# AN INVESTIGATION INTO LOSS OF CONDENSER VACUUM IN EMERGENCY CLASS DESTROYERS

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During 1948, a serious deterioration in the main condenser vacuum at full power occurred in Emergency Class destroyers, especially on the Mediterranean Station. Throughout the year energetic efforts were made by Ship's Officers and Repair Authorities to trace the cause of this epidemic. Much good work was done in finding and making good defects such as leaky joints between L.P. turbines and condensers and defective air ejectors. The results were discouraging however, for at the end of 1948 the vacuum at maximum power in some of the ships concerned stood at a record low figure of 19″ Hg and designed full power could not be obtained in high sea water temperatures in any of the ships concerned. The Engineer-in-Chief therefore sent representatives to Malta to examine the situation at first hand. As a result of the report which followed this visit, the efforts of all concerned at Admiralty, in the Dockyards and in the Fleet, were concerted to seek the cause and the remedy, both of which were found in due course.

The first stage of the investigation was one of elimination. When all other possibilities were eliminated, it was clear that the cause of the trouble was poor heat transfer in the condensers. Nevertheless the methods employed during the early and less profitable part of the search may be of interest, and are outlined in the following paragraphs before coming to the main events in this investigation. There is nothing new about any of these methods, but it is considered worthwhile to recapitulate since most marine engineers are beset by vacuum troubles at one time or another.

### Detection of Air Leakage

When condenser vacuum is low, first suspicions are naturally centred on air leakage. These suspicions are normally followed by an uncomfortable and often blasphemous search for the leaks with a lighted taper.

The existence of air leakage can however be recognised by the effect which excess air in the condensers has upon air ejector vapour suction temperature and upon air ejector interstage vacuum.

In the extreme case when there is no air leakage into the condenser, the air ejector suction temperature will be at the saturation temperature of steam at the condenser vacuum. When a mixture of air and vapour is withdrawn from the condenser, however, the temperature of the mixture is less than the saturation temperature of steam at the same pressure. This temperature difference is a measure of the proportion of air present in the mixture, in accordance with the Law of Partial Pressures.

Furthermore, if an air ejector is in an efficient condition, the interstage vacuum is an indication of the air quantity being handled. Fig. 1 shows graphically the rise in interstage pressure as the air load increases for a Weir's two-stage air ejector as fitted in Emergency Class destroyers. It will be seen that the difference between the condenser vacuum and ejector interstage vacuum increases from 2″ Hg at no load to 5″ Hg when handling maximum air quantity.

When an air ejector is handling air in large quantities, vapour is emitted in noisy bursts from the discharge. This effect however might be caused equally well by defects in the air ejector.

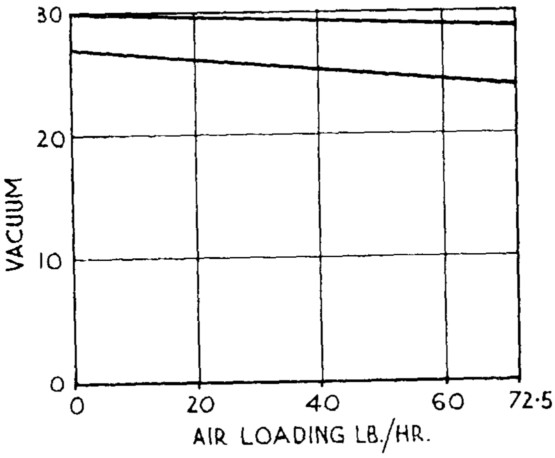

FIG. 1.

**Defects in Air Ejectors**

The quantity of air which is required to be withdrawn normally from both condensers to maintain designed vacuum at any power in an Emergency Class destroyer is well within the capacity of one air ejector. Readings of main condenser and ejector interstage vacua, first with both ejectors in use on associated condensers, and then with each ejector in turn on both condensers, give a good indication of air ejector performance.

A periodical fluctuation of the ejector interstage vacuum is sometimes observed. Each fluctuation marks a resurgence of vapour from the interstage space back into the ejector suction through the first stage and indicates that the first stage steam jet does not fill the throat of the diffuser tube. This may be caused by the steam nozzle being misaligned or not fitted at the correct axial position in relation to the diffuser.

Air ejectors in Emergency Class destroyers are sea water cooled, and the circulating water spaces are liable to become choked with marine deposits. Under these conditions, vapour is discharged in noisy bursts from the ejector, a symptom similar to that experienced when excess air is being handled.

It has been claimed by designers that steam pressure at the jets is a critical factor in air ejector performance, and that the pressure drop in the steam supply pipe between the point where the pressure gauge is connected and the steam nozzles, is sufficient to upset ejector performance. Although this pressure drop is frequently as much as 20 p.s.i. it appears to have little effect, however, on performance.

**Effect of Surplus Auxiliary Exhaust**

The quantity of surplus auxiliary exhaust which is unloaded into the main condenser affects the vacuum, but at the most this effect was found to be 1.0″ Hg at full power in Emergency Class destroyers.

The rate of scale formation which so adversely affects vacuum is considerably increased however by the admission of surplus auxiliary exhaust steam to main condensers when operating under harbour conditions without vacuum. External indications of temperature under these conditions are misleading, and there must be some very hot regions in the upper tube nests.

**Heat Transfer in the Condenser**

The elimination of defects external to the condenser by methods outlined above resulted in the recovery of a few of the missing inches of vacuum. The vacua in Emergency Class destroyers remained unacceptably low when steaming at full power in a warm sea, however, and it became abundantly clear that poor heat transfer in the condenser was the cause.

The poor heat transfer was traced to the use of cupro-nickel as a condenser-tube material. Cupro-nickel is used because it is extremely resistant to corrosion under marine conditions, but the thermal conductivity of this material is low compared with that of Admiralty brass and aluminium brass. On account of the low conductivity of cupro-nickel tubes, the cooling surface area in the condensers of the particular ships is just sufficient when the tube surfaces are clean. That is to say, there is no fouling margin, and the formation of scale on the sea water side of the tubes leads to a reduction of vacuum at maximum power under tropical conditions.

Ships with back pressure turbo-generator plant are particularly prone to scale formation on the sea water side of condenser tubes owing to the surplus exhaust steam which is admitted to the condensers. As mentioned previously conditions are particularly favourable for scaling of condenser tubes when steam is raised for auxiliary purposes in harbour.

The problem therefore was to find a means of providing a fouling margin in the condensers of Emergency Class destroyers. The remedy which became immediately apparent was to retube the condensers in these ships with a tube material possessing a high thermal conductivity, *i.e.*, aluminium brass.

In several very bad cases, condensers were retubed with aluminium brass tubes, with striking results. In sea water at a temperature of over 70°F., 27.2″ Hg vacuum was obtained at full power and performance was most satisfactory. This remedy was not adopted generally however. It was rejected owing to the doubts which were felt about the corrosion resistance of aluminium brass tubes in marine condensers. This is a contentious subject and there are many who strongly hold the view that aluminium brass is perfectly satisfactory as a condenser tube material. On the other hand, cupro-nickel has brought complete immunity from tube perforation in main engine condensers and it was decided not to make a change unless there was no alternative.

The alternative, which was eventually adopted, was to descale the sea water side of the condenser tubes and at the same time to devise a means of increasing water flow through the condensers thereby improving heat transfer to the extent that an adequate fouling margin was provided, while retaining cupro-nickel tubes.

**Descaling of Condenser Tubes**

It was found that mechanical descaling of condenser tubes, using rotary brushes or other means was impracticable, and consideration was given to chemical descaling.

At the Central Metallurgical Laboratory, samples of the materials of which condensers are constructed were immersed in various commercial descaling agents and the effect of the weak acid solutions upon these materials was assessed as regards loss of weight and effect upon the materials. The results of these laboratory tests were sufficiently encouraging to justify a ship trial, which was therefore arranged.

One condenser in a destroyer was chemically descaled, the process being as follows. The bellows piece in the inlet trunking and convenient lengths of discharge trunking were removed and blanks fitted to the condenser door openings. Two 75 gallon tanks were placed in position on the deck over the engine room. These tanks and a small circulating pump were connected up to the condensers as shown in Fig. 2. The tanks were then charged with fresh water and the descaling agent which were allowed to run down to the condenser in the proportion required to fill the sea water side with a 3% acid solution. When the system was fully charged, the solution was circulated for four hours and then left to stand in the condenser overnight. Next day, the solution was circulated again until there was no sign of gassing and then the spent liquor was blown overboard through a hose connected to the condenser drain.

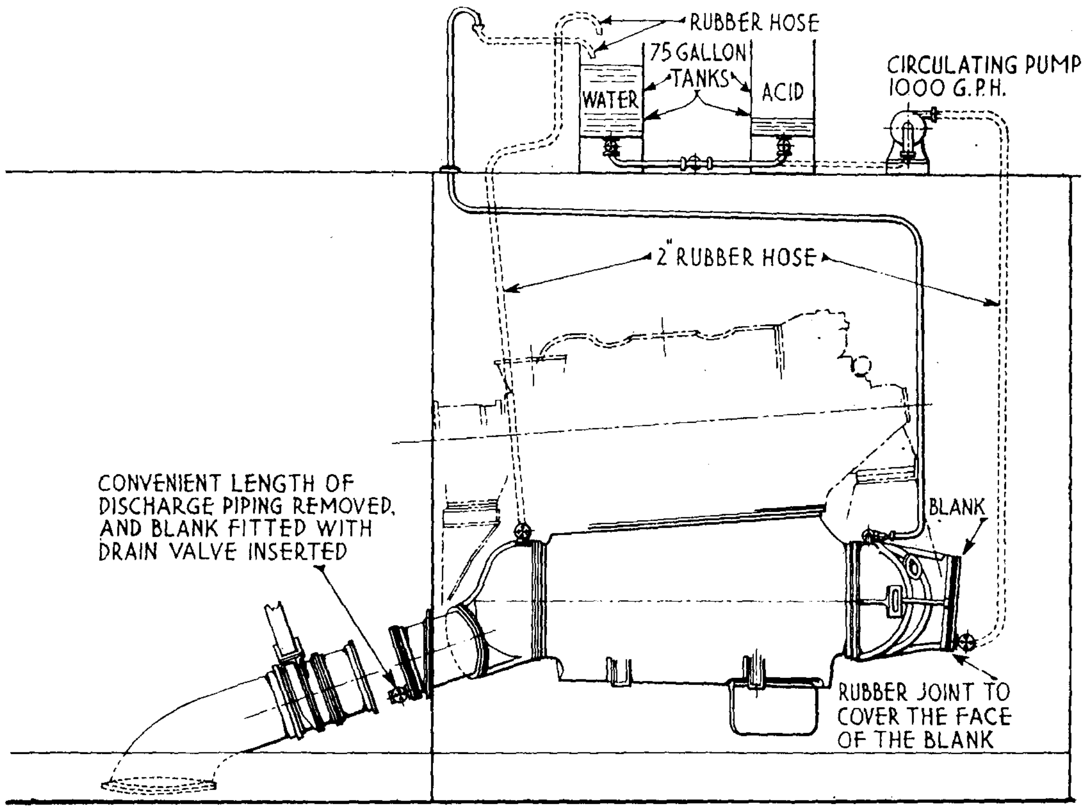


FIG. 2. DIAGRAMMATIC ARRANGEMENT FOR CHEMICAL DESCALING OF THE SEA-WATER SIDE OF MAIN CONDENSER TUBES IN DESTROYERS

The condenser was then thoroughly washed through with fresh water, and individual tubes were jetted to remove loose deposits and sludge.

This trial proved that the scale on the sea water side of condenser tubes could be removed successfully by chemical descaling.

A further service trial was carried out in an operational destroyer with similar success. There remained but one doubt about the safety of the process. Although steps had been taken to protect the tube plate from contact with acid solution during descaling, the protective paint coating was liable to peel off and it was feared that dezincification of the exposed R.N. brass tube plate may be initiated. Metallurgical examinations of cores which were trepanned from tube plates about six months after descaling showed however that this fear was unfounded.

**Circulating Water Scoops**

While the development of the condenser descaling process was in hand consideration was also given to improvement in water flow through condensers so as to create the required fouling margin. It was known that some improvement in water flow could be obtained by circulating water scoops, but the extent of this improvement could not be estimated, since knowledge of scoop design and performance was limited. The limited knowledge which was available on this subject was the result of the model experiments carried out some time ago by two Americans, Hewins and Reilly. It was decided to design circulating water scoops on the principles evolved from their model experiments and fit them in a ship for trial, and then to measure the effect of the scoops and to determine certain dimensions for optimum effect. It was essential to establish not only the increase in water flow but also the extent to which these devices increase the resistance of the ship. There is no advantage

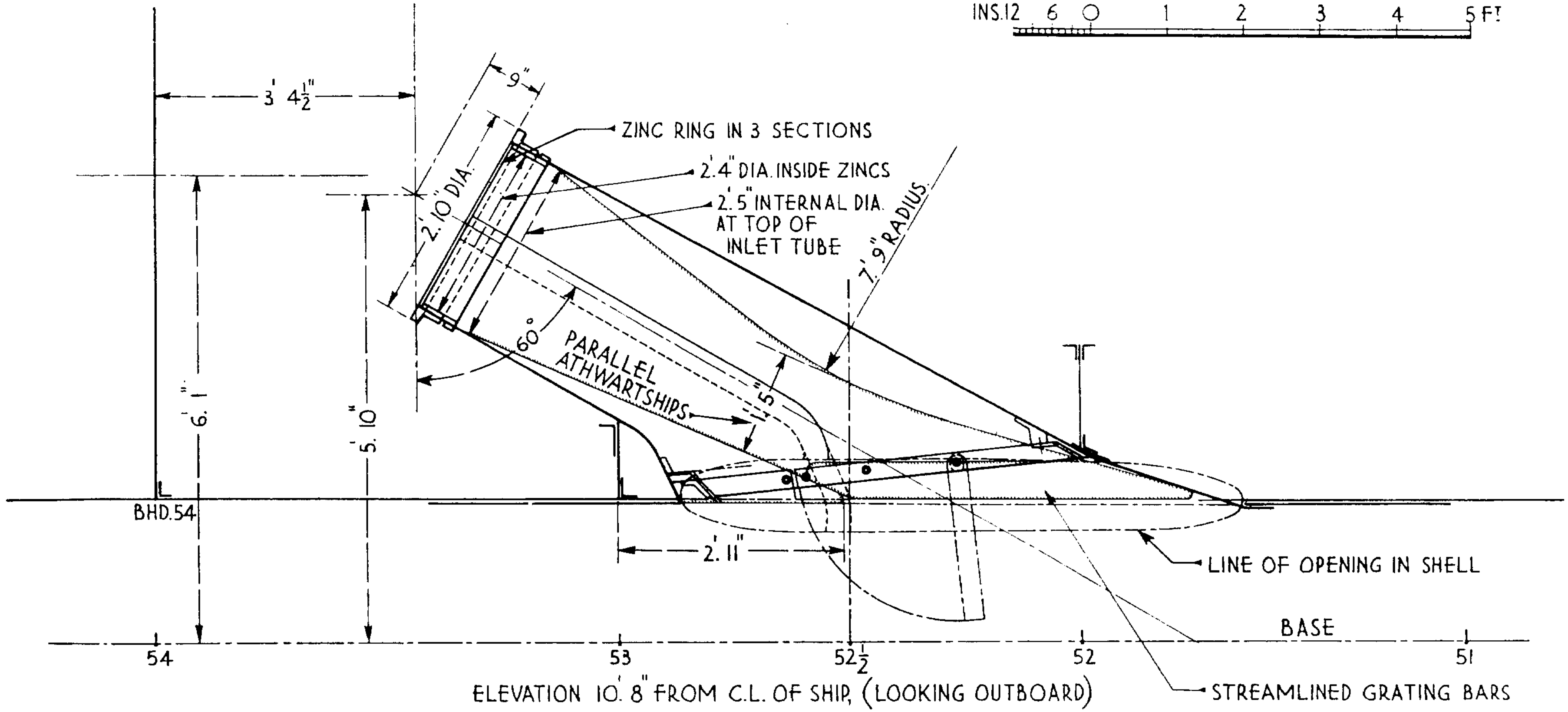


FIG. 3. EMERGENCY CLASS DESTROYERS. MAIN CIRCULATING INLET SCOOP (PORT)

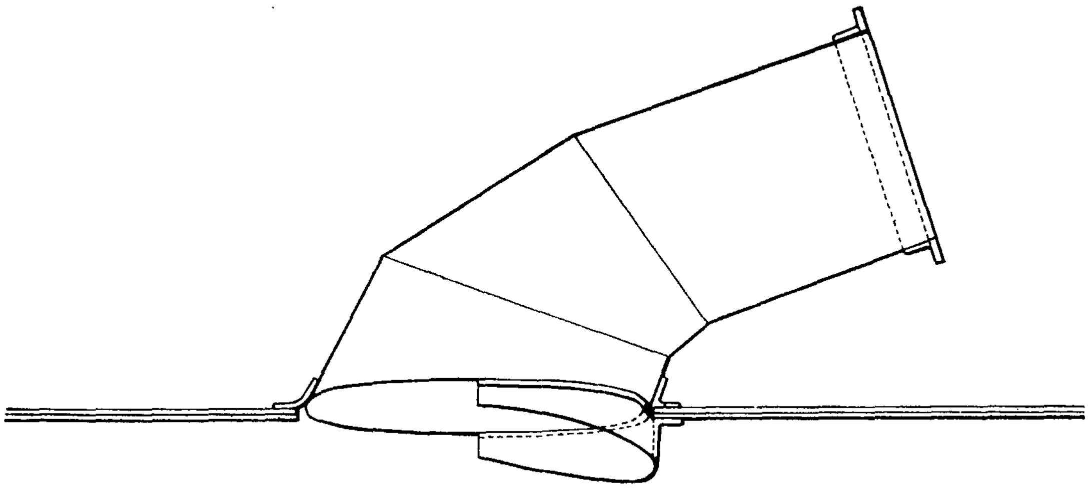

FIG. 4. ELEVATION OF MAIN OUTLET
SHOWING ANGLE RING IN LOWEST POSITION
STARBOARD SIDE SHOWN – PORT SIDE SIMILAR

in augmenting the quantity of circulating water and improving condenser vacuum unless the overall effect is an improvement in ship performance as regards speed and endurance.

The existing circulating water inlet tube in Emergency Class destroyers is a parallel circular tube angled at about 30° to the line of keel so as to derive some scoop effect. By means of fairing plates, this tube was modified to venturi form as shown in Fig. 3. No projection was fitted to this inlet.

The circulating water outlet was fitted with a projecting lip, of adjustable height, to the leading edge of the opening, as shown in Fig. 4.

**Scoop Trials**

In a destroyer selected for trials, one of the two circulating water inlets was modified, and both of the circulating water outlets were fitted with projecting lips which could be adjusted by divers to 6″, 4″, 2″ and nil height.

The inlet and discharge trunking was fitted with connections for the insertion of pitometer rodmeters which were used during the trials to obtain readings at numerous points in horizontal and vertical traverses across the trunking. An outline diagram of one of these instruments is shown in Fig. 5.

The results of each pitometer traverse were plotted, a sufficient number of points being taken to obtain a smooth curve. Readings relatively close together were taken near the walls of the pipes. Flow values were calculated from the plotted curves.

Instruments for the measurement of head at various points in the system were developed and constructed at the Admiralty Engineering Laboratory, West Drayton. These consisted of aircraft altimeters modified to accommodate a flexible bellows in place of the original barometric capsules.

No operational difficulties were experienced with the instruments in spite of the fact that there were occasions during the trials when there was a wave profile along the ship's side amounting to ten feet in height.

Trials were carried out at 15, 23 and 30 knots with 6″, 4″, 2″ discharge lips and without lips. At each speed and lip height, trials were performed with three different steam admissions to main circulators (all nozzles, trailing nozzles and none), and a set of four runs on the measured mile was carried out in each condition.

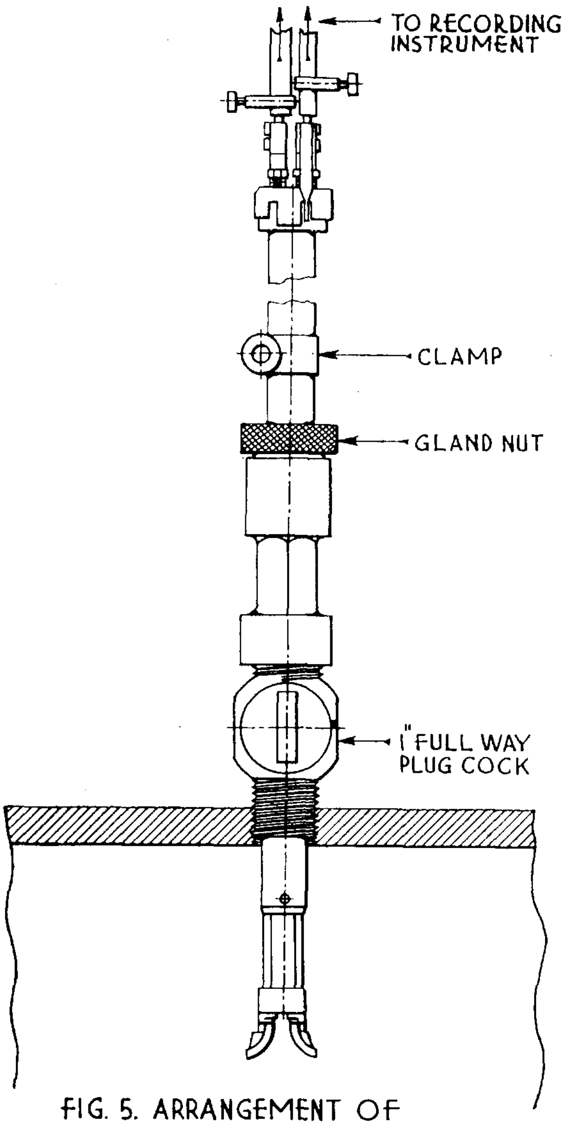


FIG. 5. ARRANGEMENT OF PITOMETER RODMETER

Trials were of long duration since the time required for a set of readings at even combination of speed, lip height and circulator steam admission was determined by the time required for a double traverse with the pitometer rod-meters. This operation required one hour at the commencement of the trials but was reduced to a half hour as the operators gained experience and became accustomed to the discomfort of their recording positions.

It was clear from these trials that a substantial increase in circulating water flow could be obtained by modifying inlet tubes to venturi form and fitting lips to the outlet openings (see Fig. 6). It was confirmed that ship resistance is not perceptibly increased by either the appendage resistance of the outlet lips or the additional water flow through the hull.

There was some increase in vacuum, although there was not much scope for improvement on this occasion since the trials were carried out in the English Channel in winter time. At full power in temperate waters no benefit is to be derived from increasing the flow of circulating water since a satisfactory vacuum can be obtained in any case.

At full power in tropical waters, however, the critical full power vacuum could not previously be obtained in Emergency Class destroyer condensers fitted with cupro-nickel tubes, even with new tubes. Using the scoop trial results, calculation has shown that optimum full power performance can be attained in these ships in tropical waters by the increased circulating water quantity derived from inlet scoops modified to venturi form and from outlet lips 3″ high, with the trailing nozzles only of the main circulators in use.

**Conclusion**

The chemical descaling of the sea water side of the cupro-nickel condenser tubes, and the fitting of circulating water scoops, as described above, has restored the main machinery performance of Emergency Class destroyers under tropical conditions.

In addition to achieving the main objective for which the circulating water scoop trials were planned, considerable information was obtained which will enable the results of model scoop tests and full scale scoop performance to be correlated for future development work on new designs.

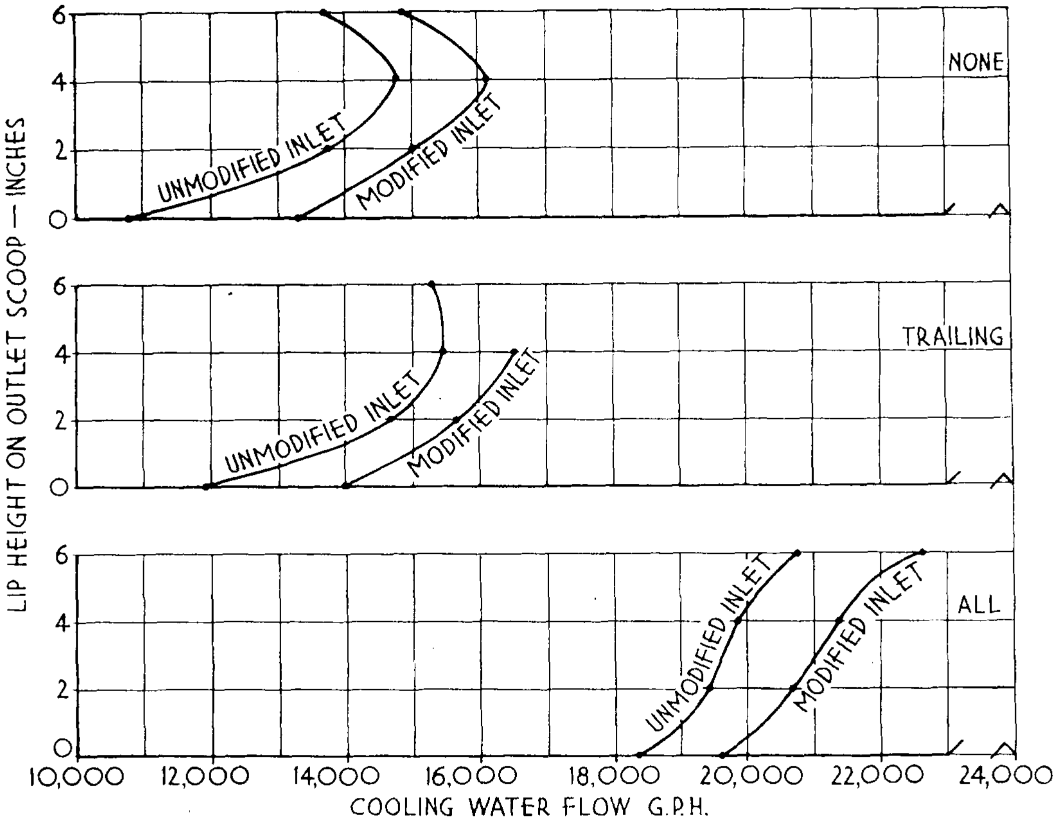


FIG. 6. EFFECT OF LIP AND PUMP ON FLOW, VACUUM AND SPEED AT FULL POWER.