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TITANIUM MANUFACTURING METHODS DEVELOPMENT

PART I

ECONOMIC STUDY & EVALUATION OF PARTS

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FOREWORD

Part I of this report presents a detail economic analysis of the newly developed process and the results of an evaluation of the parts by engine testing. In the economic analysis each of the detail operation, i.e. extrusion, forming, welding, etc., were treated independently. This provided a means of comparing this process to conventional manufacturing methods such as forging. In a similar manner the results of the engine testing were compared to results obtained from conventionally manufactured parts which were previously tested.

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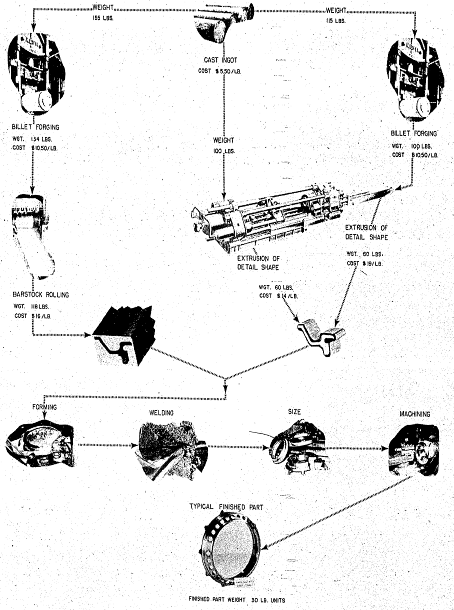
SCHEMATIC COMPARISON OF MANUFACTURING METHODS FOR TITANIUM RING SECTIONS DEPICTING THE ADVANTAGES OF EXTRUDING DIRECTLY FROM CAST INGOTS



		EXTRUSION	
	CONVENTIONAL FORGING	FORGED BILLET	CAST BILLET
PART COST $/LB. (FINISHED WEIGHT)	35	25	20
PART COST $ (30 LB. UNIT FINISHED WGT.)	1050	750	600
MATERIAL UTILIZATION %	19	26	30
PROCUREMENT CYCLE (MO.)	6	5	4

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I. INTRODUCTION

Conventional manufacturing techniques applied to titanium and titanium alloy jet engine components result in high costs primarily due to low material utilization and subsequent loss of the expensive material through machining. For titanium jet engine components applicable to the extrusion process, i.e. flange and tubular sections, a new production method capable of high material utilization has been developed. This was accomplished primarily through the use of the extrusion process. In addition, the use of cast ingots as the extrusion stock has reduced the end product cost appreciably. The flow chart presented on the previous page schematically illustrates the high material utilization and low costs available from cast ingot extrusions by comparing this method to forging and conventional extrusion of forged billets.

Consequently, compared to conventional forging, or flash-butt welding rings from barstock, this new process is capable of reducing the costs of such components by as much as 40 percent. In addition to reduced costs, through metallurgical evaluation and engine testing, these components have been demonstrated to be of equivalent quality to conventionally manufactured parts.

The results of the engine testing evaluation and a detail analysis of the economics of the process are presented in this report. Although a 12,000 ton press was used exclusively for the actual extrusions a maximum pressure requirement of 4000 tons was observed for the flange shapes. Therefore, extrusion cost figures are presented separately for both a 4000 ton and a 12,000 ton press. Lower costs result from the use of the 4000 ton press due to the lower hourly cost of this unit ($150/hr vs. $600/hr.).

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II. OBJECT

The objective of this final report is to:

1. Present an economic analysis of the developed titanium manufacturing method which utilizes the extrusion process, and

2. Present the results of engine testing of the titanium parts manufactured by this method.

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III. SUMMARY

1. Three sheet metal assemblies and the turbine rotor shaft were submitted to a 150 hour model engine test. Review of the parts after engine testing revealed no adverse effect of the test on the titanium.

2. The following lists the cost per pound of extruded sections produced from cast ingots utilizing a 4000 ton press and a 12000 ton press.

Part Number	Name	Rough Weight (lbs)	Cost of Extruded Sections (Dollars/pound) 4000 ton Press	12000 ton press
226956	Flanges, Rear Main	4.2	17.00	26.00
226961	Bearing Vapor Duct Ass'y. Mat'L. AMS 4921	8.9	14.00	18.00
226962	Flanges, Rear Main	9.7	14.50	19.50
226963	Bearing Support Cone	6.7	15.00	20.50
226964	Ass'y. Mat'l. AMS4921	5.0	18.50	27.00
226966	Flange, Combustion Chamber Heat Shield Ass'y. Matl. AMS 4921	2.4	20.50	33.00
227594	Flanges, Turbine Stator	8.4	20.50	27.00
227596	Blade Support Ass'y. Mat'l. A110-AT	9.3	22.50	30.00
226970	Shaft-Turbine Rotor Front - Mat'l. A110-AT	43.50	--	28.00

The range of prices for the AMS 4921 material using a 4000 ton press ($14.00/lb to $20.50/lb) is comparable to the cost of round mill sections. The slightly higher costs for the A110-AT sections is primarily due to the lesser die life than that obtainable for the AMS 4921 material.

3. The cost of forming, welding, and sizing of the extruded sections ranges between $4.50/lb and $10/lb. The higher costs result primarily from the smaller diameter, heavier cross-section shapes.

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III. SUMMARY (CONT'D)

4. The following tabularizes the cost of manufacture of each detail part for both a 4000 ton and a 12000 ton press. Also presented in this table is a comparison to the estimated costs by conventional techniques.

Part Number	Name	Cost by Extrusion (Dollars) 4000 ton Press	Cost by Extrusion (Dollars) 12000 ton Press	Cost By Conventional Techniques (Dollars)
225956	Flanges-Rear Main	105.00	143.00	152.00
226961	Bearing Vapor Duct Ass'y.	175.00	216.00	297.00
226962	Flanges-Rear Main	182.00	232.00	254.00
226963	Bearing Support	134.00	173.00	200.00
226964	Cone Ass'y.	129.00	171.00	157.00
226966	Flange, Combustion Chamber Heat Shield Ass'y.	74.00	104.00	76.00
227594	Flanges, Turbine	228.00	284.00	266.00
227596	Stator Blade Support Ass'y.	269.00	337.00	304.00
226970	Shaft, Turbine Rotor-Front	-	1294.00	1630.00

While a definite advantage exists for most of the larger flange shapes with the use of a 12000 ton press, a considerably lower cost would be possible with a 4000 ton press due to the lower press burden rate.

5. Compared to conventional manufacturing methods cost reductions as high as 40 percent are indicated. In all cases anaverage savings of 25 percent is indicated.

6. The procurement cycle for components manufactured from extruded sections is equivalent to that presently obtainable utilizing conventional techniques. However, with an increase in the volume of extrusions the cycle time for such components will be considerably less than that for conventionally manufactured parts.

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IV. CONCLUSIONS

1. Titanium and titanium alloy components manufactured from cast ingot extrusions have properties, as demonstrated by both metallurgical examination and engine model testing, which are equivalent to conventionally manufactured parts.

2. This newly developed method of extruding directly from cast ingots is considerably more economical than manufacture by conventional techniques such as forging or flash-butt welding barstock.

3. In addition to lower costs, considerably less raw material is required to manufacture components by this process. Consequently, the widespread use of this method will greatly reduce the procurement cycle and increase the availability of titanium mill products such as sheet.

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V. RECOMMENDATIONS

1. Disseminate the information presented in this final report throughout the aircraft industry for its use for governmental purposes.

2. Direct all users of titanium for governmental purposes to review their drawings for components applicable to the extrusion process to insure minimum cost and maximum material utilization.

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VI DISCUSSION

In the following section of this report, Part II, a production method is described for manufacturing jet engine components such as flanges and tubular shafts. Both types of parts utilized the extrusion process as the primary operation to transform cast ingots into the required basic cross-sections. For the flanges, the extruded shapes were formed into 360 degree rings, flash-butt welded and sized. These rings were then machined to the detailed part dimensions and welded to sheet metal components to form a jet engine assembly. For the shaft, the extruded tube was upset on both ends and machined to detail part dimensions, thus permitting it to become part of the turbine rotor assembly. In this manner, the detailed parts were produced utilizing considerably less material than that required to make these same parts by conventional techniques such as forging or flash-butt welding rings from barstock.

A. Engine Testing

To manufacture the parts for the production phase, both cas ingots and forged billets of A70 and A110AT material were extruded. A metallurgical analysis was then performed on the extruded lengths and the finished formed rings. This study revealed the properties of the cast ingot extrusions to be equivalent to those made from forged billets. In addition, the mechanical properties of both materials were found to conform to the applicable specification requirements.

To permit a further evaluation of the product of this newly developed manufacturing method, the assemblies, composed of the detail parts, were engine tested. These units are shown pictorially in Figures 1 through 5 and are listed below:

1. Combustion Chamber Heat Shield Assembly P/N 608120
2. Rear Main Bearing Vapor Duct Assembly P/N 608109
3. Rear Main Bearing Support Cone Assembly P/N 608118
4. Turbine Rotor Shaft - Front P/N 226970
5. Turbine Stator Blade Support Assembly P/N 608569

The first four units listed above were assembled into a J-65-W-18 model engine and were submitted to a typical development testing common to the development of other engine components currently programmed. This testing, representing an unofficial 150 hour model test, is identical to that employed in qualifying a part for flight testing or service engines.

This testing was not possible for the Turbine Stator Blade Support Assembly. This assembly was manufactured to a configuration common only to the J-65-W12 model. Since engine testing of this model is not presently active, the testing of this assembly was deleted from the program.

As previously noted, the assemblies were made of both AMS 4921 and A110AT Titanium. In engine operation the AMS 4921 material was used to replace carbon and stainless steel, thus providing a lightweight replacement for mildly stressed, and/or corrosion resistant steel parts for temperatures

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VI DISCUSSION (CONT'D)

to 700°F. The A110-AT material replaced higher stressed units made of low carbon or low alloy steels at temperatures to 1000°F. The locations of these titanium components in the engine are shown schematically in Figure 6.

The titanium assemblies will be subjected in the future to additional model testing and possibly flight testing or service engines pending continued support by the military.

B. Economic Analysis

One of the major, if not the most important aspects of the program is an economic analysis. The following presents such an analysis for this manufacturing method for a quantity of 100 units.

1. Extrusion Operation

The detail cost breakdown for the extruded sections is presented in Appendix I and summarized in Table I. To understand this analysis it is noted that all flange extrusions are made from cast ingots. Two and three hole dies are used for the extrusion of each part except P/N 226961. The cross-section area of this part is sufficiently large to permit its extrusion through a single orifice die. The rotor shaft was also extruded through a single opening die. The geometries of the finished parts are presented in Figures 7 through 15. The following presents a discussion of each of the major factors contributing to the cost of the extrusion operation presented in Appendix I and summarized in Table I.

Cost of Extrusion Stock

Two factors contribute to the cost of the raw material procured; first, and foremost, the cost per pound of the material; and second, the quantity of material required. The following lists the cost of the titanium extrusion stock for the quantities considered:

	8 in. dia. (Flanges)	16 in. dia. (Rotor Shaft)
AMS 4921	$5.50/lb	-
A110-AT	6.15/lb	$5.90/lb

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VI DISCUSSION (CONT'D)

The quantity of material procured is determined in this case, from the extrusion operation yield and the generated scrap. It was previously established that an extrusion yield of approximately 70 percent is obtainable. The material lost is primarily attributed to the unextruded butt. A scrap factor of approximately 15 percent is also required. This scrap is generated in off-dimension extrusions. Therefore, the overall yield, i.e. material purchased vs. material shipped, is between 50 and 60 percent.

Press Costs

All the work on this program was performed on the 12,000 ton horizontal extrusion press located at Metals Processing Division in Buffalo, N.Y. Only the rotor shaft required the full press capacity. Both the AMS 4921 and A110-AT flanges were extruded through multi-opening dies utilizing the 4,000 ton stage of this press. For the manufacture of production parts this situation is economically prohibitive due to the relatively high overhead rate for a 12000 ton press ($600/hr). It would be more economical to extrude these sections through multi-opening dies using a 4000 ton press directly. The overhead rate of this size press is approximately $150/hr. In addition, considerably more material can be produced per hour through a 4000 ton press vs. the use of the 4000 ton stage of a 12000 ton press due to the higher cycle rate. For these reasons, the figures for press costs are quoted separately for a 4000 ton press and a 12000 ton press.

Two cost figures are presented for the 12000 ton press. The first figures (second column under press costs) represents the cost actually incurred in manufacturing the parts on this program. Due to the limited volume of titanium processed and the intermittent use of the press for steel extrusions, only one of the salt baths was equipped with a low temperature salt for heating the titanium (1600°F).

It is noted that the salt used to heat steel at approximately 2100°F could not be used at temperatures below 1800°F without contamination of the salt and eventual attack on the furnace. Consequently, as indicated in Appendix I the number of extrusions per hour was limited because of the availably heating capacity. For a sufficiently large volume of titanium extrusions both salt baths could be converted to the lower temperature salt. If this was not the case and titanium and steel were extruded intermittently an additional salt bath would be required to obtain the optimum use of such a 12000 ton press. The press cost under the latter conditions is presented in the third column.

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VI. DISCUSSION (CONT'D)

At present, all production suppliers of titanium extrusions use single opening dies. Consequently, until all the practices presented in this series of reports are put into practice by commercial extruders with relatively small units and ring manufacturers, the values presented for the 12000 ton press may be the most economical, even considering the relatively small cross-sections involved, i.e. less than 1.5 in^2.

The rotor shaft, having a cross-section area of approximately 12 in^2 cannot be extruded through anything less than a 12000 ton press due to the required pressures.

Dies

Die inserts costing approximately $175/insert are used exclusively for the flanges. The die costs, therefore, are established by the quantity of inserts required to complete the order. For the A70 material each insert is capable of producing a total extrusion length of approximately 100 ft. The length per each extrusion is a maximum of 20 ft. and 5 extrusions can be made per die. Extruding the A110-AT material is considerably rougher on die life. Approximately 15 ft. of extrusion can be made satisfactorily and each extrusion requires the use of a new die.

Miscellaneous Charges

The value indicated in this column is primarily composed of the cost required to perform the testing for certification of the extruded sections.

Selling Price

These columns are self explanatory. The addition of G and A and profit to the actual cost, yield the selling price. Based on this selling price the following list of costs per pound of the extruded sections has been determined.

Part Number	Name	Shipping Wt.	Cost/lb 4000 Ton	Cost/lb 12000 Ton
226956	Flanges, Rear Main Brg. Vapor Duct Assembly	4.2	17.00	26.00
226961		8.9	14.00	18.00
226962	Flanges, Rear Main Bearing Support Cone Assembly	9.7	14.50	19.50
226963		6.7	15.00	20.50
226964		5.0	18.50	27.00

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VI DISCUSSION (CONT'D)

Part Number	Name	Shipping Wt.	Cost/lb 4000 Ton	Cost/lb 12000 Ton
226966	Flange, Combustion Chamber Heat Shield Assembly	2.4	20.50	33.00
227594	Flanges, Turbine Stator Blade Support Assembly	6.4	20.50	27.00
227596		9.3	22.50	30.00
226970	Shaft, Turbine Rotor Front	43.50		28.00

For the most part, the prices for the 4000 ton press are directly competitive with commercially available bar of comparable cross-section area.

2. Forming, Welding, Sizing & Upsetting

Based on the results obtained from processing the production phase parts, an engineering survey was made by the ring manufacturing and upsetting vendors to establish the cost for processing a quantity of 100 units. The established costs for these secondary operations, i.e. forming, welding and sizing for the flanges are presented in detail in Tables II through IV for each operation. The total costs for the ring manufacturing operation are summarized in Table V.

Forming

The equipment used to form the extruded sections into 360 degree rings was a Bath Radial Draw Former. Prior to forming, the extruded AMS 4921 titanium sections were heated to the temperature range of 700°F to 1000°F while the higher temperature range of 1200°F to 1400°F was required for the A110-AT sections. In general, contour forming was accomplished by three passes on the machine. The first pass is a rough forming operation followed by a second pass which formed the part to the desired diameter. The final pass was used to round-off the ends of the ring thus preparing them for subsequent welding. An end trimming operation and reheating is required between each forming pass.

A breakdown of the ring forming cost is presented in Table II. The three items contributing to this cost are the machine time, trimming and inspection time and the cost for tool maintenance. The overhead rate

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for this equipment is approximately $16.00/hr. Consequently, the actual forming cost is a direct function of the time required to form each ring. Except for the more complex shape, namely P/N 226961 and the A110-AT rings, the actual machine cost is not appreciably effected by minor variations in cross section. The next largest factor contributing to the cost of ring forming is the cost of trimming the rings between forming passes and inspecting. A nominal tooling maintenance charge is required to maintain the desired configuration of the die and rolls. The latter two charges are affected very slightly by the ring configuration.

Welding

For welding the formed sections, the cost figures are based on the use of a Thomson Model F-5 welder, Table III. The two major items contributing to the cost of welding the extruded and formed sections are the machine time and the cost for flash removal. Indeed, the cost incurred in the presently utilized method of hand chipping and grinding for flash removal represent one-half of the cost for this process.

In general, considering the variations in cross sections examined, the finished part costs were found to be only slightly effected by material or cross section. Slightly higher costs, however, did result from the smaller diameter, heavier cross section rings, (P/N 226961) as considerably more care was required in their processing. The actual welding costs vary from $3/part to $6.50/part.

Sizing

Sizing of all rings was accomplished on a 225 ton brake press. Prior to sizing the ring shapes, both the dies and rings were heated to the range of 700 to 1250°F. This permitted the AMS 4921 material to be expanded 2 to 3 percent and the A110-AT rings to be expanded a maximum of 1 1/2 percent. A two step operation was used in sizing all rings.

The detail cost breakdown for the sizing operation is presented in Table IV. The major items contributing to the sizing cost are the machine charges and the cost for inspection. In general, the cost for sizing is nominal and ranges from $5.00/part to $6.50/part.

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Selling Price of Rings

In Tables II through IV, the actual costs of forming, welding and sizing were presented, based on an engineering survey. To establish the selling price for the ring manufacturing operations, two additional factors must be considered. These factors are the cost of scrap and profit and G & A.

These items are presented at the end of Table IV. A scrap factor of 10 percent of the cost of the extruded section was added to the cost of the actual operations. This factor is exceedingly high and will remain so until considerably more experience is gained by the ring manufacturers in processing titanium. It is estimated that this factor need not exceed 2 percent in production processing once the vendors have familarized themselves with the processing of titanium. In the same way as for the extruded section, the cost of G & A and profit has been included. In this manner, a realistic cost for the present day procurement of these sections has been presented. This total cost is presented in the last column of Table IV. Prices ranging from approximately $25/part to $60/part are noted. These prices represent a cost per pound of approximately $8.00. In general, slightly higher costs are observed for the A110-AT material compared to the AMS 4921 material.

Upsetting

In processing the production phase parts, a 6" Ajax air forging machine was used to upset the flanges on the extruded tube to produce the turbine rotor shaft. In this operation, a 3 step pass with intermittent heating to 1900°F was used. While this resulted in a successful upset for the prototype part, the production parts had a lap at the inner diameter beneath the flange. This is discussed in detail in Part 2 of this final report. In performing the engineering survey to obtain the cost of upsetting 100 shafts, it was decided, due to the lap which resulted in the 3 pass operation to base the analysis on a 4 pass operation with intermittent heating. This price has been established at $83.30 per shaft. This cost is primarily that required to perform the actual upsetting and therefore, represents a machine burden charge. In addition to this cost per piece, a fixed tooling charge of $14,725. is anticipated.

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VI DISCUSSION (CONT'D)

3. Finished Detail Part Costs

Table V presents a detail summary analysis of the cost of manufacturing the complete detail part from cast ingot extrusions. In this analysis, the costs for both a 4000 ton and a 12000 ton press are presented.

Considering the use of a 4000 ton press, the finished part cost is evenly distributed among material, extrusion and ring manufacture. The following tabularizes the finished part costs.

Part Number	Name	Finished Part Cost 4000 ton press	 12000 ton press
226956	Flanges, Rear Main	$105.00	$143.00
226961	Bearing Vapor Duct Assembly	175.00	216.00
226962	Flanges, Rear Main	182.00	232.00
226963	Bearing Support	134.00	173.00
226964	Cone Assembly	129.00	171.00
226966	Flange, Combustion Chamber Heat Shield Assembly	74.00	104.00
227594	Flanges, Turbine	228.00	284.00
227596	Stator Blade Support Assembly	269.00	337.00
226970	Shaft, Turbine Rotor Front	--	1294.00

C. Economic Comparison

Prior to the initiation of this development program, three of the sheet metal assemblies and the turbine rotor shaft were procured in small quantities for development engine testing. The cost of these components is listed in Table VI. It is emphasized that these cost figures are for very small quantities procured in 1953 and 1954.

To enable a direct comparison between the two manufacturing methods, the cost figures presented in Table VI have been adjusted for larger quantities at present day material and labor costs. This comparison is presented in Table VII. This data indicates savings up to 40 percent and an average savings exceeding 25 percent of the cost by conventional methods.

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VI DISCUSSION (CONT'D)

For the four sheet metal assemblies and the rotor shaft, a total maximum savings of $745.00 has been attained. This savings considers the use of the 4000 ton press for the flanges and the 12000 ton press for the shaft. This savings is for a total of only nine specific components. Extrapolating this information to applicable shapes, i.e. rotating shrouds, stator blade carrier rings, etc. in a jet engine such as the J-65 indicates a total potential savings per engine in excess of $3500. For a total of 1000 engines, this savings rapidly increases to a value in excess of $3,500,000.

At present, the procurement cycle for parts manufactured in this newly developed way is comparable to conventional techniques. A three month procurement cycle time for extruded sections is readily obtainable. This cycle time will improve considerably with the widespread utilization of extrusions.

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VII REFERENCES

1. Final Report on "Titanium Manufacturing Methods Development" Submitted by Metals Processing Division to Wright Aeronautical Division, January, 1957.

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TABLE I

Summary Analysis of the Cost of Extruding Ring & Tubular Sections Through A 4000 Ton & A 12000 Ton Press (Quantity 100 Units)

Part Number	Cost of Extrusion Stock $	Press Costs			Die Costs $	Misc. *** Charges $	Selling Price			Fixed Tooling Charge $
		4000 Ton $	12000 Ton* $	12000** Plus Additional Heating Facilities $			4000 Ton $	12000 Ton* $	12000 ** Plus Additional Heating Facilities $	
226956	42.19	5.18	54.00	36.00	8.88	3.06	72.33	131.87	109.80	2,600.00
226961	83.82	6.53	72.00	45.00	6.33	3.42	122.07	194.20	161.30	2,600.00
226962	88.86	6.98	78.00	48.00	14.80	3.42	139.10	255.71	189.10	2,600.00
226963	63.66	5.18	54.00	36.00	8.88	3.06	98.51	158.05	136.20	2,600.00
226964	55.85	5.78	63.00	40.50	11.10	3.42	92.87	162.65	135.10	2,600.00
226966	24.59	4.13	39.00	28.50	7.40	3.06	47.78	90.30	77.60	2,600.00
227594	75.62	5.78	85.20	51.60	55.50	3.42	171.12	267.98	227.00	2,600.00
227596	87.71	6.98	108.00	63.00	74.00	3.42	209.89	333.09	278.10	2,600.00
226970	570.15	—	459.00	259.50	56.36	106.92	—	1454.18	1210.89	None

* MPD's 12000 ton unit

** MPD's 12000 ton unit with additional heating facilities

*** Chemical Analysis plus certified properties, etc.

NOTE: Hourly charge for 4000 ton press - $150/hr; 12000 ton press - $600/hr.

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TABLE II

Detailed Cost Breakdown For Contour Forming Extruded Section Into 360 Degree Rings (Quantity 100 Units)

						Forming				Trimming & Inspection				
Part Number	Name	Material	Rough Weight (lbs.)	Cross Section Area (In. ^{2})	Ring Diameter (In.)	No. of passes per ring	Pieces per hour per pass	Total hours per ring	Machine Cost at $16/hr ($/part)	Time Required (hrs/part)	Cost at $8/hr ($/part)	Tooling Maintenance ($/part)	Total Forming Cost ($/part)	Tooling Charge ($)
226956	Flanges, Rear Main Bearing Vapor Duct Assembly	AMS 4921	4.2	0.53	12.9	3	8	.375	6.00	.333	2.68	1.50	10.18	4,000
226961		" "	8.9	1.56	9.0	4	5	.800	12.80	.410	3.28	2.30	18.38	5,600
226962	Flanges, Rear Main Bearing Support Cone Assembly	" "	9.7	0.96	16.3	3	7.5	.399	6.39	.333	2.68	1.50	10.57	4,000
226963		" "	6.7	1.12	7.9	3	7	.426	6.81	.333	2.68	1.60	11.09	4,300
226964		" "	5.0	0.70	13.0	3	7.5	.399	6.39	.333	2.68	1.50	10.57	4,000
226966	Flange, Combustion Chamber Heat Shield Assembly	" "	2.4	0.29	14.4	3	10	.300	4.80	.333	2.68	1.40	8.88	3,800
227594	Flanges, Turbine Stator Blade Support Assembly	A110AT	6.4	1.04	12.9	4	5	.800	12.80	.410	3.28	2.10	18.18	4,200
227596		" "	9.3	0.81	19.5	4	6	.665	10.68	.410	3.28	2.10	16.06	4,200

NOTE: Equipment - Bath Radial Draw Former

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TABLE III

Detail Cost Breakdown For Flash-Butt Welding Extruded Sections (Quantity 100 Units)

Part Number	Name	Material	Rough Weight (lbs.)	Machine Set-up Time (hrs/part)	Welding Rate (parts/hr)	Welding Time (hrs/part)	Machine Cost at $12/hr ($/part)	Cost of Die Maintenance ($/part)	Cost of Flash Removal ($/part)	Misc. Costs i.e. X-ray, Trimming anneal, etc. ($/part)	Total Welding Cost ($/part)	Fixed Tooling Charge ($)
226956	Flanges, Rear Main Bearing Vapor Duct Ass'y	AMS 4921	4.2	0.01	20	0.05	0.72	0.15	2.40	0.60	3.87	800
226961		" "	8.9	0.02	10	0.10	1.44	1.00	3.20	0.90	6.54	2,500
226962	Flanges, Rear Main Bearing Support Cone Assembly	" "	9.7	0.015	15	0.067	0.98	0.30	2.67	1.20	5.15	1,000
226963		" "	6.7	0.02	15	0.067	1.04	0.30	2.40	0.60	4.34	1,200
226964		" "	5.0	0.01	20	0.05	0.72	0.15	2.67	0.60	4.14	800
226966	Flange, Combustion Chamber Heat Shield Assembly	" "	2.4	0.01	20	0.05	0.72	0.15	1.60	0.60	3.07	800
227594	Flanges, Turbine Stator Blade Support Assembly	A110AT	6.4	0.015	15	0.067	0.98	0.30	2.67	1.20	5.15	1,000
227596		"	9.3	0.01	20	0.05	0.72	0.15	2.67	0.60	4.05	1,000

NOTE: Equipment - Thomson Welder Model F-5

200 - 400 KVA

40,000 lbs. max. upset force.
100,000 lbs. max. clamping force.

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TABLE IV

Detail Cost Breakdown For Sizing Titanium Rings (Quantity 100 Units)

Part Number	Name	Material	Rough Weight (lbs.)	No. of passes per ring	Pieces/ hr/pass	Total hrs/ring	Machine Cost at $10/hr ($)	Inspection ($/part)	Tooling Maintenance ($/part)	Total Sizing Cost ($/part)	Tooling Charge ($/part)	Scrap Costs ($/part)	G & A & Profit	Total Cost Form, Weld & Size ($/part)
226965	Flanges, Rear Main Bearing Vapor Duct Assembly	AMS 4921	4.2	2	8	.25	2.50	1.80	1.08	5.38	3,200	7.23	5.84	32.50
226961		" "	8.9	2	6	.30	3.34	1.80	1.48	6.62	3,200	12.21	9.60	53.35
226962	Flanges, Rear Main Bearing Support Cone Assembly	" "	9.7	2	8	.25	2.50	1.80	1.08	5.38	3,200	13.91	7.64	42.65
226963		" "	6.7	2	8	.25	2.50	1.80	1.12	5.42	3,400	9.85	6.70	37.40
226964		" "	5.0	2	8	.25	2.50	1.80	1.08	5.38	3,200	9.29	6.44	35.82
226966	Flange, Combustion Chamber Heat Shield Assembly	" "	2.4	2	10	.20	2.00	1.80	.98	4.78	3,100	4.79	4.73	26.25
227594	Flanges, Turbine Stator Blade Support Assembly	A110AT	6.4	2	6	.30	3.34	1.80	1.30	6.44	3,300	17.11	10.29	57.17
227596		"	9.3	2	6	.30	3.34	1.80	1.30	6.44	3,300	20.99	10.72	57.55

NOTE: Equipment - 225 Ton Break Press
Scrap Costs Estimated At 10% of Value of Extruded Section.

[redacted]

TABLE V

Summary Analysis Showing The Cost Breakdown By Processes For Manufacturing Titanium Components From Cast Ingot Extrusions (Quantity 100 Units)

Part Number	Name	Material	Rough Weight (lbs.)	Material Cost ($/part)	Extrusion Cost ($/part)		Ring Manufacturing cost ($/part)	Upsetting Cost ($/part)	Finished Part Cost ($/part)		Cost Per Pound of Material	
					4000 Ton press	12000 Ton press			4000 Ton press	12000 Ton press	4000 Ton press ($)	12000 Ton press ($)
226956	Flanges, Rear Main Bearing Vapor Duct Assembly	AMS 4921	4.3	42.00	30.00	68.00	33.00	--	105.00	143.00	24.50	33.00
226961		" "	8.9	84.00	38.00	79.00	53.00	--	175.00	216.00	19.50	24.00
226962	Flanges, Rear Main Bearing Support Cone Assembly	" "	9.7	89.00	50.00	100.00	43.00	--	182.00	232.00	19.00	24.00
226963		" "	6.7	64.00	34.00	72.00	37.00	--	134.00	173.00	20.00	26.00
226964		" "	5.0	56.00	37.00	79.00	36.00	--	129.00	171.00	26.00	34.00
226966	Flange, Combustion Chamber Heat Shield Assembly	" "	2.4	25.00	23.00	53.00	26.00	--	74.00	104.00	31.00	43.50
227594	Flanges, Turbine Stator Blade Support Assembly	A110AT	6.4	76.00	95.00	151.00	57.00	--	228.00	284.00	35.50	44.50
227596		"	9.3	88.00	122.00	190.00	58.00	--	268.00	336.00	29.00	36.00
226970	Shaft, Turbine Rotor Front	"	43.5	570.00	--	641.00	--	83.00	--	1294.00	--	33.00

STAT

[redacted]

TABLE VI

Cost Of Detail Titanium Parts By Conventional Manufacturing Methods

Part Number	Form	Quantity	Cost Per Piece $	Weight (lbs.)	Cost Per Pound $
226956	Flash Welded Rings from Barstock	2	356.00	8.4	42.50
226961		2	353.00	16.5	21.40
226962		2	1114.00	14.1	79.00
226963		2	392.00	11.1	35.00
226964		2	191.00	8.7	22.00
226966		2	282.00	4.0	70.00
226970	Forging	2	2055.00	74.0	28.00

Note: All cost figures are for 1953 and 1954

STAT

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TABLE VII

Detail Cost Comparison Between Titanium Components Manufactured By Conventional Techniques Versus Extruding From Cast Ingots (Quantity 100 Units)

			CONVENTIONAL METHODS								EXTRUSION									
Part Number	Name	Material	Finished Part Weight (lbs.)	Rough Mat'l Weight (lbs.)	Mat'l Cost Per lb. ($)	Mat'l Cost ($)	Process	Process Cost Per lb. ($)	Process Cost ($)	Detail Part Cost ($)	Rough Mat'l Weight (lbs.)	Mat'l Cost ($)	Extrusion (Cost) ($)		Forming Welding Sizing (Cost $)	Upsetting ($)	Total Cost ($)		Cost Saving ($)	
													4000 Ton	12000 Ton			4000 Ton	12000 Ton	4000 Ton	12000 Ton
226956 226961	Flanges, Rear Main Brg. Vapor Duct Assembly	AMS 4921 " "	2.8 4.1	8.4 16.5	16.00 16.00	135.00 264.00		2.00 2.00	17.00 33.00	152.00 297.00	4.3 8.9	42.00 84.00	30.00 38.00	68.00 79.00	33.00 53.00	- -	105.00 175.00	143.00 216.00	47.00 122.00	9.00 81.00
226962 226963 226964	Flanges, Rear Main Brg. Support Cone Assembly	AMS 4921 " " " "	5.6 3.8 3.0	14.1 11.1 8.7	16.00 16.00 16.00	226.00 178.00 140.00	Ring Manufacture	2.00 2.00 2.00	28.00 22.00 17.00	254.00 200.00 157.00	9.7 6.7 5.0	89.00 64.00 56.00	50.00 34.00 37.00	100.00 72.00 79.00	43.00 37.00 36.00	- - -	182.00 134.00 129.00	232.00 173.00 171.00	72.00 66.00 28.00	22.00 27.00 0
226966	Flange, Combustion Chamber, Heat Shield Assembly	AMS 4921	1.2	4.0	17.00	68.00		2.00	8.00	76.00	2.4	25.00	23.00	53.00	26.00	-	74.00	104.00	2.00	0
227594 227596	Flanges, Turbine Stator Blade Support Assembly	A110AT "	4.8 5.4	14.0 16.0	17.00 17.00	238.00 272.00		2.00 2.00	28.00 32.00	266.00 304.00	8.4 9.3	76.00 88.00	95.00 122.00	151.00 190.00	57.00 58.00	- -	228.00 268.00	284.00 337.00	38.00 35.00	0 0
226970	Shaft-Turbine Rotor Front	A110AT	19.0	74.00	13.00	960.00	Forging	9.00	670.00	1630.00	43	570.00	—	641.00	—	83.00	—	1294.00	—	336.00

Maximum Total - $745.00

[redacted]

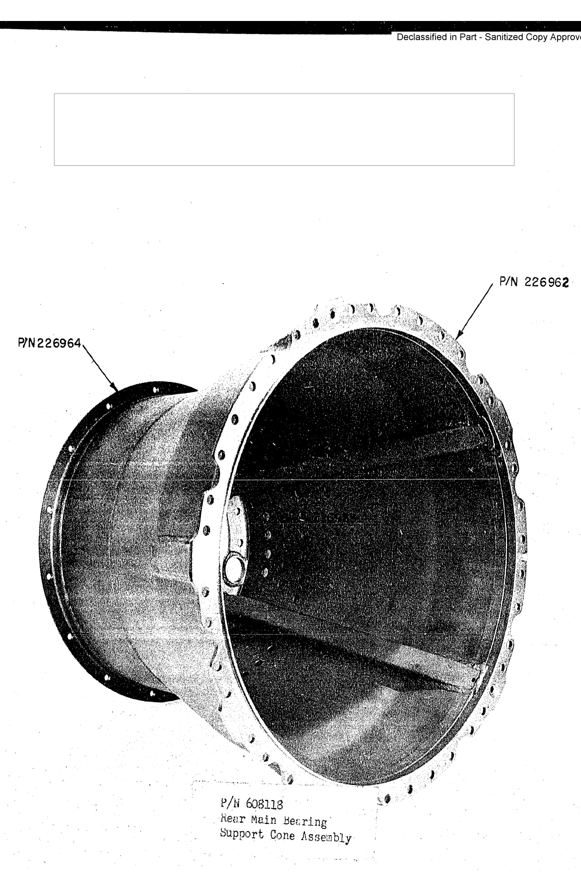

FIG. 1 - P/N 608118 - REAR MAIN BEARING SUPPORT CONE ASSEMBLY

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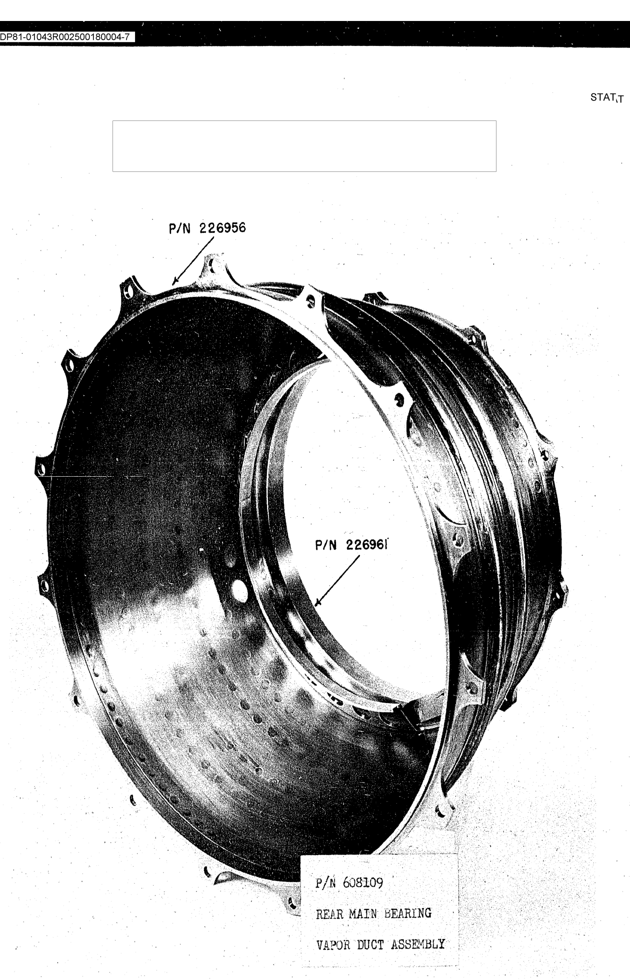

FIG. 2 - P/N 608109 - REAR MAIN BEARING VAPOR DUCT ASSEMBLY

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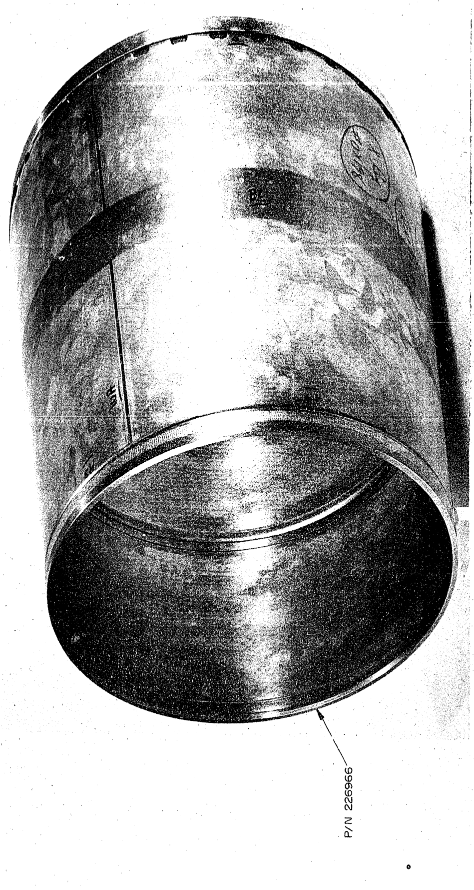

FIG. 3- P/N 608120- COMBUSTION CHAMBER HEAT SHIELD ASSEMBLY.

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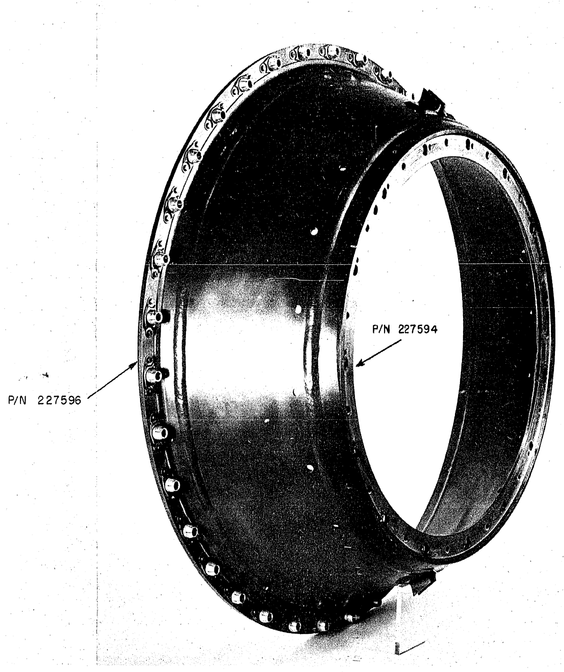

FIG. 4- P/N 608569-TURBINE STATOR BLADE SUPPORT ASSEMBLY.

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FIG. 5 - P/N 226970 - SHAFT, TURBINE ROTOR FRONT

[redacted]

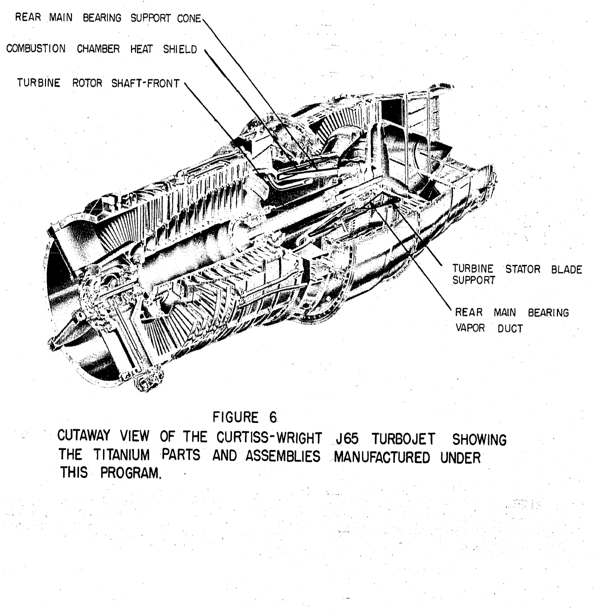

FIGURE 6
CUTAWAY VIEW OF THE CURTISS-WRIGHT J65 TURBOJET SHOWING THE TITANIUM PARTS AND ASSEMBLIES MANUFACTURED UNDER THIS PROGRAM.

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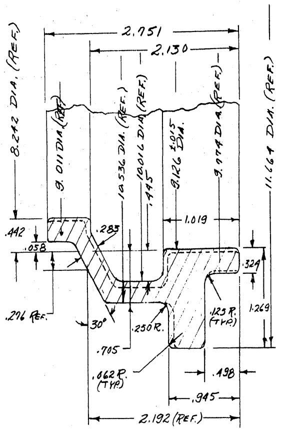

FIGURE 7. P/N 226961 - Rear Flange, Rear Main Bearing Vapor Duct Assembly, Material Ti-A70.

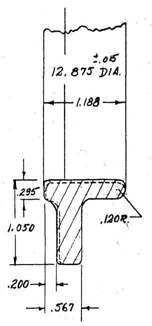

FIGURE 8. P/N 226956 - Front Flange, Rear Main Bearing Vapor Duct Assembly, Material Ti-A70.

[redacted]

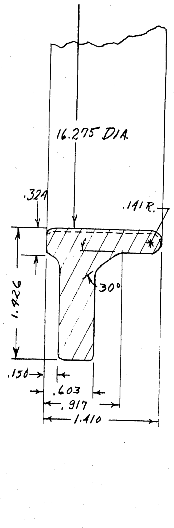

FIGURE 9. P/N 226962 - Front Flange, Rear Main Bearing Support Cone Assy'y, Material Ti-A70.

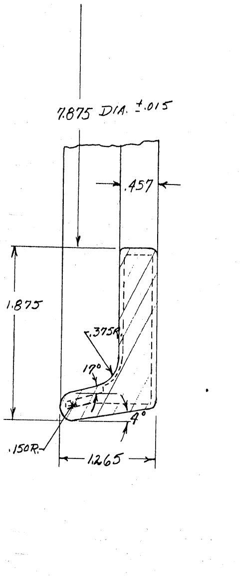

FIGURE 10. P/N 226963 - Rear Flange, Rear Main Bearing Support Cone Ass'y, Material Ti-A 70

[redacted]

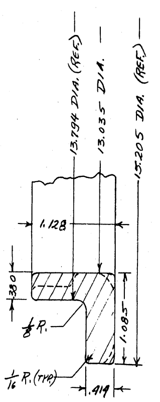

FIGURE 11. P/N 226964 - Flange Brace, Rear Main Bearing Support Cone Ass'y, Material Ti-A70

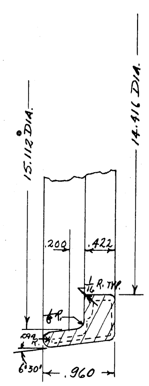

FIGURE 12. P/N 226966 - Flange, Combustion Chamber Heat Shield Ass'y, Material Ti-A70

[redacted]

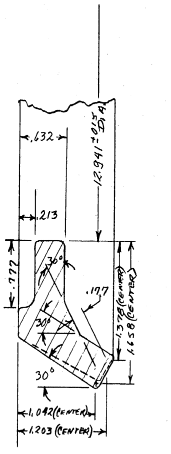

FIGURE 13. P/N 227594 - Rear Flange, Turbine Stator Blade Support Assembly, Material Ti-A 110-AT.

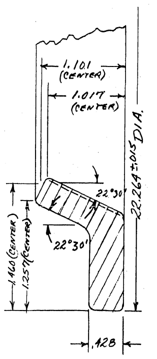

FIGURE 14. P/N 227596 Front Flange, Turbine Stator Blade Support Assembly, Material - Ti-A110-AT

[redacted]

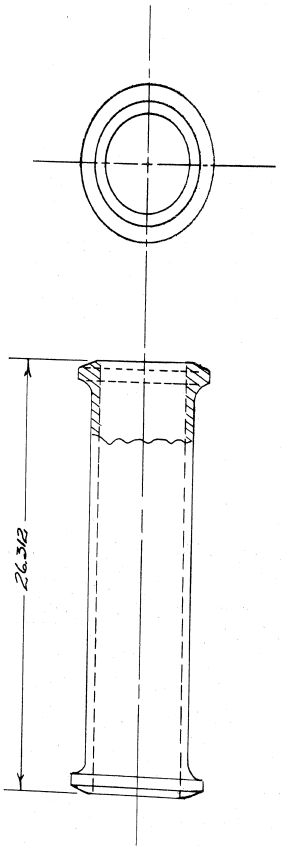

FIGURE 15. P/N 226970 - Shaft, Turbine Rotor Front, Material Ti-A110-AT

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VIII. APPENDIX I

DETAILED COST ANALYSIS OF THE EXTRUSION PROCESS

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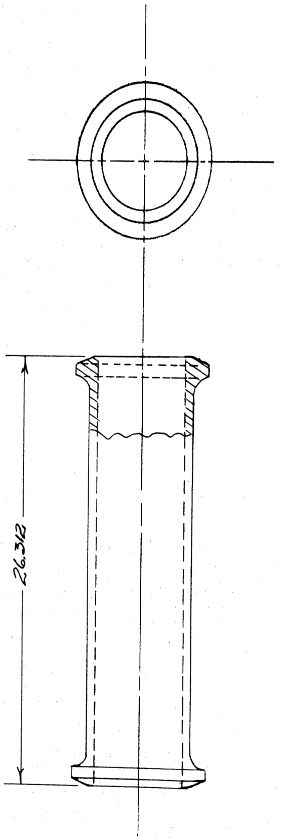

FIGURE 15. P/N 226970 - Shaft, Turbine Rotor Front, Material Ti-A110-AT

[redacted]

VIII. APPENDIX I

DETAILED COST ANALYSIS OF THE EXTRUSION PROCESS

4,000 TON PRESS ITEM 1 of 8

MP 90-5

EXTRUSION COST ESTIMATE SHEET

Customer WAD
Mat. Specs. MPD - 275
Quantity Required 100 PCS.
Inquiry No.
Part Name FLANGE
Part No. & C/L 226956
Production Rate
Date 5-22-57

MATERIAL 163

BILLET DATA		PART DATA	
O.D. 8# I.D. LGTH.	8#	O.D. .53 In Area I.D. LGTH.	4.9
WEIGHT/BILLET	65	WEIGHT/PIECE (Net)	4.23
PIECES/BILLET	10	WEIGHT/PIECE (Gross)	6.5
TOTAL BILLETS REQ. (Incl. Scrap)	12	% SCRAP	16.7
TOTAL GROSS WT.	780	% YIELD	651

MANUFACTURING DATA

PUSHES/HR.	* 7	PIECES/PUSH 2 Hole Die	10
DEV. & TOOL TRYOUT/HRS.		DEV. & TOOL PUSHES/HR. Set up	1.0
PUSHES/DIE CHANGE - MANDREL	5	TIME TO CHANGE DIE & MANDREL/HRS.	
BILLET HEATING	1	MACHINING TIME/PC.	.25
STRESS RELIEVE		MAGNA-FLUX TIME/PC.	
DESCALE	.5	PURCHASED SERVICES Mach. Spec.	36.00
		Interstitial Analysis	20.00
		20% Control Check	

SPECIAL TOOLING

SPECIAL TOOLS (List Replaceable Tools First)	CODE	COST
DESIGN HOURS 50		300
Die Insert - 6 @ $185	DT	1110
Die Back Up Plate	DT	300
Die Holder Back Plate	DT	500
Dummy Block	DT	400
Extrusion Guide	DT	800
Templates &Gages		
		3710
* 4000 Ton Press & Complete Heating Facilities		
TOTAL TOOLING COST	8410	4512

ADDITIONAL EQUIPMENT

ADDITIONAL MACHINES OR EQUIPMENT	
INSTALLATION	
RE-ARRANGEMENT	
TOTAL ADDITIONAL EQUIPMENT COST	

SHIPPING SCHEDULE

WEEKS	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
MATERIAL PROCUREMENT																								
TOOLING						Same as with 12,000 ton press																		
PROCESSING																								
MANUFACTURING																								
SHIPPING																								

MATERIAL COST

QUOTATION	COST
FIRM DATE BUYER Request 3017	
MAT. COST/LB. 5.50/# from Oregon Metallurgical Corp.	
MAT. COST/PIECE 780 @ 5.50	4290
MAT. SCRAP COST	
MAT. SCRAP VALUE 780 less 423# - 357# @ 20¢/#	(71)
	4219

MANUFACTURING COST

MANUFACTURING COST/PC. 1.7 hrs @ $150/hr on 4000 ton press/T.W.	255
DEV. & TOOL TRYOUT COST/PC. Set up & prorated channgeover of 8 items - 1.75 @ 150/hr	263
CHANGE-OVER COST/PC.	
MACHINING COST/PC. 25 hrs @ 10.00	250
MAGNA-FLUX COST/PC.	
PURCHASED SERVICES:	56
FIRM DATE BUYER	
FIRM DATE BUYER	

REPLACEABLE TOOL COST

PCS./REWORK	NO. OF REWORKS	REWORK COST	REWORK TOTAL	TOTAL TOOL COST	TOTAL PCS/TOOL	
25 Pc./insert	0	0	0			888
				TOTAL MANUFACTURING COST		
				% SCRAP Included		

LABORATORY REQUIREMENTS		
PACKAGING REQUIREMENTS		
SHIPPING REQUIREMENTS F.O.B. EXTRUSION PLANT, BUFFALO, N.Y.		
REMARKS:	TOTAL MANUFACTURING COST	
There Will Be An 6 Hr. Change Over	8 % G. & A.	
Whenever This Or A Group Of These	SUB TOTAL	
Parts Are Run	10 % PROFIT	
	SUB TOTAL	7233
Straightness 1/8" In 5'	% RENT	
	PRICE/LB. 17.10 PRICE/PIECE	7233 each

Twist 5°/FT Max. 20° In 5 Ft.

Transverse Flatness 0 .025/11

Furnished As Extruded & Scaled

DEPT.	SIGNATURES	DATE
MFG. ENG.		
WORK STDS.		
QUALITY		
PROD. CONT.		
PLANT MGR.		
COST EST.		
CONTROLLER		

[redacted]

[redacted]

4000 TON PRESS Item 2 of 8

MP 90-5

EXTRUSION COST ESTIMATE SHEET

Customer WAD
Part Name FLANGE
Mat. Specs. MPD - 275
Part No. & C/L 226962
Quantity Required 100 PCS
Production Rate
Inquiry No.
Date 5-22-57

MATERIAL .163

BILLET DATA		PART DATA	
O.D. 8" I.D. LGTH.	10"	O.D. Area-.96 In. I.D. LGTH.	62"
WEIGHT/BILLET	82#	WEIGHT/PIECE (Net)	9.7#
PIECES/BILLET	6	WEIGHT/PIECE (Gross)	13.7#
TOTAL BILLETS REQ. (Incl. Scrap)	20	% SCRAP	16.7
TOTAL GROSS WT.	1640	% YIELD	10.1

MANUFACTURING DATA

PUSHES/HR.	*70	PIECES/PUSH 2 Hole Die	6
DEV. & TOOL TRYOUT/HRS.		DEV. & TOOL PUSHES/HR. Set Up	1.0
PUSHES/DIE CHANGE - MANDREL	5	TIME TO CHANGE DIE & MANDREL/HRS.	-
BILLET HEATING	1	MACHINING TIME/PC.	.25
STRESS RELIEVE		MAGNA-FLUX TIME/PC.	
DESCALE	.5	PURCHASED SERVICES Mach.Lab. Spec	72.00
		Interstitial Analysis	20.00
		20% Control Check	

SPECIAL TOOLING

SPECIAL TOOLS (List Replaceable Tools First)	CODE	COST
DESIGN HOURS 50		300
Die Inserts - 8 @ $185	DT	1480
Die Back Up Plate	DT	300
Die Holder Back Plate	DT	500
Dummy Block	DT	400
Extrusion Guide	DT	800
Templates & Gages	DT	300
		4080
* 4000 Ton Press & Complete Heating Facilities		
TOTAL TOOLING COST	8410	4976

ADDITIONAL EQUIPMENT

ADDITIONAL MACHINES OR EQUIPMENT	
INSTALLATION	
RE-ARRANGEMENT	
TOTAL ADDITIONAL EQUIPMENT COST	

SHIPPING SCHEDULE

WEEKS	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
MATERIAL PROCUREMENT																								
TOOLING																								
PROCESSING																								
MANUFACTURING																								
SHIPPING																								

MATERIAL COST

	COST
QUOTATION	
FIRM DATE BUYER	
MAT. COST/LB. 5.50/#	
MAT. COST/PIECE 1640# @5.50	9020
MAT. SCRAP COST	
MAT. SCRAP VALUE 1640# less 970# - 670# @20¢/#	(134)
MANUFACTURING COST	8886
MANUFACTURING COST/PC. 2.9 hrs @ 150/hrs on 4,000 ton press/T.W.	435
DEV. & TOOL TRYOUT COST/PC. Set up-1hr & prorate of changeover - 1.75 @ 150	263
CHANGE-OVER COST/PC.	
MACHINING COST/PC. 25 hrs @ 10.00	250
MAGNA-FLUX COST/PC.	
PURCHASED SERVICES:	92
FIRM DATE BUYER	
FIRM DATE BUYER	

REPLACEABLE TOOL COST

PCS./REWORK	NO. OF REWORKS	REWORK COST	REWORK TOTAL	TOTAL TOOL COST	TOTAL PCS/TOOL	
15 Pc/insert	0	0	0			1480
				TOTAL MANUFACTURING COST		[illegible]
				% SCRAP Included above		

LABORATORY REQUIREMENTS
PACKAGING REQUIREMENTS
SHIPPING REQUIREMENTS F.O.B. EXTRUSION PLANT, BUFFALO, N.Y.
REMARKS:

SEE ITEM I

TOTAL MANUFACTURING COST	11406
% G. & A.	
SUB TOTAL	
% PROFIT	
SUB TOTAL	13910
% RENT	
PRICE/LB. 14.34 PRICE/PIECE	139.10 ea

DEPT.	SIGNATURES	DATE
MFG. ENG.		
WORK STDS.		
QUALITY		
PROD. CONT.		
PLANT MGR.		
COST EST.		
CONTROLLER		

[redacted]

4000 TON PRESS Item 3 of 8

MP 90-5

EXTRUSION COST ESTIMATE SHEET

Customer WAD
Part Name FLANGE
Mat. Specs. MPD - 275
Part No. & C/L 226963
Quantity Required 100 PCS
Production Rate
Inquiry No.
Date 5/22/57

MATERIAL .163

BILLET DATA		PART DATA	
O.D. 8" I.D. LGTH.	12"	O.D. Area-1.2 In. I.D. LGTH.	34"
WEIGHT/BILLET	98#	WEIGHT/PIECE (Net)	6.65
PIECES/BILLET	10	WEIGHT/PIECE (Gross)	9.80
TOTAL BILLETS REQ. (Incl. Scrap)	12	% SCRAP	16.7
TOTAL GROSS WT.	1176	% YIELD	67.8

MANUFACTURING DATA

PUSHES/HR.	*7	PIECES/PUSH	10
DEV. & TOOL TRYOUT/HRS.		DEV. & TOOL PUSHES/HR.	1.0
PUSHES/DIE CHANGE - MANDREL	5	TIME TO CHANGE DIE & MANDREL/HRS.	-
BILLET HEATING	1	MACHINING TIME/PC.	.25
STRESS RELIEVE		MAGNA-FLUX TIME/PC.	$36.00
DESCALE	5	PURCHASED SERVICES	20.00

SPECIAL TOOLING

SPECIAL TOOLS (List Replaceable Tools First)	CODE	COST
DESIGN HOURS 50		300
Die Inserts - 6 @ $185	PT	1100
Die Back Up Plate	DT	300
Die Holder Back Plate	DT	500
Dummy Block	DT	400
Extrusion Guide	DT	800
Templates & Gages	DT	300
		3700
* 4000 Ton Press & Complete Heating Facilities		
TOTAL TOOLING COST	8410	4512

ADDITIONAL EQUIPMENT

ADDITIONAL MACHINES OR EQUIPMENT	
INSTALLATION	
RE-ARRANGEMENT	
TOTAL ADDITIONAL EQUIPMENT COST	

SHIPPING SCHEDULE

WEEKS	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
MATERIAL PROCUREMENT																								
TOOLING																								
PROCESSING						Same As With 12,000 Ton Press																		
MANUFACTURING																								
SHIPPING																								

MATERIAL COST

	COST
QUOTATION	
FIRM DATE BUYER	
MAT. COST/LB. See Item #1	
MAT. COST/PIECE 1176 @ 5.50	6468
MAT. SCRAP COST	
MAT. SCRAP VALUE 1176# Less 665# = 511# @ 20¢/#	(102)
MANUFACTURING COST	6366
MANUFACTURING COST/PC. 1.7 hrs @$150 each	255
DEV. & TOOL TRYOUT COST/PC. Set up-1 hr. + .75 prorate of changeover = 1.75 @ $150	263
CHANGE-OVER COST/PC.	
MACHINING COST/PC. 45 hrs @ 10.00	250
MAGNA-FLUX COST/PC.	
PURCHASED SERVICES:	56
FIRM DATE BUYER	
FIRM DATE BUYER	

REPLACEABLE TOOL COST

PCS./REWORK	NO. OF REWORKS	REWORK COST	REWORK TOTAL	TOTAL TOOL COST	TOTAL PCS/TOOL	
25 PC/Insert	0	0	0			888
				TOTAL MANUFACTURING COST		
				% SCRAP Included		

LABORATORY REQUIREMENTS
PACKAGING REQUIREMENTS
SHIPPING REQUIREMENTS F.O.B. EXTRUSION PLANT, BUFFALO, N.Y.
REMARKS:

SEE ITEM 1

TOTAL MANUFACTURING COST	8078
% G. & A.	
SUB TOTAL	
% PROFIT	
SUB TOTAL	9851
% RENT	
PRICE/LB. $14.81 PRICE/PIECE	98.51 ea

DEPT.	SIGNATURES	DATE
MFG. ENG.		
WORK STDS.		
QUALITY		
PROD. CONT.		
PLANT MGR.		
COST EST.		
CONTROLLER		

STAT

[redacted]

4000 TON PRESS ITEM 4 OF 8

MP 90-5

EXTRUSION COST ESTIMATE SHEET

Customer WAD
Part Name FLANGE
Mat. Specs. MPD 275
Part No. & C/L 226966
Quantity Required 100 PCS
Production Rate
Inquiry No.
Date 5/22/57

MATERIAL .163

BILLET DATA		PART DATA	
O.D. 8" I.D. LGTH.	8"	O.D. Area= .30 In.² I.D. LGTH.	48"
WEIGHT/BILLET	65	WEIGHT/PIECE (Net)	2.35
PIECES/BILLET	18	WEIGHT/PIECE (Gross)	3.61
TOTAL BILLETS REQ. (Incl. Scrap)	7	% SCRAP	20.6
TOTAL GROSS WT.	455#	% YIELD	65.1

MATERIAL COST

QUOTATION

		COST
FIRM	DATE BUYER	
MAT. COST/LB.	See Item 1	
MAT. COST/PIECE	455# @ 5.50	
MAT. SCRAP COST		2503
MAT. SCRAP VALUE	455# less 235# = 220# @ 20¢/#	(44)

MANUFACTURING DATA

PUSHES/HR.	*710	PIECES/PUSH 3 HOLE DIE	18
DEV. & TOOL TRYOUT/HRS.		DEV. & TOOL PUSHES/HR. SET-UP	1.0
PUSHES/DIE CHANGE - MANDREL	5	TIME TO CHANGE DIE & MANDREL/HRS.	-
BILLET HEATING	1	MACHINING TIME/PC.	.25
STRESS RELIEVE		MAGNA-FLUX TIME/PC.	
DESCALE	5	PURCHASED SERVICES Mach. Lab. Spec's	$36.00
		INTERSTITIAL ANALYSIS 20% CONTROL CHECK	$20.00

MANUFACTURING COST

		COST
MANUFACTURING COST/PC.	1 Hr. @ 150	150
DEV. & TOOL TRYOUT COST/PC.	1 Hr. + .75 Prorate of Changeover = 1.75 @ 150	263
CHANGE-OVER COST/PC.		
MACHINING COST/PC.	25 Hrs @ 10.00/ Hr.	250
MAGNA-FLUX COST/PC.		
PURCHASED SERVICES:		56
FIRM	DATE BUYER	
FIRM	DATE BUYER	

SPECIAL TOOLING

SPECIAL TOOLS (List Replaceable Tools First)	CODE	COST
DESIGN HOURS 50		300
Die Insert - 6 @ 185	PT	1100
Die Back Up Plate	DT	300
Die Holder Back Plate	DT	500
Dummy Block	DT	400
Extrusion Guide	DT	800
Templates & Gages	DT	300
		3700
* 4000 Ton Press & Complete Heating Facilities		
TOTAL TOOLING COST	8410	4512

REPLACEABLE TOOL COST

PCS./REWORK	NO. OF REWORKS	REWORK COST	REWORK TOTAL	TOTAL TOOL COST	TOTAL PCS/TOOL	COST
30 PC/INSERT	0	0	0	0		740

TOTAL MANUFACTURING COST
% SCRAP Included

LABORATORY REQUIREMENTS
PACKAGING REQUIREMENTS
SHIPPING REQUIREMENTS F.O.B. EXTRUSION PLANT, BUFFALO, N.Y.
REMARKS:

SEE ITEM 1

		COST
TOTAL MANUFACTURING COST		3918
	% G. & A.	
SUB TOTAL		
	% PROFIT	
SUB TOTAL		4778
	% RENT	
PRICE/LB. 20.33	PRICE/PIECE	47.78 ea

ADDITIONAL EQUIPMENT

ADDITIONAL MACHINES OR EQUIPMENT	
INSTALLATION	
RE-ARRANGEMENT	
TOTAL ADDITIONAL EQUIPMENT COST	

SHIPPING SCHEDULE

WEEKS	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
MATERIAL PROCUREMENT																								
TOOLING																								
PROCESSING						Same As With 12,000 Ton Press																		
MANUFACTURING																								
SHIPPING																								

DEPT.	SIGNATURES	DATE
MFG. ENG.		
WORK STDS.		
QUALITY		
PROD. CONT.		
PLANT MGR.		
COST EST.		
CONTROLLER		

STAT

[redacted]

4000 TON PRESS ITEM 5 OF 8

MP 90-5

EXTRUSION COST ESTIMATE SHEET

Customer WAD
Part Name FLANGE
Mat. Specs. MPD 275
Part No. & C/L 226961
Quantity Required 100 PCS
Production Rate
Inquiry No.
Date 5/22/57

MATERIAL .163

BILLET DATA		PART DATA	
O.D. 8" I.D. LGTH.	10.5	O.D. Area=1.40 In.² I.D. LGTH.	35"
WEIGHT/BILLET	86#	WEIGHT/PIECE (Net)	8.9
PIECES/BILLET	7	WEIGHT/PIECE (Gross)	12.3
TOTAL BILLETS REQ. (Incl. Scrap)	18	% SCRAP	20.6
TOTAL GROSS WT.	1548	% YIELD	12.4

MATERIAL COST

QUOTATION

		COST
FIRM	DATE BUYER	
MAT. COST/LB.		
MAT. COST/PIECE	1548 @ 5.50	8514
MAT. SCRAP COST		
MAT. SCRAP VALUE	1548 less 890# = 658 @ 20¢/#	(132)

MANUFACTURING DATA

PUSHES/HR.	*7	PIECES/PUSH	7
DEV. & TOOL TRYOUT/HRS.		DEV. & TOOL PUSHES/HR.	1.0
PUSHES/DIE CHANGE - MANDREL	5.0	TIME TO CHANGE DIE & MANDREL/HRS.	-
BILLET HEATING	1.0	MACHINING TIME/PC.	.25
STRESS RELIEVE		MAGNA-FLUX TIME/PC.	
DESCALE	5	PURCHASED SERVICES Mach. Lab. Spec's	$72.00
		INTERSTITIAL ANALYSIS 20% CONTROL CHECK	$20.00

MANUFACTURING COST

		COST
		8382
MANUFACTURING COST/PC.	2.6 Hrs @ .50	390
DEV. & TOOL TRYOUT COST/PC.	1.75 @ 50	263
CHANGE-OVER COST/PC.		
MACHINING COST/PC.	25 Hrs. @ 10.00	250
MAGNA-FLUX COST/PC.		
PURCHASED SERVICES:		92
FIRM	DATE BUYER	
FIRM	DATE BUYER	

SPECIAL TOOLING

SPECIAL TOOLS (List Replaceable Tools First)	CODE	COST
DESIGN HOURS 50		300
Die Insert - 4 @ $185	DT	740
Die Back Up Plate	DT	300
Die Holder Back Plate	DT	500
Dummy Block	DT	400
Extrusion Guide	DT	800
Templates & Gages	DT	200
		3340
* 4000 Ton Press & Complete Heating Facilities		
TOTAL TOOLING COST	8410	4073

REPLACEABLE TOOL COST

PCS./REWORK	NO. OF REWORKS	REWORK COST	REWORK TOTAL	TOTAL TOOL COST	TOTAL PCS/TOOL	COST
35 PC/INSERT	0	0	0			633

TOTAL MANUFACTURING COST
% SCRAP Included Above

LABORATORY REQUIREMENTS
PACKAGING REQUIREMENTS
SHIPPING REQUIREMENTS F.O.B. EXTRUSION PLANT, BUFFALO, N.Y.
REMARKS:

SEE ITEM 1

		COST
TOTAL MANUFACTURING COST		10,010
	% G. & A.	
SUB TOTAL		
	% PROFIT	
SUB TOTAL		12,207
	% RENT	
PRICE/LB. $13.72	PRICE/PIECE	122.07 ea

ADDITIONAL EQUIPMENT

ADDITIONAL MACHINES OR EQUIPMENT	
INSTALLATION	
RE-ARRANGEMENT	
TOTAL ADDITIONAL EQUIPMENT COST	

SHIPPING SCHEDULE

WEEKS	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
MATERIAL PROCUREMENT																								
TOOLING																								
PROCESSING									Same As With 12,000 Ton Press															
MANUFACTURING																								
SHIPPING																								

DEPT.	SIGNATURES	DATE
MFG. ENG.		
WORK STDS.		
QUALITY		
PROD. CONT.		
PLANT MGR.		
COST EST.		
CONTROLLER		

STAT

4000 TON PRESS ITEM 6 OF 8

MP 90-5

EXTRUSION COST ESTIMATE SHEET

Customer WAD Mat. Specs. MPD 275 Quantity Required 100 PCS Inquiry No.
Part Name FLANGE Part No. & C/L 226964 Production Rate Date 5/22/57

MATERIAL .163

BILLET DATA		PART DATA	
O.D. 8" I.D. LGTH.	8.5#	O.D. Area=.70 In² I.D. LGTH.	50"
WEIGHT/BILLET	69	WEIGHT/PIECE (Net)	4.79
PIECES/BILLET	8	WEIGHT/PIECE (Gross)	8.62
TOTAL BILLETS REQ. (Incl. Scrap)	15	% SCRAP	16.7
TOTAL GROSS WT.	1035	% YIELD	57.6

MANUFACTURING DATA

PUSHES/HR.	*7	PIECES/PUSH 2 Hole Die	8
DEV. & TOOL TRYOUT/HRS.		DEV. & TOOL PUSHES/HR. SET UP	1.0
PUSHES/DIE CHANGE - MANDREL	5	TIME TO CHANGE DIE & MANDREL/HRS.	-
BILLET HEATING	1	MACHINING TIME/PC.	.25
STRESS RELIEVE		MAGNA-FLUX TIME/PC.	
DESCALE	.5	PURCHASED SERVICES MACH. LAB. SPEC'S	$72.00
		INTERSTITIAL ANALYSIS 20% CONTROL CHECK	$20.00

SPECIAL TOOLING

SPECIAL TOOLS (List Replaceable Tools First)	CODE	COST
DESIGN HOURS 50		300
Die Insert - 6 @ 185	DT	1110
Die Back Up Plate	DT	300
Die Holder Back Plate	DT	500
Dummy Block	DT	400
Extrusion Guide	DT	800
Templates & Gages	DT	300
		3710
* 4000 Ton Press With Complete Heating Facilities		
TOTAL TOOLING COST		4524

ADDITIONAL EQUIPMENT

ADDITIONAL MACHINES OR EQUIPMENT	
INSTALLATION	
RE-ARRANGEMENT	
TOTAL ADDITIONAL EQUIPMENT COST	

SHIPPING SCHEDULE

WEEKS	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
MATERIAL PROCUREMENT																								
TOOLING																								
PROCESSING									Same As With 12,000 Ton Press															
MANUFACTURING																								
SHIPPING																								

MATERIAL COST

QUOTATION	COST
FIRM DATE BUYER	
MAT. COST/LB.	
MAT. COST/PIECE 1035 @ 5.50	5693
MAT. SCRAP COST	
MAT. SCRAP VALUE 1035 less 497# = 538 @ 20¢/#	(108)
	5585

MANUFACTURING COST

	COST
MANUFACTURING COST/PC. 2.1 Hrs. @ $150	315
DEV. & TOOL TRYOUT COST/PC. 1.75 Hrs. @ $150	263
CHANGE-OVER COST/PC.	
MACHINING COST/PC. 25 Hrs. @ 10.00	250
MAGNA-FLUX COST/PC.	
PURCHASED SERVICES:	92
FIRM DATE BUYER	
FIRM DATE BUYER	

REPLACEABLE TOOL COST

PCS./REWORK	NO. OF REWORKS	REWORK COST	REWORK TOTAL	TOTAL TOOL COST	TOTAL PCS/TOOL	COST
20 PC/INSERT	0	0	0			1110

TOTAL MANUFACTURING COST	
% SCRAP Included	
LABORATORY REQUIREMENTS	
PACKAGING REQUIREMENTS	
SHIPPING REQUIREMENTS F.O.B. EXTRUSION PLANT, BUFFALO, N.Y.	

REMARKS:

SEE ITEM 1

TOTAL MANUFACTURING COST	7615
% G. & A.	
SUB TOTAL	
% PROFIT	
SUB TOTAL	9287
% RENT	
PRICE/LB. 18.69 PRICE/PIECE	92.87 ea

DEPT.	SIGNATURES	DATE
MFG. ENG.		
WORK STDS.		
QUALITY		
PROD. CONT.		
PLANT MGR.		
COST EST.		
CONTROLLER		

[redacted]

4000 TON PRESS ITEM 7 OF 8

MP 90-5

EXTRUSION COST ESTIMATE SHEET

Customer WAD Mat. Specs. MPD 272 Quantity Required 100 PCS Inquiry No.
Part Name FLANGE Part No. & C/L 227594 Production Rate Date 5/22/57

MATERIAL .161

BILLET DATA		PART DATA	
O.D. 8" I.D. LGTH.	11.5	O.D. Area=1.04 In² I.D. LGTH.	50"
WEIGHT/BILLET	93	WEIGHT/PIECE (Net)	8.37
PIECES/BILLET	8	WEIGHT/PIECE (Gross)	11.6
TOTAL BILLETS REQ. (Incl. Scrap)	15	% SCRAP	16.7
TOTAL GROSS WT.	1395	% YIELD	72.2

MANUFACTURING DATA

PUSHES/HR.	*7.0	PIECES/PUSH 2 Hole Die	8
DEV. & TOOL TRYOUT/HRS.		DEV. & TOOL PUSHES/HR. SET Up	10
PUSHES/DIE CHANGE - MANDREL	1	TIME TO CHANGE DIE & MANDREL/HRS.	-
BILLET HEATING	1.5	MACHINING TIME/PC.	.25
STRESS RELIEVE	5	MAGNA-FLUX TIME/PC.	
DESCALE		PURCHASED SERVICES MACH. LAB. SPEC'S	$72.00
		INTERSTITIAL ANALYSIS 20% CONTROL CHECK	$20.00

SPECIAL TOOLING

SPECIAL TOOLS (List Replaceable Tools First)	CODE	COST
DESIGN HOURS 50		300
Die Insert - 30 @ $185	PT	5550
Die Back Up Plate	DT	300
Die Holder Back Plate	DT	500
Dummy Block	DT	400
Extrusion Guide	DT	800
Templates & Gages	DT	300
		8150
*4,000 Ton Press & Complete Heating Facilities		
TOTAL TOOLING COST		9939

ADDITIONAL EQUIPMENT

ADDITIONAL MACHINES OR EQUIPMENT	
INSTALLATION	
RE-ARRANGEMENT	
TOTAL ADDITIONAL EQUIPMENT COST	

SHIPPING SCHEDULE

WEEKS	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
MATERIAL PROCUREMENT																								
TOOLING																								
PROCESSING											Same As With 12,000 Ton Press													
MANUFACTURING																								
SHIPPING																								

MATERIAL COST

QUOTATION	COST
FIRM DATE BUYER	
MAT. COST/LB. 1395 @ 5.50	
MAT. COST/PIECE	7673
MAT. SCRAP COST 1395 less 839# = 558 @ 20.00 /#	
MAT. SCRAP VALUE	(111)
	7576

MANUFACTURING COST

	COST
MANUFACTURING COST/PC. 1 Hr. @ 150	315
DEV. & TOOL TRYOUT COST/PC. 1.75 @ 150	263
CHANGE-OVER COST/PC.	
MACHINING COST/PC. 25 Hrs. @ 10.00	250
MAGNA-FLUX COST/PC.	
PURCHASED SERVICES:	92
FIRM DATE BUYER	
FIRM DATE BUYER	

REPLACEABLE TOOL COST

PCS./REWORK	NO. OF REWORKS	REWORK COST	REWORK TOTAL	TOTAL TOOL COST	TOTAL PCS/TOOL	COST
4 PC/INSERT	0	0	0			5,550

TOTAL MANUFACTURING COST	
% SCRAP Included	
LABORATORY REQUIREMENTS	
PACKAGING REQUIREMENTS	
SHIPPING REQUIREMENTS F.O.B. EXTRUSION PLANT, BUFFALO, N.Y.	

REMARKS:

SEE ITEM 1

TOTAL MANUFACTURING COST	14,032
% G. & A.	
SUB TOTAL	
% PROFIT	
SUB TOTAL	17,112
% RENT	
PRICE/LB. $20.44 PRICE/PIECE	171.12 ea

DEPT.	SIGNATURES	DATE
MFG. ENG.		
WORK STDS.		
QUALITY		
PROD. CONT.		
PLANT MGR.		
COST EST.		
CONTROLLER		

[redacted]

STAT

MP 90-5

4000 TON PRESS   ITEM 8 of 8

EXTRUSION COST ESTIMATE SHEET

Customer WAD   Mat. Specs. MPD 272   Quantity Required 100 PCS   Inquiry No.
Part Name FLANGE   Part No. & C/L 227596   Production Rate   Date 5/22/57

MATERIAL .161

BILLET DATA		**PART DATA**	
O.D. 8" I.D. LGTH.	10"	O.D. Area=81 In^2 I.D. LGTH.	71"
WEIGHT/BILLET	81#	WEIGHT/PIECE (Net)	9.26
PIECES/BILLET	6	WEIGHT/PIECE (Gross)	13.5
TOTAL BILLETS REQ. (Incl. Scrap)	20	% SCRAP	16.7
TOTAL GROSS WT.	1620#	% YIELD	68.6

MATERIAL COST

		COST
QUOTATION		
FIRM	DATE BUYER	
MAT. COST/LB.	1620 @ 6.50	
MAT. COST/PIECE		
MAT. SCRAP COST	1620 less 926# = 694 @ 20¢/#	8910
MAT. SCRAP VALUE		(139)
		8771

MANUFACTURING DATA

PUSHES/HR.	*70	PIECES/PUSH 2 Hole Die	6
DEV. & TOOL TRYOUT/HRS.		DEV. & TOOL PUSHES/HR. SET UP	1.0
PUSHES/DIE CHANGE - MANDREL		TIME TO CHANGE DIE & MANDREL/HRS.	-
BILLET HEATING	.5	MACHINING TIME/PC.	2
STRESS RELIEVE		MAGNA-FLUX TIME/PC.	
DESCALE	.5	PURCHASED SERVICES MACH. LAB. SPEC'S	$72.00
		Interstitial Analysis 20% Control Check	$120.00

MANUFACTURING COST

		COST
MANUFACTURING COST/PC.	2.9 Hrs. @ .50	
DEV. & TOOL TRYOUT COST/PC.	1.75 @ .50	435
CHANGE-OVER COST/PC.		263
MACHINING COST/PC.	25 Hrs. @ 10.00	
MAGNA-FLUX COST/PC.		250
PURCHASED SERVICES:		
FIRM	DATE BUYER	92
FIRM	DATE BUYER	

SPECIAL TOOLING

SPECIAL TOOLS (List Replaceable Tools First)	CODE	COST
DESIGN HOURS 50		300
Die Insert 40 @ $185	PT	7400
Die Back Up Plate	DT	300
Die Holder Back Plate	DT	500
Dummy Block	DT	400
Extrusion Guide	DT	800
Templates & Gages	DT	300
		10,000
* 4000 Ton Press & Complete Heating Facilities		
TOTAL TOOLING COST		12,195

REPLACEABLE TOOL COST

PCS./REWORK	NO. OF REWORKS	REWORK COST	REWORK TOTAL	TOTAL TOOL COST	TOTAL PCS/TOOL	COST
3 PC/INSERT	0	0	0			7400

TOTAL MANUFACTURING COST		
% SCRAP	Included	

LABORATORY REQUIREMENTS
PACKAGING REQUIREMENTS -
SHIPPING REQUIREMENTS F.O.B. EXTRUSION PLANT, BUFFALO, N.Y.
REMARKS:

SEE ITEM 1

TOTAL MANUFACTURING COST		17,211
% G. & A.		
SUB TOTAL		
% PROFIT		
SUB TOTAL		20,989
% RENT		
PRICE/LB. 22.67	PRICE/PIECE	209.89

ADDITIONAL EQUIPMENT

ADDITIONAL MACHINES OR EQUIPMENT	
INSTALLATION	
RE-ARRANGEMENT	
TOTAL ADDITIONAL EQUIPMENT COST	

SHIPPING SCHEDULE

WEEKS	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
MATERIAL PROCUREMENT																								
TOOLING																								
PROCESSING																								
MANUFACTURING												Same As With 12,000 Ton Press												
SHIPPING																								

DEPT.	SIGNATURES	DATE
MFG. ENG.		
WORK STDS.		
QUALITY		
PROD. CONT.		
PLANT MGR.		
COST EST.		
CONTROLLER		

[redacted]

MP 90-5

12,000 TON PRESS   ITEM 1 OF 8

EXTRUSION COST ESTIMATE SHEET

Customer WAD   Mat. Specs. MPD-275   Quantity Required 100 PCS   Inquiry No.
Part Name FLANGE   Part No. & C/L 226956   Production Rate   Date 1/31/57

MATERIAL

BILLET DATA		**PART DATA**	
O.D. 8" I.D. LGTH.	8"	O.D. Area=53 In^2 I.D. LGTH.	49"
WEIGHT/BILLET	65#	WEIGHT/PIECE (Net)	4.23
PIECES/BILLET	10	WEIGHT/PIECE (Gross)	6.50
TOTAL BILLETS REQ. (Incl. Scrap)	12	% SCRAP	16.7
TOTAL GROSS WT.	780	% YIELD	65.1

MATERIAL COST

		COST
QUOTATION 3017		
FIRM Oregon Met.	DATE BUYER G. Guerin	
MAT. COST/LB.	5.50	
MAT. COST/PIECE	780 + 5.50 = 4290	4290
MAT. SCRAP COST	120 Per #	
MAT. SCRAP VALUE	780 - 423 = 357 x .20 = 71.40	(71)
		4219

MANUFACTURING DATA

*2 BATHS   1 BATH   @ 66 2/3% EFFIC.

PUSHES/HR.	60	3.0	PIECES/PUSH 2 Hole Die	10
DEV. & TOOL TRYOUT/HRS.			DEV. & TOOL PUSHES/HR. 1006 SET UP	2.0
PUSHES/DIE CHANGE - MANDREL		5	TIME TO CHANGE DIE & MANDREL/HRS.	0
BILLET HEATING		1	MACHINING TIME/PC.	.25
STRESS RELIEVE			MAGNA-FLUX TIME/PC.	
DESCALE		.5	PURCHASED SERVICES MACHINING SPEC'S	$36.00
			INTERSTITIAL ANALYSIS 20% CONTROL CHECK	$20.00

MANUFACTURING COST

		COST
MANUFACTURING COST/PC.	6 Hrs. @ 600	.3600
DEV. & TOOL TRYOUT COST/PC.	2 Hrs. @ 600	.1200
CHANGE-OVER COST/PC.	1 Hr. - prorate of changeover	.600
MACHINING COST/PC.	25 Hrs. @ 10.00	.250
MAGNA-FLUX COST/PC.		
PURCHASED SERVICES:		56
FIRM	DATE BUYER	
FIRM	DATE BUYER	

SPECIAL TOOLING

SPECIAL TOOLS (List Replaceable Tools First)	CODE	COST
DESIGN HOURS 50		300
Die Insert - 6 @ 185	PT	1010
Die Insert Spacer	DT	120
Dummy Block * Available	DT	$400
Back Plate Adapter	DT	$750
Extrusion Guide	DT	$800
Die Back Plate	DT	$250
Templates and Gages	DT	$300
		4,030
* At present time only one low temperature salt bath is available Additional furnace required		
TOTAL TOOLING COST		1915

REPLACEABLE TOOL COST

PCS./REWORK	NO. OF REWORKS	REWORK COST	REWORK TOTAL	TOTAL TOOL COST	TOTAL PCS/TOOL	COST
25 PC/INSERT	0	0	0			888

TOTAL MANUFACTURING COST		
% SCRAP	Included	

LABORATORY REQUIREMENTS
PACKAGING REQUIREMENTS
SHIPPING REQUIREMENTS F.O.B. EXTRUSION PLANT, BUFFALO, N.Y.
REMARKS:

There will be an 8 Hr. changeover charge whenever this or a group of these parts are run.

Straightness 1/8" In 5'

Twist 50/ft. Max. 20° In 5'

Trawsverse Flatness .025"/"

Furnished "As Extruded" and "Descaled"

Note Price On One & Two Baths

TOTAL MANUFACTURING COST		10,813
% G. & A.		
SUB TOTAL		
% PROFIT		
SUB TOTAL		13,187
% RENT		
PRICE/LB. 31.17	PRICE/PIECE	131.87

ADDITIONAL EQUIPMENT

ADDITIONAL MACHINES OR EQUIPMENT	
INSTALLATION	
RE-ARRANGEMENT	
TOTAL ADDITIONAL EQUIPMENT COST	

SHIPPING SCHEDULE

WEEKS	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
MATERIAL PROCUREMENT																								
TOOLING																								
PROCESSING																								
MANUFACTURING																								
SHIPPING																								

DEPT.	SIGNATURES	DATE
MFG. ENG.		
WORK STDS.		
QUALITY		
PROD. CONT.		
PLANT MGR.		
COST EST.		
CONTROLLER		

[redacted]

12,000 TON PRESS ITEM 2 OF 8

MP 90-5

EXTRUSION COST ESTIMATE SHEET

Customer WAD
Mat. Specs. MPD - 275
Quantity Required 100 PCS
Inquiry No.
Part Name FLANGE
Part No. & C/L 226962
Production Rate
Date 1/31/57

MATERIAL .163

BILLET DATA		PART DATA	
O.D. 8" I.D. LGTH.	10"	O.D. Area .96 In² I.D. LGTH.	62"
WEIGHT/BILLET	82#	WEIGHT/PIECE (Net)	9.7#
PIECES/BILLET	6	WEIGHT/PIECE (Gross)	13.7#
TOTAL BILLETS REQ. (Incl. Scrap)	20	% SCRAP	16.7
TOTAL GROSS WT.	1640 #	% YIELD	70.1

MANUFACTURING DATA 66 2/3% Eff.

	*2 BATHS	1 BATH		
PUSHES/HR.	60	30	PIECES/PUSH 2 Hole Die	6
DEV. & TOOL TRYOUT/HRS.			DEV. & TOOL PUSHES/HR. SET UP	2.0
PUSHES/DIE CHANGE - MANDREL		5	TIME TO CHANGE DIE & MANDREL/HRS.	0
BILLET HEATING		1	MACHINING TIME/PC.	.25
STRESS RELIEVE			MAGNA-FLUX TIME/PC.	
DESCALE		.5	PURCHASED SERVICES MACH. LAB. SPEC'S	$72.00
			INTERSTITIAL ANALYSIS 20% CONTROL CHECK	$20.00

SPECIAL TOOLING

SPECIAL TOOLS (List Replaceable Tools First)	CODE	COST
DESIGN HOURS 50		300
Die Insert - 8 @ 185	PT	1480
Die Insert Spacer	DT	120
Dummy Block * Available	DT	400
Back Plate Adapter	DT	750
Extrusion Guide	DT	800
Die Back Plate	DT	250
Templates & Gages	DT	300
		4400
* See Item 1		
TOTAL TOOLING COST		5366

ADDITIONAL EQUIPMENT

ADDITIONAL MACHINES OR EQUIPMENT	
INSTALLATION	
RE-ARRANGEMENT	
TOTAL ADDITIONAL EQUIPMENT COST	

SHIPPING SCHEDULE

WEEKS	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
MATERIAL PROCUREMENT																								
TOOLING																								
PROCESSING																								
MANUFACTURING																								
SHIPPING																								

MATERIAL COST

	COST
QUOTATION	
FIRM DATE BUYER	
MAT. COST/LB.	
MAT. COST/PIECE 1640 @ 5.50	9,020
MAT. SCRAP COST	
MAT. SCRAP VALUE	(134)
	8,886

MANUFACTURING COST

MANUFACTURING COST/PC. 10 Hrs. @ 600/Hr.	6000
DEV. & TOOL TRYOUT COST/PC.	1200
CHANGE-OVER COST/PC. 1 Hr. Prorated Changeover	600
MACHINING COST/PC.	250
MAGNA-FLUX COST/PC.	
PURCHASED SERVICES:	92
FIRM DATE BUYER	
FIRM DATE BUYER	

REPLACEABLE TOOL COST

PCS./REWORK	NO. OF REWORKS	REWORK COST	REWORK TOTAL	TOTAL TOOL COST	TOTAL PCS/TOOL	
15 PC/INSERT	0	0	0			1480

TOTAL MANUFACTURING COST
% SCRAP Included Above

LABORATORY REQUIREMENTS
PACKAGING REQUIREMENTS
SHIPPING REQUIREMENTS F.O.B. EXTRUSION PLANT, BUFFALO, N.Y.
REMARKS:

SEE ITEM 1

TOTAL MANUFACTURING COST	18,508
% G. & A.	
SUB TOTAL	
% PROFIT	
SUB TOTAL	22,571
% RENT	
PRICE/LB. 23.27 PRICE/PIECE	225.71

DEPT.	SIGNATURES	DATE
MFG. ENG.		
WORK STDS.		
QUALITY		
PROD. CONT.		
PLANT MGR.		
COST EST.		
CONTROLLER		

[redacted]

12,000 TON PRESS ITEM 3 OF 8

MP 90-5

EXTRUSION COST ESTIMATE SHEET

Customer WAD
Mat. Specs. MPD 275
Quantity Required 100 PCS
Inquiry No.
Part Name FLANGE
Part No. & C/L 226963
Production Rate
Date 1/31/57

MATERIAL .163

BILLET DATA		PART DATA	
O.D. 8" I.D. LGTH.	12"	O.D. Area 1.2 In² I.D. LGTH.	34"
WEIGHT/BILLET	98#	WEIGHT/PIECE (Net)	6.65
PIECES/BILLET	10	WEIGHT/PIECE (Gross)	9.80
TOTAL BILLETS REQ. (Incl. Scrap)	12	% SCRAP	16.7
TOTAL GROSS WT.	1176#	% YIELD	67.8

MANUFACTURING DATA 66 2/3 % Eff.

	*2 BATHS	1 BATH		
PUSHES/HR.	6.0	3.0	PIECES/PUSH 2 Hole Die	10
DEV. & TOOL TRYOUT/HRS.			DEV. & TOOL PUSHES/HR. SET UP	2.0
PUSHES/DIE CHANGE - MANDREL		5	TIME TO CHANGE DIE & MANDREL/HRS.	0
BILLET HEATING		1	MACHINING TIME/PC.	25
STRESS RELIEVE			MAGNA-FLUX TIME/PC.	
DESCALE		.5	PURCHASED SERVICES Mach. Lab. Spec's	$36.00
			INTERSTITIAL ANALYSIS 20% CONTROL CHECK	$20.00

SPECIAL TOOLING

SPECIAL TOOLS (List Replaceable Tools First)	CODE	COST
DESIGN HOURS 50		300
Die Insert - 6 @ 185	PT	1110
Die Insert Spacer	DT	120
Dummy Block *Available	DT	400
Back Plate Adapter	DT	750
Extrusion Guide	DT	800
Die Back Plate	DT	250
Templates & Gages	DT	300
		4030
* See Item 1		
TOTAL TOOLING COST		4,915

ADDITIONAL EQUIPMENT

ADDITIONAL MACHINES OR EQUIPMENT	
INSTALLATION	
RE-ARRANGEMENT	
TOTAL ADDITIONAL EQUIPMENT COST	

SHIPPING SCHEDULE

WEEKS	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
MATERIAL PROCUREMENT																								
TOOLING																								
PROCESSING																								
MANUFACTURING																								
SHIPPING																								

MATERIAL COST

	COST
QUOTATION	
FIRM DATE BUYER	
MAT. COST/LB.	
MAT. COST/PIECE 1176 @ 5.50/#	6468
MAT. SCRAP COST	
MAT. SCRAP VALUE	(102)
	6366

MANUFACTURING COST

MANUFACTURING COST/PC. 6 Hrs. @ 600	3600
DEV. & TOOL TRYOUT COST/PC. 2 Hrs. @ 600	1200
CHANGE-OVER COST/PC. 1 Hr. @ 600	600
MACHINING COST/PC.	250
MAGNA-FLUX COST/PC.	
PURCHASED SERVICES:	56
FIRM DATE BUYER	
FIRM DATE BUYER	

REPLACEABLE TOOL COST

PCS./REWORK	NO. OF REWORKS	REWORK COST	REWORK TOTAL	TOTAL TOOL COST	TOTAL PCS/TOOL	
25 PC/INSERT	0	0	0			888

TOTAL MANUFACTURING COST
% SCRAP Included

LABORATORY REQUIREMENTS
PACKAGING REQUIREMENTS
SHIPPING REQUIREMENTS F.O.B. EXTRUSION PLANT, BUFFALO, N.Y.
REMARKS:

SEE ITEM 1

TOTAL MANUFACTURING COST	12,960
% G. & A.	
SUB TOTAL	
% PROFIT	
SUB TOTAL	15,805
% RENT	
PRICE/LB. 23.77 PRICE/PIECE	158.05

DEPT.	SIGNATURES	DATE
MFG. ENG.		
WORK STDS.		
QUALITY		
PROD. CONT.		
PLANT MGR.		
COST EST.		
CONTROLLER		

[redacted]

STAT

12,000 TON PRESS ITEM 4 OF 8

MP 90-5

EXTRUSION COST ESTIMATE SHEET

Customer WAD
Mat. Specs. MPD 275
Quantity Required 100 PCS
Inquiry No.
Part Name FLANGE
Part No. & C/L 226966
Production Rate
Date 1/31/57

MATERIAL .163

BILLET DATA		PART DATA	
O.D. 8" I.D. LGTH.	8"	O.D. Area 30 In^2 I.D. LGTH.	48"
WEIGHT/BILLET	65#	WEIGHT/PIECE (Net)	2.35#
PIECES/BILLET	18	WEIGHT/PIECE (Gross)	3.61
TOTAL BILLETS REQ. (Incl. Scrap)	7	% SCRAP	20.6
TOTAL GROSS WT.	455#	% YIELD	65.1

MANUFACTURING DATA 66 2/3 Eff.

* 2 BATHS	1 BATH		
PUSHES/HR. 6.0	3.0	PIECES/PUSH 3 Hole Die	18
DEV. & TOOL TRYOUT/HRS.		DEV. & TOOL PUSHES/HR. Tool Set Up	2.0
PUSHES/DIE CHANGE - MANDREL	5	TIME TO CHANGE DIE & MANDREL/HRS.	
BILLET HEATING	1	MACHINING TIME/PC.	.25
STRESS RELIEVE		MAGNA-FLUX TIME/PC.	
DESCALE	.5	PURCHASED SERVICES MACH LAB SPEC'S	$36.00
		INTERSTITIAL ANALYSIS 20% CONTROL CHECK	$20.00

SPECIAL TOOLING

SPECIAL TOOLS (List Replaceable Tools First)	CODE	COST
DESIGN HOURS 50		300
Die Insert - 6 @ 185	PT	1110
Die Insert Spacer	DT	120
Dummy Block * Available	DT	400
Back Plate Adapter	DT	750
Extrusion Guide	DT	800
Die Back Plate	DT	250
Templates & Gages	DT	300
		1030
* See Item 1		
TOTAL TOOLING COST		4,915

ADDITIONAL EQUIPMENT

ADDITIONAL MACHINES OR EQUIPMENT	
INSTALLATION	
RE-ARRANGEMENT	
TOTAL ADDITIONAL EQUIPMENT COST	

SHIPPING SCHEDULE

WEEKS	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
MATERIAL PROCUREMENT																								
TOOLING																								
PROCESSING																								
MANUFACTURING																								
SHIPPING																								

MATERIAL COST

QUOTATION			COST
FIRM	DATE	BUYER	
MAT. COST/LB.			
MAT. COST/PIECE 455 @ 5.50			2503
MAT. SCRAP COST			
MAT. SCRAP VALUE			(44)
			2459

MANUFACTURING COST

MANUFACTURING COST/PC. 3.5 Hrs. @ 600			2100
DEV. & TOOL TRYOUT COST/PC.			1200
CHANGE-OVER COST/PC.			600
MACHINING COST/PC.			250
MAGNA-FLUX COST/PC.			
PURCHASED SERVICES:			56
FIRM	DATE	BUYER	
FIRM	DATE	BUYER	

REPLACEABLE TOOL COST

PCS./REWORK	NO. OF REWORKS	REWORK COST	REWORK TOTAL	TOTAL TOOL COST	TOTAL PCS/TOOL	
30 PC/INSERT	0	0	0			740
				TOTAL MANUFACTURING COST		
				% SCRAP Included		

LABORATORY REQUIREMENTS
PACKAGING REQUIREMENTS
SHIPPING REQUIREMENTS F.O.B. EXTRUSION PLANT, BUFFALO, N.Y.
REMARKS:

SEE ITEM 1

TOTAL MANUFACTURING COST	7,405
% G. & A.	
SUB TOTAL	
% PROFIT	
SUB TOTAL	9,030
% RENT	
PRICE/LB. 38.43 PRICE/PIECE	90.30

DEPT.	SIGNATURES	DATE
MFG. ENG.		
WORK STDS.		
QUALITY		
PROD. CONT.		
PLANT MGR.		
COST EST.		
CONTROLLER		

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12,000 TON PRESS ITEM 5 of 8

MP 90-5

EXTRUSION COST ESTIMATE SHEET

Customer WAD
Mat. Specs. MPD- 275
Quantity Required 100 PCS.
Inquiry No.
Part Name FLANGE
Part No. & C/L 226961
Production Rate
Date 1/31/57

MATERIAL

BILLET DATA		PART DATA	
O.D. 8" I.D. - LGTH.	10.5	~~O.D.~~ Area 1.56"^{2} I.D. LGTH.	35"
WEIGHT/BILLET	86#	WEIGHT/PIECE (Net)	8.90#
PIECES/BILLET	7	WEIGHT/PIECE (Gross)	12.3#
TOTAL BILLETS REQ. (Incl. Scrap)	18	% SCRAP	20.6
TOTAL GROSS WT.	1548#	% YIELD	72.4

MANUFACTURING DATA 66 2/3% Effic.

* 2 Baths	1 Bath		
PUSHES/HR. 6.0	3.0	PIECES/PUSH	7
DEV. & TOOL TRYOUT/HRS.		DEV. & TOOL PUSHES/~~HR.~~ Tool Set Up	2.0
PUSHES/DIE CHANGE - MANDREL	5	TIME TO CHANGE DIE & MANDREL/HRS.	0
BILLET HEATING	1	MACHINING TIME/PC.	.25
STRESS RELIEVE		MAGNA-FLUX TIME/PC.	
DESCALE	5	PURCHASED SERVICES Mach. Lab Specimens	$72.00
		Interstitial Analysis 20% Control Check	20.00

SPECIAL TOOLING

SPECIAL TOOLS (List Replaceable Tools First)	CODE	COST
DESIGN HOURS 50		300
Die Insert - 4 @ $185	PT	740
Die Insert Spacer	DT	120
Dummy Block *Available	DT	400
Back Plate Adapter	DT	750
Extrusion Guide	DT	800
Die Back Plate	DT	250
Templates & Gages	DT	300
		3660
* See Item I		
TOTAL TOOLING COST		4463

ADDITIONAL EQUIPMENT

ADDITIONAL MACHINES OR EQUIPMENT	
INSTALLATION	
RE-ARRANGEMENT	
TOTAL ADDITIONAL EQUIPMENT COST	

SHIPPING SCHEDULE

WEEKS	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
MATERIAL PROCUREMENT																								
TOOLING																								
PROCESSING																								
MANUFACTURING																								
SHIPPING																								

MATERIAL COST

QUOTATION			COST
FIRM	DATE	BUYER	
MAT. COST/LB.			
MAT. COST/PIECE 1548 @ 5.50			8514
MAT. SCRAP COST			
MAT. SCRAP VALUE			(132)
			8382

MANUFACTURING COST

MANUFACTURING COST/PC. 9 hrs at 600			5400
DEV. & TOOL TRYOUT COST/PC. 2 "			1200
CHANGE-OVER COST/PC. 1 "			600
MACHINING COST/PC.			250
MAGNA-FLUX COST/PC.			
PURCHASED SERVICES:			92
FIRM	DATE	BUYER	
FIRM	DATE	BUYER	

REPLACEABLE TOOL COST

PCS./REWORK	NO. OF REWORKS	REWORK COST	REWORK TOTAL	TOTAL TOOL COST	TOTAL PCS/TOOL	
35 PC/Die	0	0	0			633
				TOTAL MANUFACTURING COST		
				% SCRAP Included		

LABORATORY REQUIREMENTS
PACKAGING REQUIREMENTS
SHIPPING REQUIREMENTS F.O.B. EXTRUSION PLANT, BUFFALO, N.Y.
REMARKS:

See Item I

TOTAL MANUFACTURING COST	15924
% G. & A.	
SUB TOTAL	
% PROFIT	
SUB TOTAL	
% RENT	19420
PRICE/LB. 21.82 PRICE/PIECE	194.20 ea.

DEPT.	SIGNATURES	DATE
MFG. ENG.		
WORK STDS.		
QUALITY		
PROD. CONT.		
PLANT MGR.		
COST EST.		
CONTROLLER		

[redacted]

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12,000 TON PRESS ITEM 6 of 8

MP 90-5

EXTRUSION COST ESTIMATE SHEET

Customer WAD Mat. Specs. MPD-275 Quantity Required 100 PCS. Inquiry No.
Part Name FLANGE Part No. & C/L 226964 Production Rate Date 1-31-57

MATERIAL .163

BILLET DATA		PART DATA	
O.D. 8" I.D. – LGTH.	8.5#	~~O.D.~~ Area-.70 In^2 I.D. LGTH.	50"
WEIGHT/BILLET	69#	WEIGHT/PIECE (Net)	4.97
PIECES/BILLET	8	WEIGHT/PIECE (Gross)	8.62
TOTAL BILLETS REQ. (Incl. Scrap)	15	% SCRAP	16.7
TOTAL GROSS WT.	1035#	% YIELD	57.6

MANUFACTURING DATA 66 2/3% Effic

* 2 Baths — 1 Bath

	* 2 Baths	1 Bath		
PUSHES/HR.	6.0	3.0	PIECES/PUSH 2 Hole Die	8
DEV. & TOOL TRYOUT/HRS.			DEV. & TOOL PUSHES/~~HR.~~ Tool Set Up	2.0
PUSHES/DIE CHANGE - MANDREL		5	TIME TO CHANGE DIE & MANDREL/HRS.	0
BILLET HEATING		1	MACHINING TIME/PC.	.25
STRESS RELIEVE			MAGNA-FLUX TIME/PC.	
DESCALE		.5	PURCHASED SERVICES Mach. Lab. Spec.	$ 72.00
			Interstitial Analysis	20.00
			20% Control Check	

SPECIAL TOOLING

SPECIAL TOOLS (List Replaceable Tools First)	CODE	COST
DESIGN HOURS 50		300
Die Insert – 6 at 185	PT	1110
Die Insert Spacer	DT	120
Dummy Block *Available	DT	400
Back Plate Adapter	DT	750
Extrusion Guide	DT	800
Die Back Plate	DT	250
Templates & Gages	DT	300
		6730
* See Item I		
TOTAL TOOLING COST		8207

ADDITIONAL EQUIPMENT

ADDITIONAL MACHINES OR EQUIPMENT	
INSTALLATION	
RE-ARRANGEMENT	
TOTAL ADDITIONAL EQUIPMENT COST	

SHIPPING SCHEDULE

WEEKS	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
MATERIAL PROCUREMENT																								
TOOLING																								
PROCESSING																								
MANUFACTURING																								
SHIPPING																								

MATERIAL COST

QUOTATION		COST
FIRM DATE BUYER		
MAT. COST/LB.		
MAT. COST/PIECE	1035 @ 5.50	5693
MAT. SCRAP COST		
MAT. SCRAP VALUE		(108)
		5585

MANUFACTURING COST

		COST
MANUFACTURING COST/PC.	7.5 hrs @ 600	4500
DEV. & TOOL TRYOUT COST/PC.	2 " @ 600	1200
CHANGE-OVER COST/PC.	1 " @ 600	600
MACHINING COST/PC.		
MAGNA-FLUX COST/PC.		
PURCHASED SERVICES:		92
FIRM DATE BUYER		
FIRM DATE BUYER		

REPLACEABLE TOOL COST

PCS./REWORK	NO. OF REWORKS	REWORK COST	REWORK TOTAL	TOTAL TOOL COST	TOTAL PCS/TOOL	COST
20 Pc/Insert	0	0	0			1110
				TOTAL MANUFACTURING COST		
				% SCRAP Included		

LABORATORY REQUIREMENTS
PACKAGING REQUIREMENTS
SHIPPING REQUIREMENTS F.O.B. EXTRUSION PLANT, BUFFALO, N.Y.
REMARKS:
See Item I

TOTAL MANUFACTURING COST	13337
% G. & A.	
SUB TOTAL	
% PROFIT	
SUB TOTAL	16265
% RENT	
PRICE/LB. 32.73 PRICE/PIECE	162.65 ea

DEPT.	SIGNATURES	DATE
MFG. ENG.		
WORK STDS.		
QUALITY		
PROD. CONT.		
PLANT MGR.		
COST EST.		
CONTROLLER		

[redacted]

12,000 TON PRESS ITEM 7 of 8

MP 90-5

EXTRUSION COST ESTIMATE SHEET

Customer WAD Mat. Specs. MPD 272 Quantity Required 100 PCS. Inquiry No.
Part Name FLANGE Part No. & C/L 227594 Production Rate Date 1-31-57

MATERIAL .161

BILLET DATA		PART DATA	
O.D. 8" I.D. LGTH.	11.5	~~O.D.~~ Area-1.04 In^2 I.D. LGTH.	50"
WEIGHT/BILLET	93#	WEIGHT/PIECE (Net)	8.37
PIECES/BILLET	8	WEIGHT/PIECE (Gross)	11.6
TOTAL BILLETS REQ. (Incl. Scrap)	15	% SCRAP	16.7
TOTAL GROSS WT.	1395#	% YIELD	72.2

MANUFACTURING DATA 66 2/3% Eff.

	2 Baths	1 Bath		
PUSHES/HR.		2	PIECES/PUSH 2 Hole Die	8
DEV. & TOOL TRYOUT/HRS.			DEV. & TOOL PUSHES/~~HR.~~ Set Up	2.0
PUSHES/DIE CHANGE - MANDREL		1	TIME TO CHANGE DIE & MANDREL/HRS.	0
BILLET HEATING		1.5	MACHINING TIME/PC.	.25
STRESS RELIEVE			MAGNA-FLUX TIME/PC.	
DESCALE		.5	PURCHASED SERVICES Mach Lab. Specimens	$72.00
			Interstitial Analysis	20.00
			20% Control Check	

SPECIAL TOOLING

SPECIAL TOOLS (List Replaceable Tools First)	CODE	COST
DESIGN HOURS 50		300
Die Insert – 30 : $185	PT	5550
Die Insert Spacer	DT	120
Dummy Block *Available	DT	400
Back Plate Adapter	DT	750
Extrusion Guide	DT	800
Die Back Plate	DT	250
Templates & Gages	DT	300
		8470
See Item #1		
TOTAL TOOLING COST		10329

ADDITIONAL EQUIPMENT

ADDITIONAL MACHINES OR EQUIPMENT	
INSTALLATION	
RE-ARRANGEMENT	
TOTAL ADDITIONAL EQUIPMENT COST	

SHIPPING SCHEDULE

WEEKS	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
MATERIAL PROCUREMENT																								
TOOLING																								
PROCESSING																								
MANUFACTURING																								
SHIPPING																								

MATERIAL COST

QUOTATION		COST
FIRM DATE BUYER		
MAT. COST/LB.		
MAT. COST/PIECE	1395 @ 5.50	7673
MAT. SCRAP COST		
MAT. SCRAP VALUE		(111)
		7562

MANUFACTURING COST

		COST
MANUFACTURING COST/PC.	11.2 hrs. @ 600	6720
DEV. & TOOL TRYOUT COST/PC.	2 " 600	1200
CHANGE-OVER COST/PC.	1 " 600	600
MACHINING COST/PC.		250
MAGNA-FLUX COST/PC.		
PURCHASED SERVICES:		92
FIRM DATE BUYER		
FIRM DATE BUYER		

REPLACEABLE TOOL COST

PCS./REWORK	NO. OF REWORKS	REWORK COST	REWORK TOTAL	TOTAL TOOL COST	TOTAL PCS/TOOL	COST
4 Pc/Insert	0	0	0			5550
				TOTAL MANUFACTURING COST		
				% SCRAP Included		

LABORATORY REQUIREMENTS
PACKAGING REQUIREMENTS
SHIPPING REQUIREMENTS F.O.B. EXTRUSION PLANT, BUFFALO, N.Y.
REMARKS:
See Item I

TOTAL MANUFACTURING COST	21974
% G. & A.	
SUB TOTAL	
% PROFIT	
SUB TOTAL	26798
% RENT	
PRICE/LB. 32.02 PRICE/PIECE	267.98 ea

DEPT.	SIGNATURES	DATE
MFG. ENG.		
WORK STDS.		
QUALITY		
PROD. CONT.		
PLANT MGR.		
COST EST.		
CONTROLLER		

STAT

12,000 TON PRESS ITEM 8 of 8

MP 90-5

EXTRUSION COST ESTIMATE SHEET

Customer WAD
Mat. Specs. MPD 272
Quantity Required 100 PCS.
Inquiry No.
Part Name FLANGE
Part No. & C/L 227596
Production Rate
Date 1-31-57

MATERIAL

BILLET DATA		PART DATA	
O.D. 8" I.D. LGTH.	10"	~~O.D.~~ Area-.81 In² I.D. LGTH.	71"
WEIGHT/BILLET	81#	WEIGHT/PIECE (Net)	9.26
PIECES/BILLET	6	WEIGHT/PIECE (Gross)	13.5
TOTAL BILLETS REQ. (Incl. Scrap)	20	% SCRAP	16.7
TOTAL GROSS WT.	1620"	% YIELD	68.6

MANUFACTURING DATA

* 2 Baths	1 Bath		
PUSHES/HR. 4.0	2	PIECES/PUSH 2 Hole Die	6
DEV. & TOOL TRYOUT/HRS.		DEV. & TOOL PUSHES/~~HR~~.Set Up	2.0
PUSHES/DIE CHANGE - MANDREL	1	TIME TO CHANGE DIE & MANDREL/HRS.	0
BILLET HEATING	1.50	MACHINING TIME/PC.	.25
STRESS RELIEVE		MAGNA-FLUX TIME/PC.	
DESCALE	.5	PURCHASED SERVICES Mach. Lab. Specimens	$72.00
		Interstitial Analysis	20.00
		Control Check	

SPECIAL TOOLING

SPECIAL TOOLS (List Replaceable Tools First)	CODE	COST
DESIGN HOURS 50		300
Die Insert - 40 @ $185.	PT	7400
Die Insert Spacer	DT	120
Dummy Block * Available	DT	400
Back Plate Adapter	DT	750
Extrusion Guide	DT	800
Die Back Plate	DT	250
Templates & Gages	DT	300
		10320
See Item *1		
TOTAL TOOLING COST		12585

ADDITIONAL EQUIPMENT

ADDITIONAL MACHINES OR EQUIPMENT	
INSTALLATION	
RE-ARRANGEMENT	
TOTAL ADDITIONAL EQUIPMENT COST	

SHIPPING SCHEDULE

WEEKS	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
MATERIAL PROCUREMENT																								
TOOLING																								
PROCESSING																								
MANUFACTURING																								
SHIPPING																								

MATERIAL COST

	COST
QUOTATION	
FIRM DATE BUYER	
MAT. COST/LB.	
MAT. COST/PIECE 1620 @ 5.50	8910
MAT. SCRAP COST	
MAT. SCRAP VALUE	(139)
	8771

MANUFACTURING COST

MANUFACTURING COST/PC. 15 hrs @ 600	9000
DEV. & TOOL TRYOUT COST/PC.	1200
CHANGE-OVER COST/PC.	600
MACHINING COST/PC.	250
MAGNA-FLUX COST/PC.	
PURCHASED SERVICES:	92
FIRM DATE BUYER	
FIRM DATE BUYER	

REPLACEABLE TOOL COST

~~PCS./REWORK~~	NO. OF REWORKS	REWORK COST	REWORK TOTAL	TOTAL TOOL COST	TOTAL PCS/TOOL	
3 Pc/Insert	0	0	0			7400

TOTAL MANUFACTURING COST	
% SCRAP Included	
LABORATORY REQUIREMENTS	
PACKAGING REQUIREMENTS	
SHIPPING REQUIREMENTS F.O.B. EXTRUSION PLANT, BUFFALO, N.Y.	

REMARKS:
See Item I

TOTAL MANUFACTURING COST	27313
% G. & A.	
SUB TOTAL	
% PROFIT	
SUB TOTAL	33309
% RENT	
PRICE/LB. 35.97 PRICE/PIECE	333.09 ea.

DEPT.	SIGNATURES	DATE
MFG. ENG.		
WORK STDS.		
QUALITY		
PROD. CONT.		
PLANT MGR.		
COST EST.		
CONTROLLER		

[redacted]

MP 90-5

EXTRUSION COST ESTIMATE SHEET

Customer WAD
Mat. Specs. MPD 272
Quantity Required 24 Pcs.
Inquiry No. SHEET 1 of 2
Part Name ROTOR SHAFT
Part No. & C/L Upset Only
Production Rate
Date

MATERIAL

BILLET DATA		PART DATA	
O.D. .6" I.D. LGTH.	12.0	O.D. 16 1/4 I.D. 5" LGTH.	10 1/2
WEIGHT/BILLET	386	WEIGHT/PIECE (Net)	320
PIECES/BILLET	1	WEIGHT/PIECE (Gross)	386
TOTAL BILLETS REQ. (Incl. Scrap)	25	% SCRAP	4%
TOTAL GROSS WT.	9850	% YIELD	83%

MANUFACTURING DATA

1 Bath	2 Bath **		
PUSHES/HR. 1	2	PIECES/PUSH	1
DEV. & TOOL TRYOUT/HRS.		~~DEV. & TOOL PUSHES/HR.~~ Set up	2.0
PUSHES/DIE CHANGE - MANDREL	15(Mandrel)	TIME TO CHANGE DIE & MANDREL/HRS.	1.0
BILLET HEATING 3 1/2	3 1/2	MACHINING TIME/PC.	4.0
STRESS RELIEVE		MAGNA-FLUX TIME/PC.	
DESCALE		PURCHASED SERVICES	
		Interstitial Analysis	20.00
		20% Control	

SPECIAL TOOLING

SPECIAL TOOLS (List Replaceable Tools First)	CODE	COST
DESIGN HOURS		
Die Insert 1 Required	PT	$6.50
Die Back Plate *	DT	
Die Holder Back Plate *	DT	
Mandrel - 2 Required (1 on Hand)	PT	1200.00
Pressing Disc *	DT	
		1850.00
* Available (from development programs)		
** Additional Low Temp. Bath Required		
TOTAL TOOLING COST	820	$2,256.

ADDITIONAL EQUIPMENT

ADDITIONAL MACHINES OR EQUIPMENT	
INSTALLATION	
RE-ARRANGEMENT	
TOTAL ADDITIONAL EQUIPMENT COST	

SHIPPING SCHEDULE

WEEKS	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
MATERIAL PROCUREMENT																								
TOOLING																								
PROCESSING																								
MANUFACTURING																								
SHIPPING																								

MATERIAL COST

	COST
QUOTATION 3017	
FIRM DATE BUYER	
MAT. COST/LB. 5.90/#	
MAT. COST/PIECE 9850 @ 5.90	58,115
MAT. SCRAP COST	
MAT. SCRAP VALUE 9850 less 7680 - 2170# @ 20¢/#	(434)
	57,681

MANUFACTURING COST

MANUFACTURING COST/PC. 37.5 hrs. @ $600/hr	22,500
DEV. & TOOL TRYOUT COST/PC. 2 hrs @ 600/hr	1,200
CHANGE-OVER COST/PC. 2 hrs. @ 600/hr	1,200
MACHINING COST/PC. 25 pc. @ 4hr.- 100 hrs.@ 10.00	1,000
MAGNA-FLUX COST/PC.	
PURCHASED SERVICES:	
FIRM DATE BUYER	20
FIRM DATE BUYER	

REPLACEABLE TOOL COST

PCS./REWORK	NO. OF REWORKS	REWORK COST	REWORK TOTAL	TOTAL TOOL COST	TOTAL PCS/TOOL	
25	4	$400	1600	2250	125 -$16. ea	270
15	4	720	2880	4080	75 - 54.40ea	1360

TOTAL MANUFACTURING COST	
% SCRAP Included above	
LABORATORY REQUIREMENTS	
PACKAGING REQUIREMENTS	
SHIPPING REQUIREMENTS F.O.B. EXTRUSION PLANT, BUFFALO, N.Y.	

REMARKS:

TOTAL MANUFACTURING COST	85,231
% G. & A.	
SUB TOTAL	
% PROFIT	
SUB TOTAL	85,231
% RENT	
PRICE/LB. 11.10 PRICE/PIECE	3,551.29ea.

DEPT.	SIGNATURES	DATE
MFG. ENG.		
WORK STDS.		
QUALITY		
PROD. CONT.		
PLANT MGR.		
COST EST.		
CONTROLLER		

[redacted]

STAT

MP 90-5

EXTRUSION COST ESTIMATE SHEET

Customer WAD
Mat. Specs. MPD -272
Quantity Required 100
Inquiry No. SHEET 2 of 2
Part Name ROTOR SHAFT
Part No. & C/L 226970
Production Rate
Date 5-27-57

MATERIAL

BILLET DATA		PART DATA	
O.D. 16 1/4 I.D. 5 LGTH.	10 1/2	O.D. 6 1/8 I.D. 4 7/8 LGTH.	25"
WEIGHT/BILLET	320	WEIGHT/PIECE (Net)	43.5
PIECES/BILLET	5	WEIGHT/PIECE (Gross)	64.0
TOTAL BILLETS REQ. (Incl. Scrap)	24	% SCRAP	16.7
TOTAL GROSS WT.	7680	% YIELD	68

MANUFACTURING DATA @ 66 2/3% Effic.

	1 Bath	2 Baths		
PUSHES/HR.	1.25	2.5	PIECES/PUSH	5
DEV. & TOOL TRYOUT/HRS.			~~DEV. & TOOL PUSHES/HR.~~ Set Up	2.0
PUSHES/DIE CHANGE - MANDREL	15(Mandrel)	4.0(Die)	TIME TO CHANGE DIE & MANDREL/HRS.	1.0
BILLET HEATING	2.5	2.5	MACHINING TIME/PC.	8.0
STRESS RELIEVE			MAGNA-FLUX TIME/PC.	
DESCALE		.5	PURCHASED SERVICES Mach. Specimens	72.00

MATERIAL COST

QUOTATION			COST
FIRM	DATE	BUYER	
MAT. COST/LB.			
MAT. COST/PIECE See Sheet #1			85231
MAT. SCRAP COST			
MAT. SCRAP VALUE 7680 less 4350# - 3330# @ 20¢/#			(666)
			84565

MANUFACTURING COST

			COST
MANUFACTURING COST/PC. 29 hr @ $600			17400
DEV. & TOOL TRYOUT COST/PC. 2 hrs @ 600			1200
CHANGE-OVER COST/PC. 4 hrs @ 600			2400
MACHINING COST/PC. 120 pcs. x 8 hrs - 960 hrs @ 10.00			9600
MAGNA-FLUX COST/PC.			
PURCHASED SERVICES:			72
FIRM	DATE	BUYER	
FIRM	DATE	BUYER	

SPECIAL TOOLING

SPECIAL TOOLS (List Replaceable Tools First)	CODE	COST
DESIGN HOURS		
Die Insert -6@ 6.50	PT	3900
Die Back Plate *	DT	
Die Holder Back Plate *	DT	
Mandrel 2 @ 1200	PT	2400
Pressing Disc *	DT	
		6300
* Available		
** Additional Low Temp. Required		
TOTAL TOOLING COST		7683

REPLACEABLE TOOL COST

PCS./REWORK	NO. OF REWORKS	REWORK COST	REWORK TOTAL	TOTAL TOOL COST	TOTAL PCS/TOOL	COST
20 Pc/Insert	4	400	1600	2250	100-22.50 ea	2700
75 pcs.	4	720	2880	4080	375- 10.88	1306

TOTAL MANUFACTURING COST
% SCRAP Included

LABORATORY REQUIREMENTS
PACKAGING REQUIREMENTS
SHIPPING REQUIREMENTS F.O.B. EXTRUSION PLANT, BUFFALO, N.Y.
REMARKS:

TOTAL MANUFACTURING COST	119243
% G. & A.	
SUB TOTAL	
% PROFIT	
SUB TOTAL	145418
% RENT	
PRICE/LB. 33.43 PRICE/PIECE	1454.18 ea.

ADDITIONAL EQUIPMENT

ADDITIONAL MACHINES OR EQUIPMENT
INSTALLATION
RE-ARRANGEMENT
TOTAL ADDITIONAL EQUIPMENT COST

SHIPPING SCHEDULE

WEEKS	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
MATERIAL PROCUREMENT																								
TOOLING																								
PROCESSING																								
MANUFACTURING																								
SHIPPING																								

DEPT.	SIGNATURES	DATE
MFG. ENG.		
WORK STDS.		
QUALITY		
PROD. CONT.		
PLANT MGR.		
COST EST.		
CONTROLLER		

TITANIUM MANUFACTURING METHODS DEVELOPMENT

PART II

MANUFACTURE OF PARTS

[redacted]

FOREWORD

This portion of the final report describes a production technique for the manufacture of titanium jet engine components of higher quality and at lower costs than presently employed conventional manufacturing methods. The extrusion operation, capable of yielding a high material utilization, was utilized as the basic process. The development work required to establish this production process is also reported.

The authors would like to acknowledge the work performed by the various companies responsible for the manufacture of the titanium parts and assemblies and the aid provided by coworkers in the Development Metallurgy Division of Wright Aeronautical Division in evaluating these parts and assemblies.

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[redacted]

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LIST OF FIGURES

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LIST OF FIGURES (Cont'd)

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LIST OF FIGURES (Cont'd)

[redacted]

LIST OF FIGURES (Cont'd)

FIGURE NO. Page No.

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LIST OF FIGURES (Cont'd)

FIGURE NO. Page No.

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LIST OF FIGURES (Cont'd)

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LIST OF TABLES (Cont'd)

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I. INTRODUCTION

In recent years the military, recognizing the potentiality of titanium for aircraft applications, has made a concerted effort to develop the "state of the art". Consequently, the development of titanium alloys has progressed at a rapid rate far surpassing the development of any other structural material. One obstacle, however, that of economics, must be overcome before this metal can be used to its full potential. To this end, the present program was initiated.

The relatively high cost of titanium clearly indicates that an appreciable savings will result from a high material utilization factor, i.e. the ratio of the finished part weight to that of the raw material required to produce the part. The extrusion process is ideally suited as the basic operation for the manufacture of parts with a high material utilization factor in that complex cross sections can be obtained with a minimum of machining. In addition, for the titanium materials investigated, extruding directly from a cast ingot provides an additional cost savings in that both the cost of the forging operation and the material lost in forging are eliminated.

Specific parts such as flange and tubular shapes are applicable to the extrusion process. In the case of the flanges, the basic cross section is extruded in straight sections. Subsequent forming, welding, sizing operations produce the desired circular configuration. This replaces conventional methods of forging the ring directly or fabricating rings from barstock. In both these operations considerable material is lost in machining the detail cross section. For tubular shapes, conventional forging cannot compete with extrusion for production of parts with a minimum of machining and a maximum of material utilization in the process itself.

Both flange and tubular shapes, typical of such application for titanium in jet engines were selected for study. These assemblies are shown schematically in the cutaway of a Curtiss-Wright J-65 Turbojet, Figure 1. The materials selected were both unalloyed (AMS 4921) and the A110-AT titanium alloy.

The results obtained from development directed toward the establishment of a production processing method are presented in this report. Results of subsequent engine testing of these assemblies and/or parts and economic analysis of the process were presented in the previous section of this final report.

[redacted]

II. OBJECT

The objective of this final report is to:

1. Summarize and present the results of development studies directed toward manufacturing titanium components of higher quality and at lower costs than presently available through presently employed conventional techniques, and

2. Describe this manufacturing method in sufficient detail to permit its utilization by other Air Force sub-contractors for governmental purposes.

[redacted]

III. CONCLUSIONS

The results obtained on this program permit the following generalized conclusions:

1. Detail titanium parts such as end flanges and tubular sections can be manufactured by extruding the basic configuration and performing secondary operations such as ring forming or upsetting for the desired end configuration. This technique results in considerably higher material utilization when compared to conventional methods such as forging. A machining envelope of approximately 0.050 inch has been determined as satisfactory for such parts.

2. The extrusion of the basic configuration from cast ingots of A70 and A110-AT titanium will result in mechanical properties which are equivalent to a forged section or an extrusion from a forged billet.

3. The following dimensional tolerances are obtainable in the extrusion operation for extruded lengths of twenty feet and fifteen feet for the A70 and A110-AT titanium materials, respectively.

Nominal Metal Dimension	Extrusion Tolerance
Less then 1.0 inch	± 0.010
1.0 to 2.0 inch	± 0.020
2.0 to 3.0 inch	± 0.030

4. The present limitation of approximately five extrusions per die for A70 and one extrusion per die for the A110-AT limit the linear footage of extruded material to approximately 100 and 15 feet, respectively. The use of multi-opening dies can readily increase this yield by at least a factor of three.

5. To obtain optimum surface finish on extruded sections and maximum die life the extrusion processing variables must be controlled carefully.

6. Forming of A70 rings should be performed in the temperature range of 700-1000°F, A110-AT rings should be formed in the temperature range of 1200-1400°F. In this way small diameters and complex cross sections can be formed readily.

[redacted]

III. CONCLUSIONS (Cont'd)

7. Large variations is cross section (rib ratios of 5.3:1) can be successfully flash butt welded by closely controlling the heating of the thinner sections.

8. Sizing of titanium rings should be performed in the temperature range of 700-1250°F. Expand the A70 material 2% and the A110-AT material a maximum of 1 1/2 %.

9. Conventional steel upsetting techniques and limitations do not apply to titanium.

10. The parts considered in this report cannot be manufactured as a production item without considerable production experience in the specific titanium alloys and shapes considered.

[redacted]

IV. RECOMMENDATIONS

1. Where applicable, utilize the extrusion operation as the primary operation in producing titanium parts with a maximum of material utilization.

2. For A70 and A110AT components extrude directly from cast ingots where the extrusion ratio is greater than 10:1.

3. Consider additional development along the following lines:

   a. Development of a long life extrusion die.
   b. Development studies on upsetting titanium tubing to extablish the limitations of the process.

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V. SUMMARY

The detail titanium parts studied consisted of end flanges for sheet metal assemblies and a tubular rotor shaft, see Figures 2 through 15. The titanium material used was both AMS 4921 (A70) and A110-AT for the shaft. To accomplish the development objective of utilizing a minimum amount of material to manufacture the detail components, the minimum envelope was established. The flanges were manufactured from extruded sections which were formed into rings and the rotor shaft was made by extruding a tube and upsetting the flanges.

A. Prototype Studies

1. Extrusion

The extrusions were performed on a 12,000 ton horizontal extrusion press. The extrusion stock was heated in a salt bath located immediately adjacent to the press. Forged billets were used exclusively for the extrusion stock.

a. Maximum and Optimistic Envelope Shapes

(1) Ti A70

Initial extrusions had an envelope of approximately 1/8 inch. Several extrusions were made to this "maximum" envelope configuration, see Figures 18 and 19, to establish the range of extrusion temperature required to obtain maximum mechanical properties and to provide material for forming envelope studies. Subsequent extrusions were made of each of the detail parts, Figures 21 through 26, to an "optimistic" envelope of approximately .030 inch. This represented the estimated minimum cross section required to successfully manufacture a ring.

Multi-opening dies were used to extrude the smaller cross sections. In this manner the six A70 shapes were extruded through three dies.

(a) Dimensional Inspection

Dimensional inspection of the extrusions revealed the following tolerances:

[redacted]

V. SUMMARY (Cont'd)

Nominal Metal Dimension	Extrusion Tolerance
Less than 1.000 inch	± 0.020
1,000 to 2.000 inch	± 0.030
2.000 to 3.000 inch	± 0.040

Local surface imperfections did not exceed 1/32 inch.

(b) Metallurgical Investigation

Room temperature tensile tests on the optimistic envelope extrusion made at 1850°F revealed the material to have properties in excess of the minimum specification requirements. The macrostructure revealed a fine fiber structure equivalent in uniformity to a rolled ring or a forging. The microstructure indicated minor structural variations from equiaxed alpha to bonds of "basketweave" alpha.

The microstructure and a microhardness survey revealed the extruded surface to be completely free from contamination. Due to non-uniform flow the first four inches of each extrusion was scrapped. The rear crop was approximately one-half inch and was due solely to overheating caused by the torch cut-off.

Various annealing cycles performed on the extruded sections revealed the "as- extruded" properties to be equivalent to the annealed properties.

(2) Ti-A110-AT

Prior to extruding the tube for the rotor shaft the extrusion stock was upset and pierced at 2000°F. Subsequent extrusions utilizing various lubricants, die designs and temperature were complete failures in that the extruded tubes had severe surface tears. Attempts to extrude A110-AT flanges resulted in similar surface scoring, not quite as severe as that of the tubes. These results necessitated a study of A110-AT extrusion conditions. This study is presented in Part III of this final report.

[redacted]

V. SUMMARY (Cont'd)

(a) Metallurgical Investigation

Tensile tests on the sound sections of the tubular extrusions revealed those sections to be uniform and to have properties in excess of the minimum specification requirements. The macrostructure of the sound sections was uniform. The microstructure was identified as elongated alpha grains in a matrix of recrystallized alpha.

A study of the non-uniform flow in the front end of the extruded tube revealed the front crop to be five inches. The rear crop, necessitated by the torch cut-off, was established to be one inch.

As for the A70 material, the "as-extruded" properties for the A110-AT alloy were found to be equivalent to those obtained by annealing.

2. Ring Forming

The extruded sections were formed into 360 degree rings on a Bath Radial Draw Former. Initial forming was performed on machined lengths of P/N 226966. Rings with envelopes, as little as 0.020 inch were successfully formed at room temperature. Forming the heavier rings in A70 and all the A110-AT rings required heating. These elevated temperature studies were performed on extruded maximum envelope shapes machined to an optimistic envelope.

Subsequent to these initial forming studies the optimistic envelope extruded sections were formed into 360 degree rings. The dies and material were heated to 500-700°F for the A70 material and 1200-1400°F for the A110-AT alloy. The forming of the smaller diameter rings caused a thinning of the inside flange which must be compensated for in future extrusions.

3. Flash-Butt Welding

Welding of the titanium rings was performed at two sources on a Thomson F-4 Synchromatic and a Swift Welder. Initial welding was performed on P/N 226966. The machine settings were qualified by tensile tests. Subsequently, the optimistic envelope sections were welded. Tensile tests on these welded sections established the weld settings as being capable of passing the strength requirements of AMS 7498.

[redacted]

V. SUMMARY (Cont'd)

The smaller diameter rings, P/N's 226961 and 227594, required a pre-sizing operation prior to welding to eliminate slippage of the work in the dies and subsequent distortions.

4. Sizing

The titanium rings were sized on a 225 ton press brake. The expansion of the rings was initially established to be 2 to 3 percent. In sizing the rings, the dies and material were heated to a temperature of 700-1250°F. This was satisfactory for the A70 rings. The A110-AT rings, however, could not be expanded beyond 1.5 percent. This required a slightly larger diameter welded ring for future studies.

5. Upsetting

A 6 inch Ajax Air Forging Machine was used to upset the flanges in the extruded A110-AT tubing for manufacture of the Turbine Rotor Shaft. Initial upsetting of steel tubing indicated that a 0.450 inch thick wall could be successfully upset in three passes. Attempts to upset this thickness tube in titanium at 1900°F resulted in a buckling at the inner diameter. Minor die modifications and increasing the wall to 0.600 inch, yielded the first successfully upset tube.

The tensile properties of the upset flange and adjacent tubular section were equivalent to that of the original tube.

B. Production Studies

1. Manufacture of Parts

a. Extrusion

Based on the results obtained on dimensional inspection of the finished prototype rings, the production extrusion envelopes were modified, see Figures 71 to 78. A development study of the effect of extrusion processing conditions on the mechanical properties and surface finish of extruded cast titanium ingots resulted in the use of the following extrusion conditions:

	Ti-A70	Ti-A110-AT
Extrusion Speed	100-500 in/min.	450 in/min
Extrusion Length	15-20 ft.	12-15 ft.
Lubricant	Fiske #630	Fiske #630
Billet Heating	Salt Bath	Salt Bath
Die Design	120 to 140° included angle	180° included angle

[redacted]

V. SUMMARY (Cont'd)

	TI-A70	Ti-A110-AT
Container Temperature	800°F	
Die Preheat	350 to 750°F	700 to 800°F
Die Material	5% Chrome, die steel, hard-faced with Rexweld	Vasco Supreme

Extrusions were made from both cast ingots and forged billets at extrusion temperatures of 1550°F for the A70 and 1850-1950°F for the A110-AT.

(1) Quality of the Extrusion

(a) A70

The surface finish of these extrusions had heavy surface scoring due to the run-out guides.

(b) A110-AT

The following tolerances were obtained on the flange sections:

Nominal Metal Dimension	Extrusion Tolerance
less than 1.000 inch	± 0.010
1.000 to 2.000 inch	± 0.020

In extruding the tubular sections for the rotor shaft a maximum thickness variation of 0.080 inches on an eleven foot length was noted.

(2) Extrusion Yield

The extrusion yield was approximately 70 percent.

(3) Die Life

The die life for the A70 extrusion was approximately 100 linear feet and for the A110-AT 15 linear feet.

(4) Metallurgical Evaluation

Tensile tests on the extruded sections from both cast ingots and forged billets revealed properties which surpassed the minimum specification requirements.

[redacted]

b. Forming, Welding and Sizing

The tooling for the ring manufacturing operations was modified to accommodate the changes in the extrusion envelope and the production extrusions were processed into 360 degree rings utilizing the procedure established in the prototype work. The total machine time required to produce a ring was approximately 30 minutes.

In addition to the qualifying tests for the weld settings, tensile tests were performed on the weld zone and base metal of the finished ring. These tests established the finished product to meet all applicable specifications.

c. Upsetting

Six A110-AT tubes were upset at both ends in the same manner that resulted in a successful prototype part. All of the shafts had indications of a lap on the inner diameter immediately under the upset flange. These laps could not be removed by machining to the finished I.D. dimensions. Consequently, this area was repair welded.

2. Manufacture of Assemblies

The following list associates the rings with the assemblies and indicates the corresponding assembly vendors:

Part No.	Name	Material	Flange Nos.	Vendor
608120	Combustion Chamber Heat Shield	A70	226966	Portland Copper & Tank Works
608118	Rear Main Bearing Support Cone	A70	226962 226963 226964	Smith-Morris Corp.
608109	Rear Main Bearing Vapor Duct	A70	226956	Midway Company
608569	Turbine Stator Blade Support	A110-AT	227594 227596	Alloy Product Co.

a. Weld Approval

Prior to welding the assemblies the vendor's facilities were reviewed and weld samples obtained. Weld approval was granted based on samples which were required to conform to established WAD specification, see Appendix I.

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[redacted]

b. Production Processing

Inspection of the final assemblies revealed occasional dimensional and weld discrepancies. These descrepant areas were non-critical and when they occurred, the part was procured through Material Review Action. The repair welding of the rotor shaft was in a non-critical stress area and consequently could be tolerated.

C. Material Utilization

Compared to conventional manufacturing methods, i.e. forging, etc., this newly developed method of extruding for the basic cross section utilizes approximately one-half the raw material. Material utilization factors in excess of 0.65 were obtained. The highest material utilization factor obtainable by conventional methods was 0.40, see Table XXV.

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[redacted]

VI. DISCUSSION

The detail titanium parts selected for study are shown in Figures 2 through 10. As indicated in these figures, the parts studied consist of end flanges and a tubular shaft. For engine operation, the detail flanges are welded to sheet metal components to form an integral part of the assembly, Figures 11 through 15. Major emphasis was placed on the manufacture of the detailed parts. The assemblies provided a means of evaluating the parts through engine testing.

The accomplish the development objective of utilizing a minimum amount of material to manufacture the detail parts in the most economic manner, the following was required. For the flanges, the minimum machining envelope, i.e., the stock added to the detail cross-section, had to be established. This envelope must be commensurate with the limitations of the extrusion, forming, welding, and sizing operations utilized in the manufacture of the flange rings. For the tubular shaft, the envelope must be commensurate with the limitations of the extrusion and upset operations. The limitations of the extrusion operation determined the machining envelope for most of the rings. Forming and welding limitations added to this envelope for the smaller diameter parts. The upset operation limitations established the envelope for the shaft.

Exclusive of the basic studies reported in Part III of this final report, the initial attempts to establish this machining envelope were concentrated around the extrusion operation. Subsequent to the establishment of the extrusion limitations, the limitations of the forming, welding, sizing, and upsetting operations were established by processing parts. This initial work is described in the following section entitled "Prototype Studies".

After establishing the limitations for each of the operations, the production parts were made. These parts were subsequently machined and/or fabricated into assemblies for engine testing.

A. Prototype Studies

1. Extrusion

a. Equipment

All the extrusions on this program were made on the 12,000 ton horizontal extrusion press located at Metals Processing Division, Buffalo, N. Y., Figure 16. This press is equipped with three pressure stages capable of delivering 4,000, 8,000, and 12,000 tons. On this program, the flanges were extruded utilizing the 4,000 ton stage in conjunction with an 8 inch diameter container. The shaft was extruded from a 16 inch diameter container utilizing the full press capacity of 12,000 tons.

VI. DISCUSSION

The detail titanium parts selected for study are shown in Figures 2 through 10. As indicated in these figures, the parts studied consist of end flanges and a tubular shaft. For engine operation, the detail flanges are welded to sheet metal components to form an integral part of the assembly, Figures 11 through 15. Major emphasis was placed on the manufacture of the detailed parts. The assemblies provided a means of evaluating the parts through engine testing.

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After establishing the limitations for each of the operations, the production parts were made. These parts were subsequently machined and/or fabricated into assemblies for engine testing.

A. Prototype Studies

1. Extrusion

a. Equipment

All the extrusions on this program were made on the 12,000 ton horizontal extrusion press located at Metals Processing Division, Buffalo, N. Y., Figure 16. This press is equipped with three pressure stages capable of delivering 4,000, 8,000, and 12,000 tons. On this program, the flanges were extruded utilizing the 4,000 ton stage in conjunction with an 8 inch diameter container. The shaft was extruded from a 16 inch diameter container utilizing the full press capacity of 12,000 tons.

[redacted]

VI. **DISCUSSION** (continued)

b. Method of Heating

Heating of the extrusion stock was accomplished in a barium chloride salt bath immediately adjacent to the press. Transfer of the billet from the furnace to the press is accomplished by means of an overhead hoist. Although the furnace temperature can be controlled quite closely, the transfer of the material does result in a slight drop in temperature. This drop in temperature was determined by using thermocouples to establish cooling curves for the billet. Due to the short duration of the transfer time, (approximately 1 minute), the only temperature drop of any significance is restricted to the outer surface. Therefore, the actual extrusion temperature corresponded quite closely to the furnace temperature.

To determine the heating characteristics of the various size billets and to assure thorough heating, heating curves similar to those presented in Figure 17 were established. Such curves dictate the time at temperature required to through-heat the billet.

c. Material

The material for the prototype studies consisted exclusively of forged billets. This material was purchased to the specifications shown in Appendix I. While the specification for the A70 material indicates a maximum oxygen content of 0.20%, this condition was not maintained as a sole cause for rejection. This modification was required to expedite the delivery of this material. In general, the oxygen content was approximately 0.25%.

d. Maximum and Optimistic Envelope Shapes

(1) Ti-A70 - The initial extrusions of the A70 titanium material were to the configurations shown in Figures 18 and 19. These extrusions are referred to as "maximum envelope" shapes due to the large machining envelope, approximately 1/8 inch on all surfaces, that was added to the detail cross-section. The maximum envelope shape of Part No. 226961, see Figure 18, was extruded at temperatures of approximately 1700, 1600, 1500, and 1450°F. The ram speed was approximately 2 in./sec. A photograph of sections of one of these extruded parts is presented in Figure 20. Additional extrusions of Part No. 226963, see Figure 19, were also made under similar conditions. This oversize envelope was purposely applied to these shapes to permit subsequent forming after the extruded section had been machined to various smaller envelopes. This permitted an initial approximation of the limitations of the subsequent ring producing operations. These two shapes represent the most complex configuration as well as the most difficult rings to form due to the high ratio of cross-section area to ring diameter.

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It is interesting to note that these extrusions represent one of the initial extrusions of titanium at this facility and certainly the first such extrusions in equipment of this capacity. They, therefore, also served as a means of "getting our feet wet" and generally "debugging" the equipment. The temperature range for extruding forged A70 billets was also determined from these extrusions.

To definitely establish the minimum envelope required, subsequent extrusions were made to an "optimistic envelope" shape. This envelope represents the initially estimated minimum cross-section required to successfully manufacture a ring. The specific cross-sections of each of the six shapes for this material are presented in Figures 21 through 26. These shapes are referred to as optimistic envelope shapes due to the small amount of machining envelope, approximately 0.030 inch, which was applied to the detailed part.

Except for the extrusion of the optimistic shapes of Part No. 226961, the balance of the optimistic shapes were extruded through multi-opening dies. These multi-opening dies are shown schematically in Figure 27. As shown in these figures, Part Nos. 226962 and 226963 were extruded through one of these dies while Part Nos. 226956, 226966, and 226964 were extruded through the other die. A photograph of the multi-opening die used for the extrusion of Part Nos. 227594 and 227596 is shown in Figure 28. Detail die drawings are presented in Appendix II.

Based on the experience obtained from the maximum envelope extrusions, the following conditions were used for the optimistic envelope extrusions:

Billet Temperature	1550°F
Extrusion Speed	15 ft./sec.
Lubricant	Oil dag, nicrolene, bentone, lithium carbonate
Die Temperature	250-400°F
Container Temperature	800°F
Die Material	Hard faced steel

Photographs of each of the extruded shapes are presented in Figure 29.

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VI. DISCUSSION (continued)

(a) Dimensional Inspection

Dimensional inspection reports for these extrusions are presented in Tables I through VI. These reports indicate that the following extrusion tolerances are obtainable.

Nominal Metal Dimension	Extrusion Tolerance
Less than 1.0 inch	± 0.020
1.0 to 2.0 inch	± 0.030
2.0 to 3.0 inch	± 0.040

Local surface imperfections, in general, did not exceed 1/32 inch. Considerable warpage and twisting were noted on these extrusions. This is attributed to the lack of adequate runout guides. Subsequent straightening operations corrected this condition.

(b) Metallurgical Investigation

i. Mechanical Properties

The results obtained from tensile tests on as-extruded sections of Part No. 226961 extruded to the maximum envelope shapes at temperatures from 1450°F to 1700°F are presented graphically in Figure 28 and are compiled in Table VII. This data indicates the entire temperature range to be satisfactory for this extrusion ratio. It is noted, however, that a considerably more ductile material, as exhibited in Figure 30, by the values for elongation and reduction of area and the tensile to yield spread, is obtained by extruding in the lower part of this temperature range, 1450 to 1600°F. In this range of extrusion temperature, a more ductile material was obtained by extrusion than forging as indicated by the vendor's certified data.

Tensile tests were also performed on the optimistic envelope shapes. This data, presented in Table VIII, clearly demonstrates, in all cases, that the tensile properties of the extrusions are superior to the certified minimum properties submitted by the supplier. Furthermore, the data indicates a uniformity of properties within each flange and only a small variation of properties among the flanges. It is interesting to note that, except for Part No. 226966 (the smallest cross-section examined), the tensile properties do not vary appreciably with section size, Figure 31. This small cross-section permitted only the use of sub-standard specimens which probably accounts for this small difference.

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VI. DISCUSSION (continued)

ii. Microstructure and Macrostructure

Photomicrographs of each of the sections extruded at 1500°F, Figures 32 to 37, indicate structural variations from equiaxed alpha, to bands of "basket-weave" alpha. The equiaxed alpha results from extruding in the all alpha phase, while the basket weave alpha is a transformation product, its presence indicative of extruding in the alpha-beta region. As the extrusion temperature of approximately 1500°F is close to the lower alpha-beta transus, minus variations in temperature throughout the billet could readily account for some areas being in the alpha region while others are in the alpha-beta region. The tensile tests reported in the previous paragraph clearly establish that these minor variations in microstructure are not reflected in the mechanical properties of the material. These microstructures, therefore, are concluded to be acceptable for this material.

The macrostructure of these parts, also shown in Figures 32 to 37, show a fine fibre structure which is generally more uniform than that obtainable with a forging of comparable size and at least equivalent to that of a rolled ring. These photomacrographs show a clearly defined narrow band adjacent to the surface of most of the extrusions. The microstructure of these bands have high percentages of the basket weave type alpha structure. While this structure is less than optimum, no deleterious effects have been exhibited in tensile tests or in subsequent forming operations.

iii. Surface Contamination of Extrusions

Sections of Part No. 226961 extruded at 1500°F were examined metallographically for surface contamination. A photomicrograph showing a cross-section adjacent to one of the extruded surfaces is presented in Figure 38. The lack of surface contamination is evident by the uniformity of the microstructure and the results of the hardness survey. Converted hardness readings to Rockwell C ranged from 29.5 to 30.0 which is well within the range of accuracy of the instrument. This work is in close agreement with previous data[2].

[redacted]

iv. Front and Rear Crop

Front and rear sections of the extruded A70 flanges were examined to determine the amount of material which is not of usable quality and must be cut off as scrap. From these shapes, longitudinal sections were etched for flow lines. Undesirable flow was observed up to four inches from the front of the extrusion, Figure 39.

The rear crop study was designed to determine stock removal necessary due to irregular flow and overheating due to torch cutting of the extrusion from the butt. An etched section adjacent to the cut-off area, Figure 40, indicates uniform flow from the torch cut forward. Since the point of cut-off was immediately adjacent to the unextruded butt, it is evident that non-uniform flow does not exist in the rear of the extrusion. The heat affected zone due to the torch cut-off extends into the extrusion for a maximum depth of 1/2 inch, see Figure 40.

v. Extrusion Annealing Cycles

The effect of various annealing temperatures and cooling rates was determined for extruded A70 material. The resulting mechanical properties are presented graphically in Figure 41. As indicated in this figure, the as-extruded properties were equivalent to those obtained by any of the annealing conditions examined.

(2) Ti-A110AT - The initial extrusions with this material were tubular sections for the turbine rotor shaft. Prior to actual extrusion, however, the billet material, which was in the form of a 12 inch round-cornered square, was subjected to an upset operation which increased the diameter to 16 inches. Simultaneously, the center of the billet was pierced. Initial attempts to perform this upset and piercing operation at temperatures below 1900°F resulted in severe cracking of the peripheral upset area. Heating the billet to 2000°F eliminated the cracking and resulted in a successful upset.

Subsequent to the upset and pierce operation, several tubular extrusions were attempted to the configuration of Figure 42. In these extrusions, both a re-entrant angle and a standard 130° die were used, Figure 43. Both extrusions resulted in severe surface tearing similar to that shown in Figure 44. The extrusion temperature in these tests was approximately 1900°F. A third attempt to extrude this material into a tubular shape utilized a steel jacket, i.e., the billet prior to extrusion was encased in a jacket of steel. Extruding this billet through a 130° die resulted in surface tearing and cracks similar to those shown previously, see Figure 44. The purpose of the jacket was to reduce the friction by lubricating the outer steel layer rather than the titanium.

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Attempts to extrude at temperatures below 1900°F were unsuccessful in that the press stalled. All the previous extrusions at 1900°F required forces in excess of 11,000 tons. In several instances, "break through" forces approached the press maximum of 12,000 tons. A beta transus temperature of approximately 1960°F prohibited the extrusion at higher temperatures. Results by previous investigators[3] indicate that undesirable mechanical properties can result from extruding above the 1960°F transus temperature or in the "all-beta" region.

The lubricant for the previously discussed tubular A110AT extrusion was a combination of oil dag, nacrolene, and lithium carbonate. One additional extrusion was made to this configuration with a coating of Borax as a lubricant. Although the surface quality of this extrusion was improved, it is still not satisfactory. To assure the availability of tubing for subsequent development studies on upsetting, the dies were opened to provide for a heavier walled section. This permitted a machining operation to remove the surface imperfections and allow subsequent processing.

In addition to the tubular extrusions in this material, extrusions of Part Nos. 227594 and 227596 to the configuration shown in Figures 45 and 46 were made. While the surface finish of these extrusions was improved compared to the tubular shapes, severe surface scoring did occur, Figure 47.

The above results on A110AT extrusions clearly established the need for a development program aimed at establishing

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the extrusion conditions required to produce A110AT extrusions with an acceptable surface finish. Such a program was then initiated. The results of this development program are discussed in detail in Part III of this final report[1].

(a) Dimensional Inspection

The severe surface tearing and scoring resulting in all extrusions of this material precluded any useful dimensional inspection.

(b) Metallurgical Investigation

i. Mechanical Properties

Tensile tests were performed on the sound sections of two of the tubular extrusions. These results are compiled in Table IX. As indicated by the results on this table, the tensile values of the extruded section were found to be uniform and considerably more ductile than that indicated for the base material by the vendor's certified data. Notch rupturing testing was also performed. These results confirm the satisfactory quality of this material with respect to mechanical properties.

ii. Microstructure and Macrostructure

A photomacrograph of a section of the re-entrant angle die extrusion is shown in Figure 48. While the sound section reveals an overall uniform grain distribution pattern, the metal flow in the tear area is distinctly non-uniform, yielding a non-uniform coarse grain structure. A closer examination of the sound area, Figure 49, reveals a moderately fine, randomly oriented, recrystallization structure.

The macrostructure of cross-sections of the steel jacketed extrusion is shown in Figure 50. Unlike the previous extrusion, the flow lines are clearly visible and they are generally smooth with minor turbulences at the irregular surfaces. Excluding these minor turbulences, the structure is fairly uniform from inner to outer surface. The microstructure of a section of this extrusion is presented in Figure 51. This grain structure is identified as elongated alpha grains in a matrix of recrystallized alpha. The variation in grain size between this and the previous extrusions can probably be attributed to the upset and pierce temperature which was appreciably lower for the steel jacketed extrusion. Specifically, the upset and piercing operation was performed in the beta region for the first extrusion and in the alpha-beta region for the latter.

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iii. Beta Transus Determination

The beta transus temperature for this heat of A110AT material has been metallographically determined to be approximately 1960°F, Figure 52. This temperature represents the maximum at which this material can be extruded or finished forged[3]. For although the beta phase has superior deformation characteristics than the alpha phase, recrystallization and excessive grain growth occur when this material is heated above this temperature.

iv. Front and Rear Crop

A metallographic study of the front end of the rotor shaft extrusions revealed non-uniform flow back to a distance of five inches from the front of the extrusion. The rear crop, as was the case for the A70 material, is approximately one inch and is required only to remove the heat affected zone due to torch cut-off.

v. Extrusion Annealing Cycle

The effect of varied annealing temperatures and cooling rates on the mechanical properties of extruded A110AT material is presented in Figure 53. While minor variations in yield strength and reduction in area were exhibited at various annealing temperatures, the as-extruded properties were adequate for further processing.

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VI. DISCUSSION (continued)

2. Ring Forming

a. Equipment

The machine utilized to form the extruded sections into rings is described as a Bath Radial Draw Former, Figure 54. It consists of a variable speed power driven circular table and a double acting pressure controlled cylinder. Where required, a hydraulic ram, capable of applying a side force to the section being formed, is utilized.

The contour forming dies were fabricated from AISI 1045 material. They are circular in shape with the general configuration of the part cross-section at the outer periphery. Suitable contour rolls were fabricated from Ketos die material. These rolls serve to exert a side force on the length being formed. A photograph of the rolls and dies used on this program is presented in Figure 55.

b. Initial Forming Studies

In preparation for forming the basic extrusion lengths, a program was initiated to utilize machined titanium bar stock for ring forming development. Initially, titanium bar stock machined to the configuration of Part No. 226966 with an envelope of approximately 1/16 inch was formed at room temperature with no appreciable change in dimension, Figure 56. The envelope was then reduced to 0.020 inch and a ring was produced satisfactorily.

The tolerance of 0.020 inch which had been demonstrated to be adequate for the contour forming operation is considerably less than permitted by the extrusion operation at this time. Consequently, future sections were machined to the optimistic envelope (0.030 in.) from either bar stock or maximum envelope extrusions. The parts studies were Part No. 226961, 226963, and 227594. These shapes representing both A70 and A110AT material have small diameters relative to the cross-section area and represent the most difficult sections in the program based on ring manufacture. Attempts to form these rings at room temperature were completely unsuccessful as the material did not have the required elongation necessary for this operation.

However, development directed at hot forming techniques permitted the satisfactory forming of these shapes to the desired contour, Figure 57. In this application, both the material and the dies were heated. A photograph of Part No. 226963 formed in this manner is shown in Figure 58. The application of hot forming to Part No. 226966 resulted in an appreciably better formed section.

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VI. DISCUSSION (continued)

The forming temperatures and resulting required forces for each of the parts follows:

	Part Number			
	226966	226961	226963	227594
Material Temperature	200°F	700°F	700°F	800°F
Die Roll Temperature	200°F	700°F	700°F	800°F
Force excited through rolls	12 1/2 ton	17 1/2 ton	20 ton	20 ton

In all cases, best results were obtained when the forming operation proceeded as slowly as possible which was a table speed of .4 RPM. In addition, a two pass operation, working first with a clockwise rotation of the table and second with a counter-clockwise rotation yielded the best results.

c. Optimistic Envelope Extrusions

The forming of extruded sections without any machining presented an initial problem in that these shapes were twisted and bowed whereas the machined shapes were not. For the A70 material, straightening was possible in the forming operation. For severely distorted A70 shapes and for all the A110AT shapes, it was necessary to straighten the parts by hand in an arbor press prior to forming.

Except for minor die rework required to accommodate the dimensional variations inherent in the extruded section vs. the machined sections, these extruded sections were formed with relative ease. The publication, at this time, of AMS 7498 (specification controlling Flash Welded and Titanium Rings) confirmed the previously established requirement of forming these rings hot. In general, a temperature range of 500-1000°F was established for the dies and the material. The most difficult A70 ring to form was Part No. 226963. The side (roll) pressures required to form this small diameter resulted in a loss of approximately 0.080 in. on the vertical leg, see Figure 24.

In forming the A110AT rings, Part Nos. 227594 and 227596, the high pressures required to form the ring resulted in a torn surface. Consequently, to eliminate the surface tearing, the forming temperature was increased to 1200-1400°F and a pre-form operation was employed. A reduction in thickness of the vertical leg of the ring of 0.040 inch was noted due to the forming forces.

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VI. DISCUSSION (continued)

3. Flash Butt Welding

a. Equipment

Welding of the titanium rings was performed at two welding sources, Thomson Electric Welder Company, Lynn, Massachusetts, and Cleveland Welding Company, Cleveland, Ohio. The machine specifications used at each source follows:

(1) Thomson Electric Welder Company

Model	Thomson F-4 Synchromatic
Machine Rating	250 K V A
Maximum Upset Force	32,000 lbs.
Maximum Clamping Force	23,000 lbs.

(2) Cleveland Welding Company

Model	Swift Welder 90 K V A
Machine Rating	600 K V A
Maximum Clamping Force	160,000 lbs.
Maximum Upset Force	200,000 lbs.

b. Welding Formed Shapes

The initial weld settings were based on the results obtained from the development studies on maximum rib ratios[1]. Initial studies were performed by Thomson Electric Welder on P/N 226966 formed from milled barstock, Figure 59. Several rings were welded and the machine settings were qualified by tension testing of the weld ring segments. In this manner, weld settings capable of meeting the strength requirements of AMS 7498 were established.

Similarly, the weld settings for the remaining shapes formed from optimistic envelope extrusions were established. The tensile properties of the ring weldments are presented in Table X. The welding machine settings and burn off lengths thus established are indicated in Tables XI and XII.

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VI. DISCUSSION (continued)

The welding of P/N's 226961 and 227594 presented considerable difficulty in that an out-of-round resulted, Figure 60. The relatively small diameter of P/N 226961 necessitated a pre-sizing operation prior to welding to eliminate slippage of the work in the dies during the flashing operation and minimize subsequent distortions. X-ray results on the welds of P/N 227594 revealed a complete lack of bonding. Increasing the flashing time to overcome the resistance of the A110AT material during upsetting corrected the problem.

4. Sizing

a. Equipment

The titanium rings were expanded on a 225 ton press brake located at Cyril Bath. A pin centrally located in the expander fixture engages the punch and the expanding segments. The set up is shown pictorially in Figure 61.

b. Sizing Welded Rings

The expansion of the titanium rings was initially set at 2 to 3 percent. This expansion was readily obtained for P/N 226966 at room temperature. Expanding the shape in increments of 0.42 inches resulted in a spring back of approximately 0.080 inches per increment, or approximately 20 percent. Allowance for this condition was accomplished by reworking the expanding die segments. Expansion of the larger cross section rings could only be accomplished at temperatures in excess of 700°F. The release, at this time, of AMS 7498 established the sizing temperature range to be 700 to 1250°F for all titanium rings. For P/N 226961 a pre-sizing operation, to eliminate the out-of-round condition at the weld area, was performed.

Direct application of the above results obtained for A70 titanium resulted in failure when attempted in the A100AT rings. This was due to the considerably lower ductility of this alloy as compared to the A70 (unalloyed) material. As a result, the contour form circumference was revised to show a 1.5 percent maximum expansion instead of the previously used 2 percent. Subsequent rings were successfully expanded to this revised dimension.

5. Upsetting

a. Equipment

The equipment used to upset the flanges on the extruded A110AT tubing to make the turbine rotor shaft, see Figure 10, was a 6 inch Ajax Air Forging Machine located at the Propeller Division, Curtiss-Wright Corporation, Caldwell, New Jersey. A

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photograph of this machine is shown in Figure 62.

Heating of the material was performed in a Tocco Induction Heating Unit. This unit was calibrated with the use of thermocouples attached to the tube to insure a uniform heat pattern.

b. Upsetting of Tubing

Preliminary development studies for upsetting the ends of the rotor shaft were performed on low alloy steel tubing, AMS 6422. This initial work consisted of a three pass operation on a 0.385 inch thick wall tube. The temperature employed was 2200°F. Upsetting of this tube resulted in a buckling on the I.D. surface. Increasing the wall thickness to 0.450 inch resulted in a successfully upset steel flange, Figure 63.

Concurrent with the steel upset development was a similar program utilizing plasticine in a scaled down model. This material was laminated in colors to enable a study of the flow of the material under the action of the punch. This scaled-down unit was constructed of hard wood and is shown in Figure 64. In performing the upsetting on the plasticine the material was cooled to a temperature of approximately 30°F. This lower temperature permitted a closer approximation to the real material in that it rendered the plasticine less ductile. Results of this survey indicated that the first upset pass can be successfully attempted by using a tapered punch and a 0.410 inch wall tube.

Based on the above results on steel and plasticine, tooling was designed and fabricated to permit the upsetting of a flange on A110AT tubing with a 0.410 inch wall. This three step upsetting cycle is shown pictorially in Figure 65. These operations affect the dimensions of the upset section as follows:

First Stage:	0.410" wall x 3.50" long upset to 0.724" wall x 1.62" long
Second Stage:	0.724" wall x 1.62" long upset to 1.053" wall to 1.060" long
Third Stage:	1.053" wall x 1.060" long upset to 1.379" wall x 0.625" long

This upset cycle applied to the A110AT tubing resulted in severe buckling at the inner diameter, and incomplete die fill, Figure 66.

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Upsetting of additional A110AT tubing with a 0.450" wall was attempted. This did not correct the problem of the I.D. lap. Die variations, such as tapers on the first and second stage punch, Figure 67, were also unsuccessul. Increasing the wall thickness to 0.600 inch solved the buckling problem in the first and second stages. A photomacrograph of a section formed through the second pass is shown in Figure 68(a). Applying the third stage operation to this 0.600 inch wall tube resulted in a serious fold, Figure 68(b). In all the previous attempts, the tube was heated to 1900°F prior to the first and second stage operations. In an attempt to eliminate the fold in the last operation another heating operation was performed prior to this third upset operation. This resulted in a considerably improved upset with only a slight fold.

Finally, an attempt was made to improve the flow pattern by removing the restrictive "ledge" from the punch in the third stage operation. A sketch of the new punch design is shown in Figure 69. A shaft was then successfully upset using this 0.600 inch wall tube, three heating cycles of 1900°F, and a tapered punch, Figure 70. Although a trace of a fold was detected on close examination, all defects were removed by machining 0.050 inches from the I.D. surface.

(1) Mechanical Properties - Table XIII shows the tensile properties of the upset area and adjacent tubular section (heat affected zone). These properties are equivalent to the original extruded tube. The slightly low elongation values are probably attributed to the undersized specimen.

B. Production Studies

1. Manufacture of Parts

a. Extrusion

Inspection of the prototype rings established the need for modifications of the extrusion envelope. These modifications were found necessary primarily due to (1) local thinning of a section during forming, (2) welding gripper marks, and (3) dimensional accuracy of the extrusion operation. The final production extrusion shapes thus established are presented in Figures 71 to 78. Shown also in these figures are the previous envelopes, the machined detailed part cross-sections and the finished machined assembly cross-sections.

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VI. **DISCUSSION** (continued)

Prior to the actual production extrusions, a development study aimed at obtaining optimum surface finish and mechanical properties on extrusions from cast ingots was performed. The results of this study are discussed in detail in Part I of this final report[1]. The following extrusion conditions resulting from this study were employed on the production extrusions.

	Ti-A70	Ti-A110AT
Extrusion Speed	100-500 in./min.	450 in./min.
Extrusion Length	15-20 ft.	12-15 ft.
Lubricant	Fiske #630	Fiske #630
Billet Heating	Salt Bath	Salt Bath
Die Design	120° to 140° included angle	180° included angle
Container Temperature	800°F	800°F
Die Preheat	350 to 750°F	700 to 800°F
Die Material	5% Chrome, hot worked die steel with a Rexweld hard face	Vasco Supreme (High Speed Steel)

At the above conditions, extrusions were made from both cast ingot and forged billets in both the A70 and A110AT materials. An extrusion temperature of 1550°F was used for both the A70 materials while extrusion temperatures of 1850-1900°F were used for the cast ingot and forged billets, respectively, in the A110AT alloy. As was the case for the prototype extrusions, multi-opening dies were employed, see Figures 27 and 28.

(1) Quality of the Extrusions

(a) Ti-A70 Flanges

The surface quality of the production A70 extrusions were in general not satisfactory and were inferior to those obtained in the prototype phase. Heavy striations were noted throughout the entire length of several of the shapes. These striations are

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VI. **DISCUSSION** (continued)

attributed to the run-out guides. These guides were intended to straighten the twist which occurred in the extrusions of the prototype parts. A dimensional inspection report of the typical A70 extruded shapes are presented in Tables XIV to XVIII.

(b) Ti-A110AT Flanges

The application production extrusion conditions to the A110AT material resulted in flange extrusions with an excellent surface finish. Dimensional inspection of these parts, Tables XIV and XX indicate the following tolerances are obtainable.

Nominal Metal Dimension	Extrusion Tolerance
less the 1.000	± 0.010
1.000 to 2.000	± 0.020

Comparison of these values to those reported previously for the prototype A70 shapes reveals a marked improvement which can be directly attributed to the close control of the extrusion process variables. It can logically be expected therefore, that extrusion tolerances at least as good as those obtainable on the A110AT shapes can be realized in A70 material with the use of properly designed run-out guides.

(c) Ti-A110AT Shaft

In extruding the tubular sections for the manufacture of the rotor shaft the conditions mentioned above were employed except as follows:

Die Preheat Temperature	350 to 450°F
Die Material	Rexweld hard face
Die Design	210 degrees included angle

The modifications from the optimum conditions pertain solely to the die. This was necessitated due to the lengthy procurement cycle associated with new die procurement. Consequently, modifications were made to existing dies. The die temperature was limited to

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450°F due to interference problems associated with the expansion of the dies upon heating.

The above extrusion conditions resulted in the first A110AT tubular extrusion of acceptable surface quality and minimum die pickup. Slight intermediate circumferential surface tearing was noted. Dimensional inspection results are presented in Table XXI. As indicated in this table for an eleven foot extruded section the maximum variation in wall thickness was 0.080 inch. All of these production extrusions were from forged material due to the lack of cast ingot of suitable diameter.

(2) Extrusion Yield

The extrusion yield exhibited by the A70 and A110AT flanges was approximately 70 percent. The major portion of the lost material, approximately 25 percent, represented the unextruded butt. The remaining loss, 5 percent, was due to the front and rear crop, specimen sampling, and preparation of the billet prior to extruding.

(3) Die Life

The die life obtained in extruding A70 material was five extrusion cycles per die. This represents a total extrusion length of approximately 100 ft. for a single opening die. For the A110AT flanges only one extrusion cycle per die was obtainable. This represents a total extrusion length of approximately 15 linear ft.

(4) Metallurgical Evaluation

The results of tensile tests performed on the extruded A70 and A110AT flanges are presented in Table XXII. Included also in this table are the chemical compositions of the ingot and billet materials which were extruded to obtain the shapes. The properties of all the specimens examined far exceed the minimum requirements of the applicable specifications. The specimens examined represent ramdom sampling from front and rear sections of extrusions from both cast ingots and forged billets. The extrusion

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of a forged billet or a cast ingot is not in any way reflected in these tensile properties.

Typical photomacrographs of the extruded sections are presented in Figure 79 to 84. This structure is quite similar to that obtained in the prototype studies, see Figures 32 to 37. The microstructure of the A70 material is identified as varying from recrystallized alpha with a slight flow orientation to Widmenstatten alpha platelets. The microstructure of the A110AT shapes is identified as equiaxed grains of Widmenstatten alpha platelets.

The results of tensile tests performed on extruded A110AT tubing from forged billets are presented in Table XXIII. The minimum tensile properties exhibited are in excess of the minimum specification requirements. The microstructure of these tubes are similar to that of the flanges, see Figure 82.

b. Forming, Welding and Sizing

The tooling for the ring manufacturing operations was reworked to accommodate the modifications of the production extrusion envelopes. The procedures established and described in the prototype studies were employed. These procedures are summarized as follows:

(1) Forming

(a) Receiving inspection and part identification.

(b) Preheat part and dies to 700-1000°F for the A70 shapes and 1200 to 1400°F for the A110AT parts.

(c) Form to 360 degree ring.

(d) Trim, reheat and reroll to required print dimensions.

(e) Inspect and prepare ring ends for welding.

(2) Welding

(a) Cut back thin segment 0.125 inch to retard heating of this area during flashing.

(b) Qualify machine settings.

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VI. DISCUSSION (continued)

(c) Weld (see Table XI through XII for weld machine settings).

(d) Stress-relieve (AMS 7498).

(e) Inspect and remove flash (x-ray).

(3) Sizing

(a) Preheat work to the range of 700 to 1250°F (oil dag may be used as a lubricant).

(b) Expand to print dimensions (2 to 3% for A70 and 1½% expansion for A110AT).

(c) Inspect and ship.

Photographs of rings produced in this manner are shown in Figure 85.

The manufacture of a ring from an extruded section requires approximately 30 minutes of machine time. This is distributed amont the three operations as follows: Forming 20 minutes, welding 5 minutes, and sizing 5 minutes.

(4) Inspection of Rings

Inspection layout templates were made for each ring. A typical layout is shown in Figure 86 for P/N 226962. As indicated in this layout, the detailed part cross-section was scribed within the part configuration at the weld area and 90 degrees from the weld. In general, most of the rings cleaned up to the detailed part configuration. For some of the A70 rings, which showed heavy striations due to the run-out guides, the detailed part cross-section was not obtainable, however, these shapes cleaned up in machining to the final assembly dimensions.

(5) Metallurgical Evaluation

In addition to the tensile tests performed to qualify the welding machine settings, tensile tests were performed on finished sized rings. The results of these tests are presented in Table XXIII.

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VI. DISCUSSION (continued)

Tests were performed on both the weld area and the metal. All of the rings exhibited tensile properties in excess of the material requirements and flash-butt welded ring requirements, AMS 7498.

c. Upsetting

Flanges were upset on both ends of six A110AT tubes in the same manner as that which resulted in a successful prototype parts. The operational sequence follows:

(a) Machine ends to desired dimensions, see Figure 65.

(b) Heat to 1900°F and upset 1st stage on 1st end.

(c) Heat to 1900°F and upset 2nd stage on 1st end.

(d) Heat to 1900°F and upset 3rd stage on 1st end.

(e) Repeat operation b, c and d for 2nd end upset.

(f) Dimensional Inspection

On four of these shafts fairly distinct folds were detected on visual examination. While the remaining two shafts did not have a visible fold indication, penetrant die inspection revealed folds on both of these shafts. These laps were sufficiently deep to preclude their removal by machining the inner diameter to finished size. Consequently, repair welding was performed. This is discussed in greater detail in the next section.

It is not clear as to the exact cause of the re-occurance of the lap in the third upset pass. The presence of scoring marks on the inner diameter of the tube which could not be removed on machining of these shafts may have helped to contribute to this lap.

2. Manufacture of Assemblies

The four sheet metal assemblies for which the detail rings were manufactured were shown previously in Figure 11 through 14. The following summarizes the various flanges associated with each assembly and the assembly vendors.

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VI. DISCUSSION (continued)

Part No.	Name	Material	Flange Nos.	Vendor
608120	Combustion Chamber Heat Shield	A-70	226966	Portland Copper & Tank Works
608118	Rear Main Bearing Support Cone	A-70	226962 226963 226964	Smith-Morris Corp.
608109	Rear Main Bearing Vapor Duct	A-70	226961 227596	Midway Company
608569	Turbine Stator Blade Support	A110AT	227594 227596	Alloy Products Co.

a. Weld Approval

Prior to the initiation of actual manufacture of assemblies, the vendor's welding facilities were reviewed by WAD metallurgy personnel, and sample weld panels were analyzed for weld approval.

(1) Approval Requirements

In addition to the weld requirements of WAD 5797 (Appendix I) these test panels were to conform to a set of tentative WAD titanium welding specification. The main features of this specification are:

(a) The test specimen must be taken at the beginning of the production run.

(b) Weld and heat affected zone should have no more oxide than indicated by a straw color except that 5% of the weld may have a blue oxide color.

(c) The weld must have sufficient ductility as indicated by a 90° bend test across the weld around a radius that is a function of the base material and thickness of the sheet.

(d) The maximum thickness of the weld bead shall not exceed four time the sheet thickness.

In general, automatic welding was desired. Manual welds were permitted. However, these were required to be performed in a chamber of inert gas.

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VI. DISCUSSION (continued)

All the vendors except Smith-Morris passed all of the weld approval requirements. Due to an inadequate automatic weld set-up, Smith-Morris did not pass the automatic welding requirements and consequently, all the welding of P/N 608118 was performed manually.

b. Production Processing

The production processing of the titanium assemblies consisted of manufacturing four units of each configuration. In general, most of the finished assemblies had minor weld and/or dimensional discrepancies. The major weld discrepancy was that of porosity in the weld. These weld and dimensional discrepancies were in non-critical areas, permitting the assemblies to be procured through Material Review. It was previously noted that the upset operation used to establish the flange on the tubular extrusion for manufacture of the turbine rotor shaft resulted in a lap at the inner diameter. Machining the inner diameter to the finish part dimension did not completely remove this lap. Consequently, the lap was locally removed by machining. Repair welding was then performed and the shafts were finish machined. This repair welding was an acceptable solution due to its location which was not a highly stressed zone, Figure 87.

c. Material Utilization

The results obtained from manufacturing the detail parts by this newly developed manufacturing method clearly indicate a high material utilization factor. In Table XXV a comparison is made between detail parts manufactured in this manner and parts made by conventional techniques such as forging or flash-butt welding rings from barstock. For the sections examined, conventional manufacturing yields a material utilization factor of approximately 0.35. Manufacture of these parts by extrusion techniques yields a material utilization factor upward of 0.50. Of more striking significance is that it required approximately half of the material to make the parts by extrusion compared to conventional methods.

In some cases, the material utilization factor exceeded 0.65. This is even more dramatic when one considers that the balance of the weight is primarily associated with drilled holes and not with the machined envelope.

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VII. REFERENCES

1. Reynolds, J. E., Ogden, H.R. & Jaffee, R. J., "A Study of the Air Contamination of Three Titanium Alloys", TML Report No. 10, Titanium Metallurgical Laboratory, Battelle Memorial Institute, Columbus, Ohio, July 1955.

2. Quarterly Progress Report No. 3, "Extrusion of New Titanium Alloys", Contract No. AF 33(600)28322, Submitted by Harvey Machine Company to Wright Air Development Center, June 1955.

3. WAD Serial Report No. 2006, "Titanium Manufacturing Methods Development - Part I", Quarterly Progress Report No. 1, Contract No. AF 33(600)30262, Submitted to Air Materiel Command & Wright Air Development Center, August, 1955.

4. WAD Serial Report No. 2110, "Titanium Manufacturing Methods Development, Part I", Quarterly Progress Report No. 2., Contract No. AF 33 (600)30262, Submitted to Air Materiel Command & Wright Air Development Center, November, 1955.

5. WAD Serial Report No. MP.00-16, "Titanium Manufacturing Methods Development, Part I", Quarterly Progress Report No. 3., Contract No. AF 33(600)30262, Submitted to Air Materiel Command & Wright Air Development Center, February 1956.

6. WAD Serial Report No. MP.00-31, "Titanium Manufacturing Methods Development, Part I", Quarterly Progress Report No. 4., Contract No. AF 33 (600)30262, Submitted to Air Materiel Command & Wright Air Development Center, May 1956.

7. WAD Serial Report No. MP.00-46, "Titanium Manufacturing Methods Development, Part I", Quarterly Progress Report No. 5., Contract AF 33(600)30262, Submitted to Air Materiel Command & Wright Air Development Center, August 1956.

8. WAD Serial Report No. MP.00-74, "Titanium Manufacturing Methods, Part I", Quarterly Progress Report No. 6, Contract No. AF 33(600) 30262, Submitted to Air Materiel Command & Wright Air Development Center, November 1956.

9. WAD Serial Report No. MP.00-93, "Titanium Manufacturing Methods Development, Part I", Quarterly Progress Report No. 7., Contract No. AF 33(600)30262, Submitted to Air Materiel Command & Wright Air Development Center, February 1957.

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VII. REFERENCES (Cont'd)

10. WAD Serial Report No. MP.00-109, "Titanium Manufacturing Methods Development, Part I", Quarterly Progress Report No. 8, Contract No. AF 33(600)30262, Submitted to Air Materiel Command & Wright Air Development Center, May 1957.

11. Final Report on "Titanium Manufacturing Methods Development" Submitted by Metals Processing Division to Wright Aeronautical Division, January 1957.

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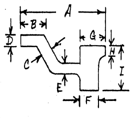
TABLE I - DIMENSIONAL INSPECTION REPORT FOR SEVERAL PROTOTYPE EXTRUSIONS OF P/N 226961



	Required Design Dimension	Location of Inspection	Billet No. A52-1 Ext. Dim.	Billet No. A52-2 Ext. Dim.	Billet No. A53-7 Ext. Dim.	Billet No. A53-8
A	2.737 +.06 -.03	Front	2.765	2.798	2.781	2.734
		Rear	2.815	2.785	2.750	2.718
		Variation	+.078	+.061	+.044	-.019
B	.561 ±.03	Front	.576	.564	.562	.567
		Rear	.590	.575	.562	.568
		Variation	+.029	+.014	+.001	+.007
C	.220 ±.02	Front	.260	.227	.235	.237
		Rear	.280	.227	.230	.233
		Variation	+.060	+.007	+.015	+.017
D	.259 ±.02	Front	.268	.264	.265	.269
		Rear	.283	.266	.266	.267
		Variation	+.024	+.007	+.007	+.010
E	.197 ±.02	Front	.225	.209	.214	.211
		Rear	.267	.215	.215	.208
		Variation	+.070	+.018	+.018	+.014
F	.462 ±.03	Front	.487	.470	.469	.480
		Rear	.518	.465	.484	.479
		Variation	+.056	+.008	+.022	+.018
G	1.037±.03	Front	1.052	1.040	1.042	1.055
		Rear	1.065	1.045	1.048	1.058
		Variation	+.028	+.008	+.011	+.021
H	.231±.02	Front	.250	.243	.234	.239
		Rear	.284	.241	.234	.245
		Variation	+.053	+.012	+.003	+.014
I	1.174±.03	Front	1.202	1.188	1.179	1.188
		Rear	1.220	1.201	1.188	1.191
		Variation	+.046	+.027	+.014	+.017

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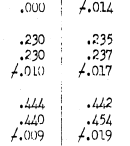
TABLE II - DIMENSIONAL INSPECTION REPORT FOR SEVERAL PROTOTYPE EXTRUSIONS OF P/N 226962



	Required Design Dimension	Location of Inspection	Billet No. A-53-5 Ext. Dim.	Billet No. A-53-6 Ext. Dim.	Billet No. A64-1 Ext. Dim.	Billet No. A64-2 Ext. Dim.	Billet No. A137F Ext. Dim.
A	1.410±.03	Front	1.422	1.418	1.402	1.410	1.419
		Rear	1.423	1.419	1.408	1.410	1.424
		Variation	+.009	+.009	-.008	.000	+.014
B	.220±.02	Front	.229	.223	.218	.230	.235
		Rear	.232	.221	.219	.230	.237
		Variation	+.012	+.003	-.002	+.010	+.017
C	.435+.03 -.00	Front	.446	.438	.436	.444	.442
		Rear	.444	.441	.435	.440	.454
		Variation	+.011	+.006	+.001	+.009	+.019
D	1.395+.03 -.00	Front	1.406	1.437	1.402	1.428	1.408
		Rear	1.406	1.432	1.404	1.428	1.412
		Variation	+.011	+.042	+.009	+.033	+.017
E	.265+.02 -.00	Front	.229	.287	.273	.282	.281
		Rear	.232	.292	.280	.281	.296
		Variation	-.036	-.027	+.015	+,017	+.031

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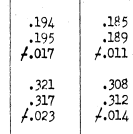
TABLE III - DIMENSIONAL INSPECTION REPORT FOR SEVERAL PROTOTYPE EXTRUSIONS OF P/N 226956



	Required Design Dimension	Location of Inspection	Billet No. A64-3 Ext. Dim.	Billet No. A64-4 Ext. Dim.	Billet No. A64-8 Ext. Dim.	Billet No. A64-9 Ext. Dim.	Billet No. A-136F Ext. Dim.
A	1.100±.03	Front	1.103	1.106	1.115	1.128	1.105
		Rear	1.112	1.109	1.123	1.137	1.122
		Variation	+.012	+.009	+.023	+.037	+.022
B	.178±.02	Front	.187	.130	.188	.194	.185
		Rear	.185	.189	.193	.195	.189
		Variation	+.009	+.012	+.015	+.017	+.011
C	.298±.02	Front	.313	.312	.313	.321	.308
		Rear	.315	.319	.318	.317	.312
		Variation	+.027	+.021	+.020	+.023	+.014
D	.201±.02	Front	.223	.219	.230	.208	.210
		Rear	.227	.236	.240	.215	.210
		Variation	+.026	+.035	+.039	+.014	+.009
F	.987+.03 -.00	Front	1.002	.995	1.101	1.022	.992
		Rear	.994	1.002	1.105	1.025	1.005
		Variation	+.015	+0.115	+0.118	+.038	+.018

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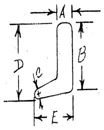
TABLE IV - DIMENSIONAL INSPECTION REPORT FOR SEVERAL PROTOTYPE EXTRUSIONS OF P/N 226963



	Required Design Dimensions	Location of Inspection	Billet No. A 53-5 Fxt. Dim.	Billet No. A53-6 Ext. Dim.	Billet No. A64-1 Ext. Dim.	Billet No. A64-2 Est. Dim.
A	.457 +.02 -.00	Front Rear Variation	.467 .460 +.010	.472 .470 +.015	.457 .455 -.002	.464 .466 +.009
B	1.732 + .06 - .03	Front Rear Variation	1.750 1.765 +.033	1.789 1.792 +.060	1.751 1.767 +.035	1.776 1.782 +.050
C	.304+.015	Front Rear Variation	.324 .325 .021	.325 .321 +.021	.319 .317 +.015	.325 .323 +.021
D	1.884+ .06 -.03	Front Rear Variation	1.906 1.906 +.022	1.875 1.875 -.009	1.898 1.896 +.014	1.892 1.891 +.007
E	1.244±.03	Front Rear Variation	1.245 1.244 +.001	1.247 1.246 +.003	1.248 1.244 +.004	1.245 1.268 +.024

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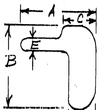
TABLE V - DIMENSIONAL INSPECTION REPORT FOR SEVERAL PROTOTYPE EXTRUSIONS OF P/N 226964



	Required Design Dimension	Location of Inspection	Billet No. A53-9 Ext. Dim.	Billet No. A64-3 Ext. Dim.	Billet No. A64-4 Ext. Dim.	Billet No A64-8 Ext. Dim.	Billet No. A64-9 Ext. Dim.
A	1.133±.03	Front Rear Variation	1.083 1.093 -.050	1.127 1.135 +.002 -.006	1.140 1.148 +.015	1.132 1.135 +.002	1.162 1.136 +.029
B	1.085+.03 -.00	Front Rear Variation	1.078 1.084 +.007	1.092 1.193 +.008	1.215 1.203 +.030	1.125 1.108 +.040	1.042 1.094 +.009 -.043
C	.500+.015 -.000	Rear Front Variation	.400 .500 -.010	.503 .502 +.003	.546 .538 +.046	.559 .554 +.059	.516 .531 +.031
D	.400+.015 -.000	Front Rear Variation	.400 .399 -.001	.418 .415 +.018	.426 .438 +.038	.458 .459 +.059	.464 .464 +.064
E	.140+.015 -.000	Front Rear Variation	.115 .144 +.025	.150 .146 +.010	.149 .176 +.036	.141 .162 +.022	.154 .189 +.049

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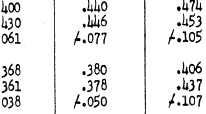
TABLE VI - DIMENSIONAL INSPECTION REPORT FOR SEVERAL PROTOTYPE EXTRUSIONS OF P/N 226966



	Required Design Dimension	Location of Inspection	Billet No. A64-3 Ext. Dim.	Billet No. A64-4 Ext. Dim.	Billet No. A64-8 Ext. Dim.	Billet No. A64-9 Ext. Dim.
A	.980±.03	Front Rear Variation	.996 .993 +.016	.980 .981 +.001	1.048 1.052 +.072	1.074 1.093 +.113
B	.369±.02	Front Rear Variation	.398 .400 +.031	.400 .430 +.061	.440 .446 +.077	.474 .453 +.105
C	.330±.03	Front Rear Variation	.364 .363 +.034	.368 .361 +.038	.380 .378 +.050	.406 .437 +.107
D	.174±.02	Front Rear Variation	.185 .190 +.016	.205 .241 +.067	.238 .260 +.086	.274 .275 +.101

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TABLE VII

AS EXTRUDED TENSILE PROPERTIES OF P/N 226961 (MAXIMUM ENVELOPE)

EXTRUDED AT VARIOUS TEMPERATURES

Billet No.	Ultimate psi	Yield psi 0.2% Offset	Elongation %	Reduction of Area %	Approx.* Extrusion Temperature °F
Required	80,000	70,000	15% Min.	30% Min.	
A 51-1	100,400	79,600	24.2	29.3	1700
	99,300	78,000	24.2	30.3	
	98,600	78,000	24.2	29.3	
	101,200	80,400	24.2	29.3	
AVG.	99,500	79,000	24.2	29.3	
A 51-3	100,800	74,660	26.4	42.7	1600
	101,100	72,240	27.1	41.0	
	107,200	81,960	25.3	35.8	
	107,100	79,800	26.4	37.1	
AVG.	104,050	77,190	26.3	39.6	
A 51-4	102,400	82,800	25.7	40.6	1450
	103,300	82,000	25.7	44.2	
	102,000	81,400	25.7	43.2	
	102,000	80,800	25.0	42.8	
AVG.	102,425	81,750	25.5	42.7	
A 51-5	103,000	80,400	24.2	38.4	1500
	101,800	79,700	25.7	38.4	
	101,200	79,200	25.0	39.3	
	101,300	78,000	25.0	41.0	
AVG.	101,825	79,325	24.9	39.2	
A 51-6	102,400	79,200	24.2	37.5	1500
	120,400	82,200	26.4	45.3	
	102,000	79,200	23.5	39.2	
	102,400	82,080	26.4	45.3	
AVG.	107,300	80,670	25.1	41.8	
Certified Physical Properties	99,800	78,000	21.9	31.3	

*Note: Indicated extrusion temperatures include temperature drop due to transfer from furnace to press.

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TABLE VIII

THE TENSILE PROPERTIES OF A-70 TITANIUM FLANGES (OPTIMISTIC ENVELOPE)

EXTRUDED WITH A 1550°F BILLET PREHEAT TEMPERATURE

Part No.	Test Temp.	U.T.S. (psi)	0.2% Y.S. (psi)	Elong. %	R.A. %	Position*	Comment
P/N 226956	RT	106,300	85,700	26.7	45.2	A	
	RT	106,400	83,600	23.6	44.2	A	
	RT	106,000	81,000	23.0	32.5	A	
	RT	106,000	83,000	25.5	41.5	A	
	650	47,200	32,100	35.9	60.6	A	Indications of poor temperature control.
	650	38,800	23,600	32.1	67.6	A	
	RT	106,100	--	17.9	43.5	B	
	RT	104,900	--	20.9	53.3	B	
P/N 226961	RT	106,000	86,600	25.5	42.3	A	
	RT	106,100	85,500	25.3	43.5	A	
	RT	107,100	85,100	24.7	41.5	A	
	RT	106,100	85,100	26.0	45.5	A	Extensometer Malfunction
	650	44,500	14,600	39.5	62.0	A	
	650	44,700	9,500	39.4	52.3	A	
	RT	101,500	--	14.0	43.5	B	
	RT	100,000		20.4	43.3	B	
P/N 226962	RT	103,000	78,500	23	39.4	A	
	RT	103,000	78,200	25	39.8	A	
	RT	104,700	82,500	22	39.8	A	
	RT	105,700	80,800	23	39.5	A	Extensometer Malfunction
	650	46,200	30,800	36	52.1	A	
	650	46,000	18,700	37	52.7	A	
P/N 226963	RT	103,700	80,400	24.0	38.9	A	
	RT	104,000	82,300	23.6	41.5	A	
	RT	103,600	82,800	23.8	39.5	A	
	RT	102,700	82,900	24.0	41.7	A	
	650	45,400	22,100	37.0	53.8	A	
	650	42,000	21,400	37.3	53.2	A	
P/N 226964	RT	106,100	84,400	24.8	42.6	A	
	RT	106,100	84,600	22.7	41.6	A	
	RT	104,800	85,500	25.5	45.0	A	
	RT	107,100	84,600	25.4	44.0	A	
	650	44,000	23,500	40.2	62.2	A	
	650	44,500	21,900	48.4	60.6	A	

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TABLE VIII (Cont'd)

THE TENSILE PROPERTIES OF A-70 TITANIUM FLANGES (OPTIMISTIC ENVELOPE)

EXTRUDED WITH A 1550°F BILLET PREHEAT TEMPERATURE

Part No.	Test Temp.	U.T.S. (psi)	0.2% Y.S. (psi)	Elong. %	R.A. %	Position*	Comment
P/N 226966	RT	102,300	--	19.2	38.8	B	
	RT	96,100	--	17.0	42.8	B	
	RT	100,300	--	18.2	44.6	B	
	RT	96,100	--	23.0	41.9	B	
	650	42,600	--	35.5	63.7	B	
	650	44,100	--	30.6	63.7	B	
	650	40,200	--	36.7	61.8	B	
	650	40,400	--	40.5	60.5	B	
AMS 4921	RT	80,000	70,000	15	--	-	Specification
RC A-70	650	40,000	25,000	--	--	-	Rem Cru Data

* Specimens from positions marked **A** are standard tensile -.252" diameter - test specimens.
Those from positions marked B are sub-standard tensiles -.150" diameter - test specimens.
The locations these specimens are taken from are indicated in Figure 31.

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TABLE VIII

THE TENSILE PROPERTIES OF A-70 TITANIUM FLANGES (OPTIMISTIC ENVELOPE)

EXTRUDED WITH A 1550°F BILLET PREHEAT TEMPERATURE

Part No.	Test Temp.	U.T.S. (psi)	0.2% Y.S. (psi)	Elong. %	R.A. %	Position*	Comment
P/N 226956	RT	106,300	85,700	26.7	45.2	A	
	RT	106,400	83,600	23.6	44.2	A	
	RT	106,000	81,000	23.0	32.5	A	
	RT	106,000	83,000	25.5	41.5	A	
	650	47,200	32,100	35.9	60.6	A	Indications of poor temperature control.
	650	38,800	23,600	32.1	67.6	A	
	RT	106,100	--	17.9	43.5	B	
	RT	104,900	--	20.9	53.3	B	
P/N 226961	RT	106,000	86,600	25.5	42.3	A	
	RT	106,100	85,500	25.3	43.5	A	
	RT	107,100	85,100	24.7	41.5	A	
	RT	106,100	85,100	26.0	45.5	A	Extensometer Malfunction
	650	44,500	14,600	39.5	62.0	A	
	650	44,700	9,500	39.4	52.3	A	
	RT	101,500	--	14.0	43.5	B	
	RT	100,000		20.4	43.3	B	
P/N 226962	RT	103,000	78,500	23	39.4	A	
	RT	103,000	78,200	25	39.8	A	
	RT	104,700	82,500	22	39.8	A	
	RT	105,700	80,800	23	39.5	A	Extensometer Malfunction
	650	46,200	30,800	36	52.1	A	
	650	46,000	18,700	37	52.7	A	
P/N 226963	RT	103,700	80,400	24.0	38.9	A	
	RT	104,000	82,300	23.6	41.5	A	
	RT	103,600	82,800	23.8	39.5	A	
	RT	102,700	82,900	24.0	41.7	A	
	650	45,400	22,100	37.0	53.8	A	
	650	42,000	21,400	37.3	53.2	A	
P/N 226964	RT	106,100	84,400	24.8	42.6	A	
	RT	106,100	84,600	22.7	41.6	A	
	RT	104,800	85,500	25.5	45.0	A	
	RT	107,100	84,600	25.4	44.0	A	
	650	44,000	23,500	40.2	62.2	A	
	650	44,500	21,900	48.4	60.6	A	

[redacted]

TABLE VIII (Cont'd)

THE TENSILE PROPERTIES OF A-70 TITANIUM FLANGES (OPTIMISTIC ENVELOPE)

EXTRUDED WITH A 1550°F BILLET PREHEAT TEMPERATURE

Part No.	Test Temp.	U.T.S. (psi)	0.2% Y.S. (psi)	Elong. %	R.A. %	Position*	Comment
P/N 226966	RT	102,300	--	19.2	38.8	B	
	RT	96,100	--	17.0	42.8	B	
	RT	100,300	--	18.2	44.6	B	
	RT	96,100	--	23.0	41.9	B	
	650	42,600	--	35.5	63.7	B	
	650	44,100	--	30.6	63.7	B	
	650	40,200	--	36.7	61.8	B	
	650	40,400	--	40.5	60.5	B	
AMS 4921	RT	80,000	70,000	15	--	-	Specification
RC A-70	650	40,000	25,000	--	--	-	Rem Cru Data

* Specimens from positions marked A are standard tensile -.252" diameter - test specimens.
Those from positions marked B are sub-standard tensiles -.150" diameter - test specimens.
The locations these specimens are taken from are indicated in Figure 31.

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TABLE IX

TENSILE PROPERTIES OF A110AT TUBULAR EXTRUSIONS

Extrusion Number	Condition	Ultimate Strength psi	0.2% Yield Strength psi	% Elongation	% Reduction of Area	Remarks
1	As-extruded	132,000	127,000	18.5	29	Upset & pierced at 2000° - Extruded at 1890° through Reentrant Die
		139,000	131,000	18.5	27	
	Average	136,000	126,500	18	28	
1	Extruded & Annealed 1500/½ hour	131,000	116,000	17	33	Upset & pierced at 2000° - Extruded at 1890° through Reentrant Die
		134,000	117,000	16	31	
		133,000	119,000	14	39	
		136,000	129,000	14	35	
	Average	133,500	120,000	14	35	
2	As-Extruded	144,000	130,500	18	32	Upset & pierced at 1900° - Extruded at 1890° - through 130° die-billet encased steel sheath.
		142,500	130,500	18	29	
	Average	143,000	130,500	18	30.5	
2	Extruded & Annealed 1500/½ hour	144,000	136,000	17	43	Upset & pierced at 1900° - Extruded at 1890° through 130° die-billet encased in steel sheath.
		142,000	134,500	17	44	
		143,000	131,000	15	42	
		141,000	131,000	14	42	
	Average	142,000	131,000	16	43	
		147,000	136,000	14	24	Certified data from Rem-Cru

[redacted]

TABLE X

THE TENSILE PROPERTIES OF RING WELDMENTS FOR CERTIFICATION OF MACHINE SETTINGS

Part Number	Welding Vendor	Rings Tested	Tester	Sect.	Tensile	Yield	Elongation	RA.
226956	C. W.	1	C. W.	Thick	100,900	88,760	16	29.44
				Thin	103,060	88,000	20	
				Parent	100,420	96,460	21	49.25
226961 (not sized)	T. W.	1	C. W.	Thin	100,810	96,420	20	--
				Thin	99,800	79,540	25	--
				Thin	93,970	82,620	25	--
				Thick	104,030	80,430	22	--
226962	T. W.	1	MPD	Thin	96,800	Not Record.	27.5	
				Heavy	111,750	87,000	28	
226963	T. W.	1	MPD	Thick	96,190	77,430	26	40.9
				Thin	88,570	Not Record.	27.1	
226964	C. W.	1	C. W.	Thin	93,440	82,900	10	
				Thick	97,730	82,920	26	38.8
				Parent	97,065	78,780	26	38.7
226966	C. W.	2	C. W.	Thin	103,800	55,560	19	
				Parent	98,630	77,260	23	
				Thin	104,720	91,070	16	
				Parent	100,930	81,370	27	
226966	T. W.	1	MPD	Thick	102,180	65,620	19	50.3
				Thin	99,310	93,060	15.7	
227594 (not sized)	C. W.	1	C. W.	Thick	135,460	127,110	16	27.4
				Parent	135,350	129,080	16	28.08

TABLE XI

CLEVELAND WELDING MACHINE SETTINGS AND BURN OFF LENGTHS

Part Number	226956	226961	226962	226963	226964	226966	227594	227596
Material	C.P.-70	C.P.-70	C.P.-70	C.P.-70	C.P.-70	C.P.-70	A-110AT	A-110AT
Initial Die Opening (inch)	1-5/16	1-3/8	1-5/16	1-1/2	1-5/8	1-3/16		1-9/16
Final Die Opening (inch)	1/2	1/2	1/2	1/2	3/4	1/2		1/2
Flash Burn Off (inch)	3/8	7/16	13/32	13/32	3/8	5/16		9/16
Upset Travel (inch)	7/16	7/16	13/32	19/32	7/16	3/8		1/2
Upset Pressure (lbs.)	42,000	45,600	42,000	42,000	38,000	42,000		45,600
Flash Time (sec.)	6.6	6.8	6.8	7.0	6.0	5.8		9.0
Initial Velocity (in./sec.)	.041	.041	.041	.033	.048	.041		.033
Acceleration (in./sec.^{2})	.0098	.0098	.0098	.0073	.0098	.0042		.0087
Voltage	6.87	5.6	6.87	7.5	5.6	5.18		6.87
Burn Off Length (inch)	3/4	1-1/8	1-1/8	1	1	3/4		1

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TABLE XII

THOMSON WELDING MACHINE SETTINGS AND BURN OFF LENGTHS

Part Number	226956	226961	226962	226963	226964	226966	227594	227596
Material	C.P.	C.P.	C.P.	C.P.	C.P.	C.P.	A-110AT	A-110AT
Work Overhang R.H.	3/8	5/8	9/16	5/8	7/16	9/16	9/16	9/16
Work Overhang L.H.	3/8	5/8	9/16	5/8	7/16	9/16	9/16	9/16
Initial Die Opening (in.)	3/4	1¼	1 1/8	1¼	7/8	1 1/8	1 1/8	1 1/8
Die Opening AT "O" (in.)	3/8	1/2	1/2	1/2	3/8	3/8	1/2	1/2
Final Die Opening (in.)	1/8	3/16	NR	3/16	1/8	3/32	NR	NR
Current Cut-Off After "O" (in.)	1/8	1/8	3/16	3/16	1/8	1/8	3/16	3/16
Flash Time (sec.)	3	12	5½	7 1/2	5	7	5 1/2	5 1/2
Flow Valve	NR	5	5	5	4	5	5	5
Clamp Pressure (lbs.) R.H.	23,000	23,000	23,000	23,000	23,000	23,000	23,000	23,000
Clamp Pressure (lbs.) L.H.	23,000	23,000	23,000	23,000	23,000	23,000	23,000	23,000
Upset Pressure (lbs.)	20,000	30,000	20,000	30,000	12,000	12,000	24,000	24,000
Tap Switch	1 P	85S	4 P	85	1 P	35	4 P	3 P
Burn Off Lengths	-	-	1 1/8	-	-	3/4	1	1

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TABLE XIII

TENSILE PROPERTIES OF THE A110-AT UPSET FLANGE

	Ultimate Strength	Yield Strength	% Elongation	% Reduction In Area	Comments
Upset Area (transverse to shaft axis)	136,000	-	8	41.5	Coarse Grains
	136,000	-	10	43	" "
	137,000	-	11	37	Relatively Fine Grains
	135,900	-	11	33	Relatively Fine Grains
Heat Affected Zone (Longitudinal specimens)	134,000	-	15	28.6	Coarse Grains-Shear fracture
	133,800	-	15	28.1	Coarse Grains-Shear fracture
	137,000	-	9	31	Shear Fracture
	136,000	-	10	29	Shear Fracture
	128,200	-	10	34	Coarse Grains-Shear fracture
	130,000	-	9	28	Coarse Grains-Shear fracture

Note: All specimens annealed 1500°F/1/2hr/Air Cool

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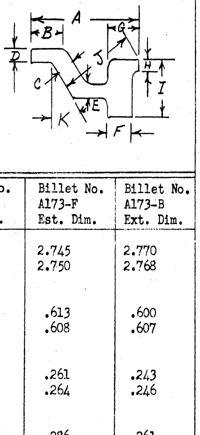
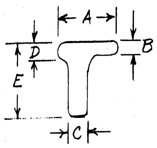
TABLE XIV - DIMENSIONAL INSPECTION REPORT FOR SEVERAL PRODUCTION EXTRUSIONS OF P/N 226961



	Required Design Dimension	Location of Inspection	Billet No. A173-B Ext. Dim.	Billet No. A173-1 Ext. Dim.	Billet No. A173-F Est. Dim.	Billet No. A173-B Ext. Dim.
A	2.801 2.707	Front Rear	2.767 2.800	2.737 2.734	2.745 2.750	2.770 2.768
B	.687 .593	Front Rear	.626 .600	.615 .610	.613 .608	.600 .607
C	.346 .252	Front Rear	.266 .261	.258 .257	.261 .264	.243 .246
D	.354 .260	Front Rear	.263 .263	.283 .271	.286 .283	.261 .268
E	.323 .229	Front Rear	.228 .225	.237 .237	.241 .236	.214 .218
F	.588 .494	Front Rear	.503 .515	.512 .511	.506 .499	.495 .498
G	1.163 1.069	Front Rear	1.088 1.082	1.086 1.084	1.103 1.100	1.080 1.075
H	.357 .263	Front Rear	.271 .264	.276 .264	.285 .280	.236 .255
I	1.269 1.175	Front Rear	1.200 1.204	1.195 1.200	1.210 1.208	1.237 1.241
J	2.043 1.949	Front Rear	1.980 1.986	1.972 1.970	1.977 1.980	1.969 1.980

[redacted]

TABLE XV - DIMENSIONAL INSPECTION REPORT FOR SEVERAL PRODUCTION EXTRUSIONS OF P/N 226956



	Required Design Dimensions	Location of Inspection	Billet No. A171-B Ext. Dim.	Billet No. A171-1 Ext. Dim.	Billet No. A179-F Ext. Dim.	Billet No. 179-1 Est. Dim.
A	1.195 1.131	Front Rear	1.157 1.156	1.137 1.096	1.164 1.167	1.105 1.120
B	.274 .210	Front Rear	.222 .223	.206 .207	.207 .195	.157 .161
C	.393 .329	Front Rear	.311 .342	.305 .280	.311 .308	.286 .300
D	.296 .232	Front Rear	.265 .265	.200 .196	.243 . -	.210 .218
E	1.082 1.018	Front Rear	1.015 1.035	1.005 1.017	- -	.980 .975

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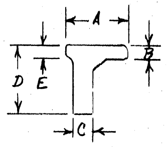
TABLE XVI - DIMENSIONAL INSPECTION REPORT FOR SEVERAL PRODUCTION EXTRUSIONS OF P/N 226962



	Required Design Dimension	Location of Inspection	Billet No. A172-B Ext. Dim.	Billet No. A173-2 Ext. Dim.	Billet No. A172-F Ext. Dim.	Billet No. A180-1 Ext. Dim.
A	1.474 1.380	Front Rear	1.437 1.437	1.432 1.447	1.437 1.421	1.421 1.421
B	.345 .251	Front Rear	.240 .233	.238 .226	.236 .227	.234 .237
C	.499 .405	Front Rear	.439 .420	.438 .419	.439 .434	.436 .414
D	1.490 1.396	Front Rear	1.429 1.437	1.428 1.429	1.421 1.437	1.421 1.453
E	.391 .297	Front Rear	.281 .281	.288 .275	.281 .234	.281 .281

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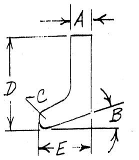
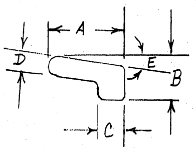
TABLE XVII - DIMENSIONAL INSPECTION REPORT FOR SEVERAL PRODUCTION EXTRUSIONS OF P/N 226963



	Required Design Dimensions	Location of Inspection	Billet No. A172-B Ext. Dim.	Billet No. A173-2 Ext. Dim.	Billet No. A172-F Ext. Dim.	Billet No. 181-B Ext. Dim.
A	.521 .427	Front Rear	.461 .457	.442 .452	.441 .452	.460 .455
B	7°45 min. ± 1°	Front Rear				
C	.184 .137	Front Rear	.163 .160	.151 .156	.156 .147	.154 .157
D	1.948 1.854	Front Rear	1.906 1.906	1.885 1.890	1.905 1.890	1.896 1.900
E	1.308 1.214	Front Rear	1.234 1.225	1.240 1.231	1.230 1.240	1.240 1.232

[redacted]

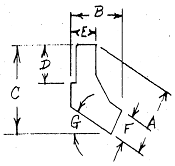
TABLE XVIII - DIMENSIONAL INSPECTION REPORT FOR SEVERAL PRODUCTION EXTRUSIONS OF P/N 226966



	Required Design Dimensions	Location of Inspection	Billet No. 171-F1 Ext. Dim.	Billet No. 171-F Ext. Dim.	Billet No. 171-1 Ext. Dim.	Billet No. 171-B Ext. Dim
A	1.044 .950	Front Rear	1.011 1.017	1.019 1.003	.982 .974	.982 .993
B	.534 .440	Front Rear	Hvy. Ribs	.479 .471	.493 .457	.497 .462
C	.456 .362	Front Rear	.342 .345	.336 .341	.365 .352	.340 .336
D	.238 .144	Front Rear	.177 .181	.182 .183	.168 .150	.165 .168
E	6°30 min ± 1°	Front Rear	6° 6°	6° 6°30 min	6°30 min 6°30 min	6°30 min 6°30 min

[redacted]

TABLE XIX - DIMENSIONAL INSPECTION REPORT FOR SEVERAL PRODUCTION EXTRUSIONS OF P/N 227594



	Required Design Dimension	Location of Inspection	Billet No. A327-1 Ext. Dim.	Billet No. A129-11 Ext. Dim.	Billet No. A323-B Ext. Dim.	Billet No. A327-T Ext. Dim.
A	1.335 1.251	Front Rear	1.250 1.260	1.252 1.249	1.249 1.243	1.256 1.237
B	1.329 1.255	Front Rear	1.250 1.245	1.260 1.240	1.240 1.240	1.259 1.264
C	1.784 1.700	Front Rear	1.680 1.700	1.695 1.695	1.700 1.695	1.696 1.700
D	.819 .735	Front Rear	.765 .781	.781 .765	.765 .796	.796 .796
E	.523 .375	Front Rear	.412 .412	.415 .409	.410 .409	.416 .414
F	.511 .427	Front Rear	.438 .436	.434 .434	.431 .428	.445 .443
G	32° 28°	Front Rear	29° 28°30'	30°30' 30°30'	29°30' 30°30'	30° 30°30'

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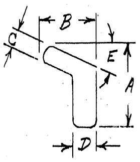
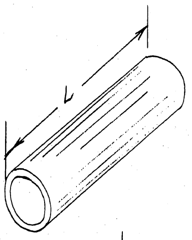
TABLE XX - DIMENSIONAL INSPECTION REPORT FOR SEVERAL PRODUCTION EXTRUSIONS OF P/N 227596

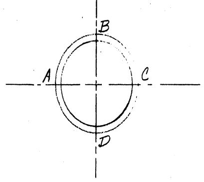


	Required Design Dimension	Location of Inspection	Billet No. A215-F Ext. Dim.	Billet No. A215-B Ext. Dim.	Billet No. A149-F Ext. Dim.	Billet No. --- Ext. Dim.
A	1.586 1.502	Front Rear	1.515 1.508	1.500 1.483	1.485 1.520	--
B	1.227 1.153	Front Rear	1.160 1.168	1.145 1.140	1.180 1.162	-- --
C	.408 .334	Front Rear	.340 .344	.330 .333	.360 .352	-- --
D	.492 .418	Front Rear	.428 .423	.407 .410	.439 .430	-- --
E	24°30' 20°30'	Front Rear	24° 21°	23°30' 24°30'	22° 23°	-- --

[redacted]

TABLE XXI - DIMENSIONAL INSPECTION REPORT FOR SEVERAL PRODUCTION EXTRUSIONS OF P/N 226970





LOCATION	ACTUAL DIMENSIONS						
	O.D. (INCH)		I.D.(INCH)		THICKNESS (INCH)		LENGTH (FEET)
	FRONT	REAR	FRONT	REAR	FRONT	REAR	
AC	6.330	6.333	4.978	5.024			
BD	6.343	6.342	4.980	5.005			
A					.690	.680	
B					.685	.610	
C					.680	.660	
D					.690	.670	
L							11

[redacted]

TABLE XXII

THE MECHANICAL PROPERTIES OF TYPICAL EXTRUDED AND ANNEALED SECTIONS FROM THE PRODUCTION FLANGE EXTRUSION

STAT

Ident.	Part Number	Billet Number	Heat Number	Location of Sample In Extrusion	Type of Material A-70	Fe	Mn	C	N	H_2	O	Oxygen Equiv.	U.T.S. (psi)	0.2% Y.S. (psi)	% Elong.	% R.A.	Comments	Notes
1	226956	A179-F	2-155S	Front	Cast (C.P.)	0.34	0.20	0.04	0.052	0.0024	0.175	0.311	106,000	81,500	23	39		ACE
2		"	"	"	"								105,500	81,000	24	39		ACE
3		A171-B	R10-483	"	Forge (C.P.)	0.12	0.17	0.09	0.015	0.0080	0.110	0.20	150,000	78,000	25	41		ACE
4		"	"	"	"								104,500	81,000	29	46.5		ACE
5	226961	A181-1	A-157S	Back	Cast (C.P.)	0.37	0.14	0.052	0.05	0.0012	0.167	0.302	103,000	80,500	25	44.3		ACE
6		"	"	"	"								102,000	73,600	24	48.0	not annealed	A-E
7		A173-F	R10-483	"	Forge (C.P.)								105,500	82,500	27	43		ACE
8		"	"	"	"								112,000	87,500	30	45.0		ACE
8-A		"	"	"	"								107,300	75,300	25	45.9	not annealed	A-E
9	226962	A172-F	R10-483	"	"								111,000	86,000	26	39		ACE
10		"	"	"	"								110,500	83,500	25	49.5		ACE
11		A218-F	2-109S	Front	Cast (C.P.)	0.27	0.08	0.042	0.048	0.0030	0.282	0.406	96,000	72,300	24	37		ACE
12		"	"	"	"								95,600	83,000	22	32.5	Ellip.(2) shear-Fracture	ACE
13	226963	A181-B	2157S	Back	"								107,000	83,500	25	45		ACE
14		"	"	"	"								104,500	84,300	23	43.5		ACE
15	226963	A-64-10	24462	Front	Forge (C.P.)	0.28	--	0.04	0.028	0.0057	0.250	0.305	107,000	--	26	42.5		ACE
16		"	"	"	"								106,000	81,600	23	38		ACE
17	226964	A171-B	R10-483	"	"								105,000	84,500	24	45.6		ACE
18		"	"	"	"								104,000	85,500	24	46		ACE
19		A179-1	2-155S	"	Cast (C.P.)								103,000	83,000	24	40		ACE
20		"	"	"	"								101,000	77,300	27	42		ACE
21	226966	A171-F	R10-483	Back	Forge (C.P.)								109,500	--	20.1	50		ACE
22		"	"	"	"								106,900	--	20.1	50		ACE
23		A179-1	2-155S	Front	Cast (C.P.)								106,800	--	18.6	44		ACE
24		"	"	"	"								107,000	--	18.6	39		ACE
25	227594	A129-10	D1221622-B	Back	Forge(A110AT)	5Al	25Sn	0.10 (max)	0.03	0.0128	0.130	--	137,000	121,000	18.0	35.6		BDE
26		"	"	"	"								136,800	121,000	18.0	34		BDE
27	227596	"	"	"	"								136,000	120,300	18.0	36.6		BDE
28		A129-10	D1221622-B	Back	Forge(A110AT)								135,900	121,000	18.0	32.3		BDE
Vendor Data AMS - 4921		Typical	C.P. (A-70		Other Elements 0.80(max.)	0		0.20(max.)					90,000	80,000	20	40		
													80,000	70,000	15	--	Minimum Properties	
Vendor Data WAD - 7852		Typical	A-110AT		0.10	0.50	0.20	0.20	0.07	0.0175	0.20(max. Chemist)		125,000	120,000	18	40		
													115,000	110,000	15	30	Minimum Properties	

Oxygen equivalent - 02% + 2N% + 2/3 C%

Notes: (A-F)

A- Commercially Pure Billets Heated 1550 F-1 hour at an approx. 30:1 Extrusion Ratio.
B- 5Al-2.5Sn (A-110AT) billet heated 1900 F-1 hour at an approx. 30:1 Extrusion Ratio.
C- C.P. Material Annealed 1300 - 2 hours in He - A.6.
D- A-110AT Material Annealed 1500 - 1/2 hours in He - A.6.
E- 0.252 Dia. Tensile Specimen.
F- 0.150 Dia. Tensile Specimen.

STAT

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TABLE XXIII

THE TENSILE PROPERTIES OF EXTRUDED A-110-AT PRODUCTION TUBING FROM FORGED BILLETS

	Ultimate Strength	Yield Strength	% Elongation	% Reduction In Area	Comments
As-Extruded	130,200	118,000	15	31	Coarse grained
Tube	126,000	115,300	16	32	" "
a) Standard					
(longitudinal)					
b) Sub-Standard	130,200	—	11.7	28	" "
(longitudinal)	132,000	—	13.6	30	" "
Flange					
a) Standard	129,000	117,900	15	31	" "
(longitudinal)	127,000	116,800	14	30	" "
b) Sub-Standard	133,000	—	10.6	27	" "
(longitudinal)	133,200	—	13.2	30	" "
Flange	139,000	126,200	15	29	Coarse grain
a) Standard	136,000	125,200	15	37	Fine grain
(transverse)	139,500	—	10.9	33	Coarse grain
b) Sub-standard	140,900	—	9.8	32	" "
(transverse)	131,000	—	10.3	29	" "
	133,000	—	10.3	28	" "

[redacted]

TABLE XXIV

THE TENSILE PROPERTIES OF THE WELD SECTION AND BASE METAL OF FORMED AND WELDED RINGS

Ident.	U.T.S.	0.2% Y.S.	% Elongation	% R. A.	Comments
A171-B-7-1	108,200	—	14.3	40	Weld
-2	101,000	—	17.3	31.3	
A173-2-3-1	111,100	--	18.9	40.6	Weld
-2	114,100	--	18	43.5	
A179-1-3-1	105,300	--	19.4	40	Weld
-2	106,000	--	17	41.5	
A179-1-4-1	104,200	--	14.9	32.8	Weld
-2	102,800	--	17.7	25	
A181-F-8-1	107,000	85,500	24	44.5	
-2	107,700	--	17	46.5	Weld
A218-F-5-1	111,800	93,000	28.5	45.4	Weld
-2	104,000	88,600	18.2	47.5	

a) Weld joint within the gauge length

[redacted]

TABLE XXV

COMPARISON OF CONVENTIONAL MANUFACTURING METHODS (FORGING AND FLASH-BUTT WELDED BARSTOCK) TO EXTRUSION ON THE BASIS OF MATERIAL UTILIZATION

Part No.	Part & Assembly Name	Finished Detail Weight (lbs)	Rough Weight(lbs)		Mat'l Utilization Factor		Percentage of Weight Saved
			Conventional*	Extrusion	Conventional*	Extrusion	
226966	Flange-Combustion Chamber Heat Shield	1.0	3.0	2.2	.33	.45	37
226962	Flanges, Front, Rear & Brace-Rear Main Bearing Support Cone	5.6	14.1	9.6	.40	.57	32
226963		3.8	11.1	5.8	.34	.66	48
226964		3.0	8.7	6.0	.36	.52	27
226956	Flanges, Front & Rear-Rear Main Bearing Vapor Duct	2.8	8.4	4.2	.33	.67	50
226961		4.1	16.5	8.3	.25	.50	50
227594	Flange, Front & Rear Turbine Stator Blade Support	4.8	-	8.0	-	.60	-
227596		5.4	-	9.2	-	.59	-
226970	Shaft, Turbine Rotor-Front	19	69.0	34.0	.28	.56	50
			130.8	70.1			45.5

*Flash-Butt Welded Rings from barstock or forgings.

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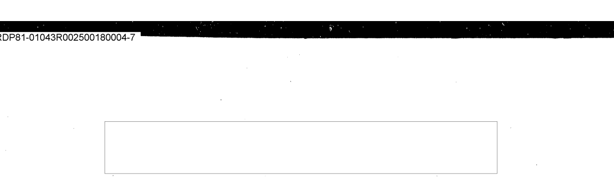

FIG. I- CUTAWAY VIEW OF THE CURTISS-WRIGHT J65 TURBOJET SHOWING THE TITANIUM PARTS AND ASSEMBLIES MANUFACTURED UNDER THIS PROGRAM.

[redacted]

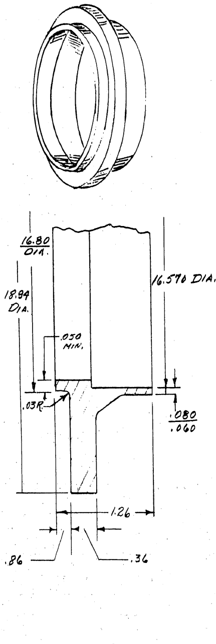

FIGURE 2. P/N 226962 - Front flange, Rear Main Bearing Support Cone Assembly, Material Ti-A-70

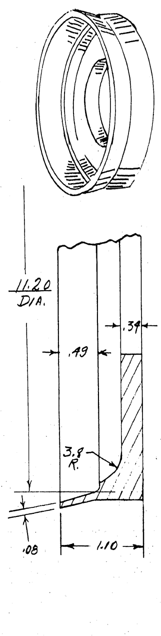

FIGURE 3. P/N 226963 - Rear Flange, Rear Main Bearing Support Cone Assembly, Material Ti-A-70.

[redacted]

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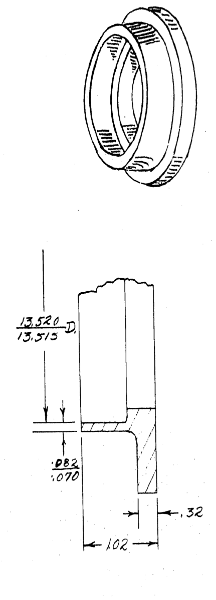

FIGURE 4. P/N 226964 - Flange Brace, Rear Main Bearing Support Cone Assembly, Material Ti-A70

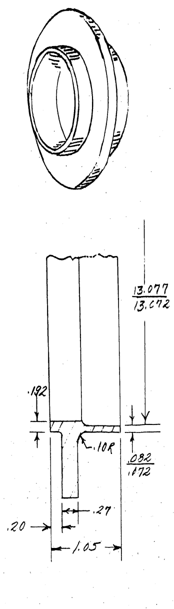

FIGURE 5. P/N 226956 - Front Flange, Rear Main Bearing Vapor Duct Assembly, Material Ti-A-70

[redacted]

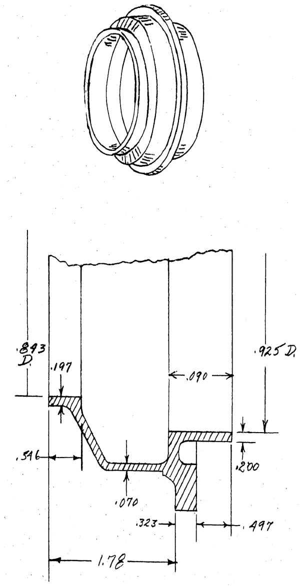

FIGURE 6. P/N 226961 - Rear Flange, Rear Main Bearing Vapor Duct Assembly, Material Ti-A70

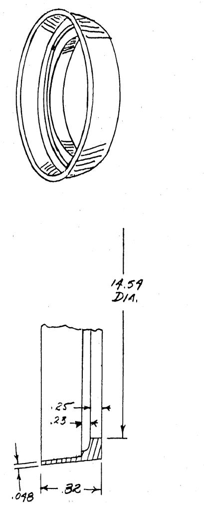

FIGURE 7. P/N 226966 - Flange, Combustion Chamber Heat Shield Assembly, Material, Ti-A-70

[redacted]

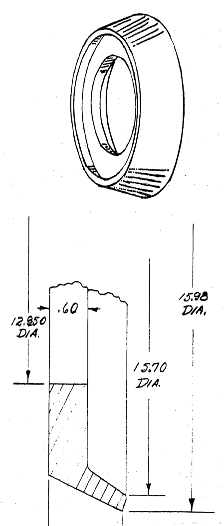

FIGURE 8. P/N 227594 - Rear Flange, Turbine Stator Blade Support Assembly, Material Ti-A110-AT

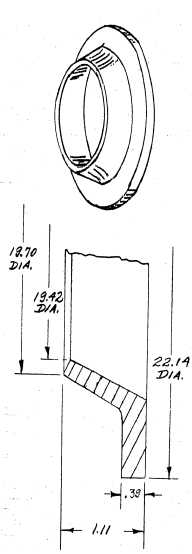

FIGURE 9. P/N 227596 - Front Flange, Turbine Stator Blade Support Assembly, Material Ti-A110-AT

[redacted]

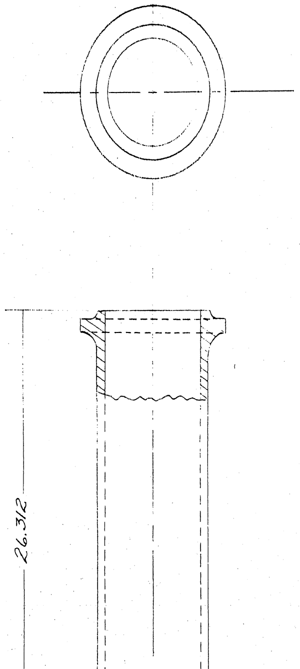

FIGURE 10. P/N 226970 - Shaft, Turbine Rotor Front, Material Ti-A110-AT

[redacted]

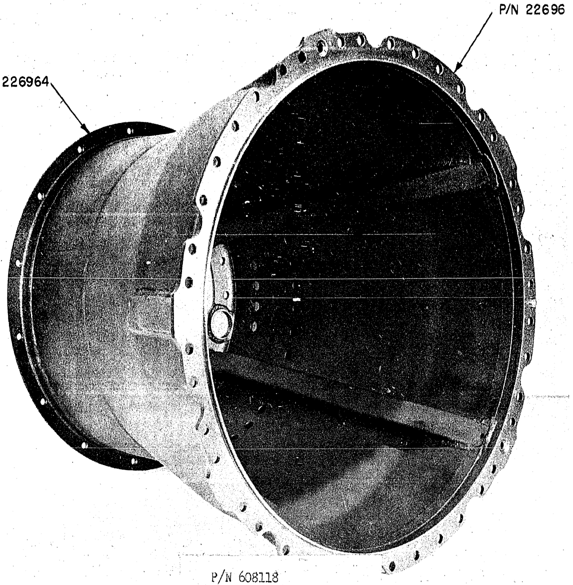

FIG.11 - P/N 608118 - REAR MAIN BEARING SUPPORT CONE ASSEMBLY

[redacted]

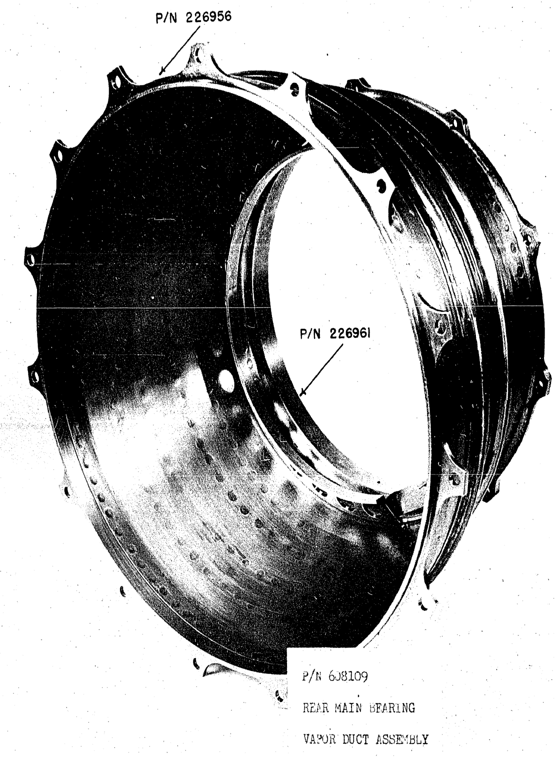

FIG. 12 - P/N 608109- REAR MAIN BEARING VAPOR DUCT ASSEMBLY

[redacted]

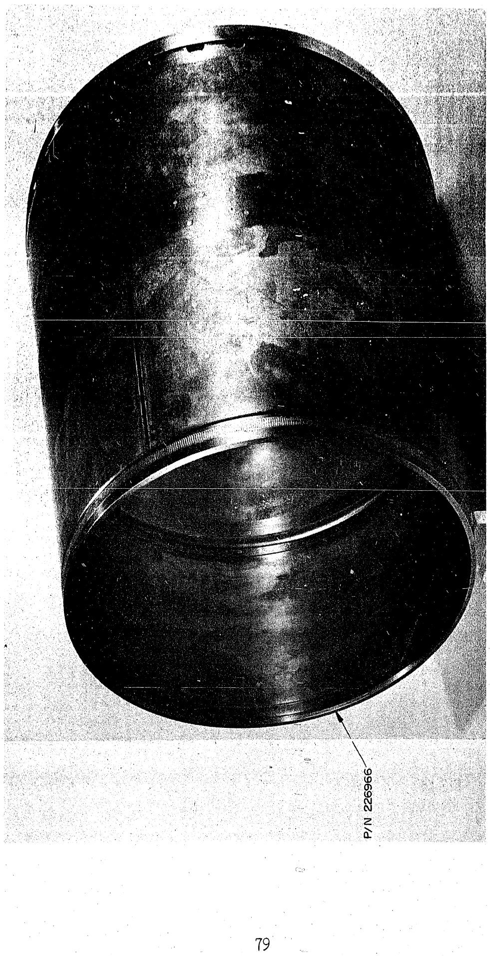

FIG. 13 - P/N 608120 - COMBUSTION CHAMBER HEAT SHIELD ASSEMBLY

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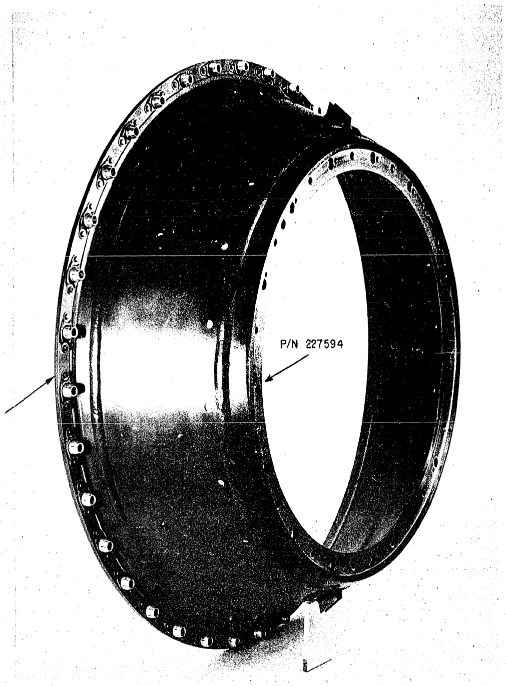


FIG. 14 - P/N 608569 - TURBINE STATOR BLADE SUPPORT ASSEMBLY.

[redacted]

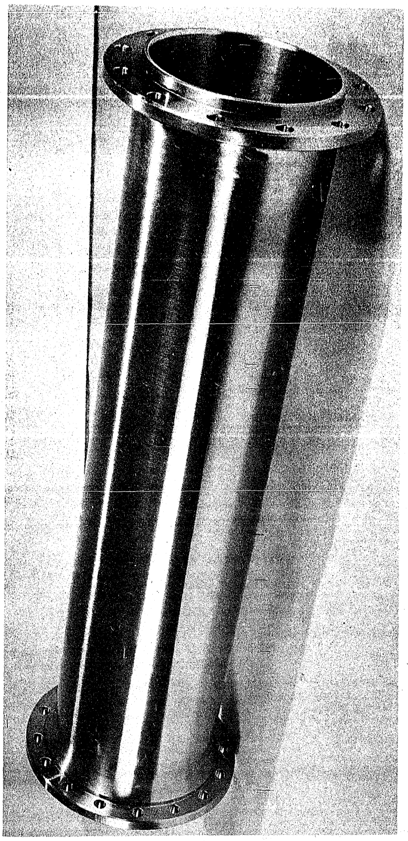


FIG. 15 - P/N 226970 - SHAFT, TURBINE ROTOR FRONT

[redacted]

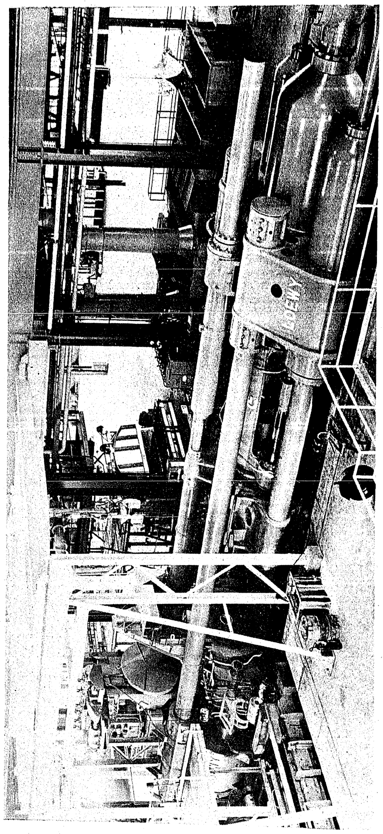


FIG. 16(A)-12,000 TON HORIZONTAL EXTRUSION PRESS

[redacted]

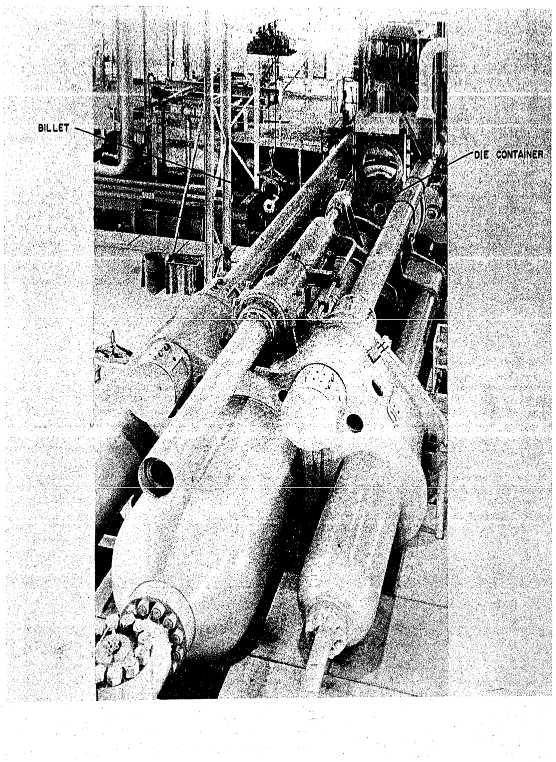
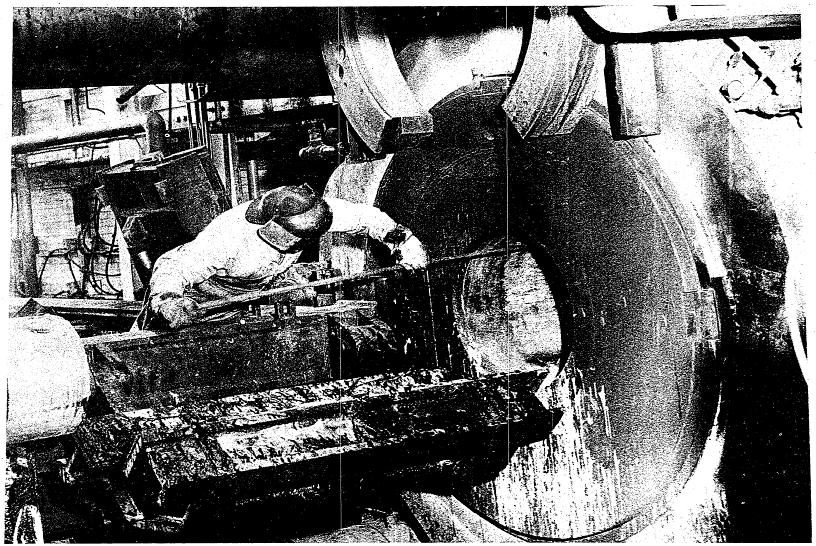


FIG. 16 (b) - TOP VIEW OF THE 12,000 TON EXTRUSION PRESS, NOTICE THE BILLET IN POSITION TO BE TRANSFERRED INTO THE CONTAINER

[redacted]



G. 16(C) – CLOSE UP VIEW OF THE CONTAINER AND DIE BEING LUBRICATED.

[redacted]

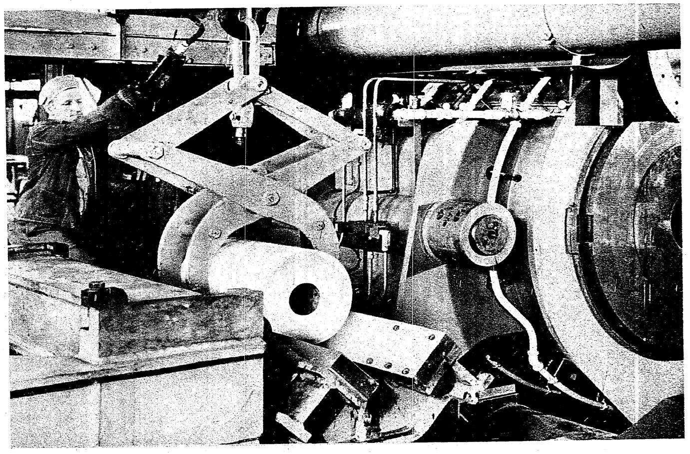


FIG. 16(d) - CLOSE-UP VIEW OF A BILLET BEING TRANSFERRED INTO THE CONTAINER

[redacted]

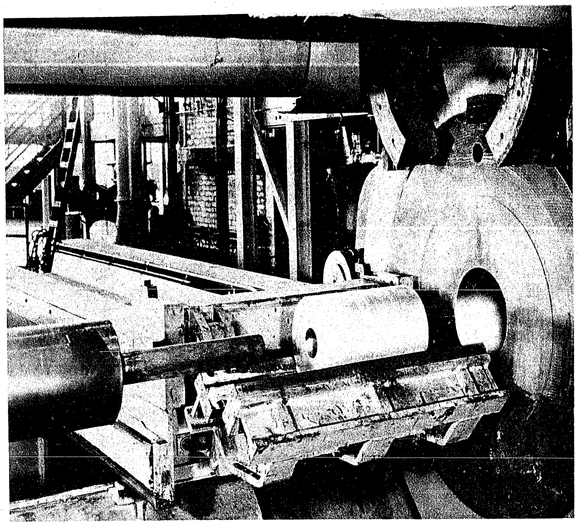


FIG. 16(e)- CLOSE-UP VIEW OF THE BILLET IN POSITION FOR EXTRUSION

[redacted]

FIG. 16 (f)- A BILLET BEING TRANSFERRED FROM THE FURNACE TO THE BILLET LOADING TABLE

[redacted]

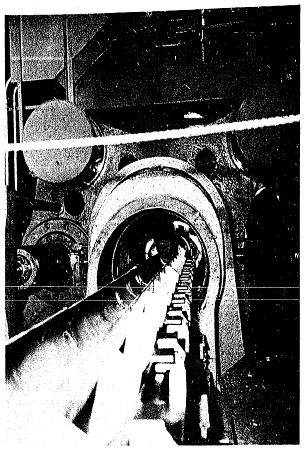


FIG. 16(g)- AN EXTRUDED SECTION MOVING INTO THE RUN-OUT TABLE

[redacted]

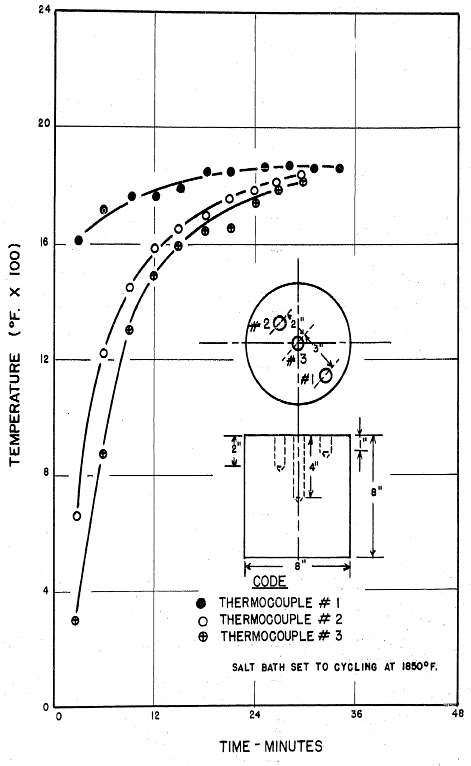
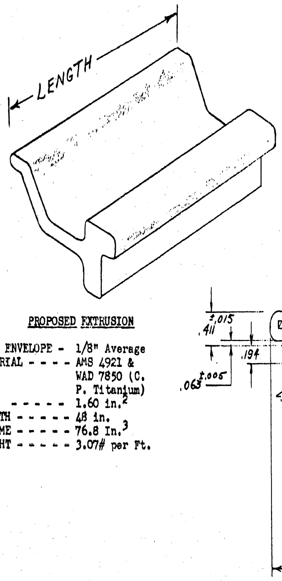


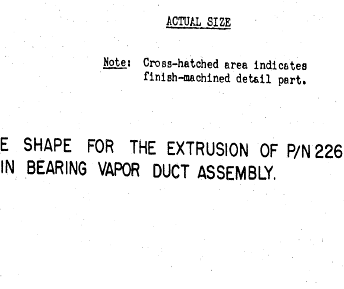
FIGURE 17 HEATING CURVE FOR AN 8 INCH DIAMETER TITANIUM BILLET HEATED IN A SALT BATH TO 1850°F.

[redacted]



PROPOSED EXTRUSION

MAX. ENVELOPE - 1/8" Average
MATERIAL - - - - AMS 4921 & WAD 7850 (C. P. Titanium)
AREA - - - - - 1.60 in.^{2}
LENGTH - - - - - 48 in.
VOLUME - - - - - 76.8 In.^{3}
WEIGHT - - - - - 3.07# per Ft.



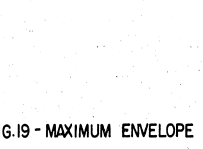
ACTUAL SIZE

Note: Cross-hatched area indicates finish-machined detail part.

FIG.18 - MAXIMUM ENVELOPE SHAPE FOR THE EXTRUSION OF P/N 226961, FLANGE, REAR MAIN BEARING VAPOR DUCT ASSEMBLY.

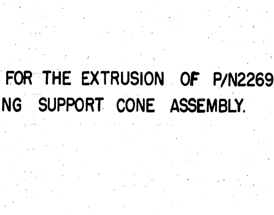
STAT

[redacted]



PROPOSED EXTRUSION

MAX. ENVELOPE - 1/8" Average
MATERIAL - - - AMS 4921 and WAD 7850 (C.P. Titanium
AREA - - - - - 1.41 In.^{2}
LENGTH - - - - 48 In.
VOLUME - - - - -67.7 In.^{3}
WEIGHT - - - - -2.71# per Ft.



ACTUAL SIZE

Note: Cross-hatched area indicated finish-machined detail part.

FIG.19 - MAXIMUM ENVELOPE SHAPE FOR THE EXTRUSION OF P/N226963, FLANGE, REAR MAIN BEARING SUPPORT CONE ASSEMBLY.

STAT

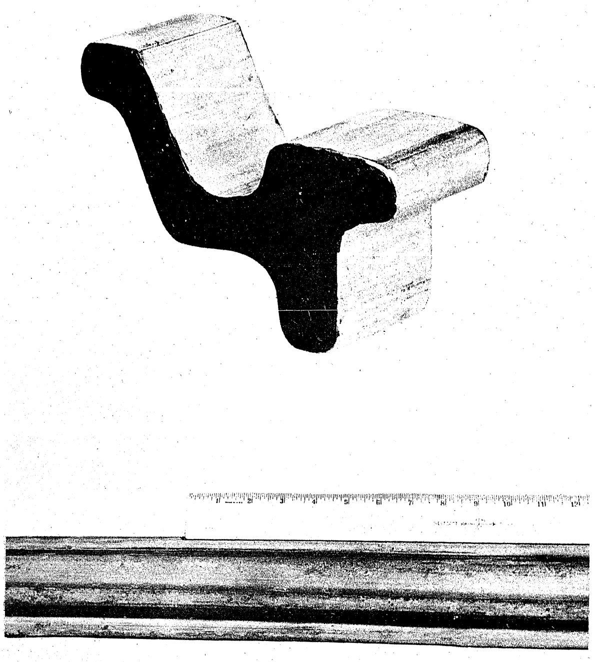
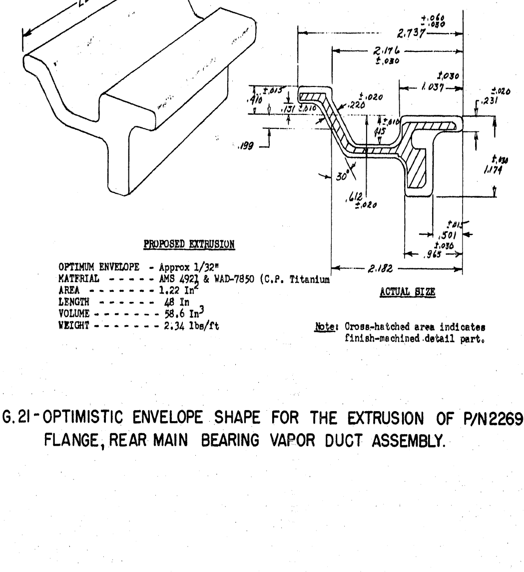


FIG. 20 PHOTOGRAPHS OF AN EXTRUDED SECTION OF P/N 226961 SHOWING CROSS-SECTION AND SURFACE QUALITY



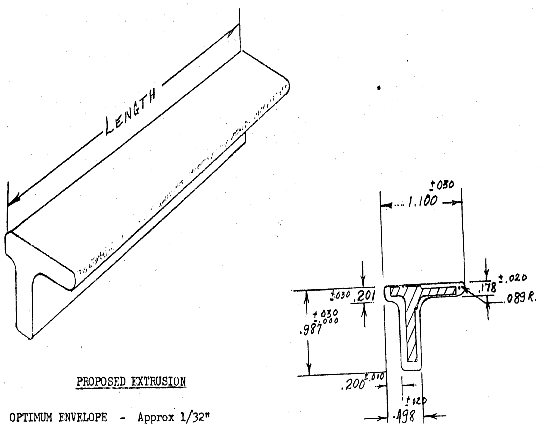
PROPOSED EXTRUSION

OPTIMUM ENVELOPE - Approx 1/32"
MATERIAL - - - - - AMS 4921 & WAD-7850 (C.P. Titanium
AREA - - - - - - - - 1.22 In^2
LENGTH - - - - - - - 48 In
VOLUME - - - - - - - - 58.6 In^3
WEIGHT - - - - - - - - 2.34 lbs/ft

Note: Cross-hatched area indicates finish-machined detail part.

FIG. 21 - OPTIMISTIC ENVELOPE SHAPE FOR THE EXTRUSION OF P/N226961, FLANGE, REAR MAIN BEARING VAPOR DUCT ASSEMBLY.

[redacted]



PROPOSED EXTRUSION

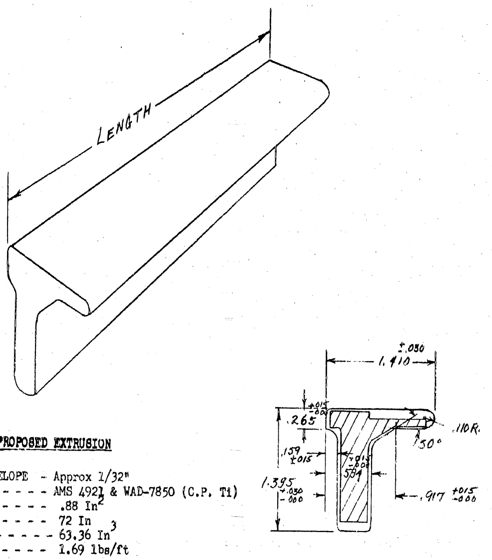
OPTIMUM ENVELOPE - Approx 1/32"
MATERIAL ------AMS 4921 & WAD-7850 (C.P.Titanium)
AREA ---------.43 In^2
LENGTH -------- 60 in.
VOLUME-------- 25.8 in^3
WEIGHT -------- .83# per ft.

ACTUAL SIZE

Note: Cross-hatched area indicates finish-machined detail part.

FIG. 22 - OPTIMISTIC ENVELOPE SHAPE FOR THE EXTRUSION P/N 226956, FLANGE, REAR MAIN BEARING VAPOR DUCT ASSEMBLY.

[redacted]



PROPOSED EXTRUSION

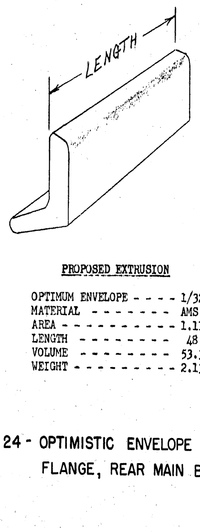
OPTIMUM ENVELOPE - Approx 1/32"
MATERIAL ----- AMS 4921 & WAD-7850 (C.P. Ti)
AREA -------- .88 In^2
LENGTH ------ 72 In
VOLUME ------- 63.36 In^3
WEIGHT ------ 1.69 lbs/ft

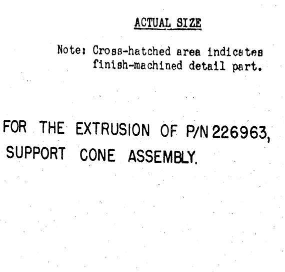
ACTUAL SIZE

Note: Cross-Hatched area indicates finish-machined detail part.

FIG. 23 - OPTIMISTIC ENVELOPE SHAPE FOR THE EXTRUSION OF P/N 226962, FLANGE, REAR MAIN SUPPORT CONE ASSEMBLY.

[redacted]





PROPOSED EXTRUSION

OPTIMUM ENVELOPE - - - - 1/32"
MATERIAL - - - - - - - - AMS 4921 & WAD-7850 (C.P. Titanium)
AREA - - - - - - - - - - - - 1.11 In²
LENGTH - - - - - - - - - 48 In
VOLUME - - - - - - - - - 53.3 In³
WEIGHT - - - - - - - - - - 2.13 lbs/ft

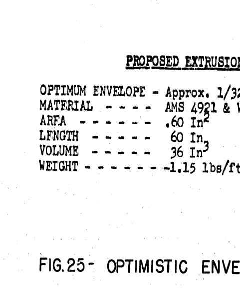
ACTUAL SIZE

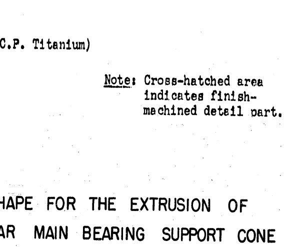
Note: Cross-hatched area indicates finish-machined detail part.

FIG. 24 - OPTIMISTIC ENVELOPE SHAPE FOR THE EXTRUSION OF P/N 226963, FLANGE, REAR MAIN BEARING SUPPORT CONE ASSEMBLY.

STAT

[redacted]





ACTUAL SIZE

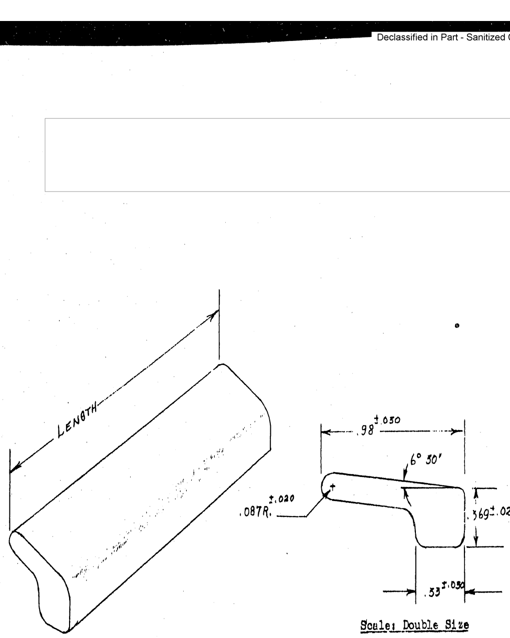
PROPOSED EXTRUSION

OPTIMUM ENVELOPE - Approx. 1/32"
MATERIAL - - - - AMS 4921 & WAD-7850 (C.P. Titanium)
AREA - - - - - - .60 In²
LENGTH - - - - - 60 In
VOLUME - - - - - 36 In³
WEIGHT - - - - - - - -1.15 lbs/ft

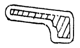
Note: Cross-hatched area indicates finish-machined detail part.

FIG.25 - OPTIMISTIC ENVELOPE SHAPE FOR THE EXTRUSION OF P/N 226964, FLANGE, REAR MAIN BEARING SUPPORT CONE ASSEMBLY.

[redacted]



Scale: Double Size



Actual Size

PROPOSED EXTRUSION

OPTIMUM ENVELOPE - Approx. 1/32"
MATERIAL - - - - AMS 4921 & WAD-7850 (C.P. Titanium)
AREA - - - - - - - .26 in.^{2}
LENGTH - - - - - - 60 in. or in 60" mults.
VOLUME - - - - - 15.6 in.^{3}
WEIGHT - - - - - .50# per ft

Note: Cross-hatched area indicates finish-machined detail part.

FIG. 26 - OPTIMISTIC ENVELOPE SHAPE FOR THE EXTRUSION OF P/N 226966, FLANGE, COMBUSTION CHAMBER HEAT SHIELD ASSEMBLY.

[redacted]

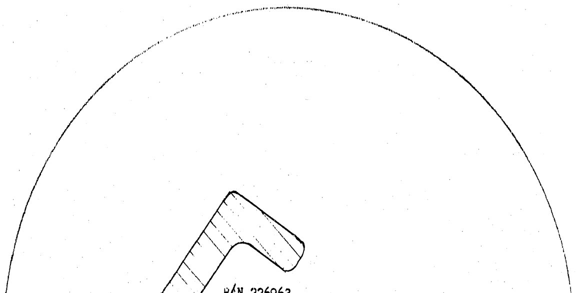


FIGURE 27a. SCHEMATIC DRAWING OF THE MULTI-OPENING DIE FOR THE EXTRUSION OF P/N'S 226962 AND 226963

[redacted]

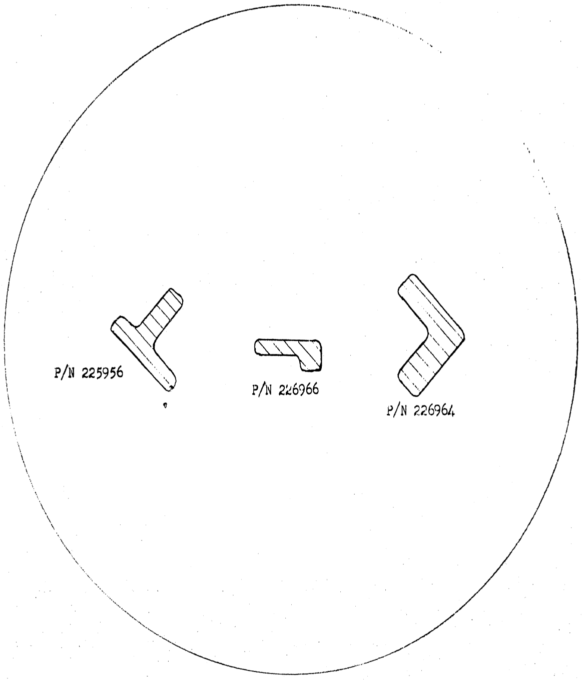


FIGURE 27b. SCHEMATIC DRAWING OF THE MULTI-OPENING DIE FOR THE EXTRUSION OF P/N'S 226956, 226966 AND 226964.

[redacted]

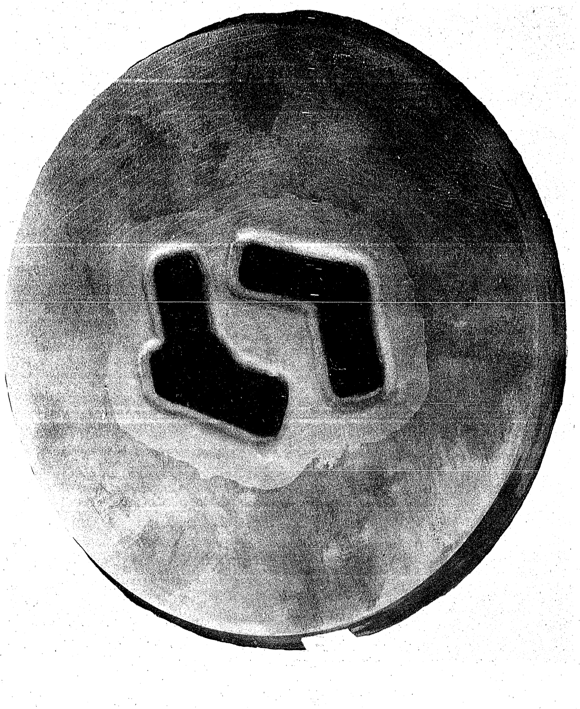


FIG. 28 - PHOTOGRAPH OF A MULTI-OPENING EXTRUSION FOR P/N 227594 AND P/N 227596

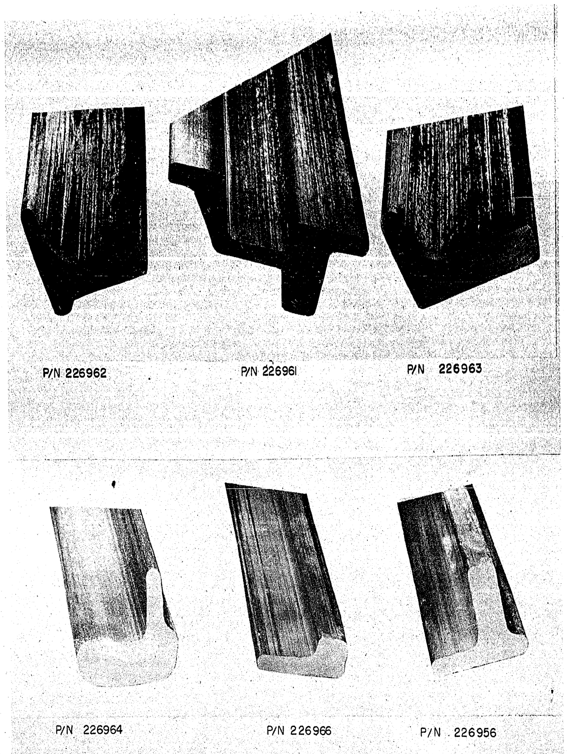


FIG.29-PHOTOGRAPHS OF THE OPTIMISTIC ENVELOPE EXTRUSION OF P/N'S 226961, 956, 962, 963, 964, AND 966, MATERIAL, Ti-A70, EXTRUSION TEMPERATURE, 1500 °F.

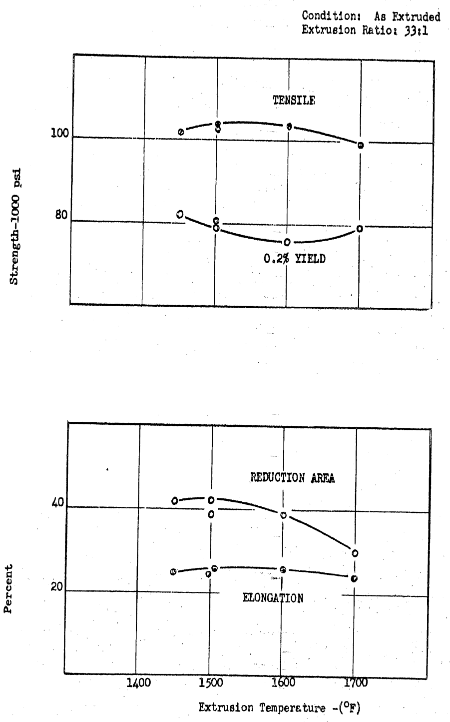
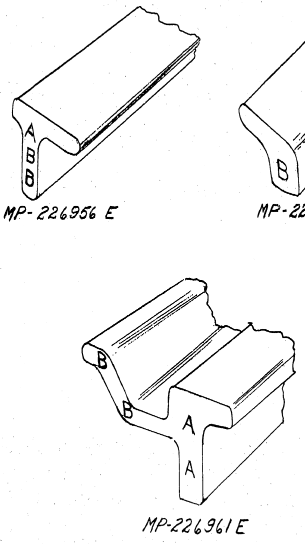


FIG.30- THE EFFECT OF EXTRUSION TEMPERATURE ON THE TENSILE PROPERTIES OF A70 TITANIUM EXTRUDED TO THE MAXIMUM ENVELOPE SHAPE OF P/N 226961.

[redacted]



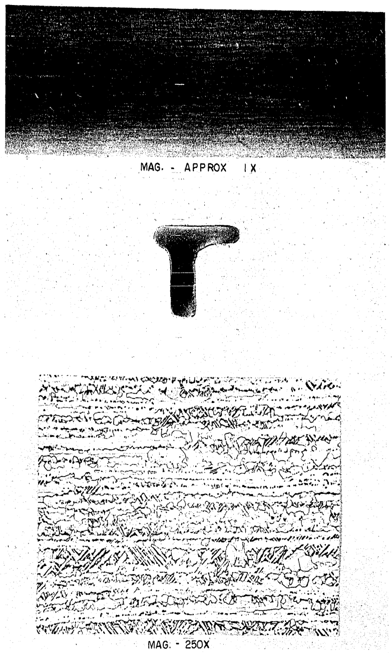
MP-226956 E

MP-226966 E

MP-226961 E

FIG. 31 - CROSS-SECTIONS OF THREE A70 FLANGES INDICATING THE LOCATIONS OF STANDARD TENSILE - (0.250"DIA.) TEST SPECIMENS (A) AND SUB-STANDARD TENSILE - (.150"DIA.) TEST SPECIMEN (B).

[redacted]



MAG. - APPROX 1X

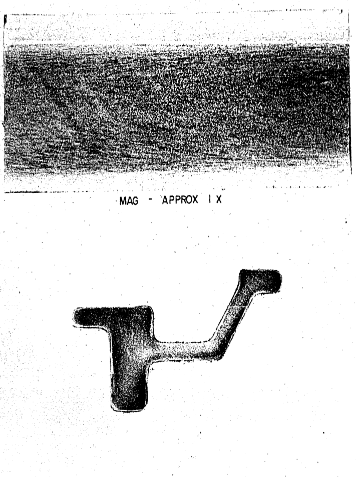
MAG. - 250X

FIG. 32 - PHOTOMACROGRAPHS & PHOTOMICROGRAPH OF A LONGITUDINAL SECTION OF P/N 226956 (A70 MATERIAL) EXTRUDED WITH A BILLET PREHEAT TEMPERATURE OF 1550°F.

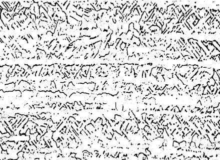
ETCHANT:

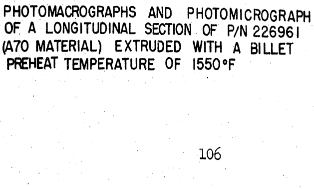
95 PARTS - H_2O
25 " - HNO_3
1.5 " - HCL
1.0 " - HF

[redacted]



MAG - APPROX I X





MAG. - 250X

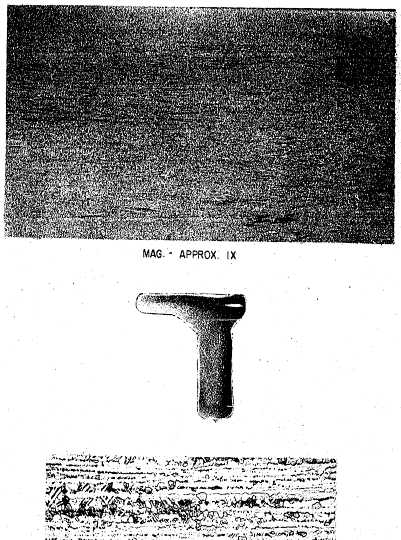
FIG.33 - PHOTOMACROGRAPHS AND PHOTOMICROGRAPH OF A LONGITUDINAL SECTION OF P/N 226961 (A70 MATERIAL) EXTRUDED WITH A BILLET PREHEAT TEMPERATURE OF 1550°F

ETCHANT:

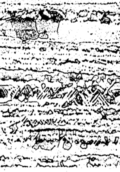
95 PARTS - H_2O
2.5 " - HNO_3
1.5 " - HCL
1.0 " - HF

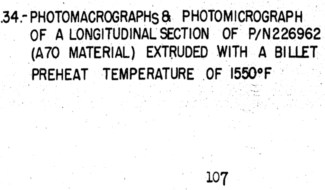
STAT

[redacted]



MAG. - APPROX. IX





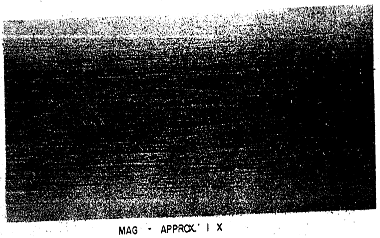
MAG. - 250 X

FIG.34.- PHOTOMACROGRAPHS & PHOTOMICROGRAPH OF A LONGITUDINAL SECTION OF P/N226962 (A70 MATERIAL) EXTRUDED WITH A BILLET PREHEAT TEMPERATURE OF 1550°F

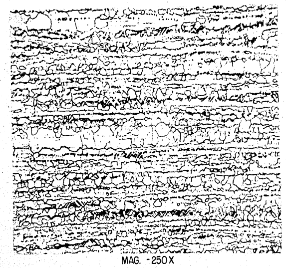
ETCHANT

95 PARTS - H_2O
2.5 " - HNO_3
1.5 " - HCL
1.0 " - HF

[redacted]



MAG - APPROX. 1 X

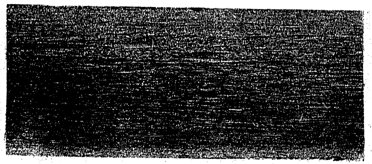


MAG. -250X

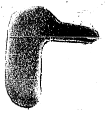
FIG. 35-PHOTOMACROGRAPHS & PHOTOMICROGRAPH OF A LONGITUDINAL SECTION OF P/N226963 (A70 MATERIAL) EXTRUDED WITH A BILLET PREHEAT TEMPERATURE OF 1550°F.

ETCHANT:
95 PARTS - H_2O
2.5 PARTS - HNO_3
1.5 PARTS - HCL
1.0 PARTS - HF

[redacted]



MAG. - APPROX. 1 X

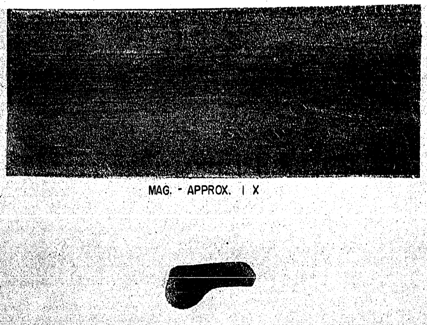


MAG. - 250 X

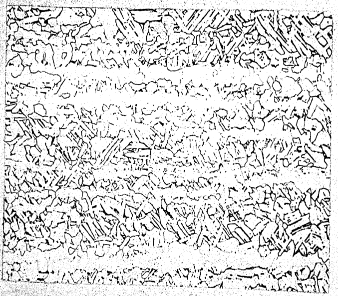
FIG.36- PHOTOMACROGRAPHS & PHOTOMICROGRAPH OF A LONGITUDINAL SECTION OF P/N 226964 (A70 MATERIAL) EXTRUDED WITH A BILLET PREHEAT TEMPERATURE OF 1550 °F.

ETCHANT:
95 PARTS - H_2O
2.5 " - HNO_3
1.5 " - HCL
1.0 " - HF

[redacted]



MAG. - APPROX. 1 X

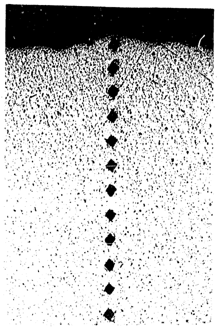


MAG. 250 X

FIG. 37 - PHOTOMACROGRAPHS & PHOTOMICROGRAPH OF A P/N 226966 (A70 MATERIAL) EXTRUDED WITH A BILLET PREHEAT TEMPERATURE OF 1550°F

ETCHANT:
95 PARTS - H_2O
2.5 " - HNO_3
1.5 " - HCL
1.0 " - HF

[redacted]



HARDNESS SURVEY

DEPTH FROM SURFACE	CONVERTED ROCK-WELL C
.001"	20.0
.004"	20.0
.007"	19.5
.010"	20.0
.013"	19.5
.016"	20.0
.019"	20.0
.022"	20.0
.025"	19.5
.028"	20.0
.031"	19.5
.034"	19.5

FIG. 38 PHOTOMICROGRAPH OF A CROSS-SECTION THROUGH THE SURFACE OF A 1500°F A70 EXTRUSION IN WHICH FREEDOM FROM SURFACE CONTAMINATIONS IS INDICATED BY THE UNIFORM MICROSTRUCTURE AND HARDNESS SURVEY.

[redacted]

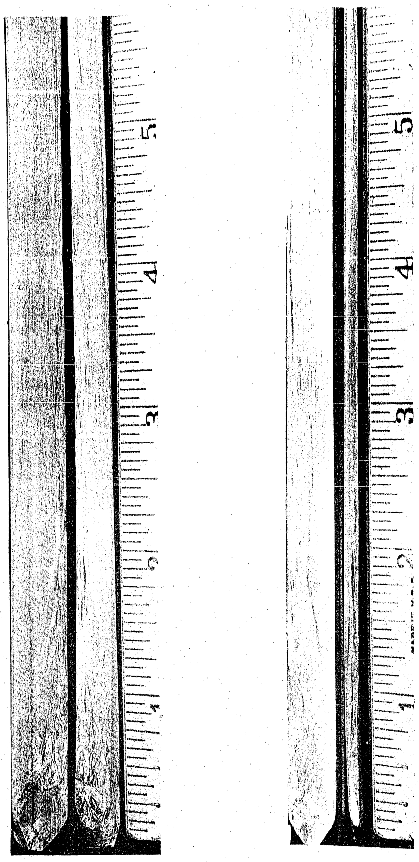


FIG. 39 - ETCHED LONGITUDINAL SECTIONS OF AN EXTUDED A70 SHAPE SHOWING THE DEPTH OF NON-UNIFORM FLOW AT THE FRONT END OF THE EXTRUSION.

STAT

[redacted]

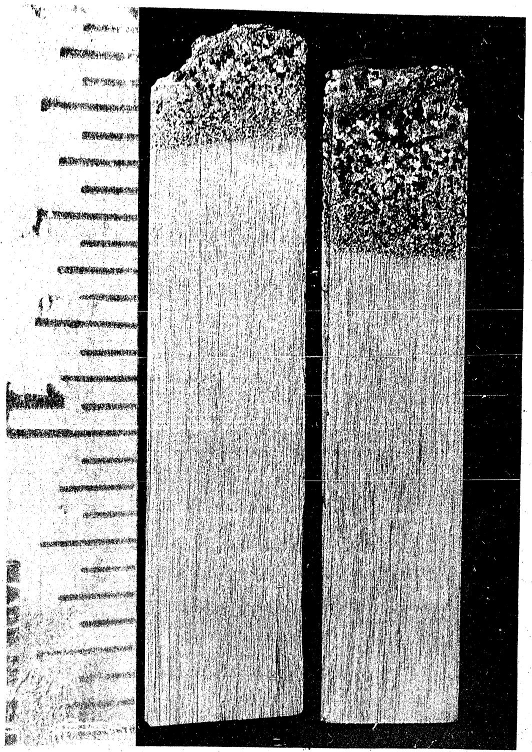


FIG. 40 - ETCHED LONGITUDINAL SECTIONS OF A70 EXTRUSION SHOWING THE GRAIN GROWTH PENETRATION DUE TO TORCH CUT-OFF OF THE EXTRUSION FROM THE BUTT.

[redacted]

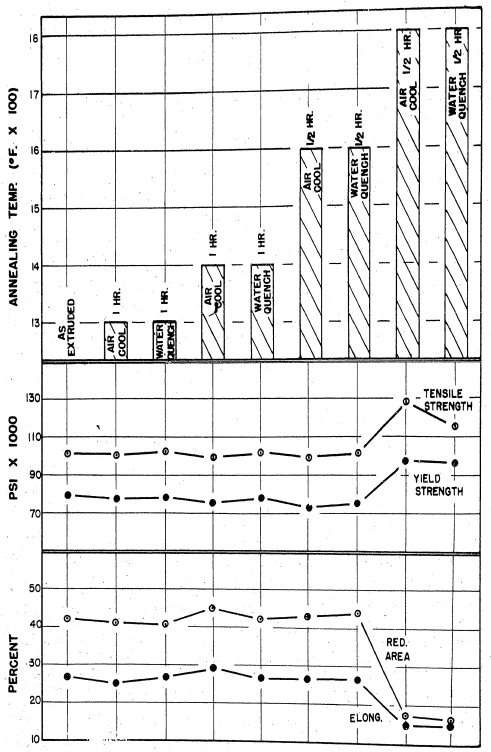
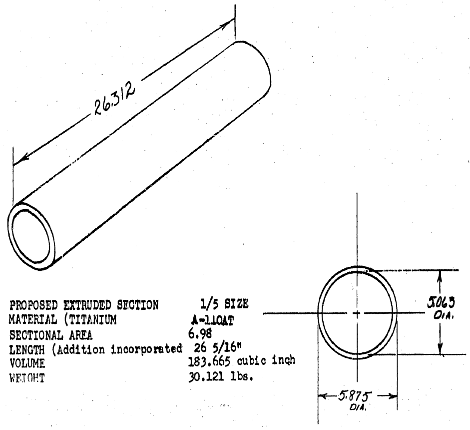


FIG. 41 - THE EFFECT OF ANNEALING TEMPERATURES AND COOLING RATES ON THE MECHANICAL PROPERTIES OF A70 TITANIUM EXTRUDED WITH A 1550 °F BILLET PREHEAT TEMPERATURE.

[redacted]

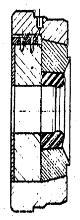


PROPOSED EXTRUDED SECTION	1/5 SIZE
MATERIAL (TITANIUM	A-110AT
SECTIONAL AREA	6.98
LENGTH (Addition incorporated	26 5/16"
VOLUME	183.665 cubic inch
WEIGHT	30.121 lbs.

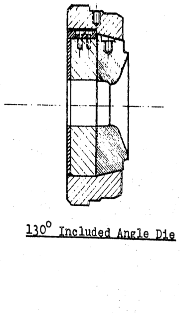
FIG. 42 EXTRUSION SHAPE FOR P/N 226970 - SHAFT, TURBINE ROTOR FRONT.

[redacted]

DIE HOLDER SUB-ASSEMBLY
FOR
PART No. 226970-ROTOR SHAFT



Re-entrant Angle Die



130° Included Angle Die

FIG. 43 DIE HOLDER AND SUB-ASSEMBLY FOR A RE-ENTRANT ANGLE DIE AND A 130° INCLUDED ANGLE DIE.

[redacted]

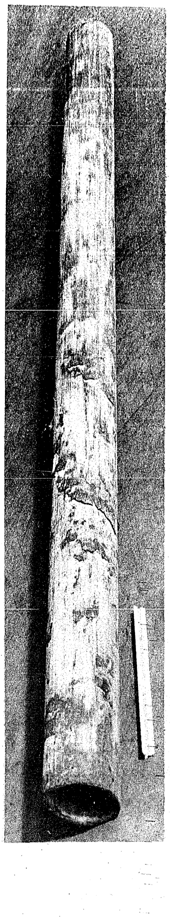
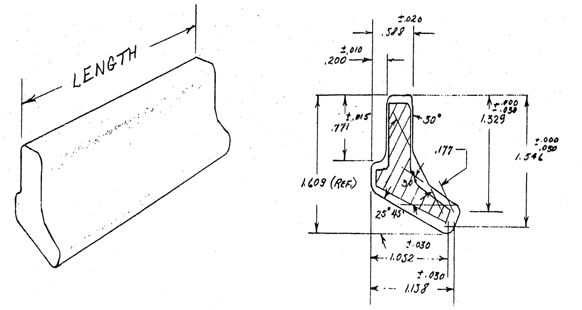


FIG.44 - PHOTOGRAPH OF AN EXTRUDED A110AT TUBE. THIS SECTION WAS EXTRUDED THROUGH RE-ENTRANT ANGLE DIE.

[redacted]



PROPOSED EXTRUSION

ACTUAL SIZE

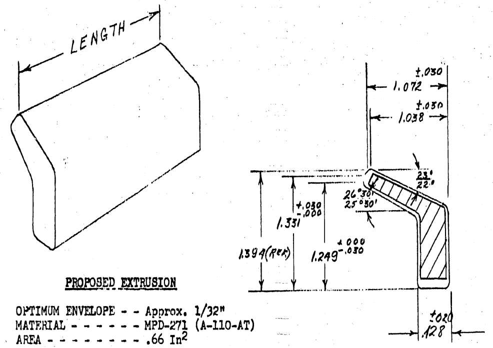
OPTIMUM ENVELOPE - -- Approx. 1/32"
MATERIAL - - - - - - - -MPD-271 (A-110-AT)
AREA - - - - - - - - - - - .87 In^2
LENGTH - - - - - - - - - - 60.In
VOLUME - - - - - - - - - - 52.2 In^3
WEIGHT - - - - - - - - - - 1.67 lbs/ft

Note:

Cross-hatched area indicates finish-machined detail part.

FIG.45-OPTIMISTIC ENVELOPE SHAPE FOR THE EXTRUSION OF P/N227594, FLANGE,TURBINE STATOR BLADE SUPPORT ASSEMBLY.

[redacted]



PROPOSED EXTRUSION

ACTUAL SIZE

OPTIMUM ENVELOPE - - Approx. 1/32"
MATERIAL - - - - - - - MPD-271 (A-110-AT)
AREA - - - - - - - - - - .66 In^2
LENGTH - - - - - - - - - 80 In
VOLUME - - - - - - - - - 52.8 In^2
WEIGHT- - - - - - - - -1.26 lbs/ft

Note: Cross-hatched area indicates finish-machined detail part.

FIG.46-OPTIMISTIC ENVELOPE SHAPE FOR THE EXTRUSION OF P/N227596, FLANGE, TURBINE STATOR BLADE SUPPORT ASSEMBLY.

[redacted]

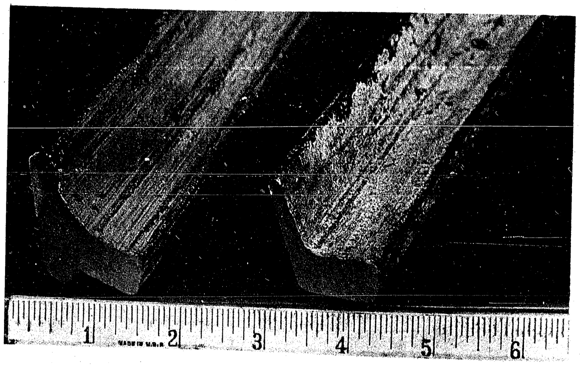


FIG. 47 - PHOTOGRAPH SHOWING THE SURFACE FINISH OF EXTRUDED A110AT FLANGES.

[redacted]

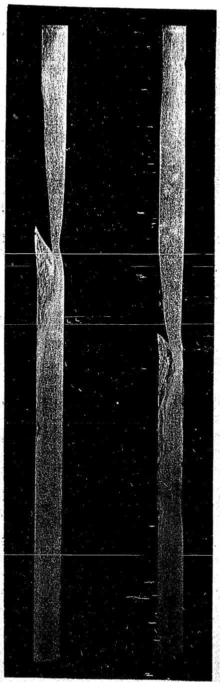


FIG. 48 MACROSTRUCTURE OF TWO SECTIONS OF THE REENTRANT ANGLE DIE EXTRUSION. (OUTER DIAMETER SURFACE TO THE LEFT) NOTE COARSE GRAIN STRUCTURE AT THE TEARS

[redacted]

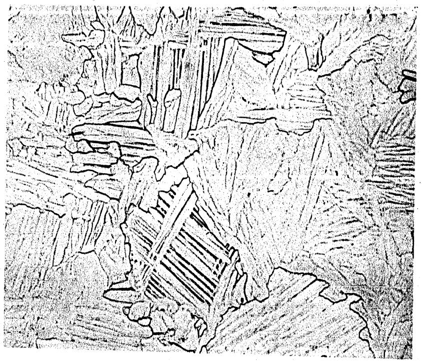


FIG. 49 MICROSTRUCTURE OF A110-AT TITANIUM EXTRUDED THROUGH THE REENTRANT ANGLE DIE. NOTE RANDOM ORIENTATION OF STRUCTURE.

[redacted]

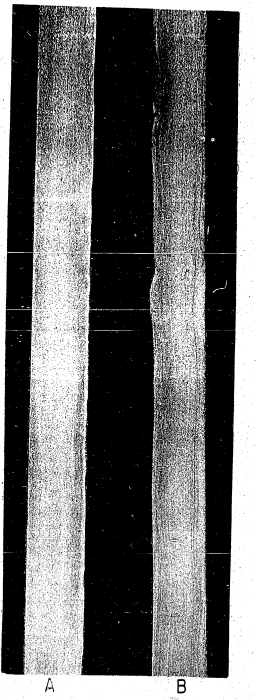
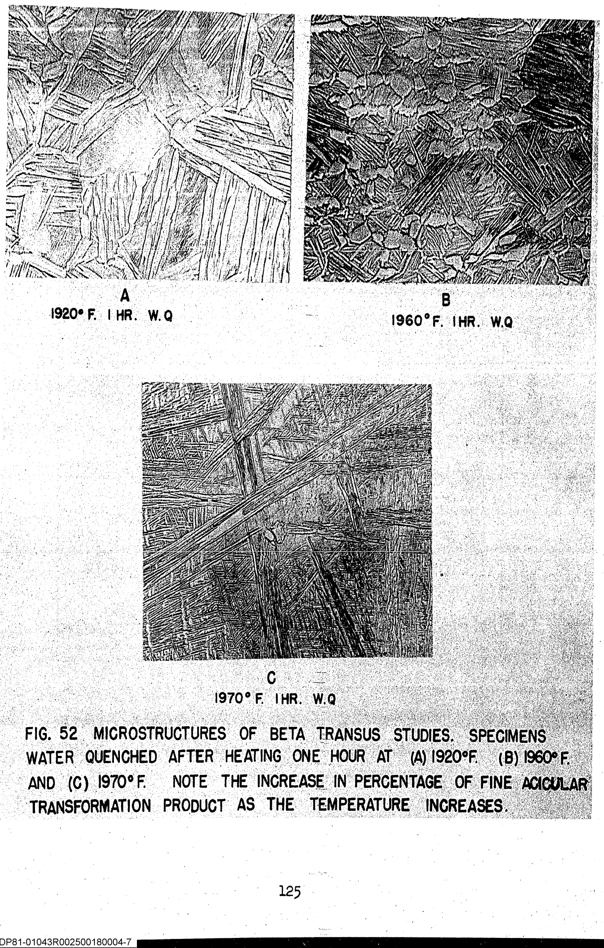


FIG. 50 MACROSTRUCTURE OF TWO SECTIONS OF THE STEEL-JACKETED EXTRUSION. (INSIDE DIAMETER OF TUBE IS ON THE RIGHT. PHOTOGRAPH SHOWS A TYPICAL SMOOTH SECTION (A) AND A TYPICAL ROUGH SECTION (B))

[redacted]

FIG. 51 PHOTOMICROGRAPH OF THE AS-EXTRUDED STEEL JACKETED TUBE. NOTE THE ALIGNMENT OF THE GRAINS IN THE FLOW DIRECTION AND SOME RECRYSTALLIZATION.

[redacted]



A
1920° F. 1 HR. W.Q

B
1960° F. 1 HR. W.Q

C
1970° F. 1 HR. W.Q

FIG. 52 MICROSTRUCTURES OF BETA TRANSUS STUDIES. SPECIMENS WATER QUENCHED AFTER HEATING ONE HOUR AT (A) 1920°F. (B) 1960°F. AND (C) 1970°F. NOTE THE INCREASE IN PERCENTAGE OF FINE ACICULAR TRANSFORMATION PRODUCT AS THE TEMPERATURE INCREASES.

STAT

[redacted]

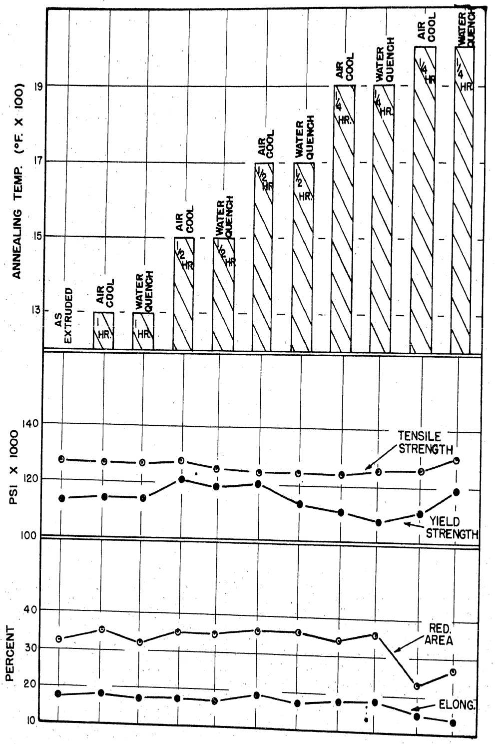


FIG. 53 - EFFECT OF ANNEALING TEMPERATURE ON THE MECHANICAL PROPERTIES OF A110AT TITANIUM EXTRUDED WITH A 1900°F BILLET PREHEAT TEMPERATURE.

[redacted]

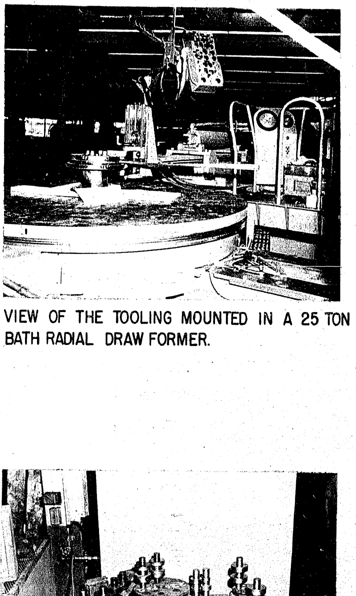


FIG. 54 - VIEW OF THE TOOLING MOUNTED IN A 25 TON BATH RADIAL DRAW FORMER.

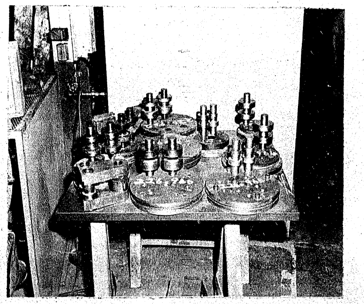


FIG. 55 - TYPICAL CONTOUR FORMING DIES, ROLLS, AND COMMON ROLLS HOLDING YOKES AS EMPLOYED IN FORMING EXTRUSIONS.

[redacted]

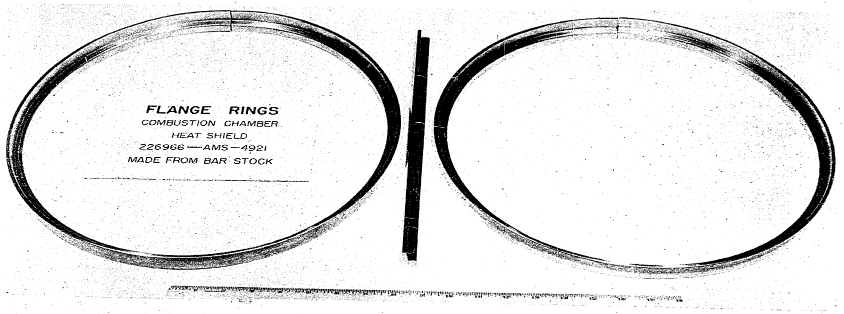


FIG. 56 PHOTOGRAPH OF 360° FORMED RINGS OF P/N 226966 FROM MACHINED BARSTOCK

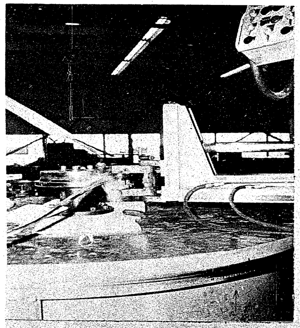


FIG. 57a - BEGINNING OF HOT CONTOUR FORMING OPERATION. THE TWIST IN THE EXTRUSION IS CORRECTED IN THE FORMING OPERATION.

FIG. 57b - CLOSE-UP VIEW OF A TYPICAL EXTRUDED PART PARTIALLY FORMED IN THE CONTOUR DIE IN THE FIRST ROLL PASS.

[redacted]

STAT

[redacted]

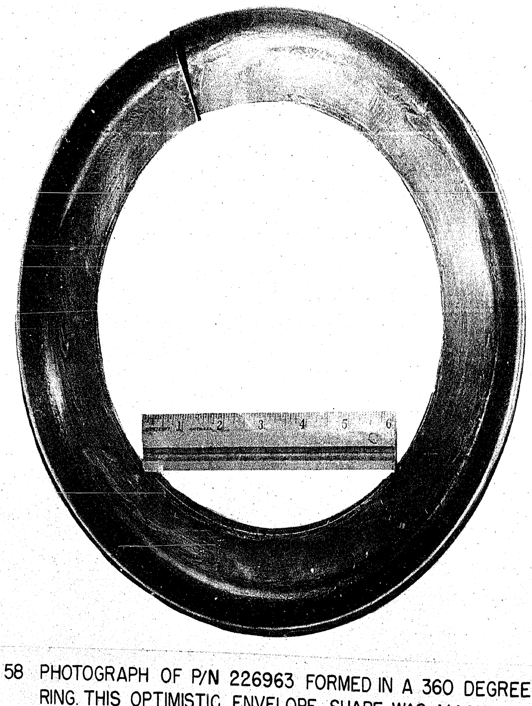


FIG. 58 PHOTOGRAPH OF P/N 226963 FORMED IN A 360 DEGREE RING. THIS OPTIMISTIC ENVELOPE SHAPE WAS MACHINED FROM A MAXIMUM ENVELOPE EXTRUSION.

[redacted]

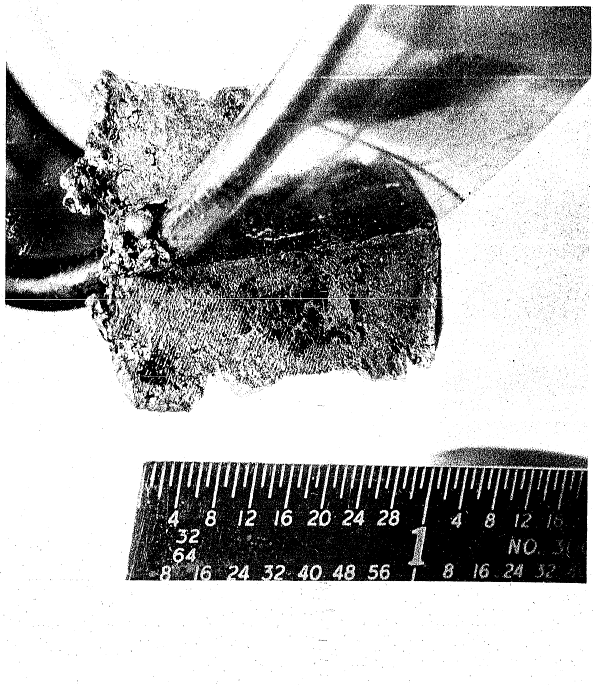


FIG. 59 CLOSE-UP PHOTOGRAPH OF P/N 226966 SHOWING THE FLASH-BUTT WELD

[redacted]

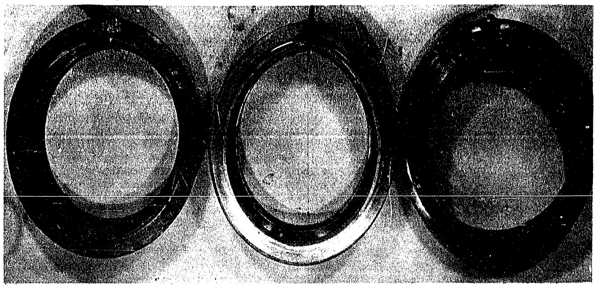


FIG. 60 - P/N 226961 RINGS FORMED AND FLASH-BUTT WELDED INTO 360.°
NOTE THE OUT-OF-ROUND CONDITION AT THE WELD JOINT.

STAT

[redacted]

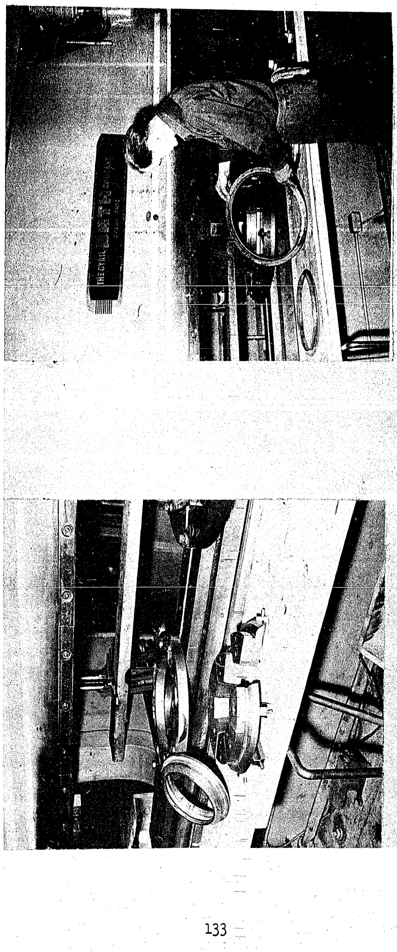


FIG. 61 - TWO VIEWS OF THE SIZING DIES AND SET-UP.

[redacted]

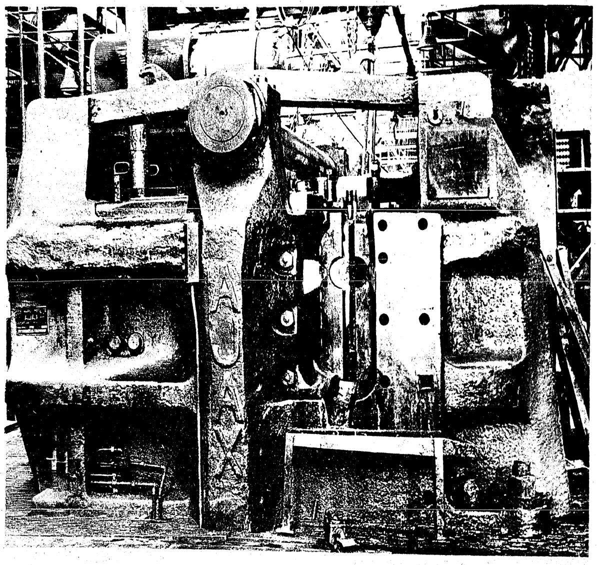


FIG.62 - PHOTOGRAPH OF THE SIX-INCH UPSETTING MACHINE.

[redacted]

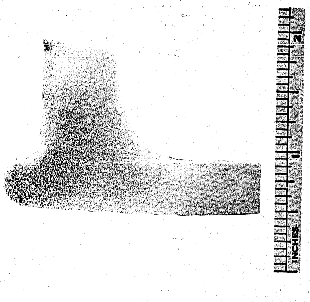


FIG.63 - PHOTOMACROGRAPH OF A SUCCESSFULLY UPSET FLANGE IN AMS 6412 MATERIAL.

[redacted]

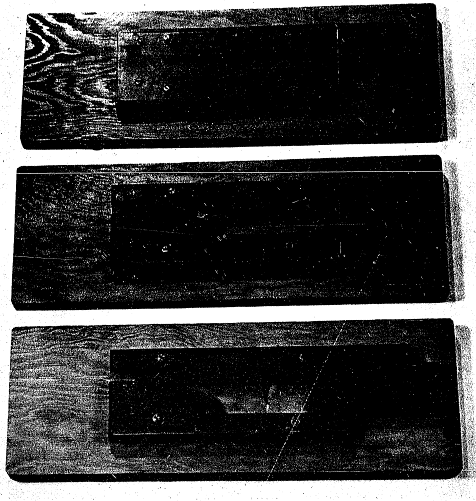


FIG.64 - WOODEN MODEL USE FOR UPSET DEVELOPMENT OF PLASTICINE.

[redacted]

STAT

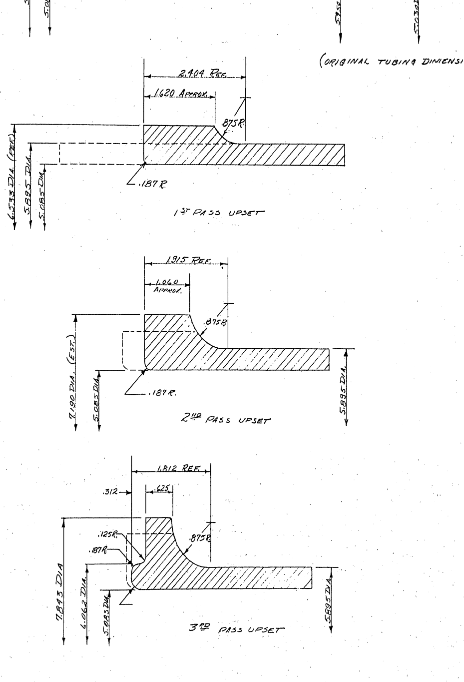


FIGURE 65 - SCHEMATIC DRAWINGS
OF THE THREE STEP UPSET CYCLE USED
TO UPSET THE FLANGES FOR THE TURBINE ROTOR SHAFT

STAT

[redacted]

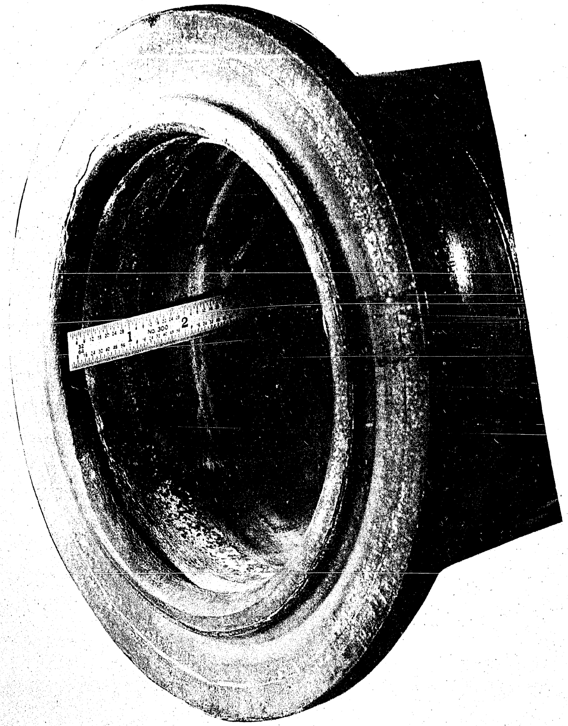
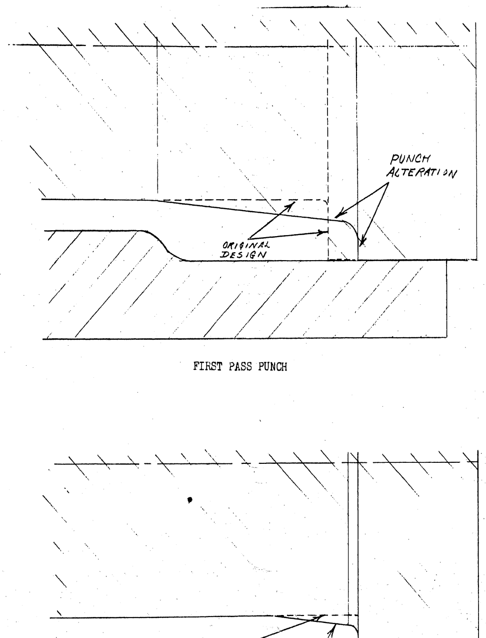
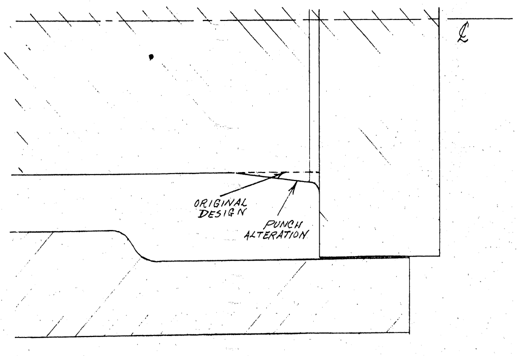


FIG.66 - THE UPSET AREA OF AN AIIOAT ROTOR SHAFT INDICATING THE BUCKLING AT THE INNER DIAMETER.

[redacted]



FIRST PASS PUNCH



SECOND PASS PUNCH

FIGURE 67. Upset punch design modifcations employed to correct the buckling problem in upsetting the rotor shaft flanges.

[redacted]

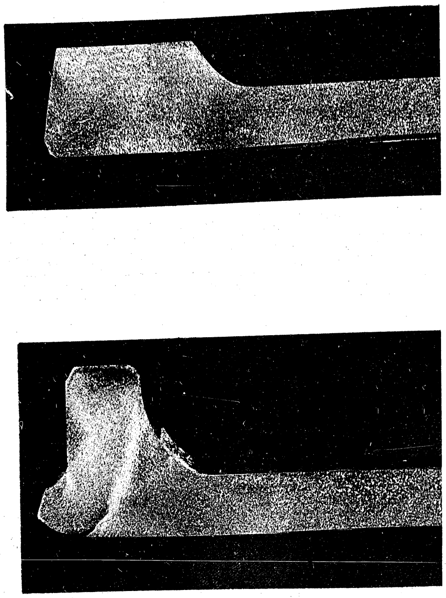


FIG.68-(a) PHOTOMACROGRAPH OF THE ROTOR SHAFTS AFTER THE FIRST AND SECOND STAGE.

(b) PHOTOMACROGRAPH OF THE FIRST UPSET PRODUCT SHOWING THE LAP AT THE INNER DIAMETER.

[redacted]

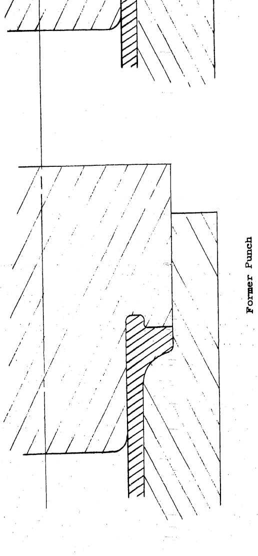


FIGURE 69. FINAL DESIGN MODIFICATIONS APPLIED TO THE UPSET PUNCH TO CORRECT THE BUCKLING PROBLEM IN UPSETTING THE THIRD STAGE FOR THE ROTOR SHAFT FLANGES.

[redacted]

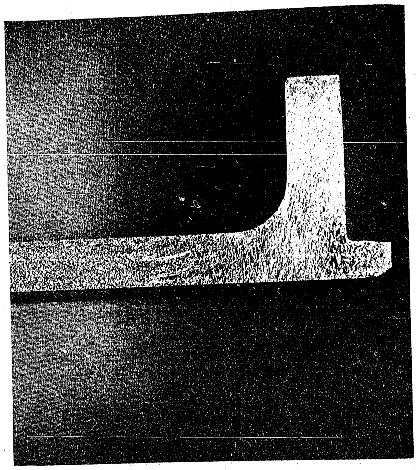


FIG. 70 - PHOTOMACROGRAPH OF A SECTION OF THE FIRST SUCCESSFULLY UPSET PROTOTYPE TURBINE ROTOR SHAFT.

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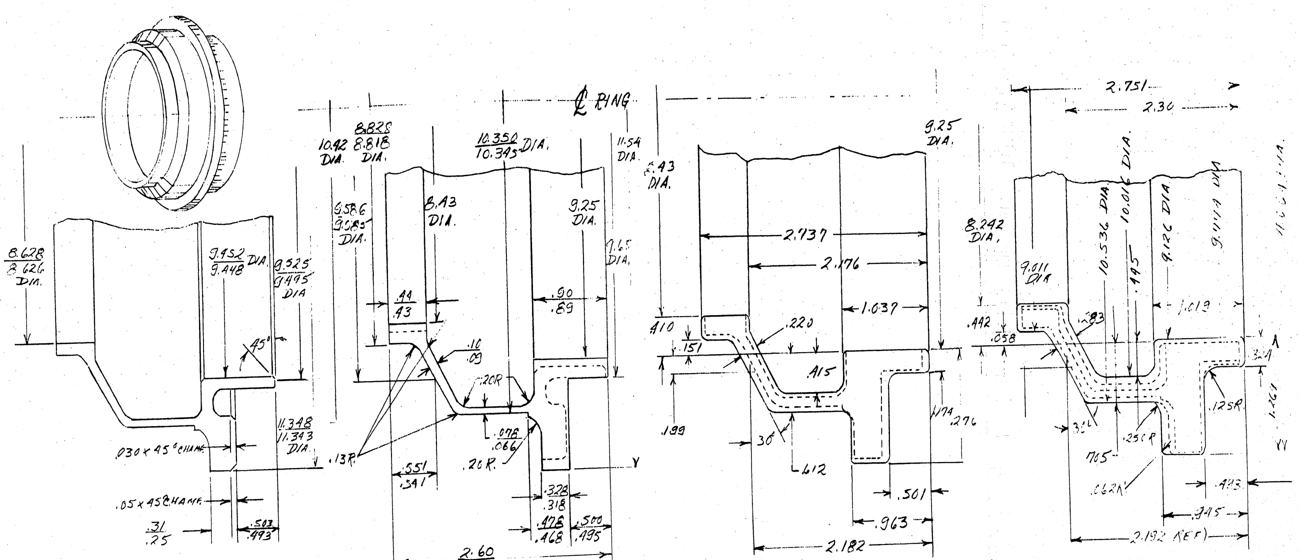
[redacted]



DETAIL SECTION
(FIN. MACH.)

Area - - - - - - - - - - - - - -.533 In^2
Length (Max.) - - - - - - - 35.665 In
Vol. - - - - - - - - - - - - - 19.01 In ^{3}
Wt. - - - - - - - - - - - - - 3.04#

DETAIL SECTION
(SEMI-MACH.)

Area - - - - - - - - - -.714 In^2
Length (Max.) - - - -36.268 In
Vol. - - - - - - - - - 25.89 In^3
Wt. - - - - - - - - - - -4.14#

OPTIMISTIC ENVELOPE
(PROPOSED EXTR.)

Area - - - - - - - - - - - - 1.22 In^2
Length (Max.) - - - - - - - 48.0 In
Vol. - - - - - - - - - - - - 58.6 In^3
W t. - - - - - - - - - - - - - 9.36#

REVISED ENVELOPE
(PROPOSED EXTRUSION)

Area - - - - - - - - - - - - -1.56 In^2
Length - - - - - - - - - - - 33.0 In
Vol. - - - - - - - - - - - - -51.5 In^3
Wt. - - - - - - - - - - - - 8.29#

FIGURE 71. PRODUCTION EXTRUSION SHAPE [redacted]

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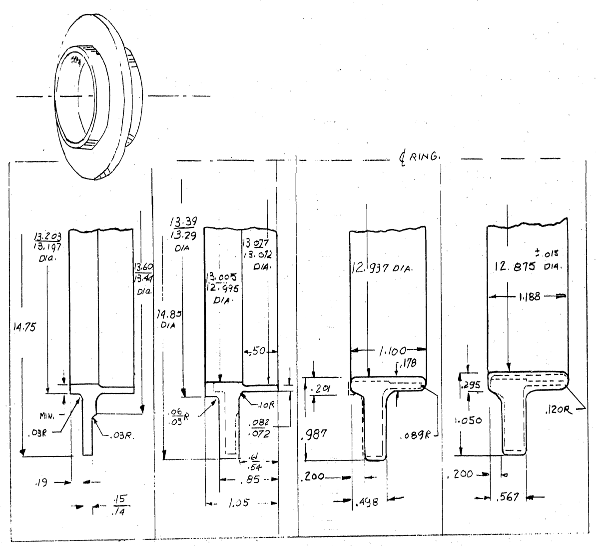
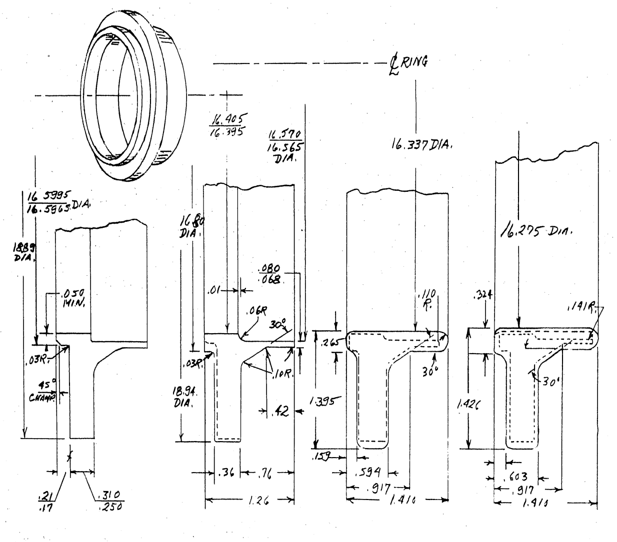
[redacted]



DETAIL SECTION (FIN. MACH.)	DETAIL SECTION (SEMI-MACH.)	OPTIMISTIC ENVELOPE (PROPOSED EXTR.)	REVISED ENVELOPE (PROPOSED EXTR.)
Area - - - - - - - .205 In.^{2}	Area - - - - - -.372 In.^{2}	Area - - - - - - - -.43 In.^{2}	Area - - - - - .53 In.^{2}
Length(Max) 46.34 In.	Length(Max) 46.66 In.	Length - - - - - 60 In.	Length - - - - 49 In.
Vol. - - - - -9.50 In.^{3}	Vol. - - - - -17.36 In.^{3}	Vol. - - - - -25.8 In.^{3}	Vol. - - - - - - 26.0In.^{3}
Wt. - - - - - - - 1.52#	Wt. - - - - - - -2.76#	Wt.- - - - - - - 4.15#	Wt. - - - - - - -4.19#

FIGURE 72. PRODUCTION EXTRUSION SHAPE FOR P/N 226956.

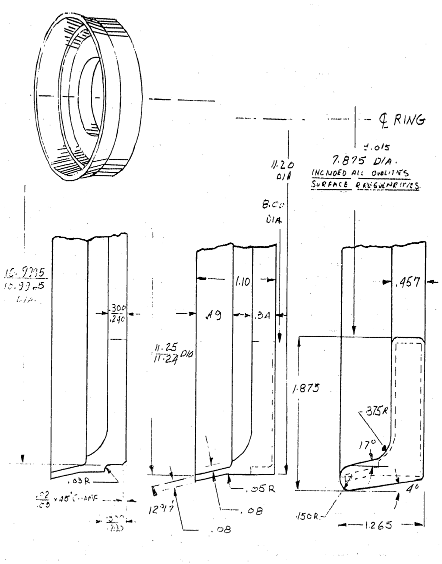
[redacted]



DETAIL SECTION (FIN. MACH.)	DETAIL SECTION (SEMI-MACH.)	OPTIMISTIC ENVELOPE (PROPOSED EXTR.)	REVISED ENVELOPE (PROPOSED EXTR.)
Area - - - - -.503 In.^{2}	Area - - - - - -.584 In.^{2}	Area - - - - - -.88 In.^{2}	Area - - - - .96 In.^{2}
Length(Max) -59.32 In.	Length(Max.) - -59.51 In.	Length - - - - - 72 In.	Length - - - - 62 In.
Vol. - - - - 29.84 In.^{3}	Vol. - - - - - 34.75 In.^{3}	Vol. - - - - - - - 63.36In.^{3}	Vol. - - - -59.51 In.^{3}
Wt. - - - - -4.77#	Wt. - - - - - -5.56#	Wt. - - - - - - - 10.14#	Wt. - - - - -9.58#

FIGURE 73. PRODUCTION EXTRUSION SHAPE FOR P/N 226962

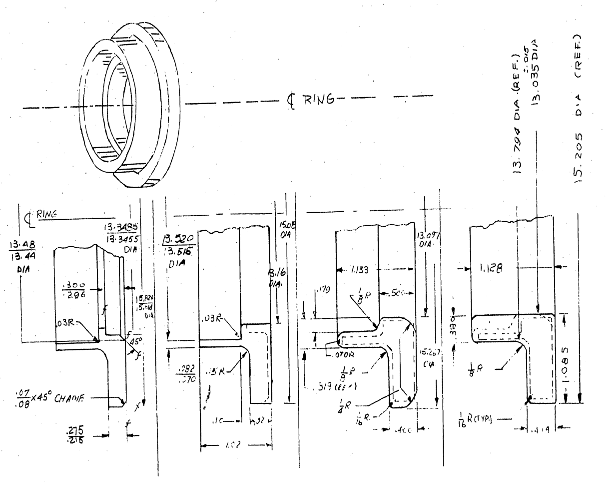
[redacted]



DETAIL SECTION (FIN. MACH.)	DETAIL SECTION (SEMI-MACH.)	OPTIMISTIC ENVELOPE (PROPOSED EXTR.)	REVISED DATA
Area - - - - -.565 In.^{2}	Area - - - - - .656 In.^{2}	Area - - - - -1.11 In.^{2}	Area - - - - - 1.12 In.^{2}
Length(Max) 35.8 In.	Length(Mas.) 35.8 In.	Length - - - -35.8 In.	Length - - - - 32 In
Vol. - - - -20.23 In.^{3}	Vol. - - - - 23.48 In.^{3}	Vol. - - - - - 53.3 In.^{3}	Vol. - - - - 35.8 In
Wt. - - - - - 3.24#	Wt. - - - - - 3.76#	Wt. - - - - - 8.52#	Wt. - - - - - - 5.76#

FIGURE 74. PRODUCTION EXTRUSION SHAPE FOR P/N 226963

[redacted]



DETAIL SECTION (FIN. MACH.)	DETAIL SECTION (SEMI-MACHINED)	OPTIMISTIC ENVELOPE (PROPOSED EXTR.)	REVISED ENVELOPE (PROPOSED EXTR.)
Area - - - - - -.386 In.^{2}	Area - - - - - -.408 In.^{2}	Area - - - - - - - -.60 In.^{2}	Area - - - - - - .70 In.^{2}
Length(Max) - 47.20 In.	Length(Max) - -47.38 In.	Length - - - - - -60 In.	Length - - - - - - 50 In.
Vol. - - - - -18.22 In.^{3}	Vol. - - - - -19.33 In.^{3}	Vol. - - - - - - - -36 In.^{3}	Vol. - - - - - - - 37 In.^{3}
Wt. - - - - - - - 2.92#	Wt. - - - - - - -3.09#	Wt. - - - - - - - - 5.75#	Wt. - - - - - - - 5.96#

FIGURE 75. PRODUCTION **EXTRUSION SHAPE** FOR P/N 226964.

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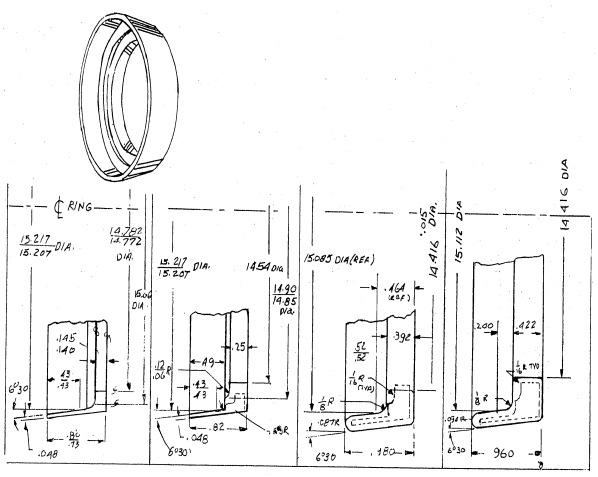
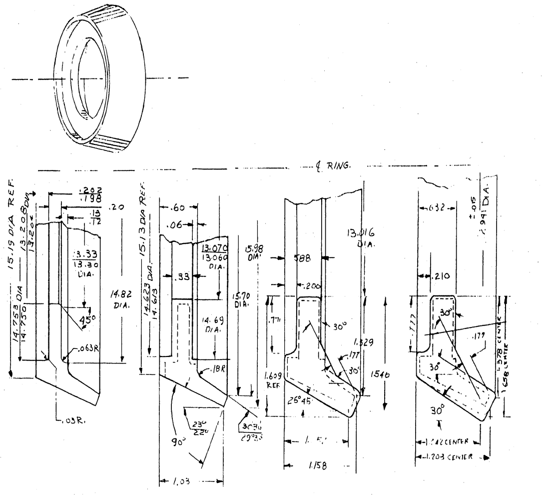
[redacted]



DETAIL SECTION (FIN. MACH)	DETAIL SECTION (SEMI-MACH)	OPTIMISTIC ENVELOPE (PROPOSED EXTR.)	REVISED DATA
Area - - - - - - - -.07 In^2	Area - - - - - - - - -.13 in^2	Area - - - - - -.26 In^2	Area - - - - - - - .20 In^2
	Length(Max) - - -48.401"	Length - - - - 60 In	Length - - - - - - -47 In
Vol. - - - - - - -3.37	Vol. - - - - - - - 6.292 In^3	Vol. - - - - - 15.6 In^3	Vol. - - - - - - 13.6 In^3
Wt. - - - - - - - - - 54#	Wt. - - - - - - - -1.006#	Wt. - - - - - - 2.5#	Wt. - - - - - - - 2.19#

FIGURE 76. PRODUCTION EXTRUSION SHAPE FOR P?N 226966

[redacted]



DETAIL SECTION (FIN. MACH)	DETAIL SECTION (SEMI-MACH.)	**OPTIMISTIC ENVELOPE (PROPOSED EXTR.)**	**REVISED ENVELOPE (PROPOSED EXTR.)**
Area - - - -.417 IN^2	Area - - - -.60 In.^{2}	Area - - - - - - -.87 In.^{2}	Area - - - -1.04 In^2
Length(Max.)50.2 In.	Length(Max.)50.2 In.	Length - - - - - -.60 In.	Length - - - 48 In
Vol. - - - - 20.93 In^3	Vol. - - - 30.12 In^3	Vol. - - - - - - - 52.2 In.^{3}	Vol. - - - - 49.9 In.^{3}
W t. - - - - 3.35#	Wt. - - - -4.82#	Wt. - - - - - - - - 8.35#	Wt.- - - - - 8.03#

FIGURE 77. PRODUCTION EXTRUSION SHAPE FOR P/N 227594.

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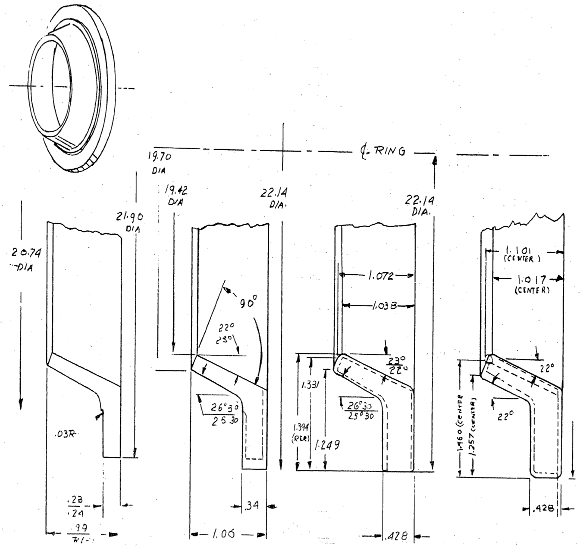
[redacted]



DETAIL SECTION (FIN. MACH)	DETAIL SECTION (SEMI-MACH.)	OPTIMISTIC ENVELOPE (PROPOSED EXTR.)	REVISED ENVELOPE (PROPOSED EXTR.)
Area - - - - - - - .367 In.^{2}	Area - - - - - -.482 In.^{2}	Area - - - - - -- .66 In.^{2}	Area - - - - - - -.81 In.^{2}
Length(Max.)- - .68.8 In.	Length(Max.)69.6 In .	Length - - - - -80 In.	Length - - - - - - 71 In.
Vol. - - - - - - -4.04#	Vol. - - - - - -33.53 In.^{3}	Vol. - - - - -52.8 In.^{3}	Vol. - - - - - - 57.5 In.^{3}
Wt. - - - - - - - 4.04#	Wt. - - - - - - 5.36#	Wt. - - - - - - 8.45#	Wt. - - - - - - -9.20#

FIGURE 78. PRODUCTION **EXTRUSION** SHAPE FOR P/N 227596

[redacted]

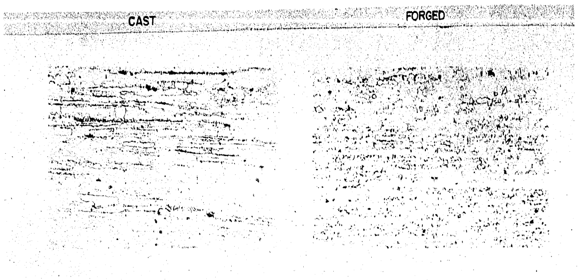


FIG. 79- PHOTOMICROGRAPHS OF P/N 226961 EXTRUDED FROM CAST AND FORGED MATERIAL.

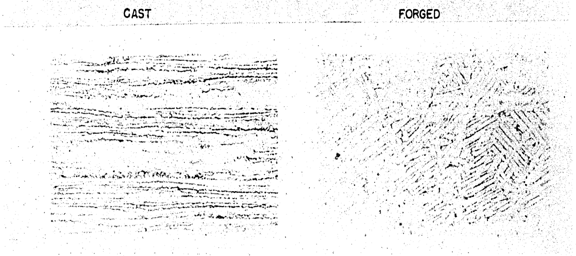


FIG80- PHOTOMICROGRAPHS OF P/N 226962 EXTRUDED FROM CAST AND FORGED MATERIAL.

[redacted]

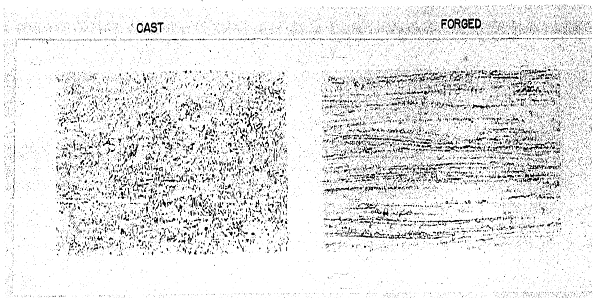


FIG. 81 - PHOTOMICROGRAPHS OF P/N 226963 EXTRUDED FROM CAST AND FORGED MATERIAL.

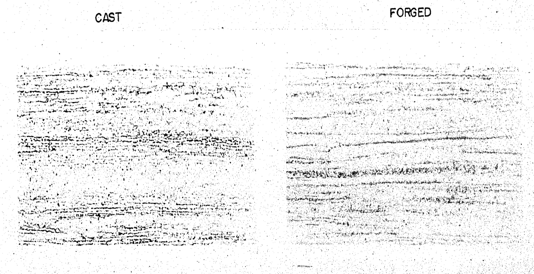


FIG. 82 - PHOTOMICROGRAPHS OF P/N 226964 EXTRUDED FROM CAST AND FORGED MATERIAL.

[redacted]

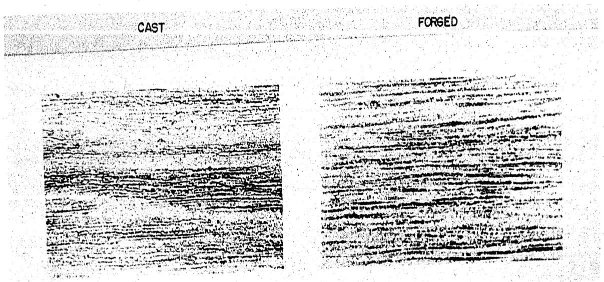


FIG. 83- PHOTOMICROGRAPHS OF P/N 226966 EXTRUDED FROM CAST AND FORGED MATERIAL.

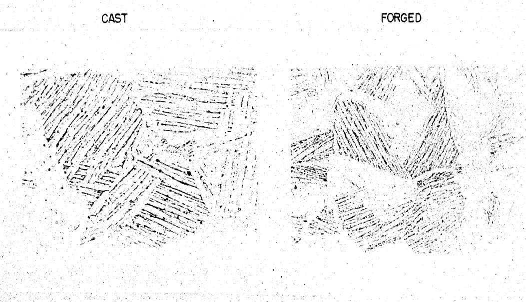


FIG. 84- PHOTOMICROGRAPHS OF P/N 227594 EXTRUDED FROM CAST AND FORGED MATERIAL.

[redacted]

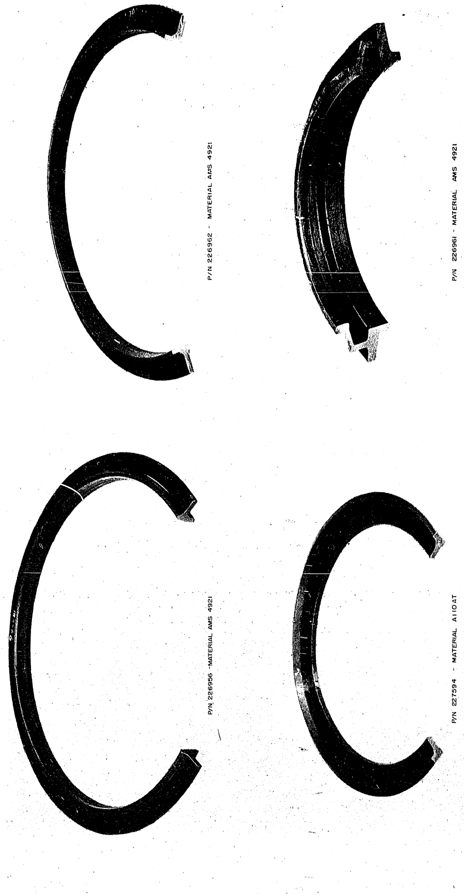


FIG. 85 - PHOTOGRAPHS OF SECTIONS OF SEVERAL OF THE FINISHED PRODUCTION RINGS

[redacted]

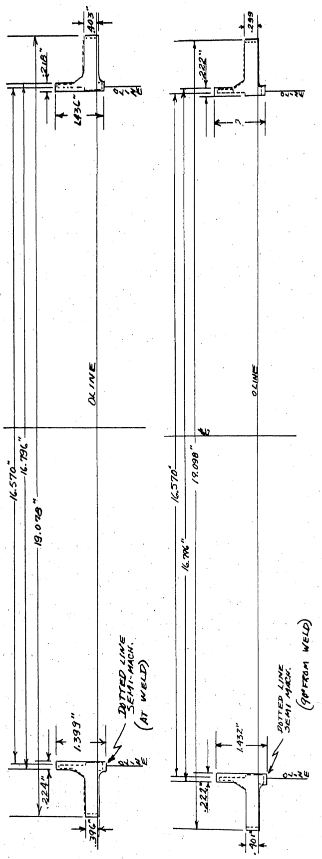


FIGURE 86. DIMENSIONAL INSPECTION LAYOUT OF P/N 226962.

[redacted]

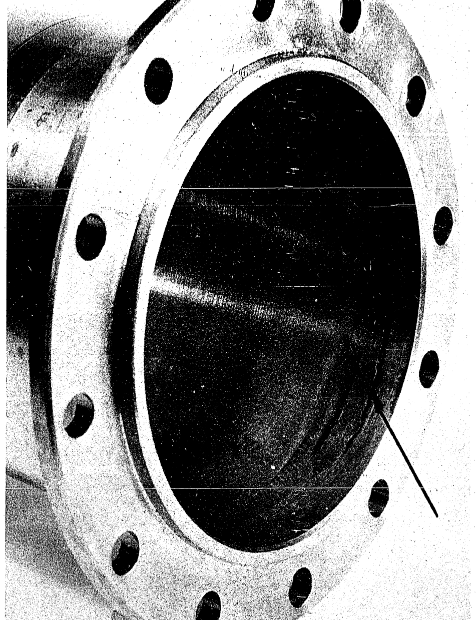


FIG. 87 - CLOSE-UP PHOTOGRAPH OF THE WELD REPAIR ZONE OF THE TURBINE ROTOR SHAFT.

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VIII. APPENDIX I

TITANIUM MATERIAL SPECIFICATIONS

1. MPD - 271 - Extrusion Stock (Forged) A110 AT
2. MPD - 272 - Extrusion Stock (Cast) A110 AT
3. MPD - 275 - Extrusion Stock (Cast) AMS 4921
4. MPD - 276 - Extrusion Stock (Forged) AMS 4921
5. WAD 7850A - Wrought Titanium & Titanium Alloys
6. WAD 7852 - Titanium Alloy - 5Al - 2 1/2 Sn Annealed - 110,000 psi yield

TITANIUM PROCESSING SPECIFICATIONS

7. AMS 7498 - Rings, Flash Welded - Titanium And Titanium Alloys
8. WAD 5797E Arc Welding
9. Tenative WAS Titanium Welding Specification

[redacted]

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[redacted]

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1. ACKNOWLEDGEMENT: A vendor shall mention this specification number and its latest revision number in all quotations and when acknowledging purchase orders

2. APPLICATION: Primarily intended for hot extrusion.

3. COMPOSITION:

Carbon	.20 max
Aluminum	4.0 - 6.0
Tin	1.5 - 3.5
Oxygen (when analyzed)	.20 max
Hydrogen	.0175 max
Nitrogen	.07 max
Other elements, total	.30 max

4. CONDITION: Vacuum melted, forged or rolled, and machined or conditioned to size. Local spot grinding and chipping is permissible to a maximum depth of 1/2" with well rounded edges.

5. QUALITY: Material shall be uniform in quality and condition, clean, sound, and free from foreign materials, and from internal and external defects.

6.1 MECHANICAL TESTS: In the annealed condition the properties shall be:

Yield Strength at .1% offset, psi	110,000 min.
Elongation, % in 4D	10 min
Reduction in area, %	30 min
Charpy V-Notch at room temperature	Results shall be reported
Notched Rupture at room temperature, 150,000 psi, shall be tested to failure or a maximum of 20 hours	" " " "

7. SAMPLING, INSPECTION AND TEST PROCEDURES:
A transverse sample from the stock to be supplied shall be hot reduced to a maximum ratio of 7 to 1. Tension and impact test specimens shall be taken transverse to the direction of major working. This sample will be the source of test specimens listed below:

[redacted]

7.1 TYPES OF SPECIMENS: The tensile test shall conform to Federal Specification QQ-M-151a, type 4. The Charpy specimen shall conform to ASTM designation E 23-47T, type A, with radius tolerance of ± .001".

8. DIMENSIONAL TOLERANCES: Dimensional tolerances shall be as specified in the order or on applicable drawings, except as noted in 4 above.

9. IDENTIFICATION: Each billet shall be clearly stamped on both ends with mill heat number and specification number.

10. REPORTS: The vendor shall furnish with each shipment a certified report of the results of tests for conformance to this specification. If a heat treatment has been used it shall be described. In addition the report shall include the purchase order number, heat number, specification number size, and quantity from each heat.

[redacted]

[redacted]

[redacted]

1. ACKNOWLEDGEMENT: A vendor shall mention this specification number and its latest revision number in all quotations and when acknowledging purchase orders.

2. APPLICATION: Primarily intended for hot extrusion.

3. COMPOSITION:

Carbon	.15 max.
Aluminum	4.0 - 6.0
Tin	1.5 - 3.5
Oxygen (when analyzed)	.20 max.
Hydrogen	.0175 max
Nitrogen	.07 max.
Other elements, total	.80 max.
Iron	.25 max.
Manganese	To be reported

4. CONDITION: Double vacuum melted and rough machined to size on the O.D. Local spot grinding and chipping is permissable to a maximum depth of 1/4" with well rounded edges.

5. QUALITY: Ingots or portions of ingots purchased to this specification shall be uniform in quality and condition, clean and free from foreign materials and external defects. Sonic testing will be employed to determine the presence of internal defects and center soundness. The sonic test observations shall be forwarded with the certified test results.

6. MECHANICAL TESTS: The tensile properties apply when the rate of strain is maintained through the yield strength between the values of 0.003 in per in. per min. and 0.007 in. per in. per min. and then increased so as to produce failure in approximately one additional minute. Mechanical test results, alone, shall not be the basis for rejection. Test specimens obtained from paragraph 7, in the annealed condition shall meet the following:

Yield Strength at .2% offset, psi	110,000 min.
Elongation, % in 4D	10 min.
Reduction in area, %	20 min.
Charpy V-Notch at room temperature	Results shall be reported
Notch Rupture at room temperature 150,000 psi, shall be tested to failure or a maximum of 20 hours	" " " "

[redacted]

[redacted]

7. **SAMPLING, INSPECTION AND TEST PROCEDURES:** A transverse sample from the stock to be supplied shall be hot reduced to a maximum ratio of 7:1. The vendor shall supply forging, & finishing temperatures and the number of reheats, if any, to accomplish this reduction. Tension and impact test specimens shall be taken transverse to the direction of major working. This sample will be the source of the test specimens listed in 6. One half of this specimen shall be forwarded to MFD for additional testing.

7.1 **Types of Specimens:** The tensile test shall conform to Federal Specification QQ-M-151a, Type 4. The Charpy specimen shall conform to ASTM designation E-23-47T, Type A, with radius tolerance of ± .001 inches.

8. **DIMENSIONAL TOLERANCES:** Dimensional tolerances shall be as specified in the order or on applicable drawings, except as noted in 4 above.

9. **IDENTIFICATION:** Each section shall be clearly stamped on both ends with the mill heat number and specification number.

10. **REPORTS:** The vendor shall furnish with each shipment a certified report of the results of tests for conformance to this specification. If a heat treatment has been used it shall be described. In addition, the report shall include the purchase order number, heat number, specification number size and quantity from each heat.

[redacted]

[redacted]

[redacted]

1. **ACKNOWLEDGMENT:** A vendor shall mention this specification number and its latest revision number in all quotations and when acknowledging purchase orders.

2. **APPLICATION:** Primarily intended for hot extrusion.

3. **COMPOSITION:**

Carbon	0.20 max.
Hydrogen	0.0125 max.
Oxygen (when analyzed)	0.20 max.
Nitrogen	0.07 max.
Iron	To be reported
Manganese	To be reported
Other elements total (including Fe & Mn)	0.50 max.
Titanium	Remainder

4. **CONDITION:** Double vacuum melted with both melts employing the consumable electrode method. The diameter may be machined. Local spot grinding and chipping is permissable to a maximum depth of 1/4" with well rounded edges.

5. **QUALITY:** Ingots or portions of ingots purchased to this specification shall be uniform in quality and condition, clean and free from foreign materials and external defects. Sonic testing will be employed to determine the presence of internal defects and center soundness. The sonic test observations shall be forwarded with the certified test results.

6. **MECHANICAL TESTS:** Material shall conform to the following requirements, and shall be capable of meeting these requirements after being heated to any temperature up to 1200°F for approximately 30 min. in air and cooled in air. These properties apply when the rate of strain is maintained at approximately 0.005 in. per in. per min. to the yield strength.

Tensile Strength, psi	80,000 min.
Yield Strength at 0.2% offset psi	70,000 - 90,000
Elongation, % in 2 in.	15 min.
Reduction of area %	30 min.
Notch Rupture tests at 75°F with an axial load of 90,000 psi shall be tested to failure or a maximum of 10 hours. Hours	5 min.

[redacted]

[redacted]

7. SAMPLING, INSPECTION AND TEST PROCEDURES: A transverse sample from the stock to be supplied shall be hot reduced to a maximum ratio of 7:1. The vendor shall supply forging, & finishing temperatures and the number of reheats, if any, to accomplish this reduction. This sample will be the source of the test specimens listed in 6. One half of this sample forging shall be forwarded to MPD.

7.1 Types of Specimens: The tensile test shall conform to Federal Specification QQ-M-151a, Type 4. Notch rupture specimens shall have a 0.25 in. diameter with a 60 degree Vee notch of 0.178 in. root diameter and 0.005 in. root radius.

8. DIMENSIONAL TOLERANCES: Dimensional tolerances shall be as specified in the order or on applicable drawings, except as noted in 4 above.

9. IDENTIFICATION: Each section shall be clearly stamped on both ends with the mill heat number and specification number.

10. REPORTS: The vendor shall furnish with each shipment a certified report of the results of tests for conformance to this specification. If a heat treatment has been used it shall be described. In addition, the report shall include the purchase order number, heat number, specification number size and quantity from each heat.

11. ACCEPTANCE: Material not conforming to this specification or to authorized modifications will be subject to rejection.

APPROVED:

Materials Laboratory	Manufacturing Engineering	Manufacturing Eng.

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[redacted]

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[redacted]

1. ACKNOWLEDGEMENT: A vendor shall mention this specification number and its latest revision number in all quotations and when acknowledging purchase orders.

2. APPLICATION: Primarily intended for hot extrusion.

3. COMPOSITION:

Carbon	0.20 max.
Hydrogen	0.0125 max.
Oxygen	0.20 max.
Nitrogen	0.07 max.
Iron	To be reported
Manganese	To be reported
Other elements total (including Fe & Mn)	0.50 max.
Titanium	Remainder

4. CONDITION: Double vacuum melted with both melts employing the consumable electrode method. The diameter may be machined. Local spot grinding and chipping is permissable to a maximum depth of 1/4" with well rounded edges.

5. QUALITY: Ingots or portions of ingots purchased to this specification shall be uniform in quality and condition, clean and free from foreign materials and external defects. Sonic testing will be employed to determine the presence of internal defects and center soundness. The sonic test observations shall be forwarded with the certified test results.

6. TECHNICAL REQUIREMENTS: Material shall conform to the following requirements, and shall also be capable of meeting these requirements after being heated to any temperature up to 1200°F for approximately 30 minutes in air, cooled in air, and descaled.

6.1 Mechanical Tests: The tensile properties listed below apply when the rate of strain is maintained through the yield strength between the values of .003 in. per. in. per min., and .007 in. per in. per min., and then is increased so as to produce failure in approximately one additional minute. In the annealed condition the properties shall be:

Tensile Strength, psi	80,000 min.
Yield Strength at 0.2% offset psi	70,000 - 90,000
Elongation, % in 2 in.	15 min.
Reduction of area %	30 min.
Notch Rupture tests at 75°F with an axial load of 90,000 psi shall be tested to failure or a maximum of 10 hours. Hours	5 min.

[redacted]

7. SAMPLING, INSPECTION AND TEST PROCEDURES: A transverse sample from the stock to be supplied shall be hot reduced to a maximum ratio of 7:1. The vendor shall supply forging, & finishing temperatures and the number of reheats, if any, to accomplish this reduction. This sample will be the source of the test specimens listed in 6. One half of this sample forging shall be forwarded to MPD.

7.1 Types of Specimens: Notch rupture specimens shall have a 0.25 in. diameter with a 60 degree Vee notch of 0.178 in root diameter and 0.005 in. root radius.

8. DIMENSIONAL TOLERANCES: Dimensional tolerances shall be as specified in the order or on applicable drawings, except as noted in 4 above.

9. IDENTIFICATION: Each section shall be clearly stamped on both ends with the mill heat number and specification number.

10. REPORTS: The vendor shall furnish with each shipment a certified report of the results of tests for condormance to this specification. If a heat treatment has been used it shall be described. In addition, the report shall include the purchase order number, heat number, specification number size and quantity from each heat.

11. ACCEPTANCE: Material not conforming to this specification or to authorized modifications will be subject to rejection.

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1. ACKNOWLEDGMENT: A vendor shall mention this specification number and its revision letter in all quotations and when acknowledging purchase orders.

2. APPLICATION: This specification covers certain compositional, technical, and quality requirements for wrought titanium and titanium alloys and is intended not to supersede or delete but to supplement the requirements of existing applicable specifications.

3. INTERSTITIAL COMPOSITION:

	Oxygen, if determined	0.20 max
	Nitrogen	0.07 max
Ø	Carbon	0.20 max
	Hydrogen	
	Bar Stock	0.0125 max
	Sheet Stock	0.0150 max
	Other Elements, Total	0.20 max

3.1 For bar stock of A110 AT alloy, the hydrogen content shall be 0.0175 maximum.
Ø

3.2 Conformance to technical requirements of section 4 shall be achieved by means of the alloying elements and not be intentional additions of interstitial elements.

4. TECHNICAL REQUIREMENTS:

4.1 Notched Rupture Test: Bars and forgings shall be capable of meeting the following test:

4.1.1 Test specimens shall have 0.25 in. diameter with a 60-degree Vee notch of 0.178 in. root diameter and 0.005 in. root radius. Maintaining a temperature
Ø of 75 F with an axial load of 160,000 psi applied, specimens shall not rupture in less than 5 hours.

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4.1.1.1 For A110 AT alloy, an axial load of 135,000 psi shall be applied.

4.1.1.2 For AMS 4921 alloy, an axial load of 90,000 psi shall be applied.

4.1.1.3 Hardness: Unless otherwise specified, AMS 4925 shall have a hardness not
Ø higher than Rockwell C 39 or equivalent.

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1. ACKNOWLEDGMENT: A vendor shall mention this specification number in all quotations and when acknowledging purchase orders.

2. FORM: Bars and forging stock.

3. APPLICATION: Primarily for parts requiring welding and having strength up to 700 F.

4. COMPOSITION:

Aluminum	4.0 - 6.0
Tin	1.5 - 3.5
Carbon	0.20-max
Oxygen (if determined)	0.20 max
Hydrogen	0.0175 max
Nitrogen	0.07 max
Iron	0.50 max
Manganese	0.20 max
Others	0.10 max
Titanium	Remainder

5. CONDITION: Unless otherwise specified, hot finished, with or without subsequent cold reduction, annealed, and descaled.

6. TECHNICAL REQUIREMENTS:

6.1 Tensile Properties: These properties apply when the rate of strain is maintained through the yield strength between the values of 0.003 in. per in. per min. and 0.007 in. per in. per min., and then it is increased to produce failure in approximately one additional minute. When a dispute occurs between purchaser and vendor over the yield strength values, a referee test shall be performed on a test machine having a strain rate pacer, using a rate of 0.005 in. per in. per min. through the yield strength.

Tensile Strength, psi	115,000 min
Yield Strength at 0.2% Offset or at 0.0182 in. in 2 in. Extension Under Load (E = 15,500,000),psi	110,000 min
Elongation, % in 4D (Sections under 3 in.)	10 min
Reduction of Area, % (Sections under 3 in.)	30 min

7. QUALITY: Material shall be uniform in quality and condition, clean, sound, and free from foreign materials and from internal and external imperfections detrimental to fabrication or to performance of parts.

[redacted]

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8. **TOLERANCES:** Unless otherwise specified, diameter or thickness tolerances shall conform to the latest issue of AMS 2241, Table II.

9. **REPORTS:**

9.1 Unless otherwise specified, the vendor of the product shall furnish with each shipment three copies of a report of the results of tests for chemical composition of each heat in the shipment and for tensile properties of each size from each heat. This report shall include the purchase order number, heat number, material specification number, size, and quantity from each heat. If forgings are supplied, the part number and size of stock used to make the forgings shall also be included.

9.2 Unless otherwise specified, the vendor of finished or semi-finished parts shall furnish with each shipment three copies of a report showing the purchase order number, material specification number, contractor or other direct supplier of material, part number, and quantity. When material for making parts is produced or purchased by the parts vendor, that vendor shall inspect each lot of material to determine conformance to the requirements of this specification, and shall include in the report a statement that the material conforms, or shall include copies of laboratory reports showing the results of tests to determine conformance.

10. **IDENTIFICATION:** Individual pieces of bundles shall have attached a metal tag stamped with the purchase order number, 7852, nominal size, and heat number, or shall be boxed and the box marked with the same information. In addition to the above identification, bars 1 in. and over in diameter or distance between parallel sides shall be stamped with the heat number within 2 in. of one end.

11. **ACCEPTANCE:** Material not conforming to this specification or to authorized modifications will be subject to rejection.

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Section 7C of the SAE Technical Board rules provides that: "All technical reports, [redacted] ding standards approved and practices recommended, are advisory only. Their use by anyone engaged in industry or trade is entirely voluntary. There is no agre t to adhere to any SAE standard or recommended practice, and no commitment to conform to or be guided by any technical report. In formulating and approving technical reports, the Board and its Committees will not investigate or consider patents which may apply to the subject matter. Prospective users of the report are responsible for protecting themselves against liability for infringement of patents."

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RINGS, FLASH WELDED
Titanium and Titanium Alloys

1. **ACKNOWLEDGMENT:** A vendor shall mention this specification number in all quotations and when acknowledging purchase orders.

2. **APPLICATION:** Primarily for parts such as flanges and rings fabricated by flash welding roll-formed strip or shapes of titanium and selected titanium alloys.

3. **MATERIAL:** Material from which rings are made shall be as specified on the drawing.

4. **FABRICATION:**

4.1 **Forming:** Rings as applicable for the particular part shall be hot formed from suitably rolled or forged shapes uniformly heated to a temperature not higher than 1200 F.

4.2 **Preparation for Welding:**

4.2.1 Formed rings shall be clean and free from foreign materials in the area of electrode contact and at the surfaces to be welded.

4.2.2 Formed rings may be pre-heated, before welding, as agreed upon by purchaser and vendor.

4.3 **Welding:** The ends of the formed rings shall be flash butt-welded together. Welding shall be performed on a machine provided with accurate control of feed of joint during flashing, rate and distance of travel of sections to be welded, secondary voltage and current magnitude, and timing and current cut-off. The flash shall be maintained during the flashing interval of the welding operation. The machine shall be capable of repeating the sequence of operations independently of the skill of the operator. A record of all machine settings and sequence of operations for welding each different ring shall be kept by the vendor and be made available to the purchaser upon written request.

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4.4 **Sizing:** Unless otherwise specified, each ring, after removal of flash, shall be sized. Ring shall be heated to a temperature not higher than 1250 F before sizing and sizing shall be completed before the ring cools to below 700 F. The stress applied for final sizing shall be sufficient to provide an increase in circumference of not less than 1% after the load is released. Sizing shall be performed in such a way as to provide uniform stress distribution throughout the ring.

4.5 **Annealing:** Unless otherwise specified, the welded rings shall be annealed by heating to 1300 F ± 25, holding at heat for 2 hr, cooling in the furnace, at a rate not to exceed 200 F per hour, to 950 F and air cooling to room temperature.

[redacted]

4.6 Restoration to Shape: If it is necessary to restore shape of rings following annealing, such operation shall be done on suitable presses and not by localized blows as from a hammer. Rings may be heated to not higher than 1000 F for such operation.

5. TECHNICAL REQUIREMENTS:

5.1 Tensile Properties: If finished welded rings are cut for examination, tensile test specimens shall conform to the following requirements:

Tensile Strength, Through Welded Area	95% min of parent metal
Elongation, Through Welded Area	50% min of parent metal

5.2 Hardness: Alloy rings shall have hardness not higher than Rockwell C 38 or equivalent, unless otherwise specified on the drawing or purchase order.

6. QUALITY:

6.1 Parts shall be uniform in quality and condition, clean, sound, and free from scale and foreign materials and from internal and external defects detrimental to fabrication or performance.

6.2 Parts shall be subject to X-ray inspection.

6.3 Parts shall be subject to fluorescent penetrant inspection.

7. REPORTS: Unless otherwise specified, the vendor of finished or semi-finished parts shall furnish with each shipment three copies of a report showing the purchase order number, material specification number, contractor or other direct supplier of material, part number, and quantity. When material for making parts is produced or purchased by the parts vendor, that vendor shall inspect each lot of material to determine conformance to the requirements of the applicable material specification, and shall include in the report a statement that the material conforms, or shall include copies of laboratory reports showing the results of tests to determine conformance.

8. APPROVAL:

8.1 To assure adequate performance characteristics, sample parts shall be approved, unless such approval be waived.

8.2 When a new vendor is being considered, or new welding equipment is being placed in operation, or settings on an old machine are changed, or changes in joint size or shape are made, the welding procedure shall be approved in the following manner: One or more rings from the first shipment of each size ring shall be selected at random. The ring or rings shall be subjected to tensile tests, hardness determinations, and examination of structure. If the requirements of 5.1 and 5.2 are met and the structure of the weld is satisfactory, the equipment and procedure will be considered satisfactory for making that weld.

8.3 Vendor shall use the same manufacturing procedures and processes for production parts as for approved sample parts. If necessary to make any change, vendor shall obtain permission from purchaser prior to incorporating such change.

9. REJECTIONS: Parts not conforming to this specification or to authorized modifications will be subject to rejection.

[redacted]

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1. ACKNOWLEDGMENT: A vendor shall mention this specification number and its revision
Ø letter in all quotations and when acknowledging purchase orders.

2. APPLICATION: This specification covers aircraft quality Arc-Welding of steels, heat resistant alloys, aluminum and magnesium alloys, and titanium and titanium base alloys, except as otherwise controlled by W.A.D. engineering specifications.

3. SYMBOLS: The symbols and definitions used to indicate the welding application on drawings shall be as shown in Figures 1 and 2.

4. WELD CLASSIFICATION: All welds shall be classified as one of the following types, unless otherwise approved by W.A.D. Engineering Department. The letter representing the applicable type shall be shown in the forked tail of the weld symbol on the drawing.

4.1 Type A: Inert Gas Shielded Tungsten Arc.

4.2 Type B: Flux-coated Consumable Metallic Arc.

4.3 Type AA: Inert Gas Shielded Consumable Electrode Metal Arc.

4.4 Type BB: Submerged Metal Arc.

4.5 Type C: Atomic Hydrogen Arc.

4.6 Type D: When "Type D" is specified, any one of the above classifications may be used.

4.7 Where Type A or B is specified on the drawing, Type AA or BB may be used if approved by the Engineering Department of W.A.D.

5. PREPARATION FOR WELDING: Surfaces to be welded shall be free of water, oil, grease, dirt, rust, scale, or other foreign matter deleterious to welding.

6. WELDING:

6.1 Unless otherwise approved by the Engineering Department of W.A.D., filler wire
Ø shall be used.

6.1.1 Unless otherwise specified, filler wire shall be of the same nominal composition
Ø as the base metal.

6.2 When either Type A or Type AA is specified, the purity of inert gas used shall
Ø be 99.9% for argon and 99.99% for helium, unless otherwise specified.

6.2.1 Welding flux is not permitted on the arc side (the side at which the welding arc
Ø is being directed) of the welded joint. Back-up flux may be used on the side of the joint opposite the arc in order to prevent oxidation or burn-through.

7. CLEANING AFTER WELDING: All welded portions of the assembly shall be cleaned in such a manner as to remove all flux, spatter, detrimental oxide, stain or foreign material.

[redacted]

8. QUALITY:

8.1 External:

8.1.1 Porosity and slag are not permitted on the finished surface of the weldment, except as follows: Indications of porosity or slag 1/64 in. or less in diameter shall be disregarded, unless clustered. A cluster is defined as two or more indications within 3/32 in. diameter. Not more than two such clusters are permitted per linear inch. Ø

8.1.2 Cracks, overlapping, and lack of fusion are not permitted on the finished surface of any weldment, or surrounding base metal, unless otherwise specified. Ø

8.1.3 Indications of imperfections revealed by etchant, fluorescent or dye penetrant, which cannot be detected under 4x magnification shall not be considered.

8.1.4 Marks caused by accidental arc scratches on welded assemblies will be acceptable provided the stock thickness of the finished part at the arc scratch is not reduced more than 5%.

8.1.5 Single pass butt welds and corner welds shall show complete penetration, unless otherwise specified. When other than complete penetration is permitted by drawing, simulated joint samples shall be prepared and submitted for evaluation by the Engineering Department of W.A.D. to determine conformance to drawing penetration requirements. Ø

8.1.6 Weld Size:

8.1.6.1 Butt Welds: The height of weld bead above the plane of the base material shall not exceed two-thirds the thickness of the base material or 1/8 in., whichever is less. Weldment below the plane of the base metal is permissible for not more than 5% of the weld length and shall be limited in depth to a percentage of the base metal thickness as follows: Ø

Nominal Stock Thickness Inch	Permissible Below Base Plane % of Stock Thickness
0.030 - 0.080	10
0.081 - 0.130	7
0.131 and up	5

8.1.6.2 Fillet Welds: The maximum size of a fillet weld shall not be more than 30% above the drawing requirements. The minimum size of a fillet weld shall not be more than 15% below the drawing requirement except that 5% of the weld length will be accepted with a weld size not more than 50% below drawing requirement, unless otherwise specified. Fillet weld size is defined as the length of the fillet leg. In no case shall the fillet throat be less than 50% of the fillet leg size required.

When no drawing value for fillet size is given and where the geometry of the joint does not define the fillet size, the nominal size of the fillet weld shall be 50% greater than the thickness of the thinner sheet but not less than 0.06 inch.

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8.1.6.3 Peening shall not be acceptable as a method for reducing weld size.

8.1.7 Undercut or removal of undercut by blending which results in a decrease of base metal thickness exceeding percentages allowed by 8.1.6.1 is not acceptable.

8.2 Internal:

8.2.1 Welds shall not show blow holes, inclusions, or porosity in excess of the following limits:

8.2.1.1 Butt Welds:

8.2.1.1.1 Imperfections with dimensions one-third or less than the joint thickness shall be disregarded unless 5 or more in any one linear inch of weld intersect any straight line. Imperfections as in 8.2.1.1.2 shall be considered as contributing to those intersecting any straight line.

8.2.1.1.2 Imperfections with a dimension greater than one-third but less than one-half the joint thickness or 1/16 in., whichever is less, are acceptable provided there are not more than three such imperfections per linear inch of weld and no two consecutive inches contain the maximum permissible number of imperfections.

8.2.1.1.3 Joint thickness as in 8.2.1.1.1 and 8.2.1.1.2 shall be interpreted to be the thinner of the base metal thicknesses as shown by drawing.

8.2.1.1.4 Unless otherwise specified, butt welds shall have complete penetration.

Ø

8.2.1.2 Fillet Welds:

8.2.1.2.1 Imperfections with a dimension one-half or less of the weld leg (fillet size) in not more than 5% of the weld length are acceptable provided there are not more than three per linear inch and no two consecutive inches contain the maximum permissible number of imperfections.

8.2.1.2.2 Fillet welds shall have a line of fusion of 90% minimum along the leg length except at joints forming angles of 75° or less.

8.3 Cracks are not permitted. Grain orientation and other metal conditions will sometimes produce x-ray indications resembling cracks. For single pass welds, such indications shall be disregarded if magnetic particle or penetrant inspection shows no actual cracks. Ø

8.4 Welded parts and assemblies are subject to x-ray examination, magnetic particle inspection, fluorescent penetrant inspection, visual inspection, etc., as will adequately determine the quality of weldments.

9. PERMISSIBLE REPAIRS:

9.1 Unless otherwise specified, imperfections beyond the limits of Section 8. may be repaired provided the measured length of any given repair or group of repairs, either singly or in combinations (to the nearest higher whole number of inches) shall be separated from any other repair by at least an equal number of inches of acceptable (without repair) weld. The measured length may be either the length of a single repair or the continuous length from the first to last of any consecutive number of repairs. In the latter case, the total length so measured shall be considered as "the measured length".

[redacted]

9.2 Repairing shall be accomplished by routing to remove the defect and re-welding
Ø by the same method as originally specified for that particular weld, unless otherwise permitted.

10. APPROVAL:

10.1 A vendor shall not supply production details or assemblies welded in accordance with this specification until production approval has been granted, unless such approval be waived.

10.2 A vendor's facilities, procedures, and materials used shall be subject to approval by the Engineering Department of W.A.D. Manufacturing materials, procedures, processes, and methods of inspection shall be the same for
Ø production parts as for approved sample parts. If necessary to make any change, a vendor shall obtain permission from purchaser prior to incorporating such change.

10.3 Automatic fusion welding equipment shall be approved by demonstrating its
Ø capability to perform the following:

10.3.1 Controls shall be set to weld a test sample at least 12 in. long and of the same nominal composition and of thickness representing the mean of the
Ø range of production parts to be welded. Sample shall meet the quality requirements of Section 8.

11. CERTIFICATION OF WELDERS:

11.1 Personnel performing manual welding on W.A.D. parts and assemblies shall be certified in accordance with MIL-T-5021 as competent to do the particular welding operations involved.

12. ACCEPTANCE: Arc-welded details and assemblies not fabricated in accordance with the requirements of this specification or authorized modifications will be subject to rejection.

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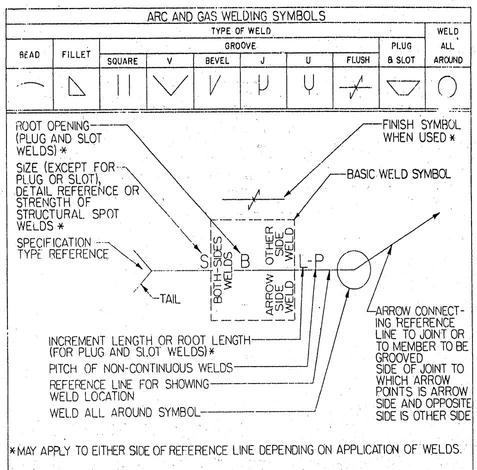
Figure 1 Symbols to be used on drawings:



1. BOTH SIDES OF WELDS OF THE SAME TYPE ARE OF SAME SIZE UNLESS OTHERWISE SPECIFIED.
2. SYMBOLS APPLY BETWEEN ABRUPT CHANGES IN DIRECTION OF JOINT OR AS DIMENSIONED (EXCEPT WHERE ALL AROUND SYMBOL IS USED).
3. ALL WELDS ARE CONTINUOUS UNLESS OTHERWISE SPECIFIED.
4. DIMENSIONS OF WELDS IN INCHES.
5. WHERE THE SYMBOL ✓ OCCURS, THE WELD FINISH SHALL BE EQUIVALENT IN QUALITY TO THAT REQUIRED FOR THE SURROUNDING BASE METAL.

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Figure 2 - Illustrative applications of welding symbols:

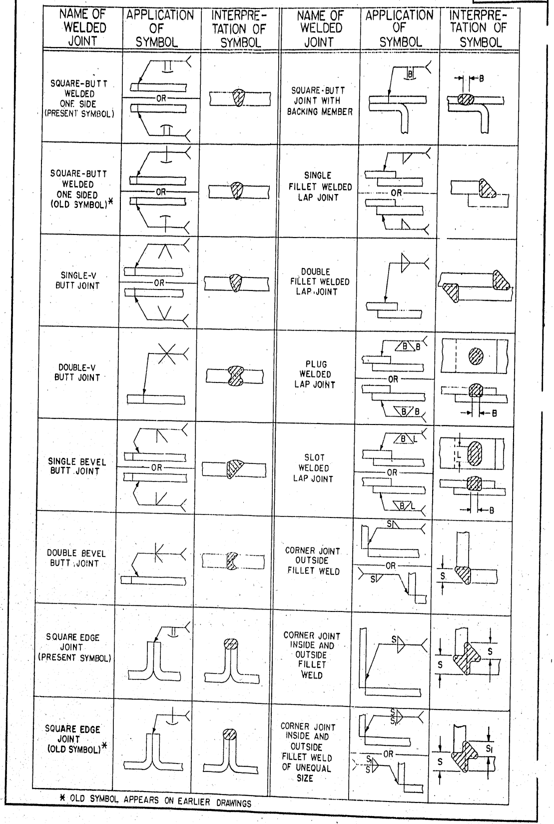

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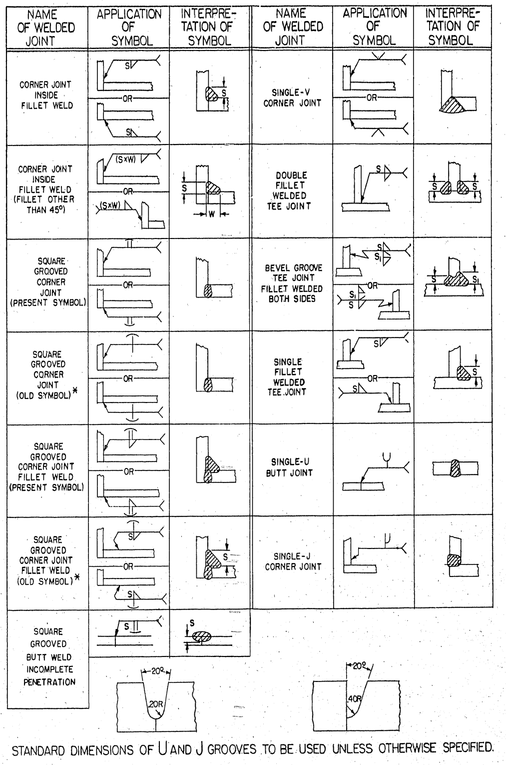
Figure 2 (Continued):



TENTATIVE WAD SPECIFICATION FOR ARC WELDING OF TITANIUM AND TITANIUM ALLOYS

1. Acknowledgement: A vendor shall mention this specification number and its revision letter in all quotations and when acknowledging purchase orders.

2. Application: This specification applies to the process and quality requirements for inert gas shielded tungsten arc welding of titanium and titanium alloys. This specification to be employed only in addition to the requirements of WAD 5797.

3. General Provisions:

3.1. An inert backup gas of either argon or helium shall be employed to protect the penetration side of the weld bead.

3.2. Argon and/or helium gas shall be employed in the welding torch nozzle when joining sheet material 0.080" or less in thickness. Helium shall be employed for all thicker material.

3.3. In all cases, the largest feasible shielding nozzle shall be used to insure adequate protection.

3.4. Whenever the part geometry and weld configuration permit, the movement of the welding torch, relative to the area being welded, shall be governed by mechanical means.

3.5. A trailing shield shall be provided for all machine welds, and shall have an individual inert gas supply.

3.5.1. The combination of a nozzle and a trailing shield shall be capable of producing a weld bead which conforms to the requirements of Paragraph 6.

3.6. Manual welding operations must be performed in an inert atmosphere container or by other approved methods capable of producing welds which meet the quality requirements of Paragraph 6.

4. Preparation for Welding:

4.1. Prior to welding, the joint surfaces shall be prepared by either of the following methods.

4.1.1. Grind the surfaces with emery rolls or other abrasive material which will remove the tight adherent surface oxide.

Chemical clean in an acid bath as follows:

Bath Analysis	
Hydrofluoric Acid	1.5% to 2.0% maximum by weight
Nitric Acid	20% to 30% by weight
Water	Remainder

Temperature of bath - 150°F
Immersion Time - 5 minutes maximum

4.2. Preparation for welding shall not reduce the metal thickness more than .003 inches.

5. Production Control

5.1. Test specimens as in 6.2 shall be made at the beginning of a production run and after any change in the welding procedure.

5.2. The specimen shall meet the quality requirements of 5797 in addition to the quality requirements of this specification.

5.3. If oxidation of the weldment surface in excess of Paragraph 6.1 appears on a production part welding shall be stopped immediately. A satisfactory test specimen shall be fabricated before resuming production welding.

6. Quality Standards (In addition to those of specification WAD 5797)

6.1. Surface Oxide

6.1.1. Weld and HAZ shall not be oxidized more than that indicated by a straw color, except that 5% of the weld may be oxidized to a blue color. An abrupt change in oxide scale shall be cause for rejection.

3.7. On multiple pass weldments, all surface oxidation must be removed before depositing subsequent weld beads.

6.2. Bend Test

6.2.1. Longitudinal bend test specimens shall be fabricated of the same alloy and thickness as the production part and under conditions comparable to that of the production component. Minimum size of specimen shall be one inch wide. The bend test specimen shall be bent 90° over a radius that does not exceed the sheet thickness by more than the bend factor listed below:

Material	Sheet Thickness	Bend Factor
AMS 4901	under 0.070	5T
AMS 4901	over 0.070	6T
WAD 7853	under 0.070	9T
WAD 7853	over 0.070	10T
WAD 7853	over 0.125	11T

6.3. Weld Size

6.3.1. Butt Welds:

Material thicknesses less than or equal to .080" shall have a maximum bead width of five times the sheet thickness while material more than .080" thick shall have a maximum bead width of four times the thickness of the sheet.

7. Reports: The manufacturer shall maintain complete records of welding and inspection, which shall be available for examination by WAD upon request.

8. Repair Welding: Repair welding shall conform to the requirements of WAD 5797 and this specification.

9. Approval: The vendors welding equipment, facilities, procedures, and material shall be subject to approval by WAD prior to acceptance of welded parts.

9.1. Unless otherwise specified, the vendor shall submit specimens simulating the actual part to be welded on the production welding future in the case of machine welds and simulating the joint in the case of manual welds and demonstrating the quality requirements of Paragraph 6 before welding production units. Specimens shall be in the as welded condition when submitted for WAD evaluation.

10. Acceptance: Arc welded components not meeting the requirements of this specification or authorized modifications shall be subject to rejection.

APPENDIX II

DETAIL EXTRUSION DIE DRAWINGS

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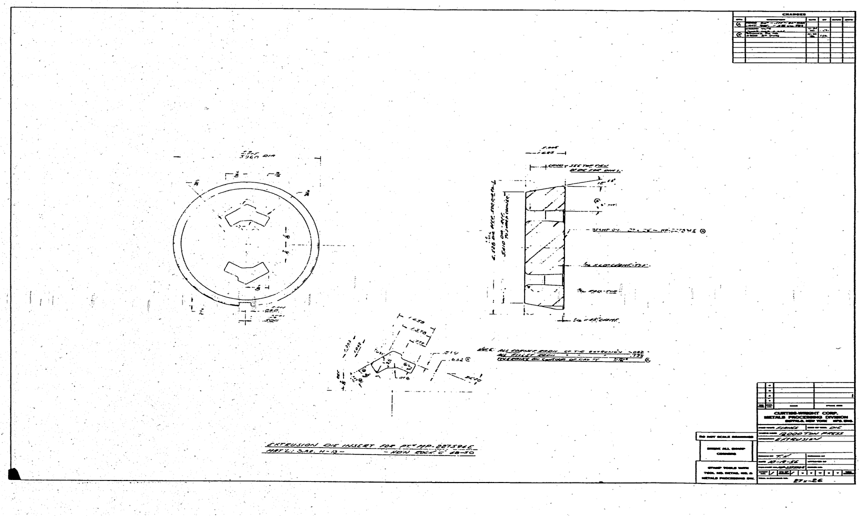

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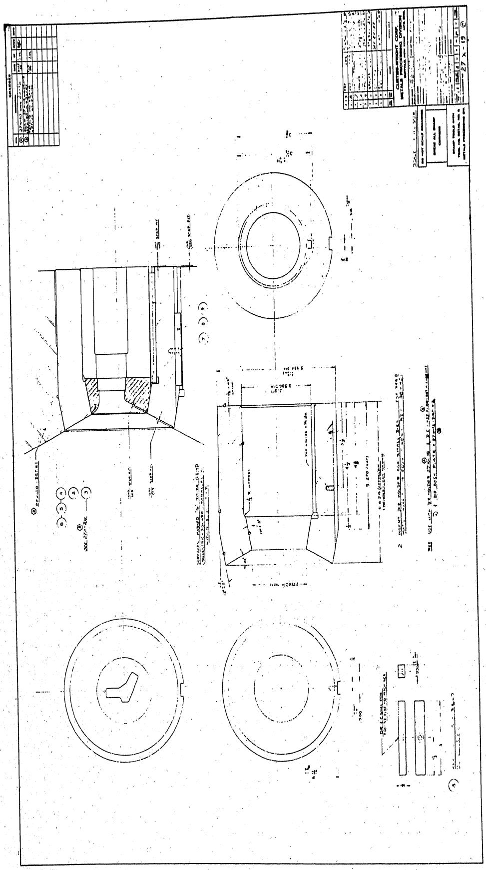

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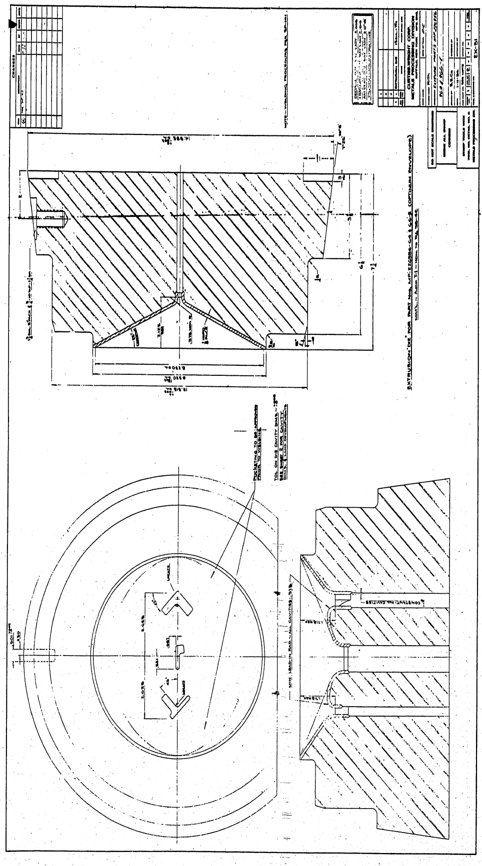

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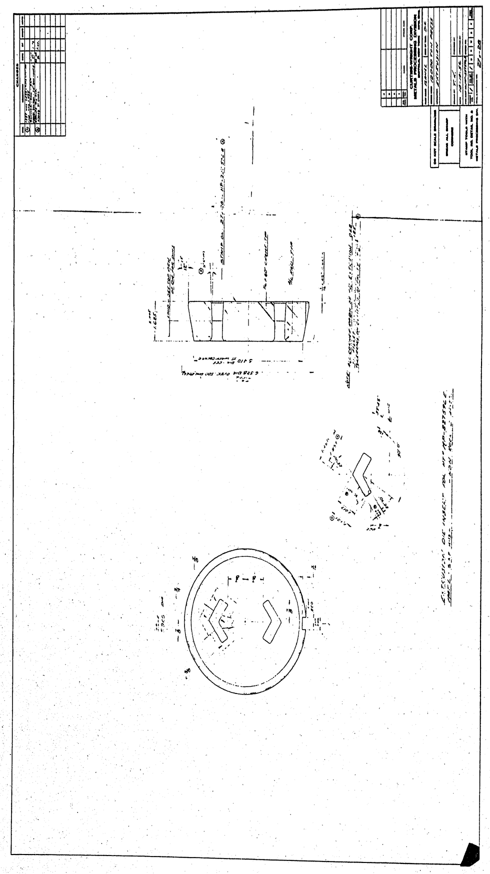

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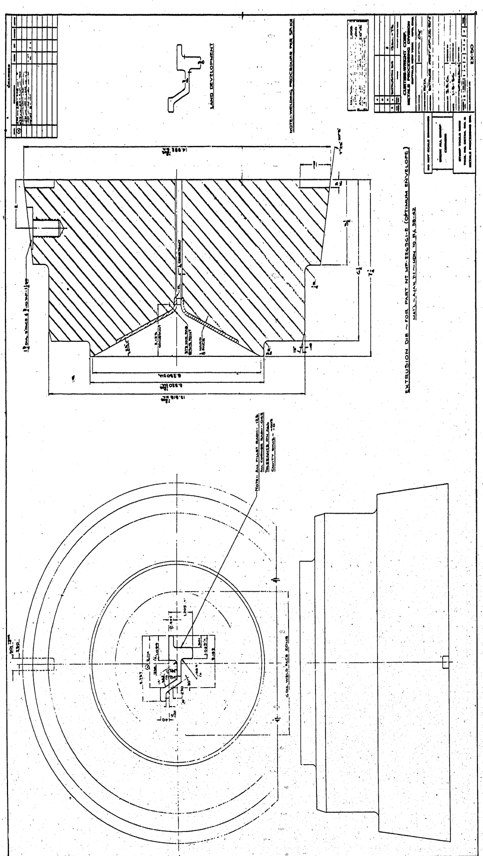

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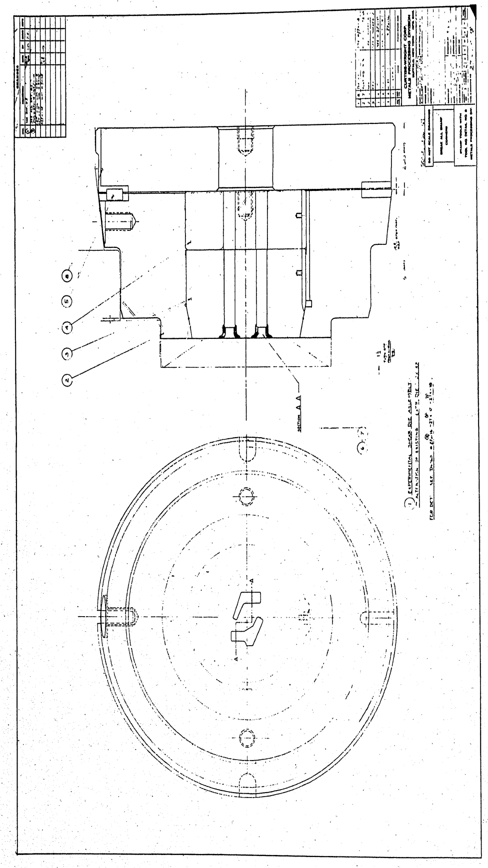

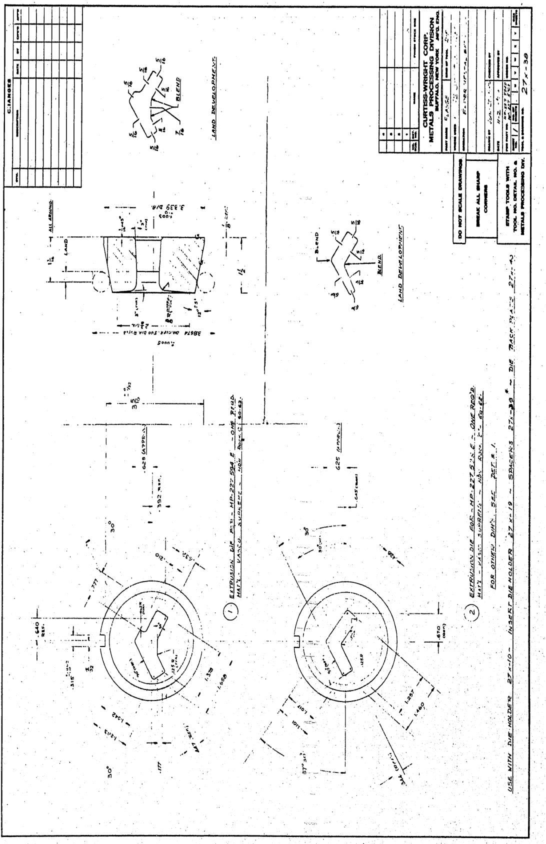

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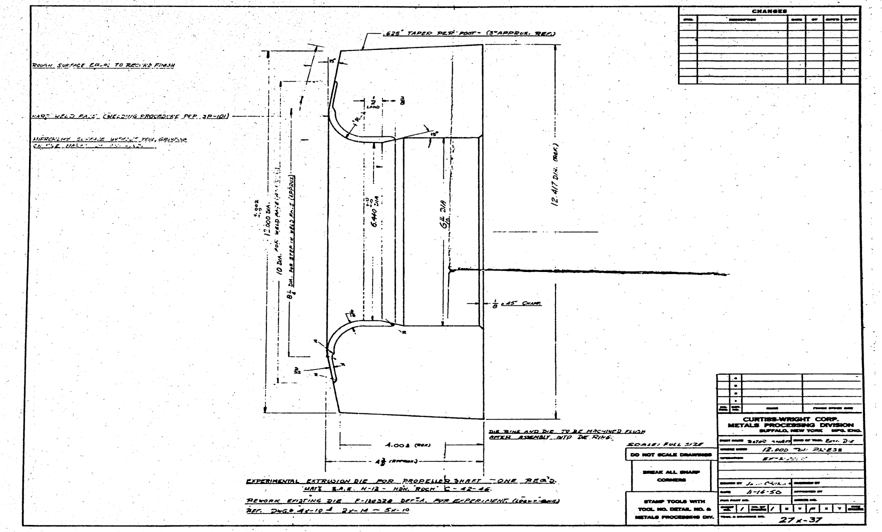

EXPERIMENTAL EXTRUSION DIE FOR PROPELLER SHAFT - ONE REQ'D.
MAT'L S.A.E. H-12 - HDN. ROCK. C-42-46.

REWORK EXISTING DIE F-180328 DET. A. FOR EXPERIMENT.

REF. DWG. 4x-10, 2x-14 - 5x-10

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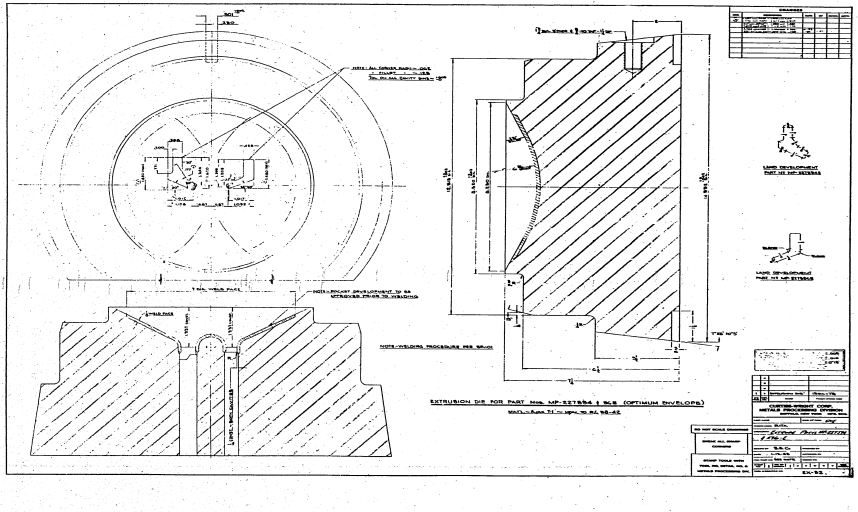

EXTRUSION DIE FOR PART Nos. MP-227594 & 968 (OPTIMUM ENVELOPE)

MAT'L - AJAX T-1 - HDN. TO R/C 38-42

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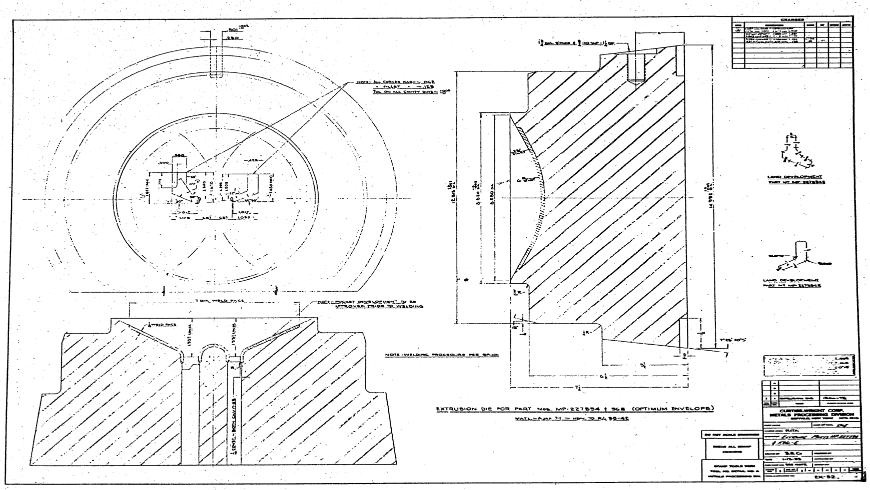

EXTRUSION DIE FOR PART Nos. MP-227834 & 36E (OPTIMUM ENVELOPE)

MAT'L - AJAX T-1 ~ HDN. TO R/c 38-42

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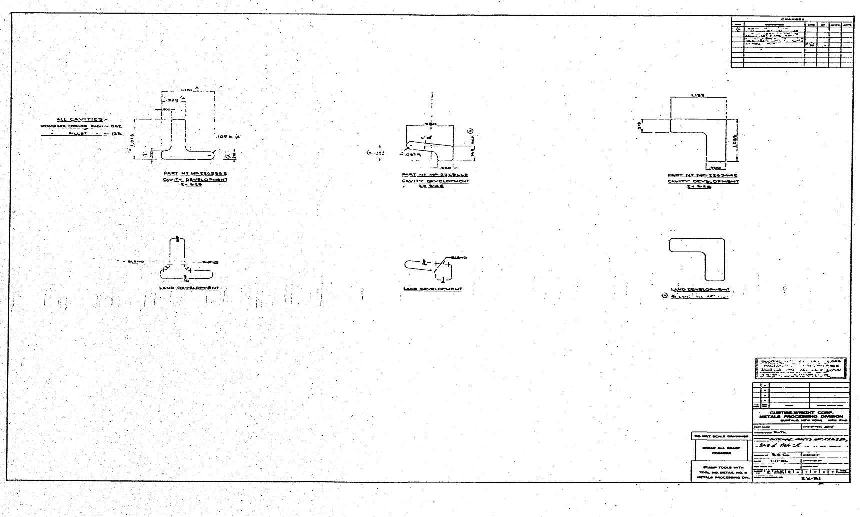

TITANIUM MANUFACTURING METHODS DEVELOPMENT

PART III

BASIC STUDIES

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FOREWORD

To realize the program objectives several development studies were performed on the extrusion of cast ingots. The results obtained from these studies are presented in this section of the report. These studies are basic in nature and therefore serve primarily as an aid in the advancement of the state of the art of titanium extrusions.

The extrusions and much of the testing was performed by the Metals Processing Division of Curtiss-Wright Corporation. The final evaluation of the material was performed in conjunction with co-workers in the Development Metallurgy Division of Wright Aeronautical Division. The Authors acknowledge these major contributions to this program.

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I INTRODUCTION

Due to the high cost of titanium material the weight advantages gained by replacing steel with titanium in jet engine applications are extremely costly. In the manufacture of steel parts the material cost generally represents a small portion of the end product cost. Consequently, the manufacturing method employed in producing such parts are governed primarily by the economics of the operation. Thus material utilization figures become secondary and in most instances run quite low. For exotic materials such as titanium however, this cannot be the case. A low material utilization factor for such materials can, and often does, result in a machining scrap cost which far exceeds the manufacturing costs.

Conventional forging of jet engine rings in titanium has a low material utilization factor and consequently is expensive. The same rings manufactured by extruding length close to the detail cross-section and forming and welding for the end product utilizes considerably less material. In addition, if cast ingots could be utilized instead of forged billets as the extrusion stock, the cost of the end product would be lowered considerably. This contract deals with the development of such manufacturing techniques toward an economical production process.

Prior to manufacturing actual parts, however, certain basic studies were performed. These studies consisted of the following:

A. Material

At present the military specification controlling the quality of AMS 4921 (Ti-A70) permits a maximum of 0.20% oxygen content. The titanium producers will not guarantee the properties of AMS 4921 and maintain an oxygen content below 0.20%. Tests were performed to determine the effects of oxygen contents in excess of 0.20% in extruded sections.

B. Extrusion

1. The extrusion of sections directly from cast ingots is a new concept. Consequently, the effect of extrusion temperature and ratios on the mechanical properties of A70 and A110AT titanium were studied.
2. Difficulties encountered in initial extrusion of the A110AT titanium alloy required a study of the effects of the extrusion processing variables on the surface quality of extruded sections.

C. Flash Butt Welding

The limited data available on the flash butt welding of titanium necessitated a study of machine settings for maximum joint efficiency and maximum to minimum rib ratios when welding complex cross-sections.

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II OBJECT

The objective of this report is to present the results of experimentation dealing with:

1. The development of mechanical properties in extrusion of A70 and A110AT titanium cast ingots.

2. The evaluation of the effect of extrusion processing variables on the surface finish of titanium extrusions.

3. The flash butt welding of titanium.

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III SUMMARY

A. Material

1. The A70 and A110AT titanium cast ingots used for this study were procured from Cramet, Incorporated. These ingots were melted utilizing an induction "stirring coil" which resulted in a homogeneous fine grained structure.

2. Notch-tensile tests were performed on extrusions from Ti-A70 cast ingots with oxygen contents of approximately 0.20% and 0.25%. The total interstitial content was approximately 0.35% oxygen equivalent. These results are summarized as follows:

   a. The transition temperature as indicated by this type of test is below -65°F for both materials.

   b. The notch-tensile properties were not effected by the range of oxygen content examined. (Total interstitial content was approximately the same)

3. Notch-tensile tests were also performed on extrusions from Ti-A70 forged billets with an oxygen content of approximately 0.25%, (Oe - 0.35%). The results obtained were identical with those described for the cast ingot extrusion.

4. Notch-tensile tests on A110AT extrusions from both cast ingots and forged billets indicated a transition temperature well below -65°F.

B. Extrusions from Cast Ingots

1. Mechanical Properties and Microstructure

   a. Ti-A70

      (1) Extrusions were made from cast ingots at extrusion temperatures of 1500, 1600, and 1700°F and extrusion ratios ranging from 10:1 to 100:1. The minimum specification requirements of AMS 4921 of 70,000 psi yield strength and 15% elongation were readily obtained for all extrusion conditions except the 1700°F extrusion at a ratio of 100:1.

      (2) The result of the above extrusion conditions on the microstructure of the extrusion was quite pronounced. Extruding in the alpha and low alpha-beta region resulted in a fine grained equiaxed structure. Extruding high in the alpha-beta region resulted in a coarser grained Widmenstatten structure.

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III SUMMARY (Continued)

(3) The endurance limit for titanium extruded from cast ingot was established to be 40,000 psi and 24,000 psi for smooth and notched specimens respectively.

b. Ti-A110AT

(1) Due to surface tearing of the extrusions the evaluation of this material was not as thorough as for the A70. The data that was obtained, however, clearly indicate extrusion temperatures below 1900°F for ratios of less than 50:1 to yield desirable properties.

(2) At an extrusion ratio of 10:1, the range of extrusion temperatures from 1650 to 1850°F resulted in a similar Widmenstatten structure. Increasing the ratio to 25:1 appreciably reduced the grain size.

(3) The endurance limit for this material was established to be 65,000 psi for smooth specimens.

c. Extrusion Pressures

In general, lower temperatures and higher ratios resulted in increased pressure. For the range of temperatures and ratios examined pressure readings from 50,000 psi to 130,000 psi were recorded.

2. Effect of Extrusion Variables on Surface Finish

a. Die Preheat Temperatures

Maximum die temperatures of 750°F resulted in optimum surface finish, minimum pressures and minimum die pick-up for both A70 and A110AT material.

b. Extrusion Speed

The extrusion speed had little effect on die pick-up. However, minimum speeds of 450 in/min resulted in optimum surface finish and required minimum pressures.

c. Die Material

Most of the die materials tested with the A70 material stood up well. Minimum die pick-up and minimum die wear were obtained from the Haynes Stellite and Vasco Supreme dies. In extruding the A110AT material, most of the dies broke down. The Haynes Stellite, Rexalloy, and Vasco Supreme dies did permit extrusions of approximately 20 foot lengths with good surface finish.

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III SUMMARY (Continued)

d. Lubricants

Of the lubricants tested, the Fiske #630 resulted in the best surface finish for both materials. Heating the billet in an inert gas chamber proved slightly better than heating directly in salt. Lubrication of the die and chamber was all that was found to be required.

e. Die Design

Conventional die angles of approximately 110 to 130 degrees resulted in an optimum surface finish and minimum pressures for the A70 material. The best combination of surface finish, pressure, and die pick-up resulted from a 180 degree die for the A110AT material.

C Flash Butt Welding

1. Minimum Joint Efficiency

The weld settings required to provide mechanical properties in the weld zone comparable with the base metal were established.

2. Maximum to Minimum Rib Ratio

Mechanical tests on welded sections with varying rib thicknesses indicate that rib ratios of 5.3:1 can be successfully welded in A110AT and A70 material.

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IV CONCLUSIONS:

The data assembled in this report permit the following conclusions:

1. The mechanical properties of titanium extrusions from cast ingots of AMS 4921 with an oxygen content of 0.25% and a total interstitial content of approximately 0.40% oxygen equivalent are acceptable for engine operation.

2. Optimum mechanical properties and microstructure developed in extrusions from A70 cast ingots by extruding in the temperature range of 1500 to 1600°F.

3. Optimum mechanical properties and microstructure developed in extrusions from A110AT cast ingots by extruding at a temperature of approximately 1850°F and below.

4. Minimum pressures result from extruding both A70 and A110AT material at the high side of the temperature range noted immediately above.

5. The following extrusion processing conditions result in optimum surface finish:

	A70	A110AT
Die preheat temperature	750 °F	
Extrusion speed	450 in/min.	
Die Material	Haynes Stellite or Vasco Supreme	
Lubricant	Fiske # 630	
Method of heating	Inert Gas	
Die angle	110 to 130 degrees	180 degrees

6. Complex cross sections of A70 and A110AT materials can be flash butt welded with excellent mechanical properties in the welds.

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V RECOMMENDATIONS:

1. Consider the relaxation of the military specifications for A70 titanium to permit an oxygen content of 0.25% with a specified total interstitial content of approximately 0.40% oxygen equivalent.

2. Utilize cast ingots exclusively as the extrusion stock for extruded sections of A70 and A110AT material.

3. The results obtained clearly indicate the need for additional work along the following lines:

    a) Extrusion of alpha-beta and beta alloys from cast ingots.

    b) Development of a long life extrusion die.

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VI DISCUSSION

A. Material

The titanium material used on the program consisted of both the unalloyed AMS 4921 (Ti-A70) grade and the 5% Al-2% Sn titanium alloy (Ti-A110AT). Procurement of the material for subsequent extrusions presented two unique problems. First, the titanium producers were reluctant to supply cast ingots. Cast ingots were desired as extrusion material to determine the feasibility of extruding directly from a cast ingot, thus eliminating the cost of and the material lost in the forging break-down operation. Secondly, the titanium producers would not guarantee a maximum oxygen content of 0.20% required by military specifications for the strength level of AMS 4921 (Ti-A70 material).

The reluctance on the part of the titanium producers to supply cast ingots was primarily due to their inability to guarantee a sound ingot to specified mechanical properties. To expedite the procurement of this ingot material the requirements for certified physical properties were waived in lieu of a certified chemical analysis. This modification permitted the procurement of both A-70 and A110AT material from Cramet, Incorporated, a newly established facility for sponge titanium and cast ingots of limited size.

The melting technique employed by Cramet utilized a low power induction "stirring" coil. The grain structure of the resulting ingot is presented in Figure 1. As indicated by this photograph the grains are essentially equiaxed, being both smaller and more uniform than would be expected from conventionally melted cast ingots.

1. Oxygen Content of A70 Material

Titanium producers will not guarantee a minimum yield strength of 70,000 psi (AMS 4921) with a corresponding maximum oxygen content of 0.20%. Unalloyed titanium derives its strength primarily from interstitial alloying of nitrogen, oxygen and carbon. These interstitials strengthen the titanium at room temperature and slightly above, decrease the ductility, and raise the ductile-to-brittle transition temperature. The combined effect of these elements can be expressed in terms of equivalent oxygen content as given by the following equation:

$$\text{Oxygen Equivalent } (O_e) = \%\,O + 2\%\,N + 2/3\%\,C$$

At present the interstitial content of AMS 4921 (Ti-A70) material is limited to the following:

$$O = 0.20\%,\ N = 0.07\%,\ C - 0.20\%$$

This is equivalent to an oxygen content of 0.47%.

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VI DISCUSSION (Continued)

While previous data (1)* on notch tensile** tests confirm this approximate value 0.5% O_e as the maximum required to maintain the transition temperature below -65°F, the specified amounts of the individual elements is not as well defined. Specifically, the following evidence to indicate that a higher oxygen value at least as high as 0.20% is tolerable if the nitrogen and carbon contents are proportionally lowered.

On the present program, extrusions were made from cast ingots with oxygen values of 0.15 and 0.25% and forged billets of 0.25%. The mechanical properties of 0.25% oxygen material are capable of meeting the requirements of AMS 4921.

To determine the suitability of this material for engine operation, i.e. the effect of the higher (0.25%) oxygen content of the ductile-to-brittle transition temperatures, additional tests were performed. The interstial content of the material and notch-tensile data are presented in Table I and Figures 2 through 4. The curves in Figures 2 and 3 are for extrusions from cast ingot while the data in Figure 4 is for an extrusion from a forged billet. For the three materials the oxygen equivalent was approximately equal to 0.35%. As illustrated, the curves for the three materials are identical and indicate transition temperatures well below -65°F. Specifically, the forged and cast material with comparable oxygen content have identical notch-tensile properties, see Figures 3 and 4. Furthermore, the extruded cast material with equivalent total interstitial content (O_e) but, different oxygen and nitrogen values also have identical notch-tensile properties, see Figures 2 and 3. In general, this data follows closely the data previously reported (1), (2) for forged titanium, Figures 5 and 6.

2. A110AT

Extrusions from both cast and forged billets of A110AT titanium were also tested. This data is presented in Table II and Figures 7 and 8. These curves agree closely with previously published data (3) and cleraly indicate the transition temperature to be

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* Numbers in paranthesis refer to references.

** The test specimen for the notched tests had a 60 degree "V" notch, a root radius of 0.002 inch maximum, and a 50% notch depth. The notch diameter was 0.212 inch. Both smooth and notch specimens were loaded through concentric fixtures to assure axial loading.

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VI DISCUSSION (Continued)

well below -65°F. The slightly inferior properties exhibited by the cast material can be attributed to the 1900°F extrusion temperature which is slightly above that which was later established to yield optimum properties.

B. Extrusion of Cast Ingots

1. Mechanical Properties and Microstructure

Cast ingots of both A-70 and A110AT titanium were extruded at various extrusion temperatures and extrusion ratios to develop the optimum mechanical properties. The chemistry of the cast ingots is presented in Table III and IV.

a. Ti-A70

This material was extruded at billet preheat temperatures of 1500, 1600, and 1700°F and extrusion ratios ranging from 10:1 to 100:1. The tensile data obtained from specimens machined from these extrusions is compiled in Table V and presented graphically in Figure 9 and 10. The tensile properties for the 70:1 extrusion ratio are not plotted in Figures 9 and 10. This lot of material had a strength level considerably below the rest of the material due to the lower interstial level (O_e = .226 vs. O_e = .36) see Table III.

Within the range of temperatures and ratios examined little variation in the tensile properties was noted. The minimum specification requirements of AMS 4921 were exceeded in all instances except for the 1700°F extrusion with a ratio of 100:1. Abnormally high strength values coupled with low ductility were obtained under these conditions. Specifically, the rear section of the extrusion was exceptionally poor.

The effect of extrusion temperature and reduction on the macrostructure and microstructure was also determined. These photomacrographs and photomicrographs are presented in Figures 11 through 15. Each of these figures depicts the effect of extrusion temperature on the macrostructure and microstructure of titanium extrusion from a cast ingot for a given extrusion ratio. As would be expected larger grains resulted from the higher extrusion temperatures. While the coarser grain structure is not objectionable as such, it it indicative of working high in the alpha-beta region or in the beta region and consequently can result in a material of lower ductility. This is illustrated by the tensile properties for the extrusion at 1700°F and at a ratio of 100:1, see Figure 9.

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VI DISCUSSION (Continued)

In general, extruding in the alpha and low alpha-beta regions results in a fine grained equiaxed alpha structure. Extruding high in the alpha-beta region (1700°F) or in the beta region results in a coarser grained Widmenstatten structure. The super imposed effect of extrusion ratio tends to increase the grain size with increased ratio.

Both the tensile data and the microstructure clearly establish the extrusion temperature range of 1500 to 1600°F to be optimum for extrusion ratios between 10:1 and 100:1. This confirms the results obtained by previous investigators (4).

The endurance limit of titanium extruded from cast ingots was also determined. This data, presented graphically in Figure 16, indicates an endurance limit of 48,000 psi and a notch endurance limit of 24,000 psi. Shown also in this figure are curves representing the endurance limit of forged material as published by the producer (5). As indicated the material extruded from a cast ingot has an endurance limit within experimental accuracy of forged barstock.

b. Ti-A110AT

The determination of mechanical properties of extrusions from A110AT cast ingots was exceedingly difficult due to the difficulty encountered in extruding this material. Conventional extrusion techniques applied to this material resulted in severe rupturing of the extruded surface. Subsequent studies were performed to develop a satisfactory extrusion technique. This is discussed in detail in the following section of this report.

The tensile data from the available extrusions is compiled in Table V. Extrusion temperatures in the range of 1650 and 1950°F and extrusion ratios ranging from 10:1 to 100:1 were examined. Due to occasional rupturing of the extrusions it was not possible to obtain tensile data for each reduction and temperature. The data that was obtained however, indicates extrusion temperature below 1900°F for reductions less than 50:1 to yield desirable properties.

In general, extrusion temperatures above 1900°F (approximate beta transus temperature 1930°F) result in an extrusion with varying properties from front to back. Extruding at temperatures below 1800 results in excessive extrusion pressures with reduction ratios in excess of 10:1. Consequently, an approximate extrusion temperature of 1850°F was selected. Tensile tests on extrusions made at this temperature and for reduction of 10:1, 25:1, and 48:1 are all well above the minimum specification requirements.

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VI DISCUSSION (Continued)

The macro and microstructures for some of these extrusions are presented in Figures 17 and 18. For the 10:1 extrusion ratio and extrusion heat temperatures between 1650 and 1850°F the microstructure remains essentially constant, Figure 17. At a reduction ratio of 25:1, Figure 18, the grain size is appreciably reduced. Both structures result from extruding in the alpha-beta region. The finer grain size results from the additional work imparted by the high reduction ratio.

The endurance limit was also established for A110AT material extruded from cast ingots. This data is presented graphically in Figure 19. The indicated endurance limit of 65,000 psi coincides quite closely with published data supplied by the producer (5).

c. Extrusion Pressures

Coincident with the determination of the effects of extrusion temperatures and ratios on the mechanical properties of extrusions from cast ingots the pressures encountered were also recorded. These results are compiled in Tables VII and VIII and presented graphically in Figure 20 for both the A70 and A110AT material. As would be expected higher extrusion ratios and lower extrusion temperatures result in higher pressures. This is shown graphically in Figure 20 for the A70 material. A similar plot for the A110AT material was not possible due to the erratic readings resulting from the severe surface tearing, see Table VIII.

2. Effect of Extrusion Variables on Surface Finsih

The application of established extrusion techniques to A70 titanium has resulted in extrusions of acceptable surface quality. The application of these same extrusion techniques to the A110AT alloy grade was completely unsuccessful. In addition to poor surface finish it was not uncommon to completely "wash-out" a die on extruding a length of approximately 10 feet. Initial attempts at improving the surface of A110AT extrusions by increasing the die preheat temperature and decreasing the extrusion speed resulted in a considerably improved surface. Based on these encouraging results a program was initiated to evaluate the effect of each of the major extrusion variables on the surface finish of extrusions. The variables examined were:

Die preheat temperature
Extrusion speed
Die material
Lubricant
Die design

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These variables were investigated for both the A70 and A110AT materials.

In order to evaluate these variables most expeditiously the tests were run as follows. First, the die preheat temperature was varied with all the other variables held fixed. The optimum die preheat temperature thus established was then applied as a fixed variable in the following tests. In a similar manner when the optimum extrusion speed, die material, etc. was determined these were also held fixed in subsequent tests. Consequently, each of the variables was not evaluated independently. The results of the investigation clearly establish this approach to be completely adequate for this problem.

a. Die Preheat Temperature

With all other process variables held constant, the die preheat temperature was varied from room temperature up to approximately 750°F. This upper limit was imposed due to the consequent expansion of the die. The results of the investigation as well as the specific processing conditions are presented in Table IX.

(1) Ti-A70

Die preheat temperature of approximately 300, 400 and 750°F were tested. While no appreciable difference resulted from die preheat temperatures of 300 to 400°F die preheat temperature of 750°F resulted in an appreciable improved surface finish and a minimum of die pick-up.

(2) Ti-A110AT

Die preheat temperatures of approximately 150, 400 and 750°F were tested. The 150°F die resulted in an extrusion that was severly ruptured and torn. Correspondingly heavy die pick-up and high extrusion pressures were noted. While the 400°F extrusion required considerably less pressure, heavy die pick-up and surface rupturing continued. As noted in Table IX the 750°F die extrusion required a minimum of pressure and only slight die pick-up. Most important, however, was the improved surface finish.

b. Extrusion Speed

Extrusion speeds of approximately 450 and 10,000 in/min. were tested. As previously noted, the optimum die preheat temperature (750°F) was applied to the series of tests. The speeds

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noted represent that of the extruded section. The accumulated results are compiled in Table X.

(1) Ti-A70

The variations in speed had little effect on the die pick-up or surface finish. The lower speed, however, did require considerable less pressure. It is interesting to note that pressure required for the 450 in/min extrusion is considerably less than that reported in the previous section for similar processing conditions, see Table IX. This difference can only be attributed to the slightly higher speed (2,000 in/min) in the first series of tests. If this effect is as pronounced as indicated, a very limited range of speed must be utilized to take advantage of the lower pressures.

(2) Ti-A110AT

As indicated for the A70 material, lower extrusion pressures result from low extrusion speeds, Table X. While the low speed essentially reproduced the results of the previous section, the fast extrusion resulted in a "washed-out" die and ruptured surface. This slow speed (400 in/min) represents the minimum obtainable with the 12,000 ton press.

c. Die Material

The die material for the previously discussed extrusions was a 5% Cr hot-worked steel, heat treated to a hardness of Rc52. The various die materials evaluated in this section are presented in Table XI. The number of die materials evaluated was necessarily limited due to the excessive procurement cycle for other die materials.

(1) Ti-A70

The results obtained from extruding through several different dies are presented in Table XII. All of the dies tested proved acceptable except a die made of A110AT titanium. Slightly better surface finish and minimum die wear resulted from the Haynes Stellite and the Vasco Supreme die. Photographs of several of these dies after extrusion are presented in Figure 21.

(2) Ti-A110AT

The results obtained from extruding through several different dies are presented in Table XIII. The Haynes Stellite held up well for the first 20 feet of the extrusion. This

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die then broke-down resulting in surface tearing over the remaining length. The Wallex "D" Moly Faced, and A110AT dies all broke down from the beginning of the extrusion. The Rexalloy die proved satisfactory for a 24 foot extruded length. All but one section of the Vasco Supreme die held up well for a 33 foot extrusion. This broken section of the die, however, faced the surface of the extrusion. Photographs of several of these dies are presented in Figure 22.

d. Lubricants

Previous results have indicated that lubricants applied to the material are not as effective as lubricating the die and container (6). In addition to the standard lubricants, chemical and metallic coatings were applied to the billet. In all cases severe rupturing occured. Initial extrusions with Fisk #630, a calcium base soap with graphite, vermiculite and calcium carbonate, applied to the die, proved encouraging. The lubricant previously applied was a combination of oil dag, nacroline, and Lithium-carbonate. In the test to be described all billets were heated in an inert (argon) chamber submerged in a salt bath unless otherwise noted. The extrusion conditions and resulting surface condition are presented in Table XIV. Due to the procurement time on new dies and the success obtained with the 5% Cr die, this die was used on all the following studies.

(1) Ti-A70

Fiske #604, Fiske #630 and no lubricant were evaluated. While lower pressures resulted from the dry die, the Fiske #630 resulted in a much improved surface.

(2) Ti-A110AT

Fiske #630 was applied to the die and container with one ingot heated in argon and a second heated directly in the salt. As pictured in Figure 23 the inert gas heated billet had an excellent surface finish for the first two thirds of the extrusion. (Extrusion length approximately twenty feet). The ingot heated directly in the salt bath had an acceptable surface finish throughout the twenty foot length, see Figure 23. The balance of the lubricants were equivalent to extruding without a lubricant, see Figure 23 and Table XIV.

e. Die Design

The final study determined the effect of die angle. Previous results (4) indicate an optimum die angle of approximately 140 degrees for Ti-A70. In this study the range of die angles investigated was 90 to 180 degrees for both A70 and A110AT materials. The extrusion conditions and results are presented in Table XV.

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(1) Ti-A70

Die angles in the range of 110 to 140 degrees resulted in minimum pressure, Figure 24. Based on surface finish and die pick-up, however, the range of angles between 110 and 130 degrees proved optimum, see Table XV.

(2) Ti-A110AT

Minimum pressures resulted from die angles of 100, 110 and 180 degrees, Table XV. Slight die pick-up and optimum surface finish, however, resulted from the 180 degree die. The unusual results were confirmed on subsequent extrusions. This is discussed in Part II of this Final Report.

C Flash Butt Welding

At the initiation of this development program only limited data existed pertaining to the limitations and machine settings required for maximum properties in flash butt welded titanium sections. To permit the welding of ring sections, a study was performed to determine the machine settings required for maximum mechanical properties and the limiting rib ratios which can be welded. These studies were performed at Thomson Electric Welder Company, Lynn, Massachusetts.

1. Maximum Joint Efficiency

a. Ti-A110AT

The initial studies on maximum joint efficiency were performed on 3/4 inch diameter A110AT titanium bar. Prior to welding the ends of the bars were beveled 5 to 10 degrees for approximately 3/32 inch from the end to be welded. The first variable investigated was the upsetting force which was varied from 12,000 to 18,000 pounds. The specific machine settings are listed in column two of Table XVI.

The results of tensile testing of these bars is presented in Table XVII, (Part I). All of the upsetting forces examined resulted in welds with tensile properties comparable to the base metal. The vendors certified properties are also shown in this table. In general, the test specimens fractured in the base metal, see Figure 25. This condition obviously indicates the weld area to be of higher strength than the base metal. A ductile fracture in the weld zone also occurred,

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VI DISCUSSION (Continued)

Figure 25. The presence of this type of fracture indicates that the upsetting pressures did not appreciably increase the hardness of the weld area.

Within the present program the maximum cross section area encountered in the ring sections is 1.22 square inches. With the machine capacity limited to 32,000 pounds upset force, the maximum pressure on this part would be 26,000 psi. This is equivalent to an upset force of approximately 12,000 pounds applied to the 3/4 inch diameter bars. This value therefore represents a limiting condition.

Twenty-five additional bars were welded at the machine settings listed in Table XVI, column three. The resulting mechanical properties are presented in Table XVII (Part I) for three of these bars. One of these bars was sectioned through the weld for metallographic inspection and a microhardness survey. Prior to sectioning, this bar was stress relieved at 1200°F for 24 hours. The resulting microstructure is presented in Figure 26.

The results of the Tukon Hardness survey follows:

	DPH	Rc (converted)
Parent Metal	325	33
Parent Metal	309	31
Parent Metal	325	33
Parent Metal	334	34
Heat Affected Zone	325	33
Weld	340	35
Heat Affected Zone	317	32
Parent Metal	352	36
Parent Metal	352	36
Parent Metal	352	36
Parent Metal	317	32

As indicated the scatter observed in this hardness study precluded the confirmation of the increase in hardness of the weld zone indicated by the photomicrograph, see Figure 26.

b. Ti-A70

Following the above study, weld studies were made on A70 material. Twenty-one bars were welded, varying the preheat, postheat, forging delay, flow valve setting, and tap setting. Preheat, postheat, and forging delay did not improve the quality of the weld, therefore, their use was discontinued. Twenty-eight bars were then welded at the machine settings listed in Table XVI, column four. The results of tensile testing these bars is presented in Table XVII (Part II).

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VI DISCUSSION (Continued)

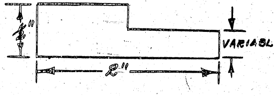
Also presented in this table are the vendor's certified properties for the material. It is noted that materials of two strength levels were used. Consequently, the low tensile values exhibited in the weld specimens are not indicative of low weld quality but merely reflect the strength level of the base material. In all the welds examined, the tensile properties were equivalent to the base metal. The specimens tested were either stress relieved at 1300°F for 1 hour or heated to 1200°F for 24 hours. No appreciable difference in properties was exhibited by the different stress-relief cycle.

Table XVII (Part II), alsp presents the results of notch rupture testing. As indicated a stress of 90,000 psi had been applied for over 15 hours without failure. These specimens were either stress relieved by heating to 1300°F for 1 hour or 1200°F for 24 hours.

Microhardness studies were performed on both the low and high strength level materials. As was the case for the A110AT material, the scatter in the hardness test did not permit a confirmation of increased hardness in the weld area indicated by the microstructure, Figure 27.

2. Maximum to Minimum Rib Ratios

Barstock of A70 material machined to the following configurations was used for this study:



Initial work consisted of a determination of a satisfactory heat balance, Figure 28. These specimens used have a 3/16" minimum rib thickness. This constitutes a 2.6 rib ratio.

All the edges of the thicker section were beveled 5 to 10 degrees for approximately 3/32" from the end to be welded. The thinner section was tapered in such a manner that the edge of the bar was 1/4" from the butted ends of the thicker section. The machine settings for this study are shown in Table XVI. Flat tensile specimens were cut from the thicker and thinner sections with the weld zone in the middle of the test length. Test results (2.6:1 ratio) are tabulated in Table XVIII. These results clearly

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VI DISCUSSION (Continued)

illustrate the resulting satisfactory mechanical properties. Figure 29 shows typical tensile fractures for these specimens.

Three welds with 3/32" minimum rib were welded at the settings listed in Table XVI. This minimum rib represents a 5.3:1 rib ratio. These tensile results are also listed in Table XVIII. The predetermined final die opening on bars #11 and #13 may account for the low reduction in area of bar #12.

While all the above data were obtained for A70 material exclusively, there is little doubt that the results apply for the A110AT material also, the only difference being the slightly higher upsetting forces required by the A110AT material due to its higher flow stress.

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VII REFERENCES

1. Klier, E.P., Feola, N.J. and Sachs, G., WADC Technical Report 55-325, "The Effect of Interstitial Contaminants on the Notch-Tensile Properties of Titanium and Titanium Alloys, Part I - Sponge Titanium", date July, 1955,

2. WAD Serial Report No. MP.00-74, "Titanium Manufacturing Methods Development - Part I " Quarterly Progress Report No. 6, Contract No. AF33(600)30262, submitted to AMC and WADC, November 25, 1956.

3. Klier, E.P. and Feola, N.J., WADC Technical Report No. 55-325, "The Effect of Interstitial Contaminants on the Notch-Tensile Properties of Titanium and Titanium Alloys - Part II - Alloy Titanium", dated October, 1955.

4. Sambrott, A.M. et. al., WADC Technical Report 54-555, "The Extrusion of Titanium", dated March 1955.

5. Rem Cru Data Sheet.

6. WAD Serial Report No. MP. 00-46, "Titanium Manufacturing Methods Development - Part I" Quarterly Progress Report No. 5 Contract No. AF33(600)30262, submitted to AMC AND WADC, August 25, 1956.

7. "Titanium Method Development Program, Final Report - Part B Materials and Basic Studies", submitted by Metal Processing Division to Wright Aeronautical Division, January, 1957.

8. Klier, E.P., and Cazzara, C., "The Tensile and Notch-Tensile Properties of Selected Titanium", Syracuse University Research Institute, submitted to Wright Aeronautical Division, January, 1957.

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TABLE I

NOTCH TENSILE PROPERTIES OF A70 TITANIUM EXTRUDED FROM CAST INGOTS & FORGED BILLETS

Material	Cross Head Movement (In/Min)	Test Temp (°F)	Tensile Strength (1000 psi)	Notch Strength (1000 psi)		Notch Strength Ratio (average)	Reduction In Area (Percent)		
							Notch		Smooth
A		75	104.8	145.0	144.0	1.38	3.94	4.80	41.5
	2.0	-65	122.0	137.0	139.6	1.14	3.38	2.82	38.2
O - 0.175%		-100	126.8	136.4	138.9	1.09	2.53	1.70	38.0
N - 0.050%		-320	177.6	165.0	159.5	0.92	1.98	1.41	30.0
		75	102.1	147.9	144.0	1.43	3.96	5.09	42.8
c - 0.043%	0.02	-65	114.2	146.2	145.0	1.28	2.28	3.10	34.8
		-100	125.0	152.0	144.2	1.19	1.98	2.54	35.4
(Cast)		-320	169.0	176.7	191.0	1.09	1.71	1.99	25.7
B		75	110.5	142.5	152.2	1.34	3.96	4.52	35.0
		-65	125.0	145.0	148.0	1.17	3.32	3.08	41.4
O - 0.24%	2.0	-100	130.5	164.0	152.0	1.21	2.83	3.12	36.6
N - 0.52%		-320	148.0	148.0	148.0	1.00	1.21	2.61	32.9
c - 0.37%		75	108.0	152.6	154.0	1.42	5.10	4.50	40.0
	0.02	-65	125.5	146.5	157.0	1.21	3.32	2.53	30.9
(Cast)		-100	131.0	164.5	159.0	1.23	3.10	1.71	38.0
		-320	182.0	184.5	173.3	0.99	2.33	1.70	23.8
C		75	105.8	137.7	135.0	1.29	5.68	5.92	45.5
		-65	120.2	145.5	141.5	1.19	3.94	3.40	42.0
O - 0.25%	2.0	-100	126.0	148.3	147.5	1.17	3.12	3.62	42.7
		-320	177.0	184.0	175.5	1.02	2.01	2.28	33.1
N - 0.028 %	0.02	75	102.9	144.8	144.3	1.40	6.20	5.43	47.5
		-65	121.3	159.0	155.0	1.29	3.15	3.97	44.6
c - 0.04%		-100	128.0	164.5	161.0	1.27	3.13	3.11	43.9
(Forged)		-320	177.0	203.0	196.0	1.13	3.12	1.97	36.3

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TABLE II

NOTCH TENSILE PROPERTIES OF A-110 AT TITANIUM EXTRUDED FROM CAST INGOTS AND FORGED BILLETS

Material	Cross-Head Movement (In/Min)	Test Temp (°F)	Tensile Strength (1000 psi)	Notch Strength (1000 psi)		Notch Strength Ratio (Average)	Reduction in Area (Percent) Notch		Smooth
D	2.0	75	133.5	197.0	193.0	1.46	7.13	6.75	26.1
		-65	153.2	209.0	211.0	1.46	6.20	5.41	23.7
O - 0.097%		-100	152.1	215.0	214.0	1.41	5.60	5.06	23.0
N - 0.017%		-320	189.0	233.0	230.0	1.23	2.85	3.06	22.3
C - 0.014%									
Al - 5.0%	0.02	75	124.5	192.5	195.0	1.56	5.10	5.37	24.6
Sn -3.2%		-65	144.1	210.0	214.0	1.38	4.52	4.55	21.7
		-100	152.1	222.0	221.0	1.46	4.80	5.09	20.4
(Cast)		-320	196.0	260.0	248.0	1.30	2.67	3.09	16.1
E									
O - 0.130%	2.0	75	135.2	193.5	190.0	1.42	5.11	5.77	35.7
		-65	152.5	211.0	201.0	1.35	3.13	4.52	28.4
N - 0.03%		-100	157.5	207.0	206.0	1.31	3.67	3.63	27.7
C - 0.10%		-320	201.0	214.0	204.0	1.04	2.27	2.55	22.9
Al - 5.0%	0.02	75	131.0	191.5	189.0	1.45	5.10	3.12	33.4
		-65	151.5	207.0	203.0	1.35	3.65	3.97	23.4
Sn - 2.5%		-100	157.5	218.0	214.0	1.37	2.85	2.55	24.4
		-320	208.0	226.0	228.0	1.09	2.00	1.98	19.4
(Forged)									

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TABLE III

CHEMICAL ANALYSIS OF CAST A70 TITANIUM INGOTS

Mill Heat Nos. & Corresponding Heat Code Nos. Assigned	O_2	H_2	N_2	C	Fe	Mn	Oe*
Spec.	.20 Max.	.0125 Max.	.07 Max.	.20 Max.	To Be Reported		
2-114S - Vendor	.240	.0030	.048	.036	.31	.08	.354
A141-1 Nat'l Res.	.24	.0019	.046				
A141-2 " "	.14*	.0053	.050				
A141-2 " "	.26	.0017	.046				
A141-3 " "	.23	.0020	.041				
	* This may be a misidentification of sample						
2-112S - Vendor	.243	.0030	.060	.055	.33	.08	.388
A140-1 Nat'l Res.	.25	.0015	.048				
A140-2 " "	.27	.0029	.048				
A140-3 " "	.26	.0030	.046				
A140-4 " "	.23	.0024	.047				
2-110S - Vendor	.243	.0024	.052	.037	.29	.07	.363
A139-1 Nat'l Res.	.28	.0017	.026				
2-59S - Vendor	.140	.0041	.026	.039	.37	.06	.226
A137-B Nat'l Res.	.14	.0017	.033				
2-1068S - Vendor	.263	.0027	.049	.039	.32	.07	.384
A136-B Natl'l Res.	.26	.0019	.052				

*Oe - Oxygen Equivalent - %O + 2% N + 2/3% C

Ingot Size - 7 1/2 in. dia. - length 36 in.

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TABLE IV

CHEMICAL ANALYSIS OF CAST A110AT TITANIUM BILLETS

Mill Heat Nos & Corresponding Heat Code Nos. Assigned	O_2	N_2	N_2	Al	Sn	C	Fe	Mn
Spec.	.20 Max.	.0175 Max.	.07 Max.	4.0 to 6.0	1.5 to 3.5	.15 Max.	.25 Max.	To Be Reported
2-134S - Vendor	.106	.0046	.024	5.1	2.9	.040	.10	.06
A145-1 Nat'l Res.	.091	.0050	.022					
A145-2 + MPD	.110	.0054	.018					
2-131S - Vendor	.112	.0059	.018	5.1	2.7	.041	.11	.08
A146-1 Nat'l Res. + MPD	.13	.0082	.025					
2-135S - Vendor	.099	.0048	.022	4.6	2.7	.038	.10	.05
A147-I Nat'l Res. + MPD	.10	.0055	.047					
A147-2 "	.26*	.0020	.047					
2-132S - Vendor	.095	.0047	.017	4.9	3.0	.042	.11	.05
A148-B Nat'l Res. + MPD	.10	.0038	.021	4.95	3.10	.04	.10	.07
A148-F "				4.85	3.05			
A129S - Vendor	.110	.0065	.018	5.2	2.8	.039	.11	.10
A150-B Nat'l Res. + MPD	.11	.0053	.020	5.1	2.9	.04	.10	.12
A150-F "				4.95	2.85			
2-130S - Vendor	.118	.0048	.019	5.2	2.9	.036	.10	.08
A151-B Nat'l Res. +MPD	.11	.0049	.021	5.0	3.0	.04	.10	.09
A151-F "				5.1	2.95			

* This may be a misidentification of sample

Ingot Size - 7 1/2 in. Dia. - Length 36 in.

Vendor: Cramet, Inc., Chattanooga, Tenn.

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TABLE V

THE TENSILE PROPERTIES OF A70 TITANIUM EXTRUDED FROM CAST INGOTS AT VARIOUS EXTRUSION TEMPERATURES & EXTRUSION RATIOS

Billet No.	Extrusion Ratio	Tensile Strength (PSI)	.2% Yield Strength (PSI)	Elongation (Percent)	Reduction In Area (Percent)	Charpy "V" Notched Impact - ft-lbs 75°F	-40°F	Billet Preheat Temperature (°F)
A139-1	10:1	114,400R	84,300	21.4	35.8	16.5	11.0	1500
		103,800R	80,400	22.8	36.9	16.0	13.5	
		103,200F	83,400	22.1	35.8	16.0	13.0	
		103,500F	81,000	23.5	38.3	14.0	15.0	
	Avg.	106,225	82,275	22.4	36.7	15.6	13.1	
A140-1	10:1	99,930R	74,700	22.8	35.4	14.5	14.5	1600
		99,000R	75,000	22.8	31.7	15.5	12.0	
		102,000F	76,800	22.8	33.5	14.5	14.0	
		102,000F	77,100	22.8	34.9	14.0	-	
	Avg.	100,730	75,900	22.8	33.8	14.6	13.1	
A141-1	10:1	99,330R	72,000	21.4	34.0	14.0	12.5	1700
		99,000R	72,300	24.2	38.0	14.0	12.0	
		102,000F	75,300	22.8	31.7	14.0	14.0	
		102,000F	76,200	23.5	38.5	14.5	13.5	
	Avg.	100,575	73,950	22.9	35.5	14.1	13.0	
A141-4	25:1	100,100R	78,390	22.8	34.0	15.0	14.0	1500
		99,490R	74,170	21.4	32.6	17.0	14.0	
		96,480F	74,170	22.1	38.0	19.5	15.0	
		98,890F	75,970	22.8	36.7	19.0	16.0	
	Avg.	98,765	75,680	22.2	35.3	17.6	14.7	

R - Rear

F - Front

[redacted]

TABLE V (CONT'D)

THE TENSILE PROPERTIES OF A70 TITANIUM EXTRUDED FROM CAST INGOTS AT VARIOUS EXTRUSION TEMPERATURES & EXTRUSION RATIOS

Billet No.	Extrusion Ratio	Tensile Strength (PSI)	.2% Yield Strength (PSI)	Elongation (Percent)	Reduction In Area (Percent)	Charpy "V" Notched Impact - ft - lbs 75°F	140°F	Billet Preheat Temperature °F
A141-3	25:1	101,400R	58,600	21.4	33.0	18.5	13.0	1600
		100,800R	77,400	21.4	30.7	18.0	13.5	
		103,800F	81,600	22.1	37.1	16.0	11.5	
		103,500F	81,000	20.7	37.7	16.0	12.0	
	Avg.	102,375	79,650	21.4	34.4	17.1	12.5	
A141-2	25:1	89,500R	67,510	27.3	40.7			1700
		105,600R	73,800	28.6	37.1			
		109,000F	81,500	22.8	28.5			
		107,500F	79,700	22.8	30.0			
	Avg.	102,900	75,625	25.4	34.0			
A140-3	50:1	114,100R	81,600	22.1	38.9	18.5	11.0	1500
		108,400R	81,000	23.5	39.3	19.0	15.0	
		103,200F	80,000	23.5	39.7	16.5	14.0	
		102,600F	80,400	23.5	39.7	16.0	14.5	
	Avg.	107,075	80,750	23.1	39.4	17.5	13.6	
A140-2	50:1	108,780R	77,280	22.8	35.8			1600
		114,000R	87,000	22.8	32.1			
		111,600F	86,400	20.0	27.4			
		111,300F	86,100	21.4	28.8			
	Avg.	111,420	84,195	21.7	31.0			

R - Rear

F - Front

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TABLE V (CONT'D)

THE TENSILE PROPERTIES OF A70 TITANIUM EXTRUDED FROM CAST INGOTS AT VARIOUS EXTRUSION TEMPERATURES & EXTRUSION RATIOS

Billet No.	Extrusion Ratio	Tensile Strength (PSI)	.2% Yield Strength (PSI)	Elongation (Percent)	Reduction In Area (Percent)	Charpy "V" Notched Impact -ft - lbs 75°F	-40°F	Billet Preheat Temperature °F
A140-4	50:1	101,400R	79,200	21.4	38.4	18.0	13.0	1700
		103,500R	75,500	22.8	37.4	17.0	13.0	
		96,000F	75,000	22.8	40.2	19.0	17.0	
		95,400F	75,000	24.2	40.2	21.5	15.0	
	Avg.	99,075	76,175	22.8	39.0	18.8	14.5	
A137-B	70:1	81,600R	62,400	26.3	43.2	*	18.0	1500
		81,600R	61,200	26.3	42.8	*	18.5	
		82,200F	61,800	24.2	38.9	16.0	15.5	
		79,800F	60,600	24.2	38.9	16.0	15.5	
	Avg.	81,300	61,500	25.3	40.9	16.0	16.8	

* Defective Impact Specimens

Billet No.	Extrusion Ratio	Tensile Strength (PSI)	.2% Yield Strength (PSI)	Elongation (Percent)	Reduction In Area (Percent)	Charpy "V" Notched Impact -ft - lbs 75°F	-40°F	Billet Preheat Temperature °F
A137-1	70:1	88,800R	66,000	24.2	42.8	29.0	21.0	1600
		85,200R	65,520	27.1	43.2	28.5	20.0	
		85,680F	63,120	25.7	40.7	25.5	19.5	
		84,960F	62,160	25.7	41.5	25.5	18.5	
	Avg.	86,160	64,200	25.6	42.0	27.1	19.7	
A137-2	70:1	94,310R	68,980	30.0	39.8	27.0	27.0	1700
		94,320R	70,800	30.0	39.4	27.0	28.0	
		88,800F	69,600	24.2	38.5	25.5	31.5	
		89,900F	67,960	24.2	38.5	33.5	32.0	
	Avg.	91,832	69,335	27.1	39.1	28.2	29.6	

R - Rear

F - Front

[redacted]

TABLE V (CONT'D)

THE TENSILE PROPERTIES OF A70 TITANIUM EXTRUDED FROM CAST INGOTS AT VARIOUS EXTRUSTION TEMPERATURES & EXTRUSION RATIOS

Billet No.	Extrustion Ratio		Tensile Strength (PSI)	.2% Yield Strength (PSI)	Elongation (Percent)	Reduction In Area (Percent)	Charpy "V" Notched Impact - ft - lbs		Billet Preheat Temperature °F
							75°F	-40°F	
A136-B	100:1		105,120R	82,320	24.2	41.0			1500
			108,240R	82,180	25.7	43.2			
			103,920F	78,240	24.2	39.7			
			103,480F	78,960	23.5	40.2			
		Avg.	104,940	80,425	24.4	41.0			
A136-1	100:1		105,000R	87,600	23.5	43.2			1600
			106,320R	87,400	22.8	43.2			
			105,600F	84,720	22.8	39.7			
			105,360F	85,010	21.4	35.8			
		Avg.	105,570	86,182	22.6	40.5			
A136-2	100:1		123,600R	102,000	5.7	**			1700
			130,200R	102,480	7.1	**			
			119,400F	87,600	14.2	14.0			
			117,600F	86,400	18.5	26.9			
		Avg.	122,700	94,620	11.4	20.4			

** Tensile Bar Broke In Threads

R - Rear

F - Front

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TABLE VI

THE TENSILE PROPERTIES OF A110AT TITANIUM EXTRUDED FROM CAST INGOTS AT VARIOUS EXTRUSION TEMPERATURES & EXTRUSION RATIOS

Billet No.	Extrusion Ratio		Tensile Strength (PSI)	.2% Yield Strength (PSI)	Elongation (Percent)	Reduction In Area (Percent)	Charpy "V" Notched Impact - ft - lbs		Billet Preheat Temperature (°F)
							75°F	-40°F	
A146-2	10:1		132,000R	120,000	15.0	27.9			1650
			133,800R	124,200	16.3	28.4			
			134,240F	127,270	14.3	29.6			
			134,240F	126,660	15.7	30.0			
		Avg.	133,570	124,532	15.3	28.8			
A147-1	10:1		125,120R	117,280	14.2	21.7	27.0	19.5	1700
			123,000	113,400	14.2	28.8	28.5	19.0	
			126,660F	115,500	14.2	26.6	26.0	19.0	
			120,600F	118,290	14.2	32.6	29.0	23.0	
		Avg.	123,845	116,115	14.2	27.4	27.6	20.1	
A146-F	10:1		132,960F	125,420	15.0	31.3			1750
			131,700F	123,900	15.0	27.9			
			131,140R	124,200	16.3	32.6			
			132,600R	126,000	15.7	34.0			
		Avg.	132,100	124,880	15.5	31.4			
A145-1	10:1		122,700R	111,000	17.1	31.7	28.0	19.0	1850
			122,700R	111,300	15.7	30.9	28.0	20.0	
			123,600F	111,000	15.7	31.4	29.0	20.0	
			123,000F	112,800	16.4	32.6	30.0	20.0	
		Avg.	123,000	111,525	16.2	31.6	29.2	19.7	

R - Rear

F - Front

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TABLE VI (CONT'D)

THE TENSILE PROPERTIES OF A110AT TITANIUM EXTRUDED FROM CAST INGOTS AT VARIOUS EXTRUSION TEMPERATURES & EXTRUSION RATIOS

Billet No.	Extrusion Ratio	Tensile Strength (PSI)	.2% Yield Strength (PSI)	Elongation (Percent)	Reduction In Area (Percent)	Charpy "V" Notched Impact - ft - lbs 75°F	-40°F	Billet Preheat Temperature (°F)
A145-F	25:1	118,800*R	106,200*	7.1*	11.3*	29.5	26.0	1850
		118,190*R	110,950*	7.1*	8.2*	29.5	25.0	
		124,620 F	108,540	14.2	30.7	27.5	26.0	
		124,820 F	114,570	14.2	30.7	28.5	26.0	
	Avg.	121,607	110,065	10.6	20.2	28.6	25.7	

** - Defective Long Test Bars

Billet No.	Extrusion Ratio	Tensile Strength (PSI)	.2% Yield Strength (PSI)	Elongation (Percent)	Reduction In Area (Percent)	Charpy "V" Notched Impact - ft - lbs 75°F	-40°F	Billet Preheat Temperature (°F)
A216F	25:1	134,460	123,010	10.0	18.6			1900
		136,960	126,660	8.5	17.2			
		126,000	113,400	11.4	24.0			
		125,420	114,570	10.0	19.1			
		122,420	113,930	11.4	25.7			
		126,630	114,570	10.0	23.1			
	Avg.	128,931	117,996	10.2	21.3			
A216-1	25:1	113,330	121,210	10.0	17.8			1900
		113,330	121,810	8.5	18.7			
		126,730	115,410	10.0	23.2			
		124,240	112,120	10.0	21.8			
		125,000	112,800	11.4	24.2			
		125,000	113,410	10.0	22.2			
	Avg.	127,938	116,132	10.0	21.3			
A217-	25:1	139,390	129,090	10.0	18.7			1900
		130,000	118,180	10.0	20.8			
		127,430	115,850	11.4	23.7			
		125,000	112,800	11.4	28.1			
		126,060	114,540	12.8	-			
		132,000	120,600	8.5	18.1			
	Avg.	129,980	118,430	10.7	21.9			

R - Rear

F - Front

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TABLE VI (CONT'D)

THE TENSILE PROPERTIES OF A110AT TITANIUM EXTRUDED FROM CAST INGOTS AT VARIOUS EXTRUSION TEMPERATURES & EXTRUSION RATIOS

Billet No.	Extrusion Ratio	Tensile Strength (PSI)	.2% Yield Strength (PSI)	Elongation (Percent)	Reduction In Area (Percent)	Charpy "V" Notched Impact - ft - lbs 75°F	-40°F	Billet Preheat Temperature °F
A145-3	48:1	127,230R	115,290	14.2	29.0	30.0	23.5	1850
		127,230R	114,570	14.2	28.0	25.5	23.5	
		124,800F	112,200	15.7	32.6	26.0	23.0	
		126,600F	115,200	15.0	34.4	26.0	23.5	
	Avg.	126,465	114,315	14.7	31.0	26.8	23.3	
A151-B	70:1	102,600*R	93,600R	--*	--*			1950
		121,300	108,540	14.2	29.4			
		123,010	110,950	12.8	25.1			
		130,850	120,000	11.4	21.2			
	Avg.	119,440	108,270	12.6	25.2			

* Defective Tensile Bar

Billet No.	Extrusion Ratio	Tensile Strength (PSI)	.2% Yield Strength (PSI)	Elongation (Percent)	Reduction In Area (Percent)	Charpy "V" Notched Impact - ft - lbs 75°F	-40°F	Billet Preheat Temperature °F
A151:1	100:1	122,420F	108,540	14.2	30.3			1950
		122,240F	108,000	15.7	30.7			
		125,470	112,160	11.4	22.7			
		127,700	114,540	11.4	25.2			
	Avg.	124,457	110,810	13.2	27.2			

R - Rear

F - Front

[redacted]

TABLE VII

THE PRESSURE REQUIRED TO EXTRUDE A70 TITANIUM FROM CAST INGOTS AT VARIOUS EXTRUSION TEMPERATURES AND RATIOS

Billet Number	Extrusion Ratio	Billet Temperature-°F	Extrusion Speed (in/min)	Extrusion Pressure (PSI)
A-139-1	10:1	1500	58	68,320
A-140-1	10:1	1600	69	52,140
A-141-1	10:1	1700	68	35,560
A-141-4	25:1	1500	105	97,100
A-141-3	25:1	1600	108	86,300
A-141-2	25:1	1700	134	57,540
A-140-4	50:1	1500	122	111,480
A-140-3	50:1	1600	203	100,690
A-140-2	50:1	1700	144	64,730
A-137-B	70:1	1500	138	125,900
A-137-1	70:1	1600	250	97,090
A-137-2	70:1	1700	321	61,130
A-136-B	100:1	1500	14	133,050
A-136-1	100:1	1600	127	107,900
A-136-2	100:1	1700	371	71,900

Extrusion Conditions:

(1) Valve - 4
(2) Red. Ratio - Variable
(3) Billet Size - 7 1/2 dia. x 14"
(4) Ext. Lgth. - 8' - 31'
(5) Lubricant - Oil Dag
Necrolene
Lithium

(6) Billet Heating - Salt
(7) Die Design - 130° - 90° Incl.Angle
(8) Die Material - 5% Ch. H.W.
(9) Billet Temperature - as shown
(10) Container Temperature - 800°
(11) Die Preheat - 280°F

[redacted]

TABLE VIII

THE PRESSURES REQUIRED TO EXTRUDE A110AT TITANIUM FROM CAST INGOTS AT VARIOUS EXTRUSION TEMPERATURES AND RATIOS

Billet Number	Extrusion Ratio	Billet Temperature-°F	Extrusion Speed (in/min)	Extrusion Pressure(PSI)
A-145-1	10:1	1850°	63	57,540
A-145-F	25:1	1850	81	71,920
A-150-B	25:1	1925	140	61,130
A-145-3	50:1	1850	162	125,860
A-151-2	50:1	1925	225	79,110
A-147-1	50:1	1950	133	86,300
A-151-B	70:1	1950	326	79,110
A-151-1	100:1	1950		79,110

Extrusion Conditions:

(1) Valve -4
(2) Red. Ratio - Variable
(3) Billet Size - 7 1/2" Dia. x 14" L
(4) Ext. Lgth. - 3' - 27'
(5) Lubricant - Oil Dag
Necrolene
Lithium

(6) Billet Heating - Salt
(7) Die Design - 130° - 90° Incl. Angle
(8) Dia Mat'l - 5% Ch. H. M.
(9) Billet Temp. - As shown
(10) Container Temperature - 800°F
(11) Die Preheat - 280°F

[redacted]

TABLE IX

THE EFFECT OF DIE TEMPERATURE ON THE SURFACE FINISH OF EXTRUDED A70 AND A110 AT TITANIUM

A70 - Titanium

Billet No.	Die Temperature-°F	Extrusion Speed (in/Minute)	Extrusion Pressure (PSI)	Extrusion Length	Die Pickup	Surface Finish
A-142-1	280	360	79,112	12'	Heavy	Heavy Stria. (one side). Fair finish Slivering last 2'
A-130-B	400	480	79,112	10'8"	Medium	Med. Stria. Fair Finish. Slivering last 3'.
A-142-B	750	2,340	82,700	12'11½"	Slight	Slight to Med. Stria. Fair to good finish.
A-110AT Titanium						
A-245-B	150	360	106,080	17'8"	Heavy	Severe rupturing and tearing.
A-245-1	400	363	79,112	16'	Heavy	Heavy Stria, rupturing and tearing
A-245-T	740	480	57,536	15'8"	Slight	Medium finish

Extrusion Condition:

(1) Valve - 1/4 (Closed)
(2) Reduction Ratio - 25:1
(3) Billet Size - 7 1/2 Dia. x 12" Long
(4) Ext. Lgth - 12" - 15'
(5) Lube - Fiske #630

(6) Billet Heating - Argon - Salt
(7) Die Design - 130° - 90° Incl. Angle
(8) Die Material - 5% Ch. H.W. Rc-52
(9) Billet Temp. - 1 Hr. @ 1550°- A70
(10) Container Temp. - 800°F
(11) Die Preheat - Variable

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TABLE X

THE EFFECT OF EXTRUSION SPEED ON THE SURFACE FINISH OF EXTRUDED A70 AND A110 AT TITANIUM

A70 Titanium

Billet No.	Valve Setting	Die Temperature-°F	Extrustion Speed (in/minute)	Extrustion Pressure (PSI)	Extrustion Length	Die Pickup	Surface Finish
A-209-B	Closed (¼)	700	450	46,748	11' 2"	Medium	Med. to Heavy striations. Bad finish
A-142-T	2	700	15,600	75,516	13'	Medium	Med. -first half, med. to heavy-1st half, fair to good finish.
A-110AT Titanium							
A-246-B	Closed (¼)	750	420	53,940	13' 6"	Land Partially Washed Out	Rupt. & tearing condition. Fair to good finish.
A-247-B	2	750	8,880	61,132	12' 4"	Land Washout	Rupt. & tearing throughout.

Extrusion Conditions:

(1) Valve - Variable
(2) Reduction Ratio - 25:1
(3) Billet Size - 7¼" dia x 12" long
(4) Ext. Length - 12' - 15'
(5) Lube - Fiske No. 630

(6) Billet Heating - Argon - Salt
(7) Die Design - 130° - 90° incl. angle
(8) Die Mat. - 5% Ch. H.W. Rc-52
(9) Billet Temp. 1 hr. @ 1550° - A70
1 1/4 hr. @ 1900° - A-110AT
(10) Container - 800°F
(11) Die Preheat - 700° - 800°

[redacted]

TABLE XI

EXPERIMENTAL DIE MATERIALS EVALUATED

Manufacturer	Trade Name	Type	Composition	Rock "C"	Remarks
1. Haynes Stellite Co.	Stellite #6	Cast	1C, 27Cr. .6Mn, 65 Co. 4V, 3 Fe, 8Si	42-52	High impact, tough resistance to hot checking.
2. Wall Colmonoy Corp.	Wallex "D"	Cast	Tungsten, Chromium, Cobalt, & Carbon	48-53	Excellent abrasive resistance, and corrosion resistance. Fair impact, very good falling, excellent red. hardness.
3. Crucible Steel	Rexalloy #33	Cast	2.25C, 33Cr, 44Co,17W	55-63	High red, hardness superior resist, to abrasion and corrosion. Low coefficient of friction.
4. Beryllium Corp.	Beryllium Nickel	Cast	.5Cr, Bal Ni, 2.75Be	50-52	High Strength & Hardness.
5. Hard Face Weld	Moly Faced	Hard Faced	.34C, 5Cr, 2.28 Moly, 20V .30mn, 1.35W, 1Si, .025P, .0258		
6. Indus.City Boring Linde	Ceramic Coated al Si Mag	Hard Faced	al. Si, Mag.	Like Diamond	Resistance to Abrasion
7. Vanadium Alloys Steel Company	Vasco Supreme	High Speed	1.57 C, 475Cr, 5V, .25 Mn., 5 Co, 12.5W, .25Si	64	High hardness, hot hardness, wear resistance.

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TABLE XII

THE EFFECT OF VARIOUS DIE MATERIALS ON THE SURFACE FINISH OF EXTRUDED A70 TITANIUM

A70 Titanium

Billet No.	Die Material	Extrusion Speed (in/minute)	Extrusion Pressure (PSI)	Extrusion Length	Die Condition	Surface Finish
A-209-T	Haynes Stellite	840	82,708	29'7"	Med. Erosion; Lost .005" on Dia.; Front to Back.	Slight Stria. Last 5' badly torn.
A-212-1	Wallex "D"	480	107,880	15'6"	Slight Erosion; Lost .004" on Dia.; Die split.	Med. to heavy Striations finish good 3/4 of lgth.
A-212-T	Rexalloy	960	86,304	18'11"	Slight die pickup; Dia. held constant; Die cracked.	Med. to heavy striations deep score one area.
A-214-B	Ceramic Coated			19'4"	Slight die pickup; Lost .035" Front to Back.	Medium to heavy striations one area.
A-213-B	Vasco Supreme			21'6"	Slight die pickup; Lost .010" Front to Back.	Good Finish except med. to heavy striations - one area.
A-213-1	A-110-AT			21'4"	Slight die pickup; Lost .020" Front to Back.	Medium to heavy striations.

Extrusion Conditions:

(1) Valve - 1/4 (Closed)
(2) Reduction Ratio - 50:1
(3) Billet Size - 7 1/2 Dia. X 12" Long
(4) Ext. Length - 12' - 15'
(5) Lube - Fiske #630
(6) Billet Heating - Argon - Salt -
(7) Die Design - 130 - 90° Incl.
(8) Die Material - Variable
(9) Billet Temp. - 1 hr. @ 1550°F A70
(10) Container Temp. - 800°F
(11) Die Preheat - 550°F
(12) Billet Temp. - 1 1/4 hr. @ 1900°F A-110-AT.

[redacted]

TABLE XIII

THE EFFECT OF VARIOUS DIE MATERIALS ON THE SURFACE FINISH OF EXTRUDED A-110-AT TITANIUM

A-110-AT - Titanium

Billet No.	Die Material	Extrusion Speed (in/minute)	Extrusion Pressure (PSI)	Extrusion Length	Die Condition	Surface Finish
A-248-1	Haynes Stellite	960	57,536	35'6"	Heavy erosion; Lost size completely.	First 20' good, Rupturing & Tearing last 15'.
A-248-B	Wallex "D"	720	57,536	30'1"	Die broke down after 2'; Cracked.	Very bad.
A-321-T	Rexalloy	1,200	57,536	24'	Medium Die pickup; Lost, .010" Front to Back.	Light to medium Striations. Fairly good finish.
A-247-B	Moly Faced	540	39,560	13'11"	Heavy die pickup; slight erosion - one area.	Extreme tearing 4'; minor tearing throughout.
A-247-1	A-110-AT	1,020	50,344	30'2"	Completely broke-down.	Very bad
A-247-T	Vasco Supreme	780	57,536	33'3"	Eroded; one area split.	Rupturing & Tearing; Some Surfaces Fair.
A-331-1	Beryllium Nickel	540	-	-	Die broke-down; Die not fully extrude..	

Extrusion Conditions:

(1) Valve - 1/4 (Closed)
(2) Reduction Ratio - 50:1
(3) Billet Size - 7 1/2 Dia. X 12" Long
(4) Ext. Length - 12' - 15'
(5) Lube - Fiske #630
(6) Billet Heating - Argon - Salt -
(7) Die Design - 130 - 90° Incl.
(8) Die Material - Variable
(9) Billet Temp. - 1 hr. @ 1550°F A70
(10) Container Temp. - 800°F
(11) Die Preheat - 550°F
(12) Billet Temp. - 1 1/4 hr. @ 1900°F A-110-AT.

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TABLE XIV

THE EFFECT OF VARIOUS LUBRICANTS ON THE SURFACE FINISH OF EXTRUDED A70 AND A-110-AT TITANIUM

A70 Titanium

Billet No.	Lubrication	Extrusion Speed (in/minute)	Extrusion Pressure (PSI)	Extrusion Length	Die Pickup	Surface Finish
A-211-1	Fiske #604*	300	82,708	10'4"	Medium	Medium Striations- 1 area
A-150-B	Fiske #630**	140	61,130	12'	Slight	Slight Striations.
A-210-B	NONE	540	43,152	13'2"	Medium	Medium to Heavy Striations.

A-110-AT Titanium

Billet No.	Lubrication	Extrusion Speed (in/minute)	Extrusion Pressure (PSI)	Extrusion Length	Die Pickup	Surface Finish
A-320-T	Fiske #604	300	89,900	9'1"	Washout	Rupturing & Tearing.
A-217-B	Fiske #630	1,375	46,748	18'5"	Slight	Slight Striations.
A-216-F	Fiske #630 (ingot heated directly in salt)	1,275	46,748	18'5"	Medium	Slight to Medium, Striations
A-216-1	Necrolene 50% Lithium Carbonate 50%	1,800	48,500	17'4"	Slight	Slight Striations.
A-324-B	NONE	360	53,940	5'11"	Slight	Slight Striations.

*Penetration of 350 to 370 - Soapless type grease - no corrosion, high graphite content - percent mica.

**Calcium base soap with graphite, vermiculite, and calcium carbonate.

Extrusion Conditions:

(1) Valve - 1/4 (Closed)
(2) Reduction Ratio - 25:1
(3) Billet Size - 8 1/4" Dia. X 14"
(4) Ext. Length - 6' - 18'
(5) Lube - Variable.
(6) Billet Heating - Argon - Salt
(7) Die Design - 130° - 90° Incl. Angle
(8) Die Material - 5% CH H.W.
(9) Billet Temp. - 1 Hr. @ 1550° A70
(10) Container - 800°F
(11) Die Preheat - 800°F
(12) Billet Temp. - 1 Hr. @ 1900°F - A-110-AT

[redacted]

TABLE XV

THE EFFECT OF DIE ANGLE ON THE SURFACE FINISH OF EXTRUDED A70 AND A-110-AT TITANIUM

A70 Titanium

Billet No.	Die Angle	Extrusion Speed (in/minute)	Extrusion Pressure (PSI)	Extrusion Length	Die Pickup	Surface Finish
A-210-1	90°	333	102,486	13'4"	Light	Medium Striations.
A-210-B	100°	398	107,880	13'2"	Medium	Medium to Heavy Striations.
A-138-B	110°	397	82,708	11'7"	Slight	Slight to Medium Striations.
A-218-1	120°	591	71,920	17'4"	Slight	Medium to Heavy Striations.
A-138-1	130°	382	89,900	12'1"	Slight	Medium Striations.
A-132-B	140°	515	61,130	14'2"	Heavy	Rupturing and Tearing.
A-132-1	150°	405	89,900	13'6"	Spotty	Heavy Striations.
A-132-F	180°	670	89,900	18'6"	Heavy	Medium to Heavy.

A-110-AT Titanium

Billet No.	Die Angle	Extrusion Speed (in/minute)	Extrusion Pressure (PSI)	Extrusion Length	Die Pickup	Surface Finish
A-248-T	90°	478	133,052	18'4"	Heavy	Rupturing and Tearing.
A-249-B	100°	1680	75,516	14'	Heavy	Rupturing and Tearing.
A-249-1	110°	510	79,112	12'9"	Heavy	Rupturing and Tearing.
A-249-2	120°	394	104,284	11'6"	Heavy	Rupturing and Tearing.
A-249-T	130°	249	118,668	11'5"	Medium	Medium to Heavy Striations.
A-320-B	140°	368	104,284	15'4"	Heavy	Badly Torn.
A-320-1	150°	455	100,688	13'8"	Heavy	Badly Torn.
A-320-2	180°	445	97,092	13'	Slight	Good Finish.

Extrusion Conditions:

(1) Valve - 1/4 (Closed)
(2) Reduction Ratio - 25:1
(3) Billet Size - 7 1/2" Dia. X 12" Long
(4) Ext. Length - 12' - 15'
(5) Lube - Fiske #630
(6) Billet Heating - Argon - Salt
(7) Die Design - Variable
(8) Die Material - 5% CH. H.W. Rc-52
(9) Billet Temp. - 1 Hr. @ 1550°F A70
1 1/4 Hr. @ 1900°F A-110-AT
(10) Container Temp. - 800°F
(11) Die Preheat - 700° - 800°F

[redacted]

TABLE XVI

WELDING MACHINE SETTINGS FOR THE STUDY ON MAXIMUM JOINT EFFICIENCY AND MAXIMUM TO MINIMUM RIB RATIOS

Identification	12,000-18,000 lbs. Upsetting Force	25 A-110-AT 3/4 in. dia. bars	28 C.P.-70 3/4 in. dia. bars	Max.-Min. Study 2.6:1 Ratio	Max.-Min. Study 5.3:1 Ratio	Max.-Min. Study 5.3:1 Ratio
Material	A-110-AT	A-110-AT	A-70	A-70	A-70	A-70
Work Overhang	1/2	1/2	1/2	9/16	1/2	1/2
Initial Die Opening	1	1	1	1 1/8	1	1
Final Die Opening	NR*	NR	NR	5/16	3/8	5/16
Current Cut Off After "0"	1/8	3/16	1/8	3/16	1/16	1/16
Flash Time-Seconds	5	4 1/2	5	5 1/2	6	6
Flow Valve Setting	3 1/2	4	4	5	4	4
Clamping Pressure (lbs.)	23,000	23,000	23,000	23,000	23,000	23,000
Upset Pressure (lbs.)	12,000-18,000	12,000	12,000	10,500	12,000	12,000
Tap Switch	1S [xx]	5S	2S	3S	3S	3S

[xx] S = Series

* NR = Not Reported

Machine Specifications:
Model - Thomson F4 Synchromatic
SN. 18777 250 KVA
Max. Upset Force 32,000 lbs.
Max. Clamping Force 23,000 lbs.

[redacted]

TABLE XVII-(PART I)

THE MECHANICAL PROPERTIES OF SPECIMENS WELDED FOR THE STUDY ON MAXIMUM JOINT EFFICIENCY

Ti-A110AT

Specimen Ident.	Certified Rem-Cru Barstock		1200# Upset			1500# Upset			1800# Upset		1 of First 25 A-110 - AT Bars Welded	
Tensile Strength (1000 PSI)	141.8	138.6	136.5	140.2	139.3	139	139	140.5	140.3	146	135 .	137.87
Yield Strength .2% Offset (1000 PSI)	134.6	130.5	127.2	129	130.35	131.4	129.3	132.9	130.65	131.15	128.41	127.27
Elongation (Percent)	17.0	17.1	15.7	16.4	15.7	16.4	17.1	16.4	16.4	17.8	17.1	15.7
Reduction of Area (percent)	N.R.	40.2	41.9	41.9	39.4	40.2	43.6	40.2	40.0	40.3	43.6	42.1
Notch Rupture Stress (PSI)											135,000	
Hours											15.6	
Failure											No Failure	

STAT

[redacted]

TABLE XVII-(PART II)

THE MECHANICAL PROPERTIES OF SPECIMENS WELDED FOR THE STUDY ON MAXIMUM JOINT EFFICIENCY

Ti-A70

Specimen Ident.	Certified CP Rem-Cru Barstock		2 of 28 A70 Welds 1300F 1 hr.		1 of 28 CP 1200F 24 Hrs.	Barstock Check	2 of 28 A70 Bars 1300F 1 Hr.		2 of 28 A70 Bars		1 of 28 A70 Bars 1200F 24 hrs.
Tensile Strength (1000 PSI)	88	98.2	98.89	83.81	82.32	82.43					
Yield Strength .2% Offset (1000 PSI)	68.1	83.8	81.4	62.31	61.2	56.4					
Elongation (Percent)	28	24.7	22.8	20.7	19.2	30					
Reduction of Area (Percent)	47.4	----	43.7	47.4	45.7	49.7					
Notch Rupture (1000 PSI)							90	90	90	90	90
Hours							7.5	15.8	7.7	7.6	12.8
Failure							No Failure	No Failure	No Failure	No Failure	No Failure

[redacted]

TABLE XVIII

THE MECHANICAL PROPERTIES OF SPECIMENS WELDED FOR THE STUDY ON MAXIMUM TO MINIMUM RIB RATIO

MAXIMUM - MINIMUM RATIO 2.6:1

Specimen Ident.	Thin Spec. #1	Thin Spec. #1	Thin Spec. #2	Thin Spec. #2	Thin Spec. #3	Thin Spec. #3
Tensile Strength (PSI)	95,080	94,240	93,730	95,130	95,130	94,310
Yield Strength .2% Offset (PSI)	85,910	86,390	84,440	77,100	77,100	85,610
Elongation (Percent)	20	26	22	26	26	22
Reduction In Area (Percent)	45.4	38.3	45.5	39.1	39.1	40.9

MAXIMUM - MINIMUM RATIO 5.3:1

Specimen Ident.	Thin Spec. #11	Thin Spec. #11	Thin Spec. #12	Thin Spec. #12	Thin Spec. #13	Thin Spec. #13
Tensile Strength (PSI)	88,870	90,870	92,270	96,350	90,180	89,290
Yield Strength .2% Offset (PSI)	82,870	82,270	85,060	84,970	81,300	78,990
Elongation (Percent)	17	25	12	15	19	29
Reduction In Area (Percent)	38.1	43.0	33.5	12.4	37.4	44.4

STAT STAT

[redacted]

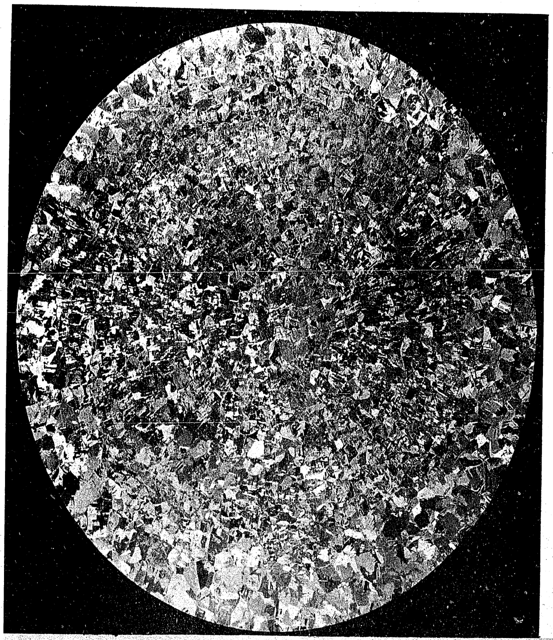

FIG.1- PHOTOMACROGRAPH OF AN A70 TITANIUM CAST INGOT.

NOTE THE UNIFORM GRAIN STRUCTURE RESULTING FROM THE LOW VOLTAGE "INDUCTION STIRRING" COIL. INGOT DIAMETER APPROX. 7 1/2 INS.

ETCHANT:
10% HF
90% H_2O

STAT STAT

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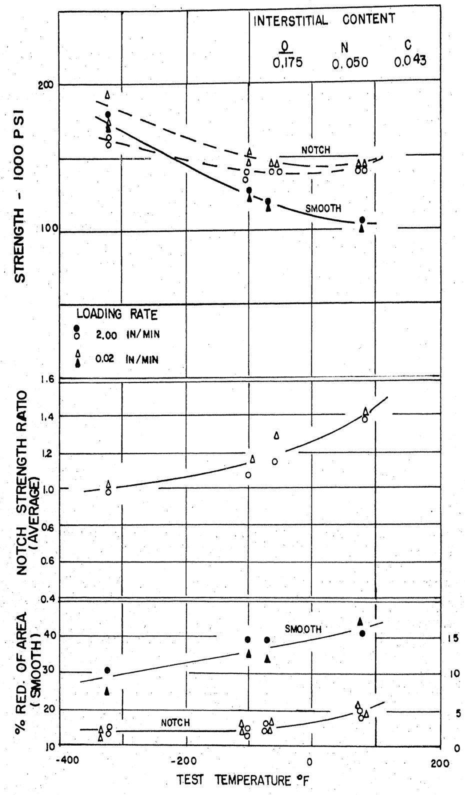

FIGURE 2 THE NOTCH-TENSILE PROPERTIES OF LOW OXYGEN (0.20%) A70 TITANIUM EXTRUDED FROM A CAST INGOT (MATERIAL A O_E= 0.33)

[redacted]

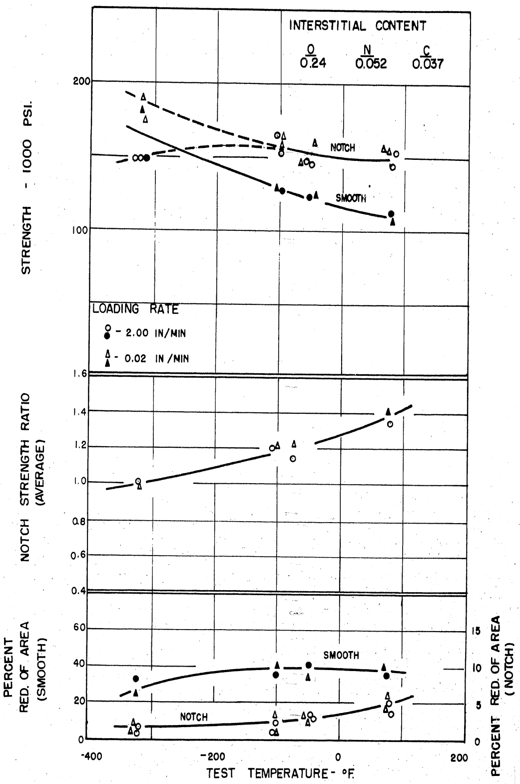

FIG. 3 THE NOTCH-TENSILE PROPERTIES OF HIGH OXYGEN (0.25%) A70 TITANIUM EXTRUDED FROM A CAST INGOT (MATERIAL B, O_E=0.38)

[redacted]

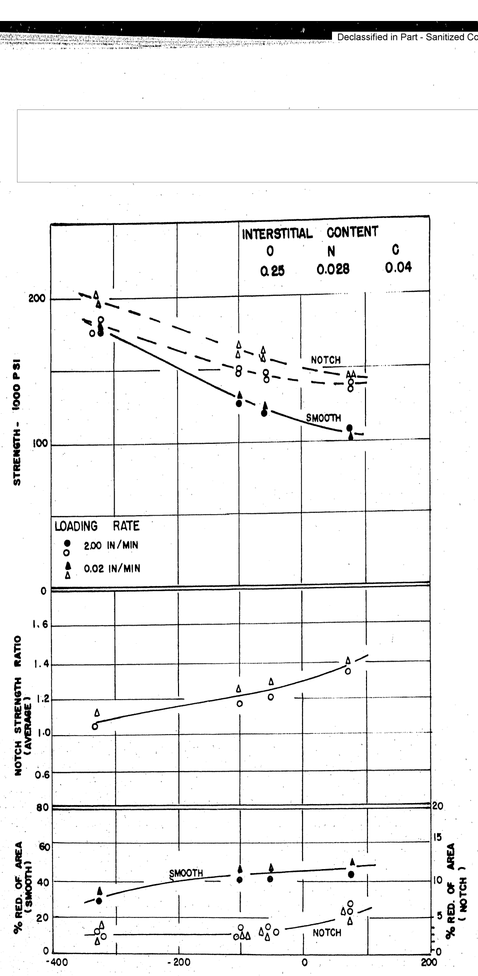

FIGURE 4 THE NOTCH-TENSILE PROPERTIES OF HIGH OXYGEN (0.25%) A70 TITANIUM EXTRUDED FROM A FORGED BILLET (MATERIAL C, O_E= 0.34)

[redacted]

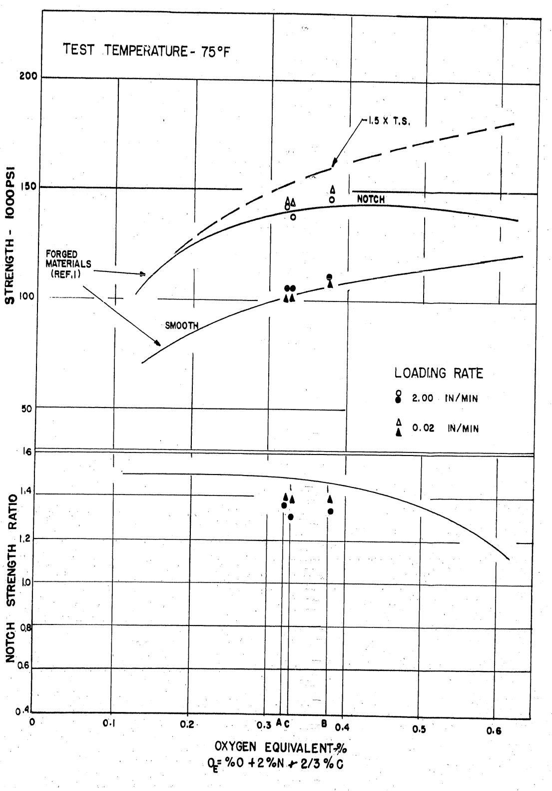

FIGURE 5 COMPARISON OF THE EFFECT OF INTERSTITIAL CONTENT ON THE NOTCH-TENSILE PROPERTIES OF A70 TITANIUM IN FORGED AND IN EXTRUDED MATERIAL AT 75°F

[redacted]

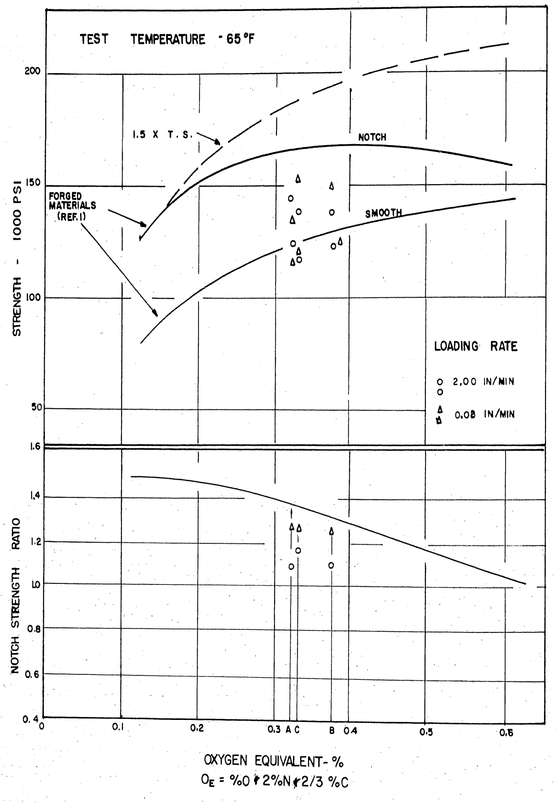

FIGURE 6 COMPARISON OF THE EFFECT OF INTERSTITIAL CONTENT IN THE NOTCH-TENSILE PROPERTIES OF A70 TITANIUM IN FORGED AND IN EXTRUDED MATERIAL AT -65°F

STAT STAT

[redacted]

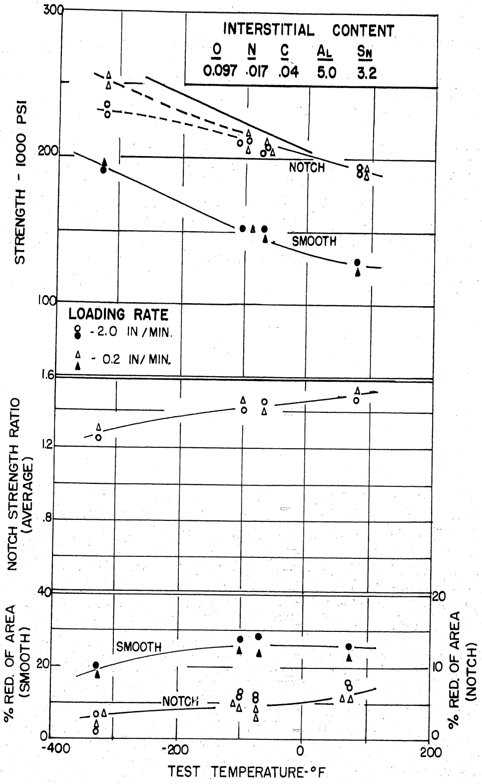

FIG. 7 THE NOTCH TENSILE PROPERTIES OF A110AT TITANIUM EXTRUDED FROM A CAST INGOT (MAT'L-D)

[redacted]

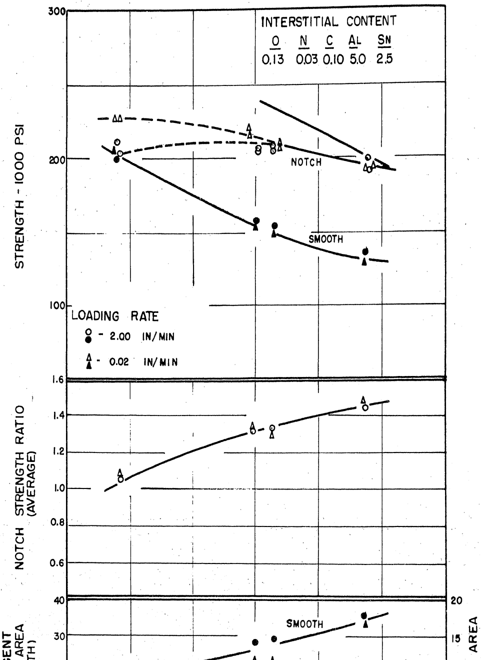

FIG. 8 THE NOTCH-TENSILE PROPERTIES OF A-110AT TITANIUM EXTRUDED FROM A FORGED BILLET (MATERIAL E)

[redacted]

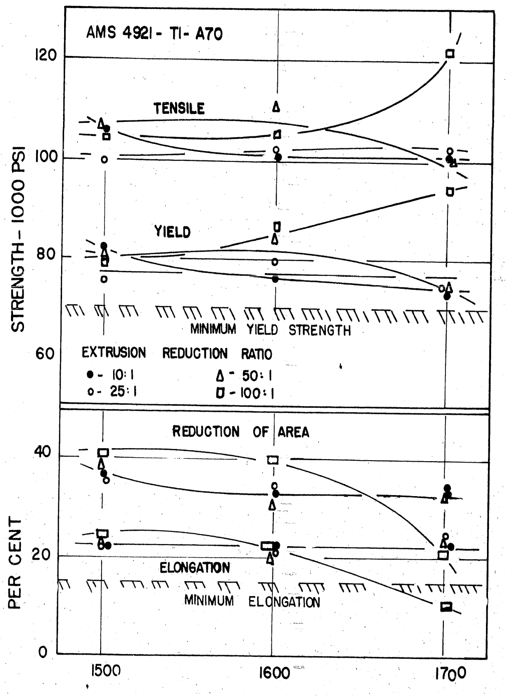

FIGURE 9

THE EFFECT OF EXTRUSION TEMPERATURES ON THE TENSILE PROPERTIES OF A70 TITANIUM EXTRUDED FROM CAST INGOTS OF VARIOUS EXTRUSION RATIOS

[redacted]

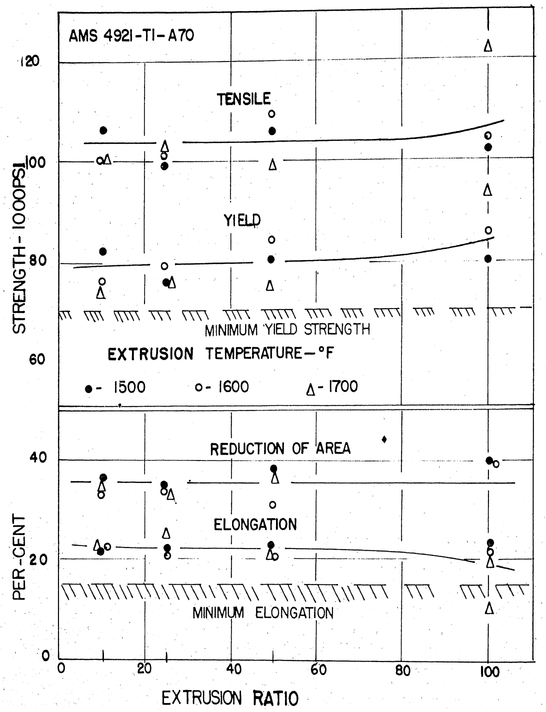

FIGURE 10

THE EFFECT OF EXTRUSION RATIO ON THE TENSILE PROPERTIES OF A70 TITANIUM EXTRUDED FROM CAST INGOTS AT VARIOUS EXTRUSION TEMPERATURES

[redacted]

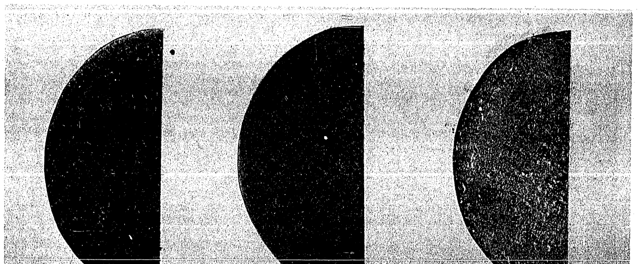

FIG. 11 THE EFFECT OF EXTRUSION TEMPERATURE ON THE MICROSTRUCTURE AND MACROSTRUCTURE OF A70 TITANIUM EXTRUDED FROM CAST INGOTS AT AN EXTRUSION RATE OF 10:1

MICRO MAG. - APPROX 200 X
MACROS - BAR DIA. APPROX 2.5 IN.

[redacted]

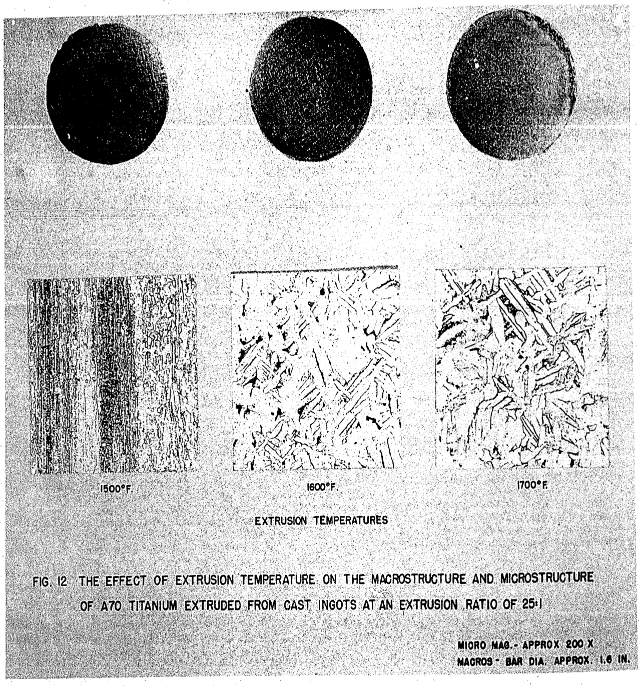

FIG. 12 THE EFFECT OF EXTRUSION TEMPERATURE ON THE MACROSTRUCTURE AND MICROSTRUCTURE OF A70 TITANIUM EXTRUDED FROM CAST INGOTS AT AN EXTRUSION RATIO OF 25:1

MICRO MAG.- APPROX 200 X
MACROS - BAR DIA. APPROX. 1.6 IN.

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[redacted]

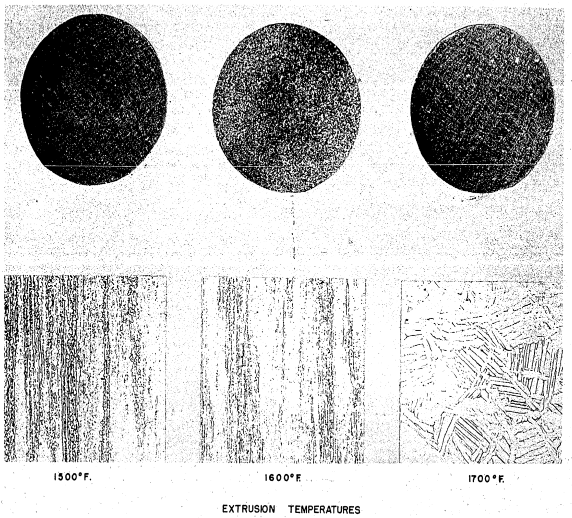
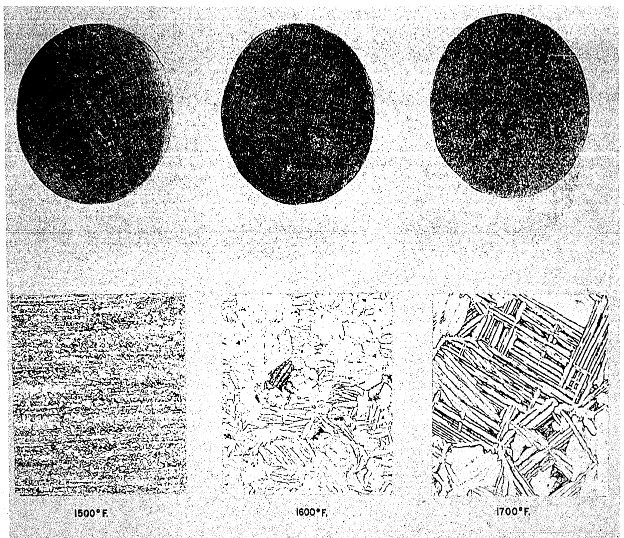


FIG. 13 THE EFFECT OF EXTRUSION TEMPERATURE ON THE MACROSTRUCTURE AND MICROSTRUCTURE OF A70 TITANIUM EXTRUDED FROM CAST INGOTS AT AN EXTRUSION RATIO OF 50 : 1

MICRO MAG. - APPROX. 200X
MACROS - BAR DIA. APPROX 1.1 INCH

[redacted]



1500° F.

1600° F.

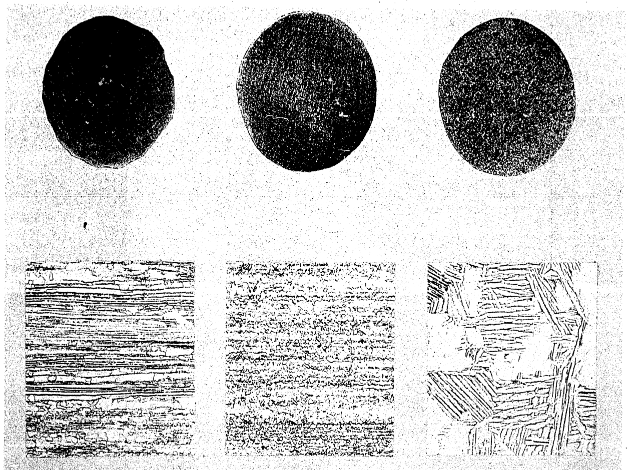
1700° F.

EXTRUSION TEMPERATURES

FIG. 14 THE EFFECT OF EXTRUSION TEMPERATURE ON THE MACROSTRUCTURE AND MICROSTRUCTURE OF A70 TITANIUM EXTRUDED FROM CAST INGOTS AT AN EXTRUSION RATIO OF 70:1

MICROS - APPROX MAG. 200 X
MACROS - APPROX BAR DIA. .95 IN.

[redacted]



1500° F.

1600° F.

1700° F.

EXTRUSION TEMPERATURES

FIG. 15 THE EFFECT OF EXTRUSION TEMPERATURE ON THE MACROSTRUCTURE AND MICROSTRUCTURE OF A70 TITANIUM EXTRUDED FROM CAST INGOTS AT AN EXTRUSION RATIO OF 100:1

MICROS - APPROX. MAG. 200 X.
MACROS - APPROX BAR DIA. .95 IN.

[redacted]

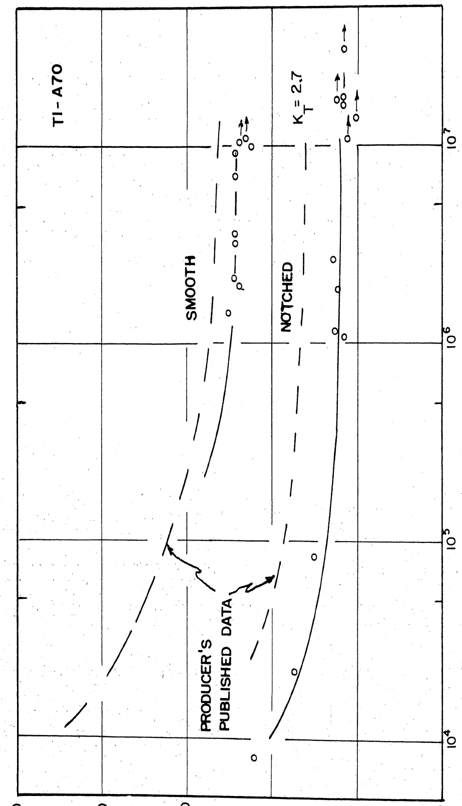


FIG. 16 ROTATING BEAM FATIGUE RESULTS FOR SMOOTH AND NOTCHED A-70 TITANIUM EXTRUDED FROM CAST INGOTS

STAT

[redacted]

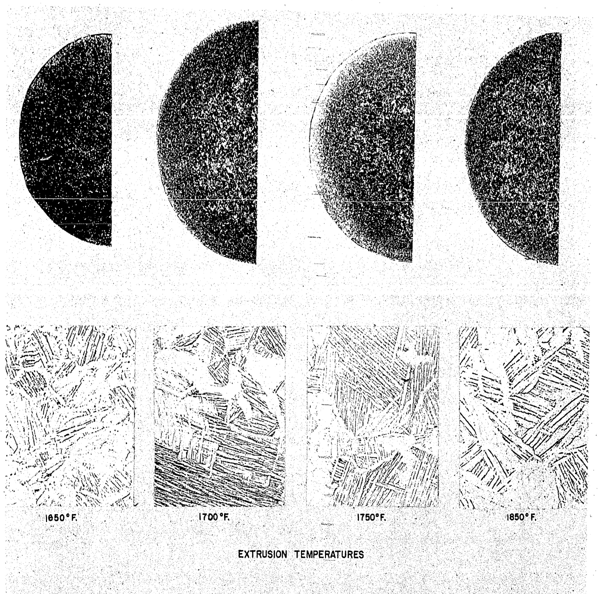
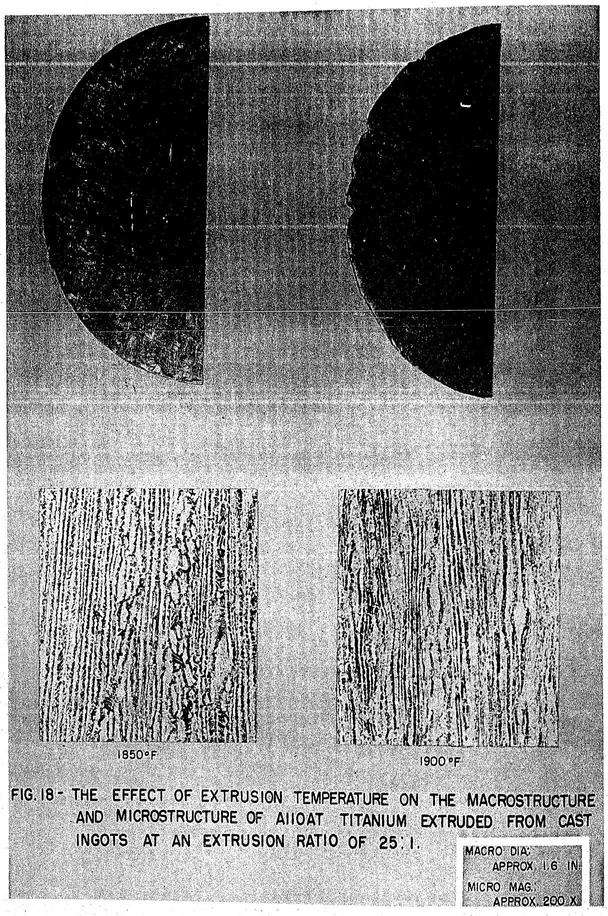


FIG. 17 THE EFFECT OF EXTRUSION TEMPERATURE ON THE MACROSTRUCTURE AND MICROSTRUCTURE OF A110AT TITANIUM EXTRUDED FROM CAST INGOTS AT AN EXTRUSION RATIO OF 10:1

MICROS - APPROX. MAG. 200 X.
MACROS - APPROX. BAR DIA. 2.5 IN.

STAT STAT

[redacted]



1850°F 1900°F

FIG. 18 - THE EFFECT OF EXTRUSION TEMPERATURE ON THE MACROSTRUCTURE AND MICROSTRUCTURE OF A110AT TITANIUM EXTRUDED FROM CAST INGOTS AT AN EXTRUSION RATIO OF 25:1.

MACRO DIA. APPROX. 1.6 IN.
MICRO MAG. APPROX. 200 X

[redacted]

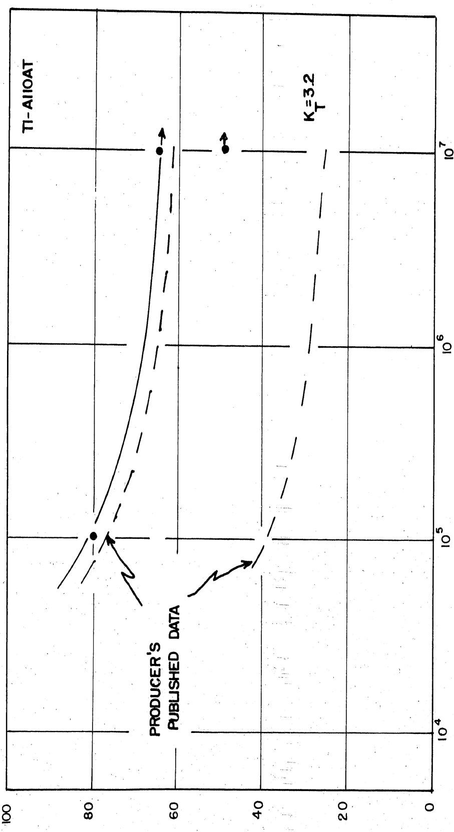


FIG. 19 ROTATING BEAM FATIGUE RESULTS FOR A-110AT TITANIUM EXTRUDED FROM CAST INGOTS

[redacted]

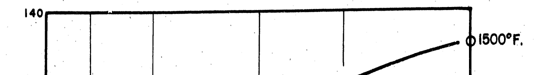


FIGURE 20 THE EFFECT OF EXTRUSION RATIO ON THE PRESSURE REQUIRED TO EXTRUDE A70 TITANIUM FROM CAST INGOTS AT VARIOUS EXTRUSION TEMPERATURES

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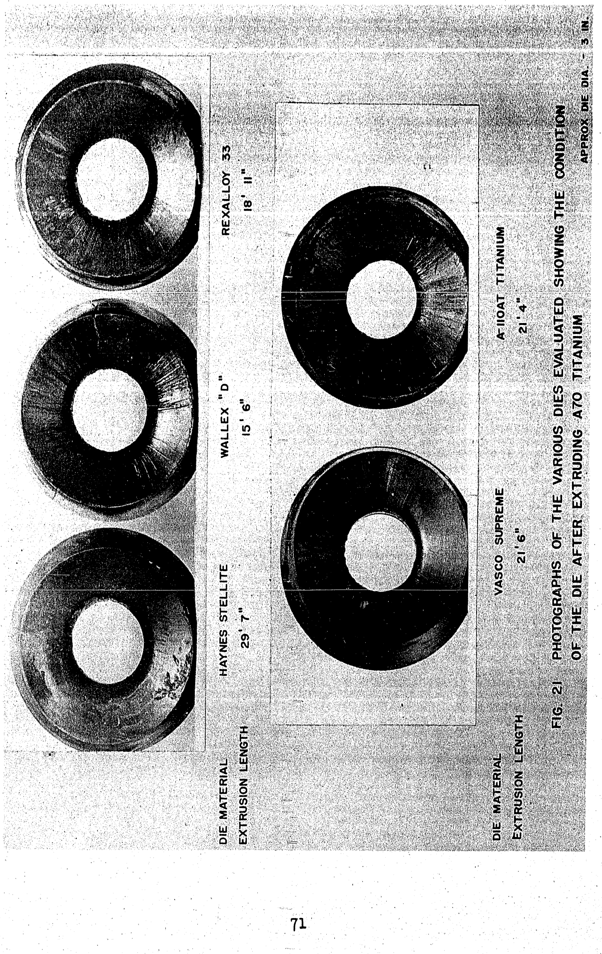
[redacted]



DIE MATERIAL	HAYNES STELLITE	WALLEX "D"	REXALLOY 33
EXTRUSION LENGTH	29' 7"	15' 6"	18' 11"

DIE MATERIAL	VASCO SUPREME	A-110AT TITANIUM
EXTRUSION LENGTH	21' 6"	21' 4"

FIG. 21 PHOTOGRAPHS OF THE VARIOUS DIES EVALUATED SHOWING THE CONDITION OF THE DIE AFTER EXTRUDING A70 TITANIUM

APPROX DIE DIA. - 3 IN.

[redacted]

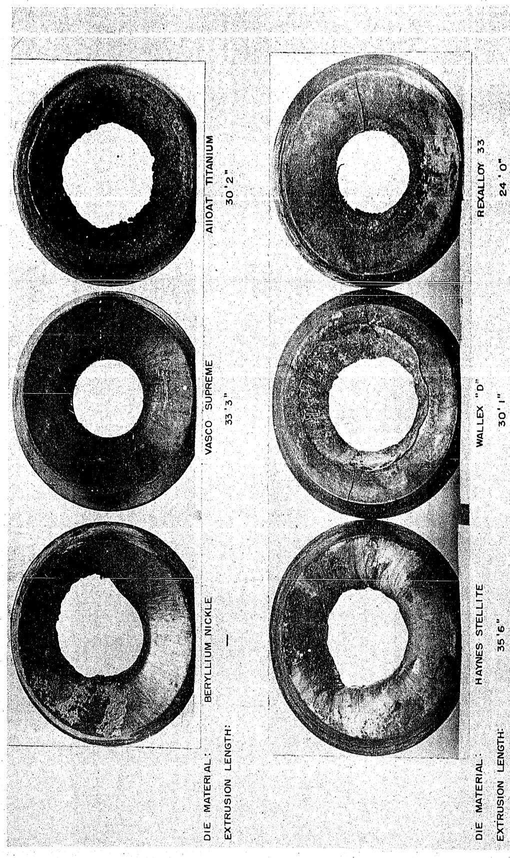


FIG. 22 - PHOTOGRAPHS OF THE VARIOUS DIES EVALUATED SHOWING THE CONDITION OF THE DIE AFTER EXTRUDING AIIOAT TITANIUM.

APPROX DIE DIA. - 3"

STAT

STAT

[redacted]

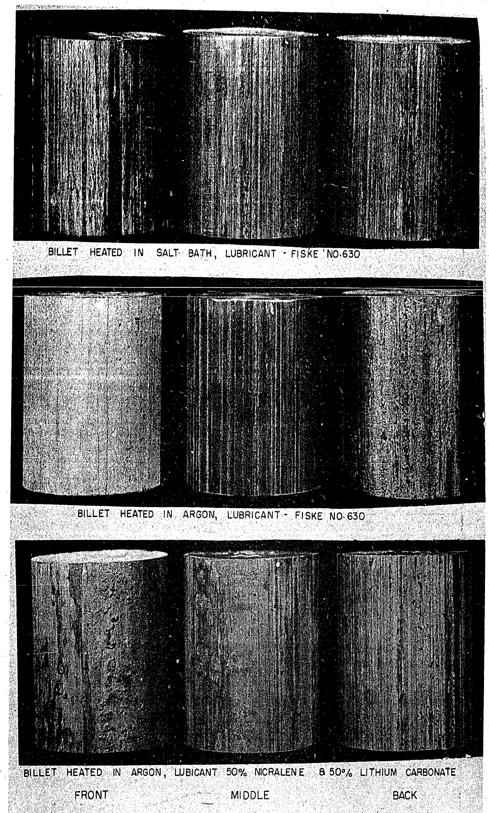


FIG. 23 - PHOTOGRAPHS SHOWING THE SURFACE FINISH OF SEVERAL AIIOAT TITANIUM EXTRUSIONS UTILIZING VARIOUS LUBRICANTS.

[redacted]

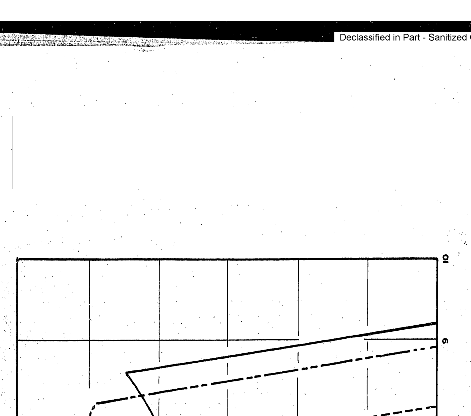


FIGURE 24 THE EFFECT OF DIE ANGLE ON THE PRESSURE REQUIRED TO EXTRUDE A70 TITANIUM

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[redacted]

FIG. 25- TYPICAL FRACTURES OF WELDED TEST BARS USED IN THE MAXIMUM JOINT EFFICIENCY STUDY.

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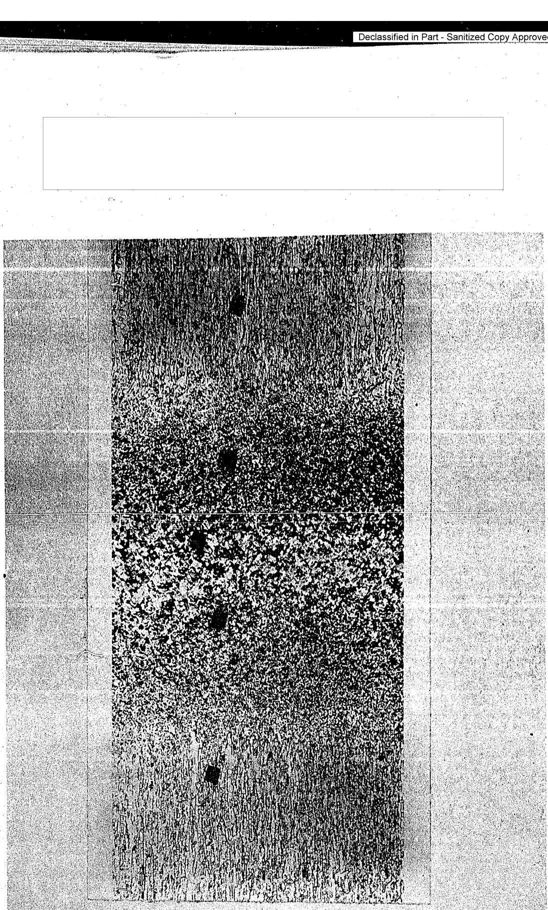

FIG.26- PHOTOMICROGRAPH OF THE WELD AREA OF A FLASH-BUTT WELDED SECTION OF A110AT TITANIUM.

ETCHANT:
2% HF
8% HNO_3
90% H_2O

MAG: APPROX. 100 X

[redacted]

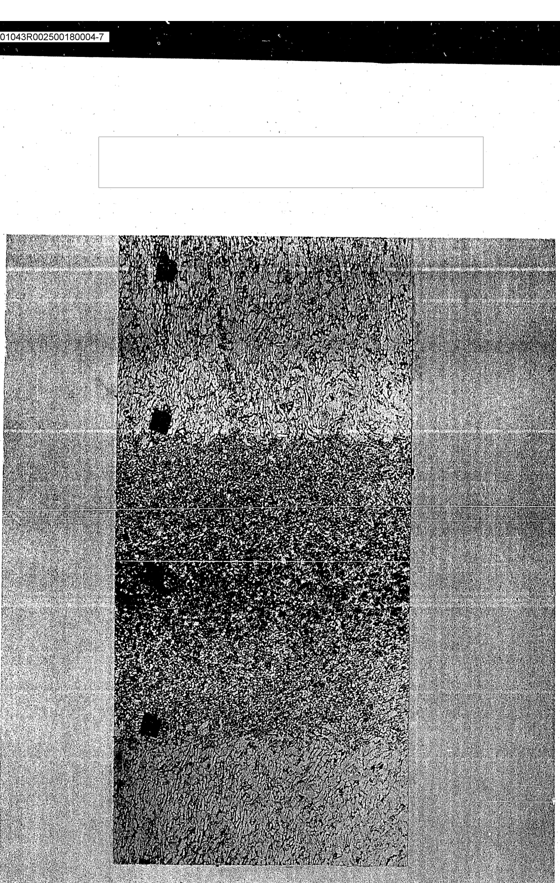

FIG. 27- PHOTOMICROGRAPH OF THE WELD AREA OF A FLASH-BUTT WELDED SPECIMEN OF A70 TITANIUM.

ETCHANT:
2% HF
8% HNO_3
90% H_2O

MAG: APPROX. 100 X

[redacted]

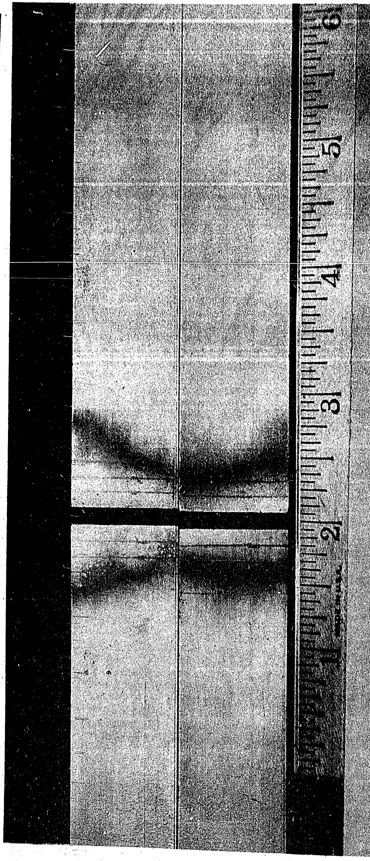

FIG. 28 - PHOTOGRAPH OF A TITANIUM SAMPLE USED TO OBTAIN A HEAT BALANCE FOR WELDING.

NOTE: THE HEAT PENETRATION IS DETERMINABLE BY THE SURFACE DISCOLORATION.

STAT STAT

[redacted]

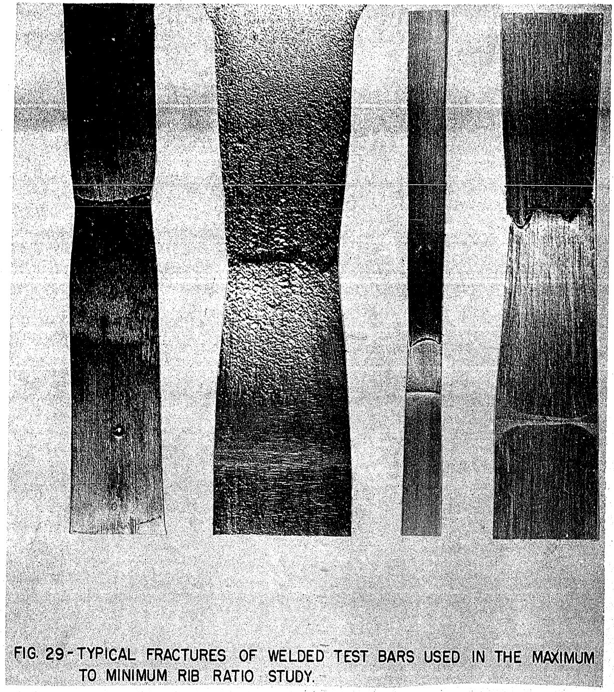

FIG. 29 - TYPICAL FRACTURES OF WELDED TEST BARS USED IN THE MAXIMUM TO MINIMUM RIB RATIO STUDY.