THE DEVELOPMENT OF NYLON PROPELLERS

BY

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Introduction

For some years, the Admiralty has been concerned at the large demand for replacement propellers for small craft such as ship's boats and harbour craft.

These demands, which are estimated to be in the region of some 500 propellers each year, arise from damage sustained by grounding, striking submerged objects and cavitation erosion damage to which the small high speed propellers are particularly prone. Additionally, damage to propellers caused by striking underwater obstructions invariably leads to damage to propeller shafting and 'A' brackets.

In 1957, active investigations were started into the possible use of several different forms of plastic materials for small boat propellers, and from the materials investigated—and in some cases, tried—Nylon 6 came out as offering the most promising solution.

Design of Propellers

As the investigations into the use of plastic materials progressed, the problem of obtaining a readily available supply of Nylon 6 propellers became evident. No manufacturer in the United Kingdom was in a position to be able to satisfy the Admiralty's requirements, but it was discovered that two Danish firms, Hundested Motor Fabrik Ltd. and Dansk Thermo Plastik Ltd., had carried out a great deal of pioneering work in this field.

It was also discovered that a British firm, Messrs. F. Bamford and Co. Ltd. of Stockport, had entered into an arrangement with the latter Danish firm whereby Bamfords supplied the moulds which were then sent to Denmark for the actual moulding process to be carried out. The moulded blades were then returned to Stockport for cleaning up and installing in bronze hubs to complete the propellers.

In view of the supply situation and the prohibitive costs of an experimental mould, the nearest commercial design of propeller had to be accepted as a compromise, it being appreciated that this would mean some loss in the performance of whichever type of boat was selected for trials.

As regards the stresses allowed in the propeller blades, a study of the mechanical properties of the nylon material was made—again largely based on Danish experience, but also from the limited (at that time) knowledge of the I.C.I. who were carrying out extensive tests on the material. From this, it was decided that in the first propeller to be tried, the stresses should be limited to 1,000 lb/sq in. In subsequent designs, stresses up to 4,000 lb/sq in. have been permitted, these comparing with some 8,000—10,000 lb/sq in. for standard H.T. brass propellers.

Properties of Nylon 6 Material

As mentioned previously, little was known initially about the mechanical and physical properties of Nylon 6, which was the Continental Specification number given to the material used by the Danish firms. I.C.I., in this country, were extensively testing an equivalent type of nylon—known as Nylon 66—and it was from these tests that the bulk of the information was obtained.

TABLE I

Material	*Tensile Strength (lb/sq in)*	*Young's Modulus (lb/sq in)*	*Specific Gravity* —	*Elongation at break (percentage)*
Nylon 66 (Dry)	11,500	$4{\cdot}3 \times 10^5$	1·14	80—100
Nylon 66 (Wet)	8,300	$1{\cdot}2 \times 10^5$	—	—
MC Nylon 901 (Dry)	11,000—14,000	$3{\cdot}5 \times 10^5$	1·16	20—30
H.T. Brass	74,000	$13{\cdot}0 \times 10^6$	8·0	15·0

The main characteristics of the Nylon 66 material are given in TABLE I. Equivalent values for the normal H.T. brass propeller material are also given for comparison.

A major factor which emerged from the I.C.I. (and later tests made at the Admiralty Materials Laboratory) was that Nylon 66 absorbs moisture, and in so doing, although losing some degree of strength, becomes what is known as stabilized. At a later date, it also became apparent that if the material was not fully stabilized before being put into service, a moisture content differential could exist across the material which could give rise to internal stresses which, in turn, could cause internal cracks and hence lead to early failure under operating conditions.

Impact strength values for nylon have been quoted to various Standards, and consequently are difficult to correlate. Some such values are given in TABLE II.

FIG. 1 shows the variation of maximum moisture content with humidity at room temperature and for complete immersion, the Equilibrium Water Content (percentage) at room temperature is quoted as being 9·0—10·0 per cent.

If nylon was left to absorb moisture from the atmosphere by its natural process, it would take a long time before the equilibrium state was reached, but this process can be accelerated by immersion in boiling water. FIG. 2 shows the rate of moisture pick-up for various thicknesses of Nylon 66 material under the latter conditions.

In recent months, following development work in the U.S.A., it has now been found possible to cast (as opposed to extrude) a type of nylon known as Monomer Cast Nylon — MC Nylon 901, for short. This process has been developed by the Monsanto Chemical Co. and the Polymer Corporation in the U.S.A.,

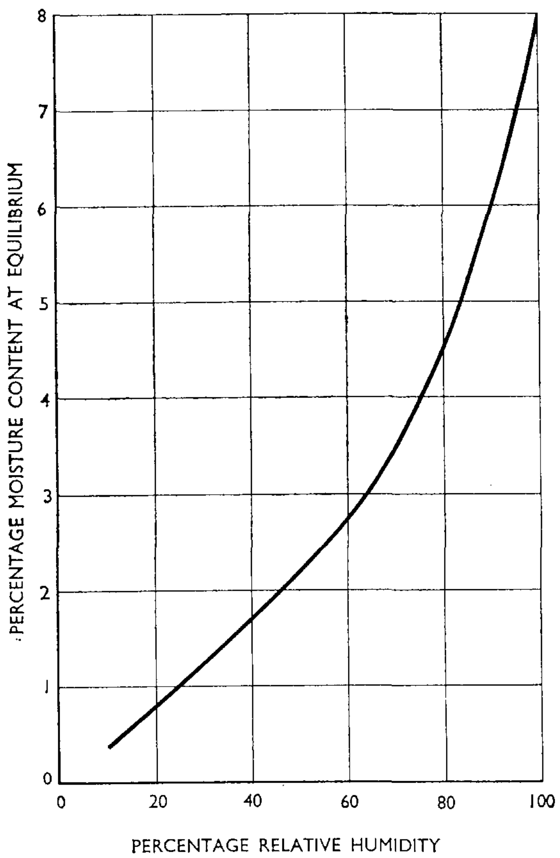

FIG. 1—VARIATION OF MAXIMUM MOISTURE CONTENT WITH HUMIDITY AT ROOM TEMPERATURE.

TABLE II

Material	*Percentage Moisture Content*	*Standard Izod Notch*	*Ft Lb per inch Notch*	*Ft Lb per ½-inch Notch*	*Tensile Impact Ft Lb/in²*
Nylon 66	0·6—0·8	—	0·8—0·9	1·0—1·5	—
Nylon 66	9·0—10·0	—	8·0—10.0	—	—
MC Nylon 901	Dry	—	—	—	80—100
H.T. Brass	—	15·0	—	—	—

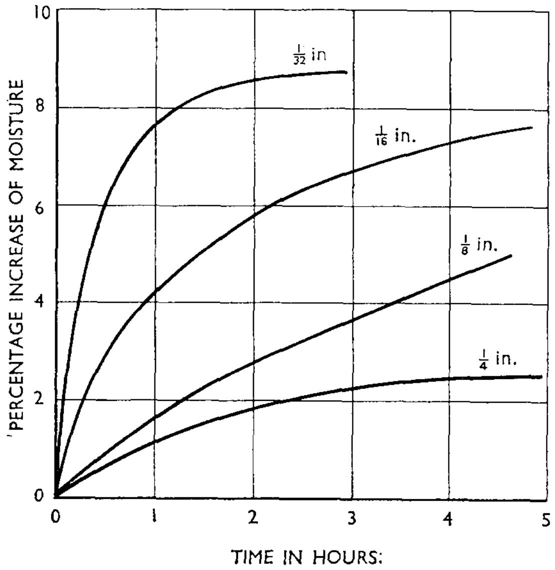

FIG. 2—RATE OF MOISTURE PICK-UP FOR NYLON 66 IN BOILING WATER

and licensing arrangements exist between the latter firm and Polypenco Ltd. of Welwyn Garden City to carry out the process in the United Kingdom. It is claimed that the cast nylon material has similar mechanical properties to Nylon 66, and the information given in TABLE I is that published by Polypenco Ltd. Tests are currently in hand at the Admiralty Materials Laboratory to confirm these values and, in addition, to determine the water absorption characteristics of this material in order to establish its suitability for future propellers as an alternative to extruded nylon.

Methods of Manufacture

The Danish firm were known to produce their propellers by an extrusion moulding process but, not unnaturally, were loath to divulge full details of their processes. In this country, I.C.I. have done a great deal of work along similar lines and it is known that the extrusion process involves high pressures (about 90 atmospheres) and temperatures of some 300 degrees Centigrade. The I.C.I. plant is, however, very much of an experimental nature, and it is not possible therefore to make much use of it for purely production purposes. In any case, the size of I.C.I.'s extruding machines is such that only small blades can be moulded on them.

Another disadvantage which has been apparent with this method of manufacture is that, because of the high pressures involved, the moulds have to be of very rigid construction, and have to be accurately finished such that the two halves when clamped together form a perfectly tight joint. To date, it has been found that this can only really be satisfactorily achieved by the use of stainless steel moulds which consequently are very expensive. FIG. 3 shows in diagrammatic form, a typical extrusion moulding machine.

Following the moulding of the blades, it is then necessary to ' clean ' up the blade edges and to machine the root fixing arrangements. Subsequently, the blades are immersed in boiling water under a pressure of 5 lb/sq in. for six to twelve hours (depending on the blade thickness) in order to condition the material.

The method of locating the blades and clamping the halves of the bronze boss together are shown in FIG. 4.

It will be appreciated that lack of production facilities in this country has

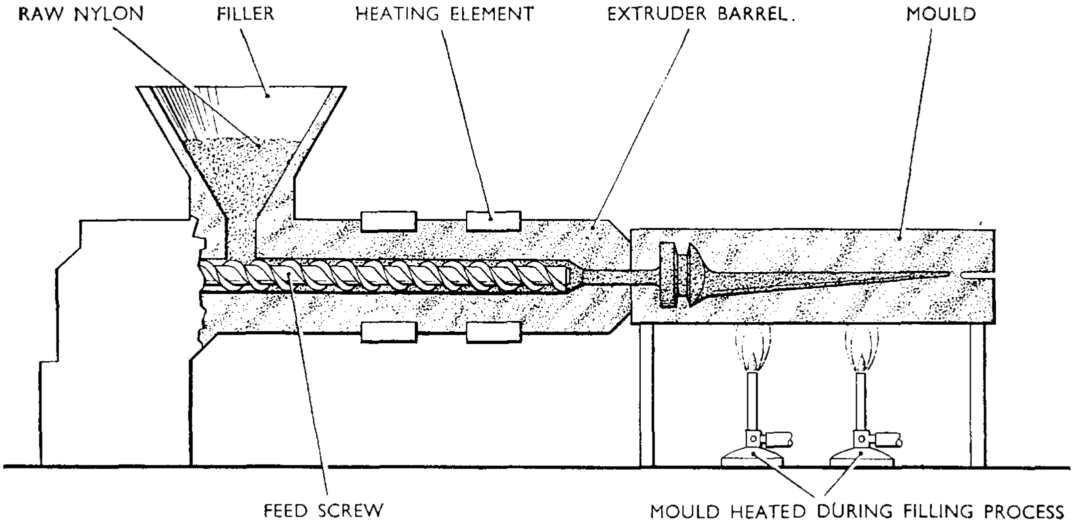

FIG. 3—DIAGRAM OF EXTRUSION MACHINE

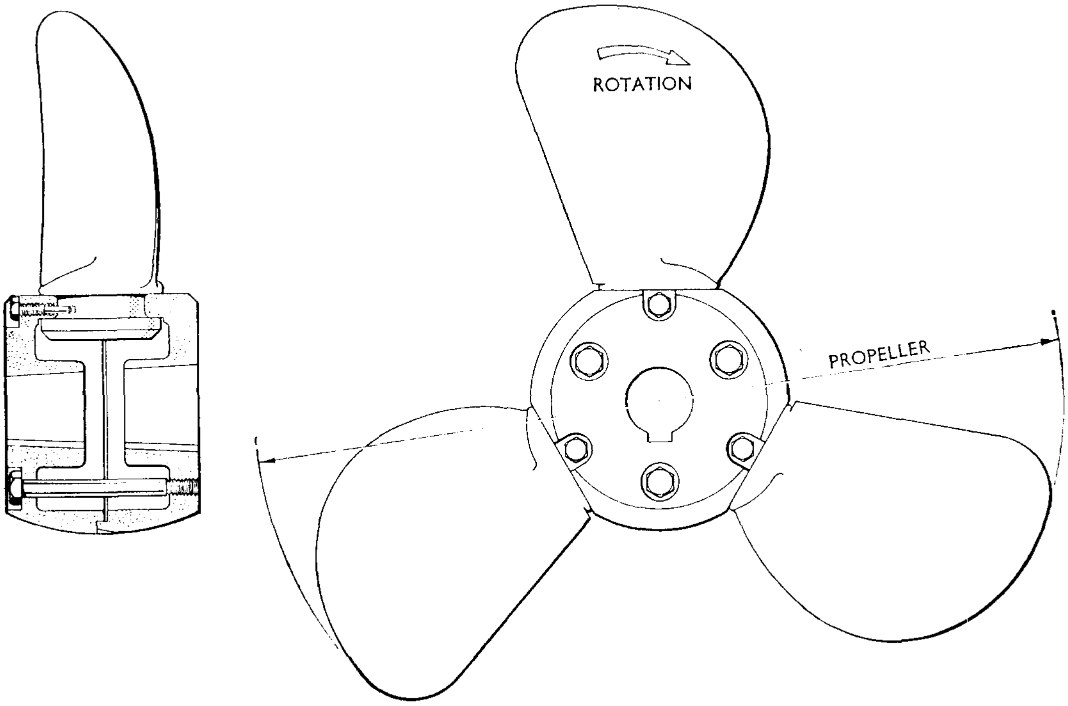

FIG 4.—DRAWING OF BOSS ARRANGEMENT

seriously delayed the evaluation of nylon bladed propellers in the Service, but now that the casting of nylon is possible, it is expected that the supply situation will eventually be much improved.

With regard to the casting process, again few details have been released, but such information as has been published indicates that the casting is achieved by the use of what are known as monomers rather than the nylon-polymer powders used in the extrusion or injection moulding processes, and that while a heat of some 150 degrees Fahrenheit is required to melt the Caprolactum monomer, the actual casting is performed at normal atmospheric pressure. Large expensive moulds are therefore not necessary.

FIG. 5—M.F.V. PROPELLER AFTER 300 HOURS (9-12-'58)

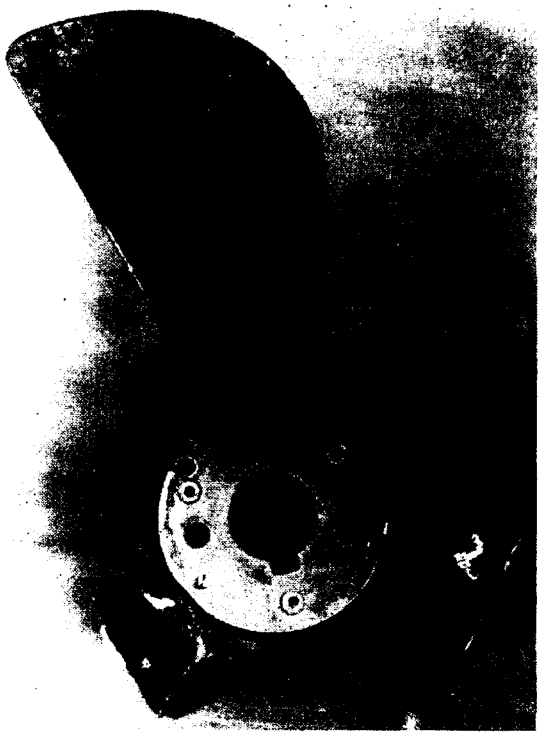

FIG. 6(*a*)—BROKEN BLADES OF M.F.V. PROPELLER

It is also claimed that, whereas there is a limitation on the thickness of the material which can be formed by the extrusion process of some 3—4 inches, no such limitation exists with the casting process because, it is claimed, the latter produces a bubble free, uniform material capable of completely filling all shapes and sizes of moulds.

Results of Experience to Date

In the first instance a compromise design of propeller had to be accepted in order to obtain early delivery of any propeller for evaluation. This compromise resulted in a propeller of 27-inch diameter and 22-inch pitch being donated by Messrs. F. Bamford and Co. for trials in a 61½-ft. M.F.V. operating in Portsmouth Harbour. No special trials programme was laid down but the vessel was requested to do as much normal running as possible.

This propeller was first fitted to M.F.V.9 in August, 1958, and at the first inspection on the 9th December, 1958, after 300 hours' running, the blades were found to be in perfect condition. FIG. 5 shows the propeller at this stage.

The next examination was made on the 7th July, 1959, when it was discovered that two of the three blades had broken off near, but not at, the roots. At this stage the propeller had been in service for 951 hours.

An investigation into the failure revealed that the boat's crew had not noticed any difference in performance of the boat prior to going on the slip, but inspection and tests on the remaining material showed that the moisture content varied from 2·85 per cent at the surface of the blades to 0·6—0·8 per cent at the centre.

Test pieces showed that the impact value of the material in the centre of the blades was very low being some 0·8—0·9 Ft Lb per inch notch compared with values of 8—10 Ft Lb per inch notch for the material in the equilibrium state having a moisture content of [illegible]—10 per cent. It was therefore concluded that the blades had failed because of some impact on moving on to the slip, coupled with the material being in a

FIG. 6(*b*)—BROKEN BLADES OF M.F.V. PROPELLER

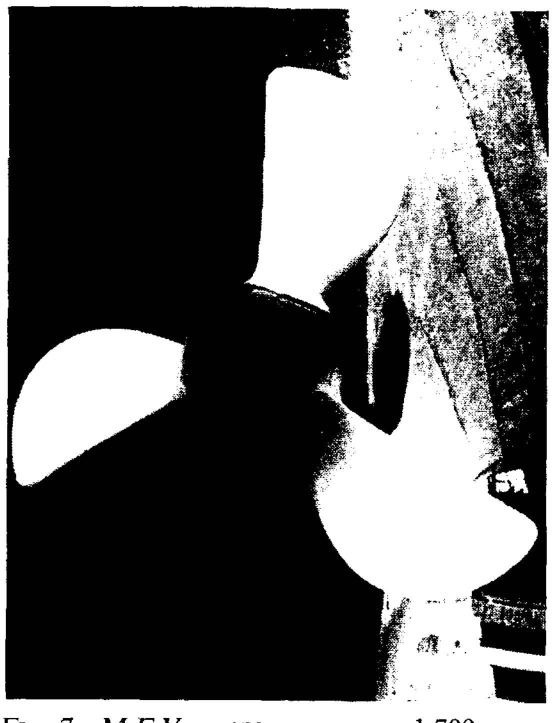

FIG. 7—M.F.V. PROPELLER AFTER 1,700 HOURS (NOV. 1960)

weakened state. FIGS 6(*a*) and (*b*) show the broken blades of the propeller.

Spare blades were fitted to the existing hub and the boat put back in service, the blades this time being conditioned to what was thought to be the equilibrium state by immersion in boiling water. Unfortunately, incorrect assembly of the spare blades resulted in the propeller being underpitched which, in turn, resulted in an engine speed limitation being placed on the M.F.V. until such time as the propeller could be corrected.

This opportunity occurred in May, 1960, when M.F.V.9 was taken in hand for refit, at which time the propeller (after re-pitching) was transferred to M.F.V.2 in order to continue the evaluation.

M.F.V.2 was slipped in November, 1960, when the propeller had completed 1,700 hours' running. FIG. 7 shows the condition of it on this occasion.

Following this examination, the propeller was put back in service and continued to give satisfactory performance until November, 1961, when it was reported that there was some loss in the top speed of the boat. The M.F.V. was eventually slipped in January, 1962, (the time lag indicating that the loss in performance was not considered to be so serious) and it was

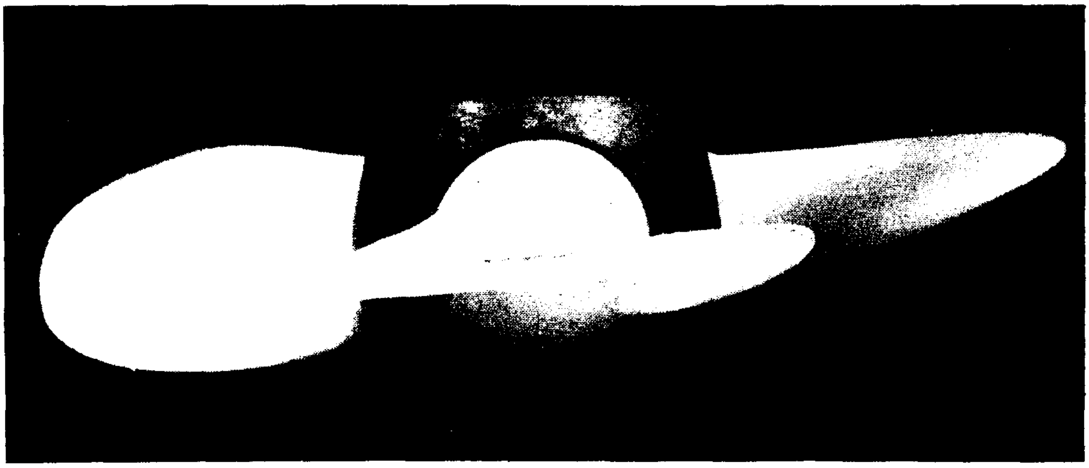

FIG. 8(*a*)—45-FT POLICE LAUNCH DAMAGE (JUNE, 1960)

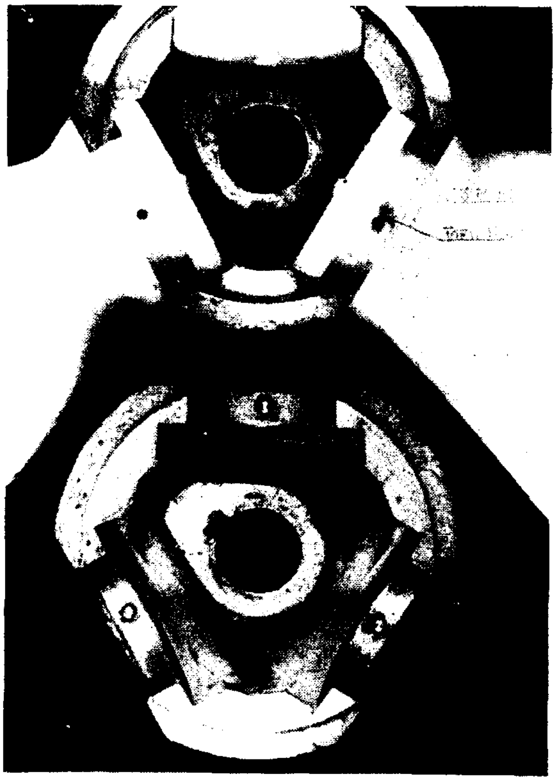

FIG. 8(*b*)—45-FT POLICE LAUNCH DAMAGE (JUNE, 1960)

found that one blade had broken off.

No reports were received of any excessive vibration such as would be expected with this degree of damage, and it may be that the loss of the blade was again sustained on moving on to the slip, the loss in performance being due possibly, to additional moisture absorption in service causing excessive flexure of the blades under the hydrodynamic loading.

It was established that the pitch locking arrangements were completely satisfactory so there was no question of the blades tending to 'feather'.

Up to the time of slipping, the propeller had completed a total of 2,935 hours' running and, consequent upon the failure, it has been returned to the manufacturer for re-blading.

After the encouraging results initially obtained with the first M.F.V. propeller, it was decided to extend the trials of nylon propellers to cover a smaller diameter, higher shaft speed range. For this purpose, it appeared that there was a satisfactory commercial design which would be suitable (although again it would be a compromise, particularly as regards blade area) for the 45-ft Police launches operating in Portsmouth Harbour. As a trials vehicle, these boats were considered to be very suitable since they are required to do extensive running in the Harbour, including periods in shallow waters, and on the average, it was found that the standard H.T. brass propellers were remaining serviceable for only four months.

A contract was placed for the supply of four propellers, again of the loose bladed type, having 3 blades, 19 inches diameter, 16½-inch pitch, and the first boat to be so fitted carried out initial trials in May, 1960.

The time lapse between the placing of the contract (April, 1959) and first fitting is indicative of the production difficulties which have been encountered throughout this project.

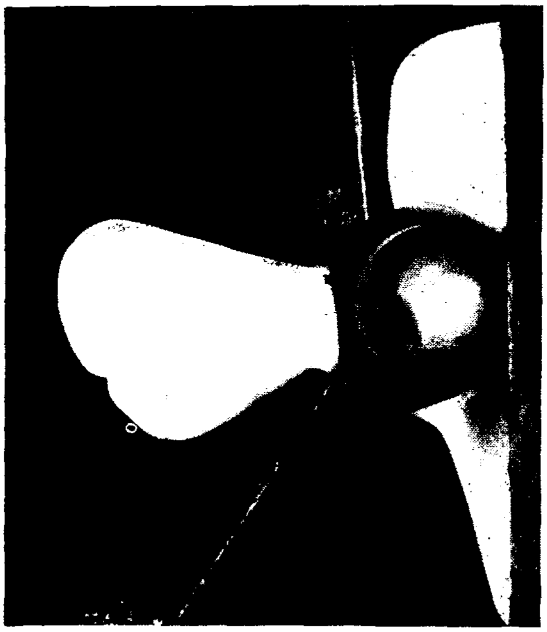

FIG. 9—45-FT POLICE LAUNCH—CUT IN PORT PROPELLER (AUG. 1960)

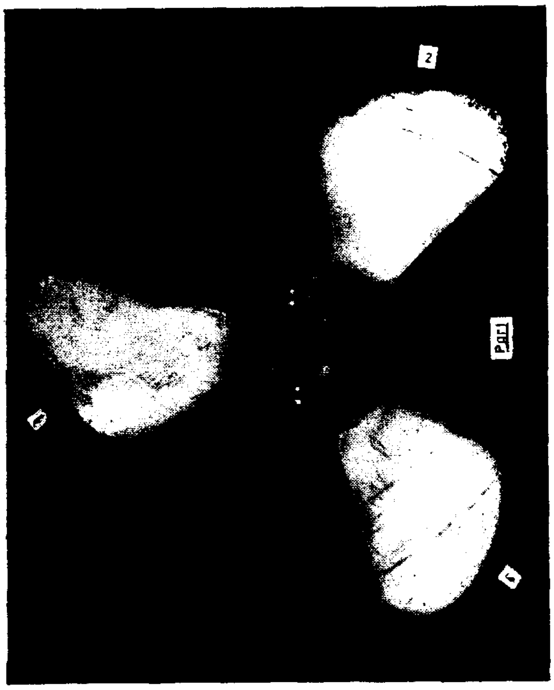

FIG. 10(*a*)—45-FT POLICE LAUNCH—NYLON PROPELLERS, 2,500 HOURS

In June, 1960, this boat sustained underwater damage through striking a submerged object. The boat was slipped for repair of hull damage but a visual examination of the propellers revealed no apparent damage to them. On being put back into service, however, excessive vibration and loss of power was experienced and the boat had to be re-slipped for a more detailed examination of the propellers. This inspection showed that elongation of the hole in the root of one blade of the starboard propeller in which is fitted the locking pin for setting (and holding) the pitch of the blade, had occurred. The blade had subsequently ' feathered ' under the hydrodynamic forces with consequent loss of power. FIGS. 8(*a*) and (*b*) show this damage to the locking arrangement and the feathered blade.

The starboard shaft was fitted with a new nylon propeller and evaluation was resumed, the damaged propeller being subsequently repaired by re-drilling the hole and fitting a larger diameter locking pin. Apart from this, the propeller suffered no damage and was held as a spare for further fitting if required.

The next examination was made in August, 1960, after the propellers had completed 1,500 hours' running. On this occasion, it was discovered that the port propeller had fouled a wire at some stage and one blade had a cut on the edge approximately $\frac{3}{8}$-inch deep. No other damage had been sustained so the damaged blade was faired off and the boat put back into service. FIG. 9 shows the cut in the edge of the damaged propeller blade.

Such damage to a standard H.T. brass propeller would inevitably have caused the blade to bend as well as cut the edge, and if the blade had not actually broken off, the cavitation set up would certainly have caused severe erosion damage.

After 2,500 hours' running, the boat was again slipped in December, 1960, and the propellers were dismantled for a complete examination. It was found that the damage previously sustained to the edge had not increased but there was evidence, in the form of superficial scratches on the blade surface as well as slight elongation of the pitch locking arrangements, that they had suffered further minor damage through striking underwater obstructions. It was encouraging to note that although there was some superficial de-zincification of the bronze hubs, with areas of local pitting adjacent to the trailing edges of the blades, there was a complete absence of any cavitation damage to the blades themselves.

FIGS. 10(*a*), (*b*) and (*c*) show the state of the propellers at this stage, and for comparison FIG. 11 shows a standard H.T. brass propeller removed from another Police launch after 2,500 hours' running.

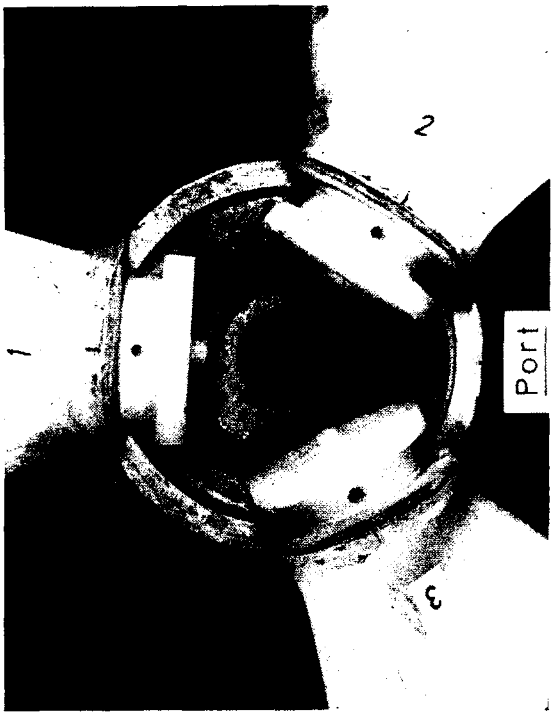

FIG. 10(*b*)—45-FT POLICE LAUNCH—NYLON PROPELLERS, 2,500 HOURS

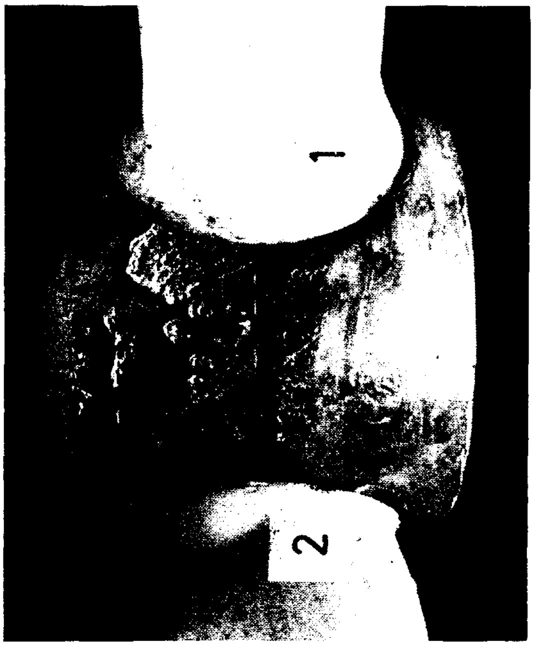

FIG. 10(*c*)—45-FT POLICE LAUNCH—NYLON PROPELLERS, 2,500 HOURS

In view of the slight elongation of the holes of the pitch locking arrangements, the propellers were re-pitched and put back into service, giving very satisfactory service until June, 1961, when it was reported that the port propeller was missing. The reason for this loss was never satisfactorily determined, but a report from Portsmouth at the time indicated that, on slipping the boat, it was found that the key of the starboard propeller had corroded and was in two pieces such that there was no mechanical connection between the boss and the shaft. It was therefore concluded that this had also happened to the port propeller key and that, in this case, relative movement between shaft and propeller had caused the securing nut to unscrew.

On the remaining starboard propeller, there were signs that the blade tips had been fouling the skeg of the 'A' bracket, this being attributed to the material having absorbed so much water as to give excessive flexibility of the blades under load. The reason for this excessive flexibility is again not fully understood, but it is thought likely that the initial conditioning of the blades did not result in complete stabilization of the material, i.e. the moisture content was somewhat less than 10 per cent and that subsequent immersion in service eventually increased the moisture content to this value.

This propeller was therefore considered to have reached the end of its useful life, although had it not been worn away at the tips of the blades, it could have been reclaimed by drying out. Nevertheless, these propellers were considered to have been successful in that it was estimated they had outlived by some three to four times the life of the standard H.T. brass propellers.

FIG. 11—45-FT POLICE LAUNCH—H.T. BRASS PROPELLER, 2,500 HOURS

Replacement nylon propellers are being obtained for this boat in order to continue the evaluation.

Future Trials

To advance still further experience of the behaviour of nylon propellers, it is intended to provide a limited number of them for the following types of vessels:—

(*i*) 25-ft Motor Cutters
(*ii*) 52½-ft Harbour Launches
(*iii*) One Inshore Minesweeper, Type I
(*iv*) Blades for the controllable-pitch propeller of an Inshore Survey Craft
(*v*) L.C.A.(2)

As regards the 25-ft motor cutters it is intended to obtain 20 propellers which will be distributed to selected H.M. ships and establishments so as to obtain the widest possible experience under service conditions, and it is hoped that now manufacturing difficulties appear to be easing, delivery of these propellers will be effected in the near future.

In addition to the anticipated greater facility for production, it is believed that, as a long term development, the casting process will lend itself to the introduction of reinforced blades (by steel or bronze inserts) which, while retaining the advantage of resistance to cavitation damage, would not suffer from the flexure problem at present experienced. It may then be found possible to extend the range of propellers for which nylon may be considered, and if this turns out to be the case, nylon, because of its high internal damping characteristics, may well provide an answer to the problems connected with 'singing' propellers.

Conclusions

With regard to the life of nylon propellers, it would appear that a compromise must be reached between allowable stresses, initial ductility (as determined by moisture content) to provide resistance to impact damage and lessen the risk of suffering early failure through the creation of internal stresses, and subsequent service life to the stage where the moisture content gives rise to excessive flexure under hydrodynamic loading. While optimum conditions may not have been achieved to date, such experience that has been accumulated has been most encouraging, and it is confidently expected that in the near future it will be possible to adopt nylon propellers for all small craft used by the Royal Navy.

Acknowledgement

The assistance given by Mr. F. Smith of Messrs. F. Bamford and Company, in the preparation of this article is acknowledged.