R.A.N. INVESTIGATION INTO

MARINE FOULING AND ITS PREVENTION

BY

LIEUTENANT-COMMANDER W. J. ROURKE, R.A.N., A.M.I.MECH.E.

Introduction

The problem of controlling marine fouling is common to shipping authorities in all countries. Fouling is severe in tropical and sub-tropical waters, and Sydney Harbour can claim the dubious distinction of being one of the worst fouling areas in the world. Effective anti-fouling measures are, therefore, of particular importance to the Royal Australian Navy and a broad programme of research and trials is being carried out. This article is intended to explain the importance of fouling prevention, identify some common fouling organisms, describe the general development of anti-fouling paints, and outline the progress of research and trials in the R.A.N.

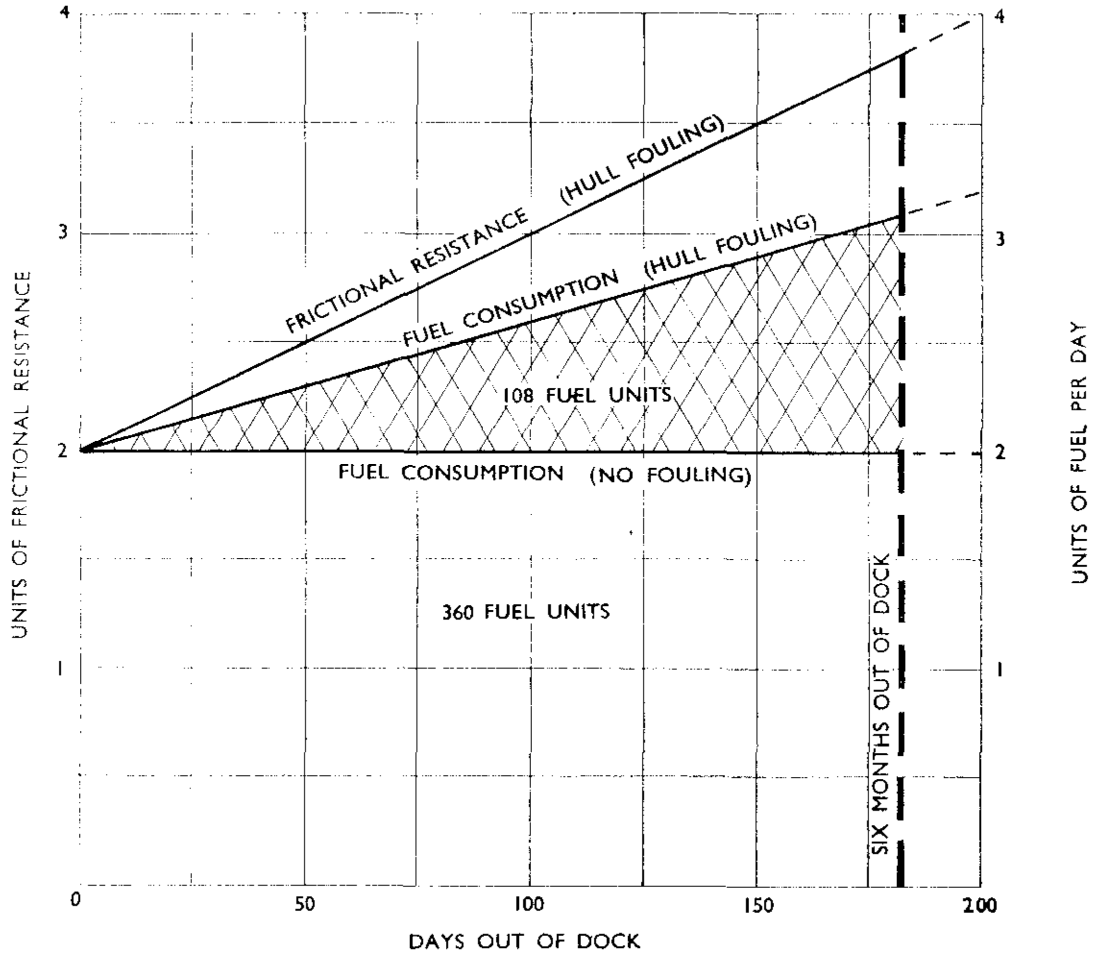

FIG. 1 EFFECT OF FOULING ON FRICTIONAL RESISTANCE AND FUEL CONSUMPTION—TYPICAL DESTROYER IN TROPICAL WATERS AT ECONOMICAL SPEED

$$\frac{\text{Fuel Consumption Due to Fouling}}{\text{Total Fuel Consumption}} = \frac{108}{360+108} = \text{24 per cent } \textit{Possible Saving if Fouling Eliminated}$$

THE COST OF FOULING

Fuel Consumption

In a destroyer at economical speed the frictional resistance of the hull is approximately 70 per cent of the total resistance to motion. The proportional effect of frictional resistance is reduced for larger hulls and higher speeds, but is still an important factor. This frictional resistance is greatly increased by fouling and can be almost doubled after some months out of dock.

The Admiralty allows, for design purposes, an increase of frictional resistance of $\frac{1}{4}$ per cent per day out of dock in temperate waters, and $\frac{1}{2}$ per cent per day out of dock in tropical waters. The effect of this resistance on fuel consumption is that a destroyer six months out of dock in temperate waters burns about 30 per cent more fuel than with a clean bottom, and in tropical waters up to 60 per cent more (see FIG. 1). These estimates are supported by practical experience as is clearly shown in Commander (now Captain) I. G. Aylen's article (Vol. 4, No. 3) on the effects of marine fouling. The maximum range of a ship can be reduced by one-third at six months out of dock, and the increased resistance at full power will cause a speed loss of from one to two knots. Fouling on propellers can cause further speed losses as slight roughness has a marked effect on propeller efficiency.

Fouling in Australian waters, particularly Sydney Harbour, is severe, and it is estimated that the direct costs of increased fuel consumption due to fouling, for an R.A.N. destroyer, are over £20,000 per year.

It should be stressed that heavy fouling, and its associated effect on fuel consumption, is incurred as a result of time spent *in harbour* in regions of high fouling activity. Naval vessels in peace-time are, therefore, more liable to foul than merchant ships with a short turn-round. Recent trials on a passenger cargo liner on the Antwerp-Congo run showed an increased consumption due to fouling of two per cent per month out of dock.

Docking Intervals

Limitations of anti-fouling paints have made it necessary to dock ships for a 'haircut and shave' at six-monthly intervals. Considerable financial savings would result if this interval could be extended to twelve months or more. It is, of course, of great importance that in war-time ships maintain their best speed and endurance without frequent docking. The loss of the *Graf Spee* was attributed, in Germany, to the speed reduction caused by fouling.

Design Considerations

It is reasonable to assume, that if prevention of fouling could be ensured, requirements for speed and range would be maintained with lower machinery weights and reduced fuel stowages. Alternatively, improved performance could be obtained from existing designs.

COMMON FOULING ORGANISMS

Several thousand different fouling organisms have been identified and recorded. They range from microscopic bacteria to the edible oyster, not unfortunately of major import in fouling studies.

Plants

Bacteria

Although microscopic bacteria have little obvious effect on fouling they form slime films which encourage attachment of larger organisms.

Algae (Seaweed)

The types of algae range from brown kelp which grows to 500 feet in length, to microscopic diatoms that provide food for larger organisms and form grey-brown gritty slimes on immersed objects. The most common fouling algae are the widely distributed green enteromorpha (grass) and ulva (sea-lettuce) ; red algae are found mainly in tropical waters, and brown algae are prevalent in colder seas. Algae require light to develop and attach mainly in the boot-topping area.

Animals

Barnacles

Two general types of barnacle are easily distinguished—the ' acorn ' and the ' goose ' barnacles. Acorn barnacles are those whose shells attach direct to the fouled surface. Settling on ships' hulls they not only increase frictional resistance but by penetration of the paint film permit corrosion pits to form beneath their bases.

Goose barnacles derive their name from a mediaeval belief that they produce the young of the European sea goose. They attach by means of a fleshy stalk about three or four times the length of the terminal shell. These barnacles are found mainly on stationary offshore structures such a sbuoys and light vessels.

Molluscs (Shellfish)

Only the bivalves of this family—mussels, scallops and oysters, are important in fouling, and the mussel is the type usually encountered. The common mussel is a lustrous blue-black colour and reaches 3–4 inches in length. They have a world-wide distribution and settle when the water temperature is about 60 degrees F.

FIG. 2—SEVERE TUBEWORM FOULING. CONVENTIONAL PAINT SYSTEM AFTER 14 WEEKS' IMMERSION

Serpulids (Tubeworm)

These worms secrete a thin, white, calcareous tube in which they live. Often they occur in such numbers that they accumulate a great mass of tubes often incorrectly termed ' coral '. Tubeworm is particularly severe in tropical waters, adheres firmly to the fouled surface, and is often found on propellers.

Bryozoa (Sea-Moss)

This species, also called polyzoa, occurs either in flat encrustations, nodular masses, or as an erect branching growth. Watersipora, a warm water variety of the encrusting type, attaches as a thin, flat, brittle disc, dark red-brown in colour. It has a high resistance to copper and its flat surface provides a base for the settlement of other organisms. Schizoporella, a nodular bryozoan, develops into a hard purplish-brown irregular mass up to twelve inches across. Bugula, an abundant group of the branching type, looks like seaweed, and grows in bushy tufts to a height of an inch or more.

Hydroids

This family has a tree-like appearance with slender stems supporting larger buds or polyps. It breeds in colonies in water temperatures between 65 and 85 degrees F.

Tunicates (Sea Squirts)

These soft-bodied animals have a tough, rubbery coat or ' tunic ' and when squeezed expel a jet of water. They occur commonly on stationary objects, as on active ships they are torn away by water flow.

THE PREVENTION OF FOULING

Historical Notes

It is nearly two hundred years since the use of copper sheathing, the first relatively effective method of fouling prevention, was recommended to the Admiralty as protection against weed and worm. Since the days of the Phoenician traders, seafarers had coated their ships with pitch, wax, arsenic,

FIG. 3—FOULING ON POCOPTIC AFTER 5 MONTHS' IMMERSION

sulphur, sealfat, animal hair, and other unusual coatings in attempts to discourage the ravages of teredo and ship stopping growth. In 1720, the *Royal William* was built for the Admiralty completely from charred wood, in the hope that fouling might be prevented.

Following successful trials in H.M.S. *Alarm* in 1763, copper sheathing was widely adopted for all wooden vessels, but serious difficulties arose with the introduction of iron hulls to the Navy a hundred years ago. Copper, in contact with iron or steel, accelerated hull corrosion to such an extent that one ship reported that she was only kept afloat by her barnacles. As copper could not be used on iron hulls, fouling again became such a problem that ships were often dangerously unmanageable during their return from foreign stations. Some iron ships were sheathed first with wood and then with copper, but this method of protection was so expensive that efforts continued to find an anti-fouling coating that could be applied directly to the hull. Such diverse materials as lead, canvas, rubber, cork, tiles, brown paper, manure and suet, were tried with uniform lack of success. Several cases were reported of bigger and better barnacles growing on the compositions offered for their consumption.

In 1860, the first practical anti-fouling paint appeared, a hot plastic soap composition using a copper sulphate toxin, and by 1900, many relatively effective compositions incorporating copper, arsenic and mercury toxins in resin and other vehicles were in common use. Since that date gradual progress has been made in obtaining improved anti-fouling properties but until recently such development was achieved mainly by trial and error.

Trials of various mechanical devices using knives and scrapers have been carried out from time to time, and as recently as 1943–44, when attempts to increase the speed of merchant ships in convoy by such procedures met with little success. Steam has been tried, and electrolytic methods, but neither has been effective. A recent innovation is the use of ultrasonics, now under trial.

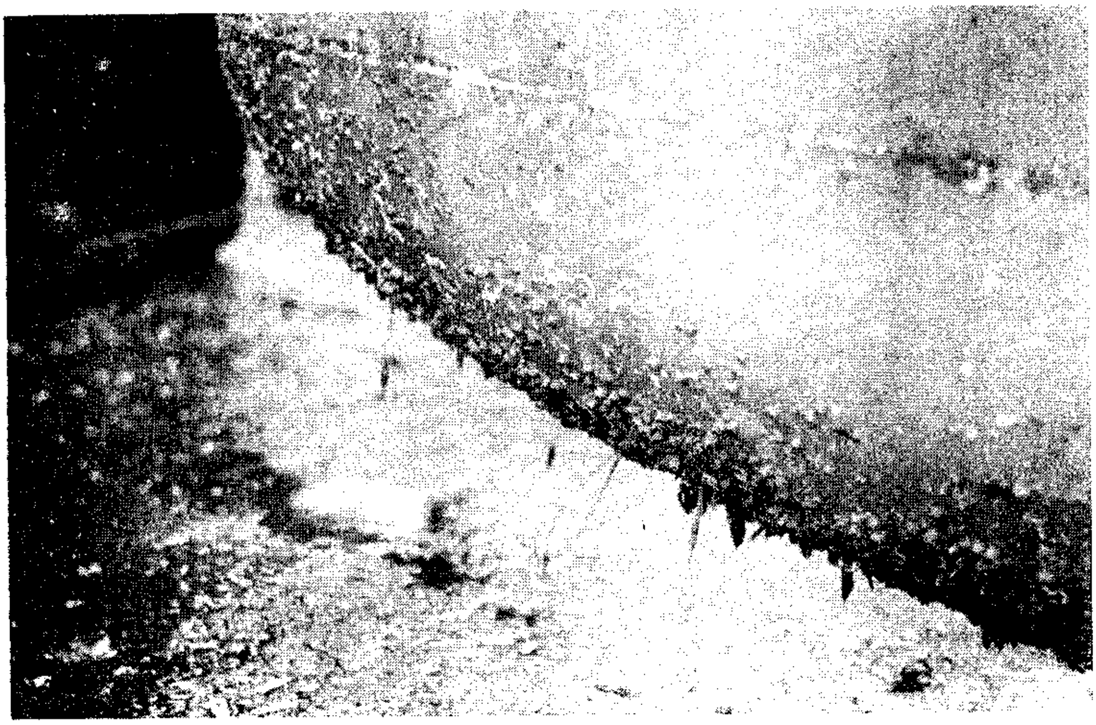

FIG. 4—ACORN BARNACLE FOULING OF A.S. DOME AFTER 4 MONTHS OUT OF DOCK

but indications are that it, too, is ineffective unless prohibitively high sound energy levels are used.

Behaviour of Fouling Organisms

It is known that fouling organisms :

(*a*) Will not attach at water speeds over 1·5 knots
(*b*) Attach more readily to roughened surfaces
(*c*) Are attracted by light but perfer darker surfaces for settling
(*d*) May be encouraged to settle by slime films
(*e*) Are discouraged by very high energy sound levels
(*f*) Can be shed from exfoliating surfaces
(*g*) Are killed and or repelled by certain toxins.

Although it has not been conclusively established whether toxins in anti-fouling paints actually kill the fouling larvae on settlement, or repel the larvae as they approach the surface, such poison bearing materials are the only proved, practical method of fouling prevention.

The Action of Toxins on Organisms

Salts of certain metals, particularly copper and mercury, are lethal to fouling larvae and are commonly used in anti-fouling paints. Some organisms are more sensitive to copper, and some to mercury, so it can be an advantage to combine both toxins in the one paint. Certain organic toxins have shown promise but are selective in their effect ; e.g. D.D.T. is lethal to barnacles but does not affect other fouling.

Several investigators have shown a definite relationship between the leaching rate of toxins from a paint film, i.e. the rate at which a toxin enters solution, and the fouling resistance of the paint under test. The minimum rates to prevent fouling are :

Copper or cuprous oxide 10/μg/cm^2/day
Mercury . . . . 2/μg/cm^2/day

and if at any stage leaching rates fall below these figures, fouling may start.

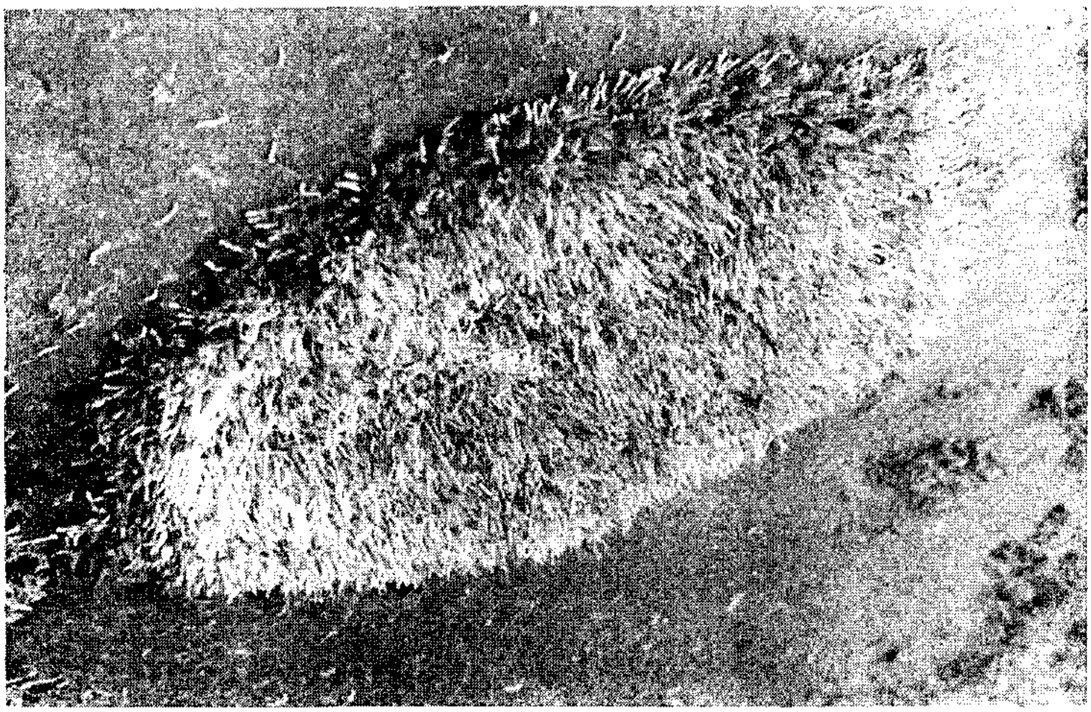

FIG. 5—DENSE TUBEWORM BLOCKING SEA INLET GRATING AFTER 4 MONTHS' IMMERSION

Leaching Mechanisms of Anti-Fouling Paints

It has been shown that a minimum toxin leaching rate is vital to the effectiveness of an anti-fouling paint. This is achieved in 'contact leaching' paints by the toxin alone going into solution, and in 'matrix-soluble' paints by the combined dissolution of both toxin and matrix, the vehicle or binder of the paint. In the first method direct contact of toxic particles is necessary so that as each is dissolved, another is exposed, and the toxin is gradually extracted from the matrix solution. The leaching rate will fall with the time in use, reflecting exhaustion of chains of particle contact, and a very high proportion of toxin, approximately 65 per cent by volume for six months' life, is required to maintain effective anti-fouling properties. The effective life of this type of paint cannot be prolonged by increasing the film thickness above the critical extraction depth. A further disadvantage is that an excessive amount of toxin is leached in the early part of its life in order to maintain an effective solution rate after some months' immersion.

In matrix soluble paints, commonly using resin as the toxin vehicle, both matrix and toxin dissolve together. The desired toxin leaching rate can be achieved either by using a rapidly dissolving matrix with a low toxin proportion, or a slowly dissolving matrix with a high toxin proportion. The anti-fouling life of the paint is directly proportional to its thickness. Unfortunately, most soluble matrix paints are comparatively soft and film thickness may be limited by mechanical strength.

General Requirements of Anti-Fouling Paints

In addition to providing protection against fouling, ships bottom paints must resist erosion, adhere firmly to the surface, and prevent corrosion. Unfortunately, copper and mercury are both cathodic to steel and accelerated corrosion can occur at points of coating breakdown.

As low frictional resistance is an important gain from fouling prevention the coating should have a smooth surface. The expense of application and basic paint cost should be kept as low as possible. Application expenses make

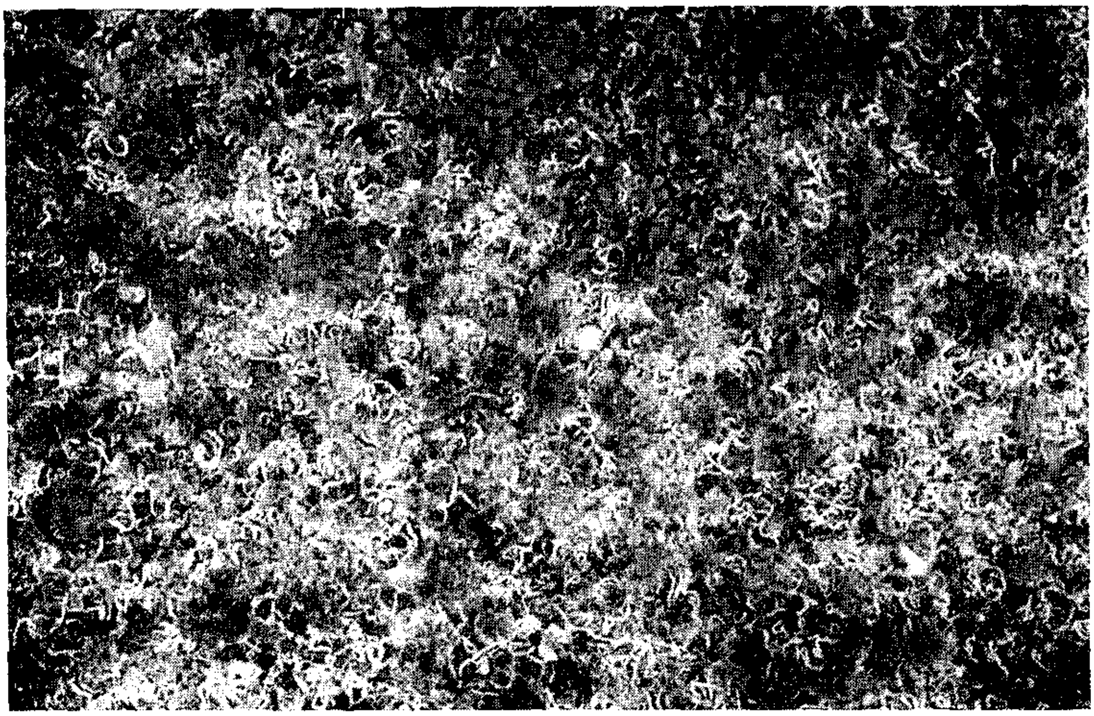

FIG. 6 – TYPICAL APPEARANCE OF UNDERWATER HULL OF CONVENTIONALLY PAINTED DESTROYER AFTER 4 MONTHS OUT OF DOCK

up the greater proportion of these costs, particularly as most modern anti-fouling paints require high standards of surface preparation, and special application procedures.

If ships are to be fitted with cathodic protection, the outer bottom paints applied must withstand the alkaline conditions existing at a cathodically protected surface. For certain purposes particular colours are required, and often the addition of a colouring pigment will reduce the effectiveness of anti-fouling.

Modern Anti-Fouling Paints

Even today there are extremely wide variations in the type, quality, and performance of anti-fouling paints in common use. Although different requirements exist in different localities, and difficult application techniques prevent more general adoption of certain paints, the continued use of anti-fouling paints of inferior quality can only be attributed to lack of knowledge on the part of ship owners.

Naval anti-fouling paints are generally of higher standard than those in general commercial use. (The term 'Admiralty quality' is often used to describe a manufacturer's highest grade product). The United States Navy, who have been responsible for great progress in fouling research, use hot plastic (Formula 15 H.P.), cold plastic (Formula 105) and vinyl (Formula 121) anti-fouling. The hot and cold plastic paints are matrix-soluble and have given a service life of up to two years.

The Royal Navy use 'Pocoptic', similar to an early U.S.N. cold plastic, and are carrying out trials with other matrix-soluble formulations. The Royal Canadian Navy require an anti-fouling that will withstand the alkaline conditions on cathodically protected surfaces, and use bituminous or vinyl anti-fouling paints. Vinyls have given excellent anti-fouling performance but severe random failures have occurred due to loss of adhesion. Trials are at present being carried out with chlorinated rubber systems with promising results.

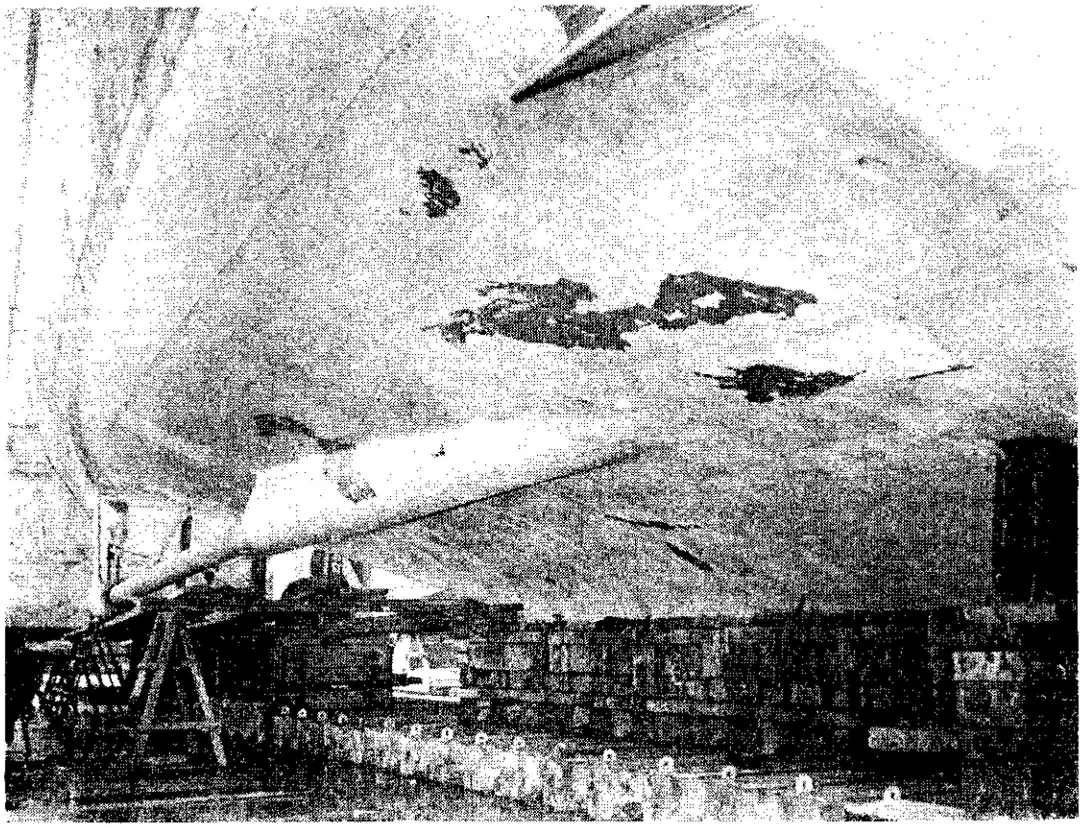

FIG. 7 UNTOUCHED UNDERWATER HULL OF VINYL PAINTED DESTROYER AFTER 7 MONTHS OUT OF DOCK. DARK PATCHES SHOW PREVIOUS COAT OF ANTI-FOULING STILL UNFOULED

Of the many paints tested in the severe fouling conditions of Australian waters, only the U.S.N. vinyl formulation (Formula 121) has given satisfactory performance, and is being generally adopted in the R.A.N. This paint shows negligible fouling, and therefore has little effect on fuel consumption, after twelve months' immersion. Difficulties in obtaining good adhesion have been largely overcome by insistence on high standards of surface preparation. There is still, however, room for improvement in many characteristics of the best anti-fouling systems, and research and trials are continuing on an increasing scale. Some recent examples of fouling and variation in paint performance are shown in FIGS. 2 to 7. All photographs are of active R.A.N. destroyers after service in tropical waters.

TRIALS AND RESEARCH IN THE R.A.N.

The Post-War Position

In 1945, the R.A.N. used standard commercial anti-fouling paints of the contact leaching type using a combination of copper and mercurial toxins. This paint has a poor performance and, as the necessary raw materials became available to manufacturers, a change was made to locally produced paints of the U.S.N. cold plastic formulation. However, during several years' experience severe failures of this type of anti-fouling occurred, and proprietary brands of ' mercurial ' anti-fouling were used once more, but again without achieving a long life. Trials were carried out by quartering ships with the products of different manufacturers to determine which product should be generally adopted. The best of these paints fouled after four or five months' immersion.

Some biological research on fouling organisms was carried out at this time

TABLE I

R.A.N.—*Vinyl Underwater Paint Systems—Application Instructions*
COMPLETE REPAINTING (Every 3 years)
1. Scrub down hull. Wash with fresh water.
2. Clean to bare metal by wet sandblasting.
3. Apply phosphoric acid solution immediately after sandblasting.
4. Wash down with fresh water to remove excess inhibitor.
5. Apply 1 coat Wash Primer (MIL-P 15328) 3 coats Vinyl Zinc Chromate (MIL-P-15930) 2 coats Vinyl Red Anti-fouling (MIL-P-15931)
TOUCH-UP REPAINTING (Intermediate Dockings)
1. Scrub down hull. Wash with fresh water.
2. Areas of paint failure treat as for complete repainting.
3. Where paint is in good order apply 2 coats Vinyl Red Anti-fouling.

by the Commonwealth Scientific and Industrial Research Organization, and the Maritime Services Board of N.S.W. tested various anti-fouling compositions. There was, however, no combined effort to attack the fouling problem.

Recent Progress

In 1952, an Underwater Paint and Fouling Committee was formed to coordinate and further research into fouling organisms, and to develop anti-fouling measures. Membership comprised the C.S.I.R.O., the M.S.B. of N.S.W., and the Commonwealth Departments of Navy, Shipping and Transport, and Supply (Defence Standards Laboratories).

In addition to continuation and extension of the biological studies by C.S.I.R.O., raft testing facilities were provided by the Navy, and a broad programme of tests and trials was initiated. Promising results were obtained from butyl titanate paints developed by the Defence Standards Laboratories. During these tests it became evident that the performance of U.S.N. vinyl paint was greatly superior to any other anti-fouling composition, and long term trials were carried out on ships in service. Several early adhesion failures were considered due to residual corrosion inhibitor at the primer-metal interface. Revised application procedures, shown in TABLE I, have now been adopted and excellent performances obtained. It has been found that reduced fuel bills will more than compensate for application costs, and it is hoped to effect further savings by an extension of docking intervals.

On the biological side it was decided that the best method of investigation would be the study of fouling organisms at the settling larvae stage by direct stereo-microscopic observation of their reaction to toxins and toxic surfaces. Young fouling larvae must settle at a certain stage of their life, or die, but exercise choice of the surface on which they will settle. It is not known whether anti-fouling toxins actually kill the organisms as they approach the surface, or repel them so that they sheer off to seek a friendlier resting place ; this fundamental point must be resolved. As these observations cannot be made on raft or ship trials it is necessary to provide a continuous supply of healthy settling larvae in the laboratory, and considerable progress has been made in breeding these larvae and observing their behaviour.

Future Research

A broad programme of research has now been established and will be carried out jointly by the C.S.I.R.O. and Defence Standards Laboratories under the sponsorship of the R.A.N. The aim of this research is to develop a ship's bottom coating, compatible with corrosion prevention methods, that will maintain an effective anti-fouling life of two years in Australian waters.

The problem is being attacked in three stages. The first and current stage consists of the breeding of settling stage larvae, the development of valid techniques for the assessment of effects of common toxins, the application of these techniques to assess the effect of ' new ' organic and inorganic toxins, and the investigation of the mode of action of these toxins on the settling stage larvae by histological methods and observation of the effects of selected toxin groups.

In the second stage of research, promising toxins will be incorporated into paint vehicles and the performance of these paints checked by leaching rate measurements, and direct microscopic examination of their effect on settling stage larvae. If effective results are obtained, coated glass slides will then be tested by immersion in a natural fouling community.

Finally, anti-fouling paints suitable for ship's bottom application will be manufactured and tested on raft panels and on ships in service. Large scale immersion testing of the best products of commercial suppliers, and of special formulations, will be continued concurrently with the broader programme of research. It is hoped that within a few years some definite advance will be made in methods of fouling prevention.