26-8-55

PRODUCTION OF SMALL PROPELLERS WORKING NEAR THE CAVITATION ZONE.

BY R.T.WRIGHT

Introduction.

It may well be asked why the particular reference in the title of this paper is to small propellers working near the cavitation point. The reason is that all the work outlined herein was undertaken in order to solve the particular problem of ensuring maximum performance of an existing type of high speed craft fitted with a previously selected type of machinery. The high thrust loading on the fitted propellers had given rise to some doubt about their efficiency in service, and it was evident that under certain loading conditions cavitation was being experienced. Further experience had shown that in tropical and sub-tropical waters the original propellers, cast in manganeze bronze, deteriorated very quickly, being very badly pitted around the edges and on the faces of the blades due to corrosion, andstriated on the backs of the blades, and to a lesser extent on the faces, due to erosion. In overcoming these problems, methods, first of satisfactorily casting the propellers in aluminium bronze, then of maching the faces of the blades in machines available, and finally dynamically balancing had to be devised. Ultimately it was necessary to consider a method which would physically indicate by graphical means that induced vibration had been considerably reduced, besides running a complete series of progressive speed trials on one particular vessel, using the original propellers and the newly developed blades under similar conditions, proving the gain in performance of the blades.

Analysis of the Problem.

The craft to be propelled by the propellers under consideration were of vee bottom type, 63ft. overall length.

Length waterline	-	59ft.
Maximum Beam	-	15 ft.
Maximum Draft	-	3ft. 10"
Loaded Waterline Beam	-	13ft.10"
Displacement	-	53,000 lbs.

Main propulsion machinery, consisting of two petrol engines rated as 630 BHP each at 2000 rpm, the propellers to be driven direct from the engines. No information was available concerning the actual speed which may be anticipated under the newly refitted condition in which the displacement had been increased by the addition of new equipment and heavier fittings. The craft as originally fitted out were said to have achieved a speed of 33 knots, so an estimate of speed was made, using the results of model tests of similar types of craft. The result being that a speed of 29 knots could be anticipated, and it was decided to work on this basis. The original propellers as fitted to this craft were available, but no accurate drawing was in existence, consequently a rough drawing was lifted, and the leading particulars of the blades could be worked out. However before any further development was considered a design analysis, using standard propeller curves, was made, and all computations indicated that propellers of the type fitted originally should still be satisfactory, if care were taken to ensure that the newly produced propellers were no less accurate in form.

The leading particulars of the blades are -

Diameter	$23\frac{3}{4}$"
Pitch	$23\frac{1}{4}$"
Developed area	397.5 sq. inches.
DAR	.9
RPM	2100
NO. of blades	3
Section type	Flat face circular back

Before final detailed design, it was considered advisable to study the effects of cavitation more thoroughly, and to use such information in final design, for it was assumed at this stage that cavitation could influence the ultimate performance considerably.

Lerbs, one of the founders of experimental investigation of the cavitation problem defines cavitation as "a modification of the flow in fluid, characterised by the fact that in certain regions of the velocity field, the pressure drops until it reaches the vapour pressure of the fluid. The phenomenon is accompanied by a change of some of the fluid into saturated vapour, as a result of which the homogenity of the flow is disturbed". These regions of minimum pressure in steady flow in an ideal fluid coincide, according to Bernouli's law, with regions of maximum velocity. In other words there is a breakdown in the smooth flow of solid water as it flows over the surface profile, and a change in profile characteristics may be expected when the cavitation zone is sufficiently extended.

Today it is generally appreciated that there are two basic kinds of cavitation, Laminar cavitation and burbling cavitation. Laminar cavitation is characterised by a cavity stretched out in a long thin sheet or tube, Burbling cavitation by cavitation in the form of bubbles, some times spherical and in some cases hemispherical.

In the case of the propeller, cavitation gives rise to an increase in the revolutions per minute, owing to a reduction in thrust and torque. At the same time the screw efficiency materially drops, so that finally, though the power is greatly increased, no increase in ship speed is achieved.

In the classical "Daring" trials, it was noted, that with the original propellers a speed of 24 knots could be obtained with 3700 IHP and 384 rpm. Further propellers were designed and tried, the sixth screw having 45% more blade area than the first. The same speed of 24 knots was reached with 3050 IHP and 317 rpm, the top speed being 29.25 knots at 394 rpm. At a speed of 25.5 knots it was computed that the mean thrust amounted to about 14 lbs per sq. inch of projected surface of the blades, and it was assumed that .6 of the mean thrust or 8.5 lbs per sq. inch was due to the suction on the backs of the blades, (this being about the usual proportion of lift contributed by an aerofoil under normal conditions.)

Assuming that the pressure head of water over the blade tips due to immersion was so small that it could be ignored, then this pressure at the blade tips was atmospheric or about 15 lbs per sq. inch, hence it was concluded that the suction of the propeller blades reduced the pressure by approximately 60% and so developed a condition in which cavities might be formed at the backs of the blades. It was Dr. R. E. Froude who suggested that the term "cavitation" be used to describe this phenomenon, and it has remained in use since.

The experience gained from the "Daring" trials led to a suggestion that a definite figure for thrust loading would provide a criterion for cavitation. This was later found to be correct up to a point, but the suggestion was too general, for it has been shown that the propellers of large vessels can remain fairly free from cavitation up to speeds of 30 knots with tip speeds of 10,000 ft/M and blade loading of 15 lbs per sq. inch. Small boats on the other hand find cavitation occuring at 18 knots with tip speeds of 8000ft/M and blade loading of 8 lbs per sq. inch.

It will be appreciated then, that in designing a blade to avoid cavitation, it is not merely a matter of adding surface to reduce the pressure per unit of blade area to a known standard, but rather the question involves more complex considerations involving shape of section, blade speed, tip immersion, pitch variations over the b blade surface, roughness and wake variations.

To try and estimate the degree to which cavitation could effect the propeller, consideration was given to the theoretical background and derived cavitation criterion.

Assuming the inflow to the propeller to be horizontal the relation between pressure and velocity along a stream tube in a fluid flowing toward and past the propeller is:-

$$p + \frac{1}{2}\rho V^2 = \text{Constant} = H$$

If we consider a point distant from this where Vr is the remote velocity and p_0 the pressure, then:-

$$p_0 + \frac{1}{2}\rho Vr^2 = H$$

Hence

$$P + \frac{1}{2}\rho V^2 = p_0 + \frac{1}{2}\rho Vr^2$$

$$\text{or } P = p_0 - \frac{1}{2}\rho(V^2 - Vr^2)$$

Where V is zero the result is

$$P = p_0 + \frac{1}{2}\rho(Vr^2)$$

$\frac{1}{2}\rho Vr^2$ being the kinetic pressure or stagnation pressure, and the point at which it occurs the 'Stagnation Point'. This stagnation point occurs on, at, or close to, the leading extremity of a body moving through a fluid and in the case of propellers the location of this point is quite important.

It will be seen that when an increase in velocity flow alongside a body becomes so great that $\frac{1}{2}\rho(V^2 - Vr^2)$ is larger than p_0 the local pressure becomes negative, causing, in the case of water, the formation of cavities or bubbles, and these may form even before this particular condition arises, beginning when the local pressure becomes equal to the vapour pressure of water, i.e. with p_v as the vapour pressure, the formation of cavitation begins when $p_v = p_0 - \frac{1}{2}\rho(V^2 - Vr^2)$

In order to arrive at some basis for comparison between propellers and models the increments of pressure in relation to the stagnation pressure shall be the same i.e.

$$\frac{\frac{1}{2}\rho(V^2 - Vr^2)}{\frac{1}{2}\rho Vr^2} = \text{a constant}$$

or, substituting from above

$$\frac{p_0 - p_v}{\frac{1}{2}\rho V^2} = \text{a constant}$$

where $p_0 - p_v$ is (atmospheric pressure plus hydrostatic pressure) - vapour pressure in pounds per square foot at the shaft axis and V_r is taken to be the relative velocity of body and water. There is some difference of opinion as to the actual values of V_r as in reality the basic assumption assumes it to be a factor in the stream tube relationship. It is now accepted as the velocity of advance measured in feet per second.

This quantity

$$\frac{p_0 - p_v}{\frac{1}{2}\rho V^2}$$ — is now commonly known as the 'Cavitation

number denoted by the symbol σ and generally expressed as

$$\frac{p_0 - p_v}{\frac{1}{2}\rho V^2} = \sigma$$

The other non dimensional coefficients used in analysis of cavitation criteria, and which can be derived from consideration of dimensional analysis are

Advance coefficient $J = \frac{V}{ND}$

Thrust coefficient $K_T = \frac{T}{\frac{\rho}{g} n^2 D^4}$

Torque coefficient $K_Q = \frac{Q}{\frac{\rho}{g} N^2 D^5}$

Efficiency $\eta = \frac{K_T}{K_Q}$

Cavitation number $\sigma = \frac{p_0 - e}{\frac{1}{2}\rho V^2}$

where V Stream velocity in relation to the propeller
N Propeller revolutions per second
D Propeller diameter in feet
T Propeller thrust in pounds
Q Propeller torque in foot pounds
P_o Hydrostatic pressure at centre of screw
g Acceleration due to gravity
e Vapour pressure of fluid
ρ Fluid density.

The particulars of these propellers are now used and the various factors derived.

Dia. $23\frac{3}{4}$" 1·98'
Pitch $23\frac{3}{4}$" 1·98'
V 29 knots 48·5 ft/sec
$\frac{P}{D}$ 1
N 2000rpm 33·3 revs/sec
Developed area 397·5 sq. ins 2·76 sq. ft
Projected area 345 sq. ins. 2·4 sq. ft.
Hub immersion 2·5 ft.
Salt water temp. 60°F
1·988 slugs/ ft^3

$P_s = P_o - P_v \quad P_o - e$
$\{(14\cdot7 \times 144) + (2\cdot5 \times 64)\} - 0\cdot25 \times 144 = 2241 \text{ lbs/ft}^2$

$$K_c = \frac{P_s \times \text{Dev. Area}}{N^2 D^4} = \frac{2241 \times 2\cdot76}{1\cdot988 \times 1109 \times 15\cdot35} = 0\cdot183$$

$$J = \frac{V_o}{ND} = \frac{48\cdot5}{33\cdot3 \times 1\cdot98} = 0.741$$

$$\sigma = \frac{P_o - e}{\frac{1}{2}\rho V^2} = \frac{2241}{\frac{1}{2} \times 1\cdot988 \times 48\cdot5^2} = 0.96$$

In Lerb's criteria

$$\frac{F_a}{F} = 0\cdot96 \times 0\cdot9 = 0\cdot862$$

Using the Robb formulation

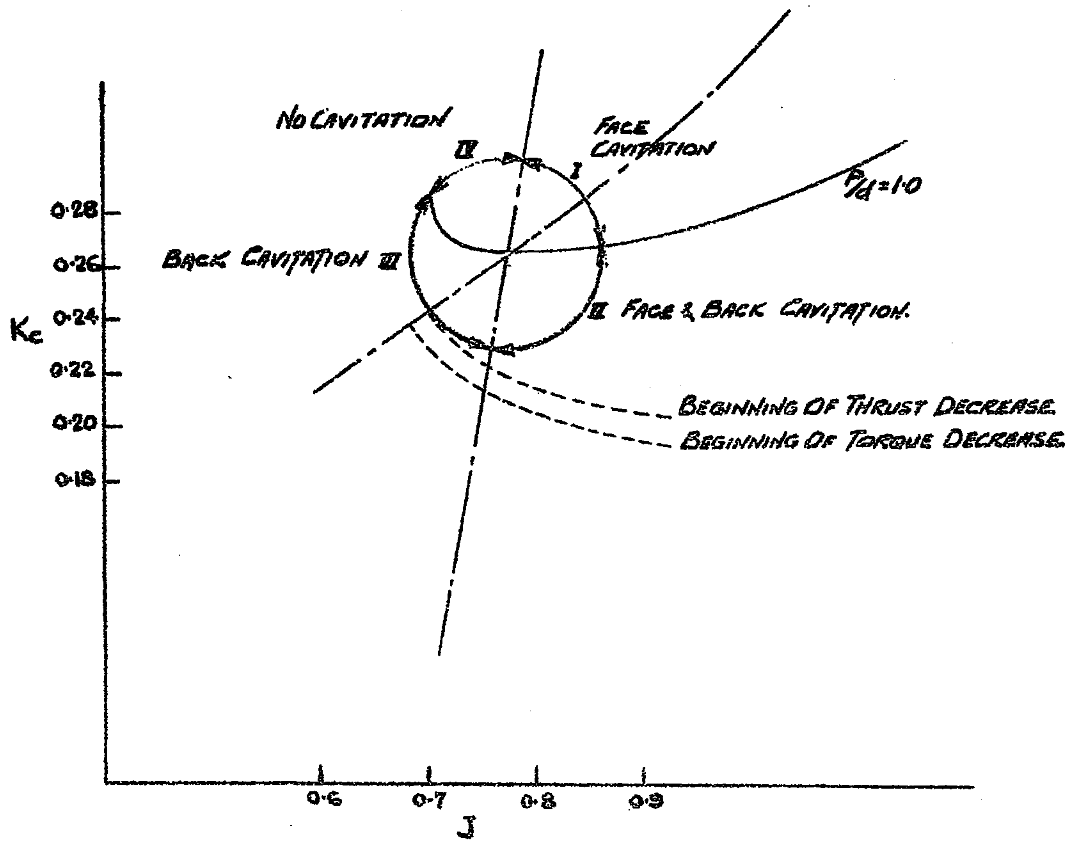
$$K_c' = \rho(1\cdot067 - 0\cdot229P)K_c$$
$$= 1\cdot988(1\cdot067 - 0\cdot229)0\cdot183$$
$$= 0\cdot31$$

Using Lerb's cavitation criteria for three bladed Schaffran B_2 series propellers and the basic velocity derived from the hull analysis we find that back cavitation can definately be anticipated, possibly face cavitation as well, with a beginning of thrust decrease, which not being of major intensity indicates that any increase of area, though increasing efficiency slightly at full power, considerably reduces the efficiency at lower cruising speeds.

The slide illustrates the effect of increase in blade area at similar cavitation numbers. The propellers considered are somewhat similar to No.5 shown in the series, though the illustrations are for propellers running at $\sigma = 0\cdot675$.

At this stage the basic particulars of the propellers had been confirmed and consideration was given to the detailed design of the blade sections, one point in particular being borne in mind. The late Dr. G.S. Baker in a Paper to the Institute of Mechanical Engineers analysed the conditions of working of wide bladed screws and concluded that, as these blades worked at very small angles of attack where transmitting low thrust, the small inaccuracies in the pitch face of the bladecould cause considerable increase in torque and consequent inefficiency.

For instance - considering a blade working at below the cavitation limit



NO CAVITATION
FACE CAVITATION
IV
I
P/d = 1.0
BACK CAVITATION III
II FACE & BACK CAVITATION.
BEGINNING OF THRUST DECREASE.
BEGINNING OF TORQUE DECREASE.
0.28
0.26
0.24
0.22
0.20
0.18
Kc
0.6
0.7
0.8
0.9
J

$$\frac{P}{d} = 1 \cdot 2$$

and corrected for intake velocity and rotary velocity the angle of attack is about 1^{o} at the tip and 5^{o} at 40% of the blade radius from the boss. If the blade width for this xxxxxxxxx condition is increased the zero lift angle is reduced and the angle of attack becomes smaller for a similar thrust relationship.

Other points considered in the design being-

1. The blade thickness ratio was kept as small as possib-le at the root of the blades in order to reduce the cascade effects in this region.

2. It was decided to use flat faced, and circular backed blades, as aerofoil sections do not lend themselves to use oh highly loaded blades, as the locally produced peaks in pressure can cause breakdown of flow and the onset of serious cavitation.

3. The finishing of the blade sections at the leading edge was considered most important, and the gradual rounding off the ends of the section working in from the outer ends of the blades as most carefully defined.

4. It was not considered advisable to use any of the recently developed cavitation resistant sections involving the adoption of a concave face in order to reduce water xxxxxxx the shock effect of water entering the propeller area mainly due to the diffuculty in defining the surface for machine reproduction.

SECTION 11.

Having dealt with the theoretical consideration involved in the selection of the particulars for the propeller the next question arose concerning material and casting. The original propellers had been cast in manganese bronze B.s.s./STA7/C x 3, and due to the effects of corrosion and erosion a considerable proportion of these propellers were considered unserviceable. Other experiences with cast manganese bronze in tropical and sub-tropical conditions when fitted to wooden vessels had raised a doubt as to the desirability of using this material in any new propeller to be produced, particularly in view of the fact that at high thrust loading, cavitation, both laminar and burbling, could be expected. Many theories have been advanced concerning the actual mechanism of cavitation erosion and in 1919 the Report of the Propeller Sub-committee of the Board of Invention and Research advanced the suggestion that surface erosion resulting from cavitation is due to "pin point" water hammer caused by the unresisted or uncushioned collapse of spherical cavities on the surface of the material considered.

The calculations of the magnitude of the impact forces made at the time, have been shown to have overlooked some facts of the problem and recent experiments by Bottomley have been carried out using a convergent, divergent nozzle with perspex sides. The pressure head across the nozzle can be altered at will, similarly the vapour pressure can be changed by heating the water in the system and air introduced into the system to further simulate working conditions. A general statement of the conclusion is that-

(a) Water is in a state of supersaturation during the process of formation and collapse of cavitation bubbles.

(b) Water pressure at which the bubbles collapse is practically the same as the pressure at which they form.

(c) It is not necessary for the water pressure to fall to the vapour pressure to produce cavitation erosion.

This latter point has been a stumbling block to quantitative experiment for some time and accounts for the "spread" of experimental test results.

During the collapse of the cavitation bubbles the implosion results in high concentration of pressure, and it has been calculated that, taking into account a certain elasticity of the metal surface, the impact due to destroying the velocity of the water is at least 120 tons per sq. inch, which is well above the elastic limit of materials used in propellers and sufficient to account for the damage experienced in practice.

Understanding the mechanical nature of cavitation erosion, theories have been advanced relating the pitting resistance of metals available for use where cavitation may be expected to

(1) The corrosion fatigues limit,
(2) The Brinnel hardness,
(3) The tensile strength,

however marked inconsistencies in results obtained have left the matter open to speculation though it is generally conceded that the following characteristics of metals are of influence.

Yield point, capacity of deformation, tensile strength, fatigue properties, cold working properties or susceptibility to strain hardening, grain shape, size and structure and distribution of alloy constituents.

Mousson in a paper to ASME 1937 refers to two types of failure observed during cavitation erosion tests.

(a) Failure due to ~~successive~~ deformation in the zone of highest stress concentration after the capacity of yield had been exhausted.

(b) Failure due to ~~successive~~ fatigue beneath the zone of possible yield, and from observation made, came to the conclusion that the primary properties to be analysed in selection of materials when cavitation erosion may be expected are -

Yield point, capacity of deformation, tensile strength and fatigue limit, all other points may be considered of a secondary nature. With these points in mind the physical properties of a number of suitable and well known propeller metals were analysed as below :-

	U	Y Point	Elongation	B. Hardness	Cavitation Loss mg/16hrs
Everdur	50,000	25,000	22	82	258.0
Al. Bronze	70,000	35,000	12-20	107	41.6
Gun Metal	40,000	20,000	20-25	61	391
Mn. Bronze	65,000	30,000	15-22	129	135

Results from other experiments are as follows with the inclusion of a figure of merit.

	U U.T.S.	Elong.	BH.	wt/loss	F. of merit
Admiralty mon Bronze	35	27	156	18.9	1.0
Al. Bronze DTD 412	40.42	24	169	4.75	4.0
Gun Metal	16.6	20-25	84	18.9	1.15

Further, in view of the well known corrosion resistance of cast aluminium bronze when coupled with monel or 18.8 stainless steel it was decided that if Aluminium Bronze castings could be satisfacorily produced, future propellers should be made in this material as defined BSS/STA7/CA4 or D.T.D. 412.

SECTION111. Castings.

Due to the large blade area of the propeller designed, the only method of obtaining a satisfactory casting was to use a single bladed wooden master pattern and make core boxes for each blade handing. This was done and the first castings were produced at a Queensland foundry from approved Al. Bronze ingots. The only test requirements laid down to be satisfied by the metal as cast were -

(a) Two only test bars - cast off
(b) Visual inspection of casting itself.

Both the castings and test bars proved satisfactory, and it was decided that machining could commence. At this stage, I must anticipate further results, for on final trials of the craft itself, extremely bad flaws become evident on the blades after ten days immersion in the water and full power speed trials, as indicated in the accompanying photograph and plate.

Many theories were advanced, and it became apparent that the only satisfactory method of examination was by radiological means. The first examinations were carried out by the Ipswich Railway Workshops, Test House, in Queensland, and the results obtained indicated inconsistency in the cast alloy even where the surface of the blade appeared unmarked, consequently a full report was obtained from the Defence Standard Laboratories and I quote from the report presented.

"Numerous sharp cavities were present on the trailing faces of the blades (meaning the suction faces or backs of the blades), being more pronounced at the junction of the blades and the hub."

Radiological examination of the blades showed that scattered oxide inclusions, some containing entrapped air were present. Shrinking cavities, visible on the surface, were present on each blade."

__Remarks.__

1. The cavities on the surface of the blades were caused by erosion of the oxide inclusion, some of the inclusions probably containing entrapped air.
2. Surface shrinkage cavities and oxide inclusion are present on each blade; some of these defects would be uncovered on resurfacing the blade.

I would further point out again that to visual inspection before trials there were no defects evident of any type, the finished polished blade appearing to be of perfectly homogeneous alloy.

Evidently the pouring technique used for these propellers had been wrong, for the most difficult problem in the production of aluminium bronze castings is the prevention of oxide formation on the metal during casting, Provided the melting procedure has been all that is desired, very little oxide or dross should be present in the metal. Actually the oxide originates from the tough proctective film or skin which is formed by the metal on exposure to the atmosphere, During pouring, this film is likely to break away and enter the mould.

Should pouring be at all turbulent the formation of oxide is accentuated and unlike some of the bronzes the oxide film will not remix with the parent alloy.

It is thus essential that the gating arrangements be such that the metal will flow gently to the level of the bottom gate and enter the mould quietly. In other words the mould is filled gradually from below rather than by a stream of metal falling through the main header.

Another essential point is the provision of adequate risers and feeding heads, these should be so located that shrink cavities and pipes will be formed in the risers and not in the casting itself, whilst the main header should be of ample proportion to ensure a sound dense casting.

In the first casting made the metal had been poured and the mould filled from the top, and this turbulent pouring had been responsible for the oxide inclusion later found evident in the casting. With this experience gained, the core boxes were redesigned and the method of pouring changed so that the main flow is from the bottom of the casting through four horngates, one at each blade tip and one at the boss, with approximately four risers all told.

The first castings produced by this method have been radiologically examined and no defects have been evident from this examination, further no visual defects have shown during machining.

__SECTION 1V.__ Machining Technique.

As mentioned earlier the basic method to be used in production of the finished blade was to produce a planed helical surface to act as datum from which all measurements of thickness could be taken, ac so from the rough casting the next important step was boring which was carried out in a Vertical Boring machine using a taper reamer drill. In view of the fact that a number of blades would ultimately ve required, it was considered advisable to have these taper reamer drills manufactured to match a sample plug made from the existing propeller shafts. Having set up the blade on the turntable the time expended in boring the boss of the blade was about 3/4 an hour. The blade was next transferred to a lathe where the diameter was checked so giving a location point at the tips of all blades, next came the machining process. The only machine available for machining the faces of the blades was a Cincina tti Milling machine with a special long arbour for holding the cutter. The propeller was set up on a turning arbour on the plate of the miller and so arranged that as the propeller was turned on the centralarbour, the whole plate was traversed at a uniform rate, the distance traversed per revolution being equal to the pitch of the blade helix.

By use of a dividing head and the geared drives available on the machine the exact pitch could be reproduced.

When the trial machining methods were being investigated on old propeller was used and it was found a simple matter - over the area of blade considered, to bring the milling cutter, in this case 3" diam, and 1" width, into contact with the face of the blade and allow it to follow out the helix angle across the width of the blade. However it was not unril the first cut had been made with an actual casting that it was realised that in carrying out the first experiments a section of blade had been used when the change of helix angle along the face of the blade was not great. On coming closer to the boss however, the aspect of the problem of face machining changed greatly for it was then realised that previous assumption had been that the cutter was infinitely thin and of infinitely small diameter, in other words the geometry of the machine drives had been worked out on the basis that the cutter represented a point traversing the face of the blade and being moved from tip to root.

It was evident that the whole theoretical approach would have to be revised as the strikle line producing the helix of the face of the blade was in reality the point of contact of the cutter and its tangent at the particuaarpoint considered, for (referring to the diagram), if A were the point of contact where the helix angle at the point considered is β and the change in helix angle from the point considered to the next point is α, when the helix angle is ($\alpha + \beta$).

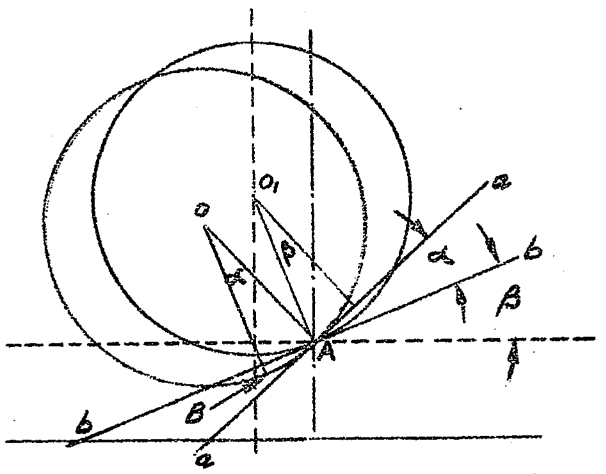


FIG 4.1

Then at this new section instead of the point of contact being A, the point of contact would have been B if the cutter had not been moved and all the excess metal cut off by the chord bb would have been removed by the miller.

It thus became evident that point A to remain a contact point must remain fixed and centre of the milling "O" cutter must be moved in a circular arc around A as shown in the new diagram Fig. 4.2.

Once again this proved a comparatively simple correction to be made as the arc O O' could be approximated to by available movements in the machine, i.e. a plate depression and a direct translation being the two resolved components of the required movement.

However this still did not eliminate the assumption that the milling cutter was of infinitely thin section, for in the length of the cutter itself, the change of helix angle caused one end of the cutter to "dig in", whilst the other end merely touched the surface of the blade. This in turn meant that the cutter had to be angled across the face of the blade to approximate to this new condition. In actual fact though the points of contact at both ends of the cutter were correct the correction did not entirely overcome the difficulties at the mid point along the cutting tool and it was calculated the slight irregularity so formed would be approx 5 thousandths of an inch, close to the boss, which was considered an acceptable error, particularly as this would possibly be eliminated in the first hand finishing and buffing of the blade.

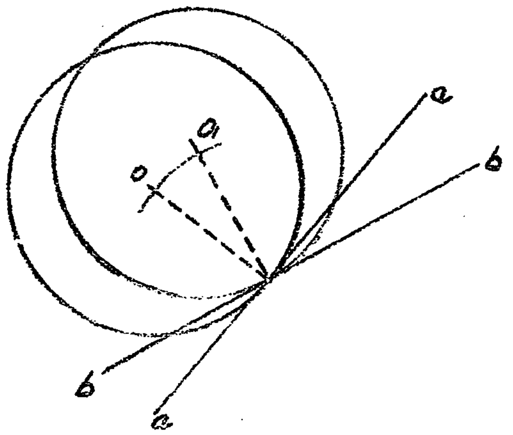


FIG. 4.2

Diagramatically this is ~~shown~~ above.

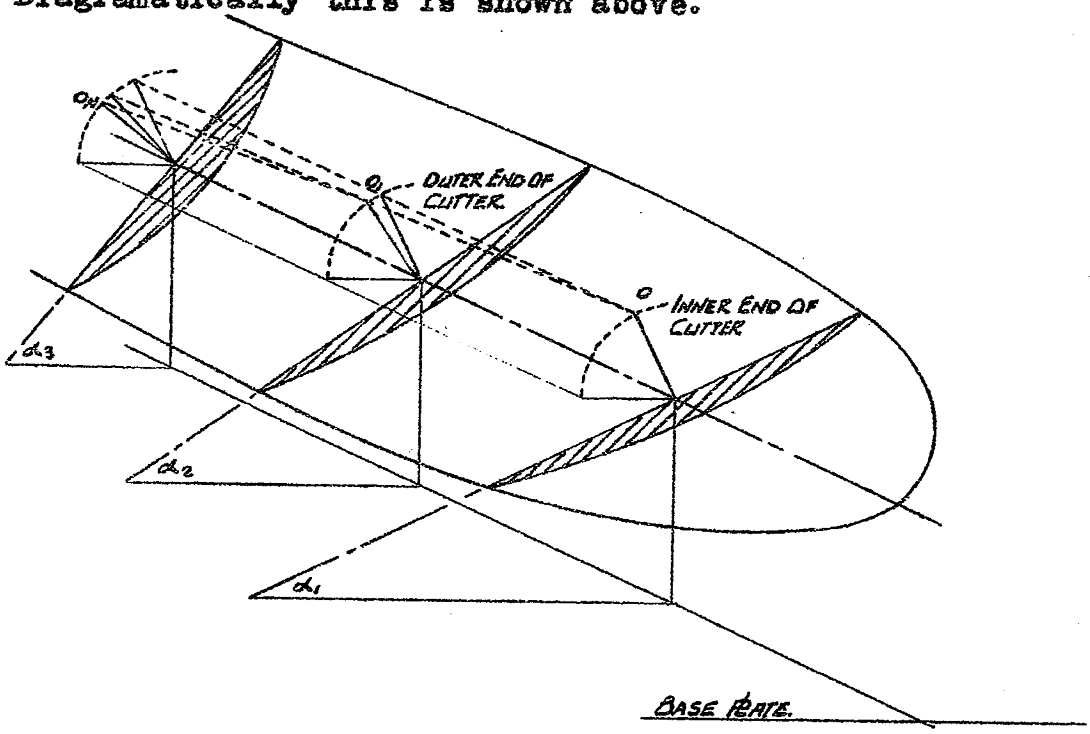


DIAGRAM OF CUTTER ROTATION

FIG 4.3

Plates 5, 6, and 7 illustrate the propeller set up in the milling machine. Views from different angles illustrate rough cuts being taken. Plate 11 shows a large radial planer being used to generate the surface of a large ship propeller.

The tolerances used in the production of the propeller under consideration were:-

Diameter	± ½%
F & A Alignment	± 1/16"
Pitch Mean	± ½%
Thickness	±.01"
Blade outline	± 1/32"
Blade centres	± 15 mins.
Edges	.01"

Though the method of machining was derived entirely for a propeller in which the helix is traced out by the strickle line at right angles to the shaft centre line and the helix is of uniform pitch, it can be modified to produce any helical face provided the pitch remains constant. It can even be modified to take into account change in pitch, but the decision as to the advisability of going to such lengths depends entirely upon the particular circumstances involved.

It must be stressed at this point that the only reason underlying the development of this technique was to produce a face machined propeller with existing machines. In other parts of the world special back and face planing machines are available through the actionof producing required helix is not one of milling, but rather of planing, as the cutting tool works radially along the blade and not transversely across its face as described above.

Having produced a planed surface to serve as a datum surface for the measurement of blade section thickness ordinates the backs of the blades can now be finished off to the required contours. In doing this it was thought desirable to use a blade outlined template with numerous holes punched in it corresponding to the check points given on the drawing.

<u>SECTION V.</u> Balancing.

On completion of hand dressing before buffing, the propellers were next statically balanced using a tapered mandril and knife edges. In general this out of balance was found to be very small, the acceptable limiting moment being of the order of six inch ounces.

The operation of dynamic balancing was next carried out. The propeller was first run in the dynamic balancing machine and readings obtained of the position of the unbalanced weight, with an indication of the degree of unbalance. A known weight was then added in a definite position and on re-running the degree of correction estimated. Having removed metal to try and correct the indicated out of balance the propeller is again run in the balancer and the effect noted. This process was repeated until the required degree of balance was achieved.

The accompanying slides (8,9,10) show the propeller set up in the machine with the control panel in the back-ground. It was found with these propellers as the machining and finishing technique had trued the blades beyond the point normlily experienced in propeller manufacture, the degree of out of balance was very small and any attempts to improve matters generally had the opposite effect.

As a basis of comparison one of the best of the original propellers was run in the balancer and it was found that the unbalanced moment was approx. three times that accepted for the new propellers. The remarks of Professor Burrill in his recent paper to the Institute on "Propeller Manufacture" confirm these findings.

The propellers were next returned to the fitting shop for final buffing and despatch.

<u>SECTIONVI .</u> Trials.

During the trial programme the basic results required were
(a) A progressive speed trial to compare the results of trials with a pair of original propellers in serviceable condition.
(b) A recorded indication of the frequency and amplitude of vibration produced in each case.

One boat was used for all trials and the displacement was kept comparable for all trials by the limiting of the personnel aboard and the checking of keel and water levels before each individual trial. It was found by exercising reasonable care there would not have been more than 400lbs difference in displacement during the trials.

Referring to the accompanying diagram it will be seen that with the new propellers the cruising speed at 1400 engine revolution amounted to 19.69 knots - with the original propellers the speed was 17.2 knots, the mazimum operational speeds being 28.76 knots and 27.05 knots with the engines running at 2000rpm. I might mention at this point that all times on trials were run over a measured distance between two piles in open water, the depth being approximately 45 feet along the measured course, with ampàe water at each approach end. Two independent stopwatches were used for taking times, andboth mechanical and electrical tachometers used to check engine revolutions at all times.

Vibration Tests.

The equipment used here as illustrated in the accompanying plate was a small seismic head, consisting of a mass suspended horizontally between two leaf springs, the natural period of vibration being great compared with the frequency of anticipated vi vibration due to the propellers. This mass formed a plunger in wound coils - the Inductance of the unit varying with the movement of the so formed pendulum. YHis unit was connected to the recording unit of a Kelvin Hughes Dynamic Strain Gauge unit, so that when the base plate of the Seismic Head was clamped to the vibrating structure the pendulum remained undisturbed and the relative movement of coil and plunger was recorded by pen mechanism on paper. Before assembly on the boat the unit was tested under static conditions and each division between parallel lines represented approximately .002 of an inch.

The slide shows the record obtained during these trials and an examination of the revolution vibration curves will reveal that for all propellers and at all revolutions the main resultant vibration induced has a frequency of twice engine speed based on the time period indicated.

This cannot be attributed to any particular fact without a lengthy analysis of all frequencies and their causes which are indicated on the graph. However, remembering that out of balance dynamic moments are being detected, it is reasonable to assume that the major deflections are arising from this source. Further, it is ~~important~~ interesting to note that third harmonics have also been detected, which are due to impulse effects of the several blades and also from torsional accelerations induced by the working strokes of the engines.

Inspection will indicate the relative merits of the different propellers, though one point of difference in the curve characteristics ~~xxxx~~ is noteworthy, the records of the American propeller characteristics were obtained by steadying engine revolutions and obtaining a record after about 30 seconds of even running. The records for the Australian screws were obtained by running at constant revolutions for about 6 seconds then accelerating for the next revolution band and holding these revs for about 6 seconds and then on the full throttle band.

Note that with the Australian screws effects due to non-synchronisation of the screws whilst the boat is still accelerating are evident, though towards the end of the graph in each case the large fluctuations tend to disappear.

Both progressive speed trials test and vibration tests proved conclusively that the carefully machined, contoured, and balanced blades had a much higher performance than the sand cast hand dressed and buffed blades originally fitted. It may be asked whether the extra expense in going to all the trouble of machining and carefully finishing such blades is worth while, the answer is that due to superior performance at cruising speeds their is anoverall reduction in fuel consumption, the improvement resulting in the saving of the cost of maching in less than 6 months on normal operational duties.

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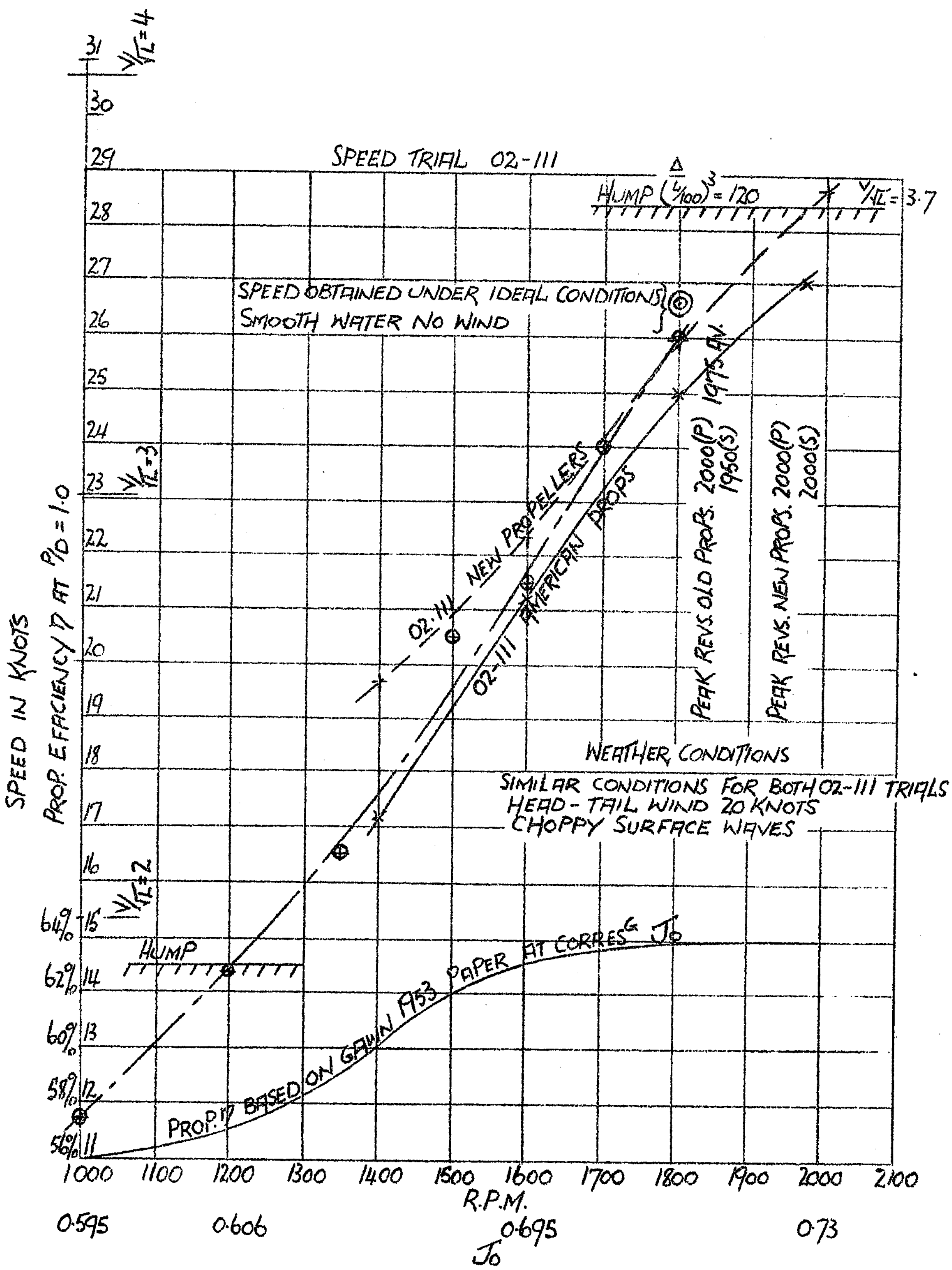

SPEED TRIAL 02-111
SPEED IN KNOTS
PROP. EFFICIENCY η AT P/D = 1.0
HUMP (Δ/(L/100)³) = 120
V/√L = 3.7
V/√L = 4
V/√L = 3
V/√L = 2
SPEED OBTAINED UNDER IDEAL CONDITIONS
SMOOTH WATER NO WIND
02-111 NEW PROPELLERS
02-111 AMERICAN PROPS
1975 AV.
PEAK REVS. OLD PROPS. 2000(P) 1950(S)
PEAK REVS. NEW PROPS. 2000(P) 2000(S)
WEATHER CONDITIONS
SIMILAR CONDITIONS FOR BOTH 02-111 TRIALS
HEAD - TAIL WIND 20 KNOTS
CHOPPY SURFACE WAVES
HUMP
PROP. η BASED ON GAWN 1953 PAPER AT CORRESG J0
R.P.M.
J0
0.595
0.606
0.695
0.73

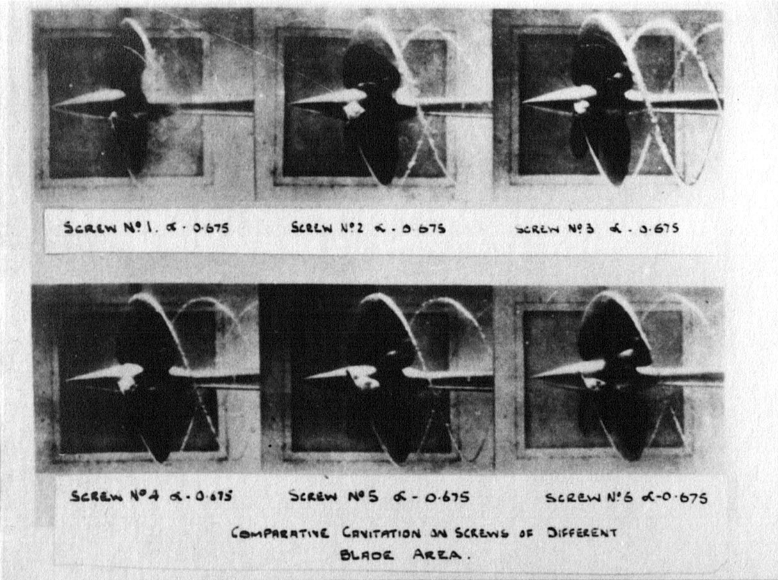

Fig. 2.

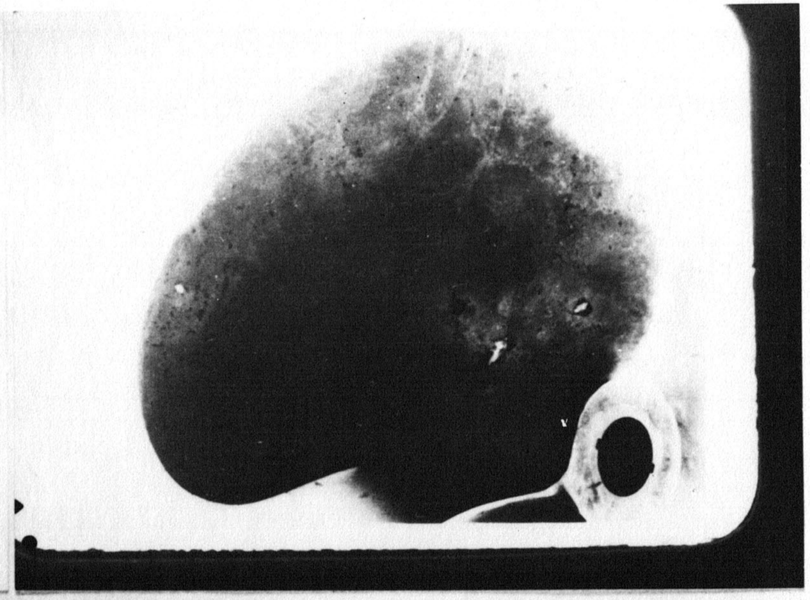

Fig. 3

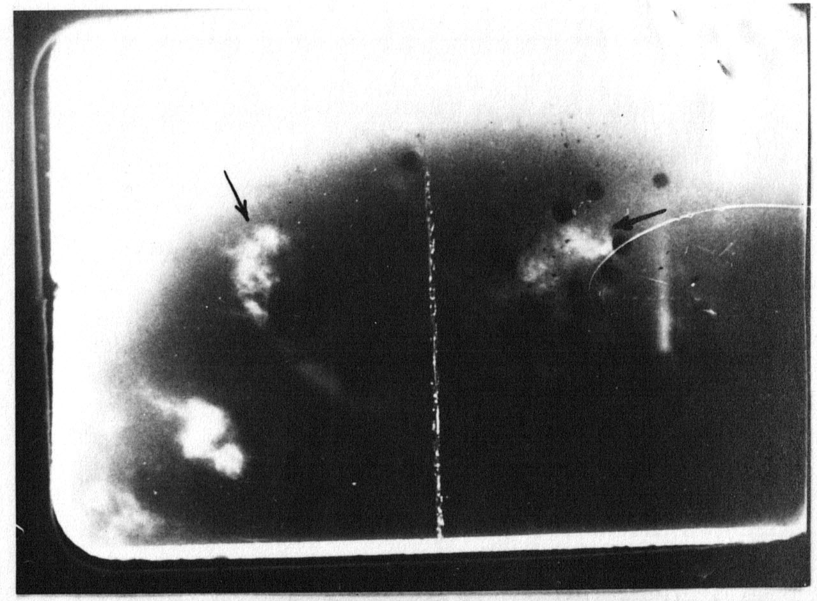

Fig. 4

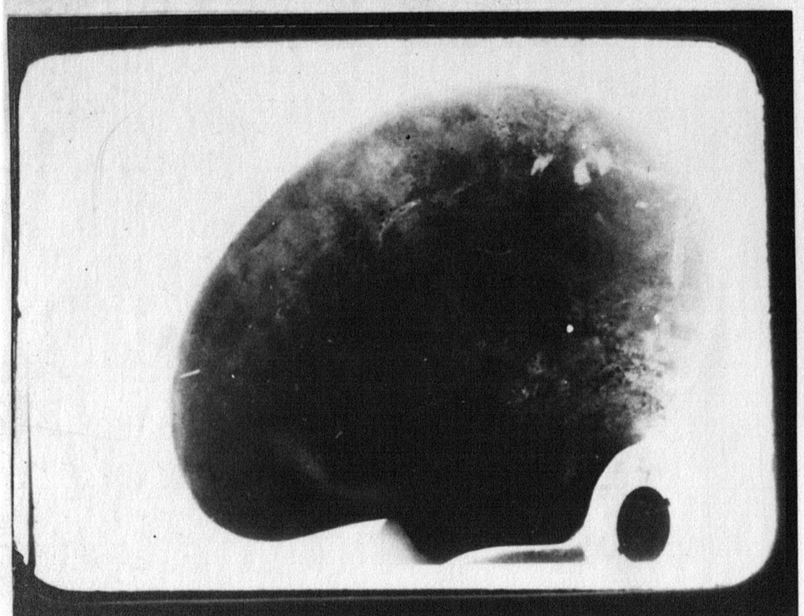

Fig. 4a.

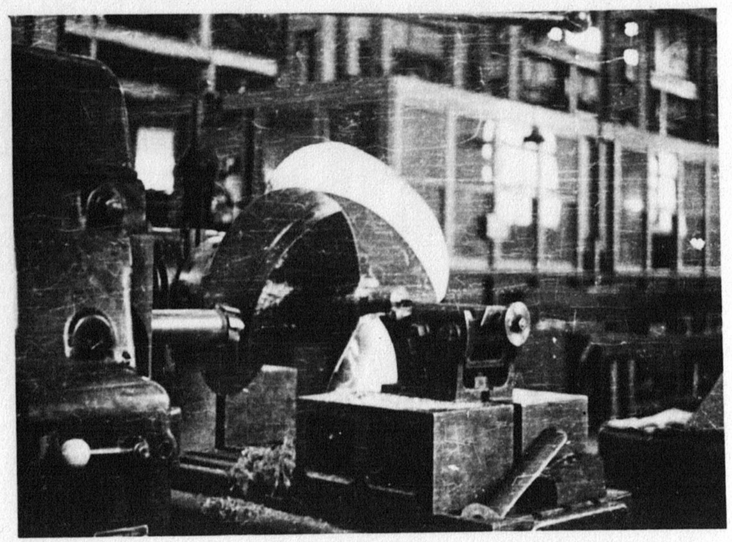

Fig. 5

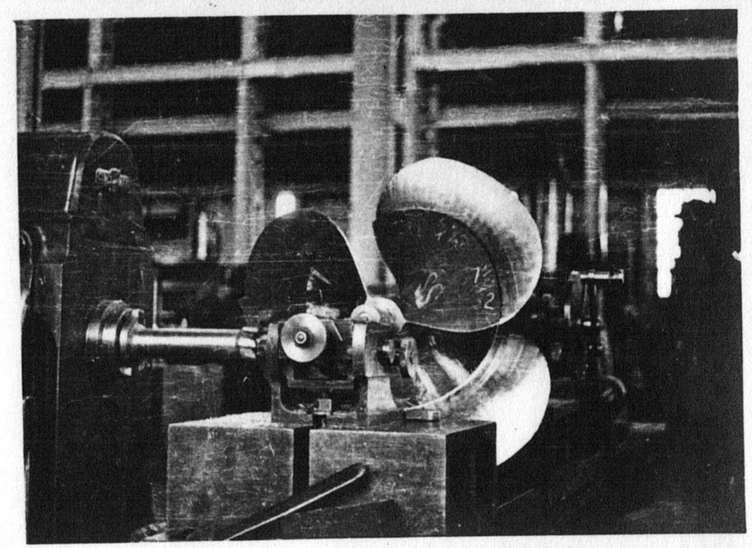

Fig. 6

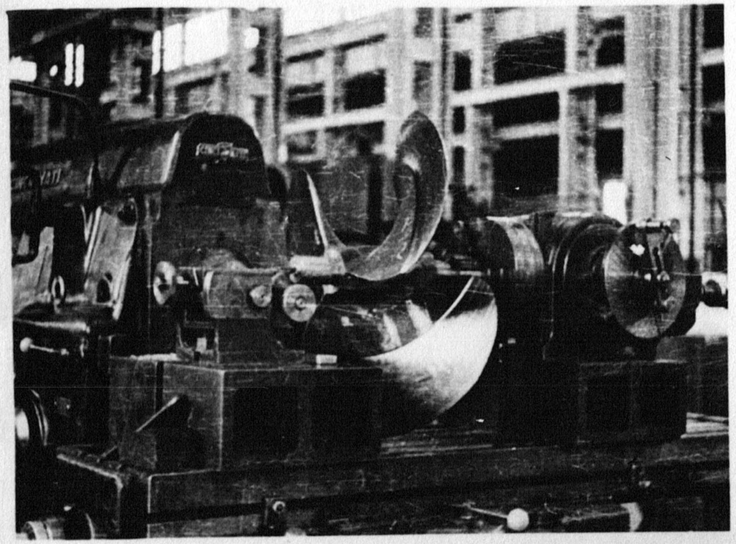

Fig. 7

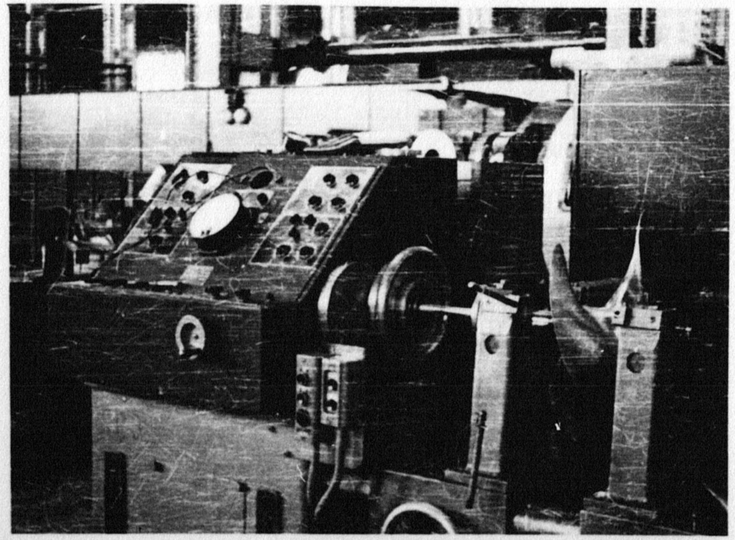

Fig. 8

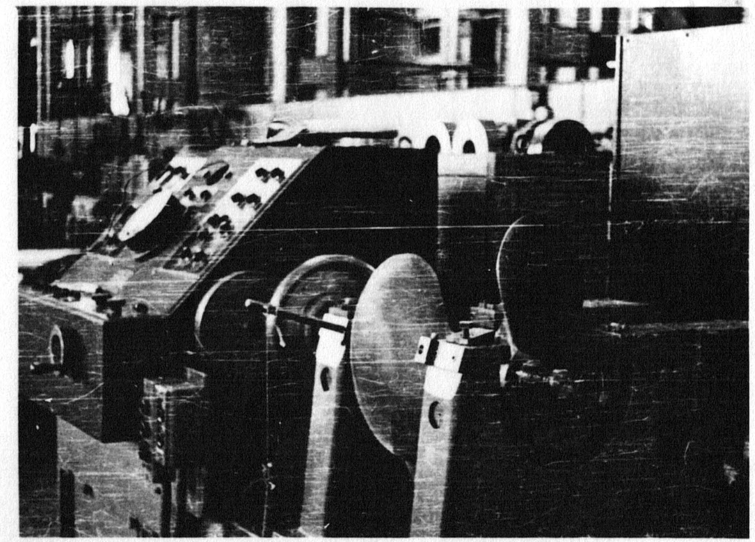

Fig. 9

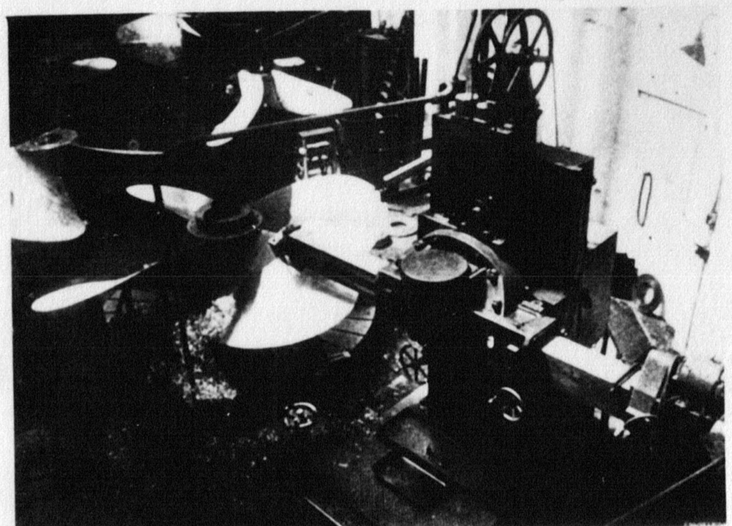

Fig. 10

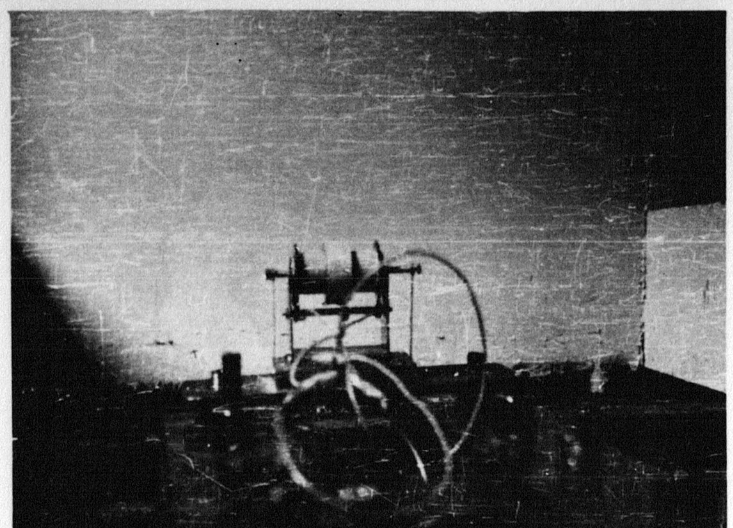

Fig. 11

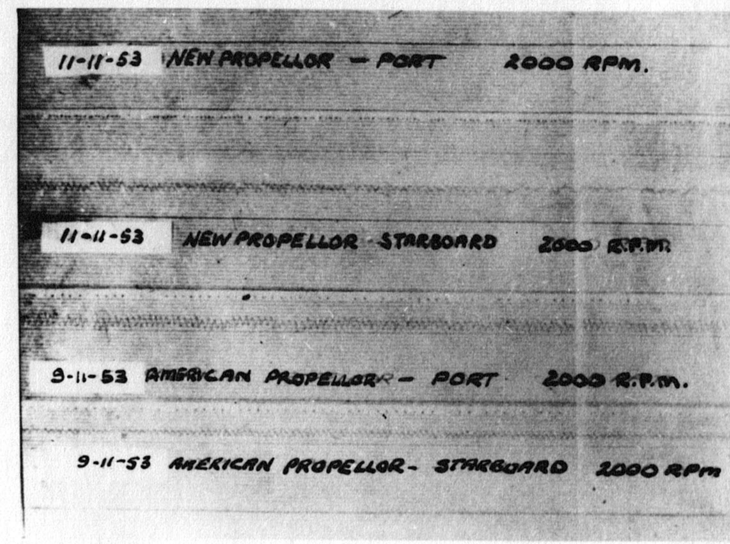

Fig 12.