MACHINING APPROACH TO AIRCRAFT PRODUCTION

BY HAROLD YOUNG

AVRO AIRCRAFT LIMITED

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In delivering this paper on the machining approach to Aircraft Production, I propose to present to you some of the problems we have encountered and the action taken, on our latest Aircraft program, to prepare ourselves for this relatively new type of manufacturing.

Very early in the Design Scheme stages our Product Engineers determined that integrally stiffened skins and completely machined structural members were necessary to meet the Design requirements. From this overall requirement the first essential to be settled was the choice of materials. We decided to use the experience gained in the United Kingdom and the United States and machine from solid billets and rolled plate. We were advised by Companies using heavy plate that this material should be stretcher stress relieved to minimize distortion during machining.

SLIDE NO. I

Our first slide shows the advantages of material in this condition. The skin on the left hand side was made from stretcher stress relieved plate, and has no appreciable bow, while the skin on the right hand side was made from standard rolled stock, the advantages of stress relieving are very apparent.

SLIDE NO. 2

To obtain the maximum flatness of plate, a stretch of one half per cent is sufficient, but to stress relieve the plate two per cent is required.

SLIDE NO. 3

The size of stretcher level plate available on the commercial market at the present time is limited to the capacity of this machine which has a maximum pull of six million pounds, and is capable of stretching a cross sectional area of one hundred and forty square inches.

Though not clearly shown on this slide the Hydraulic Jaws will handle a three inch thick plate.

It is understood that the suppliers of plate are investigating the possibility of doubling the cross sectional area and thickness I have quoted in the very near future.

So much for the stretcher levelling process in the manufacturing of plate.

To overcome the disadvantages encountered with commercial specifications for rolled 75S plate our own specification was compiled for the Ultra Sonic quality requirement. In this specification the limitation on inclusion content is laid down; The majority of inclusions are usually located within the plate and not apparent as surface imperfections so it is important that the location and size of such imperfections are known before machining is started, to obtain this information Ultra Sonic Reflector Scopes as shown in this slide are required.

SLIDE NO. 4

We decided that provision of such equipment by Avro for one hundred per cent inspection was unnecessary and that this problem could be handled by the supplier, who would supply this information with the Material Certificates. We have, however, installed Ultra Sonic Testing equipment to spot check incoming material.

We submitted this specification to the supplier and obtained their concurrence before issue, so that at an early stage our Procurement and Inspection Departments were able to ensure suitable material availability to meet the manufacturing schedule.

It should be noted that stretcher stress relieved plate is received fully heat - treated and machined in this condition.

In covering stretcher stress relieved plate we have accounted for approximately eighty-five per cent of the heavy machined parts required for this program, the remaining fifteen per cent being covered by hand forgings.

SLIDE NO. 5

Our next slide will illustrate why hand forgings were chosen instead of die forgings.

This slide illustrates a typical Wing spar as it would appear in the finished condition. You will note that web thickness of one tenth of an inch are called for and tolerances of plus or minus five thousandth of an inch are required by our Design Office for weight control purposes.

To date, die forgings are not practical for web thickness of less than three sixteenth of an inch, so that a part manufactured from a die forging would require machining on all of these surfaces.

To further illustrate the point here are cost comparisons based on fifty Aircraft sets of parts made from die forgings and from hand forgings.

In the case of the die forgings the die cost is $2,380.00 per part, the forging cost $360.00, plus the machining cost $240.00, making a total of $2,980. per part.

In the case of the hand forging there is no die cost, a cost of $1,279.00 for the forging, $546.00 for machining, making a total of $1,825.00

showing a saving of $1, 155.00 per part in favour of the hand forging.

SLIDE NO. 6

The problem of distortion during machining operations is very prevalent when using hand forgings, as the next slide shows. A comparatively new forging alloy 79S when produced in the T 8 E 13 condition may be a solution to some of these distortion problems. Although at present its use is confined to hand forgings with two parallel sides and restricted to a maximum cross sectional area of seventy-two square inches and a thickness of six inches. Tests have indicated that heavier cuts may be taken on this material with much less distortion than that which occurs with 75S and 14S. Furthermore, the material is received in the T 8 E 13 condition and requires no heat-treatment after machining. With handforgings made from 75S or 14S it is customary to rough machine forgings in the as fabricated condition leaving about one - eighth to one quarter of an inch on all surfaces for finish machining after heat treatment.

I have reviewed some of our exceptional material problems we are now encountering and have purposely not mentioned conventional materials such as extrusions, castings and bar stock that we have used on previous programs and will continue to use.

So much for material coverage. Now to talk about machine tools.

SLIDE NO. 7

Our next slide will show a special saw which was designed and built by Avro Aircraft. This machine has cutting capacity for plate three inches thick and lengths up to twenty feet.

SLIDE NO. 8

The average time for cutting this three inch by twenty feet plate is fifteen minutes or one and one half feet per minute, giving an accuracy of plus or minus one sixteenth of an inch on the final width.

In preparing layout sketches for sawing it is essential that the grain-flow is taken into consideration, where any deviation from longitudinal flow is specified on the Engineering part drawing, allowance is made in the width of the blank to permit swinging of the part centre line to the required angle. After sawing, part blanks are numbered and marked with grain flow direction. Just as a point of interest, it was considered economical to locate this saw in our Material Receiving Stores where all cutting operations are performed, thus minimizing our Material handling problems.

When approaching the problem of heavy metal removal requirements along with complex shapes of heavy structural members we were forced to leave behind the rules that governed conventional Machine Shop practice. Speeds, feeds and H. P. requirements have to be tailored to suit the light alloys. Consequently, speeds of 3600 R. P. M., feeds of 100 inches per minute and up to one hundred H. P. are required. Large component parts require similarly large machines.

Few machine tool suppliers have such machines available as standard, in fact it is rare that two or more Aircraft Companies will have the same ideas where procurement of machines is concerned. The Machine Tool Manufacturers have, however, collaborated closely with the Aircraft Industry toward the establishment of standard specifications for large profile and skin milling machines.

Initially on our program we were concerned with procurement of machines capable of producing Wing skin panels and, also, machines suitable for profile milling ribs, spars and formers. Both types of machine would be basically similar in function, the difference being mainly in size of work to be handled. At an early stage Production Engineering and Design teams investigated Production methods employed by other companies and collected together all available information on Methods used.

Basic Design schemes, available for a number of Major components, were analysed. Specifications for the necessary machines were then prepared based on the preliminary scheme drawings and the information collected. It transpired that the machines required would be of copy Milling type, with possibly some automatic tracing features.

Copy Machining has, of course, in recent years become one of the most useful tools in the hands of the Production Engineer, with development proceeding at a rapid pace towards full automatic control.

SLIDE NO. 9

This Skin Milling Machine is now being installed at our Plant, and is equipped with automatic tracer control for both horizontal plane and rise and fall vertical plane movements.

The following figures will give you some idea of the size of our Machine.

Working surface of table - 9 Feet by 28 Feet

Total Weight - 100 Tons

Weight of Beam alone is 15 Tons.

Machines of this size require solid foundation.

SLIDE NO. 10

This slide will serve to illustrate better than words the extent of the foundation required for a Skin Milling Machine of this size. Some two hundred and fifty cubic yards of concrete were used for this foundation.

REVERT BACK TO SLIDE NO. 9

You will observe that the Machine is a gantry type. The tables stay put and the beam carrying the Tracer and Cutter heads moves over them. Advantages this type of Machine has over the moving table type is the saving in floor space and full utilization of work table.

The work table is equipped with a universal vacuum chuck. Holding of large sheets flat during machining operations is essential and has been accomplished most successfully with vacuum pressure. The vacuum chuck on this Skin Miller has provision for tilting in two directions and can be rotated on the Machine table to permit Milling of compound tapers and converging stringers.

The Tracer unit is located on an extension of the beam and follows the contour of templates which are mounted on the template table.

An indexing mechanism is provided whereby the horizontal cutter head can be indexed, across the beam, whilst at the same time the stylus is indexed over the template table in a direct ratio. This is accomplished automatically so that on the completion of one cut both cutter and stylus are indexed across the machine in readiness for the next cut.

Two spindle heads are carried on the Beam for horizontal and Vertical Milling. The Vertical head has provision for tilting the spindle in two directions.

SLIDE NO. 11

Our Design Engineers have co-operated wherever possible in eliminating unnecessary end Milling operations. Where end Milling is unavoidable, mismatch for cutter blend out has been provided. All blend radii are large to enable use of sturdy cutters.

SLIDE NO. 12

The present Skin Milling program necessitates use of the horizontal Milling head for the greater proportion of metal removal work on each panel.

Some idea of the speed with which metal is removed can be gained from the following example of a horizontal Milling cut. Employing rise and fall trace for thickness variation, width of cut two and one half inches, depth of cut one and one half inches, speed 3600 R.P.M., feed one hundred inches per minute. Cutter diameter ten inches.

This results in a metal removal rate of three hundred and seventy - five cubic inches per minute.

SLIDE NO. 13

It is intended that the large skin mill be supplemented by a smaller vertical profile Milling Machine. This machine, whilst not as large as the skin miller, is capable of handling work of similar proportions (twenty feet long by six feet wide). It also is equipped with horizontal and vertical tracing attachments, and is capable of performing many of the same operations.

Unlike the skin mill this machine is a planer type with moving table. The vertical type spindle head can be traversed across the beam, and this in turn can be raised and lowered relative to the work table. For horizontal Milling cuts an attachment is mounted on the spindle nose.

Three positions are provided on the spindle head for attachment of the horizontal plane hydraulic tracer unit. With this arrangement complete utilization of work table area is accomplished.

For rise and fall Milling a separate Tracer unit is employed. This is mounted on a fixed column off the bed of the machine. No direct mechanical tie-in with the spindle exists, vertical movement during rise and fall cuts is effected through an Electro-Hydraulic system from the Tracer unit.

Both templates and work are located on the Machine Table. On the large Skin Mill a separate template table is provided. However, both machines are intended to carry out similar operations in the Milling of Skin panels and though there are several differences between them we have been able to utilize the same tooling.

SLIDE NO. 14

A third machine which is also a gantry type machine, but smaller and much simpler, will further supplement the Skin Mill. This Machine is essentially a development of the power router. It will be used for end Milling and Routing operations only. Templates are mounted directly above the work as in sheet routing operations. Though this machine does not have all the automatic tracing features associated with the Skin Miller it is felt that a considerable metal removal rate can be achieved. Since there are no tilting features finishing operations are confined to parts in which pockets and peripheries are at right angles to the plane of the work table.

The working table on this machine can accommodate skins up to twenty feet by six feet. Unlike the large Skin Mill which has a single beam to the gantry the Invo Mill has two fixed beams.

SLIDE NO. 15

The cutting spindle is suspended between the two beams and can be rotated in its mounting. It is also provided with a pneumatic compensator which assists the operator in maintaining contact with the template.

The Machine operator rides on the gantry and his primary function is to keep the template follower in contact with the template. Control of directional movement is effected by a simple joystick, this also controls the rate of feed. The farther the "Joystick" is moved in any direction the greater is the speed of head travel in that direction.

A second lever controls the rotation of the spindle head in its mounting and also the direction in which the compensator pressure is applied. Actual contact of the follower with the template and therefore proper positioning of the cutter in relation to the work is maintained by pneumatic pressure through the compensator.

Two additional machines designed primarily for profile Milling integrally stiffened ribs, spars and formers are also in build at the present time. Both machines will be equipped with automatic tilting heads to facilitate production of bevel angles on Aerofoil contoured flanges.

SLIDE NO. 16

An essential feature of the tilting head is the location of the point of tilt. To simplify template manufacture, this has been arranged below the cutter head, and can be adjusted to coincide with the mould line of the part.

Control of tilt angle is effected by a template mounted on the side of the machine table; Linear rise and fall on the template is converted into an angular movement at the cutting head (Hydraulically).

One of these machines is virtually identical to the second skin Milling Machine which I have just described. The only basic difference being in the provision of the tilting head and additional tracer unit to operate same. The remaining machine has the same tilting features but is much smaller in size. The working table is four feet by eight feet and, on this machine, the beam is fixed, vertical adjustment of the spindle head is therefore effected through a slide behind the tilt quadrant.

SLIDE NO. 17

For 360° (Horizontal Plane) profiling we have, except in the case of the skin Milling machines, specified hand control. In our investigations we have found that hand profiling can be more advantageous.

Most automatic systems require the feed rate to be held at a speed slow enough to permit the tracer to negotiate sharp changes in direction at corners. With hand control, corners can be rounded at slow speed, and on straight or shallow contours higher feeds can be employed.

SLIDE NO. 18

Our next slide shows the floor layout of the machine we have just reviewed. The prime reason for concentrating all this equipment in a single layout is to isolate the problems we know we shall be encountering in a program of this type. Storage space for the fixtures and templates adjacent to the machines is proposed to reduce handling problems.

For the skin panels and larger forged billets special pallets and transport trolleys have been constructed. These provide for handling and storing of raw material and may be used as work tables for some of the initial operations. Special handling boxes for the smaller finished parts are a good insurance against the possibility of damage. A finished machined rib or spar is an expensive item and every precaution must be taken to avoid careless handling and consequent damage.

Modern high speed Aircraft require much closer control of assemblies to meet Aerodynamic requirements. This entails more accuracy in detail part manufacture.

SLIDE NO. 19

For profiling operations robust fixture design is essential, both part and template locations should be on a common base. Close co-ordination between pocket and external profile templates is mandatory to maintain flange and stiffener thicknesses and to eliminate tolerance build up. To this end it is necessary that both Tool and Quality Inspection departments keep a close watch on the Tools throughout the build period. At this time Inspection facilities can be incorporated in the fixture design, thus permitting inspection of first off parts in the fixtures, whilst they are on the machine. This obviates the need for inspection set-ups in the view room and provides a useful check on the accuracy of machine settings. In many cases the external shape of a finished part can only be defined by a Loft Line or Layout Line. It is therefore only possible to check such shapes to templates. By reducing the number of templates and using the one provided with the fixture it is possible to reduce errors.

Concurrently with the trend to integral structural members there is, also, the requirement for the fuel tight sealing of some areas of skins and structure, to provide Integral Fuel Cells, as shown on this slide of a test tank.

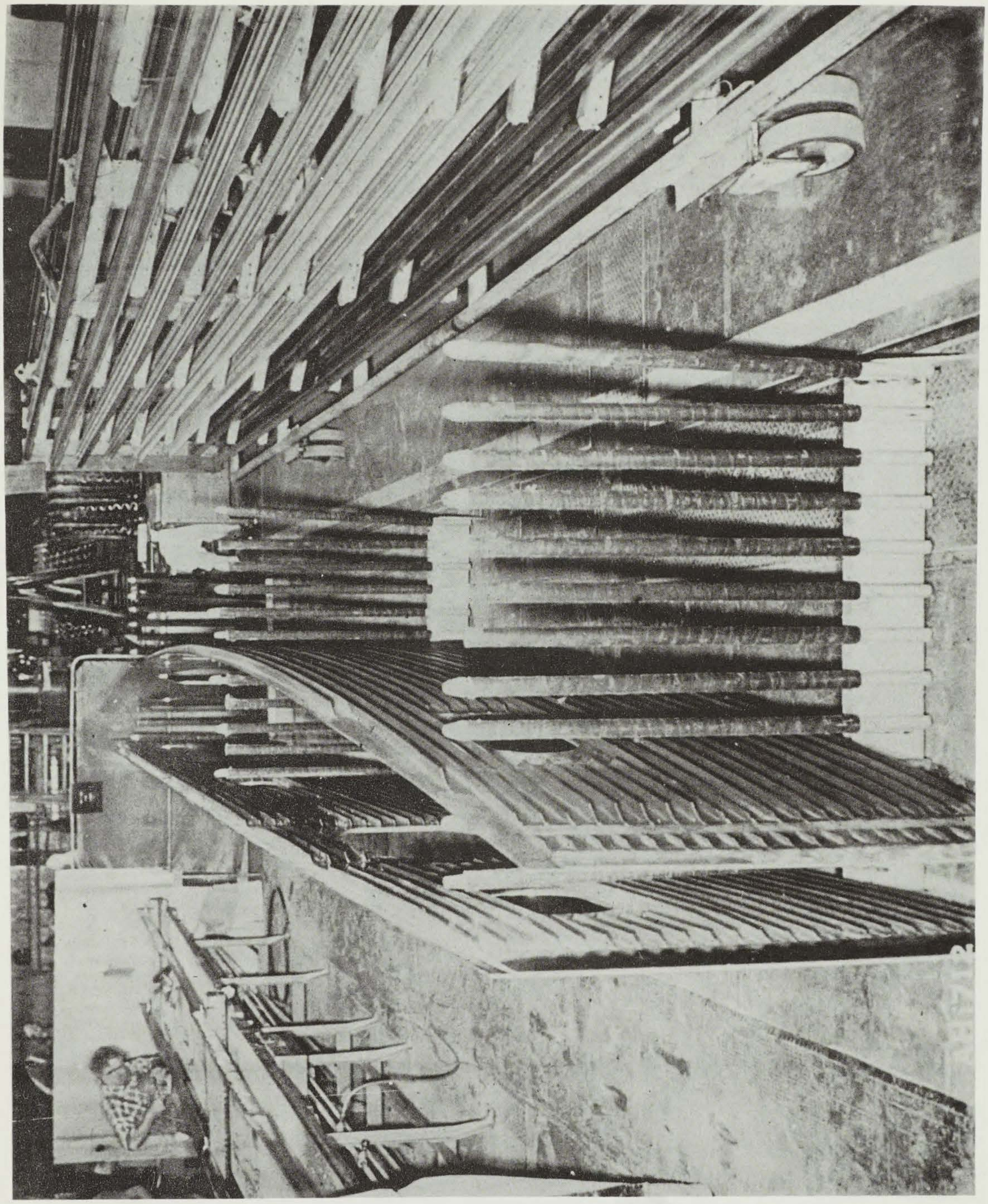
SLIDE NO. 20

This further complicates the assembly problems. To achieve efficient sealing, gaps at mating surfaces of fuel tight joints must not exceed three thousandth of an inch before application of the sealer. In spite of matched contour templates it is inevitable that mismatch will occur due to machining tolerances.

SLIDE NO. 21

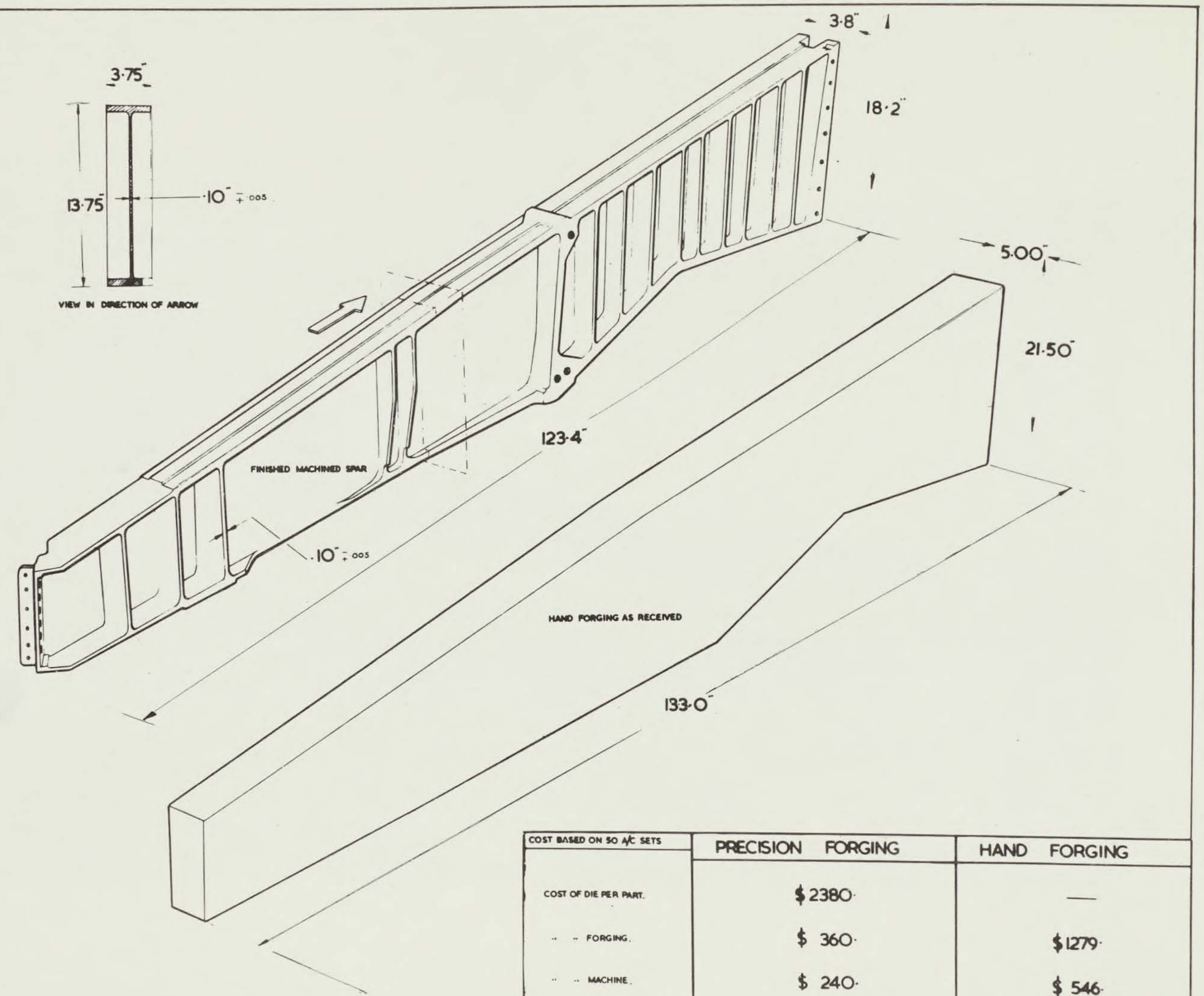
Correct and final matching can only be achieved on assembly by metal removal or by area build up. We decided that metal removal at assembly would be the most work-wise approach. This is accomplished by machining the span-wise members to their correct size and leaving a wedge of material on the chord-wise ribs where these ribs join together. The amount of metal left on the chord-wise ribs is between twenty thousandth and thirty thousandth of an inch thick and blends out to correct size five inches to six inches from the joint. This blending is done at Final Assembly with a portable hand sander.

This concludes my paper on the machining approach to Aircraft Production. Only a few highlights have been touched on today. The detail problems that have been worked out have made this an extremely interesting program for all of us. Completion of the work that still lies ahead I am sure will be equally interesting, keeping current with the vast amount of progress being made on Electronic Machine Tool automation and adapting these advances to Production makes the outlook for the future most promising.

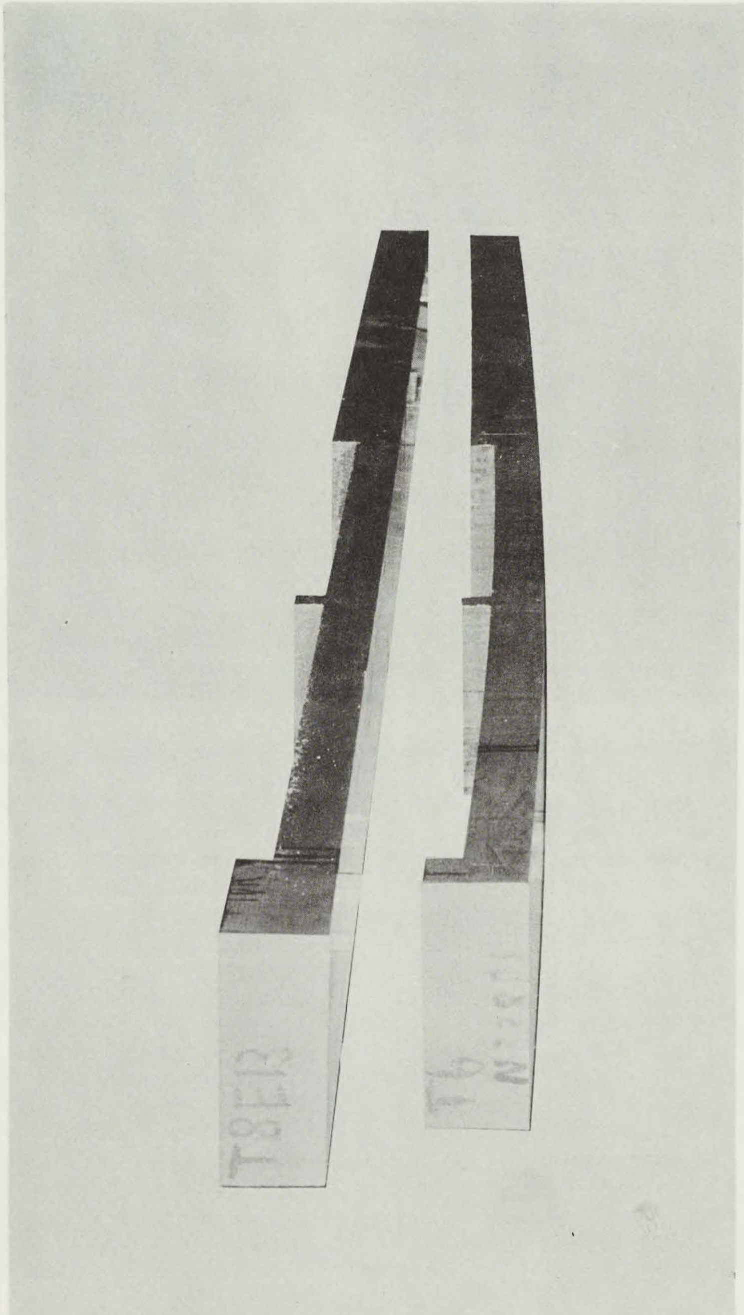


SLIDE 1

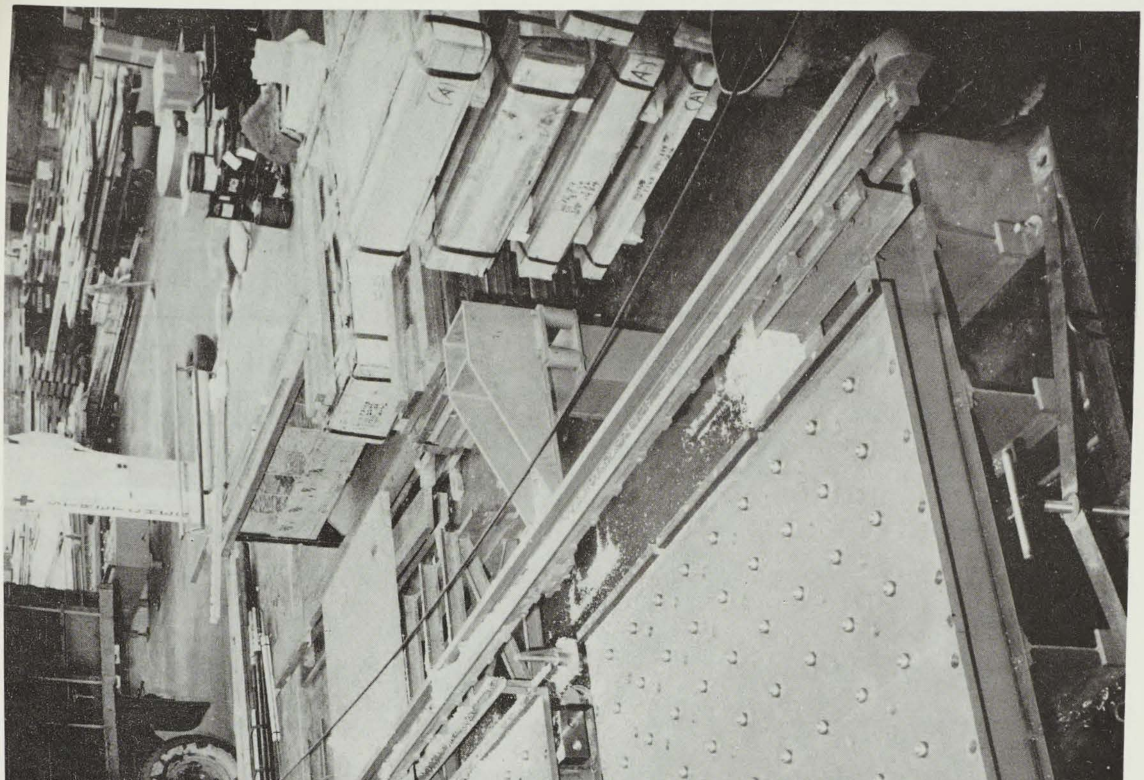
SLIDE 5



COST BASED ON 50 A/C SETS	PRECISION FORGING	HAND FORGING
COST OF DIE PER PART.	$2380·	—
" " FORGING.	$ 360·	$1279·
" " MACHINE.	$ 240·	$ 546·
TOTAL COST.	$2980·	$1825·

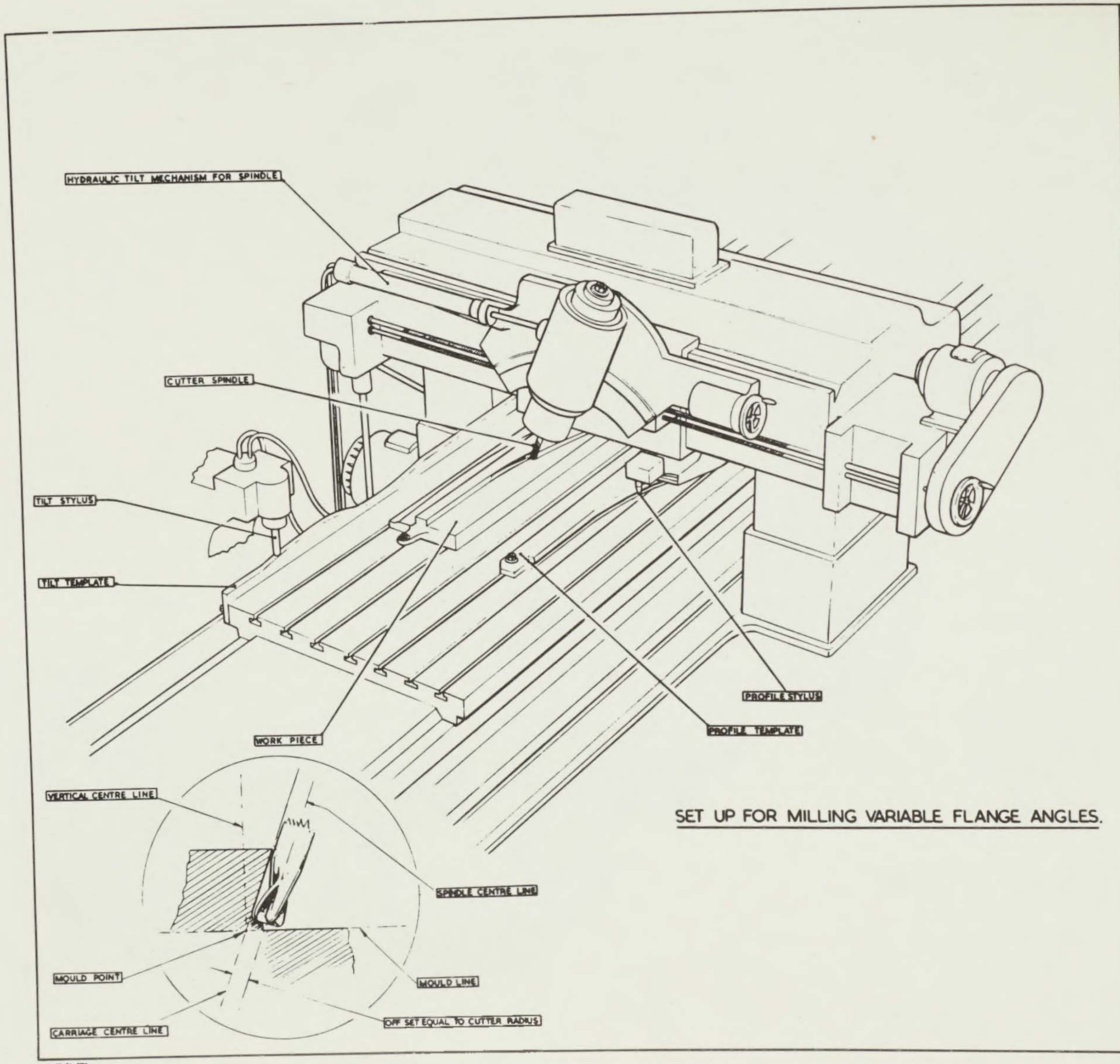


SLIDE 6

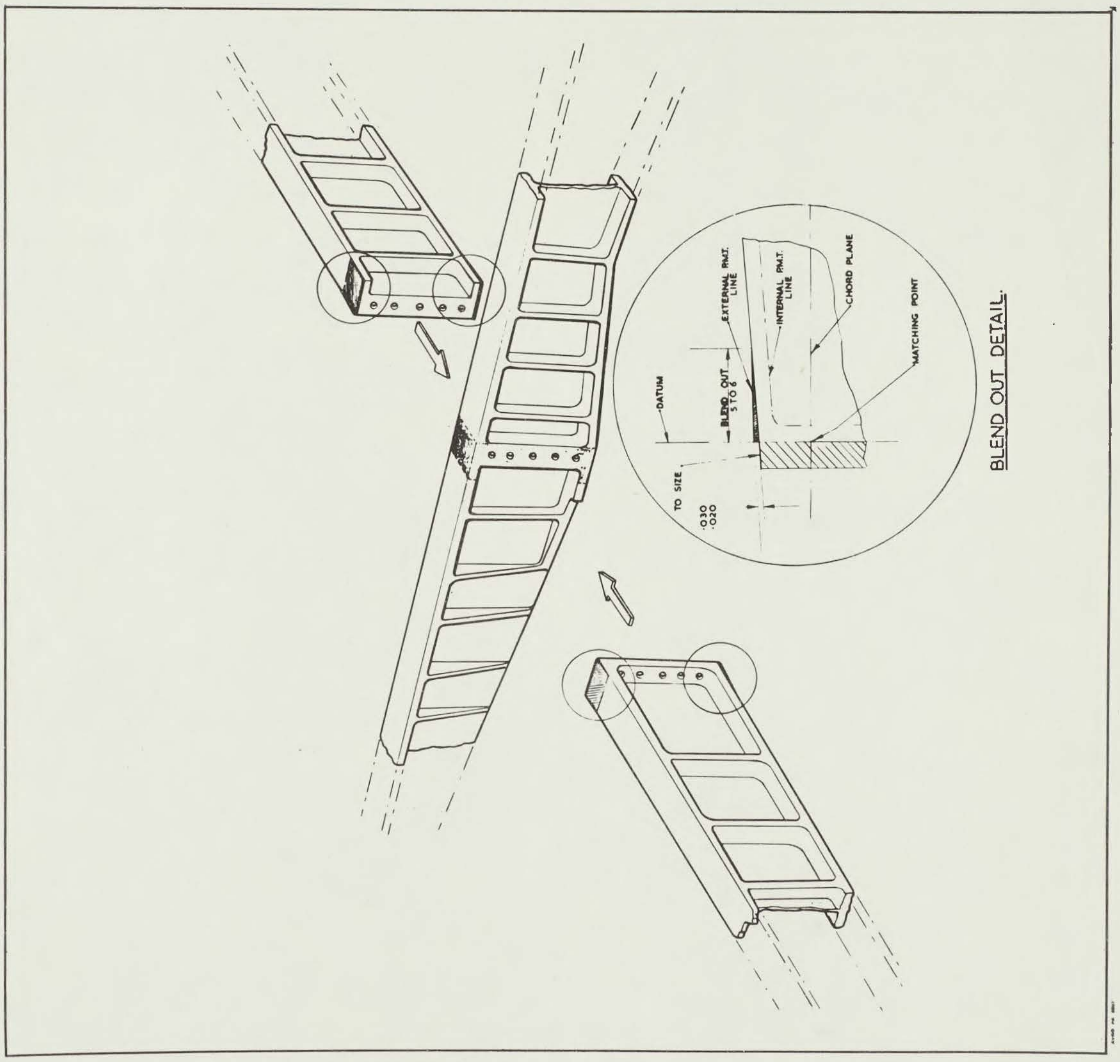


SLIDE 7

SLIDE 16



SET UP FOR MILLING VARIABLE FLANGE ANGLES.


BLEND OUT DETAIL.
DATUM
EXTERNAL P.M.T. LINE
INTERNAL P.M.T. LINE
CHORD PLANE
MATCHING POINT
TO SIZE

SLIDE 21