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C R A N F I E L D



An Interim Note on Machining
Super High Tensile Steel ^{3E}

- by -

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S U M M A R Y

A series of tests have been carried out to determine the machinability characteristics of Ultra High Tensile Steels in the 120 tons sq.ins. T/S range with hardness values of 550 to 600 V.P.N.

Tool geometry and cutting conditions for end and face milling, drilling and tapping were investigated. A basic approach to tapping tests and tap design was developed.

Short descriptions of the tests and a graphical presentation of the results are included. These show optimum conditions and the very critical nature of the variables on tool efficiency for the processes of drilling and end and face milling, under finishing conditions.

^{3E} This note is based on theses submitted in June 1958 by Ellis and Vicary in part fulfillment of the requirements for the award of the Diploma of the College of Aeronautics.

CONTENTS

	<u>Page</u>
Summary	1
Introduction	2
Section 1. The Properties of the Testpiece Material	2
Section 2. Descaling the Testpiece	3
Section 3. Sawing the Testpiece Specimens	3
Section 4. Drilling	4
Section 5. Tapping	6
Section 6. End Milling	12
Table 1.	17
Table 2.	18
Table 3.	19
Table 4.	20
Figures 1 - 31	
Graphs 1 - 9	

INTRODUCTION

The machining of high tensile steels in the range 110 to 120 tons UTS presents severe conditions of very high specific cutting edge loading, these conditions becoming more critical when complex tool geometry is necessary.

Preliminary investigations into the drilling, tapping, and milling, face milling and turning processes have been published (Ref.1). It has been found advantageous to resort to basic principles and hence gain more detailed knowledge of the machining characteristics of the material.

Steady progress has been made. The drilling results have enabled some 18 inches of hole length to be achieved per regrind. The tapping of this material has not been successfully carried out but work completed to date has revealed valuable information which suggests that the process will be accomplished with further tap and coolant development. End milling and face milling under finishing conditions may be achieved with one hour tool life per redress of the cutters. The results for rough milling have not proved so satisfactory and work is to be continued on this application.

SECTION 1.

The test pieces were supplied in the fully heat treated condition by Rolls Royce under ref. Snd./DMH.2/SM.

Test piece dimension:

Turned from 3.25 ins. square section to 3 inches diameter in soft condition.

Length 24 inches.

Material specification: Super Hykro to DTD.730

Chemical analysis:

Carbon	0.3 - 0.4%	Molybdenum	0.7 - 1.2%
Silicon	0.1 - 0.35%	Vanadium	0.1 - 0.3%
Manganese	0.4% max.	Sulphur	0.045% max.
Chromium	2.5 - 3.5%	Phosphorus	0.045% max.

Physical properties (supplied by Rolls-Royce)

Ult. tensile strength 120 tons/sq. in.

1% proof 80 tons/sq. in.

% elongation 12%

Izod impact 10 ft. pounds

Brinell 495

Hardness tests carried out at Cranfield before machining:

Lengthwise : 550 - 580 V.P.N.
Cross section : 550 - 585 V.P.N.

The results from hardness tests showed slightly greater hardness near the outer skin than in the core, see Figs. 30 and 31.

SECTION 2. DESCALING

The test pieces as supplied carried slight scale, the hardness V.P.N. 580 - 600. This scale was removed by turning with the cross chord tool (a Cranfield development). Full details of this tool are given in C. of A. report No. 58 - Interim report on turning Ultra High Tensile Steels).

Details of test piece preparation

The test piece was carried in a four jaw chuck. The lathe a 15 ins. centre, 50 h.p. Sculfort (French) in good condition. Centre drilling was carried out using a dormer standard H.S.S. centre drill, surface speed 15 ft. per minute, hand feed, coolant used 1 in 15 by volume, Shell M.3 soluble oil and water.

Turning using the cross chord tool with Per Pro A S. grade tungsten carbide tip.

Conditions for turning to remove scale :

Surface speed = 40 ft. per minute
Feed rate = 0.030 ins per revolution
Depth of cut = .035 inches variable due to distortion in material
Flood coolant 1 in 15 Shell M.3 soluble oil and water (by volume).

Under the above conditions no difficulty was experienced and the bars were parallel with good surface finish.

SECTION 3. SAWING THE TEST PIECE SPECIMENS

From the test piece descaled and centred one end, it was required to prepare six slices of $\frac{3}{4}$ inch thick, these being used for drilling and tapping test pieces.

The initial attempts to saw these slices from the bar using a Rapidor hacksaw and Eclipse HSS blade failed. No progress was made due to the relatively high saw stroke speed.

The problem was overcome by making a sawing attachment to be carried on the planing machine. This saw frame was made to clear the work on the return stroke and be capable of heavy positive loading during the sawing stroke.

Conditions for sawing :

12 ft. per minute

Eclipse HSS standard 4 teeth per inch saw

Cutting dry

Under the above conditions one slice per regrind of the blade was achieved. The regrind life of the saw was not exploited to the full and with some risk of work hardening and possibly damage to the blade, two or three slices may have been possible.

SECTION 4.

DRILLING

The slices from the test piece were face turned in the lathe to a thickness of $\frac{5}{8}$ inch. These were used for drilling tests, holes to be produced through their thickness, i.e. $\frac{5}{8}$ inches deep through holes.

The drill manufacturers were asked to co-operate in these tests. Many supplied test drills and some information. Two sizes of drills were adopted, these being $\frac{3}{8}$ " and $\frac{1}{4}$ " diameter, straight shank type.

All drills were hardness tested V.P.N. and selected to be of equal hardness for test. The web thickness was also selected to be approximately equal in all test drills, the hardness being checked after each test and regrind.

Regrinding of the Drills

An Ortlieb model O.S2 twist drill grinding machine was used. The grinding wheel was used at 5,000 ft. per minute surface speed, 60 grit Vitrified.

Coolant : Shell Soluber M.3 1 in 15 water; delivery 8 pints per minute.

Each drill was sparked out and checked for point angle symmetry by use of 25 magnification projector. This equipment also showed the straightness of the drills.

The Drilling Machine

A G.S.P. (French) 4 ft. 6 in. Radial Arm drilling machine was used, the drilling spindle located as near to the column as possible and securely

locked. All drills were carried in a $\frac{5}{4}$ inch capacity Jacob chuck checked for concentricity to 0.0002 inch run out max.

The test pieces were secured to the table of a Cranfield drilling dynamometer, from which thrust and torque loads may be obtained.

Drilling Tests.

Tests were carried out to select the optimum conditions of the following variables :-

- Spiral angle (From standard range available)
- Drill point angle
- Drill front clearance angle
- Surface speeds
- Feed rates

Different manufacturers' samples were also tested and the best performance accepted for all further tests.

The criteria used to determine the optimum in the above test was force measurements, thrust and torque. This method resulted in a number of drills and point geometry being reasonable equal. Further tests were carried out using length of hole drilled to destruction as the final elimination method.

The Dormer standard helix angle drills with the following point geometry proved best at this stage. (Work is continuing on drill selection).

- Helix angle 28° standard
- Drill point angle 110°
- Drill front (lip) clearance angle 12°

Conditions

- Surface speed 16 ft./minute
- Feed rate 0.002 inches per revolution
- Coolant 1 in 15 Shell M.3 soluble oil in water (by volume)

Under the above conditions using a mild steel break through backing plate under the test piece, the following results were achieved :-

<u>Drill</u>	<u>dia.</u>	<u>No. of holes</u>	<u>Total depth drilled</u>
1	$\frac{1}{4}$	28	17.5"
2	$\frac{1}{4}$	26	16.25"
3	$\frac{1}{4}$	30	18.75"
4	$\frac{1}{4}$	24	15.0"
1	$\frac{3}{8}$	24	15.0"
2	$\frac{3}{8}$	20	12.5"
3	$\frac{3}{8}$	28	17.5"

The end of drill life in the above test was at complete failure, i.e. one drill shattered, the remainder suffered breakdown of the chisel point or radial cutting edges.

The resulting holes from the above test were checked for size. It was found that all holes had good surface finish. The roundness and diameter depreciated with drill life.

The diameter of the $\frac{1}{4}$ " drill was found to be 0.251 initially and 0.254 towards the end of the drill life.

Further tests were carried out dispensing with the mild steel break through backing plate; all other conditions remained constant.

The results of these tests showed the average total depth drilled before failure to be only 6 inches.

This depreciation in drill life was due to the metal being deformed before break through, and eventually grabbing the final lip, causing cutting edge breakdown.

The investigation into drilling this material is continuing, together with coolant selection.

SECTION 5.

TAPPING

Many attempts have been made to tap ultra high tensile strength steels. The methods used have been a direct approach, i.e. to drive a tap through a drilled hole, and observe the results; various rotational speeds, coolants and tap geometry have been tried.

The progress made in this way has not been encouraging and it was decided to make a more basic approach to the problem as follows:

1. To use a circular thread chaser which could be economically and easily ground to assimilate any single tooth on a tap.

The variables to be investigated :-

Chip thickness per tooth

Radial rake

Helix angle

Surface speed

Tooth life

Coolants

Cutting force (Torque)

The above tests were to be carried out on each tooth form of taper, 2nd and plug standard taps.

2. With optimum geometry of the tap teeth and an efficient coolant, the torque on each tooth in a tap can be assimilated and measured. The sum of these torques would be an indication of the total torque to be carried by the tap.
3. Torque tests to destruction of standard taps - this to ensure that the tap material is capable of withstanding the torque required to drive it through the prepared hole.
4. From the knowledge gained from the tests in 1 to 3, it should be apparent whether the tapping of this material could be achieved.
5. The design of an optimum shape tap used under best conditions on which practical tapping test can be carried out.

Test procedure

Surface speed = 15 ft. per minute

Tooth load (chip thickness) = 0.002 inches (18 T.P.I. second tap 0.004 inches).

All chasers were carried by special adaptor in the Cranfield Lathe tool dynamometer.

The lathe was 15 ins. V.D.F. in new condition.

The test piece dimensions

24 inches long 3" dia. (2.5 inches dia. at end of test).

This was carried in a four jaw chuck and supported by a revolving tailstock centre.

All tests, except coolant tests, were made cutting dry.

Test Results - all based on 2nd tap taper angle.

Load tests

The torque was found to be proportioned to the width of cutting edge presented. 8, 10, 14 and 18 T.P.I. thread forms were tested. The results are included in Figs. 11 - 17.

Radial rake angle tests

An increase in radial rake angle showed small decrease in cutting forces (simulated by back top rake on the chaser - See Fig. 18).

Helix angle tests

These tests showed large decrease in cutting forces with an increase in flute Helix angle (simulated by side top rake on the chaser) See Fig. 19.

Surface speed tests

The optimum cutting speed was found to be from 15 to 20 ft. per minute. Any increase in this maximum resulted in rapid wear on the cutting edge. The effect of varying surface speed is shown in Fig. 20. Fig. 21 shows the effect of the width of cutting edge plotted against cutting forces.

Coolants test

Initial test on coolants was carried out. 1 vol. Shell M.3 in 20 vols. of water was found to reduce cutting forces significantly. The addition of 10% Wynns friction proofing liquid showed a further large decrease in cutting forces.

The results are included in Figs. 22 and 23.

A built up edge was present during cutting dry tests and to a lesser extent during coolant tests with coluble oil. The addition of 10% Wynns fluid eliminated all built up edge. (An extended coolants test programme is to be carried out).

The application of screwing results to the tapping process

The load - flank width graph for Whitworth form threads may be divided up for certain threads per inch values as in Fig. 24. The thread thickness at the root and crest form are considered as being made up of flats, i.e. radii being ignored.

Taking the 16 T.P.I. thread form, the depth of thread is 0.040 inches. The depth of the basic thread triangle (see Fig. 10) is made up of the depth of thread (h) + the basic truncation (S) at each end. The thread thickness at each end of the depth is thus a function of thread angle and Pitch (P)

$$\text{i.e. } t_2 = 2(h + S) \tan \frac{\alpha}{2}$$

$$\text{and } t_1 = 2.S.\tan \frac{\alpha}{2}$$

where t_1 and t_2 are thread thickness at the top and bottom of the form respectively and α is thread angle.

Both (h) and (S) are functions of the Pitch (P) of the thread,

$$\text{i.e. } h = 0.640327 P$$

$$\text{and } S = 0.160082 P$$

thus the thread thickness t_1 t_2 may be expressed for Whitworth form as

$$\begin{aligned} t_1 &= 2 \times 0.160082 P \times \tan 27\frac{1}{2} \\ &= 0.320164 P \times 0.52057 \\ &= 0.167P \end{aligned}$$

$$\begin{aligned} \text{and } t_2 &= 2(0.640327P + 0.160082P) \tan 27\frac{1}{2} \\ &= 1.600818P \times 0.52057 \\ &= 0.835P \end{aligned}$$

thus for 16 T.P.I. thread

$$t_1 = 0.167 \times 0.0625 = 0.0104 \text{ inches}$$

$$\text{and } t_2 = 0.835 \times 0.0625 = 0.052 \text{ inches}$$

Hence, the tap loading may be read off at 0.0104 inches and 0.052 inches flank width, Fig. 24 and presented graphically as Fig. 25.

The base of this graph (Fig. 25) is then divided up into the number of cutting edges necessary to give a tooth load of 0.002 inches. The sum of the separate tooth loads will give total tap load.

Fig. 25 consists of a rectangle, its height 6.5 pounds with a length of 20 threads and a height of $31 - 6.5 = 24.5$ pounds.

Thus, the sum of loads is given by

(a) The rectangle

$$= 20 \times 6.5 = 130 \text{ pounds}$$

(b) 20 x mean height of triangle

$$= 20 \times \frac{24.5}{2} = 245 \text{ pounds.}$$

Hence, total load = $245 + 130 = 375$ pounds and the calculated torque will be given by the result of total load x mean radius of the tap,

i.e. for 16 T.P.I. $\frac{1}{2}$ in. dia. tap 100% depth of thread,

$$\text{Calculated torque} = 375 \times \left(0.25 - \frac{h}{2}\right)$$

$$= 375 \times 0.250 - \frac{0.040}{2}$$

$$= 86 \text{ pound inches where } (h) = \text{depth of thread.}$$

The tap loading characteristic is that as each progressive cutting thread becomes engaged, the increment of load will be large at first, reducing with progress until all tapered and one full form thread is engaged. Thence the maximum torque will be experienced and this condition remain constant (other than swarf interference and full form friction) until the tap emerges from the end of the hole, when the load will be progressively reduced by increments in the reverse pattern as for tap starting. See Figs. 26 and 27.

Any change in the taper of the standard taps will not reduce the total loading but merely effect load distribution. Only a tap taper extending to a length which is greater than the depth of hole to be tapped can reduce the total loading.

Series type taps may be designed to give a reduced increment build up and reduced total loading. The series type will be investigated in a later programme, one disadvantage being the time required to use the complete series instead of one pass when standard full form taps are used.

Reduction in percentage of thread depth

"The influence of tap drill size and length of engagement upon the strength of tapped holes" by Oxford and Cook, a paper presented at a meeting of the A.S.M.E. December, 1954, Paper 54-A-85.

This paper suggests very little depreciation in the strength of tapped holes for a 25% reduction in thread depth. Hence, a major reduction of torque load increment can be achieved by this oversize hole method as the reduction in loading gained is derived from the first tooth on the tap, and these are carrying the major load increment.

This reduction in loading is presented in Fig. 28 in which total loading is plotted against % depth of thread, from which it is shown that an increase from 50% to 100% depth of thread, total load changes as 125 pounds and 375 pounds.

Tap Failure Tests

At the time the values for torque strength were required, no torque testing mechanism was available. The required values were obtained by inserting the taps to be tested into a flat bottomed previously tapped hole to a depth of twice their diameter. The tapped block (mild steel) was secured to a drilling machine table the taps were supported by a live centre in the machine spindle which followed the tap down as torque was applied through a spring balance and lever arm.

The results of these tests are included in Fig. 29. (This investigation will be continued using a torque testing machine), as it was found that rate of torque loading has an important effect on total torque applied before failure.

From the calculated results, on screwing and tests to failure on torque test, it would appear that successful tapping could be achieved.

The indicated values for $\frac{1}{2}$ in. B.S.F. tap 16 T.P.I. :-

Total torque load to be expected = 100 pound inches approx.
Torque failure of this tap = 800 pounds ins.

The following conditions were selected for the tapping test :-

The machine B.S.A. Huller No. 5 fitted with a spindle speed reduction gear box (condition as new).

The torque measurement - A Cranfield drilling dynamometer modified to withstand the greater torque loading.

Coolant : Shell M.3 soluble oil. 1 vol. in 20 vols. water.

Continuous flood supply.

Cutting speed = 15 ft. per min.

The taps selected for the test were :-

$\frac{1}{2}$ in. dia. B.S.F. 2nd tap and $\frac{3}{8}$ in. dia. Whitworth 2nd tap.

Both these have 16 T.P.I. thus providing a means of checking that the torque loads would be similar for similar thread cutting tooth form, and the torque should be proportioned to the tap diameters.

A trial run under the above conditions was carried out using a mild steel test piece and the results of these tests showed :-

Standard $\frac{1}{2}$ " B.S.F. 2nd tap 78% depth of thread

Maximum torque load = 112.5 pound inches

Standard $\frac{3}{8}$ " Whitworth 2nd tap = 86 pound inches

Standard taper angle = 8° Radial rake = $+5^{\circ}$

The table for chip thickness per tooth gives approximately 0.0022 inch for both the tested taps.

Tapping test on 120 ton steel

All taps failed by fracture at the driving square intersection before full engagement of the cutting teeth.

Discussion

There is probably a 50% increase in the torque experienced due to friction and distortion of the tap and workpiece material.

The rate at which the load is imposed is high, and the figures obtained for torque failure under rate of loading is to be investigated together with improved tap design.

SECTION 6 MILLING

Summary

Material Specification

The billet of material on which the tests were made was supplied by Bristol Aircraft Company.

Their specification BAC.A.1018.

110 tons 3% C_r - M_o Steel bars and forgings.

Limited ruling section 4 inches.

Specification based on D.T.D.551 modified to B.A.C. requirements.

- (a) Bars and billets for forgings
- (b) Black and bright bars for machining
- (c) Forgings

Chemical Composition

	<u>Minimum</u>	<u>Maximum</u>
Carbon	0.35%	0.45%
Silicon	0.10%	0.35%
Manganese	0.40%	0.80%
Nickel	0.40%	-
Chromium	2.90%	3.50%
Molibdenum	0.80%	1.20%
Sulphur	-	0.045%
Phosphorous	-	0.045%
Vanadium	0.10%	0.30%

Mechanical Properties

0.1% proof tensile stress	not less than 80 tons per sq. in.
Ultimate tensile strength	not less than 110 tons per sq. in. not more than 120 tons per sq. in.
Elongation	not less than 12%
Izod	not less than 10ft per pound
Brinell hardness number	
Softened condition	not more than 277
Hardened and tempered condition	not less than 489 not more than 533

The purpose of the investigation is to determine the machinability characteristics for finishing and roughing cuts and so evaluate the machining conditions required for economic production.

The method of approach was to investigate the effect of grades of Tungsten Carbide to be used as the cutting tools. Tool geometry and machining conditions on the rate of tool flank wear and to stipulate optimum valve to be employed which will result in economical tool life.

The variables to be evaluated for rough and finish machining. As the initial cost of Tungsten Carbide end milling cutters is relatively high it is suggested that drawing tolerances should be used to extend the size life of the cutters as follows :

Consider a $\frac{1}{2}$ " dia. cutter working in a component carrying $\frac{1}{4}$ " radius with $\begin{matrix} +0.005 \\ -0.000 \end{matrix}$ tolerance. The new cutter is specified 0.510 inches O.D.,

i.e. on top limit a 1 hr. service life as found from test results to lose 0.004 ins. on diameter in reservice. Hence 1 hr. would leave the cutter radius 0.253 ins. and a further 1 hr. life would bring the cutter to the lowest tolerance limit. After the third redress the cutter could be either used on wider tolerance work or used as a roughing cutter until reservicing brought the size down to the next standard when it would again give a series of dimensional lives or decimal tolerances may be met with very small losses from one size to the next lower size.

The results of the investigation to date are specifically for end and face milling. It was found that particular attention must be paid to rigidity and concentricity of the cutter and indeed all other machining variables in order for satisfactory results to be achieved.

The end milling results, included in Tables 1, 2 and 3 show that a tool life of 1 hr. could be achieved under the following conditions :-

Cutter diameter	= 0.375 ins.		
Grade of carbide	per pro P.C. Grade		
Low helix angle (15°)		High helix angle (30°)	
Radial rake	= 0°	Radial rake	= $+5^{\circ}$
Primary clearance	= 8°	Primary clearance	= 8°
Secondary clearance	= 12°	Secondary clearance	= 12°
Cutting speed	= 25ft. per min.		
Tooth load	= 0.0015		
Depth of cut	= 0.025 ins.		
No coolant was used.			

Great care must be taken when cutter workpiece contact is made due to the brittle nature of small diameter solid tungsten carbide tools of this type. With face milling a more robust cutter may be used and the results of tests for finishing conditions show that 100 minute cutter life can be achieved under the following conditions.

The cutter standard per pro 4 in. dia. 6 tooth face mill the teeth are brazed to the cutter body.

Grade of carbide Per Pro A.S. Grade

Tool Geometry.

Axial angle	= -10°
Radial rake	= 0°
Primary clearance	= 2°
Secondary clearance	= 6°

Face clearance = 6°
Chamfer angle = 30°

Machining conditions.

Cutting speed = 80 ft. per min.
Tooth load = 0.0015 ins.
Depth of cut = 0.050 ins.
No coolant was used.

Machining Variables

The severe cutting conditions presented by this test piece material in the fully heat treated condition necessitates that precise control must be maintained over all elements in the cutting operation and where possible optimum conditions must prevail.

The variables which are investigated and on which work is continuing are as follows :-

1. Depth of cut
2. Cutting speed
3. Tooth load
4. Cutting tool material
 - (a) red hardness
 - (b) strength compressive and shear
 - (c) resistance to physical or thermal shock
 - (d) resistance to abrasion
 - (e) resistance to the formation of burnt up edge (gawling)
 - (f) low coefficient of friction
 - (g) capable of taking a good surface finish

Cutter Geometry

- (a) Number of teeth
- (b) Cutter diameter
- (c) Radial rake
- (d) Helix angle
- (e) Primary and secondary clearance angles
- (f) Chamfer angles
- (g) Width of land (primary clearance angle)

- (h) Radius effects
- (i) Positive and negative helix angle effect

Evaluation of Coolants

This interim note reports the results from work carried out to date which is presented as early as possible to be of benefit until completion of the investigations can be reported.

The included graphs Nos. 1 to 9 are self explanatory. From these graphs it is clearly seen the critical nature of the variables and the deterioration in efficiency with but small deviation from optimum conditions.

Work on the conditions for rough machining has not revealed results which can be considered economical. Further development is to continue and will be reported in further Notes, to be published as information of value is available.

TABLE 1

EXPERIMENT : END MILLING Tungsten Carbide
REMARKS : LIFE TEST Tipped

CONDITIONS

1. <u>Tool Geometry</u>			<u>Flank Wear on Each Tooth</u>				
			<u>Passes</u>	<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>
No. of Teeth	=	4	10	3	4	3½	3
Diameter	=	⅜"	15	4	4	5	3
High Helix Angle			25	4	6½	6	3
Radial Rake	=	+5°	35	8	9	7	6
Pry. Clearance	=	6°	45	11	11	14	11
Sec. Clearance	=	10°	55	13	15	16	12
			65	18	22	24	20
			75	21½	26	26	21
			85	26	30	29	23
			88	Cutter fractured.			
2. <u>Cutting Conditions</u>							
R.P.M.	=	250					
Feed Rate	=	1⅝					
∴ Tooth load	=	.0016					
Depth of cut	=	0.020"					
Pass Time	=	30 secs.					
Coolant		None					
Flank wear in 1/100 mm							
							Total cutter life = 44 mins.
							Loss on diameter to reservice
							= 0.004"
Machine :-		Loewe FH5 Horiz. Mill.					

TABLE 2

EXPERIMENT : END MILLING

Tungsten Carbide
Tipped Tooth

REMARKS : LIFE TEST

CONDITIONS

1. <u>Tool Geometry</u>	Passes	<u>Flank Wear on each tooth</u>			
		1	2	3	4
High Helix Angle (R.H.)	5	-	-	6	-
No. of Teeth = $\frac{4}{8}$ "	10	-	-	6	-
Cutter dia. = $\frac{3}{8}$ "	20	1 $\frac{1}{2}$	1 $\frac{1}{2}$	8	-
Radial rake = +5°	30	2	4	8	2
Pry. clearance = 8°	40	4	5	8	3
Sec. clearance = 12°	50	4	6	9	5
2. <u>Cutting conditions</u>	60	5 $\frac{1}{2}$	8	10	5
R.P.M. = 250	70	6 $\frac{1}{2}$	10 $\frac{1}{2}$	11	6
Feed Rate = $\frac{5}{8}$	90	12	17	14	11
∴ Tooth load = .0016	100	12	17	14	11
Depth of cut = 0.020	110	15	20	14	12
Pass Time = 30 secs.	120	21	21	17	21
Coolant = None					
Flank wear in 1/100 mm.					

Machine :- Loowe FH5 Horizontal Miller

Total cutter life = 1 hour

Loss in diameter to reservice = 0.003"

TABLE 3

EXPERIMENT : PERPRO END MILL
(LOW HELIX ANGLE)

CONDITIONS

1. Tool Geometry

	Developed Geometry	As Received	Time per pass = $\frac{1}{3}$ min.
			Wear measured in 1/100 mm.
Helix angle =	15°	15°	<u>1st test as received</u>
Radial rake =	0°	- 5°	
Pry. Clearance =	8°	3°	Tooth 1 2 3 4 5 6
Sec. Clearance =	12°	10°	
No. of Teeth =	6	6	
Cutter dia. =	$\frac{3}{8}$ "	$\frac{3}{8}$ "	Wear after 15 mins. 27 21 18 0 8 23.5 Flank Chip

2. Cutting Conditions

- R.P.M. = 250
- ∴ Cuttin Speed = 25 ft. per min.
- ∴ Feed rate = 2.3 ins/min.
- ∴ Tooth Load = 0.0015
- ∴ Depth of Cut = 0.025"
- Coolant = None

See following page for test with developed geometry.

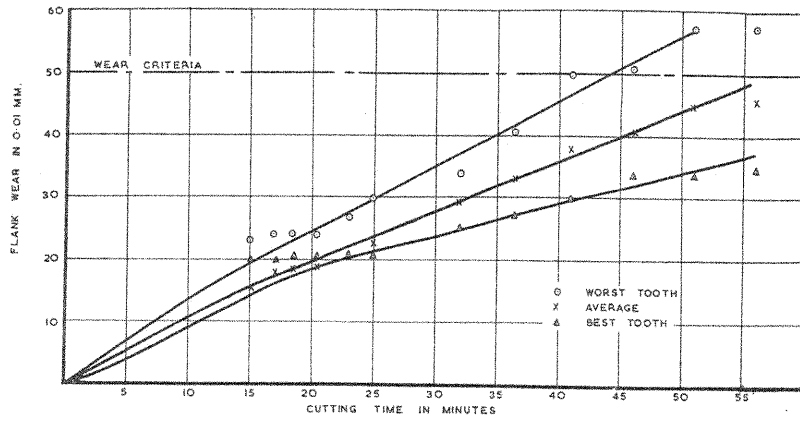
TABLE 4.

EXPERIMENT : CONTINUED

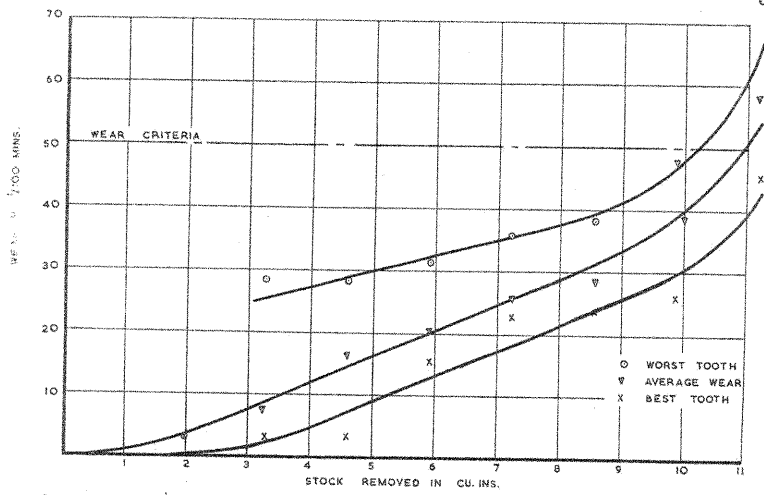
Passes	Measurement of flank deterioration in 1/100 mm.																		MV
	1			2			3			4			5			6			
25	2			6.5	5		10			0			0			3.5			
30	2			6.5	6	4	10	3.5	3.5	0			4.5			3.5			
35	2			8.0	6.0	4	10	4.5	3.5	0			4.5			5			
40	2			8.0	6.0	4	10	5	4.5	4.4	0		5.5	1		8	4		
45	3.5			8.0	6.0	4	13.5	10	5.5	4.8	0		6			8.5	5		
50	4	2.5	2	9	6.0	4.5	14				0		6			8.5	6		
55	7	5	2.5	2	10.5	7	4.5	2			0		6.5			8.5	5.5	3	
60	7	5	2.5	2	10.5	5					0		6.5			8.5	5	5	
65		6.5	5		16	12.5	5				0		6.5			9	5	4.5	
70	10	6.5			16	10	10				0		6.5			9			
75	12				16						0		6.5			9			4.8
80	12				16						0		7.5			9			
85	12				16						0		7.5			9			4.85
90	12				16						3		7			9			5.0
95	12				16						4		7			9			4.8
100	12	7.5	5.2		17						5	5	7			9			4.8
105	12	7	6	3	17.5	14					8		7			9	5.5	5	4.9
110	12	7	6	3	17.5	14	5	5	15	15	8		7			6.9	5.5		4.8
115	12	7.5	5	5	17.5	14			15	9	8		7			9	8	5	
120	12	7.5	6	5	17.5	14			15	9	7.5		7			6.9			
125	12	7.5	7		17	15			15	12	10	9.5	8	5	5	9	6	5	5.1
130	12	9	7	6.5	17	16			13				8			9	7	5	5
135	12	9	7.5		17				13	13	13		8.5			9	6.5	6	5.1
140	12	9		6.5	18				13	13	13	14	10	7		9	6.5	5.5	5.4
145	12			6.5	18	6.5			13				10	8.5	5	9	5.5	6	5.3
150	12				18				13				10.5	8		9	7		5.25
155	12	12			18				14				10.5	0.5		9	8		5.6
160	12				18				14				13			9	8		5.7
165	12				18				14				14	5		9	8		6.0
170	12				18				14				14	5		9	9		6.3
175	14				18				14				14	5		9	9	9.5	6.5
180	14				19				14				14	5		11.5			6.75
													15			11.5			5.8

180 passes at 1/3 min = 1 hours tool life before re-servicing.

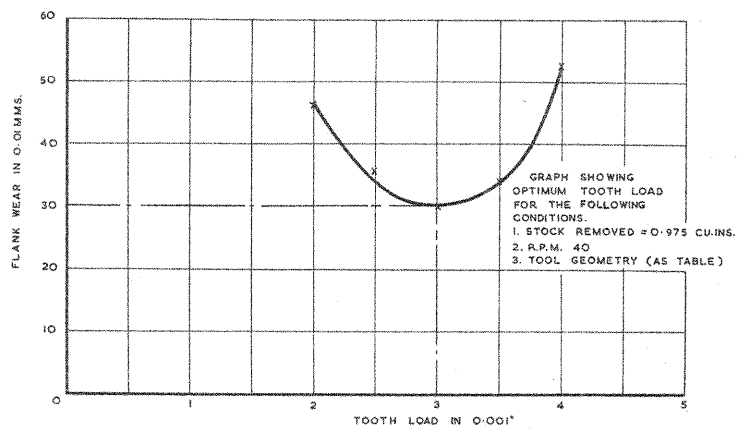
NOTE: The several figures under each tooth for the same pass are the values of flank wear and chips at various positions along the cutting edge of the tool. These readings were kept to determine whether, once a chip had formed, it spread along the flank or whether in fact fresh chips were formed. The latter was correct.



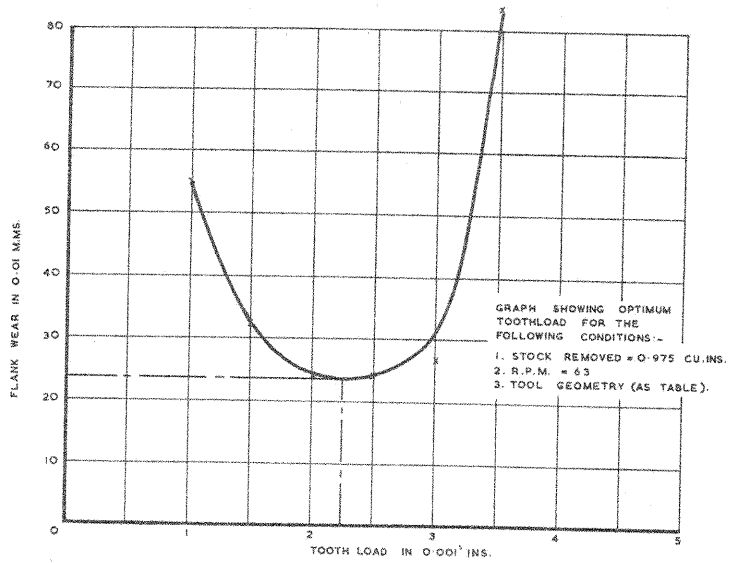
GRAPH 1
 LIFECURVE FOR 4" DIA. 6 TOOTHED A.S. GRADE (PERPRO) TUNGSTEN CARBIDE TIPPED FACE MILL, CUTTING AT 63 R.P.M. & 0.825 INS./MIN. FEED (TOOTH LOAD = 0.002) DEPTH OF CUT 0.025" TOOL GEOMETRY AS TABLE.



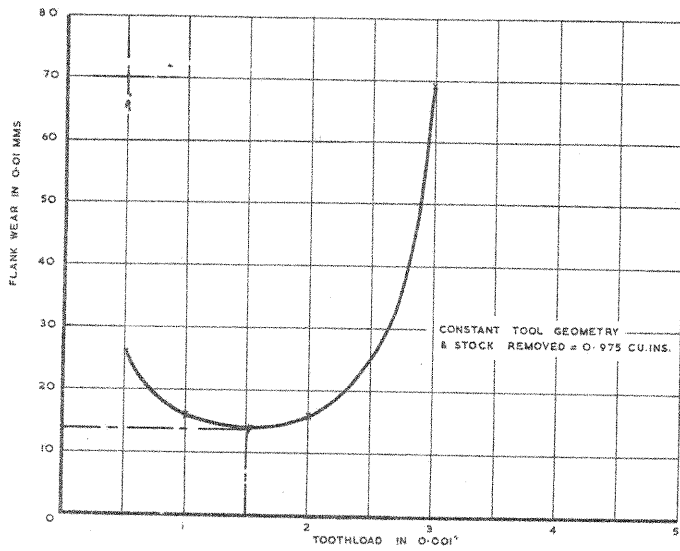
GRAPH 2
 LIFECURVE FOR 4" DIA. FACE MILL WITH A.S. GRADE (PERPRO) TUNGSTEN CARBIDE TIPS TAKING 0.05" DEPTH OF CUT AT OPTIMUM SPEEDS & FEEDS.



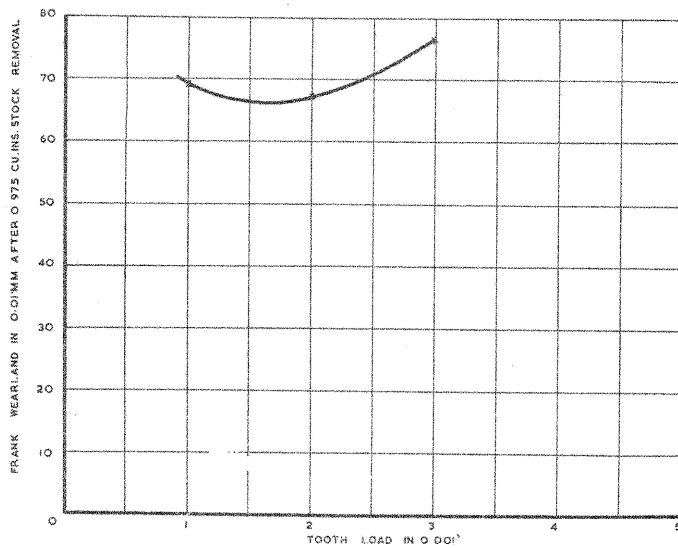
GRAPH 3



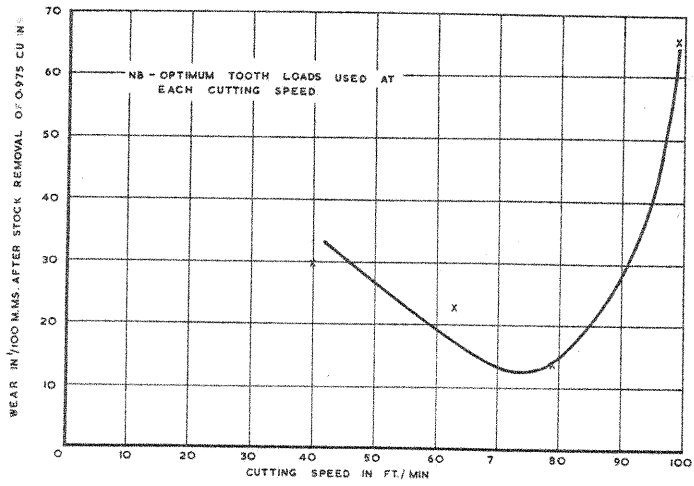
GRAPH 4



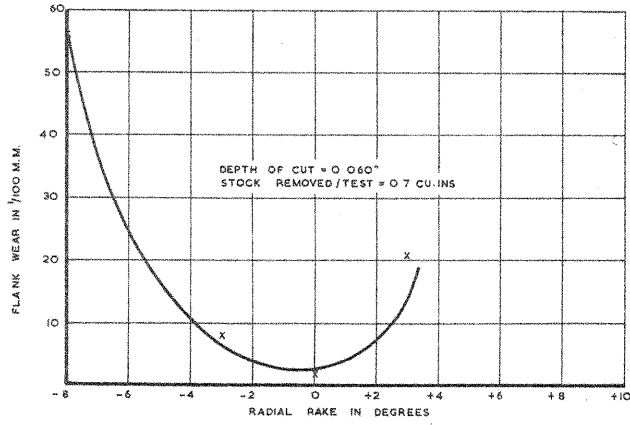
GRAPH 5
OPTIMUM TOOTH LOADING FOR 79 R.P.M.



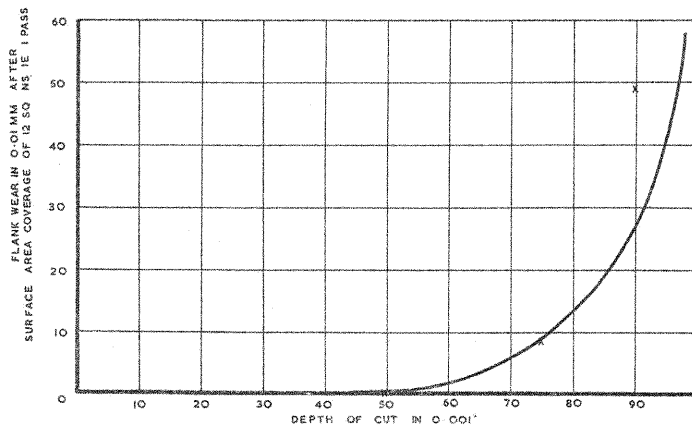
GRAPH 6
OPTIMUM TOOTH LOADING FOR 99 FT./MIN. CUTTING SPEED.



GRAPH 7
EFFECT OF CUTTING SPEED ON RATE OF FLANK WEAR.



GRAPH 8
DETERMINATION OF THE BEST RADIAL RAKE FOR CUTTING SPEED OF 80 FT.P.M. & TOOTH LOAD OF 0.0015.



GRAPH 9
EFFECT OF DEPTH OF CUT ON RATE OF WEAR.

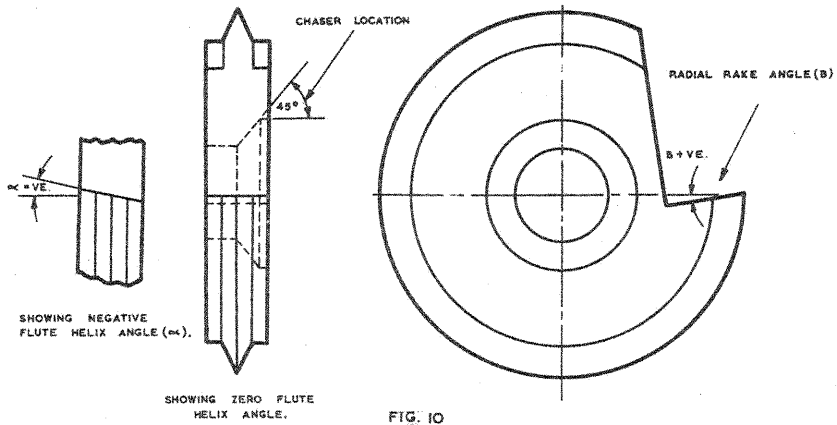


FIG. 10
MACHINE CHASER DETAILS
(SINGLE CUTTING EDGE ONLY SHOWN)

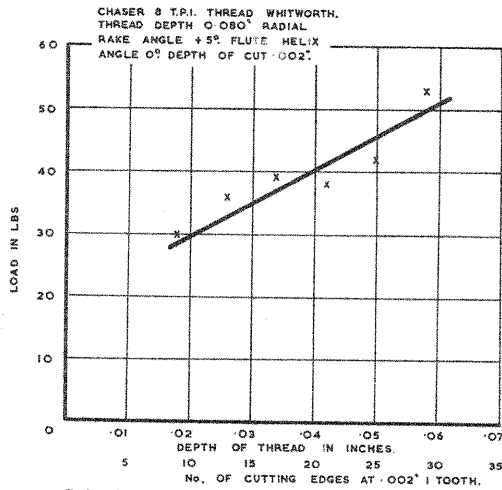


FIG. 11
CUTTING LOADS FOR 8 T.P.I. CHASERS.

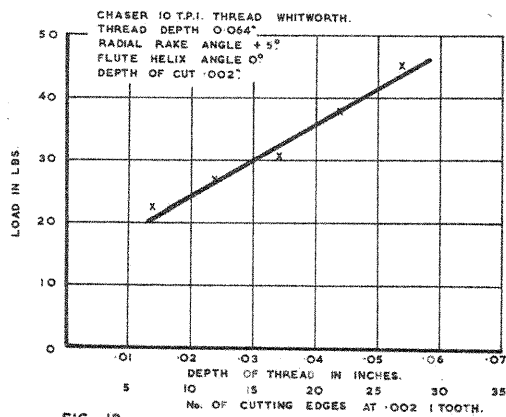


FIG. 12
CUTTING LOADS FOR 10 T.P.I. CHASERS.

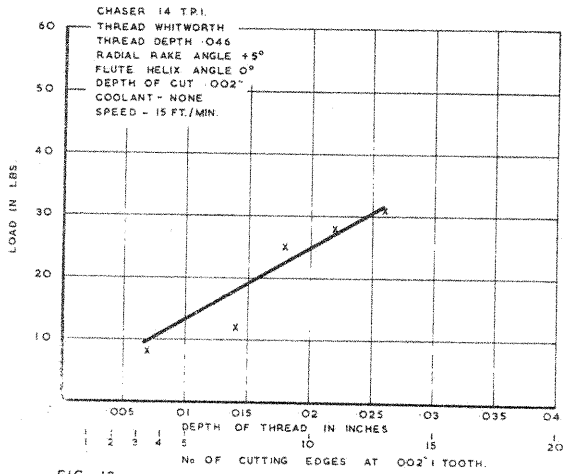


FIG. 13
 CUTTING LOADS FOR 14 T.P.I. CHASERS.

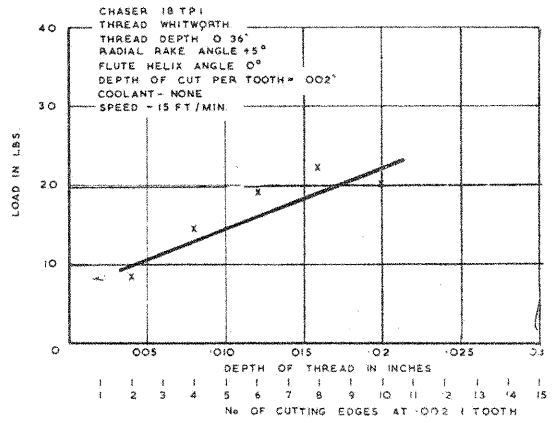


FIG. 14
 CUTTING LOADS FOR 18 T.P.I. CHASERS.

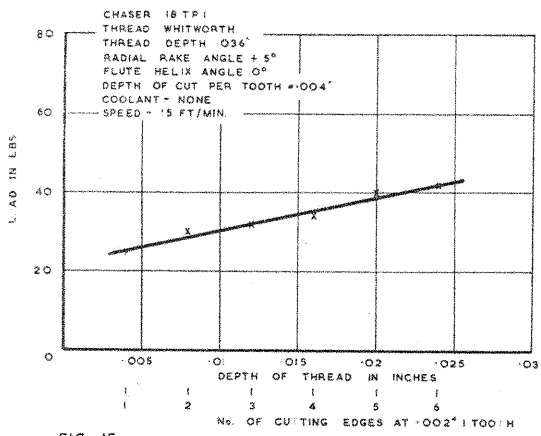


FIG. 15
 CUTTING LOADS FOR 18 T.P.I. CHASERS.

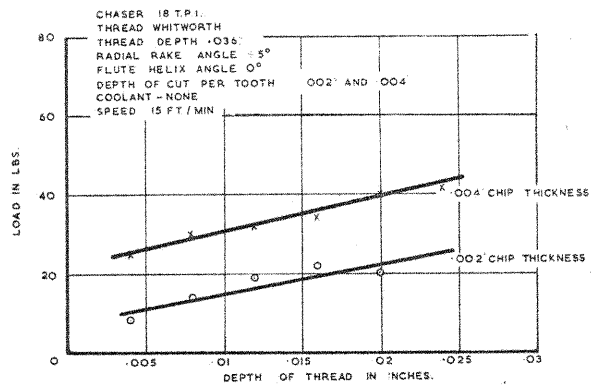


FIG. 16
 THE EFFECT OF CHIP THICKNESS ON CUTTING LOAD.

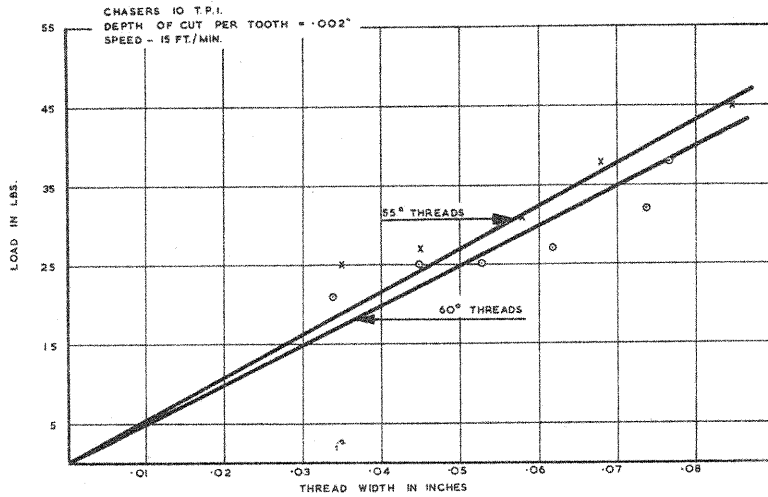


FIG. 17
CUTTING LOADS (DRY) FOR 55° AND 60° THREADS

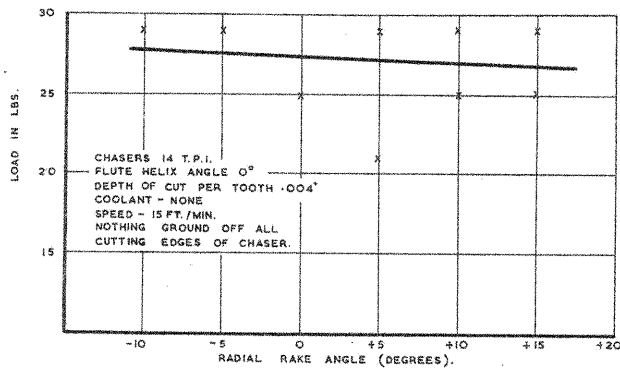


FIG. 18
THE EFFECT OF RADIAL RAKE ANGLE ON CUTTING LOADS.

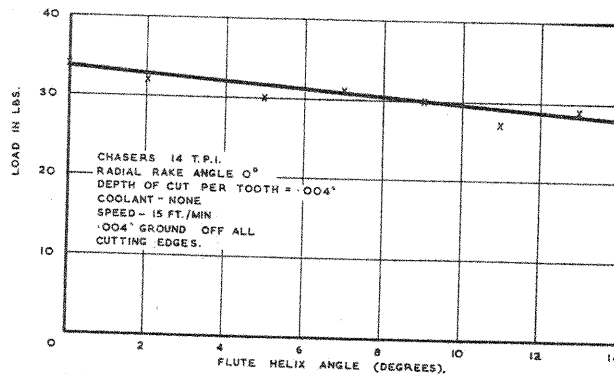
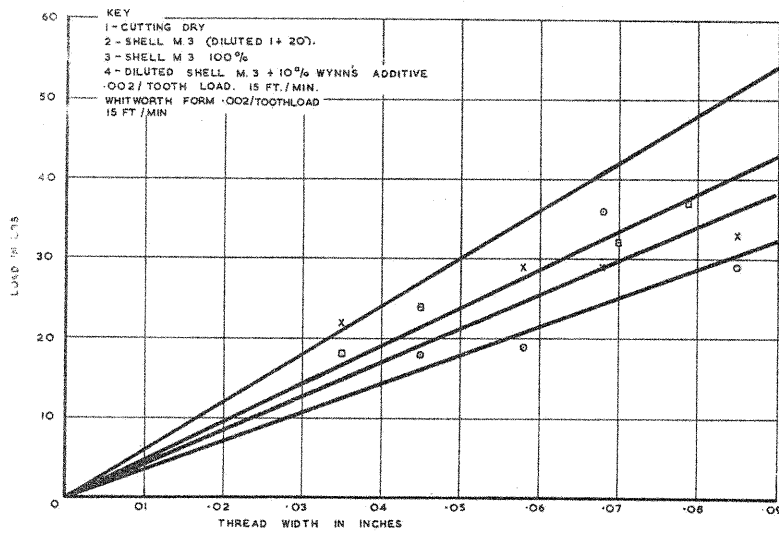
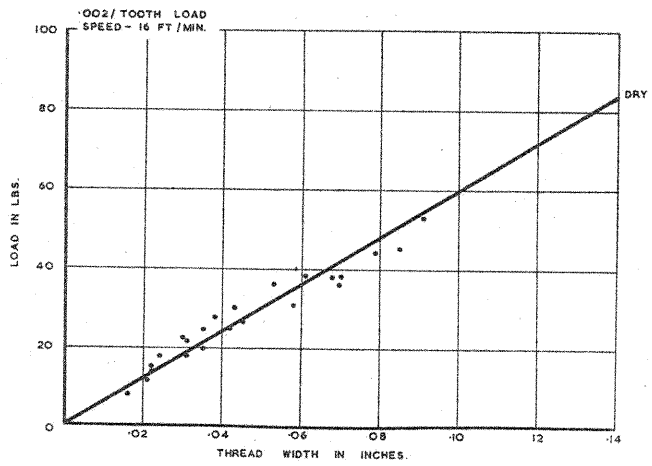
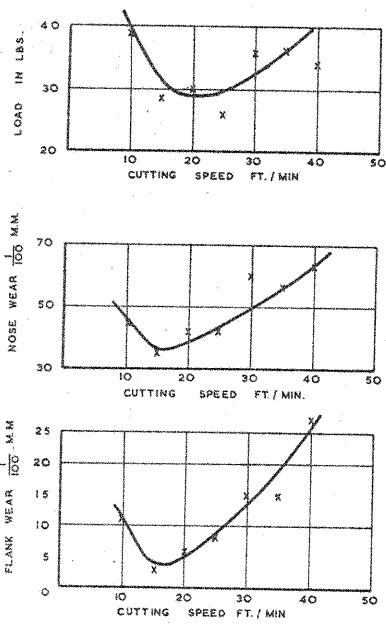


FIG. 19
THE EFFECT OF FLUTE HELIX ANGLE ON CUTTING LOADS.



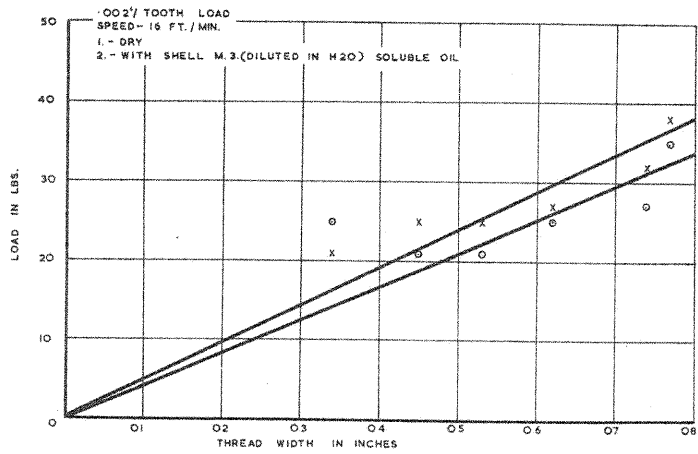


FIG. 23
LOAD - THREADWIDTH GRAPH FOR 60° (METRIC AND UNIFIED
THREADS.)

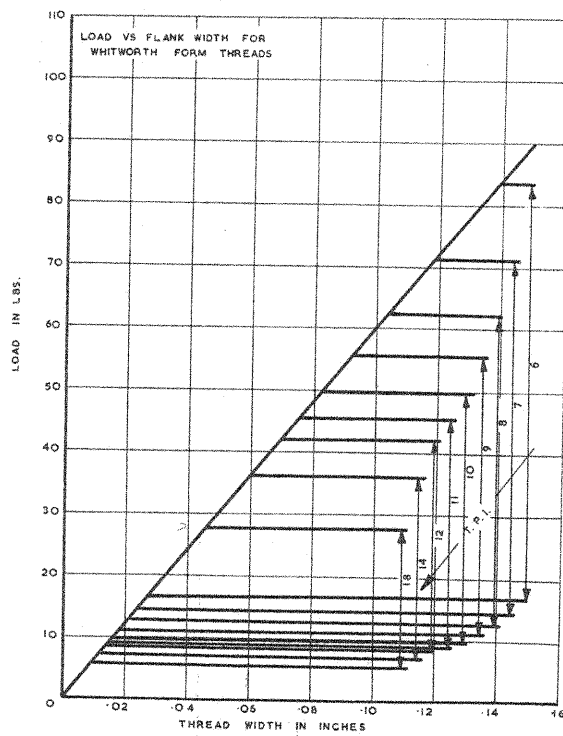


FIG. 24

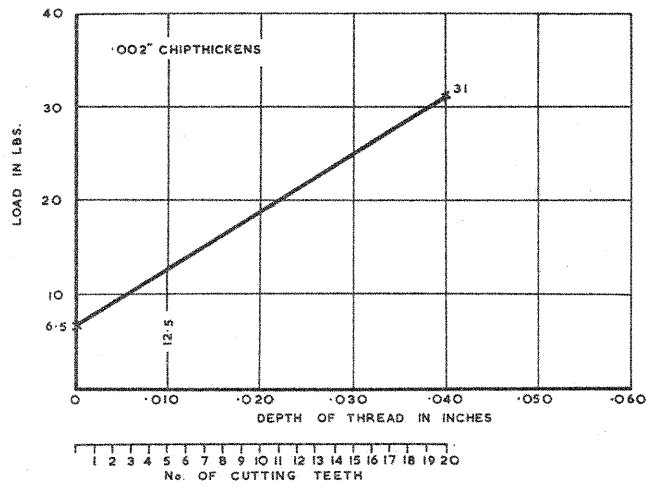


FIG. 25
 EXPECTED LOADS FOR A 16 T.P.I. TAP 100% DEPTH
 OF THREAD.

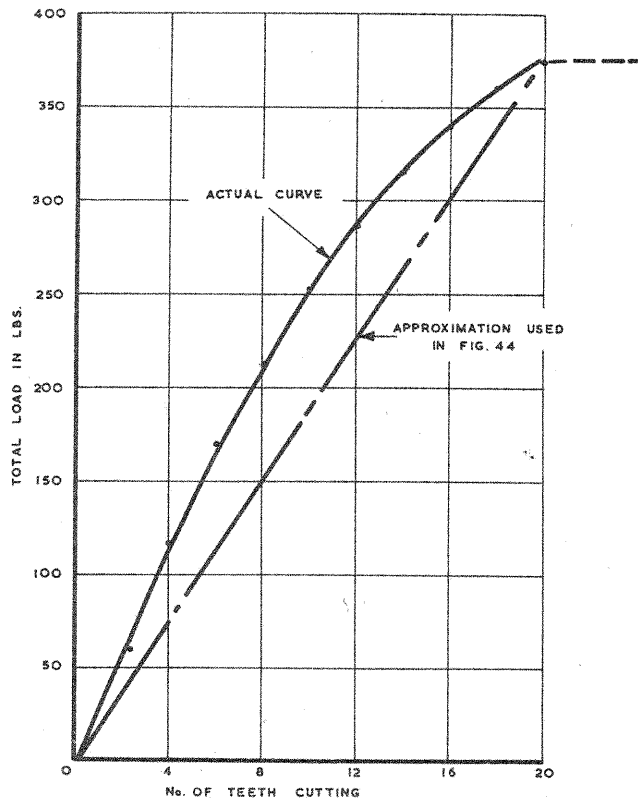


FIG. 26
 THE BUILD UP OF CUTTING LOADS WHEN
 TAPPING 100% DEPTH OF THREAD.

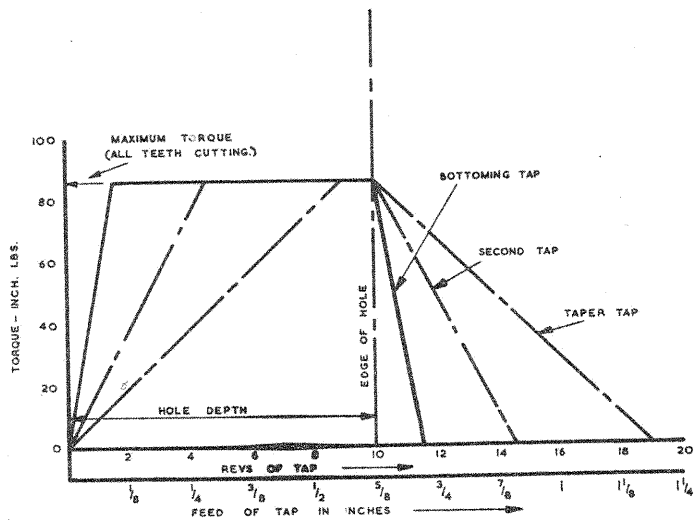


FIG. 27 TAPPING TORQUE CURVES FOR DIFFERENT TAPS (PLOTTED FROM SCREWCUTTING RESULTS).

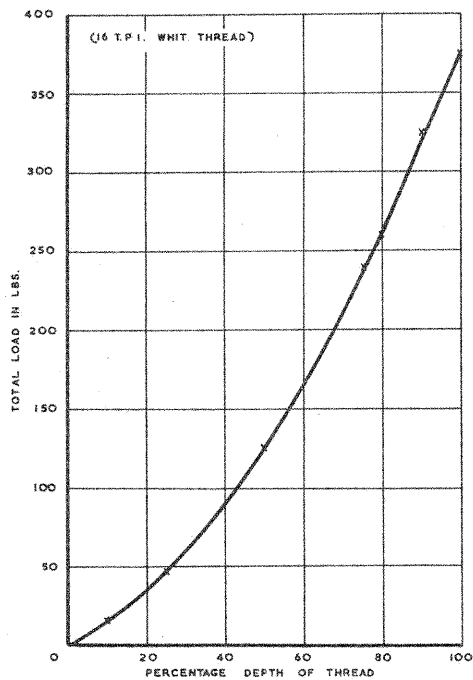


FIG. 28 THE EFFECT OF PERCENTAGE DEPTH OF THREAD ON CUTTING LOADS.

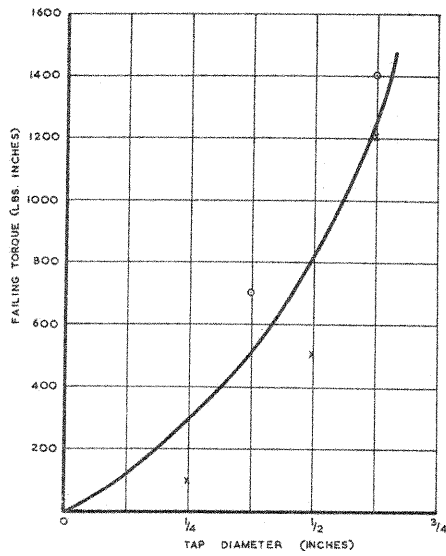
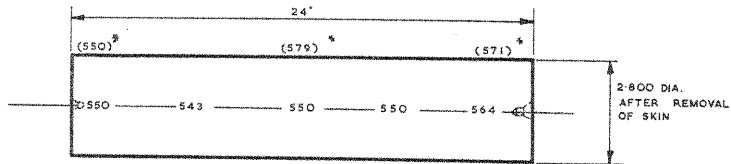


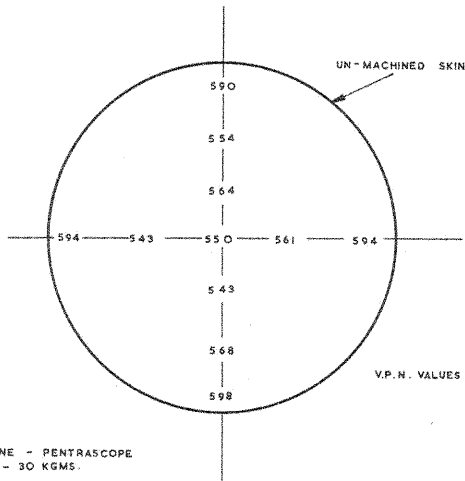
FIG. 29
 FAILING TORQUES FOR TAPS IN TORSION AFTER
 BOTTOMING IN A BLIND HOLE OF DEPTH EQUAL
 TO TWICE THE TAP DIAMETER.



PENETRASCOPE V.P.N. VALUES
 LOAD - 30 KGMS.

LONGITUDINAL HARDNESS VALUES. * AFTER REMOVAL OF SKIN
 * BEFORE REMOVAL OF SKIN

FIG. 30
 SUPER-HYDRO 12 TON TEST BARS.



MACHINE - PENETRASCOPE
 LOAD - 30 KGMS.

FIG. 31
 CROSS-SECTION OF BAR 3" DIAMETER SHOWING
 OUTER HARDER BAND.