SOME REFLECTIONS ON THE HISTORY OF STEAM TURBINES IN THE ROYAL NAVY

BY

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In the Royal Naval Engineering College's Centenary Year, it is apposite to reflect that the use of steam turbines in surface warships has been spanned during that hundred years: almost, but definitely not quite. In an era when the liquid fuel reserves are being depleted, it may well be that the need to burn alternative fuels—nuclear or other solids—will become an economic necessity. If this happens, it may well be expedient to renew the use of steam, which almost certainly means the use of steam turbines. However, this will need a fresh form of industrial approach and support if the Navy is to be properly served.

The early days of the application of steam turbines to ships were dominated by Charles Parsons who obtained his first patent in 1884, seven years after graduating at Cambridge. He set up C. A. Parsons & Co. to make turbo-generators in 1889. In that year, De Laval patented his single-stage impulse turbine and seven years later, in 1896, Rateau and Curtis patented their compounding of impulse turbine stages.

In 1894, Parsons took out his patent 'for propelling a vessel by means of a steam turbine actuating the propeller or paddle shaft either directly or through gearing.' In the same year, he set up the Marine Steam Turbine Co. and built *Turbinia.*

This was a vessel of 100 ft long and of 44½ tons displacement which he fitted with steam turbine drive; first a radial turbine on a single shaft and then three parallel-flow turbines in three stages, each on its own shaft. With three propellers on each turbine running at 2000 rev/min or over, she reached 34½ knots on trial and was demonstrated to an astonished world, steaming up and down the lines of warships at the Spithead Review of 1897. Of the 165 ships of the Royal Navy assembled there, all but a few sailing brigs had reciprocating engines; by 1914, all important naval ships were turbine driven.

In 1898 the Admiralty ordered from Parsons Marine Steam Turbine Co. the turbine-driven destroyer H.M.S. *Viper*. In every respect except the engines, she was like existing 30-knot destroyers. The Armstrong Co. at Elswick built a similar vessel, *Cobra*, as a private venture which the Admiralty bought after trials. These ships were accepted by the Admiralty in 1901 and before the end of the year both had been lost: *Viper* ran aground in the Channel Islands and broke up, and *Cobra* broke in two on the way to Portsmouth to have her armament fitted, and sank. The inquiries made it clear that the engines had nothing to do with these disasters.

The trials of these two ships had revealed a low cruising economy, and in 1901 as a speculation the Parsons Co. laid down the *Velox*, a 30-knot destroyer, with two reciprocating engines of 150 ihp coupled through clutches to the low pressure turbine shafts and exhausting into the H.P. turbine at low speeds; they were disconnected at over 13 knots. This ship was acquired by the Admiralty in 1903, the same year that H.M.S. *Eden*, of practically the same dimensions but fitted with cruising turbines, was launched. Trials with these two ships and another with reciprocating engines clearly demonstrated the superiority of turbines for high speeds and the need for cruising turbines for fuel economy at lower speeds.

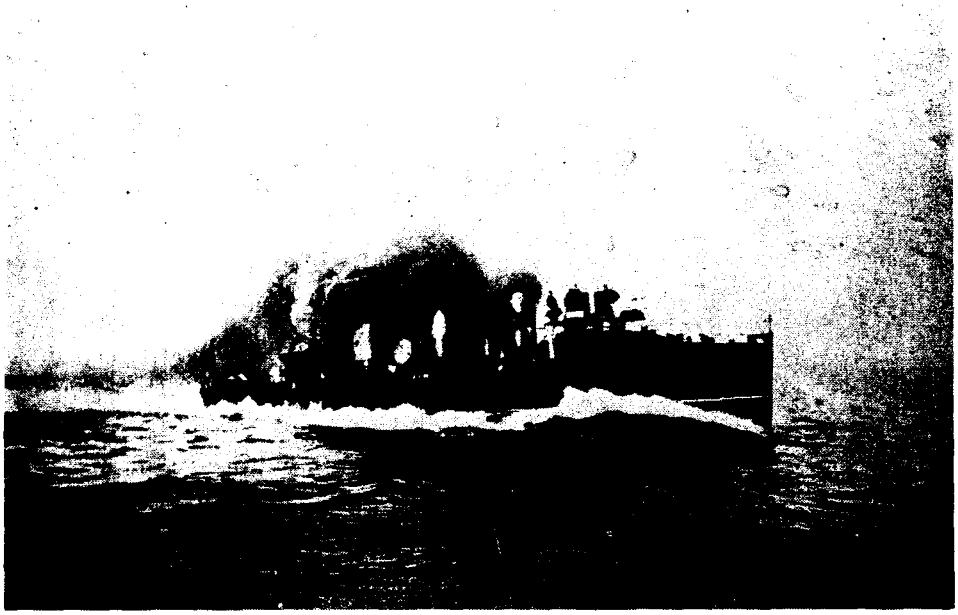

FIG. 1—H.M.S. 'VIPER' AT FULL SPEED

The early years of Keyham were in an age when the steam reciprocating engine reigned supreme. The college was set up seventeen years before Charles Parson's *Turbinia* made her sensational debut. It was another eight years before Admiral Sir John (Jackie) Fisher committed all future R.N. warships—from *Dreadnought* down to destroyers—to be turbine driven. Trials of the turbine-driven cruiser, H.M.S. *Amethyst*, in 1904 had confirmed that turbines offered a greater maximum power, a much better efficiency at full power (and hence less boiler output), and (a point made by the First Lord) fewer stokers to obtain full power. However, there was a corresponding lack of efficiency at powers less than 15 per cent. full power and thus higher coal costs.

FIG. 2—H.M.S. 'AMETHYST' 1904

The U.S.N. also ran trials in 1906 on three cruisers of the same class but fitted with different machinery: one had reciprocating engines, one has Curtis turbines, and one had Parsons turbines. The trials showed that the turbines had a great advantage at high speeds but had a much higher fuel consumption than the reciprocating engines at low speed; this caused a delay in the introduction of turbines. As a result of similar trials of battleships in 1912, the U.S.N. fitted quadruple-expansion reciprocating engines with forced lubrication systems in the ships *New York*, *Texas*, and *Oklahoma*, the ultimate in the development of reciprocating engines in the U.S.N.

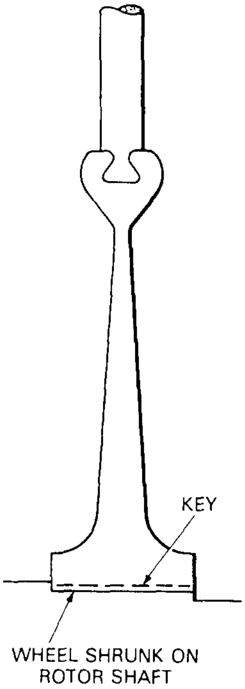

FIG. 3—BROWN-CURTIS WHEEL AND BLADE

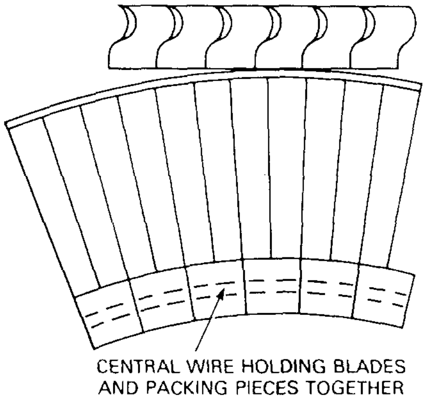

FIG. 4—PARSONS SEGMENTAL BLADING (BRAZED)

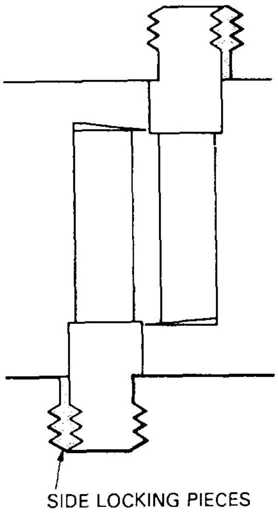

FIG. 5—PARSONS END-TIGHTENED BLADING

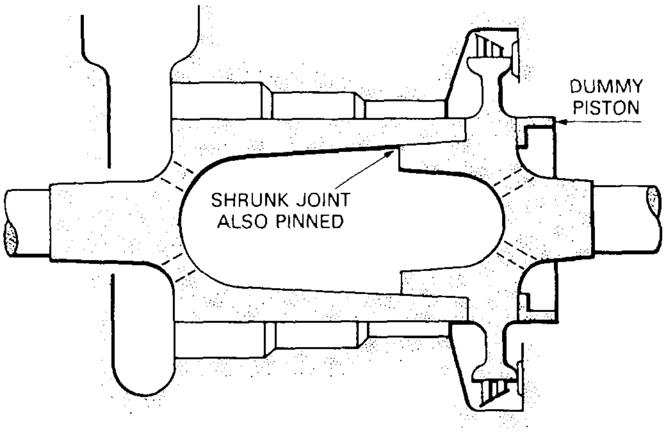

FIG. 6—SECTION OF PARSONS IMPULSE-REACTION H.P. TURBINE ROTOR

The direct-drive turbines in R.N. ships, however, suffered from certain limitations. Higher turbine blade speeds were desirable to improve turbine stage efficiency or to reduce the number of stages; however, increased revolutions would further reduce the propeller efficiency and increased diameter of the turbines (particularly for large passenger liners and battle-cruisers) would make them so heavy and bulky that cross-country transport of castings would become very difficult and handling them in the workshops would be cumbersome and inconvenient. They were also likely to change shape after machining. The need for a method of reducing propeller speed and increasing turbine rev/min was clear.

In 1910, Charles Parsons installed single-reduction gearing in S.S. *Vespasian*, a ship which his company bought and ran for two sets of trials: the first with the original reciprocating engines refitted, and the second with a set of geared turbines which saved 15 per cent. on coal. Starting with the two cross-Channel steamers, *Hantonia* and *Normania*, a steadily increasing number of geared turbines were then fitted to ships. The limitation on power was the gear-hobbing machine capacity.

From 1914, this research effort was devoted to warships and, when H.M.S. *Hood* was fitted with single-reduction gearing on four shafts, each transmitting 36 000 shp, it became clear that such gearing could be applied to turbines of any power. In 1919, Sir Tennyson D'Eyncourt, the Director of Naval Construction from 1912 to 1924, said that gearing had been responsible for raising the efficiency of propellers from 40 per cent. to 60 per cent.

It is of interest that, although all the marine turbine building companies in the shipbuilding industry were licensed to build Parsons turbines, Brown-Curtis turbines gained much popularity in the second decade of the century. In destroyers between 1912 and 1918 the proportion of each class engined with Brown-Curtis turbines rose steadily. However, when a destroyer programme was started again in 1927, only the two ships built by John Brown & Co. had these turbines.

Their popularity in the Navy was perhaps due to the large radial clearances acceptable in them without loss of efficiency, making them comparatively insensitive to bending of the rotor, which the methods of 'warming-up' then encouraged. Reaction turbines had small radial clearances at the blade tips, which made them very susceptible to damage from distortion of the rotor. Increase of these clearances caused loss of efficiency. The development by Parsons of 'end-tightened' blading with axial instead of radial clearances to maintain stage efficiencies certainly reduced the penalties of rotor distortion. The development of brazed segmental blading, with side locking pieces to secure it, made production much easier. These developments occurred when it was suspected that the fairly frequent failures of blading in Brown-Curtis turbines might be caused by overstressing the neck of the dovetail roots when they were being driven in the rotor grooves during blading of the turbines.

In the early years of the Second World War, repeated failures of the same rows of blades made it clear that these had been due to vibration, excited by variations in the steam forces acting on the blade arising from interruption in the steam flow as the blade passed nozzle vanes or the casing horizontal joint or other forms of cyclical interruption.

In 1918, the introduction of double reduction gearing in s.s. *Somerset* proved successful but in a number of other ships it ran into trouble. In the U.K. it was seen as unreliable and dropped. In the U.S.A., however, the troubles were overcome and it was accepted.

Their delay in introducing steam turbines seems to have given the impression that the U.S. were generally behind in marine engineering, but their introduction of double-reduction gearing as early as 1915 and their success by 1918 in curing the troubles from which these sets suffered belies this. In a paper on the 'Development of Marine Engineering' given in 1943 by John F. Nichols to the Society of Naval Architects and Marine Engineers on the occasion of their Jubilee Year Historical Transactions, after referring to the U.S.N's. cure by 1918, the author adds that double-reduction gears continued to give trouble 'abroad'. In fact at the time when the causes of the trouble had been diagnosed, British ships had abandoned double-reduction gears as unreliable. This happened in the 1920s and World War II saw all R.N. ships fitted with single-reduction gearing (as, indeed, were the German ships too).

Most engineers have got used to taking the main turbines in steam plant for granted. The majority of the work of upkeep is caused by far less important components of the plant. But for the first half of the century, the steam conditions and thus the thermal efficiency of the plant as a whole was mainly settled by what the turbine designer was prepared to accept. It is of interest that there were exceptions. s.s. *King George V*, Parsons's last serious effort to improve the steam plant efficiency in merchant ships by operating at 550 lbs/in^2 at

750°F, suffered successive failures of boilers and this idea fell into disrepute. H.M.S. *Acheron* (1926) on the other hand using similar steam conditions failed because the turbine was unable to cope with the transient thermal conditions when slowing down from high powers. The result was, however, that Royal and Merchant Navy ships built in this country (as most of them were) advanced their steam conditions slowly as compared to the electrical generating steam plant ashore.

In the later 1930s, the United States Navy adopted as their own suppliers the turbine and boiler companies who supplied power-station machinery. With their experience of using double-reduction gearing, they were able to use small, high-rev/min turbines and to adopt the higher steam conditions of which their new suppliers had experience ashore. The way in which this was done is related in Vice-Admiral H. G. Bowen's book *Ships Machinery and Mossbacks* (Princetown University Press, 1954) where he writes of how, as the last Engineer-in-Chief of the Bureau of Engineering, he was convinced that the U.S.N. would have to fight a war in the Pacific and therefore needed much improved endurance in their ships. This could be obtained by raising steam conditions to those current in power stations if their main component suppliers could be used. By inviting Gibbs and Cox of New York to get machinery designed for a new class of destroyers (and facing the fact that this was likely to put the shipbuilders' turbine manufacturing shops out of business) Rear-Admiral Bowen achieved his aim of getting all U.S. destroyers from then on fitted with machinery operating at 650 lb/sq. in and 850°F. In 1942, when the two navies started to operate together, the reports to the Admiralty from all over the world told of how badly the endurance of our ships compared with those of the U.S.N. and, indeed, made unfavourable comparisons of much of the engineering in R.N. ships with that of the U.S.N.

Up to that time it had been the Admiralty's policy to invite tenders from the shipbuilders for the ship and its propulsion machinery. The main machinery contractor (MMC), who was often, but by no means always, the shipbuilder (for example, Wallsend Slipway & Engineering Co. were often the MMC for warships built by Swan Hunter), usually obtained the basic plans of the appropriate turbines from Parsons Marine Steam Turbine Co. His designers then developed the whole turbine design from the basic details, i.e. rotor diameters and rev/min, pitch circle diameters and heights of blading in each stage, length between bearings, etc. The main machinery contractor then usually manufactured the turbines and the lead yard developed the machinery design as a whole.

In considerable anxiety about the shortcomings of our machinery, the Engineer-in-Chief therefore invited in 1943 the shipbuilders to recommend what he should do about raising the steam conditions in the DARING Class destroyers to the same level as that used by the U.S.N. A Shipbuilders' Committee was thus formed with Commander I.G. Maclean (Inspector of the Turbine Section) as a staff officer; to this were added sub-committees on certain of the components (such as turbines and steam valves) and on these sub-committees members of a number of the specialist suppliers of the power stations were invited to sit, thus incorporating some experience of operating at the higher steam conditions.

Recognizing that dependence on Parsons Marine for all turbine designs was no longer acceptable, the shipbuilders got together and decided to form the Parsons and Marine Engineers Turbine Research and Development Association (PAMETRADA) to build a research and test establishment. Further, they decided, with the help of C. A. Parsons (the 'land' firm created by Sir Charles Parsons), to create a turbine design team (who would take over the licence arrangements that Parsons M.S.T. Co. had had with the shipbuilders) as a source of turbine designs for manufacture by the licencees. The Engineer-in-

Chief had already obtained approval to have his own turbine and boiler test station built; this he now agreed to transfer as a project to the shipbuilders and to support the new organization by getting the Daring Class steam plant tested there and also by obtaining some Government financial assistance. He insisted, however, that he must be free to use the whole of British Industry for the source of his designs and not be confined by having to use only the warship turbine designs of the new PAMETRADA. The upshot of the Shipbuilders' Committee for Darings was a recommendation that the turbine design of mainly reaction stages devised by English Electric Co. for the turbine sub-committee should be developed by PAMETRADA and adopted for the Class. However, the alternative design put forward by E.E. Co. of impulse stages, using new rotor materials and wheels machined out of solid forgings, offered such advantages that it should be further developed. In the event, John Brown had also used B.T.H. to produce a HP turbine of impulse stages to be coupled to the PAMETRADA low-pressure turbine, and this was accepted by the Admiralty for the ship for whose construction John Brown had won the contract.

Sir Harold Yarrow was the only shipbuilder who offered to install the English Electric Co. 'advanced design' of turbines in the two ships of the Class for which he had won contracts, and to these were coupled hardened and ground gears—one set being ordered from M.A.A.G. in Switzerland to start us on a new road for gearing manufacture.

The Pacific War was brought to an end before the Daring Class destroyers were finished, but the determination to ensure that the R.N. regained its place in the forefront of marine engineering remained. Because Yarrow & Co. had already had experience of working with E.E. Co. and because the latter were consistently willing to help the Navy in its efforts to improve the reliability and efficiency as well as reducing the weight and size of its turbines, Sir Harold Yarrow was invited to form a team with E.E. Co. This team was to survey the steam plant practice of 'land' and of marine applications in the U.S.A., Germany, and the U.K., and to recommend the best steam plant for one shaft of 30 000 shp for a two-shafted destroyer and which could be devised within the immediate future. It was intended subsequently to investigate another stage of development ahead.

The invitation was accepted, the survey done, and the work of the combined team was going ahead on the so-called Yarrow, English Electric Advanced Design 1 (YEAD1), using British firms from land and marine markets, when the Korean War gave rise to a new and urgent requirement for an A/S escort vessel for the R.N. The displacement had to be severely limited to allow the necessary manoeuvrability for A/S work and this in its turn gave rise to a limitation on the permitted weight of machinery plus fuel to give the specified endurance. It represented a major departure from established norms of weight per horsepower, and something of the order of 25 per cent. reduction of the specific weight of the Daring Class machinery and an improved fuel consumption at the lower speeds.

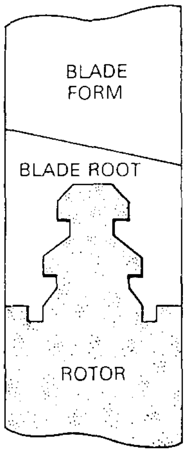

Fig. 7—Modern highly stressed rotor and blade root

YEAD1 was put aside for the time being (It was eventually built and tested at PAMETRADA) and the team were asked to undertake the development of a new plant for 15 000 shp on each of two shafts for a convoy escort frigate, to be within the limitations stated and to be designed for rapid production if required. A few months later, the R.C.N. decided to fit the same design of machinery in a new

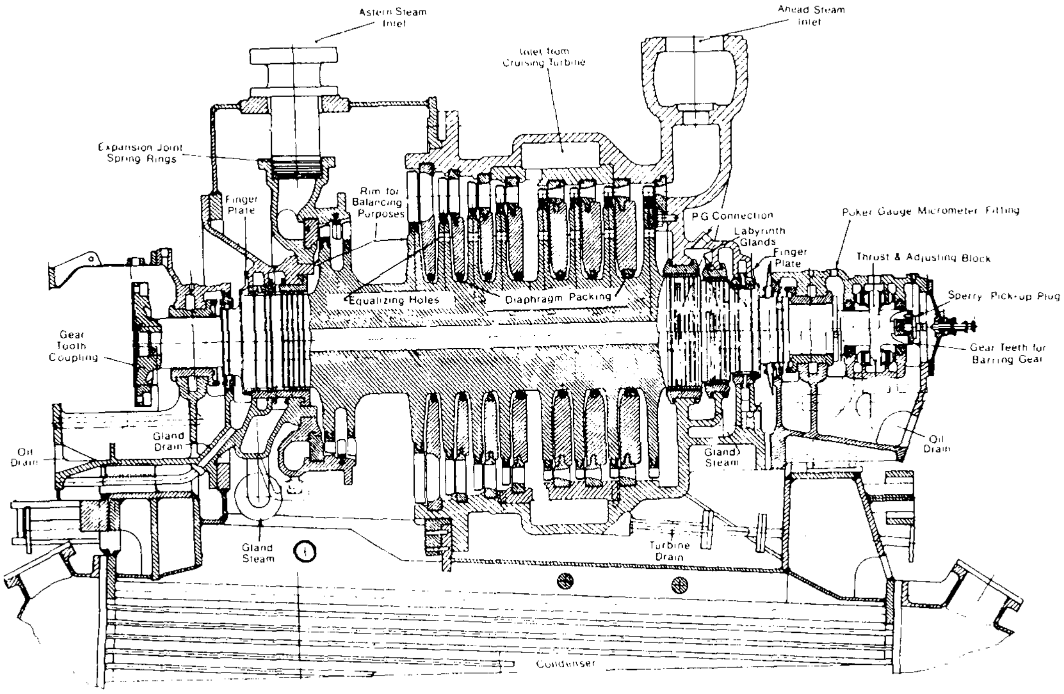

FIG. 8—Y100 MAIN TURBINE

This English Electric Co. design won the competition to find the most suitable machinery and was fitted in frigates until gas turbines were adopted

Class of frigates using U.S. standards for some aspects of pipe work and flanges, and with the proviso that all but the first set should be manufactured in Canada. The first set (built in Britain) was to be up the St. Lawrence in Montreal before the river froze in the winter of 1951. But there were two major changes before the project got under way. The first was the withdrawal of the E.E. Co. members of the team so that the firm could compete for the turbine design (which in the event they won). The second was a declaration by Yarrow and Co. that they would no longer compete for the boiler designs for naval ships, thus preserving the impartiality of the team in selecting component designs for the plants they would be recommending and for which they were given a contract to produce the specifications and guidance drawings with which the shipbuilders winning the 'building' contracts would be furnished.

The design conditions were so severe that the need to invite the co-operation of any firms willing to contribute was not contested. A current programme of building power stations was already absorbing the capacity of E.E. Co. as well as the boiler winning contestant, Babcock & Wilcox, who were also involved in the heavy programme of rebuilding the world's merchant fleets. These firms, apart from proving that they could produce the machinery they had designed, were agreeable to licensing shipbuilders to manufacture their designs. Thus the worst fears attending the competition—that of 'land' firms in the naval market—were not justified.

The shipbuilders resisted any suggestion that their turbine manufacture should be concentrated in one specialized shop in each of the shipbuilding areas. The need to retain the balance of activities in each shipyard was the reason given, but the trend was clear: design and production of machinery, reaching ever more demanding standards of reliability and other qualities, was becoming progressively a highly specialized activity, and the general engineering shops of the shipbuilders were more and more at a disadvantage. As far as the R.N. was concerned, this trend came to its logical conclusion with the adoption of aero-derived gas turbines supplied by aero-engine specialists.

The guided-missile destroyers have not been mentioned because they are doubtful as an example of the primary influence of turbines on steam plant efficiency. The limiting steam temperature was, by the time of the G.M. destroyers, much influenced by considerations of superheater tube temperatures at partial powers and a major part of the turbine design considerations had to do with the 'boost' concept. It was, nevertheless, another step on the road to specialization to meet modern requirements. It may also be relevant to state that the steam conditions in Y100 were fixed to allow of rapid production rather than from thermo-dynamic considerations. 850°F required no special materials that might become 'difficult' in wartime, and the pressure was decided to facilitate the production of boiler drums.

Looking back over this brief story, two things seemed to be remarkable. The decisions which put each Navy ahead—confining the comparison to the U.S.N. and the R.N.—were made without the primary objective of financial advantage. 'Jackie' Fisher was always conscious of the financial consequences of his decisions on DREADNOUGHTS, but they did not stand in the way of his primary objective of military superiority. Admiral Bowen writes in his book a great deal about the introduction of proper accounting methods in the organizations for which he was responsible and yet his determination, in the face of much opposition, to ensure that the U.S. Navy was properly equipped with machinery that would allow her ships to fight a Pacific Ocean War seems to have been held without any particular regard to the financial consequences. (They must have been insignificant in the event or they would surely have been raised as a major objection by the people who opposed his actions.) In the case of Y100, the urgency and the breaking of new ground were such that it was not until after the design aspects of the project had been fairly well covered that the cost was investigated. In spite of accepting all sorts of production methods more sophisticated than usual to keep down the weight, the cost per horsepower was lower than normal for destroyer machinery.

This leads to the second observation. The important decisions have to be taken before it is possible to prove that they are right, otherwise they are almost certainly too late.

These observations are by no means intended to cast doubt on the present preoccupation of those who have to consider the financial consequences of these decisions. Such considerations should undoubtedly be properly investigated as far as this is possible and taken into account. It is, however, becoming increasingly difficult to put any other than financial values into the equation on which decisions are taken. The only alternative seems to be to have a long-term development policy whereby one's ambitions for the future are under continual scrutiny against developing knowledge, and there is then a line by which the consistency of decisions can be judged. The article by Dr. Reuven Leopold, reprinted in the December 1978 issue of the *J.N.E.* (Vol. 24, No. 3) is worth much thought in this connection.