV)

ASD INTERIM REPORT 7-556
JUNE 1963

IMPROVED METHODS FOR THE PRODUCTION OF TITANIUM ALLOY EXTRUSIOI

JOHN J. CHRISTIANA

REPUBLIC AVIATION CORPORATION
MANUFACTURING RESEARCH

CONTRACT: AF 33(600)34098
ASD PROJECT: 7-556

INTERIM TECHNICAL ENGINEERING REPORT

1 MARCH 1963 TO 1 JUNE 1963

A three section tungsten carbide draw die was modified to permit drawing o tee shapes without restraining of the edges. Two tee shapes, each of Ti-7Al-4Mo and Ti-4Al-3Mo-1V alloys were successfully drawn through the required final pass of 0.043 inch.

BASIC INDUSTRY BRANCH
MANUFACTURING TECHNOLOGY LABORATORY

AERONAUTICAL SYSTEMS DIVISION (AFSC)
UNITED STATES AIR FORCE
WRIGHT-PATTERSON AIR FORCE BASE, (OHIO)

ABSTRACT-SUMMARY
24th Interim Technical Progress Report

ASD INTERIM REPORT 7-566 (XXIV)
June 1963

IMPROVED METHODS FOR THE PRODUCTION OF TITANIUM ALLOY EXTRUSIONS

Manufacturing Research Department
Republic Aviation Corporation

The two tee shapes selected for Part V were extruded in 6Al-4V titanium alloy at 1800°F and stretch straightened at 1000°F - 1100°F. The tee extrusions are .093" and .063" cross section and will be warm drawn to .080" and .043" respectively.

Good dimensional uniformity of the extrusions after the first several feet was obtained, but good surface finish free from defects could not be consistently obtained.

Very little wear or wash of the alumina coated dies was experienced and 75% of the 3-piece dies will be used for the next trial.

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ASD TR-7-556 (XXIII)

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J. J. Christiana

Republic Aviation Corporation

Contract: AF33(600)-34098
ASD Project 7-556

Interim Technical Engineering Report
1 March 1963 - 1 June 1963

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NOTICE

The work reported in this document has been made possible through the support and sponsorship extended by the Air Materiel Command under Contract No. AF33(600)-34098. It is published for technical information only and does not necessarily represent recommendations or conclusions of the sponsoring agency.

FOREWORD

This Interim Technical Progress Report covers the work performed under Contract AF33(600)-34098 from 1 March 1963 to 1 June 1963. It is published for technical information only and does not necessarily represent the recommendations, conclusions or approval of the Air Force.

This Contract with Republic Aviation Corporation, Farmingdale, Long Island, New York, was initiated under the Aeronautical Systems Division Project 7-556, "Improved Methods for the Production of Titanium Alloy Extrusions." It is administered under the direction of Mr. T.S. Felker of the Basic Industry Branch (ASRCTB), Manufacturing Technology Laboratory, Aeronautical Systems Division, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio.

Mr. J. J. Christiana of the Manufacturing Research Department, Republic Aviation Corporation, is the project engineer. Messrs. M. Negrin, Manufactur Research Engineer and T. Gorecki, Engineer, The Babcock and Wilcox Compan have cooperated in the research and in the gathering of data for this report.

The primary objective of the Air Force Manufacturing Methods Program is to increase producibility and improve the quality and efficiency of fabrication of aircraft, missiles and components thereof. This report is being disseminated in order that methods and/or equipment developed may be used throughout industry, thereby reducing costs and giving "MORE AIR FORCE PER DOLLAR"

Your comments are solicited on the potential utilization of the information contained herein as applied to your present or future production programs. Suggestions concerning additional manufacturing methods developed required on this or other subjects will be appreciated.

Written by: J. J. Christiana
J. J. Christiana
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PUBLICATION REVIEW

Approved by: Robert W. Hussa
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Manufacturing Research Engineer

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HISTORY OF THE PROGRAM

"Improved Methods for the Production of Titanium Alloy Extrusions" is sponsored by the Air Materiel Command under Contract No. AF33(600)-34098. The development program was originally scheduled in five parts to produce titanium alloy structural shapes in three size categories. The extrusion development for the first and second category shapes (Figures 1 and 2) has been completed in Parts II and III of the program. A double tee shape originally selected for extrusion development in Part IV, has been replaced with a thinner tee shape (Figure 3) to be produced by a combination of extrusion and subsequent drawing. Such thinner shapes represent current design requirements in advanced airframe structures. The scope of the program was further increased by the addition of Parts V to produce a typical B-70 titanium alloy shape (Figure 4) and Part VI to develop heat treatment procedures for full length titanium alloy extrusions. Part VI was subsequently deleted. The program parts are listed below as originally scheduled and as revised.

Status	Original Program	Revised Program	Status
Complete	**Part I** Determination of Shapes and Materials **Part II** Extrusion of First Category Shapes (Fig. 1) **Part III** Extrusion of Second Category Shapes (Fig. 2)		
Deleted	**Part IV** Extrusion of Third Category Shape (Fig. 3) **Part V** Final Report	**Part IV** Extrusion and Drawing of Third Category Shapes (Figure 4) **Part V** Extrusion and Drawing of Typical B-70 Shape	
		Part VI Heat Treatment Development	Deleted 12 Oct. 1962

Part I

The survey of airframe producers was concluded in Part I and resulted in the selection of typical extrusion shapes desired in titanium alloys for airframe design. These shapes are illustrated in Figures 1, 2 and 3. The survey also determined the test properties required of titanium alloy extrusions for high temperature service. The major titanium producers and research laboratories were consulted for information and recommendations for the choice of alloys most closely conforming to the property requirements.

Part II

The alloys which were selected for extrusion in Part II are listed below:

C-135 AMo	7.0% Al. 4.0% Mo.
MS-821	8% Al. 2% Cb. 1% Ta.
Ti-155A	5% Al. 1.4% Fe. 1.5% Cr. 1.2% Mo.

The extruders who participated in the Part II extrusion development are:

The Babcock and Wilcox Company
The United States Steel Corporation
The H. M. Harper Company

The sections and alloys which were extruded in Part II by these extruders are:

Company	Billet Dia.	Section	Alloys
Babcock & Wilcox	4"	Angle	C135 AMo and MS 821
U. S. Steel	2-3/4"	Channel	Ti 155A and C135 AMo
H. M. Harper	3-7/8"	Zee	MS 821 and Ti-155A

The extrusion development of the Part II section is described in detail in Quarterly Report Nos. 3, 4 and 5. The dimensional objectives established in Part I were approached but were not fully realized during the Part II extrusion development. Various lubricants, die materials and extrusion techniques were investigated and the best results were obtained with hot work tungsten steels and glass lubrication techniques.

The straightening trials which were conducted with the channel and angle extrusions produced in Part II are described in Quarterly Reports 5, 6 and 7. Report No. 7 also contains a dimensional evaluation of the straightened lengths which indicates that the extrusions approached but did not realize the straightness and twist specifications for aluminum extrusions of similar cross section.

Part III

The Part III development of extrusion techniques for the tee and hat shapes (Figure 2) was conducted by Babcock and Wilcox and by Compagnie due Filage des Metaux et des Joints Curty (Cefilac), the French company that developed the glass lubrication technique for steel extrusion. The Part III extrusion trials are described in Reports 8, 9, 10, 12, 13 and 14. The most successful Cefilac trials are described in Report 12 and the most successful Babcock and Wilcox trials are described in Reports 9 and 14. Similar results in reasonable dimensional uniformity with good surface finish in 15-25 foot lengths were obtained by both extruders. Effective glass lubrication held die wear to a negligibl degree and permitted reuse of the dies. Pickup scoring lines in the extruded surface due to titanium pickup upon the extrusion die were present to a degree varying from negligible to appreciable severity. This condition was finally avoided in the last Part III trials at B & W apparently due to clean billet heating and handling practice in which stainless steel billet heating cans and a 900°F chromium plated extrusion liner were used. See Report No. 14. Practically all extrusions produced in Part III were extruded by the full flow lubrication technique in which the billet skin elongates in passing through the extrusion die and separates into discreet particles in the extruded surface. These particles are not in themselves undesirable when small and well divided but are the nucleu for surface depression adjacent to the marks. In addition, when the billet skin contamination in heating is appreciable, the particles produce die abrasion. A study of contamination depth as dependent upon heating time and protective glass coating is still in progress in an effort to determine if the present extrusion process can be improved with better heating practice.

A representative evaluation of the Part III tee extrusions is presented in Reports 13 and 15. The best extrusions are within the dimensional straightness and twist tolerance of aircraft specifications for aluminum extrusions of similar siz and shape. However, there is a sufficient range of variation to indicate that a subsequent sizing operation such as "warm" drawing would be advantageous. Further, the current interest in titanium extrusions lies in thinner shapes with smaller tolerances than permitted in aluminum extrusions. As a consequence, the program has been amended as previously described to produce such shapes by means of extrusion and subsequent drawing.

A heat treatment procedure that will consistently produce the objective of 180,0 psi ultimate strength with 8% elongation has not been determined. In many case tensile results have been erratic after heat treatment. For earlier mechanical property test results and heat treatment studies, see Reports 4, 5, 6 and 7. A study of heat treatment parameters conducted by Crucible Steel with channel an angle extrusions in 7A1 4Mo alloy is included in Report No. 8. Results with recommended heat treatments and modified treatments are described in Report 9, 10 and 11. In the latter report, as-extruded material consistently tested 170,000 UTS, 150 YTS and 8% elongation. After heat treatment, results were typically 185 UTS, 175 YTS with 2.5% elongation.

Straightening trials conducted with the Part III tee extrusions at B&W are described in Reports 9, 13, 15 & 17. The last two reports contain an evaluation of t dimensional uniformity and mechanical properties of the straightened Part III tee extrusions produced by B&W in terms of straightening temperatures and modification of jaw assembly.

Part IV

In a previous quarter, a Part IV extrusion and straightening trial was held at Babcock and Wilcox. The purpose of this trial was to establish the reproducibility of the process developed under the Part III extrusion of tee shapes, determine the best lubrication practice, and to extrude an .092" thick tee shaped section based upon the best techniques developed under the 1/8" thick tee shape reproducibility phase. The procedures and results of this trial are discussed in Report No. 17.

Glass contamination studies were conducted at Republic Aviation Structures Laboratory and at the Babcock and Wilcox Production and Process Laboratory facilities to determine the influence of billet heating times and glass composition on contamination of titanium extrusions (Report No. 18). For previous studies related to surface contamination, see Reports 10, 12, 14 and 17. The influence of reduced billet heating times on extrusion pressures is discussed in Report No. 19.

Extrusion techniques and results of the extrusion trials (Group No. 17) in which 20-foot lengths of .092" and .062" tee shaped sections were successfully extruded using alumina coated die material, are discussed in Quarterly Report No. 19. The extrusion pressures required were comparable to pressure experienced with the smaller ratio .125" extrusions. Use of alumina coating on the die material prevented die wear, wash and hot deformation of the die. Uniform cross section dimensions from front to back along the extrusion length can be realized using the alumina coated dies.

A combination of hot stretch and punch straightening of the Group 17 extrusions produced the straightest extrusion lengths to date. The various extrusion techniques which influence the cross section dimensions of the as-extruded length, and subsequently affect the resistance heating stretch-straightening and detwisting procedure, are discussed in Report No. XX.

High frequency induction heat equipment, coils and accessory equipment have been installed at the Allegheny Ludlum Steel Corporation draw bench facility and are described in Report No. 18. The temperature sensing devices and controllers, induction coil and stress loading cells were calibrated. A four-foot tee section was reduced from a nominal .130" to a uniform .118" cross section in one pass. The procedure and results are discussed in Report No. 19. Ten foot lengths of as-extruded and straightened .125" tee shapes were successfully reduced in one reduction pass to a uniform .110" thickness. The problems encountered and recommended solutions for maintaining constant temperature control of the induction coil, cracking of carbide draw dies, and choice of compatible lubricant are discussed in Report XX and XXI.

The final series of Part IV extrusion trials were conducted at Babcock and Wilcox Company completing the extrusion portion of Part IV. Tee sections, ranging from 20 to 30-foot lengths of 1/16" cross section, were successfully extruded in 7Al-4Mo, 6Al-4V and 4Al-3Mo 1V titanium alloys using alumina coated dies and a combination glass wool-granular glass die pad lubricant. The extrusion procedures and results are discussed in Interim Technical Report XXI.

A fourth series of extrusion trials were conducted at Battelle Memorial Institute to determine the optimum glass wool composition for the die lubricant system at 1800°F. The glass compositions were melted and blown to fiber form at Battelle Memorial Institute. The results of this trial series are described in Report No. XXII.

For the warm drawing phase of Part IV the tee sections were heated in the resistance heated muffle furnace which was installed in October. Twenty-seven as-extruded 20 feet long nominal 1/16" cross section tee shapes consisting of 7Al-4Mo, 6Al-4V and 4Al-3Mo-1V titanium alloys were sized through a .065" draw die. Eight sized .065 shapes were drawn to .058" cross section. Two of the .058" cross section tees were further drawn to .052" cross section

Warm drawing of four tee sections to a final .043" cross section thickness was accomplished during the last quarter using modified tungsten carbide draw dies. The modified die configuration, drawing procedure and results are described in Report XXIII.

During the last quarter, shapes were selected for Part V which involves the fabrication of shapes for the B-70 aircraft. The shapes selected are North American Aviation Shape Nos. 64E15 and 64E12 (modified). NAA No. 64E15 is an .080" tee section with a 1.750" flange and 1.00" stem. The modified NAA No. 64E12 is an .043" tee section with a 1.750" flange and 1.600" stem. The alloy for both shapes is 6Al-4V titanium alloy. Shape No. 64E15 will be extruded to .093" cross section and warm drawn to .080". Shape No. 64E12 (modified) will be extruded to .063" cross section and warm drawn to .043".

During this quarter, the warm drawing program was transferred from the Allegheny Ludlum Steel Corporation plant at Watervliet, New York to the newly installed warm draw facilities of Titanium Metals Corporation of America at Toronto, Ohio. Modification of the TMCA die housing in terms of enlarging the back-up block orifice, machining a new die cover plate, and machining steel wedges and shim plates to accommodate the original tungsten carbide draw dies has been completed. However, no work on the TMCA facility has been accomplished.

An extrusion trial was held during this quarter for the two B-70 shapes, using the practices developed during the Part IV extrusion effort. Included in this trial were two pushes with dies having two tee port openings per die to demonstrate multihole extrusion capability. The shapes were straightened by a combination of hot stretch and punch straightening. The procedures and results of the extrusion and straightening trials are described in this report.

SHARP CORNERS .015 RAD. MAX.
STRAIGHTNESS .050" PER FOOT
TWIST 1° PER FOOT
ANGLES ± 2°

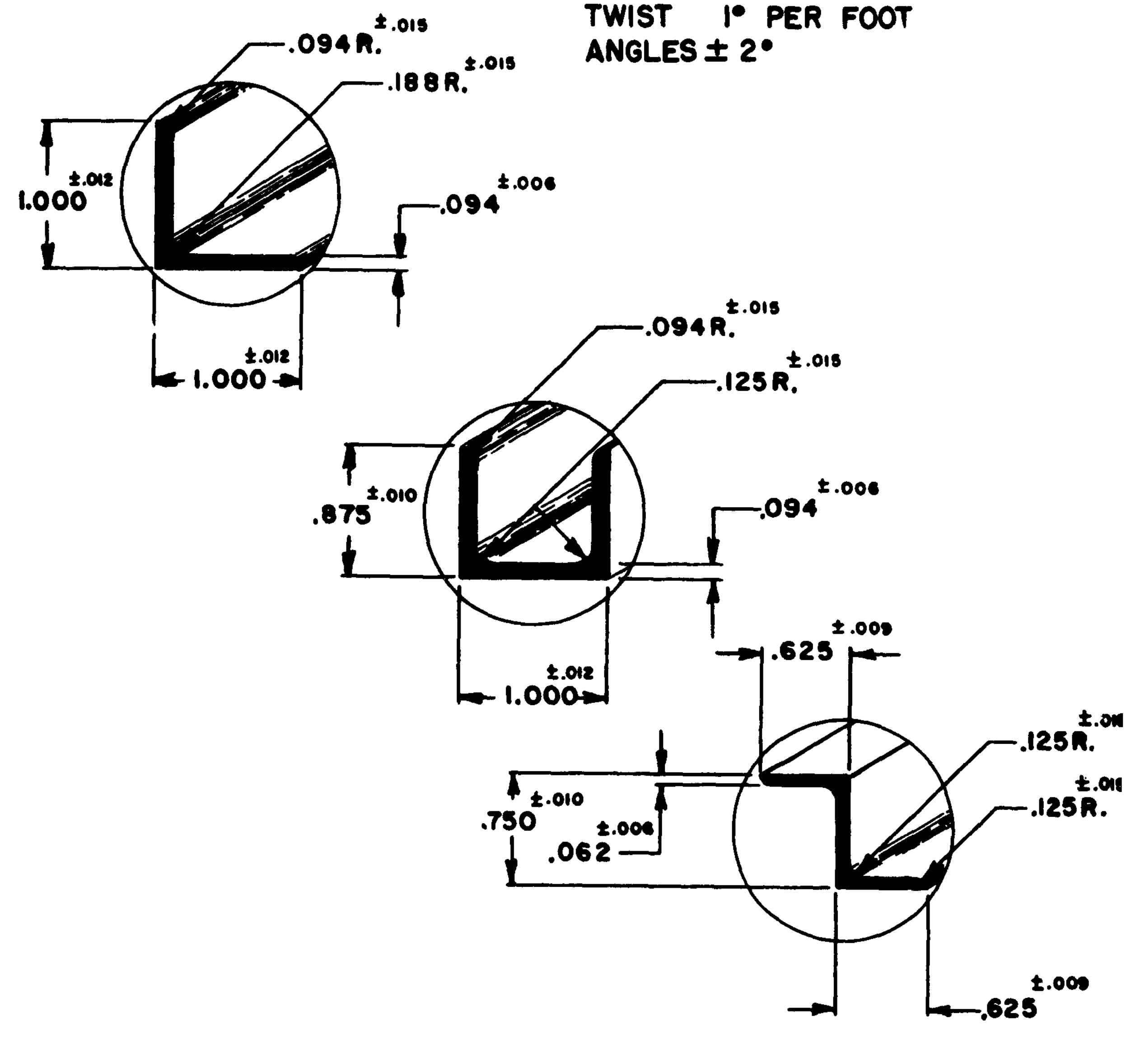


FIGURE I
SHAPES SELECTED FOR EXTRUSION METHOD DEVELOPMENT
PART II
AF 33 (600) 34098

SHARP CORNERS .015 RAD. MAX.
STRAIGHTNESS .0125" PER FOOT
TWIST 1/2° PER FOOT, MAX. 5°
ANGLES ± 2°

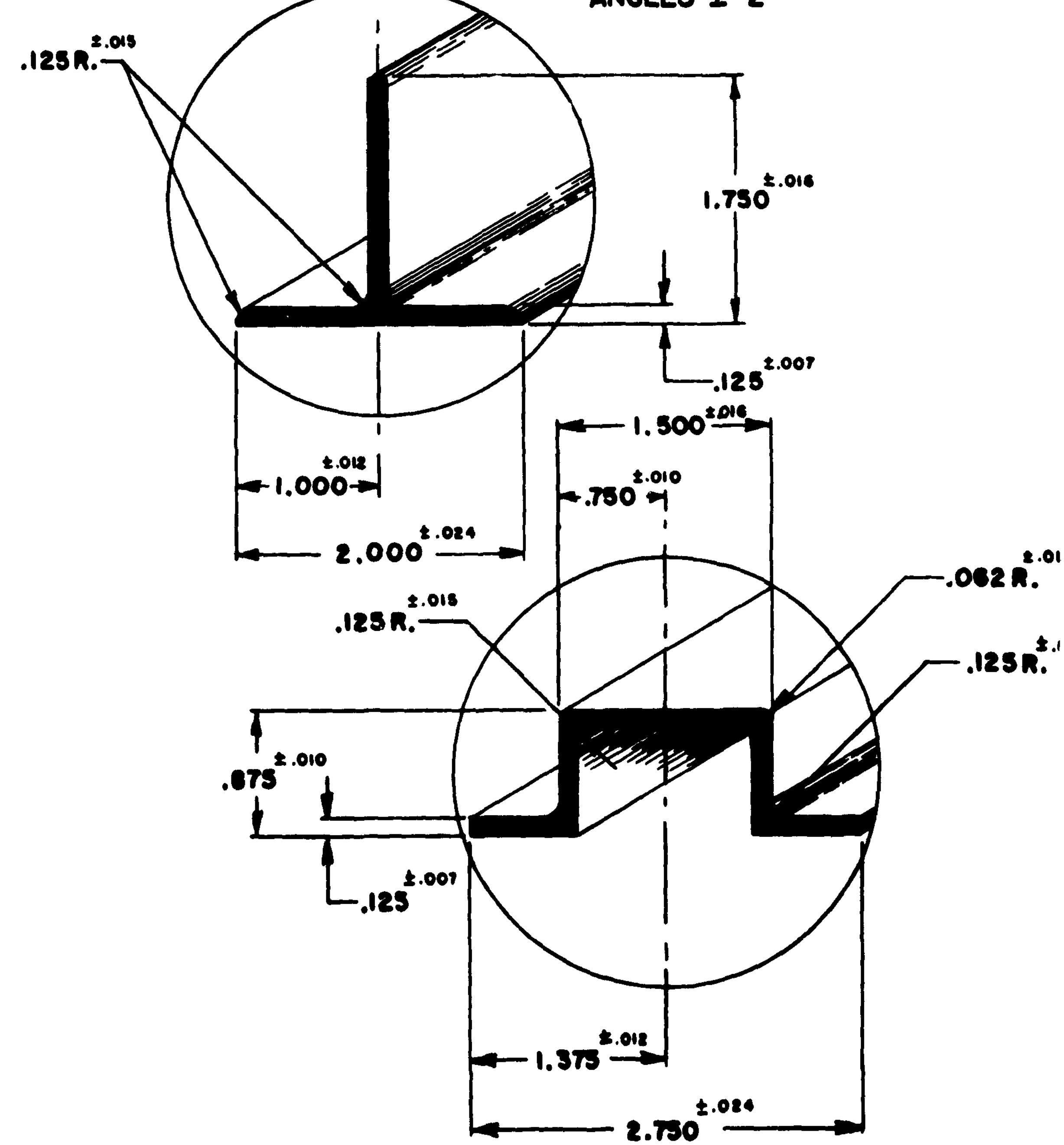
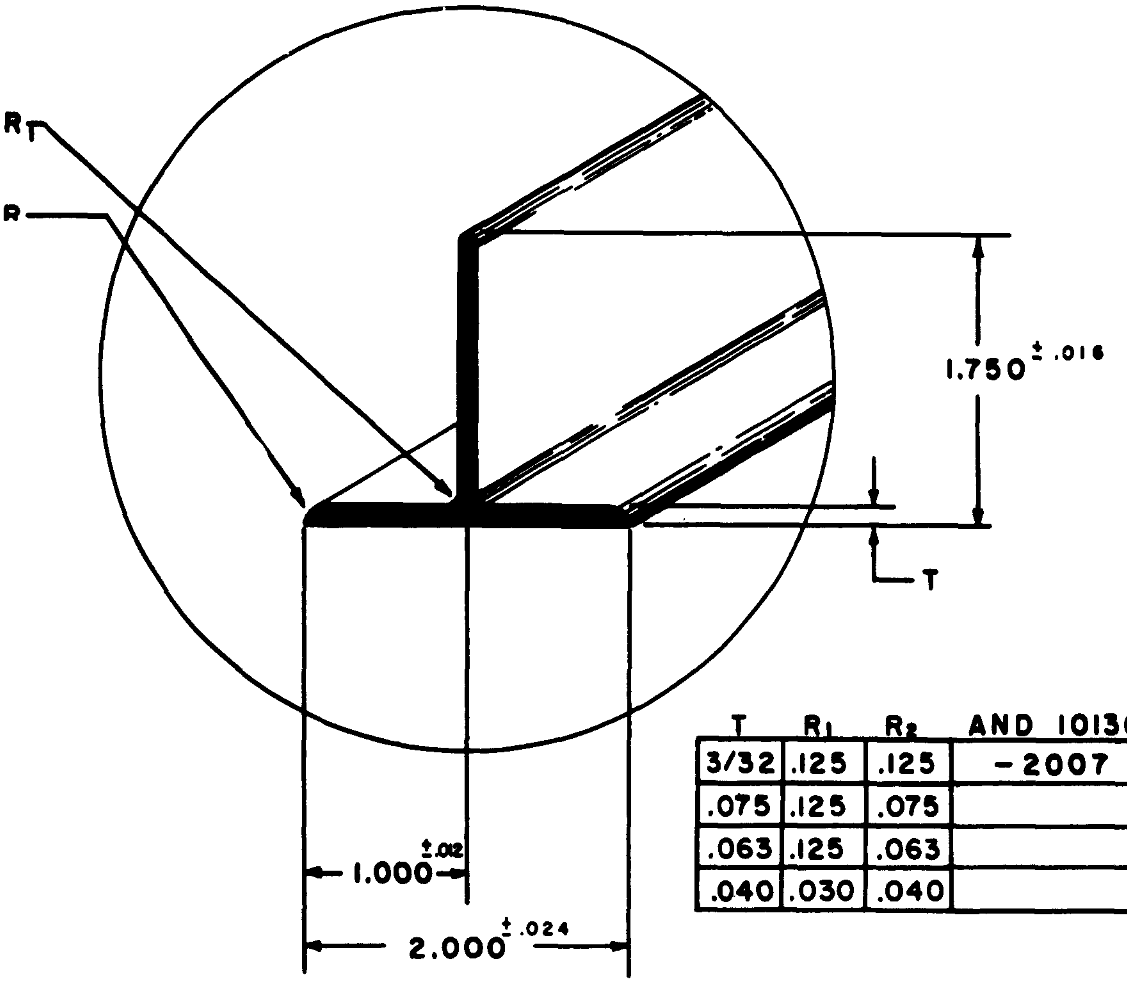


FIGURE 2.
SHAPES SELECTED FOR EXTRUSION
METHOD DEVELOPMENT
PART III
AF 33 (600) 34098

SHARP CORNERS .005 RAD. MAX.
STRAIGHTNESS 0.0063" PER FOOT
TWIST 1/4° PER FOOT, MAX. 2 1/2
ANGLES ±1°



T	R_1	R_2	AND 10136
3/32	.125	.125	-2007
.075	.125	.075	
.063	.125	.063	
.040	.030	.040	

FIGURE 3

SHAPE SELECTED FOR EXTRUSION
METHOD DEVELOPMENT
PART IV
AF 33 (600) 34098

STRAIGHTNESS .010" PER FOOT

TWIST 1/2° PER FOOT, MAX. 3°

ANGLES ± 1/2°

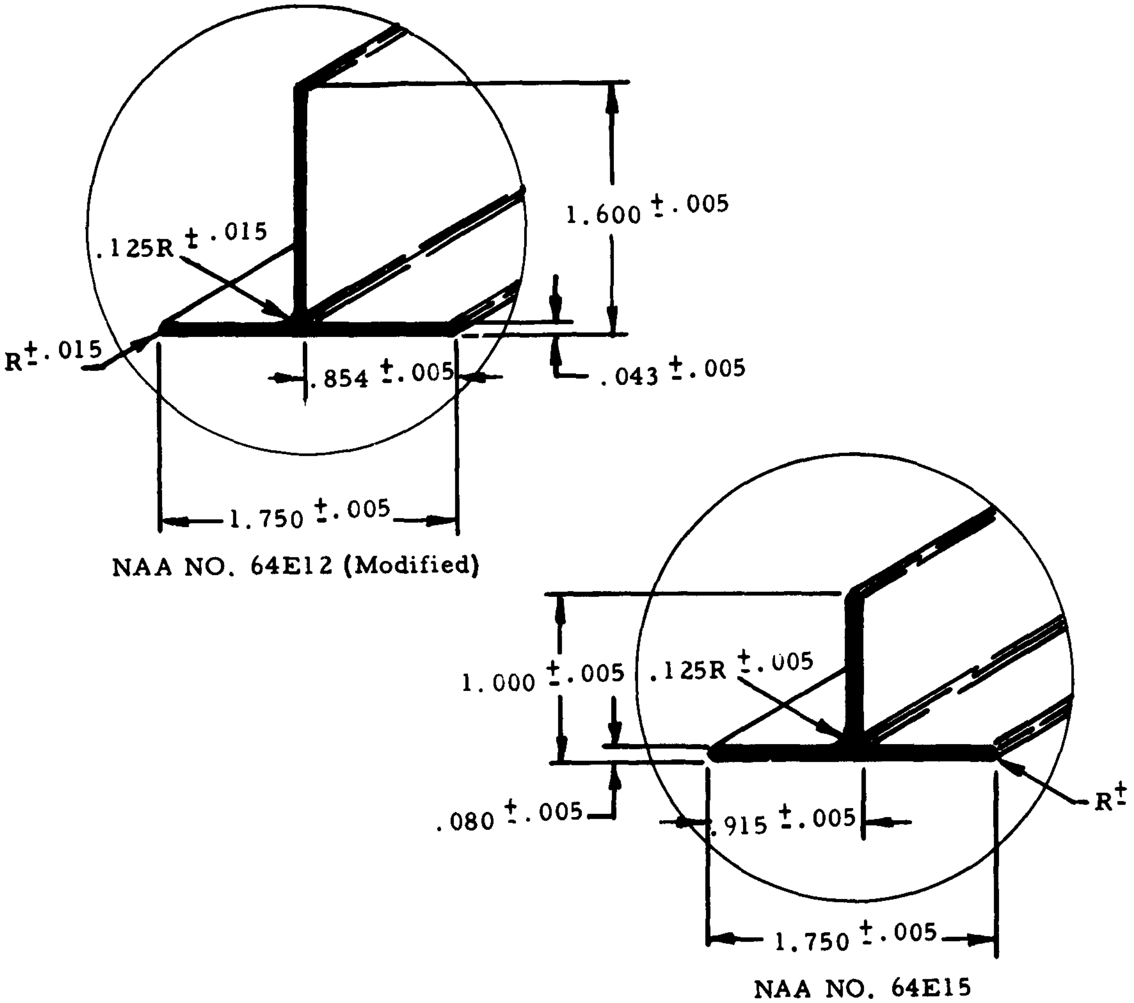


FIGURE 4

SHAPES SELECTED FOR FABRICATION AS TYPICAL
B-70 AIRCRAFT TITANIUM ALLOY EXTRUSIONS

PART V

INTRODUCTION

In order to determine the practicability of the techniques developed under Part IV, two shapes required for the B-70 Weapons System were selected for fabrication. The two shapes are shown in Figure 4. These shapes were selected since they represent a significant increase in the state-of-art of titanium extrusion and at the same time are compatible with the existing warm draw tooling. The shapes will be fabricated in minimum lengths of 20 feet to North American Aviation material specification LB0170-112, Class I.

To produce these shapes it is economically advantageous to extrude to as close to the finished dimensions as possible, consistent with the limitations of the extrusion process, so that the required draw reduction will be a minimum With this in mind, it was decided to produce shape 64E15 by extruding to .093" cross section and warm drawing to the final .080", providing a reduction of .013". The modified shape 64E12 will be produced by extruding to .063" cross section and warm drawing to .043", providing a reduction of .020". Detailed data will be obtained, relative to dimensional uniformity, surface finish, micro structure and mechanical properties for both shapes, in the as-extruded condition and after various draw stages to ascertain the degree of improvement in warm drawing. In this manner, the required amount of reduction in each size category will be established. This data can be used as a guide in the design of extrusion dies and draw dies for the production of aircraft quality long, thin sections.

In addition the effect of the extruded shape variations on the warm draw process will be noted so as to establish proper dimensional size and tolerances on extrusions to suit the warm draw process. For example, it was reported in a previous report (ASD Interim Report 7-556 XXIII, page 47) that 0.005" to 0.015" lateral expansion of the leg extremities occurred during the draw pass when the edges were unrestrained. Since restraint of the edges during a draw reduction resulted in buckling and development of a "Chevron" defect with eventual tearing of a leg of the tee extrusion, it was found necessary to extend the orifice extremities of the draw die and allow the leg to "grow". This data would suggest that an allowance be made in the design of the extrusion die to accommodate the growth per draw pass times the number of draw passes contemplated. In other words, the extrusion die opening would be made smaller. However, it was found that on certain shapes that were drawn, the reverse was true (i.e. the cross sectional width and height dimensions decreased during the draw pass). On examination, it was found that in the latter case, the fillet radius of the shape was undersize while in the former case, the fillet radius was oversize. One of the objectives of Part V of the program will be the generation of data relative to the above which can be used by the extrusion die designer to determine optimum die design.

EXTRUSION OF PART V SHAPES - GROUP 1

OBJECTIVES

The objective of this extrusion trial was to extrude 20' lengths of extrusions in .093" and .063" cross sections.

A second objective of this trial was to demonstrate multi-hole extrusion capability for relatively thin shapes by extruding through (2) tee port openings of .093" cross section. A third objective of the trial was to evaluate the two glass combinations that showed the most promise during the extrusion trial of 6Al-4V titanium alloy conducted in Part IV of the program (See ASD Interim Report 7-556 XXI, Babcock & Wilcox extrusion trial Group 19.). The two glass combinations are the composition 318 OD lubricant coupled with composition 3KB die glass pad and composition E71B OD lubricant coupled with composition E71 die glass pad. The best glass combination will be used for the remainder of the program.

A series of (17) extrusion pushes were scheduled by mutual agreement between Republic Aviation and Babcock & Wilcox personnel. The (17) scheduled pushes included (7) pushes through the .093" die orifice, (7) pushes through the .063" die orifice and (3) pushes through the multi-port die.

FACILITIES AND EXTRUSION PRACTICE

The extrusion press is a 2500-ton Loewy hydropress with pressure accumulators capable of operating the press at the fast extrusion speeds necessary in steel and titanium extrusion. A photograph of the press is shown in Figure 5 and a cross section view of the press tooling arrangement is shown in Figure 6.

The extrusion press is equipped with a 4-3/16" I.D. container and a 4-1/16" hardened steel stem for extruding 4" diameter billets. The 180,000 psi stress limitation in the steel stem required that the press extrusion force be limited to 1100 tons (1540 psi bottle pressure).

The billet surfaces are belt ground to 100 grit, degreased, heated to 300°F and sprayed with #85 protection glass slurry prior to heating. The billets are then placed into a pre-heated (1800°F) stainless steel can, covered and given a 60 second argon purge. The can is then placed into a controlled argon atmosphere, electric resistance furnace. During billet heating, the glass slurry forms a protective film of glass over the billet. In subsequent extrusion, the glass film on the billet surface insulates the hot (1800°F) billet from the relatively cooler container liner (900°F).

The billets are transferred to the extrusion press with the two-man carrying device illustrated in Report No. 13. The single can method was used and the billet was tipped out of the transport can onto the runout table where additional glass powder is applied.

After the billet is in position in the container, the stem is advanced rapidly until contact is made with the billet. The stem remains in this position for one or two seconds while upsetting the billet, and then extrusion proceeds in about two seconds.

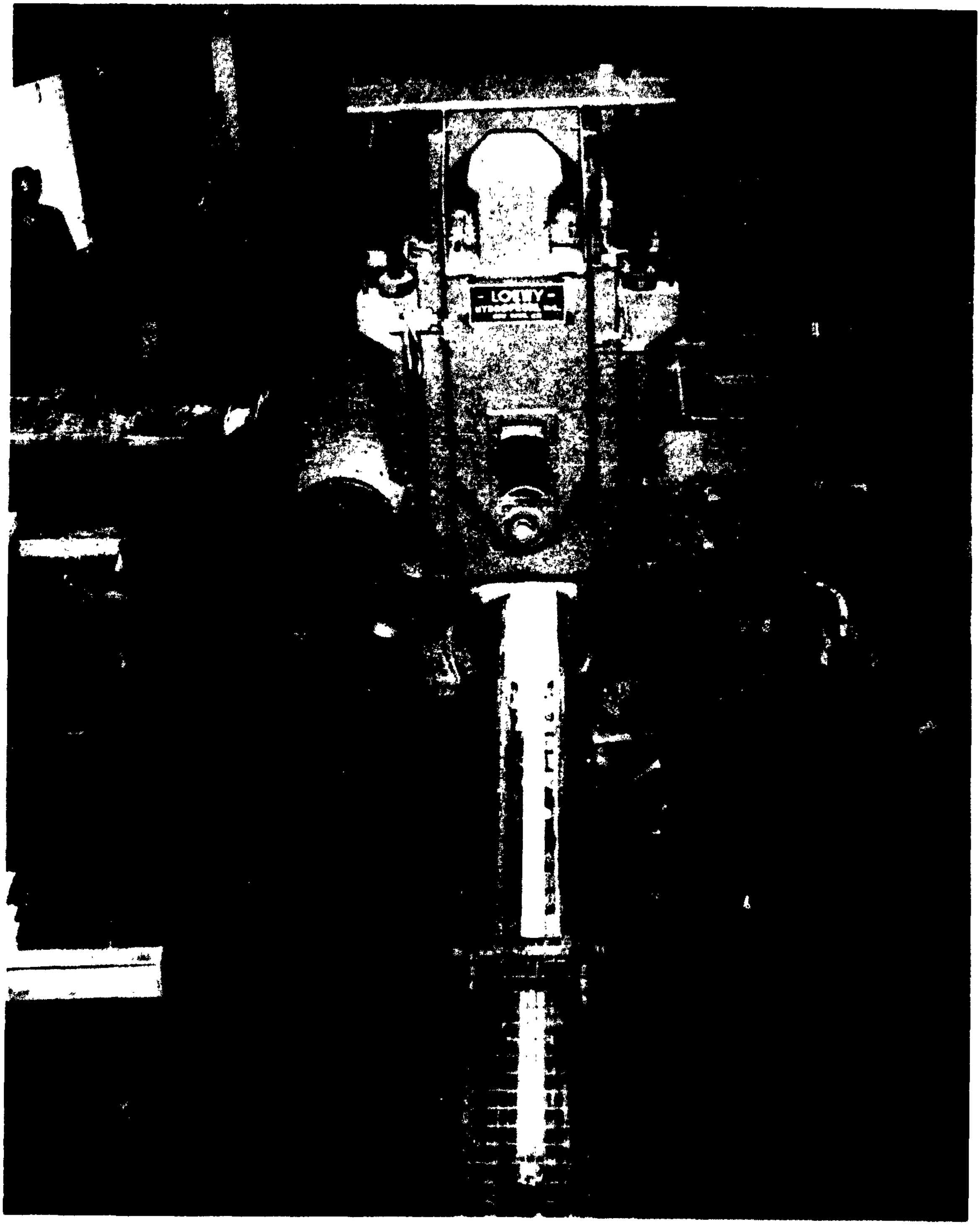
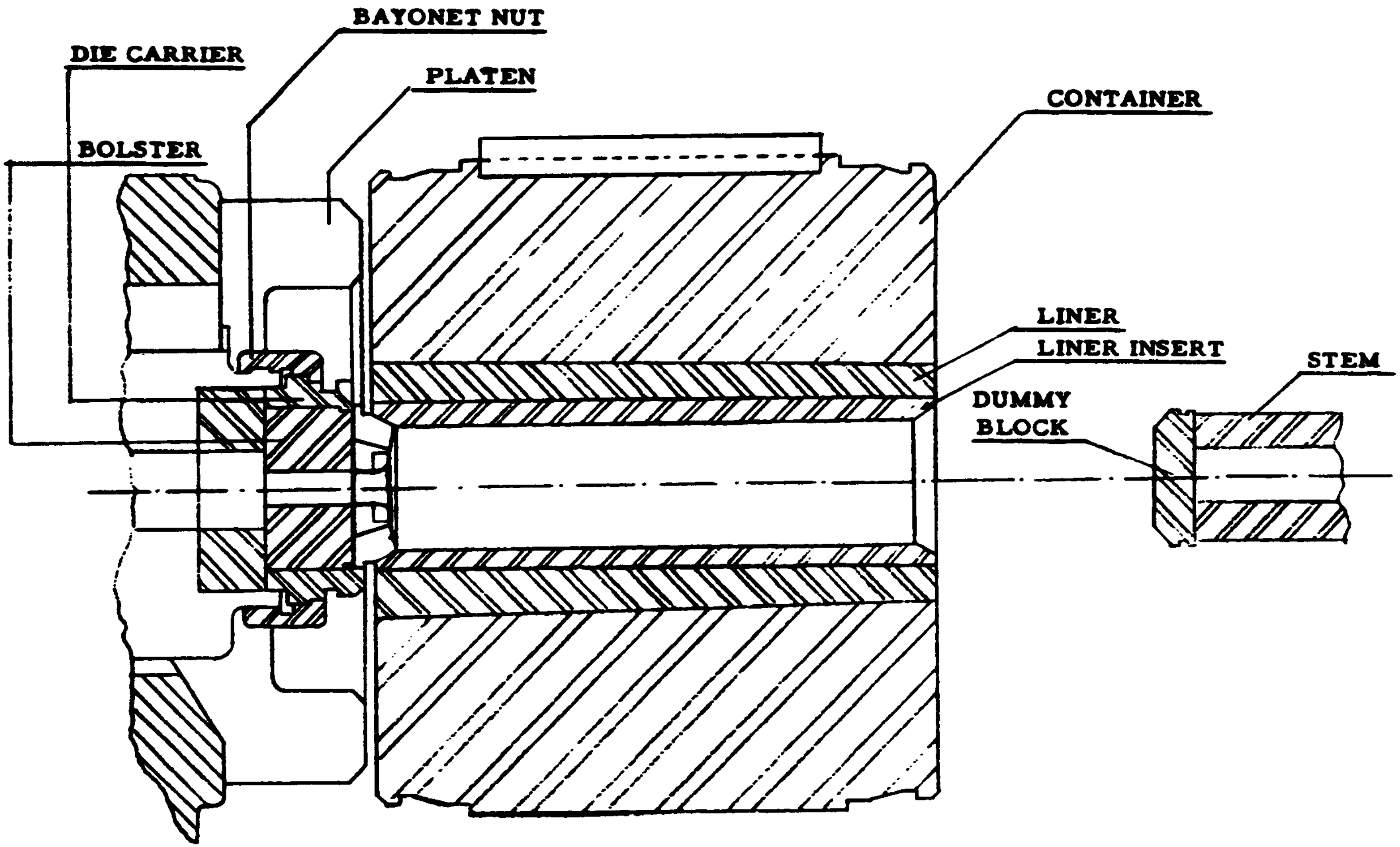


FIGURE 5
2500-Ton Loewy Extrusion Press at Babcock & Wilcox, Beaver Falls



BABCOCK AND WILCOX

Cross Section View
of
Press Tooling Arrangement

The die is lubricated and protected from washout during extrusion by a film of glass which is continuously fused from a pad of compacted glass powder, or a composite of glass powder and glass wool which is placed between the die and billet. (See Interim Report #19)

A new chromium plated and polished liner was used for the trial.

EXTRUSION PARAMETERS

The .093" shape represents a cross sectional area of .257 in^2 and with a billet diameter of 4", the extrusion ratio for this section is 48 to 1. A billet length of 6.75" was selected so that with a discard of approximately 20% or 1.35" the material available for the extruded length would be 4" diameter x 5.4" or 67.4 in^3. This volume would supply an extruded length of 22 ft.

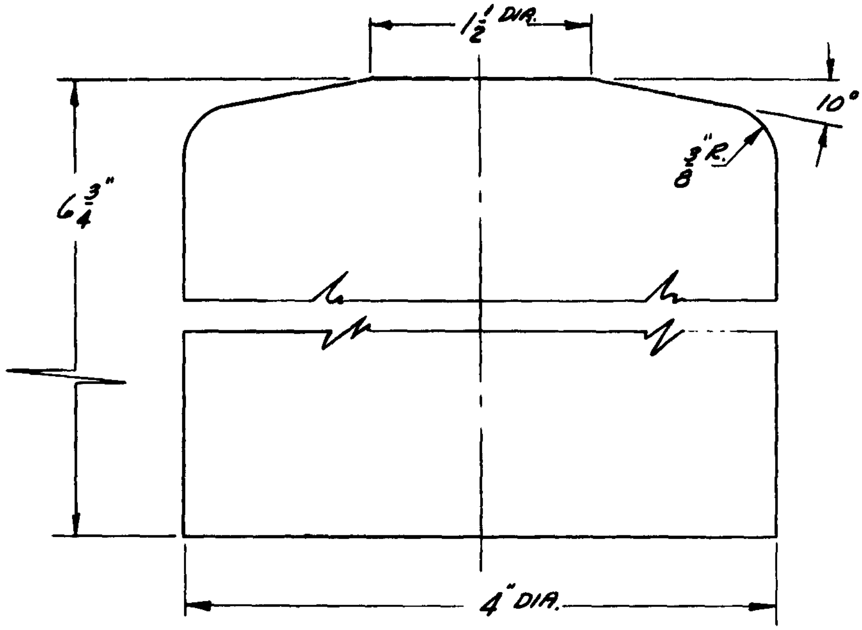
Similarly, the .063" shape has an extrusion ratio of 58 to 1 and the 6 3/4" billet length will yield an extruded length of 26 ft. A 9 1/4" billet length was selected for the multi-port die which would yield (2) extrusions of 15' for each push at an extrusion ratio of 24:1.

The height dimension of both tee openings in the multi-port die was reduced to allow sufficient distance between the two tee openings for proper material and glass flow.

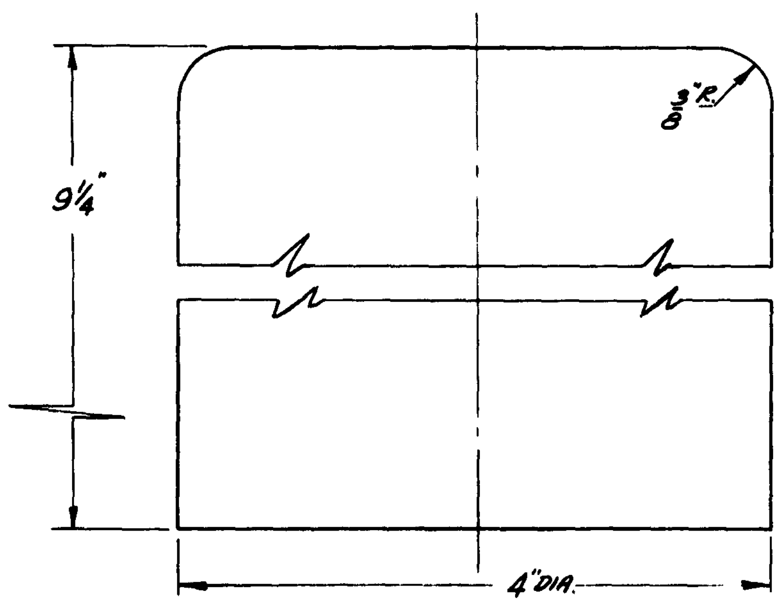
The billet configurations are shown in Figure 7. The convex faced nose configuration seen in Figure 7A was used for all pushes with the single port die. The convex billet configuration creates a greater reservoir of molten die glass which is available to the billet surface at the die opening.

The flat faced billet configuration (Figure 7B) was planned for the three pushes with the multi-port die. The relatively small radius (3/8'') at the front face of the billet is employed to obtain good fillout of the front of the extrusion.

The glass pad configurations employed to lubricate the dies are shown in Figure 8. Figure 8A shows the glass ring used for lubrication of the single port die while Fibure 8B is a sketch showing the approximate dimensions of the pad used with the multi-port die. The glass pad is designed so that the large "boss" in the center of the pad is available throughout the extrusion cycle for continuous feeding of glass to both port openings. For the single port, glass wool pads were used in conjunction with the granular glass pad. The glass wool pads were placed between the die and the granular glass ring. (See ASD Interim Report 7-556 XIX for sketch showing arrangement of die, glass wood pads, granular glass ring and billet) The thin glass fibers of the glass wool pads melt easily and provide the initial lubrication at breakthrough while the granular glass provides the lubrication during the latter part of the extrusion. The three glass wool pads were slotted and shaped by hand into a "doughnut" form, the I.D. of which was larger than the tee opening of the die (to avoid die clogging).



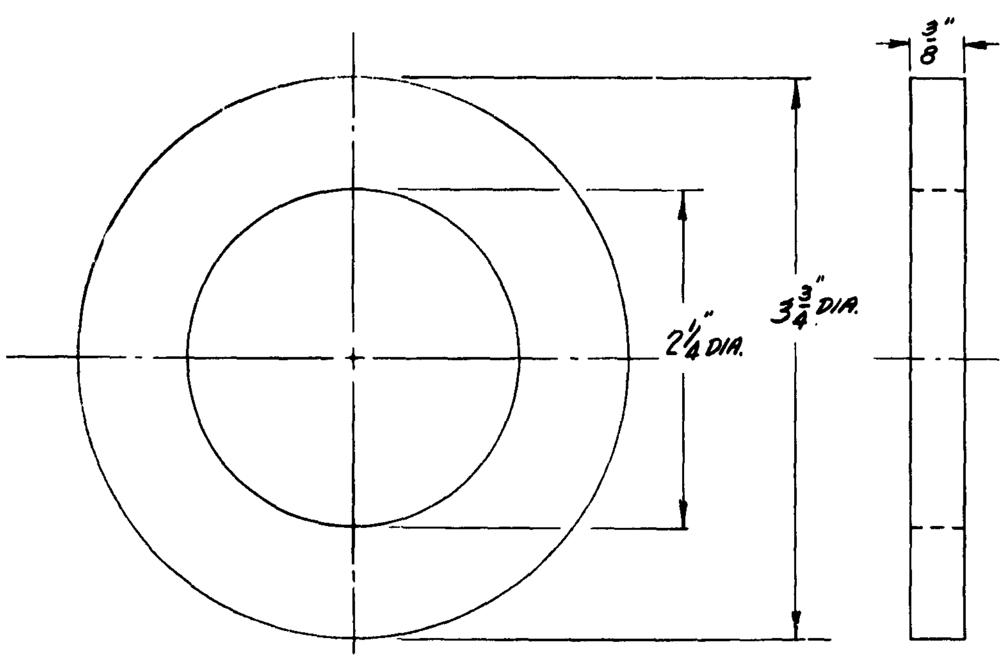
A) Convex Shaped Nose Billet Used For Three-Piece Single Port Die



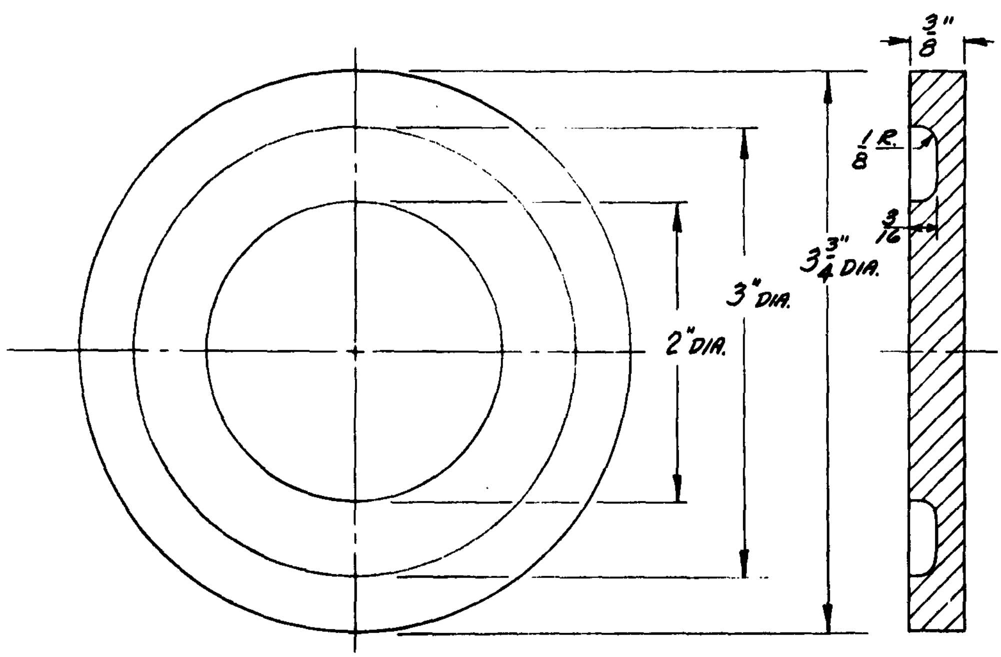
B) Flat Faced Billet Used for One-Piece Multi-Port Die

BILLET CONFIGURATIONS USED FOR GROUP 1 PART V TRIAL

FIGURE 1



6A) PAD CONFIGURATION USED FOR SINGLE PORT DIE



6B) PAD CONFIGURATION USED FOR MULTI-PORT DIE

GRANULAR GLASS PAD DESIGNS
FIGURE 8

Peerless A tungsten steel dies were used for both the three-piece single port dies and the one-piece multi-port dies. The single port dies used the three piece design to allow the application of ceramic coating by the flame spray method to the land areas. Figure 9 shows the eight single port dies used for the trial after flame spraying the ceramic coating (prior to extrusion). The 1/16" orifice dies are in the upper portion of the photograph while the 3/32" orifice dies are in the lower part of the photograph. Figure 10 is a closeup of one of the dies showing the ceramic coating along the die lands. The dies contained a .002" undercoat of molybdenum with an .008" - .010" coating of alumina. The die orifice dimensions after coating are shown in Table 1. The dimensions were obtained by feeler gage measurement with the die in the die holder.

The temperature of the tooling during the trial was as follows:

die	-	1000°F
container	-	900°F
dummy block	-	400°F

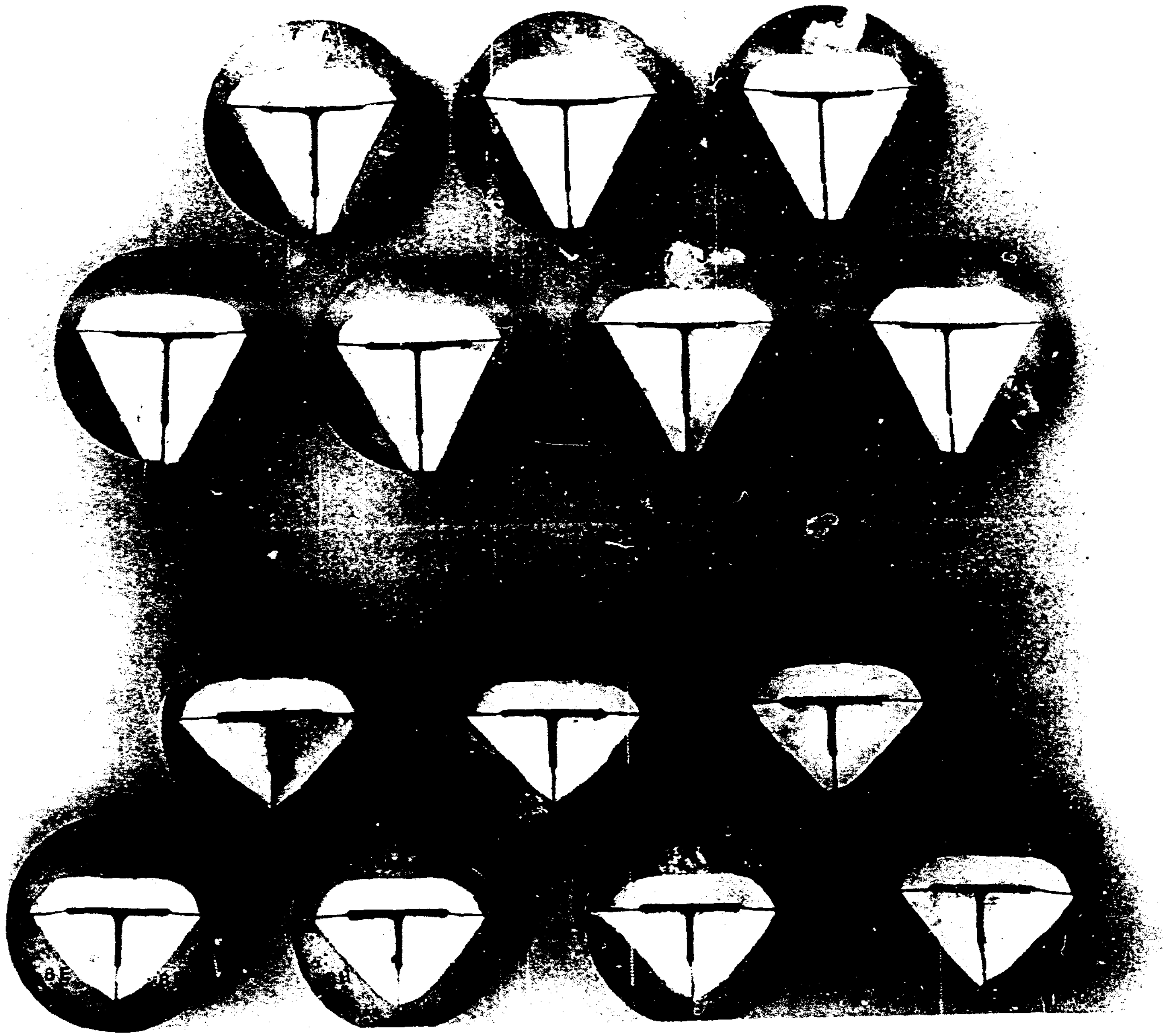
EXTRUSION TRIAL

The trial schedule is listed in Table II with the conditions for each push. Force measurements are not listed due to faulty instrumentation. The data listed under the Remarks column are notes that were made during the trial and reflect the impressions made as the events occurred. A more detailed analysis of the conditions of the shapes, dies and discards are presented in the Results section.

Four stainless steel heating cans were available which allowed flexibility in the billet heating cycle. Previously sprayed glass coated billets were categorically lined up in front of the four furnace entry positions in order to maintain continuous availability of hot billets in accordance with the heat soak schedule. The billets were charged into the furnace one every fifteen minutes. The die carrier was heated with a torch on the die rack. The granular glass ring and glass wool pads were inserted by hand into the container after torch heating the container to 900°F. All billets were extruded by the full lubrication practice using a double roll pass over glass powder on the run-out table.

The trial was set up to extrude (7) lengths of shape No. 676, and (7) lengths of shape No. 677. These shapes are the .093" and .063" shapes respectively that will be used for warm drawing to the sections shown in Figure 4. In addition, (3) pushes were planned through the multi-port dies (shape no. 678). This shape is similar to No. 677, except for a shorter stem height.

The first two pushes were made through the .093" die using the E71B-E-71 glass combination. Both of the shapes were badly scored and titanium pickup was note on the die. The next two pushes were for the same section but with the 318-3KB glass combination. The shapes were much improved and showed good metal flow and glass flow.



FLAME SPRAYED ALUMINA COATED TEE SHAPED DIES (3-Section Dies) PRIOR TO GROUP I PART V TITANIUM EXTRUSION TRIALS. ALUMINA COATING RANGES FROM .005" TO .010" PER SIDE

FIGURE 9

MR 158
C

MR 3387

TYPICAL THREE PIECE DIE USED FOR TRIAL SHOWING EXTENT OF CERAMIC COATING IN DIE OPENING

FIGURE 10

TABLE I

DIE ORIFICE DIMENSIONS PRIOR TO EXTRUSION
(.008" - .010" ALUMINA FLAME SPRAY COATING)

DIE NO.	DIMENSIONS (INCHES			PUSH NO.
	A	B	C	(REFERENCE)
7A	.064	.063	.064	266
7B	.063	.063	.063	-
7C	.063	.063	.063	261
7E	.063	.063	.063	265
7H	.066	.066	.066	260
7J	.066	.066	.066	264
7K	.066	.066	.066	259
8A	.097	.097	.096	262
8B	.103	.100	.103	253
8C	.093	.100	.100	251
8E	.096	.096	.094	252
8H	.097	.097	.097	254
8I	.097	.097	.097	-
8K	.097	.097	.097	263

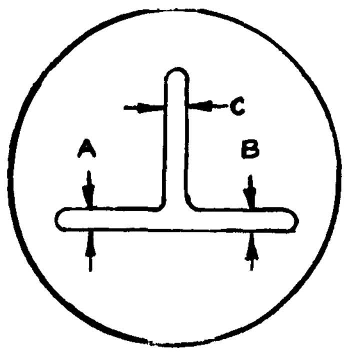


TABLE II

TEST DATA OF EXTRUSION TRIAL CONDUCTED AT BABCOCK AND WILCOX COMPANY
ON 2 MAY 1963 - PART V GROUP 1. MATERIAL 6Al4V TITANIUM ALLOY (FORGED STOCK)
(SEE TEXT FOR WORKING CONDITIONS AND PROCEDURE)

PUSH NO.	HEAT NO.	BILLET LENGTH	BILLET WGT.	BILLET COATING	BILLET TEMP.	HEATING TIME MIN.	BILLET TRANSFER TIME (SECS.)	OD LUB.	DIE GLASS	DIE GLASS CONFIGURATION	DIE NO.	DIE ORIFICE	SHAPE NO.	BILLET CONFIG.	REMARKS
251	D4050	6 3/4	13.5	85	1800	67	33	E71B	E71	Ring + 30W pads	8C	093	677	Convex Face	Extrusion broke off - striated and grooved surface - poor glass coverage on discard and on extrusion - titanium pickup on die - force seemed high.
252						72	43	E71B	E71	Ring + 30W pads	8E	093	677	Convex Face	Striated and grooved surface - heavy glass coating on die - some titanium pickup on die - billet glass coating appeared dull - back of tee shape looked good - force still high.
253						75	34	318	3KB	Ring + 30W pads	8D	093	677	Convex Face	Extrusion good - slight striation in radius - good glass coverage - good flow on discard - die appeared good (no wash) - die coating stood up - lower force reflected normal operation.
254						74	37	318	3KB	Ring + 30W pads	8H	093	677	Convex Face	Extrusion good - good glass coverage on extrusion - heavy glass coating on die - low force.
255	D2449	9 1/4	18.5			77	43	E71B	E71	Dished Pad	Multi Port #1	093	678	Flat Face	Sticker - approximately 2' extruded - probably chilled billet.
256						98	38	E71B	E71	Dished Pad	Multi Port #2	093	678	Flat Face	Sticker - approximately 2' extruded - may be due to long length.
257							PULLED OFF LINE							Flat Face	Pulled off line - will use shorter billet.
258	D4050	6 3/4	13.5			90	31	318	3KB	Dished Pad	Port #3	093	678	Convex Face	Extruded shapes fair - nose indicated poor breakthrough - possibly due to convex face.
259						75	UNKNOWN	E71B	E71	Ring + 30W pads	7K	062	676	Convex Face	Score mark on one side - titanium pickup on die on same side as score mark - E71B - E71 glass combination not lubricating properly.
260						81	34	318	3KB	" "	7H	062	676	"	Good surface on extrusion - die looked good - discard looked good except for lap which did not get into extrusion - will use 318-3KB glass for balance of trial.
261						75	28	318	3KB	" "	7C	062	676	"	Good extrusion - slight scoring due to some pickup - no scalp on discard.
262						83	30	"	"	" "	8A	093	677	"	Sticker - 2" extruded - billet coating appeared darker than others coming out of furnace.
263						74	28	"	"	" "	8K	093	677	"	Good extrusion - scalp again noted on discard but did not get to die.
264						63	32	"	"	" "	7J	062	676	"	Score mark on extrusion leg - die looked good - discard looked good but again had lap condition (scalp).
265						69	29	"	"	" "	7E	062	676	"	Badly scored extrusion on bottom - die looked good - discard scalped - extended into shape - noted stem on press tooling was bent upwards.
266	D3025					87	31	"	"	" "	7A	062	676	"	Ripple on left flange - discard scalped badly extending into shape.
267						79	42				Multi Port #1A	093	678	"	Good shapes - no scalping on discard - good glass coverage and metal flow.

As per the pre-planned schedule, the next two pushes were multi-ports using the E71B-E71 combination followed by a multi-port with the 318-3KB combination. Difficulty was experienced getting the billet can from the electric furnace for push no. 255. The can was inadvertently moved laterally during insertion into the furnace and was misaligned with the overhead gripping mechanism. In order to remove the can, an overhead crane was employed. Approximately 5 minutes elapsed in removing the billet. The temperature of the tooling was checked prior to insertion of the billet into the container to insure that the tooling hadn't cooled appreciably during the delay and was found satisfactory. However, the billet jammed the press after approximately 2' of extrusion. It was felt that the billet might have chilled during the delayed transfer. As expected, the die was difficult to remove from the discard. The surface of the extruded length looked good with good glass coverage. The billet showed good metal flow into both orifices and good glass flow to the openings. The remaining billet length was approximately 8".

Prior to push no. 256, the glass pad broke in transport from the bench to the press. However, the billet had not been removed from the furnace. A new glass pad was machined (hand ground as per sketch in Figure 8B) and the tooling was reheated prior to extrusion. However, another sticker occurred after approximately the same length of extrusion. It was felt that the length to diameter ratio was too high to extrude the 6Al-4V alloy at the 1800°F temperature. To insure the obtainment of a multi-port extrusion with the third and last multi-port die the 9 1/4" billet scheduled for push no. 257 was pulled off the line and the next 6 3/4" billet was used for the multi-port push. The extruded shapes were fair with good glass coverage. The nose of the extrusions indicated poor breakthrough. However, the billet face had a convex configuration since the billet was planned for a single port die, and the poor breakthrough could be attributed to this fact.

Push no. 259 was the first push through the .062" orifice and employed the E71B-E71 glass combination. Comparison of this push with no. 260 using the 318-3KB glasses as well as evaluation of pushes no. 251 through 254 indicated the superiority of the 318-3KB glasses and this combination was used for the balance of the trial.

There was no apparent reason for the sticker in push no. 262. One possible explanation is that the wrong billet was inadvertently removed from the furnace and had not undergone sufficient soak time but this could not be verified.

During the trial, it was noted that the coating on one of the billets awaiting heat soak had flaked off. The coating was removed and the billet was resprayed with the no. 85 slurry. This billet was used for push no. 267.

An examination of the multi-port dies from pushes nos. 255 and 256 (both stickers) revealed that the dies were in excellent condition. Multi-port die no. 1 was cleaned up and reused for another multi-port push (no. 267).

The stem was deformed slightly (best upwards) and was first noted after push no. 263. It became progressively worse and necessitated filing of the top surface after push no. 265 to avoid excessive rubbing with the container.

RESULTS

The extruded shapes are ahown in Figure 11. The push numbers progress from left to right as marked. The 2' lengths from the stickers in push nos. 255 and 256 are shown at the bottom left. The photograph shows the extrusions as deglassed except for nos. 255 and 256. The poor breakthrough on the multi-port shapes of push nos. 258 and 267 can be adjudged by the shape of the nose on these extrusions. The amount of twist of the extrusions appears to be normal for these shapes. The extrusions were visually inspected along the entire length and cross sectional measurements were taken at 2' intervals along the length. The measure ments are tabulated in Table III.

The discards are shown in Figure 12 and are lined up in the push sequence as numbered. The dies are shown "after extrusion" and "after extrusion and sand blasting" in Figures 13 and 14 respectively. The dies are also lined up in push sequence for ready identification with the shape and discard.

The results of the trial will be discussed under the individual push number and the reader is invited to make continual reference to the photographs as the results are discussed for greater clarity of the data.

Push No. 251

Shape - light to heavy scoring on all surfaces from front to back getting progressively worse toward the back end - scoring on back end very deep - shape rated poor - relatively good fillout on height and width - thickness dimensions undersize on back end indicating slight closure of die opening from titanium pickup - extrusion length 18' 11".

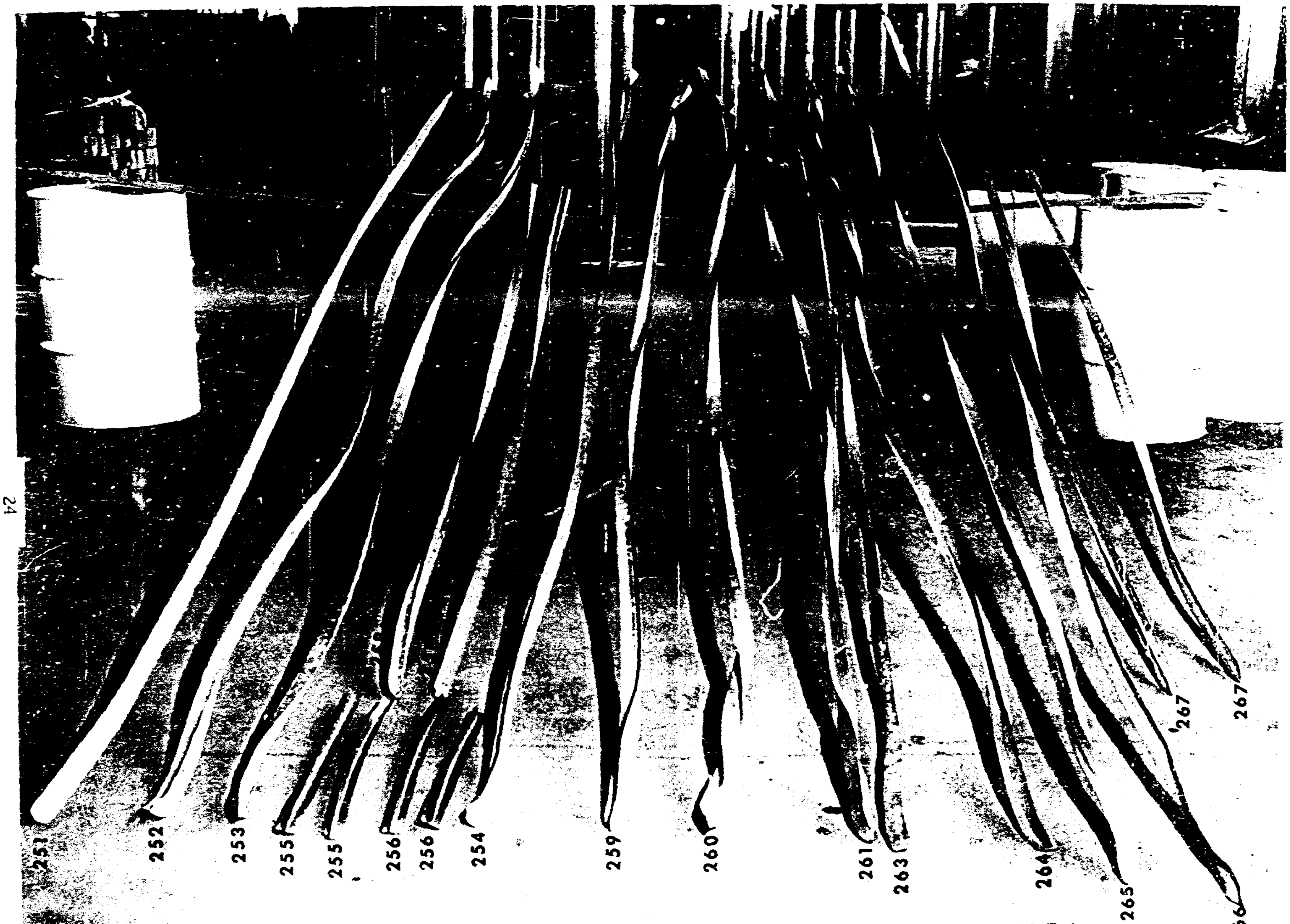
Discard - heavy scoring on all surfaces of shape discard - very little glass coverage with only fair glass flow - billet discard scalped but did not get to shape.

Die - heavy titanium pickup on fillet radius - light pickup on bottom of tee - rest of land o.k. - not reusable

Push No. 252

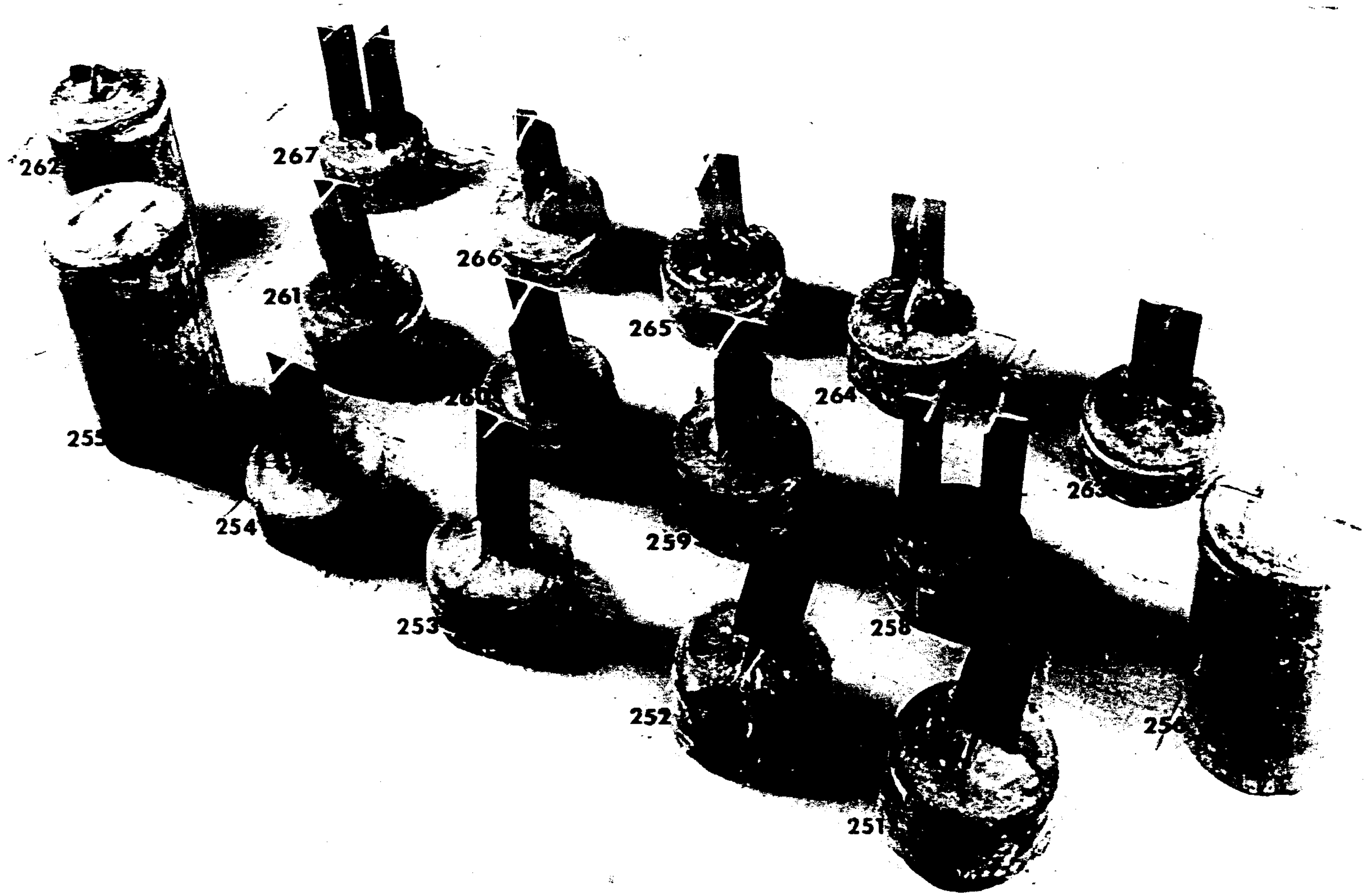
Shape - light scoring uniform front to back on right flange and right stem - light to heavy scoring front to back on left flange, radius and stem - bottom smooth all the way - shape rated poor - good uniformity in cross sectional dimensions - length 18' 11"

Discard - heavy scoring on left flange and left stem - heavy scalp with scalped portion missing from discard



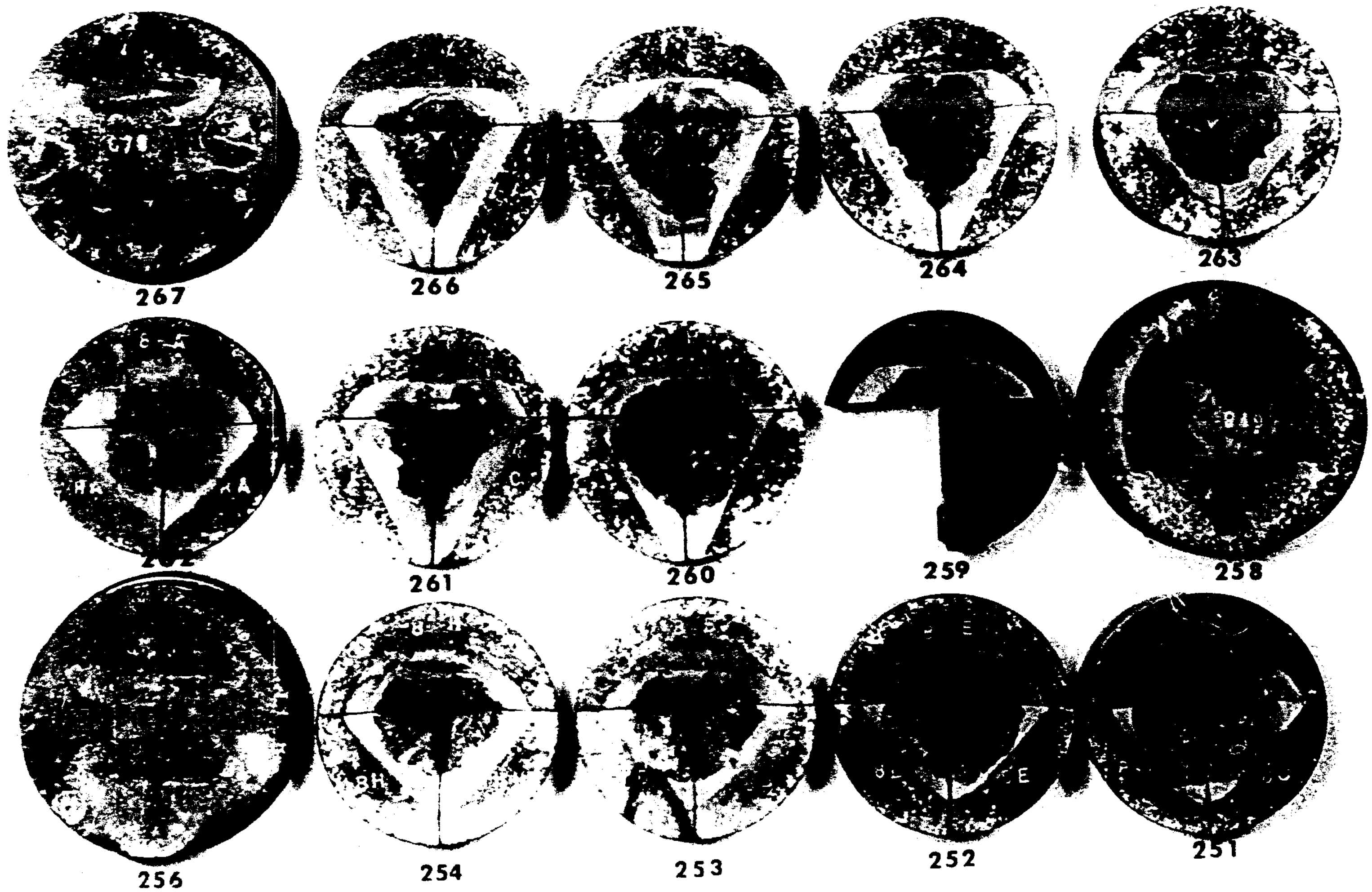
AS-EXTRUDED .063" AND .093" 6Al-4V TEE SECTIONS FROM PART V GROUP 1 TRIAL. THE PUSH NO. IS SHOWN ALONGSIDE EACH EXTRUSION

FIGURE 11



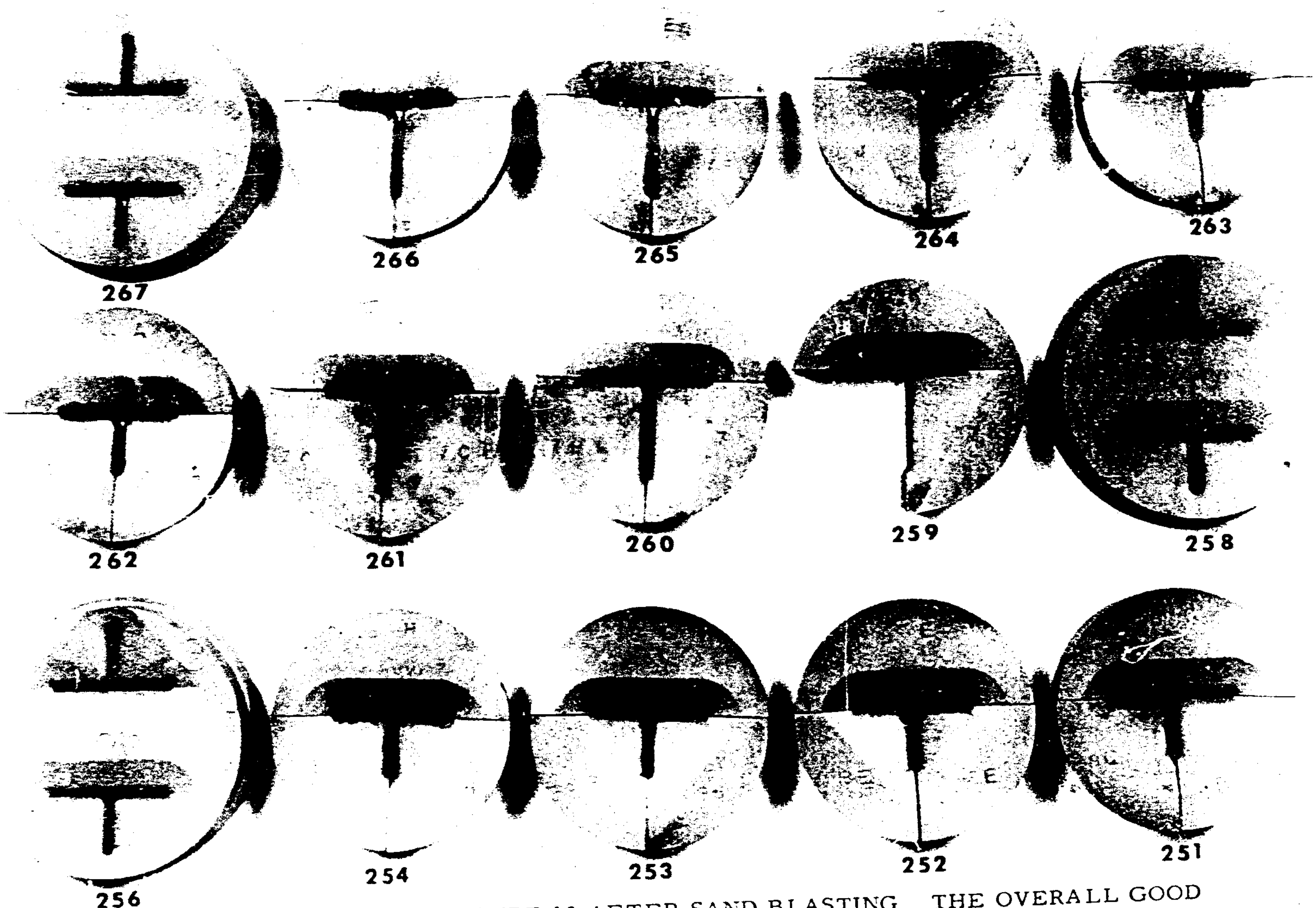
BILLET DISCARDS FROM PART V GROUP 1 EXTRUSION TRIAL. EACH DISCARD IS IDENTIFIED BY ITS RESPECTIVE PUSH NO.

FIGURE 12



DIES USED ON PART V GROUP I TRIAL SHOWN AFTER EXTRUSION. DIE USED ON PUSH 267 (upper left) WAS ALSO USED FOR PUSH 255. SECTION OF DIE #7K (Push 259) WAS MISSING AT TIME OF PHOTOGRAPH

FIGURE 13



DIES SHOWN IN FIGURE 13 AFTER SAND BLASTING. THE OVERALL GOOD CONDITION OF THE DIES AFTER THE TRIAL CAN BE SEEN.

FIGURE 14

TABLE III

Cross Section Dimensions (As Extruded)

Extrusion Number	Feet From Front End	A	B	C	D	E
		Dimension Locations (Inches) (See Sketch)				
251	0	.091	.093	.091	1.738	.976
	2	.093	.092	.090	1.754	.985
	4	.093	.093	.090	1.754	.983
	6	.093	.092	.090	1.754	.983
	8	.093	.092	.090	1.753	.984
	10	.092	.091	.090	1.752	.984
	12	.092	.089	.090	1.749	.984
	14	.088	.088	.088	1.748	.976
	16	.085	.084	.084	1.748	.974
	18	.083	.079	.079	1.747	.970
252	0	.088	.093	.087	1.736	.974
	2	.089	.091	.086	1.748	.983
	4	.090	.090	.087	1.749	.983
	6	.088	.090	.088	1.749	.983
	8	.088	.092	.086	1.749	.982
	10	.089	.091	.086	1.749	.980
	12	.089	.091	.086	1.750	.981
	14	.090	.091	.086	1.750	.982
	16	.088	.090	.085	1.750	.980
	18	.089	.090	.083	1.752	.980

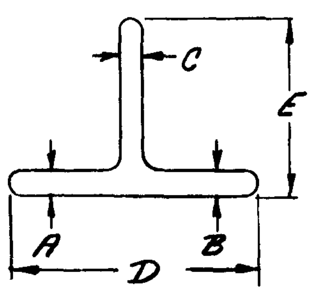


TABLE III (Continued)

Cross Section Dimensions (As Extruded)

Extrusion Number	Feet From Front End	Dimension Locations (Inches) (See Sketch) A	B	C	D	E
253	0	.089	.094	.095	1.761	.983
	2	.090	.094	.094	1.746	.982
	4	.089	.094	.094	1.745	.981
	6	.088	.093	.095	1.747	.982
	8	.089	.094	.094	1.747	.979
	10	.090	.093	.094	1.749	.977
	12	.090	.093	.094	1.748	.978
	14	.090	.094	.094	1.759	.980
	16	.090	.093	.095	1.750	.981
	18	.090	.092	.095	1.750	.982
254	0	.092	.093	.097	1.742	.945
	2	.094	.094	.098	1.751	.968
	4	.093	.094	.098	1.758	.997
	6	.093	.093	.098	1.758	.982
	8	.094	.093	.098	1.762	.984
	10	.093	.093	.098	1.766	.986
	12	.094	.094	.098	1.769	.985
	14	.093	.093	.098	1.766	.986
	16	.094	.093	.098	1.764	.987
	18	.094	.093	.098	1.765	.986
	20	.094	.092	.098	1.759	.988

TABLE III (Continued)

Cross Section Dimensions (As Extruded)

Extrusion Number	Feet From Front End	Dimension Locations (Inches) (See Sketch) A	B	C	D	E
258A	0	.096	.094	.095	1.736	.948
	2	.100	.098	.098	1.743	.950
	4	.100	.099	.098	1.747	.942
	6	.100	.099	.098	1.761	.948
	8	.100	.100	.099	1.760	.947
	10	.102	.101	.099	1.758	.948
258B	0	.097	.094	.099	1.754	.900
	2	.100	.098	.102	1.762	.915
	4	.102	.099	.101	1.768	.929
	6	.102	.099	.103	1.768	.949
	8	.104	.101	.103	1.768	.953
	10	.104	.102	.104	1.771	.952
259	0	.059	.064	.062	1.588	1.491
	2	.058	.063	.062	1.650	1.516
	4	.059	.064	.063	1.723	1.551
	6	.058	.064	.063	1.742	1.581
	8	.058	.063	.063	1.743	1.590
	10	.058	.063	.063	1.745	1.590
	12	.059	.063	.063	1.743	1.589
	14	.059	.063	.063	1.742	1.586
	16	.058	.063	.062	1.742	1.587
	18	.058	.062	.060	1.741	1.587
	20	.059	.063	.059	1.737	1.585
	22	.059	.060	.057	1.736	1.586

TABLE III (Continued)

Cross Section Dimensions (As Extruded)

Extrusion Number	Feet From Front End	Dimension Locations (Inches) (See Sketch) A	B	C	D	E
260	0	.089	.092	.086	1.717	1.486
	2	.088	.095	.086	1.743	1.512
	4	.088	.094	.086	1.751	1.535
	6	.089	.093	.087	1.753	1.557
	8	.089	.094	.087	1.757	1.570
	10	.089	.092	.087	1.759	1.577
	12	.090	.095	.087	1.756	1.581
	14	.090	.093	.087	1.756	1.581
	16	.089	.094	.087	1.759	1.582
	18	.089	.092	.086	1.762	1.582
	20	.089	.093	.087	1.763	1.582
	22	.089	.092	.088	1.765	1.583
261	0	.059	.064	.060	1.611	1.378
	2	.060	.064	.060	1.663	1.423
	4	.061	.065	.059	1.691	1.467
	6	.061	.065	.061	1.708	1.511
	8	.062	.065	.060	1.732	1.530
	10	.062	.065	.059	1.742	1.550
	12	.062	.066	.062	1.744	1.566
	14	.062	.065	.061	1.749	1.572
	16	.062	.065	.061	1.753	1.576
	18	.062	.065	.059	1.758	1.579
	20	.062	.065	.059	1.763	1.581
	22	.061	.065	.060	1.763	1.584

TABLE III (Continued)

Cross Section Dimensions (As Extruded)

Extrusion Number	Feet From Front End	Dimension Locations (Inches) (See Sketch) A	B	C	D	E
263	0	.094	.093	.092	1.737	.976
	2	.094	.093	.091	1.750	.980
	4	.093	.092	.093	1.750	.984
	6	.094	.093	.091	1.751	.983
	8	.094	.093	.091	1.753	.985
	10	.094	.093	.091	1.755	.983
	12	.094	.093	.091	1.755	.984
	14	.094	.093	.091	1.756	.985
	16	.094	.093	.092	1.754	.982
	18	.094	.093	.092	1.757	.984
	20	.094	.093	.092	1.758	.985
264	0	.063	.064	.067	1.679	1.457
	2	.065	.065	.069	1.697	1.475
	4	.064	.064	.068	1.719	1.495
	6	.063	.064	.068	1.734	1.516
	8	.064	.066	.068	1.744	1.527
	10	.063	.065	.069	1.746	1.549
	12	.064	.065	.068	1.747	1.565
	14	.063	.066	.068	1.750	1.578
	16	.063	.065	.069	1.751	1.580
	18	.064	.065	.069	1.751	1.582
	20	.063	.065	.068	1.751	1.583

TABLE III (Continued)

Cross Section Dimensions (As Extruded)

Extrusion Number	Feet From Front End	Dimension Locations (Inches) (See Sketch) A	B	C	D	E
265	0	.064	.059	.063	1.580	1.508
	2	.064	.059	.063	1.623	1.535
	4	.063	.059	.062	1.664	1.557
	6	.064	.058	.063	1.706	1.575
	8	.064	.059	.062	1.739	1.579
	10	.063	.058	.062	1.745	1.578
	12	.064	.059	.062	1.746	1.578
	14	.064	.057	.063	1.748	1.580
	16	.064	.059	.062	1.747	1.581
	18	.063	.059	.062	1.747	1.582
	20	.063	.059	.062	1.747	1.584
	22	.064	.056	.063	1.746	1.587
	24	.063	.054	.063	1.736	1.592
266	0	.059	.065	.056	1.670	1.367
	2	.059	.065	.055	1.719	1.381
	4	.060	.067	.056	1.733	1.412
	6	.059	.065	.057	1.736	1.443
	8	.061	.065	.056	1.742	1.461
	10	.061	.066	.056	1.745	1.479
	12	.061	.065	.057	1.746	1.498
	14	.060	.065	.056	1.746	1.514
	16	.061	.065	.057	1.746	1.536
	18	.059	.065	.056	1.746	1.556
	20	.060	.065	.059	1.745	1.569
	22	.058	.065	.055	1.740	1.575
	24	.059	.066	.056	1.733	1.573

TABLE III (Continued)

Cross Section Dimensions (As Extruded)

Extrusion Number	Feet From Front End	Dimension Locations (Inches) (See Sketch) A	B	C	D	E
267A	0	.095	.098	.099	1.746	.794
	2	.099	.103	.103	1.757	.913
	4	.100	.105	.102	1.765	.932
	6	.101	.105	.103	1.767	.937
	8	.101	.106	.103	1.738	.938
	10	.102	.107	.103	1.768	.943
267B	0	.095	.100	.096	1.717	.871
	2	.098	.103	.099	1.753	.903
	4	.100	.104	.101	1.764	.934
	6	.101	.105	.100	1.764	.948
	8	.101	.105	.101	1.762	.951
	10	.101	.106	.100	1.763	.950

Die - some titanium pickup at fillet radius and along land on stem and flange adjacent to radius - ceramic still intact on bottom and on outside radii - reusable

Push No. 253

Shape - light scoring front to back on all surfaces - shape rated good - good fillout and dimensional uniformity - length 20' 0"

Discard - good discard - no scalping - good glass coverage and glass flow - very light scoring

Die - very light titanium pickup at fillet radii - ceramic coating removed in land areas - die reusable

Push No. 254

Shape - very light scoring all over front to back - both fillet radii had light to medium scoring front to back - shape rated fair to good - good cross sectional thickness uniformity - poor fillout of height and width dimensions for first 3' - good dimensional uniformity for balance - length 20' 2"

Discard - good glass flow - good metal flow except for scalp which leads up to shape but stopped short of entering shape. Very slight scoring in radius

Die - extremely light titanium pickup in fillet radius - ceramic removed from land areas - die showed no wear or wash - reusable

Push No. 255

Shape - both pieces inspected with glass coverage - smooth surface - fair breakthrough - length 2'

Discard - good glass coverage on billet - appeared to have sufficient glass available for extrusion - good metal flow

Die - excellent condition - reusable

Push No. 256

Shape
Discard - Same as push No. 255
Die

Push No. 258

Shape A	-	light to medium score lines on full length - heavy scoring on bottom - medium herringbone pattern on surface of right flange, radius and stems - poor breakthrough - poor fillout for first 4' - shape rated fair - length 10' 6"
Shape B	-	light to medium scoring front to back - poor breakthrough - poor fillout for first 4' - shape rated fair - length 10' 6"
Discard	-	good glass flow - scalp all the way up discard
Die	-	very light pickup in fillet radius - light wash at center of both flange openings - remainder of land in good condition - reusable

Push No. 259

Shape	-	light to heavy scoring front to back on right flange radius and stem - light scoring full length on left surfaces and bottom - shape rated fair - poor fillout for first 4' - good thickness uniformity - length 22' 11"
Discard	-	heavy scoring on right flange and stem - no glass on scored side - ripple on left flange - scalp on billet extending to shape
Die	-	extra heavy die wash and pickup on side corresponding to scoring marks on shape - die not reusable

Push No. 260

Shape	-	very good - scoring very light in all areas - good fillout after first 4'
Discard	-	good glass flow and coverage - good metal flow small scalp on discard did not reach shape
Die	-	titanium pickup in both fillet radii light pickup on remaining land - reusable

Push No. 261

Shape	-	fair to good - deep scoring in left radius - good fillout
Discard	-	good - no scalp, good metal and glass flow - light scoring in corners

Die	-	pickup and washing in fillet radii - rest of land O.K. Bottom land good - not reusable

<u>Push No. 262</u>

Shape	-	sticker
Discard	-	only 1/2" of product - billet coating looks poor compared to # 255 and 256
Die	-	excellent condition - reusable

<u>Push No. 263</u>

Shape	-	very good - scoring very light in all areas
Discard	-	good metal flow, good glass flow, scalp on discard - does not effect shape
Die	-	good - washed in right fillet radius - rest of land O.K. - reusable

<u>Push No. 264</u>

Shape	-	very good - light socring on bottom - one deep score starting 10' to 16' from front end
Discard	-	scalp did not come over corner - metal flow and glass coverage good
Die	-	light pickup in one radius, rest of land good reusable

<u>Push No. 265</u>

Shape	-	poor - heavy scoring on bottom side, other surfaces very good
Discard	-	scalped all the way into shape - good glass flow over most of discard
Die	-	titanium pickup on one radius, die wash on other radius, rest of land in good condition - reusable

Push No. 266

Shape - light rippling first 19', heavy rippling last 6' - otherwise good

Discard - scalped all the way into shape - light scoring on rest of surface

Die - die wash in both radii, titanium pickup on stem - reusable

Push No. 267

Shape A - good - poor breakthrough

Shape B - light scoring - both shapes had rougher surface than those extruded with ceramic coated dies

Discard - no scalp, good glass coverage and flow

Die - same die used on push no. 255 - light die wash on bottom of both flanges - remainder of land in good condition - not reusable

It is noteworthy that of the twelve alumina coated dies employed, nine dies are reusable. These dies require slight dressing and recoating of ceramic prior to use in the next trial scheduled for the B-70 shapes.

EVALUATION

Extrusion Defects and Surface Finish

The overall results indicate two major defects occurred during the trial - scoring and laminations due to scalping.

In almost all cases, the scoring started very light, part way up the shape and grew progressively worse toward the back end. Examination of the dies showed this condition to be due almost exclusively to titanium pickup. The pushes utilizing the E71B - E71 glass combination were very heavily scored and it is apparent that these glasses did not do an efficient job. Typical surface finish of the shapes using the E71B - E71 glass combination are shown in Figure 15. The upper extrusion in the photograph is push no. 259 (.063" section) and the lower extrusion is push no. 251 (.093" section). The sections on the left are from the front ends of the shapes while the sections on the right are the back ends. Figure 15 vividly shows the heavy grooves and scoring on the back ends of the shapes.

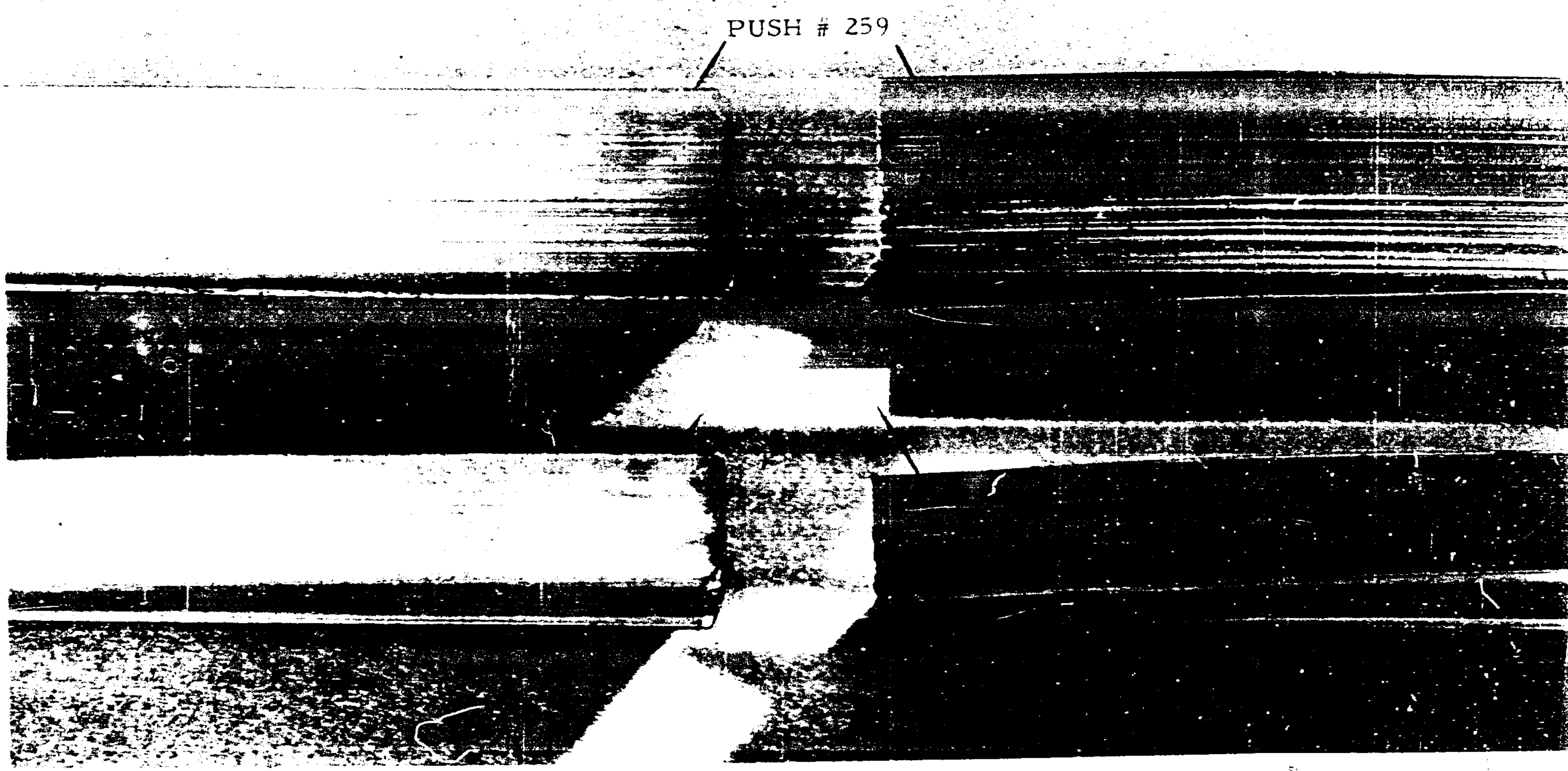
Figure 16 shows the dies that were used for push nos. 251 and 259*. The dies have been sand blasted to remove the glass and ceramic coating so that the die surface could be inspected. The die on the left shows the extremely heavy titanium pickup on the fillet radii. The die on the right shows the high degree of die wash that occurred on push no. 259. Die # 8C on the left has an .093" port opening while die #7K has an .063" opening. Both dies were used in conjunction with the E71B - E71 glass combination.

The 318-3KB glasses appeared to lubricate the extrusions properly during the early part of the trial but towards the end of the trial, bad scoring resulted on the shapes using 318-3KB combination.

Similarly, the lamination condition became progressively worse as the trial progressed. Almost all of the billets were scalped but in the early pushes the lamination did not reach the die and never entered the shape. For each succeeding push, the lamination appeared to progress further and further into the shape indicating that scalping of the billet was occurring earlier.

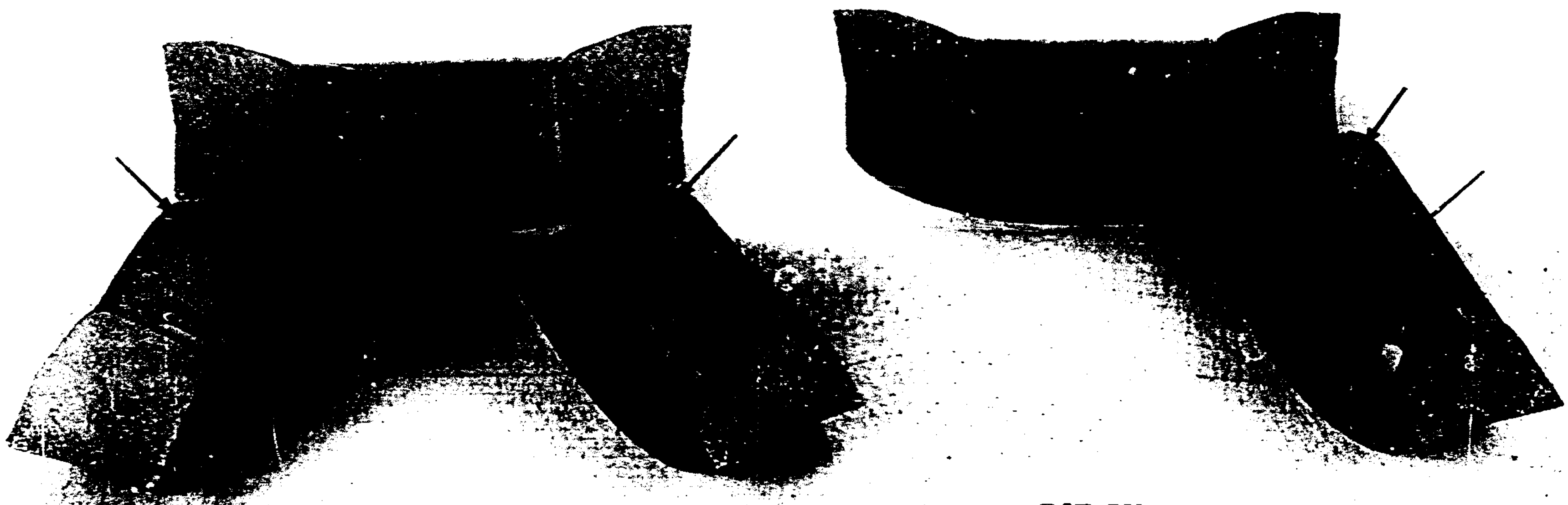
Figure 17 is a closeup of two discards showing the scalp condition. The discard on the left is from an early push (#252) in which the lamination did not reach the extrusion but stopped on the face of the billet discard. As can be seen, the scalped portion of the discard is missing. The discard on the left is from a push later in the trial (#266) and shows how the scalp extended into the extrusion resulting in a lamination. The two discards are typical of the discards obtained from the trial and indicate the uneven metal flow that was occurring during the trial. The scalping is an internal shearing of the billet that occurs due to the slower flow of the relatively cool billet surface as compared with the faster flow of the hotter interior billet metal. The lamination defect is caused by

* The left piece of die 7K was missing for the photograph.



TYPICAL SURFACE CONDITION OF .063" (Top) AND .093" (Bottom) TEE EXTRUSIONS PRODUCED WITH E71B-E71 GLASS COMBINATION DURING PART V GROUP 1 TRIAL. THE SECTIONS ON THE LEFT ARE FROM THE FRONT END OF THE EXTRUSION AND SHOW THE LIGHT SCORING MARKS. THE SECTIONS ON THE RIGHT ARE FROM THE BACK END AND SHOW THE VERY HEAVY SCORING.

FIGURE 15

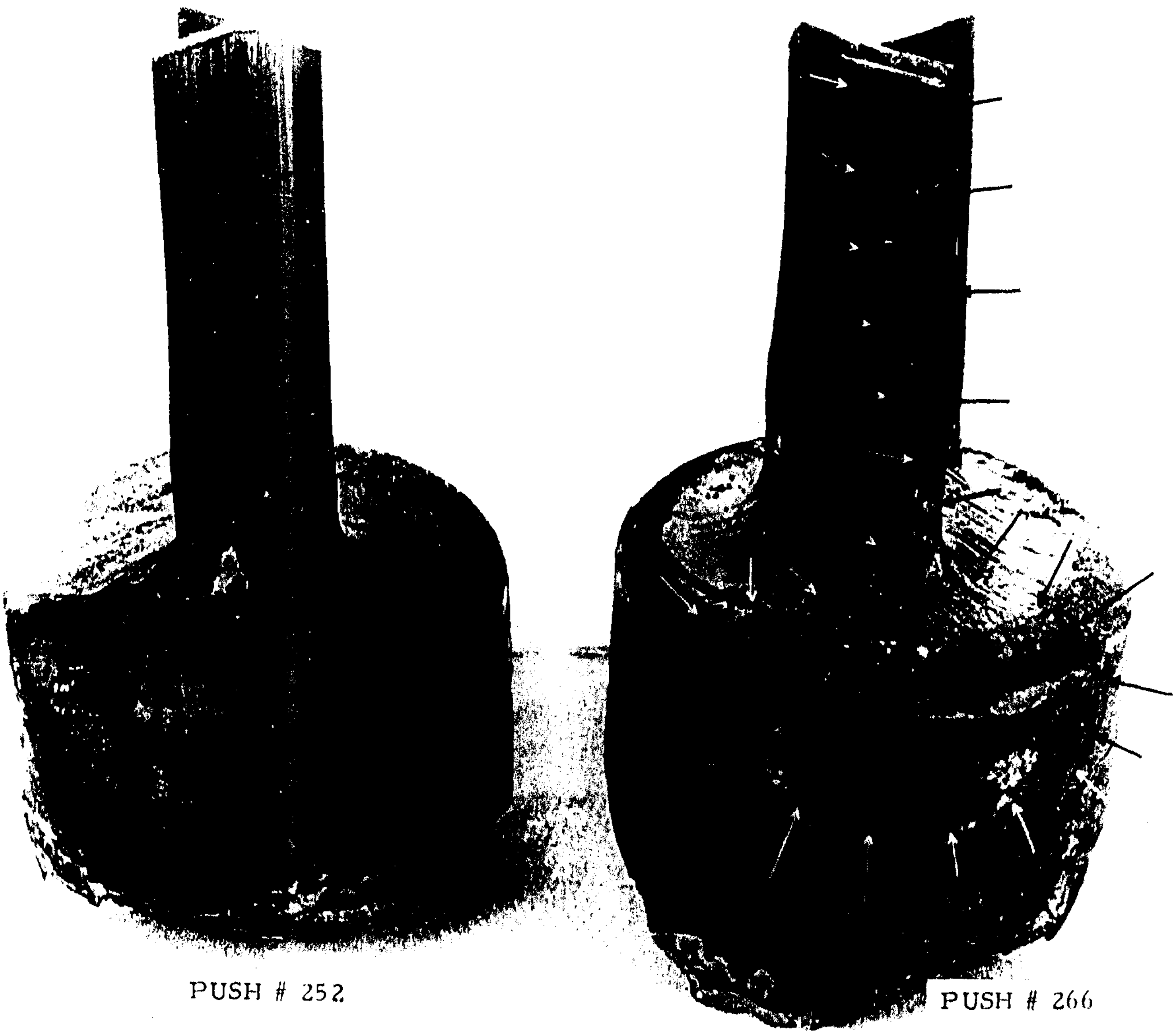


DIE 8C
(PUSH # 251)

DIE 7K
(PUSH # 259)

TYPICAL DIE DEFECTS OBTAINED WITH THE E71B-E71 GLASS COMBINATION. THE ARROWS MARK THE VERY HEAVY TITANIUM PICKUP ON DIE 8C AND THE PICKUP AND DIE WASH ON DIE 7K. THE DIES HAVE BEEN SAND BLASTED.

FIGURE 16



BUTT DISCARDS SHOWING TYPICAL BILLET SCALPING AND LAMINATION. THE ARROWS ON PUSH # 266 DISCARD SHOW THE LAMINATION LEADING UP INTO THE SHAPE. THE SCALPED PORTION OF PUSH # 252 DISCARD IS MISSING.

FIGURE 17

uneven metal flow which is due to non uniform glass lubrication.

Both conditions suggest a poor lubrication condition but the exact reason for the poor lubrication cannot be ascertained. The glasses did not react with the titanium since a microstructural analysis and micro hardness survey of the shapes revealed no contamination (for both glass combinations). A possible cause might have been a poor coating of #85 protective glass. Several people at the trial independently observed that the billet appeared darker than usual coming out of the can and it is possible that the coating did not have sufficient thickness. However, this is only a surmise and the effect of the coatings on the results cannot be determined accurately.

After the trial, the stem and container were inspected at length to see if the bent stem caused excessive wear to the container and possibly contributed to the scalping. However, the container was not scored and showed very little signs of wear (the chrome plating appeared dull at the point of rubbing).

The surface finish of several sections was measured by profilometer with the stylus movement perpendicular to the extrusion direction. The microinch surface finish measurements are presented in Table IV. The table shows that even at the front end of the extrusion where little or no scoring was obtained, the average surface finish was 200 u in RMS. This order of magnitude requires refinement and the trial indicates that warm draw processing is required if the shapes are to be considered aircraft quality.

Dimensional Uniformity

The cross section dimensions are listed in Table III. The height and width dimensions for all three shapes are plotted versus the length in Figures 18, 19, 20, 21, 22 and 23. The graphs show at a glance:

1. the poor fillout of the front end of the shapes
2. the good dimensional uniformity of each shape along its length
3. the relatively wide variation from one shape to the next

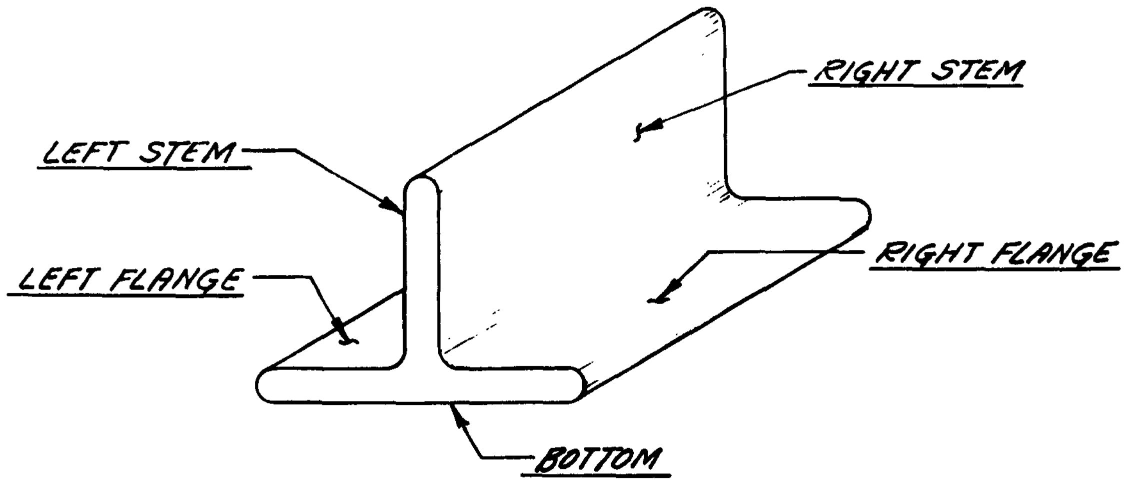
The tolerances shown on the graphs are equivalent to tolerances for similar aluminum extrusions and are for reference only. It can be seen that the dimensions for the stem height (dimension E) are all on the low side of the target dimension which indicates an inaccurate allowance in the determination of the die orifice size.

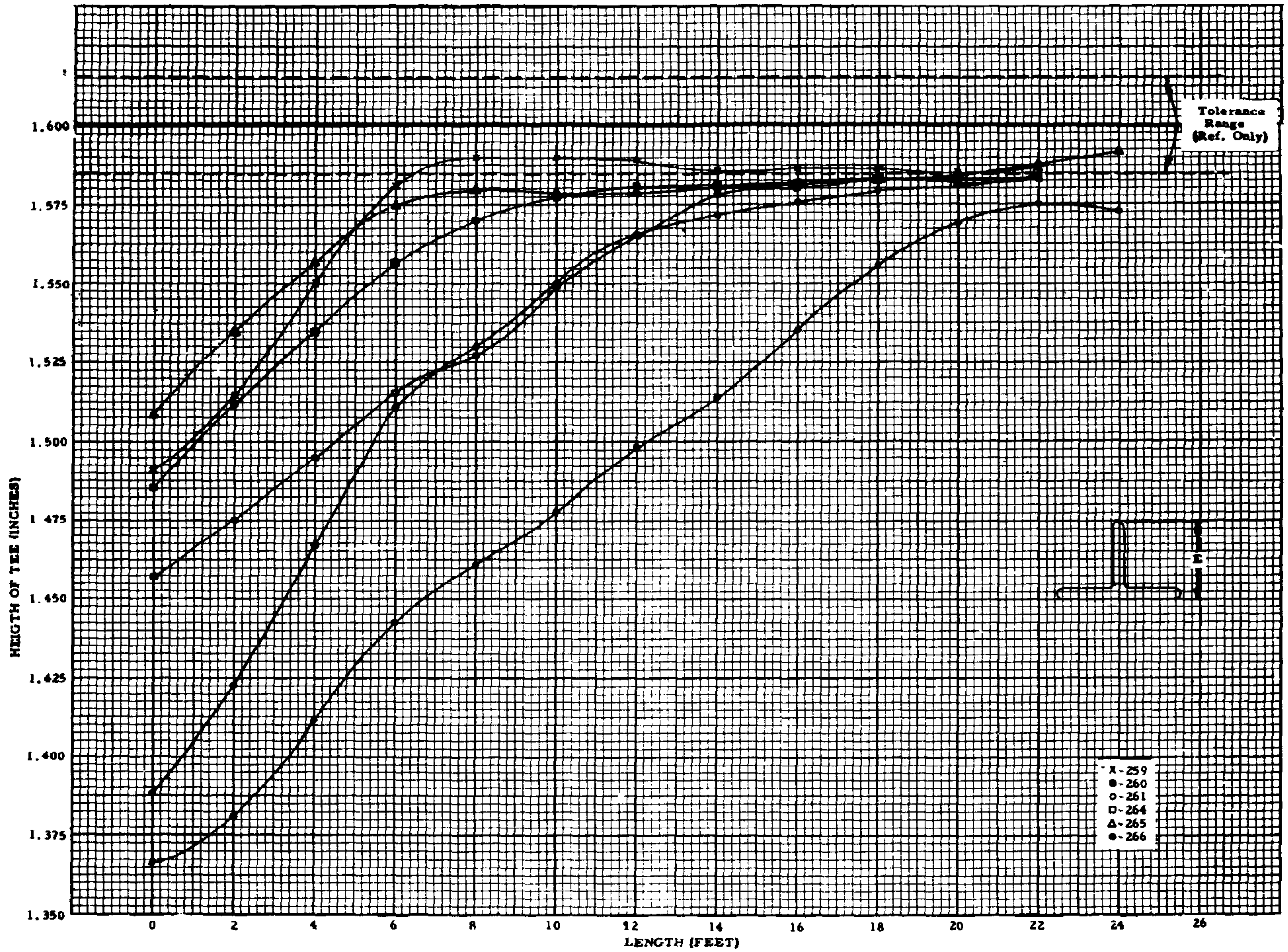
Figure 18 is a graph showing the height of shape 676 (1/16" section) along the length. It shows extremely poor fillout for push nos. 261, 264 and 266. Die fillout was not obtained for the first 12' of nos. 261 and 264 and was not obtained until the end of push no. 266. The other three extrusions had poor fillout for the first 6' with the remainder of the lengths within a narrow dimensional range (.015"). The width of the shapes (Figure 19) again shows poor fillout for the first 6' with the extrusions well within tolerance for the remaining length.

TABLE IV

SURFACE FINISH MEASUREMENTS

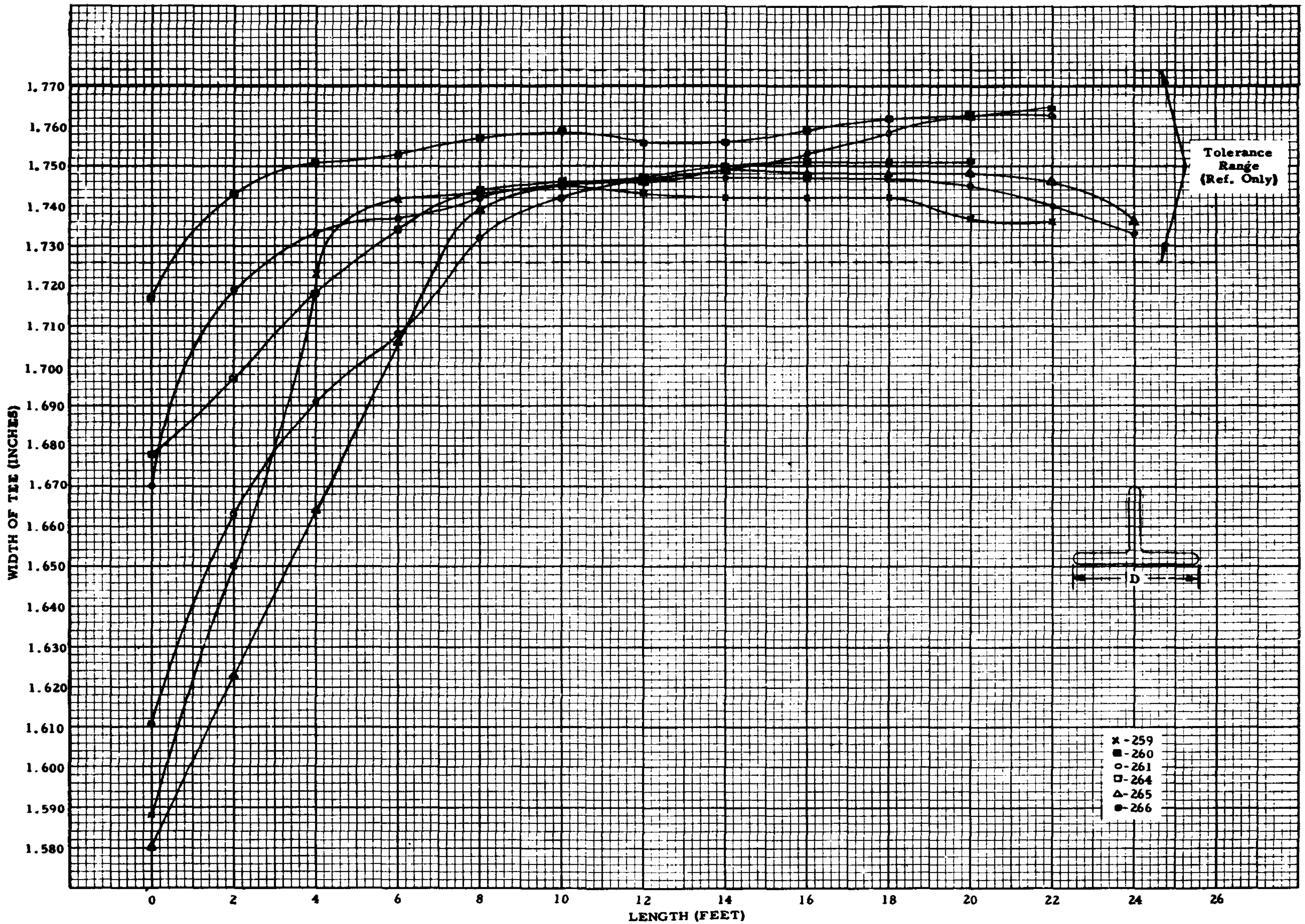
EXTRUSION NO.	LOCATION	RMS (u in.)	EXTRUSION NO.	LOCATION	RMS (u in
259 (front end as extruded)	Bottom	125 - 175	251 (front end after straightening)	Bottom	300 - 40
	Left Stem	200 - 225		Left Stem	100 - 15
	Left Flange	150 - 175		Left Flange	200 - 30
	Right Stem	75 - 100		Right Stem	150 - 20
	Right Flange	150 - 175		Right Flange	100 - 15
259 (back end as extruded)	Bottom	100 - 150	261 (back end after straightening)	Bottom	100 - 15
	Left Stem	100 - 150		Left Stem	100 - 12
	Left Flange	100 - 150		Left Flange	100 - 12
	Right Stem	300 - 600		Right Stem	100 - 15
	Right Flange	300 - 600		Right Flange	100 - 12



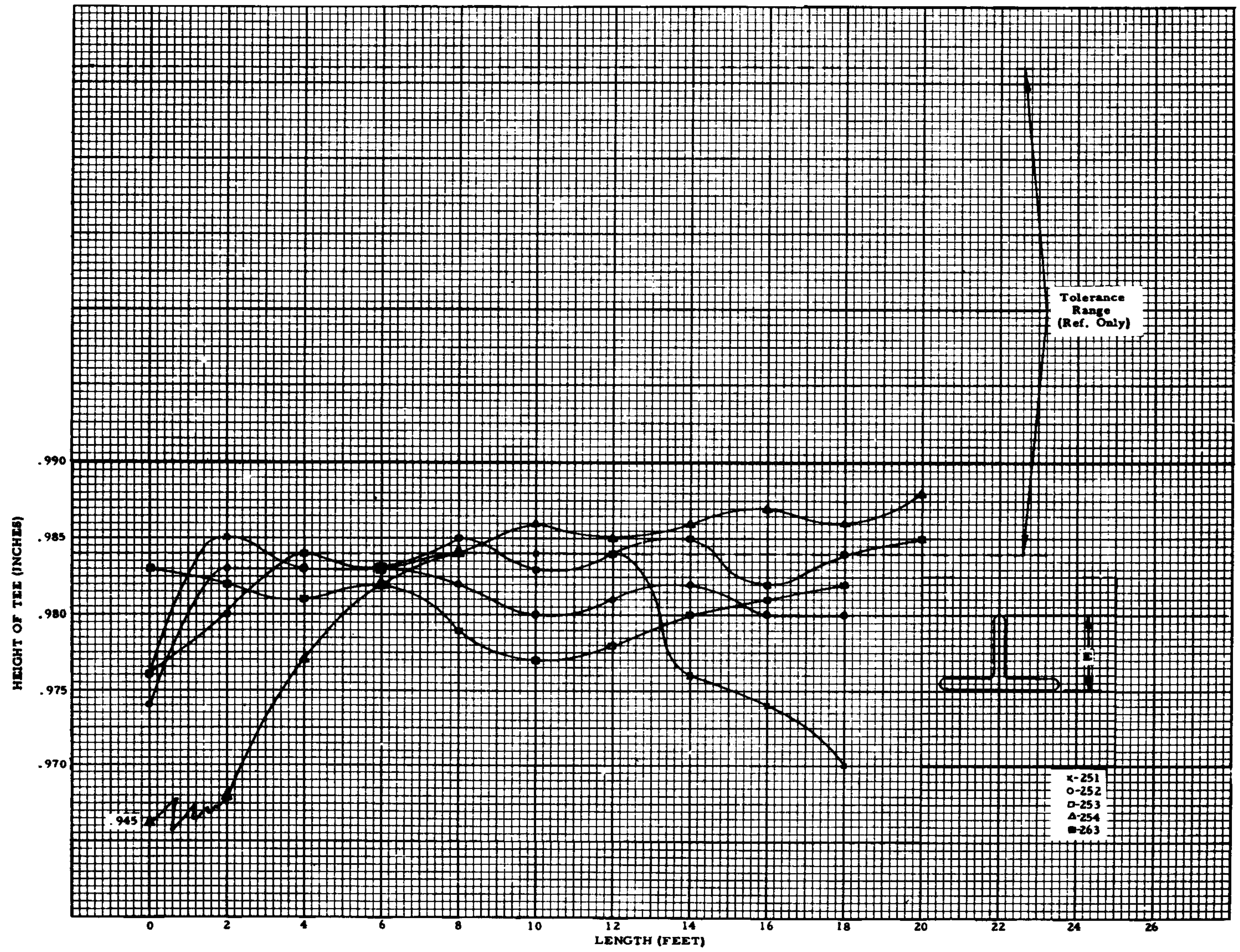


VARIATION OF TEE HEIGHT ALONG EXTRUSION LENGTH FOR SHAPE #676
(.063" SECTIONS) IN THE AS-EXTRUDED CONDITION

FIGURE 18



VARIATION OF TEE WIDTH ALONG EXTRUSION LENGTH FOR SHAPE # 676
(.063" SECTIONS) IN THE AS-EXTRUDED CONDITION

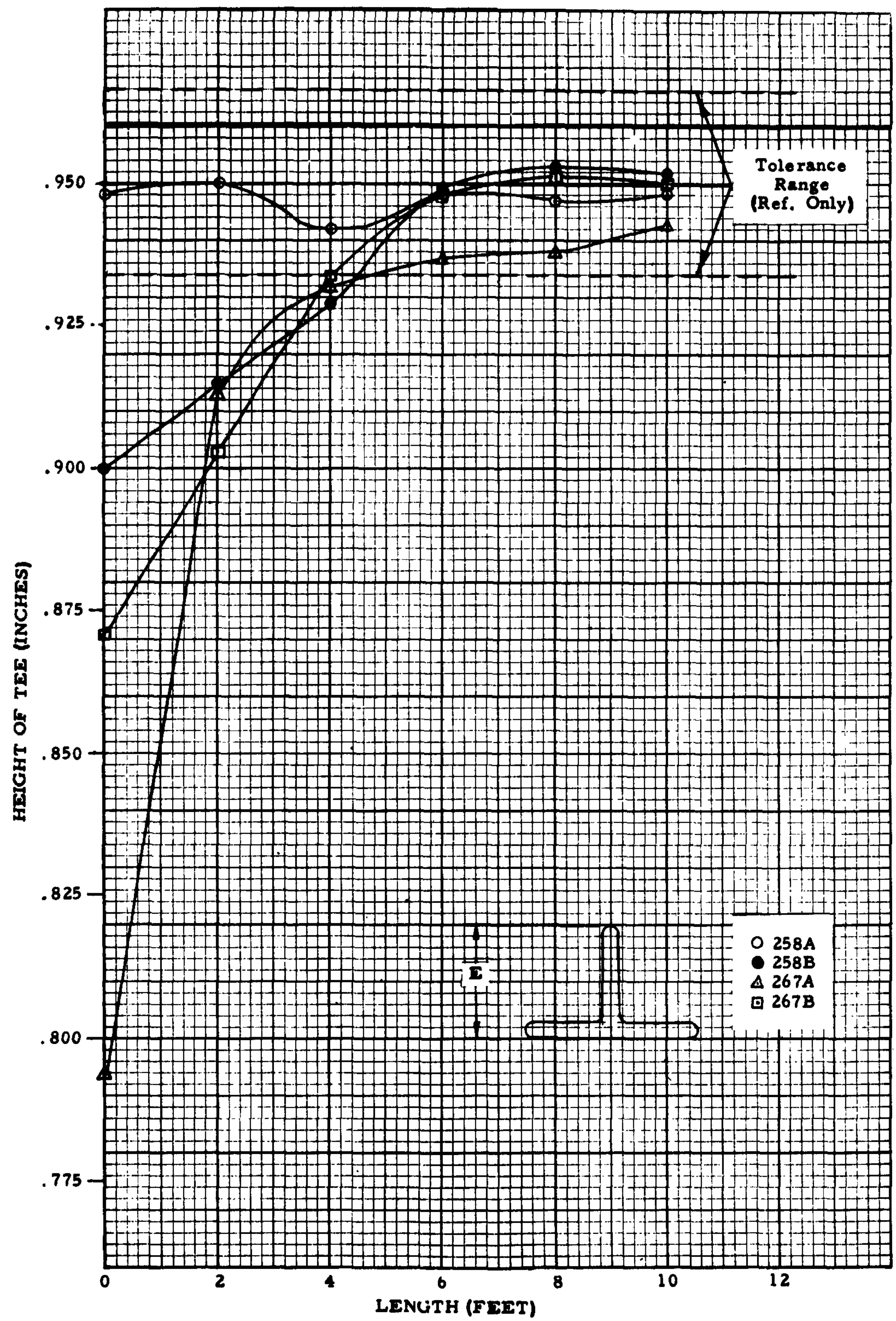


VARIATION OF TEE HEIGHT ALONG EXTRUSION LENGTH FOR SHAPE # 677
(.093" SECTIONS) IN THE AS-EXTRUDED CONDITION

FIGURE 20

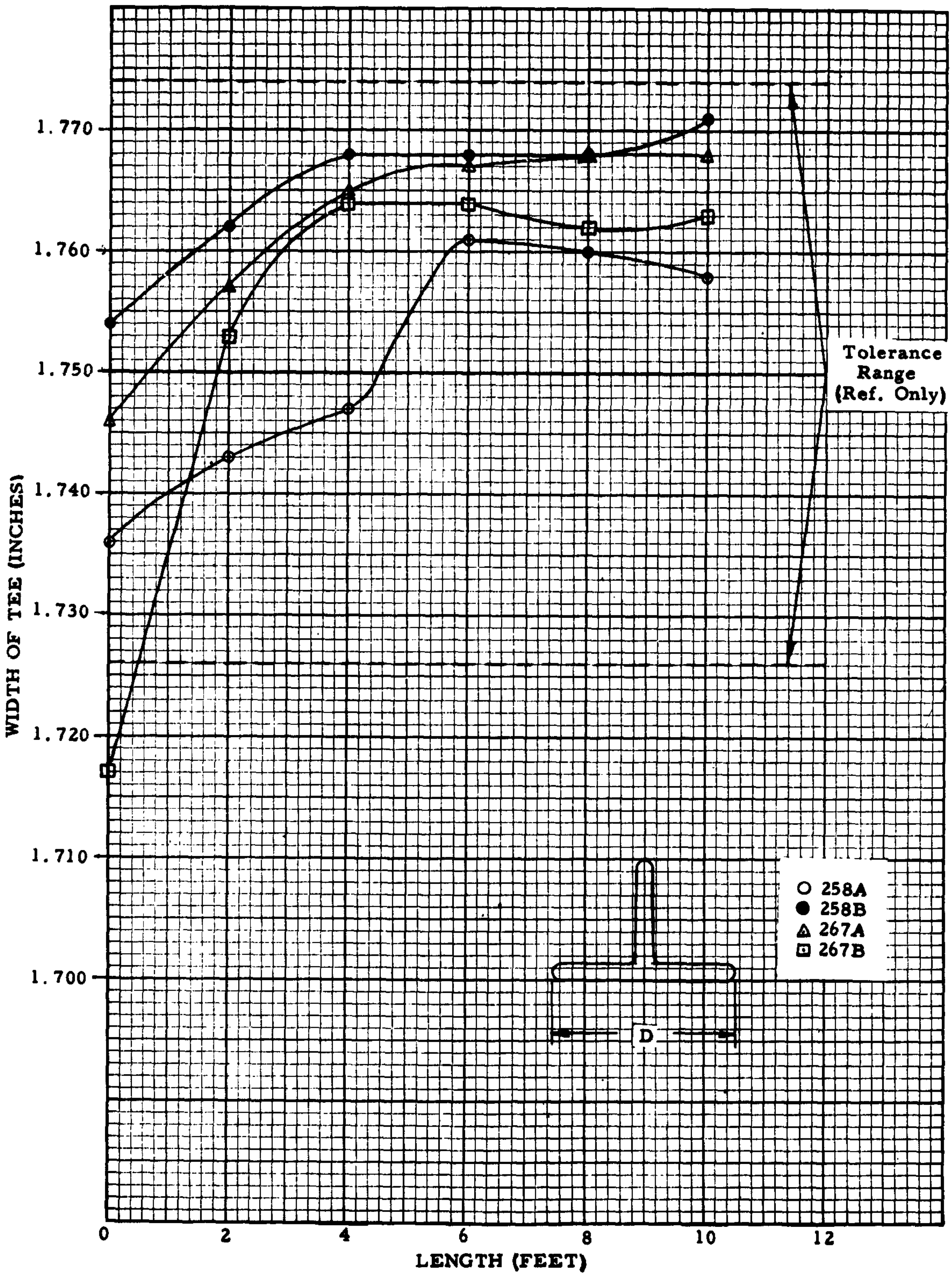
VARIATION OF TEE WIDTH ALONG EXTRUSION LENGTH FOR SHAPE #677 (.093" SECTIONS) IN THE AS-EXTRUDED CONDITION

FIGURE 21



VARIATION OF TEE HEIGHT ALONG EXTRUSION LENGTH FOR SHAPE # 678 (.093" MULTI-PORT SECTIONS) IN THE AS-EXTRUDED CONDITION

FIGURE 22



VARIATION OF TEE WIDTH ALONG EXTRUSION LENGTH FOR SHAPE # 678 (.093" MULTI-PORT SECTIONS) IN THE AS-EXTRUDED CONDITION

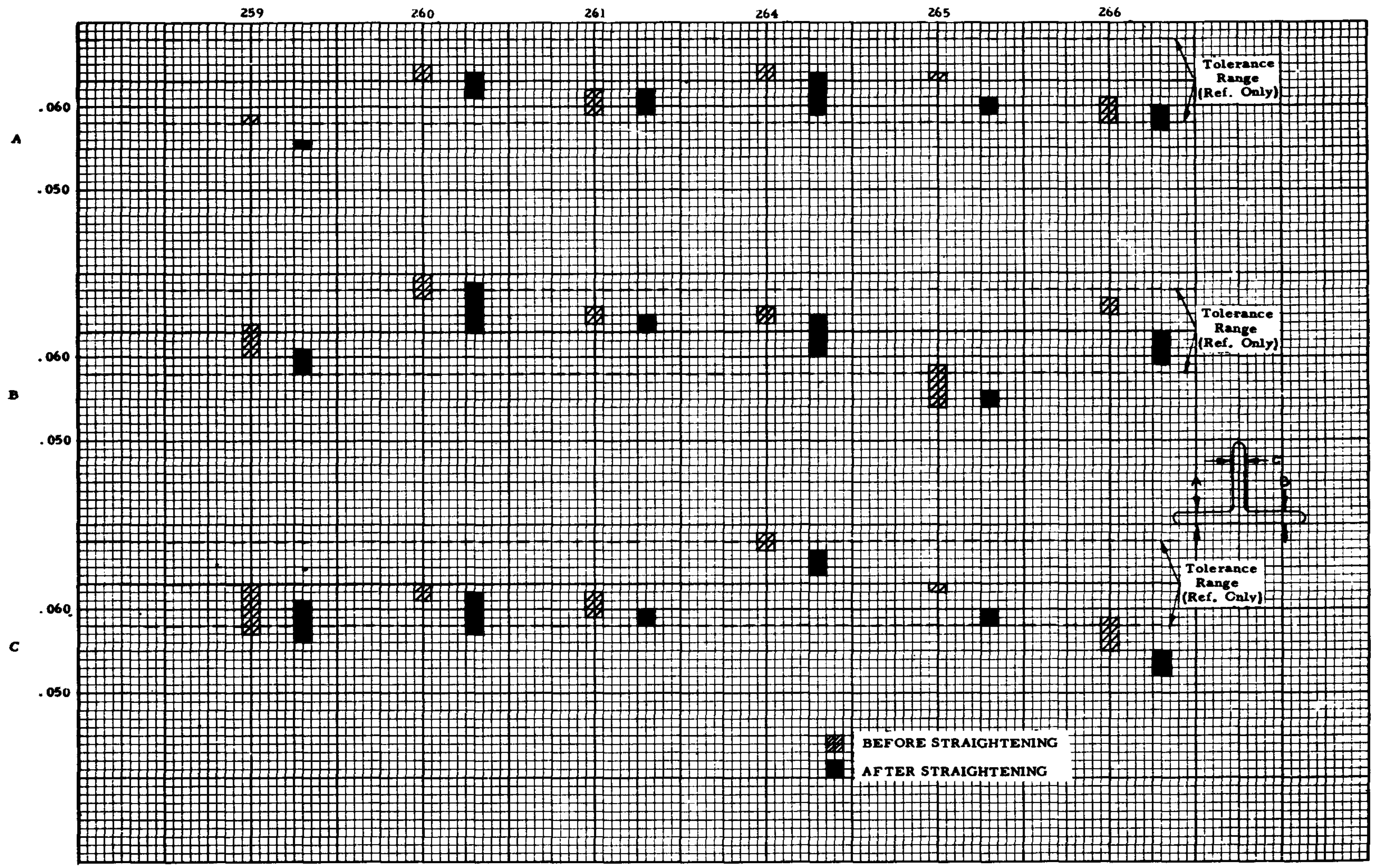
FIGURE 23

Surprizingly, shapes no. 677 (the .093" sections) show a wider variation along each individual length and from extrusion to extrusion (See Figures 20 and 21). However, much better fillout was obtained for these extrusions (good die fillout 2' from the front end). As can be seen in Figures 22 and 23, poor fillout was obtained for the first 4' of shapes 678 (extruded through the multi-port dies). This may be attributed to the front end configuration of the billet (convex faced billets were used for these pushes due to the inability to extrude the longer flat faced billets). Several multi-port extrusions will be made in the next trial with flat faced billets and it will be of interest to determine if better fillout is obtained.

Generally, a small radius on the face of the billet will provide good fillout in the early stage of the extrusion. As can be seen in the sketch of the billet configurations (Figure 7) a relatively small (3/8") radius was employed for all pushes, so that the poor fillout obtained in the trial is difficult to explain.

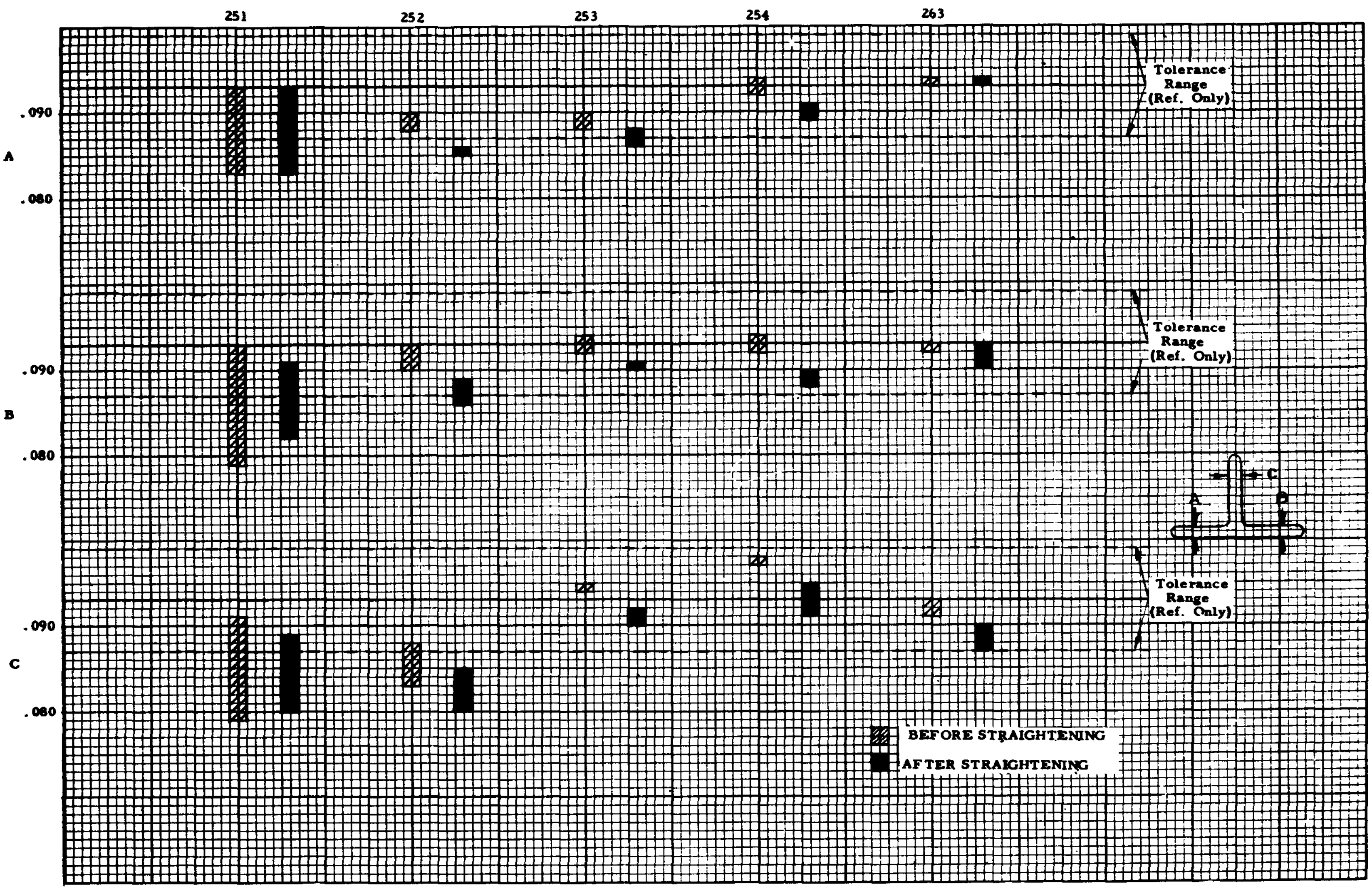
Figures 24, 25 and 26 show the range of variation along the length for shape nos. 676, 677 and 678 respectively. These graphs show the extremely small range of thickness variation for the ceramic coated dies. The exception is extrusion 251 which has a total thickness variation of .010", .014" and .012" for the left flange, right flange and stem respectively. The balance of the ceramic coated die extrusions are within .005" total variation with the majority within .001" to .002" total variation along the entire length. The multi-port die extrusions without ceramic coating are not as uniform as can be seen from a comparison of Figure 26 with Figures 24 and 25.

Included on the three graphs are the range of thickness variations of the extrusion after warm stretch straightening. This data will be discussed in the next section.



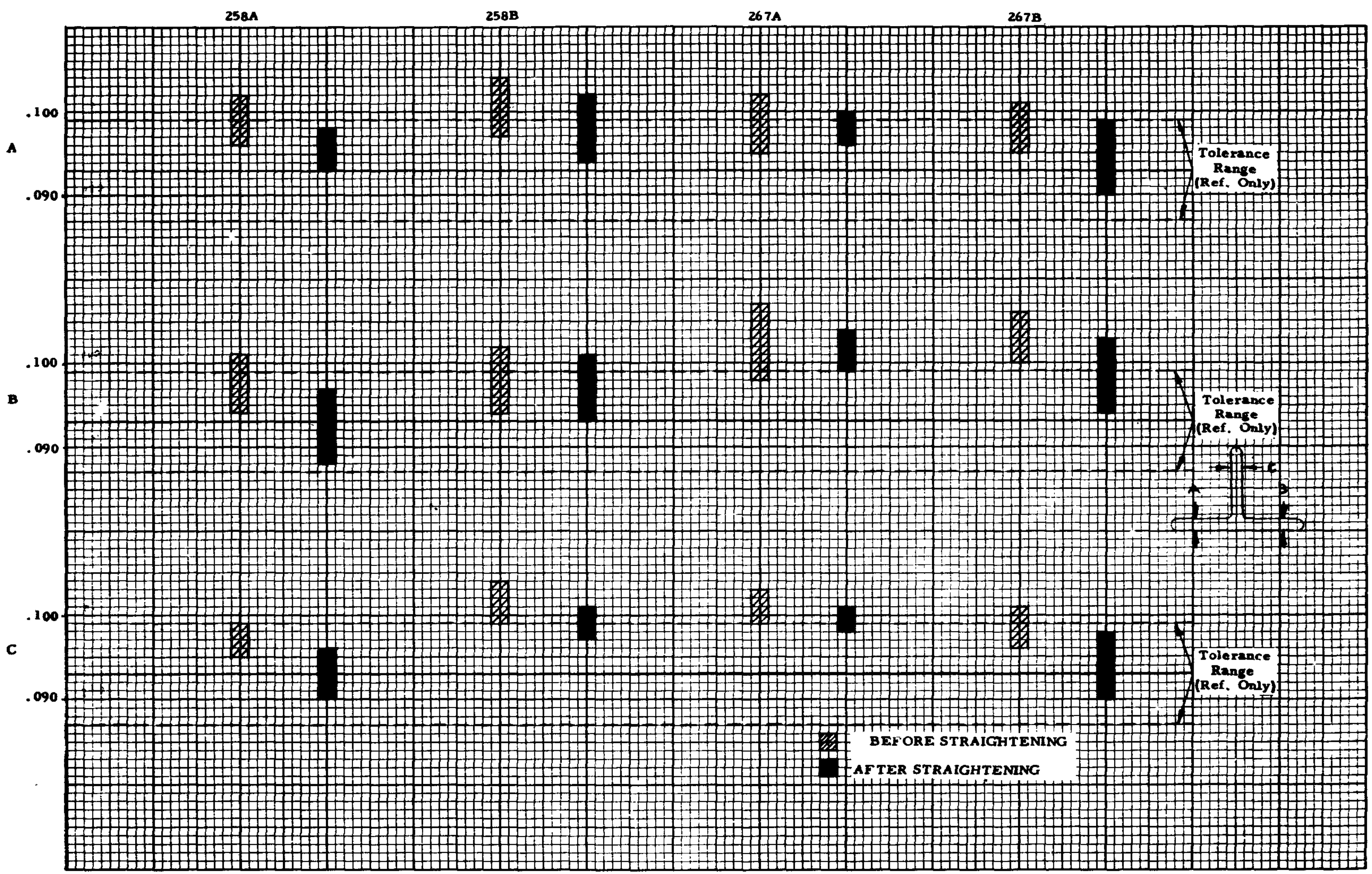
RANGE OF THICKNESS VARIATIONS FOR SHAPE # 676 (.063" SECTIONS)
BEFORE AND AFTER STRAIGHTENING

FIGURE 24



RANGE OF THICKNESS VARIATIONS FOR SHAPE # 677 (.093" SECTIONS)
BEFORE AND AFTER STRAIGHTENING

FIGURE 25



RANGE OF THICKNESS VARIATIONS FOR SHAPE # 678 (.093" MULTI-PORT SECTIONS BEFORE AND AFTER STRAIGHTENING

FIGURE 26

STRAIGHTENING TRIAL OF GROUP 1 SHAPES

OBJECTIVES

The general objectives of the trial were to detwist and straighten the .063" and .093" cross section tee shapes extruded during 2 May 1963 extrusion trial. The major objective was to obtain shapes suitable for warm drawing and subsequent B-70 application evaluation. However, sections that were not suitable for B-70 application evaluation (due to either short length and/or badly scored surface) were also straightened to accumulate data on the straightening process for thin titanium sections for aircraft use.

EQUIPMENT AND PROCEDURES

The straightening trials were conducted at Babcock and Wilcox Company on 15 May 1963. The extrusions were stretch straightened on a 25 ton capacity stretch press which is described and illustrated in Quarterly Report No. 20. The extrusions were resistance heated using two welding generators connected in parallel to supply a 40 volt, 700 ampere input to the insulated gripper jaws which serve as electrical contacts. The operation of the pneumatic operated jaws is described in Quarterly Report No. 15.

The procedure for straightening the as-extruded shapes was:

1. Insert one end of tee extrusion between jaws of stationary head.

2. Detwist manually sufficiently so that shape can be completely detwisted on press with one revolution of rotating head. This eliminates the necessity of detwisting one revolution from shape, removing shape from head and rotating head to original position, reinserting shape in head for additional detwisting, etc. Lock the detwisted end in the movable jaw. With this procedure, when, the heads are lined up, the piece detwists itself as it is stretched.

3. Resistance heat extrusion to 1000-1100°F, maintaining tension in the shape

4. Stretch to approximately 3% of the original extrusion length. An allowance of about 3" of springback for the 20' lengths is made in determining the amount the shape is stretched.

5. Cut the power and air cool the shapes under a constant diminishing tension until approximately 2" of contraction occurs; releasing the air pressure holding the jaw grips so that further contraction of the shape automatically disengages the extrusion from the jaw grips.

6. Remove camber and bow by gag straightening on a horizontal press (while the extrusion is still warm - over 300°F).

DESCRIPTION AND RESULTS OF STRAIGHTENING TRIAL

The Part V Group 1 extrusions were resistance heated and straightened as described in Steps 1 through 6 in the previous section. The data for the straightening trial is listed in Table V.

The sequence of the straightening runs was determined by the length of the shapes in order to minimize manual adjustment of the back head position along the bed of the press. The press has a 26' capacity and the movable head has a stroke of 18".

The shapes were cropped to remove ends with excessive twist which could not be gripped in the heads. The starting and finish lengths were tape measured and are listed in Table V.

Very little difficulty was experienced and the trial ran rather smoothly. This is attributed to the good uniformity of the cross section dimensions of the shapes (See Table III). The front end of the shapes (with poor fillout) were slightly undersize and the front portion of some of the shapes heated up faster than the balance of the shape. This factor limited the amount of stretch applied to some of the shapes.

During the trial only 3 sections broke, 2 of them at the front end. The other section (#253) broke in half at almost dead center. This section was one of the better extrusions obtained from the extrusion trial, relative to both surface defects and dimensional uniformity and the reason for the fracture cannot be explained; visual examination of the fracture did not reveal any apparent defects. An investigation of the reason for the failure is in process.

Figure 27 shows the product of the straightening trial. Each shape is identified by the extrusion number. The cross sectional dimensions were micrometer measured at 2' intervals along the length after straightening and are listed in Table VI. The measurements were taken at the same locations as the measurements before straightening (Table III.) The range of thickness variation is plotted in Figures 24, 25 and 26 both before and after straightening. The graphs show that the thickness dimensions are reduced rather uniformly and predictable in all cases. The graphs also show that a wider range of variation is obtained in the sections after straightening. The average amount of thickness reduction after the straightening operation is 0025".

Figures 28, 29, 30, 31, 32 and 33 are graphs showing the variation of the height and width dimensions along the length for the three groups of shapes that were straightened at the trial. Comparison of these graphs with the graphs of Figures 18 through 23 reveal that the height and width of the tees are reduced after the straightening. The reduction is quite uniform and consistent for both dimensions and for both the .093" and .063" cross sections. The average reduction is .017".

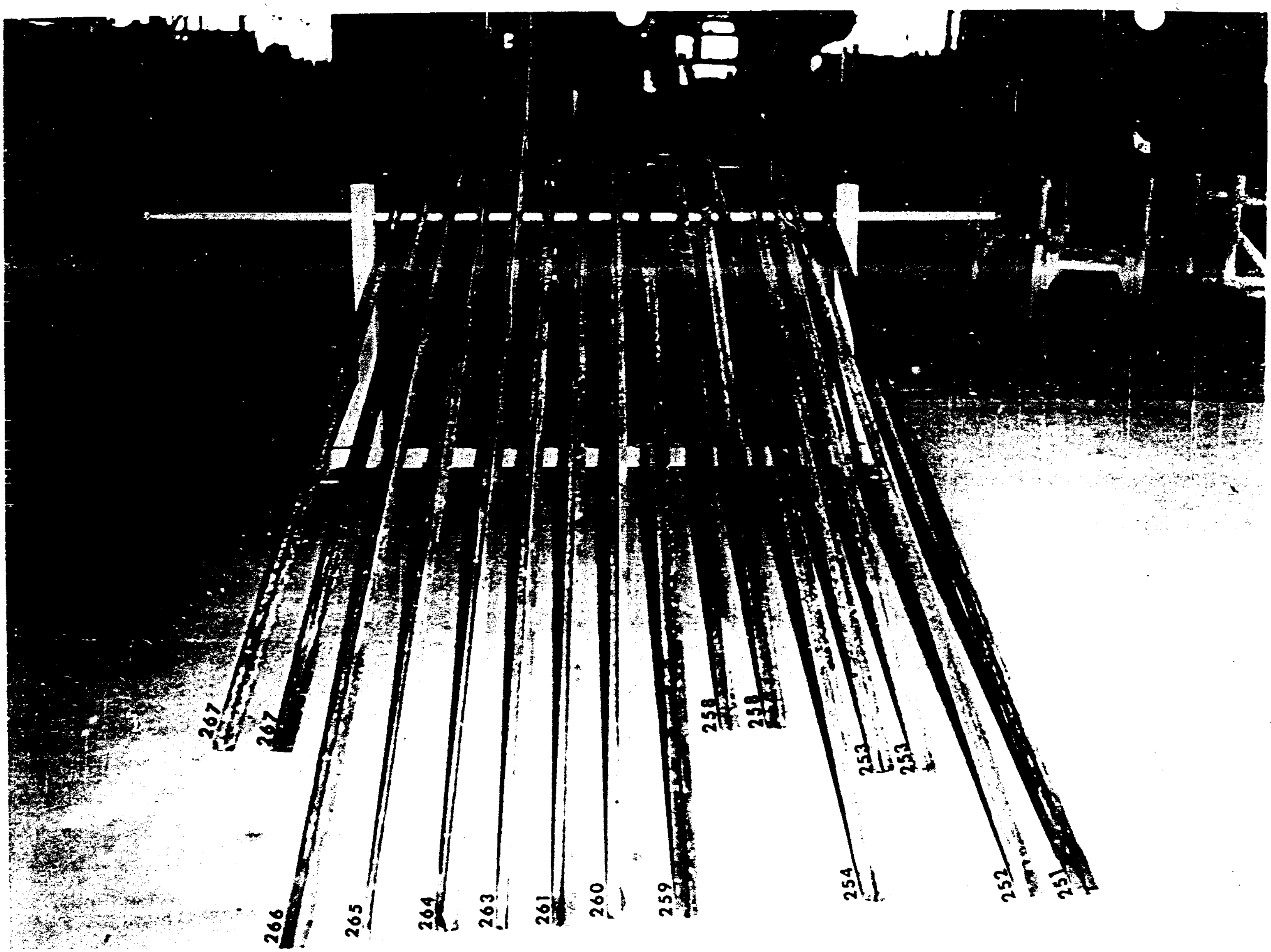
TABLE V

STRETCH STRAIGHTENING DATA FOR PART V GROUP 1 EXTRUSIONS
(Shapes are listed in the order in which they were straightened)

SHAPE NO.	STARTING LENGTH	OVERALL STRETCH	FINISHED LENGTH	REMARKS
266	22' 5"	4 1/2"	22' 8 7/8"	Most of ripple removed - still contained some ripple at back end - stopped when front end overheated.
265	22' 2"	11"	23' 0 3/8"	Large amount of bow and camber - Bow removed in gag straightening - camber could not be removed due to tendency of shape to buckle.
260	21' 7"	10"	22' 5"	Severe twist on front end caused difficulty in gripping shape.
261	21' 2"	9"	17' 4 5/8"	1' 2" of front end broke after 3" of stretch-tapered front end at fracture - back end still had slight twist. Since the front end is dimensionally undersize and back end has good surface as well as dimensions, attempt to remove twist at back end and sacrificing front end was made - at 2nd attempt 1' 1" broke fron front end after 3" stretch red heat on front end indicated approximately 2 1/2" was undersize - therefore cropped 2' 8 1/2" prior to 3rd attempt - stretched 3" on 3rd attempt - most of twist removed.
264	20' 10"	8 1/2"	21' 7 3/4"	Stopped when shape started to taper at front end - straightness looked good.
263	20' 5"	8"	21' 0 3/8"	Heated uniformly.
259	19' 5"	7 1/2"	19' 11 7/8"	Heated uniformly.
253	19' 5"	6 3/4"	9' 10 1/8"; 9' 11 5/8"	Shape broke in half at dead center after 6 3/4" stretch.
254	19' 3 1/2"	7 1/2"	19' 10 1/2"	Front end was much hotter than back end - stopped to avoid breakage.

TABLE V (Continued)

SHAPE NO.	STARTING LENGTH	OVERALL STRETCH	FINISHED LENGTH	REMARKS
252	19' 1"	7"	19' 8 3/8"	Shape heated uniformly.
251	16' 6"	6"	16' 11 1/2"	Back end became hotter than front end - stopped after 6" of stretch to avoid breaking.
258B	10' 1"	4"	10' 3 5/8"	Front end became very hot while back end was just starting to heat - cut power and hooked out one welder to throw less current into shape (relatively short length was getting too hot).
267A	9' 9 1/2"	3"	9' 6 1/4"	5 1/2" broke at front end.
267B	9' 6"	3"	9' 8 7/8"	Heated and straightened OK.
258A	9' 2 1/2"	4"	9' 5 5/8"	Heated and straightened OK.



PART V GROUP I EXTRUSIONS AFTER WARM (1000-1100°F) STRETCH STRAIGHTENING.
PUSH NUMBERS ARE MARKED ALONGSIDE EACH LENGTH

FIGURE 27

TABLE VI

Cross Section Dimensions (After Straightening)

Extrusion Number	Feet From Front End	Dimension Locations (Inches) (See Sketch) A	B	C	D	E
251	2	.093	.091	.089	1.752	.984
	4	.093	.091	.089	1.750	.980
	6	.093	.091	.089	1.749	.981
	8	.093	.091	.089	1.748	.983
	10	.092	.090	.089	1.746	.982
	12	.091	.090	.089	1.748	.975
	14	.088	.088	.086	1.750	.963
	16	.083	.082	.080	1.746	.946
252	0.75	.085	.089	.083	1.734	.966
	2	.086	.088	.084	1.735	.972
	4	.086	.088	.085	1.733	.973
	6	.085	.088	.084	1.730	.975
	8	.085	.088	.084	1.728	.970
	10	.086	.089	.083	1.735	.973
	12	.086	.088	.082	1.727	.968
	14	.085	.087	.082	1.726	.967
	16	.085	.086	.080	1.714	.965
	18	.086	.087	.080	1.728	.970
	19	.086	.088	.080	1.735	.966

TABLE VI (Continued)

Cross Section Dimensions (After Straightening)

Extrusion Number	Feet From Front End	Dimension Locations (Inches) (See Sketch) A	B	C	D	E
253 (Front Half)	1	.086	.091	.092	1.737	.970
	2	.086	.091	.091	1.734	.974
	4	.087	.091	.091	1.727	.971
	6	.087	.091	.091	1.734	.974
	8	.087	.090	.091	1.735	.973
	9.75	.087	.091	.091	1.730	.970
253 (Back Half)	11	.087	.090	.090	1.734	.969
	12	.087	.090	.091	1.730	.970
	14	.087	.090	.091	1.730	.968
	16	.087	.090	.091	1.735	.972
	18	.087	.090	.091	1.735	.973
	19.3	.088	.090	.091	1.745	.976
254	.8	.089	.088	.091	1.717	.935
	2	.090	.090	.093	1.730	.960
	4	.089	.089	.094	1.732	.965
	6	.089	.090	.094	1.740	.968
	8	.090	.090	.095	1.746	.972
	10	.089	.089	.093	1.740	.973
	12	.090	.089	.094	1.749	.975
	14	.089	.089	.094	1.740	.974
	16	.090	.090	.094	1.742	.976
	18	.090	.089	.095	1.750	.979
	19.3	.091	.089	.095	1.755	.976

TABLE VI (Continued)

Cross Section Dimensions (After Straightening)

Extrusion Number	Feet From Front End	Dimension Locations (Inches) (See Sketch) A	B	C	D	E
258- A	1	.093	.088	.090	1.692	.925
	2	.096	.094	.094	1.723	.936
	4	.096	.096	.094	1.719	.928
	6	.097	.097	.095	1.749	.944
	8	.097	.097	.096	1.750	.942
	9	.098	.097	.096	1.750	.940
258- B	1	.094	.093	.097	1.730	.895
	2	.097	.096	.098	1.746	.910
	4	.099	.096	.098	1.755	.923
	6	.100	.098	.099	1.752	.937
	8	.101	.099	.101	1.757	.946
	10	.102	.101	.101	1.762	.950
259	1	.056	.059	.059	1.675	1.515
	2	.056	.060	.060	1.702	1.531
	4	.055	.061	.060	1.724	1.564
	6	.056	.060	.061	1.728	1.574
	8	.056	.060	.060	1.729	1.576
	10	.056	.061	.060	1.724	1.572
	12	.056	.060	.060	1.722	1.569
	14	.055	.059	.059	1.715	1.560
	16	.055	.059	.056	1.709	1.554
	18	.056	.060	.057	1.718	1.566
	19	.056	.058	.057	1.717	1.563

TABLE VI (Continued)

Cross Section Dimensions (After Straightening)

Extrusion Number	Feet From Front End	Dimension Locations (Inches) (See Sketch) A	B	C	D	E
260	1	.068	.063	.057	1.640	1.430
	2	.061	.064	.058	1.682	1.455
	4	.063	.067	.060	1.724	1.510
	6	.064	.069	.061	1.737	1.540
	8	.064	.069	.061	1.737	1.552
	10	.064	.068	.061	1.736	1.556
	12	.064	.068	.061	1.737	1.562
	14	.064	.067	.061	1.742	1.570
	16	.064	.067	.061	1.740	1.564
	18	.064	.068	.062	1.744	1.566
	20	.064	.069	.061	1.746	1.567
	22	.063	.068	.062	1.755	1.573
261	7	.059	.063	.058	1.691	1.492
	8	.059	.064	.058	1.700	1.502
	10	.060	.065	.058	1.721	1.532
	12	.060	.064	.058	1.726	1.545
	14	.060	.065	.059	1.729	1.553
	16	.061	.065	.059	1.731	1.555
	18	.062	.064	.059	1.743	1.562
	20	.061	.064	.060	1.750	1.567
	22	.061	.065	.059	1.755	1.572

TABLE VI (Continued)

Cross Section Dimensions (After Straightening)

Extrusion Number	Feet From Front End	Dimension Locations (Inches) (See Sketch) A	B	C	D	E
263	1	.093	.090	.087	1.719	.962
	2	.093	.091	.088	1.725	.968
	4	.094	.091	.089	1.727	.973
	6	.093	.092	.090	1.726	.971
	8	.093	.092	.090	1.739	.974
	10	.094	.092	.089	1.735	.972
	12	.093	.092	.088	1.735	.974
	14	.094	.092	.088	1.737	.974
	16	.093	.093	.090	1.738	.974
	18	.093	.092	.090	1.738	.975
	20	.093	.092	.089	1.742	.976
264	1	.059	.060	.064	1.618	1.399
	2	.061	.063	.066	1.664	1.444
	4	.063	.064	.067	1.709	1.486
	6	.064	.064	.067	1.717	1.500
	8	.054	.064	.066	1.721	1.510
	10	.062	.065	.067	1.729	1.533
	12	.063	.064	.066	1.728	1.548
	14	.064	.065	.067	1.733	1.564
	16	.064	.065	.067	1.740	1.568
	18	.064	.064	.067	1.739	1.570
	20	.063	.065	.067	1.739	1.570

TABLE VI (Continued)

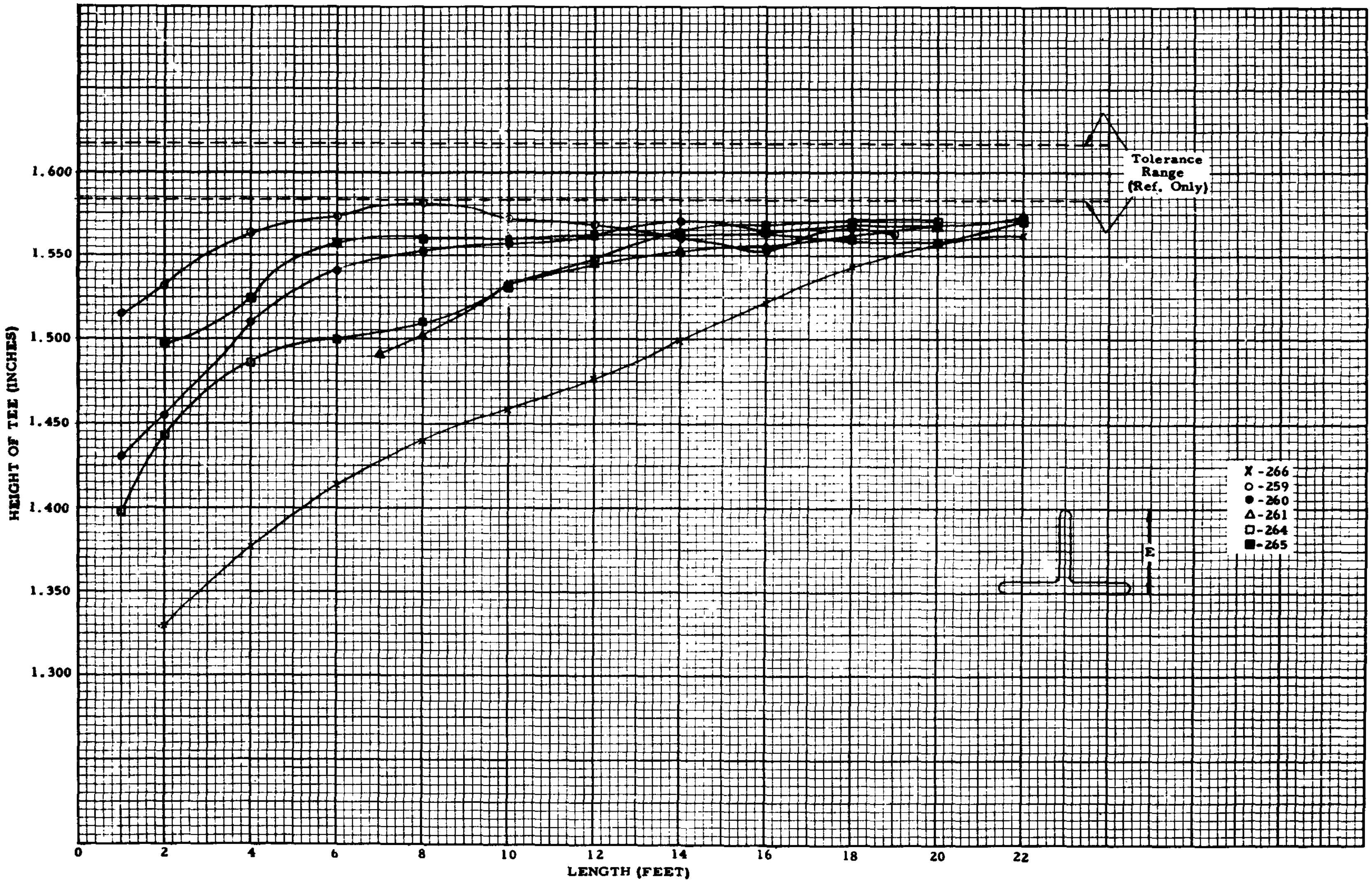
Cross Section Dimensions (After Straightening)

Extrusion Number	Feet From Front End	Dimension Locations (Inches) (See Sketch) A	B	C	D	E
265	2	.060	.054	.059	1.584	1.498
	4	.059	.055	.058	1.632	1.525
	6	.061	.055	.060	1.684	1.558
	8	.061	.055	.059	1.720	1.560
	10	.061	.055	.059	1.724	1.559
	12	.061	.056	.059	1.724	1.562
	14	.060	.056	.059	1.726	1.561
	16	.060	.056	.059	1.727	1.563
	18	.060	.056	.059	1.722	1.560
	20	.059	.056	.058	1.718	1.557
	22	.059	.055	.060	1.728	1.570
266	2	.060	.059	.053	1.660	1.330
	4	.058	.061	.052	1.693	1.377
	6	.057	.061	.054	1.706	1.414
	8	.057	.063	.054	1.721	1.440
	10	.057	.063	.054	1.723	1.458
	12	.057	.062	.055	1.724	1.476
	14	.059	.062	.054	1.727	1.499
	16	.059	.063	.054	1.730	1.522
	18	.058	.063	.054	1.735	1.543
	20	.057	.062	.054	1.732	1.557
	22	.057	.062	.054	1.731	1.561

TABLE VI (Continued)

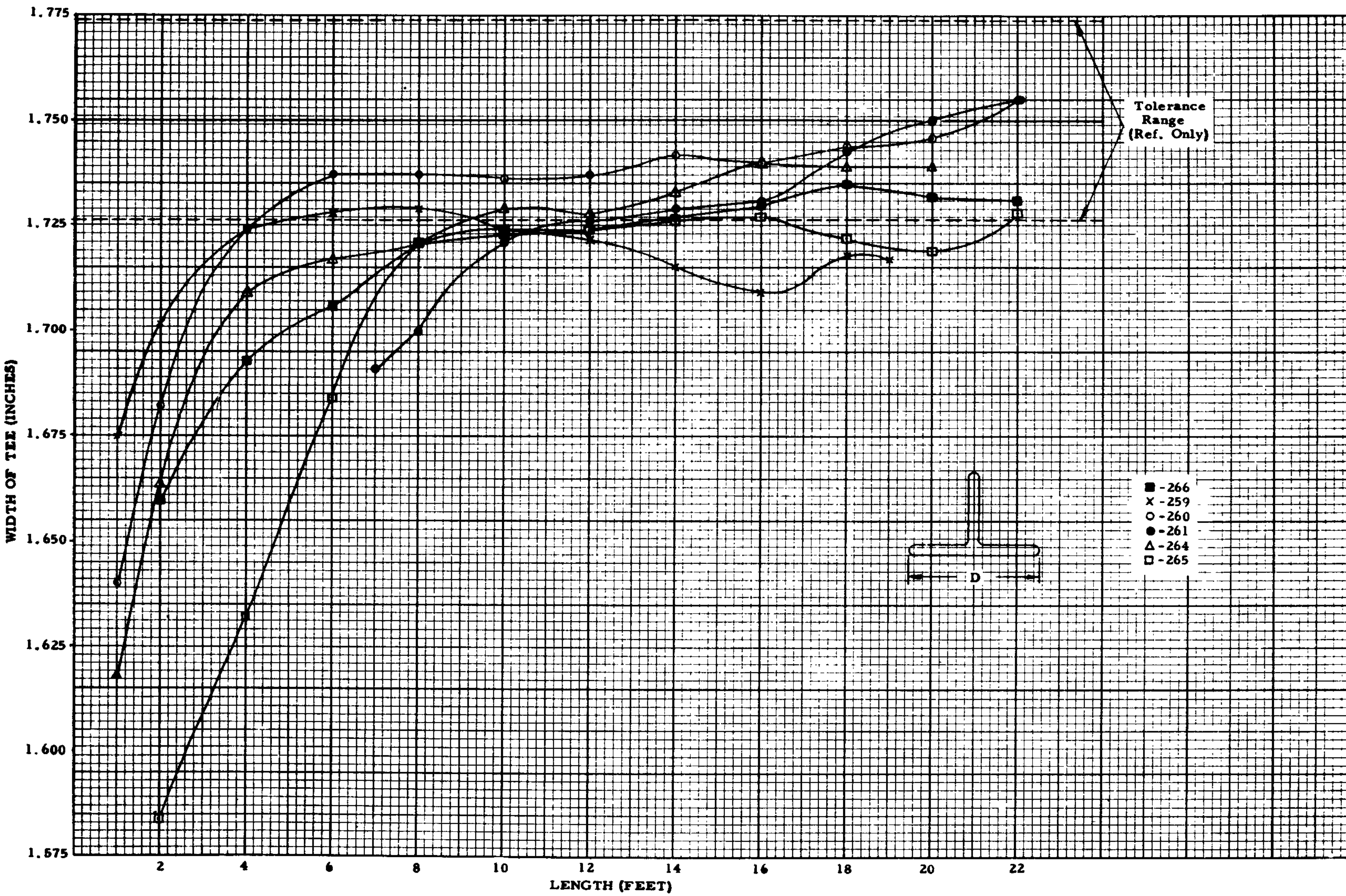
Cross Section Dimensions (After Straightening)

Extrusion Number	Feet From Front End	Dimension Locations (Inches) (See Sketch) A	B	C	D	E
267- A	1.5	.096	.099	.098	1.737	.900
	2	.097	.101	.099	1.740	.904
	4	.098	.103	.099	1.756	.920
	6	.099	.102	.101	1.758	.929
	8	.099	.103	.101	1.757	.932
	10	.100	.104	.101	1.765	.940
267- B	1	.090	.094	.090	1.686	.860
	2	.094	.099	.094	1.726	.914
	4	.098	.101	.097	1.750	.926
	6	.098	.102	.098	1.753	.941
	8	.099	.103	.098	1.754	.945
	9.5	.099	.103	.098	1.753	.946



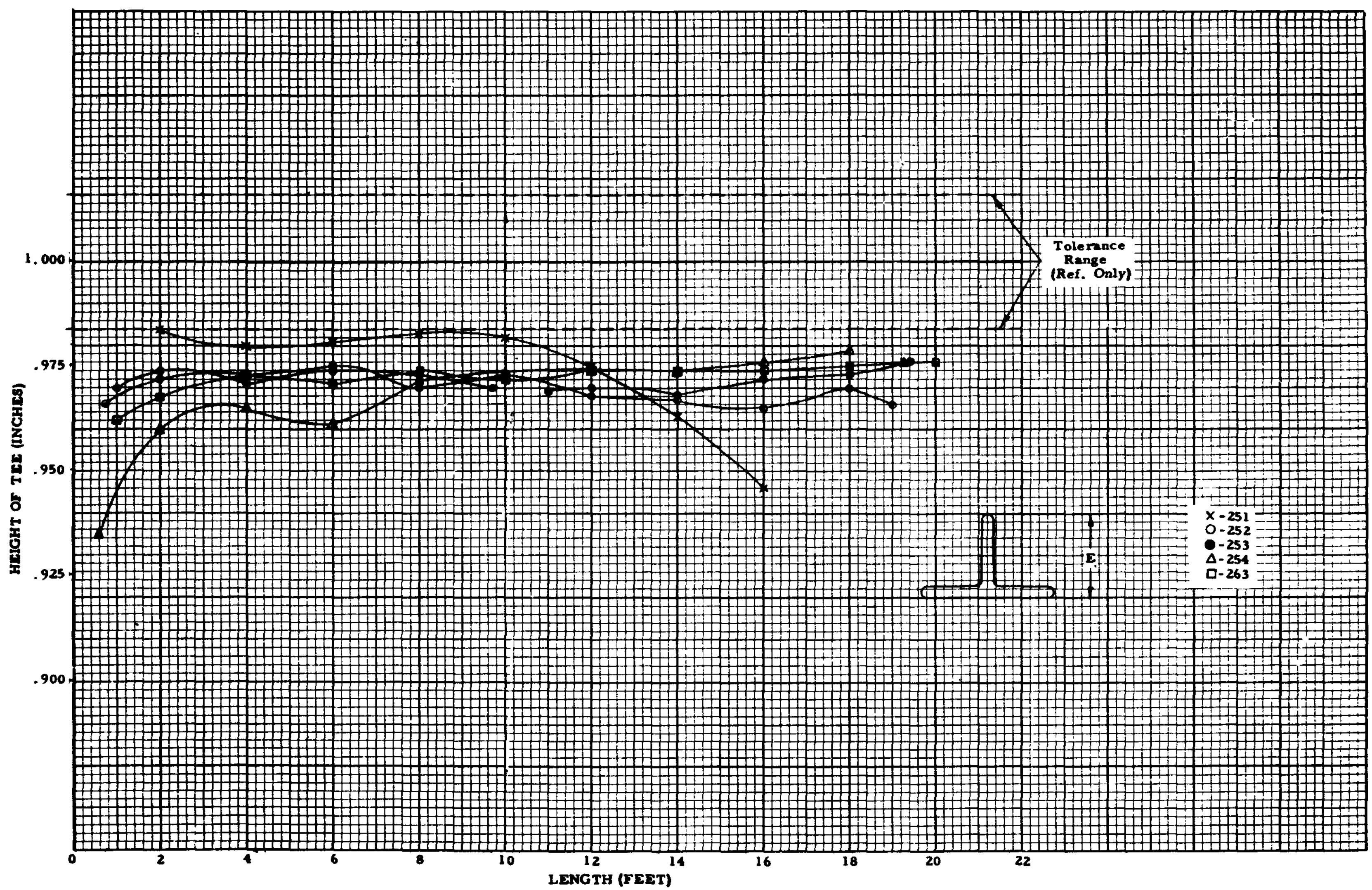
VARIATION OF TEE HEIGHT ALONG EXTRUSION LENGTH FOR SHAPE #676
(.063" SECTIONS) AFTER STRAIGHTENING

FIGURE 28



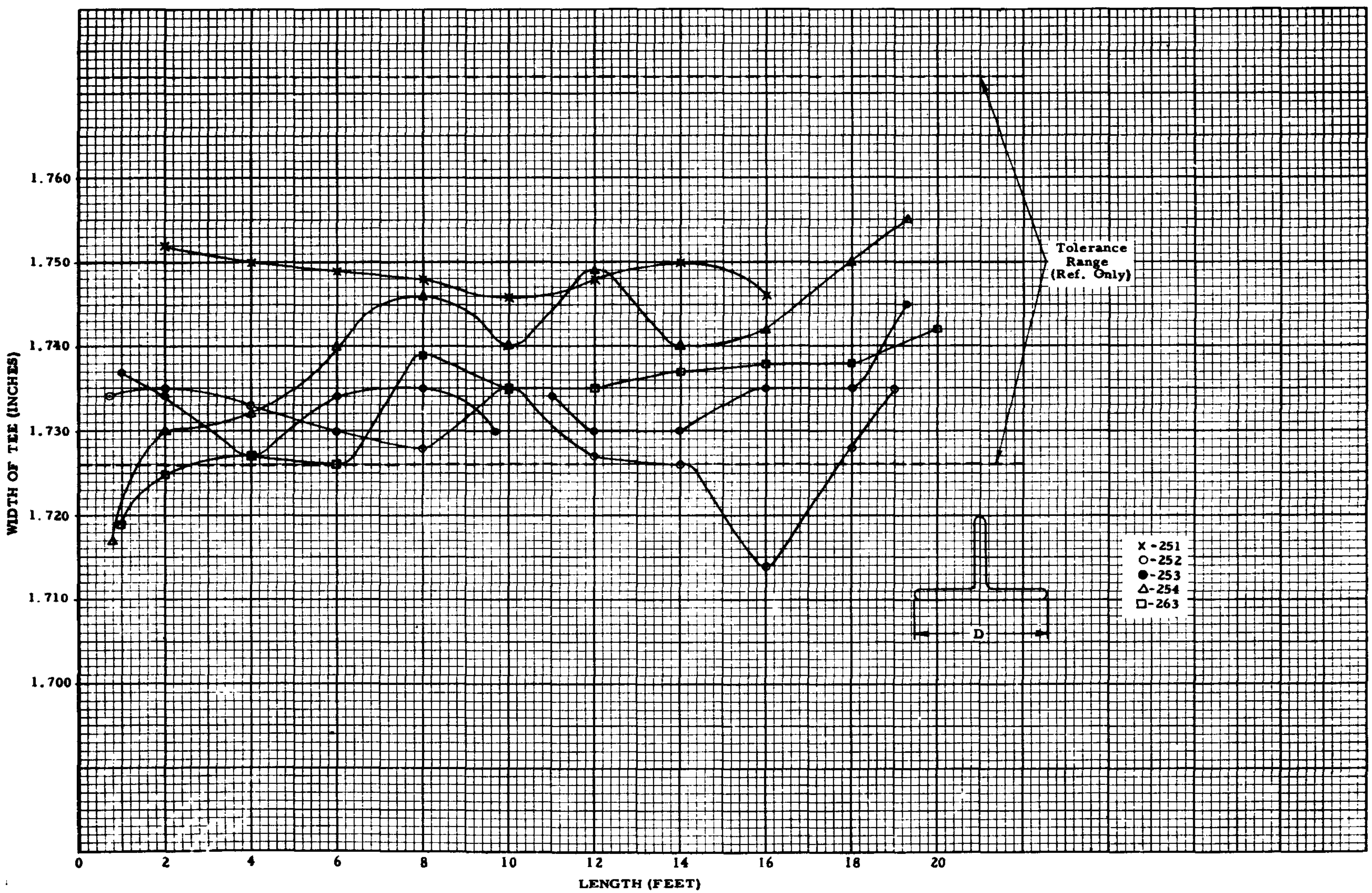
VARIATION OF TEE WIDTH ALONG EXTRUSION LENGTH FOR SHAPE # 676
(.063" SECTIONS) AFTER STRAIGHTENING

FIGURE 29



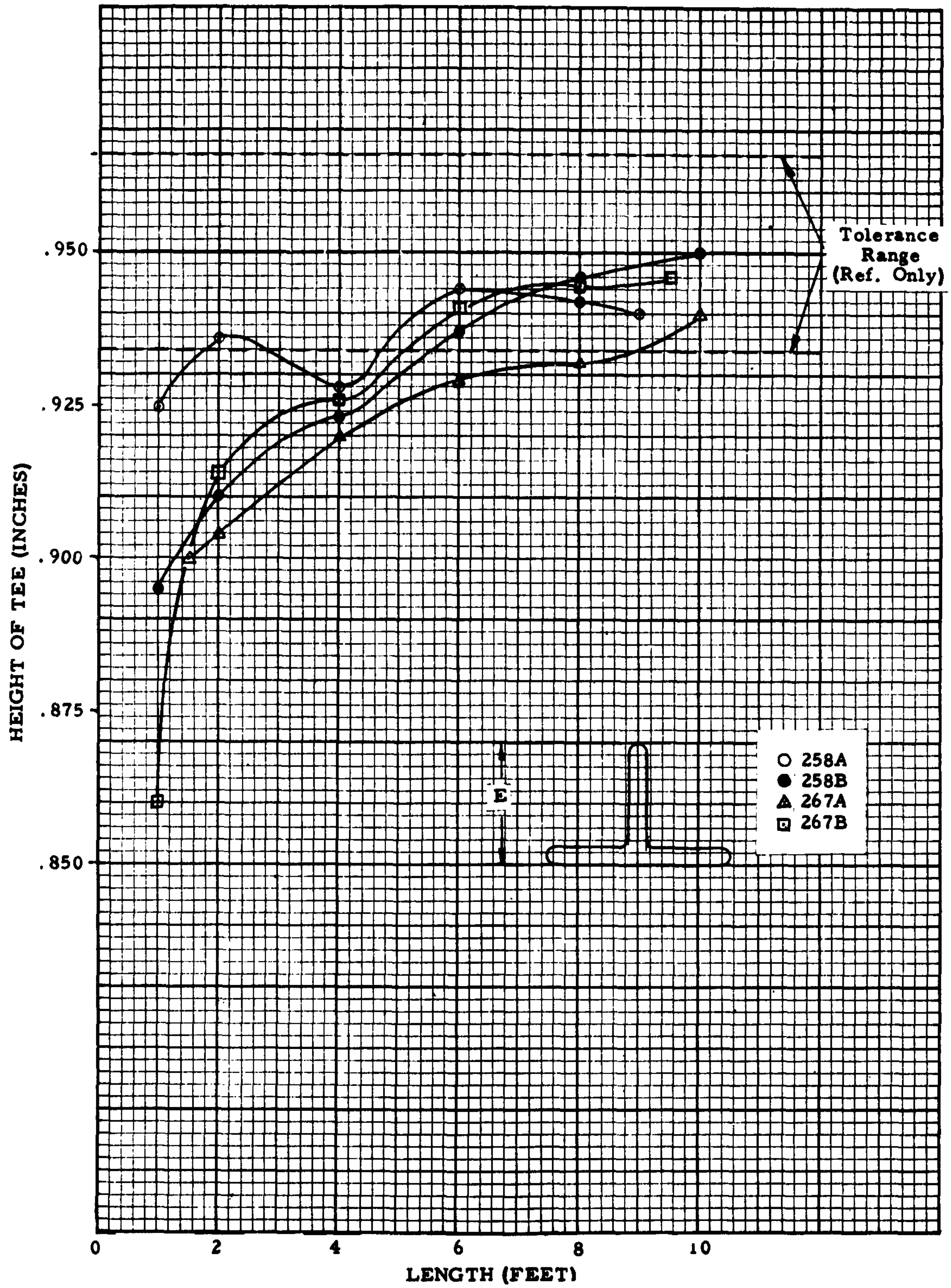
VARIATION OF TEE HEIGHT ALONG EXTRUSION LENGTH FOR SHAPE # 677
(.093" SECTIONS) AFTER STRAIGHTENING

FIGURE 30



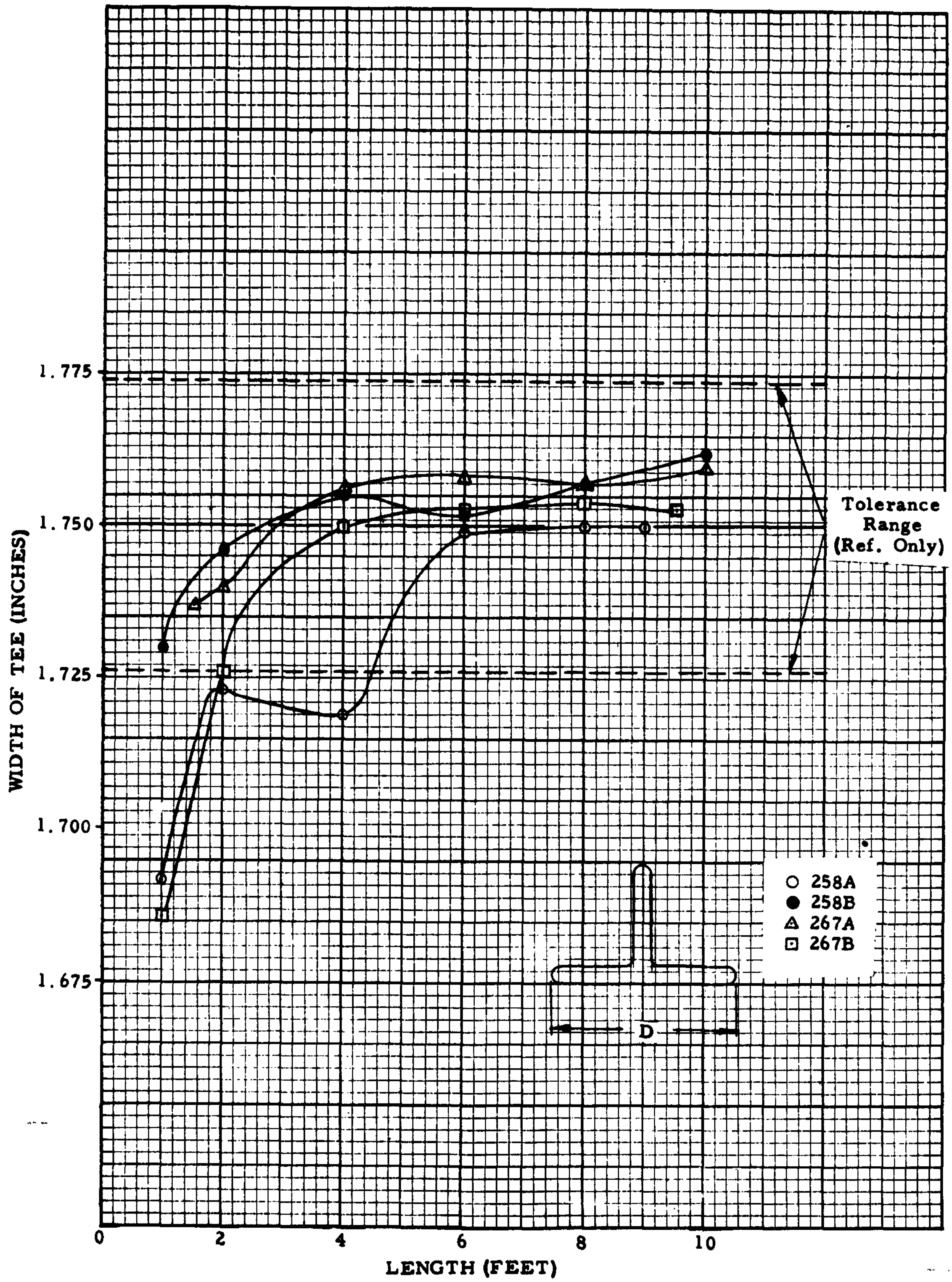
VARIATION OF TEE WIDTH ALONG EXTRUSION LENGTH FOR SHAPE # 677
(.093" SECTIONS) AFTER STRAIGHTENING

FIGURE 31



VARIATION OF TEE HEIGHT ALONG EXTRUSION LENGTH FOR SHAPE # 678
(.093" MULTI-PORT SECTIONS) AFTER STRAIGHTENING

FIGURE 32



VARIATION OF TEE WIDTH ALONG EXTRUSION LENGTH FOR SHAPE # 678
(.093" MULTI-PORT SECTIONS AFTER STRAIGHTENING

FIGURE 33

METALLURGICAL EVALUATION OF GROUP 1 SHAPES

To determine the relative merits of the lubricants and extrusion parameters employed during this phase, representative specimens were sectioned from several extrusions for metallographic and mechanical property determinations. Extrusions number 259, 251 and 261 were tested and the results are tabulated in Table VII . These data indicate no differences in properties attributed to the type of lubricant employed. As can be seen from Figure 34 the difference in properties noted are a function of the degree of stretch imposed upon the extrusion during the straightening operation. It should be noted that although the ultimate strength remains constant, the yield strength varies directly and elongation inversly as the percent stretch. From the above it appears that some strain aging of the alloy has occurred.

Table VIII shows the results of hardness traverses taken at various locations to determine whether any contamination was produced during extrusion. These data indicate no contamination in either of the specimens evaluated, and no differences between the glasses employed. This confirmed the conclusions drawn from metallographic examination. Figures 35 and 36 illustrate photomicrographs of specimens sectioned from extrusions number 259 and 261. No differences in microstructure between these two extrusions are evident. Although the billets were heated to 1800°F (below the beta transus for this alloy) from the microstructure it appears that internal friction heating raised the temperature beyond the beta transus (approximately 1825°F). The often seen "basketweave" alpha-beta structure is a result of heating in the beta field at some stage of fabrication or heat treatment. The structure consists of alpha phase as thin platelets within the beta grains and in the prior beta grain boundaries. Although the cooling rates in the flange and stem areas appear uniform some minor evidence of slower cooling rate was shown (Figure 36C) in the thickest areas at the radii where there appears to be a heavier transformed (to alpha) structure. Examination of the as-extruded material showed a somewhat smaller grain size and greater evidence of beta phase. This beta phase subsequently transformed to alpha plus beta upon reheating to 1000-1100°F during straightening. The additional strength accrued during the short 1000-1100°F treatment as discussed above is a result of the strain induced during straightening.

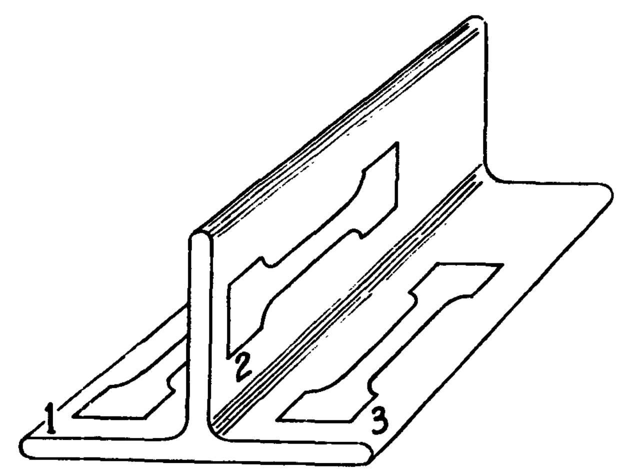
TABLE VII

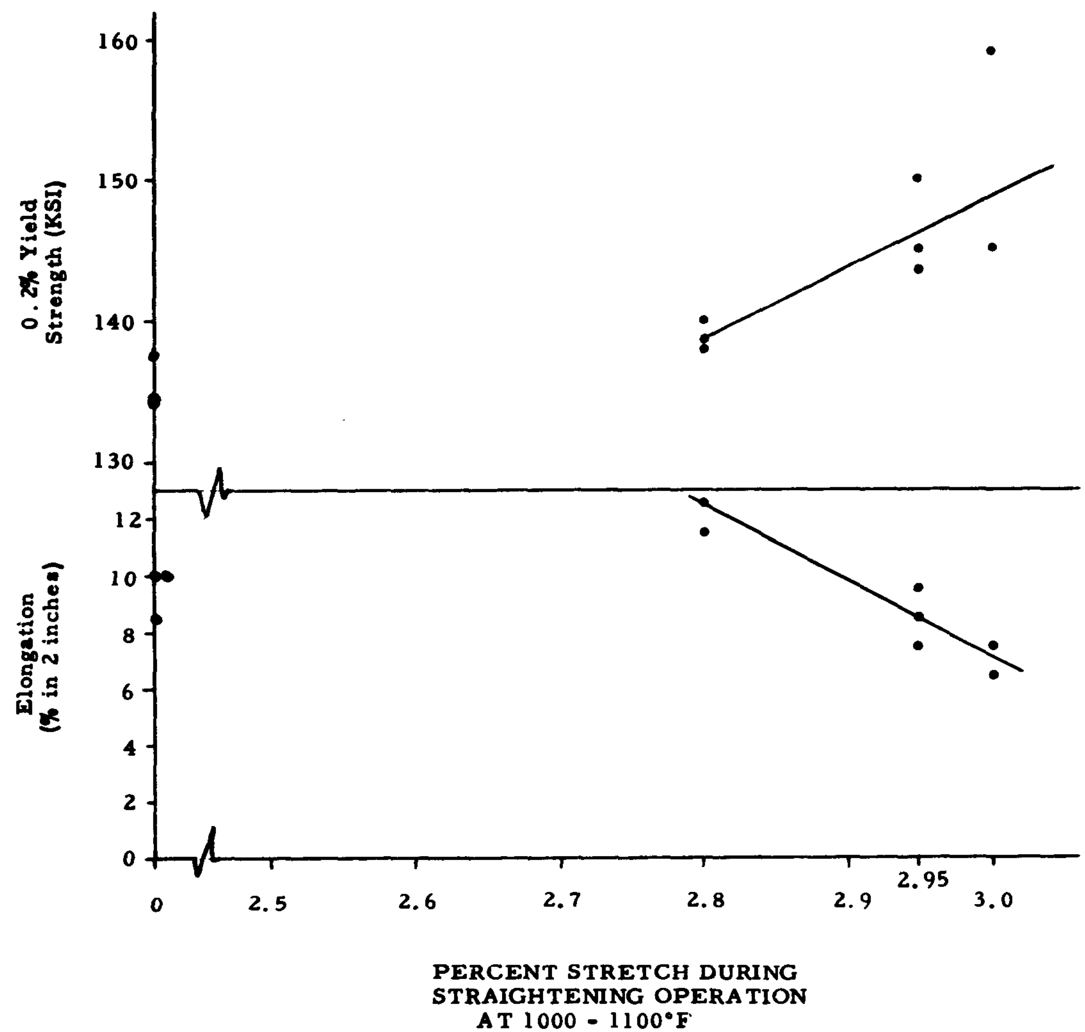
MECHANICAL PROPERTIES * OF SPECIMENS SECTIONED FROM EXTRUSIONS #251, #259 AND #261 6Al-4V TITANIUM ALLOY

SPECIMEN	LOCATION**	CONDITION	LUBRICANT BILLET	LUBRICANT DIE	ULTIMATE TENSILE STRENGTH	0.2% YIELD STRENGTH	ELONGATION (IN 2 INCHES)	MODULUS OF ELASTICITY
259F-1	1 Front	As Extruded (1800°F)	E-71B	E-71	156.9 ksi	134.1 ksi	10.0%	16.7 x 10^6 psi
-2	2 Front	As Extruded (1800°F)	E-71B	E-71	160.5	137.7	8.5	16.8
-3	3 Front	As Extruded (1800°F)	E-71B	E-71	156.4	133.8	10.0	16.7
259FS-1	1 Front	Extruded +	E-71B	E-71	156.4	144.2	9.5	17.0
-2	2 Front	Stretch Straightened	E-71B	E-71	157.8	148.8	8.5	17.1
-3	3 Front	2.95% (1000-1100°F)	E-71B	E-71	156	145.0	7.5	16.7
251-FS-1	1 Front	Extruded +	318	3KB	152.4	138.0	12.5	16.3
-2	2 Front	Stretch Straightened	318	3KB	153.2	140.0	11.5	16.5
-3	3 Front	2.8% (1000-1100°F)	318	3KB	152.3	138.5	12.5	16.7
261-BS-1	1 Back	Extruded +	318	3KB	156.0	144.9	6.5	16.9
-2	2 Back	Stretch Straightened 3% (1000-1100°F)	318	3KB	164.0	158.6	7.5	17.1

* All specimens tested with surfaces ground flat to remove all ridges produced during extrusion.

** Location of specimens is shown below.





THE EFFECT OF STRETCH STRAIGHTENING ON THE MECHANICAL PROPERTIES OF TITANIUM 6Al-4V EXTRUSIONS

FIGURE 34

TABLE VIII

HARDNESS TRAVERSES CONDUCTED ON EXTRUSIONS #259 (E-71B LUBRICANT ON BILLET, E-71 LUBRICANT AT DIE) AND #261 (318 LUBRICANT ON BILLET AND 3KB LUBRICANT AT DIE).

EXTRUSION	TRAVERSE *	DISTANCE FROM EDGE	KNOOP HARDNESS NUMBER (50 gm)	Rc
#259	1	.0004 inches	403	40
		.0012	403	40
		.0024	367	36.5
		.0036	385	38.5
		.0048	385	38.5
		.0060	403	40.0
		.0072	403	40.0
		.0084	367	36.5
		.030	367	36.5
	2	.0004	367	36.5
		.0008	367	36.5
		.0012	403	40.0
		.0016	367	36.5
		.0020	385	37.5
		.0024	385	38.5
		.0028	367	36.5
		.0032	367	36.5
		.030	367	36.5
		.035	367	36.5

* PATH OF TRAVERSE INDICATED ON SKETCH BELOW

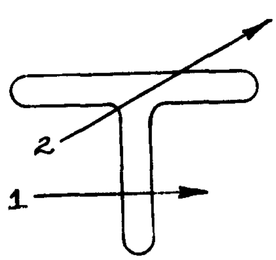


TABLE VIII (Cont'd)

EXTRUSION	TRAVERSE #	DISTANCE FROM EDGE	KNOOP HARDNESS NUMBER (50 gm)	Rc
#261	1	.0004 inches	385	38.5
		.0008	385	38.5
		.0012	368	36.5
		.0016	368	36.5
		.0020	368	36.5
		.0024	368	36.5
		.0028	368	36.5
		.0032	368	36.5
		.0036	336	33.0
		.0040	368	36.5
		.0056	351	35.0
		.0072	-	-
		.0088	368	36.5
		.0094	385	38.5
		.0120	385	38.5
		.0160	351	35.0
		.0200	351	35.0
		.0240	368	36.5
	2	.0004	368	36.5
		.0008	368	36.5
		.0012	368	36.5
		.0016	351	35.0
		.0020	385	38.5
		.0028	351	35.0
		.0036	368	36.5
		.0044	368	36.5
		.0052	385	38.5
		.0060	368	36.5

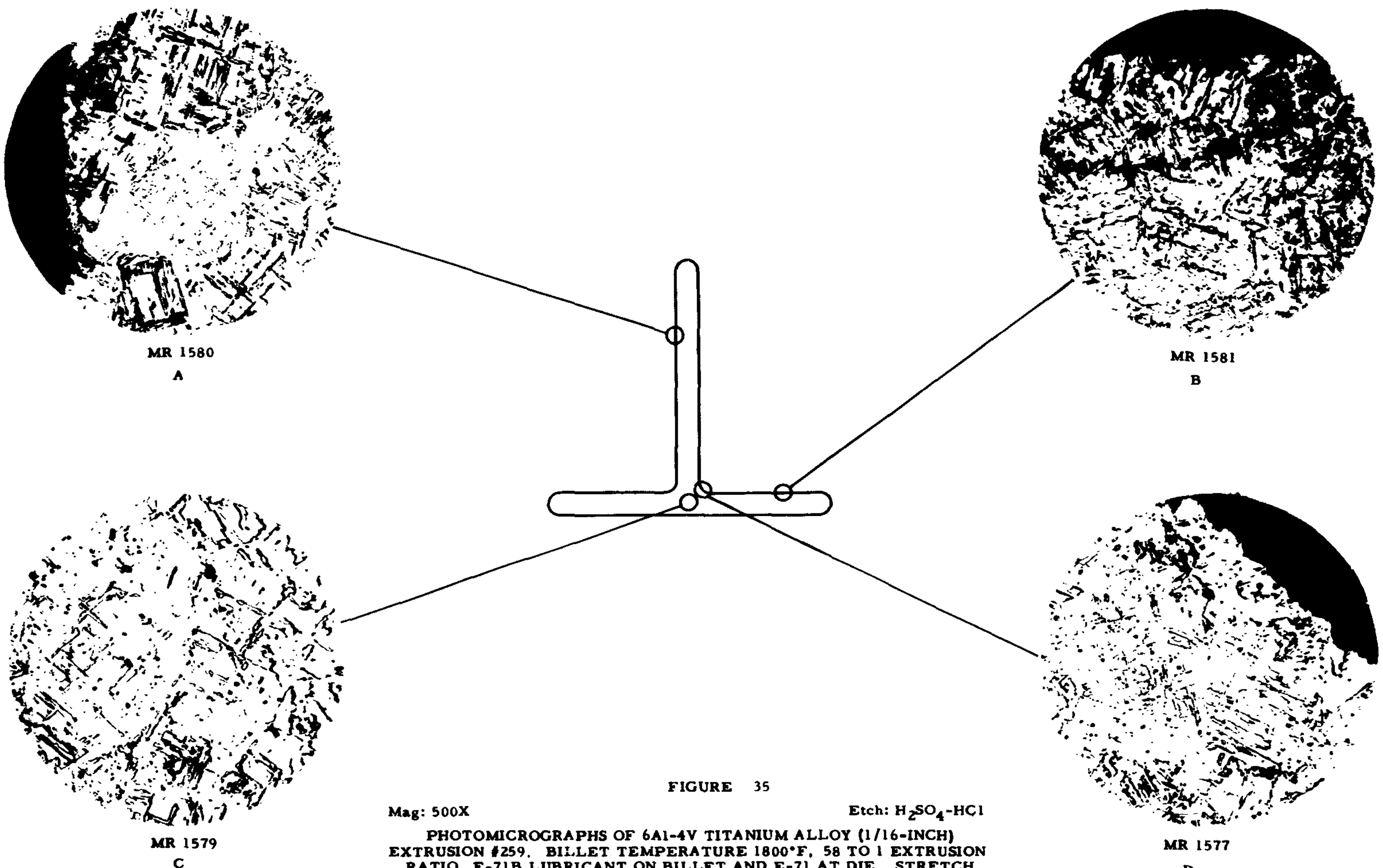


FIGURE 35

Mag: 500X Etch: H_2SO_4-HCl

PHOTOMICROGRAPHS OF 6Al-4V TITANIUM ALLOY (1/16-INCH) EXTRUSION #259. BILLET TEMPERATURE 1800°F, 58 TO 1 EXTRUSION RATIO, E-71B LUBRICANT ON BILLET AND E-71 AT DIE. STRETCH STRAIGHTENED 2.95% AT 1000-1100°F.

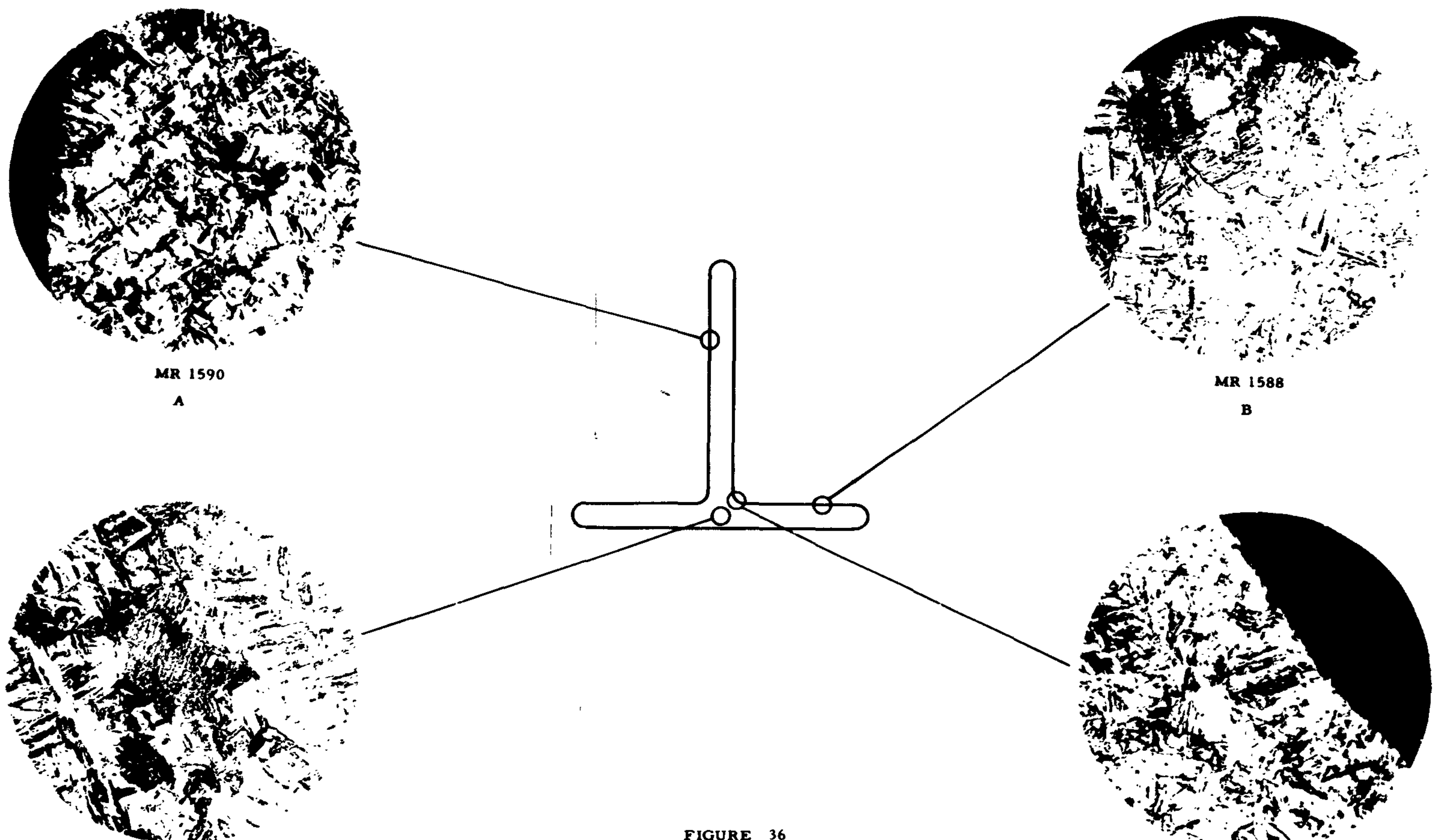


FIGURE 36

Mag: 500X Etch: H_2SO_4-HCl

PHOTOMICROGRAPHS OF 6Al-4V TITANIUM ALLOY (1/16-INCH) EXTRUSION #261. BILLET TEMPERATURE 1800°F, 58 TO 1 EXTRUSION RATIO, 318 LUBRICANT ON BILLET AND 3KB AT DIE. STRETCH STRAIGHTENED 3% AT 1000-1100°F.

CONCLUSIONS AND RECOMMENDATIONS

1. Good dimensional uniformity of cross section thickness dimensions can be obtained for 20' extrusions of .093" and .063" cross section in 6Al-4V titanium alloy.

2. The first several feet of the extrusions are not useable due to undersize width and height dimensions from poor die fillout. Therefore, several feet must be added to the target length to allow for this condition.

3. Good dimensional uniformity of the height and width of the tee can be obtained after the first several feet.

4. Good surface finish free from defects was not consistently obtained on the relatively thin tee shapes. Further effort is required.

5. Warm drawing is required to improve the micro inch surface finish of the shapes.

6. Extreme care is required in the exercise of the basic extrusion techniques to obtain a good product.

7. Multi-hole extrusion of tee shapes of .093" section in 6Al-4V titanium is a present capability. The maximum length that can be extruded is undetermined.

8. The E71B-E71 lubricating glass combination performed poorly with the extrusion conditions in the Part V Group 1 trial. This glass combination will not be considered for further trials with the 6Al-4V titanium alloy.

9. Neither the E71B-E71 or 318-3KB glass combinations contaminated the titanium extrusions.

10. The alumina coated dies performed very well with 9 out of 12 dies being reused for the next trial.

11. The press tooling is operating at the limits of its capacity as evidenced by the bent stem.

12. An allowance must be made in extrusion die design for reduction of the cross sectional dimensions of shapes by stretch straightening.

    For the tee sections of Part V, the allowance should be .017" for the height and width dimensions and .0025" for the thickness dimensions.

13. Minimum loss of length is obtained during stretcher straightening if the extrusion dimensional variation along the length is within tolerance. However, an allowance of at least 1' must be made for cropping the ends which are marred by gripping in the stretcher press heads.

PROGRAM FOR THE NEXT QUARTER

1. Procure 6Al-4V titanium billet material for 30 additional pushes.
2. Conduct Groups 2 and 3 extrusion trials.
3. Conduct straightening trials for Groups 2 and 3 extrusions.
4. Complete warm drawing of Part IV shapes.
5. Warm draw Part V shapes.

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